EPRI JOURNAL

JULY/AUGUST 1998

Daylight Harvesting
New Controls and Strategies

Smart Materials
Prospects for Power Systems

Ecological Assets

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 700 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: Satellite images of a region's vegetation help utilities characterize natural habitats and identify the species these habitats most likely support. (Map created by Richard Podolsky, Avian Systems. Inset photos courtesy West Virginia Natural Heritage Program: running buffalo clover by Bill Roody; Cheat Mountain salamander and long-stalked holly by Craig Stihler; northern flying squirrel by Larry Master.)

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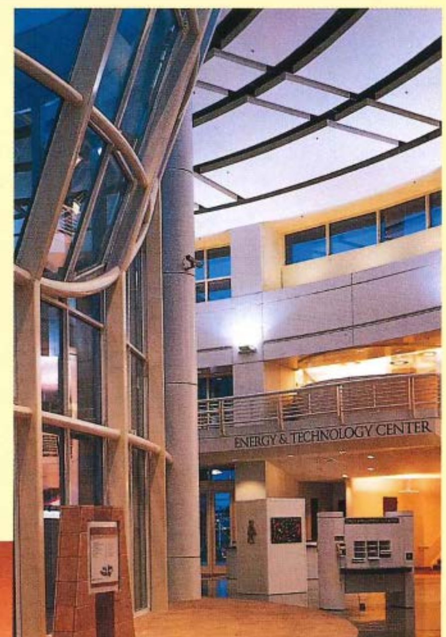

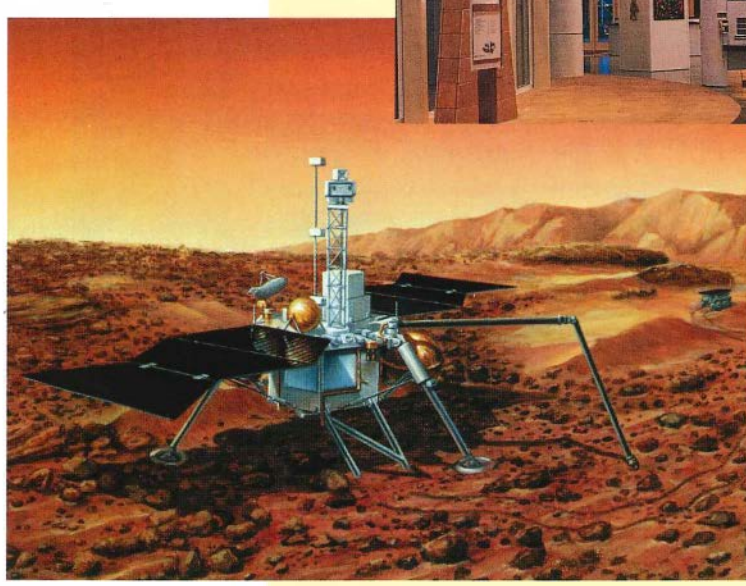

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Editorial

Power Generation Diversity: A Global Imperative

A central challenge of the twenty-first century will be to continue to improve the standard of living of an increasing world population without causing unacceptable damage to the global environment. During the next 50 years, the world's population is expected to grow from about 6 billion to about 10 billion, with most of the increase occurring in today's underdeveloped regions. Continued global economic growth—at the rate achieved during the twentieth century but including substantial economic development in currently underdeveloped regions—will be required to avoid widespread poverty with potentially serious consequences for both the environment and global security.

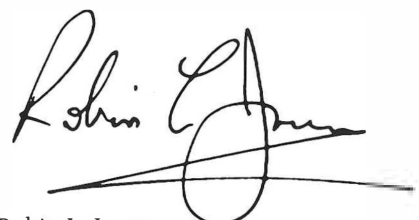
Because energy is the engine of economic growth, a substantial increase in per capita energy use is expected, along with an even larger increase in the use of electricity, the clear choice for cleaner, more efficient power. Even with significant improvements in energy efficiency, in both production and use, the electric generating capacity needed worldwide in 2050 may be as much as three times today's 3000 GW—a projection that would require a new 1000-MW plant to come online somewhere in the world every two to three days for the next 50 years!

No single technology can optimally meet the challenges posed by such a massive increase in global electricity demand. Differences in national aspirations, indigenous fuel resources, existing infrastructure, economic flexibility, energy security considerations, and population patterns will cause individual countries to take distinctly different approaches to satisfying their electricity needs. A broad portfolio of fossil, nuclear, and renewable options—both central and dispersed power generation alternatives—will be needed to respond to the widely disparate situations that will exist during the next half century in, for example, Africa, China, and the United States.

A well-balanced R&D program that builds on the full range of options and possibilities known today is a prerequisite for ensuring the ongoing availability of a robust portfolio of power generation options. Unfortunately, R&D on advanced power generation in this country currently is neither well balanced nor well funded, largely owing to energy industry deregulation and the current availability of cheap energy. Further, unlike developing countries, the United States does not need a range of generation options in the near term: its expected load growth for at least the next five years can be met almost entirely by variations on the gas-fired combustion turbine theme.

However, an exclusive focus on gas-fired generation would be a poor long-term strategy for the United States for at least two reasons. First, most of our existing baseload capacity will have to be replaced before 2030, and relying entirely on gas for this replacement capacity would create a serious energy security vulnerability. Second, if we invest only in our short-term needs, we will be ceding to others technical leadership of what will unquestionably become a globally defined energy enterprise and, in the process, will be risking our position as the world's leading economic power.

Science and technology innovation will be critical to solving the global population-poverty-pollution "trilemma." The Electricity R&D Roadmap is being developed to create a consensus vision of R&D possibilities and priorities—not just for EPRI but for the entire community concerned with the interrelationships between electricity and society. By building on the emerging consensus about the need for a continuing broad program of basic and applied research funded by public-private partnerships, it is within our power to develop the robust portfolio of electric generating options that will be needed in the coming century. The stakes—for both our nation and the world—are too high not to do so.



Robin L. Jones
Vice President, Energy Conversion

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The Value of Ecological Resources (page 8) was written by science writer Christopher R. Powicki with technical assistance from William Coleman of EPRI's Environment Division.

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He has been with EPRI since 1985, serving in both technical and client relations capacities. Earlier, as a loaned executive from Entergy Corporation to the Edison Electric Institute, he spent two years as EEI's liaison to Congress, specializing in environmental and governmental affairs. During 10 years with Entergy, he served as manager of environmental affairs, with responsibility for all corporate environmental programs. Coleman received a bachelor's degree in environmental studies, with emphasis in terrestrial ecology, from the University of New Mexico.

Harvesting Daylight Inside Buildings (page 18) was written by Taylor Moore, *Journal* senior feature writer, with technical assistance from John Kesselring of the Energy Delivery and Utilization Division.

JOHN KESSELRING joined EPRI in 1986 after four years as a vice president with Alzeta Corporation. Earlier he was associate manager of the Combustion

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JOHN STRINGER was appointed executive technical fellow in the Energy Conversion Division in 1991. Earlier he held the same title in Strategic Science and

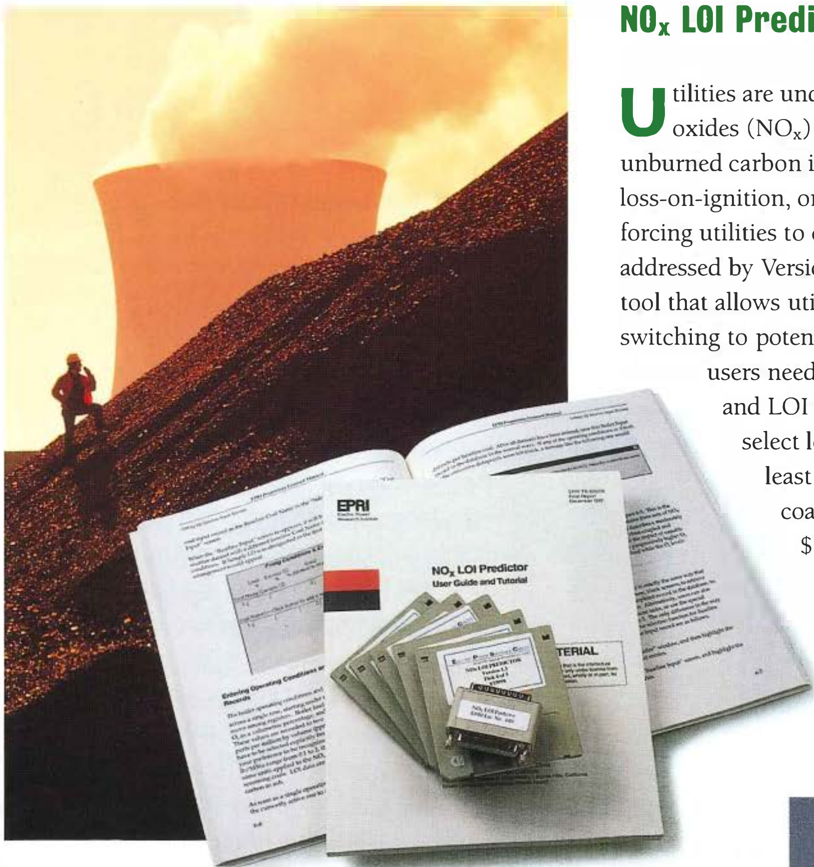
Technology and, before that, was director of applied science and technology in Strategic R&D. Stringer came to EPRI in 1977 as a project manager in the Materials Science Group and became the group's manager in 1984. He helped design EPRI's Exploratory Research program—the predecessor of Strategic R&D—which was launched in 1985. Before joining EPRI, Stringer headed the Metallurgy and Materials Science Department at the University of Liverpool, England, and from 1963 to 1966, he worked in the Metal Science Group at Battelle Memorial Institute. He holds BS and doctorate degrees in engineering, as well as a PhD in materials science, from Liverpool.

MARK PERAKIS is a team manager in the Energy Conversion Division, directing research in generation plant maintenance optimization, instrumentation and

control technologies, and training and simulation for human performance enhancement. Before joining EPRI in 1993, he worked as a design engineer for Pacific Gas and Electric Company, where he was responsible for power plant design and construction. In this capacity, he participated in the development of geothermal, cogeneration, and alternative energy generation facilities and managed the retrofit of a number of fossil power plant control systems. He also worked as a power production engineer at PG&E's Pittsburg plant. Perakis has a BS in chemical engineering from the University of California at Berkeley.

Products

Deliverables now available to EPRI members and customers



NO_x LOI Predictor

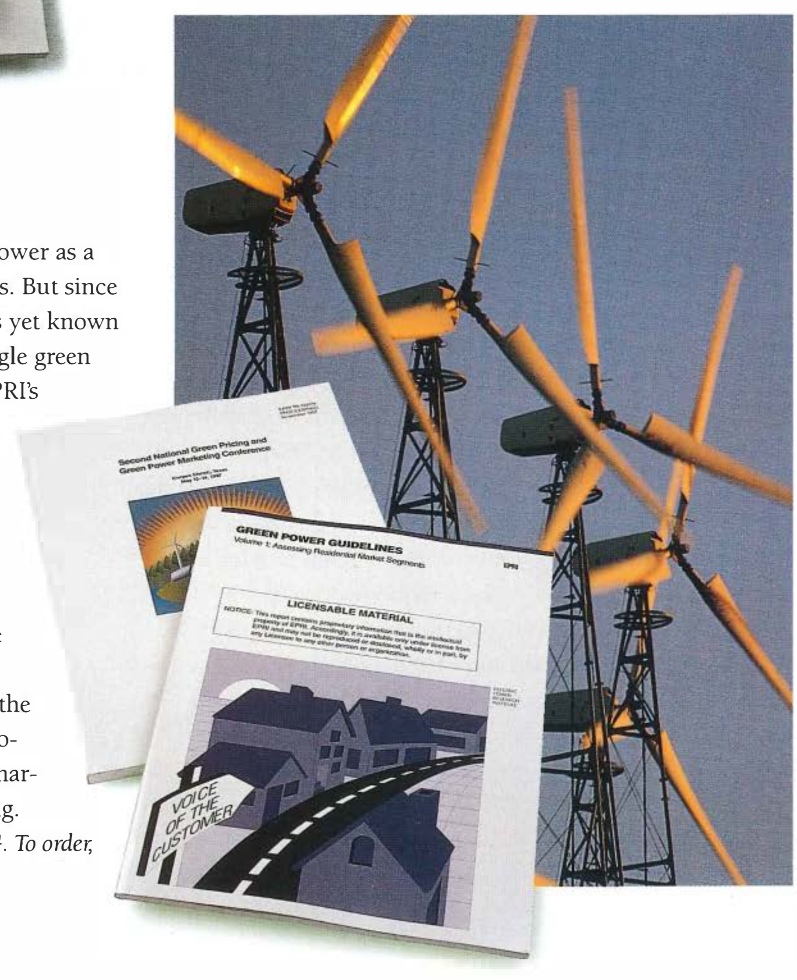
Utilities are under constant pressure to reduce emissions of nitrogen oxides (NO_x) from coal-fired boilers while maintaining low levels of unburned carbon in the fly ash (carbon that is generally measured through loss-on-ignition, or LOI, testing). In addition, industry restructuring is forcing utilities to cut costs to become more competitive. These issues are addressed by Version 1.1 of the NO_x LOI Predictor software, a screening tool that allows utilities to quickly assess the environmental impacts of switching to potentially lower-cost coals on the spot market. With this tool, users need only input readily available coal data to predict NO_x and LOI values for a candidate coal. The software will help them select less-expensive coals whose use will either lower or at least not increase NO_x and LOI levels. Making the right coal-purchasing decisions can result in annual savings of $500,000 or more for a 500-MW plant.

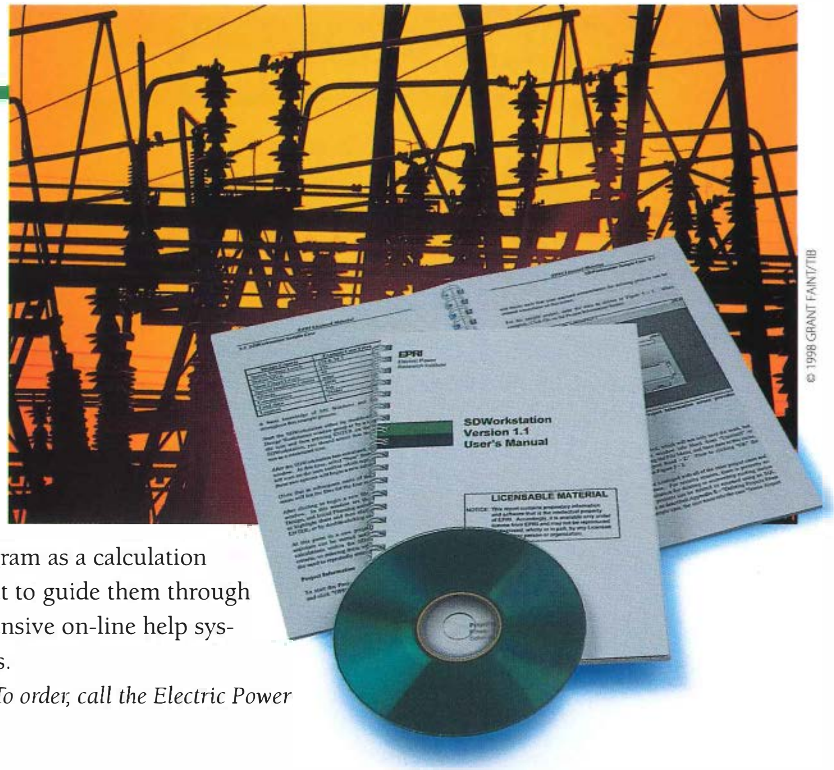
■ *For more information, contact Jeff Stallings, (650) 855-2427. To order, call the Electric Power Software Center, (800) 763-3772.*

Green Power Guidelines

Many energy service companies are turning to green power as a way to distinguish themselves from their competitors. But since this is a new and rapidly evolving product category, little is yet known about how customers view green power and whether a single green electricity product will meet the needs of all customers. EPRI's *Green Power Guidelines: Assessing Residential Market Segments* (TR-109192-V1) offers this much-needed perspective on residential customer attitudes. Based on a series of customer focus groups and the results of a subsequent national survey of 25,000 consumers, this report defines six segments in the residential market and identifies the best ways to approach these groups. A second volume, due out later this year, will focus on similar issues in the commercial sector. Additional background on recent events in the green power marketplace is available in TR-109179, the proceedings of EPRI's second green pricing and green power marketing conference, held in Corpus Christi, Texas, last spring.

■ *For more information, contact Terry Peterson, (650) 855-2594. To order, call the EPRI Distribution Center, (510) 934-4212.*





SDWorkstation

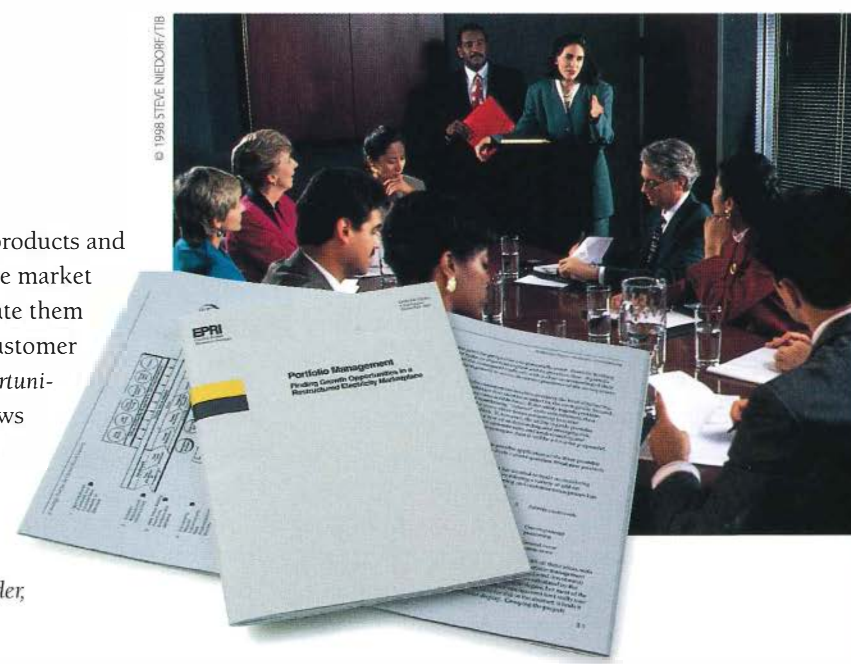
Both knowledgeable and less-experienced engineers will benefit from Version 1.1 of EPRI's Substation Design Workstation. This CD-ROM software enables users to quickly develop conceptual designs for substations and efficiently estimate construction costs and schedules. It includes all the necessary information and calculation tools to perform an initial substation design. While the experienced engineer may prefer to use the program as a calculation and reference tool, less-experienced engineers can rely on it to guide them through the complete design of a substation. The workstation's extensive on-line help system includes general information as well as design tutorials.

■ *For more information, contact Ben Damsky, (650) 855-2385. To order, call the Electric Power Software Center, (800) 763-3772.*

Neptune Washer

This front-loading washing machine, developed by Maytag in partnership with EPRI, has proved a big hit since its release last year as both a coin-operated unit for commercial laundries and a residential unit. The Neptune is gentler on clothing and better at stain removal than conventional washers with agitators. It also offers water savings of nearly 40% and energy savings of over 60%. For easy loading and unloading, the Neptune's tub is tilted upward at a 15-degree angle and has an extrawide access opening. And the washer has 20% more usable capacity than standard top-loading machines.

■ *For more information, contact John Kesselring, (650) 855-2902. To order, call your local Maytag dealer.*



Portfolio Management Report

Energy service companies are rapidly creating a host of new products and services for their customers. One strategy for maximizing the market penetration and market share of these new offerings is to integrate them into a cohesive portfolio that can address a broad array of key customer needs. This report—*Portfolio Management: Finding Growth Opportunities in a Restructured Electricity Marketplace* (TR-108106)—reviews product and service portfolio management in other competitive industries. It explains how energy providers can develop and apply processes and techniques from those industries to establish competitive and strategic advantage in their own markets.

■ *For more information, contact Burk Kalweit, (650) 855-2329. To order, call the EPRI Distribution Center, (510) 934-4212.*

Discovery

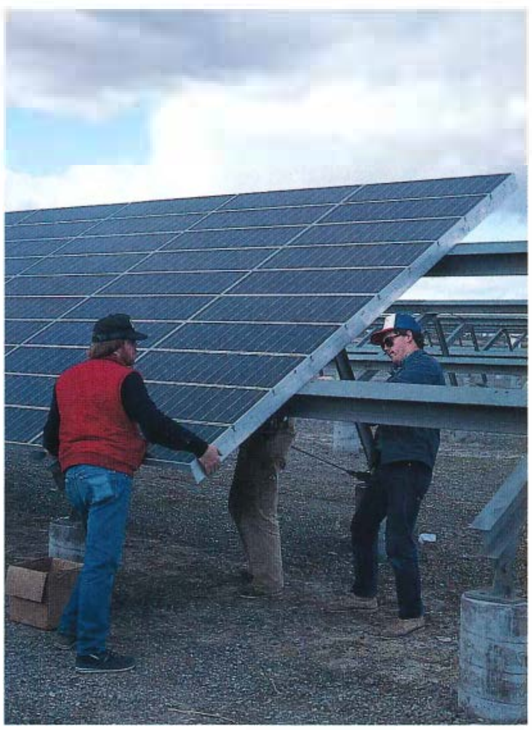
Basic science and innovative engineering at the cutting edge

Stabilizing a-Si Thin-Film PV Materials

The phenomenon by which exposure to sunlight degrades the electricity-generating efficiency of thin-film photovoltaic (PV) devices based on amorphous silicon (a-Si) has been a barrier to lower-cost PV technology for more than 20 years. It has also been a puzzle to scientists, who call it the Staebler-Wronski effect for their colleagues who discovered it. Today's commercially manufactured a-Si thin-film PV modules can lose 15–20% of their energy conversion efficiency within the first month of sunlight exposure, after which efficiency stabilizes at about 7–8%. Understanding the mechanism of the effect and finding a means of preventing or limiting it "have been the Holy Grail of physics and materials research in thin-film PV for two decades," notes Terry Peterson, manager for solar power in EPRI's Energy Conversion Division.

Recent EPRI strategic R&D in a-Si thin-film PV has confirmed the efficacy of approaches for reducing the Staebler-Wronski effect and has shed new light on a likely mechanism, raising hopes for an eventual practical solution to the problem. Through a combination of laboratory experiments and computer modeling, electronics engineering researchers at Pennsylvania State University and Iowa State University confirmed dramatic improvement in the resistance of experimental a-Si thin-film PV cells to light-induced degradation when they substituted deuterium for hydrogen in the silane gas used for growing thin films by plasma vapor deposition. Results from the collaborative research highlight the critical importance of weak hydrogen-silicon chemical bonds and also suggest possible approaches for optimizing the nucleation and growth of submicrometer-scale nanocrystalline a-Si thin films for PV cells.

Researchers at Japan's Electrotechnical Laboratory (ETL) first reported in the late 1980s that the substitution of deuterium (an isotope of hydrogen with twice its mass) for hydrogen in silane (SiH_4, an analog of methane with carbon replaced by silicon) produced more-stable a-Si thin films. After that, researchers at the University of Illinois reported that thin-film crystalline silicon transistors became more stable with deuterium substitution. More recently, United Solar Systems Corporation—a thin-film PV manufacturing joint venture of Canon and Energy Conversion Devices—produced more-stable thin-film solar cell structures by substituting deuterium, concluding on the basis of limited experiments that the substitution improved the microstructure of a-Si thin films.



Earlier work at Japan's ETL also found that the stability of a-Si thin films was improved by simply diluting the pure silane with hydrogen to make about a 10-to-1 hydrogen-silane mixture. That result has since been replicated elsewhere, including at Penn State.

"Obviously, hydrogen plays a key role as far as the Staebler-Wronski effect is concerned," observes electrical engineering professor Chris Wronski, one of the principal investigators for the EPRI-funded work at Penn State and one of the discoverers of the effect, first reported in 1976 when Wronski and David Staebler worked for RCA Laboratories. "All of the generally accepted theories for the mechanism of the effect relate to the hydrogen bonds in the microstructure. Hydrogen must be present in the a-Si alloy to passivate broken bonds in the microstructure that would otherwise act as defects and degrade electronic properties. But at the same time, it is believed that the light-induced degradation of properties is associated with hydrogen."

Penn State researchers observed greater improvement in stabilized efficiency in thin-film solar cells produced from silane diluted with hydrogen than in those produced from undiluted silicon deuteride. But they reported the greatest stabilization effect with deuterium-diluted silicon deuteride. Theoretical molecular dynamics modeling led by Rana Biswas at Iowa State indicates that the deuterium-silicon chemical bond is 50 times more stable with respect to light-induced changes than the hydrogen-silicon bond.

"The substitution of deuterium for hydrogen in the plasma definitely leads to better-quality material and, consequently, solar cells," says Wronski. "Now the question is to figure out why. Without doubt, the substitution dramatically changes the kinetics of film growth at the microstructure level. From a practical standpoint, one would not want to use deuterium-diluted silicon deuteride to grow thin films, and dilution presents the separate problem of reducing film deposition rates, which hurts the manufacturing economics. But I am heartened that we now have taken another step that shows a systematic, fundamental improvement in thin-film stability that is also proven in solar cells."

■ *For more information, contact Terry Peterson, (650) 855-2594.*

Carbon Burn-Out Improves Fly Ash Quality

A new technology developed by EPRI and Progress Materials improves the quality of fly ash so that it can be readily marketed. The first full-scale facility to apply the technology has been built at a South Carolina power plant.

The sale of fly ash is a flourishing business for a lot of electric utilities. Some 12 million tons of fly ash produced by coal-fired power plants in the United States are sold to the cement and concrete industries annually. The business may be in danger, however, as many utilities are finding that the technologies installed to control nitrogen oxides (NO_x) to meet the emissions standards of the 1990 Clean Air Act Amendments can increase the unburned-carbon content of fly ash, making it unsuitable for cement and concrete.

A typical 800-MW coal-fired plant creates more than 700 tons of ash per day. The ash is often used for landfill or piped into ash ponds, but a growing number of power producers are selling it as filler for concrete for the construction of roadbeds, buildings, and other structures. This beneficial use is dependent on the amount of carbon left in the ash after combustion: too much carbon makes it unusable.

The newly developed technology, called the Carbon Burn-Out (CBO) process, produces a high-quality, low-carbon fly ash, and the heat recovered in the process improves the efficiency of the host power plant. "CBO improves fly ash quality by combusting the carbon contaminating the ash; this carbon is the fuel for the CBO process," explains Pete Hay, who is president of Progress Materials. "The heat recovered in the process improves the power plant heat rate, which means that emissions of carbon dioxide into the atmosphere are reduced."

CBO can handle the variations in the carbon content of fly ash from the day-to-day operations of a single plant and from different generating stations and still yield a beneficiated product that is consistent in quality, says Tom Boyd, EPRI manager for the project. "By taking the higher-carbon issue out of the equation, plant operators can focus on efficient boiler operation while maintaining environmental compliance," he notes.

South Carolina Electric & Gas began considering its alternatives for the processing of fly ash as soon as the Clean Air Act Amendments were passed. "We anticipated that retrofitting low-NO_x burners on our plants would increase the carbon in our fly ash, multiplying the ash loss on ignition from 2–5% to perhaps 10–15%," recalls SCE&G's Ted Frady, senior engineer in charge of the utility's ash utilization program. "We have been successfully marketing over 80% of our ash, and we have a vision of selling 100%."

SCE&G decided to proceed with a full-scale facility on the basis of successful pilot plant tests on its fly ash conducted by EPRI and Progress Materials. The beneficiated fly ash was evaluated by both the utility and its marketer, Southeastern Fly Ash Company.

The full-scale facility is designed to produce approximately 160,000 tons of low-carbon beneficiated fly ash per year. Located at SCE&G's Wateree station and scheduled to begin operation this summer, the facility will process fly ash from Wateree and from two other SCE&G power stations, McMeekin and Urquhart.

The successful development of the CBO technology offers utilities an alternative to landfilling fly ash if they are located in areas with markets for the ash. Application of the burn-out process will enable them to optimize boiler operations while maintaining environmental standards and controlling fly ash quality. CBO can also support fuel-switching strategies. Further benefits include reducing the quantity of landfilled ash and avoiding ash disposal costs.

■ *For more information, contact Tom Boyd, (704) 547-6033.*

The Value of ECOL

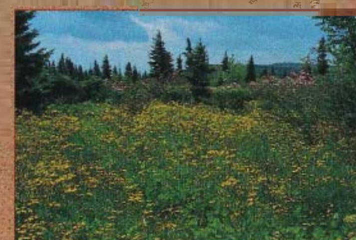
THE STORY IN BRIEF

Human survival depends on natural ecosystems and the physical, chemical, and biological functions they perform. A new approach to environmental management is emerging as the enormous economic and social contributions of species, habitats, and ecological services become more widely recognized. EPRI, in partnership with energy companies, conservation groups, and other stakeholders, is developing and applying methods to help landowners quantify, maximize, and extract this once-intangible value while protecting and managing important ecosystems.

RES

OGICAL

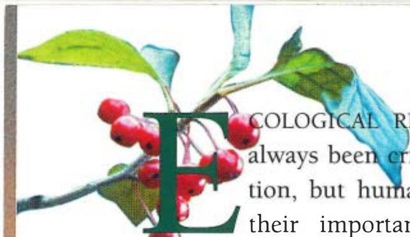
For Al Noia, the Canaan Valley in West Virginia is a favorite getaway destination for hiking, cross-country skiing, and other recreational activities. Numerous outings there have afforded him an appreciation of the valley's unusual flora and fauna—unusual largely because their habitats are more typical of southern Canada or Minnesota than the mid-Atlantic region where the valley is located. The valley floor, about 1000 meters above sea level, includes some 8000 acres of wetlands that feed the Blackwater River and its tributaries. These wetlands are similar to those found in the subarctic tundra, and certain Canaan Valley species reside otherwise only in more northerly latitudes, if found elsewhere at all.



Al Noia is chairman, president, and chief executive officer of Allegheny Energy. His company happens to own 20,675 acres in the valley's undeveloped northern region, where nature has more or less been allowed to run its course for the past 70 years. Noia understands that in the increasingly competitive energy marketplace, his company needs to extract value from every physical asset to ensure continued success and meet shareholder expectations. He knows that the optimal business strategy regarding the future of the Canaan Valley parcel might conflict with his personal desire for its preservation. And so he watches with great interest as his company teams up with EPRI to assess the value of managing its part of the Canaan Valley as an ecological resource.

by Christopher R. Powicki

OURCES



ECOLOGICAL RESOURCES have always been critical to civilization, but human awareness of their importance has varied through history. In recent times, the management of ecological resources has been characterized more by exploitation than by concern for the form and function of natural systems. Today, a more integrated management philosophy is evolving in both the public and private sectors. This philosophy is based on the growing recognition that intact ecosystems—habitats, the species they harbor, and the services they provide—are invaluable for the economic and social well-being of this and future generations of humankind.

The new philosophy is leading to a major shift in emphasis in environmental policies. Efforts increasingly focus on the preservation of critical habitats, communities, and ecosystems rather than on the protection of individual species. Also, command-and-control regulations are in many cases being replaced by approaches that rely on market-based mechanisms or community-based consensus building. By establishing broad performance standards rather than prescribing treatment technologies or rigid permit limits, these approaches introduce flexibility and provide incentives that promote cost-effective compliance and protection.

Meanwhile, companies in energy and other industries are responding to the competitive marketplace by adopting a more strategic approach to environmental management. Their objective is to move beyond compliance, which has traditionally been viewed as a resource-intensive obligation. Early on in planning and operational decision making, forward-thinking companies are looking for ways to turn environmental liabilities into environmental assets. The desired end is to create opportunities for reducing compliance costs, enhancing revenues, demonstrating stewardship to customers, and, ultimately, increasing shareholder value.

Strategies for ecological resource management—supported by methods of assessing and quantifying the economic value of species, habitats, and ecosystems—represent a promising way to capitalize on environmental asset management. Companies that develop a sound understanding of the total value of individual properties may be able to realize substantial economic benefits by investing in the enhancement and preservation of ecologically significant areas, such as wetlands, forested watersheds, and habitats for important species. These areas may be managed as revenue-producing mitigation and conservation banks or to maximize the ecological credits they may qualify for in the near future, depending on policy and market developments.

"Landholdings identified as having actual or potential importance to society can take on an exchange value," says William Coleman, who manages EPRI's work on biodiversity protection. "Conserving these ecological assets, as they are coming to be called, may enable companies to alleviate capital- or resource-intensive compliance requirements elsewhere; to show their environmental good faith to stakeholders as they develop other, less sensitive properties; or to create new revenue streams through low-impact development or the sale of conservation easements. And any opportunity to demonstrate environmental leadership—alone or, better yet, with other stakeholders—can help companies become energy providers of choice."

Ecological values

Natural ecosystems are fundamental to human survival. At the most basic level, the conditions they create and the processes they sustain enable our life-support functions, delivering the clean air we breathe, the clean water we drink, and the foodstuffs we eat.

Known as ecosystem services, these conditions and processes produce countless other benefits as well. For example, they are primary sources for current and future pharmaceutical and industrial products. They help control the aquatic, terrestrial, and atmospheric cycling of nutrients and other important chemicals. They help generate and renew productive soil. They help moderate climate, mitigate flooding and erosion, and screen out the sun's ultraviolet rays. And they offer recreational, aesthetic, and spiritual benefits.

In efforts to promote the conservation and restoration of ecological resources, scientists are attempting to characterize and quantify the value of ecosystem services to society. Breathable air, potable water, and waste assimilation alone are worth some $33 trillion annually, according to a recent article in *Nature* magazine by Robert Costanza (of the University of Maryland's Institute for Ecological Economics) and others. By contrast, the annual global gross national product is estimated at $18 trillion.

Recent funding decisions by New York City exemplify the growing recognition of the value of ecosystem services. The city's water supply system delivers almost 1.5 billion gallons per day (66,000 L/s) through a network of reservoirs and pipelines that tap a 2000-square-mile (5200-km^2) watershed extending 125 miles (200 km) north and west of the city. Because of the watershed's superior cleansing capability, at present no filtration is required to deliver high-quality water. Recognizing the threat posed by future development, the city has committed hundreds of millions of dollars to fund land acquisitions, purchase conservation easements, and promote sound management within the watershed. By protecting hydrologically sensitive lands and creating green buffers around streams and reservoirs, the city expects to preserve the watershed's natural capability while avoiding the need to install what would be the world's largest filtration plant, at an estimated cost of $6 billion. For taxpayers, the estimated benefit-to-cost ratio for this ecologically based decision is on the order of 10 to 1.

In addition, many government agencies, corporations, conservation groups, and other landowners are responding to emerging regulatory and market conditions by setting up mitigation or conservation banks. Such a bank is created when a landowner sets aside areas of wetlands or other valuable habitats that have been restored, enhanced, created, or preserved. Other landowners can then purchase credits corresponding to the set-aside acreage, which enables them to proceed with development, construction, or maintenance activities that impact equivalent or smaller ar-

PAGES 8–9: BACKGROUND PHOTO AND TOP TWO INSETS DANA RUSKE/ALLEGHENY POWER; BOTTOM INSET CRAIG STIHLER/WV NATURAL HERITAGE PROGRAM

eas of similar habitat. Bank-and-trade values ranging from \$30,000 to \$200,000 per acre (\$7 million to \$50 million per square kilometer) have been established for various types of wetlands. In some cases, the credit value of intact or restored wetlands far exceeds current real estate prices for equivalent commercial or residential developments.

"Establishing market values for ecological resources and ecosystem services promotes the protection of species and habitats by quantifying externalities that have previously gone unconsidered," says Coleman. "But the science of ecological economics is in its infancy, with many critical questions unresolved: Which ecological attributes can we establish realistic values for? How do we measure, monitor, or enhance their worth? And how do we incorporate these valuations into workable ecological resource management policies and systems?"

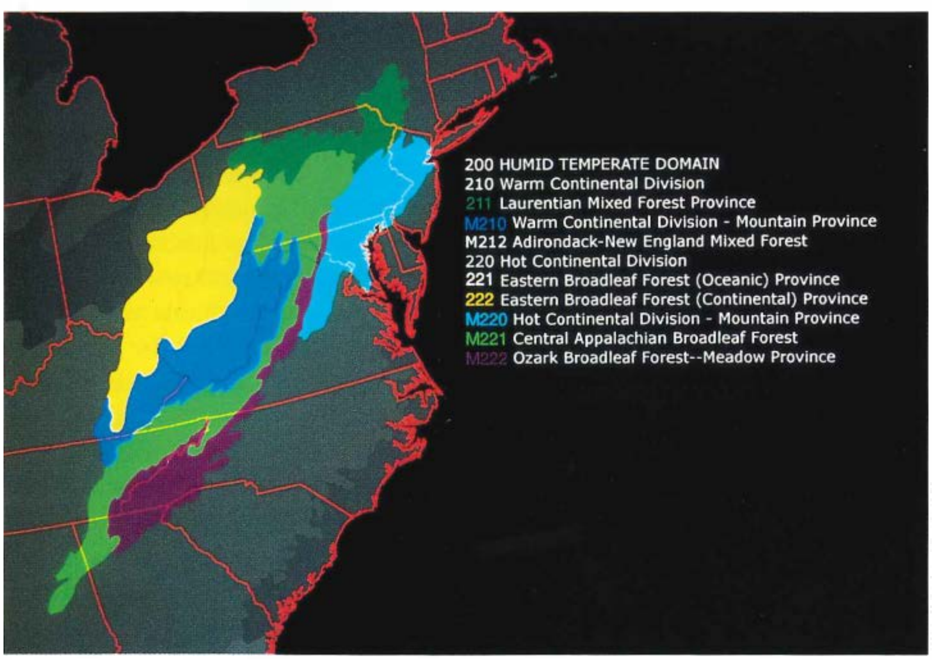
EPRI is advancing the science of ecological economics and resource management through a series of interdisciplinary studies. Existing and historical valuation measures are being assessed for species, habitats, and intact ecosystems; cost-effective methods are being developed for characterizing and valuing the ecological resources of specific properties or regions; and management approaches are being devised for maximizing the direct or indirect economic value of a landholding. In addition, EPRI is partnering with conservation groups, corporations, and other stakeholders to address the development of regulatory and other incentives that will enable landowners to gain economic or other benefits by protecting ecological resources.

Transforming intangibles

Many energy companies own huge but largely undeveloped tracts of land, such as transmission corridors, watersheds associated with hydro facilities, and sites for future infrastructure expansion. "Most properties—if managed for any reason other than to optimize the operating and maintenance costs of generation and delivery systems—have been managed to maximize traditional commodity values, as in timber production, mining, or real estate development," says Coleman. "But methods and strategies for ecological resource management have the potential to unlock the nontraditional, heretofore intangible value of ecosystem services provided by certain landholdings."

EPRI is helping Allegheny Power (as Allegheny Energy's utility subsidiaries are collectively known) incorporate the principles of ecological resource management into a companywide land management plan. AP's overall objective is to maximize shareholder value from some 60,000 acres (240 km^2) of holdings. Recently the company's land management team identified 12 tracts—consisting of approximately 38,500 acres (156 km^2) and ranging in size from 150 to more than 20,000 acres (0.6–80 km^2)—that might contain potentially valuable ecological resources.

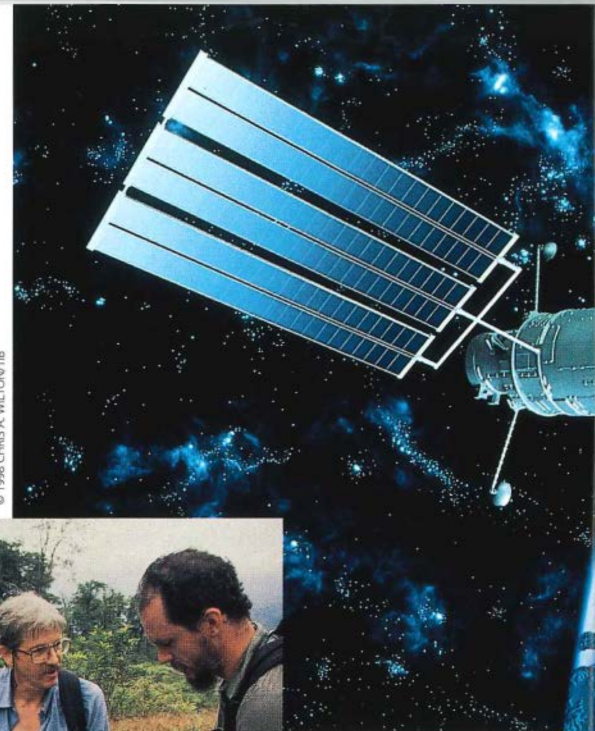
The bulk of these lands are in West Virginia, the remainder in Pennsylvania and Maryland. Some may be prized by academic or public-interest groups because the Allegheny Mountains functioned as a refuge for flora and fauna during final



Ecoregions, which define unique assemblages of interdependent biological communities, form a rich mosaic that can help utilities characterize and evaluate their ecological resources. EPRI and Allegheny Power are collaborating to define ecological resource values for properties in the Allegheny Mountain subregions.

Cost-effective ecological characterization methods exploit the visual richness and high resolution of commercially available satellite imagery to minimize the need for extensive aerial and ground surveys. Labor-intensive fieldwork can thus focus on the verification and analysis of species and habitat data rather than on exploration and data collection. During initial ground-truthing efforts led by Richard Podolsky (shown in helicopter), the rare *Trillium grandiflora* was encountered in the Canaan Valley area.

RICHARD PODOLSKY



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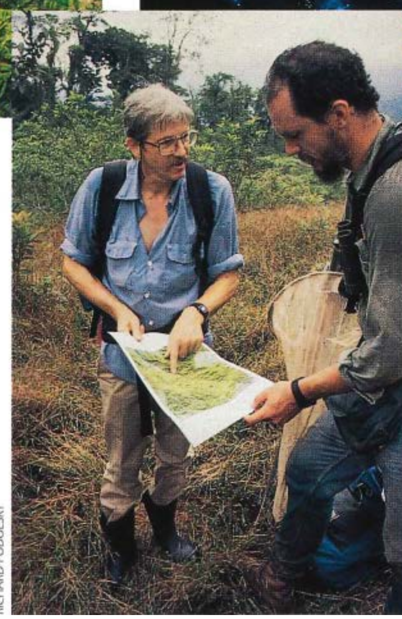


RICHARD PODOLSKY

glaciation episodes 10,000 years ago. After the glaciers retreated north, newly exposed land was recolonized by species that survived the glacial maximum. Today, this region supports one of the greatest diversities of plant and animal species in the Northern Hemisphere.

The Canaan Valley parcel and AP's other major West Virginia holdings—Big Sandy River (2070 acres; 8.4 km^2), Upper Cheat River (1400 acres; 5.7 km^2), and Middle Cheat River (4930 acres; 19.9 km^2)—are also highly valued by the public for recreational purposes. For example, adventurers from around the globe make springtime pilgrimages to run world-class rapids through the Cheat River Canyon. Other recreational uses include hiking, camping, cross-country skiing, and hunting.

"Some of these properties have been on our books since the 1920s, and our management approach has traditionally been pretty laissez faire," says George Yost, land management representative for AP. "That's no longer the case because certain recreational uses—such as riding all-terrain vehicles and dirt bikes—can destroy sensitive habitats. We've become more proactive, both in protecting ecological resources and in learning more about what is out there so that we can figure out how best to manage the properties in the future. Our land management team is leaving no stone unturned, and EPRI is playing a valuable role in the process."

Ecological characterization of the four major West Virginia properties is nearly complete. The next phase will involve assessing relative ecological values, quantifying the potential value of species and habitats on the basis of an assessment of regional ecosystem services, and identifying management priorities. Resource management plans will then be created, implemented, and monitored on the basis of ecological resource values, traditional commodity values (for timber production or mineral extraction, for example), and AP's business goals. Outcomes could include preservation, enhancement or restoration, conservation banking and trading, environmentally sensitive development, or outright liquidation.

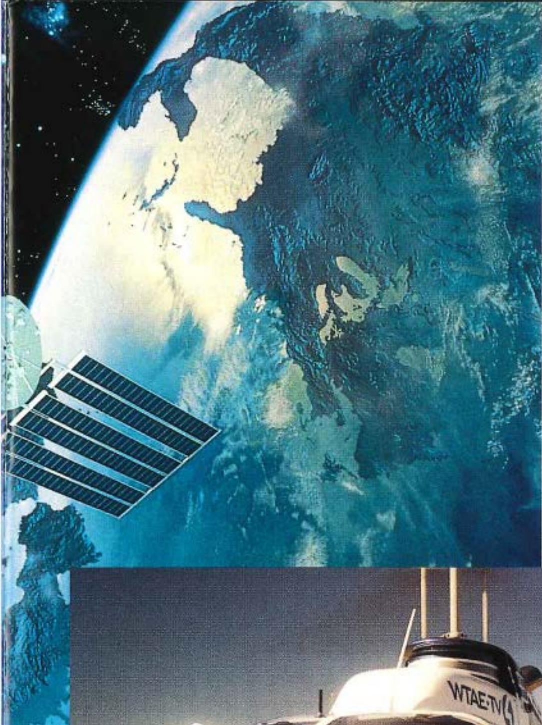
"We're in a new environment where the optimization of all corporate assets is ever more important. We've known that some of our properties are truly unique, but it's always been very difficult to factor the intangible value of these physical assets into the land management equation. That value needs to be unlocked so that we can get the optimum return for shareholders while at the same time remaining environmental stewards," says AP's Noia. "Most companies want to be seen as stewards, but truth to tell I think that over the years the prevailing notion has been of minimum cost to operate and serve. We'd like to go beyond that while serving our customers and safeguarding the interests of our shareholders."

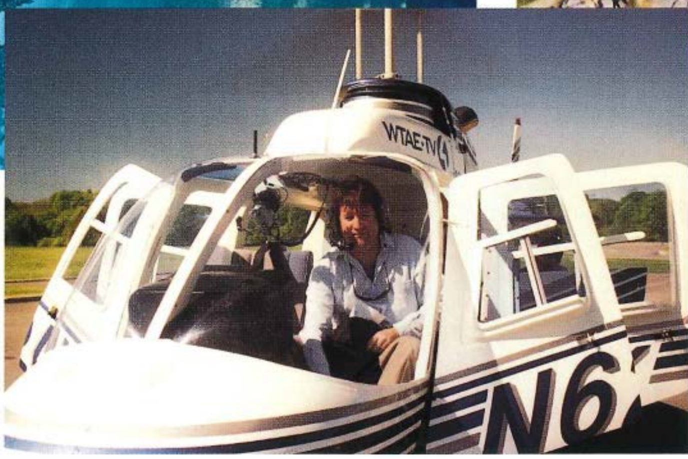
Advancing characterization

In order for ecological resource management to be successful, a property's actual or perceived ecological value must be established. That value can then be weighed against or added to the property's other values to determine the optimal management approach.

The foundation for ecological valuation is accurate characterization. The traditional, direct approach to characterization is to estimate the future viability of species within a region. This method requires extremely expensive field surveys to collect detailed information on the reproductive performance of specific plant and animal communities. Indirect approaches focus on the quality of habitat rather than the viability of species. Because these landscape-based methods use more-accessible types of information, they require much less labor and are at least an order of magnitude more cost-effective.

Bidirectional mapping, a new landscape-based technique, was applied to characterize the AP lands. Bidirectional mapping integrates two powerful and readily available sources of data: digital





satellite imagery and element occurrence data, which indicate geographic locations where threatened or endangered plant and animal species have been sighted. "The visual richness and spatial resolution of satellite images help us characterize habitats on the basis of vegetation classifications, and element occurrence data allow us to determine the habitat preferences of targeted species," explains Richard Podolsky of Avian Systems. "Using this information, we can evaluate AP's lands to identify locations where we might expect to find habitats where populations of these species might exist," continues Podolsky, who developed bidirectional mapping in concert with EPRI and serves as lead contractor for the AP project.

In addition to satellite imagery from CNES/SPOT Image Corporation, Podolsky used vegetation classifications and element occurrence data from the Natural Heritage Program of the West Virginia Division of Natural Resources; the vegetation classifications are regional extensions of a nationwide scheme proposed by The Nature Conservancy. Over 20 threatened or endangered species—including plants, mammals, and insects (see table, p. 14)—were addressed in the bidirectional mapping exercise. Analyses of similarity indexes that characterize tracts with respect to the species' habitat requirements indicate that the Upper Cheat River lands have the greatest likelihood of supporting many of these species. The other parcels also are likely to harbor key populations and thus to represent significant ecological resources.

"The West Virginia properties appear to be ecological hot spots of regional importance," says Coleman. "Bidirectional mapping not only suggests this conclusion but tells us where we should look in the field to cost-effectively verify the presence of key vegetation classes and habitat types. Every indication from our initial ground truthing is that these properties do possess unique natural attributes that will enhance AP's asset base."

At present, EPRI's team of expert ecological economists is developing new concepts, valuation measures, and pricing methods that could be applied by AP and other private landholders in managing properties to maximize future value. The team includes David Simpson from Resources for the Future; Gretchen Daily from Stanford University's Center for Conservation Biology; Booker Holton from TOVA: Applied Science and Technology Resource Management; Paolo Ricci from the University of California at Berkeley; Linda Fernandez from UC Santa Barbara; Robert Costanza from the University of Maryland's Institute for Ecological Economics; and Steven Farber from the University of Pittsburgh.

Enabling conservation planning

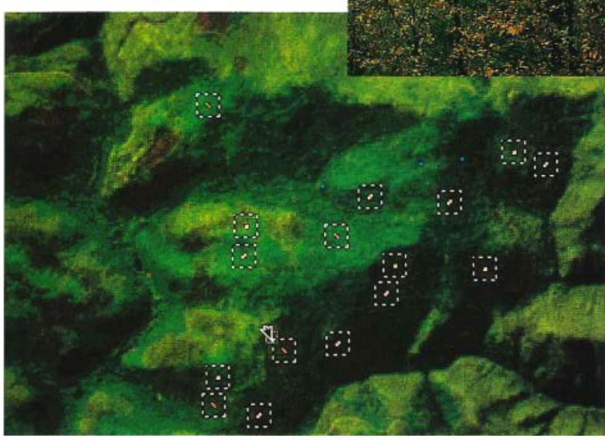
EPRI is also lending support in ecological resource methods and management to San Diego Gas & Electric Company and Southern California Edison Company, which are actively involved in the Natural Community Conservation Planning (NCCP) program in southern California. This program currently aims to protect and enhance large, interconnected blocks of southern coastal sage scrub and other regional habitats. More than 100 threatened or endangered species—notably the California gnatcatcher, cactus wren, and button celery—call this much-fragmented ecosystem home.

In contrast to the federal and state endangered species acts (ESAs), which are designed to identify and protect individual at-risk species, the NCCP effort focuses on ensuring the long-term stability of natural habitats and processes. Whereas ESAs prohibit the unauthorized "taking" of listed species—that is, the deliberate or unintentional causing of harm to individual plants and animals or their habitats—NCCP programs address broad habitat types across entire regions. They prohibit takings of listed species in open-space areas designated as preserves but allow them in other areas if, in conducting development activities, NCCP permit holders adhere to mandated field protocols and mitigate any adverse impacts.

"NCCP seeks to balance the needs for environmental protection and economic development by accommodating compatible land uses," says Coleman. "This also helps conserve the species, habitats, and wildlife corridors sustaining natural ecosystems in regions disturbed by human activities. Once preservation goals are established for NCCP regions, market forces come into play. Ecologically important properties that might have been viewed as worthless from a development perspective are suddenly seen to have value because of their natural assets, creating strong incentives for their protection. But for market forces to do their magic, sound resource characterization, monitoring, and management are critical."

EPRI has played two roles in the southern California NCCP process. First, it has worked to build consensus for habitat management plan implementation, to facilitate the sharing of data and the coordination of monitoring activities, and to identify appropriate technologies for habitat monitoring and management functions. Second, it has supported the development of tools for modeling the population dynamics of key species, analyzing their preferred habitats, and identifying landscape components that should be preserved, enhanced, or restored to improve their prospects for survival.

DANA RUSKE/ALLEGHENY POWER



RICHARD PODOLSKY

In satellite images, pixels surrounding geographic locations where endangered or threatened species have been sighted indicate vegetation classifications that can serve as a proxy for the species' habitat preferences. By searching for similar pixel distributions in imagery for Allegheny Power's landholdings, researchers can identify other locations where suitable habitat for these species might exist. As the table shows, the Upper Cheat River lands rate very high on similarity indexes for a number of species and therefore have potentially high ecological value.

Matching needs with technologies

The southern California NCCP program is divided into subregions, each of which has its own habitat management plan. San Diego Gas & Electric's service territory is one subregion, in which the company's properties and easements, particularly transmission rights-of-way, form important connections between small islands of natural habitat that are otherwise isolated by development. The SDG&E subregional plan—the first to be approved in California—emphasizes the avoidance of impacts on 110 plant and animal species. It was developed in cooperation with, and was approved by, state and federal wildlife agencies.

"During the evolution of the NCCP process, SDG&E's strategy—like that of other stakeholders—was to identify the most effective approach for protecting species and habitats," says Tim Hurley, budget and systems supervisor for the company's real estate operations department. "By establishing a subregion that coincides with our service territory, we've had the opportunity to take a leadership role in developing and implementing a management plan that safeguards designated plants and animals while reducing our exposure to 'surprises' during maintenance and new construction activities."

In accordance with the subregional plan, SDG&E operates under a habitat conservation permit for all activities within its service territory, eliminating the need to acquire permits on a project-by-project basis. This blanket permit mandates field protocols that must be followed to avoid adverse impacts, and it establishes mitigation requirements in the event that takings occur. Temporary impacts are usually reversed by means of revegetation and restoration. If impacts are permanent, SDG&E uses mitigation credits granted through the company's purchase of more than 270 undeveloped acres (1.1 km^2), which were deeded to local wildlife agencies for the establishment of subregional preserves.

"Because our primary goal is avoidance, SDG&E does not want to use mitigation credits. But having them on hand provides a safety net as we pursue our business," says Hurley. "In fact, we will do everything possible to make the credits last for the next 25 to 50 years by applying state-of-the-art habitat monitor-

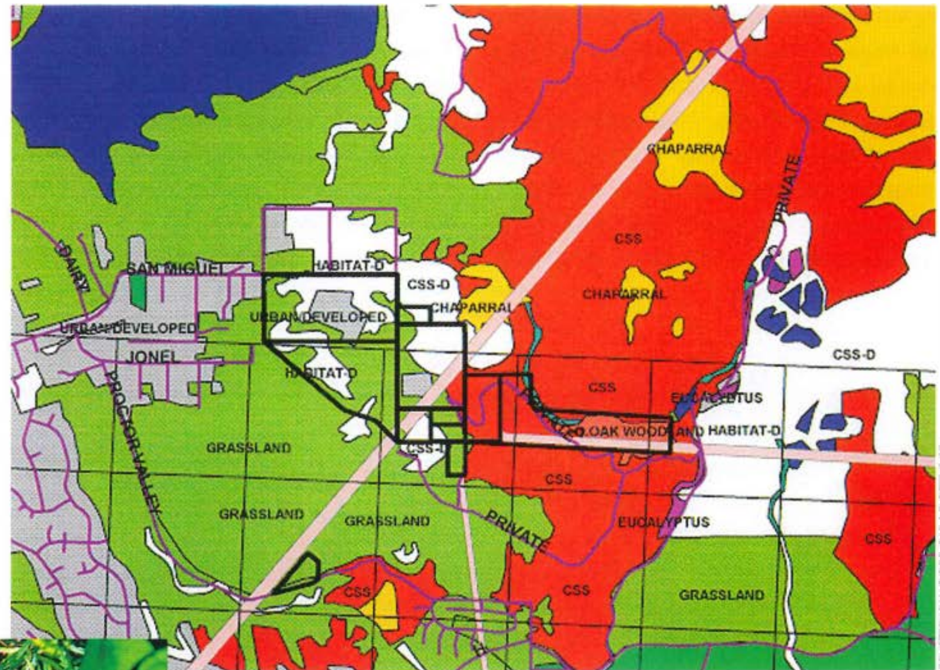
Species, Status, and Similarity Indexes for AP Properties

	Rarity Rankings*		Similarity Indexes (%)			
Species	Global/ National	State	Upper Cheat	Middle Cheat	Canaan Valley	Big Sandy
Appalachian blue violet	3.5	2	68.4	20.4	22.2	16.1
Barbara's buttons	2	2	38.5	63.6	38.2	39.9
Butternut	4	3	54.9	14.0	24.5	12.5
Cheat Mountain salamander	2	2	49.5	14.2	17.0	14.0
Green salamander	3.5	3	46.0	25.3	43.8	23.6
Jacob's ladder	3	2	30.3	27.5	31.9	37.9
Long-stalked holly	3	3	71.6	30.0	36.7	23.3
Northern flying squirrel	5	2	35.8	15.3	20.1	14.7
Running buffalo clover	3	1	82.2	28.2	34.7	20.3
Southern water shrew	5	2	27.8	8.5	28.9	18.1
White monkshood	3	2.5	44.5	12.5	23.2	10.0
Caveforms†	1–4	1–3	82.1	31.8	40.7	25.9

*Rankings range from 1, extremely rare or critically imperiled, to 5, very common and demonstrably secure.
†Includes 11 cave-dwelling species (mostly insects and bats).

ing and management practices, and that's where EPRI has made some important contributions."

EPRI and SDG&E teamed up to support a technology assessment project in cooperation with Ed Almanza of the Superpark Project and Doug Stow of San Diego State University. In the first phase of the project, the focus was to build consensus among NCCP permit holders, reserve managers, and state and federal agencies regarding permit obligations and conservation goals. Under the NCCP process, the quantity, spatial distribution, and configuration of habitats must be monitored. Habitat value—in terms of the ability to support viable ecosystems and populations of listed species—must be assessed. And effective management strategies must be devised to restore and improve substandard habitats and restore natural processes that have been disturbed or eliminated.



In southern California, energy companies and other stakeholders are applying geospatial technologies to map, monitor, and protect critical habitats and the species that call them home, including the orange-throated whiptail lizard and the California gnatcatcher.

According to Hurley, bringing together the various constituencies proved extremely valuable. For the first time, the types of raw data and practical information necessary to meet monitoring, assessment, and management challenges were identified. In addition, processes and collaborative partnerships were established to coordinate not only the collection, analysis, and sharing of specific types of data but also the development of information to support management decision making.

In the second phase of the project, recommendations were developed for applying existing and emerging geospatial technologies—including global positioning systems, remote sensing, and geographic information systems—to meet data and information requirements cost-effectively.

"Almost everything we do under NCCP has a spatial component. When we begin planning a maintenance or construction project, primary concerns are whether the site is within or near a sensitive habitat and, if so, whether protected species are present," says Hurley. "The EPRI project provided guidance on how best to apply and integrate geospatial technologies for locating, visualizing, and analyzing landscape features and species occurrences; for documenting and tracking changes over time; and, most important, for avoiding impacts. Intelligent use of these technologies will undoubtedly reduce the costs and increase the effectiveness of SDG&E's habitat management program."

Managing populations and habitats

Southern California Edison helped formulate the Orange County central-coastal subregional plan, cooperating with 10 other landowners to establish a 37,380-acre (151-km^2) reserve system and a managing board. Two of SCE's major transmission rights-of-way are incorporated in the reserve system, and all operating and maintenance activities for these lines are conducted under NCCP permits. SCE has collaborated with EPRI in several areas to avoid species and habitat impacts in this NCCP subregion and to enable the development of ecosystem-based reserves throughout its some 50,000-square-mile (130,000-km^2) service territory.

In one area of collaboration, models of desert tortoise, California gnatcatcher, and cactus wren metapopulations are being developed and refined by using EPRI's RAMAS® (Risk Analysis Management Alternatives System) software, which was developed with Applied Biomathematics. Metapopulations consist of a number of spatially separated subpopulations that may or may not interact; a metapopulation-based approach for modeling population dynamics is appropriate for species living in fragmented habitats like those under study in southern California.

For the desert tortoise, RAMAS-based metapopulation models are being applied to better understand the impacts of habitat fragmentation caused by rights-of-way, roads, and other infrastructure. Also being quantified are the effects of ravens on metapopulation viability; the predation of young tortoises by individual ravens or nesting pairs appears to significantly reduce the ability of some subpopulations to sustain themselves.

For the California gnatcatcher and cactus wren, population viability and habitat suitability are being studied by using RAMAS-based models that link demographic data from field studies with vegetation distribution, elevation, species occurrence, and other data from SCE's geographic information system. These models guide SCE, other property owners, and reserve managers in the monitoring and management of key populations and habitats. They also enable critical evaluation of the effectiveness of specific management activities.

Current efforts focus on the effects of the 1997–1998 rainy season on these species. "Major declines in survival and fertility rates occurred in the winter of 1994–1995, and we suspect that last win-

Conference on Incentives for Ecosystem Protection

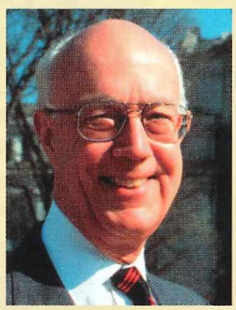
EPRI is teaming up with Resources for the Future, the Smithsonian Institution's National Museum of Natural History, Southern Company, The Nature Conservancy, and Elsevier Science Ltd. to convene an international conference on the creation and use of incentives to protect and enhance ecosystems and species. "Managing for Biodiversity: Incentives for the Protection of Nature" is scheduled for November 16–18 in Savannah, Georgia.

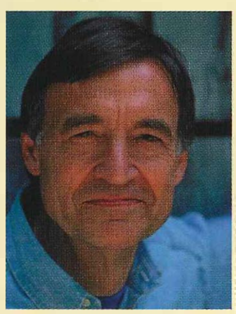
"Methods for characterizing, quantifying, and managing ecological resource value are important building blocks, but economic, political, and social incentives will be the drivers of a new approach to environmental management," explains William Coleman, conference chair and EPRI project manager. "Market forces, regulatory mechanisms and structures, and public perceptions will align the interests of corporations and other private landowners with the interests of society in general—in preserving the intact ecosystems critical to economic and social well-being."

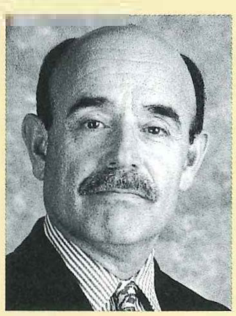
At the conference, speakers will review the roles of policy, science, economics, and collaboration in incentive creation, as well as identify R&D priorities. Below are some initial thoughts from several participants:

Robert Woodall, *vice president of environmental policy, Southern Company*
"Energy companies initially recognized biodiversity's importance because of regulatory requirements. But in recent years our actions have become more voluntary through proactive programs benefiting important species and habitats. As deregulation proceeds, enhancing biodiversity becomes both more challenging and more critical. Knowing which resources to protect, how to best manage them, and how to develop incentives for their protection are important considerations."


Robert Woodall


Robert Fri


John Sawhill


Paul Portney

Robert Fri, *director, National Museum of Natural History, Smithsonian Institution*
"Economic pressures tend to stimulate actions that can degrade habitats and species because these resources have never been valued; instead they've been viewed as free or expendable. Incentives can have a salutary effect on behavior by assigning a value. Although incentives are outside the realm of most of the Smithsonian's scientists, the institution has a strong interest in working with economists, social scientists, regulators, and industry to reverse some of the troubling trends we've observed during our 150 years of studying the history of life on this planet."

John Sawhill, *president, The Nature Conservancy*
"Science tells us that we need to preserve large amounts of land, much of which, in the United States at least, is privately owned. Politics tells us that a strictly regulatory approach is unrealistic. Economics tells us that the costs of this degree of preservation through land purchase likely exceed the financial capacity of any individual institution but that affordable alternatives may exist for society as a whole. Moving beyond the stalemate created by current regulatory approaches requires cooperative alliances between conservationists and the private sector, along with incentive-based programs."

Paul Portney, *president, Resources for the Future*
"Pressures on species and habitats are many, resources for their conservation are scarce, and there is great interest in environmental decision making that is sensible from a benefit-cost perspective. No matter how difficult, we must think hard about ways to attach dollar values to at least some of the benefits of preservation. We must also look to incentive-based approaches as a way to help stretch conservation resources as much as possible."

ter's extreme and protracted El Niño event will have a similar or greater impact," notes Dan Pearson, project manager for land services at SCE. "The experience gained from previous RAMAS analyses should provide insights into the future productivity and survivability of subpopulations, guiding our management actions."

A second area of EPRI-SCE collaboration involves the exploration of geospatial technologies. In an early application of the bidirectional mapping technique now being used to characterize AP's landholdings, habitat selection by the California gnatcatcher and cactus wren was analyzed. At the 20-meter resolution of commercially available SPOT satellite imagery, the species appear to have nearly identical landscape requirements—a finding that provides important information about the landscape components that should be preserved, enhanced, or restored.

Airborne data acquisition and registration (ADAR) is an emerging remote sensing technology that offers a resolution of 1 meter or less. "ADAR has been applied experimentally elsewhere, and it looks like a good approach for rapid but very detailed habitat characterization," says Pearson. "We're seeing how far we can push the technology for locating particularly valuable habitats so that they can be preserved and for monitoring habitat quality over time to ensure proper management. A key issue is cost-effectiveness: how much is ADAR's extremely high resolution worth in relation to the cost of the aerial flights for data collection?" ADAR test overflights are under way for the ecological characterization of SCE's 806-acre (3.26-km^2) Blackstar property in Orange County.

Banking on assets

EPRI's work also supports SCE's entry into the conservation banking business. One of the company's prized ecological assets—the Viejo site—was purchased in the 1960s as the future site for a substation. The development that largely surrounds this 99-acre (0.40-km^2) parcel did not meet SCE's load growth projections, eliminating the need for a substation. But it has placed a premium on the site's high-quality coastal sage scrub habitat, southern sycamore woodlands, and vernal pools. The parcel is also the only remaining habitat corridor between Orange County's central-coastal and southern NCCP subregions.

SCE had initially agreed to sell the Viejo parcel to the NCCP reserve system, but a potentially more profitable alternative has emerged. "During a biological inventory of the Viejo site, we detected 27 sensitive species, including fairy shrimp," says Kim Gould, vice president of conservation banking for SCE. "Most of the very few remaining vernal pools are unlikely to be preserved, limiting mitigation options for fairy shrimp habitat. We don't expect to get returns commensurate with those for residential, industrial, or commercial real estate, but the property's unique character implies a relatively high bank-and-trade value. Many parties—including developers and conservation groups—are expressing strong interest in buying credits."

SCE is now in the final stages of securing regional, state, and federal approvals to operate the site as a conservation bank. Once all the credits are sold, the land will be donated to the Orange County reserve system for management in perpetuity.

"A new approach to environmental management is taking shape—one in which the contributions of ecological resources to society are explicitly recognized and high-quality habitats and natural communities are becoming desirable assets," notes EPRI's Coleman. "We are working on several fronts to study the technical, economic, and institutional foundations leading to the widespread adoption of the principles of ecological resource management."

Federal, state, and local agencies will play a key role by highlighting the importance of intact ecosystems and by creating economic or other incentives for their protection. Watershed management, NCCP efforts, habitat conservation plans, and other government initiatives provide concrete evidence of a shift toward ecosystem-based policies and programs. Another example is the U.S. Environmental Protection Agency's recent announcement that to support sound policy decision making, it is shifting the focus of its global climate research program to emphasize possible consequences for ecosystem services. To study the big picture of policy, economics, and science—and their roles in creating incentives for ecosystem protection—this fall EPRI is sponsoring an international conference on ecological resource value (see sidebar).

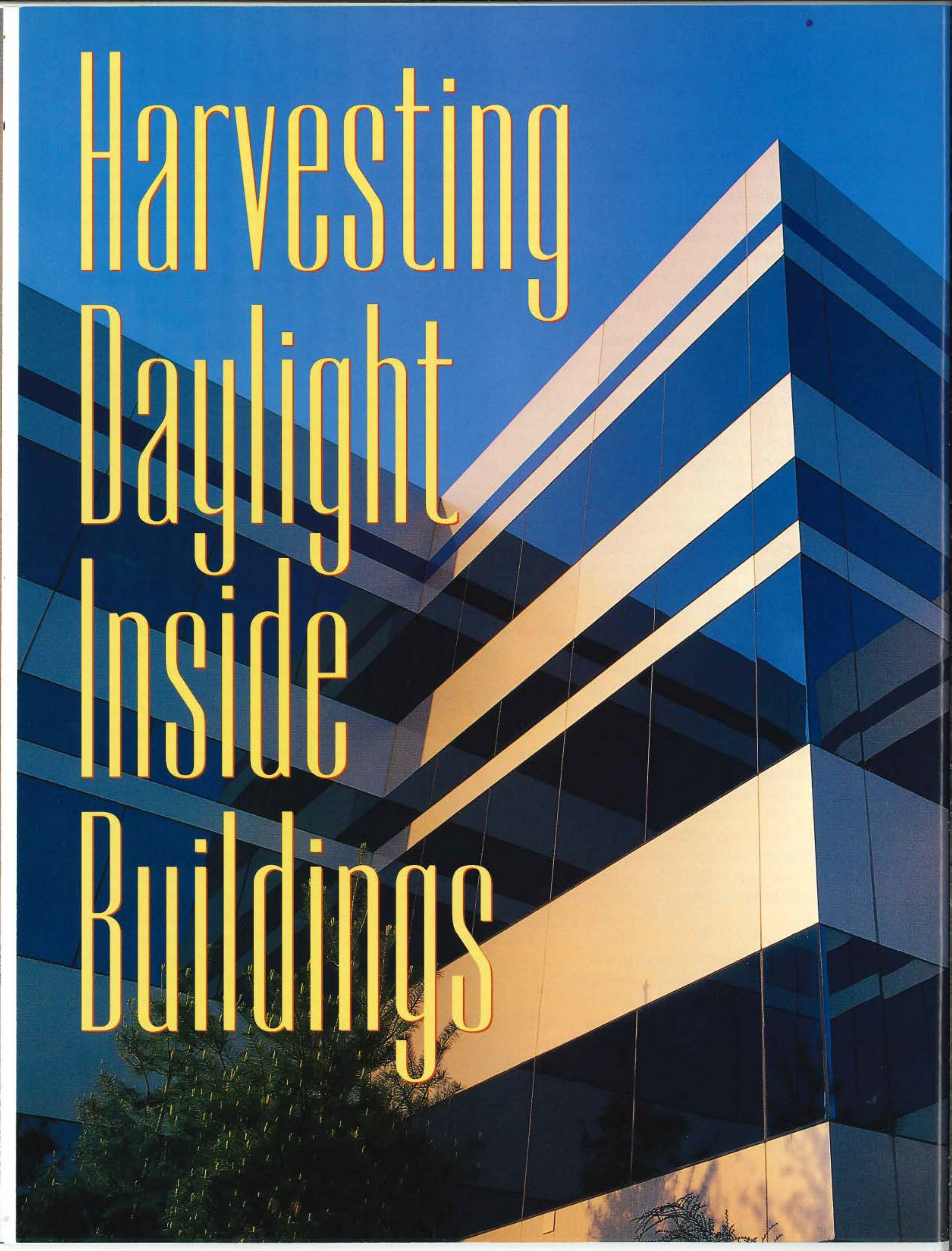
The potential economic and environmental benefits of ecological resource management are what is catching the attention of energy companies. "We continue to own a fair amount of property with potentially high ecological resource value, and methods for incorporating that value into our traditional land use plans would be advantageous," says Larry Olmsted, director of scientific services at Duke Energy. "EPRI's work in this area looks very intriguing, particularly when we set future priorities for resource management and preservation."

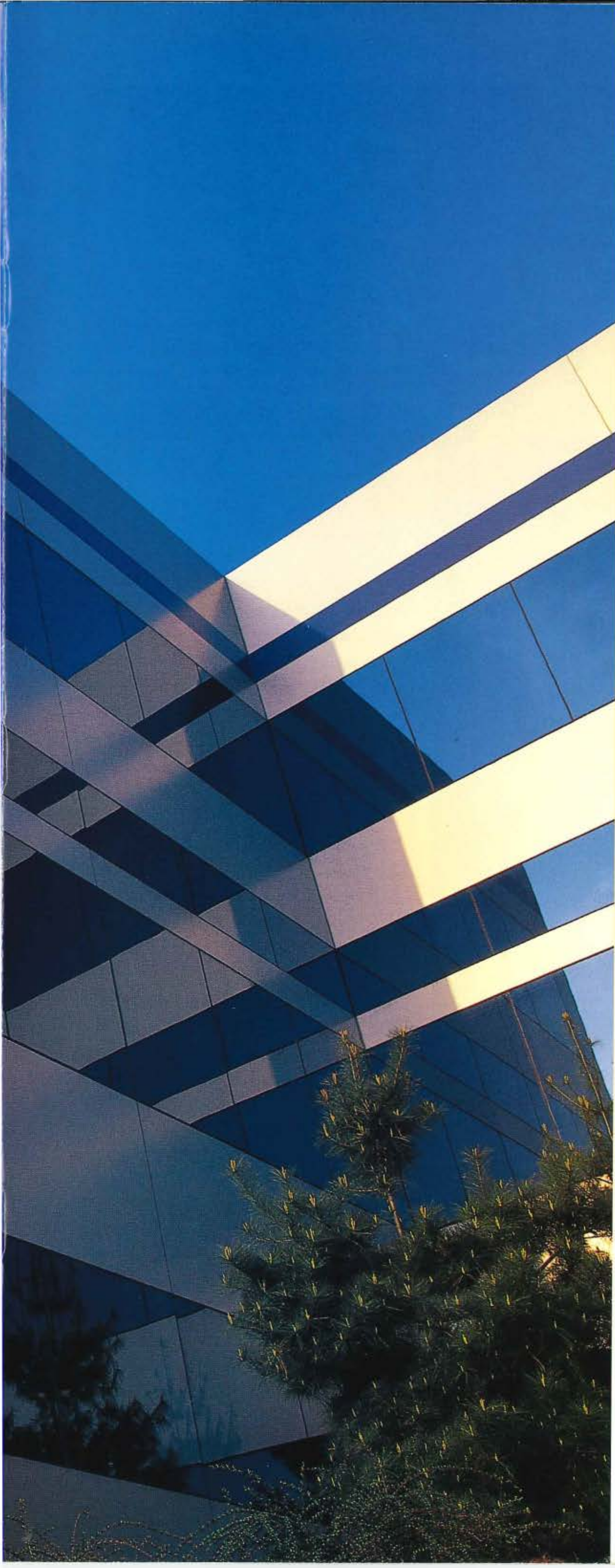
Adds Noel Cutright, senior scientist at Wisconsin Electric Power, "From our perspective, EPRI's program is ahead of the curve. We view improving the ecological character of our landholdings as a worthwhile endeavor in and of itself, but future business opportunities may exist. We'll be watching closely to see how we might draw on the EPRI knowledge base as regulatory and market conditions evolve."

Some companies are already sold on the concept of ecological resource management. "Economists say that a for-profit company should have only one goal—to maximize shareholder value. But if a company doesn't do the right things with respect to its social, moral, and environmental obligations, then one could argue that it will be punished in some fashion by the public, by the customers, and by its shareholders because they won't want to invest in the company," says AP's Noia. "So I believe that it really pays in the long run for a company to have a set of values, one of which is being a good environmental steward. And what do I mean by 'pays in the long run'? One answer is that we can quantify, measure, and extract the intangible values of well-managed natural ecosystems for the benefit of society and our shareholders—and that is what makes EPRI's work in ecological resource management so appealing." ■

Background information for this article was provided by William Coleman, Environment Division.

Harvesting Daylight Inside Buildings





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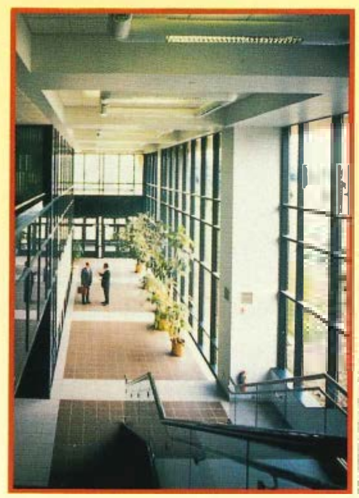
The Story in Brief

Daylight harvesting—maximizing the use of available sunlight to illuminate building interiors—can yield significant savings on electricity for lighting and contribute to improved productivity among office workers. As part of a broad array of commercially available lighting control upgrades, new dimmable electronic ballasts for fluorescent lights—used in combination with simple photocell sensors—are enabling the automatic dimming of interior perimeter lighting in response to natural daylight. EPRI offers practical design guidelines for evaluating these and other lighting control strategies that can help utility customers take advantage of the benefits of letting the sunshine in.



by Taylor Moore

Many office employees have by now developed a working relationship with the blinking occupancy sensor that turns off their lights when they are out of the office or when they sit still for more than a few minutes. It has become automatic for these workers to wave at the infrared sensor to get the lights back on. The occasional annoyance caused by such lighting controls is far outweighed by the electricity savings they offer, compared with relying on office occupants to manually switch off lights.

A skylight helps illuminate the Way Station medical center in Frederick, Maryland.

For many office buildings, such electricity savings can add up to real money. Approximately 41% of the energy used in commercial buildings is attributable to lighting (35% for illumination and another 6% for air conditioning to remove the excess heat generated by lighting). Despite the significance of this load, however, lighting and such vision-related equipment as computer monitors are rarely integrated and optimized for energy or illumination efficiency.

But the situation is now changing. For example, building owners and in some cases tenants are replacing power-hungry magnetic fluorescent ballasts with energy-saving electronic ballasts, which can be installed with low-cost, occupancy-sensing switches to cut nearly two-thirds of office lighting-related electricity use.

Some building owners are going a step further and installing advanced lighting controls that make use of daylight dimming. These systems use ceiling- or luminaire-mounted photocells to sense the level of light coming through the windows and signal the electronic ballast to gently adjust the indoor illumination to take advantage of the daylight. Primarily intended for window offices on a building's perimeter, daylight dimming can save up to 80% of lighting energy under optimum conditions for normal work hours. Used in combination with architectural designs that maximize the penetration of daylight into building interiors, daylighting strategies not only can save substantial amounts of lighting energy but can also create a more comfortable, productivity-enhancing work environment.

Until recently, relatively high hardware costs for dimming ballasts and advanced controls made it difficult to justify lighting control retrofits on the basis of economics alone. But lower-cost ballasts are becoming more widely available, with prices for some new electronic dimming ballasts as much as 50% lower than those of competing models.

"If cost-effectiveness and a quick cost payback are the only criteria, then you might not choose daylight dimming. But especially if you're constructing a new building and considering its overall budget, the intangible benefits of this option can make it pretty attractive," says Don Frey, executive vice president of Architectural Energy Corporation, a Boulder, Colorado, consulting firm. "Our experience has been that daylit buildings provide a better work environment in terms of employee comfort and productivity. Natural daylight adds a quality to the environment that is conducive to the workers' well-being, and that translates into increased productivity, greater job satisfaction, and reduced absenteeism."

EPRI offers many valuable lighting technology products and resources for companies interested in daylighting controls, including two related practical design guidebooks that can help in the evaluation and implementation of retrofit projects, new construction, and major renovations in commercial buildings. In 1997, EPRI documented the performance of energy-efficient office technologies and lighting, including daylight dimming, in a federal office building in New York City; it also documented the performance of advanced lighting and other electrotechnologies in a North Carolina elementary school. Through the Commercial Building Lighting Target, there are many opportunities for EPRI members to participate in tailored collaboration projects demonstrating daylight dimming and advanced lighting controls.

EPRI has also developed several lighting-related software products. These include a building energy and daylighting simulation program; LightCAD for lighting layout and design; LightPAD 2.0 for lighting auditing; BEEM (Building Energy Estimation Module) for analyzing daylight and other window energy effects; the Lighting Evaluation System for performance analysis; and the Lighting Diagnostic and Commissioning System for initially adjusting controls and then monitoring ongoing performance. BEEM can be used with LightCAD for lighting layout and decision making.

Retailer Wal-Mart found that skylights increased sales in areas where they were installed in a test store in Lawrence, Kansas.

Direct and indirect benefits

As EPRI's most recent design guidebook—*Daylighting Design: Smart and Simple* (TR-109720)—points out, the direct benefits of daylight inside buildings are both tangible (e.g., energy savings) and intangible (e.g., occupant satisfaction). Moreover, intangible benefits can result in tangible ones, such as the 10–20% higher rental income that daylit spaces often command. Light-sensing controls also enable by-product savings, including energy savings from reduced air conditioning, from the tuning of illumination levels, and from lumen maintenance to reduce initial overillumination by new fixtures and lamps.

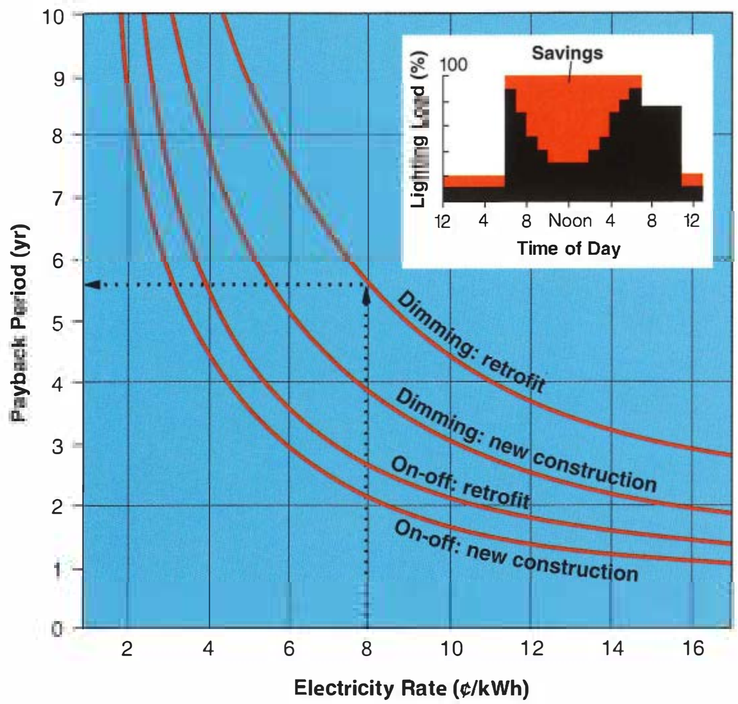
Two examples of daylighting applied in the real world illustrate the benefits. At a test store in Lawrence, Kansas, Wal-Mart found that sales increased in departments located under skylights installed in half the store. Departments that moved from areas without skylights to areas with them saw sales increase, while sales decreased in departments moving the other way. Dimming controls on lighting were estimated to have a three-year cost payback, but the sales benefits of daylighting were far greater than the energy savings.

In several schools in Wake County, North Carolina, daylighting apparently improved test scores. Students moving to a new, generously daylit elementary school showed greater improvement in achievement test scores than the same-grade students who remained in the old school. Students in the new school outperformed those in the old school by 5% after one year and 14% after three years. Students who moved to a new school that did not have much daylighting showed no such improvement.

Significant savings in energy costs can be achieved if lights are turned off or dimmed when there is adequate daylight. Daylighting controls with dimming ballasts have typical paybacks of two to eight years. The shortest payback for retrofit installations is obtained by upgrading from magnetic to electronic ballasts. For reno-

Several elementary schools near Raleigh, North Carolina, reported improved achievement test scores among students who moved into daylit classrooms. This classroom features a roof monitor–type skylight with light-diffusing baffles.

Automatic daylighting controls can produce significant savings in the electricity used to light buildings. The payback period for such controls depends on the type of control selected and on the local cost of electricity. In the example shown, electricity sells for 8¢/kWh, and the cost of retrofitting continuous dimming controls will be recouped through lower electric bills in about 5.6 years. Installing simpler (and less expensive) on-off controls cuts the payback time about in half.



vation or new construction, the incremental cost of dimming ballasts is lower and the payback is even quicker.

Daylighting controls can also harvest by-product energy savings that can total more than half again as much as the direct lighting energy savings alone, according to Robert Rundquist of R. A. Rundquist Associates, the Northampton, Massachusetts, energy consulting firm that produced both the new daylighting design guide and a related controls guide (TR-107230) for EPRI and Empire State Electric Energy Research Corporation, a New York utility research consortium.

"Daylight dimming reduces the heat gain from lights, and that reduces the need for air conditioning. But in the winter it almost never increases the need for heating because daylight usually provides a solar heat gain to a space," says Rundquist. The effects of daylighting controls on heating and air conditioning typically increase the energy savings from daylighting by 15–30%, depending on the climate. And in addition to the energy savings, there may be first-cost savings if a renovation or new construction project includes new air conditioning equipment. The reason is that daylighting can allow engineers to downsize cooling equipment, yielding savings that can offset as much as half the cost of the lighting controls.

Other lighting strategies made possible by the installation of continuous dimming ballasts and photosensors for daylighting can provide still more energy savings at little or no added cost. Tuning, in which the illumination levels of installed lights are reduced to match occupants' needs or desires, can typically save 10–30% of lighting energy. Lumen maintenance—lowering illumination levels when lamps are new and lumen output is higher than needed, then gradually increasing to full power at the end of the maintenance cycle to maintain proper illumination levels—can save 10% of lighting energy. A combination of tuning, lumen maintenance, and daylight dimming can easily cut lighting energy costs by more than 50%. But because successive strategies affect a load that's already reduced, the achievable savings percentages are not additive.

"The savings from occupancy sensors will be reduced if there is also daylight dimming, since the lighting may already be dimmed when an occupant leaves the office. Conversely, if the occupant is often out of the office, the savings from daylight dimming will be reduced," explains Larry Ayers, who runs EPRI's Lighting Information Office. "But with the combination of daylight dimming and occupancy sensors, building owners can feel confident that they're saving about as much lighting energy as possible."

Ayers notes there are actually two general categories of electronic dimming ballasts available for commercial buildings. One category dims light levels from 100% down to 5–20% of the maximum output and is designed for daylight dimming applications in work areas. The other category is designed for decorative, architectural light dimming to as little as 1% of the maximum output. The latter ballasts are more expensive and require 1–5 more watts of power per ballast for proper operation. Dimming work area lights to below the 50% level requires good lighting quality, without glare or shadowing (conditions that should be avoided anyway).

Daylighting need not be terribly complicated, notes Rundquist. "Daylighting has been mystified too much. You don't need light shelves, roof monitors or other skylights, or cavernous ceilings to daylight a space. For instance, in a typical office, 4-foot-high glass with a light tint will yield an average of about 40 foot-candles [430 lux] of daylight on a desk 10 feet from the window and will save about 40% of the electricity for lighting in the outer 15 feet of floor space. With average electricity rates—8¢/kWh—dimming controls will have a payback of about five years. All in all, daylighting is an attractive option: we already have the windows for the view; controls and ballasts are now ultradependable; and workers might like having some additional control (perhaps manual dimming) as a perk."

Mix and match may not plug and play

Until fairly recently, a barrier to the adoption of daylight dimming controls was the unavailability of a complete system (dimming ballasts, photocells, and controls) from a given manufacturer. Lighting or electrical engineers had to select components from a variety of suppliers and expend time and effort to get the pieces to work together—a task that added to the overall costs. Complete systems are now available from a number of manufacturers, including Electronic Lighting, Lightolier (a division of the Genlyte Group), and Lutron.

The time, cost, and expertise required to properly calibrate photocells and dimming controls and to commission newly installed systems for building owners are currently the biggest barriers to the wider use of daylight-linked lighting controls—particularly in large, older commercial office buildings. So says Francis Rubinstein, a research scientist in the Building Technologies Program at Lawrence Berkeley National Laboratory (LBNL). "If calibration and commissioning are not done properly, you're not going to get the energy savings anticipated, and if the control system does not operate correctly, some people may go out of their way to defeat the controls, which kills the energy savings very quickly," Rubinstein points out.

LBNL, in partnership with the U.S. General Services Administration (GSA) and Pacific Gas and Electric (PG&E), is monitoring the performance and cost-effectiveness of advanced daylight-linked lighting controls installed on 3 of 21 floors at the Phillip Burton Federal Building in San Francisco. On the basis of six months of monitoring data from this large-scale test-bed, the LBNL researchers estimate annual lighting energy savings of 41% and 30% for the outer row of lights on the south and north sides of the building, respectively.

If cost-effectiveness is the only criterion, it's important that installed-system costs be kept as low as possible. "Typically, the incremental cost of daylight dimming is somewhere between $1 and $2 per square foot. To sell dimming just for its ability to save energy, you don't want it to cost more than about $1 per square foot," says Rubinstein. "At $2, even with significant energy savings, it's very hard to make an economic cost-benefit case for daylight dimming by itself—that is, as a retrofit rather than in new construction or a major renovation. The cost of some of the latest dimmable ballasts gets you down close to $1, a cost that would provide a reasonably quick payback for typical commercial buildings."

Daylighting controls were installed in this McDonald's restaurant near Pittsburg, California. The fast-food chain is considering offering such controls as an option for new franchisees.

The project in San Francisco confirmed that daylight harvesting "is one of the most powerful energy-saving measures we have for buildings," says PG&E daylighting specialist George Loisos. "But unlike simpler measures, such as motor replacement or lamp and ballast replacement, daylight harvesting requires an integrated design approach, including the use of windows that make sense for admitting daylight. Otherwise, windows can become problem areas, with occupants blocking them—leaving shades drawn, for example. Then you don't get enough light, and that undermines the effectiveness of daylight harvesting."

PG&E has participated in several other demonstrations of daylighting controls at customer sites, including one at a McDonald's restaurant near Pittsburg, California, and another at a California State Automobile Association office building in Antioch, California. At the McDonald's, dimmable ballasts and daylighting controls from Electronic Lighting reduced lighting energy use in the dining and lobby areas by 30–45%, according to Tor Allen, a PG&E research engineer. "This is an easy winner that more and more customers are becoming aware of," he concludes. McDonald's spokesman Tony Spata says the fast-food restaurant chain is considering offering daylighting controls as an optional building feature to its franchisee-lessees, who would pay the installation costs and reap the energy savings.

Last year, one of the first demonstrations of advanced lighting controls from a single-source manufacturer was conducted as part of the renovation of a GSA building in Manhattan occupied by the U.S. Immigration and Naturalization Service. The lighting demonstration was a collaborative effort by Consolidated Edison Company of New York, EPRI, and Genlyte.

The project used the Genlyte Lightolier advanced lighting system, which includes fixtures, controllable ballasts, occupancy and daylight sensors, and multiscene preset dimming systems—all developed with support from EPRI and participating utilities. Energy Star–compliant office equipment systems were also part of the renovation project.

The monitoring and evaluation of the advanced lighting system, performed for EPRI by Architectural Energy, showed that the system achieved all the goals set at the onset of the project—low lighting density, improved lighting quality, system flexibility, and reduced installation and operating costs. The lighting energy density of 0.97 W/ft^2 was less than half the prerenovation power density (2.56 W/ft^2), according to the EPRI report (TR-108366) documenting the project. Although the installed cost of the new lighting system was 9.5% more than that of a standard office lighting system, its projected 20-year life-cycle cost is 16% lower than a standard system's.

"We proved in this GSA project that using the one-stop shopping approach—and having one manufacturer warranty for the

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Daylit break room

The customer service center of the Sacramento Municipal Utility District (SMUD) integrates architectural daylighting design with a number of advanced lighting efficiency and control features, including indirect lighting, occupancy sensors, daylight dimming, and low-power adjustable task lighting for workstations. The Lighting Research Center at Rensselaer Polytechnic Institute documented savings of 8% of the building's daytime electric lighting load as a result of using daylight dimming controls near windows and in skylight areas.

system—can eliminate the technical incompatibility conflicts and finger-pointing that often arise with multiple equipment suppliers," says Peter Jacobson, Con Edison's lighting specialist. "The system approach of integrating controls for daylighting and other multifunction energy-saving techniques is beginning to show up in more building specifications. This will help drive down the cost of dimmable ballasts and controls and help the specifier and end users understand the technologies better and have more confidence in them."

Jacobson says the GSA building example, along with other marquee building projects that take advantage of the system approach, will create a market-driven demand for "smart" buildings. Such projects exemplify the guidelines and standards that are the basis for the ASHRAE/IES 90.1 lighting compliance standards for new commercial buildings.

"These technologies can give the utility industry new approaches for creating value-added services for customers in a deregulated, competitive business environment," says Jacobson. "Customers can be confident of saving energy without sacrificing high-quality lighting and multifunction capabilities."

SMUD sets an example

One of the most acclaimed and impressive projects demonstrating the integration of daylighting controls and other energy-efficient lighting products with modern architectural daylighting design is the new customer service center of the Sacramento Municipal Utility District (SMUD). The 184,000-square-foot facility, which has four wings extending from a central lobby, was specifically designed to take advantage of the area's typically abundant sunshine. The center's advanced lighting system was featured in a case study by Rensselaer Polytechnic Institute's Lighting Research Center as part of its DELTA (Demonstration and Evaluation of Lighting Technologies and Applications) program.

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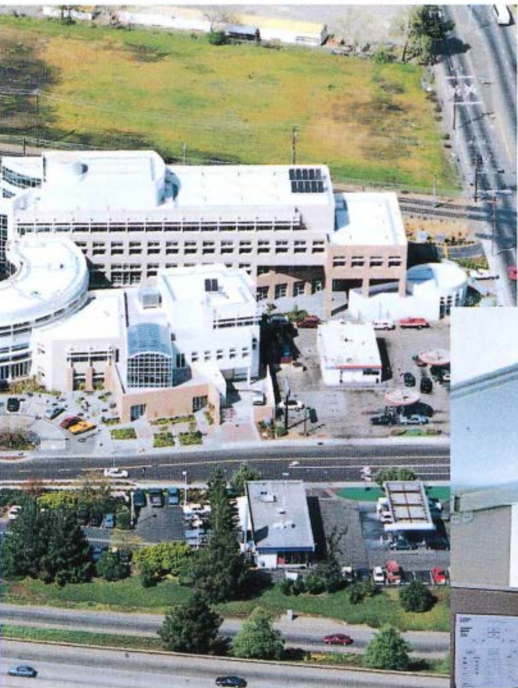
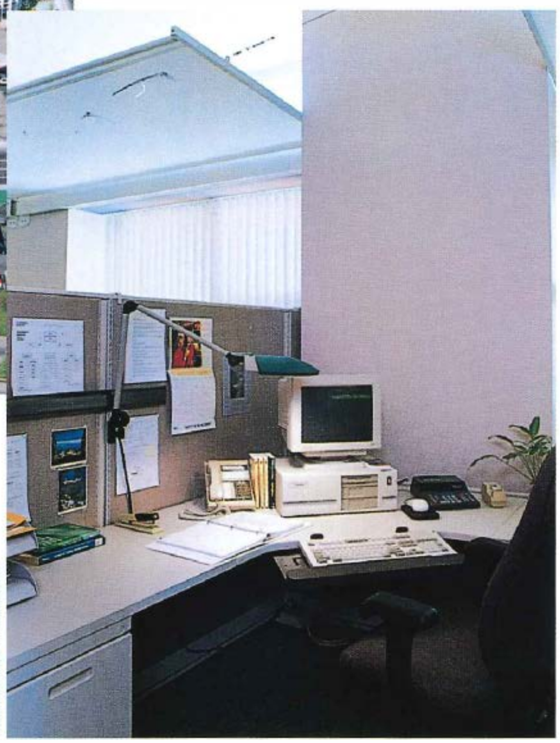
SMUD's customer service center

Three-story windowed lobby with metal halide uplights

The north-facing walls of the customer service center have large windows, while its south-facing walls have small windows with exterior and interior light shelves that bounce light deeper into the office space and limit glare. Vertical blinds enable employees to further control glare. Deep-well skylights admit additional daylight on the top floor of each wing. In order to maintain 30 foot-candles (320 lux) of illumination on work surfaces, luminaire-mounted photosensors signal electronic dimming ballasts to continuously adjust the electric lighting in response to the available daylight. Occupancy sensors are installed in offices and photocopy rooms.

As reported in the Lighting Research Center's DELTA case study, the advanced lighting products and control system in-





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Workstation with adjustable task lighting

stalled at SMUD's customer service center reduced the lighting power density to well below the California Energy Commission's energy efficiency standard of 1.5 W/ft^2, which is slightly more stringent than the ASHRAE/IES 90.1 standard. The total connected lighting power density at the center is 0.87 W/ft^2, and the power density for lights in use during core operating hours is only 0.58 W/ft^2. The case study estimates that daylight dimming saves an average of about 8% of the SMUD facility's connected load during core office hours. Although the cost of daylighting controls made the overall system's payback period longer, the case study concluded that such controls could provide greater energy savings in buildings with bigger connected loads or higher electricity costs.

Again, the importance of proper photocell calibration was highlighted during the commissioning of the SMUD center's lighting system. The initial set-point adjustments for the photosensors were made while the building was still unfurnished, but once all the furniture, partitions, and people were in place, the lighting conditions had changed and employees complained that light levels were too low for comfort. A follow-up visit by a lighting equipment factory engineer to readjust the set-points solved the problem. The DELTA case study noted that although SMUD employees are generally happy with the amount of light, there was one area where photosensors had been covered with paper in order to defeat daylight dimming.

Integration with real-time pricing

The ultimate application of daylight dimming and other advanced lighting control strategies, say researchers and developers, may be their integration with computerized building energy management systems that can respond to real-time price signals from energy service providers and automatically perform load management and peak-shaving functions. Some utilities are also investigating the potential for a portion of building lighting to be treated as a dispatchable load through the use of utility-signaled ballast dimming. The tighter integration of advanced lighting controls with building energy management systems and utility price or control signals could add value that would improve the controls' cost-effectiveness.

"You could make the argument that, if executed properly, a centralized strategy for real-time pricing and dispatchable light dimming could be a significant money saver," says LBNL's Rubinstein. "If, for a few hours of a few days a year, a kilowatthour cost \$1.40 instead of 7¢ and you knew when those times were, you could avoid using energy then," he explains.

"The caution is that you might affect office worker productivity if you dropped light levels by, say, 20%. But my gut feeling based on observation is that you can reduce light levels by up to 20% in a typical work environment, and as long as the fade rate is pretty slow, people will not notice. So potentially this is a strategy that would not cost much more in terms of equipment than a daylighting program without the pricing and dispatchable elements and that could probably save a fair amount more money," Rubinstein concludes. The third-generation lighting controls for such a strategy would ideally include lighting energy monitoring capabilities that are now commercially available as part of central-relay or energy management systems. Today's central control systems also offer the capability for tracking cumulative lighting use and for scheduling tube replacement.

The advent of electric lighting early in this century "seduced us away from using daylight to illuminate the inside of buildings," notes EPRI's new guidebook on daylighting design. "We are now rediscovering the personal desire for windows and, aided by recent advances in lighting controls and glazings, realizing how daylighting can help us achieve savings in energy costs." ■

Further reading

Advanced Electric Technologies in a School Environment. Final report for WO4939-1, prepared by Architectural Energy Corporation. Forthcoming. EPRI TR-111089.

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Smart Materials *for the* Power Industry

THE STORY IN BRIEF

Smart materials and structures—nonbiological, physical structures that sense and react to environmental changes—have shown their potential in the rarefied fields of aerospace and defense technology. Now researchers are looking to identify the best prospects for applications in the electric power business. Already finding use in the area of advanced sensors, smart structures and systems promise to reduce maintenance costs and improve operations at power plants and may someday enable entirely new methods of generating and distributing electricity.

by Taylor Moore

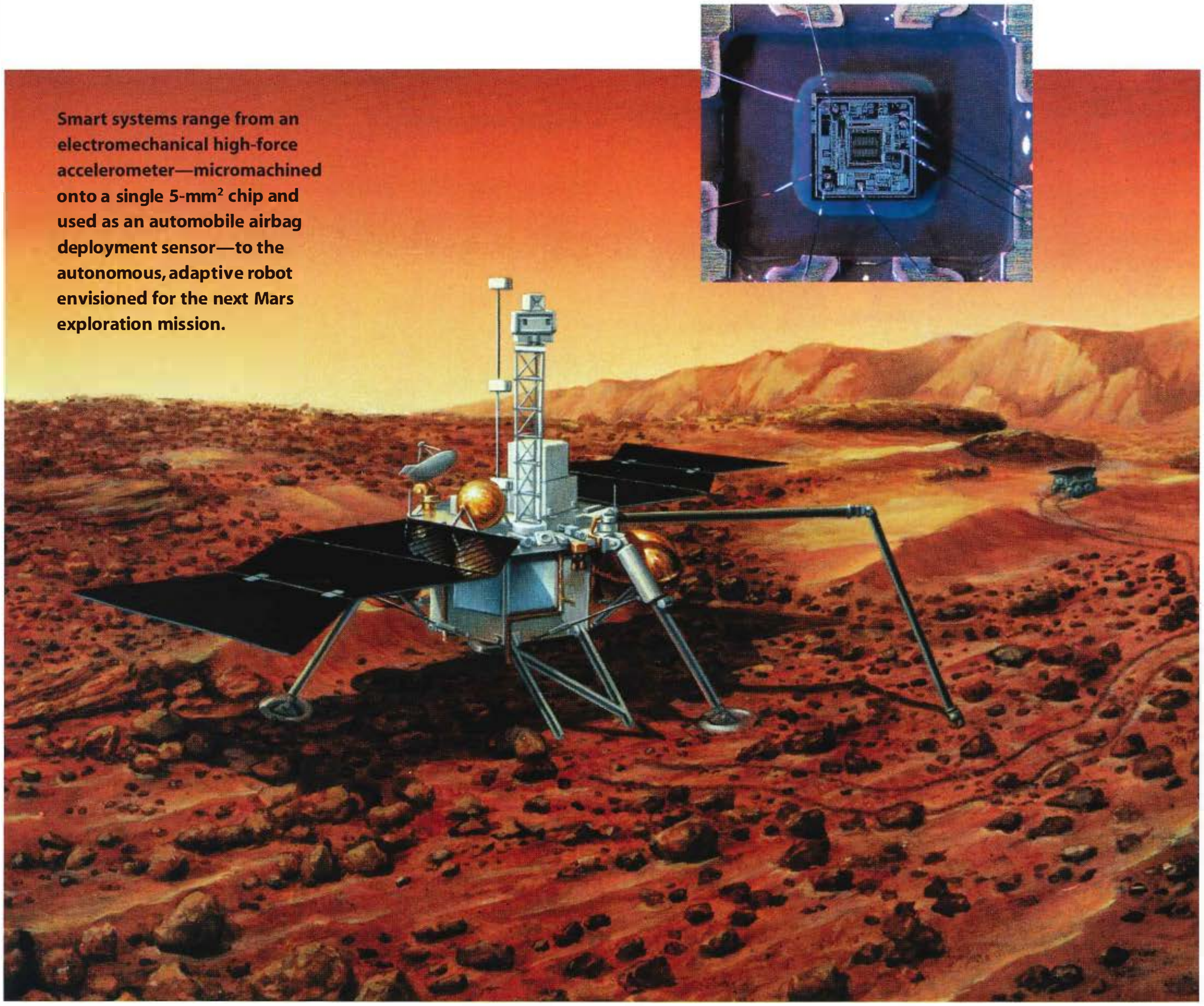
Making something "smart" by embedding electronics in it or by incorporating distributed computing power is increasingly common in today's information age. In the near future, one may drive a smart car on a smart expressway, automatically paying tolls with a smart card, to commute between one's smart house and a smart office building. Already, the trend to incorporate intelligence into just about everything is extending to many of the fundamental components and constituent materials of the human-crafted world.

Scientists and engineers have long been fascinated by specialized materials—and the structures and systems built with them—that can sense and respond to environmental changes in an automatic, almost biological, way. These materials include conductive polymers, electrorheological fluids that become highly viscous when exposed to an electric field, magnetostrictive materials that change dimension when exposed to magnetic fields, and piezoelectric ceramics and polymers that change dimension in response to electric current or that generate current in response to strain. There are also polymeric biomaterials like polypeptides that contract and expand in response to temperature or chemicals and shape-memory alloys and polymers that revert to an original, undeformed state at a certain temperature.

Applications of such smart materials and structures (SMS) include advanced aircraft skins that incorporate radar sensors, skis made with self-actuating piezoelectric devices that damp vibration, smart windows that automatically darken to block sunlight, and even protective clothing made with a conducting polymer and capable of sounding an alarm on exposure to hazardous materials or radiation.

The diverse group of smart materials runs the gamut from high-tech (polymer diodes that emit various colors of light for use in programmable signs, signals, and large flat-panel displays) to the more mundane (concrete with embedded fibers that can sense cracks and release a self-repairing chemical). Because the basic categories and functional aspects of many smart materials mimic or resemble human biology in some important way, some even hold promise as synthetic sensory organs and muscles in robotic devices and bioengineered prosthetic equipment.

Several industries, particularly those related to aerospace and defense, are actively



COURTESY ANALOG DEVICES

Smart systems range from an electromechanical high-force accelerometer—micromachined onto a single 5-mm² chip and used as an automobile airbag deployment sensor—to the autonomous, adaptive robot envisioned for the next Mars exploration mission.

applying SMS, largely on an experimental basis. Areas of focus for space systems include vibration control using springs made from shape-memory alloys and adaptive space structures that can adjust their own geometry or the shape of their antennas. Electroactive materials are used to fine-tune the optics of the Hubble Space Telescope, for example. The ultimate smart space structure may someday assemble itself.

One aircraft application is a variable-geometry smart wing whose camber and twist can be continuously optimized on the basis of sensor data for various flight and environmental conditions. Other applications include not only structural condition monitors that make use of distributed sensors and processors but also piezoelectric actuators embedded in wing structures for the rapid control of surfaces to suppress high-frequency flutter or unsteady buffet loading. Meanwhile, various smart materials, including piezoceramic and magnetostrictive actuators and shape-memory alloys, have been evaluated for use in optimizing camber control and reducing vibration in helicopter rotors—an application that could increase performance and reduce noise.

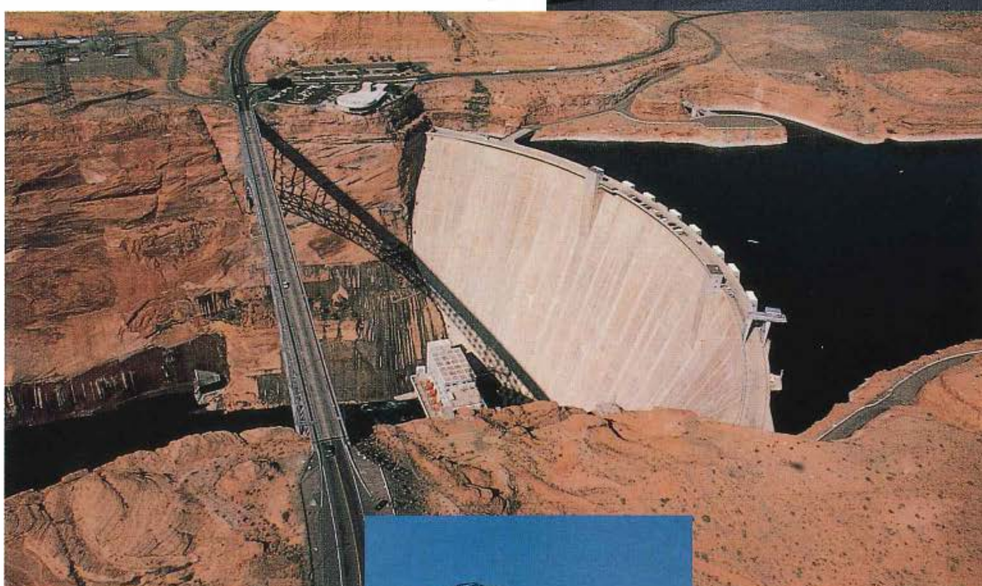
"In principle at least, smart materials and structures can fulfill virtually any engineering purpose imaginable," says John Stringer, a materials expert and an EPRI executive technical fellow. What has limited the development of complete smart systems to date is that every application is unique and task specific. Generic, off-the-shelf solutions that can be directly transferred across industries appear unlikely.

Yet the emerging field of SMS, still in its infancy, potentially could have a major impact on the electricity industry, where applications could reduce maintenance costs and improve plant operations in a multitude of ways. Optical fiber networks could monitor and assess the condition of rotating equipment and transmission lines around the clock, flagging components or locations for inspection or perhaps triggering self-repair mechanisms. Civil structures—for example, hydroelectric dams—with embedded sensors could similarly warn of incipient or internal corrosion and even take corrective action. Vibration and noise in plant machinery and substations could be actively damped. Smart control systems could continuously monitor and adjust power

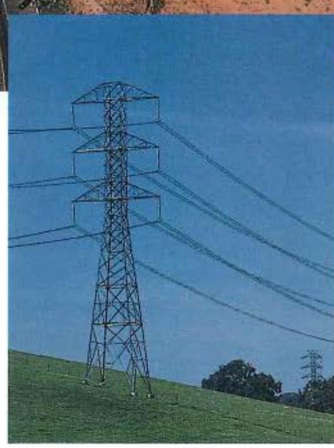
Smart sensors, structures, and systems have potential applications in virtually every arena of power generation and delivery. Self-repairing smart concrete could make hydroelectric dams or other large structures last longer. Advanced sensors could warn of corrosion in transmission towers, with fiber optics providing real-time measurement of conductor temperatures and current loadings. Sensors that directly measure coal flow rate, boiler conditions, and emissions chemistry would allow greater optimization of generating plant performance. Smart materials and structures may ultimately provide capabilities for real-time condition assessment of critical components and active control for avoiding such problems as vibration and subsynchronous resonance.

RON MAY

Performance monitoring



Concrete integrity



RON MAY

Conductor loading

plant cycle chemistry and combustion conditions to minimize emissions and heat rate.

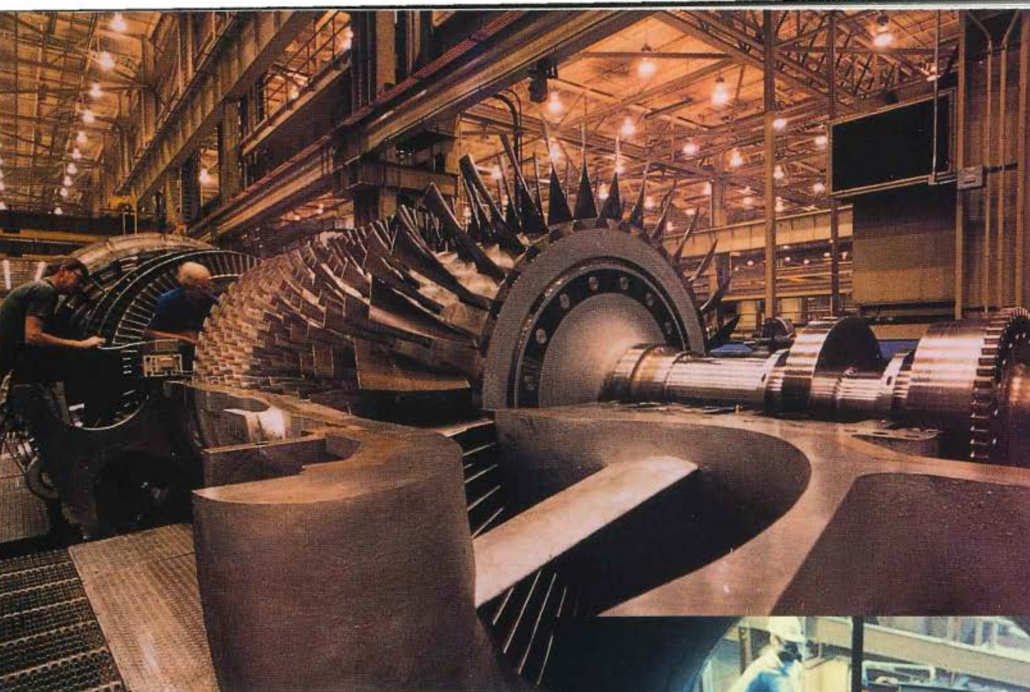
In the long run, SMS may even provide entirely new methods of efficiently and cost-effectively generating, distributing, and using electricity. This future might include button-size, micromachined gas turbines for distributed generation. On the end-use side, microscale heat pumps with greatly reduced thermal losses could be installed like wallpaper in individual rooms. Such nanotechnologies could operate within complex, distributed networks that would continuously adapt to changing conditions.

To help client utilities assess their own needs for possible SMS applications, EPRI recently commissioned a detailed technical overview to summarize the history and current status of SMS, as well as recent research in the field. The study also evaluated the applicability of SMS for current and anticipated needs of the electric power industry. Utilities will find the resulting technical report (TR-108377), which is available to all EPRI members, indispensable for critically assessing the potential usefulness of SMS for their particular needs. The report's results will also help guide EPRI's planning for possible future R&D on SMS.

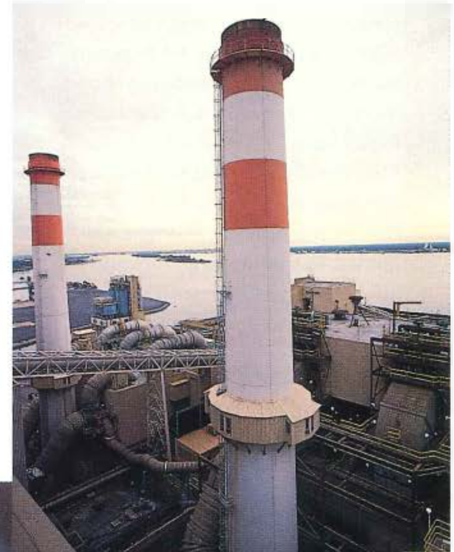
Why get smart?

As EPRI's overview report explains, in the most general sense a smart structure consists of three parts: a sensor, an actuator, and a processor. In this technology paradigm, sensors correspond to biological nervous systems, reacting to stimuli (stress, strain, heat, electricity, or the like). A sensor signals an actuator (analogous to a muscle), which appropriately modifies the characteristics of a structure. A processor performs brainlike control functions to ensure that the structure responds in the prescribed way. Although the individual technologies for sensors, actuators, and processors are well advanced, the next R&D challenge is to physically and functionally integrate them into complete, full-size, application-specific systems.

Despite the limited use of SMS already in several industries, routine applications, particularly for utility needs, are probably years away, notes EPRI's Stringer. Then why, in a competitive marketplace that encourages a focus on short-term results, should electricity companies be interested? "Because smart materials and structures are ideally suited to address operations and maintenance concerns in today's power plants," says Stringer. "They may provide early warning of structural deterioration to avoid forced outages; improved maintenance planning as a result of real-time



Turbine vibration



Emissions chemistry

Coal feed

Corrosion control

PHOTOS BY RON MAY

condition assessment; real-time vibration control in rotating machinery; noise abatement; and rapid, automatic response to nonstandard conditions. In addition, SMS technologies have significant promise for solving important materials and system shortcomings in the longer term and may someday enable totally new electricity-related technologies."

Utilities and energy companies may not have to develop a fully integrated smart system to benefit from the use of smart materials. As in biology, there is a hierarchy of function for SMS that moves from standard structural design to versatile, intelligent structures that integrate many of the higher-order functions like analysis, decision making, and learning from past experience.

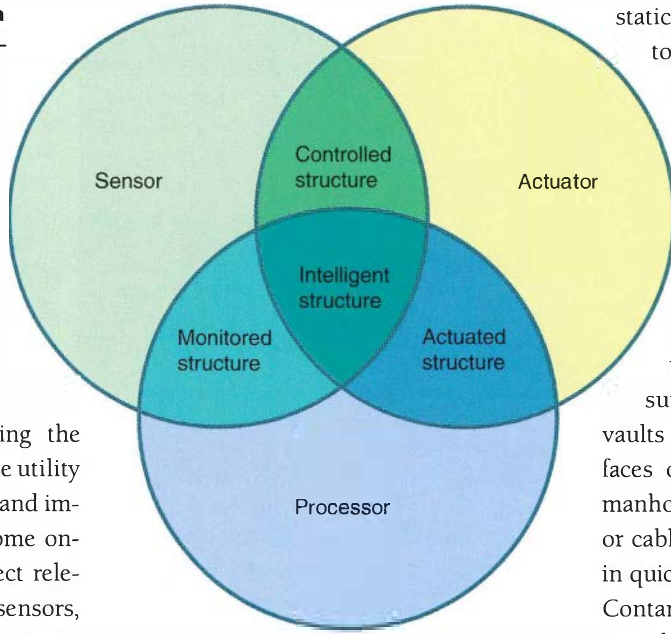
"We believe there are several application areas of interest to utilities where a limited degree of smartness could be introduced quite quickly to yield economic benefits," says Stringer. "These include applications in which a device can't automatically make a repair but is intelligent enough to call for a doctor. One example is distributed fiber optics on transmission lines for real-time temperature monitoring—an application for which EPRI has already demonstrated feasibility. Even if it does nothing more than tell you where there is a problem, a smart sensor can make repairing the problem go a lot faster. Ideally, of course, if a smart system can't make a repair itself, it could at least apply a bandage while calling for help."

Stringer continues, "At the other end of the spectrum, there may be opportunities to deploy distributed actuators that could, indeed, fix something remotely and automatically, with a minimum of sensors and data. Smart concrete is an example. Here, some limited research could produce valuable near-term results." He notes, however, that cost is an important limit for smart materials and that turning a low-tech job like pouring concrete into a precision technical task could pose problems. "You have to consider what kinds of adjustments in practice and attitude may be required to deal with new smart infrastructures. If you're going to add a smart system to a basic material, the new system has to be installable by the craft industry that uses the material as we know it now."

Utility needs for smart solutions

Attempts to find utility applications for existing SMS are frustrated at the outset by a key characteristic of smart systems: each system is designed for a very specific function that is dictated by the intended application. Already-developed SMS technologies are neither off-the-shelf products nor solutions to utility needs in their current form. Moreover, many of the generic benefits associated with SMS in other industries, such as weight saving, are signifi-

Smart structures typically consist of a sensor, an actuator, and a processor—which may be embodied as separate parts or integrated and embedded in the same component. A hierarchy of functionality reflects a continuum from standard structural design to versatile, intelligent structures that integrate higher-order capabilities. The ultimate goal would be intelligent, adaptive structures capable of self-learning and flexible response.



cantly different from those driving the adoption of new technologies in the utility industry—for example, lower cost and improved efficiency. Nevertheless, some ongoing SMS research will have direct relevance for utilities in the areas of sensors, fiber optics, and processor technologies.

Utility applications for one component of smart systems—advanced sensors—have been extensively investigated. Quite apart from their use in SMS, advanced sensor technologies offer significant benefits for the power industry. A 1993 workshop sponsored by EPRI and the National Science Foundation identified more than two dozen technical problem areas in power delivery that might be addressed with improved sensors. Those areas fall mainly into the categories of overhead transmission structures and foundations, underground transmission and distribution (T&D), and substations.

For lattice steel towers, improved sensors could continuously monitor soil displacement of foundations, wear and tear at hardware-structure interfaces, integrity of bolts and connections, and weld integrity. Sensors could detect and assess internal decay and damage of wood poles. And in overhead transmission rights-of-way, they could monitor erosion from storm water.

On overhead transmission lines, improved sensors could be used to monitor static conductors and hardware, conductor core and splices, and the condition of support hardware. Other sensors could detect and assess corrosion and relate those results to remaining conductor life. Sensors could also monitor the wear, corrosion, and overall condition of insulator hardware and fasteners.

Improved sensors for use in underground T&D could help ensure the integrity of manholes and vaults by monitoring utility system interfaces or the interfaces at buildings and manhole entrances for conduit settlement or cable shearing. Sensors could also help in quickly locating underground facilities. Contaminants seeping into vaults from outside sources (for example, road salt or gasoline from a leaking underground tank) could be monitored, as could stress induced on cables or sheaths during pulling.

At T&D substations, the integrity of structures (including buildings and their foundations) could be kept under surveillance. Control of erosion and of storm water could also be better managed with the help of advanced sensors. Oil spills, pollution discharges, roof leaks, and other water intrusion could likewise be monitored.

There are also broader problem areas that might be addressed by SMS. Because

Types of Smart Materials

By automatically responding to changes in a wide range of variables—from pressure to temperature to pH—smart materials provide the base functionality for higher-level smart structures and systems.

Conductive polymers Polymers that undergo dimensional changes on exposure to an electric field. These versatile materials can be used not only as sensors and actuators but also as conductors, insulators, and shields against electromagnetic interference.

Electrorheological fluids Actuator materials containing polarized particles in a nonconducting fluid that stiffens when exposed to an electric field.

Magnetostrictive materials Molecular ferromagnetic materials and other metallic alloys that change dimensions when exposed to a magnetic field.

Piezoelectric ceramics and polymers Materials, such as lead zirconate titanate ceramics and polyvinylidene fluoride polymers, that react to physical pressure. They can act as either actuators or sensors, depending on their polarity.

Polymeric biomaterials Synthetic, muscle-like fibers, such as polypeptides, that contract and expand in response to temperature or chemical changes in their environment.

Hydrogels Cross-linked polymer networks that change shape in response to electric fields, light, electromagnetic radiation, temperature, or pH.

Shape-memory alloys Metal alloys, such as nitinol, that can serve as actuators by undergoing a phase transition at a specific temperature and reverting to their original, undeformed shape.

Shape-memory polymers Elastomers, such as polyurethane, that actuate by relaxing to their undeformed shape when heated above their glass transition temperatures.

Fiber optics Fine glass fibers that signal environmental change through analysis of light transmitted through them. Perhaps the most versatile sensor material, optical fiber can indicate changes in force, pressure, density, temperature, radiation, magnetic field, and electric current.

the in-service deterioration of critical plant equipment and components is a major concern for all utilities, condition assessment is an area with the potential for wide SMS application. In the case of fossil fuel steam power plants, for example, it has been estimated that half of all forced outages are attributable to corrosion. Although generalized corrosion can be readily detected and measured, environmentally induced cracking (including stress corrosion cracking and corrosion fatigue) is difficult to detect and respond to. Damage caused by creep and by creep fatigue is even more difficult to assess.

Defense and aerospace technology are key areas of current focus for the development of leading-edge, specialized applications of smart materials and structures, including adaptive smart wings with variable geometry for different flight and environmental conditions. Advanced sensors embedded in aircraft skins for radar detection are already likely being used in current state-of-the-art defense aircraft, such as the F-117A Stealth fighter.

The uncertainties and complexities of component condition assessment have resulted in a conservatism in present-day design and practice that can lead to the significant and costly overdesign of structures in order to meet worst-case loadings. Technologies that are central to improved condition assessment (chemical sensors, microsensors, fiber optics, and crevice-corrosion detectors) and to remaining-life evaluation, self-diagnosis, and self-repair are expected to provide fertile ground for applying SMS.

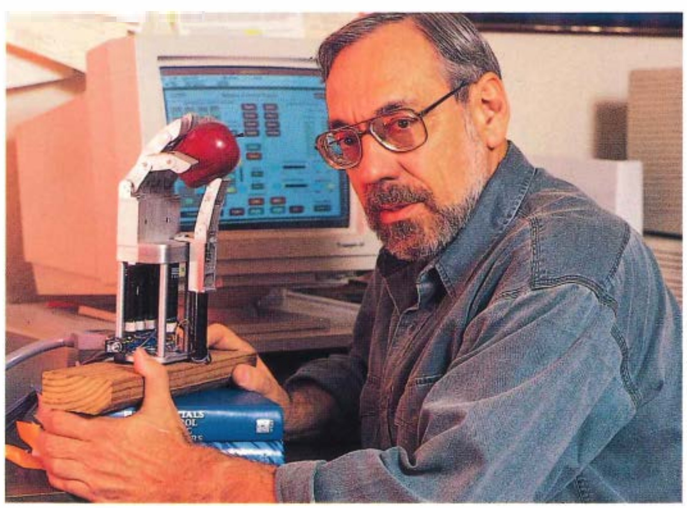
Just as in condition assessment, SMS researchers are acutely aware of the need for smartness in utility-related civil structures and in the materials from which they are made—concrete, for example. Dam safety is a prominent concern in hydroelectric generation. Of value to the utility industry would be fiber-optic sensors that could monitor the state of cure of concrete, detect corrosion in steel reinforcing bars, assist in nondestructive evaluation for corrosion in such structures as cables, measure aerodynamic and hydraulic loadings, and detect crack propagation in concrete through acoustic emissions.

Power plants contain a wide variety of large rotating machines and components, including steam turbine rotors and blades, fans, pumps, generators, and motors. Uncontrolled vibration in any of these machines or components raises concerns not only about safety but also about costly equipment damage. SMS technologies could monitor and in some cases damp such vibration. They could also yield performance improvements by active shape control of, for example, steam and wind turbine blades.

In an application related to vibration control, active or passive SMS could also be used to reduce noise from power generation equipment. As an additional benefit, SMS-based noise mitigation technologies for the large fans used to keep air-cooled motors from overheating could potentially reduce the parasitic power losses attributable to these fans. Noise control technologies might also be used at substations, where the mitigation of transformer humming can result in considerable expense.

In power system operation, a smart system might also be applied to handle the complex mechanical-electrical control problem called subsynchronous resonance (SSR). In this insidious form of vibration in rotating equipment, the natural frequency of rotating components in a generator matches the electrical resonant frequencies of the interconnected power grid—a potentially catastrophic phenomenon that can destroy a generator or trigger a widespread blackout. The installation of series-connected capacitors on transmission lines to increase power transfer capability can also create an electrical resonance circuit and establish SSR conditions.

Large numbers of extensive computer simulations are currently performed to evaluate the potential for SSR, given all the likely combinations of transmission circuits and generating stations. Capacitors may be reduced in size and electrical filters may be used to de-tune a circuit to avoid critical mechanical frequencies, but these



San Diego State University Professor Marko Vuskovic has developed a multifunctional biomechanical hand that can be interfaced with muscles in the human arm to become a prosthesis or can be mounted on a robotic arm and computer-controlled for manufacturing and industrial use. The hand is actuated by six tiny dc motors and is equipped with 16 touch sensors. Control algorithms for grasp recognition were derived from recordings of electrical signals from forearm muscles of human subjects.

measures also reduce power transfer capabilities. A smart system that enabled the increased use of series compensation could yield substantial economic benefits by effectively doubling the transfer capability of a transmission line. Such a system might include sensors on key mechanical equipment and the transmission system to detect incipient SSR, an intelligent processor to integrate signals and responses, and appropriate actuation of switchable parallel filters and series capacitors.

Another SMS application that could boost transmission line power transfer capability is the use of fiber-optic sensors to measure real-time conductor temperature. Today, thermal operating limits are calculated on the basis of air temperature, wind speed, incident sunlight, and a derating factor, but it is estimated that transmission lines could safely carry 5–15% more power if actual thermal conditions were known on a continuous basis. Fiber-optic systems on transmission lines could also be used to detect overheating, galloping, and conductor flaws and to control circuit breakers along a broken line where electromagnetic interference might cause conventional control systems to fail.

Smart systems for power plants

In fossil or nuclear power plants, the health of components that are touched by water or steam depends on the purity of the process fluids. Dissolved oxygen, chloride ions, and a host of other impurities must be controlled at the parts-per-billion level—a formidable challenge, considering that a large steam generator circulates millions of pounds of water and steam per hour. Rapid response to impurity ingress, corrosion, and deposition is critical.

Camera- and sensor-equipped remote inspection robot

Penalties for exceeding contaminant limits may include boiler tube failures, fouling of heat transfer surfaces, localized corrosion, cracked steam turbine disks and blades, and increased erosion of turbine components. Any one of these can cause a forced outage of substantial duration. EPRI has identified a clear need for distributed on-line sensors, chemical injectors to counter pollutants or chemical imbalances, processors to coordinate multifunctional sensors, and actuators that can meet the challenge.

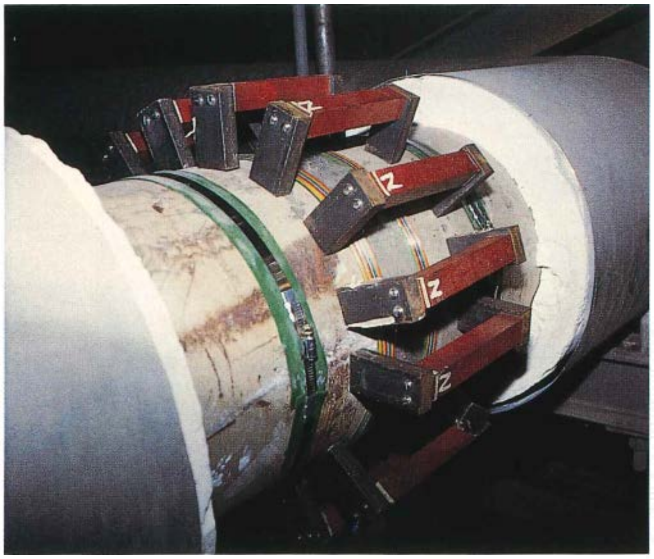
As is the case with improved control of plant cycle chemistry, substantial economic and environmental benefits can be gained by reducing fossil plant pollutant emissions into the atmosphere. Various configurations of sensors, processors, and actuators could integrate fuel delivery to the boiler, burner controls, and combustion conditions in real time to minimize the formation of pollutant emissions and selectively activate controls that maximize the extraction of pollutants from the stack gas while optimizing plant performance. A smart system with an advanced sensor able to reliably, precisely, and continuously measure the mass flow of pulverized coal through a burner feed pipe would have major value to operators of coal-fired plants everywhere, says Mark Perakis, manager for maintenance instrumentation and controls in EPRI's Energy Conversion Division.

ROVVER robotic crawling cameras for remote inspection

Houdini—a hydraulically powered, bulldozer-like mobile robot for tank-waste retrieval

Remotely operated robots—equipped with video cameras, sensors (for radiation, temperature, or chemicals), and specialized tools—represent a significant platform for future utility applications of smart systems. Increasingly used in nuclear power plants and other hazardous environments for a variety of inspection, repair, and cleanup tasks, advanced robots may eventually incorporate sufficient intelligence and adaptive capability to perform multiple tasks autonomously, without a control cable.

"Today, no reliable analyzer is available that provides accurate, precise measurements of coal flow in real time. We've looked at sensor applications to monitor coal constituents, but they are relatively expensive and not very rugged. They also have a hard time keeping up with fast-changing coal properties," notes Perakis. Additional challenges to be considered in the development of smart combustion and emissions control systems are, first, the lack of economically priced sensors and, second, important gaps in the knowledge of plant technical staffs about how to sustain the operation of advanced or commercially immature laboratory-grade sensors.



Magnetostrictive sensor coils wound around either end of a pipe length promise a new nondestructive method for quickly screening piping for trouble spots with minimum removal of insulation. A pulse generator at the transmitting coil produces a guided wave that travels down the pipe to the receiving coil. Received signals are analyzed by computer to reveal defects encountered in the pipe. The technique, developed by Southwest Research Institute, is being evaluated for utility application in EPRI-sponsored R&D.

"Utilities want a system with a sensor that can be calibrated during a plant overhaul and will not need checking or recalibration until the next overhaul or beyond," says Perakis. "There's a lot of discussion today about using some of these smart systems to validate the performance of sensors so that they alert the technicians when maintenance or calibration is actually needed."

Leeds & Northrup, a manufacturer of control systems, has developed what it calls a smart system for controlling the flow of coal to burners in once-through boilers. The system computes Btu content from sensor measurements of seven temperature and pressure variables and optimizes fuel flow for the desired combustion conditions. The Btu compensation scheme is based on technology developed at Ente Nazionale per l'Energia Elettrica of Milan, Italy.

In addition to the potential for smart sensors and systems to optimize plant cycle chemistry, combustion conditions, and emissions controls, SMS technologies may be valuable for the on-line assessment of the condition of major plant components. Equipment condition assessment is a key element of predictive maintenance capabilities that have been a goal of EPRI R&D for many years. The vision of this research is that real-time equipment condition monitoring not only provide early warning of a need for maintenance but also enable plant personnel to identify and possibly alter operations to minimize stress on the equipment.

"We would like to find economical sensors to help in understanding the condition of major components—including rotating equipment, components associated with high energy, and thermally stressed parts. Such sensors could be a high-value area for smart systems applications," says Perakis.

EPRI's Instrumentation and Controls Center at the Tennessee Valley Authority's coal-fired Kingston plant near Knoxville, Tennessee, could be an appropriate place for testing and evaluating smart sensor technologies and smart systems for power plant monitoring and possibly other applications, Perakis notes. "The center operates as a virtual technology transfer center. It can stage tests or demonstrations at power plants anywhere and can help identify the value or lack of value of a new technology in utility applications. Among our goals are to identify emerging sensors and new control technologies, to match them up with power plant applications, and to identify the demonstration opportunities to evaluate them in actual industrial use."

What's next?

According to John Stringer, "Smart materials and structures is a current buzz phrase in a number of technical fields. But is there substance behind the words? Our report demonstrates clearly that the answer is yes. Now the question is, what do we do next? We need to decide on the next step to demonstrate in some simple way the value of using SMS and to analyze the costs and benefits of developing an actual application. We hope our members will give us feedback on that."

Noting that "a truly smart system involves three different but integrated functions—a detector that can identify a system's local conditions, especially faults or deviations from expected behavior; an actuator that can cure the problem; and an intelligence that is capable of planning and executing the appropriate action"—Stringer emphasizes that at this stage, most research results relate to developments in the detectors. "To realize the possible benefits of smart materials and systems, however, developments in the other two components—in particular in the intelligence—will be essential." ■

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Background information for this article was provided by John Stringer and Mark Perakis, Energy Conversion Division.

Around the World

Focus on international projects and alliances

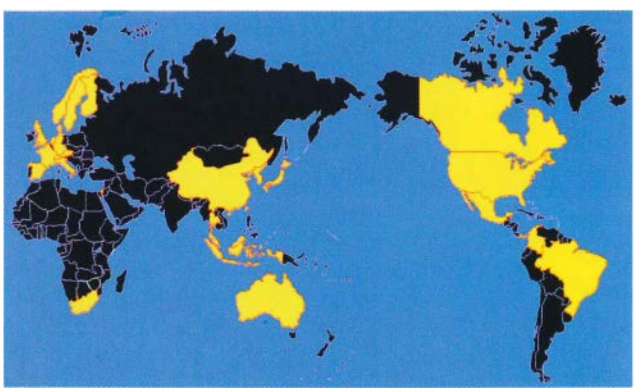
Lightning Detection Takes Off Internationally

An EPRI-developed technology for anticipating, tracking, and analyzing lightning strikes is now sweeping the international market. Known in the United States as the National Lightning Detection Network™ (NLDN), the technology consists of a network of strategically placed electromagnetic sensors that relay cloud-to-ground lightning data via communications satellites to the network's control center for processing and distribution. The resulting data are displayed on a geographic map—which includes electrical transmission and distribution systems—so that users can easily monitor, in real time, lightning activity in and near their regions.

U.S. electric utilities provided the first significant market for the technology. That is not surprising, since more than 30% of power outages in this country are caused by lightning, resulting in $100 million to $300 million in annual damage to power lines, transformers, and other utility equipment. When outage revenue losses are also taken into account, the estimated total loss approaches $1 billion annually. Power companies have come to rely on NLDN technology to help them react faster to storm threats, avoid outages, and minimize the unnecessary deployment of storm-watch crews. They also use it to determine whether lightning caused specific outages, analyze how well their systems performed during thunderstorms, and prioritize the upgrading of transmission and distribution lines.

These days, many others—including the forestry, airline, insurance, and meteorological industries; the U.S. Air Force; and various recreational operations—also rely heavily on lightning detection data. And users are drawing not only on the NLDN but also on networks around the world. According to Rick Villa, international sales manager for Global Atmospherics, Inc. (GAI), which now owns the EPRI-developed technology, international interest in the technology has increased dramatically in the past five years. Today, GAI's networks are operating in some 25 countries and on every continent. GAI has in fact established 95% of all the lightning detection networks in the world.

"Other countries have seen the value of data from the U.S. network," says EPRI's Ralph Bernstein, who managed the development and commercialization of the NLDN technology, "and they know it's much cheaper for them to apply the technology than it was for us to develop it." Bernstein cites several other factors influencing the international interest. "As countries develop, they become more vulnerable to natural phenomena like lightning, and their customers become less tolerant of power disruptions." Countries planning transmission lines can benefit from a network that lets them assess the lightning-flash density of a given region and either design for or avoid the high-lightning areas, Bernstein says. He also notes that as international travel increases, the airline industry is becoming more concerned about lightning-related safety issues. With detailed data from a network, planes can be safely rerouted when necessary.



Countries with lightning detection networks (yellow)

Artur Gluszek, a representative of the Polish Power Grid Company who works from EPRI's Palo Alto, California, headquarters, says PPGC is very interested in being a leader with this technology. "To be the first country in eastern Europe to have such a lightning system is a great opportunity," he says. PPGC—Poland's transmission company and an EPRI member—is currently considering a proposal from GAI to establish a network designed to monitor lightning in and around the country. Being able to identify lightning-caused outages and to better maintain transmission lines to resist lightning strikes is the motivation for PPGC's interest, Gluszek explains. There is also the lure of a future business opportunity: the possibility of selling data from the network to other industries that can benefit from it.

If PPGC wants to be the first in eastern Europe, it's going to have to move quickly. Villa of GAI reports that the Czech Republic has decided it also wants to implement a lightning detection network. GAI is now completing a proposal for that job.

Villa says the U.S. network is an example for other regions of the world that could operate interconnected lightning detection networks. Already, he says, the Scandinavian countries have put together an agreement to share their data. And European countries that have established separate networks are discussing a similar arrangement. In fact, Germany has already completed hookups with Austria and Switzerland.

The very severity and frequency of lightning strikes represent a significant motivation for some countries to establish a detection network. One of the most active regions on earth for lightning strikes is the island of Java in Indonesia. Thunderstorms occur there 223 days a year, on average. That compares with 90 days a year for the central Florida region, the most active area for lightning strikes in the United States. Java's vulnerability was a major factor in the acquisition of a lightning detection network there. The network is based in Bandung—a city of 1.5 million located southeast of Jakarta.

The NLDN was developed in the mid-1980s by the State University of New York under contract to EPRI. In 1991, GeoMet Data Services (now called GAI) assumed operational responsibility for the network. EPRI continues to receive royalties for the sale of data from the U.S. network.

"This is a very successful example of the commercialization of an EPRI technology that has benefited EPRI customers as well as a range of other groups," says Ralph Samm, EPRI's manager for distribution systems. "I think EPRI can be proud of the fact that we funded the development and commercialization of this network and that now our international members are also benefiting."

■ *For more information, contact Ralph Samm, (650) 855-2289, or Ralph Bernstein, (650) 855-2023.*

Improving Power Quality in British Columbia

A new EPRI technology developed to resolve power quality problems on distribution systems has been applied successfully in Canada by BC Hydro.

DSTATCOM, a novel distribution static compensator developed jointly with Westinghouse, is designed to protect the distribution system from power "pollution" caused by certain customer loads. Typically the device is placed between the feeder and a heavy, fluctuating load, whose operation would otherwise produce disturbances—voltage sags, swells, and harmonics—that could adversely affect other customers' power quality.

In BC Hydro's situation, that load was a sawmill. BC Hydro serves British Columbia, a province whose main industry is forestry. In rural areas of the province, it is not uncommon for residential properties to be interspersed with industrial operations like lumber mills. And power quality problems can result. When an International Forest Products lumber mill in the community of Adams Lake announced plans to install a new whole-log chipper driven by a single 1200-horsepower motor, a red flag went up at the utility.

From previous experience with similar equipment, BC Hydro knew that the chipper would cause voltage flicker for the nearest 100 neighbors on the 25-kV distribution feeder and would potentially adversely affect all 800 customers on the 30-kilometer line. Rather than waiting for customer complaints, the utility took a proactive approach and requested that the lumber company review its installation design to identify modifications that would reduce the impact of the chipper on the electrical system. In the meantime, BC Hydro set out to find a power-conditioning technology capable of mitigating the voltage flicker. The plan was to install the conditioning equipment at the sawmill temporarily and to remove it once the mill's design modifications proved effective.

As it turned out, EPRI had completed a prototype of DSTATCOM and was looking for a site to test the device. The BC Hydro application seemed like an ideal fit. An engineering study using computer simulation confirmed that DSTATCOM was appropriate for the application, and BC Hydro proceeded with a purchase order.

The mobile DSTATCOM unit, in service at the sawmill from January 1997 to June 1998, proved itself in the field. Without it, the line's voltage flicker rate typically was 7–8%; DSTATCOM reduced that rate to an acceptable 4%. In addition, it mitigated harmonics generated by sawmill motor drives and provided real-time voltage regulation during sags and swells resulting from log carriage startup and braking operations. Part of DSTATCOM's attractiveness was that it cost BC Hydro just $600,000—between $400,000 and $1.2 million less than the cost of alternative strategies. Those strategies included building a dedicated distribution line and installing diesel drives on the chipper.

The lumber mill is now implementing its design-based remedies to address the power quality concerns. And BC Hydro plans to install DSTATCOM at a new site—an existing sawmill near the town of Kaslo that has drawn customer complaints about voltage flicker. The utility hopes to repeat its success with this second customer, using DSTATCOM as an immediate solution while assisting the customer in resolving the problem for the long term.

■ *For more information, contact Ralph Samm, (650) 855-2289, or Ashok Sundaram, (650) 855-2304.*

In the Field

Demonstration and application of EPRI science and technology

Rochester Gas and Electric Pioneers New Radiographic NDE Technique

The nondestructive inspection of nuclear plant piping to detect wall thinning caused by flow-accelerated corrosion often involves the use of ultrasonic examination techniques. Such techniques typically require the removal of piping insulation and must be applied during a plant shutdown. Some inspections can be performed during plant operation by using conventional film radiography. But film-based radiography, which requires storage of the film, can be costly, slow to yield usable results, and cumbersome.

Recently, with assistance and expertise from EPRI's Nondestructive Evaluation (NDE) Center, the staff at Rochester Gas and Electric's (RG&E's) Ginna nuclear plant demonstrated the ability of a new NDE technology—phosphor plate radiography—to reduce the cost of radiography and to eliminate the need to store radiographic film. Inspections were completed while the plant was operating and without removing insulation. Projected labor cost savings from the elimination of film developing for an annual plant inspection amount to $11,500, or approximately $115,000 over 10 years.

Phosphor plate technology has several inherent advantages over film radiography. The plates can be reused up to 2000 times and do not require the chemical processing that entails waste disposal. Phosphor plates can be processed about 10 times faster than film. Photographic-quality hard-copy images can be easily made for assessing component condition, and those images can be digitally stored. And phosphor plates can provide meaningful images over a wide range of exposure times, eliminating the need for test exposures. Moreover, images can be obtained using lower-strength radioisotope sources than those used in film radiography, thereby minimizing the high-radiation area that must be roped off during exposures.

In work that began as a tailored collaboration project, EPRI provided RG&E with phosphor plate equipment from several manufacturers, helped train utility personnel in the use of the equipment, and assisted the utility in developing methods for measuring pipe wall thickness with the technology. "By using phosphor plate technology to perform radiography in our plants, we can provide a more cost-effective option for on-line examinations of small-diameter piping systems, as well as for valve diagnostics," notes Mike Saporito of RG&E.

An EPRI technical report (TR-107499) on RG&E's application of phosphor plate radiography is available from the EPRI Distribution Center, (510) 934-4212.

■ *For more information, contact Jack Spanner, (704) 547-6065, or Kim Kietzman, (704) 547-6163.*

Field Tests of Photovoltaic Heat Pumps

One of the few field test studies to evaluate the use of on-site photovoltaic (PV) arrays in supplying electricity directly in residences and small businesses was recently completed for EPRI. The study focused on four sites in the South and Southwest characterized by high cooling loads. Conducted at residences in Arizona, North Carolina, and Texas and at a government laboratory in Texas, field tests examined novel photovoltaic heat pump (PVHP) systems to assess the feasibility and value of on-site PV for reducing heat pump electricity use and peak demand. Summer air conditioning loads typically drive peak electricity demand, and utility system peaks typically coincide with prolonged spells of clear, sunny weather.

All of the PVHP systems tested were site customized. All used PV arrays with nominal outputs of 2.3–3.2 kW to drive variable-speed heat pumps with nominal cooling capacities of 3–5 tons. The PV arrays were sized to provide 50–60% of the full-load power of the heat pump. Researchers developed power-conditioning circuitry that permitted the heat pump to operate on dc from the PV array and to use ac from the grid for backup. Performance data for a full year were collected at each site.

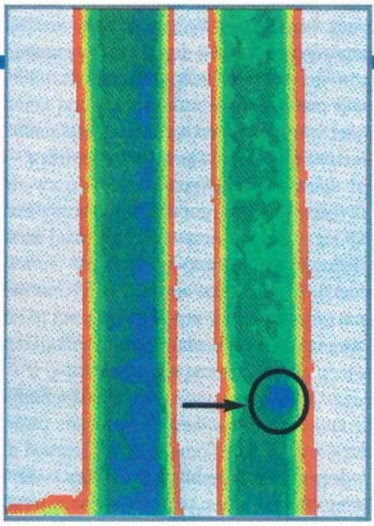
At the residential sites, heat pump utilization of PV array output was poor when averaged over 12 months, ranging from 23% in Arizona to 47% in Texas. Array utilization during the summer months was better, ranging from 61% to 85%. The Texas laboratory site showed relatively good PV utilization—74%—throughout the year because high cooling loads kept the heat pump operating almost continuously.

The effect of PV arrays on heat pump electricity demand was limited. Researchers found that residential cooling loads tended to peak in late afternoon when insolation was relatively low. For the 10 hottest days at each test site, the PVHP systems reduced the average peak demand by 70–570 W at the residences and 1.1 kW at the laboratory. Those demand reductions correspond, at most, to 15% of the peak average load of the heat pumps on a hot summer day. Both PV array utilization and demand for grid power could be improved by storing energy (electric or thermal) during periods of peak insolation. EPRI has collected data from a fifth field test site—a residence equipped with a PVHP and batteries—to quantify the potential improvement with storage.

"Distributed systems are among the many options utilities are considering for the competitive marketplace. This research provides quantifiable data on photovoltaic heat pumps as one type of potentially attractive distributed system. The project particularly evaluated the usefulness of PVHPs in reducing peak cooling demand," says Carl Hiller, manager for residential systems in EPRI's Energy Delivery and Utilization Division. A technical report on the initial PVHP field tests (TR-109256) is available from the EPRI Distribution Center, (510) 934-4212.

Ensuring Synthetic Liner Quality With Infrared Thermography

Geomembrane liners made from impermeable materials such as high-density polyethylene (HDPE) are increasingly used by power producers to store liquid and solid wastes in ash and evaporation ponds, reservoirs, and landfills. Produced in rolls up to 10 meters wide, the liners are typically used to cover areas of up to 50,000 square meters (5 hectares), requiring that sheets of liner be bonded together in the field, creating significant lengths of seam. These seams may be either the fusion type (overlapped sheets with heat applied in the interface to form a uniform weld) or the extrusion type, which is more labor-intensive (and therefore more expensive) and more prone to failure.


COURTESY GEOTECHNICAL FABRICS REPORT

Sand particles (shown by arrow) trapped within a seam

To ensure liner integrity, workers must test the entire geomembrane, particularly the seams, for leaks before it is put into service. Current standards and practices involve various nondestructive evaluation (NDE) techniques. Although current practices can identify actual holes that penetrate the geomembrane, these techniques are time-consuming and cannot detect seam defects (such as partially penetrating channels and cracks), dirt trapped in the interface, or internal voids that have the potential to develop into cracks.

An NDE method that could identify nonpenetrating flaws would improve seam integrity by eliminating the need to destroy and patch portions of seam. EPRI recently investigated the feasibility of using infrared thermography (IRT), an already proven technique for detecting hot spots in boiler tubes and electrical equipment. By measuring the differences in surface temperature at various points on the liner material, IRT can detect anomalies such as flaws, voids, and trapped dirt.

Arizona Public Service hosted EPRI's IRT field trials at its Palo Verde nuclear station. Approximately 5 kilometers of seam were evaluated, using IRT on a 2-millimeter-thick HDPE liner that covered 1 square kilometer (100 hectares) and had a total of more than 95 kilometers of seam. An infrared camera able to distinguish temperature variations as small as 0.006°C was mounted, along with a visible-light camera, on a tractor-pulled trailer 3.7 meters above the liner. With the survey limited to the seams, the infrared images could be magnified to achieve maximum resolution of structural variations and to provide a solid basis for comparison with destructive methods. Controlled laboratory tests were conducted in parallel to confirm the field performance of IRT.

IRT successfully identified structural defects that had the potential to develop into leaks. Numerous nonpenetrating anomalies were detected, as was insufficient bond width on the seam due to inadequate overlap. Center channel blockage in two-track fusion welds was also detected. Infrared images were compared with flaws that were known to exist, and seam samples were prepared with defects for evaluation by both IRT and destructive testing to validate the results of the IRT survey. The destructive test results correlated well with the IRT findings.

EPRI is developing a fracture mechanics method to quantify the influence of cracklike flaws on long-term liner integrity and to set minimum flaw detection requirements for such NDE methods as IRT. And a system that combines IRT liner inspection and fracture mechanics methods with an artificial intelligence technique is being explored for its potential as an automated system for rapid, reliable seam surveying and interpretation.

By eliminating the need to destroy and patch otherwise good sections of seam, IRT can improve liner integrity and durability and save the labor costs of repair. The method also produces a real-time record of the inspection data on videotape. ■ *For more information, contact Dean Golden, (650) 855-2516.*

Technical Reports & Software

To order reports, contact the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, CA 94523; (510) 934-4212. To order software, contact the Electric Power Software Center, 11025 North Torrey Pines Road, La Jolla, CA 92037; (800) 763-3772.

Energy Conversion

Guidelines for PWR Steam Generator Tubing Specification and Repair, Vol. 1, Revision 1: Tube Section Removal and Examination
TR-016743-V4R1
Target: Nuclear Power
EPRI Project Manager: A. McIlree

PWR Advanced Amine Application Guidelines, Revision 2
TR-102952-R2
Target: Nuclear Power
EPRI Project Manager: P. Millett

CHECWORKS™ Application Manager: User Guide
TR-103198-P3
Target: Nuclear Power
EPRI Project Manager: B. Chexal

Steam Generator Vibration and Wear Prediction
TR-103502
Target: Nuclear Power
EPRI Project Manager: D. Steininger

State-of-the-Art Weld Repair Technology for High-Temperature and -Pressure Parts, Vol. 4: Weld Repair of Pipe/Header Girth Welds
TR-103592-V4
Targets: Boiler Life and Availability Improvement; Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: V. Viswanathan

Oxide-Film Compositions on Alloy 600 Tubes From Steam Generators: Palo Verde and St. Laurent
TR-104066
Target: Nuclear Power
EPRI Project Manager: A. McIlree

License Renewal Industry Reports Summary
TR-104305
Target: Nuclear Power
EPRI Project Manager: J. Carey

Evaluation of Thermal Aging Embrittlement for Cast Austenitic Stainless Steel Components in LWR Reactor Coolant Systems
TR-106092
Target: Nuclear Power
EPRI Project Manager: J. Carey

Demonstration of the Management of Aging Effects for B&W Pressurizers
TR-106106
Target: Nuclear Power
EPRI Project Manager: J. Carey

Proceedings: 1992 EPRI Workshop on Secondary-Side IGA/SCC
TR-106546
Target: Nuclear Power
EPRI Project Manager: A. McIlree

Oconee-2 Steam Generator Tube Examination
TR-106863
Target: Nuclear Power
EPRI Project Manager: A. McIlree

Disposal Cost Savings Considerations in Curie Reduction Programs
TR-107305
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Status of the Ultrasonic Examination of Reactor Coolant Loop Cast Stainless Steel Materials
TR-107481
Target: Nuclear Power
EPRI Project Manager: S. Walker

Age-Related Degradation Inspection Method and Demonstration in Behalf of Calvert Cliffs Nuclear Power Plant License Renewal Application
TR-107514
Target: Nuclear Power
EPRI Project Manager: J. Carey

Evaluation of Thermal Fatigue Effects on Systems Requiring Aging Management Review for License Renewal for the Calvert Cliffs Nuclear Power Plant
TR-107515
Target: Nuclear Power
EPRI Project Manager: J. Carey

EPRI DFD (Decontamination for Decommissioning) Process Evaluation: Overview of EPRI DFD Process Applications
TR-107707
Target: Nuclear Power
EPRI Project Manager: C. Wood

Nuclear Power Plant License Renewal Environmental Compliance Program: Donald C. Cook Nuclear Plant Case Study, Phase 2—Strategic Planning and Data Gathering
TR-107868
Target: Nuclear Power
EPRI Project Manager: J. Carey

Proceedings: 1993 EPRI Workshop on Secondary-Side IGA/SCC
TR-107883
Target: Nuclear Power
EPRI Project Manager: A. McIlree

Yankee Rowe Decommissioning Experience Record, Vol. 1
TR-107917-V1
Target: Nuclear Power
EPRI Project Manager: C. Wood

Fort St. Vrain Decommissioning: Final Site Radiation Survey—Summary Report and Lessons Learned
TR-107979
Target: Nuclear Power
EPRI Project Manager: C. Wood

Mixed-Waste Advanced Treatment Technology: Waste-Processing Products and Their Recycling Applications
TR-107990
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

EDE Implementation: Electronic Dosimetry Angular Dependency
TR-107994
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Marble Hill Thermal Annealing Demonstration Project
TR-108316
Target: Nuclear Power
EPRI Project Manager: S. Rosinski

Application of Master Curve Fracture Toughness Methodology for Ferritic Steels
TR-108390
Target: Nuclear Power
EPRI Project Manager: S. Rosinski

Cavitation-Induced Excess Heat in Deuterated Metals
TR-108474
Target: Nuclear Power
EPRI Project Manager: T. Passell

Data Needs for Long-Term Dry Storage of LWR Fuel
TR-108757
Target: Nuclear Power
EPRI Project Managers: O. Ozer, A. Machiels

In-Vessel Core Debris Heat Transfer Experiments: COPO II-AP Experiments
TR-108877
Target: Nuclear Power
EPRI Project Manager: M. Merilo

Experimental Investigation of Natural Convection Heat Transfer in Volumetrically Heated Spherical Segments
TR-108878
Target: Nuclear Power
EPRI Project Manager: M. Merilo

Evaluation of Crack Initiation in Alloy 600 Reactor Vessel Head Penetration Materials
TR-108970
Target: Nuclear Power
EPRI Project Manager: R. Pathania

Fort St. Vrain Decommissioning: Public Relations and Human Resources Issues—Personnel Plans and Communications During Decommissioning of Nuclear Power Plants
TR-109030
Target: Nuclear Power
EPRI Project Manager: C. Wood

Trojan Nuclear Plant Decommissioning: Final Survey for the Independent Spent-Fuel Storage Installation Site
TR-109031
Target: Nuclear Power
EPRI Project Manager: C. Wood

Regulatory Process for Decommissioning Nuclear Power Reactors
TR-109032
Target: Nuclear Power
EPRI Project Manager: C. Wood

Green Power Guidelines, Vol. 1: Assessing Residential Market Segments
TR-109192-V1
Target: Renewables and Green Power Marketing
EPRI Project Managers: T. Peterson, R. Gillman

Proceedings: Distributed Resources Week 1997 (EPRI's Third Annual Distributed Resources Conference)
TR-109722
Target: Distributed Resources for Energy Services and Delivery Enhancement
EPRI Project Manager: G. Heffner

Determination of the Accuracy of Utility Spent-Fuel Burnup Records (Interim Report)
TR-109929
Target: Nuclear Power
EPRI Project Manager: J. Yedidia

Use of Level 3 PSA in Risk-Informed, Performance-Based Regulation of Nuclear Power Plants
TR-109930
Target: Nuclear Power
EPRI Project Manager: F. Rahn

Reevaluation of the Benefits of Implementing Enriched Boric Acid
TR-109992
Target: Nuclear Power
EPRI Project Manager: H. Ocken

Tube Support Plates Corrosion Assessment Within the Crevices of Ringhals-3 and Dampierre-1 Retired Steam Generators
TR-110005
Target: Nuclear Power
EPRI Project Manager: A. McIlree

Proceedings: EPRI/NEI Decommissioning Workshop, San Antonio, Texas, December 10–12, 1997
TR-110006
Target: Nuclear Power
EPRI Project Manager: C. Wood

Evaluation of Environmental Fatigue Effects for a Westinghouse Nuclear Power Plant
TR-110043
Target: Nuclear Power
EPRI Project Manager: J. Carey

User's Guide to IARDATA: Irradiation-Anneal-Reirradiation Database, Beta Version
TR-110123
Target: Nuclear Power
EPRI Project Manager: S. Rosinski

Evaluation of Pipe Failure Potential via Degradation Mechanism Assessment
TR-110157
Target: Nuclear Power
EPRI Project Manager: J. Mitman

Measuring Fatigue Damage in Materials: Phase 1
TR-110250
Target: Nuclear Power
EPRI Project Manager: S. Rosinski

Influence of Irradiation and Stress/Strain on the In-Reactor Behavior of High-Purity Stainless Steels and Ni-Base Alloys: Task B
TR-110304
Target: Nuclear Power
EPRI Project Manager: L. Nelson

Evaluation of Environmental Thermal Fatigue Effects on Selected Components in a BWR Plant
TR-110356
Target: Nuclear Power
EPRI Project Manager: J. Carey

Losses of Off-Site Power at U.S. Nuclear Power Plants Through 1997
TR-110398
Target: Nuclear Power
EPRI Project Manager: A. Singh

ORAM-SENTINEL™ Development at Calvert Cliffs
TR-110473
Target: Nuclear Power
EPRI Project Manager: J. Mitman

SENTINEL™ Technical Basis Report for Peach Bottom
TR-110504
Target: Nuclear Power
EPRI Project Manager: J. Mitman

CHIRON: Coolant and Offgas Activity Data Management and Analysis Tool
Version 3.0 (Windows)
Target: Nuclear Power
EPRI Project Manager: B. Cheng

GTOP™ (Gas Turbine Overhaul Plan) Combined Cycle
Version 1.0 (PC-DOS)
Target: Combustion Turbine and Combined-Cycle O&M
EPRI Project Manager: R. Frischmuth

GTOP™ GESSC
Version 1.0 (PC-DOS)
Target: Combustion Turbine and Combined-Cycle O&M
EPRI Project Manager: R. Frischmuth

Energy Delivery and Utilization

Active Power Line Conditioning Technologies Application Guide
TR-106535
Target: Power Quality
EPRI Project Manager: B. Banerjee

Humidity Control Strategies Demonstration in a Library
TR-106601
Target: Commercial Building Heat Pump Technology
EPRI Project Manager: M. Khattar

Desk Book™: Commercial End-Use Technologies, Version 1.0
TR-108045
Target: Commercial Building Chillers
EPRI Project Manager: J. Kesselring

Longitudinal Load and Cascading Failure Risk Assessment (CASE): Central Louisiana Electric Cooperative's 500-kV Toledo-Coushatta Transmission Line
TR-108192
Target: Overhead Transmission
EPRI Project Manager: P. Lyons

Longitudinal Load and Cascading Failure Risk Assessment (CASE): Tennessee Valley Authority's 161-kV Lowndes–West Point Transmission Line
TR-108479
Target: Overhead Transmission
EPRI Project Manager: P. Lyons

Commercial Heat Pump Water Heater Applications Handbook
TR-108484
Target: Commercial Building Water Heating
EPRI Project Manager: C. Hiller

Inventory of Available Methods and Processes for Assessing the Benefits, Costs, and Impacts of Demand-Side Options, Vol. 3: Computer Tools for Integrated Planning
TR-108506-V3
Target: Producing Successful Product and Service Portfolios
EPRI Project Manager: G. Heffner

Proceedings: International Sustainable Thermal Energy Storage Conference
TR-108927
Target: Commercial Building Thermal Storage
EPRI Project Manager: M. Khattar

Wind Tunnel Study of Drag Coefficients of Single and Bundled Conductors
TR-108969
Target: Overhead Transmission
EPRI Project Manager: P. Lyons

Future Forecasting Directions in the Evolving Electric Power Industry
TR-109056
Target: Producing Successful Product and Service Portfolios
EPRI Project Manager: P. Meagher

The High-Efficiency Laundry Metering and Marketing Analysis (THELMA) Project, Vol. 1: Final Research Plan
TR-109147-V1
Target: Residential Appliances
EPRI Project Manager: J. Kesselring

The High-Efficiency Laundry Metering and Marketing Analysis (THELMA) Project, Vol. 3: General Market Assessment
TR-109147-V3
Target: Residential Appliances
EPRI Project Managers: R. Gillman, J. Kesselring

Distribution Cost Structure: Methodology and Generic Data
TR-109178
Target: Distribution System
EPRI Project Manager: S. Okonek

Residential Heat Pumps: Defending and Growing Market Share
TR-109188
Targets: Enhancing the Success of New Customer Technologies; Residential Heat Pump Technology
EPRI Project Manager: T. Henneberger

Electric Lift Trucks: Market Description and Business Opportunities
TR-109189
Targets: Nonroad Electric Vehicles; Enhancing the Success of New Customer Technologies
EPRI Project Managers: G. Purcell, T. Henneberger

Green Power Guidelines, Vol. 1: Assessing Residential Market Segments
TR-109192-V1 (see listing under Energy Conversion)

Field Testing of Photovoltaic Heat Pumps
TR-109256
Target: Residential Heat Pump Technology
EPRI Project Manager: C. Hiller

Energy Market Profiles: Hospital Buildings, Equipment, and Energy Use
TR-109363
Target: Healthcare Industry
EPRI Project Managers: R. Gillman, R. Wilson

Ion-Trapping Jacket for Cables
TR-109365
Target: Underground Distribution Infrastructure
EPRI Project Manager: B. Bernstein

Inspection and Detection Techniques: Defects in Porcelain Insulator Strings
TR-109451-V2
Target: Overhead Transmission
EPRI Project Manager: P. Lyons

Survey of Unbundled Electric Power Services
TR-109461
Target: Power Markets and Resource Management
EPRI Project Manager: C. Clark

Market Assessment of Thermal Energy Storage
TR-109478
Target: Commercial Building Thermal Storage
EPRI Project Manager: M. Khattar

Voltage Stability Studies for Southern Company Services
TR-109490
Target: Grid Operations and Planning
EPRI Project Manager: D. Maratukulam

Performance Evaluation of the National Lightning Detection Network in the Vicinity of Albany, New York
TR-109544
Target: Underground Distribution Infrastructure
EPRI Project Manager: R. Bernstein

National Electric Vehicle Infrastructure Working Council: Committee Meeting Minutes #97-3
TR-109561
Target: Infrastructure Deployment and EV Benefits
EPRI Project Manager: L. Sandell

The Benefits of and Potential Markets for High-Speed Electrical Machines: Scoping Study
TR-109616
Target: New Electric Motor/Drive Markets and Solutions
EPRI Project Manager: B. Banerjee

Overvoltages in Underground Systems: Phase 1 Results
TR-109669
Target: Distribution System
EPRI Project Manager: R. Bernstein

Testing of Lightning Arresters and Improved Lightning Protection: Preliminary Results
TR-109670
Target: Distribution System
EPRI Project Manager: R. Bernstein

Daylighting Design: Smart and Simple
TR-109720
Target: Commercial Building Lighting
EPRI Project Manager: K. Johnson

Manhole and Service Box: Explosion Suppression and Mitigation
TR-109741
Target: Underground Distribution Infrastructure
EPRI Project Manager: R. Bernstein

Simulation Program for On-Line Dynamic Security Assessment
TR-109751
Target: Grid Operations and Planning
EPRI Project Manager: D. Sobajic

Water Treatment Systems for Utilities, Phase 1: Technology Assessment
TR-109753
Target: Underground Distribution Infrastructure
EPRI Project Manager: R. Bernstein

Laser-Triggered Lightning Laboratory Tests: Preparation for Testing at Mississippi State University High-Voltage Laboratory
TR-109754
Target: Distribution System
EPRI Project Manager: R. Bernstein

SAR Applications Toward Flood Mapping: Current Status
TR-109755
Targets: Underground Distribution Infrastructure; Disaster Planning and Mitigation Technologies
EPRI Project Manager: R. Bernstein

Near-Optimal Cool Storage Controller Development
TR-109756
Target: Commercial Building Thermal Storage
EPRI Project Manager: M. Khattar

Post-Storm Damage Assessment Survey
TR-109757
Target: Disaster Planning and Mitigation Technologies
EPRI Project Manager: R. Bernstein

Direct Stability Analysis of Large Electric Power Systems Using Energy Functions: Foundations, Methods, and Applications
TR-109763
Target: Grid Operations and Planning
EPRI Project Manager: P. Hirsch

Guidebook on Analytical Methods and Processes for Integrated Planning: Development of Improved Methods for Integrating Demand-Side Options Into Resource Planning
TR-109801
Target: Producing Successful Product and Service Portfolios
EPRI Project Manager: G. Heffner

Electric Bus Life-Cycle Cost Study
TR-109802
Target: Public Transportation Systems
EPRI Project Manager: L. Sandell

Shuttle Bus Market Assessment
TR-109803
Target: Public Transportation Systems
EPRI Project Manager: L. Sandell

Procurement Guidelines for Battery-Electric Buses
TR-109804
Target: Public Transportation Systems
EPRI Project Manager: L. Sandell

The Future of Power Delivery in the 21st Century
TR-109806
Target: Grid Operations and Planning
EPRI Project Manager: R. Adapa

Technology Assessment and Business Planning for Power-Conditioning Technologies
TR-109896
Target: End-Use Power Quality Mitigation Systems
EPRI Project Manager: B. Banerjee

ASD Ride-Through Technology Alternatives and Development
TR-109903
Target: New Electric Motor/Drive Markets and Solutions
EPRI Project Manager: B. Banerjee

Active Filter Application Guide
TR-109904
Target: End-Use Power Quality Mitigation Systems
EPRI Project Manager: B. Banerjee

Flywheel Power Systems: Market Analysis
TR-109911
Target: New Electric Motor/Drive Markets and Solutions
EPRI Project Manager: B. Banerjee

Advanced Trolleybus Cost-Benefit Analysis
TR-109945
Target: Public Transportation Systems
EPRI Project Manager: L. Sandell

Analysis of Control Interactions on FACTS-Assisted Power Systems
TR-109969
Target: Substations
EPRI Project Manager: A. Edris

Ultrasonic Chemistry: A Survey and Energy Assessment
TR-109974
Targets: Natural Gas, Petroleum, and Chemicals Industries; Strategic Science and Technology
EPRI Project Manager: A. Amarnath

Protecting Electrical Equipment From Red Imported Fire Ants
TR-109987
Target: Distribution System
EPRI Project Manager: H. Ng

Demonstration of Electric Bus Operations in the United Kingdom
TR-110037
Target: Infrastructure Deployment and EV Benefits
EPRI Project Manager: G. Purcell

Framework for Stochastic Reliability of Bulk Power System
TR-110048
Target: Grid Operations and Planning
EPRI Project Manager: R. Adapa

Capacitor Bank Series Group Shorting (CAPS) Design Study
TR-110273
Target: Substations
EPRI Project Manager: A. Edris

Compressed Natural Gas (CNG) Vehicle Infrastructure Opportunity Assessment
TR-110300
Target: Infrastructure Deployment and EV Benefits
EPRI Project Manager: L. Sandell

Power Quality for Distribution Planning
TR-110346
Target: Power Quality
EPRI Project Manager: A. Sundaram

The Chiller's Role Within a Utility's Marketing Strategy: Using Chiller-Related Products and Services to Win and Retain Customers
TR-110373
Target: Commercial Building Chillers
EPRI Project Manager: W. Krill

Life Evaluation of Direct-Buried, In-Service Cables: In-Service Cable Testing
TR-110374
Target: Underground Distribution Infrastructure
EPRI Project Manager: B. Bernstein

Dual-Bridge Inverters: A New Approach to Bearing Currents and Conducted EMI
TR-110378
Target: New Electric Motor/Drive Markets and Solutions
EPRI Project Manager: B. Banerjee

Advanced Power Supplies: Scoping Study and Technology Assessment
TR-110405
Target: New Electric Motor/Drive Markets and Solutions
EPRI Project Manager: B. Banerjee

National Electric Vehicle Infrastructure Working Council: Committee Meeting Minutes #98-1
TR-110544
Target: Infrastructure Deployment and EV Benefits
EPRI Project Manager: L. Sandell

Thyristor-Controlled Series Compensation (TCSC) Impedance and Linearized Models for Power Swing and Torsional Analysis
TR-110553
Target: Grid Operations and Planning
EPRI Project Manager: R. Adapa

Acceptance Testing for Battery-Electric Bus Procurements: Planning, Inspection, and Testing Guidelines
TR-110615
Target: Public Transportation Systems
EPRI Project Manager: L. Sandell

LPDW™ 4.1: Lightning Protection Design Workstation
Version 4.1 (Windows 95/NT)
Targets: Overhead Transmission; Distribution System
EPRI Project Manager: V. Longo

Environment

Oil Combustion By-Products: Chemical Characteristics, Management Practices, and Groundwater Effects
TR-108014
Target: Combustion Wastes and Groundwater Protection
EPRI Project Manager: I. Murarka

Literature Review: Asphalt Batching of MGP Tar–Containing Soil
TR-108597
Target: Combustion Wastes and Groundwater Protection
EPRI Project Manager: I. Murarka

Evaluation of Flue Gas Mercury Speciation Methods
TR-108988
Target: Plant Multimedia Toxics Characterization
EPRI Project Manager: B. Nott

Developing and Implementing a Company-Wide Waste Accounting System at Public Service Electric and Gas
TR-109203
Target: Environmental Asset Management
EPRI Project Manager: M. McLearn

Analyzing Health Risks Due to Trace Substance Emissions From Utility Fossil-Fired Plants
TR-109206
Target: Air Toxics Health and Risk Assessment
EPRI Project Manager: L. Levin

Evaluation of the Possible Copromoting Effect of a 60-Hz Magnetic Field During Chemically Induced Carcinogenesis in Skin of SENCAR Mice
TR-109471
Target: EMF Health Assessment
EPRI Project Manager: R. Kavet

Real-Time Studies on the Calcium Response of Cells to Low-Level, Extremely Low Frequency Electric Field Exposure
TR-109488
Targets: EMF Health Assessment; Strategic Science and Technology
EPRI Project Manager: C. Rafferty

Effects of Electromagnetic Field Stimulation on Cellular Signal Transduction Mechanisms: Analyses of the Effects of Low-Frequency EMF on Calcium Spiking in ROS 17/2.8 Cells
TR-109489
Targets: EMF Health Assessment; Strategic Science and Technology
EPRI Project Manager: C. Rafferty

Accounting for Location and Timing in NO_x Emission Trading Programs
TR-109515
Target: Tropospheric Ozone and Precursors
EPRI Project Manager: G. Hester

Land Application Uses for Dry Flue Gas Desulfurization By-Products: Phase 2
TR-109652
Target: Combustion Wastes and Groundwater Protection
EPRI Project Manager: I. Murarka

Modification of the EPRI CompMech Trout Model for Larger Rivers
TR-109665
Target: Assessment Tools for Clean Water Act and Impoundment Issues
EPRI Project Manager: D. Dixon

Program on Compensatory Mechanisms in Fish Populations (CompMech): User's Guide to the Key Species Models
TR-109714
Target: Assessment Tools for Clean Water Act and Impoundment Issues
EPRI Project Manager: D. Dixon

Nitrogen Oxides Transport From La Cygne Station, Kansas: A Study for Assessing Its Influence on Urban Ozone
TR-109800
Target: Tropospheric Ozone and Precursors
EPRI Project Managers: P. Mueller, C. Hakkarinen

Natural Gas Environmental Research and Development: A Market Analysis
TR-109895
Targets: All Environment targets; Strategic Science and Technology
EPRI Project Manager: V. Evans

Evaluation of In Situ Remedial Technolgies for Sites Contaminated With Hydrocarbons
TR-110230
Target: Combustion Wastes and Groundwater Protection
EPRI Project Managers: I. Murarka, A. Jain

RAMAS® Ecotoxicology Version 1.0a User's Manual, Vols. 1–2
CM-110332
Targets: Water Toxics Assessment; Assessment Tools for Clean Water Act and Impoundment Issues
EPRI Project Manager: R. Goldstein

PCDDs and PCDFs in Coal Combustion By-Products
TR-110399
Target: Combustion Wastes and Groundwater Protection
EPRI Project Manager: I. Murarka

EPRICSG

Low-Cost NIALMS Technology: Technical Assessment
TR-108918-V2
Target: Information and Energy Management Services for Mass Markets
EPRI Project Manager: S. Drenker

Market Tracking: Assessing Sources and Access to Appliance Sales Data
TR-108928
Target: Understanding Energy Markets
EPRI Project Manager: R. Gillman

The Retail Market: An Introduction to Business Characteristics, Energy-Use Patterns, and Decision Criteria
TR-109021
Target: Understanding Energy Markets
EPRI Project Manager: R. Gillman

The Education Market: Energy-Use Characteristics and Opportunities
TR-109141
Target: Understanding Energy Markets
EPRI Project Manager: R. Gillman

The Small and Medium Business Market: An Investigation of Attitudes and Loyalty Toward Electric Providers
TR-109144
Target: Understanding Energy Markets
EPRI Project Manager: R. Gillman

Buildings With Multiple Businesses: An Introduction to Business Characteristics, Energy-Use Patterns, and Decision Criteria
TR-109207-V1
Target: Understanding Energy Markets
EPRI Project Manager: R. Gillman

Customer Choice: A Framework for Leveraging Loyalty
TR-109242
Target: Understanding Energy Markets
EPRI Project Manager: R. Gillman

An Assessment of the Residential Remodeling Market
TR-109491
Target: Understanding Energy Markets
EPRI Project Manager: R. Gillman

Automation Support for Critical Portable/Mobile Business Processes in Utilities
TR-109498
Target: Wireless Applications and Services
EPRI Project Manager: S. Drenker

K–12 Education Sector Desk Reference
TR-109941
Target: Education/Public Facilities Solutions
EPRI Project Manager: K. Johnson

EPRIGEN

Operations and Maintenance Workstation: Interface Tool to Plant Operations and Maintenance Data
TR-109729-V1–V2
Target: Plant Maintenance Optimization
EPRI Project Manager: R. Pflasterer

Strategic Science and Technology

Status of Weld Repair Technology for Nickel-Based Superalloy Gas Turbine Blading
TR-108272
Target: Strategic Science and Technology
EPRI Project Manager: V. Viswanathan

Intelligent Unified Control of Unit Commitment and Generation Allocation
TR-108318
Target: Strategic Science and Technology
EPRI Project Manager: R. Adapa

Real-Time Studies on the Calcium Response of Cells to Low-Level, Extremely Low Frequency Electric Field Exposure
TR-109488 (see listing under Environment)

Effects of Electromagnetic Field Stimulation on Cellular Signal Transduction Mechanisms: Analyses of the Effects of Low-Frequency EMF on Calcium Spiking in ROS 17/2.8 Cells
TR-109489 (see listing under Environment)

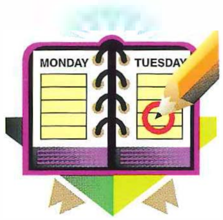
Laser Chemistry: A Survey and Energy Assessment
TR-109510
Target: Strategic Science and Technology
EPRI Project Manager: A. Amarnath

Development of Advanced Flow-Through External Pressure-Balanced Reference Electrode for Temperatures up to 400°C
TR-109577
Target: Strategic Science and Technology
EPRI Project Managers: B. Syrett, B. Dooley

Natural Gas Environmental Research and Development: A Market Analysis
TR-109895 (see listing under Environment)

Ultrasonic Chemistry: A Survey and Energy Assessment
TR-109974 (see listing under Energy Delivery and Utilization)

Laser Welding Survey for Power Generation Industry
TR-110355
Target: Strategic Science and Technology
EPRI Project Manager: V. Viswanathan



EPRI Events

September

1–3
1998 PWR Plant Chemistry Meeting
Huntington Beach, California
Contact: Barbara James, (707) 829-3500

3
Transformer Monitoring System Workshop
Chicago, Illinois
Contact: Peggy Amann, (650) 855-2259

8–9
Phased-Array Inspection Seminar
Portland, Maine
Contact: Susan Otto-Rodgers, (704) 547-6072

9–11
Cranes Component Working Group Meeting
Charlotte, North Carolina
Contact: Brent Lancaster, (704) 547-6017

9–11
Reactor Coolant Pump Workshop
Portland, Oregon
Contact: Linda Suddreth, (704) 547-6061

14–15
2d Annual Power Switching Safety and Reliability Conference
Chattanooga, Tennessee
Contact: Arthur Beare, (410) 740-1560

14–18
Cyclone Boiler Unit Operations
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

15–17
Predictive Maintenance Program
Long Beach, California
Contact: Esther Blanco, (562) 493-7741

15–18
Basic Vibration Testing and Analysis
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

16–18
Constructing and Using Forward Price Curves
Orlando, Florida
Contact: Vic Niemeyer, (650) 855-2744

17–18
2d Gas-Electric Partnership Symposium
Houston, Texas
Contact: Lynn Stone, (972) 556-6529

20–24
ASHES (American Society for Healthcare Environmental Services) Annual Conference
New Orleans, Louisiana
Contact: Kelly Ciprian, (614) 855-1390

21–23
1998 Heat Rate Improvement Conference
Baltimore, Maryland
Contact: Megan Boyd, (650) 855-7919

21–25
Infrared Thermography: Level 2
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

22–23
Operational Reactor Safety Engineering and Review Group
Baltimore, Maryland
Contact: Cindy Layman, (650) 855-8763

22–24
Technical Workshop on Clean Water Act: Section 316(b) Issues
Berkeley Springs, West Virginia
Contact: Cindy Layman, (650) 855-8763

22–24
Underground Transmission Technical Review
Annapolis, Maryland
Contact: Kathleen Lyons, (650) 855-2656

22–25
Air-Operated Control Valves: Advanced Level
Logan, Utah
Contact: Edie McFall, (800) 745-9982

23
New Electric Motor/Drive Markets and Solutions
Tempe, Arizona
Contact: Teri De Breau, (650) 855-2833

24–25
ProfitManager Software Training and Users Workshop
Dallas, Texas
Contact: Lynn Stone, (972) 556-6529

28–Oct. 2
Boiler Operating Theory Fundamentals
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

29
Adjustable-Speed Drive Master Training Course
Green Bay, Wisconsin
Contact: Teresa Boykin, (800) 982-9294

29–Oct. 1
Fluid-Film Bearing Diagnostics
Long Beach, California
Contact: Esther Blanco, (562) 493-7741

29–Oct. 2
Protective Coatings
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

29–Oct. 2
Small Diesels Component Working Group Meeting
Charlotte, North Carolina
Contact: Brent Lancaster, (704) 547-6017

October

1
Adjustable-Speed Drive Master Training Course
Lakewood, Ohio
Contact: Teresa Boykin, (800) 982-9294

4–7
1998 Gasification Technologies Conference
San Francisco, California
Contact: Michele Samoulides, (650) 855-2127

5–6
Power Quality Opportunities in a Changing End-Use Market
Knoxville, Tennessee
Contact: Martha Powers, (423) 974-8288

5–9
Turbine Operating Theory Fundamentals
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

6
Adjustable-Speed Drive Master Training Course
Steven's Point, Wisconsin
Contact: Teresa Boykin, (800) 982-9294

6
End-Use Power Quality Mitigation Systems
Phoenix, Arizona
Contact: Teri De Breau, (650) 855-2833

6–9
Hydrogenerator Maintenance Course
Sacramento, California
Contact: Karen Goodeve, (416) 620-5600

7–9
Substation and Switchyard Predictive Maintenance
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

8
Aging of Distribution Nonceramic Insulators
Tempe, Arizona
Contact: Andrea Duerr, (650) 855-2719

8–9
Lightning Protection Workshop
Gainesville, Florida
Contact: Ralph Bernstein, (650) 855-2023

11–15
Managing the Market Research Process
Dallas, Texas
Contact: Clay Bellew, (800) 766-3774

11–15
Understanding Energy Markets
Dallas, Texas
Contact: Clay Bellew, (800) 766-3774

12–16
Generator Operating Theory Fundamentals
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

13–14
Nuclear Plant Preventive Maintenance Basis Workshop
Charlotte, North Carolina
Contact: Brent Lancaster, (704) 547-6017

13–15
ASM Heat Treat for Metals
Rosemont, Illinois
Contact: John Galatis, (800) 336-5152

14–16
Rolling-Element Bearings: Life Improvements
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

15–16
EPRI Healthcare Conference
Miami, Florida
Contact: Kelly Ciprian, (614) 855-1390

15–16
EPRI Partnership for Industrial Competitiveness
Charlotte, North Carolina
Contact: Bill Smith, (650) 855-2415

19
Water and Energy Conference
New York City, New York
Contact: Kim Shilling, (314) 935-8590

19–20
Chemical and Petroleum Industry Electrotechnologies Workshop
Houston, Texas
Contact: Lynn Stone, (972) 556-6529

19–21
Advanced Power Quality Workshop
Knoxville, Tennessee
Contact: Martha Powers, (423) 974-8288

19–23
Drum Boiler Unit Operations
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

20–23
Pressure Relief Valve Applications, Maintenance, and Testing
Long Beach, California
Contact: Esther Blanco, (562) 493-7741

21–23
Distributed Resources Conference
Milwaukee, Wisconsin
Contact: Cindy Layman, (650) 855-8763

22–23
HELM Software Training Workshop
Dallas, Texas
Contact: Paige Schaefer, (800) 298-0081

24–27
1998 Indoor Air Quality and Energy Conference
New Orleans, Louisiana
Contact: Mort Blatt, (650) 855-2457

26–28
Air-Operated Control Valve Applications, Maintenance, and Diagnostics
Long Beach, California
Contact: Esther Blanco, (562) 493-7741

26–30
Simulator Instructor Techniques
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

27–30
Maintenance and Repair of Heat Exchange Equipment
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

November

1–4
Annual International Ground-Source Heat Pump Conference
Chicago, Illinois
Contact: Shelly Fitzpatrick, (800) 626-4747

1–4
Making Money in Risky Markets: Power Trading, Transmission, and Retail Prices
Washington, D.C.
Contact: Michele Samoulides, (650) 855-2127

2
Business Opportunities for Power Quality Programs
Corpus Christi, Texas
Contact: Marsha Grossman, (650) 855-2899

2–6
Infrared Thermography: Level 2
Long Beach, California
Contact: Esther Blanco, (562) 493-7741

2–6
Supercritical Boiler Unit Operations
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

3–4
Power Quality Interest Group Meeting
Corpus Christi, Texas
Contact: Marsha Grossman, (650) 855-2899

3–5
Steam Turbine Performance Monitoring and Diagnostics Course
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

4–5
Lightning Protection Design Workstation 4.1 and 5.0b
Dallas, Texas
Contact: Lynn Stone, (972) 556-6529

8–11
Fuel Supply Seminar
Cleveland, Ohio
Contact: Megan Boyd, (650) 855-7919

9–11
PQA '98: Southern Hemisphere
Cape Town, South Africa
Contact: Marsha Grossman, (650) 855-2899

9–13
Simulator Instructor Station Operations
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

11–13
Root-Cause Analysis
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

16–18
Advanced Power Quality Workshop
Knoxville, Tennessee
Contact: Martha Powers, (423) 974-8288

16–18
Biodiversity
Savannah, Georgia
Contact: Melita Guellert, (650) 855-2010

16–20
Simulator Instructor Techniques
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

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