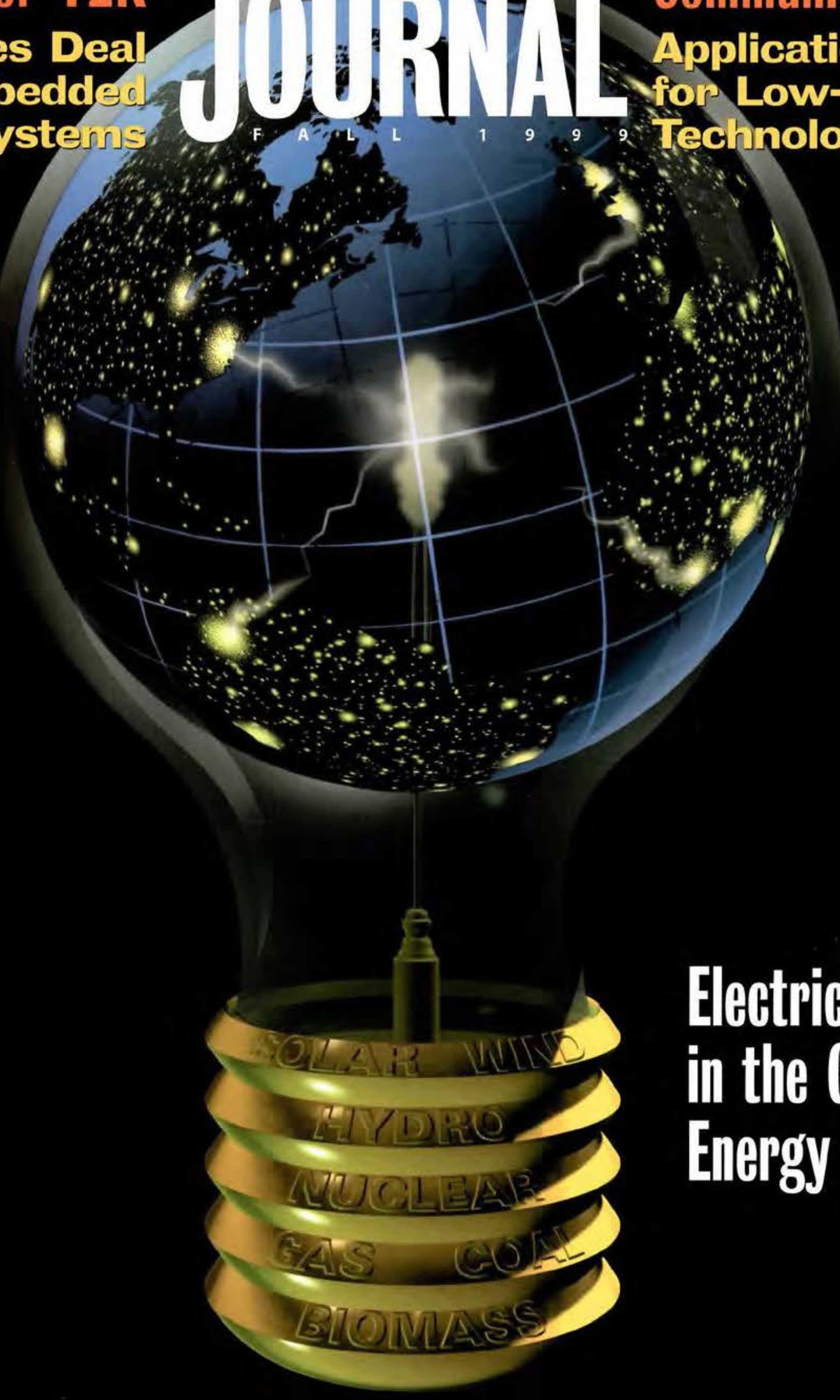
EPRI JOURNAL
FALL 1999

Preparing for Y2K

Utilities Deal With Embedded Systems

Satellite Communications

Applications for Low-Orbit Technologies



Electricity in the Global Energy Future

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: A diverse portfolio of energy resources and advanced generating technologies will be required to power an expanding global economy in the coming century. (Art by James William Gary)

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Editorial

Sequestration: Mastering the Transition Game

The long-term prospects for a clean energy future look quite good. We are confident that with sufficient R&D investment, we will be able to develop and increasingly deploy reliable, affordable carbon-free energy options in the twenty-first century. As this issue's cover story observes, however, we will need to continue to draw on coal and other fossil fuels as a significant part of our energy resource portfolio for at least the next 50 years—a difficult situation in light of concerns about carbon dioxide emissions. In the United States, environmental concerns are already contributing to the investment risk for new coal power, and if these issues are not addressed, new coal-fired capacity will be effectively choked off, even plants based on advanced clean coal technologies. In this context, carbon sequestration provides an option for the continued use of our most abundant energy source as we make the transition to carbon-free generation in the coming decades.

The developing world is also playing a transition game, one that involves economic growth as well as energy. China and India, for example, will unquestionably use their large indigenous coal reserves for power generation, since the widespread availability of cheap electricity is crucial for their national economic development and for breaking the cycle of poverty, disease, and hopelessness. The development of technology to capture and sequester carbon will be key to reducing the environmental impact of this global growth scenario. In the developing countries, as in the United States, the availability of clean options for the continued use of coal would provide much-needed flexibility in forging a workable overall response to climate change issues.

Fortunately, work on carbon sequestration is going on all over the world. The Japanese program—which, at around $100 million, is probably the world's largest—is focused on deep ocean disposal: pumping CO_2 down 3000–5000 feet (900–1500 meters), where it spreads out as a supercritical liquid on the seafloor. A multinational pilot-scale field experiment on such long-term deep ocean disposal is scheduled to take place off the Kona coast of Hawaii in the summer of 2000. Meanwhile, for the past two years, a European research team has been injecting CO_2 into a deep saline aquifer under the bed of the North Sea off Norway. This project, which is being carried out at actual power plant scale, is providing real-world cost information and best-practice guidelines for aquifer injection. Other carbon storage options being pursued include sequestration in underground coal seams and in oil or gas fields, whose fuel production life can be significantly extended by CO_2 injection.

A particularly interesting research avenue that EPRI is investigating involves biomimesis, the engineered mimicry of biological processes found in nature. Specifically, scientists are looking at the enzyme that allows mollusks to quickly convert CO_2 from seawater into the inert calcium carbonate they use for shell growth. There is evidence that this enzyme—found in a wide variety of living things—could be easily and inexpensively mass-produced. A sequestration system based on this concept and located at a power plant site might be able to fix carbon from flue gas in a single step, without the need for separation and concentration. The end product—essentially limestone—could be disposed of in a landfill.

These are just a few of the many approaches to carbon capture and storage that are being studied worldwide and are outlined in a technology compendium recently developed by the U.S. Department of Energy with EPRI participation. The next step will be to rigorously evaluate the options against performance and cost criteria and to narrow the focus to those that offer the best opportunities for successful development. Considering the global implications of the CO_2 transition game, such work deserves a high priority in our R&D planning.

Stephen Gehl

Stephen M. Gehl
Director of Strategic Technology and Alliances

Contributors

Electricity in the Global Energy Future (page 8) was written by Taylor Moore, *Journal* senior feature writer, with assistance from two EPRI staff members.

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Utility Communications Go Into Orbit (page 18) was written by Taylor Moore, *Journal* senior feature writer, with assistance from two EPRI staff members.

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The Power to Transcend Y2K (page 28) was written by science writer Dawn Levy, with assistance from three EPRI staff members.

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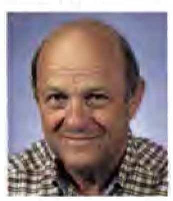

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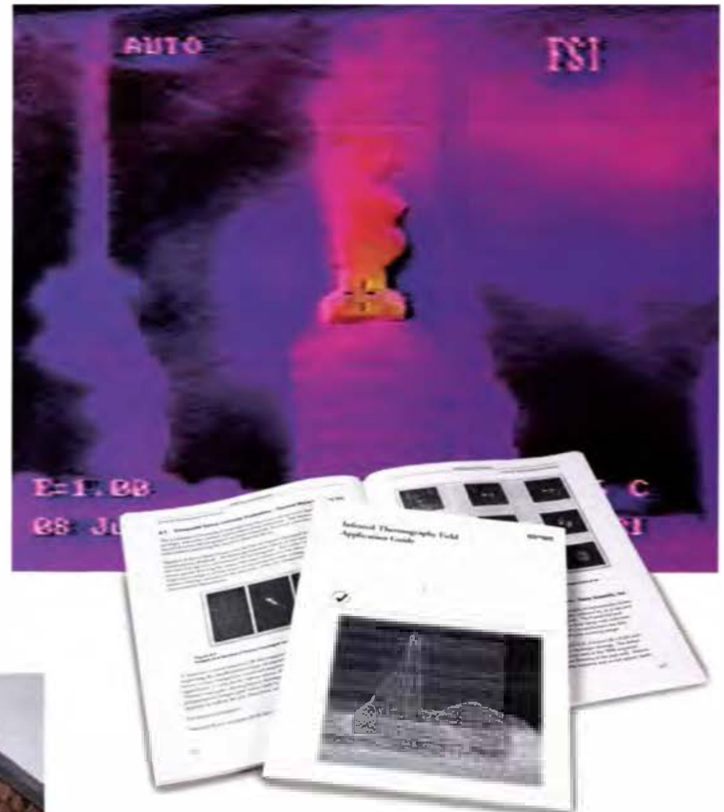
Analyzing the thermal signature of operating mechanical and electrical components provides valuable insight into their continued operability. Infrared thermography, with its noncontact, remote inspection capabilities, is very appealing for on-line, in-service inspections and is widely used by utilities as part of predictive maintenance programs. The *Infrared Thermography Field Application Guide* (TR-107142), which supplements an earlier EPRI guide (NP-6973), provides information on using the method for transmission and distribution lines, substations, and nondestructive testing. Based on information from utility thermographers and other industry experts, the new guide includes specific examples and sample images for each application area.

■ *For more information, contact Paul Zayicek, pzayicek@epri.com, 704-547-6154. To order, call EPRI Customer Service, 800-313-3774.*



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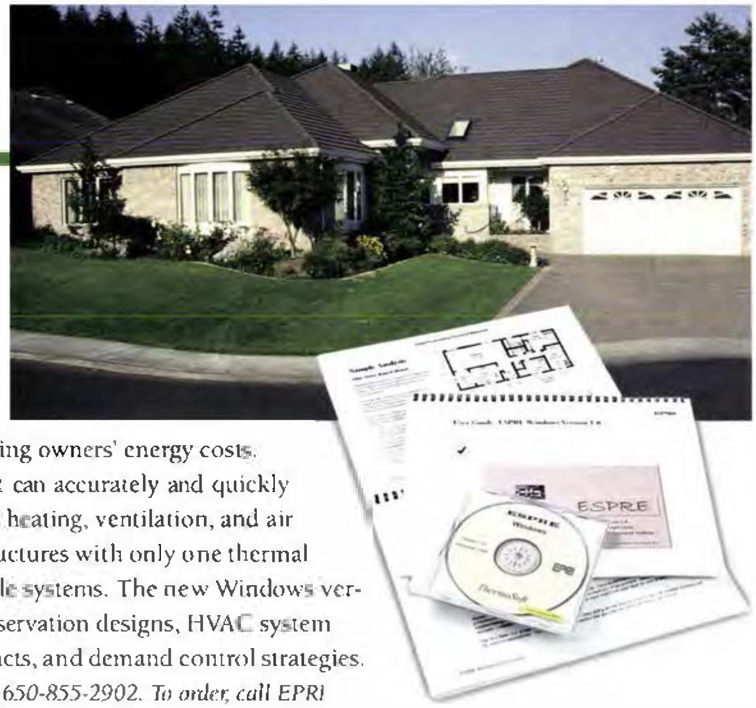
PV Project Development Guidelines

The hundreds of thousands of photovoltaic power systems in operation in the United States have helped utilities reduce their cost of service, expand their customer service options and customer base, decrease their emissions, and enhance their public image. An organized approach to developing successful PV-based projects and ventures is presented in new EPRI guidelines based on direct utility experience with the technology. The guideline report (TR-111892) describes the advantages and the most effective uses of PV systems, as well as their costs and limitations. The information presented was obtained through interviews and from publications of all major organizations actively involved with the technology and its applications.

■ *For more information, contact Terry Peterson, tpeterso@epri.com, 650-855-2594. To order, call EPRI Customer Service, 800-313-3774.*

ESPRE Windows Version 1.0



ESPRE (EPRI Simplified Program for Residential Energy) simulates energy use patterns for a variety of residential building designs and can help utilities quickly determine building owners' energy costs. Developed a decade ago, ESPRE has evolved to the point that it can accurately and quickly analyze interactions between a building and the elements of its heating, ventilation, and air conditioning system. ESPRE's modeling powers range from structures with only one thermal zone and one HVAC system to complex structures with multiple systems. The new Windows version of ESPRE was designed to analyze building loads and conservation designs, HVAC system performance, water heater energy use, electric rate design impacts, and demand control strategies.

■ *For more information, contact John Kesselring, jkesselr@epri.com, 650-855-2902. To order, call EPRI Customer Service, 800-313-3774.*

Turbo-X Software

EPRI's new Turbo-X decision analysis tool helps utilities maximize the intervals between major inspections and overhauls of steam turbine–generators while ensuring protection of the equipment. To provide a confident basis for extended operating intervals, the software performs engineering, economic, and risk analyses and determines life consumption, performance degradation, and probability of failure for critical components. The O&M and replacement power cost savings from shifting to longer intervals between maintenance outages can total tens of millions of dollars for a large fossil plant. Turbo-X runs on Microsoft Windows NT 4.0, Windows 95, and later versions.

■ *For more information, contact Tom McCloskey, tmcclosk@epri.com, 650-855-2655. To order, call EPRI Customer Service, 800-313-3774.*

Green Power Guidelines

Volume 2 of EPRI's *Green Power Guidelines* (TR-109192-V2) describes research to assess the market among small and medium-size businesses for electricity produced by green, or environmentally friendly, renewable energy resources. (A similar study of residential customers is documented in the report's first volume.) According to the findings, the market for green power among these businesses is potentially significant but is complex and difficult to assess because of the sector's diversity and fragmented nature. One clear conclusion is that green programs sell better at a discount than at a premium in this sector. The report outlines strategies for incorporating the findings into green power marketing programs and for better targeting the businesses most likely to accept a green power product mix.

■ *For more information, contact Terry Peterson, tpeterso@epri.com, 650-855-2594. To order, call EPRI Customer Service, 800-313-3774.*

Discovery

Basic science and innovative engineering at the cutting edge

Protective Biofilms Could Control Corrosion

Corrosion costs the U.S. electric power industry $5 billion to $10 billion a year. In steam generating plants, an estimated half of all forced outages are caused by corrosion. According to Barry Syrett, an EPRI technical fellow in science and technology development, the cost of dealing with corrosion adds more than 10% to the cost of electricity—more than to any other U.S. product. But genetically engineered bacteria could change all that.

The first field trials of bacterial films that have been genetically altered to combat corrosion are expected to begin later this year at one or possibly two utility sites. The trials are contingent on the success of initial testing by researchers at the University of California, Irvine, and the University of Connecticut, Storrs, in a collaborative project with EPRI.

When exposed to most process waters, metal surfaces at power plants become colonized by microbes that form a biofilm. Biofilms are often damaging. For instance, sulfate-reducing bacteria can cause pitting and other forms of corrosion in some alloys, including normally corrosion-resistant metals like stainless steel, copper alloys, and aluminum.

PHOTOS BY BARRY SYRETT

A test loop in UC Irvine's central plant (left) is being used to determine the feasibility of controlling corrosion with bacteria. The colors of the above biofilm samples from the loop are a function of the nutrients and indicator dyes present in the media.

The focus of the EPRI work, notes Syrett, is to engineer biofilms to have a protective effect. Under laboratory test conditions, aerobic bacteria cause as much as a 40-fold decrease in the corrosion rate of steel and significant decreases in aluminum and copper corrosion rates; they do this largely by consuming oxygen, which would otherwise oxidize the metal. "If, in addition, these bacteria are genetically engineered to release an antimicrobial substance, they can deter the effects of harmful bacteria, such as sulfate reducers," Syrett points out. "The antimicrobial substance kills or severely restricts the growth of the harmful bacteria."

Thomas Wood, a research scientist at the University of Connecticut, is investigating several methods of using bacteria to prevent corrosion. He explains, "Wherever there is water, bacteria are present in the form of a biofilm, which is difficult to eliminate. Biofilms are not just slime; they have a distinct and complex architecture. Why not have these biofilms work for us and be protective?" Wood adds it is unlikely that a single type of bacterium will fill the bill in all situations. A more likely scenario is that scientists will sample bacteria already thriving in the biofilm at a specific site, give them the genes to manufacture antimicrobials, and reintroduce them at the site.

Under the direction of Jim Earthman, a materials scientist, initial tests are being conducted in a test loop in the chilled-water system of the UC Irvine campus. Florian Mansfeld, a corrosion expert at the University of Southern California, is assisting with electrochemical data analysis and interpretation.

In addition, biofilm samples are being collected for analysis from Entergy Operations, GPU Nuclear, New Century Energies, the New York Power Authority, Niagara Mohawk Power Corporation, and the Tennessee Valley Authority. These analyses will enable collaborating researchers at the University of Nevada, Reno—Peggy Arps and Lois Tack—to understand what bacterial populations typically exist in the samples so that the most appropriate beneficial bacteria can be selected and genetically engineered for corrosion resistance.

The field work planned for later this year will entail side-loop tests in the service water or fire protection system of at least one of the power plants owned by the six participating utilities.

■ *For more information, contact Barry Syrett, bsyrett@epri.com, 650-855-2956.*

Collaboration Advances EV Batteries

The U.S. Advanced Battery Consortium—a development program formed in 1991 by U.S. automakers, EPRI, and the U.S. Department of Energy—reports substantial progress toward achieving goals for batteries that could extend electric vehicle (EV) range and performance beyond the capabilities possible with today's lead-acid batteries. Thanks to the USABC's effort and support, nickel–metal hydride (NiMH) batteries have been successfully field-tested in prototype EVs and are now in pilot-plant production. Meanwhile, lithium-polymer batteries continue to show the most promise for meeting the consortium's long-term cost and performance standards.

"In the roughly eight years since its formation, the USABC—in partnership with many cost-sharing battery manufacturers—has accomplished much, but a lot more work remains to be done before victory can be declared," says Eric Heim, EPRI's transportation area manager and USABC representative. "The consortium's cost and performance goals were based on a relatively singular objective: a battery system that would give EVs mass-market appeal by achieving commercial cost parity and acceptable performance in relation to internal combustion engine vehicles."

The identification of NiMH technology as the prime midterm candidate and the in-vehicle testing of NiMH battery packs from two manufacturers are among the consortium's accomplishments during Phase 1 and Phase 2 (which extends through this year). In addition to EPRI, Southern Company and Edison EV are providing utility industry support for the USABC.

The USABC's midterm battery cost and performance criteria would mean that a typical passenger EV would have a driving range of 100–125 miles (160–200 km) per charge and could accelerate from 0 to 50 miles per hour (0–80 km/h) in 12 seconds. A battery pack would last at least five years and cost $6000 or less (depending on production volumes). Batteries that meet the USABC's long-term criteria would enable an EV to go 200 miles (320 km) per charge and accelerate from 0 to 60 miles per hour (0–96 km/h) in 9 seconds; the life of a battery pack would be 10 years and its cost under $4000. Intermediate commercialization goals have been set as a stepping-stone between the midterm and long-term criteria. The performance defined by these goals is considered the threshold for wide consumer acceptance—that is, the level needed to successfully launch an EV market in advance of achieving the long-term, fully competitive EV.

Nickel–metal hydride batteries from GM Ovonic are already commercially available and are being used in the General Motors EV1. Shown here is the second-generation, 95-Ah, 12-V module the company expects to begin producing later this year.

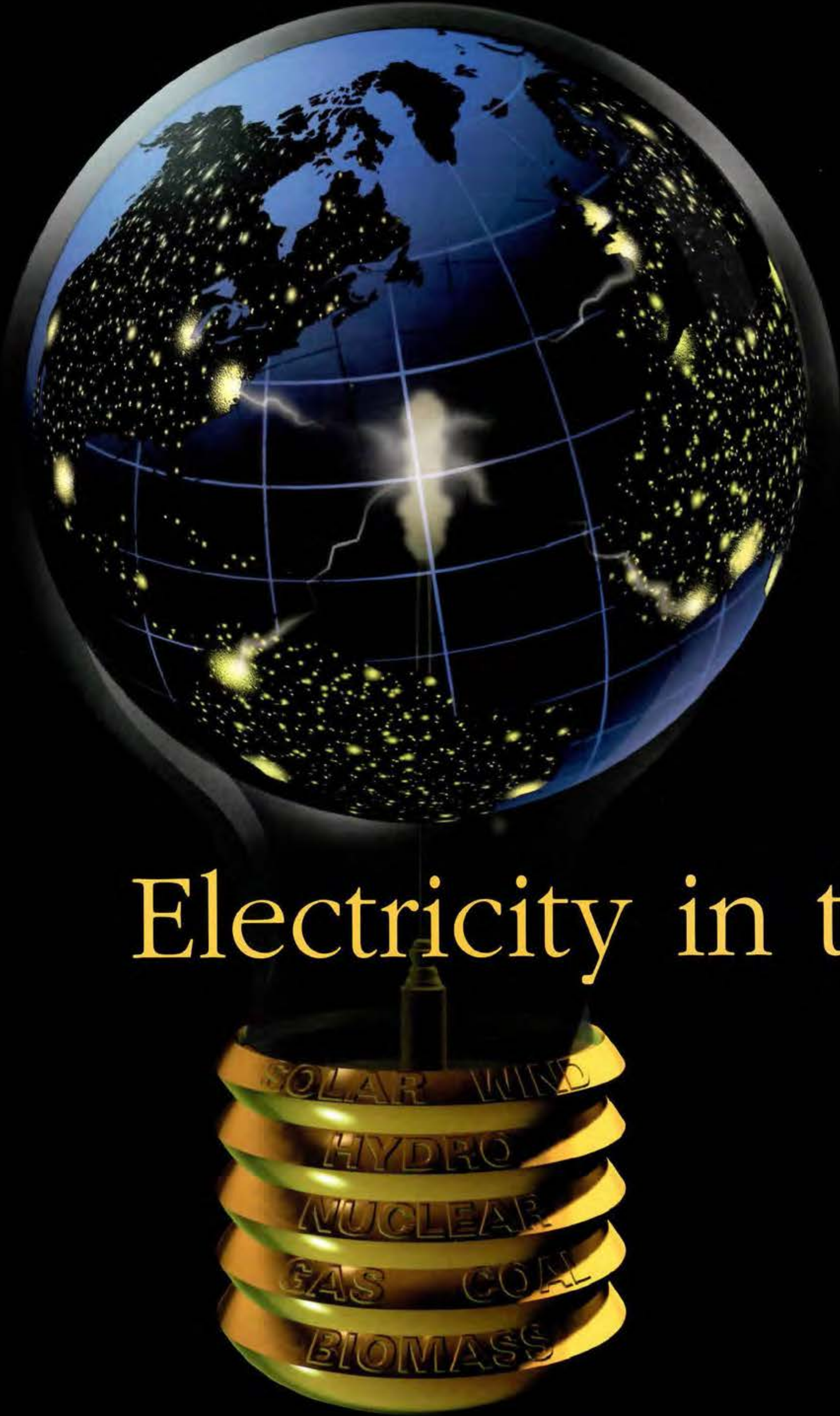
NiMH batteries that meet most of the USABC's midterm criteria are expected to be commercially available by the end of this year. The technology is expected to sustain the early-adopter market for vehicles like the General Motors EV1. Current USABC efforts on NiMH batteries include more-extensive durability, abuse tolerance, and verification testing, as well as research aimed at reducing the batteries' cost. The prospective use of advanced batteries in stationary (non-EV) applications is also being addressed.

Work involving the lithium-polymer technology is focused on pilot-plant design and on battery testing and cost reduction. "If the current rates of technical progress are maintained, EVs powered by lithium-polymer batteries are expected to approach the performance of conventional gasoline-powered vehicles within the next five years," says Heim.

To capitalize on the success achieved thus far, the USABC participants are discussing prospects for a Phase 3 initiative, which may result in additional EPRI funding for an additional four years (2000–2003). "The participants' preliminary thinking is that Phase 3 would effectively achieve for lithium-polymer technology what Phase 2 has achieved for NiMH technology—that is, to bring it to the pilot-plant stage of production," says Heim. Of the proposed Phase 3 budget of $62 million, EPRI's commitment would be approximately $1 million a year for four years.

■ *For more information, contact Eric Heim, eheim@epri.com, 650-855-2162.*

Electricity in the



Global Energy Future

THE STORY IN BRIEF Supplying the energy needed by an expanding global economy in the next century while also reducing the risk of climate change poses some of the greatest technological challenges the human race has ever faced. Global electrification represents the crucial technological lever for achieving these seemingly contradictory objectives. For such a strategy to succeed, however, a balanced portfolio of energy resources and advanced generating technologies—including low-carbon and noncarbon technologies—will have to be deployed on a massive scale, for both central station and distributed generation. This, in turn, requires numerous scientific and engineering breakthroughs that only a major new commitment to R&D can make possible. EPRI's Electricity Technology Roadmap defines the technology development milestones on a possible path to a sustainable global energy future. **BY TAYLOR MOORE**

JUST IN THE PAST CENTURY, electricity has become the foundation and prime mover of society. And over the next century, the world faces a surge in the demand for electricity, driven by such powerful forces as population growth, urbanization, expanding global commerce, and the imperatives of human welfare. By 2050, these forces could result in global electricity consumption that is four times greater than today's level.

Such a dramatic increase in electrification addresses a three-sided dilemma, or "trilemma," that promises to define human progress in the twenty-first century. The trilemma is how to simultaneously meet the energy needs of a burgeoning global population, achieve people's quality-of-life aspirations, and conserve natural resources and promote other environmental values.

The threat of climate change is the biggest environmental concern. Many experts agree that a prudent goal for the next century is to constrain the global atmospheric concentration of CO_2 to no more than 550 parts per million. This concentration—twice the level that existed at the dawn of the Industrial Age, or about 50% greater than today's level—may then eventually decline. Given the long atmospheric residence time of CO_2, it would likely take up to a century to reverse the current trend in atmospheric concentration.

ILLUSTRATION ON PAGE 8 BY JAMES WILLIAM GARY

In such a carbon-constrained energy future, the only hope for satisfying basic human needs in the fast-growing developing world—and for sustaining the quality of life enjoyed by the developed world—is to accelerate the pace and extend the reach of global electrification. This approach promises a more equitable distribution of global energy resources and their economic benefits around the world, with reduced environmental impact. A plentiful global supply of electricity has become the essential pathway to a sustainable, clean energy future.

A goal of universal electrification by 2050 will mean bringing electricity in some form to at least 100 million more people in the world every year for the next 50 years, or more than tripling the rate of electrification of the past quarter century. Just to increase average per capita consumption in developing countries to the level that existed in the United States in 1950, the world is likely to need some 10,000 GW of new generating capacity by 2050.

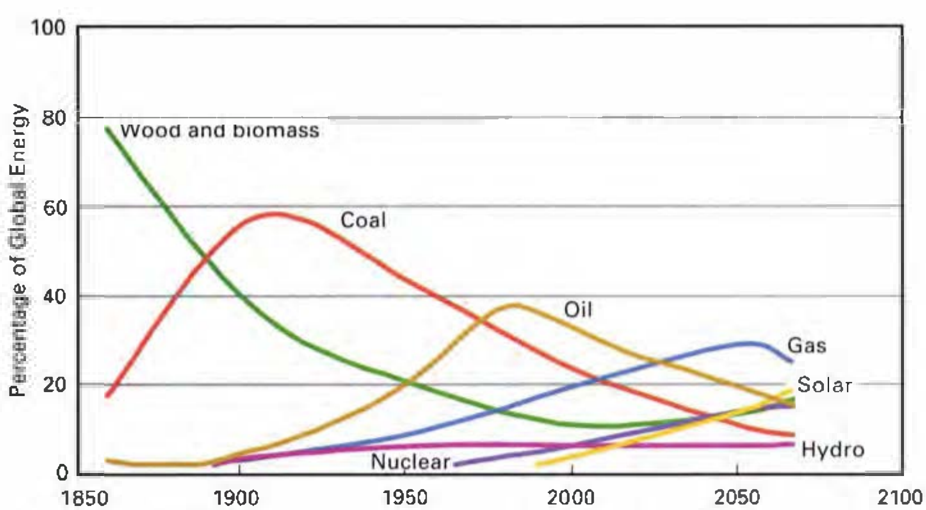
This accelerated pace of global electrification will require adding the equivalent of 1000 MW of generating capacity every one to two days for at least the next 50 years, while meeting ever more demanding environmental and cost constraints. Because half of this new capacity will need to be carbon-free, most of these power plants will have to be very different from those being built today.

The drive to stabilize atmospheric carbon concentrations will require a robust portfolio of clean, economical, practical, and acceptable technologies—including renewables, nuclear power, and hydrogen—to manage the transition to a low-carbon energy future. The transition will also require the development of methods for capturing and sequestering carbon from the use of fossil fuels.

In the near term, however, policies mandating reductions in the use of fossil fuels could result in significant economic dislocations. Such policies could lead to an overreliance on the lowest-carbon fossil fuel technologies currently available, like natural-gas-fired combustion turbines, and could reduce interest in the development of advanced low- and noncarbon options. Flexibility about when and where emissions are reduced will be essential to ensure that least-cost reductions are made first and that technology is not locked in at today's level of performance. Delaying reductions until lower-cost noncarbon alternatives are available could cut the overall cost of emissions reduction by as much as two-thirds.

While achieving such a greatly expanded future role for electricity seems like a daunting challenge, it can be done—and at a cost of less than 0.5% of the world's gross domestic product. That is the reasoned conclusion of a wide-ranging, collaborative initiative called the Electricity Technology Roadmap. Spearheaded by EPRI, this effort has drawn participation from more than 150 stakeholder organizations. Through a series of workshops and seminars and the publication of a groundbreaking, multivolume initial roadmap progress report, the initiative has forged a comprehensive vision of the opportunities and challenges for electricity-related innovation to benefit the world's peoples and economies. The roadmap outlines a series of interdependent goals, or technology development destinations, for realizing this vision and lays out the R&D pathways to reach them.

The roadmap's ultimate goal for electricity and energy-related industries in the



Wood, coal, and oil have successively dominated the world's total energy mix in the past, but most scenarios for future energy supplies emphasize the need for a diverse, balanced portfolio of resources. The ultimate goal envisioned by the EPRI Electricity Technology Roadmap is an electricity-hydrogen economy that provides abundant, clean, low-cost energy. (Source: World Energy Council.)

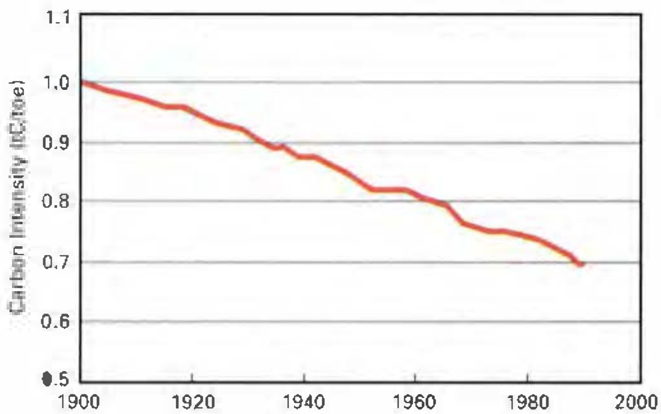
twenty-first century is to manage the global sustainability challenge—that is, to satisfy the needs of a growing world population for clean, efficient energy and for the quality of life that electricity makes possible, while meeting the technical challenge of controlling greenhouse gas emissions and addressing other environmental issues. Reaching these inherently linked destinations—in addition to equally important, nearer-term destinations—will require many substantial breakthroughs in science and technology that only a massively greater global commitment to energy and environmental R&D can make possible.

"As the most fuel-diverse—and potentially (through technology) the least carbon-intensive—energy form, electricity will play a critical role in solving the trilemma of reconciling population growth, economic aspirations, and resource utilization, including environmental quality," says Kurt Yeager, EPRI's president and chief executive officer, who conceived the Electricity Technology Roadmap Initiative. "The electricity- and hydrogen-based energy economy that the roadmap envisions for 2100 could set the world on a path of global sustainability, allowing vigorous economic growth and enabling billions of people to lift themselves from poverty to prosperity, health, and hope for a better life."

Sustaining a world of 10 billion people

The world's population has doubled in the past 50 years to more than 6 billion people and will nearly double again in the next 50 years to about 10 billion people. While global population overall is not exploding at the previous rates that led some people in the 1970s to predict a Malthusian collapse in the next century, there are nevertheless major global demographic shifts under way. Some 85–90% of the world's expected new citizens will be born in developing countries in Asia, Latin America, and Africa. Global population is projected to grow at an average rate of 1.3% a year over the next 50 years, and the population in developing regions may continue to increase beyond midcentury, unless replacement fertility rates can be consistently achieved around the world.

But it is not simply population growth that drives the projected future need for energy. Urbanization is occurring even faster, as impoverished people seek opportunity by migrating to already crowded cities. By 2050, there will be more than 60 megacities with populations of over 10 million each—four times as many such cities as today—and nearly all of them will be in the developing world. Essential infrastructure capabilities for housing, sanitation, health services, transportation, and energy are sorely lacking in most of today's megacities.



The continuing decarbonization of world energy over the past century is primarily the result of the increasing efficiency afforded by electricity, combined with the use of a progressively less carbon-intensive mix of primary energy resources, including nuclear and renewables. But over the next century, the historical rate of decline in carbon intensity (tons of carbon per ton of oil equivalent energy) must triple to contain global atmospheric concentrations of CO_2. (Source: National Academy of Engineering, 1997.)

In addition, the residents of developing countries have aspirations for a better quality of life, which are reinforced by television images, advertisements, and other communication links with the developed world. "In terms of energy and other resource demands, this growth in aspirations multiplies the effect of global population growth and sharpens the issues posed by the trilemma," notes Steve Gehl, EPRI's manager for strategic technology and alliances and a leader of the roadmap initiative.

Another dimension of the demographic explosion is the aging of the world population, the otherwise fortunate result of improved health care and lower birthrates in some countries. As early as next year and for the first time in history, the number of people 60 and older in the developed world will exceed the number of those 14 and under. By 2050, the same shift will have occurred in developing countries, delayed by only a couple of generations. The majority of people growing old in those countries, however, will not be as fortunate as their counterparts in the developed world, where economies have prospered before the aging of the population.

"The implications of this situation—in terms of both the economic growth needed to care for the world's aging population and the willingness of a younger minority to support a growing majority of older people—are very important drivers for future energy needs," notes Gehl. "The roadmap has identified a critical role for electricity in providing the foundation needed for intergenerational investment. Electricity's ability to increase human productivity and facilitate the creation of jobs with improving average wages can help provide a better quality of life and create a variety of social and environmental investment programs."

For the year 2050, the roadmap targets a per capita energy consumption goal of at least 1000 kWh per year for the world's poorest inhabitants and a per capita average of at least 3000 kWh per year for the developing world as a whole—a level just above the U.S. per capita consumption in 1950. As noted by Chauncey Starr, EPRI's founding president, 1000 kWh per year represents the energy foundation necessary for education, economic development, environmental improvement, and intergenerational investment.

Everywhere it has become available, electricity has stimulated and sustained economic growth and improved the efficiency of all factors of production, particularly the productivity of labor and energy.

The overall energy intensity of economic growth is declining as the electricity intensity of the world's energy system increases. In the United States, for example, energy intensity—the total energy required to produce a unit of gross domestic product (GDP)—has dropped by one-third since 1950, while electricity's share of total energy has increased from 15% to nearly 40%.

Over the next 50 years, U.S. energy intensity is expected to steadily decline further—by about half if electricity's share of total energy consumption climbs to 70% through new electrotechnology opportunities, including some for transportation. In addition, these electrotechnology-based innovations could double the growth rate of economic productivity and eliminate most industrial and urban waste streams. Achieving these major stretch goals could add at least a trillion dollars a year to the U.S. GDP.

At the same time, advanced electrotechnologies for various industrial and commercial applications could enable developing countries to bypass the historically less efficient development pathways followed by today's developed nations. The growing panoply of electrotechnologies, including information technologies, can accelerate efficiency gains and the decarbonization of energy in many ways—by substituting directly for fossil fuel technologies, by performing old tasks in new ways, or by providing new functional capabilities.

The roadmap's projections of future electrification suggest that it is indeed possible to cut the global energy intensity of economic growth approximately in half by 2050. Greater end-use efficiency potentially could account for about half of this improvement, reducing both energy consumption and carbon emissions per unit of GDP by at least 25% over the next 50 years. As a result, the 3000-kWh average per capita electricity use targeted for developing countries by 2050 will go much further in providing lighting, space conditioning, industrial energy, computing, communications, and the like than did the same U.S. per capita amount in 1950. Already in China, the production of compact fluorescent lightbulbs is a priority, for reasons of both energy efficiency and export value.

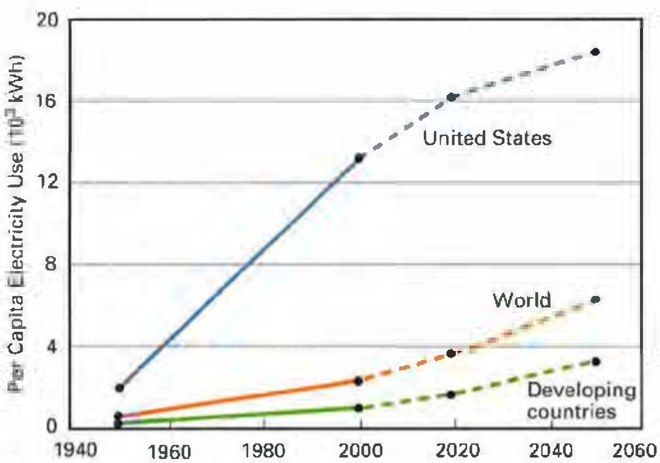
The portfolio imperative

Resolving the energy-carbon challenge and meeting the rapidly growing global requirements for energy in the most efficient manner—and at the same time preserving the environment—will require a portfolio of technologies using the full array of energy resources. Developing a diverse, flexible portfolio limits the risk that specific primary resources will become unavailable or too expensive and increases the likelihood of successfully meeting the uncertainties of the future. Moreover, given the diversity of market conditions and living standards around the world and the uneven geographic distribution of resources, no single energy source or technology can meet all of the world's energy requirements.

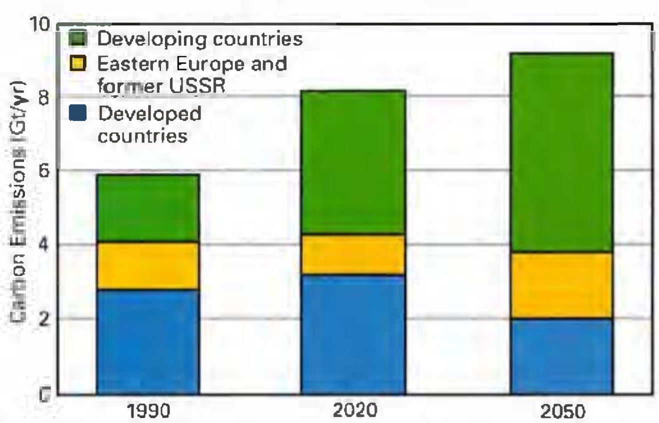
The portfolio approach will require far more efficient and environmentally advanced technologies for converting fossil fuels to electricity (and, eventually, for capturing and sequestering carbon as part of the process). It will also require the increasing use of noncarbon energy sources. Historically, the global rate of the decarbonization of energy use has been gradual—0.3% per year. Solving the energy-carbon conflict will require tripling that rate, to 1% per year, even as total energy demand continues to increase.

Over the past 200 years, first wood, then coal, and more recently oil and natural gas have dominated as a percentage of the world's total energy mix, each with progressively less carbon per unit of energy. The World Energy Council (WEC) envisions that by 2050 the global mix will include at least seven sources, none of which will have more than a 30% share of the market.

Only electricity can make such a diverse supply portfolio possible while meeting environmental demands. Nearly all of the energy scenarios developed for analyzing future energy demand entail substantial growth requirements for electric generating capacity in order to satisfy the expected growth in popula-



For the developing countries as a whole, the 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 an average per capita consumption level of at least 1000 kWh per year by 2050. (Sources: International Institute for Applied Systems Analysis, World Energy Council, and EPRI analyses.)



The developed countries and the countries of eastern Europe and the former Soviet Union now account for two-thirds of annual global carbon dioxide emissions. But early next century, the developing countries' emissions of CO_2—and their burden for limiting them—will begin to increase substantially. (Source: World Energy Council.)

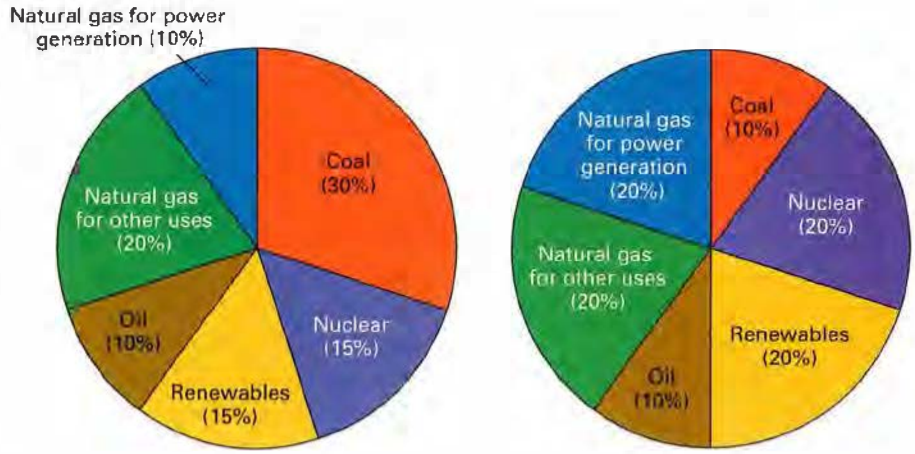
tion. The WEC and the International Institute for Applied Systems Analysis have defined a series of such scenarios.

The Electricity Technology Roadmap's analysis targets a level of economic growth equaling that in the WEC's high-growth scenarios—but with a level of primary energy consumption similar to that in the council's environmentally driven scenarios, in which carbon emissions are constrained. This is accomplished by increasing the projected level of electricity use by almost 50% beyond that of the WEC high-growth scenarios. Thus the roadmap analysis captures the best of both worlds envisioned by the WEC scenarios—robust economic growth and environmental protection—through more-aggressive electrification. However, the roadmap concludes that to realize these goals, substantial technological advancements beyond those factored into the WEC scenarios will be necessary.

In order to supply the energy needed by a world of 10 billion people in 2050 while simultaneously reducing total energy intensity and carbon intensity, the electricity fraction of total primary energy use will have to rise, and continuous efficiency improvement will be required at every link in the electricity chain of generation, delivery, and end use.

The roadmap's high-electrification scenario is compatible with several different fuel and primary energy portfolios. Coal-intensive portfolios are one example. These assume that countries with large coal reserves will continue to use coal to meet their energy needs at the least cost, and that environmental issues will be addressed by gains in the environmental performance of coal-based generation and by the development of low-cost carbon sequestration. Under such conditions, the world's use of coal could conceivably double by 2050, and the use of natural gas could more than double. Since the high-electrification scenario anticipates that approximately 50% of current petroleum use will be displaced by higher-efficiency, electricity-based propulsion in the transportation sector, oil's share of primary energy use would fall from 40% today to about 10% in 2050.

Possible Portfolios for a High-Electrification Scenario



The roadmap proposes a high-electrification scenario that integrates accelerated economic development with environmental protection and is compatible with a broad array of fuel and primary energy portfolios. (The scenario is based on a primary energy forecast of 17 gigatons of oil equivalent and a 70% electricity share.) Assuming that environmental issues are addressed, the scenario can accommodate a doubling of the global use of coal by 2050. In this coal-intensive portfolio (left), natural gas use could more than double today's level, and given the necessary breakthroughs, nuclear power and renewable energy forms would each account for 15% of primary energy. The high-electrification scenario is also compatible with a high renewables and nuclear portfolio (right), in which coal use could decline by about 40% over the next 50 years.

Even in such coal-intensive portfolios, nuclear power and renewable energy forms are expected to make important contributions to the energy mix. Each is expected to account for at least 15% of primary energy by 2050 if the necessary breakthroughs in safety, reliability, and public acceptance of new nuclear plants and in the performance and cost of renewables are achieved. As renewables and nuclear power account for progressively larger fractions of total electricity generation, global carbon emissions are expected to begin a downward trend in the latter half of the next century.

Several primary energy portfolios that are much less fossil fuel intensive could also meet the needs of the roadmap's high-electrification scenario. For example, given a portfolio with high levels of renewables and nuclear power, coal use could decline by about 40% over the next 50 years. The upshot of the variety of possible scenarios is that the roadmap's high-efficiency, high-electrification goal enables the broadest array of primary energy mixes while fostering both accelerated economic development and environmental protection.

"The electrification goal put forward in the roadmap is not so much a prediction as a stake in the ground," notes Brent Barker, EPRI's manager of corporate communications and a key contributor to the roadmap initiative. "It is the most practical means of reducing future demands on scarce resources and the environment while maximizing economic development, personal opportunity, and education in the developing world. This should help moderate the pressures of population growth."

The roadmap's ultimate goal—an electricity-hydrogen economy with globally abundant, clean, low-cost energy for use in fuel-cell-powered vehicles, distributed generating units in homes and businesses, and large gas turbine combined-cycle power plants—is feasible. But it requires urgent global deployment of advanced coal-refining technology now, as well as the resources to pursue fundamental breakthroughs in nuclear and renewables-based technologies.

Potential breakthrough goals include the transformation of the energy and resource recovery efficiency of coal-based generation by means of conversion technologies that will be competitive in cost and environmental performance with natural-gas-fueled combined-cycle generation in the 2010 to 2020 time frame. These include integrated gasification–combined-cycle and pressurized fluidized-bed combustion technologies. Further out, the roadmap has an efficiency goal of 75% for central station gas turbine combined-cycle plants in 2050. Such plants could produce electricity at a cost sufficiently lower than today's average to support an overall roadmap cost goal: retail electricity half as expensive as it is today.

The U.S. Department of Energy is also developing a coal-based technology roadmap for the next century, called Vision 21. This includes a coal refinery, or "powerplex," concept combining electricity generation, hydrogen separation, chemical production, and CO_2 sequestration. The approach offers the most efficient and complete use of coal's total resource value, but major infusions of R&D funding will be needed in order for the technology to achieve commercial viability before 2020.

Among renewables, solar photovoltaics (PV) could have a profound effect on future electricity supply, considering the more-than-ample availability of the resource. But according to Terry Peterson, EPRI manager for solar power, "For PV to become a major source of electricity will require approximately another 5-fold improvement in cost and performance beyond the 100-fold improvement attained over the past 20 years. The speed with which this additional improvement will happen depends on the pace of continuing technology investments." An example of breakthrough PV technology would be 25%-efficient, multijunction thin-film modules that cost $50 per square meter.

The renewable technologies of wind turbines and biomass fuels are already deployed around the world at about 10 times the currently installed PV capacity, and both have significant potential for further contributions to global electrification. Breakthroughs in low-cost, practical electricity storage technologies could greatly increase the value of renewable resources for dispatchable electricity generation. Perhaps the greatest opportunity for distributed power will be in bringing electricity to rural regions in the developing world. In this context, it can have many advantages over the more conventional central station–delivery grid structure in providing basic levels of electricity service.

Other, perhaps unexpected, breakthroughs may ultimately contribute to global electricity supplies, leading, for example, to space- or moon-based PV arrays beaming power to the earth in the form of microwaves for ground-based conversion. Or the long-sought goal of practical energy from nuclear fusion may ultimately be realized through as-yet-unknown fundamental scientific breakthroughs.

A potential breakthrough technology that could greatly broaden the economical application of nuclear power is the modular high-temperature helium-cooled reactor. Originally developed in Germany, this technology is being considered by South Africa's ESKOM at the 100-MW scale for distributed applications that combine heat and power. Because of its suitability for a variety of process heat applications, a compact high-temperature reactor like this would be a very efficient energy source.

Biomass (bagasse)

Ultimately, such technology could power the high-efficiency electrolysis of water during off-peak periods, producing hydrogen for use as a peak generating fuel in advanced gas turbines or as a transportation fuel in fuel cell vehicles. For long-term public acceptance, however, the development of any advanced reactor would have to be coupled with engineering advances in cost, waste handling, and proliferation protection. Indeed, altering public perceptions of the importance of nuclear power may be the most difficult challenge in a developed world awash in cheap energy. The precarious nature of global energy security in a carbon-constrained world must be better appreciated in order for nuclear power to be broadly considered as an essential option.

Meanwhile, breakthroughs in such technologies as fuel cells and biomass gasification would help broaden the array of available energy sources for distributed power applications, both stationary and mobile. Continuous improvement in energy efficiency at the point of end use may be possible if breakthroughs can be achieved across an array of industrial electrotechnologies, including high-temperature plasmas, microwave synthesis and processing, and electron beams.

Confronting carbon

Even if developed as rapidly as possible, advanced low- and noncarbon energy technologies may be insufficient to produce the reductions in CO_2 emissions that may be needed in the next century. Capping atmospheric concentrations of CO_2 at the levels believed necessary to reduce the risk of climate change will require containing cumulative emissions in the next century within a budget of 800–1000 gigatons of carbon.

In order to reduce the net global atmospheric venting of CO_2, carbon sequestration technologies that either capture CO_2 at the point of energy conversion or remove it from the atmosphere may be necessary. The CO_2 would have to be securely stored over the long term in carbon sinks, such as geological formations, terrestrial ecosystems, or the ocean. Both the global terrestrial carbon reservoir and the ocean are larger sinks than the atmosphere.

Carbon sequestration is valuable for

both the carbon reduction it achieves and the risk mitigation it represents. By eliminating or weakening the link between fossil fuel use and carbon emissions, low-cost sequestration technologies would give power project developers greater flexibility in designing and operating fossil plants. Such technologies will be essential for ensuring investor interest in preserving fossil fuel options through the transition to a more diversified energy future. Many environmental, chemical, and engineering challenges remain to be solved, however. Breakthroughs in basic science as well as in process engineering will be needed to achieve the technological capability for large-scale, economical carbon sequestration.

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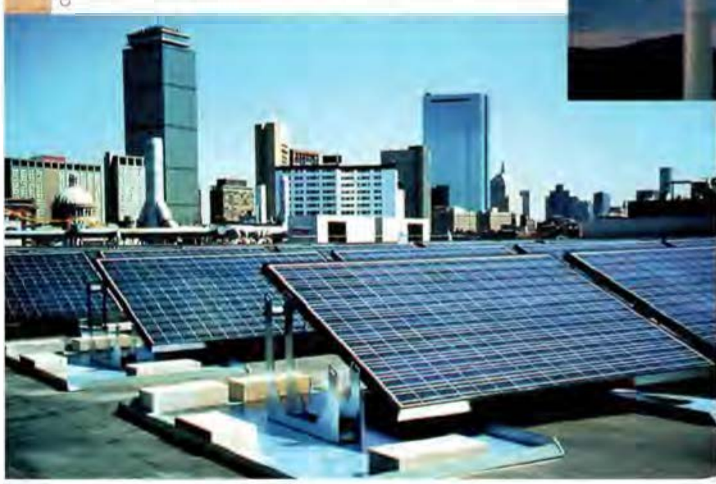
Most scenarios for the world's future primary energy mix project a significant increase in the use of low- and noncarbon resources, including renewables-based forms like solar photovoltaics, wind turbines, and biomass fuels. Substantial cost and performance breakthroughs are essential in order for environmentally preferred renewable technologies to economically supply a significant share of the world's energy needs.



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Solar photovoltaics

A possible harbinger of the future could come into being in just a couple of years if a 1300-MW combined-cycle plant proposed by Norsk Hydro is blessed by the Norwegian government. The project aims to reform natural gas (in a process similar to that used for ammonia production) to produce hydrogen-rich gas for use in gas turbines. CO_2, a waste product, would be separated out by means of a conventional absorption process and then injected into an offshore oil field in the North Sea for enhanced oil recovery. The plant's gas turbines, modified to accommodate the fuel, would generate 9% of Norway's total electricity. The likely result would be to reduce the need for power from offshore gas turbines, which now account for all of Norway's electricity-related carbon emissions. But the project also points out a problem with current carbon removal technologies. It is estimated that because of the significant efficiency penalty for capturing CO_2, electricity from the project would cost over one-third more than electricity from a similar natural-gas-fired plant with no CO_2 capture.

One of the bolder ideas for the future of fossil fuels—proposed by Jesse Ausubel, who directs the Program for the Human

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Wind turbines

Environment at New York City's Rockefeller University—entails the integration of industrial ecology and sustainable electrification. The concept put forth by Ausubel and others is based on 5-GW, ultracompact (locomotive-size), zero-emission power plants. These ZEPPs would feature a wet oxidation process with circulating supercritical CO_2. Methane would be injected into the CO_2 to react with oxygen and drive an ultrahigh-speed, high-efficiency turbine operating at very high pressure. Liquid CO_2 would be bled off for sequestration. Ausubel envisions a fleet of 500 such ZEPPs—sited near major gas transmission pipelines—in operation by 2050.

In Norway, Aker Maritime recently announced an initiative to develop a similar ZEPP. The development of ZEPPs for commercial applications, however, will require breakthroughs in turbine design, high-pressure systems, materials for high temperatures and pressures, and long-term CO_2 storage. Any of these breakthroughs would be valuable for meeting other critical energy technology needs even if ZEPPs are not successfully developed.

The promise of distributed generation

Certain technologies may play a strong enabling role for more than one destination envisioned in the Electricity Technology Roadmap. Among the most promising of these are technologies for distributed generation, which can be sited close to end users for increased conversion efficiency and reduced delivery infrastructure requirements. Most distributed generation technologies also have broad potential application in areas where no electricity infrastructure exists, including developing countries.

Fuel cells are an important distributed technology, with half a dozen types under development for powering vehicles or for use as stationary generators. These stationary generators could range from small-scale, distributed units for on-site premium power to larger modules ideal for coupling with gas turbines for central station or distributed generation. Combined fuel cell–gas turbine plants promise the highest conversion efficiency (above 70%) of any known fossil fuel generating cycle and, therefore, the lowest carbon emissions of any fossil power system. And low-cost fuel cells may eventually be coupled with PV to form an innovative energy storage technology.

With their strong promise of high efficiency, emerging fuel cells are an attractive option. However, their currently high capital cost must be reduced by at least an order of magnitude for them to be widely used for bulk power generation. Cost may be a less important factor in distributed applications.

Proton exchange membrane (PEM) fuel cells are a focus of current R&D for use in

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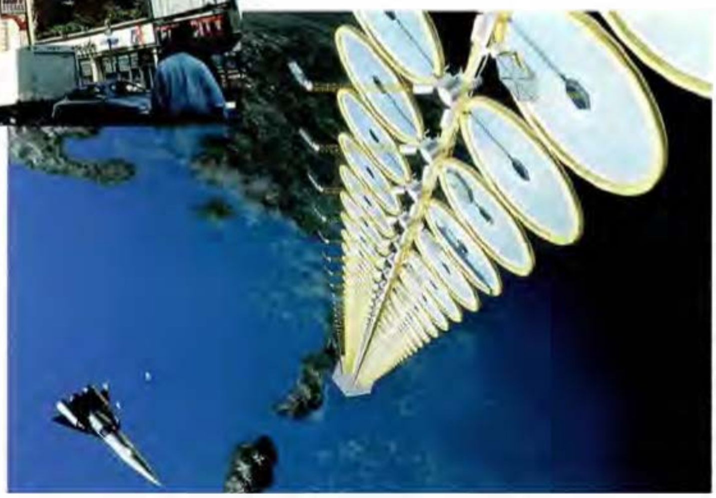
Cost reductions and increases in conversion efficiency, combined with innovative application concepts, could lead to the widescale deployment of photovoltaic technology over the next 50 years. The possibilities range from PV systems integrated into the exterior walls of buildings, as at 4 Times Square in New York City, to a network of PV power satellites in space. First proposed in the 1970s, power satellite concepts are being reassessed as launch and PV costs come down. Envisioned are arrays capable of beaming gigawatts of power to the earth as microwaves for conversion to electricity. Thousands of square meters in area, such arrays would require an order-of-magnitude reduction in cost to be economical.



PAT RAWLINGS, COURTESY NASA

advanced electric vehicles beginning in the next decade. They also could eventually see wide-scale use in distributed generation applications if progress in cost reduction and performance improvement continues on track.

Electric-drive vehicles powered by small, lightweight PEM fuel cells operating at about the boiling temperature of water are under development by more than a dozen firms worldwide, including General Motors, DaimlerChrysler, and Toyota. The PEM fuel cell designs of interest to automakers—50–100-kW units with 40% efficiency—would also be attractive for stationary distributed applications, including backup or premium power for residences or commercial buildings. If cost and performance targets for vehicle applications can be reached, stationary PEM fuel cells are likely to cost less than \$500–\$700/kW.

Once fuel cell or hybrid-electric vehicles are in common use, they could be connected to buildings or local distribution networks when not needed for travel, forming an extensive distributed power generation and storage network. One million such vehicles in use by 2010 could contribute 50–100 GW of generating capacity, or 5–10% of anticipated U.S. capacity. To enable the remote control and management of the complex networks, interactive communications technologies would also have to be widely available.

Energy R&D requirements

For creating the needed energy portfolio of the future, the roadmap targets as imperative an increase in electricity generation and end-use R&D of at least \$2 billion a year, to be shared between the public and private sectors. The roadmap calls for these resources to be focused primarily on knowledge development in the essential environmental sciences, on technical breakthroughs in noncarbon energy sources, and on the more intelligent use of energy through digital control and process miniaturization. This proposed increase in R&D investment is consistent with the 1997 conclusions of the Energy Research and Development Panel of the President's Committee of Advisors on Science and Technology, but the roadmap goes significantly beyond the PCAST panel in terms of the scope and pace of recommended research.

As a first step toward achieving the roadmap's near-, mid-, and long-term goals, the participants produced a preliminary estimate of the U.S. R&D funding needed over the next 10 years for progress toward the destinations in all areas (not just generation). According to this estimate, the total U.S. funding requirement for the R&D envisioned in the roadmap is about \$7.7 billion a year, or about \$4.6 billion a year more than current U.S. funding for energy R&D. The needed increase is the equivalent of only about 2% of all current U.S. R&D spending.

Any reasonable estimate of the total research funding required globally pales in comparison with the growing gross world product, which now exceeds \$30 trillion a year. This suggests that mustering the political consensus to invest in the necessary broad-based, collaborative research program and to implement its results is likely to be a greater challenge than generating the needed financial and human resources. The world can afford to achieve sustainability if it chooses, and it would thrive if it did so. Yet around the world, energy R&D funding is on the decline. More enlightened, forward-looking thinking is urgently needed. The required R&D commitment cannot wait for the imminent crisis.

Beyond electricity

The roadmap envisions a sustainable, environmentally benign global society for the year 2050—a society powered by a robust, balanced portfolio of supply technologies capable of providing reliable, affordable electricity. But ensuring that future requires action now. Achieving the signifi-

Energy-Carbon Conflict R&D Funding Requirements			
	10-Year Funding ($ millions/yr)		
Goals and Technology Gaps	**Current**	**Additional Needed**	**Total Needed**
Increasing the efficiency of natural gas central stations to over 70%	100	100	200
Materials to withstand high temperature and pressure in high-efficiency designs			
Innovative cycle designs			
Reducing emissions of gas-fired distributed generation systems by half	<100	100	200
Ceramic blades and recuperators for gas turbines for increased operating temperature and efficiency			
Materials for high-reliability fuel cells			
Improving the thermal and resource efficiency of coal-based generation to reduce emissions by half	100	200	300
High-temperature materials for ultrasupercritical steam cycles			
Hot-gas cleanup for gasification and pressurized fluidized-bed combustion systems			
Commercially viable advanced coproduction systems (coal and biomass refineries)	<100	200	300
Low-cost air separation and advanced catalysts for higher efficiency and reduced emissions in coal processing			
Coal and biomass process development			
Carbon capture and sequestration technology with a cost of under $40 per ton of carbon	100	300	400
Low-cost methods for capture at ambient temperature and pressure			
Assessments of feasibility and environmental acceptability of final storage methods			
Cost-competitive renewable generation technologies	300	400	700
Smaller footprint, lower-cost solar and wind generators through increased efficiency			
Low-cost mass production of equipment			
Reliable, maintenance-free distributed renewable power systems for rural and remote locations			
Public acceptance of a new generation of cost-competitive nuclear power plants	<100	500	600
Resolution of safety and proliferation concerns			
High-fuel-utilization designs			
Short construction times and low initial cost			
Integration with the production of hydrogen for use as an energy carrier			
Environmental knowledge base for global climate change	700	200	900
Realistic global models and assessments of global climate change			
Strategies and policies that protect the environment at the least total cost for all global users			
Total funding	1600	2000	3600

cant global deployment of such technologies in 50 years means they must be ready for introduction by 2020–2025.

"Realizing electricity's full potential for solving the trilemma will require the development and deployment of myriad new technologies—some evolutionary, some revolutionary," says EPRI's Yeager. "Success will come only from the dedication of purpose and commitment of resources from a broad range of stakeholders. The world needs a visionary program of coordinated R&D, collaboratively supported by private enterprise and public institutions, in order to achieve the broad and global societal benefits offered by innovation in power-generating and electricity-based technologies. The time to act is now if we are to identify, develop, and deploy at the required pace and scale the energy technologies the world needs for the twenty-first century."

The initial Electricity Technology Roadmap effort illuminates a path to a better future—for the United States and for the world. Its vision extends far beyond electricity as merely a form of energy. It fuses power with the information technology revolution and the many innovations enabled by and dependent on this new mega-infrastructure. The roadmap's integrated portfolio of opportunities and potential innovations can benefit humanity everywhere on the planet. Success will fuel the development of global markets and accelerate growth, while protecting global security and the environment and broadening the base of human opportunity. ■

Further reading

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Background information for this article was provided by Brent Barker (bbarker@epri.com), Corporate Communications; Steve Gehl (sgehl@epri.com), Strategic Technology and Alliances; and Dan Rastler (drastler@epri.com), Terry Peterson (tpeterso@epri.com), and John Stringer (jstringe@epri.com), Science and Technology Development Division.

THE STORY IN BRIEF New satellite technologies and services are creating innovative communications solutions for energy companies—solutions that match the industry trends toward distributed resources, two-way customer communications, and business expansion into new areas. In addition, utilities interested in diversifying their businesses by investing in telecommunications have a growing number of opportunities in the satellite sector. The high costs and signal delays that limited the use of satellites in the

Utility Communications

past are giving way to the expanded capabilities of small, low-earth-orbit (LEO) satellites. These can meet a broad range of operational and strategic business objectives in energy system management and customer-oriented information services. Networks of higher-altitude, bigger LEO satellites are an emerging broadband communications vehicle that will be able to meet the more advanced needs of utilities well into the next decade.

More than half a century ago, Arthur C. Clarke predicted that a revolution, possibly as far-reaching in its effects as the printing and electronics revolutions, would result from the use of satellite networks in space for global, real-time communications. Today, his vision is validated nearly every time someone watches television, pays for gasoline with a credit card, or makes an international telephone call. But probably not even Clarke could have imagined the full magnitude of the explosion ignited as satellites have converged with other technologies for voice and data communications—not just with telephony and broadcasting but also with cellular radio and the Internet.

According to the U.S. National Aeronautics and Space Administration, more than 3500 satellites now orbit the earth, relaying enormous amounts of voice and data traffic in frequent bursts of low-power, radio-frequency transmissions. Until fairly recently, the high costs of satellites, both to manufacture and to launch, and of the large ground stations they typically required had confined their use to very high value applications. These include defense communications and intelligence, weather and other environmental monitoring, public communications networks, and broadcast and cable television.

Over the past decade or so, as the responsibility for launching and operating satellite networks has extended beyond military and government hands to the private sector, the array of commercial and business-oriented applications has been growing. Some of the more familiar examples are detailed earth imaging, remote monitoring of dispersed locations, and highly accurate location and tracking using the continuous signals of the Global Positioning System (GPS).

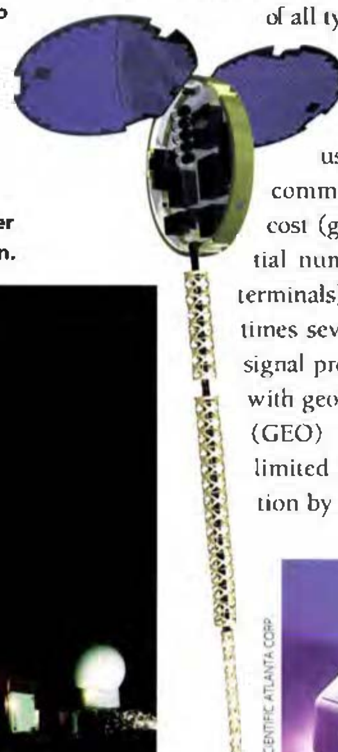
Satellite-based business and personal voice and data services are now available throughout much of the world. Meanwhile, advances in technology continue to reduce the size and cost of satelby Taylor Moore

Go Into Orbit

lites and also of ground terminals, some current examples of which are handheld and cost under $300.

North and South America will see a mammoth new wave of business and consumer applications of satellite communications in the next five to six years if even half of the projects that have been announced come to pass. In just the past few years, major aerospace, electronics, communications, direct satellite broadcasting, and Internet service companies have unveiled ambitious plans to roll out very high speed, very high capacity broadband data services (some with voice) for Internet, multimedia, and corporate networks. Some 1200 additional low- and medium-earth-orbit satellites deployed in large constellations are required for these networks, which are expected to cost more than $20 billion; many of the new satellites are already in orbit.

Orbcomm Global operates the first commercial network of LEO satellites for mobile data and messaging communications. The network has 28 satellites in orbit and 15 gateway ground stations installed or under construction on five continents; it is coordinated by a control center in the United States. Multiple satellites can be carried into orbit by a single rocket, either a rocket launched from a high-flying L-1011 airplane or an Orbital Sciences pad-launched Taurus rocket. A commercially available Orbcomm application for electric utilities features Scientific Atlanta's compact, fixed-site remote terminal unit for customer meter reading and distribution system automation.



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The convergence of computers, television, and the Internet against the backdrop of an ongoing revolution in communications technology is rapidly creating a greed for speed and a virtually insatiable appetite for bandwidth, or high data capacity, among users of all sorts the world over. Many of the major technology companies view satellites as essential for realizing the vision of global broadband wireless communications.

Satellite technology, specifically the technology for small, low-earth-orbit (LEO) satellites, makes it possible to remotely monitor and control dispersed equipment and systems by using relatively inexpensive, rapidly deployable infrastructure on the ground. The technology's relevance to numerous applications by energy companies has long been recognized. Satellites are used to a limited extent by oil and gas companies, for example, to control and communicate with far-flung production, pipeline, and tanker networks.

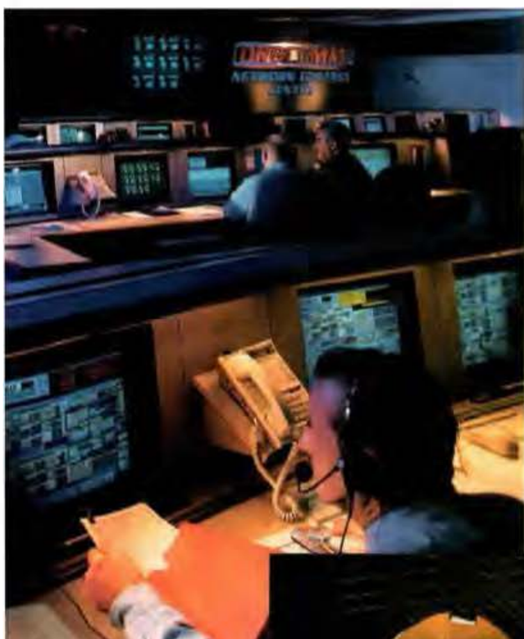
Electric utilities, which are major users of all types of terrestrial communications technologies, also use some satellite communications. But cost (given the potential number of ground terminals) and the sometimes several seconds of signal propagation delay with geostationary-orbit (GEO) satellites have limited their application by electric utilities until very recently. Typically, the economics have been compelling for only a few important sites, such as remote substations. And the propagation delay has made the technology unsuitable for applications involving critical, real-time protection mechanisms, which abound in utility power system operations.

New and emerging LEO satellites—classified by their size, operating altitude and frequency, and bandwidth capacity as big LEOs and little LEOs—effectively counter the constraints of cost and propagation delay. They are expected to offer energy companies a multitude of innovative communications capabilities that could have a huge impact on the companies' ability to manage assets and resources at remote or widely dispersed locations.

The new capabilities are highly relevant to the current industry trends toward distributed energy and information assets, improved two-way customer communications, and business expansion beyond traditional boundaries, both nationally and globally. Continued advances in satellite technology will radically extend the scope of economic deployment throughout the energy industry, even where near-real-time system performance is required.

"The increasingly complex and data-intensive energy systems of the future will require communications capabilities that go far beyond those of the technologies now being employed," points out Steve Drenker, area manager for information systems and telecommunications in EPRICSG. "New generations of satellites are creating more options for solving many of the economic and technical problems of dispersed, low-intensity data communications. The new satellites are directly applicable for remote monitoring, metering and control, and portable communications.

"Electric utilities and other energy companies that are diversifying through investments in telecommunications are discovering that the satellite sector is rich with opportunity. A recent round of licensing by the U.S. Federal Communications Commission has brought several new entrants to the satellite network field, and new business alliances are being formed. In addition, the next generation of satellites will greatly expand the universe of economical, even revenue-generating, communications applications for energy companies."



Business context of communications

Energy companies expect communications technologies to meet demanding standards of reliability and availability. And in order for satellites to be widely used by utilities, they must satisfy those requirements at a lower cost than terrestrial options, including telephone circuits, Internet virtual private networks, microwave radio, and the large broadband fiber-optic networks that many utilities are installing for their most data-intensive, corporate-level applications.

A key determinant of the cost of terrestrial options is the distance that signals must travel. In contrast, satellites can provide wide-area coverage with circuit costs that are insensitive to distance. Also, satellite circuits are unaffected by terrestrial emergencies, such as hurricanes, tornadoes, and floods (although some signals can fade out in heavy rain). And satellites can be combined with terrestrial systems to provide economical coverage that meets diverse needs. San Francisco–based Pacific Gas and Electric, for example, manages its mobile workforce by using a combination of 70% terrestrial wireless data service and 30% satellite service.

In an EPRICSG strategic assessment of satellite technology for utility applications published last year, the direct relevance of satellites to two critical business imperatives for utility companies was highlighted. The first of these imperatives is cost reduction.

"Cost reduction is directly related to the use of physical and human assets, which in turn depends on information about system or asset state and on the ability to control that state," explains Ron Skelton, the computer and communications consultant and former EPRI employee who produced the assessment. "To reduce costs, the power transmission and distribution systems and the mobile utility workforce of the future will be highly instrumented. With improved sensing and data processing, in the near future we may see several orders of magnitude more data being captured and communicated. The trend toward distributed generation likewise will dramatically increase the number of sites and the amount of information required for monitoring, diagnostics, and control."

The second business imperative for utility companies is the need to find and develop new sources of revenue. Wide-area communications technologies, especially satellites, provide innovative opportunities for expanding customer bases and offering additional services. "Utilities are no longer constrained by their traditional service areas, and strategic plans to derive additional revenue from both national and international expansion are not uncommon," notes Skelton.

Judging from these assumptions about the future, information infrastructure will become more critical to companies in achieving their operational and strategic objectives. "The scenarios being considered would potentially have very large numbers of remote, distributed elements," Skelton says. "For example, one could imagine every insulator or valve having a built-in processor and communications device. Such a topology means that the communications infrastructure elements

PHOTOS COURTESY ORBITAL SCIENCES CORP.

will always have a major, even dominant, influence on what is economically feasible. Terrestrial communications infrastructure costs are often prohibitive for many of tomorrow's utility applications."

Wide range of applications and options

Satellite technology is well suited for a wide range of utility core business applications and for providing more-advanced support for applications involving two-way customer communications and Internet access. Utilities' primary internal communications needs are for system operation, telemetry and metering, mobile messaging, and data communications in support of asset management and work-force automation.

COURTESY SALT RIVER PROJECT

As a value-added reseller of Orbcomm USA services, Salt River Project markets Spātia—a satellite-based system for near-real-time communications and the processing of remote monitoring and metering data for water, electricity, and natural gas utilities in the western states.

Telemetry applications typically involve one-way monitoring or two-way monitoring and control modes. Many trends in the electric utility industry today—including business expansion into new territory (e.g., through merchant power or distributed generation), real-time pricing, and national account marketing—involve telemetry. There are also increasing requirements for more-refined metering of power flows and sensing of power quality at more locations. A key driver for telemetry is communication with field personnel for dispatch, reporting, and access to the geographic information system databases used in automated mapping and facilities management.

Relatively small, inexpensive LEO satellites in nongeosynchronous orbit at altitudes of 750–1500 kilometers (470–930 mi) operate at VHF and UHF frequencies below 500 MHz, which allows their signals to penetrate foliage and some building structures. Little LEOs offer narrow bandwidth but potentially global coverage, given a constellation with enough satellites to hand off or store and forward traffic as they move across the line of sight. Each satellite is visible only intermittently and for short periods.

Little LEO satellites are expected to be ideal as a low-cost communications infrastructure for simultaneously supporting telemetry and other applications, particularly in situations where there are no viable alternatives. For example, many oil and gas wells in Canada are in remote areas where telephone lines do not reach and even cellular service is not available. The production companies use GEO satellites to closely monitor pressures, temperatures, and flow rates for those wells and to open or close them or adjust flows remotely. The technology is expensive—costing five times what cellular service would cost if it were available—but its ability to meet the companies' business requirements is invaluable. Little LEO systems are expected to offer service and equipment at significantly lower cost than the GEO technology.

Metering and connect-disconnect services, two utility applications of conventional telemetry that are usually costly when performed by field personnel, are prime candidates for the use of satellite communications. For a typical utility with remote terrain, as few as 3% of the meters can account for nearly 20% of total meter reading costs. Several companies already offer, or have announced plans to offer, automated meter reading equipment and services using little LEO satellites.

Another satellite service, implemented in combination with land-based networks, gives fleet managers the ability to communicate instantly with their drivers. The voice dispatch service features a push-to-talk communications channel. A manager could even have a real-time desktop computer display of fleet activity and location: vehicles could be equipped with GPS receivers and transmitters that would route data to a satellite, which would then relay the information, either directly or over the Internet, to the manager's computer.

According to EPRI's assessment, little LEOs are the best option for a broad range of bidirectional data communications when the total amount of data to be transmitted is relatively small and the length of individual messages is short (typically 500 characters or less). They are also the preferred choice for two-way communications when low-cost terminal equipment and low service rates are required. Applications of possible interest to utilities include meter reading and load management, supervisory control and data acquisition (SCADA) for distribution systems, monitoring of field personnel, industrial monitoring and control, vehicle monitoring, asset tracking and status reporting, emergency communications, security and other alarm monitoring, point-of-sale vending, and direct-to-home interactive services (i.e., as a return path).

Big LEOs have higher capacity and operate at microwave frequency bands above 1 GHz. They are the best option for mobile voice communications and data communications when the amount of data is significant and warrants the additional cost of link setup and takedown time. Big LEOs can provide continuous regional or global coverage like little LEOs, but they are generally restricted to applications for which higher-cost terminal equipment and service rates of $3 per minute can be justified.

As a result of the advent of commercial satellite imaging networks, there are new possibilities for detailed mapping of utility service areas. Resolution is already as fine as 5.8 meters (19 ft), and in the near future, it will be 1 meter (3.3 ft) in black and white and 4 meters (13 ft) in color. Satel-

How Leo One Works

Messages will be sent between users—persons or machines—when one or both are equipped with a Leo One communications device.

1 A communications device will send a message to the nearest in-view Leo One satellite.

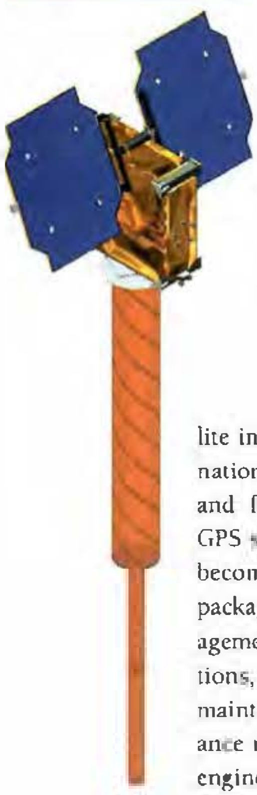
2 The satellite will forward the message to a gateway for validation and optimal routing.

3 The gateway will forward the message to the recipient via the best communications path—satellite, Internet, private or public data network (PDN), or the public switched telephone network (PSTN).

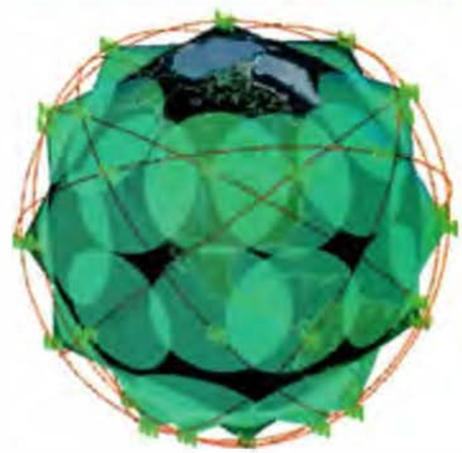
4 In some cases, the receiving gateway will route the message to another gateway, from which it will be delivered via the appropriate communications path.

5 Users connected to the wired terrestrial network will also initiate messages, which will be routed to a Leo One gateway and delivered via a Leo One satellite to a communications device.

ARTWORK COURTESY LEO ONE USA CORP.



Leo One USA Corporation has a license to begin operating a constellation of 48 high-capacity LEO satellites in 2002. This network will provide a range of near-real-time communications services to users around the world, including tracking and fleet management, monitoring and remote control, two-way messaging, emergency services, and transaction processing. Each satellite's footprint—the area on the earth where it is visible at any given point in its orbit—will be roughly the size of the United States. The constellation's orbital configuration and inclination will provide global, overlapping-footprint coverage, with more than one satellite visible to users at all times. Two primary gateway ground stations in the continental United States are planned, with a third in Alaska.



lite imaging in combination with mapping and facility data and GPS signals is quickly becoming a powerful package for asset management, field inspections, calibration and maintenance, compliance reporting, on-site engineering, and fleet management. Providing messaging capabilities to mobile workers equipped with laptop computers or personal digital assistants is enabling an unprecedented level of workforce management that can be invaluable during emergencies.

GPS applications for vehicle navigation, which have been booming in Japan and Europe, are now beginning to take off in the United States. Combining navigation and communications functions would allow rapid position fixing in case of emergencies, and integrating GPS and cellular radio in single units could allow map displays to be embedded in hands-free mobile phones. In fact, within the next couple of years, the Federal Communications Commission will require all new cell phones in the United States to be equipped with GPS signal receivers.

Meanwhile, innovative applications in fleet management and network time stamping—applications that are of keen interest to utilities—are emerging for GPS. Because they are as accurate as atomic clocks at a fraction of the cost, GPS signals can be used for the precise synchronization of a variety of voice and data networks. Such timing accuracy could be of considerable benefit in improving the management of the electric power grid by making it possible to record system anomalies precisely.

An information superskyway?

The Internet is rapidly expanding the range of applications for satellite-based data communications. Two of the most popular of the applications are accessing the Internet itself and connecting remote sites to corporate networks. Some satellite systems, including those of satellite TV providers, allow users to browse Web pages and download data—at 400 kilobits per second (kbps)—through a 21-inch (53-cm) roof-mounted dish receiver connected to a personal computer with an in-

Utilities Invest in Satellite Communications

A significant number of electric utilities—investor-owned companies, rural cooperatives, and public and municipal utilities—are using satellite communications today, primarily for limited telemetry and control functions at remote substations. Other applications include reading remote customer meters automatically; managing the power demand of customer loads, including hot water heaters and air conditioners; and managing mobile utility workforces, with satellites typically serving as a remote extension of cellular radio. Meanwhile, utility use of Global Positioning System data for mapping and mobile location tracking is increasingly common.

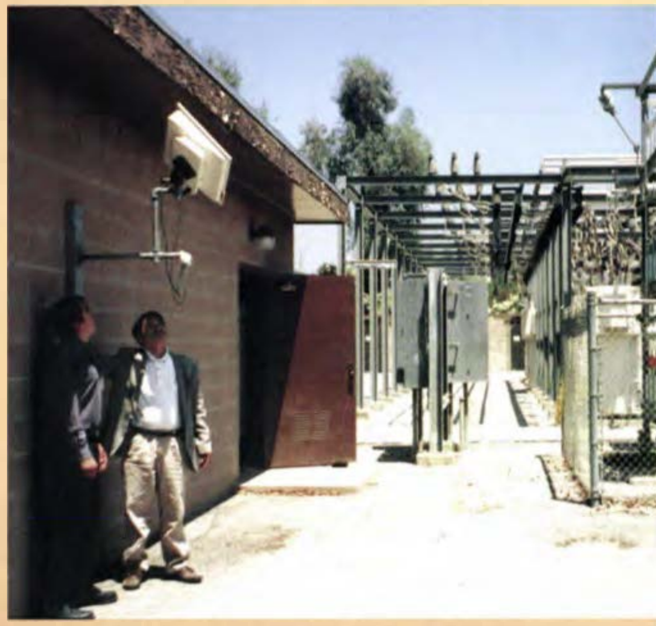
To cost-effectively automate the remote substations across its large service territory, Southern California Edison (SCE) developed the world's first ultrasmall-antenna-terminal commercial satellite system licensed by the Federal Communications Commission for substation SCADA (supervisory control and data acquisition) applications. Deployed in 1995, the system features flat-array ground terminals with antennas 0.3 meter (1 ft) across. The terminals communicate with a geosynchronous-orbit satellite via spread-spectrum, Ku-band microwave at data rates of up to 2.4 kbps. An external notebook-size electronics module handles signal transmission, conversion, and processing.

SCE's Ross Fernandes, satellite communications program manager and senior consulting engineer, says that the system—called Ultra-Net™—is used for SCADA communications to monitor and control over 150 remote substations. The substation remote terminal units are polled every 4 seconds to report any change in the status of substation equipment. In the first year of operation, SCE estimated that Ultra-Net saved it $30 million compared with other automation and communications options.

SCE says Ultra-Net is the first Ku-band satellite communications technology capable of error-free data communications, even during heavy rain (exceeding 3 inches an hour). In addition to SCADA for electric, gas, and water utilities and for oil and gas pipelines, the system can support distribution automation, pole-top monitoring and control, and weather or hydrological data collection.

In another effort, Phoenix-based Salt River Project developed and markets Spãtia™, a satellite-based system for near-real-time communications and the processing of remote monitoring and metering data for water, electricity, and natural gas utilities. SRP markets Spãtia—primarily in the western states—as a value-added reseller of Orbcomm USA network services. These services are available via the first commercial LEO (low-earth-orbit) satellite constellation, which was developed by Orbital Sciences Corporation and Teleglobe of Canada. (Recently, Orbcomm announced that a licensee in the Ukraine is planning to use its satellite network and equipment to monitor environmental conditions at the Chernobyl nuclear power station.)

Bruce Hallin, director of business development for Spãtia, says SRP is installing low-cost remote terminal units at about 200 sites for its customers, which include municipal water systems and electric utilities, irrigation districts, government agencies, mines, and other industrial operations. Electric utility applications include remote substation telemetry, load profiling and analysis, system control, alarm notification, and near-real-time monitoring of



Southern California Edison uses its Ultra-Net system to monitor and control over 150 remote substations in its service area. Ultra-Net features very small antenna (0.3-meter), flat-array ground terminals, which communicate with a GEO satellite via Ku-band microwave.

terface card. This capability could become a valuable tool for extending a utility's enterprise network to remote offices around the world.

Many utilities are basing their enterprise strategy on the use of Internet technologies on private networks, called intranets. The value of the Internet as a research tool and a vehicle for communicating with customers is likely to continue to expand exponentially. But for many companies, although their fixed campus networks have sufficient bandwidth to support intranets, their remote offices, customers, and mobile workers generally do not. Intranets require powerful servers and sophisticated networking, and despite the gains in time and cost efficiencies they can help companies achieve, inadequate bandwidth can make network performance unacceptable to users.

The explosion of the Internet and the World Wide Web, multimedia, streaming video, and compressed audio downloads—together with the almost total acceptance of remote workers—has nearly exhausted the bandwidth capabilities of peak electricity use for customers. The system can also remotely monitor reactive power and temperature and could be used for customer billing applications. "The business is in a real growth mode, and as we work with more customers, we're discovering new applications that we hadn't envisioned," says Hallin.

Satellite systems featuring very small aperture terminal (VSAT) technology are being used by dozens of rural electric cooperatives and municipal utilities for SCADA applications at remote substations, for customer meter reading, and, in some cases, for load control. Several of these utilities are using low-cost (about $6000) ground terminals developed by Nova-Net Communications in research that was supported by EPRI and the National Rural Electric Cooperative Association (NRECA). Now a wholly owned subsidiary of Stratos Global Corporation, Nova-Net offers integrated hardware and network services customized for SCADA applications for the electricity, gas, and oil industries.

COURTESY SOUTHERN CALIFORNIA EDISON

Called SCADA-SATs, Nova-Net's all-weather terminals are capable of operating with other distribution system monitoring and control equipment because they incorporate the EPRI-developed Utility Communications Architecture (UCA™). "The result," says Bill Blair, the EPRI project manager for both the SCADA-SAT and UCA efforts, "is an integrated distribution automation system." The terminals can also be linked with radio systems to operate as signal repeaters for communication with other remote sites. Models are available for ac or dc (including photovoltaic) power.

A major user of Nova-Net's VSAT technology is Buckeye Power, which began applying it nearly a decade ago to monitor and manage the loads of its member distribution cooperatives in Ohio. During periods of peak electricity use, some customer loads are remotely controlled via radio signals to reduce the need for additional purchased power. A recent expansion has brought Buckeye Power's network to around 250 ground terminals.

Carolina Power & Light was attracted to the Nova-Net technology not only because it costs less and is easier to install than leased telephone circuits but also because it can withstand extreme weather. CP&L's service territory, which includes Cape Hatteras, was severely damaged by Hurricane Fran in 1996. Land-line and cellular communications to 80–90% of the utility's substations were lost, in some cases for weeks. All ground-based communications infrastructure had to be rebuilt.

CP&L noticed that VSATs installed by the neighboring North Carolina Municipal Power Agency enabled it to maintain SCADA communications with distribution substations through the full course of Fran's fury. "That impressed us quite a bit," says Scott Bowen, a CP&L senior technical specialist for distribution systems. "We had looked into satellite communications in the 1980s, but the costs appeared prohibitive. When we investigated again after Fran, the costs had declined enough to be comparable to those of dedicated telephone circuits."

Bowen explains that "such items as requirements for trenching and fault protection were continually driving up the cost of telephone circuits, and at some point, the curves crossed. We can now install VSAT satellite communications at a substation a lot more quickly and, in many cases, at a lower cost than we can a telephone circuit. Monthly service costs are comparable to those for phone circuits, and I expect they will be lower in the long run. In our experience, the day-to-day reliability has been better than that of phone circuits." CP&L expects to soon have about 185 VSATs installed at substations; units are routinely specified for new substations.

Recently, in half a dozen states, members of NRECA's Cooperative Research Network participated in a successful field test of Orbcomm's little LEO satellite communications for remote meter reading and substation monitoring; terminal hardware from Scientific Atlanta was used. One participating utility, East Mississippi Electric Power Association, developed a customized application for operating a distribution circuit recloser at a remote substation.

"LEO technology looks promising and should be valuable to electric cooperatives for remote meter reading, monitoring, and, to some extent, control of field equipment," says Marty Gordon, senior program manager for the NRECA research network. "Although LEO satellites are not suitable for use with real-time SCADA systems at substations that require device scanning every few seconds, they can be a valuable communications tool for an electric cooperative's distribution automation and meter reading efforts." □

the so-called last mile of land-based circuits (i.e., the connection to the user). As a result, the prospect of a massive-bandwidth, satellite-based Internet service, planned as part of several major global satellite networks whose deployment will begin early in the next decade, is appealing to many companies.

"If a company pays three times more for its Internet access but gets a 10-fold increase in bandwidth, the economics could be compelling," says Skelton. "If satellite Internet access indeed ushers in the levels of bandwidth that many satellite experts are talking about, business users could actually interconnect their local area networks across their intranets as a private switched network. Such a network would operate at significantly higher speed and lower cost than currently possible with public data network services."

The consulting firm Booz-Allen & Hamilton forecasts that the global market for broadband communications will grow to nearly $200 billion by 2005 and that space-based systems will capture 10–15% of that market. The majority of broadband communications will be carried by terrestrial fiber, local microwave, and digital cable networks that telephone and cable companies are already expanding and upgrading. However, the cost of these services could be undercut by operators of big LEO satellite networks who, after selling a firm amount of reserved capacity, offered discounted bandwidth on a nonguaranteed basis.

Nova-Net Communications provides private satellite networks that use VSAT (very small aperture terminal) technology for virtually error-free, high-reliability data communications. The company specializes in SCADA (supervisory control and data acquisition) applications for remote facilities. Its customers include oil and gas pipelines and more than a dozen electric utilities. EPRI provided support for Nova-Net's development of a low-cost VSAT that is used by several rural electric cooperatives.

Satellites and strategic options

EPRI's strategic assessment of satellite communications for utilities includes an overview of the technology: the various classes of satellites, their technical features, and a comparison of the range of performance and appropriate application options. It also provides a detailed description (current as of late 1997) of the business plans of various satellite network ventures.

The lower-altitude orbit of little LEO satellites reduces the one-way signal propagation delay to 6.3 milliseconds, with significantly reduced latency (cumulative delay), and also reduces signal attenuation. These features make the satellites directly applicable for some utility remote monitoring and control functions. Propagation delay at any altitude tends to be the controlling performance issue for most time-sensitive utility applications, such as distribution system SCADA. (One 60-Hz cycle lasts 17 milliseconds.)

In addition, the reduced signal attenuation means that ground terminal antennas can be simple; some can even be as small as the whip antenna of a cell phone. Satellite voice service using a handheld terminal is expected to be available from networks of little LEOs.

Because little LEOs use more fuel to remain in proper orbit, their life spans (five to seven years) can be as little as half those of bigger satellites operating at higher altitudes. A constellation of 48–50 little LEOs would be required for continuous coverage of either the world or the continental United States, depending on their orbital pattern and altitude.

The only current constellation of little LEOs is operated by Orbcomm Global, a joint venture of Orbital Sciences Corporation and the Canadian company Teleglobe. The constellation consists of 28 satellites that provide intermittent global coverage for two-way communications services, including messaging, emergency alerts, position reporting, and remote data collection. Orbcomm has a license for up to 36 satellites.

Leo One USA Corporation is planning a new constellation of 48 satellites to provide continuous coverage of the continental United States. Recently licensed, the constellation is scheduled to begin operating by the end of 2000, initially with just 2 satellites. When all 48 are operating by late 2002, says the company, the Leo One network will provide near-real-time, low-intensity data communications with latencies under 30 seconds.

In general, large GEO satellites are the system of choice for applications requiring either continuous service or bandwidth on demand and data rates of 1.5 Mbps and higher. GEOs are most appropriate for applications that do not require mobility and can accommodate dish antennas of 1–3 meters (3.3–9.8 ft) in diameter. Terminal costs range from $5000 to $25,000, and monthly continuous-service rates of $50,000–$100,000 must be justified.

Most current and planned LEO networks involve the use of very small aperture terminal (VSAT) technology, which for many utility applications provides the best combination of cost, capability, control, and coverage. ComTier Corporation recently announced that as a result of improved electronics design and signal modulation, it is developing a VSAT-based LEO system that will offer substantially greater bandwidth (for data rates of up to 155 Mbps) at even lower cost, enabling multiple simultaneous applications in a complete enterprise network. These could include live mobile video monitoring from dispersed remote sites, coupled with voice and data communications.

EPRI's strategic assessment discusses the key terrestrial communications technologies competing with satellites and also offers insights on important technical and operational issues confronting the commercial satellite services industry. One problem is that of rocket launch failures. During the past year, half a dozen failures involving civilian and military payloads have resulted in losses totaling $3.5 billion. Another problem is that many announced satellite communications ventures are struggling financially because of overoptimistic projections of early customer commitments.

Satellite System Characteristics

	Little LEOs	Big LEOs/ MEOs	GEOs
Satellites			
Altitude	750–1500 km	750–11,000 km	36,000 km
Bands and frequencies	VHF, UHF below 500 MHz	L and S microwave (1.6 and 2.5 GHz)	K microwave (19 and 29 GHz)
Weight	40–125 kg	350–500 kg	Up to 1200 kg
Complexity	Low	High to very high	Variable low to high
Cost to build, launch, operate	Low	Very high	High to very high
Terminals			
Power required	Low	Low	High
Type	Handheld or embedded	Handheld fixed and portable	Fixed and portable
Antenna	Whip, helix, or dipole	Helix	Dish or phased array
Location and orientation limits	Medium	High	Very high
Propagation			
Rain attenuation	Low	Medium	High
Foliage penetration	High	Low	Low
Building penetration	Medium	Low	Very low
Multipath interference	Medium	High	High
Noise background	High	Medium	Medium
Services			
Position location	Yes	Yes	Yes
Data communications	Yes	Yes	Yes
Voice communications	No	Yes	Yes
Cost			
Terminals	$50–$500	$2000+	$2000+
Monthly services	Low	High	High

Note: LEO stands for low earth orbit; MEO, medium earth orbit; GEO, geosynchronous orbit.

Opportunity and timing

EPRI's assessment of satellite communications concludes there is ample opportunity for low-risk utility applications that can deliver business advantages. Moreover, the study suggests, the time is ripe for utility equity investments with satellite service providers as strategic business partners.

A clear distinction is drawn between little LEOs, which are optimized for low-cost, low-data requirements, and big LEOs, which are aimed at greater-bandwidth applications. The markets and the technical risks of big LEOs are formidable, and currently their services are not well aligned with the core utility businesses of electricity generation and delivery. However, big LEOs may provide new opportunities for broadband communications for the energy industry.

Regarding little LEOs, a distinction is made between constellations that are designed for continuous coverage and those that are not. The latter's temporal and spatial gaps in communication will require users to make trade-offs, which could be significant for some applications. Little LEOs meet many of the core telemetry needs of energy industries now and will be capable of meeting growing requirements in the future. The systems that provide continuous service will be the most useful to utilities. ■

Further reading

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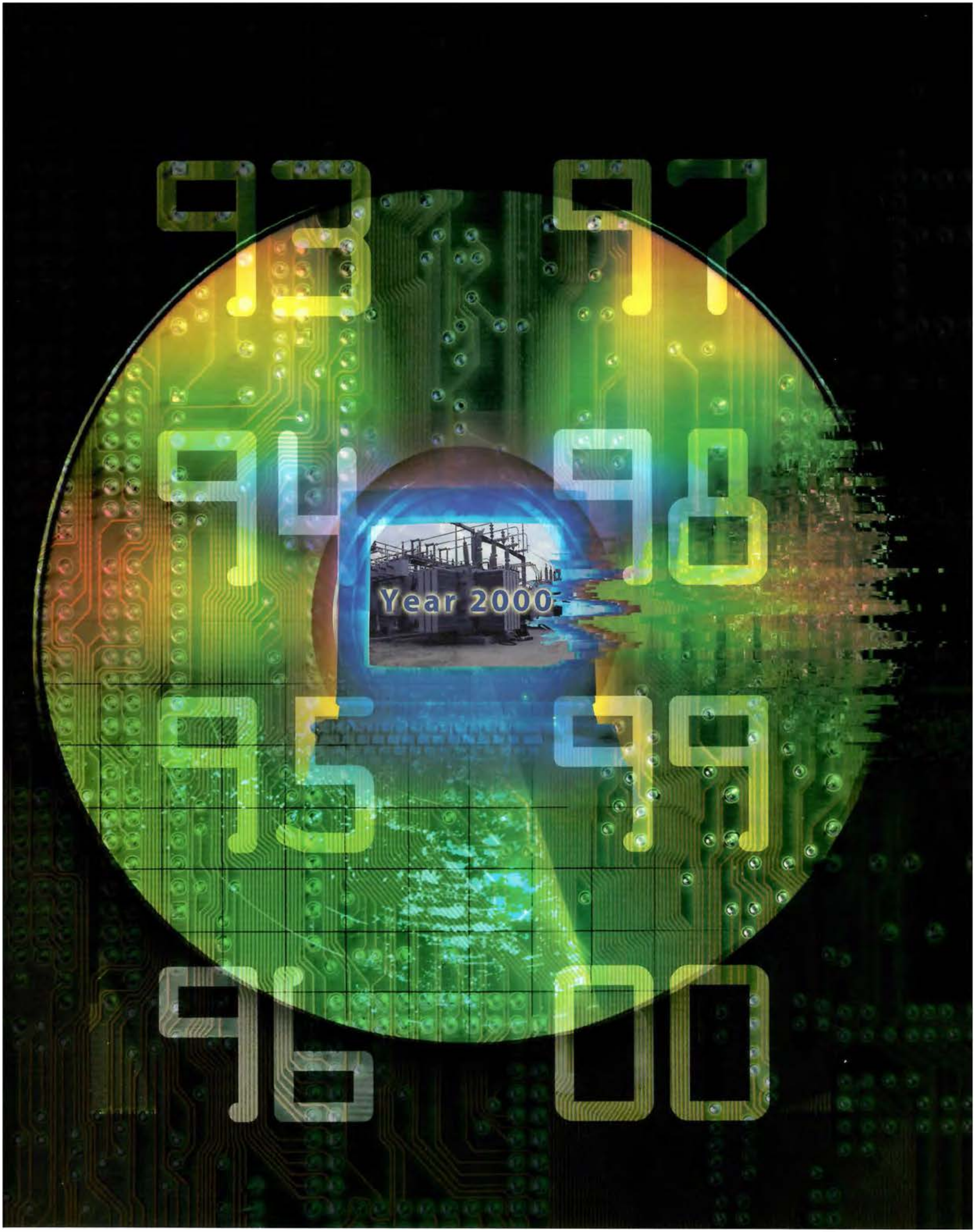
Bi-Directional Satellite Communications Terminal. EPRI. December 1995. TR-103577.

Background information for this article was provided by Steve Drenker (sdrenker@epri.com), EPRICSG, and William Blair (bblair@epri.com), Science and Technology Development Division.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As the final days of the twentieth century approach, time is running out for dealing with the so-called millennium bug, which threatens virtually all commercial computer-based systems. For the electric power industry, embedded systems in control hardware—systems featuring built-in microprocessor chips—have posed the most difficult challenge, since the chips are often harder to locate and deal with than software problems. The utility industry, assisted by EPRI's Embedded Systems Program, has gotten a firm handle on this problem and has now nearly completed its Y2K preparations.

Y2K: The Power to Transcend

by Dawn Levy

The deregulation of the power industry has spurred unprecedented competition. Yet utilities are showing that they can still cooperate—at least when faced with a technical problem too big for any one company to handle alone. The most pressing such problem is the year 2000 (Y2K) issue, which originated in the decision of early computer programmers to take a shortcut and encode year dates with two rather than four digits. When 1999 passes into the year 2000, many digitally based systems may malfunction by misinterpreting 00 as 1900, 1980, or some other default date.

As providers of a crucial national infrastructure, electric utilities have taken Y2K seriously from the start. The software issues have been under study and remediation since the mid-1990s. Not until 1996–1997, however, was it realized that Y2K problems could also strike the microprocessors that are built into digital control, monitoring, and data acquisition systems—devices used to run industrial processes and plants, route telephone calls, operate household appliances, and perform a myriad of other applications in both the home and the workplace. Embedded microprocessor-based systems control and monitor electricity generation and flow at hundreds of points in a power plant and along the way to end-use sites.

Once alerted to the potential impact of Y2K on embedded systems, the industry asked EPRI to create a collaborative program for sharing technical information and building an industrywide knowledge base. Begun in the fall of 1997, this effort produced an industry consensus on assessing Y2K problems and developing solutions. As a result, by mid-1998 almost the entire industry was well on the way to remedying the embedded-system problems in a cost-effective, timely manner. On August 3, 1999, the North American Electric Reliability Council (NERC) stated that "more than 99% of the U.S. and Canadian electricity supply systems are ready for Y2K." But some final

ILLUSTRATION BY BOB MATTHEW

testing and contingency planning remain, and as Jim Fortune, operations manager of the EPRI Y2K Embedded Systems Program, says, "This is a problem for which you cannot be a second late."

The embedded problem

Embedded systems based on dedicated microprocessors are a major issue because of their widespread use in a variety of equipment and because of different standards for designing and manufacturing both the systems and the microprocessors. Worldwide, more than a billion embedded chips control electronic equipment ranging from telephones, thermostats, and televisions to cars, credit card readers, and CAT scanners.

In the power industry, embedded systems control mission-critical operations in energy generation, transmission, distribution, and metering. On the generation side, for instance, they run a plant's distributed control systems, programmable logic controllers, environmental control systems, and process instrumentation. On the delivery side, they control substation automation, protective relays, energy management systems, and supervisory control and data acquisition systems.

With embedded systems, clocks may be either hard-wired as chips or encoded in software; thus, to properly assess potential Y2K problems, one must consider both the microprocessor and the system in which it operates. If the microprocessor is susceptible to a Y2K failure that will cause the system to malfunction or stop running, the microprocessor must either be replaced or be reprogrammed by replacing the EPROM, a programmable memory device. If neither is possible, the entire embedded system must be replaced. But many embedded devices in the power industry are integrated with others to form large, complex systems that operate in concert with complex software routines, which themselves may have Y2K problems. Early on, this situation was a major headache for utility engineers.

To deal with embedded systems, a company must inventory every piece of equipment that has a chip in it—a difficult challenge in itself. In some cases, embedded chips are inaccessible. And an engineer trying to find the clocks in an embedded system may not be able to see them all: large control systems can have 60 or 70 clocks, not all of which are displayed on the operators' screens. It's hard to tell if some devices even have clocks.

The next step is to assess the criticality of each device to the company's business. Whether or not a device is mission critical depends on its importance to ensuring safety, the continuation of business, and regulatory compliance, and that varies from plant to plant. If a device is found to be critical, it must be tested. That entails advancing the built-in electronic clocks to December 31, 1999—usually while equipment is down for scheduled maintenance or refueling—and letting the device run into the simulated year 2000. Then engineers check to see whether the device performed its critical function. For instance, if it was programmed to flip a switch, did it? If it did flip the switch correctly, did performance monitors display the wrong date or print out nonsense data?

The testing problem is complicated by the fact that there are a number of dates, both before and after December 31, 1999, that can cause Y2K problems, and devices must be tested for each of these dates as well. Another issue is the sensitivity of some embedded systems to power on/off functions; that is, some noncompliant devices may appear to operate properly as long as they are powered on, but if the power goes off in 2000 and then back on, their internal clocks may reset to 1900.

Embedded microprocessor-based systems control mission-critical functions in all stages of power production and delivery. To identify and remediate potential Y2K problems in these ubiquitous devices, power companies around the world have undertaken unprecedented equipment testing.

Generation
- Distributed control systems
- Programmable logic controllers
- Remote terminal units
- Communications devices
- Relays
- Meters

Control Centers
- Energy management systems

Transmission
- Programmable logic controllers
- Remote terminal units
- Digital fault recorders
- Communications devices
- Sequence-of-event recorders

As utilities conducted testing and learned more about the scope and depth of the Y2K problem, they came to appreciate that it would be impossible to identify and fix all the potential embedded-chip problems in time. "Fortunately, a significant fraction of the devices are what we call date dumb —the date doesn't matter," explains Charlie Siebenthal, director of the EPRI Y2K program. The vast majority of Y2K noncompliance problems are cosmetic in nature and do not affect the functional performance of the devices. Therefore, the program participants have focused on the most important work—dealing with mission-critical devices. This decision has served to maintain all critical functions while saving billions of dollars and several years of testing.

Response to deadline 2000

In mid-1997, EPRI Y2K technical manager Joe Weiss first warned EPRI and its members of the potential for embedded-systems problems. In September 1997, EPRI hosted an industry meeting in Scottsdale, Arizona, to find out the level of concern about the issue. Power companies responded by asking EPRI to take the lead in developing an industrywide Y2K knowledge base. To build such a base, the companies would have to put competition on the back burner and share information openly.

Y2K was a problem the likes of which utilities and their vendors had never seen before. They had a little more than two years to find or create solutions—but no experience, books, or blueprints to guide them. Together the industry and EPRI had to learn in real time what the problem was, how big it was, and what it took to solve it.

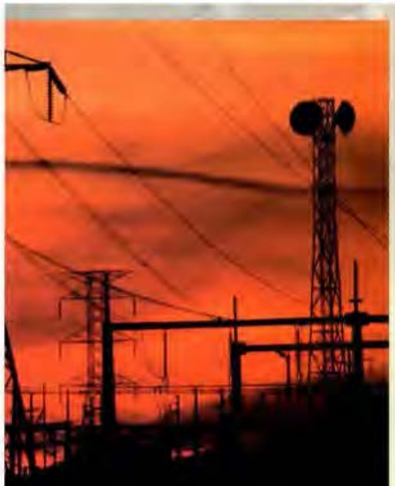
"EPRI's program was designed to provide a forum for a coordinated industry technical response to the Y2K problem," says Siebenthal. "It has served as a focal point for systematically collecting, organizing, sharing, and discussing technical information about embedded systems so that participants can assess and mitigate potential problems." Members get access to a continuously updated technical database, a World Wide Web site for the rapid dissemination and discussion of results, and workshops for education and networking. They also receive a newsletter, system and component testing guidelines, reports of lessons learned, contingency plans and reactive strategies, and help in forming collaborative test teams.

As a result of EPRI's high credibility in the area of embedded systems, program membership has grown beyond the power industry (see sidebar, p. 34). Weiss, who had worked with the major control system vendors in EPRI's Instrumentation and Control Program, helped build a strong network of organizations with good technical information to contribute. This network includes the U.S. Department of Energy, the U.S. Department of Defense, and such companies as Microsoft, Motorola, Intel, Hewlett-Packard, DEC (now Compaq), and the Big Three car manufacturers. "General Motors, Ford, and Chrysler probably know more about embedded microprocessor-based systems than anybody because they've been putting them in cars for years," says Weiss, who arranged for the sharing of test information between EPRI, the automakers, and six large electric utilities that serve them.

"EPRI's Embedded Systems Program is a model for Y2K cooperation and information sharing across company and industry lines," says John Koskinen, chair of President Clinton's Council on Year 2000 Conversion. "It has helped utilities deal more effectively and efficiently with this unique problem. I am confident that the lines of communication established through this program will be valuable to the industry well after January 1, 2000."

Building and sharing the data

The Y2K knowledge base, which contains inventory lists, test procedures, and test results, is at the heart of the EPRI program. Recently the base has been expanded to include contingency-planning



- Global Positioning System receivers
- Interutility ties
- Relays
- Meters

Distribution

- Supervisory control and data acquisition systems
- Programmable logic controllers
- Remote terminal units
- Digital fault recorders
- Communications devices
- Sequence-of-event recorders
- Global Positioning System receivers
- Load tap changers
- Relays
- Meters

Residential Customers

- Meters

strategies, both internal and external communications plans, and information about facility operations.

The EPRI-organized Y2K Gateway Team facilitates data identification, acquisition, and entry into the knowledge base. Team personnel work with program members on a daily basis through face-to-face contact, phone calls, mail, and the Internet. "To ensure the integrity of the knowledge base and reduce problems associated with the high degree of variability in the data, one service we provide is data entry," says team manager John Allen. "It's basically a quality control function. We input the participants' information in a consistent way so that it can be efficiently retrieved by members using the database."

The Gateway Team also coordinates activities of common interest to members, as when one member wants to witness another's test of a particular component or system. By facilitating the sharing of test information, the team helps to prevent duplicated efforts. For example, since the Honeywell TDC 3000 distributed control system is found in both fossil power plants and oil refineries, members as diverse as Texaco and Louisville Gas and Electric could directly use Y2K test data on this system from any other participating company.

The Y2K knowledge base currently has more than 20,000 items, only a small fraction of which have been deemed critical. Aggregated test results for critical items are presented and are linked via hypertext to the original test data.

Internet communications help members get information quickly, and the EPRI Y2K Web site has evolved to meet changing member needs. The technical knowledge base is posted on the Web site, making it possible for members to upload and download data directly. The site also contains information about the Y2K workshops and other program activities. Members can register on-line for upcoming events or can access presentations and minutes from events they were unable to attend. They can also use the Web site to post information directly to interest groups. Although regional and customized training is available on request, members can consult a complete on-line training manual that includes an orientation to the Web site and instructions for searching the database by company, vendor, component, and testing information. All member inquiries are addressed within 24 hours. The Web site has been such a success that federal officials have encouraged other trade groups to create similar Y2K information-sharing sites.

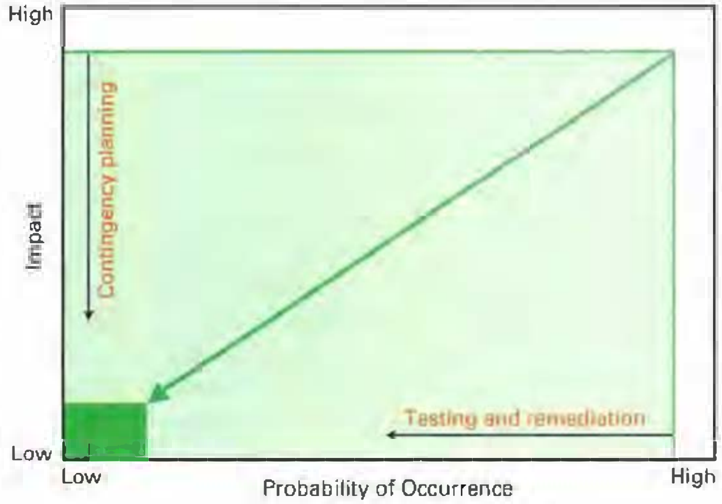
Early on, the program expanded beyond the Web site and database to facilitate networking and the sharing of remediation experiences. The program has hosted over a dozen workshops—a general quarterly series, plus regional and specialized meetings—with more than 2500 participants. "One of the keys to success has been anticipating the members' needs," points out Siebenthal. "Each quarterly workshop has introduced them to the next step in the process and pushed them to move faster." At the first workshop, participants looked at the questions, what is the problem and what is EPRI's role in solving it? The second workshop focused on designing a program that would address embedded systems. The third, fourth, and fifth workshops dealt with technical issues concerning the equipment found in power plants, transmission systems, and substations.

EPRI's Embedded Systems Program has assembled—and continually updates—a comprehensive, international on-line knowledge base of Y2K equipment test results and other technical information. The program also sponsors regular quarterly workshops, regional and specialized workshops, and Web site training sessions to keep its members abreast of the latest Y2K developments.

The workshops have covered issues with practicality and depth. "For instance, transmission and distribution workshops initially focused on sharing test plans, procedures, and results for various specific T&D devices and systems," says EPRI Y2K T&D manager Bill Steeley, "and then moved on to address integrated tests designed to roll over entire substations and other parts of the T&D system."

As more devices have been tested and more problems remediated, the program's workshops have evolved to address such interface issues as contingency planning and supply chains and such emerging topics of concern as distributed control systems, boiler control systems, and natural gas distribution.

An interface issue that has received considerable attention is telecommunications, which early on was recognized to be the glue that held utility operations and grid operations together. While most energy companies own and operate private telecommunications systems to support their business activities, they still have critical dependencies on public networks for both voice and data communications. Thus telecommunications was added to the critical technical areas and has been addressed in both workshops and pilot programs involving information sharing and contingency-planning discussions between utilities and their telecommunications service providers.



The goal of the industry's Y2K preparation is to shrink the field of probable events to avoid a high likelihood of serious problems, such as the loss of a generator or transmission line. Testing and remediation efforts reduce an event's probability of occurrence, while contingency planning can minimize the impact of any problems that do develop. Low-probability, low-impact events are essentially nuisance problems, such as incorrect dates on data screens, that do not impair mission-critical functions.

Lessons learned

One of the biggest lessons learned was that business readiness is an acceptable goal. Siebenthal tells of one very progressive participant that channeled considerable executive and budgetary support into proactively dealing with Y2K: "Basically they were going to fix everything, as good engineers do. But when they came into the program, they discovered that this approach was not time- or cost-effective and really was not even necessary. Instead, the company became comfortable with the concept of making systems business-ready."

Another key lesson, according to EPRI's Jim Fortune, was that companies themselves are responsible for the equipment they use and had best avoid relying *solely* on information from others, including vendors.

The crucial issue of vendor responsibility in the Y2K problem needed to be addressed, but the fear of litigation had stopped nearly everyone's tongue. Nine months before any federal legislation, EPRI legal counsel Barbara Greenspan negotiated 120 separate agreements in which members and vendors pledged to share Y2K technical information because of the national urgency of the issue. EPRI also facilitated a series of workshops to help program participants' lawyers better understand the significance of Y2K technical issues and the value of information sharing. To further facilitate the exchange of information, the Edison Electric Institute and the National Association of Manufacturers worked for legislation—signed into law by President Clinton in October 1998—that provides liability protections for organizations with respect to their Y2K information disclosures and statements.

Taking vendors out of the adversarial role and making them a part of the program benefited everybody, says Siebenthal. EPRI has organized meetings with many equipment vendors, both large and small, so that members conducting field tests could benefit from their input. Such well-known companies as Honeywell, Bailey Controls, Foxboro, Bentley Nevada, ABB, Siemens, and Allen-Bradley agreed to meet with teams of program participants, provide information for the knowledge base, and make workshop presentations about their Y2K activities.

"We got the vendors involved to the extent that if we tested a device and it failed, they didn't have to come out and figure out why, because we were using the same test program they used," says Siebenthal. "In many cases we drafted a test program and gave it to the vendor, who said, yes, that will work, or told us how to modify it."

EPRI's Joe Weiss cites another major advantage of the program's collaborative approach: individual members have provided demonstration sites for the benefit of the entire membership. In early July of this year, for example, EPRI helped TransAlta Utilities perform a test at its Sundance unit 6 coal-fired plant near Edmonton, Canada, to confirm the relationship between the displays that a plant operator views and the communication stream at the microprocessor level. Many program members helped review the specification, and the key equipment vendors provided access to their proprietary communications protocols.

"The TransAlta test was very ambitious," says Weiss, "and it bolstered confidence in the plant tests performed up till then. While the earlier tests assessed the function of integrated systems, this was the first test to examine what happens to each individual chip." In addition, the test demonstrated the value of open discussions internationally and between customers and vendors—hallmarks of the EPRI Y2K program.

Do companies joining the program late in the game still benefit? "If they're really behind the eight ball, there's a *huge* amount of value to them," says Fortune. "The program immediately helps them get up to speed so they can decide what to accept from other companies' testing and where they'll have to do testing of their own. If they're ahead or think they're ahead, it's a great way to benchmark their efforts against what others have done."

"The program has allowed the industry to look at the Y2K issue in a much more comprehensive way than an individual utility ever could," says Ric Rudman, EPRI's chief operating officer and the program's executive sponsor. "The comprehensive database has enabled the industry to quickly assess its mission-critical systems and identify areas where problems existed. The quarterly workshops have enabled real-time sharing of test information among the program participants."

Are we ready?

There is good reason to believe that the North American power industry is prepared for the turn of the millennium. In general, the industry's Y2K testing has gone smoothly. More than 100 fossil plants and many transmission facilities have moved their clocks forward to 2000 without any significant problems, and many companies have announced the readiness of key facilities. These companies include American Electric Power, Baltimore Gas and Electric, Consolidated Edison Company of New York, Florida Power & Light, Niagara Mohawk, Ontario Hydro, Public Service Company of Oklahoma, Southern California Edison, Southern Company, Virginia Power, and Wisconsin Electric.

On the nuclear side, plant operators have generally performed their Y2K testing during scheduled maintenance or refueling shutdowns—or during forced outages—for economic reasons. (At this writing, a handful of the country's over 100 nuclear power plants still had to complete the testing of nonsafety systems; most of these plants are duplicates of types where remediation work has already been completed.) None of the Y2K problems identified in nuclear plants have involved safety systems.

Ontario Hydro was one of the first utilities to conduct large-scale testing at a remediated nuclear plant, setting computer clocks forward at its Bruce unit 5 reactor and monitoring the simulated passage into the year 2000. The reactor, which was scheduled for a routine maintenance outage after the test, continued to operate without incident at full generating capacity. "Everything worked the way it was supposed to," says David Kwan, the utility's Y2K project manager. Two weeks before advancing the clocks at Bruce 5, a duty shift crew had rehearsed the test on a simulator.

There is also confidence regarding overall reliability issues. John Koskinen—who as chair of the president's Y2K council works closely with the Department of Energy, the Federal Energy Regulatory Commission, and other government agencies—says that any outages in the United States will be in the nature of minutes or hours, not days or weeks. NERC, the industry or-

Participation Crosses Borders and Industries

Globally, the Y2K issue is so important that it has forced industries to look beyond their own geographic borders and traditional enterprises to find good technical information. The EPRI Y2K Embedded Systems Program currently has 114 participants representing over 200 companies in the United States, Canada, Mexico, Bermuda, Puerto Rico, Barbados, the Cayman Islands, St. Lucia, Belize, Colombia, France, England, Finland, South Africa, Israel, China (Hong Kong), Singapore, Taiwan, Japan, Australia, and the Philippines.

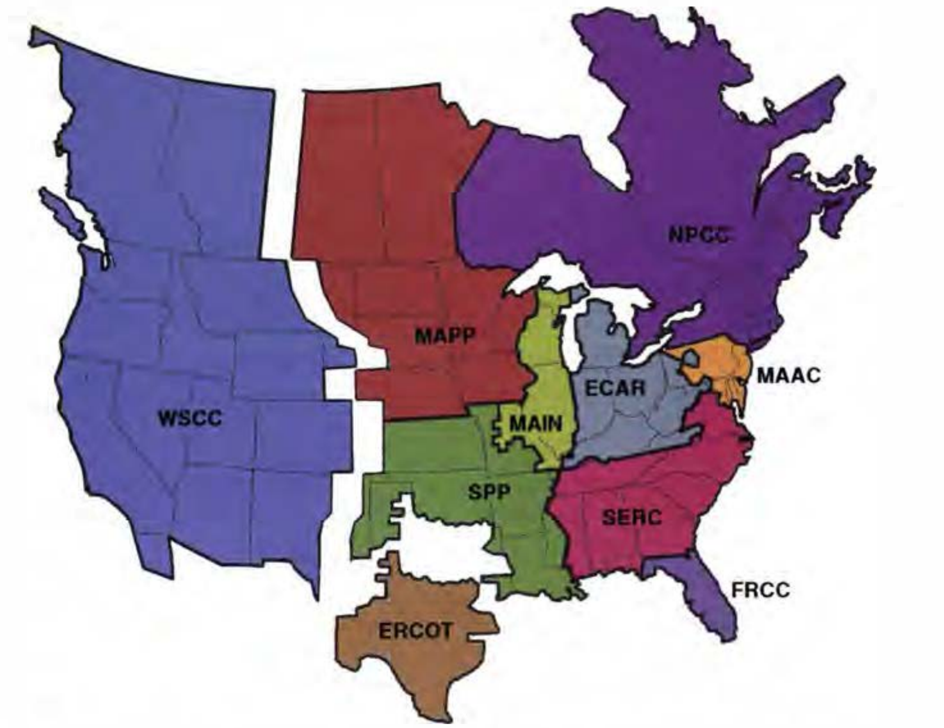
"We now represent over 80% of all electricity sales in North America," says program operations manager Jim Fortune. Since many electric utilities are also retail distributors of natural gas and since most generating companies include a significant amount of natural-gas-fired generation in their product mix, natural gas was added to EPRI's Y2K program as a major technical area. To avoid duplication of effort, EPRI has coordinated its activities in this area with those of the Gas Research Institute. It has also cosponsored a number of contingency-planning workshops with GRI in order to ensure that the Y2K efforts of the two industries are synergistic.

In addition to the electric and gas utilities that constitute most of EPRI's membership, a broad range of other organizations are finding what they seek in EPRI's Y2K program. These include international energy companies, such as Shell, Texaco, Chevron, Conoco, Enron, and Pemex; independent power producers, such as Calpine, InterGen, and Sithe Energies; and even industrial enterprises, such as Newmont Gold and Lucent Technologies. All companies have been encouraged to join at the corporate level so that their subsidiaries, both domestic and international, can share the benefits and so that the program can obtain information on a broad range of equipment. To join, a company need not be an EPRI member, but it must have embedded systems similar to those found in the power industry, and it must agree to share its Y2K findings with other program participants.

"We've gotten our money's worth," says Chevron's Steve Stadnicki, an expert on embedded systems. He coordinates all the oil company's domestic and international Y2K efforts involving these systems, which play roles in such facilities as refineries and chemical plants and in operations ranging from oil production and pipeline operation to shipping and marketing. "I've been very happy with the information-sharing and technical aspects of the EPRI program," he says, "especially the detailed information on compliance, contingency planning, and communications. Our lawyers have been very happy with the legal workshops, and others have benefited from the project management workshops." □

ganization responsible for managing power grid reliability issues in North America, agrees. A NERC report indicated that, by April, fewer than 3% of all tested components needed Y2K fixes. Errors tended to be nuisances rather than serious threats; most would not affect functions that keep lights on in homes and businesses.

NERC has been intimately involved with the Y2K issue since May 1998, when it was charged by DOE, acting on behalf of the president's Y2K council, to verify that the North American electric power industry would be Y2K ready by July 1, 1999. NERC established a monthly survey process to monitor the progress of individual utilities toward the industry readiness goal. Also, to ensure that Y2K technical information is readily available to smaller organizations, EPRI and NERC cosponsored a series of five regional workshops. Over 250 companies—including rural electric cooperatives, municipally owned utilities, public utility districts, and investor-owner distribution companies—participated in these workshops.



EPRI has worked closely with NERC, which is responsible for grid reliability issues, to ensure that any local Y2K problems will not build into major, wide-area disturbances in the 10 NERC reliability regions. The three North American ac power grids—the eastern, western, and Texas grids—are connected by dc tielines, across which disturbances and instabilities cannot pass.

Contingency planning

Contingency planning is an important part of overall Y2K preparedness. NERC spearheads contingency planning at the national and regional grid levels, while EPRI focuses on technical issues and individual corporate contingency planning. On September 8 and 9, NERC will conduct an extensive drill to test backup communications systems and practice the contingency processes necessary for maintaining electricity service in the event of a Y2K problem. Utilities have been developing contingency plans that include training people to run power plants manually in the event of unforeseen malfunctions of electronic controls, bringing back retired personnel who know how to operate facilities manually, and staffing normally unmanned substations on the night of the big rollover.

EPRI is working closely with NERC to determine what has to be done cooperatively between now and the end of the year, especially in terms of NERC contingency-planning drills, to ensure grid reliability. EPRI is also developing an early warning system to monitor possible technical failures at international sites where clocks will first roll over to the year 2000.

EPRI and its members also are currently assessing the role of the program in the post-2000 period. "It won't suddenly end on December 31," says Rudman. "There will be a winding-down period as utilities continue to test systems and assess their performance on other tricky dates—including February 29, which causes problems in certain digitally based equipment."

Despite some doomsayers, most people don't seem all that worried about Y2K. In an April 1999 public opinion poll of 600 U.S. adults conducted by Research International/Cambridge, awareness of the Y2K issue was high (91%), but most people were not worried about Y2K and electricity disruptions. A key finding was that reliable, reassuring information at the local level and normal preparedness for winter events will help maintain this calm as the millennium approaches.

Siebenthal says that industry officials expect the Y2K transition to cause isolated blips similar to those they handle all the time—as, for example, when a tree falls across a distribution line. Incidences are expected to be isolated rather than widespread and their impacts manageable. "We want to reduce the probability of something significant happening to the probability of an ice storm or a hurricane," Siebenthal concludes.

John Ballance manages Southern California Edison's power grid dispatch and operations. He will spend New Year's Eve at Edison's grid control center and expects a boring evening with few or no problems related to Y2K. Ballance is more worried that the turn of the millennium will bring out more revelers than usual, resulting in an increased number of minor power disruptions due to cars hitting electrical poles, gunshot damage to electrical insulators, and the like. "The real challenge on New Year's Eve," he says, "will be to prevent all problems from being labeled Y2K related." ■

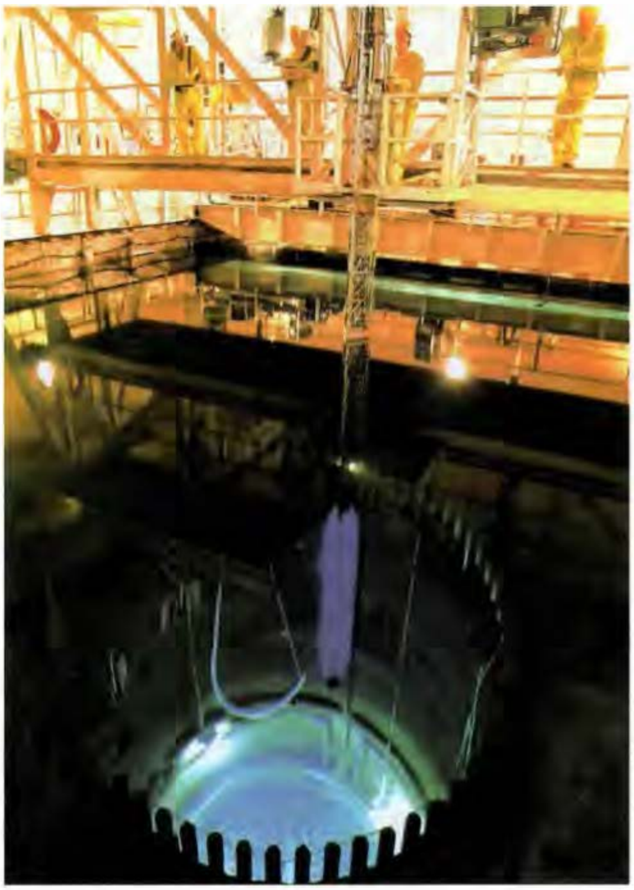
Background information for this article was provided by Charlie Siebenthal (csiebent@epri.com), Jim Fortune (jfortune@epri.com), Joe Weiss (joeweiss@epri.com), Bill Steeley (wsteeley@epri.com), and Susan Marsland (smarslan@epri.com) of the Science and Technology Development Division.

In the Field

Demonstration and application of EPRI science and technology

River Bend Uses EOOS for Shutdown Safety

Maintenance outages at nuclear power plants typically entail complex task networks, whose safety implications must be analyzed. To enhance safety and shorten outages at its River Bend nuclear plant in Louisiana, Entergy Corporation wanted an analysis tool for automating outage safety reviews. Specifically, it wanted a tool that would require no additional training for outage planning staff and that would have sufficient detail to let them determine how component outages affect the status of outage safety functions. Moreover, River Bend's outage planners could not afford to use conservative assumptions that would adversely limit planning flexibility and force longer outages.



Entergy chose to use EPRI's EOOS (Equipment out of Service) software to develop a probabilistic safety analysis for shutdown operations at River Bend and to evaluate the plant's shutdown operations protection plan (SOPP). EOOS translates a schedule of work activities into a set of color-coded timelines, each of which is associated with specific administrative guidelines. The program also generates a risk profile that displays the chance of core damage in each shutdown condition. River Bend staff then make scheduling decisions on the basis of this profile and the plant's defense-in-depth measures.

The River Bend plant was already using an EOOS model for power operations, so extending the analytical method to outage safety analysis offered economic benefits. The shutdown model uses a lot of the same data as the model for power operations, for example. As a result of this data sharing and the consistency between the models, costs for additional staff training and for maintaining two sets of data have been avoided, and meaningful safety comparisons between on-line and shutdown operations can be made.

Because EOOS can simultaneously record inputs from both Scheduling and Operations, points out Entergy's David Weller, the effects of adding emergent work can be monitored efficiently and without delay. "EOOS better enables the staff to know what scheduled work to put on hold in order to accommodate an unplanned event and ensure plant safety," he says.

"EOOS also operates on a component-level model. This helps us maintain a short outage," Weller adds. "In past outages, we had to wait for one system work window to close before opening the next. Our EOOS model allows us to continue work on a system as long as the components needed for its safety function remain available."

With the EOOS shutdown model in place, River Bend staff can quickly evaluate changes in the outage schedule. In a few minutes, with essentially two clicks of a computer mouse—to import schedule data and to run the schedule assessment—the staff can generate an outagewide SOPP safety review.

The EOOS software (SW-105871-DK) is currently in use at more than 70 nuclear plants at 30 utilities, including some plants outside the United States. Entergy is among several utilities that have adopted EOOS at all their plants for all modes of operation.

■ *For more information, contact Frank Rahn, frahn@epri.com, 650-855-2037.*

Manhole Cover Remover Tested

Utility personnel who respond to cable failures and other problems in urban underground distribution systems often encounter smoke and fire. And the first priority before fire fighting or other measures can be implemented—removing the manhole cover—can create the most dangerous of conditions: an explosion triggered by the rush of oxygen into the underground structure. Electric utilities experience about one major underground event—typically an explosion—per year for every 10,000 manholes, says Ralph Bernstein, a program manager in EPRI's Science and Technology Development

Division. Small fires, smoke, and other minor events occur 10–50 times more frequently.

The current method of removing a manhole cover is to secure a 2-foot (0.6-m) steel hook into an opening in the 300-pound (140-kg) disk and manually pull it off. Caked-on dirt and other debris can make a cover especially difficult to remove. For some time, the utility industry has sought a safer alternative to this practice. Researchers have envisioned a remotely controlled robotic device that could loosen and reliably lift a stuck manhole cover while all personnel remained a safe 20 feet (6 m) away.

Recently, EPRI and Consolidated Edison Company of New York funded the development of a prototype device for removing manhole covers. The contractor, Foster-Miller, modified a remotely controlled robot—called the ferret—that was originally developed to help police defuse bombs.

A trailer-mounted, remotely controlled manhole cover removal system has evolved in this work. The system features an impact hammer called a RAM and a powerful electromagnet with a lifting force of more than 5000 pounds (2250 kg). Both the electromagnet and the impact hammer are raised and lowered by battery-powered linear actuators. A handheld remote control box is connected to the system by cable but remains safely electrically isolated.

Once the system is rolled into position and braked, the operator can quickly engage the electromagnet and lift a manhole cover. If the cover is stuck in its frame, the operator can hit it with the RAM, which produces a force comparable to that of a 12-pound (5.4-kg) sledgehammer.

Last February, EPRI and Con Edison personnel observed the initial field trials of the manhole cover removal system in the streets of Boston, where Foster-Miller is based. Because the utility distribution system in the area is not situated underground, the device was tested on 210-pound (95-kg) sewer and telephone system manhole covers.

A manhole cover is lifted by the remotely controlled system's electromagnet during trials in Boston. The RAM impact hammer is the vertical cylinder to the left of the magnet.

The device easily lifted two sewer covers and a telephone cover. It initially had difficulty with another telephone cover, on which there was sand. After the sand was brushed off, however, the electromagnet held on to the cover, and its linear actuator—with a pulling force of 3500 pounds (1600 kg)—pulled the cover up. As Piero Brentani of Foster-Miller notes, "In some cases, like this one, the linear actuator's pulling force is enough to break a cover loose from the mounting ring without the operator's having to use the RAM."

Brentani also emphasizes the electrical isolation of the handheld control box as a key safety feature of the cover removal system. The box is neither grounded nor connected to any part of the wiring; all the connections to switches are through double-insulated, automotive-type relays, with a minimum insulation to ground of 500 V. The 125-V (ac) switches themselves are rated to military specification. "Thus the possibility that the switch levers or the control box enclosure will become energized is practically nil," Brentani says.

After the initial trials in Boston, the prototype manhole cover removal system was transported to New York City, where Con Edison's underground distribution crews will use it, as needed, in actual service. "We will be getting feedback from the field operations crews as they become familiar with the system," says Leonard Burshtein, Con Edison's manager for the project. "As the crews respond to events, use of the system has to be incorporated into the sequence of steps they are trained in and routinely follow. Until our personnel are fully familiar with the system, it will be used in streets that do not have heavy traffic."

EPRI's Bernstein says that after testing is completed this year, a prototype of the manhole cover removal system could be available to other utilities, and, if there is enough demand, a commercial version could be developed.

■ *For more information, contact Ralph Bernstein, rbernste@epri.com, 650-855-2023, or Walter Zenger, wzenger@epri.com, 650-855-8943.*

Inside EPRI

News and information highlighting EPRI staff and operations

EPRI Customer Assistance Center Delivers Solutions

Delivering the products, resources, and expertise that customers need—when they need them—is the primary purpose of the EPRI Customer Assistance Center. Established in 1998, the center is designed to streamline the crucial transfer of EPRI technology to ensure that solutions are readily available in today's competitive environment. Over the past year, it has helped more than 12,000 customers on a wide range of energy-related issues.

"We set up the Customer Assistance Center as a real one-stop, full-service resource," explains center manager Rob Glover. "In many cases, all the client needs is quick information about an EPRI product or publication. But when the problem is more involved—and it often is—our customer service team can work as in-depth facilitators to ensure that it is solved. This means working directly with the client to identify the EPRI knowledge, tools, or expertise that will address the problem, making sure that the technology or information is actually delivered, and assisting in its application, if necessary. Our goal is complete customer satisfaction, with particular attention to quick response and closure," says Glover.

The center's information hotline is the starting point for its services, providing customers a single-point entryway into the EPRI organization. A technical resource specialist works with the caller and arranges for a response from the appropriate technical staff member within 48 hours. The center fields inquiries on a range of topics, from the latest advances in fuel cell technology to nuclear plant water chemistry guidelines. Customers can also access the center by e-mail or fax, if they prefer, and get the same personalized service.

In many instances, providing information is only the first step in dealing with a caller's problem. When further, hands-on activity is required, the center's JumpStart program can help clients with the design and implementation of custom projects in the field. In addition to tapping the expertise of EPRI's in-house staff and technology centers for such projects, JumpStarts allow customers to draw on preapproved contractors, who have demonstrated their capabilities in the area of interest. Standardized contract terms make it possible to start up projects in one or two days, and because center staff handle the paperwork, customers can focus on technical issues and stay on schedule.

Sunflower Electric Power Corporation turned to the Customer Assistance Center for help in fast-tracking NPDES (National Pollutant Discharge Elimination System) permit applications. The project was put into action without costly delays through the JumpStart program. A permit application for Sunflower was filed within two months of project startup, and the company was granted a permit in time to restart the generating units in question as scheduled.

To further speed the startup of projects, customers can manage the funding under the center's deposit account program, which holds an undedicated member deposit in an account administered by EPRI staff. When the company needs funds—to cover the costs for JumpStart projects, training sessions, tailored collaboration projects, or any other EPRI service—it has immediate access to its account, thereby streamlining the procedures involved in project implementation. Currently, EPRI members have established 39 deposit accounts.

The center also offers customized client services in the publication and training areas. For example, it helped Wisconsin Electric Power Company repackage EPRI information as a document tailored for the utility's own customers. "Center staff coordinated the publication's customization and distribution to our customers by market segment," says Julie Thorsen of Wisconsin Electric. "They really went out of their way to tailor EPRI information to our needs."

Customized workshops and seminars are also available through the center to help members apply EPRI products for maximum value. A company can send employees to courses offered by EPRI offices or technology facilities around the country, arrange to bring trainers to its own sites, or work with center personnel to develop special classes on issues of high priority to the company or its customers.

Solving individual problems is the center's daily challenge, but it has a longer-term focus as well. "We pay a lot of attention to what the hotline callers are asking for, since it gives us both broad-brush and detailed information about members' needs," says Liane Freeman, EPRI's director of communications and customer service. "Such knowledge not only helps us respond more effectively to future requests but also provides us with a kind of feedback about what we could spend more effort on. It's really another way EPRI listens to its customers."

How to Contact the EPRI Customer Assistance Center

Hotline: 800-313-3774 (press 4) or 650-855-2121 (press 4)
E-mail: askepri@epri.com
Fax: 972-556-6521

Customers outside the United States can access the center by dialing the AT&T toll-free access code for the appropriate country and then dialing or asking the operator for 800-313-3774.

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.

Energy Delivery

Multimode Transportable Battery Energy System for Salt River Project, Vol. 1: Design and Installation
TR-110859-V1
Target: Distribution Systems
EPRI Project Manager: S. Eckroad

PTLOAD (Power Transformer Loading Software) Version 5.0 for Windows 95/NT 4.0: User's Manual
AP-111247
Target: Substation Operation and Maintenance
EPRI Project Manager: S. Eckroad

Aging of Polymeric Distribution Insulators
TR-111515-V1
Target: Distribution Systems
EPRI Project Manager: B. Bernstein

Distribution Cable Containing Moisture-Resistant, Liquid-Crystalline Polymer
TR-112238
Target: Underground Distribution Infrastructure
EPRI Project Manager: B. Bernstein

Reliability-Centered Maintenance for Distribution Systems and Equipment: Four Application Case Studies
TR-112924
Target: Distribution Systems
EPRI Project Manager: H. Ng

DTCR: Dynamic Thermal Circuit Rating
Version 2.0 (Windows 95, NT)
Target: Substation Assets Utilization
EPRI Project Manager: A. Edris

LPDW™ 5.0: Lightning Protection Design Workstation
Version 5.0 (Windows 95, NT)
Targets: Overhead Transmission; Distribution Systems; Underground Distribution Infrastructure
EPRI Project Manager: V. Longo

PTLOAD: Power Transformer Loading Software
Version 5.0 (Windows 95, NT)
Target: Substation Operation and Maintenance
EPRI Project Manager: S. Eckroad

XVisor: Expert System for Transformer Assessment
Version 1.0 (Windows 95, NT)
Target: Substation Operation and Maintenance
EPRI Project Manager: B. Ward

Energy Utilization

A Business Guide to Foodservice
TR-106841-R1
Target: Foodservice Facilities Solutions (EPRICSG)
EPRI Project Manager: J. Kuegle

Green Power Guidelines, Vol. 2: Assessing Small- and Medium-Sized Business Market Segments
TR-109192-V2
Targets: Understanding Energy Markets (EPRICSG); Renewable Technology Options and Green Power Marketing
EPRI Project Managers: B. Kalweit, T. Peterson

Building Successful Customer Relationships (Training Course Through the Retail Market Assistance Center)
TR-111432
Targets: Understanding Energy Markets (EPRICSG); Enhancing the Success of Innovative Customer Technologies (EPRICSG); Producing Successful Retail Products and Services
EPRI Project Manager: L. Ness

Power Quality for Electrical Contractors: Applications Guide, Vol. 1—Power Quality Fundamentals
TR-111762-V1
Targets: Power Quality for Satisfied Commercial and Residential Customers; Power Quality for Improved Industrial Operations; Power Quality Basics (EPRICSG)
EPRI Project Managers: M. Grossman, W. Moncrief

Power Quality for Electrical Contractors: Applications Guide, Vol. 2—Recommended Practices (Revision 1)
TR-111762-V2R1
Targets: Power Quality for Satisfied Commercial and Residential Customers; Power Quality for Improved Industrial Operations; Power Quality Basics (EPRICSG)
EPRI Project Managers: M. Grossman, W. Moncrief

Forward Price Forecasting for Power Market Valuation: Excerpts Introducing Valuation and Forecasting Approaches
TR-111860-R1
Target: Power Markets and Risk Management
EPRI Project Manager: V. Niemeyer

21st Century Customers, Vol. 1: Industry and Manufacturing
TR-111918-V1
Target: Technology Innovation and 21st Century Strategy (EPRICSG)
EPRI Project Manager: T. Henneberger

21st Century Customers, Vol. 2: Business and Commerce
TR-111918-V2
Target: Technology Innovation and 21st Century Strategy (EPRICSG)
EPRI Project Manager: T. Henneberger

Independent Restaurants: An Introduction to Business Characteristics, and Energy-Use and Decision Criteria
TR-112005
Target: Understanding Energy Markets (EPRICSG)
EPRI Project Manager: R. Gillman

Methods for Customer Information System and Billing Evaluation: Advanced Billing and Customer Operations Support
TR-112067
Target: Advanced Billing and Customer Operations Systems (EPRICSG)
EPRI Project Manager: D. Cain

Anticipating Competitor Response in Retail Electricity Price Design
TR-112087
Target: Power Markets and Risk Management
EPRI Project Manager: A. Faruqui

The Small Office Market: Size, Business Diversity, and Energy Choices
TR-112097
Target: Understanding Energy Markets (EPRICSG)
EPRI Project Manager: R. Gillman

User Guide: ESPRE Windows Version 1.0
AP-112119
Targets: All residential targets
EPRI Project Manager: J. Kesselring

Assessing Changes in the Residential Telecommunications and Electric Marketplace: Parts 1–3
TR-112125-P1–P3
Target: Understanding Energy Markets (EPRICSG)
EPRI Project Manager: R. Gillman

Manufactured Housing Heat Pump Demonstration Program
TR-112340
Target: Residential Heat Pump Technology
EPRI Project Manager: S. Saleh

Power Electronics in the Healthcare Industry
TR-112431
Target: Power Electronics (EPRICSG)
EPRI Project Manager: B. Banerjee

Power Electronics in the Semiconductor Fabrication Industry
TR-112432
Target: Power Electronics (EPRICSG)
EPRI Project Manager: B. Banerjee

Pulsed Power Technology and Applications: Scandinavia
TR-112566
Target: Customer Power Conditioning Solutions (EPRICSG)
EPRI Project Manager: C. Mansson

Waveform Characteristics of Voltage Sags: Statistical Analysis
TR-112692
Target: Power Quality for Improved Energy Delivery
EPRI Project Manager: A. Sundaram

Load Profiling and Settlement for Retail Markets Methods Assessment Study
TR-112785
Targets: Understanding Energy Markets (EPRICSG); Load Data Analysis for Power Marketing (EPRICSG)
EPRI Project Manager: R. Gillman

■ Market Forecasting Workstation
Version 2.1 (Windows 95, NT)
Target: Producing Successful Retail Products and Services
EPRI Project Manager: B. Kalweit

Environment

Review of Methods for Source Apportionment and Sensitivity Analysis in Three-Dimensional Air Quality Models for Particulate Matter
TR-112070
Target: Atmospheric Particulates and Precursors
EPRI Project Manager: M. A. Allan

Users Guide for LARK-TRIPP Version 1.0: A Toxic Release Inventory Estimation Tool for Land Release Estimating and Record Keeping at Power Plants
AP-112371
Target: Groundwater and Combustion By-Products Management
EPRI Project Manager: A. Quinn

1998 Summary of Consortium on Alkali-Aggregate Reactivity in Concrete
TR-112453
Target: Combustion By-Product Use
EPRI Project Managers: C. Dene, D. Golden

Power Plant Validation of the Mercury Speciation Sampling Method
TR-112588
Target: Plant Multimedia Toxics Characterization (PISCES)
EPRI Project Manager: P. Chu

Proceedings: 1998 EPRI Clean Water Act Section 316 (b) Technical Workshop
TR-112613
Target: 316 (a) and (b) Fish Protection Issues
EPRI Project Managers: D. Dixon, K. Zammit

Generic Sampling and Analytical Plan for Mercury Speciation Stack Sampling
TR-112687
Target: Plant Multimedia Toxics Characterization (PISCES)
EPRI Project Manager: P. Chu

■ PISCES: Power Plant Chemical Assessment Model
Version 3.03 (Windows)
Target: Plant Multimedia Toxics Characterization (PISCES)
EPRI Project Manager: P. Chu

■ RAMAS GIS: Linking Landscape Data With Population Viability Analysis
Version 3.0 (Windows 95, 98, NT)
Target: 316 (a) and (b) Fish Protection Issues
EPRI Project Manager: R. Goldstein

■ RAMAS Risk Calc: Risk Assessment With Uncertain Numbers
Version 3.0 (Windows 95)
Target: 316 (a) and (b) Fish Protection Issues
EPRI Project Manager: R. Goldstein

Fossil and Renewable Generation

Proceedings: 1996 EPRI Workshop on NO_x Controls for Utility Boilers (August 1996; Cincinnati, Ohio)
TR-107629
Target: Coal Boiler Performance/Combustion NO_x Control
EPRI Project Manager: J. Stallings

Cost Benefit Analysis for Maintenance Optimization
AP-107902
Targets: Steam Turbines, Generators, and Balance of Plant; Plant Maintenance Optimization (EPRIGEN)
EPRI Project Manager: R. Pflasterer

Predictive Maintenance Program: Development and Implementation
TR-108936
Target: Plant Maintenance Optimization (EPRIGEN)
EPRI Project Manager: R. Pflasterer

Value-Based Maintenance Grid for Assessing Work Management
TR-108937
Targets: Steam Turbines, Generators, and Balance of Plant; Plant Maintenance Optimization (EPRIGEN)
EPRI Project Manager: R. Pflasterer

Green Power Guidelines, Vol. 2: Assessing Small- and Medium-Sized Business Market Segments
TR-109192-V2 (see listing under Energy Utilization)

Improving Existing Fossil-Fired Power Plants: Industry Discussions—Vol. 1, Highlights; Vol. 2, Details
AP-109342
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Manager: A. Armor

Cyclone NO_x Control: Technology and Issues Assessment
TR-110499
Target: Coal Boiler Performance/Combustion NO_x Control
EPRI Project Manager: D. O'Connor

Turbine-Generator Maintenance Outage Interval Extension: Turbo-X Version 1.0a User's Manual
AP-110998
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Manager: T. McCloskey

CMMS Implementation at Cinergy: Computerized Maintenance Management System
TR-111151
Target: Plant Maintenance Optimization (EPRIGEN)
EPRI Project Manager: R. Pflasterer

Superheater Corrosion in Ultrasupercritical Power Plants: Long-Term Field Exposure at TVA's Gallatin Station
TR-111239
Target: Boiler Life and Availability Improvement
EPRI Project Manager: W. Bakker

Achieving NO_x Compliance at Least Cost: A Guideline for Selecting the Optimum Combination of NO_x Controls for Coal-Fired Boilers
TR-111262
Target: Coal Boiler Performance/Combustion NO_x Control
EPRI Project Manager: G. Offen

How Competitive Market Dynamics Affect Coal, Nuclear, and Gas Generation and Fuel Use: A 10-Year Look Ahead
TR-111506
Target: Fuel and Power Supply
EPRI Project Manager: J. Platt

Fuel and Power Price Volatilities and Convergence
TR-111564
Target: Fuel and Power Supply
EPRI Project Manager: J. Platt

Robust Controller Design for Simultaneous Control of Throttle Pressure and Megawatt Output in a Power Plant Unit
TR-111629
Target: I&C and Automation for Improved Plant Operations (EPRIGEN)
EPRI Project Manager: R. Torok

Proceedings: Workshop on Intelligent Sootblowing Applications
TR-111631
Target: I&C and Automation for Improved Plant Operations (EPRIGEN)
EPRI Project Manager: R. Shankar

Photovoltaic-Based Projects and Ventures: Development Guidelines
TR-111892
Target: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: T. Peterson

Maintenance Optimization Project at Merom, Vol. 1: Work Culture and Process Improvements
TR-111897-V1
Target: Plant Maintenance Optimization (EPRIGEN)
EPRI Project Manager: R. Pflasterer

Maintenance Optimization Project at Merom, Vol. 2: Heat Rate Improvement
TR-111897-V2
Target: Plant Maintenance Optimization (EPRIGEN)
EPRI Project Manager: R. Pflasterer

Preliminary Economic and Engineering Evaluation of the Foster Wheeler Advanced Pressurized Fluidized-Bed Combustor Technology With Advanced Turbine System (ATS) Gas Turbines
TR-111912
Target: Coal Power Systems Development
EPRI Project Manager: J. Wheeldon

Sodium Phosphate Hideout Mechanisms: Data and Models for the Solubility and Redox Behavior of Iron (II) and Iron (III) Sodium Phosphate Hideout Reaction Products
TR-112137
Target: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: B. Dooley

Hydro Relicensing Forum: Preferred Practices Guidebook
TR-112168
Target: Hydropower Operations, Relicensing, and Environmental Issues
EPRI Project Manager: M. Blanco

Distributed Generation Market Study: Advanced Turbine System Program
TR-112174
Targets: Emerging Distributed Resource Technologies (EPRIGEN); Distributed Resources Information and Tools for Business Strategy Development
EPRI Project Manager: D. Rastler

Survey of Instrumentation and Control Practices in the Process Industries for Application to the Power Utilities
TR-112230
Target: I&C and Automation for Improved Plant Operations (EPRIGEN)
EPRI Project Manager: R. Torok

Proceedings: Distributed Resources Week 1998, Strategies for Successful Implementation
TR-112300
Target: Distributed Resources Information and Tools for Business Strategy Development
EPRI Project Manager: D. Rastler

Proceedings: Third National Green Power Marketing Conference—Selling Green Power in Competitive Markets
TR-112315
Target: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: T. Peterson

Nuclear Generation

Recommendations for an Effective Flow-Accelerated Corrosion Program
NSAC-202L-R2
Target: Nuclear Power
EPRI Project Manager: B. Chexal

Guidelines for PWR Steam Generator Tubing Specifications and Repair, Vol. 2, Revision 1: Guidelines for Procurement of Alloy 690 Steam Generator Tubing
TR-016743-V2R1
Target: Nuclear Power
EPRI Project Manager: A. McIlree

Guideline for Sampling in the Commercial-Grade-Item Acceptance Process
TR-017218-R1
Target: Nuclear Power
EPRI Project Manager: L. Aparicio

PWR Primary Water Chemistry Guidelines, Revision 4, Vols. 1 and 2
AP-105714-R4
Target: Nuclear Power
EPRI Project Manager: P. Millett

Valve Application, Maintenance, and Repair Guide
TR-105852-V1
Target: Nuclear Power
EPRI Project Manager: V. Varma

GERS Formulated Using Data From the SQURTS Program
TR-105988-V2
Target: Nuclear Power
EPRI Project Manager: R. Kassawara

Infrared Thermography Field Application Guide
TR-107142
Target: Nuclear Power
EPRI Project Manager: P. Zayicek

Air-Operated Valve Evaluation Guide
TR-107322
Target: Nuclear Power
EPRI Project Manager: J. Hosler

Fiber-Optic Sensors in Nuclear Power Plant Radiation Environments, Phase 1
TR-107326-V1
Target: Nuclear Power
EPRI Project Manager: R. Shankar

Steam Generator In Situ Pressure Test Guidelines (Revision 1)
TR-107620-R1
Target: Nuclear Power
EPRI Project Manager: M. Merilo

Experience With Depleted Zinc Oxide Injection in BWRs: 1999 Progress Report
TR-108741
Target: Nuclear Power
EPRI Project Manager: H. Ocken

Use of Chemical Pretreatment to Enhance Liquid Waste Processing
TR-109437
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Utility Use of Constant Scaling Factors
TR-109448
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Guideline for the Evaluation and Treatment of Corrosion and Fouling in Fire Protection Systems
TR-109633
Target: Nuclear Power
EPRI Project Manager: T. Eckert

Flow Meter Guideline
TR-109634
Target: Nuclear Power
EPRI Project Manager: T. Eckert

The Boraflex Rack Life Extension Computer Code, RACKLIFE: Verification and Validation
TR-109926
Target: Nuclear Power
EPRI Project Manager: R. Mahini

Evaluation of Combined-Cycle Combustion Turbine and PWR Nuclear Plant
TR-109961
Target: Nuclear Power
EPRI Project Manager: J. Carey

Design and Testing Description of an Application-Specific Integrated Circuit for Reactor Protection and Control
TR-110044
Target: Nuclear Power
EPRI Project Manager: J. Naser

Experience-Based Interview Process for Power Plant Management With a Pilot Application to Aging of Outage Support Equipment
TR-110089
Target: Nuclear Power
EPRI Project Manager: G. Sliter

Eddy Current Testing of Service Water Heat Exchangers for Engineers: Guideline
TR-110392
Target: Nuclear Power
EPRI Project Manager: K. Krzywosz

ORAM-SENTINEL Demonstration at Indian Point 3
TR-110716
Target: Nuclear Power
EPRI Project Manager: J. Mitman

Proceedings: Embedded Pipe Decontamination Technology Workshop
TR-111277
Target: Nuclear Power
EPRI Project Manager: R. Thomas

Secondary Degradation of Defective Fuel Rod: Simulation Test at the Halden Reactor (Part 1: IFA-600)
TR-111590
Target: Nuclear Power
EPRI Project Manager: B. Cheng

User Manual: Alloy 600 in PWRs Database, Version 2.0 for Microsoft Windows
AP-111607
Target: Nuclear Power
EPRI Project Manager: R. Pathania

ORAM™ Version 4.0 Functional Specification Outline
TR-111652
Target: Nuclear Power
EPRI Project Manager: J. Mitman

Proceedings: 1997 EPRI International Low-Level-Waste Conference
TR-111657
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Evaluation of the Decontamination of the Reactor Coolant Systems at Maine Yankee and Connecticut Yankee
TR-112092
Target: Nuclear Power
EPRI Project Manager: C. Wood

Characterization of Ringhals-3 Tube Support Plate Crevice and Tube Deposits
TR-112110
Target: Nuclear Power
EPRI Project Manager: A. McIlree

PWR Restart Ramp Rate Restrictions
TR-112140-V1
Target: Nuclear Power
EPRI Project Manager: B. Cheng

Effect of Startup Ramp Rate on Pellet-Cladding Interaction of PWR Fuel Rods
TR-112140-V2
Target: Nuclear Power
EPRI Project Manager: B. Cheng

Boron Control and Monitoring for a PWR Fuel-In Full System Decontamination
TR-112145
Target: Nuclear Power
EPRI Project Manager: H. Ocken

Spent Fuel Pool Cooling and Cleanup During Decommissioning: Experience at Trojan Nuclear Power Plant
TR-112351
Target: Nuclear Power
EPRI Project Manager: C. Wood

Proceedings: 1996 EPRI Surface Chemistry Workshop
TR-112481
Target: Nuclear Power
EPRI Project Managers: A. McIlree, P. Millett

Proceedings: 1997 ASME/EPRI Radwaste Workshop
TR-112658
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Capsule Corrosion Tests on Alloy 600 Steam Generator Tubes in Acid Environments
TR-112748
Target: Nuclear Power
EPRI Project Manager: A. McIlree

A Parametric Study of the Lead-Induced Stress Corrosion Cracking of Alloy 690
TR-112775
Target: Nuclear Power
EPRI Project Manager: A. McIlree

Film Analysis of Alloy 600
TR-112776
Target: Nuclear Power
EPRI Project Manager: A. McIlree

Circuit Breaker Timing and Travel Analysis
TR-112783
Target: Nuclear Power
EPRI Project Manager: J. Sharkey

Isolated Phase Bus Maintenance Guide
TR-112784
Target: Nuclear Power
EPRI Project Manager: J. Sharkey

Proceedings: 1999 EPRI Workshop on Startup Oxidant Control
TR-112815
Target: Nuclear Power
EPRI Project Manager: A. McIlree

IPEEE Seismic Insights
TR-112932
Target: Nuclear Power
EPRI Project Manager: R. Kassawara

■ EOOS: Risk and Reliability Workstation Module
Version 2.6b (Windows)
Target: Nuclear Power
EPRI Project Manager: F. Rahn

Strategic Science and Technology

Volatility of Aqueous Sodium Hydroxide, Bisulfate, and Sulfate
TR-105801
Program: Strategic Science and Technology
EPRI Project Manager: B. Dooley

Steam, Chemistry, and Corrosion in the Phase Transition Zone of Steam Turbines (Vol. 1; Vol. 2, Parts 1 and 2)
AP-108184
Program: Strategic Science and Technology
EPRI Project Manager: B. Dooley

Capacitors for Electric Utility Energy Storage
TR-108888
Program: Strategic Science and Technology
EPRI Project Manager: S. Eckroad

Home Networks and Personal Access Devices: A State-of-the-Art Assessment Study
TR-111375
Program: Strategic Science and Technology
EPRI Project Manager: J. Kesselring

Compressed Air Storage with Humidification: An Economic Evaluation
TR-111691
Program: Strategic Science and Technology
EPRI Project Manager: A. Cohn

Measurement of Creep Crack Growth Using Miniature Specimens
TR-111716
Program: Strategic Science and Technology
EPRI Project Manager: V. Viswanathan

Covolume Simulation of Thermal-Hydraulic Phenomena on Two- and Three-Dimensional Unstructured Grids
TR-112000
Program: Strategic Science and Technology
EPRI Project Manager: L. Agee

Reference Manual for On-Line Monitoring of Water Chemistry and Corrosion: 1998 Update
TR-112024
Program: Strategic Science and Technology
EPRI Project Manager: B. Syrett

A Dynamic Information Manager for Networked Monitoring of Large Power Systems
TR-112031
Program: Strategic Science and Technology
EPRI Project Manager: N. Abi-Samra

Colloids in Saturated and Partially Saturated Porous Media: Approaches to the Treatment of Colloids in Yucca Mountain Total System Performance Assessment
TR-112135
Program: Strategic Science and Technology
EPRI Project Manager: J. Kessler

Vapor-Liquid Partitioning of Sulfuric Acid and Ammonium Sulfate
TR-112359
Program: Strategic Science and Technology
EPRI Project Manager: B. Dooley

Real and Reactive Power Tracking: Proof of Concept and Feasibility Study
TR-112416
Program: Strategic Science and Technology
EPRI Project Manager: N. Abi-Samra

Decentralized Damping of Power Swings: Feasibility Study
TR-112417
Program: Strategic Science and Technology
EPRI Project Manager: N. Abi-Samra

Optimal Control of Nonlinear Systems With Neural Networks, Vols. 1 and 2
TR-112422-V1–V2
Program: Strategic Science and Technology
EPRI Project Manager: D. Sobajic

Multilayer Nanoscale Thermal Barrier Coatings
TR-112440
Program: Strategic Science and Technology
EPRI Project Manager: W. Bakker

Creep Strength and Fracture Resistance Evaluation for High-Temperature Materials
TR-112778
Program: Strategic Science and Technology
EPRI Project Manager: W. Bakker

Gas-Phase Formation of Water-Soluble Organic Compounds in the Atmosphere: A Retrosynthetic Analysis
TR-113096
Program: Strategic Science and Technology
EPRI Project Manager: A. Hansen

EPRI Events

September

15–17
Value and Risk Management: Essential Skills
Hilton Head, South Carolina
Contact: Cara Lee Braithwait, 888-332-8258

20–21
Condition Assessment and Failure Mitigation of Splices and Connectors
Las Vegas, Nevada
Contact: Gayle Robertson, 817-439-5900

20–21
Switching Safety and Reliability Conference
Denver, Colorado
Contact: Debbie Marcin, 410-379-8020

20–24
Combined-Cycle Operations for Utility Engineers
Kansas City, Missouri
Contact: Cassandra Maslowski, 816-235-5623

20–24
Operations Training for Nonoperators
Kingston, Tennessee
Contact: Sherryl Stogner, 704-547-6174

20–October 1
Ultrasonic Examination Technology: Level 1
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

21–22
Power Transformers Working Group
Portland, Oregon
Contact: Barry Ward, 650-855-2717

21–23
Introduction to Hydro Asset Optimization
Dallas, Texas
Contact: Carolynn Santos, 650-855-2889

21–24
Steam Turbine Performance Monitoring, Diagnostics, and Improvement
Eddystone, Pennsylvania
Contact: Melanie Moore, 610-490-3216

22–24
High-Voltage Current Transformers and Bushings: Failure Prediction and Prevention
Portland, Oregon
Contact: Cindy Layman, 650-855-8763

23–24
3d Gas-Electric Partnership Symposium
Houston, Texas
Contact: Lynn Stone, 972-556-6529

27–28
4th Annual Global Climate Change Seminar
Columbus, Ohio
Contact: Christopher Gerlach, 650-855-8579

27–29
RCM Users Group
Las Vegas, Nevada
Contact: Lora Cocco, 650-855-2620

27–October 1
Drum Boiler Unit Operations
Kansas City, Missouri
Contact: Cassandra Maslowski, 816-235-5623

28–30
Infrared Thermography: Level 3
Eddystone, Pennsylvania
Contact: Melanie Moore, 610-490-3216

29–30
Valuing Generation Assets in Competitive Markets
Cambridge, Massachusetts
Contact: Cheryl Mumm, 617-864-7900

29–October 1
Detection and Control of Flow-Accelerated Corrosion in Fossil Power Plants
Dallas, Texas
Contact: Doug Munson, 650-855-2573

October

1
Industry Overview Courses: Petrochemicals, Petroleum Refining
TBA
Contact: Sam Woinsky, 281-419-1122

4–5
Containment Inspection: Visual Examination Training, Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

4–8
Cyclone Boiler Unit Operations
Kansas City, Missouri
Contact: Cassandra Maslowski, 816-235-5623

5–8
Pressure Relief Valve Application, Maintenance, and Testing
Orlando, Florida
Contact: Melanie Moore, 610-490-3216

6–8
ASME Section XI Flaw Evaluation
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

6–8
Substation/Switchyard Predictive Maintenance
Eddystone, Pennsylvania
Contact: Melanie Moore, 610-490-3216

11–12
New Product Development for the Impending Energy Market
Scottsdale, Arizona
Contact: Lynn Stone, 972-556-6529

11–13
Air-Operated Control Valve Application, Maintenance, and Diagnostics
Orlando, Florida
Contact: Melanie Moore, 610-490-3216

11–14
Boilers and Boiler Controls/Burner Management Systems
Kingston, Tennessee
Contact: Sherryl Stogner, 704-547-6174

12–13
Power Quality Interest Group
Clearwater, Florida
Contact: Marsha Grossman, 650-855-2899

12–13
Simulator Specification and Procurement Workshop
Kansas City, Missouri
Contact: Cassandra Maslowski, 816-235-5623

12–14
Valuation, Pricing, and Risk Management: Energy Book System Training
Austin, Texas
Contact: Cara Lee Braithwait, 888-332-8258

13–14
Healthcare Initiative Conference
Charleston, South Carolina
Contact: Kelly Ciprian, 614-855-1390

13–14
Live-Working Workshop
Lenox, Massachusetts
Contact: Judy MacPherson, 413-499-5701

14–15
Capitalizing on the Load Management Opportunity
Palm Beach, Florida
Contact: William Smith, 650-855-2415

17–20
Gasification Technologies Conference
San Francisco, California
Contact: Barbara Freel, 650-855-2253

18–19
Motor Rewind Seminar
Farmington, New Mexico
Contact: Jan Stein, 650-855-2390

18–20
Transmission Inspection and Maintenance (TIM) System Users Group
Dallas, Texas
Contact: Gayle Robertson, 817-439-5900

18–22
Operations Training for Nonoperators
Kingston, Tennessee
Contact: Sherryl Stogner, 704-547-6174

18–22
Visual Examination Technology: Level 1
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

19–20
Instrument Monitoring and Calibration Users Group Meeting
Harriman, Tennessee
Contact: Vicky Buchanan, 704-547-6158

19–21
Power Quality Technical Training
Knoxville, Tennessee
Contact: William Berry, 423-966-5429

19–22
Maintenance and Repair of Heat Exchange Equipment
Eddystone, Pennsylvania
Contact: Melanie Moore, 610-490-3216

20–22
1999 Distributed Resources Conference
Phoenix, Arizona
Contact: Cindy Layman, 650-855-8763

21–22
Municipal Water and Wastewater Program Meeting
Nashville, Tennessee
Contact: Kim Shilling, 314-935-8590

24–27
Managing the Marketing Research Process in a Deregulated Environment
Dallas, Texas
Contact: Lynn Stone, 972-556-6529

25–26
Workshop on the Application of Transmission Line Nonceramic Insulators
Lenox, Massachusetts
Contact: Judy MacPherson, 413-499-5701

25–November 5
Ultrasonic Examination Technology: Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

26–27
Gas-Electric Partnership Workshop
Houston, Texas
Contact: Dick Schmeal, 713-963-9307

26–27
Transmission Transfer Capabilities Workshop
Birmingham, Alabama
Contact: Peter Hirsch, 650-855-2206

26–29
Protective Coatings
Eddystone, Pennsylvania
Contact: Melanie Moore, 610-490-3216

28–29
Power Electronics Experts Conference
Monterey, California
Contact: Teresa Boykin, 919-859-5010

28–31
Worldwide Food Expo '99
Chicago, Illinois
Contact: Barry Homler, 419-534-3713

November

1–2
PQ501: Power Quality Business Opportunities
Knoxville, Tennessee
Contact: William Berry, 423-966-5429

2–4
Second EPRI European Conference
Vienna, Austria
Contact: Stephen Lee, 650-855-2486

8–11
Advanced Structural Analysis and Design Methods for Electric Power Line Upgrading
Haslet, Texas
Contact: Gayle Robertson, 817-439-5900

9–10
Center for Waste Reduction Technologies–EPRI Water Management Workshop: Issues, Technologies, and Solutions
St. Louis, Missouri
Contact: Sam Woinsky, 281-419-1122

9–11
PQ301: Advanced Power Quality Workshop
Knoxville, Tennessee
Contact: William Berry, 423-966-5429

11–13
Root-Cause Analysis
Eddystone, Pennsylvania
Contact: Melanie Moore, 610-490-3216

15–17
Service Water Corrosion: CHECWORKS Cooling Water Application Training
Palo Alto, California
Contact: Doug Munson, 650-855-2573

15–19
International Conference on Sealing Technology and Plant Leakage Reduction
Charlotte, North Carolina
Contact: Brent Lancaster, 704-547-6017

15–19
NDE for Engineers
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

15–19
Visual Examination Technology: Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

16–17
Power Quality for the Polymer Processing Industry
Charlotte, North Carolina
Contact: Pam Helms, 704-602-4100

17–18
Operational Reactor Safety Engineering and Review Groups
San Antonio, Texas
Contact: Cindy Layman, 650-855-8763

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

30–December 2
Nuclear Utility Procurement
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

December

6–7
Second Workshop on Intelligent Sootblowing
Las Vegas, Nevada
Contact: Brent Lancaster, 704-547-6017

6–10
NDE Technical Skills Training: Level 3 Basic/Specific
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

7–9
PQ311: Advanced Power Quality Workshop
Knoxville, Tennessee
Contact: William Berry, 423-966-5429

8–9
Maintenance Rule Users Group
Scottsdale, Arizona
Contact: Brent Lancaster, 704-547-6017

13–17
Operations Training for Nonoperators
Kingston, Tennessee
Contact: Sherryl Stogner, 704-547-6174

13–17
Visual Examination Technology: Level 3
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

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