The Future of Power Delivery
A Technology Roadmap

EPRI JOURNAL
SUMMER 1999

Greenhouse Gas Leak Detection
The GasView Camera for SF_6

Merchant Power

About EPRI

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

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COVER: The dozens of merchant power plants expected to pop up over the next few years will sharply increase wholesale price competition in several regions of the United States. (Illustration by Doug Buchman/The Big Pixel)

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EDITORIAL

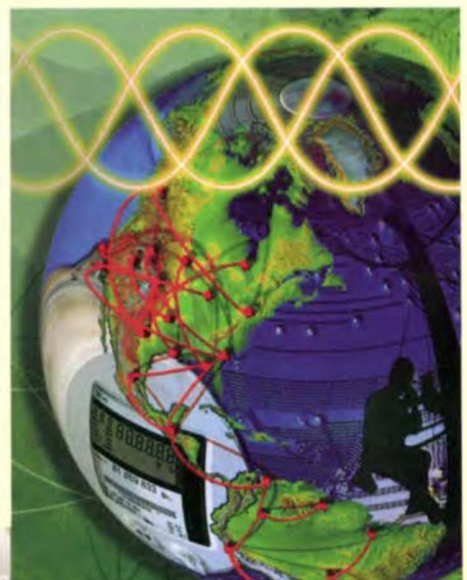
COVER STORY

Built on speculation to compete aggressively in wholesale electricity markets, merchant power plants will define the open-market dynamics of an increasingly deregulated industry.

8 Merchant plants

FEATURES

EPRI's Electricity Technology Roadmap outlines the electricity-related innovation that will be needed over the next 50 years. The roadmap's pathway to the future begins with one of the most fundamental of electric utility functions: power delivery.



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A new laser-based infrared camera system can detect and display on video even pinhole leaks of sulfur hexafluoride switchgear insulation gas.

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Editorial

Electric Transportation: Growing an Industry

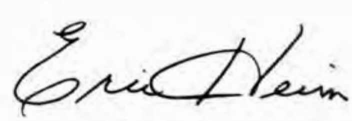
As energy providers, we have played a role in both the creation and the cleanup of air emissions. While overall air quality in the United States has improved, many cities around the globe are still shrouded in a thick brown haze, and the U.S. Environmental Protection Agency still classifies 24 American cities or regions as serious, severe, or extreme air quality nonattainment zones. We continue to make progress in reducing emissions from stationary sources, but much of the problem, especially in urban centers, comes from cars, trucks, and other moving machinery—sources outside the traditional utility purview.

A number of forward-looking power companies have incorporated electric transportation ventures into their business planning, a move that makes both environmental and business sense. Of all the technologies envisioned for the next 50 years, successfully commercialized electricity-powered vehicles promise to deliver the single most effective environmental improvement and the largest new market for electricity. Advanced transportation options offer important public benefits in addition to improved air quality. Electricity-powered vehicles are two to three times more energy efficient than their internal combustion counterparts. And given that transportation accounts for more than 65% of U.S. oil consumption and that more than half the oil consumed in the country is imported, a transition to electric transportation will increase national energy security. The transportation market offers tremendous potential that we are only beginning to tap.

Around the globe, companies large and small are joining the race to develop and commercialize the technology and fuel that will replace the gasoline engine. EPRI has been closely involved in this effort for the past 20 years, pushing the envelope in early electric vehicle design, EV drive systems, and fleet applications and, more recently, promoting the development of advanced batteries and charging infrastructures. Most of this work has focused on "pure," battery-powered EVs—the only technology platform that appeared capable of achieving the envisioned goal of zero emissions.

But as consumer and industrial markets come to be defined more by the services provided than by the technologies used to provide them, a broader platform mix is likely for the future. Just as today's television options include broadcast, cable, satellite, and soon even Internet-based viewing, advanced transportation technology will probably be a mix of battery-only EVs, hybrid vehicles, and fuel-cell-powered cars. These options could be competing aggressively in the personal transportation market by the year 2020. Which technology platform will be of most interest to power companies will depend on their individual business plans and core services. Electricity providers will look forward to the success of battery-powered EVs and battery-dominated hybrids. Vehicles fueled by compressed natural gas will appeal to a new generation of utilities set to provide both power and natural gas in an emerging "Btu business sector." And a number of utilities have already entered into alliances and joint ventures with fuel cell manufacturers to hedge their bets with both stationary and mobile distributed power systems.

The advanced automotive business is essentially a new market for all players—a market so huge that all players have an opportunity to profit from its development. Beyond the personal vehicle market is a world of opportunity in industrial equipment, specialty vehicles, and public transit. EPRI, by collaborating with its members, automotive and industrial equipment manufacturers, component manufacturers, academic and research entities, and government, can strengthen collective resources and help develop a more cohesive approach to the future transportation challenge. Now is the time to take advantage of EPRI's work and carve out a place in this rapidly changing market. To delay is to risk losing the opportunity; and the benefits—new revenue streams, greater efficiency, and a substantially cleaner environment—are worth the effort.



Eric Heim
Area Manager, Transportation

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BRENT BARKER is manager of strategic and executive communications. Earlier he served for 12 years as editor-in-chief of the *EPRI Journal*. Before joining EPRI in 1977, Barker spent four years as a private communications consultant and as an analyst for URSA, an economics consulting firm. Earlier he worked as an industrial economist and staff author at SRI International and as a commercial research analyst at USX Corporation. He graduated in engineering science from Johns Hopkins University and earned an MBA at the University of Pittsburgh.

Seeing SF_6 in a New Light (page 26) was written by Taylor Moore, *Journal* senior feature writer, with assistance from Ben Damsky and Ken Loynes.

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KEN LOYNES, a project manager at the Energy Delivery and Utilization Center in Lenox, Massachusetts, joined EPRI in 1998 after three years as a project manager for J. A. Jones Power Delivery at the center. Before that, he was employed by General Electric as a technical specialist. Loynes received an associate's degree in electrical technology from Berkshire Community College in Pittsfield, Massachusetts.

Products

Deliverables now available to EPRI members and customers

F30 Feeder Management Relay

UCA-Compliant Distribution Automation

The first distribution automation products to use EPRI's Utility Communications Architecture are now available from GE Power Management. An ensemble of open protocols and standards, UCA™ enables the interoperability of equipment from different manufacturers and the interconnectivity of databases for high-speed, real-time data exchanges. To date, GE has released two UCA-compliant digital relays. The F30 Feeder Management Relay provides power metering and feeder protection against current and voltage faults. The L90 Line Differential Relay, part of a complete substation system, provides protection for transmission lines of any voltage level. The interoperability provided by the relays promises to significantly reduce automation system integration costs for utilities. GE expects to add five more UCA-compliant relay products to its line this year.

- *For more information about UCA, contact EPRI's UCA Exchange Office, (800) 822-3924 (UCA-EXCH). For more information about the relay products, visit GE Power Management's Web site (www.ge.com/edc/pm).*

MYGRT 3.0

The MYGRT™ software enables utility managers to conveniently, quickly, and inexpensively estimate the possible effects of waste disposal sites or spills on the local groundwater. With Version 3.0, managers can predict the downgradient distribution of organic and inorganic solutes in unsaturated, saturated, and partially saturated zones. Modeled processes include advection, dispersion, retardation, and decay. In addition, the software can simulate problems in one, two, or three dimensions, using either horizontal or vertical views. Designed to run on Microsoft Windows 95 or Microsoft NT 4.0, MYGRT 3.0 features enhanced mathematical routines and is Y2K compliant.

- *For more information, contact Adda Quinn, aquinn@epri.com, (650) 855-2478. To order, call EPRI Customer Service, (800) 313-3774.*

Defrost Controller

Defrosting is one of the most energy-intensive processes in supermarket refrigeration systems, but a new smart controller for timing defrost cycles can cut energy use. The digital controller—available from Johnson Controls/Encore—has yielded large energy savings in supermarket field tests on both electric and hot-gas defrost systems. In smart, or on-demand, defrosting, a defrost cycle is started only when required. Using a proprietary EPRI algorithm (now being patented), the controller analyzes past defrost patterns for each refrigerated case to predict when the next cycle is needed. The algorithm is available as a software addition to the control system. A stand-alone version of the controller, scheduled for introduction this year, is expected to replace the mechanical timer controls used in most of today's supermarkets.

■ *For more information, contact Mukesh Khattar, mkhattar@epri.com, (650) 855-2699. To order, contact Jim Hindmond at Johnson Controls/Encore, (770) 427-9808.*

Supermarket Simulation Tool

Conventional software for simulating hourly building energy use is not well suited for application to supermarkets, which have unusually complex, energy-intensive electrical and mechanical systems. Thus it has been difficult to estimate the impact of more-efficient technologies in this sector. In response, EPRI developed the Supermarket Simulation Tool, which models the complex hour-by-hour interactions of supermarket refrigeration, HVAC, and building envelope systems. Now available in Version 2.0 for Microsoft Windows 95, the SST software greatly increases engineers' ability to select the most effective electrical and mechanical systems. Incorporating information from EPRI's extensive field-testing and analysis work, SST 2.0 allows users to quickly assemble a supermarket model from a library of standard components and evaluate a wide array of technologies.

■ *For more information, contact Mukesh Khattar, mkhattar@epri.com, (650) 855-2699. To order, call EPRI Customer Service, (800) 313-3774.*

ChemExpert

ChemExpert is an on-line expert advisor that delivers real-time information and analytical capabilities for optimizing water-steam chemistry at fossil-fired steam power plants. Developed in coordination with more than 20 energy companies worldwide, ChemExpert synthesizes the technical knowledge and hands-on experience of EPRI's operating guidelines and field-proven cycle chemistry improvement and training programs. Easily customized to any drum or once-through unit operating on any chemistry, ChemExpert can continuously monitor conditions throughout water-steam cycles to detect and diagnose problems, recommend corrective actions, and ensure that normal operations have been restored. The software is commercially available, and a users group is planned.

■ *For more information, contact Barry Dooley, bdooley@epri.com, (650) 855-2458. To order, call EPRI Customer Service, (800) 313-3774.*

Project Startups

New ventures of importance to power and service providers

Helping Coal Plants Respond to Mercury Directive

Utilities that operate coal-fired power plants and other interested companies are invited to participate in a collaborative EPRI project to promote the best sampling and analytical techniques for responding to the U.S. Environmental Protection Agency's Mercury Information Collection Request. The ICR requires all coal-fired power plants to analyze their feed coal for mercury and chlorine. In addition, 84 selected plants must analyze their flue gas for mercury compounds. Because these data will be used in making a regulatory determination on mercury around the end of the year 2000, it is important for the power industry to provide the most accurate data possible.

EPRI has developed a summary of good sampling practices and the various sample preparation and analytical techniques that laboratories currently use to quantify the levels of mercury and chlorine in coal. "The mercury content of coal is very low—less than 1 part per million—and choosing the laboratory to perform an analysis is critical to the accuracy of the results," says Paul Chu, the EPRI project manager. "EPRI's current push is a round-robin study to assess the performance of various laboratories and the different analytical methods they employ. This will provide useful details on precision, accuracy, and variability."

The round-robin study will consist of two testing phases. The first phase—screening of the various labs and methods—has already begun. In the second, more detailed phase, each lab will perform multiple analyses on about eight coal samples. The results will be used to determine both intra- and interlaboratory variability. In addition, the EPRI coal samples will be made available to Mercury ICR participants for use in auditing the performance of their chosen labs.

For those plants selected by the EPA for stack testing, EPRI has developed a generic test plan that plant operators can tailor to their sites before submission to the agency. Alternatively, EPRI can develop the plan and conduct the stack testing for a plant. EPRI has contracted with two leading stack-testing firms to help participants create a site-specific plan, perform sample collection and lab analysis, and prepare the final report for submission to the EPA.

EPRI will review coal and stack data as they are reported. Winston Chow, environment product line manager, notes that the development of accurate data in this study is important to all coal-fired plants because of the regulatory implications. EPRI is therefore opening project participation to nonmembers, consultants, and other interested parties. International facilities and firms with an interest in mercury may also participate.

■ *For more information, contact Paul Chu, pchu@epri.com, (650) 855-2812.*

Fuel Cell Venture Launched

EPRI and the Gas Research Institute (GRI) are pursuing the commercialization of advanced planar solid oxide fuel cells (SOFCs) for decentralized power systems through a consortium formed with the University of Utah and Materials and Systems Research, Inc., both of Salt Lake City. MSRI has been awarded a $3 million grant by the National Institute of Standards and Technology's Advanced Technology Program to develop planar SOFCs.

The consortium members, who will pool the intellectual property they have developed individually, plan to introduce a precommercial demonstration advanced planar SOFC unit within three to four years. The group is seeking key manufacturing and end-use partners to help commercialize the technology.

GRI and EPRI have sponsored planar SOFC development under Anil Virkar at the University of Utah for more than four years. In the technology developed there, a thin-electrolyte, thick-electrode design enables SOFCs to operate reliably at 600–800°C and use low-cost, metallic materials for cell interconnections. Recent developments have been especially encouraging. Extremely high, state-of-the-art power densities (over 2 W/cm^2) have been achieved in single cells at 800°C, and the densities achieved in small stacks of metal-interconnected cells are increasing rapidly.

Dan Rastler, who manages EPRI's distributed resources programs, and Kevin Krist, GRI's principal technology manager for energy conversion—while acknowledging that a commercial product is still several years away—note the importance of high power density in reducing the cost of fuel cell technology.

The planar SOFCs developed by the University of Utah and MSRI can be manufactured at much lower cost than current technology. The consortium believes the new technology can achieve a total system cost of less than $700/kW, even in small production volumes and for small-size units.

SOFCs have extremely high fuel-to-electricity conversion efficiencies (47–65%). Since they operate at high temperatures, they have less difficulty using natural gas fuel directly than other types of fuel cells—thus eliminating the need for costly fuel processing systems. They can be packaged in a wide variety of energy systems, including residential furnaces and appliances and on-site energy and power systems for commercial and small industrial markets.

While polymer electrolyte membrane fuel cell technology figures prominently in developments in the transportation sector, advanced SOFCs may leapfrog that technology through the introduction of very high efficiency distributed power systems that combine heat and power services to the stationary market. EPRI is planning further advanced SOFC product development work and is seeking strategic partners for a private EPRIGEN collaboration to build on the consortium's work.

"We are extremely excited about our alliance with GRI. It combines the leadership skills of both organizations," says Kurt Yeager, EPRI's president and CEO. "Fuel cells have been a part of EPRI's research program for the past 25 years, and both GRI and EPRI have been leaders in advancing solid oxide fuel cells."

Steve Ban, GRI's president and CEO, calls the collaboration with EPRI "an excellent example of how our organizations plan to pool key science and technology resources to jointly commercialize new products that provide a least-cost option to serve our customers better." The Chicago-based GRI manages R&D programs for its 335 members and the natural gas industry.

■ *For more information, contact Dan Rastler, drastler@epri.com, (650) 855-2521.*

Utilities Field-Test Microturbines at Customer Sites

Some 20 utilities are participating with EPRI in a collaborative field evaluation program for microturbines installed at commercial customer sites. Beta-series prototypes from the five microturbine manufacturers that have products for testing are being installed as they become available. Microturbines with generating capacities of 30–200 kW are being targeted for commercial establishments requiring backup power, cogeneration, off-grid power, and peak shaving.

Simple machines that have few moving parts, microturbines can be connected to a power grid or operated independently, using natural gas, propane, or other hydrocarbon fuel. Their emissions of nitrogen oxides are expected to be low.

The microturbine manufacturers that have introduced or are expected to introduce beta-series commercial units by the end of this year or early next year are AlliedSignal, Bowman, Capstone, Elliott, and Northern Research and Engineering.

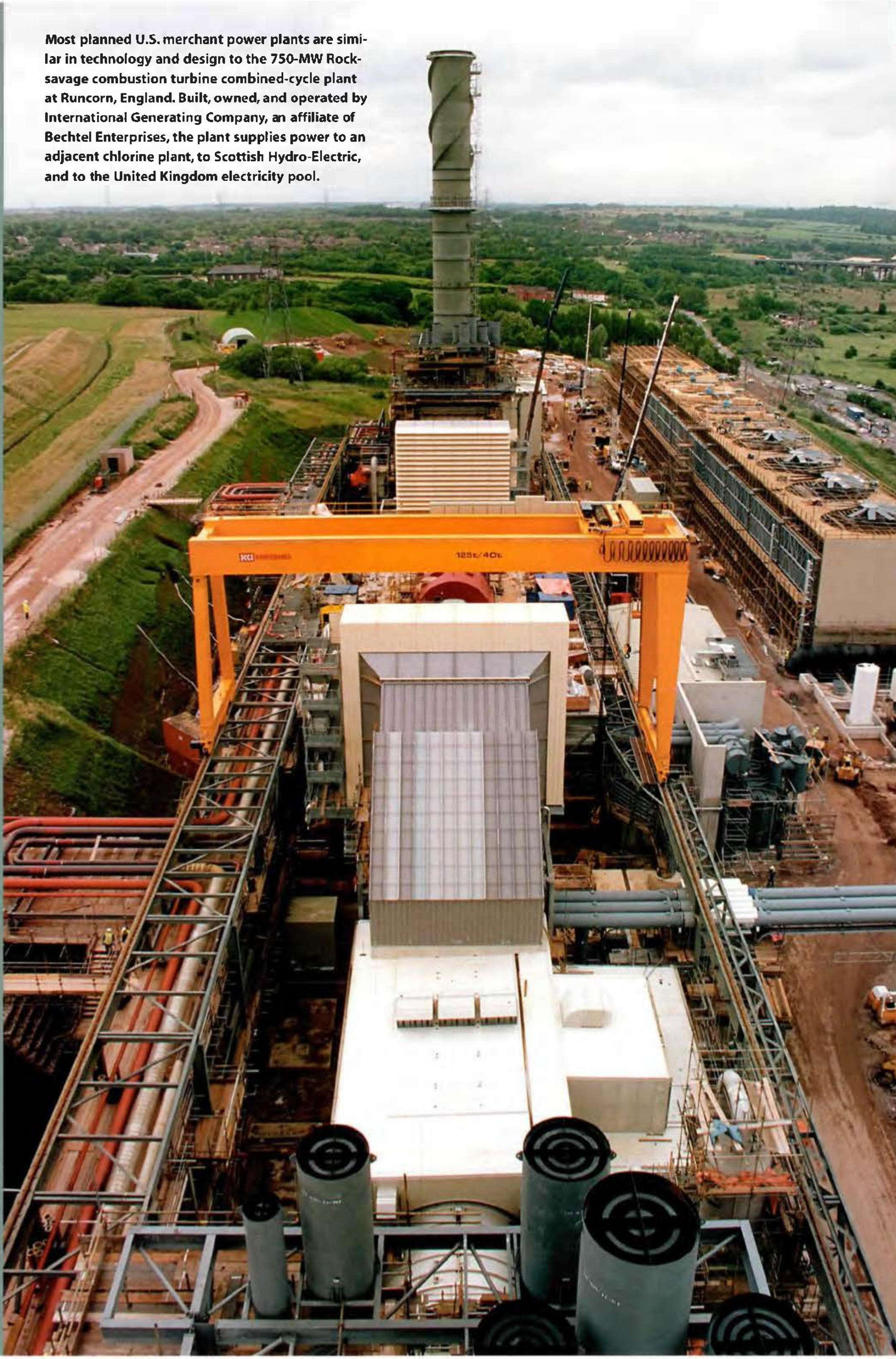
EPRI is leading the evaluation and demonstration program to assess the technical and economic potential of microturbines. The field tests, for which a uniform protocol has been developed, will provide host companies with data on microturbine performance, reliability, and durability. EPRI is focusing on microturbine module installation, grid interconnection, and operation and maintenance. It also manages a microturbine users group.

"Microturbines are poised to take advantage of the opportunities created by the restructuring of the electricity industry. They can be used to reduce costs and enhance service reliability for retail customers," says Doug Herman, EPRI project manager for distributed generation. "This field test and evaluation program will help EPRI and its members assess the potential of microturbines in mass commercial markets."

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

COURTESY EDISON TECHNOLOGY SOLUTIONS

This 45-kW Bowman microturbine was installed for cogeneration at a University of California, Irvine, laboratory. Cosponsoring the project with EPRI are Edison Technology Solutions, DOE, and the California Energy Commission.



Most planned U.S. merchant power plants are similar in technology and design to the 750-MW Rocksavage combustion turbine combined-cycle plant at Runcorn, England. Built, owned, and operated by International Generating Company, an affiliate of Bechtel Enterprises, the plant supplies power to an adjacent chlorine plant, to Scottish Hydro-Electric, and to the United Kingdom electricity pool.

COURTESY BECHTEL CORP.

Merchant Plants Drive Market Competition

THE STORY IN BRIEF The growing demand for electricity and the anticipation of deregulated, competitive power markets are creating business opportunities for a new type of electricity producer. Merchant power plants, built on speculation for competing aggressively in wholesale power markets, are already operating in a few areas, with many more planned in several regions of the United States. The new competitive electricity producers include unregulated subsidiaries of traditional utilities, other established energy companies, and new entrants to the electricity generating business. With the open-market imperative to be cost-competitive from the day of startup, merchant producers must employ every tool available to manage risk across the broad spectrum of planning, design, operations, maintenance, and environmental issues. **by Taylor Moore**

A new breed of generating company has emerged in the increasingly competitive wholesale U.S. electricity market to satisfy growing demand and to profit from regional price differences, just as many traditional, regulated utility generating assets are changing hands. This new breed of generator is known as a merchant power producer. In the purest form, a merchant producer serves only the open market for electricity, forgoing the financial comfort of long-term power supply contracts and their dependable cash flow to pursue potentially greater profits as a nimble, low-cost supplier to the highest bidders.

COURTESY BRIDGEPORT ENERGY

COURTESY PG&E GENERATING

About a dozen merchant power plants are commercially operating in the United States, primarily in New England and Texas, and many more are on the way. This year, Bridgeport Energy expanded its merchant plant in Connecticut—which began operation with two simple-cycle gas turbines—into a 540-MW combined-cycle facility (above). PG&E Generating is building merchant plants in half a dozen states, including the 360-MW gas-fired Millennium Power project (left) in Charlton, Massachusetts, which is expected to go on-line in mid-2000.

Until just a few years ago, merchant power plants were entirely theoretical. Yet they were anticipated by the architects of the deregulated, open competition that is now transforming the $50 billion wholesale electricity business and that is widely expected to spread to the $215 billion retail consumer market early in the next decade. Today about a dozen merchant power plants are in operation from California to New England, and a flood of new merchant generating capacity is on the way. By mid-1998, more than 50 GW of merchant capacity was operating, under construction, or under active development or consideration in the United States. Over half of the projects are expected to be built within the next two years.

The Electric Power Supply Association, the national trade group that represents competitive power producers, reports that these producers have over 4400 active projects (not all merchant plants) totaling more than 93 GW—equal to about 12% of existing U.S. generating capacity. The EPSA also says that competitive power producers have accounted for half of all new generating capacity brought on-line since 1990 and are expected to account for more than half of the new capacity that will go on-line by the end of the decade.

Most new merchant generating capacity under development is gas fired by combustion turbines, usually in combined-cycle configurations for baseload or cycling operation. The low capital cost, short construction time, and fuel efficiency of gas turbines and combined-cycle plants typically make them the generating technologies of choice for merchant producers. These technologies also are ideal for phased deployment: simple-cycle gas turbines can initially serve as merchant peaking or cycling units and then later be converted to combined-cycle operation.

The construction of new capacity at greenfield sites is not the only route being taken by merchant producers. Existing fossil boiler plants—which already have site permits and transmission connections—can be repowered with gas turbines less expensively than new plants can be built. Such repowering can effectively triple the generating capacity and double the efficiency of an existing fossil steam plant for about the same Btu-equivalent of fuel consumption. While this efficiency may still be lower than that of a new plant, the $75–$100/kW capital savings will often make repowering the better competitive option.

Utility industry restructuring is encouraging such conversions by making older plants available for merchant operation. In just the last couple of years, large amounts of fossil capacity that had been part of traditional, regulated rate bases have been divested by utilities in California and Massachusetts as a prerequisite for competitive markets. California's three investor-owned utilities, for example, have sold over 15 GW of generating capacity to other energy companies. Divestments have also been made by utilities in Illinois, New York, and other states in anticipation of joining the trailblazers in market deregulation.

At the same time, the retirement of a significant amount of existing utility generating capacity is adding to the demand for merchant capacity. Nearly half of the approximately 750 GW of installed U.S. generating capacity is more than 25 years old, and most of that will have to be replaced over the next decade and a half. Around the country, generating reserve margins are declining as older, uneconomic fossil capacity and some nuclear capacity is retired.

In the six northeastern states that, after California, are most rapidly opening to competition, more than 20 GW of new merchant capacity is planned or already being built to replace much of the region's aging, fossil-fired capacity. Severe transmission constraints in the Northeast, which make it difficult to import large amounts of power from other regions, contribute to the high electricity prices creating market opportunities for lower-cost, local merchant generation.

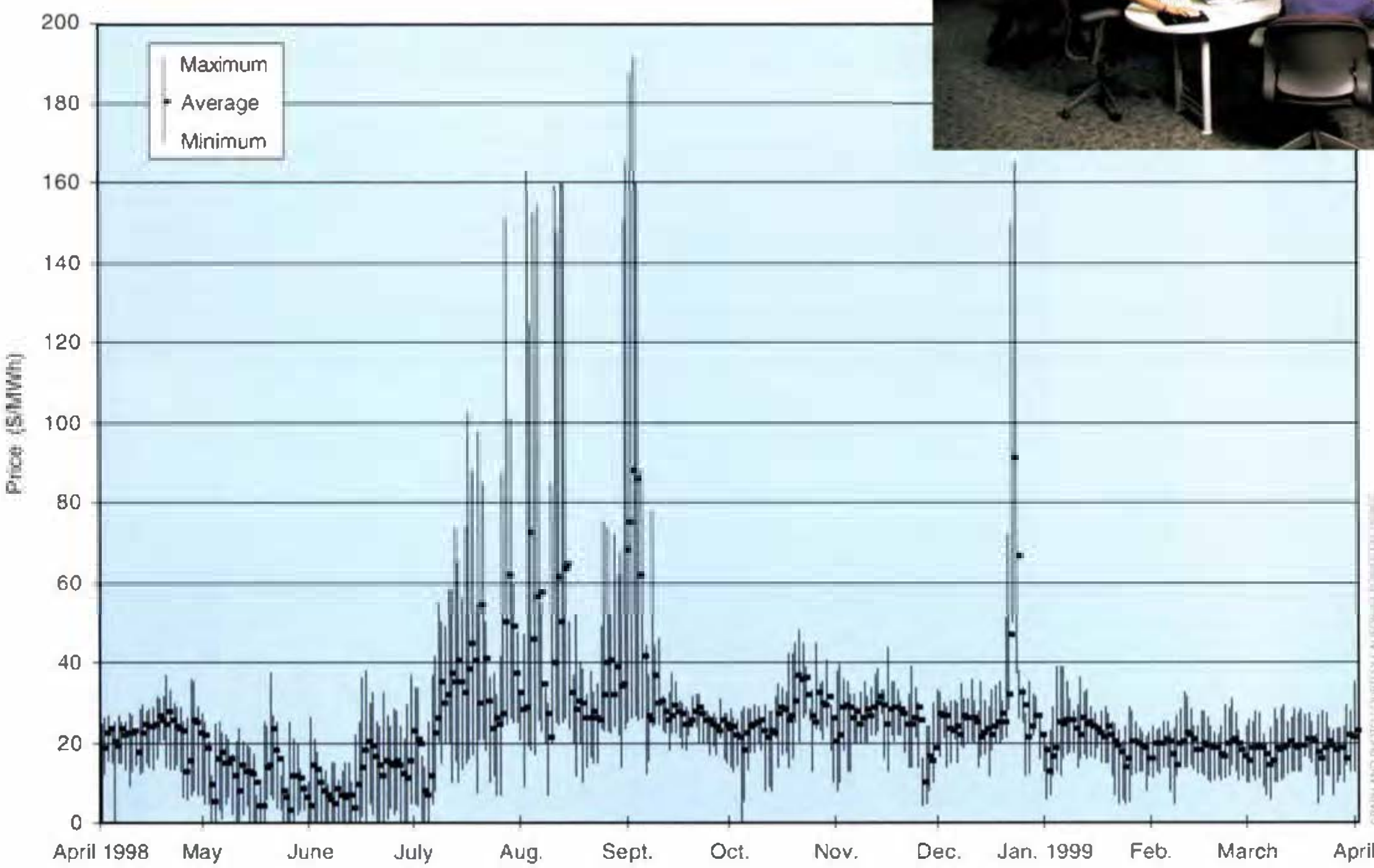
In Texas, some two dozen merchant plants totaling more than 10 GW are being built or are planned over the next two years. The Texas Public Utility Commission says that if only half that capacity is actually completed, it won't be enough to keep up with the statewide load growth of 3.6% a year and maintain the Texas Electric Reliability Council's required capacity reserve margin of 15%.

Meanwhile, proposals for about 8 GW of new merchant generating capacity are expected to be submitted to the California Energy Commission for approval over the next few years.

Assets change hands, new players join

Observers expect that some 80 GW, representing more than 300 plants, will be auctioned or put up for bid around the country over the next few years. Some of these plants, either as currently configured or after being repowered, may be operated as merchant plants.

Potential merchant generating capacity is also created when utilities buy out supply contracts previously made with independent generators, whose output the utilities were required to purchase under the Public Utility Regulatory Policies Act of 1978. (This act spawned the industrial cogeneration and wind power industries.) Utility buyouts of such contracts in New York and New Jersey have freed up some dedicated capacity that is now being dispatched as merchant plants.



The California Power Exchange, which conducts electricity auctions for buyers and sellers, is emblematic of the deregulated open markets for wholesale electricity that are evolving state by state. More than 80% of California's electricity has been traded through CalPX since it opened in March 1998, and the exchange is cited as a reference on daily prices for other markets. As the graph shows, the unconstrained market-clearing price for power varies substantially in response to daily market demand.

The buyers of existing utility generating plants and the developers of new merchant power projects include unregulated, competitive subsidiaries of some of the biggest companies in the electric utility industry. These subsidiaries include Duke Energy North America, CSW Energy, Southern Energy, PG&E Generating, Reliant Energy Power Generation, Edison Mission Energy (a subsidiary of Edison International), and Sempra Energy Resources.

COURTESY GE S&S ENERGY PRODUCTS

Most major oil companies—including BP-Amoco (which has agreed to acquire Atlantic Richfield), Texaco, and Shell—have demonstrated an interest in expanding their role as competitive power producers. Some of them have already set up power generation subsidiaries. (The interested companies all power their refineries with gas turbines and combined-cycle units.)

Other energy companies, such as Enron, Sithe Energies, and the British utilities National Power and Powergen, are major participants in U.S. power markets as merchant plant partners or developers. For example, National Power, through its American National Power subsidiary, holds a stake in half a dozen U.S. power stations and is building an 1100-MW gas turbine combined-cycle plant near Dallas, Texas. The company says it plans to invest $1.6 billion in new U.S. gas-fired power projects over the next three years.

The new competitive subsidiaries of traditional utilities and other energy companies are joined by a growing list of independent competitive power companies, including Calpine, CalEnergy (now MidAmerican Energy Holdings), Constellation Energy, Dynegy, Indeck, Polsky Energy, and Tenaska. Calpine, for one, has announced plans to develop nearly a dozen gas-fired merchant plants totaling 7000 MW in the next six years, with the initial focus on California. Meanwhile, Tenaska's 830-MW combined-cycle Frontier station at Shiro, Texas, is expected to be completed by mid-2000. This site was chosen so that the plant's four generators can be independently dispatched to either the Texas grid or the Eastern grid.

Gas-fired combustion turbines and combined-cycle units are the preferred technologies for merchant power projects because of their low costs, quick construction time, and fuel efficiency. Most plants use heavy-frame industrial combustion turbines with generating capacities of more than 100 MW. But packaged aeroderivative gas turbines—for example, the 47-MW, intercooled LM6000 Sprint system from General Electric's S&S Energy Products—offer similarly high efficiency and reliability in smaller increments of capacity.

COURTESY GE POWER SYSTEMS

COURTESY GE POWER SYSTEMS

Risks sharper for merchant producers

As Howard Mueller, EPRI's manager for corporate strategy, points out, the term *merchant producer* is industry jargon used to distinguish non-price-regulated generating assets from those in existing utility rate bases. The distinction may be important only during the transition period when regional U.S. power markets are deregulated and reorganized for competition. In fully competitive markets, which could emerge within the next seven or eight years, most power plants will be operated outside regulated rate bases as merchant plants.

By definition, merchant power producers are risk takers in a speculative market. In return for the potential for profit that is not limited by regulatory mandate, they shoulder increased, even unique risks: regulatory (siting) and legal risks, project and finance structure risks, power market risks, fuel market risks, and performance and financial viability risks.

In most cases, the risks are similar to those faced by regulated utilities. But for merchant producers, the risks are far more intense because each individual plant must be a low-cost producer—on paper before it is built, the moment it generates its first kilowatthour, and for the next 20 years or more, despite whatever changes may occur in fuel costs or the market price of electricity during the plant's operating life.

In contrast, the economics of a generating plant built under a regulated rate base were fixed for its projected life during the initial rate proceedings. The projected need for additional capacity was of greater concern than the cost of production, and new plants were financed under cost recovery guarantees that allowed decades of amortization, regardless of a plant's operating economics. With costs recovered through the rate base, it was difficult for regulated utilities to lose money.

Merchant power projects have involved a variety of innovative financing structures combining equity, or balance sheet, financing from developers with syndicated debt financing raised in private capital markets. Such deals typically entail extensive, exacting requirements for economic analyses, including projections of electricity forward-price curves, fuel prices, and operating revenue and earnings. Errors in estimating such variables can spell the difference between a project that returns profits to its owners and one that does not.

Location and timing are critical to a project's success. Most merchant project development is centered in states with historically high electricity prices, including California, Connecticut, Massachusetts, New York, and Rhode Island. And much of the new merchant plant development planned for the next few years is timed to coincide with the expected completion of natural gas pipeline expansions under way from Canada into the northeastern and midwestern United States.

Texas, with generally lower energy prices, is home to many industrial plants that take some of the steam or electricity from merchant plants as anchor tenants. With part of a plant's output dedicated under contract, a merchant operator can reduce overall market risk exposure and be more confident of covering some operating costs while still having most of the capacity available to be marketed. It is one way that many merchant producers can hedge uncertainties in electricity generation costs.

Competitive advantages can be gained by early market entrants with merchant plant projects strategically sited near gas pipelines, power transmission corridors, and cooling water supplies. But regulatory problems with a proposed site—for example, involving a plant's projected emissions of nitrogen oxides—can delay a project's completion date and alter its power market risk profile.

Indeed, the risk that market demand for power will be significantly less when a project is completed than when it was announced is acute for merchant producers. Not all competitive power projects that have been announced will come to fruition. The EPSA says that between 37 GW and 47 GW of new competitive power generating capacity (or about half of the new capacity under active development), representing investments of some $60 billion, is projected to come on-line through 2005. Other organizations, including the consulting firm Hagler Bailly, have made substantially higher estimates.

"Power markets in the United States are regional, and each market has distinct capacity-addition requirements through time," Lawrence Makovich, director of research at Cambridge Energy Research Associates, has written (see "Further reading" at the end of this article). "If capacity additions are timed properly, and demand and supply remain in balance, then market-clearing prices are likely to provide investors with their expected returns. However, since investors act independently, the possibility exists that aggregate investor decisions will produce ill-timed and improperly sized supply additions. In particular, investor enthusiasm may cause too many investors to add capacity within a particular regional market. Such an investment boom creates surplus-capacity conditions that cause market-clearing prices to decline."

Makovich noted in particular that almost half of the currently proposed merchant plant projects target the 25-GW New England market, despite the absence there of a significant amount of economically obsolete generating capacity. About 400 MW per year of supply expansion is actually needed to balance demand and supply. "The risk is clear—if all of the planned projects are completed. . . . electric supply in New England would rapidly increase by over one-third and surplus-capacity conditions would depress market-clearing prices," he wrote. "Thus, unless the mortality rate on proposed project development exceeds 90 percent, the New England market is very likely headed toward a price bust and poor investor returns."

Much more than regulated utilities, merchant producers must employ every tool available to manage and contain risks, both on an individual project basis and across their dispersed generating fleets. In addition to risks related to the financial, technical, and market analyses in the front-end development and financing phases of a project, there are risks stemming from the absolute imperative that the complex machines on which a company's revenue and earnings depend achieve the highest levels of reliability, availability, and operating performance. Yet many competitive power producers operate without the large engineering staffs that most regulated utilities have to help mitigate and manage risks; instead these producers rely on suppliers, consultants, and legal counsel.

"The competitive power business is absolutely bottom-line-driven, absolutely focused on profit margins and on growing those margins, and whatever helps producers shape margins is important," says EPRI's Mueller. "Whether it's planning tools, management tools, information management, operating tools, design tools, monitoring tools, environmental management and mitigation tools—there is an entire set of content areas in which they are absolutely driven and have specific needs.

"Competitive producers have to make money in real time and from quarter to quarter. Not only do they have to make money now, but over time they have to improve their rate of making money. As

A Portfolio of Exceptional Value

EPRI offers a comprehensive portfolio of application- and results-oriented R&D targets of potentially enormous value to merchant power producers. The targets can provide immediate returns on investments by damping the business and technology risks of competitive electricity markets.

Turbines and power cycles

Flexibly packaged targets in combustion turbines (CTs) and combined cycles (CCs) leverage the expertise of EPRI scientists and engineers to help merchant producers get the most out of plant investments. And they provide the detailed, objective technical intelligence these producers need to plan, finance, and insure new projects built around advanced and emerging CTs and cycle configurations. Risk mitigation is a central focus of this activity.

A target in design, repowering, and risk mitigation provides industry intelligence on emerging turbine and ancillary equipment designs, as well as on over-the-horizon developments. It enables funders to tap EPRI's practical experience with advanced turbine designs—experience obtained in an ongoing series of durability surveillance projects with machine owners. These intensive monitoring and diagnostics efforts, involving the latest, fleet-leading turbine models, provide a cost-effective means for minimizing risks in startup, commissioning, and operation.

"EPRI can help merchant plant developers determine how aggressive their technology must be to achieve the rate of return needed for a project to be financeable," says John Scheibel. "We've characterized technologies that would perform better as merchant plants. A merchant plant has to be aggressive to make money in the marketplace. Just how aggressive depends on whether you're repowering existing assets or building new capacity that must be competitive for many years down the road. Not having all of a plant's output at risk in the market—say, by getting an anchor tenant for some of the steam or electricity—can also affect a project's aggressiveness."

Enhancements to EPRI's award-winning State-of-the-Art Power Plant (SOAPP™) CT Workstation enable users to make sharper evaluations of advanced cycle alternatives and, in turn, to develop better, lower-risk project proposals. This SOAPP workstation is a proven desktop software product for creating preliminary and conceptual designs of new CT or CTCC projects or for evaluating the economics of a competitor's project. Integrating the latest engineering knowledge with regularly updated equipment cost and performance models, the workstation covers a range of turbines, from industrial aeroderivatives to heavy-frame units. Included are the F-, G-, and H-class advanced high-firing-temperature machines, and as DOE's Advanced Turbine Systems machines under development become available, they will be added to the workstation.

The workstation was formerly available from SEPRIL, a joint venture of EPRI and Sargent & Lundy; EPRI has recently acquired S&L's interest in that venture. The wholly EPRI-owned company will continue to aggressively develop, distribute, and support the SOAPP family of software products. Commercial users of the SOAPP CT Workstation include American Electric Power, BP-Amoco, CSW Energy, Enron Engineering & Construction, Enron Europe, FPL Group, PSEG Global, Sempra Energy Resources, Shell, Texaco, and the Tennessee Valley Authority.

Operation and maintenance

EPRI offers power producers O&M assistance in a variety of areas. Cost-effective solutions are available through the collaborative monitoring of industrywide problems, the sharing of experiences and data, and the development of life management O&M procedures and guidelines. Automated monitoring, trending, and diagnostic software is helping to identify problems with CT thermal efficiency and power out-

put degradation. Retrofit options for increasing the capacity of CTs are being proven in order to make widespread deployment possible.

A target in CT and CC O&M has the products and services that plant owners and operators need to improve profitability and manage risks. By combining worldwide expertise with leveraged funding, EPRI is developing solutions for common technological and operations problems—solutions that most producers could not afford to develop on their own. A central resource for information, expertise, and application services is EPRI's Combustion Turbine Center, which includes an office focusing on turbine blade thermal barrier coatings and another focusing on the analysis of operating-reliability data.

The O&M target develops machine life prediction codes to help operators of specific turbine models evaluate the manufacturers' recommended refurbishment and replacement intervals for hot-gas-path components, extend life on the basis of operating history, and safely plan replacements before failure.

For example, REMLIFE—a predictive maintenance tool—calculates turbine blade and vane life as a function of machine starts and fired hours. Versions for GE Frame 7 and Siemens V84.2/94.2 machines are available, and versions for GE 7FA and 9FA models are being developed. Through one target option, REMLIFE is applied on-line to a plant control system, creating the potential for life-cycle savings of up to $35 million from optimal component replacement scheduling.

Software and guidelines to reduce downtime and the costs of overhauling CTs are a key focus of the O&M target. EPRI's Gas Turbine Overhaul Plan (GTOP) software helps users develop comprehensive plans for various CT models or evaluate third-party overhaul proposals. Turbine manufacturers promote extended parts and service packages as part of equipment sales, but GTOP and the ORAP (Operating Reliability Analysis Package) database can be applied to more cost-effectively manage parts and maintenance in-house. GTOP also includes guidelines and monitoring methods for critical components like compressors.

Risk and asset management

A power markets and risk management target provides methods and tools to help companies make profitable decisions and avoid potentially huge losses. Modern finance theory has been applied to develop option valuation techniques that enable users to better estimate the value and risk of transactions and assets in competitive markets.

The Electricity Book software helps users assess and manage risk across a portfolio of assets or contracts and calculate the value of individual transactions to identify the most profitable opportunities. Other tools are available for estimating forward-price curves and other critical market price data. Ongoing research is exploring methods for profiting from emerging opportunities in the still largely theoretical market for ancillary services—voltage and VAR support, frequency control, and spinning reserve.

For power producers with generation assets that may be candidates for sale or repowering as merchant capacity, asset valuation takes on a new dimension under market competition. At the same time, competition is changing the economics of plant maintenance and investment. The creation of shareholder value has replaced cost recovery as the paramount objective. EPRI's target in generation asset management offers a framework for making an integrated evaluation of a range of issues facing generating companies. The framework lets companies use option valuation techniques to better estimate the value and risk of assets in competitive markets.

Environmental management

EPRI has considerable strength in developing and demonstrating environmental compliance tools, optimizing the management of environmental assets, and providing scientific expertise for responding to regulatory initiatives.

EPRI's databases, models, and software are providing companies with estimated emissions and discharge information for the EPA's new Toxics Release Inventory reporting; EPRI's TRUE model can be used to model emissions from individual plants and calculate human health risk. Other environmental solutions include innovative technologies for reducing nitrogen oxides (NO_x), options for fish protection at cooling intake structures, and alternatives to chlorine and other oxidants for biofouling control.

Environmental operations, typically a cost center, can produce revenue when compliance commitments have exchange value. EPRI has tools for evaluating such emissions trading opportunities. The EA Manager software, for example, helps users assess sulfur dioxide compliance options, including the buying and selling of allowances. Also being developed are tools for NO_x trading in the eastern Ozone Transport Region and effluent trading models that respond to the EPA's interest in watershed-based water quality management. The watershed models will help companies minimize the impact of new requirements and will provide bank-and-trade strategies for effluent and runoff controls.

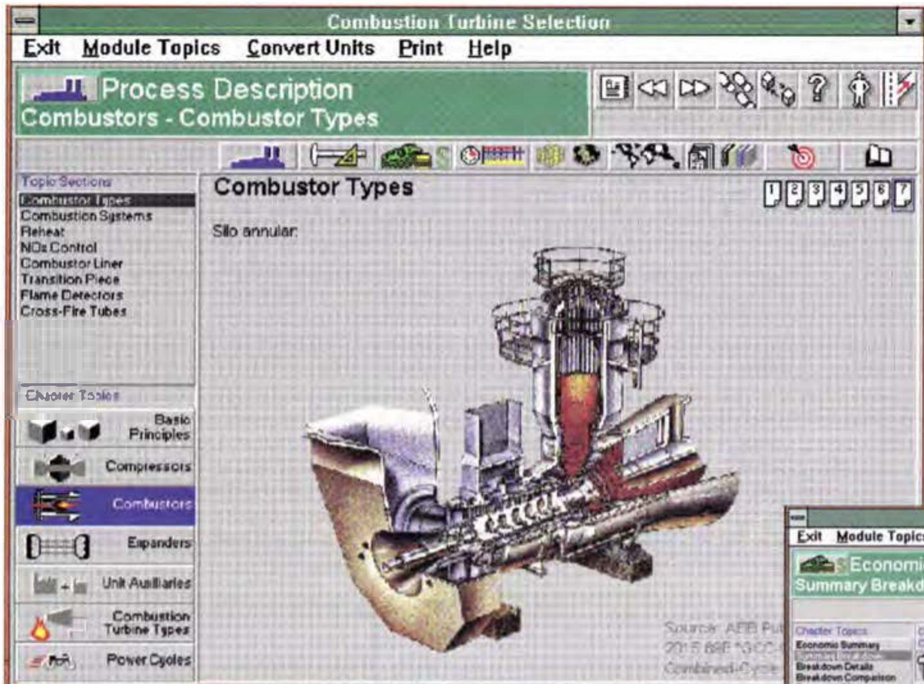
Competitive power generators also have a stake in public policy and regulatory outcomes. Leveraged participation via EPRI means efficient, low-cost entry into these interactions and a way to make sure that company interests are brought to the fore. EPRI also provides scientific and engineering bases that individual companies and their associations can use to support both regulatory positions and plant operational permitting negotiations on a wide variety of environmental concerns. □

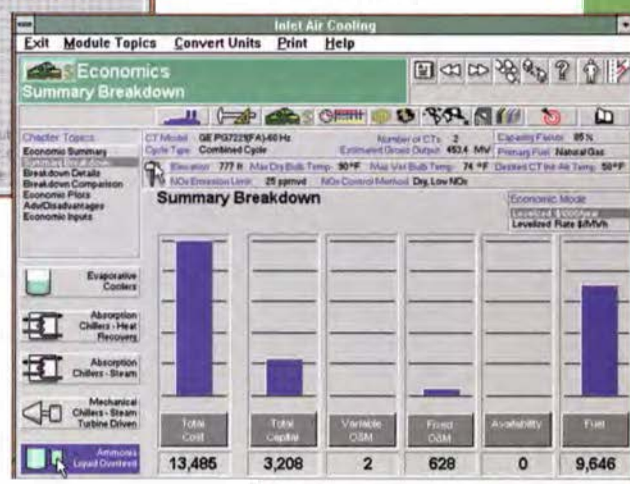
more-efficient generating capacity enters the marketplace, gradually a plant's profit margin will shrink unless its owner can continuously improve performance."

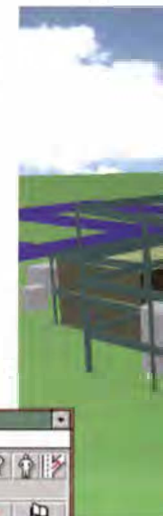
A need for technology

As new sellers in markets where largely depreciated existing capacity typically sets the market-clearing price for additional supply, merchant power developers are under intense pressure to adopt the most aggressive gas turbine and combined-cycle technology available. But recent industry experience with large, high-firing-temperature heavy-frame turbines has raised questions about the risks of premature wear and failure, life-cycle costs, and financing and insurance costs. Such uncertainties are multiplied for projects based on less-proven commercial technologies or emerging advanced technologies—for example, still-higher-temperature, closed-loop turbines with steam-cooled blading.

As well as facing the greatest pressure to deploy the most advanced turbines, merchant plant developers face the greatest risk of penalty for nonperformance, since they typically have no reserve capacity for keeping the revenue stream (and debt payments) flowing. A catastrophic blading failure on a single machine can cost up to $3 million for an eight-week outage, and collateral damage can extend the outage to four months and cost $45 million to repair. Business interruption, replacement power, and contractual default charges can raise the cost to $90 million. With such high financial risks associated with failures, the owners of new or repowered combustion turbine and combined-cycle plants must closely monitor the condition and performance of their equipment.







"Different strategies for approaching the merchant power market can lead to different choices in technology," says John Scheibel, EPRI business unit manager for new central stations. "If you're going after peak loads with a merchant combustion turbine plant, that's a very different type of asset than a combined-cycle plant and one for which you may be willing to accept some compromise on performance. An intercooled aeroderivative turbine, with simple-cycle operating characteristics but somewhat higher efficiency than a simple-cycle heavy-frame turbine, could be a better performer in that application. It's important to be very clear on the mission you're selecting a technology for."

Even if the key technology choices and cycle configuration decisions have been made on the basis of the most up-to-date intelligence and operating experience, there is no letup of financial and performance pressures on merchant plant operators once a plant is built and running. "The very low operating costs and very high reliabilities that a merchant producer needs are somewhat in conflict with each other," explains Scheibel. "An anchor tenant can help minimize the plant's overall market exposure, but operating practices are the dominant influence on how quickly the manufacturer-estimated service life of critical hot-gas-section components is consumed. These components represent approximately a third of the total cost of a combustion turbine."

EPRI's SOAPP™ (State-of-the-Art Power Plant) multimedia software contains modules that allow developers and planners of combustion turbine and combined-cycle plants to quickly screen, analyze, and visualize alternative plant configurations on a desktop computer.

By effectively managing overhauls and operation and maintenance, applying life optimization methods to costly and critical components, and prudently investing in performance and capacity enhancement technologies, power producers can maximize the profitability of combustion turbine and combined-cycle plants. In competitive markets, producers can realize immediate returns on investments in cost-effective technologies designed to manage operating risks, prevent the failure of hot-gas-path components, reduce outage time, and improve performance and capacity.

Equipment concerns include failures from cracks in turbine blades and vanes and performance degradation from erosion in compressors. Overhauls can require extended plant downtime. New life management tools are emerging for predicting the remaining life of such parts and for avoiding failure, but these tools require further development for broader application to individual machines.

Market price volatility comes with the territory of competitive bidding and spot pricing, in which merchant producers vie on a daily basis. In the open market, the

price of electricity can change more in one day than the prices of many other commodities change in a year. Merchant producers that successfully manage the high risk of operating in electricity and energy markets to their benefit stand to increase profits tremendously. But they require sophisticated methods and tools that reflect the value of resources and that enable them to take advantage of today's market opportunities to an extent not possible with traditional, discounted-cash-flow analysis.

There is also typically a seasonal aspect to market volatility, notes Lance Dohman, EPRI market segment leader for generation, who formerly worked in corporate development for Enron Capital & Trade Resources. "In contrast to the more fruitful days of power purchase agreements, a merchant plant may, during much of the time it operates, be generating electricity at a cost higher than the pool price and thus be losing money.

"During the heat of summer, combined-cycle costs of production are considerably better than pool prices, and the merchant plant can pay its bills," says Dohman. "Even when winter and summer peaks in forward-price curves are taken into consideration, however, the justification for the capital investment to build a plant may still not be compelling. A key feature of projects that do come to fruition is that they exploit a host of embedded options, including cycling and peaking capability, in order to seize price spikes and emerging ancillary service opportunities. Physical mechanisms that provide competitive producers rapid access to these market opportunities or coverage for trading commitments are rich in option premium.

"The sum of these option values is the cement for a decision to proceed to build a plant. The new merchant power plants clearly are becoming a platform for wholesale trading, and their operations ultimately will be controlled on energy trading floors where producers seek to profit from market volatility and to satisfy real-time market demands. Eventually, a convergence of electricity demand and physical supply will lead to a more efficient market, but let's not forget that the physical equipment must make good on short-run promises while maintaining operational integrity for the long haul."

Market savvy in managing the so-called spark gap—the difference between the equivalent market price of a kilowatthour leaving a merchant plant and the cost of the natural gas Btus fueling the plant—is critical for energy companies that straddle both regional gas and electricity markets. Again, location is a key determinant of the magnitude of the spark gap: potential merchant plant sites where gas pipelines and power transmission lines are in close proximity offer the greatest opportunity for arbitrage.

"Technologies will matter a lot in determining how much of the spark spread a company is able to capture," explains Mueller. "Market knowledge and real-time information systems will influence how quickly a company can decide whether to sell kilowatthours or Btus, depending on their relative value to its cost structure. Here's an example where EPRI has tools (or could readily redesign tools)—including fuel impact and power trading models—that could work together as real-time information systems for competitive producers and help them take advantage of the spark spread."

Maximizing investment returns

EPRI offers merchant producers much more than individual products of uncommon value. These products are supported through a network of specialized centers that directly assist in rapidly applying results for immediate benefit to a project's economic bottom line. "EPRI offers a suite of products and services of direct value to merchant producers—deliverables that address everything from market issues to hardware issues," says Stu Dalton, product line director for fossil, hydro, and renewables. "It's powerful coverage that really no other firm can provide."

Adds Tony Armor, EPRI technical executive and director of generation marketing, "It's one thing to build a plant and find buyers for the power, but it's quite another altogether to operate it efficiently and reliably for many years. No matter what the risks—power market, fuel market, technology performance, financial viability—once a plant is running, a merchant producer above all wants it to be reliable and not to fail. This is where EPRI can make a difference in merchant producers' profitability." ■

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Background information for this article was provided by Tony Armor and John Scheibel (jscheibe@epri.com), Science and Technology Development Division; Stu Dalton (sdalton@epri.com), Product Management Division; Lance Dohman and Tom Morasky, Client Relations; and Howard Mueller, Corporate Development.

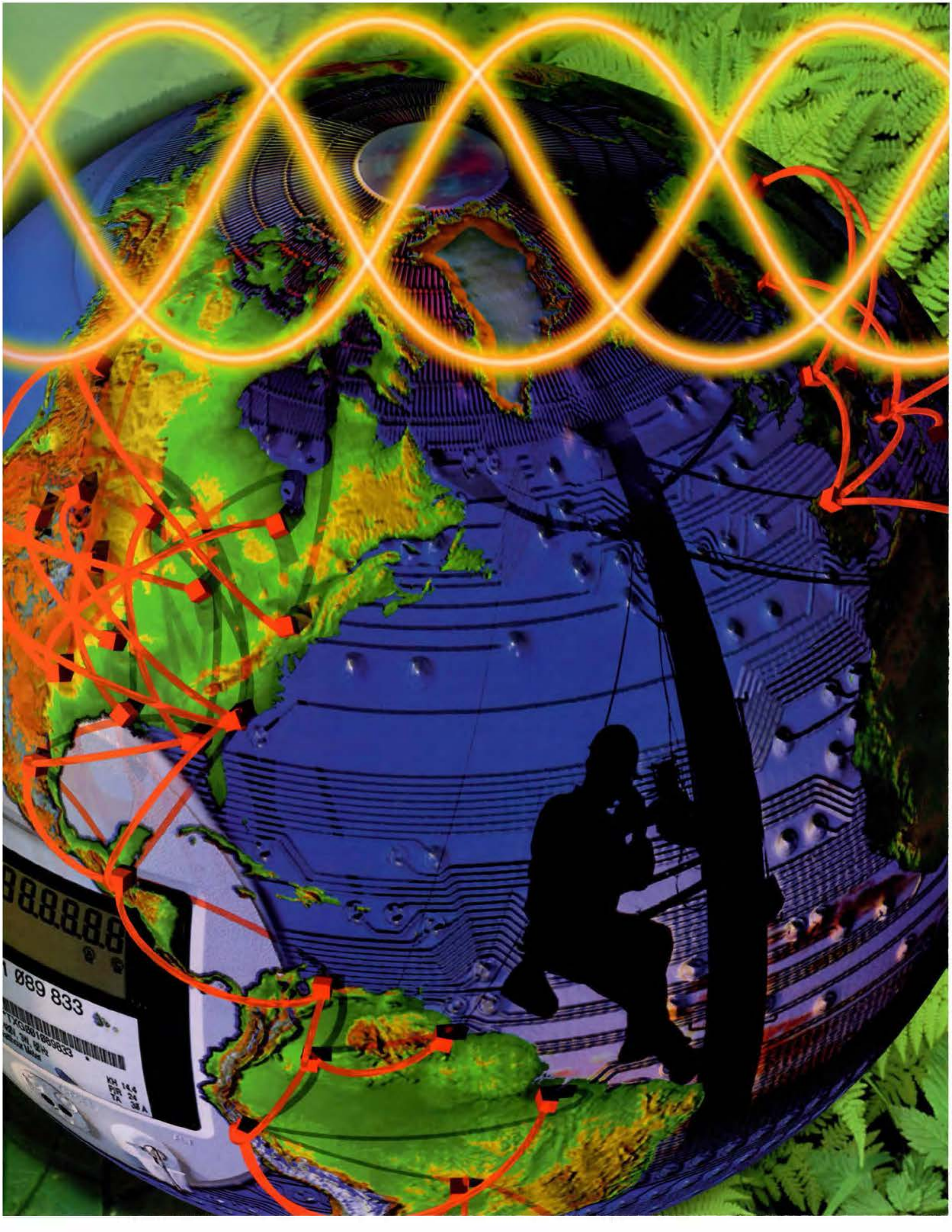
The Electricity Technology Roadmap

Power Delivery in the 21st Century

THE STORY IN BRIEF

EPRI's Electricity Technology Roadmap Initiative seeks to develop a comprehensive vision of opportunities for electricity-related innovation through the mid-twenty-first century. The roadmap's pathway to the future begins with one of the most fundamental electric utility functions: getting electricity from the point of generation to the point of use. The power delivery function is changing and growing more complex with the exacting requirements of the digital economy, the onset of open power markets, the introduction of modern distributed generation and self-generation, and the saturation of existing transmission and distribution grids. Advanced technologies for dealing with many of these issues are now under development, and a vision of a more robust, flexible, and precise power delivery infrastructure is emerging. However, building this infrastructure in time to avoid serious problems will require that current restructuring activities not discourage the R&D investments needed for major system upgrades.

by John Douglas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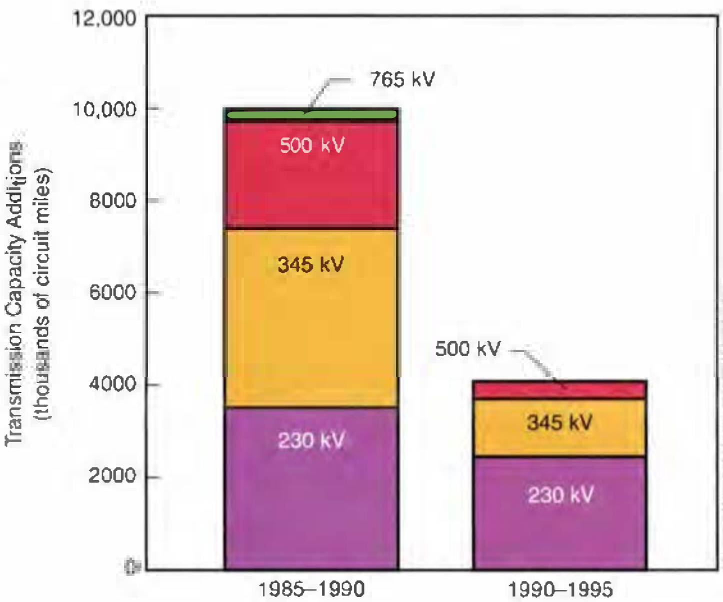
The U.S. electric power system is one of the largest and most complex machines of the technological age. As overall power loading continues to grow with deregulation and as the power quality demands of a digital society increase, managing this system—especially the delivery function—will become increasingly difficult. Indeed, power delivery has become the focus of electricity industry restructuring, creating challenges for existing transmission and distribution networks that can be met only through the application of advanced technologies.

Following the passage of the Energy Policy Act of 1992, which requires open access to utility transmission lines, the Federal Energy Regulatory Commission issued Orders 888 and 889, establishing rules for wholesale power wheeling and encouraging the formation of independent system operators. The result has been a greatly increased volume of bulk power sales—a development that threatens the reliability of today's transmission systems, which were not designed to support a wholesale electricity market of this magnitude.



Transmission capacity additions have declined in the past decade just as the tremendous growth in bulk power transactions begins to put new strains on the grid.

About one-half of all domestic generation is now sold on the wholesale market before it is delivered to customers. The growth of this market, however, comes at a time when many parts of the North American transmission system are already operating close to their stability limits, as illustrated by recent widespread outages in the western United States. The cost of the August 10, 1996, outage alone was estimated to be nearly $1 billion. Traditionally, utilities would add new transmission capacity to handle expected load increases, but because of the current difficulty in obtaining permits and the uncertainty about achieving an adequate rate of return on investment, the total transmission circuit miles added annually are declining while the total demand for transmission resources continues to grow.

In addition to changes in the wholesale market, several states have begun to implement retail access, which will provide consumers a choice among electric service providers. As a result, many new competitors are entering the retail electricity market, offering a variety of customized services. Existing distribution systems, however, were not designed to support either multiple suppliers or value-added services, such as premium power for customers with sensitive equipment. Further complicating the task of coping with these changes are that no single pattern for retail access has emerged from the state plans and that the future scope of federal legislation in this area remains uncertain. In many cases, de facto restructuring policies actually disguise market signals and discourage investments in transmission system upgrades.

Concerns over transmission system integrity go beyond the needs of individual customers. Various infrastructures, including transportation, telecommunications, oil and gas, and financial systems, depend on the electric power infrastructure to energize and control their operations. The interconnectedness of these sectors and their dependence on electricity mean that a power failure in one sector can easily propagate to others, multiplying the damages associated with the failure.

In the electricity industry of the future, every utility computer is likely to be connected to every other computer in the energy and information network. These interconnections, which may increase vulnerability to human error and intentional attack, create a situation that strongly favors collaboration to address the common problems of computer security and power supply reliability, collaboration both within the electricity industry and between it and other industries.

This cross-industry collaboration is already beginning. The President's Council on Critical Infrastructure Protection has spawned several strategic planning studies, including one on the electric power sector. That study identified the following technology and policy objectives:

- To balance public and private interests in the nation's electricity supply; to ensure that public policy, roles, and responsibilities guarantee the public good while permitting free market forces to serve private interests
- To guarantee the safety, availability, and quality of the nation's electric power grid; to continue fundamental research to understand, create, and apply power technology products and management tools critical to the reliability of the power grid
- To guarantee the integrity, confidentiality, and availability of the information network; to research, develop, and apply secure, robust, and adaptive information systems, network technologies, and management tools
- To ensure the integrity of interdependent infrastructures; to increase understanding of what each infrastructure owner or operator must know about other infrastructures to enable rational contingency planning; to develop new cooperative agreements within the industry and

between interdependent private and public service providers

These objectives reflect the importance of developing effective technology responses to policy concerns in order to create a plan of action for improving the reliability and security of the power system. Improvements to the system can be made progressively, with the new technologies and the products and services they generate phased in as they make good business sense. If technology investments are made in a timely manner, there is a real possibility of creating a robust delivery system that is capable of supporting a universal digital economy. The resulting upgraded power delivery system will be key to U.S. economic growth and to sustained productivity advantage.

In addition to transforming the U.S. power grid, technology advances could lead to the creation of streamlined transmission systems in developing nations, including both long-distance and urban delivery capabilities. Investments in technology would enable new business opportunities in power marketing, long-distance power transmission, and end-user services in the most rapidly growing regions of the world. Major intercontinental power transfers could become possible, thus helping solve regional inequities in energy supply and demand. The creation of such a global electricity market could support mutual economic development in the countries involved and could offer a more environmentally desirable mix of power generation alternatives.

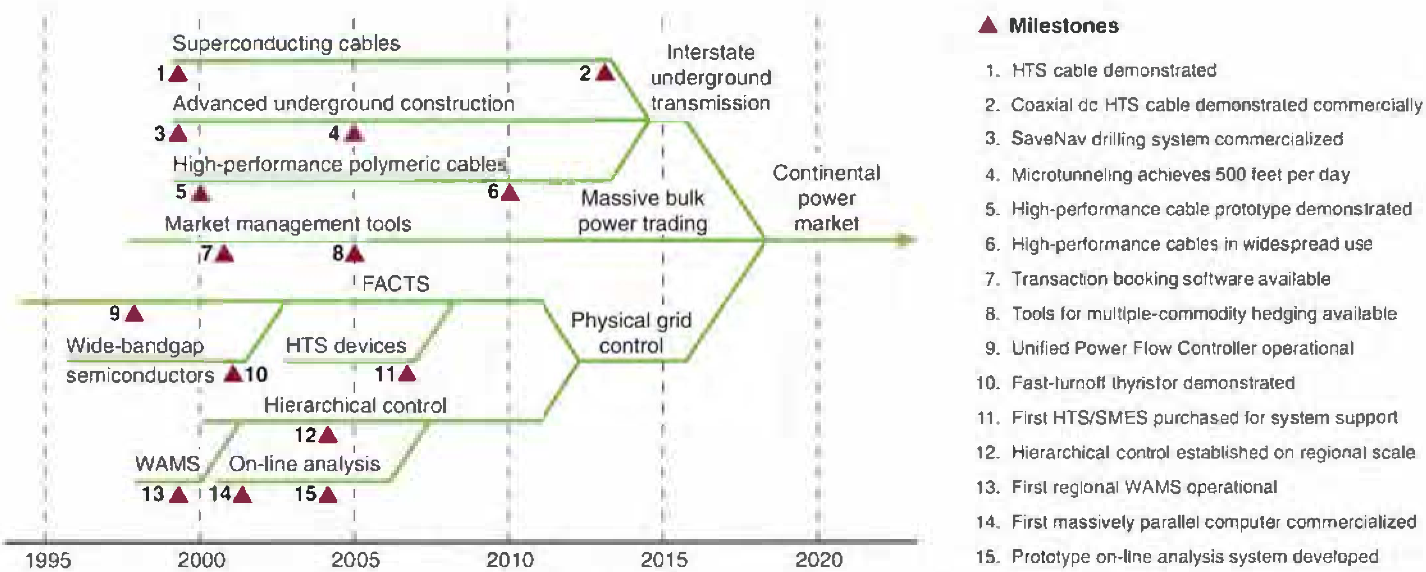
Advanced control technologies

New technologies that can improve the robustness and increase the precision of the power delivery system are becoming available. Thus the opportunity exists not only to solve the current slate of problems but also to create a new infrastructure that will meet the exacting needs of the digital economy and support aspirations for an ever-better quality of life in the twenty-first century. By 2020, it is anticipated, a unified, digitally controlled transmission grid will be needed to move large amounts of power precisely and reliably throughout North America, while managing an exponentially growing number of commercial transactions.

The first technological steps toward establishing physical control over such a continental-scale transmission grid have already been taken. High-voltage electronic FACTS (Flexible AC Transmission System) controllers, for example, have already been deployed on several utility networks to increase the capacity of individual lines and improve overall system stability. Conventional electromechanical controllers are too slow to govern the flow of alternating current in real time, with the result being loop flows and bottlenecks. By acting quickly enough to control such events, electronic FACTS controllers can increase or decrease power flow on particular lines, alleviating transmission system congestion. In addition, these controllers can enhance system reliability by counteracting transient disturbances almost instantaneously, allowing transmission lines to be loaded closer to their inherent thermal limits and thereby effectively increasing throughput.

New wide-bandgap semiconductor materials—such as silicon carbide, gallium nitride, and thin-film diamond—could dramatically lower the cost of FACTS devices by providing the basis for developing a power electronics equivalent of the integrated circuit. The demonstration of a fast turnoff thyristor based on wide-bandgap semiconductors could take place as early as 2001. Such a thyristor will reduce the cost of ac/dc converters for making dc interconnections between asynchronous ac power systems and for increasing the use of long-distance dc transmission.

Exercising control over continental-scale power systems, including the widespread use of FACTS devices, will require gathering vast quantities of real-time data for on-line analysis of system conditions. The first Wide-Area Measurement System (WAMS), based on satellite communications, is currently being established for the



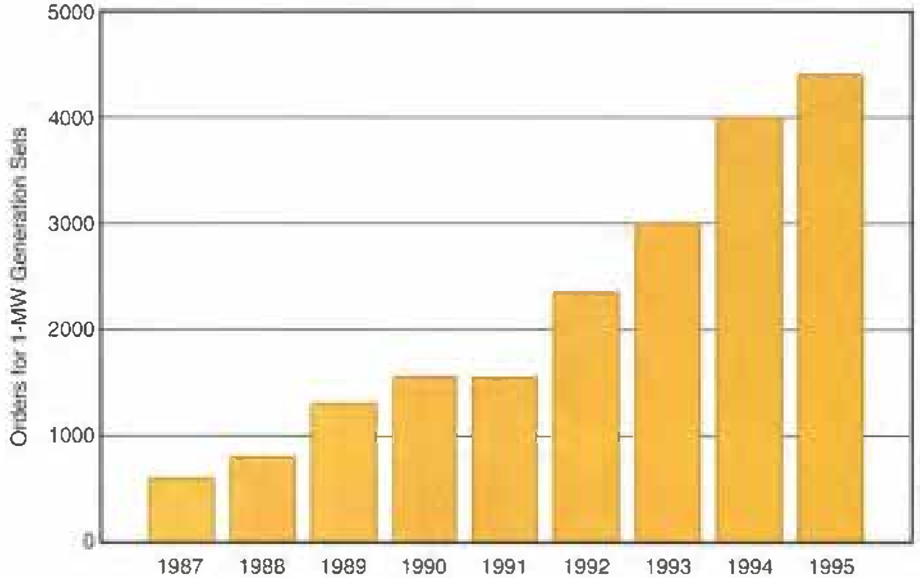
The development of a true continental-scale power market will require advanced technologies for long-distance overhead and underground transmission, bulk power trading, and grid control. Innovations already under development could make such a market possible by 2020.

western U.S. power grid. Using the data gathered by WAMS for on-line system analysis, however, will require the availability of massively parallel computers. Currently, it takes about 20 minutes to perform a stability analysis for a major power system. Meeting real-time control requirements will require completing such analysis within a fraction of an ac cycle. Combining FACTS, WAMS, and on-line analysis to facilitate the integration of power grids on a continental scale is expected to take place by 2010–2015.

Another technological pathway that will contribute to the long-distance transfer of low-cost power is the development of superconducting transmission cables. Such cables have been made possible at a reasonable cost by the discovery in 1986 of a new class of high-temperature superconducting (HTS) materials created from ceramic oxides rather than metals. The advantage of these materials is that they can be cooled by using cheap liquid nitrogen rather than extremely expensive liquid helium. Laboratory tests on a single-phase HTS cable are currently under way, and the first utility demonstration of a three-phase, 24-kV cable—to be used in upgrading an aging urban power infrastructure—is scheduled to take place at Detroit Edison over the next two years. The next R&D steps will be to reduce the cost of HTS materials by using textured oxide films and to develop coaxial configurations for HTS cables. It has been estimated that a superconducting coaxial cable using dc power could carry 5000 MW of power at voltages of only ±50 kV, with early commercial applications expected around 2010–2015.

Power quality for a digital society

Ours is an increasingly digital society, dependent on microprocessor technology to operate everything from home appliances to whole factories. For this technology to operate properly, however, customers need to receive power of the highest quality—free from interruptions and voltage disturbances. Providing the premium power required by the widespread use of sensitive electronic equipment will necessarily involve the application of new power delivery technology on utility distribution systems.



Demand is growing rapidly for small, distributed generation units that can meet customer requirements for improved reliability and power quality in an increasingly digital environment.

One set of these technologies will form the basis of advanced distribution automation, which differs considerably from traditional approaches based on simply automating existing functions. The new approach uses low-cost sensors and accompanying software to allow a distribution company to detect and correct problems on its system more quickly. Already, EPRI is developing a distribution fault anticipator/locator that will use sensors scattered along a line to predict incipient faults and detect momentary line contacts, such as those caused by tree branches. Next will come automated isolation and restoration capabilities, which will greatly reduce the impact of outages when they do occur. The application of such advanced distribution automation technologies could become widespread around 2005–2010.

A second stream of technology related to the delivery of high-quality power is the Custom Power family of electronic controllers designed for use on distribution systems. Several Custom Power devices have already entered utility service, including the Dynamic Voltage Restorer, designed to protect sensitive customer equipment from power line disturbances, and the Distribution Static Compensator, designed to prevent disturbances that originate at a customer's site from affecting the quality of power on a feeder line. Next will come combinations of Custom Power devices to provide premium-quality power to groups of customers with special needs, such as an industrial park with multiple high-tech companies. In such premium-power parks, outages on one distribution feeder would be counteracted by instantly switching the power supply of the whole park to an independent feeder, using a solid-state transfer switch.

Eventually, Custom Power devices will be combined with advanced energy storage systems to provide outage ride-through capability—first for individual customers and premium-power parks and then for major sections of a distribution system. Multiple storage technologies will be required to fulfill the needs of these various applications. One recent breakthrough in this area was the development of a transportable battery energy storage system capable of delivering up to 2 MW of power for 15 seconds and thus able to protect customers from most brief interruptions resulting from faulted lines. Because the system is transportable, it can be installed quickly to meet uninterruptible power needs as they arise.

For several seconds of ride-through capability at higher power levels (10–100 MW), superconducting magnetic energy storage (SMES) will probably be the preferred technology. The first demonstration of a SMES unit based on HTS materials may come as early as 2003. (Low-temperature SMES devices are already available in very small sizes but will likely remain uneconomical for large-scale applications.) The widespread use of combined Custom Power and energy storage technologies for distribution system support could occur by around 2005–2010.

Emergence of the distributed utility

Any discussion of the future of power delivery will include the rapidly developing area of small, affordable electricity generation and storage units known collectively as distributed resources. With capacities in the range of 1 kW to 10 MW, these diverse DR units will move generation closer to the point of use, enabling improved power quality and reliability and providing the flexibility to meet a wide variety of customer and distribution system needs.

Small-scale distributed generation and storage systems can thus become valuable new elements of the distributed, or "virtual," utility of the future. DR systems now under development have the potential for offering significant new advantages: lower cost to the end-use customer; higher reliability and power quality; higher efficiency, especially in cogeneration configurations; and flexibility to meet a variety of industrial, commercial, residential, and transportation applications. All these advantages of distributed generation will spur healthy competition and create synergies with the distribution system, leading to improved performance and cost there as well.

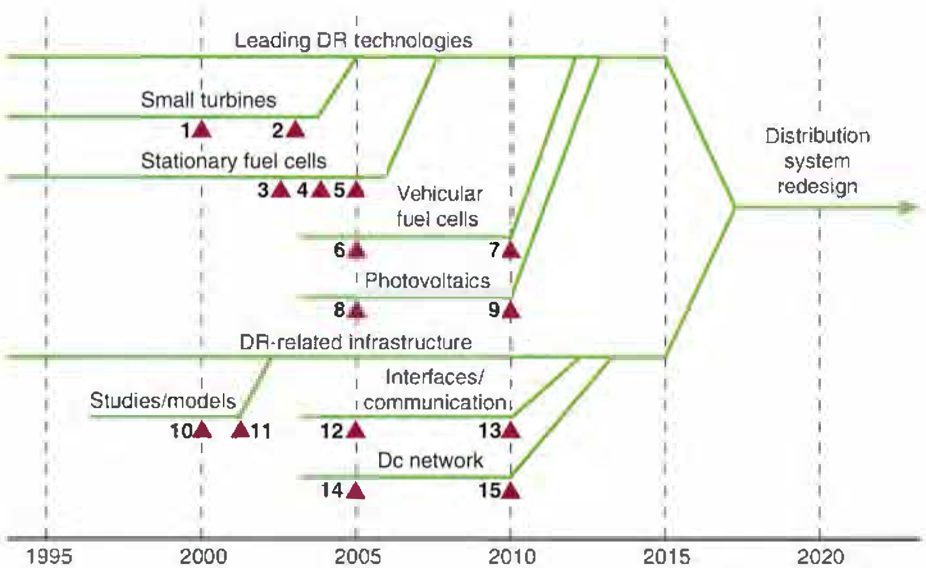
Gas turbines are setting the pace in the growth of DR use. By 2003, a new generation of microturbines (10–250 kW) is expected to achieve full commercial viability (prototypes are being sold now), opening up new opportunities for peak shaving and cogeneration by small businesses. Fuel cells should also be well suited for a wide range of DR applications because they are clean, compact, efficient, and highly modular. Assuming sustained investment, at least 20 GW of DR capacity is forecast for installation in the United States during the coming decade alone.

Connecting a large number of DR units to a distribution system will have profound effects on both utility structure and system architecture. The utility itself will become more decentralized, relying less on power generated at large plants and delivered via transmission lines. A variety of integration issues will immediately impact system operations. Double isolation systems, for example, will be required in some situations to protect line workers, since power could flow in either direction along a distribution feeder if DR units are located throughout a network. Distribution systems with mixed distributed and central assets are also likely to require dedicated VAR (volt-ampere-reactive) generation for system support. DR units will, in general, produce VARs, but probably not in the quantity and location necessary for meeting grid stability requirements. Distribution system operators will need the capability to produce VARs to balance the system.

Some utilities will also want to arrange with DR owners to make the distributed units dispatchable and thus provide peaking power to the system as a whole. For this to occur, however, a variety of remote communications, monitoring, and control functions would need to be added to each DR unit. As the cost of power electronics continues to decline, Custom Power devices are expected to play a major role in integrating DR units with existing distribution systems by performing the necessary control functions and power conditioning.

Dc distribution networks

The use of direct current in power delivery may also increase in the next decade. The problem up to now has been that ac/dc converter technology was too expensive for routine use on utility distribution systems. But again, with the rapid decline in the cost of power electronics, such converter technology should become inexpensive enough to facilitate dc distribution systems by about 2005.



Milestones

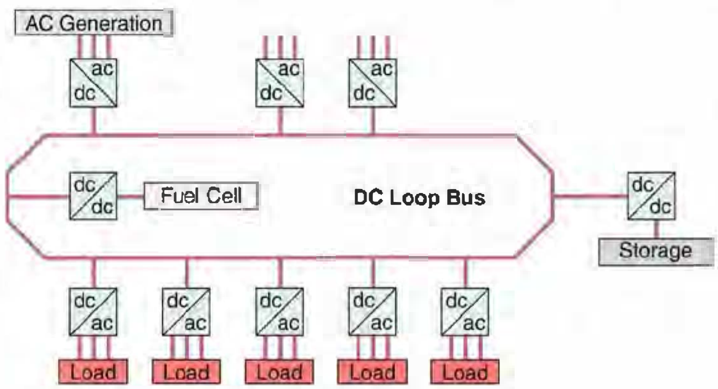
1. Miniturbines (250 kW–1 MW) commercialized
2. Microturbines (10–250 kW) commercialized
3. Solid oxide fuel cells commercialized
4. Hybrid SOFC–gas turbines commercialized
5. Stationary PEM fuel cells commercialized
6. Fuel cell vehicles introduced commercially
7. Electric-drive vehicles exceed 2 million units
8. PV panels achieve 17% efficiency, $2/peak watt
9. One million rooftop PV units deployed
10. Studies of DR impact completed
11. DR analytical models available
12. Smart static power converters in significant use
13. Control systems for DR dispatch in routine use
14. Inexpensive converters allow dc distribution
15. Dc loops become common distribution option

Distributed resource (DR) technologies, including fuel cells and photovoltaics, are undergoing rapid development along independent paths. The full integration of these resources into the power grid will eventually require a substantial redesign of the distribution system.

Dc has several advantages for distribution networks. Dc distribution links, for example, can directly supply power to digital devices on the customer's site and can connect distributed generation systems to the grid without the need for dc/ac converters. They can also increase service reliability by reducing the spread of disturbances from one customer to another and can allow each customer facility to use distributed generation and storage technologies in order to operate as independently as desired. Because dc cables eliminate the generation of ac-induced currents, they could be placed in the same ducts as gas and water pipes. Potentially, dc cables would cost less than ac cables of the same power rating because they need less electrical insulation and because they experience lower resistive losses and no dielectric losses.

One dc distribution option uses a superconducting dc loop bus to integrate bulk power from a transmission network with local distributed resources. The emergence of such a network would require the widespread use of low-cost dc/ac converter technology to provide power to retail customers. Superconducting dc loops could provide premium-quality power for large urban regions, in contrast to today's networked distribution systems, which serve mainly downtown areas. Dc loops may become a common feature in distribution systems by 2010.

Eventually, the incorporation of DR and other advanced technologies into utility distribution systems will reach a point at which fundamental redesign must be considered. A key aspect of such redesign will almost certainly involve the reconfiguration of distribution feeders from a primarily radial system into a more highly interconnected network. The primary advantage of such networking is that it offers more opportunity for supply redundancy to customers, who will become even more dependent on access to premium power. Already, new reliability indexes are being developed by various industry groups, including EPRI, to benchmark new distribution system design concepts. These designs will probably assume the full integration of DR units, the pervasive use of power electronics, and the presence of dc cables and superconducting loops.



Dc loops provide one option for tying local distributed dc generation and storage technologies in with bulk ac power. Loops based on superconducting dc cable could provide premium-quality power for large urban regions, in contrast to today's networked distribution systems, which mainly serve downtown areas.

Convergence of utility services

As deregulation provides customers with greater choice among retail electricity suppliers, competition will drive the customization of service to meet the divergent needs of various market segments. In addition to their need for higher levels of power quality, customers are demanding lower rates and a greater variety of service options. In response, many utilities are experimenting with real-time pricing and seeking ways to integrate electricity with other services, including gas, cable television, and telecommunications. More than 100 electric utilities are already offering Internet access, and about 85 have established or are planning to offer telecommunications services, using their own private fiber-optic networks. Over the next several years, such horizontal integration of utility functions is likely to accelerate, giving customers a greater choice of services, plus the convenience and economic efficiency of one-stop shopping.

Two major areas of technology development will be required to bring about such a revolution in retail utility services. The first area encompasses advanced meters, standards, broadband communications, and pricing and billing software capable of handling multiple utility services. The second involves cable design and construction techniques for installing combined utility services underground.

Providing multiple utility services—including electricity, gas, telecom, Internet access, cable television, and water—will require new customer interface technology. In particular, a low-cost electronic meter with two-way communications capability is needed to provide real-time pricing options, which will be the cornerstone of a competitive retail market. Even more sophisticated interface technologies will be required to facilitate integrated utility services, such as telecom, that depend on broadband communications links. Low-cost, modular electronic meters developed by EPRI are currently undergoing utility demonstration, and "virtual meters" capable of providing integrated billing for multiple utility services could be available by 2003—perhaps in the form of a low-cost network computer that monitors the services and delivers a variety of information to consumers.

Handling the data gathered from advanced meters and other sources for the purposes of pricing and billing promises to be a major challenge. In particular, existing customer information systems need to be restructured to allow greater flexibility in changing the products and services offered to customers. Because of this requirement, new systems will need to have modular architecture, organized around a simplified customer database. The first prototype of such a modular customer information and billing architecture will be introduced in 1999 and should progress to the point of commercialization by 2004.

Broadband communications capability will also be required if multiple utility services are to be integrated with two-way cus-

Power Delivery System R&D Funding Requirements			
	10-Year Funding ($ millions/yr)		
Goals and Technology Gaps	**Current**	**Additional Needed**	**Total Needed**
Increased grid reliability and carrying capacity	**100**	**100**	**200**
Wide-bandgap semiconductors for FACTS			
Satellite-based WAMS			
High-performance polymeric and HTS cables			
Streamlined, lower-cost construction techniques for underground transmission			
Power flow control in complex grids (hardware, software, communications systems, integration with transaction management function)			
Information technology systems to control the grid and manage transactions			
Removal of geographic constraints on transmission	**100**	**100**	**200**
Increased transmission capacity to connect electricity demand with supply			
Capability for continental-scale power wheeling			
Emergence of the distributed utility	**200**	**200**	**400**
Cost-effective distributed generation and storage technologies			
Control and protection systems for mixed central and distributed systems			
Low-cost converter technology to enable dc distribution networks			
VAR support without requiring new generating capacity			
Infrastructure stability and protection	**NA**	**200**	**200**
Methodology to understand and manage power system complexities and vulnerabilities			
Real-time wide-area communications and control systems			
Hardware, software, and procedures to prevent cascading failures			

tomer interaction. Fiber optics and other broadband technologies are steadily decreasing in cost so that, by around 2005–2010, they are expected to be available for use in integrating utility services. In addition, the availability of broadband communications could revolutionize telecommuting and provide new economic development options for urban and rural areas alike. One could imagine, for example, new settlement patterns in which today's urban sprawl is replaced by "virtual cities" in which people live along maglev transportation corridors but do most of their work at or near home, relying on telecommuting.

The integration of multiple utility services will probably be accompanied by increased pressure to place more of the required infrastructure underground. The growing use of superconducting distribution cables and dc loops, discussed earlier, will help make this possible. Also, improved underground construction methods will make buried utility facilities more attractive for distribution systems. In the short term, the use of guided boring technology—such as EPRI's SafeNav guidance system—will rapidly lead to improved productivity in underground construction. In addition, the development of microtunneling for utility applications has benefited from recent experience with laser-guided equipment in constructing the Channel Tunnel and other major public works projects. By around 2005, construction rates of 400–500 feet per day (120–150 m) should be possible for building a 6-foot-diameter (2-m) tunnel capable of acting as an integrated utility corridor for electricity, gas, communications, and other services. The standardization of underground designs and the expanded use of robots would further reduce construction costs.

Fulfilling the promise

A critical assumption underlying the Electricity Technology Roadmap is that, by 2050, electricity will account for nearly 70% of total energy use in the United States. In the research goals just described, the roadmap's primary concern is to ensure an adequate power delivery infrastructure to support such an electric society.

Fulfilling this power delivery promise, however, will require the resolution of several technology-related policy issues, as EPRI vice president Karl Stahlkopf of the Applications Division explains: "The most serious problem preventing the introduction of new power delivery technologies is that adequate cost-recovery mechanisms for investment in transmission upgrades in a deregulated environment have not yet been established. Resolving this issue will require coordinated policy clarification by federal, state, and regional reliability authorities. For distribution systems, the biggest need is for internationally recognized communications and control standards to facilitate the convergence of multiple utility services and the integration of distributed resources. Finally, providing the innovations needed to meet the power delivery challenges of the next century will require broader public-private collaboration in R&D. The Electricity Technology Roadmap offers an excellent foundation on which to build such a cooperative effort." ■

Background information for this article was provided by Brent Barker (bbarker@epri.com), Strategic and Executive Communications, and Steve Gehl (sgehl@epri.com), Strategic Technology Alliances.

Seeing SF_6 in a New Light

PHOTO BY JIM MAY; COURTESY ILLINOIS POWER

THE STORY IN BRIEF

Concerns about atmospheric emissions of greenhouse gases and about the economic cost of leaks from operating equipment are converging to increase incentives for electric utilities to locate and stop leaks of an essential gas insulator for high-voltage switchgear. A new, high-tech laser-based camera system developed for utility application with EPRI support can detect and display on video even pinhole leaks of this gas—sulfur hexafluoride. Through EPRI, member utilities can obtain SF_6 leak detection services that feature inspections with the GasVue camera and discounts on the purchase of an advanced model expected to be available next year. Some two dozen utilities have already witnessed the GasVue's capabilities in demonstrations on energized substation equipment.

by Taylor Moore

THE FLUORINATED SULFUR compound known as sulfur hexafluoride, or SF_6, is an almost perfect dielectric (nonconductor). This invisible gas is inert, nontoxic, nonflammable, and five times denser than air. Because of its unique combination of chemical and physical properties, SF_6 is ideally suited for several specialized applications. In the largest of these, it serves as an insulating gas in high-voltage electrical switchgear, including circuit breakers. SF_6 is also used as a cover gas in magnesium smelters and for plasma-etching tungsten in the electronics industry. In Germany, it was used until recently to fill sound-insulating windows and, because of its adiabatic properties, by automakers to fill tires for a firmer ride. SF_6 reportedly is still used in sealed stereo speaker cabinets to improve bass response, and until recently it was SF_6—not air—that gave Nike Air sneakers their bounce.

But SF_6 also has a dark side—one that clouds the outlook for some basic applications of the gas. Because of its efficient absorption of infrared energy at certain wavelengths and its extremely long lifetime in the upper atmosphere (estimated to be about 3200 years), SF_6 is considered the most potent of all known greenhouse gases. The atmospheric accumulation of these gases, many scientists believe, is causing a slow but discernible warming of the earth's climate. The Intergovernmental Panel on Climate Change estimates the global warming potential of SF_6 to be some 23,900 times greater, per molecule, than that of carbon dioxide, the greenhouse gas of greatest concentration in the atmosphere.

Although its atmospheric concentration is a hundred million times lower than that of CO_2 and its estimated contribution to total man-made global warming to date is

The GasVue camera can be used to inspect substation equipment, like this 500-kV SF_6-insulated circuit breaker, while the equipment is energized.

only 0.1% that of CO_2, SF_6 was among six types of greenhouse gases targeted for emissions reduction at the 1997 Kyoto Summit. On an equivalent basis of global warming potential, SF_6 accounts for 14% of the reductions in greenhouse gas emissions that the United States and more than 150 other nations agreed to make by 2012.

Even before the Kyoto Protocol is submitted to the U.S. Senate for ratification, environmental regulators are forging ahead with programs aimed at the voluntary reduction of emissions of SF_6 and other greenhouse gases. Last October, the U.S. Environmental Protection Agency began promoting voluntary emissions prevention agreements with industries that are the largest emitters of these gases. Under a memorandum of understanding (MOU) aimed at electric utilities, companies are being asked to report annually on their SF_6 use and emissions, as well as to establish corporate policies that will reduce emissions to the extent economically and technically feasible and will ensure the proper handling of SF_6. The EPA is pursuing similar agreements with other industries, including the magnesium casting and semiconductor manufacturing industries.

Regulatory efforts to better quantify the use and emission of SF_6 and to promote its recapture and recycling are expected to add further incentives to an already strong economic motivation among electric utilities for SF_6 recycling. The commercially produced, high-purity industrial gas is now selling for up to three times its longtime historical price of $3–$4 per pound, and until recently it was five times the historical price. Sold as a liquid under moderate pressure, the SF_6 is contained in tanks with a capacity of about 110 pounds (50 kg).

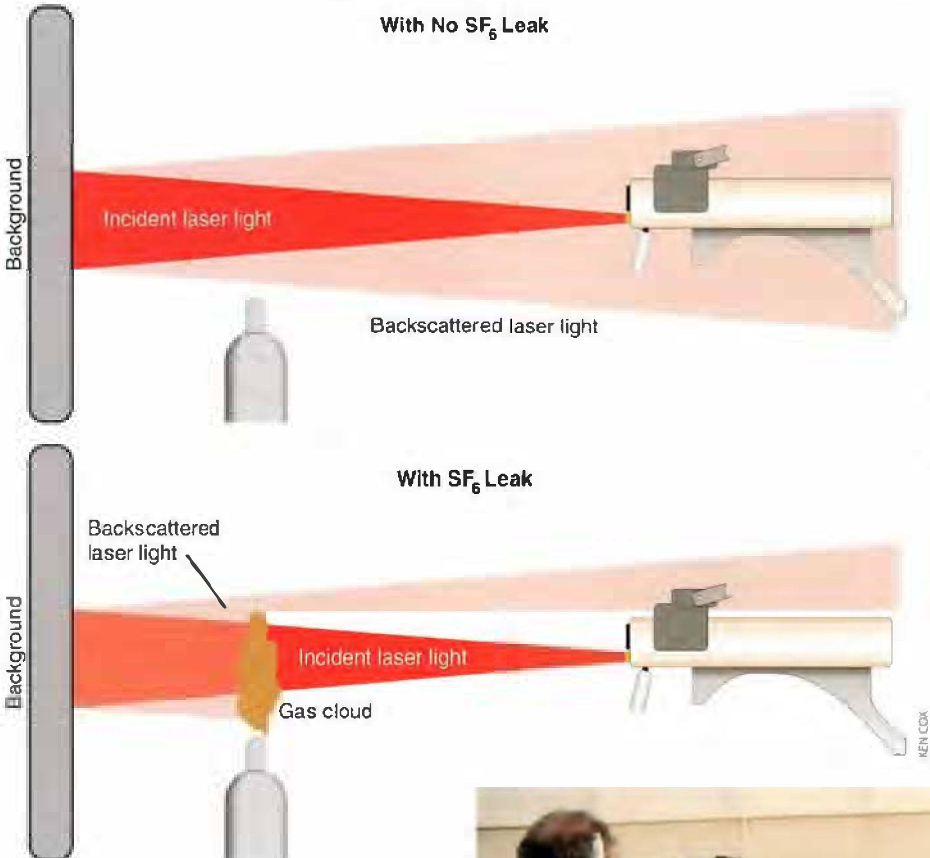
In 1995, U.S. manufacturers of electrical equipment purchased approximately 140 tons (130 metric tons) of SF_6 for new gas-insulated equipment, according to the National Electrical Manufacturers Association. NEMA also reported that in the same year, U.S. and Canadian electric utilities bought an estimated 700 tons (640 metric tons) for, among other uses, possible leakage replacement in existing power equipment—equipment with a total installed SF_6 capacity of 3500 tons (3200 metric tons). It is commonly estimated that, directly or indirectly, electric utilities purchase some 80% of all SF_6 produced.

Worldwide sales of SF_6 have grown dramatically since 1972, when industrial production and use of the gas began to spread beyond the United States, where commercial use was pioneered in 1953. Scientists at the Max Planck Institute for Chemistry in Germany have shown that the growth in SF_6 sales correlates strongly with the increase in the accumulated atmospheric loading of the gas.

"SF_6 is a wonderful dielectric, a highly electronegative gas with insulating and arc-interrupting properties that no alternative or substitute material can match," says Ben Damsky, a manager in EPRI's Science and Technology Development Division. In 1982, before the role of SF_6 as a greenhouse gas was well known, EPRI funded an exhaustive search by Westinghouse Electric and Du Pont for a gas or a gas mixture superior to SF_6 for use in high-voltage equipment; the search was unable to identify any such substitute.

But with SF_6 coming under greater scrutiny as a result of both climate change and cost concerns, EPRI is mounting a multifaceted initiative to support voluntary efforts by member utilities to reduce atmospheric releases of SF_6. Many utilities have already begun the process by adopting improved handling procedures and equipment and by taking steps to reduce leaks from their gas-insulated equipment.

This spring, EPRI began offering products and services related to that initiative through its Energy Delivery and Utilization Center (EDUC) in Lenox, Massachusetts. One of these products is GasVue, a new laser-based infrared camera that can detect even pinhole leaks of SF_6 from gas-insulated substation equipment while it is energized. Using the GasVue camera for such leak snooping has already yielded significant documented savings for Illinois Power and South Africa's ESKOM from avoided purchases of replacement gas. EPRI's SF_6 leak detection technology could



How GasVue works: Developed by Laser Imaging Systems, the GasVue camera combines a CO_2 laser (tuned to an infrared absorption wavelength of SF_6) with an electronic infrared imaging system. Normally the laser beam bounces off the background surface, and the backscatter is picked up by the imaging system. When a leak is present, part of the incident beam is absorbed by the SF_6 gas, as is all of the backscattered light that travels back to the gas cloud. The leaked gas appears on the GasVue's video display as an inky black plume against the lighter backscattered image.

eventually prove to be of substantial value to member utilities if greenhouse gas emissions permit trading is implemented, as is called for under the Kyoto Protocol, or if an early emissions reduction credit program is put into place, as is being discussed by U.S. policymakers.

An affinity for electrons

The virtual indestructibility of atmospheric SF_6 on a timescale relevant for climate change policy stems directly from the compound's molecular stability—ironically, the key to the very properties that make it an indispensable dielectric for high-voltage applications. "Molecules of SF_6 are very symmetrical, are very stable, and have a heavy mass," explains Damsky. "The gas is a strong electron capturer, so if some of it becomes ionized, other molecules will attract the resulting free electrons and grab them. SF_6 smothers arc discharges just as they begin, and it withstands dielectric breakdown better than any other practical gas."

Stability and voltage-withstand capability are highly desirable in applications in gas-insulated substation equipment like high-voltage circuit breakers. SF_6 surrounds the breaker in a large tank, Damsky says, "and when the contacts are parted to open a circuit, the resulting arc rapidly heats everything up and breaks down some molecules of SF_6. But because SF_6 is very effective at conducting heat out of the arc, it rapidly recovers its dielectric strength. The arc interruption capability of SF_6 is unmatched, and in addition, almost all the SF_6 that is broken down into smaller molecules returns to its original, stable state once the arc terminates. That is a very useful property for a dielectric gas."

Although air or nitrogen can be used to insulate high-voltage circuit breakers, their lower dielectric strength and voltage-withstand capability result in much higher operating pressures; these, in turn, necessitate larger breakers with thicker walls. "An SF_6-insulated circuit breaker can break three times the voltage an air-blast breaker

Illinois Power, one of two dozen utilities that have hosted GasVue demonstrations, used the system to test for SF_6 leaks from circuit breakers and other energized equipment at its Clinton substation. In an economic comparison with conventional bubble testing, the utility documented savings of $12,000 in avoided costs in just this single GasVue application.

of the same size can handle," says Damsky. "In other words, to do the same job that SF_6 breakers can do, you need three times as many air-blast breakers. The cost of circuit breakers is fairly proportional to the number and size of the breaks needed. But the real difficulty is that utility transmission and distribution substations were built around the circuit breakers. If you wanted to replace all SF_6 circuit breakers with air-blast breakers, the entire substation would have to be redesigned and enlarged."

Questions about the future

Understandably, electric utilities are worried that the environmental need to reduce greenhouse gas emissions may eventually affect the commercial application of SF_6. But according to Eric Dolin, program manager for the EPA's SF_6 Partnership for Electric Power Systems, the agency's agenda is not to eliminate use of the gas. "The SF_6 partnership is focused only on minimizing emissions. The EPA realizes that SF_6 is a gas that has been very useful to the electric utility industry," he says.

"We sponsored some research a couple of years ago at the National Institute of Standards and Technology to look into whether there was a drop-in replacement gas for SF_6 that worked as well, and the answer at the time was no. So the partnership makes no judgment, implicit or explicit, about whether SF_6 should be used by utilities," continues Dolin. He notes that the MOU for which the EPA is soliciting utility partners calls for a voluntary commitment to reduce SF_6 emissions "to the extent that is economically and technically feasible, as determined by the companies themselves, not the EPA."

Dolin says that, as of mid-April, the EPA had received written confirmation from about 50 utility companies indicating they would join the partnership. "So far, we have gotten only positive feedback from utilities that have SF_6-insulated equipment," he adds. The various partnership programs the EPA is pursuing with industry sources of greenhouse gas emissions were planned before the Kyoto Protocol, Dolin says, and were motivated by the EPA's interest in obtaining a better quantitative picture of emissions and opportunities for reducing them.

U.S. electric utilities are keenly aware of policy proposals—proposals endorsed by the Clinton administration—to allow companies to take credit for actions to reduce greenhouse gas emissions in advance of any mandated reductions that would take effect if the Senate ratifies the Kyoto Protocol. The utilities are also interested in the emissions permit trading system called for by the protocol to minimize the cost of reducing emissions.

As major industrial point sources of CO_2 emissions, the utilities are especially concerned about credit and trading proposals in relation to that gas. Also, Dolin says, "many utilities have asked whether the SF_6 partnership MOU can ensure that they will get future credit for any near-term SF_6 emissions reductions. Many companies in a wide variety of industries have chosen to work with the EPA to document their greenhouse gas emissions reductions. We believe that cooperation on monitoring and verifying greenhouse gas reductions will be of value if and when credits for early action become available."

Focus on leak detection and prevention

Utility handling of SF_6 was much simpler when the gas was less expensive and before it was recognized as a potent greenhouse gas. When SF_6-insulated equipment was scheduled for inspection or thought to need repair, the typical practice was to take the equipment out of service and use a soap solution around bushings and seals to check for leaks, much as one would with automobile tires. If repairs were needed, the gas was vented to the atmosphere with pressurized air; but cost considerations and concern for the environment have put an end to that approach.

Today, virtually all utilities with SF_6-insulated equipment use a movable recycling cart equipped with a pump, transfer hoses, and a large tank that temporarily holds the gas while equipment repairs are made. This increasingly common practice, which EPRI has helped to promote through workshops and training for utility personnel, is believed to have cut utility SF_6 emissions in half just by itself. A major drawback of this approach, however, is that gas-insulated equipment still must be deenergized for inspection or repair. "You can't look for gas leaks with soapy water on energized equipment, so a substation typically has to take an outage and switch loads to other breakers or equipment," says Ken Loynes, a project manager at the EDUC. The result is that costs for maintaining and repairing gas-insulated equipment are still quite high.

EPRI's GasVue laser camera provides an attractive alternative. "Not only does it let you see in real time on a video display where SF_6 is escaping from equipment," explains Loynes, "but it also allows you to do this from a safe distance while the equipment is energized. This is a big advantage because you can take the camera into a substation at any time without having to plan and coordinate a shutdown or switch equipment off-line."

The GasVue laser camera was developed with EPRI support by Laser Imaging Systems of Punta Gorda, Florida. It is based on CO_2 laser backscattering technology originally developed at Lawrence Livermore National Laboratory for the U.S. Navy (to enable hazardous gas leaks from ships in distress to be identified by helicopter). Tom McRae, the former Livermore physicist who invented the technology, is now chairman, president, and chief executive officer of Laser Imaging Systems, which has an exclusive license for the patented technology from the U.S. Department of Energy.

EPRI funded field trials at several utilities of a prototype GasVue camera for utility application, generating user feedback for an advanced professional model that is expected to become commercially available from Laser Imaging Systems next year. EPRI expects to begin field demonstrations of a prototype of the advanced model before the end of this year. Member utilities will have the option of purchasing their own GasVue camera at a discount or of buying EPRI service offerings that include GasVue inspections.

The GasVue laser camera employs an infrared detector to identify leaks of SF_6 around equipment seals, joints, and bushings. It can even identify small casting voids in solid metal walls. A key to the detector's operation is that SF_6 absorbs but does not emit infrared light. The CO_2 laser is tuned within the 9–11-µm wavelength range of SF_6's infrared absorption spectrum. The laser bounces this precisely tuned infrared energy off the equipment behind an SF_6 leak for detection by the camera, which outlines the leak as an inky black plume against a lighter background on a black-and-white video display.

The South African utility ESKOM successfully used the GasVue leak detection system on energized equipment at two gas-insulated substations and two outdoor substations.

"The GasVue camera is a very sensitive detector of SF_6 leaks," says McRae. "It takes advantage of SF_6's strong absorption of infrared light, using that against the gas to make it easier to find leaks. The technology's sensitivity and its remote-detection capability, which allows inspections while equipment is in service, are its two primary advantages. You don't have to touch equipment but can inspect it for leaks from 40 to 50 feet [12–15 m] away."

Utilities put camera to test

In demonstrations at substations over the past year and a half, nearly two dozen EPRI member utilities have had opportunities to put the GasVue camera to work spotting SF_6 leaks. One utility with a large amount of SF_6-insulated equipment on its delivery system, Consolidated Edison Company of New York, cofunded the prototype development effort with EPRI and has used the camera on several occasions for periods of up to a month, according to Mike Lebow, a Con Edison R&D manager.

"The GasVue camera is unique and extremely valuable," says Lebow. "There's no other tool available that can provide the kind of information it does. We want to be good environmental neighbors, and this camera helps us find SF_6 leaks expeditiously and minimize releases of the gas. But apart from the environmental aspect, we have a large quantity of SF_6 in insulated equipment on our system, and we do not want leaks causing us to have to replace it at significant cost."

The GasVue camera's ground-level, remote capability for inspecting energized equipment is also safer than traditional approaches, which often require equipment to be taken out of service and personnel to be on ladders or scaffolding, Lebow notes. "In addition, the camera has the ability—which we have verified—to detect leaks that could not be detected with conventional methods, even when you can get at the equipment."

An example of the savings that can be realized from a single application of the GasVue camera was documented last year by Illinois Power. By using the camera to detect and locate SF_6 leaks from circuit breakers and other equipment at its Clinton substation, the utility avoided $12,000 in costs associated with conventional bubble testing.

At Clinton, the camera located leaks on known problem circuit breakers as well as on tanks that were believed to be leak free. For example, when aimed at an energized tank thought to have had no leaks for 18 months, the camera quickly detected four pinhole leaks on a rupture disk. In addition, because Illinois Power staff were able to identify problem parts before shutting a breaker down for repair, later out-of-service time was minimized. "EPRI's infrared laser camera is precisely the type of technology we need to support efficient substation maintenance work and curtail SF_6 gas leaks," says Jim Vandegraft, an Illinois Power switchyard repair worker and electrician.

The South African utility ESKOM tried the GasVue camera last September at two gas-insulated substations and two outdoor substations. Luke van der Zel of ESKOM's Technology Group reported in a paper given at a professional conference that the camera was highly effective in detecting and locating SF_6 leaks.

"From ESKOM's perspective, the main benefits over traditional SF_6 leak detection are twofold: first, the ability to perform leak detection without having to take equipment out of service, and, second, the dramatic reduction in time necessary to detect a leak site," van der Zel reported. He noted that effective leak detection reduces emissions, saves on SF_6 replacement costs, and reduces the frequency of topping off leaking SF_6 compartments—activity that increases the risk of a trip as a result of either human error or particle or moisture ingress.

EPRI has helped promote the use of movable SF_6 recycling carts, such as this model, for temporarily containing gas removed from deenergized high-voltage equipment before either inspection by conventional methods or repair.

At ESKOM's 400-kV gas-insulated Koeberg substation, the EPRI laser camera accurately located an SF_6 leak on a feeder link compartment. "What was significant about this specific location was the large distance between the camera and the leak site," van der Zel explained. Although the feeder link was approximately 9 meters (30 ft) above the ground and the camera, the GasVue was able to detect and locate the SF_6 leak to within approximately 1 centimeter (0.4 in). Detection by conventional means would have been extremely difficult, van der Zel reported, because of "the inconvenient location of the leak and the fact that SF_6 was being vented from a number of locations simultaneously."

As a result of the successful demonstrations last year, ESKOM is planning to use the GasVue camera for a complete scan of a gas-insulated substation that was recently refurbished to repair SF_6 leaks. The full scan "will provide an excellent quality control check on the substation refurbishment," noted van der Zel.

Immediate benefits, perhaps more later

EPRI's GasVue laser camera offers immediate benefits to utilities seeking to reduce unnecessary environmental releases of a potent greenhouse gas that is also costly to replace but is essential for high-voltage power delivery equipment. Part of EPRI's ongoing program to provide member utilities the necessary tools and information to improve SF_6 handling practices, the GasVue camera offers value that could be multiplied severalfold if current regulatory initiatives to quantify and reduce greenhouse gas emissions are eventually expanded to include credits for companies that have already begun leak reduction efforts at their facilities.

"Whether a utility is focused on immediate cost benefits or on longer-range greenhouse gas emissions issues, the ability to demonstrate convincingly that SF_6 management and recycling procedures are effective is becoming increasingly important to the industry," says EPRI's Damsky. "The GasVue camera is a tool that allows a utility to do exactly that." ■

For SF_6 leak detection inspections or demonstrations with the GasVue laser camera, contact Ken Loynes, kloynes@epri.com, (413) 499-5712.

Further reading

"EPRI Laser Camera Reveals Costly SF_6 Gas Leaks for Illinois Power." *EPRI Innovator*, December 1998. EPRI IN-111382.

"Worldwide Effort Underway to Reduce SF_6 Greenhouse Gas Emissions," *Environmental Science & Technology*, Vol. 32, No. 21 (1998), p. 487A.

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Background information for this article was provided by Ben Damsky (bdamsky@epri.com) and Ken Loynes (kloynes@epri.com), Science and Technology Development Division.

In the Field

Demonstration and application of EPRI science and technology

RCM Helps Detroit Edison Optimize Line Clearance

Using EPRI's Reliability-Centered Maintenance (RCM) methodology, Detroit Edison has demonstrated it can save $17 million annually—while improving reliability—by moving from a 6-year to a 4-year cycle for trimming trees that might hamper distribution line performance. The company reports that effective line clearance also increases customer satisfaction.

Optimizing maintenance can help electric power companies balance the often-competing goals of containing the costs and enhancing the reliability of distribution systems. RCM is a method for establishing maintenance intervals on the basis of actual system and component performance, rather than solely on the basis of manufacturer specifications, calendar-driven schedules, or past company practices. It uses functional analysis to focus maintenance resources on preventing those failures that have the most significant consequences.

Detroit Edison used EPRI's RCM techniques to identify how various categories of maintenance affect the performance of its overhead distribution system (13.2-kV and 4.8-kV lines). Line clearance was found to be not only the leading factor impacting system reliability but also the most expensive maintenance task. Methods were developed to calculate and optimize clearance intervals for the company's distribution lines, especially those whose reliability is most affected by tree-caused outages.

Detroit Edison found that significant net savings result from major decreases in downed 4.8-kV wires and outages of 13.2-kV lines, both in routine operation and as a result of storm damage. The RCM results revealed that a line clearance cycle of 4.3 years would maximize effectiveness and savings. Annual net savings close to $17 million could be achieved by using the shorter cycle rather than a 6-year cycle. A cycle of less than 4 years would result in higher maintenance costs with little reduction in outages, while one of more than 4.3 years would result in higher costs related to outages and downed wires.

"The application of RCM's logical, structured analysis helps show the true value of preventive maintenance programs," says Hawk Asgeirsson of Detroit Edison.
■ *For more information, contact Harry Ng, hng@epri.com, (650) 855-2973.*

Chromium Coatings Shine in Nuclear Plant Testing

As shown in a series of field trials, electroplating a thin layer of chromium onto the surface of reactor components can reduce the incorporation of radionuclides that contribute to occupational radiation exposure at nuclear power plants. EPRI-sponsored researchers have observed significantly lower dose rates from chromium-coated manway seal plates (installed as part of steam generator replacement projects) at three U.S. PWRs and from chromium-coated sections of reactor water cleanup system piping at a U.S. BWR.

The chromium-coating process involves electropolishing the surface of a component, electroplating hexavalent chromium onto it, and then oxidizing the component in moist air. In the first plant applications, the standard plating approach was used. Now under development are plating techniques for larger components, such as steam generator channel heads, and components with complex shapes, such as valve internals. An EPRI report (TR-111666) presents the most recent technology developments and in-plant monitoring results.

The EPRI researchers made dose rate and gamma spectroscopy measurements on chromium-coated components placed in service earlier at the nuclear plants. Dose reduction factors were about 15–20 for chromium-coated manway seal plates at one PWR after exposure for an 18-month fuel cycle. Measurements after exposure for another third of a cycle showed the improvement factor to range from 5 to 10. At the other two PWRs, dose rate measurements for the chromium-coated seal plates showed reductions of more than a factor of 10, compared with electropolished-only seal plates. Gamma spectroscopy indicated that cobalt-58 accounted for most of the deposited activity; cobalt-60 and chromium-51 accounted for the rest.

After several hundred hours, contact dose rates at a BWR that operates on hydrogen water chemistry fell from a few thousand millirems per hour (measured on the original carbon steel pipe) to 10–20 millirems per hour (measured on the chromium-coated stainless steel pipe). In contrast, the measured reduction in dose rates on chromium-coated test spools installed in BWRs operating on normal water chemistry was small.

The researchers also evaluated two alternative approaches for electroplating hexavalent chromium coating onto the internal surfaces of 4-inch (10-cm) valves. On the basis of visual inspection, both electroplating techniques were effective. The New York Power Authority will chromium-coat sections of reactor water cleanup system piping and some valve internals at its FitzPatrick BWR during the plant's spring 2000 outage.

"Data obtained from components that have been placed in service in commercial nuclear plants operating in reducing environments continue to show the significant benefits of electroplated chromium in reducing radioactivity deposition," says Howard Ocken, EPRI manager for radiation control. "The reductions in activity deposition on manway seal plates are impressive—typically a factor of 10 lower on chromium-coated surfaces than on electropolished surfaces. The effectiveness of chromium coating has led two utilities to request that bids for replacement steam generators include chromium coating of the entire channel head surface. Another utility is looking to use the process to coat pump components."

A chromium-plated valve body

■ *For more information, contact Howard Ocken, hocken@epri.com, (650) 855-2055.*

Fuel Cell Performs Well on Anaerobic Digester Gas

Phosphoric acid fuel cells (PAFCs) can convert the methane-rich anaerobic digester gas (ADG) produced at municipal waste treatment plants to electricity at an efficiency of 40%, using a gas cleanup system developed through a joint effort of the New York Power Authority (NYPA), the New York State Energy Research and Development Authority, the U.S. Department of Energy, and EPRI. In a successful field test at the Yonkers wastewater treatment plant in Westchester County, New York, a commercial 200-kW PAFC unit modified for ADG use and equipped with the cleanup system is converting about 50% of the plant's excess digester gas. This technology produces no emissions of methane, a significant greenhouse gas, and limits emissions of nitrogen oxides to below 1 part per million (ppm).

The ADG produced in U.S. waste treatment plants is approximately 60% methane; this translates to about 5 cubic feet (0.14 m^3) of methane per person in the country per day, enough to fuel a power plant of at least 500 MW. At the treatment plant, ADG is frequently burned in boilers to heat the digesters or in engines to generate power. Unused gas is typically flared to avoid atmospheric emissions of methane. But flaring ADG still contributes carbon dioxide to the atmosphere without creating a useful by-product—either electricity or heat.

To be usable as a fuel for producing electricity, ADG requires some cleanup. Less cleanup is needed for use in engines than in fuel cells, but engines are less efficient than fuel cells, produce more emissions, and have higher operating and maintenance costs.

As part of their effort to demonstrate effective, efficient PAFC operation on ADG at the Yonkers treatment plant, the project sponsors funded the development of a gas cleanup system. The plant's ADG contains about 60% methane, 37% carbon dioxide, and 500 ppm of hydrogen sulfide, which is a poison to fuel cell systems and must be removed to below 4 ppm.

In the Yonkers cleanup system, hydrogen sulfide is absorbed in an activated-carbon bed, and the spent carbon is landfilled. (For larger systems, the carbon bed can be regenerated.) The system has performed satisfactorily since April 1997, with the activated-carbon filters requiring replacement approximately every four months. Broad variations in the ADG's methane concentration have led to power fluctuations between 85% and 100% of the PAFC's rated capacity. O&M costs have been approximately \$0.015–\$0.02/kWh, and all emissions have been at or below predicted levels.

"Application of the emerging technology of fuel cells with a nontraditional fuel like ADG requires organizations that are willing to take risks to obtain the increased benefits of reduced emissions," says John O'Sullivan, EPRI manager for distributed generation technologies. "Since the EPRI-NYPA application at the Yonkers wastewater treatment plant, another utility has successfully installed a fuel cell running on ADG. Also, at other sites, NYPA plans to install three PAFC units that will use natural gas."

■ *For more information, contact John O'Sullivan, johsulli@epri.com, (650) 855-2292.*

Technical Reports & Software

To place an order, call EPRI Customer Service at (800) 313-3774 or (650) 855-2121, and press 1 for software or 2 for technical reports.

Energy Delivery

Location of Faults on Primary Distribution Systems With Multiple "Tee" or "Y" Connections, Vol. 2: Final Report of Field Trials
TR-106267-V2
Target: Distribution Systems
EPRI Project Manager: H. Ng

Overvoltages in Underground Systems: Phase 2 Results
TR-109669-R1
Target: Distribution Systems
EPRI Project Manager: R. Bernstein

Improved Lightning Arrestor Protection Results: Final Results
TR-109670-R1
Target: Distribution Systems
EPRI Project Manager: R. Bernstein

Central and South West Services Transmission System Studies: Rio Grande Valley FACTS Studies
TR-111048
Target: Grid Operations and Planning
EPRI Project Manager: D. Maratukulam

Battery Monitoring System, Phase 4: Field Evaluation
TR-111092
Target: Substations
EPRI Project Manager: S. Eckroad

Ramapo Static Electrification Tests (EPRI and Consolidated Edison Co. of New York)
TR-111386
Target: Substations
EPRI Project Manager: S. Lindgren

Power Transformer Oil Leak Mitigation: Technology Assessment
TR-111593
Target: Substations
EPRI Project Manager: P. Dessureau

Lessons Learned From Substation Predictive Maintenance Project (TC Project 7014)
TR-111594
Target: Substations
EPRI Project Manager: P. Dessureau

Longitudinal Load and Cascading Failure Risk Assessment (CASE): BPA's 230/500-kV Longview-Olympia Transmission Line
TR-111660
Target: Overhead Transmission
EPRI Project Manager: M. Ostendorp

Distribution Systems Redesign
TR-111683
Targets: Distribution Systems; Underground Distribution Infrastructure
EPRI Project Manager: H. Ng

Transmission Cable Life Evaluation and Management
TR-111712
Target: Underground Transmission
EPRI Project Manager: W. Zenger

Options for Reducing Environment-Related Utility Costs Associated With Dielectric Fluids in Cables and Transformers
TR-111722
Target: Underground Transmission
EPRI Project Manager: D. Von Dollen

Power System Disturbance Prediction
TR-111740
Target: Distribution Systems
EPRI Project Manager: D. Richardson

Southwestern Indiana Disaster Recovery Business Alliance: An Interim Report
TR-111861-V1
Target: Disaster Planning and Mitigation Technologies
EPRI Project Manager: J. Oggerino

Dynamic Security Assessment Functional Specification
TR-112055
Target: Grid Operations and Planning
EPRI Project Managers: D. Sobajic, P. Hirsch

Development of the Platform-Mounted Dynamic Voltage Restorer
TR-112114
Target: Distribution Systems
EPRI Project Manager: A. Sundaram

Energy Utilization

Investigation of R-22 Low-Temperature Refrigeration for Supermarkets
TR-104366
Target: Retail/Supermarket Establishment Solutions (EPRICSG)
EPRI Project Manager: M. Khattar

Predicting Customer Choices Among Electricity Pricing Options, Vol. 2: Retail Markets
TR-108864-V2
Target: Producing Successful Retail Products and Services
EPRI Project Managers: A. Faruqui, P. Meagher

Government Facilities Segment Analysis
TR-110968
Target: Education and Government Facilities Solutions (EPRICSG)
EPRI Project Manager: B. Lindsay

Trouble-Shooting Guide for Low-Voltage ASD/Motor Systems
TR-111097
Target: New Electric Motor/Drive Markets and Solutions
EPRI Project Manager: B. Banerjee

Supermarket Simulation Tool Version 2.0: Installation and User Guide
TR-111112-R2
Target: Retail/Supermarket Establishment Solutions (EPRICSG)
EPRI Project Manager: M. Khattar

Desk Book: Residential End-Use Technologies (for Windows)
AP-111493
Targets: All residential targets
EPRI Project Manager: J. Kesselring

Lodging Industry Solutions: Heating and Cooling Space-Conditioning Technology
TR-111676-V1
Target: Lodging and Hospitality Industry Solutions
EPRI Project Manager: A. Saleh

Static Transfer Switch Primer
TR-111697
Target: End-Use Power Quality Mitigation Systems
EPRI Project Manager: B. Banerjee

Medium-Voltage (2300/4260-V) Adjustable-Speed Drive Ride-Through Options and Implementation Methods
TR-111760
Target: New Electric Motor/Drive Markets and Solutions
EPRI Project Manager: B. Banerjee

Testing and Analysis of the Single-Phase Written-Pole Motor
TR-111772
Target: New Electric Motor/Drive Markets and Solutions
EPRI Project Manager: B. Banerjee

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

Photocatalysis: An Analysis of Its Applications and Market Potential
TR-111898
Target: Enhancing the Success of Innovative Customer Technologies (EPRICSG)
EPRI Project Manager: B. Kalweit

Ozonated Laundry: An Analysis of Its Applications and Market Potential
TR-111899
Target: Enhancing the Success of Innovative Customer Technologies (EPRICSG)
EPRI Project Manager: B. Kalweit

650 V DC Ride-Through System Ultra Capacitor Version: System Description and Test Results
TR-111919
Target: New Electric Motor/Drive Markets and Solutions
EPRI Project Manager: B. Banerjee

COSS Service Bureau: Advanced Billing and Customer Systems
TR-111924
Target: Advanced Billing and Customer Operations Systems (EPRICSG)
EPRI Project Manager: D. Cain

Energy Market Profiles: 1997 Commercial (Vol. 1); 1997 Residential (Vol. 2); Industrial (Vol. 3)
TR-111946-V1–V3
Target: Understanding Energy Markets (EPRICSG)
EPRI Project Manager: R. Gillman

Evaluation of Ride-Through Options for Adjustable-Speed Drives
TR-111952
Target: Power Quality
EPRI Project Manager: W. Moncrief

Chiller Performance Evaluation Report
TR-111981
Target: Commercial Building Chillers (EPRICSG)
EPRI Project Manager: B. Lindsay

Demonstration and Testing of a Low-Temperature Compressor Waste Heat Regenerated Desiccant Dehumidification System
TR-111990
Target: Commercial Building Heat Pump Technology
EPRI Project Manager: M. Khattar

Assessment of High-Performance AC Motor Drives Versus DC Motor Drives
TR-112111
Target: Power Electronics (EPRICSG)
EPRI Project Manager: B. Banerjee

Refrigerated Display Case Demand Defrost Controller: Field Demonstration Results
TR-112121
Target: Retail/Supermarket Establishment Solutions (EPRICSG)
EPRI Project Manager: M. Khattar

■ ESPRE: EPRI Simplified Program for Residential Energy
Version 1.0 (Windows 95, 98, NT)
Targets: All residential targets
EPRI Project Manager: J. Kesselring

Environment

Low-Volume Wastes With High-Volume Coal Combustion By-Products: P4 Site
TR-108420
Target: Groundwater and Combustion By-Products Management
EPRI Project Manager: A. Quinn

Watershed Analysis Risk Management Framework
TR-110709
Target: Watershed Risk Management and Ecosystem Protection
EPRI Project Manager: R. Goldstein

Mineral Oil Transport and Fate Investigation at Franklin Station
TR-111238
Target: T&D Soil and Water Issues
EPRI Project Manager: M. McLearn

Using RAMAS® Methods to Solve Ecological Problems Facing Utilities
TR-111387
Target: Assessment Tools for Clean Water Act and Impoundment Issues
EPRI Project Manager: R. Goldstein

Interlaboratory Validation of EPA 1600 Series Methods: Draft EPA Method 1631 for Analysis of Mercury in Water by Oxidation, Purge and Trap, and CVAFS
TR-111424
Target: Plant Multimedia Toxics Characterization (PISCES)
EPRI Project Manager: B. Nott

Delineation of Coal Tar Dense Nonaqueous Phase Liquid and Groundwater Plumes at a Former Manufactured Gas Plant Site
TR-111537
Target: MGP Site Remediation and Health Risk
EPRI Project Manager: A. Quinn

Passive Shielding System for the NYPA 345-kV Cross-State Corridor
TR-111718
Target: EMF Management
EPRI Project Manager: F. Young

User's Guide for MYGRT™ 3.0: Software for Simulating Migration of Organic and Inorganic Chemicals in Groundwater
AP-111748
Target: Groundwater and Combustion By-Products Management
EPRI Project Manager: A. Quinn

Proceedings: 13th International Symposium on Use and Management of Coal Combustion Products (Vols. 1–3)
TR-111829-V1–V3
Targets: Groundwater and Combustion By-Products Management; MGP Site Remediation and Health Risk; T&D Soil and Water Issues
EPRI Project Manager: D. Golden

Nontoxic Biofouling Control Technologies
TR-111830
Target: Power Plant Water Management
EPRI Project Manager: K. Zammit

Assessment of Coal Cleaning for Trace Element Control
TR-111852
Target: Plant Multimedia Toxics Characterization (PISCES)
EPRI Project Manager: B. Toole-O'Neil

American Eel Scoping Study: Literature and Data Review of Life History, Stock Status, Population Dynamics, and Hydroelectric Impacts
TR-111873
Target: Various environmental targets
EPRI Project Manager: D. Dixon

Effects of Sulfate Concentration on Acute Toxicity of Selenite and Selenate to Invertebrates and Fish
TR-111878
Target: Water Toxics Assessment
EPRI Project Manager: R. Carlton

Regional Climate Simulations for Impact Assessment: PIRCS (Project to Intercompare Regional Climate Simulations) Interim Report
TR-111887
Target: Assessment of Potential Impacts of Global Climate Change
EPRI Project Manager: C. Hakkarinen

Magnetite-Based Biological Effects in Animals: Biophysical, Contamination, and Sensory Aspects
TR-111901
Target: EMF Health Assessment
EPRI Project Manager: C. Rafferty

Biochemical and Hormonal Evaluation of Pineal Glands Exposed in Vitro to Magnetic Fields
TR-111913
Target: EMF Health Assessment
EPRI Project Manager: C. Rafferty

■ LARK-TRIPP: Toxic Release Inventory Estimation Tool for Power Plants
Version 1.0 (Windows 95, NT)
Target: Groundwater and Combustion By-Products Management
EPRI Project Manager: A. Quinn

■ SmartPlaces
Version 4.0 (Windows 95)
Target: Environmental Assets Management
EPRI Project Manager: P. Radcliffe

Fossil and Renewable Generation

Predictive Maintenance Guidelines, Vol. 3: PDM Implementation Plan
TR-103374-V3
Target: Plant Maintenance Optimization (EPRIGEN)
EPRI Project Manager: R. Pflasterer

Simulator Procurement Guidelines for Fossil Power Plants: Simulator Specifications
AD-103790
Target: Simulators, Training, and Production Automation
EPRI Project Manager: M. Perakis

Fixed Costs of Providing Ancillary Services From Power Plants: Reactive Supply and Voltage Control, Regulation and Frequency Response, Operating Reserve Spinning
TR-107270-V5
Targets: Repowering Strategies (EPRIGEN); Generation Asset Management (EPRIGEN)
EPRI Project Manager: J. Stein

Streamlined Reliability-Centered Maintenance (SRCM) Implementation Guidelines
TR-109795-V2
Target: Plant Maintenance Optimization (EPRIGEN)
EPRI Project Manager: R. Pflasterer

Enhancement of the Accuracy of Steam Temperature Measurement by ESKOM
TR-110712
Target: Instrumentation and Control
EPRI Project Manager: M. Perakis

Power Plant Optimization Guidelines
TR-110718
Target: Coal Boiler Performance/Combustion NO_x Control
EPRI Project Manager: J. Stallings

High-Resolution Pyrometry Measurements on a GE Frame 7FA Gas Turbine at the Wabash River Repowering Project
TR-111085
Target: New Combustion Turbine/Combined-Cycle Design and Risk Mitigation (EPRIGEN)
EPRI Project Manager: N. Holt

Updated Cost and Performance Estimates for Clean Coal Technologies
TR-111210
Target: Coal Power Systems Development
EPRI Project Manager: N. Holt

Clean Coal Technology Demonstration Projects: Operating Experience and Risk Assessment Through September 1998
TR-111212
Target: Coal Power Systems Development
EPRI Project Manager: N. Holt

Resource Allocation Tool 1.0 User's Guide
AT-111336
Target: Generation Asset Management (EPRIGEN)
EPRI Project Manager: D. Gray

Proceedings: Workshop on Corrosion of Steam Turbine Blading and Disks in the Phase Transition Zone
TR-111340
Target: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Managers: R. Dooley, T. McCloskey

EPRI Generation Asset Management 1998 Conference: Opportunities and Challenges in the Electric Marketplace
TR-111345
Target: Generation Asset Management (EPRIGEN)
EPRI Project Managers: D. Gray, D. Rastler

Proceedings: 1998 NO_x Control Workshop
TR-111356
Target: Coal Boiler Performance/Combustion NO_x Control
EPRI Project Manager: D. O'Connor

Central and South West Wind Power Project Second-Year Operating Experience (1997–1998): DOE-EPRI Wind Turbine Verification Program
TR-111436
Target: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: C. McGowin

Green Mountain Power Wind Power Project First-Year Operating Experience (1997–1998): DOE-EPRI Wind Turbine Verification Program
TR-111437
Target: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: C. McGowin

Wisconsin Low-Wind-Speed Turbine Project Development: DOE-EPRI Wind Turbine Verification Program
TR-111438
Target: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: C. McGowin

Integration of Distributed Resources in Electric Utility Distribution Systems: Distribution System Behavior Analysis for Suburban Feeder
TR-111490
Target: Distributed Resources for Energy Services and Delivery Enhancement
EPRI Project Manager: F. Goodman

Integration of Distributed Resources in Electric Utility Distribution Systems: Functional Definition for Communication and Control Requirements
TR-111491
Target: Distributed Resources for Energy Services and Delivery Enhancement
EPRI Project Manager: F. Goodman

Minimizing Slagging for Combustion of Powder River Basin Coals
TR-111498
Target: Coal Boiler Performance/Combustion NO_x Control
EPRI Project Manager: A. Mehta

Low-Load, Low-Airflow Optimum Control Applications
TR-111541
Target: I&C and Automation for Improved Plant Operations (EPRIGEN)
EPRI Project Manager: R. Shankar

Distributed Generation Implementation Guidelines: Operations, Maintenance, and Training
TR-111544
Target: Distributed Resources for Energy Services and Delivery Enhancement
EPRI Project Manager: J. O'Sullivan

Distributed Generation Implementation Guidelines: Siting, Environmental Permitting, and Licensing
TR-111545
Target: Distributed Resources for Energy Services and Delivery Enhancement
EPRI Project Manager: J. O'Sullivan

Boiler Condition Assessment Guideline
TR-111559
Target: Boiler Life and Availability Improvement
EPRI Project Manager: R. Tilley

Preliminary Design and Cost Structure of a 50-kW Polymer Electrolyte Membrane Fuel Cell (PEMFC) System for Stationary Applications
TR-111584
Target: Distributed Resources Hardware Development for Retail Markets (EPRIGEN)
EPRI Project Manager: J. O'Sullivan

Thermal Performance of the ABB GT24 Gas Turbine in Peaking Service at the Gilbert Station of GPU Energy
TR-111644
Target: New Combustion Turbine/Combined-Cycle Design and Risk Mitigation (EPRIGEN)
EPRI Project Manager: J. Scheibel

Testing and Performance of the Seimens V84.3A Gas Turbine in Peaking Service at Hawthorn Station of Kansas City Power & Light Company
TR-111645
Target: New Combustion Turbine/Combined-Cycle Design and Risk Mitigation (EPRIGEN)
EPRI Project Manager: J. Scheibel

Development of a 70-kW Gas Turbine System as Prime Mover for Multiple Applications
TR-111675
Target: Distributed Resources Hardware Development for Retail Markets (EPRIGEN)
EPRI Project Manager: J. O'Sullivan

Polymer Electrolyte Membrane (PEM) Fuel Cell/Uninterruptible Power Supply (UPS) Development for Electric Utility Battery Replacement Markets
TR-111678
Target: Distributed Resources Hardware Development for Retail Markets (EPRIGEN)
EPRI Project Manager: J. O'Sullivan

Methods and Guidelines for Assessing the Feasibility of District Energy Projects
TR-111694
Target: District Energy/Load Retention and Growth
EPRI Project Manager: D. Gray

Methods and Guidelines for Assessing Customer District Energy Needs
TR-111695
Target: District Energy/Load Retention and Growth
EPRI Project Managers: W. Piulle, D. Gray

Development of Fireside Performance Indices
TR-111755
Target: Coal Boiler Performance/Combustion NO_x Control
EPRI Project Manager: A. Mehta

Pilot Plant Assessment of Blend Properties and Their Impact on Critical Power Plant Components
TR-111756
Target: Coal Boiler Performance/Combustion NO_x Control
EPRI Project Manager: A. Mehta

Competitive Generation Market Study: California
TR-111857
Target: Repowering Strategies (EPRIGEN)
EPRI Project Manager: J. Scheibel

Predictive Maintenance Program Implementation Experience
TR-111915
Target: Plant Maintenance Optimization (EPRIGEN)
EPRI Project Manager: R. Pflasterer

Infrared Thermography Anomaly Assessment
TR-111916
Target: Plant Maintenance Optimization (EPRIGEN)
EPRI Project Manager: R. Pflasterer

Quantifying the Market for Distributed Resource Technologies: Profiles of the Specialty Chemicals, Food Processing, Electronics, and Hotel Industries
TR-111962
Target: Distributed Resources for Energy Services and Delivery Enhancement
EPRI Project Manager: D. Herman

Progress Report on Development of NDE for Corrosion-Fatigue Cracking
TR-112107
Target: Boiler Life and Availability Improvement
EPRI Project Manager: R. Tilley

CBAM: Cost-Benefit Analysis Module
Version 2.0 (Windows 3.1)
Target: Plant Maintenance Optimization (EPRIGEN)
EPRI Project Manager: R. Pflasterer

Nuclear Generation

Handbook for Verification and Validation of Digital Systems: Revision 1
TR-103291-R1; TR-103291-CD
Target: Nuclear Power
EPRI Project Manager: R. Torok

User's Guide for Steam Generator Analysis Package—ATHOS/SGAP
TR-105253-R1
Target: Nuclear Power
EPRI Project Manager: G. Srikantiah

Method to Monitor Assembly of High-Pressure Bolted Connections
TR-106827
Target: Nuclear Power
EPRI Project Managers: J. Jenco, N. Hirota

P-T Calculator for Windows User's Manual, Version 3.0 (Revision 0)
TR-107450
Target: Nuclear Power
EPRI Project Manager: S. Rosinski

Stress Indices for Elbows With Trunnion Attachments
TR-107453
Target: Nuclear Power
EPRI Project Manager: R. Carter

Valuation and Management of Nuclear Assets: Nuclear Options Model (NOM, Version 1.0)
TR-107541
Target: Nuclear Power
EPRI Project Managers: R. Goldberg, G. Sliter

Methodology to Assess the Economic Feasibility of Implementing Risk-Informed In-Service Inspection (RI-ISI) Programs
TR-107613
Target: Nuclear Power
EPRI Project Manager: J. Mitman

Yankee Rowe Decommissioning Experience Record, Vol. 2
TR-107917-V2
Target: Nuclear Power
EPRI Project Manager: C. Wood

Application of Alternative Method for Performing Regulatory Guide 1.154 PTS Risk Analysis to Beaver Valley Unit 1
TR-107954
Target: Nuclear Power
EPRI Project Manager: R. Carter

BWR Iron Control Monitoring: Interim Report
TR-108737
Target: Nuclear Power
EPRI Project Manager: P. Frattini

Development of a Steam Generator Heated-Crevice Monitor
TR-108755
Target: Nuclear Power
EPRI Project Manager: P. Millett

MAAP-4N: Modular Accident Analysis Program Developmental Version With I-D Neutronics Capability
TR-108796
Target: Nuclear Power
EPRI Project Manager: J. Chao

Review of Experience With the EPRI DFD Process: Decontamination for Decommissioning of Reactor Coolant Systems and Plant Components
TR-109036
Target: Nuclear Power
EPRI Project Manager: C. Wood

Monitoring Performance of Valves With NOREM Hardfacing
TR-109345
Target: Nuclear Power
EPRI Project Manager: H. Ocken

Cost Reduction Strategies for Mixed Waste
TR-109449
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

PWR Shutdown Chemistry Practices
TR-109569
Target: Nuclear Power
EPRI Project Manager: P. Frattini

Guidance on Routine Preventive Maintenance for Magne-Blast Circuit Breakers (Supplement to NP-7410-V2P2)
TR-109641
Target: Nuclear Power
EPRI Project Manager: J. Sharkey

Microstructural Characterization of RPV Steels: Summary of Phases 1 and 2 and Program Plan for 1999–2004
TR-110086
Target: Nuclear Power
EPRI Project Manager: R. Carter

Nuclear Reactor Piping Failures at U.S. Commercial LWRs, 1961–1997
TR-110102
Target: Nuclear Power
EPRI Project Manager: J. Mitman

Piping System Reliability and Failure Rate Estimation Models for Use in Risk-Informed In-Service Inspection Applications
TR-110161
Target: Nuclear Power
EPRI Project Manager: J. Mitman

Stress Indices for Straight Pipe With Trunnion Attachments
TR-110162
Target: Nuclear Power
EPRI Project Manager: R. Carter

High Range Radiation Monitor Cable Study: Phase 1
TR-110379
Target: Nuclear Power
EPRI Project Manager: J. Hutchinson

Eddy Current Analysis Course for Practical Examination, Version 1.0
TR-110389
Target: Nuclear Power
EPRI Project Manager: K. Krzywosz

Stress Intensification Factors and Flexibility Factors for Unreinforced Branch Connections
TR-110996
Target: Nuclear Power
EPRI Project Manager: R. Carter

Proceedings: 1998 EPRI/NEI Decommissioning Technology Workshop
TR-111025
Target: Nuclear Power
EPRI Project Manager: C. Wood

Vibration Fatigue Testing of Socket Welds
TR-111188
Target: Nuclear Power
EPRI Project Manager: R. Carter

MAAP Users Group Meeting Presentations and Meeting Minutes: April 1998 (Vol. 1); October 1998 (Vol. 2)
TR-111240-V1-V2
Target: Nuclear Power
EPRI Project Manager: J. Chao

Instrument Drift Study: Ontario Hydro Bruce Nuclear Generating Station
TR-111348
Target: Nuclear Power
EPRI Project Manager: R. Shankar

Evaluation of Zinc Addition in Cycle 12 at Farley Unit 2
TR-111349
Target: Nuclear Power
EPRI Project Manager: R. Pathania

Updated Template for the Submission of Revised Risk-Based Technical Specifications
TR-111379
Target: Nuclear Power
EPRI Project Managers: F. Rahn, J. Haugh

Mechanism of Hydrogen Pickup in Zirconium Base Alloys, Part 2: Electrochemical Investigations
TR-111384-P2
Target: Nuclear Power
EPRI Project Manager: S. Yagnik

Steam Generator Automated Eddy Current Data Analysis: A Benchmarking Study
TR-111463
Target: Nuclear Power
EPRI Project Manager: J. Benson

Concrete Decontamination Technology Workshop Proceedings
TR-111596
Target: Nuclear Power
EPRI Project Manager: R. Thomas

Field Testing of Chromium Coating Technology
TR-111666
Target: Nuclear Power
EPRI Project Manager: H. Ocken

Qualification of the NP/LOMI Decontamination Process for BWRs Under HWC
TR-111667
Target: Nuclear Power
EPRI Project Manager: H. Ocken

Crack Growth of Alloy 182 Weld Metal in PWR Environments: Interim Report
TR-111993
Target: Nuclear Power
EPRI Project Manager: R. Pathania

Guidelines for Condensed Documentation of a Probabilistic Risk Assessment
TR-112159
Target: Nuclear Power
EPRI Project Manager: F. Rahn

ATHOS/SGAP
Version 2.0 (Windows 95, NT)
Target: Nuclear Power
EPRI Project Manager: G. Srikantiah

Strategic Science and Technology

Transparent Neural Networks
TR-108599
Program: Strategic Science and Technology
EPRI Project Manager: M. Wildberger

Assessment of CBM (Capacity Benefit Margin) and TRM (Transmission Reserve Margin)
TR-110766
Program: Strategic Science and Technology
EPRI Project Manager: P. Hirsch

Genetic Optimization of Neural Network Architectures for Power Industry Problems: Phase 2
TR-110870
Program: Strategic Science and Technology
EPRI Project Manager: M. Wildberger

Predictive Maintenance of NPP Machinery Through Active/Passive Monitoring of Electric Current Frequency Spectra: Proof-in-Principle
TR-110899
Program: Strategic Science and Technology
EPRI Project Manager: R. Kerr

Small-Punch Testing for Nuclear Reactor Vessel Steel Embrittlement
TR-111116
Program: Strategic Science and Technology
EPRI Project Manager: V. Viswanathan

Compact Heat Pump, Refrigeration, and Air Conditioning Systems With Natural Refrigerants
TR-111125
Program: Strategic Science and Technology
EPRI Project Manager: A. Saleh

Assessment of Advanced Batteries for Energy Storage Applications in Deregulated Electric Utilities
TR-111162
Program: Strategic Science and Technology
EPRI Project Manager: S. Eckroad

Electrodistillation: Fundamental Research and Development Program
TR-111326
Program: Strategic Science and Technology
EPRI Project Manager: A. Amarnath

China: Power and Environmental Issues, Options, and Opportunities
TR-111328
Program: Strategic Science and Technology
EPRI Project Manager: N. Holt

Method for Repair of Steam Generator and Heat Exchanger Tubing by Partial Replacement
TR-111355
Program: Strategic Science and Technology
EPRI Project Managers: G. Frederick, S. Findlan

Exploratory Research on MEMS (Micro Electrical-Mechanical Systems) Technology for Air Conditioning and Heat Pumps
TR-111699
Program: Strategic Science and Technology
EPRI Project Manager: A. Saleh

Magnetic Field Shielding Project
TR-111763
Program: Strategic Science and Technology
EPRI Project Manager: F. Young

Net Current Control Device
TR-111764
Program: Strategic Science and Technology
EPRI Project Manager: F. Young

Post-Storm Damage Assessment and Vegetation Monitoring Using Remote Sensing Techniques
TR-111838
Program: Strategic Science and Technology
EPRI Project Managers: M. Ostendorp, R. Bernstein

Environmental Microsensors: A Survey of Current and Potential Applications
TR-111865
Program: Strategic Science and Technology
EPRI Project Manager: F. Young

Robust Analysis and Design as Controls in Power Systems
TR-111922
Program: Strategic Science and Technology
EPRI Project Managers: N. Abi-Samra, C. Nicholas

Use of Stable Mercury Isotopes and Surrogate Tracers to Investigate Source-Receptor Relationships
TR-111977
Program: Strategic Science and Technology
EPRI Project Manager: L. Levin

Identifying Strategic Technologies Based on Your Knowledge of Markets, Competitors, and Leverage
TR-112173
Program: Strategic Science and Technology
EPRI Project Manager: T. Henneberger

EPRI Events

June

15–17
Power Quality Technical Training
Knoxville, Tennessee
Contact: William Berry, (423) 966-5429

15–17
3d Annual ISI and NDE Workshop
Minneapolis, Minnesota
Contact: Sherryl Stogner, (704) 547-6174

15–18
Feedwater Heaters Short Course
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

16–18
Healthcare Initiative Conference
Seattle, Washington
Contact: Kelly Ciprian, (614) 855-1390

17–18
CHUG Meeting
Portland, Maine
Contact: Lynn Stone, (972) 556-6529

20–24
Bioelectromagnetics Society Meeting
Long Beach, California
Contact: Chuck Rafferty, (650) 855-8908

21–22
Meeting of the American Society of Healthcare Engineers
Philadelphia, Pennsylvania
Contact: Kelly Ciprian, (614) 855-1390

21–22
Power Quality Business Opportunities
Knoxville, Tennessee
Contact: William Berry, (423) 966-5429

21–23
Plant Maintenance Conference
Atlanta, Georgia
Contact: Cindy Layman, (650) 855-8763

22–24
Machinery Balancing Short Course
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

22–25
Steam Chemistry: Interaction of Chemical Species
Freiburg, Germany
Contact: Barry Dooley, (650) 855-2458

23–25
5th Piping and Bolting NDE Conference
San Antonio, Texas
Contact: Susan Otto-Rodgers, (704) 547-6072

27–30
Technology Management Workshop
San Francisco, California
Contact: Megan Boyd, (650) 855-7919

28
Water and Energy Conference
Vancouver, Canada
Contact: Kim Shilling, (314) 935-8590

28–July 1
Risk-Informed In-Service Inspection and In-Service Testing Workshops
Cape Cod, Massachusetts
Contact: Susan Otto-Rodgers, (704) 547-6072

29–30
Municipal Water and Wastewater Program Meeting
Vancouver, Canada
Contact: Kim Shilling, (314) 935-8590

29–July 1
Predictive Maintenance Program: Development and Implementation
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

July

6
EPRI's Hydropower Research Program
Las Vegas, Nevada
Contact: Paige Polishook, (650) 855-2010

6–9
WAPA Waterpower '99 Conference
Las Vegas, Nevada
Contact: Paige Polishook, (650) 855-2010

9
EPRI/WAPA Symposium/Workshop: Hydroelectric Sediment Management and Project Decommissioning Issues
Las Vegas, Nevada
Contact: Paige Polishook, (650) 855-2010

12–13
Service Water System Reliability Improvement Seminar
Biloxi, Mississippi
Contact: Elizabeth Marlowe, (704) 547-6036

12–14
International Low-Level-Waste Conference and Exhibit
McAfee, New Jersey
Contact: Michele Samoulides, (650) 855-2127

12–14
NDE Workshop
Palm Beach, Florida
Contact: Ulla Gustafson, (650) 941-8552

12–15
Advanced Structural Analysis and Design Methods for Electric Power Line Upgrading
Dallas, Texas
Contact: Gayle Robertson, (817) 439-5900

12–16
Combined-Cycle Operations for Utility Engineers
Castine, Maine
Contact: Cassandra Maslowski, (816) 235-5623

12–16
Ultrasonic Examination Technology: Level 3
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

13–15
Turbine-Generator Troubleshooting Short Course
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

14–16
ASME/EPRI Radwaste Workshop
McAfee, New Jersey
Contact: Michele Samoulides, (650) 855-2127

19–23
NDE Technical Skills Training: Level 3 Basic/Specific
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

19–23
Steam Plant Operations for Utility Engineers
Castine, Maine
Contact: Cassandra Maslowski, (816) 235-5623

20–21
On-Line Condition Assessment of Generators, Motors, and Plant Electrical Auxiliaries Using Electromagnetic Interference Analysis
Annapolis, Maryland
Contact: Megan Boyd, (650) 855-7919

20–22
Introduction to Computer-Aided Power Plant Control System Analysis
Kingston, Tennessee
Contact: Sherryl Stogner, (704) 547-6174

20–22
Nuclear Utility Procurement
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

20–22
Valve Packing Configuration, Implementation, and Program Development
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

20–23
Infrared Users Group
Toledo, Ohio
Contact: Paul Zayicek, (704) 547-6154

26–28
International Joint Power Generation Conference
San Francisco, California
Contact: Patricia Irving, (800) 843-2763

26–30
Infrared Thermography: Level 2
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

26–30
Terry Turbine Users Group
Sanibel, Florida
Contact: Linda Parrish, (704) 547-6061

26–30
Visual Examination Technology: Level 3
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

27
9th Annual NDE Issues Meeting
Sunset Beach, North Carolina
Contact: Susan Otto-Rodgers, (704) 547-6072

27–29
Instrumentation and Controls Interest Group
Raleigh, North Carolina
Contact: Ramesh Shankar, (704) 547-6127

29–30
In-Service Inspection/In-Service Testing Regional Workshop
Sunset Beach, North Carolina
Contact: Susan Otto-Rodgers, (704) 547-6072

August

2–5
Ultrasonic-Testing Operator Training for Weld Overlay Examination
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

3–5
Advanced Power Quality Workshop
Knoxville, Tennessee
Contact: William Berry, (423) 966-5429

4–6
Radiation Exposure Control Seminar
Seattle, Washington
Contact: Paige Polishook, (650) 855-2010

10–12
Power Plant Pumps Short Course
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

11–13
Service Water Engineer Training
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

16–19
Microbiologically Influenced Corrosion
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

16–20
Mega Symposium: Combined NO_x, SO_2, Particulates, and Air Toxics
Atlanta, Georgia
Contact: Cindy Layman, (650) 855-8763

16–20
NDE Instructor Training
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

17–19
Reliability- and Risk-Centered Maintenance
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

17–19
Rolling Element Bearing Life Improvement
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

17–20
6th Steam Turbine–Generator Workshop
St. Louis, Missouri
Contact: Paul Sabourin, (704) 547-6155

19–20
Flow Measurement
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

19–20
Non-Road Electric Vehicle Conference
Orlando, Florida
Contact: Michele Samoulides, (650) 855-2127

23–27
Westinghouse Circuit Breaker Users Group
Pittsburgh, Pennsylvania
Contact: Linda Parrish, (704) 547-6061

24–26
Advanced Power Quality Workshop
Knoxville, Tennessee
Contact: William Berry, (423) 966-5429

24–26
Charging-Pump Users Group
Charlotte, North Carolina
Contact: Linda Parrish, (704) 547-6061

24–26
Lubricant Oil Analysis
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

24–27
NDE of Fossil Plants
Charlotte, North Carolina
Contact: Melanie Moore, (610) 490-3216

25–27
Air-Operated Valve Workshop
Indian Lakes, Illinois
Contact: Linda Parrish, (704) 547-6061

30–September 3
Condenser Technology Seminar and Conference
Charleston, South Carolina
Contact: Brent Lancaster, (704) 547-6017

September

6–10
Integrated Global Water Management
Prague, Czech Republic
Contact: Robert Brocksen, (303) 840-7389

8–10
Rotating Electrical Machinery Colloquium
Orlando, Florida
Contact: Michele Samoulides, (650) 855-2127

13–17
NDE of High-Energy Piping
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

14–15
Distribution Engineering Workstation Users Group
Kansas City, Missouri
Contact: Harry Ng, (650) 855-2973

14–16
Introduction to Distributed Control Systems
Kingston, Tennessee
Contact: Sherryl Stogner, (704) 547-6174

14–17
Protective Coatings
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

20–21
3d Annual Switching Safety and Reliability Conference
Denver, Colorado
Contact: Sara Lutterodt, (410) 379-8020

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

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

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

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

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

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

October

1
Industry Overview Courses: Inorganic Chemicals, Petrochemicals, Petroleum Production, Pharmaceuticals
TBA
Contact: Sam Woinsky, (713) 963-9336

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

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

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

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

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

12–13
Power Quality Interest Group
Clearwater, Florida
Contact: Terri De Breau, (650) 855-2833

13–15
Healthcare Initiative Conference
Charleston, South Carolina
Contact: Kelly Ciprian, (614) 855-1390

17–20
Gasification Technologies Conference
San Francisco, California
Contact: Michele Samoulides, (650) 855-2127

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

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

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

20
Water and Energy Conference
Nashville, Tennessee
Contact: Kim Shilling, (314) 935-8590

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

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

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

26–27
Water Chemistry and Corrosion Control in Steam Systems
Kingston, Tennessee
Contact: Sherryl Stogner, (704) 547-6174

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

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

November

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

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

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

9–11
Root-Cause Analysis
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

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

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

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

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

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

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

December

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

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

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

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