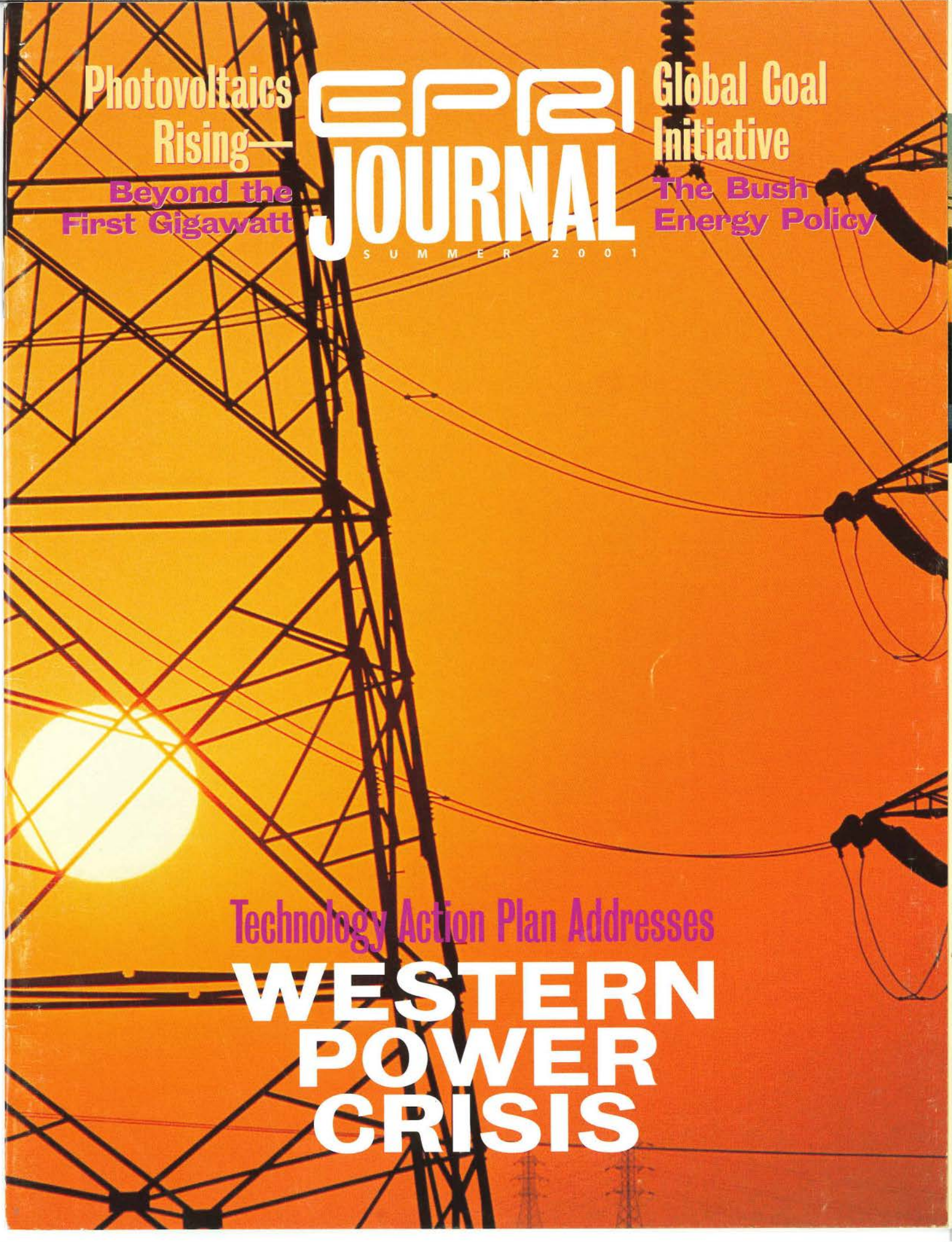
Photovoltaics Rising—
Beyond the First Gigawatt
EPRI JOURNAL
SUMMER 2001
Global Coal Initiative
The Bush Energy Policy
Technology Action Plan Addresses
WESTERN POWER CRISIS

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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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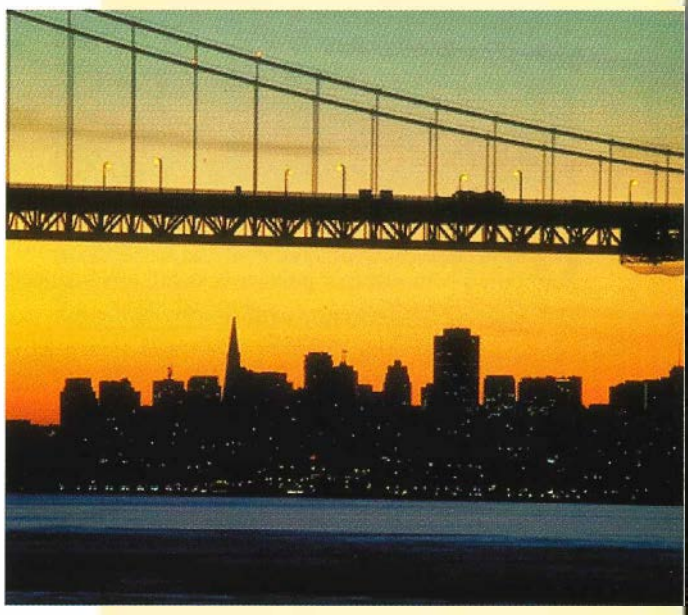

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Guide to Visual Inspection of Non-Ceramic Insulators

Utilities have been using non-ceramic insulators (NCI)—also called composite or polymeric insulators—since the late 1970s, and their use has increased significantly in the past decade. With the large number of these units that have been in service for significant periods of time, utilities are now facing important NCI inspection and maintenance issues. To help in this process, EPRI investigated tools and methods that utility inspectors can use to identify defective NCI prior to failure. One of the best ways is through detailed visual inspection. But inspectors often have limited knowledge of NCI and the types of defects that affect them, so visual inspections are not always effective. EPRI's *Guide to the Visual Inspection of NCI* addresses this problem. Intended for use by inspectors, line crews, engineers, and managers, the eighty-page guide provides descriptions, risk assessments, and recommended actions for twenty-seven types of conditions illustrated by ninety high-quality photographs.

■ *For more information, contact Andrew Phillips, aphillip@epri.com, 413-499-5701 or Judy MacPherson, jmacpher@eprisolutions.com, 413-499-5701. To order the guide (Product ID 1000098), call EPRI Customer Service, 800-313-3774.*

Gas Turbine Environmental Siting Considerations

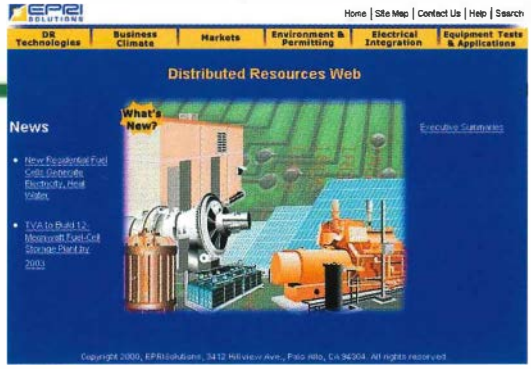
A dramatic upsurge in U.S. gas turbine generating capacity over the past two years is continuing, even in the face of regulatory pressure and technological advances in control equipment that are rapidly driving down emission limits for nitrogen oxides (NO_x) and other pollutants throughout the country. Mandated NO_x levels are now as low as two parts per million in several locations. Power generators need as much relevant information as possible to support technology selection and environmental compliance decisions, where technological and regulatory complexities can significantly delay or add to project costs, or even result in project cancellation. A new report from EPRI presents crucial information for generating companies faced with air quality permitting decisions for combustion turbines in a rapidly evolving technical and regulatory environment. It characterizes the air permitting, emission control, and monitoring requirements for gas turbine projects greater than 20 MW and identifies the current trend in regulatory and permitting actions that could affect the siting of these projects. Turbine technologies include simple-cycle peaking units, cogeneration plants, and combined-cycle plants. The review of NO_x control technologies spans water/steam injection, dry low-NO_x combustion, catalytic combustion, selective catalytic reduction, and emerging technologies such as SCONO™.

■ *For more information, contact Leonard Angello, langello@epri.com, 650-855-7939. To order the report (100065151), call EPRI Customer Service, 800-313-3774.*

Renewable Energy Technical Assessment Guide

Renewable energy resources like wind, solar, and biomass are playing an increasingly strategic role in meeting demand for electricity, whether by supplying energy for green-pricing programs, for sale on the open market, or as part of a utility's generating mix. But the profitability of a renewable energy project is variable and depends on many factors. Evaluating the technical and economic bases for choosing one technology over another can be a complex process. The latest addition to EPRI's *Technical Assessment Guide (TAG)* series provides a basic reference for evaluating commercially available renewable generating technologies, including wind, biomass, solar photovoltaic, geothermal, and solar thermal. Companies can use the guide's up-to-date information to make preliminary capital investment evaluations in a consistent manner. This first edition of the TAG to address renewable technologies exclusively encompasses three decades of EPRI research in renewables. Available in hard copy or on compact disk, the *Technical Assessment Guide: Renewable Energy* will be updated annually.

■ *For more information, contact G. Ramachandran, gramacha@epri.com, 650-855-2722. To order TAG:RE (item 1000574), call EPRI Customer Service, 800-313-3774.*



Distributed Resources

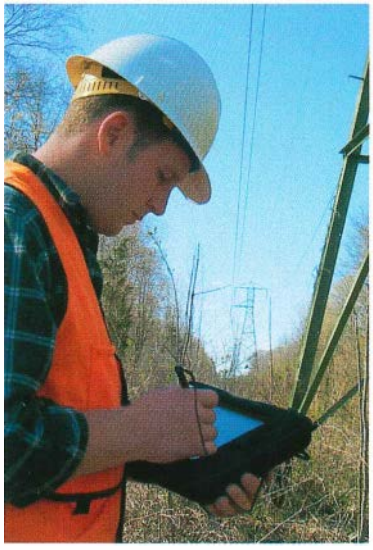
www.disgen.com

EPRIsolutions' Distributed Resources Web is a comprehensive, on-line information resource on all aspects of DR—technologies (fuel cells, microturbines, combustion turbines, reciprocating engines, storage, etc.), market analyses and business strategies, environmental impacts and regulations, field test data and application experiences, electrical integration issues, and more. Distributed power generation is increasingly being considered as an approach for meeting a variety of customer needs, including premium power for enhanced reliability and power quality, peak shaving, cogeneration, and reduced emissions. DR Web provides an organized, searchable encyclopedia of more than 1000 pages of up-to-date information needed by electric utilities, energy service companies, end users, investors, policy makers, and regulators.

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

Transmission Inspection and Maintenance System

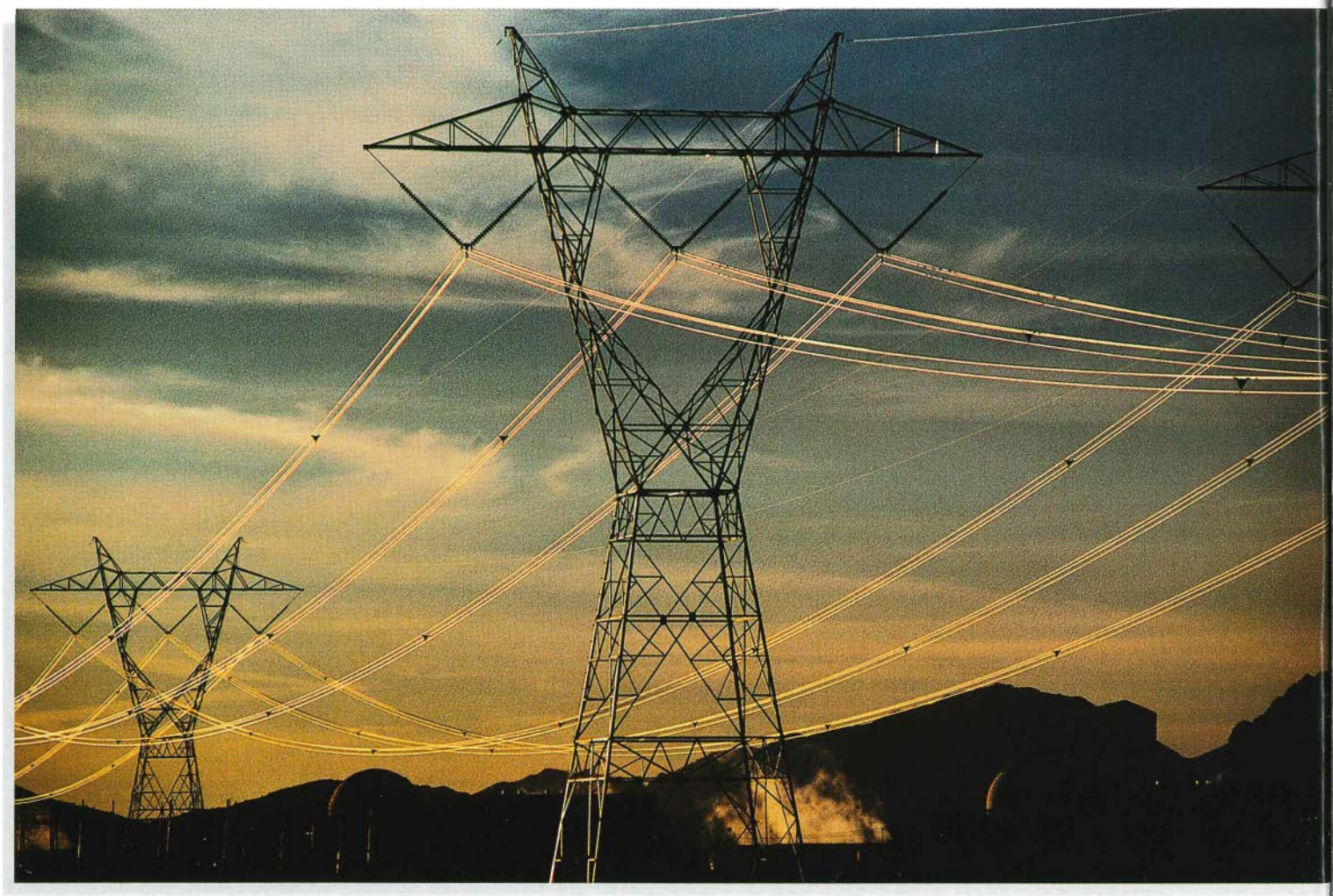
Streamlined inspection and maintenance procedures for overhead transmission systems that help ensure the levels of reliability expected by customers are critical priorities for utilities today. Most utilities still gather inspection data using clipboards and paper forms or their electronic equivalent. But too often, information collected this way is inconsistent and can vary significantly from one inspection to another. As a result, the information is underutilized in transmission line management decisions concerning equipment repair, replacement, and upgrades. EPRI developed an integrated, hand-held computer system for collecting, maintaining, and analyzing line inspection and maintenance data that reduces time, cuts costs, and improves the accuracy of overhead transmission line inspection practices. Called the Transmission Inspection and Maintenance (TIM) System, the pen-based computer quickly records inspection results in the field with a graphic interface that simplifies data input and reduces errors. Users have immediate access to previous inspection and line repair history for reference. First introduced in 1999, the latest version of TIM—(V3.1)—incorporates many functional enhancements and enables improved customization.



■ *For more information, contact Paul Lyons, plyons@epri.com, 817-234-8200, or Don Cannon, dcannon@epri.com, 817-234-8209. To order TIM V3.1, call EPRI Customer Service, 800-313-3774.*

Technology Action Plan Addresses

WESTERN POWER CRISIS



THE ELECTRIC POWER INDUSTRY'S science, technology, and research organization—EPRI—has issued a comprehensive, multi-billion dollar technology action plan for solving market and infrastructure-related issues contributing to the electricity crisis that began last year in California and now involves the 11-state Western power grid, with the potential for spreading further. Noting that electricity is the life-blood of the nation's economy, EPRI says the cost of failing to act promptly could be devastating. The plan, summarized in a white paper, recommends a series of 18 actions to help resolve the current crisis and provide the technological means to put the electricity infrastructure back on a solid footing, capable of meeting the escalating power demands of the twenty-first century.

A comprehensive action plan is proposed for solving technology issues related to the electricity crisis in California and the West.

The plan's recommended actions—spanning the near, intermediate, and longer term—reflect input and consensus from a diverse group of stakeholder representatives in California and other Western states that met at a June 7–8 workshop at EPRI headquarters in Palo Alto. The workshop itself was an outgrowth of EPRI's Electricity Technology Roadmap and discussions at EPRI's annual summer seminar series that have highlighted the vulnerability of the North American power system. The central thesis of the plan is that the present power crisis requires a fundamental reassessment of the critically integrated role technology and policy play in both infrastructure and markets.

"By integrating technology into policy solutions, we're trying to ensure that society continues to be well-served by the electricity infrastructure," says EPRI President and Chief Executive Officer Kurt Yeager. "The California power crisis is part of a larger and growing energy problem in the United States that has resulted from more than a decade of inadequate investment in power generation, transmission, distribution, and customer demand-response programs. The growth of the power system has also failed to keep up with the demands of the digital economy for a reliable supply of high-quality power." Power interruptions and inadequate power quality already cause economic losses to the nation conservatively estimated at more than $100 billion a year.

Supply-demand imbalance precipitated crisis

EPRI's action plan says that major new investment for strengthening the electricity supply and delivery infrastructure is urgently needed to meet the current crisis, while simultaneously building the new infrastructure for the twenty-first century. The costs of failing to act promptly will undermine the economy and quality of life in California and potentially throughout the West.

Rolling blackouts in California are having both direct and indirect impacts on the economy. In terms of direct costs, estimates in the Bay Area run as high as $1 million per minute of lost economic output for

firms in high-tech manufacturing. At least $50 billion will be paid this year for all of the electricity used in California, according to projections by the California Independent System Operator. That is nearly twice the $28 billion paid in 2000 and more than seven times the $7 billion paid in 1999 before the current crisis began. Indirect costs are more difficult to measure, but could be even larger. These include the cumulative impact of rolling blackouts, such as the failure of small businesses, the movement of industry out of the state, and intangibles such as the effect of power outages on public health and safety.

In all likelihood, California will be facing as much as one hundred hours of rolling blackouts this summer, a figure that could grow several fold if power plants are forced offline, or if summer weather is warmer than normal in the West, according to the EPRI report. "A major outage is not out of the question. Critical equipment, such as transformers, will be running at maximum capacity this summer. Failure of a single critical component could result in a major outage spreading throughout the Western Systems Coordinating Council at considerable cost, which, based on recent experience, could result in billions of dollars in lost economic output."

Priorities for short-term action

The action plan developed by EPRI calls for immediately available response measures over the next year to 18 months. Such measures include comprehensive emergency planning for multiple, rolling blackouts (as well as a sustained, region-wide outage); expanded conservation and load management programs—to rapidly curtail demand during power emergencies; the introduction of time-sensitive price signals for the state's larger electricity users; and improved power system maintenance practices.

A number of technology solutions can address specific needs in the generation, delivery, and use of electricity in the mid-term as parts of an integrated package that, together with new market design, would put the power system well on the path to restoring the needed supply/demand balance by 2003, EPRI's White Paper on the Western States Power Crisis notes.

In addition to repairing dysfunctional wholesale markets, actions are recommended to enable retail customer markets to benefit from deregulation and restructuring through market-driven demand response programs such as time-of-use or real-time pricing. Development of consistent standards for regional energy information and forecasts will help foster greater market coordination.

Other key steps recommended for the mid term of 2002–2003 include:

- Upgrade the transmission system, using reliability-centered and other advanced maintenance procedures, greater regional coordination, and new technology to increase throughput capacity. In terms of the latter, power electronic-based FACTS and other transmission technologies pioneered by EPRI could greatly improve the current-carrying capacity, stability and robustness of the western regional power system.
- Accelerate the automation of local power distribution systems to improve reliability of service.
- Upgrade existing power plants to cost-effectively increase capacity in California by up to 5000 megawatts through advanced maintenance, diagnostics, and cost-effective retrofits of key components.
- Expand the use and effectiveness of small, modular forms of distributed generation by accelerating their electrical interconnection with the grid, resolving environmental constraints, and streamlining the siting process.

Transforming the electricity infrastructure

Longer-term objectives, aimed at transforming the electricity infrastructure to be capable of supporting continued growth and diversification of the digital economy, also strengthen a fully functioning, competitive electricity market, according to EPRI. Given the risks in the current, near-exclusive focus on natural gas-fired plants for new capacity, greater fuel diversity must be a regional and national priority.

Beyond 2003, the plan recommends the following actions:

- Undertake a risk assessment of long-term U.S. reliance on gas-fired generation, along with analysis of the value of risk management through fuel diversity.
- Introduce time-varying prices and competitive market dynamics for all customers.
- Undertake regulatory reform of utility distribution systems to provide incentives for technology innovation and accountability for R&D.
- Create a planning process to design power markets that afford better coordination of wholesale and retail markets.
- Establish a regional transmission agency with the authority for siting new lines, upgrading existing lines, and allocating costs.
- Develop and implement a comprehensive architecture for the power supply infrastructure that anticipates the rapidly escalating demands of the twenty-first century digital society.

Few of the recommended actions can be implemented in the absence of an improved investment climate that encourages technology innovation, EPRI notes. Uncertainties surrounding industry restructuring and continued use of cost-plus investment returns have hobbled the flow of advanced technology into the electricity infrastructure, it says. Regulatory reform is needed to stimulate the adoption of technology innovation.

Next steps

EPRI plans to present these technical recommendations to the broad range of public and private stakeholders for their consideration and to seek collaborative funding and joint action for critical assessments and development activities. Critical assessments include accurately benchmarking the full costs of power outages and power quality problems as a point of reference for public/private investments in infrastructure.

EPRI's White Paper on the Western States Power Crisis is available in its entirety on epri.com as an Adobe Acrobat pdf file. ■

For more information, contact Steve Gehl, sgehl@epri.com, (650) 855-2770.

Energizing Customer Demand Response in California

By Taylor Moore

EPRI is helping electricity customers take an active role in addressing California's electricity crisis with the development of a load management system funded by the California Energy Commission. A system developed under the project's initial phase was successfully tested in May, with participating customers demonstrating actual electricity demand reductions. The CEC has since provided additional funding to scale up the system to include many more customers in this load management activity.

If California's capacity-strained generating capabilities and transmission interconnections are the weak links in the state's electricity delivery infrastructure, the lack of responsiveness of customer demand to power shortages and high wholesale prices surely is the market's missing link.

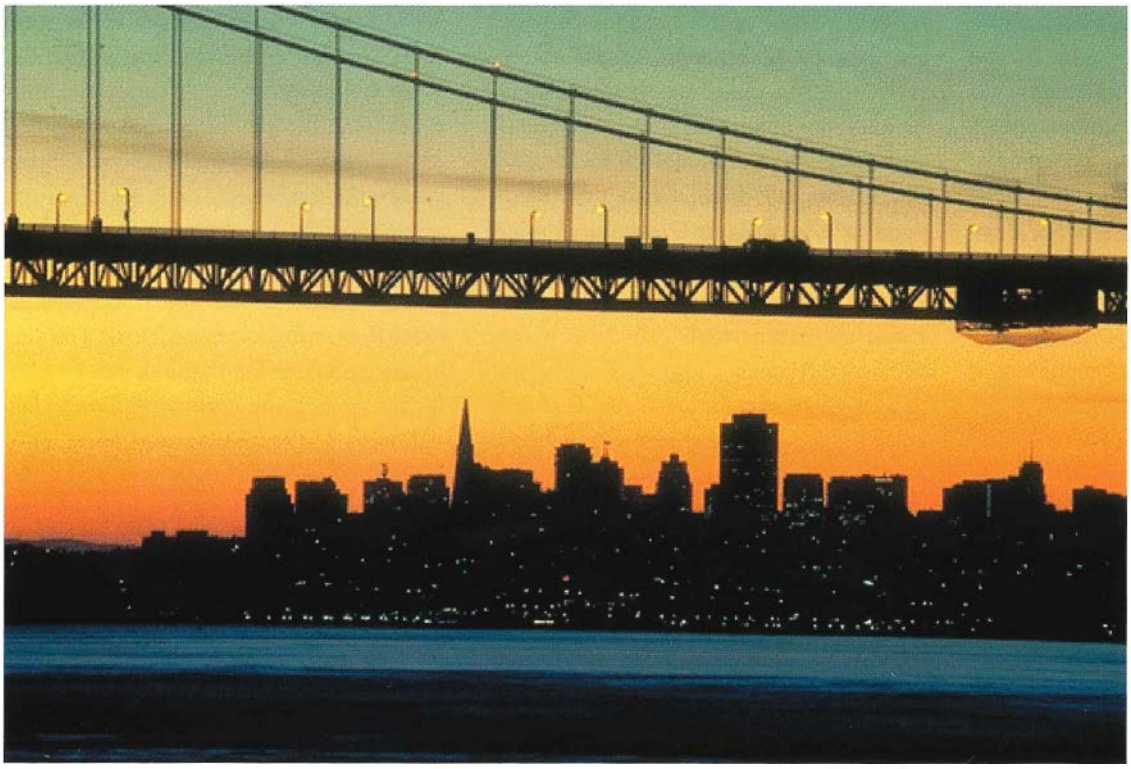
Despite the substantial economic impact that fairly limited rotating blackouts have had thus far, whenever inland temperatures climb above the low 80s Fahrenheit, spurring building and home air conditioning systems into service, California can suddenly find itself several thousand megawatts short of available generating capacity in-state to meet demand.

The freeze on retail rates since deregulation began in March 1998 until this summer, combined with the lack of incentives for utilities to offer innovative retail pricing programs, have ensured that California's daily electricity demand curve remains stiff and inelastic—unresponsive, for the most part, to the market price. Rotating blackouts are a brute force, last-ditch measure available to the grid operator to reduce demand in order to preserve system reliability; even a relatively modest amount of demand responsiveness (e.g., 10% of peak demand) can drastically reduce the frequency and extent of blackouts.

New approaches to pricing and load management—in concert with new technology and operating practices in generation and delivery—can fill the gaps that are missing for a functional competitive electricity market in California. Although 13 new power plants are under construction or in the planning stages, not enough additional generating and transmission and distribution capacity can be brought online by this summer or next to do the job alone.

Load management a near-term solution

As outlined in EPRI's 2001 White Paper on the Western States Power Crisis, the only strategic option that is available now for the near term is to enlist customers to become active participants in balancing supply and demand. Faced with a capacity shortage, the best near-term option is to provide customers an incentive to reduce demand during times of constrained or costly electricity supplies. This reaction to the time-value of electricity can be accomplished through load management programs that make customer electricity demand responsive to price changes. Such programs have the potential for reducing demand substantially, at low cost, and without adverse environmental impacts.



Customers that are willing to pay for the high cost of power would continue to use it at their 'normal' levels, while those that are willing to lower demand or shift demand to lower-cost periods benefit from lower bills. Demand response programs that explicitly incorporate time-dependent price signals to customers include real-time, coincident peak, and time-of-use rates (see article on page 8). Such pricing approaches

encourage customers to invest in technologies and operating practices that will alter their electric demand to relieve generation and T&D constraints. However, a barrier for some customers is the availability and cost of electronic meters with two-way communication that are needed for time-interval recording and price signaling.

Demand response programs also include market-driven load management technologies that give customers the choice of whether to curtail their demand when prices are high. These technologies include automated energy control systems; examples range from inexpensive programmable smart thermostats to energy management computer systems for large buildings. Two-way communication between customers and energy suppliers is a key enabling technology. Another form of demand responsiveness is the growing variety of distributed generating technologies such as cogeneration systems, microturbines, and fuel cells.

Networks enable customer choice

Meanwhile, continuing progress in electronics and computers has resulted in new digital communications technologies that were not available in the early days of utility load management in the 1980s. "By taking advantage of communication system backbones like cellular, paging, and Internet technologies, the new networks enable the provision of customer choice for the first time," says Dr. William M. Smith, manager of market-driven load management at EPRI. "These options can also operate two-way and closed-loop for credible verification of customers' receipt of requests for demand response."

Using demand response technologies, customers can consciously trade off a degree of discomfort, inconvenience, and distraction from normal business against incentives, communications and control technologies, degree of exposure to load management requests, and the like. The impact of such trade-offs—that is, such increased elasticity of demand—can be very significant. An EPRI study concluded that a 2.5% reduction in electricity demand statewide could reduce wholesale spot prices in California by as much as 24%; a 10% reduction might slash wholesale price spikes by half.

Linking markets, customer choice to save megawatts

One of the earliest measures approved by the California Legislature in reaction to the state's electricity crisis last August was a bill designed to encourage greater demand responsiveness and peak load reduction through technological innovation. The California Energy Commission (CEC) administers a variety of load reduction programs funded under the legislation, and the California Independent System Operator (Cal ISO) offers market-based incentive programs for demand reduction as well.

Through its for-profit energy engineering affiliate Global Energy Partners (GEP, a joint venture of EPRI, the Gas Technology Institute, and Daniel, Mann, Johnson and Mendenhall), EPRI is part of one team working under contract for the CEC to implement a system for demand responsiveness in California. Under an initial $1.4 million contract, the team is equipping hundreds of buildings and other facilities statewide that have electricity demand of 200 kW or more with automatic load management devices. When remotely activated, these devices can interact with the customers' lighting control panel, HVAC control panel, or energy management system, instructing them to go into preprogrammed 'curtailment mode'. The system can also notify customers of the need to curtail electric demand through multiple two-way communications platforms to reliably deliver megawatts of demand reduction when called on by the ISO (or other incentive program providers).

Key load management strategies for commercial buildings include raising thermostat settings and dimming non-essential lighting. While the interval meter data is available for most of the participating buildings/facilities, the team hopes to obtain additional assistance from the CEC to install or upgrade interval meters at all program participant locations to be able to collect near-real-time (overnight) data for verifying customer performance.

With GEP as the prime contractor responsible for engineering, assessment, and most customer field work, EPRI is involved in recruiting customers through its network of contacts and in training/technology transfer for building managers in various aspects of load management.

The project's concept and design, systems integration, and initial marketing are the product of Infotility, a small, privately held East Bay Area startup company whose investors include Electricité de France. The Pleasanton, California, company, which calls itself an online energy 'infomediary,' is headed by Joe Desmond, president, a veteran of energy efficiency ventures. "Infotility's focus is on collecting and disseminating high-value, time-sensitive information on supply, demand, and price by designing solutions that work in the marketplace and help create price transparency," says Desmond.

Customer organizations participating in this demand response project include the California Department of General Services' Building and Property Branch, the Association of Bay Area Governments, Los Angeles County, the City of Oakland, and various members of the Silicon Valley Manufacturers Group. Although most participants are office building owners, some are industrial customers, such as a north coast cement plant that can reduce demand by 3 MW by shutting down some production equipment.

The communications and monitoring system that underpins the project continuously synchronizes a database of customer preferences and thresholds with external databases like the ISO's system condition status indicator. Using a variety of user-preferred communications platforms (email, Internet, telephone, fax, wireless pager), the system automatically notifies building owners and tenants whenever electrical emergencies and requests for demand reduction are in effect. Each participant's receipt of notification, and response indicating either intent to reduce demand or to decline the request, are also communicated back to the system.

"We're pursuing permission-based load control, which is similar to permission-

based e-marketing," Desmond explains. "Incorporating two-way communications gives customers some ability to manage the process as curtailment events occur." Customer-specified thresholds for specific action may also include projected day-ahead wholesale price curves. "We designed the system from a customer-centric perspective," adds Desmond. "Our goal is to only give customers the information they need when, where, and how they need it, and to help them use that information to save money and avoid rolling blackouts." The project has a website, www.PowerPact.com, that provides customers with energy-saving tips and educational flash animations to explain concepts such as load shapes and demand elasticity.

System test a success

A test demonstration of the notification and load curtailment system was conducted in late May. About 5000 buildings up and down the state—including around 4000 used or owned by Los Angeles County—participated. About 150–200 of the building sites were equipped with electronic interval meters, from which measurement data would verify actual load reductions. Some of these latter customers have also placed some large building HVAC and office lighting systems under automatic load control that is activated by the curtailment notification signal.

The systems deployed by the various teams funded under the CEC program must provide building operators or utilities the capability to quickly reduce power requirements of HVAC and lighting or other building systems within 30 minutes of a signal from the ISO, local utility, or central dispatcher. Peak load reductions of 10–20% of baseload power requirements are expected of participants.

GEP applies a combination of engineering analysis and building energy simulation modeling to estimate load reductions at buildings not equipped with interval meters. Adjustments are made to account for the effects of previous energy conservation measures. The company also serves as an intermediary between project participants and the various demand reduction incentive programs in which they are enrolled, verifying demand reductions and allocating pro-rated incentive payments.

For the system test, the project's contract with the CEC called for a minimum demand reduction of 12 MW. But participants' estimated demand response exceeded 16 MW which, when confirmed by meter data, will put the project in line for a significant contract performance bonus.

Cement plant pitches in

A late addition among participating customer firms or organizations was RMC Pacific Materials, a cement-plant operator at Davenport just north of Santa Cruz. Previously an interruptible-rate customer of Pacific Gas & Electric, the company is willing to voluntarily curtail electric load during ISO-declared emergencies to help avert system-wide blackouts. Taking part in the system test involved shutting down a finishing mill and some other equipment for RMC Pacific resulting in a 3 MW reduction, while causing minimal disruption to its 24-hour per day, seven day per week operation, according to Greg Galvin, electrical engineer.

"Most of the time we can schedule our downtime and coordinate activities so there is limited negative impact to the plant," says Galvin. "We can curtail a few megawatts without incurring damage or a major system impact, but it means we are producing less product than if we're running at 100 percent of capacity.

"RMC Pacific has not yet decided which route to take with demand reduction incentive programs. Each has its benefits and drawbacks. Our goal is to make as much cement as we can, given the present situation, and not have to pay exorbitant prices for power." Galvin adds. "Although our plans for curtailment programs are uncertain, we have rearranged our scheduled maintenance to peak-demand hours, from the evening and early morning shifts. This allows us to spend less for electricity during the peak-rate times and also helps the grid by not using several megawatts during the afternoon hours."

Expanding the customer base

Greg Wikler, a principal at GEP and manager of the demand response project for the CEC, says he anticipates about 275 buildings or other facilities will be equipped with real-time load monitoring capability by mid-summer, out of a total of several thousand participants in the notification system. The project's contract with the CEC was extended in late May to support a $3 million second phase expansion, which is expected to add an additional 45 MW of demand response capability to the original commitment to deliver 12 MW.

While the CEC demand response project currently is GEP's largest in terms of contract amount, the work is very much in line with the company's engineering expertise and experience. "We're excited about where this work might lead us in the future in terms of where these types of services are going to be needed. We anticipate there will be a need for this same type of consulting, implementation, and technical support in other parts of the country as early as this fall," says Wikler.

According to Desmond, the next technology step under development at Infotility is continuous, real-time streaming of electricity price data to customers over the Internet in a desktop instant messaging application. "The opportunity for peer-to-peer computing applications and the potential benefit it may hold for the energy sector are tremendous," says Desmond, adding that it includes enabling widespread use of real-time pricing directly interfaced with building energy management computers. "The technology we're working on can send real-time price information simultaneously to a large number of customers using the Internet, to any device with a persistent Internet connection, anytime—and that system will be operational very soon."

EPRI's Smith sums up the experience so far: "We're proud that the CEC, electricity customers, and the ISO have placed their confidence in the team and the technologies we have woven together to create the load management system for the next millennium." □

For more information, visit www.PowerPact.com on the Web, or contact Dr. William M. Smith, wmsmith@epri.com, (650) 855-2415.

Real-Time Pricing Could Signal Consumer Conservation

California's current electricity crisis is the result of a confluence of unfortunate developments, not least of which is a fundamental imbalance between the available supply of electricity and growing customer demand throughout the Western states. Other contributing factors were an over-reliance on spot market transactions—and an under-reliance on long-term contracts—for wholesale power purchases, problems in the market- and system-operating entities, a lack of price-responsive demand in the retail electricity market, rising natural gas prices, and the exercise of market power by generators.

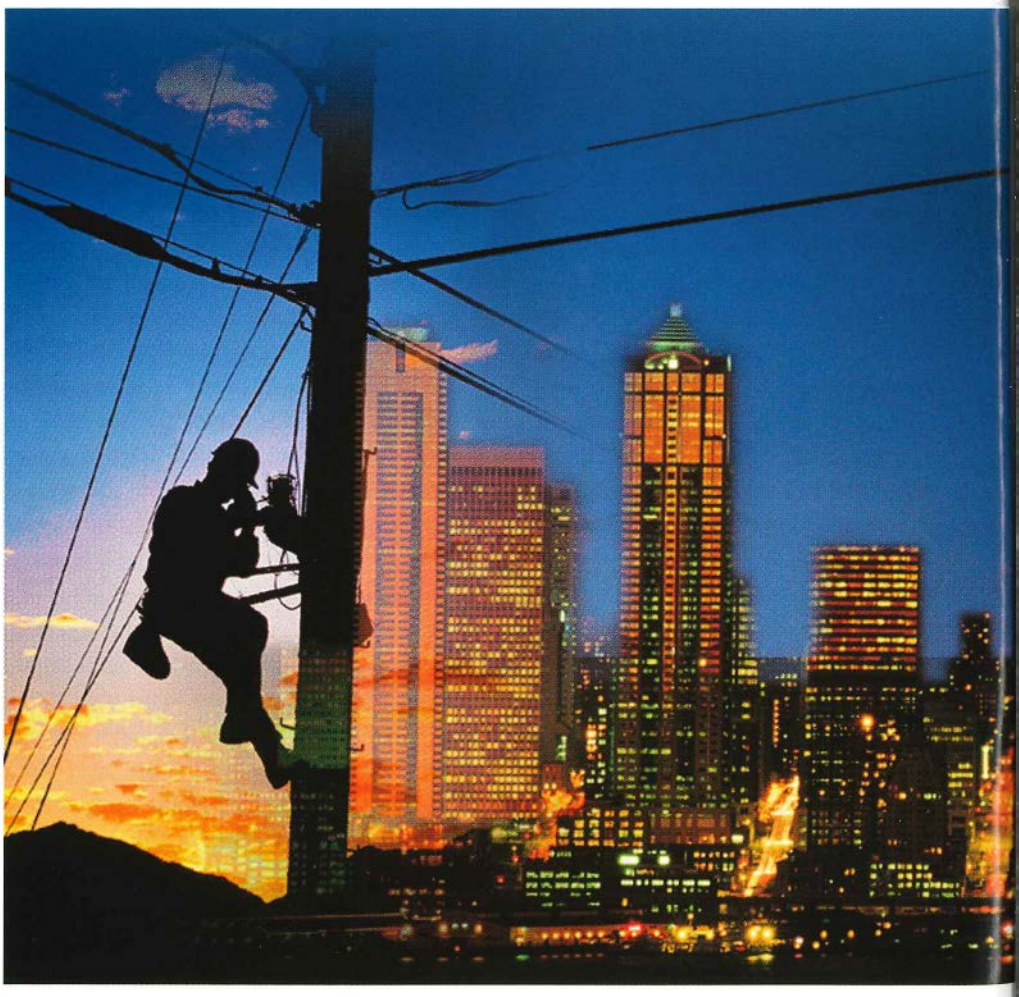
With the benefit of hindsight, many experts agree that a critical flaw in California's deregulation plan was to keep retail consumer rates frozen while wholesale electricity prices were set free to reflect the market interplay of supply and demand. The inability by the state's deregulated utilities to recover the cost of soaring wholesale prices in retail customer rates precipitated a credit and financial crisis for the utilities that eventually forced the state to take over most wholesale power purchasing.

In a bid to avert further blackouts as summer weather approaches this year, authorities in California are pursuing a number of solutions to increase supply and reduce peak demand for electricity. A recent EPRI study highlights the potential for a long-ignored option for achieving a more rational balance between supply and demand. That is, to give large customers so-called real-time, variable prices that reflect the true cost of power at times of peak demand and thus provide an incentive to conserve electricity.

Real-time pricing (RTP)—part of an overall demand-response approach—directly addresses the disconnect between wholesale and retail market prices in California's original electricity market deregulation design. Under RTP, some electricity consumers, primarily large commercial and industrial (C&I) customers who already have time-interval meters, would face hourly prices that reflect wholesale market prices. The response of these customers to the price signals during periods of thin capacity margins and high prices can help relieve the resource constraints and exert downward pressure on the market price.

According to Ahmad Faruqui, EPRI manager for retail and power markets, empirical evidence from customer-testing of RTP in the southeastern United States and in Britain's Midlands region shows that C&I customers respond to hourly prices. Even modest amounts of demand response can lead to significant reductions in wholesale prices when supplies are constrained. Moreover, hourly pricing can be implemented in California—even under the perceived complications of a current rate freeze. In a recent article in *Public Utilities Fortnightly*, Faruqui and co-author Steven Braithwait, a vice president of the consulting firm Christensen Associates, describe how hourly RTP can be compatible with retail rate stability, while giving consumers an incentive to reduce electricity use during high-cost periods.

Faruqui and Braithwait cite results—based on data from limited RTP programs in the United States and Britain, and on actual data from California last summer—suggesting that customer demand response to hourly, market-based retail prices could produce load reductions of 1000 to 2000 MW in California this summer. Such results would also reduce prices during peak summer demand by six to nineteen percent and save between $300 million and $1.2 billion. Thus, demand response to RTP could deliver critical, short-term relief to this summer's looming ca-

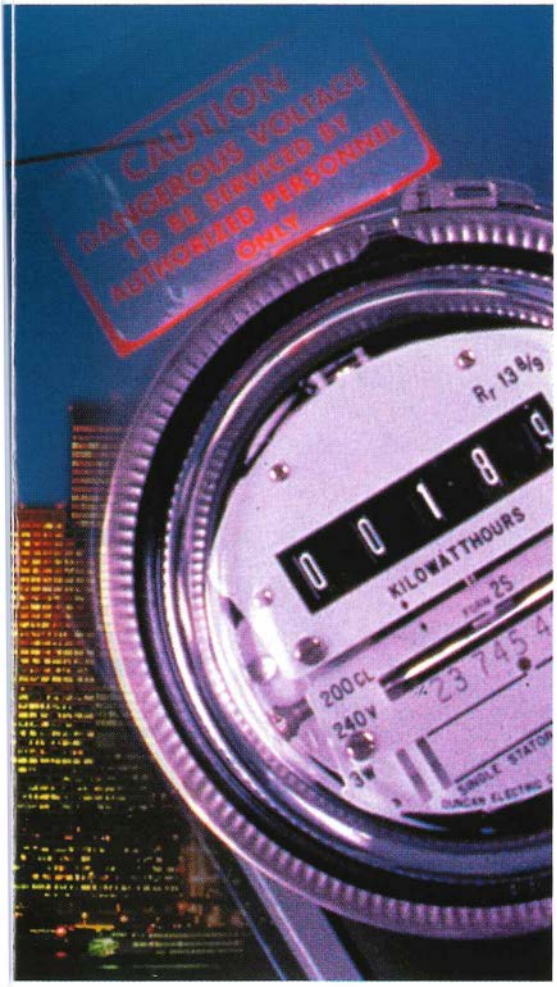


pacity shortages while other efforts are pursued to address the longer-term financial and resource issues.

Approaches to dynamic pricing

Dynamic pricing, in which retail prices vary hourly at least part of the time, can take a number of forms in a competitive energy market. The key difference is the degree to which price risk is shared between the energy supplier and the customer. At one extreme is a guaranteed price offer, in which a supplier bears all financial risk of uncertainty about future prices and customer energy use. At the other extreme is spot pricing, in which all price risk is passed on to the consumer.

To lessen the risk, spot pricing can be combined with mechanisms such as a price cap or forward contract for a certain portion of the customer's load at a fixed, forward-market price. This approach is analogous to two-tier RTP programs in which customers are guaranteed to pay no more or less than a standard tariff price for a baseline level of consumption. But the consumer stands to benefit from hourly prices by using additional electricity beyond the baseline level when prices are low, and reducing consumption when prices are high.



One price structure with a partial guarantee may be viewed as "occasional" spot, or real-time, pricing. For example, a guaranteed price might hold during all hours in which wholesale prices remain below a certain level, but convert to spot pricing whenever the wholesale price exceeds that level. A limit could also be placed on the number of hours in which spot prices would be passed through. Because this type of product reduces suppliers' price risk, they will be able to offer lower prices during the hours under guarantee than for a fully guaranteed-price product.

Occasional spot pricing may also take the form of an interruptible load program with a buy-through provision. Customers lose the right to buy firm power at a guaranteed price during high-price episodes, but are free to buy as much as they want at spot market prices. Simplified versions of such products have been designed that substitute pre-specified "critical" or "super-peak" prices in place of spot prices during high-price episodes. Examples are an innovative time-of-use pilot program at GPU Energy, and a coincident peak pricing program developed by Seattle City Light (in conjunction with EPRI).

Market-based interruptible load programs

Another price structure with occasional hourly pricing consists of a guaranteed price with an interruptible load provision. In this scenario, customers are compensated for reducing usage below an agreed-upon reference level during periods of high prices. In contrast to traditional utility interruptible rate programs, market-based programs provide a smaller up-front incentive, or capacity payment, but instead pay for performance during each interruption. They may also have no requirement for compliance, but will pay for over-compliance.

Market-based interruptible programs are analogous to the airline industry's incentive payments to customers who are willing to forego a flight reservation temporarily in order to bring demand in line with available capacity. Examples of market-based interruptible electricity demand programs include those recently established by PJM Interconnection and the New England Independent System Operator, as well as buy-back programs offered by companies including Portland General Electric, GPU Energy and Wisconsin Electric Power. The utilities and customers in these programs share the savings from load reduction during high-cost hours.

In California, Pacific Gas and Electric, Southern California Edison, and the California Independent System Operator tested pilot demand relief programs in 2000, but the tests involved relatively few customers as participants. For 2001, the California ISO has developed three new demand response programs. One of these, a participating load program, is market-based, and allows customers to bid load into certain ancillary service markets, such as for those for spinning reserves. The demand relief program is an emergency curtailment program, to be used only as a last resort to avert blackouts, that involves a combination of capacity payments and pay for performance. The discretionary load curtailment program, meanwhile, entails voluntary interruptions, with no capacity payment, but pays customers $250 for every megawatt-hour of reduced consumption.

Technology will boost response

Braithwait and Faruqui point out that market-based interruptible load programs, as well as spot pricing programs, will benefit from the application of new monitoring, energy control, and communication technologies. These technologies will improve the ability of customers to respond to hourly prices in an automated fashion, with predetermined strategies that cause minimal disruption, thus enhancing demand response and customer benefits.

For example, EPRI developed a prototype Automated Energy Control System that offers customers energy management flexibility under hourly electricity pricing. The system is installed and operating at

two New York City buildings—the World Financial Center and the Marriott Marquis Hotel—in cooperation with Consolidated Edison Company of New York.

Another striking example of this flexibility can be found in the GPU Energy pilot time-of-use (TOU) rate program, which included a communication and control device that allowed customers to pre-program their responses to both traditional TOU prices and to occasional "critical" prices. The price responsiveness of these customers was found to be twice as great as in most previous studies of TOU price response where such control technologies were not involved.

New metering technology poses a potential incentive for many more customers to respond as if they faced hourly prices even though they do not actually pay such prices. Although it has been little appreciated until recently, its viability is emerging as more customers have their electricity use metered on an hourly basis. With hourly meter data, suppliers are able to more accurately calculate the cost to serve customers and adjust price offers for those customers whose usage tends to be high during high-cost hours. To the extent that customers understand this process, they will have an incentive—lower prices on non-hourly tariffs—to reduce load during high-price periods, even if they don't explicitly face hourly prices. Recently, Puget Sound Energy began installing hourly meters for nearly half of its customers and providing them information on hourly energy costs, although not billing on an hourly basis.

Meanwhile, two licensed meter manufacturers—Global Power Products and Powell Power Electronics—are expected to begin production in 2001 of EPRI's SE-240 modular, electronic residential meter, which features plug-in modules that enable value-added customer services like RTP at minimal expense. In fact, the SE-240's greatest potential benefit is in reducing the impact of price spikes during peak demand periods through RTP.

Barriers to hourly pricing

Given the benefits to be gained and the widespread agreement that price-responsive demand is key to mending California's energy market problems, the question naturally arises: Why hasn't hourly pricing been adopted more extensively? Braithwait and Faruqui say several barriers and misconceptions are continuing to delay the implementation of hourly pricing. The most notable are a lack of experience and, specifically in California until this summer, the freeze on retail rates.

California's major utilities have conducted pilot RTP programs, but have not expanded them. RTP requires hardware and software for communicating prices to customers (for example, on a day-ahead basis), metering customers' energy consumption on an hourly basis, and billing customers on the basis of hourly prices and usage. Some of the key features are in place (for example, hourly interval meters are already installed at most large C&I customers) and expertise in implementing RTP is available.

A perceived political constraint that consumers must not be charged an average price that exceeds a retail rate cap presently appears to be preventing the consideration of hourly pricing as part of the solution to California's electricity market woes. But hourly pricing designs are available that could largely ensure the stability of consumers' bills at guaranteed prices, note Braithwait and Faruqui. For example, customers under two-tiered RTP pricing could effectively lock in a standard rate for a baseline level of usage. In addition, they would pay (or receive) market-based hourly prices for usage greater than (or less than) a contracted level. They would thus receive a price guarantee for most of their load, but still have an incentive to reduce load during high-cost periods. Such hourly pricing with a contract for difference at a capped rate could easily be implemented in California, say the experts.

Some observers have suggested that all customers should face hourly prices, but Braithwait and Faruqui say it would be difficult to justify the cost of the metering and other requirements compared to the likely benefits realized. Moreover, they note that such a blanket approach would violate one of the tenets of deregulation: greater customer choice. They point out that only a portion of the total peak demand needs to be reduced to substantially reduce wholesale prices.

The bottom line on real-time pricing

Braithwait and Faruqui say there is ample evidence to project how customers will respond to hourly electricity prices and that such demand response can help reconnect California's wholesale and retail power markets to yield reduced prices. Moreover, concerns about retail rate caps and potentially higher electricity bills do not have to stand in the way of implementing hourly pricing, they add. Financial risk management mechanisms are available that can allow customers to lock-in regulated price levels on baseline usage and limit, but not eliminate, increased customer bills while providing the desired incentive for demand response during times of high prices.

"The exact form of pricing that is implemented is of less importance than the fact that some form of demand response is added to the California power markets," Braithwait and Faruqui conclude. "Price-responsive demand will not solve the California problem completely; additional generating capacity is clearly needed, and the extent of price manipulation by market power is still under study. However, demand response can help matters in the short term, and can be implemented more quickly than needed capacity can be added and can provide continuing long-term market efficiencies." □

Further reading

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PHOTOVOLTAICS RISING—
Beyond the First Gigawatt

PV integrated into building materials, such as this 125-kW rooftop system installed by PowerLight Corporation atop its Berkeley, California factory, can help decrease the initial cost impact of solar power.

Solar photovoltaic (PV) power has long been regarded as a clean and promising "green" technology that was too expensive for widespread use. Today, as the cost of manufacturing PV drops and its efficiency rises, that view is changing. Industry restructuring, net metering laws, and uncertainties in the future price and availability of natural gas and fossil fuel are making PV ownership easier and more attractive than ever. The technology may be nearing a breakthrough in which government-private partnership and the forces of the free marketplace combine to make it a widespread and economical generation option for rapidly growing numbers of customers.

by Brian Fies

From rooftops to mountaintops to space stations, photovoltaic (PV) power is a $2.5 billion industry. It attracts investment capital from some of the largest multinational corporations in the world, while enjoying a devoted following among environmentalists. Governments subsidize it and the public rightly regards it as a clean, quiet, high-tech source of power elegantly tapped from Earth's nearest star.

So with so much working in favor of PV, why isn't there more of it? Cost provides much of the answer; perception provides the rest. PV is too expensive today to compete in conventional energy markets already served by mature generation technologies and a reliable grid. Electricity produced by PV currently costs at least three times more per kilowatt-hour than the same electricity tapped from the local utility. However, a price-only analysis hides solar power's most attractive features. Many PV manufacturers, vendors, government officials, and customers argue that when PV is judged in terms of its value as a hedge against future energy and fuel costs, its environmental benefits, its long-term reliability and stability, and its distributed nature, a compelling case can be made for it as a significant option for energy portfolios even today—a case that will only grow stronger in the future.

Birth of an Industry

In 1839, French scientist Edmond Becquerel discovered that light shining onto metal electrodes in an electrolytic solution produced a tiny flow of electricity. This photovoltaic effect remained a curiosity of little practical value until 1954, when Bell Laboratory scientists used then-new semiconductor technology and silicon crystals to produce the first modern PV solar cell. Research and development continued through the 1960s largely due to the United States space program, which needed a safe, reliable, and lightweight method of powering satellites and space probes in the frigid vacuum of space for months or years at a time. The PV industry received a further boost with the oil crisis of the early 1970s, during which PV efficiency (expressed as the percentage of potential solar energy that a cell actually converts to electricity) increased, prices dropped, government support grew, and the first practical commercial products were introduced. PV cost and performance continued to improve through the 1980s and 1990s, and new technologies emerged to satisfy growing specialty markets.

PV is generally considered a distributed generation resource deployed near its point of use, typically on the ground or a rooftop. Many PV arrays are designed as stand-alone systems that are equipped with batteries to store electricity for sunless hours and operate completely independent of the grid. However, grid-connected PV, in which PV backs up or supplements standard grid power, represents the fastest growing market segment today, already comprising some 40% of current sales according to industry observer Strategies Unlimited. Industry forecasts by the National Center for Photovoltaics (NCPV) and others project that by 2020 approximately one-half of the PV market will consist of distributed generation applications, one-third will consist of familiar remote and high-value applications, and one-sixth will consist of wholesale utility-scale grid generation.

The Jarecki Center at Michigan's Aquinas College is powered by a 12-kW PV system integrated into the structure's roof. The system is manufactured by Bekaert ECD Solar Systems.

Several types of PV are in production or nearing commercialization. Monocrystalline cells, the direct descendants of the first Bell cells, are made of thin wafers sliced from large single crystals of silicon. They remain the most efficient PV available, with system efficiencies averaging 12 percent in typical commercial products. Polycrystalline cells are composed of ribbons or wafers containing many silicon crystals fused together, which makes them less efficient but also less expensive to produce. Typical system efficiencies are approximately 10 percent. Because they are easier and more economical to manufacture, polycrystalline cells are used in many commercial applications for which space is not a critical constraint.

Thin-film PV is a newer technology that promises great cost reduction through automation. It is made by layering microscopically thin coatings of semiconductor material onto an underlying material such as plastic, metal or glass. Although not yet as efficient on a commercial scale as crystalline PV—current system efficiency is approximately 5 percent—the efficiency of thin-film PV in the laboratory is approaching that of crystalline PV. A big advantage of thin-film PV is that it can be more easily and aesthetically incorporated into building components such as roof shingles, siding, and window glass so that a structure can be built from the ground up to generate its own power. Most industry watchers expect this building-integrated market to grow enormously. Several companies, including industry leaders BP Solar and Siemens Solar, have recently begun mass-producing thin-film products and expect them to be widespread within a few years.

"Thin films have been improving pretty consistently, but they've also run up against many serious technical problems," explains Ken Zweibel, manager of the Thin-film PV Partnership Program for the U.S. DOE's National Renewable Energy Laboratory (NREL). "I do expect continued progress. Technologies being developed and going through early commercialization right now have the potential to reach an installed system price of two dollars per watt or lower," a price that some studies indicate would make them competitive with grid power. NCPV's PV Tech-

nology Roadmap has set end-user price goals of a challenging but achievable three dollars per watt by 2010 and approximately $1.50 per watt by 2020, while EPRI's Electricity Technology Roadmap targets system costs of around $2.20 per watt in 2020 and $1.80 per watt in 2030.

Taking the long view

The economic argument for PV ownership is straightforward: large up front costs are offset over time by generating "free" electricity that would otherwise need to be generated by and purchased from a utility. The first question most commonly asked of PV concerns its payback period—the amount of time it takes the value of electricity produced by a system to offset its cost. PV proponents have two answers: first, as PV technology improves and costs drop, PV payback periods are becoming much shorter. Second, that's the wrong question to ask.

"Unfortunately, people do not think long term about energy," says Rick Nuessle, a design engineer with California PV vendor Solar Depot, which sells both commercial and residential systems. "Payback for residential systems is about fifteen years, which is still fairly long. It is significantly less than that for commercial systems, on the order of five to ten years. But our PV systems have a twenty-five-year warranty and an expected life span of decades, and they offer high-quality clean power whose fuel supply is free and whose price will never go up. I've talked to companies that have rejected solar power because they say a five-year payback is too long, but they'll still be buying power from their utility in 20 or 30 years." In fact, such companies illustrate an understandably common and critical distinction that many consumers make between capital and operating costs. Energy has always been regarded and budgeted as an operating cost, while purchasing PV would tie up capital that a company might prefer to commit elsewhere. Seeing PV as a long-term investment in energy independence often requires a difficult shift in perspective.

13.2-kW (ac) system using Atlantis PV modules, installed by New York Power Authority on a community center in Tuckahoe, New York.

"What's wrong with the way most people view PV is they're not thinking about full product and life-cycle cost," says Janice Lin, director of business development for PowerLight Corp. PowerLight's PV systems are designed for quick turnkey installation at commercial sites. "For example, people don't factor in the fuel cost, and that's huge. One of the reasons our customers are investing in PV as part of their portfolio of energy technologies is that it's a hedge against future energy costs. Few of the other generation technologies offer that benefit."

A potential PV owner must also consider some questions that don't have easy answers: What is the price of grid power likely to be years into the future? What type and size of array do I need? How much of my energy needs do I expect PV to satisfy? What are the environmental benefits of PV worth to me? And given the answers to those questions, does PV still make sense?

Until recently, PV was a sensible solution only for high-value uses too difficult or expensive to serve with grid power. Specialized applications such as remote telecommunication equipment, mountain cabins, lighting systems, and military installations made up much of the market. Since the 1970s, however, the retail price of PV has dropped by roughly two orders of magnitude while at the same time installed capacity has increased by three orders of magnitude. Today, there is approximately one gigawatt of PV operating in the world, with over 250 megawatts added just last year. To put those numbers in perspective, one gigawatt is about the output of a single large central-station power plant—globally, a relatively insignificant sum. However, a consequence of PV's continued exponential growth is that it will emerge within the next decade as a substantial energy contributor. Industry analysts at Strategies Unlimited forecast that

A 73.6-kW (ac) system using ASE Americas PV modules, installed for the Hawaiian Electric Light Company by PowerLight Corporation on the Mauna Lani Hotel on the Kona coast of Hawaii.

PV sales may grow to nearly 700 megawatts per year by 2005 and to 2000 megawatts (two gigawatts) per year by 2010.

NCPV looks for the domestic PV industry to provide up to 15 percent—approximately 3.2 gigawatts—of the new U.S. peak electricity generating capacity expected by 2020. By then, NCPV anticipates a cumulative installed capacity of fifteen gigawatts in the United States and seventy gigawatts worldwide. By most estimates, the off-grid market continues to grow at 15 to 20 percent per year while the grid-connected market is expanding at a healthy rate of 25 to 30 percent per year. PV vendors say that much of that new capacity is ending up on ordinary homes and businesses.

"In the last three or four years the real growth has come from grid-connected power plants, both residential and commercial," says Lin. While environmental arguments are well and good, Lin says her customers have their eyes on the bottom line. "One reason PowerLight has been successful is that we do focus on PV's economic benefits," she says. "Nobody is going to invest hundreds of thousands of dollars in a solar energy system unless it makes sense financially."

"About 60 to 80 percent of our business is grid-tied interactive PV," agrees Nuessle. "Probably the majority of those installations are still residential, although we are seeing rapid growth in commercial installations that require large three-phase systems rather than small 3- to 5-kilowatt single-phase.

"People still have the old 1970s' mentality that PV isn't very powerful, it's much too dilute, it's too expensive," Nuessle continues. "They have no idea that the technology has improved so much, and that there are new policies and sophisticated inverters out there that make it easy to sell the power they generate back to the utilities. You don't need a battery bank and all the equipment that you used to." In effect, a grid-connected PV owner can use the utility system itself as a 100%-efficient battery, putting excess energy into the grid when it is generated and removing it when needed.

Market challenges open opportunities

Almost any discussion with PV manufacturers or vendors quickly turns to the California energy crisis. Thanks to what Governor Davis refers to as a "failed" implementation of deregulation and insufficient generation and transmission capacity, the state has endured months of power shortages along with rapidly rising electricity and natural gas prices. As price caps are phased out in coming years, Californians' electric bills could multiply several-fold as a result of consumption during only a few high-cost periods. The economics and attributes of PV suddenly look a lot more attractive.

Also working in PV's favor is California's status as an international center of high-tech industry, the world's sixth largest economy, and home to a passionate environmentalism. Public sentiment and environmental regulation discourage or prohibit the construction of new coal, diesel, hydro, or nuclear generation in the state. Even new natural gas plants have been protested and blocked in some communities. At the same time, much of California comprises some of the sunniest terrain in the United States. This unique confluence of circumstances has PV proponents cautiously predicting a California gold rush the like of which hasn't been seen since 1849.

"We're booming," says Solar Depot's Nuessle. "We are going to do a hundred times as much business this year as last. Right now I have five new contracts on my desk, each of which is for more than our annual revenue in 2000." Other vendors such as Delaware's AstroPower, Colorado's Altair Energy, and California's PowerLight Corp. all report a sudden surge in interest and more business than they can handle throughout the country, with California leading the pack. So far, PV manufacturers have been able to meet the growing demand. A key uncertainty is how long such strong demand will last, and whether manufacturers will risk responding to it with major new investments and increased capacity.

"What has to happen to advance PV is what's happening in California now: economic impetus and market instability," Nuessle says. "It's really hitting home that we have way too much power consumption and not enough generation, and we're not willing to build any other kind of power plant. Traditionally, people who bought PV were interested in protecting the environment or just wanted to do something good and be different. But as energy gets more expensive the economic argument has really become number one."

The Sacramento Municipal Utility District has installed a 540-kW PV system in a parking lot at Cal Expo, site of the California State Fair. The sun-tracking arrays, made up of 13,700 PV modules, provide shaded parking for more than 1000 cars.

The California Solar Energy Industries Association (Cal SEIA), a nonprofit trade group with more than 80 members, issued a white paper earlier this year arguing that solar energy could help solve the state's energy crisis by reducing peak demand and decentralizing power generation.

"With the rapid increase in natural gas and fossil fuel prices, solar electricity is rapidly becoming one of the most competitive electric generation options on the market," says Cal SEIA Executive Director Les Nelson. "Unlike other available distributed electricity generation alternatives such as fuel cells and microturbines, only PV enables 100% renewable, zero-emission electricity production that is modular, scalable, and completely hedged against future fossil fuel and natural gas price increases." The California SEIA also echoes a warning voiced by others: California may be the first to face steeply rising energy prices, but it won't be the last.

SOLAR POWER ELECTRIC ASSOCIATION

A 2.9-kW (ac) system using Solarex PV modules is installed on Montgomery County Community College in Germantown, Maryland.

This is a 1.6-kW (ac) system using AstroPower PV modules, installed by GPU Solar in Lakewood, New Jersey.

"The issue of deregulation in California is really a red herring," says Tom Tanton, EPRI's general manager for renewables. "Of course, I don't know if the series of confounding events—such as concurrent plant outages for maintenance and natural gas pipeline explosions—or their consequences could have been predicted. Perhaps the most important lesson, as always, is to not put all your eggs in one basket, but also to not view any particular technology as a 'silver bullet.' Avoiding risk through portfolio management is the key; in turn, employing a variety of options, such as PV, is the key to portfolio management. Tempering of boom-bust cycles is a critical element of risk avoidance."

Finding a market

PV players range from multi-billion-dollar international petroleum giants to storefront mom-and-pops. The strategies they pursue reflect their corporate strengths, their expectations for future energy markets, and to some extent their environmental and philosophical perspectives. Although traditional utilities might seem to be natural candidates to lead PV development they have with few exceptions ignored it as a business opportunity, arguing that it is uneconomical and doesn't meet the needs of their customers. Large oil companies such as BP, Arco, Shell, and Mobil were among the earliest and largest investors in PV, generally treating solar power as another energy source to be explored and a potential hedge against future unstable fossil fuel price and availability. Their interest has waxed and waned over the years depending on their view of the energy market, and now appears to be on an upswing. For example, BP Solar, which designs and markets both crystalline and thin-film products, claims a global market share of 20 percent and annual revenues of more than $200 million. The company produced approximately forty megawatts of PV in 2000 and has lately focused on rural electrification efforts in Southeast Asia and the heavily subsidized residential market in Japan. Arco Solar built two megawatt-scale demonstration PV power plants in California in the 1980s, both of which were sold and then decommissioned because their new owners found their components were more valuable sold piecemeal. In 1990, Arco sold its solar business to Siemens AG of Germany to create Siemens Solar, a world leader in the deployment of utility-scale PV. Now another oil company, Shell, has announced a partnership with Siemens Solar.

One of the few electric energy companies to step into the PV arena is GPU Solar, a joint venture company owned by GPU International, a developer of independent power plants, and PV maker AstroPower. GPU Solar President Jim Torpey, who also chairs the nonprofit Solar Electric Power Association (formerly the Utility Photovoltaic Group, or UPVG), says many companies like his are trying to figure out how PV can fit into their business strategy. Sometimes the effort demands a little trial and error. For example, in 1997, GPU Solar began selling a system in which PV charged a battery that would then provide power to critical circuits during power outages. It was aimed at homes and small businesses.

"We spent a year and a half marketing that product, and learned that the market was a bit immature and prices were still a bit too high to support a number of middlemen," says Torpey. "We needed to

APS Plans Largest PV Concentrator Project

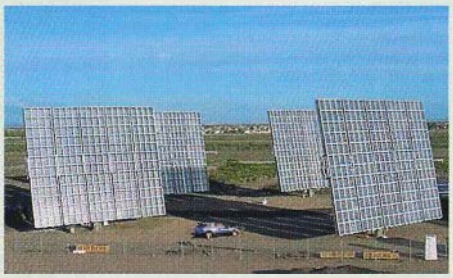
Arizona Public Service Company (APS) is planning the world's largest high-concentration solar photovoltaic (HCPV) project, using commercially available technology that evolved from research and development supported in large part by EPRI. APS plans to install 500 kW of distributed, 25-kW sun-tracking HCPV arrays at multiple sites in Arizona this year. The plans were announced in April by APS and Amonix Incorporated of Torrance, California, which developed and patented the high-efficiency, potentially low-cost utility-grade PV generating technology.

Amonix's fifty-five-ft (16.8-m) wide, forty-five-ft (13.7-m) tall HCPV arrays are comprised of five MegaModule™ blocks, each rated 5 kW and mounted on a two-axis drive-structure that tracks the sun with high precision. Molded acrylic Fresnel lenses concentrate the sun's rays by a factor of 250 onto small-area, point-contact silicon solar cells, which originated from EPRI-funded work by researchers at Stanford University in a ten-year program from the late 1970s to the late 1980s. During that time, APS was among five EPRI-member companies that participated in a collaborative project to supplement HCPV funding.

With an overall efficiency converting sunlight to direct current that exceeds seventeen percent, Amonix's solar array is projected to cost less than two dollars per watt when manufactured in large volume. Achieving such production costs would make solar-generated electricity more competitive with conventional sources and open the way to broader application and market penetration.

The first 100 kW of APS's HCPV project came on line on April 5, 2001, with the dedication of four 25-kW arrays at the Glendale (Arizona) Municipal Airport. An additional 400 kW, or sixteen additional HCPV arrays, are planned for installation at other locations this year. The Glendale installation—along with two others in Prescott and Gilbert that involve different PV technology—brought APS's total installed solar generating capacity to nearly 1 MW. The utility says it plans to have another megawatt of solar generating capacity installed by the end of 2001.

"We are pleased to reach the one megawatt milestone with the dedication of these three plants, but it's only the beginning," says Ed Fox, APS vice president for communications, environment, and safety. "With the energy shortages faced across the country and especially the West, every kilowatt of power we can generate is important. These plants showcase our commitment to developing earth-friendly, renewable energy resources."



Amonix concentrator arrays installed at the Glendale, Arizona, municipal airport.

Herb Hayden, APS solar program coordinator, notes that the utility—the largest subsidiary of Pinnacle West Capital Corporation—has worked with Amonix for several years to develop the HCPV technology and field-tested an earlier model of the Amonix array. "We're pleased to be constructing and operating these first commercial solar power generating facilities, and we're confident this installation will demonstrate that high-concentration PV is ready for large-scale commercial use."

When completed and fully operating, the HCPV installations will generate over 1000 megawatt-hours per year. Their output will be fed into APS's electrical grid and displace an equivalent amount of electricity that would have been generated by more traditional methods. All of the utility's solar plants are financed in part by APS and nearly 2500 customers participating as APS Solar Partners, who each pay $2.64 per month to have fifteen kilowatthours of their electricity needs generated by solar power. Additional funding support is provided by the U.S. Department of Energy through the Utility Photovoltaic Group.

Amonix advanced its HCPV technology from concept to commercial status through early collaboration with EPRI and with support from DOE, including the National Renewable Energy Laboratory and Sandia National Laboratory. "Our technology has an opportunity to play a major role in solving our country's energy crisis," says Vahan Garboushian, president and founder of Amonix. "Our system can be readily manufactured in volume and has great potential to be the world's lowest-cost solar option."

Amonix's HCPV technology is well-suited to high-volume production that can be easily ramped up as demand for solar electricity increases. As with most manufacturing industries, such as automotive and electronics, unit costs decline dramatically with increasing production. These factors position Amonix's systems well for producing large amounts of solar electricity.

"Environmental benefits and cost are both important factors that must be balanced, which is why APS has been so supportive of solar development," according to Hayden. "We're excited about the potential that Amonix and its high-concentration PV have as a large-scale solar generation resource."

Tom Tanton, EPRI general manager for renewables and hydropower, calls the success of Amonix's HCPV technology "an excellent example of fruit born through the determination and vision of collaborative research, development, and demonstration. EPRI is proud of our contribution to this outcome." □

For more information, contact Eric Dominguez at Amonix, edominguez @amonix.com, 310-325-8091, or Tom Tanton, ttanton@epri.com, 650-855-2470.

streamline the consumer chain to have any margin, and we decided that particular product didn't draw on the strengths we offer as a generation company." That product was turned over to AstroPower and GPU Solar subsequently set its sights on developing, operating, and maintaining independent solar plants to serve customers interested in supporting green power. The strategy allows GPU Solar to bypass the wholesale power market, in which their PV would be noncompetitive, and directly address customers willing to pay a premium to reap the environmental benefits of PV.

"Until now the entire energy industry has been run by engineers and financial people, not marketing people," Torpey says. "Real success for PV will come through marketing—treating these products like others that were initially niche products before they caught on in the general market. We're just starting to see companies like Green Mountain and New Energy starting to stretch the minds of the public, and that's very good for the PV business." Smaller solar vendors and entrepreneurs are limited by budgets that can rarely afford an ambitious advertising campaign. Some aim their outreach efforts at very specific audiences to, for example, provide training seminars so that electrical and building contractors can learn to install PV, making it easier for them to present it as an option to their clients.

A role for government

Given the resources required as well as solar power's genesis in national space and defense programs, it is not surprising that government support has been and remains central to the development of PV. In the United States, the U.S. DOE provides key funding through research and development (R&D) work done primarily by NREL and Sandia National Laboratories.

"Historically, the government has been involved because PV, like other alternative energies, was seen as a social need rather than an economic need," says NREL's Zweibel. "Until recently there hasn't been much economic drive for PV except for high-value markets. The government was there because, lacking sizable markets, private enterprise couldn't be there. We need to keep the thread of government resources involved in developing these new technologies that aren't yet fully cost competitive and paying their own way."

"What we've seen recently is a movement away from strictly R&D to more of a market-based approach, including transformation of markets," says EPRI's Tanton. "Fostering R&D and funding some of that R&D to enable entire industries is an important role for government, but making the results of R&D used and useful is most effectively undertaken by the private sector.

"There is also the compelling need for infrastructure development given the change from a point-to-point electric grid to an increasingly networked one," Tanton continues. "Government's role in infrastructure remains key. The delineation is not clear-cut, but what is clear is the need for public and private cooperation and collaboration. Neither the public sector nor the private sector can be the sole driver along a technology innovation's trajectory."

Government programs can also encourage PV by providing another important resource: financial support through tax breaks and rebates. A 10 percent federal solar energy tax credit is currently available to any taxpaying business in the United States, and some states offer cash rebates on both residential and commercial PV systems.

"As the price of PV and the price of electricity approach each other, it becomes more realistic to leverage quite a bit of volume through a subsidy or tax rebate," says Zweibel, who adds that any rebate should be based on a system's wattage rather than its price tag. Calculating rebates as a percentage of system cost, Zweibel argues, only encourages the purchase of increasingly expensive systems, while basing rebates on output encourages consumers to find the most efficient PV available and prods manufacturers to improve their technology. "Any kind of government scheme should foster the greatest competition and the lowest cost systems," he says.

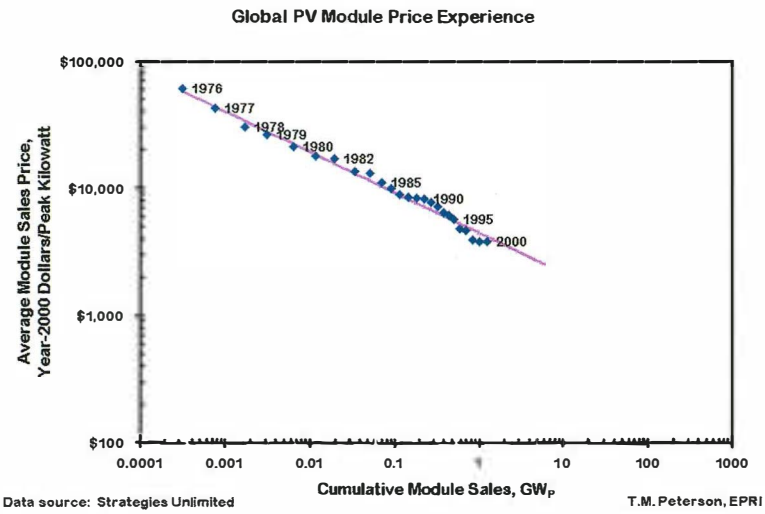
On another front, the federal Million Solar Roofs Initiative, begun by the Clinton administration in 1998, aims to install one million solar energy systems—including PV, water heating, and space heating—on the rooftops of American homes and businesses by 2010. The initiative includes federal procurement programs, technology grants, and lending programs. Its stated goals include reducing greenhouse gas and other emissions, creating high-tech jobs, and keeping the United States' solar industry competitive internationally. Officials say that meeting the initiative's targets over the next decade will create 70,000 new jobs and reduce atmospheric carbon by an amount equivalent to the emissions from 850,000 automobiles. The Bush administration's commitment to the Million Solar Roofs program is currently unclear, although President Bush's position papers on energy policy voice support for solar and other renewable energy technologies, calling for tax credits for electricity produced from alternative re-

SOLAR POWER ELECTRIC ASSOCIATION

This 100%-solar-powered modular home, featuring both rooftop and building-integrated PV technologies, was erected on the National Mall in Washington, DC for the American Solar Energy Society's annual meeting in April 2001.

sources. Bush also proposed that companies wanting to explore for oil and gas on federal lands should bid for the opportunity, with the resulting funds—an estimated $1.2 billion over ten years—dedicated exclusively to basic research in renewable energy.

Many in the PV industry argue that current levels of state and federal support in the United States are inadequate and look longingly overseas for examples of more aggressive solar energy policies that work. According to Strategies Unlimited, Japan installed approximately 60 megawatts and Europe approximately forty megawatts of PV in 2000, compared to the U.S. total of just eight megawatts.



Historically, PV module prices have comprised about half of typical PV total system installed costs. This graph shows how module prices, in constant dollars, have steadily and consistently declined with cumulative sales over the past 25 years.

Germany's Green Party coalition government has set a target of providing 50 percent of that nation's energy supply via renewable resources by 2050—"50 by 50." To advance that goal, in February 2000 the German parliament passed the Renewable Energy Law (REL), which sparked a stampede of installation proposals. Under the law, companies and individuals that install PV will receive a paid incentive of 0.99 DM—approximately fifty cents—per kilowatt-hour generated for 20 years. REL-related PV efforts are fully funded by a nominal 0.1-pfennig (0.05-cent) per kilowatt-hour surcharge on electric bills. Another German program that offered zero-interest loans to cover the complete cost of a PV system, of which the borrower would have had to repay just 87.5%, had to be scaled back when it was deluged with more than 15,000 requests in its first month.

In Japan, home to the 1997 Kyoto Protocol that called for worldwide cuts in greenhouse gas production, government guidelines call for 4600 megawatts of PV power generation by 2010. Two Japanese policies adopted in the 1990s, the "Action Plan to Arrest Global Warming" and the "Basic Guidelines for New Energy Introduction," have led to aggressive new measures in energy conservation. Renewable resource development programs, including a "70,000 Solar Rooftops" program that predated U.S. efforts, were well received. Japanese "buydown" programs pay for one-third to one-half the cost of a solar energy system with no size restrictions.

"Most of today's PV applications are not being installed in the United States," Torpey says. "For a number of reasons, I think it would be an important policy for the United States to begin to reestablish leadership in PV technology which, due to lack of government support, I'm afraid is going to drift elsewhere."

Those involved in PV research, development, and sales forecast continued incremental gains in economy and efficiency over the coming years. Most say that spectacular scientific breakthroughs, although they would certainly be welcome, are not necessary for PV to advance and succeed. The downward slope of the "PV Module Price Experience" curve (graph above) has held steady for decades and in fact may have slightly accelerated since the early 1990s, indicating that prices may be dropping faster than in the past. Thin-film PV in particular shows great potential for technological and manufacturing improvements that could open vast new markets. At the same time, deregulation is making it possible, for the first time, for consumers to choose their electricity provider and even generate electricity themselves.

"Electricity has always been thought of as a commodity, so all generation technologies have always been compared on a cost-per-kilowatt first-cost basis," says Torpey. "What people are beginning to recognize—although certainly not in the mass market yet—is that an electron is a very valuable product. It allows you to maintain your lifestyle as you see fit and express your opinion about the environment. As we get more sophisticated about how we look at energy, more of that value will be recognized by customers."

Although deregulation promises to lower energy costs in many markets, its actual impact—as demonstrated in California—can be unpredictable. In addition, concerns about global climate change and the environment are making many competing generation technologies less attractive. Oil is subject to fluctuations in price, availability, and politics; natural gas faces problems with potential shortages and delivery. If history is a guide and those trends continue, at some point the falling price curve for PV and the price curve for grid power will intersect. Companies and individuals that prepare for that day now will benefit the most when it arrives.

"We are in one of a continuing series of interesting times," says Tanton. "Each period has different causes and manifestations, but each also teaches the same message: think and act strategically, keep all options open, look forward not backward, and watch for unintended consequences. I expect PV to be more than an option unexercised, but to become a used, useful, and significant element of the energy mix. I would be pleased, though not surprised, to see PV's contribution approaching 10 percent of all electricity by about 2020 and perhaps 15 to 20 percent in 2040. Achieving that will require on-going public and private-sector cooperation." ■

Bush Energy Policy Resonates with Global Coal Initiative

MANY ELEMENTS OF THE BUSH Administration's proposed energy policy—a product of Vice President Cheney's task force, unveiled in May—no doubt resonate with advocates in the oil, gas, coal, and electricity industries who favor supply-side solutions as centerpieces of national policy. The task force envisions a need for up to 400 GW of new generating capacity (or as many as 1900 new power plants, including nuclear units) as well as 263,000 miles of new distribution lines by 2020. It recommends extension and expansion of tax credits for electricity produced using wind and biomass, and construction of a national grid to facilitate interregional power transfers.

One of the task force's few specific funding recommendations—one that likely is getting an equally warm reception from the coal and electric utility industries—would provide an additional $2 billion over the next ten years for continued development of advanced clean coal technologies.

If approved by Congress, the policy would ensure continuation of a 16-year public-private partnership development program, representing $5.2 billion of shared investment to date, that has essentially commercialized more than half a dozen key technologies for coal-fired electricity generation with significantly greater efficiency and reduced emissions. These technologies include both atmospheric and pressurized fluidized-bed combustion, coal gasification combined

cycles, and advanced environmental control options. EPRI's fossil power development programs over the years have closely paralleled many of the technical objectives of the U.S. Department of Energy's Clean Coal Technology Program.

Initiative charts course on roadmap

The Bush Administration's recognition of the strategic importance of advancing the environmental sustainability of the United States' most relied-on fuel for electricity generation—the Administration's rejection of the Kyoto Protocol limiting carbon dioxide emissions notwithstanding—resonates strongly with a major new EPRI offering: the Global Coal Initiative (GCI).

Launched in 2000, the GCI encompasses some $25 million of proposed work in six critical areas of focus that are aimed at maintaining the strategic value of coal as a power generating fuel worldwide. By incorporating a longer-term focus on the development of options for resolving the carbon-energy conflict and enabling the sustainable, competitive use of coal at near-zero emissions by 2020, the GCI directly supports the goals of EPRI's Electricity Technology Roadmap.

According to Tony Armor, EPRI technical executive, "the long term viability of coal as a generating fuel depends on finding ways to further reduce or even eliminate coal's environmental impact, including CO_2 emissions. We're engaging the world's major coal-burning electricity generators, coal suppliers, coal transporters, and equipment manufacturers with a portfolio of projects that focus on near-term operational improvements and longer-term coal-retention solutions. These projects will help sustain a diversity of generating fuel resources as a hedge against price fluctuations, enhance the value of existing coal-fired power plants, and provide options for using coal in new plants."

The GCI's essential elements, endorsed by the various factions of the global coal community, are ultrasupercritical plant designs, the value of real options for coal, CO_2 control options, gasification and other advanced coal options, lignite and low-rank coal plant improvements, and low volatile coal combustion.

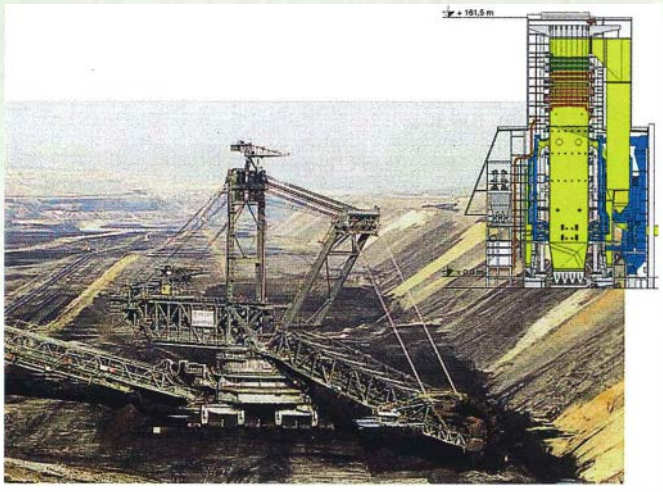
More specifically, the initiative envisions the use of real options financial analysis to value the flexibility of coal in the generation mix from the perspective of both the public interest and individual generation companies. New alloys, fabricating processes, coating methods, and innovative equipment designs will enable supercritical, pulverized-coal steam plants operating at 760°C (1400°F) and beyond.

Economic and technical analyses of options for the separation and sequestration of CO_2 will identify potential sinks and relate them to generation sources; technical issues for ocean disposal and the enhancement of carbon sinks will be explored. Innovative methods for using low-cost, low-volatility coals with high efficiency and

Conference Probes Issues for Lignite, Low-Rank Coals

About 90 leaders from three continents in technology for generating electricity using lignite and other low-rank coals explored key operating and environmental issues facing these fuels at a conference last month cosponsored by EPRI and VGB, a European organization similar to EPRI. Held in Wiesbaden, Germany, the conference drew attendees from 18 organizations in Europe, Australia, and the United States for a worldwide assessment of the state of the art in burning lignite and low-rank coals, which account for approximately half of the world's use of coal for power generation.

According to Tony Armor, EPRI technical executive, the two-day conference provided the first opportunity for lignite power experts from around the world to engage on a broad range of operating, environmental, and advanced technology issues. EPRI President and Chief Executive Officer Kurt Yeager delivered the summary address. Proceedings of the conference are in preparation for publication by EPRI and VGB.



A series of concurrent sessions featured expert presentations on fuels, combustion technologies, operating experience, and emission controls and costs. "A goal of the conference was to establish lignites and low-rank coals as key global resources in a sustainable world, given the imperative to control air emissions from power plants and the rapid deregulation and growing competition within the electric power industry," says Armor. "The extent of lignite resources around the world is huge. Although U.S. lignite resources are presently underutilized, that's about to change in the near future." High-moisture fuels such as lignite are prone to slagging and fouling problems; improved technologies for addressing such issues could have broad impact.

At an informal gathering the day before the start of the conference, representatives of VGB, EPRI, and Australia's Coal Research Consortium (CRC-Lignite) reached tentative consensus on the beginning of a global collaborative effort focused on advancing the technology for lignite-fu-

low NO_x emissions will be developed. Solutions to the operating problems associated with using high-moisture coals such as lignite will enable wider user of this abundant, widespread resource. Ultimately, the initiative will support the private sector's development of advanced coal gasification and fluidized-bed cycles and plants.

Coal's resurgence

Armor notes that renewed R&D interest in coal-fired generating technology comes amid a surprise resurgence in the use of coal. "A remarkable turnaround has happened in the United States over the past year," he says. "Coal-fired plants, once thought to be facing a rapid demise, have surged back as perceived vital generation assets of the future. Across the country, coal is a strong part of an unprecedented power plant building boom, with plans announced for nearly 25 GW of new coal-fired capacity, some of which is already under construction. As recently as two years ago, there were essentially no announced plans for large, new U.S. coal-fired units. Now the forecasted new capacity includes both PC and fluid-bed units, and both sub- and supercritical steam conditions likely will be deployed. The fuels range from lignites to bituminous coals."

U.S. coal demand continues to increase in response to electricity demand growth of about 2.4% per year. Total U.S. coal production, now at 1100 million tons per year, is expected to increase by 5.9% over the next five years, with Western U.S. coal consumption projected to increase by 11.4%.

Armor points out that the U.S. fleet of coal-fired power plants, which supplies more than 50% of U.S. electricity generation, numbers about 1000 large units, concentrated in the 500–600 MW range. The plants typically are more than 30 years old and compete with other regional coal-fired plants at the cost margin. Fuel cost is frequently the determining factor in a plant's competitiveness. "For this reason, and also to reduce the cost of emissions control, many eastern U.S. coal-fired units now burn a mixture of eastern coal and coal from the low-sulfur deposits of the Powder River Basin of Wyoming and Montana.

"The average coal-fired unit's capacity factor is about 68%, up from 60% only a few years ago," adds Armor. "Equivalent availabilities average about 85%, close to a ten-year high, and are achieved despite an aging fleet and reduced staffing levels. Sulfur dioxide and nitrogen oxide emissions are down 40% and 20%, respectively, since 1980, even though electricity production climbed by 35% in that period.

"These impressive performance indicators reflect progressive advances in our understanding of the combustion of coal, the most important of all our energy sources," concludes Armor. ■

For more information on EPRI's Global Coal Initiative, contact Tony Armor, aarmor @epri.com, (650) 855-2961.

eled generation. This collaboration, initially based on the development of an information-sharing website operated jointly by interested companies worldwide, could eventually include technology interchange and future joint R&D activity.

Many of the U.S. and Australian attendees took the opportunity for a side visit to the Niederaussem lignite power plant near Cologne that is operated by the German utility RWE and coal producer Rheinbraun, both of which were conference participants. "The Niederaussem mining area provides more than half of all the coal mined in Germany for electricity generation, around 100 million tons per year," notes Armor.

"The latest generating unit at Niederaussem is a supercritical (275 bar, 580/600°C) 1000 MW unit currently under construction, the largest in the world. It incorporates new concepts in lignite drying and advanced environmental controls for SO2 and NO_x. Our tour group were briefed by the station manager and his staff, who later answered extensive questions from our delegates.

"Overall, it's clear that Germany is pushing very hard for new supercritical pulverized coal (PC) plants based on lignite fuels, which are abundant in many parts of the world including East and West Europe, Russia, India, China, Australia, and the U.S." adds Armor. "Australia is also looking to build new lignite plants and is exploring gasification options for new or upgraded plants. And in the United States, new PC or fluidized-bed plants are in the planning stages in the North Dakota and Texas-Mississippi lignite basins."

Symbolizing the germination of a global collaboration to advance lignite power technology, the executives of conference cosponsors VGB and EPRI initialed a memorandum of understanding (MOU) for joint activities in coal-fired plant technology and operation. "In choosing an optimum path forward for energy, particularly electric power, and acknowledging the opportunities and pitfalls offered by each option in the full range of energy alternatives, we recognize the major role to be played by coal, our most abundant fossil energy resource," said the MOU signed by Karl Theis of VGB and Yeager of EPRI.

"Coal has several hundred years of proven reserves and is mined across the world in various forms. In utilizing coal, whether from bituminous, subbituminous, lignite, peat, or low-volatile anthracite deposits, the focus of the future is to reduce emissions, improve operating efficiencies, and find solutions to all equipment reliability issues. All these concerns can be handled by technology and operation advances that our organizations are pursuing," the two-year MOU states.

The range of coal-related technology R&D for both VGB and EPRI spans coal supply, transportation, combustion, environmental controls, and power generation. Opportunities for cooperation that could enhance the value for VGB and EPRI stakeholders may include future jointly sponsored conferences and workshops, periodic joint assessments of coal-related issues, jointly funded technical work of global potential, and sharing of selected technical results and information.

For more information, contact Tony Armor, aarmor@epri.com, (650) 855-2961.

In the Field

Demonstration and application of EPRI science and technology

NYPA Dedicates Most Sophisticated FACTS Controller

A high-speed, electronic device that affords unprecedented control of the flow of electricity on high-voltage transmission systems is operating on the New York power grid, providing a glimpse of how solid-state, semiconductor switches can relieve bottlenecks and revolutionize power networks in the future.

The latest in a series of increasingly advanced FACTS (Flexible AC Transmission Systems) technologies pioneered by EPRI in conjunction with power equipment manufacturers, the device is installed at the New York Power Authority's Marcy, New York, substation. It permits more electricity to be carried on existing transmission lines that link upstate New York with New York City. Such capability strengthens the New York grid's reliability and efficiency and reduces the need for new transmission lines.

New York Lt. Gov. Mary Donohue led a contingent of public and power industry officials in dedicating the start of operation on June 21 of NYPA's convertible static compensator (CSC), the world's most advanced and versatile device for controlling the transmission of electricity.

The technology at Marcy is important in light of New York State's growing demand for electricity, according to Lt. Gov. Donohue. "It will bolster the reliability of the state's transmission system and will give residents and businesses greater access to low-cost electricity as the power industry moves further into the competitive era," Donohue said. "For the longer term, the CSC could provide major benefits not only in our state, but throughout the nation and the world. We fully expect others to adopt this technology for their own needs."

Transformers at the Marcy substation take electricity flowing on 765-kV lines from Canada and send it to New York City at 345 kV along two transmission arteries. One line runs through Albany (and is often nearly fully loaded) and another, less-heavily loaded line extends over the Catskill Mountains.

PHOTO COURTESY OF NYPA

Aerial view of NYPA's Marcy substation; CSC is housed in larger building, left foreground.

Product of collaboration

The $48 million CSC at Marcy was developed and built by Siemens Power Transmission and Distribution in a collaborative effort cosponsored by NYPA, EPRI, Siemens, and a group of 32 utilities and independent transmission system operators in the United States, Canada, and New Zealand.

The CSC installation at Marcy is comprised of two Gate Turn-Off (GTO) thyristor-based inverters, known as STATCOMs (static synchronous compensators) that can each be connected in shunt and/or in series to one of the two 345 kV lines. The STATCOMs can be configured to provide ± 100–200 MVAR of voltage support to the Marcy substation.

By relying on high-speed, solid-state electronics rather than much slower, traditional electromechanical controls for switching high-voltage electricity, the CSC and other FACTS devices "could one day revolutionize the delivery of electricity from power plants to consumers," said Joseph L. Seymour, NYPA chairman and chief executive. "This sophisticated technology will dramatically increase our ability to get power from where it's produced to where it's needed."

Proving its worth

Completion of the CSC's first phase has strengthened voltage support and permitted increased transmission capacity by 60 megawatts on the heavily used lines between Utica and Albany and by 114 MW statewide, NYPA says.

Banks of gate-turnoff thyristor control valves are the electronic heart of the CSC.

But the impact of the CSC will be even greater when it is fully operational. By next summer, the device will provide unprecedented flexibility by allowing the selection of several additional operating modes to control power flow on separate lines simultaneously in the substation. "The CSC can then operate as a United Power Flow Controller or as an Interline Power Flow Controller on two or more lines," explains Abdel-Aty Edris, EPRI manager for FACTS technologies. When completed, the CSC is expected to permit total power transfer increases of 120 MW on the Utica-Albany lines and 240 MW statewide.

Relieving bottlenecks

"NYPA has become a leader in FACTS technology worldwide by deploying a new high-power electronic design topology that will enable power to be transferred from one transmission line to another in milliseconds," said Robert B. Schainker, transmission and substations product line leader at EPRI. "This will allow underutilized lines to relieve bottlenecks on overloaded lines in the increasingly competitive and complex utility industry," he noted at the dedication ceremonies.

Schainker said that "NYPA's management and technical staff have set a new electric utility standard for successfully leading an effort that brought together multiple utility, manufacturer, and government stakeholders to solve a complex transmission problem in a timely and cost-effective manner."

Maximizing the existing grid

FACTS devices like the CSC that increase the effective capacity and operating flexibility of existing transmission lines could be critical to expanding the nation's power delivery infrastructure. Growth in transmission has not kept pace with that of power generating capacity or with escalating demand for electricity.

The deregulation of wholesale electricity markets and utility industry restructuring have stifled new investment in transmission capacity. Announced plans for additional high-voltage U.S. transmission capacity in the next decade amount to little more than a 4% increase, while the Department of Energy projects a 20% increase in total installed generating capacity over the same period. In many areas, siting and permitting for new transmission lines can be more difficult and protracted as a result of public opposition than new power plant construction.

"In the absence of new transmission, a device such as [the CSC] will allow us to maximize the use of the existing transmission network," said Michael Calimano, vice president for operations and reliability at the New York Independent System Operator.

Jan Robjohn, vice president of Siemens Transmission and Distribution's FACTS and Power Quality Divison, called the CSC an "ambitious and innovative project." He commended NYPA "for having the long-range vision to address the needs of New York's electricity consumers. The CSC should serve as a model for energy providers throughout the country as we enter a new and open market."

Adds Shalom Zelingher, NYPA's director of research and technology development, and a champion of the CSC project, "this technology benefits both our customers and the environment. It bolsters our transmission system and allows us to deliver more power to our customers, while avoiding the need to build more transmission lines."

■ *For more information, contact Abdel-Aty Edris, aedris@epri.com, (650) 855-2311.*

Putting the CART Before the Backhoe

A computer-aided radar tomography system (CART) for underground mapping that employs ground-penetrating imaging radar—developed with EPRI sponsorship—is now available commercially from Witten Technologies, Inc. (WTI). An EPRI final report on the ground-penetrating imaging radar (GPiR) developed for the system is available (Order #1006152). A project development team, led by Dr. Mike Oristaglio, was named by *Engineering News-Record* as one of its "Top 25 Newsmakers" in construction for 2000.

Based in Boston, WTI provides advanced underground locating and imaging services for the construction and utility industries. The company's mission is to provide accurate digital maps of the world's underground infrastructure. WTI is offering commercial GPiR mapping services as part of its CART Imaging System™, a new mobile ground-penetrating radar that allows rapid underground mapping of large areas.

The system uses a parallel, sixteen-channel radar array and advanced signal-processing algorithms developed by Schlumberger and WTI in the GPiR project to rapidly scan an area and generate precise three-dimensional (3D) images of the underground infrastructure. It will locate buried objects, such as electric and gas lines, water pipes, heating and cooling pipes, telecommunications cables and tunnels. The array, which covers a two-meter swath on the ground and can move at speeds up to one kilometer per hour, collects enough data in a single pass to form a full 3D image beneath its track. The CART Imaging System can conduct "virtual digs" ahead of excavation effi-

FIELD, *continued on page 29*

Field Tests of Regenerative Biofilms for Corrosion Control

Additional utility power plant sites are being sought as hosts for the current round of field testing in EPRI's project on corrosion control using regenerative biofilms (CCURB). Field tests are continuing this year at Amergen's Three Mile Island plant in Pennsylvania, and discussions are under way with two other utilities, but additional companies are encouraged to participate and host tests in sidestream flow loops of plant service water or fire protection water.

The estimated annual cost of chemicals added to control corrosion in one large recirculating service water tower can be as much as $1 million, notes Barry Syrett, an EPRI Technical Fellow for corrosion science and technology. "Given that there are over 200 large open cooling towers at U.S. power plants, the cost of these chemicals to the industry is enormous," Syrett adds. "CCURB is an approach that may replace chemical treatment and greatly reduce both the cost of corrosion control and the associated adverse impact on the environment."

Contrary to the widely held opinion that bacteria only have an adverse effect on corrosion resistance, the presence of certain aerobic bacteria have been shown to significantly reduce corrosion of mild steel, stainless steel, brass, and aluminum alloys (see EPRI reports TR-110734, TR-113713, and TR-114824). The observed corrosion protection has been attributed, at least in part, to the consumption of oxygen by the bacteria in the biofilm resulting in the elimination of an essential reactant in the corrosion process. There is also evidence that some bacteria secrete metabolic products that act as corrosion inhibitors.

Syrett's project team of scientists at the University of California, Irvine, the University of Connecticut, and the University of Southern California has further improved these beneficial bacteria by genetically engineering them to secrete antimicrobial compounds. These compounds suppress the growth of sulfate reducing bacteria that would otherwise stimulate microbiologically influenced corrosion. Unlike paints and other conventional coatings, protective biofilms regenerate themselves within a few hours if mechanically damaged, thereby providing continuing protection.

Laboratory testing under controlled conditions indicates that CCURB can lead to factors of thirty or more reduction in corrosion rate. Bacteria that were shown to be

beneficial in the laboratory are now being evaluated under more realistic field conditions in preliminary field tests in flow loops at TMI and UC Irvine's central generating facility (CGF). The flow loops contain waters taken from TMI's service water system and the CGF's chilled water system. Despite the competition from other microbes in the process waters, preliminary tests have already shown that some genetically engineered bacteria can cause up to 8-fold reductions in corrosion rate.

The current round of field tests aims to optimize the CCURB techniques and ensure they are widely applicable. Researchers will investigate the effects of adding both single-strain and mixtures of bacteria, the effects of pre-existing native biofilms, the need for nutrient additions, and the role of local water chemistry and pH. The feasibility of the commercialization of CCURB for service water corrosion control will also assessed. The current round of tests could extend from one to three years, depending on industry interest, says Syrett.

At each test site, two flow loops operate in parallel. One (the control loop) contains unaltered service water and the other contains service water that has been inoculated with the beneficial bacteria under test. These flow loops will be completely closed to the external environment and no human pathogens will be used. One pair of transportable sidestream flow loops will be constructed by the EPRI project contractor and will be available for the duration of the tests. Preference will be given to hosts that are willing to finance the construction of a pair of flow loops to the project's specifications. In addition, the host should be willing to provide a sheltered site for the flow loops, a power supply for the pumps and instrumentation, and a dedicated telephone line to facilitate remote control of the equipment via a modem.

During the testing, water and biofilm samples will be taken first to identify the native bacteria and to select from among them those bacteria that can be genetically engineered to provide CCURB. Electrochemical monitoring equipment with a supporting computer will track corrosion rates of metal coupon and pipe specimens in both flow loops throughout the test period (three to twelve months). This equipment will be controlled remotely by the contractor so plant personnel will not need to have knowledge of the test software. Each flow loop will have parallel flow paths to allow simultaneous testing under three flow conditions that are representative of those in the host's service water system.

Plant personnel will be expected to work closely with the EPRI contractor to make periodic inspections, ship specimens, and safely dispose of waters after

testing in the flow loops. Addition of biocides or some other method of killing the bacteria may be necessary before disposal.

Interested member utilities should contact Barry Syrett, bsyrett@epri.com, (650) 855-2956.

Mimicking Nature's Way of Capturing and Storing Carbon

Increasing concerns that changes in global climate could result from human-caused emissions of infrared-absorbing greenhouse gases inevitably focus on carbon dioxide (CO_2) which, although not the most potent of greenhouse gases, accounts for the largest quantity of emissions. The Intergovernmental Panel on Climate Change estimates that annual global emissions from all sources were around 7.4 gigatonnes (billion metric tons) of carbon in 1997, corresponding to twenty-seven gigatonnes of CO_2.

Possible approaches to carbon management range from improving the efficiency of fossil-fuel-fired electricity generation, improved efficiency in electricity-using appliances and equipment, accelerated decarbonization of primary energy fuels in favor of renewable and hydrogen-rich fuels, and a long-term shift to an energy economy that is not based on fossil-fuel combustion.

But because coal-fired power plants currently generate more than half of the world's electricity, it is unlikely that even all of the above-mentioned approaches to carbon management combined would be sufficient to cap atmospheric CO_2 levels over the next forty to fifty years. If such a global environmental objective is to be achieved while increasing world demand for energy and the developing world's demand for a better quality of life are met, dealing with the products of carbon-based fuel combustion through on-site CO_2 capture and reasonably local sequestration will be necessary. Compounding the difficulty of the problem is the requirement for the capability of retrofitting CO_2 control systems to existing coal-fired plants.

Geological and marine sequestration

Most studies on local CO_2 capture and sequestration have been based on the assumption that CO_2 would first have to be concentrated from the dilute exhaust gas from fossil-fuel combustion and, in general, that it would then have to be transported to a suitable disposal site. The initial flue-gas composition contains only 10% to 15% CO_2. Although technologies for concentrating and transporting CO_2 exist—such as chemical absorption (typically in alkanolamines such as monoethanolamine) followed by steam stripping—they add significant economic penalties (as much as 50%) to the cost of generating electricity. Moreover, the material masses that would be involved if, for example, all the CO_2 in a hypothetical plant's exhaust were completely sequestered as calcium carbonate exceed those involved in flue-gas desulfurization (FGD) by more than a factor of fifty.

Concentrated CO_2 can be transported by pipeline as a supercritical fluid and disposed of in depleted, underground oil and gas fields. This technology is already well-established—but still not cheap—for the purpose of enhanced oil recovery. Supercritical CO_2 can also be disposed of in deep saline aquifers, in the deep ocean, or by carbonation with certain minerals.

Despite the injection of CO_2 for enhanced oil recovery, significant uncertainties surround the widespread, large-scale implementation of deep geological and marine sequestration methods, including the behavior and ultimate fate of the injected CO_2, safety concerns, and the impact of high costs for capture and separation on electricity rates.

Taking a cue from nature

In pursuit of geological sequestration of carbon, work is being done at Los Alamos National Laboratory to develop an industrial-scale process based on the carbonation, or weathering, of serpentinites and peridotites.

Another type of geological process that can be viewed as a model for the sequestration of anthropogenic CO_2 is the generation of calcium carbonate by various types of marine animals, such as those that form extensive oolitic limestone beds on the ocean floor.

For several years, EPRI has supported work by Professor Gillian Bond at New Mexico Tech to develop a process analogous to this natural method of carbon capture. In this biomimetic process, a biological catalyst—the enzyme carbonic anhydrase—is used to accelerate an aqueous route to carbonate formation. Potentially, such a novel approach offers several advantages over alternative methods for carbon management, including the possibility of on-site CO_2 scrubbers at individual power plants and elimination of the need to concentrate and transport CO_2. Not only would the processing method itself be environmentally benign, the ultimate product—calcium carbonate—would be safe, stable, and benign as well.

In recent articles in professional journals, EPRI Technical Executive John Stringer, Professor Bond, and colleagues report experimentally demonstrating proof of principle for the biomimetic, catalytic process for carbon sequestration. The researchers analyzed and tested the performance of the carbonic anhydrase enzyme in the presence of other chemical species likely to be present in industrial use that could inhibit the hydration reaction, such as small amounts of sulfur and nitrogen oxides. So far, "results are extremely encouraging," the researchers note.

Unlike the proverbial new material in search of an application, the biomimetic approach followed by the researchers began with a specific problem to solve, explains Stringer. "We have an engineering problem. We look for an example in nature where a similar problem has been solved. We determine how nature has solved the problem, and then we see if we can imitate—mimic—the method in an engineering context."

Researchers analyzed the rate-limiting step in the chemistry of CO_2 fixation into calcium carbonate in aqueous solution and looked for lessons from biological systems that could accelerate that step. A key parameter is pH, because of its strong effect on the proportions of the carbonic species present. And at low pH, carbonates tend to dissolve rather than precipi-

tate. Although carbonate can be formed rapidly at high pH, a process that operates at very mildly basic pH values would pose fewer economic and environmental concerns. Thus, if a viable approach to accelerate the hydration of CO_2 in aqueous form could be found, it should be possible to fix large quantities of CO_2 into calcium carbonate at moderate pH.

Speedy catalyst

The scientists did not have to look far afield for a biological catalyst to accelerate CO_2 hydration. The carbonic anhydrases (CAs) are a large group of zinc metalloenzymes and are ubiquitous in nature. Among the fastest enzymes known, they catalyze the reversible hydration of CO_2. The fastest CA enzyme known is the human isozyme HCA II; each molecule can hydrate at least 1.4 million molecules of CO_2 per second. Carbonic anhydrase appeared to promise the feasibility of sequestering large quantities of CO_2 into carbonate form, without recourse to caustic conditions. The enzyme is also of interest to other researchers for CO_2 sequestration in closed systems such as a space station.

Bond and her colleagues performed two types of experiments to demonstrate the feasibility of the biomimetic approach to carbon sequestration. One type—vital to indicate potential industrial applicability—was designed to show acceleration of the overall process of forming calcium carbonate in the presence of the enzyme. The other type focused on demonstrating the accelerated hydration of CO_2 with the enzyme. The experiments initially were performed with bovine carbonic anhydrase (BCA), which is commercially available in purified form. Tests were also performed on crude (dilute) extracts from plant sources that contain CA, including spinach, parsley, and yeast. Researchers reported observing very large accelerations of both CO_2 hydration and precipitation of calcium carbonate with the BCA and significant accelerations with the dilute plant extracts.

The lowest-cost source of large quantities of CA likely will involve overexpression by a genetically modified bacterial system, the researchers noted. They turned their attention to HCA II—the human isozyme—after colleagues at the University of Florida donated cloned HCAII in a T7 phage vector. The *Escherichia coli* (*E. coli*) host for this vector was obtained from Fischer-Promega. This is a patented strain capable of expressing a T7 RNA polymerase (Promega, 1997), which is required for the over-expression of carbonic anhydrase. Ampicillin resistance is the marker for successful transfer of the gene into the host organism, and iso-thio-galactopyranoside (IPTG) is the inducer that provokes the overproduction of the enzyme by the host cell. The cloned CAII was successfully expressed in the E. coli system. A crude extract from the E. coli was produced for initial testing. Again, excellent results were reported with crude extracts of HCA II—a key finding, since enzyme purification is expensive.

"It's important that the enzyme catalyst is 'immobilized' to prevent its being washed away in the process stream," notes Stringer. "Bond's team developed a very effective low-cost immobilization procedure using porous alginate beads with an abrasion-resistant chitosan coating—again, based on naturally-occurring materials with no adverse environmental consequences."

Questions for further research

Beyond the basic proof of principle, the New Mexico Tech researchers identified several topics that require further study. These include further studies related to the optimization of the catalyst, for example looking at isozymes from species known to live in more extreme environments, and the likely source of cations, particularly calcium ions, for the reaction. Three possible sources of cations could also serve as an aqueous process stream: seawater, waste brines from desalination operations, and brines from saline aquifers. The ultimate choice may depend on site-specific aspects at a particular power plant.

The researchers are investigating the possibility of forming magnesium carbonate as well as calcium carbonate. "In this context it is interesting to note that in marine environments animals do not form magnesium carbonate, although the concentration of magnesium ions is appreciably greater than that of calcium ions. The reasons for this are under investigation," Stringer adds.

For any approach to CO_2 capture and sequestration from fossil-fuel power plants, the huge quantities of flue gas and aqueous processing media that are involved will require innovative engineering. If all the CO_2 produced by a hypothetical 300-MW(e) coal-fired power plant were sequestered by pumping seawater through an on-site separation vessel, with a calcium ion concentration in the seawater of 400 grams per tonne, 100% removal would require 18 million tonnes of seawater per day. "This is a very large number, indeed," notes Stringer, "but it is less than an order of magnitude greater than the cooling water flow for a generating unit of that size, which is around 2.4 million tonnes per day." The researchers note that seawater is the most dilute of the brines being considered as possible cation sources and it is not clear that seawater flow would necessarily be that large.

If 100% of such a unit's CO_2 were sequestered as calcium carbonate, this would correspond to 16,000 tonnes per day. As noted, this is more than fifty times greater than the material masses involved in FGD systems. The equivalent of 9000 tonnes per day of cations would be required to combine with the carbon. This compares with a coal supply of 3000 tonnes per day and an ash production of 270 tonnes per day.

The question of what could be done with very large quantities of calcium carbonate inevitably arises, based on experience with efforts to market the gypsum by-product of FGD. In that case, the amount of gypsum produced by U.S. utilities quickly exceeded the market for gypsum wallboard. Although carbonates are common materials, notes Stringer, the fine particle size that is likely for calcium carbonate powder produced by a CO_2 scrubber may make the product compete well with mined and crushed carbonate.

"We are actively looking at possible geometries of a commercial system based

on our proposed biomimetic sequestration method," the researchers report. "At this time, there is still too much research remaining to be done for us to describe the design of a potential scrubber in detail." They noted that the different types of scrubber that have been proposed for FGD systems probably will not be scalable to the requisite size, but that gas-liquid contacting systems likely will be similar.

Assuming that a CO_2 scrubber would be installed downstream of an FGD system at a power plant, relatively few other contaminants would be expected in the flue gas. NO_x and SO_x may be present, but in very small amounts, unlikely to exceed 100 parts per million, the researchers point out. The laboratory studies have shown that the enzymatic catalysis is unaffected by these impurities at quantities an order of magnitude greater than could be expected in service. Work is continuing to analyze other possible contaminants that could inhibit the enzymatic catalysis. Flue gas that had passed through an FGD system would have been in contact with a relatively basic (calcium hydroxide) environment, with other acid gases removed. The researchers note the only issue regarding pH is the acidity of the CO_2 itself and they are investigating possible buffering systems.

The New Mexico Tech researchers are now performing laboratory experiments similar to those already published based on bovine carbonic anhydrase, using other solution chemistries and the HCA II isozyme produced by bacterial overexpression. "The results are extremely encouraging, because they indicate that the robustness of mammalian CA II may well be adequate for its application in a CO_2 scrubber, as envisaged," they report.

Stay tuned for further developments in this journey of discovery.

Further reading

Bond, G.M., et al. "Development of Integrated System for Biomimetic CO_2 Sequestration Using the Enzyme Carbonic Anhydrase," *Energy & Fuels*, Vol. 15, No. 2 (2001), pp. 309–316.

Medina, M.G., et al. "An Overview of Carbon Dioxide Sequestration," *Interface* (The Electrochemical Society), Spring 2001, pp. 26–30.

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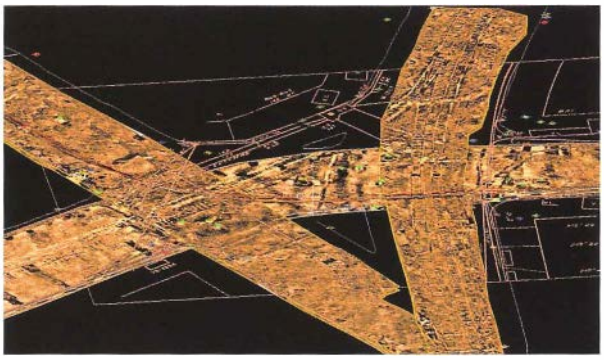
FIELD, *continued from page 25*

ciently and on a large scale, enhancing both productivity and safety on utility construction and maintenance jobs.

Several years ago, EPRI began a project with Schlumberger Technology—a project that was later joined by the Gas Technology Institute (GTI, formerly the Gas Research Institute)—to develop a new radar mapping system that would produce accurate images of underground objects. The primary motivation was accident avoidance and reduced operations and maintenance costs. The prototype system combined commercially available ground-penetrating radar technology with precise positioning and advanced, sophisticated signal- and image-processing to create accurate 3-D images of underground infrastructure. The prototype was tested at seven utilities at eighteen different sites chosen by EPRI member utilities. The sites included a typical construction



scene, downtown streets and intersections, a proposed street vault location, and underground cables at a substation. Images were made down to depths of 1.5 to 3 meters (5 to 10 ft).

WTI's commercial CART Imaging System uses a patented, parallel radar array specially built for WTI by the Swedish company Malå Geoscience. The new system enables utilities, construction companies, and others involved with underground infrastructure to create precise 3-D maps of the complex array of electric, gas, water, and communications lines and also impediments to construction and excavation lying beneath today's busy city streets. Armed with this information, the utilities and construction companies can better manage, maintain, and build underground networks that serve downtown business centers and residential areas.

Under an agreement with the initial contractor, Schlumberger, commercialization of GPiR services in North America is being handled by WTI as part of its CART and associated mapping services. EPRI, GTI, and their members will benefit from this technology and from future royalty. Beyond North America, Schlumberger is the exclusive contractor for CART services through its newly formed StreetLOG division.

The project team that developed the GPiR was acknowledged by *Engineering-News Record*, which named the technology one of its Top 25 NewsMakers of 2000. "Mike Oristaglio broke new ground in adapting seismic mapping techniques used in oil and gas exploration to a scale and definition that will let contractors and utility workers learn what's underground before they dig," the citation reads. "Oristaglio and his team created software algorithms that simultaneously interpret radar returns from multiple emitters traveling across the ground to generate real-time 3-D images of objects buried to depths of 3 meters. The technique is now being offered as a commercial service."

The EPRI report includes project update presentations made during the last two years, results of field tests at Consolidated Edison Company of New York, Duquesne Light & Power, San Diego Gas & Electric, Seattle City Light, PSE&G, OPPD, and others, plus technical articles. It is available to funders of the Underground Distribution Infrastructure target.

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