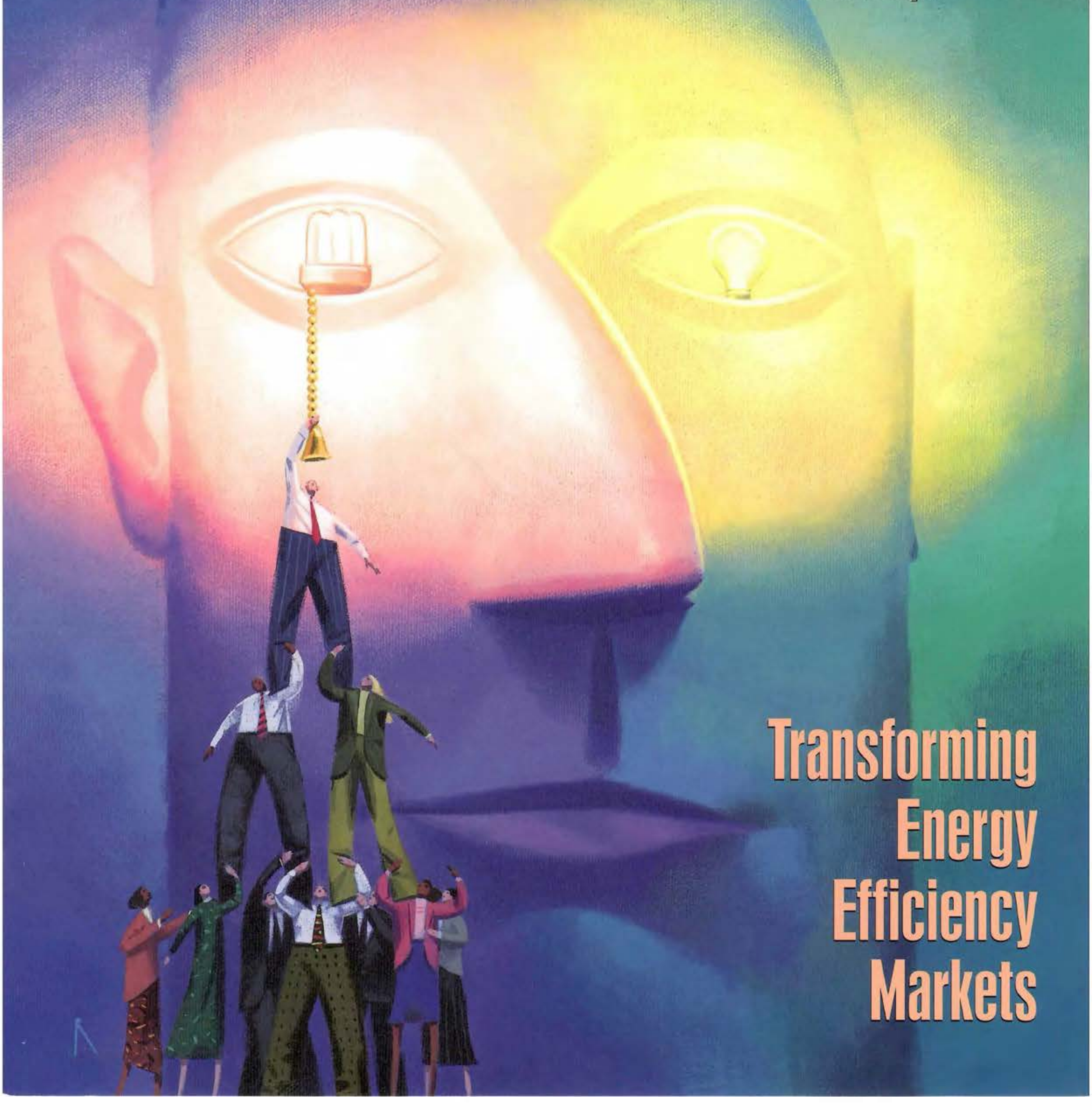
Precision Power Networks
Advances in Electronic Control

EPRI JOURNAL

NOVEMBER/DECEMBER 1998

R&D's Path to the Future
The Electricity Technology Roadmap



Transforming Energy Efficiency Markets

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 700 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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COVER: Turning customers on to energy-efficient products and services can be a tough challenge. Transforming markets to successfully incorporate such options typically requires careful customer research, advanced technology, and cooperative implementation efforts involving a number of interested parties. (Illustration by Rob Barber)

EPRI JOURNAL

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EDITORIAL

COVER STORY

Integrating customer research with technology development, EPRI engages the right combination of stakeholders to transform important markets through lasting gains in energy efficiency.

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The Unified Power Flow Controller—a third-generation FACTS device—is providing unprecedented levels of control and operating flexibility at an American Electric Power Company substation.

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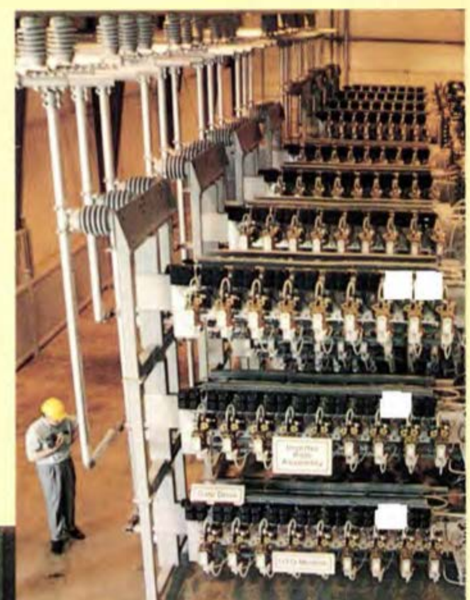

This comprehensive vision of opportunities for electricity-related innovation is intended to guide broad-based public and private R&D investment well into the coming century.

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Editorial

Market Transformation: Learning to Like Our Vegetables

For many of us, vegetables are an acquired taste. As children we may have been forced or bribed to eat them, but as adults we've come to appreciate them not only for their nutritional value but for their taste and the balance they bring to our meals. Energy efficiency is in many ways the vegetable portion of our energy consumption. We know it's good for us, but we've typically been a lot more interested in the other stuff on our plate—particularly, low electricity bills and enough power on demand to run our increasingly electric lifestyles. Under the highly regulated utility structure of the recent past, energy efficiency was managed by utilities, largely through demand-side management (DSM) programs. The cost of these programs was recouped, with regulatory approval, through rates.

Now, with power generation and energy services quickly diverging and preparing to operate in open, competitive markets, new approaches are needed. While DSM programs were effective under regulation, they have key drawbacks in the emerging business environment. First, they typically involve short-term marketing efforts with individual customers and depend on financial incentives to keep program participants interested. Efficiency gains tend to disappear when the incentives are dropped. Second, power providers have no profit motive for encouraging energy efficiency under an open market: it's extremely difficult to make more money by selling less product. New alternatives to DSM must be firmly market-based.

There is no way to build a real market for energy efficiency without translating it into tangible benefits that consumers can relate to. Fortunately, energy efficiency brings with it an enormous opportunity: the potential for a 20–40% reduction in energy consumption carries a clear business advantage for anyone who can make such efficiency gains work for the customer's bottom line. The key is to understand market transformation—the process of making a fundamental change in the market for energy-efficient products, services, and practices in such a way that the change becomes permanent. Suppliers of energy and energy services who learn to use market transformation effectively will succeed in a competitive marketplace.

Some state regulators are anxious to find mechanisms to accelerate the transformation of energy efficiency markets, and a few states, including California, are considering investing public funds in privately managed programs. In its most effective form, this market transformation approach is highly collaborative, involving cooperation among manufacturers, retailers, utilities, standards-setting organizations, government, and public-interest groups. Because the energy-efficient technologies and methods produced in market transformation efforts synthesize detailed market research results with the concerns and innovative ideas of many participants upstream of the buying interface, they tend to have a great deal of customer pull and a good chance of establishing a permanent presence in the marketplace without the need for ongoing incentives.

As this issue's cover story illustrates, EPRI has incorporated market transformation techniques for many years in its development and commercialization of advanced end-use technologies. In addition, EPRI recently joined with the Gas Research Institute and the architect-engineering firm of Daniel, Mann, Johnson & Mendenhall to form Global Energy Partners, a company designed to administer market transformation projects on behalf of state regulatory agencies and other similarly interested parties. Global Energy Partners is looking forward to working with our members or stakeholders to assist in managing and administering market transformation. I believe we are especially well equipped to do this—our efforts to create new recipes for efficient energy use in a broad range of applications have been quite successful. And when you succeed in developing palatable options, those vegetables can go down very easily.

Clark W. Gellings
Vice President, Client Relations

Contributors

Selling Customers on Energy Efficiency (page 8) was written by science writer Christopher R. Powicki, with technical assistance from Morton Blatt and Jeremy Bloom.

MORTON BLATT, director of the Energy Delivery and Utilization Division, previously managed EPRI's Residential and Small Commercial Business Unit. Before coming to EPRI in 1985, he was manager of end-use efficiency programs at Science Applications International Corporation. Blatt holds a bachelor's degree in mechanical engineering from Cooper Union, an MS in industrial engineering from New York University, and an MS in business administration from San Diego State University.

JEREMY BLOOM, manager of the market analysis and resource management product line, joined EPRI in 1992 to lead its integrated resource planning program. Before that, he spent 10 years at General Public Utilities, where he specialized in demand-side planning. Bloom previously taught operations research at Cornell University for four years. He earned a BS degree in electrical engineering from Carnegie Mellon University and MS and PhD degrees in operations research from the Massachusetts Institute of Technology.

Power Precision With UPFC (page 18) was written by Taylor Moore, *Journal* senior feature writer, with technical assistance from Abdel-Aty Edris of EPRI's Energy Delivery and Utilization Division.

ABDEL-ATY EDRIS is manager for Flexible AC Transmission System (FACTS) technology. He joined EPRI in 1992 after 12 years with ABB Asea Brown Boveri in Sweden and the United States, where he worked in the development and application of reactive power compensators and high-voltage dc transmission. Edris received a BS degree from Cairo University, an MS from Ain-Shams University in Egypt, and a PhD from Chalmers University of Technology in Sweden.

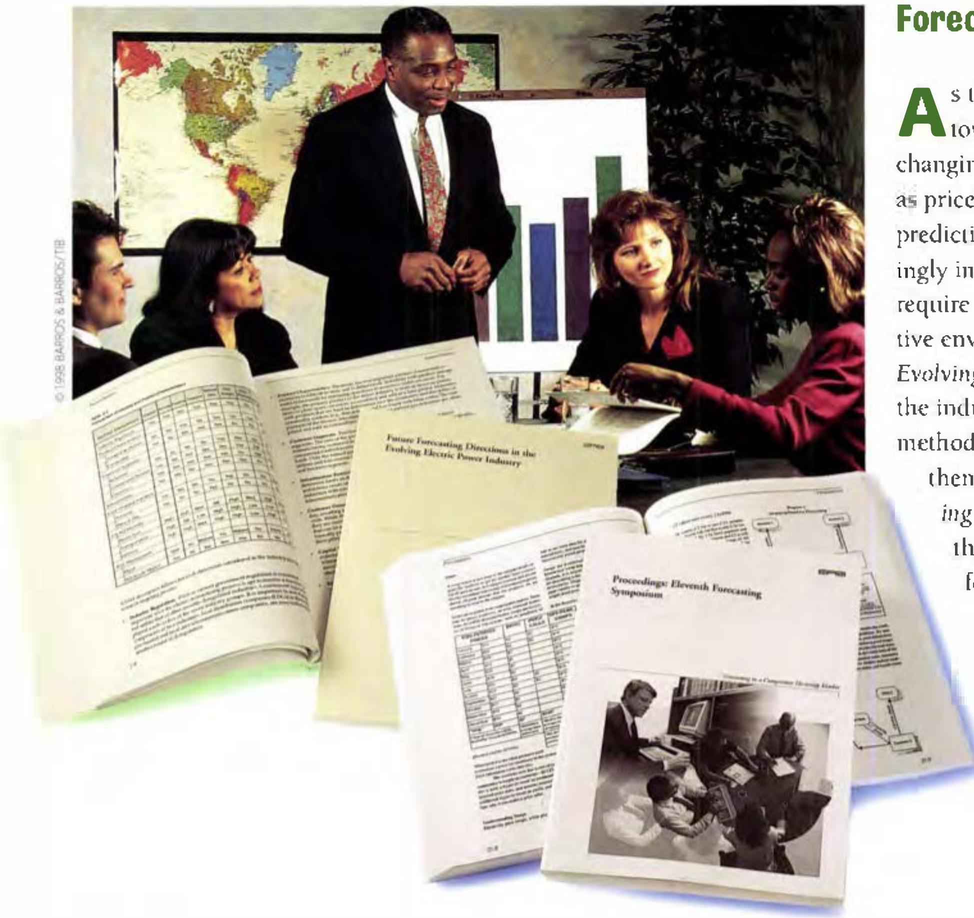
The Electricity Technology Roadmap (page 24) describes a highly collaborative, long-term R&D planning initiative currently being managed by EPRI's Steve Gehl and Brent Barker.

STEVE GEHL, as director of strategic technology and alliances, has led the roadmap initiative since 1997. Previously he served as director of strategic synthesis and as a manager of generation and nuclear power programs. Before coming to EPRI in 1982, he was a staff metallurgist at Argonne National Laboratory, where he conducted research on nuclear fuel performance. Gehl received a bachelor's degree in metallurgical engineering from the University of Notre Dame and a PhD in materials science and engineering from the University of Florida.

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

Products

Deliverables now available to EPRI members and customers



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Forecasting Reports

As the electric power industry moves rapidly toward competition, the role of forecasting is changing dramatically. Market-related activities, such as price forecasting, market share analysis, and the prediction of competitors' costs, are becoming increasingly important. Tackling these new activities will require approaches better suited to the more competitive environment. *Future Forecasting Directions in the Evolving Electric Power Industry* (TR-109056) identifies the industry's key forecasting needs and discusses the methods, tools, data, and skills essential for meeting them. A useful companion to this report is *Forecasting in a Competitive Electricity Market* (TR-110424), the proceedings of EPRI's eleventh electric utility forecasting symposium.

■ *For more information, contact Ahmad Faruqui, (650) 855-2096. To order, call the EPRI Distribution Center, (925) 934-4212.*

THELMA

This 10-volume report, *The High-Efficiency Laundry Metering and Marketing Analysis (THELMA) Project* (TR-109147), provides a readable overview of a four-year EPRI study of the market potential of efficient residential washing machines. The report offers a market analysis template applicable to any type of product or service offering. It lays out a coordinated strategy for acquiring valuable information from consumers, manufacturers, distributors, and retailers to enhance market assessment, distribution analysis, and impact analysis. The data-gathering techniques discussed include mail and phone surveys, focus groups, product demonstrations, and in-home interviews.

■ *For more information, contact John Kesselring, (650) 855-2902. To order, call the EPRI Distribution Center, (925) 934-4212.*

LightPAD 2.0

The rapid growth of lighting conservation programs in recent years has resulted in increased demand for lighting audits. EPRI's LightPAD software is designed to improve the speed and accuracy of these audits. It may be used to quickly estimate a building's lighting energy consumption and current lighting levels or to define and compare alternative lighting systems. For ease of use at the work site, LightPAD 2.0 is designed to operate on both desktop and portable computers, including notebook and lightweight, pen-based tablet computers.

■ *For more information, contact EPRI's Lighting Information Office, (800) 525-8555. To order, call the Electric Power Software Center, (800) 763-3772.*

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PQ Database for the Healthcare Industry

The sophisticated hospital environments of today are full of advanced electronic devices that can be vulnerable to power quality problems. EPRI developed the Power Quality Database for the Healthcare Industry (CD-109129) to help utilities and their customers identify, solve, and prevent such problems. This product is the first industry-specific power quality and electromagnetic compatibility reference database to be developed. Designed for use with EPRI's broader PQ Database, also available on compact disc, the database is a searchable file containing 21 case studies and four sets of system compatibility test reports. A document template customized for medical facilities is included so that users can develop their own case studies.

■ *For more information, contact Sid Bhatt, (650) 855-8751. To order, call the Electric Power Software Center, (800) 763-3772.*

Digital Smart Ground Multimeter

Increased competition has led to more sales and purchases of electric utility substations. The digital Smart Ground Multimeter (SGM) offers power companies a fast, accurate way to assess substation design and integrity to ensure the soundness of their investment as well as the safety of their workers. Using advanced current-injection techniques and digital signal processing, the SGM can quickly and easily measure the ground impedance on substation grounding systems—regardless of whether they are energized or de-energized. The SGM can also measure touch voltage, step voltage, soil resistivity, tower ground resistance, transfer voltage, and low impedance/continuity.

■ *For more information, contact Jerry Melcher, (650) 855-2299. To order, call Lyn Cosby at Hood-Patterson & Dewar, (404) 296-5990.*

Around the World

Focus on international projects and alliances

International Interest in Y2K Project Rises

A growing number of international companies are joining with U.S. firms in EPRI's Year 2000 (Y2K) Embedded Systems Project, which aims to help participants get a handle on the Y2K problem before the fast-approaching deadline of January 1, 2000.

So far, the program participants include companies from Australia, Barbados, Bermuda, Canada, the Cayman Islands, China, Colombia, England, Finland, France, Israel, Mexico, the Philippines, Puerto Rico, St. Lucia, and South Africa. More international companies are expected to follow suit in the coming months; among those that have expressed interest are companies in Egypt, Germany, Holland, Japan, Korea, and Russia. In addition, many Y2K program participants based in the United States have operations in South America, Europe, Australia, and Asia.

The EPRI program was established in October 1997 to address the Y2K issue in embedded computer systems (computer hardware and firmware). This summer, it was expanded to incorporate the concerns of natural gas transmission and distribution companies. As of mid-November, 110 companies had joined the program, including utilities, major oil companies, gas pipeline operators, telecommunications companies, and mining firms.

EPRI's initiative is designed to increase understanding of the Y2K issue in embedded computer systems. The participants can use this understanding to enhance their own remediation work. Y2K is an infrastructure problem that has the potential to impact EPRI members, their suppliers, and their customers. The implications for the power industry could be significant, with problems ranging from system outages to reduced power quality if the issue is not appropriately addressed.

The program members share information through such avenues as quarterly workshops and EPRI's Y2K Web site. As participants in the program, companies can maximize the value of their in-house resources by avoiding duplicate efforts, and they can benefit from the lessons learned by other companies. Overall, they can acquire a broader perspective on the Y2K problem, the ability to benchmark their efforts, a greater voice in the vendor community, and the capacity to accelerate their own work.

As Joe Weiss of EPRI explains, international companies use much of the same operating equipment that U.S. companies use. "Although there are cases in which the equipment is different, the methodology and approaches being shared in the EPRI program are directly applicable," says Weiss, who heads up the technical aspects of the program. "The Y2K issue is just as relevant to the international community. Everyone is working to keep the lights on, keep the oil flowing, and maintain the production of fundamental commodities."

■ *For more information, contact Joe Weiss, (650) 855-2751.*

New EPRI-ESKOM Center Targets Power Systems

A new EPRI center, conceived to address the many transmission and distribution challenges South Africa faces since emerging from its period of political, economic, and technical isolation, just completed its first year of operation. Launched jointly by EPRI and ESKOM—South Africa's largest electric utility—on November 3 of last year, the South African Power Systems Studies Institute (SAPSSI) focuses on training and research in power systems analysis, planning, operations, and control.

In South Africa's now-normalized political environment, engineers must plan for the interconnection of previously isolated regional transmission networks. Such interconnections are taking place at a rapid rate. At the same time, cost pressures and other factors mean that more power is required to flow along existing transmission corridors. Adding to the challenge is a big push for electrification throughout the country and southern Africa in general; the delivery network must be expanded to provide the additional energy at decreasing costs per connection. And the emergence of new competitive and cooperative power pools requires that network design,

COURTESY ESKOM

control, and operation must be well understood. Power quality is also a growing concern.

Clearly, engineers in southern Africa must take extraordinary care in designing and operating the region's future power delivery networks. However, the skills needed to tackle the new technical challenges are not abundant in the region. SAPSSI (which is not to be confused with another EPRI-ESKOM center, the South African Centre for Essential Community Services) was created to bridge this gap. Its main goal is to help enable the region's electricity industry to optimize and expand its transmission and distribution networks. SAPSSI is working toward this goal through formal training and education, supported by technology transfer, applied research, and technical consultation.

The key priority in the center's first year was to train practicing engineers in the application of EPRI R&D relevant to the issues they face. In all, 22 training courses, seminars, and workshops were held, with most of the attendees from South Africa. The topics ranged from system stability to Flexible AC Transmission System, or FACTS, technology. Ultimately, the center aims to establish itself as the "institute of choice" in power systems training and research for all of southern Africa.

Once SAPSSI's training and research plan has met its objectives, EPRI and ESKOM will consider starting a for-profit consulting and troubleshooting subsidiary. The EPRI-ESKOM partnership has agreed to finance the center for three years, after which it will be self-supporting.

■ *For more information, contact Ray Lings, (650) 855-2177.*

EPRI Ramps Up International Loan-In Program

Recognizing the great value that international personnel bring, EPRI is working to enhance the program whereby employees of its international member companies are loaned to EPRI for assignments ranging from six months to two years. EPRI has always valued a worldwide perspective; its international loan-in program dates back 20 years. But through EPRI International, a new division launched last January, EPRI has placed increased emphasis on formalizing this program.

As part of this effort, in July EPRI established the International Loan-in Forum—a series of bimonthly meetings at which the loan-in employees discuss their needs and provide valuable insights on the international market. (The forum is cochaired by Robert Holmes, a loan-in employee from PowerGen of the United Kingdom, and Martha McNeal, EPRI International's general manager of sales operations.) And this fall, for the first time, EPRI asked the international loan-in personnel to review some proposed research targets in order to assess their potential value to the international community.

"Having these employees on-site has been a tremendous benefit," says Greg Lamb, a customer service manager for EPRI International. "They offer us a very effective way to become more familiar with our members' needs."

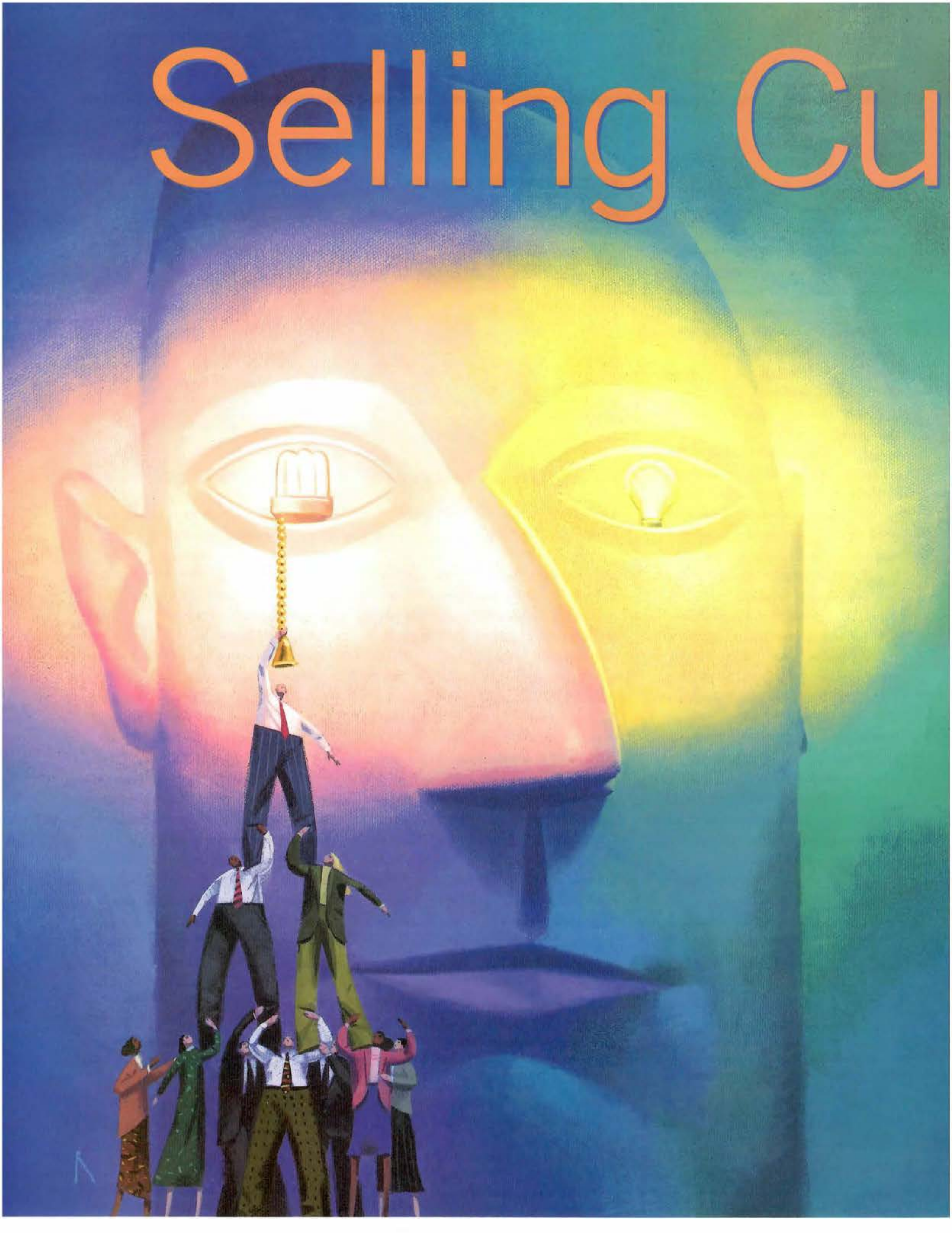
As of early November, EPRI had 17 international loan-in employees from 10 countries (Argentina, Finland, France, Japan, Korea, Mexico, Poland, South Africa, Sweden, and the United Kingdom). Typically, their salaries are paid by the member company, with EPRI subsidizing some of the housing expenses. Most of the employees are middle-level managers and are responsible for overseeing their companies' relationship with EPRI.

When the loan-ins arrive at EPRI, they are given information on and assistance with housing, as well as help in obtaining a driver's license. EPRI also strives to assist the loan-ins with cultural adjustments—both to the United States and to the EPRI work environment. In addition, it offers English classes for these employees.

In 1999, with input from the International Loan-in Forum, EPRI plans to help the loan-ins better define their daily responsibilities while working at EPRI.

■ *For more information, contact Martha McNeal, (650) 855-2922.*

Selling Cu



stomers on Energy Efficiency

by Christopher R. Powicki

STORY IN BRIEF

Despite energy efficiency's inherent economic and environmental advantages, most residential, commercial, and industrial customers pay it little heed in their purchasing decisions. Often, a concerted effort is required to transform existing markets—to find ways of overcoming barriers to the adoption of energy-efficient products, services, and practices. In addressing this challenge, EPRI integrates customer research with technology development, engaging the right combination of stakeholders to produce lasting efficiency gains in important market sectors.

Imagine yourself working for a major appliance manufacturer in the early 1990s. The U.S. Department of Energy has just indicated that it would propose new energy efficiency standards for residential washing machines. These standards will effectively require you to produce and sell a front-loading horizontal-axis (H-axis) washer similar to those found in commercial laundromats. Unfortunately, 93% of consumers surveyed express a strong preference for conventional, top-loading vertical-axis (V-axis) machines.

Do you toss corporate stewardship out the window and aggressively challenge the standards? Put your head in the sand, hoping that other manufacturers will develop an acceptable H-axis washer that you can knock off and exploit as a fast second? Or do you partner with an organization that specializes in bringing energy-efficient technologies to commercial reality, revisit consumer perceptions, and take a shot at transforming the existing market with the development of a truly superior machine?

The last option is obviously the preferred alternative. But it's obvious only because the Neptune front-loading H-axis washer codeveloped by Maytag and EPRI is flying off showroom floors at retail outlets across the country. Ironically, DOE has yet to officially propose new washer standards, but the brisk sales of the Neptune and other domestically manufactured H-axis machines are quickly slicing into the overwhelming market share of the less-efficient V-axis machines.

"The ongoing transformation of the residential washer market is just one example in EPRI's long history of marrying market research with the development and transfer of energy-efficient technologies and practices," says Jeremy Bloom, manager of EPRI's market analysis and resource management product line.

"There is no simple recipe for achieving lasting change, because each market carries its own unique problems and opportunities. Our success has come from finding the critical path for an innovative product or technology and then bringing to bear technical and business acumen, a detailed understanding of customers and markets, and an unrivaled international presence in energy efficiency. Once EPRI identifies an opportunity for substantial efficiency improvement, all aspects are analyzed in detail to develop an integrated course of action for overcoming barriers throughout the product cycle. By bringing together the right combination of stakeholders, we intervene where necessary to enable lasting market effects."

Transformation basics

Market transformation is a fundamental objective of every entrepreneurial organization, from inventors tinkering in the garage to multinational corporations looking to launch new products or services. At its heart is the creation of a new set of customer expectations or needs—a vacuum that the entrepreneurial organization hopes to be uniquely qualified to fill.

"Conceptually, market transformation is a very simple process; it's a matter of understanding and influencing the behavior of customers and other market actors," notes Bloom. "But making it happen can be extremely challenging, as generations of entrepreneurs well know. There is no uniformly applicable formula. Because barriers come in multiple forms, shift over time, and pop up in unexpected places, many different types of interventions can be required to achieve lasting market effects. And the watershed events in a successful transformation are usually easier to identify in hindsight than before or as they occur."

Market transformation is emerging as a central policy objective of publicly funded energy efficiency programs. Traditionally, the emphasis has been on utility-directed efforts to minimize the need for new generating capacity. The California Public Utilities Commission (CPUC), for example, has long required the state's investor-owned electric utilities to offer programs helping customers in their service territories improve energy efficiency. As has been the case in many other states, the California utilities have offered rebates and low-interest financing, performed educational campaigns, provided on-site technical assistance, and conducted other market interventions to reduce barriers to the adoption of energy-efficient technologies and practices.

Once retail competition began in the state on March 31, 1998, however, the California utilities were released from the obligation to plan for and acquire energy resources for a captive set of customers. As a consequence, the costs of energy efficiency programs can no longer be automatically recouped through a regulated rate structure, weakening incentives for utilities to offer and manage effective programs. In response to these changes, the CPUC determined that future ratepayer-funded energy efficiency programs should emphasize lasting market transformation and that program administration and implementation should be open to both utilities and other organizations.

From an energy efficiency perspective, there are four basic types of transformation: incremental improvement of commercially available products, redesign or reengineering of multicomponent systems or multistep processes, modification of the behavior or practices of customers and other market actors, and introduction of new technologies. Successfully transformed markets are characterized by increases in the demand for or use of more-efficient options. These increases result from interventions that reduce barriers to the options and help bring about changes in market structure or in the behavior of market actors. Transformation can be temporary, partial, or complete, depending on the degree to which market effects last after the interventions have been eliminated, reduced, or changed. In completely transformed markets, further intervention may be unnecessary. The products, services, or practices have reached a threshold—the so-called tipping point—beyond which they become self-sustaining.

"EPRI has been in the business of transforming energy markets since its inception," says Morton Blatt, director of EPRI's Energy Delivery and Utilization Division. "Identifying, developing, and commercializing energy-efficient technologies and practices are EPRI's core functions, but knowing what to pursue and how to pursue it are not enough. Experience has shown that, for most customers, energy efficiency is not a fundamental expectation or need. To achieve success in the marketplace, most energy-efficient products or services must satisfy other primary needs. For example, they may improve the productivity, enhance the quality, reduce the cost, or mitigate the environmental impact of manufacturing processes. Or they may demonstrate environmental stewardship or enhance the comfort and functionality of home and workplace environments. In addition to packaging efficiency with other preferred attributes, we need to make customers desire energy efficiency in and of itself—to elevate its position in their hierarchy of needs—because of its economic and environmental advantages. These considerations are absolutely critical in product design, development, and promotion, and they are major challenges to lasting market transformation."

First cost is also a common problem: the purchase price of energy-efficient products is often higher than that of comparable less-efficient ones. Unlike economists, most consumers do not consider product life-cycle costs, and long-term energy savings are less certain than sticker-price differentials. The natural reluctance to adopt new, unfamiliar, and unproven technologies and practices is an obstacle in all sectors. Split incentives are another significant barrier throughout the commercial sector and in certain residential developments; for example, builders or owners typically pay for energy-efficient improvements, but it is the tenants who benefit from the lower energy bills. These are just a few of the many possible technical, institutional, economic, and perceptional barriers.

EPRI's successful transformation efforts consist of several elements. The needs, perceptions, and motivations of customers and other market actors guide product design, development, and commercialization. Alliances with government agencies, industry groups, major manufacturers, trade allies, and others leverage resources, provide valuable feedback, and facilitate the identification and elimination of important barriers. Technology transfer activities—including unbiased demonstrations and multifaceted educational and training programs—effectively neutralize many others. Given the inherent complexity of market behavior and the fact that energy efficiency is usually not a major customer expectation, the importance of innovation and persistence throughout the process cannot be overestimated.

Partnering pays off

Working directly with major manufacturers to develop state-of-the-art products is a powerful approach for delivering the advantages of energy efficiency to customers, primarily because manufacturers already know a lot about their markets. From the outset, the Neptune washer's development was driven by customer perceptions and market conditions.

"In the early 1990s, the residential laundry market stood out as a segment ripe for rapid transition to higher-efficiency technology," says John Kesselring, EPRI project manager. "DOE was beginning to look at new standards, and the technology platform required to meet them was already available. But the high-efficiency H-axis washers that dominate European markets were attracting scant domestic interest. Clearly, we needed a better understanding of consumer needs and perceptions in order to develop H-axis machines that would move in the U.S. marketplace. The alliance with Maytag in 1992 provided immediate access to application-specific information about customer beliefs. And there were other advantages: attaching a brand name to new technologies can help overcome consumer confidence barriers, and established marketing, sales, and service infrastructure can eliminate barriers to commercial success."

Maytag's market research had uncovered an extremely strong preference for the top-loading configuration characteristic of the V-axis machines that account for more than 98% of U.S. residential washer sales. From an operating perspective, however, H-axis technology makes sense only in a front-loading configuration; a top-loading machine would require an inconvenient two-door design, with an external door providing access to a curved internal one in the tub itself.

"We were flying in the face of conventional wisdom, given stated consumer preferences, but we thought H-axis technology was worth pursuing because future energy efficiency standards would virtually ensure a significant market share," says Maytag's Dick Stilwell, director of R&D engineering services. "We joined other manufacturers in expressing concern over the standards, but we had a small project going on in the background, just in case. EPRI's interest in a joint venture piqued management interest, and the more we looked at the technology, the more enthusiastic we got."

Digging below the surface of customer research revealed that consumers were not averse to energy-efficient front-loading clothes washers per se but to the bending and stooping they seemed to require. By working out new technical solutions to this ergonomic problem, EPRI and Maytag created the extremely successful Neptune washer.

To guide the development of an acceptable and workable design, Maytag conducted surveys to evaluate responses to wooden mock-ups with various loading configurations and to gain further insight into consumer beliefs. In parallel, EPRI, DOE, the U.S. Bureau of Reclamation, and 26 electric, gas, water, and wastewater utilities (primarily in the western United States) launched The High-Efficiency Laundry Metering and Marketing Analysis (THELMA) Project in 1993 to analyze perceptions of washer technologies and features through focus group discussions, nationwide consumer surveys, and interviews with manufacturers, distributors, and retailers.

"Careful interpretation of market research is a must, because customers don't always say exactly what they mean," explains Kesselring. "We quickly learned that customers were not saying they would never purchase a front-loading washer. Instead, they were expressing dissatisfaction with the bending required to load and unload laundry through the small door typical of conventional front-loaders. Ergonomics became a major design issue."

Other identified barriers to residential market penetration included consumer satisfaction with V-axis washers, unfamiliarity with H-axis technology, concerns about capacity and cleaning performance, and higher costs. None were perceived as insurmountable; rather they provided critical feedback for technology development and market interventions.

The Neptune incorporates major ergonomic innovations: to facilitate loading and unloading, the tub is tilted 15 degrees from the horizontal and is accessed through an extrawide, "slant-front" door. In addition, the tub has a capacity of 2.9 cubic feet—20% more usable capacity than in standard top-loading machines. Further important selling points for the Neptune and other H-axis washers were quantified in THELMA field tests supported by DOE: H-axis machines use 65% less energy and 40% less water than V-axis machines and are 25% more effective at soil removal; they also remove up to 30% more water during the spin cycle, for shorter drying cycles and additional energy savings.

Maytag introduced the Neptune to residential consumers in a nationwide marketing campaign in June 1997. Meanwhile, under THELMA, electric and water utilities in the Pacific Northwest collaborated with dealers on promotional and educational programs for high-efficiency washers. The utilities also designed incentive programs on the basis of THELMA recommendations, offering cash rebates of up to $150 at the point of purchase.

"All across the country, consumer response to the new generation of high-efficiency machines has far exceeded expectations," says Kesselring. "The Pacific Northwest utilities, which had set aside rebate funds for about 2800 washers during the first year, had to dig into their pockets for almost four times that amount to meet the demand, which represented a 10% jump in market share for H-axis machines. On a national level, the Neptune's sales figures look very good—Maytag has had to double planned production volume—and other domestic manufacturers of H-axis machines are benefiting from increased consumer awareness. THELMA research indicated that U.S. consumers would buy high-end, high-efficiency washers if they were American made, and experience is bearing that out."

Adds Stilwell, "Although the Neptune has carved out a pretty good niche, there's an even greater opportunity within sight. We recently proposed an industrywide collaboration with environmental groups to reach consensus on DOE's standards. We've come full circle: the anticipated standards that looked like a threat just a few years ago now represent an opportunity for greater market share. The sooner they are in place, the more dramatic the market transformation, and the better it will be for Maytag."

Raising the bar on efficiency

Notwithstanding the Neptune's triumph as an example of market transformation via new product introduction, simply working with major manufacturers to build a better mousetrap is no guarantee of success, as EPRI's work on another residential technology—electric heat pumps—illustrates.

EPRI's interest in increasing heat pump market penetration through incremental technology improvement dates back to the late 1970s. By combining space heating and cooling capabilities, heat pumps are often more efficient than the standard two-technology solution—heating via electric resistance units or gas furnaces and cooling via electric air conditioning units. The HydroTech 2000 heat pump was commercially introduced in January 1989 by EPRI and Carrier Corporation after an eight-year joint development program. In addition to being 30% more efficient at space conditioning than conventional air-source electric heat pumps, the HydroTech 2000 offered water heating and

The most advanced electric heat pump of its time, the HydroTech 2000 failed commercially because of its high initial cost. Nevertheless, the HydroTech's unprecedented efficiency and innovative features were too important for the marketplace to ignore and were soon incorporated into other, more successful commercial products.

a host of new comfort, control, and reliability features.

"From a purely technological standpoint, the development effort was a success, producing lasting market effects," recalls Kesselring. "Within a couple of years, virtually all electric heat pump manufacturers were offering units approaching the HydroTech 2000's efficiency, permanently raising the bar for the technology. Also, such innovative features as multiple-speed indoor fans, self-diagnostic capabilities, and integrated water heating and space conditioning began popping up in other commercial products. The problem was that we advanced heat pump technology beyond what the market would bear, producing a unit with unprecedented efficiency, performance, and comfort but at a cost prohibitive to all but the most avid technology enthusiasts. This experience emphasized the importance of market research in setting technology development goals and in devising effective commercialization strategies, and we've certainly taken the lesson to heart."

EPRI's subsequent heat pump activities have focused on major market barriers; have targeted specific market segments, such as manufactured homes and multifamily buildings; and have been guided by customer needs, including affordability as well as comfort and reliability. In the early 1990s, for example, research revealed a stubborn market barrier that was substantially limiting the penetration of all heat pump products: although the technology offered some clear advantages over traditional space conditioning options, its sales and service infrastructure was lagging behind. Salespeople tended to recommend the conventional systems they knew best. Consumers who did buy heat pump equipment sometimes experienced problems because of faulty installation or inadequate maintenance—problems that sullied the technology's reputation.

In response, EPRI initiated a market intervention effort to increase customer satisfaction with heat pump technology by promoting the development of strong sales and service networks. Support from trade groups and major manufacturers and suppliers was enlisted to form the North American Technician Excellence (NATE) program, which provides certification services for technicians who work with electric heat pumps and other heating, ventilation, and cooling (HVAC) systems.

"By increasing the competence of technicians, the NATE program is expected to enhance the quality of heat pump installations and maintenance," says Nance Lovvorn, manager of marketing training at Alabama Power. "This will allow the technology to perform as billed, which at present is far more important on the showroom floor than any additional efficiency gains. Dealers who know that customer expectations will be met are likely to push electric heat pumps more aggressively than they have in the past, and satisfied customers are likely to boost word-of-mouth sales."

The power of advocacy

Energy-efficient refrigeration has great cost-saving potential for supermarkets, since refrigeration systems account for the majority of their electricity costs. But when EPRI's efficiency improvement program was in the formative stages in the mid-1980s, the initial challenge was to reopen the lines of communication between supermarket companies and electricity providers. "The appearance and lifespan of perishable foodstuffs—which strongly influence store profitability—depend on reliable refrigeration and uninterrupted service," says Mukesh Khattar, EPRI project manager. "The supermarket industry had formed a negative perception of utilities because of the adverse effects of unforeseen power interruptions, even though they were infrequent."

EPRI sponsored a national workshop to break the ice, bringing together the utility, supermarket, and refrigeration industries to establish a joint technology planning and development process. At this workshop, the capabilities of some recently developed high-efficiency refrigeration systems were described by equipment manufacturers, but supermarket representatives expressed doubts about field effectiveness and reliability.

"EPRI's original plan was to pursue the development of new refrigeration technology, but we found that significant efficiency gains could be realized just by increasing the use of certain recently introduced equipment," recalls Khattar. "But because refrigeration systems are mission critical, laboratory test results and manufacturers' reliability and efficiency claims were not enough to gain the supermarket industry's acceptance. To overcome the performance uncertainty barrier, we gave the industry a major role in designing a field demonstration program that would provide the real-world operating data required for informed technology decision making."

In 1987, a state-of-the-art refrigeration

With high-efficiency refrigeration equipment facing a hard sell at supermarkets, EPRI proved the technology's reliability and cost savings in a comparative demonstration at a busy Safeway store. The convincing performance results, widely disseminated by supermarket organizations, utilities, and other allies, helped increase the market share for high-efficiency equipment from less than 5% to more than 50% within two years.

system was installed in the machine room of a busy Safeway store in Menlo Park, California, right next to a conventional commercial system. The two systems were operated interchangeably, enabling quantification and comparison of electricity consumption under the same field conditions. The new system—which included such features as a multiplexed compressor design, evaporative condensers, floating head pressure, hot-gas defrosting, mechanical and ambient subcooling, and liquid-to-suction heat exchangers—reduced peak demand by 30% and used 23% less energy overall. In addition, concerns about system integration were satisfied, and requirements associated with reliability, ease of operation and maintenance, and food quality were met or exceeded.

The findings were disseminated through industry channels. They also received a stamp of approval from a design review panel that was formed by EPRI and included store owners and operators, utilities, and other market actors. "Although the supermarket industry's response was gradual, the results were dramatic. Early installations in various operating environments proved successful, boosting confidence and adding to the momentum. Within two years, the market share for high-efficiency refrigeration equipment increased from less than 5% to over 50%," says Khattar. "Customer involvement and advocacy fueled this transformation, as grocery stores and energy companies worked together toward common goals."

The supermarket industry's needs continue to guide EPRI's efforts to increase energy efficiency. New high-efficiency store designs and technologies such as intelligent defrosting and dual-path HVAC systems are being developed and demonstrated in collaboration with major U.S. food retailers, energy companies, equipment manufacturers, component suppliers, and other market actors. Working with the major grocery chains—a dozen to date—is an important element in EPRI's strategy, because proven efficiency gains in one store can lead to corporate-level design changes with regional or national benefits. Safeway, for example, has widely adopted cost-effective efficiency measures on the basis of the test store demonstration results.

"We look at energy efficiency as a great opportunity for profit making—anything that cuts costs without impacting sales goes straight to the bottom line," says Rob Uhl, refrigeration manager for Safeway. "But we are inherently suspicious of manufacturers offering higher-efficiency technology. EPRI separates the wheat from the chaff by demonstrating new equipment under real-world conditions, producing the performance data we need for effective technology evaluations."

Elevating awareness

In some sectors, participants are so focused on meeting a single business objective that they become blind to other opportunities for improving performance, such as increasing energy efficiency. Municipal water and wastewater (MWW) utilities share one overarching goal: to protect public and environmental health by meeting regulatory requirements. In complying with existing and emerging standards, water supply and wastewater treatment facilities use huge, and growing, amounts of electricity. These facilities currently account for about 2–3% of total U.S. electric power consumption. To increase their energy efficiency, EPRI initiated a cooperative MWW program in 1990.

"Going in, we knew that transforming this market to promote wiser energy use was possible but that we had to take into account a few intrinsic challenges," recalls EPRI's Myron Jones, then project manager. "When you are dealing with public and environmental health issues, some degree of overconservatism in system engineering and operations is necessary. So we had to determine where, and by how much, energy efficiency could be increased without compromising safety. But to have any impact in the marketplace, EPRI first had to position itself as a credible source of technical information and expertise—as an organization that understands the municipal water and wastewater industries and can work within their institutional framework to meet regulatory requirements in a more cost-effective, energy-efficient way."

Collaborative alliances were established with EPRI's counterparts in the water and wastewater fields, the American Water Works Association Research Foundation and the Water Environment Research Foundation, respectively. Through these and other industry connections, market research was conducted to identify significant energy efficiency opportunities and barriers.

"The sector's single minded emphasis on meeting regulatory standards had overshadowed the consideration of energy costs," says Jones. "By raising municipalities' awareness of the economic ramifications of energy use, we thought we might be able to create the impetus for more-efficient operation." EPRI's market interventions, combined with tightening municipal budgets and the trend toward plant privatization or contract operation, are overcoming these institutional barriers. Simple consciousness-raising was the first step. Thousands of brochures and educational materials were distributed to help plant managers and other key municipal decision makers understand electricity pricing and to give them information on the potential cost savings and operational advantages associated with efficiency upgrades.

On-site energy audits, new design standards, and system optimization guides are helping to increase the energy efficiency of ozonation facilities and to dispel the misconception that ozone technology is a prohibitively expensive solution for municipal water disinfection.

In addition, the technical services offered by EPRI's MWW program were widely publicized. This program, administered by the Community Environmental Center (CEC) at Washington University in St. Louis, performs energy audits and helps optimize the use of existing and emerging energy-intensive technologies and practices.

Audits have been conducted at numerous MWW facilities to determine where, how much, and how efficiently electricity is used. Frequently, audits are subsidized by the local electric utility. "Audits are a great way to learn more about important customers," says Keith Carns, MWW program manager and director of EPRI's CEC. "Once they have a foot in the door, utilities can offer facility-specific operating strategies, incentives for the purchase of more-efficient equipment, or rate programs that yield utility load management benefits as well as energy and cost savings for the customer."

On the basis of detailed audits, payback periods can be calculated and staged implementation plans developed for immediate, low-cost operational modifications and longer-term, capital-intensive improvements. Common recommendations include the rescheduling of noncritical operations, the purchase of standby generators to reduce peak demand, and the installation of more-efficient equipment and modern instrumentation and control systems to optimize energy-intensive operations.

"Energy surveys have been performed at more than 30 facilities in our service territory since 1994," says Elizabeth Kimmel, industrial and commercial market manager at PECO Energy. "These surveys have awakened facility managers to opportunities for significant bottom-line savings and have led to the implementation of energy-efficient technologies and practices by many of our customers. In addition, the surveys have positioned us as energy consultants who know the water and wastewater business."

EPRI's technology-based efforts complement the auditing activities in promoting awareness of, and confidence in, more-efficient processes and practices. These efforts focus on energy-intensive operations identified in prior market research, such as pumping, aeration of wastewater, and ozone disinfection of drinking water. Market interventions take the form of technology innovations, performance evaluations, field tests, large-scale installations, operating guidelines, technical reference materials, conferences, and training seminars.

For pumping systems, new operating strategies, supervisory control and data acquisition systems, and adjustable-speed drives are reducing overall energy use at many MWW facilities. In aeration-based wastewater treatment, fine-bubble diffusers and feedback control systems are decreasing electricity consumption without sacrificing treatment performance. One example is a new, high-efficiency fine-bubble diffused-air system known as the Biomixer, which EPRI has helped overcome performance uncertainty barriers.

"EPRI's structural and process engineering review, performance testing, and subsidized installation have been absolutely critical in gaining market acceptance," says Wayne Bailey, president and CEO of Biomixer Corporation. "With EPRI's backing, we reengineered our product to maximize operating and energy efficiency advantages for customers and then conclusively demonstrated them in the field. The Biomixer is now perceived as a proven aeration solution, as evidenced by increased market interest and a growing number of commercial installations."

In some cases, the problem is not in selling the advantages of a technology but in correcting misconceptions. Ozone disinfection systems for drinking water facilities provide an example. The installation of these systems is largely being driven by tougher regulatory requirements to eliminate persistent pathogens, such as *Cryptosporidium*, and to control by-products of traditional chlorination disinfection, such as trihalomethanes. Ozone water treatment should be an easy sell, since it's the only technology that can effectively deal with both challenges. "But ozone systems have a reputation for being tremendously costly to install and operate, causing water treatment facilities to think twice before committing to the technology," explains Carns.

"Transforming the water disinfection market requires that we eliminate the decision-making barrier created by cost misconceptions. The problem is that ozone systems are typically overbuilt, and energy-intensive ozone generators are commonly run nonstop at full capacity, with no regard for variations in water quantity and quality. To get a true handle on operating costs, we've helped optimize existing installations by matching ozone production to disinfection requirements and by improving maintenance practices."

EPRI's reference and optimization guides for ozonation facilities are being widely applied to help improve operating efficiencies, yielding average energy savings of 10–15%. Design standards are being developed to minimize oversizing and promote staged construction and thus to reduce installation costs. Also, new geometric configurations for contact basins show promise for improving energy efficiency by minimizing the amount of ozone required to treat a unit volume of water.

Industry analysts predict that during the next 10 years, facilities producing over 15% of U.S. drinking water will switch to ozone disinfection. EPRI's unbiased assessments and practical guidelines are facilitating this market transformation by making the decision to switch easier from an economic perspective.

The development of a mobile demonstration unit was the key to promoting highly efficient membrane technology for by-product recovery and recycling at food processing plants. Designed with the support of utility and food industry organizations, the unit lets food processors try out dozens of commercially available membrane products to identify the most effective system for site-specific needs.

Taking the mountain to Mohammed

Innovative interventions can be as important to lasting market transformation as sound, energy-efficient technology, as demonstrated by EPRI's efforts to increase the use of membrane technology for the recovery and recycling of by-products in the food processing industry. In the early 1990s, selling the bottom-line advantages of by-product recycling to this sector was not the challenge. Transforming typically discarded by-products into useful process inputs reduces the consumption of raw materials and increases total process efficiency; cuts waste treatment and disposal costs; reduces the regulatory responsibilities associated with the discharge of effluents and the landfilling of solids; and demonstrates corporate environmental stewardship.

Moreover, membrane filtration systems are more compact, modular, and selective than conventional evaporation and distillation systems. And they afford "global" energy efficiency benefits: in-plant increases in electricity use (due to the pumping energy required to force certain products through a membrane) are more than offset by reduced energy consumption for delivering process water and other raw materials and for treating and disposing of wastes.

Still, with all its advantages, food processors have been reluctant to try membrane technology. According to EPRI's market research, the problem—as in the case of ozonation—was a bad reputation. A couple of unsuccessful experiences with membranes in the food processing industry had been widely publicized. These experiences were most likely the result of improper membrane selection. Membranes are available in a bewildering array of configurations and materials, and the performance of each commercial product varies widely, depending on process stream characteristics. Unfortunately, manufacturers provided customers with little help in identifying the optimal membrane for a specific application.

EPRI determined that changing this negative perception would be difficult: successful membrane applications had not been publicized in the past, and were unlikely to be in the future, because of the industry's proprietary nature. "We decided that the only way to get individual food processors to revisit their opinions about membrane technology was through unbiased, on-site performance testing of a wide variety of commercial products," recalls Ammi Amarnath, EPRI project manager. "Developing a cost-effective testing program was going to be a challenge, and simply trying to coordinate the efforts of membrane manufacturers wouldn't work. Instead, we conceptualized a novel market intervention for promoting the technology as a whole and then engaged other trade allies to successfully execute it."

Amarnath came up with the idea of a portable, self-contained application test system for on-site experimentation with various membrane products at food processing plants. With support from three California utilities, the National Food Processors Association, the California League of Food Processors, and others, a mobile trailer demonstration unit was designed and built, and commercial membranes were procured from manufacturers. Application studies were performed at eight plants in 1992, involving the analysis of process water, the identification and testing of potentially appropriate membranes, and the evaluation of performance data to determine technical and economic feasibility.

Several participating food processors subsequently contacted membrane manufacturers for more-detailed testing of specific products, leading to a number of installations. One example involved an Oberti Olive Company plant that was under severe regulatory pressure to address environmental issues associated with waste ponds and solid wastes. Pilot tests performed with the mobile demonstration unit indicated that all process by-products could be recovered and recycled, and ultimately a full-scale, zero-discharge membrane and wastewater reclamation system was designed and implemented, eliminating the threat of plant closure.

EPRI and other participants publicized the mobile unit's success, attracting the interest and support of several national trade associations. These groups in turn promoted the unit's testing capabilities to food processors throughout the United States. Under EPRI's aegis, membrane technology has been investigated at more than 100 food processing plants since 1992. Recently, on the basis of promising test results, EPRI performed a complementary market intervention to further the technology's prospects: membranes are now approved by the U.S. Department of Agriculture's Food Safety Inspection Service for chilled-water cleaning and recycling at poultry processing plants.

Although the increased penetration of membranes in the food processing sector cannot be quantified because of confidentiality agreements, EPRI's collaborative efforts have produced lasting market effects. The industry clearly looks at the technology in a much more favorable light. In addition, membrane manufacturers frequently donate new, state-of-the-art membrane modules to secure a spot on the mobile unit and introduce their wares to potential customers and new applications.

"Innovation, collaboration, impartiality, and credibility—embodied by the mobile demonstration unit—have helped put the best foot forward for membrane technology," says Amarnath. "The turnaround in the food processing industry's perception represents major progress toward enduring market transformation, with significant energy efficiency and environmental benefits."

Persistence pays

Electric vehicles (EVs) represent one of the great opportunities for energy efficiency and environmental improvement in the twenty-first century. Japan's Institute of Applied Energy estimates that EVs would be over 40% more efficient for congested urban driving than conventional automobiles, and significant air quality benefits are anticipated from widespread EV use, even if today's fossil fuel–heavy electricity generation mix is maintained.

Despite its tremendous potential, modern EV technology has faced daunting technical and market barriers. First, it seeks to supplant a ubiquitous and strongly entrenched technology—the internal combustion automobile—that has well-established and fundamentally different fuel and maintenance infrastructures. In addition, consumer expectations for automobiles, especially with regard to driving range and acceleration, are extremely high.

During the oil crises of the 1970s, interest in EV technology rose substantially, and consumer surveys indicated that the environmental and efficiency goals of EVs were valued by much of the public. But interest faded when fuel prices fell, and major auto companies questioned whether a real market existed or could be developed for EVs. With much technical work to be done and the lack of a firm commitment from the auto industry, the push for EV development was essentially dead by the end of the 1970s.

Transforming such a market requires patience, tenacity, and a sharp eye for the critical path. Since its initial involvement in EV technology in 1977, EPRI has played an ever-changing array of roles to address shifting political conditions, technology development needs, and market barriers. "Over the last two decades, EPRI has exhibited an unflagging commitment to bringing EV technology to the marketplace," says Ed Riddell, EPRI product line leader. "We've been the catalyst for constructive dialogue and collaboration between key market actors. We've bridged the gap when support from other major research sponsors has lagged, and we've provided continuous leadership, focusing attention and resources on the most critical technical challenges at any given time."

One key milestone in EPRI's sustained EV development and market transformation programs occurred in 1983, when EPRI and electric utilities formed the Electric Vehicle Development Corporation (EVDC) in response to a drastic reduction in DOE funding for EV research. DOE, in collaboration with so-called converter companies, had just completed a series of unsuccessful vehicle testing programs; the EVDC was founded to engage major U.S. automakers in vehicle prototyping and testing. "We needed to reestablish the credibility of EV technology in the eyes of the government and other stakeholders. As original equipment manufacturers, automakers know a lot more about developing successful vehicles than converters can ever hope to," recalls Riddell. "The other objective was to establish a working relationship between automakers and electric utilities, the two most important players in building viable EVs and the requisite support systems."

In 1984, guided by EPRI market segmentation research and a collaborative design feasibility study with DOE, the EVDC initiated efforts to develop and deploy electric delivery vans in service fleets. This niche-focused strategy was considered to be ideal for field-proofing the state of the art in EV technology because limited range, sluggish acceleration, extended charging time, and other characteristics were not showstoppers for utilities and other fleet-operating businesses. Under a joint EPRI-General Motors program, 128 full-size G-Vans were placed in utility service, and companies that recognized the technology's limitations were able to successfully integrate the vans into their fleet operations. Similar work with Chrysler resulted in the development of the TEVan, which was also tested in fleet applications.

"By 1990, the G-Van's performance in the field, encouraging results from DOE's renewed testing and demonstration program, and GM's unveiling of the Impact concept car had combined to signal that commercially viable EVs were within reach," says Riddell. "The California Air Resources Board responded with a major market push, mandating that the seven largest automakers introduce production EVs by the turn of the century. EV technology had been advanced to the stage where automakers were ready to assume the lead in vehicle development, and it was time for EPRI to shift its focus to other critical issues—infrastructure and EV performance. Regarding infrastructure, automakers were content to let EPRI represent their interests in resolving the challenges associated with the fender-to-grid interface, which they didn't understand."

EPRI formed the Infrastructure Working Council (IWC) in 1991 to help steer research to develop and standardize the connection between EVs and the utility grid. IWC participants include automakers, utilities, battery and component manufacturers, and support groups such as Underwriters Laboratories. Infrastructure standardization breaks down a major market barrier for all stakeholders by eliminating compatibility concerns. Article 625 of the 1996 National Electrical Code—largely written by the IWC—provides the first safety and installation guidelines for EV charging equipment, and technologies, codes, and standards are being developed to address other interface issues.

To upgrade EV performance, EPRI, together with major U.S. automakers and DOE, also established the U.S. Advanced Battery Consortium (USABC) in 1991. Battery technology has long been the primary constraining factor for EV technology, limiting driving range, acceleration, cost-effectiveness, and other important characteristics. "Battery manufacturers have never had large R&D budgets, and in the absence of a viable EV market, they've had little incentive to investigate anything other than incremental improvements to the existing lead-acid technology platform," says Riddell. "The USABC supplies significant funding and provides detailed technical and economic criteria for the focused pursuit of mid- and long-term batteries, and in the last seven years, manufacturers have made significant strides."

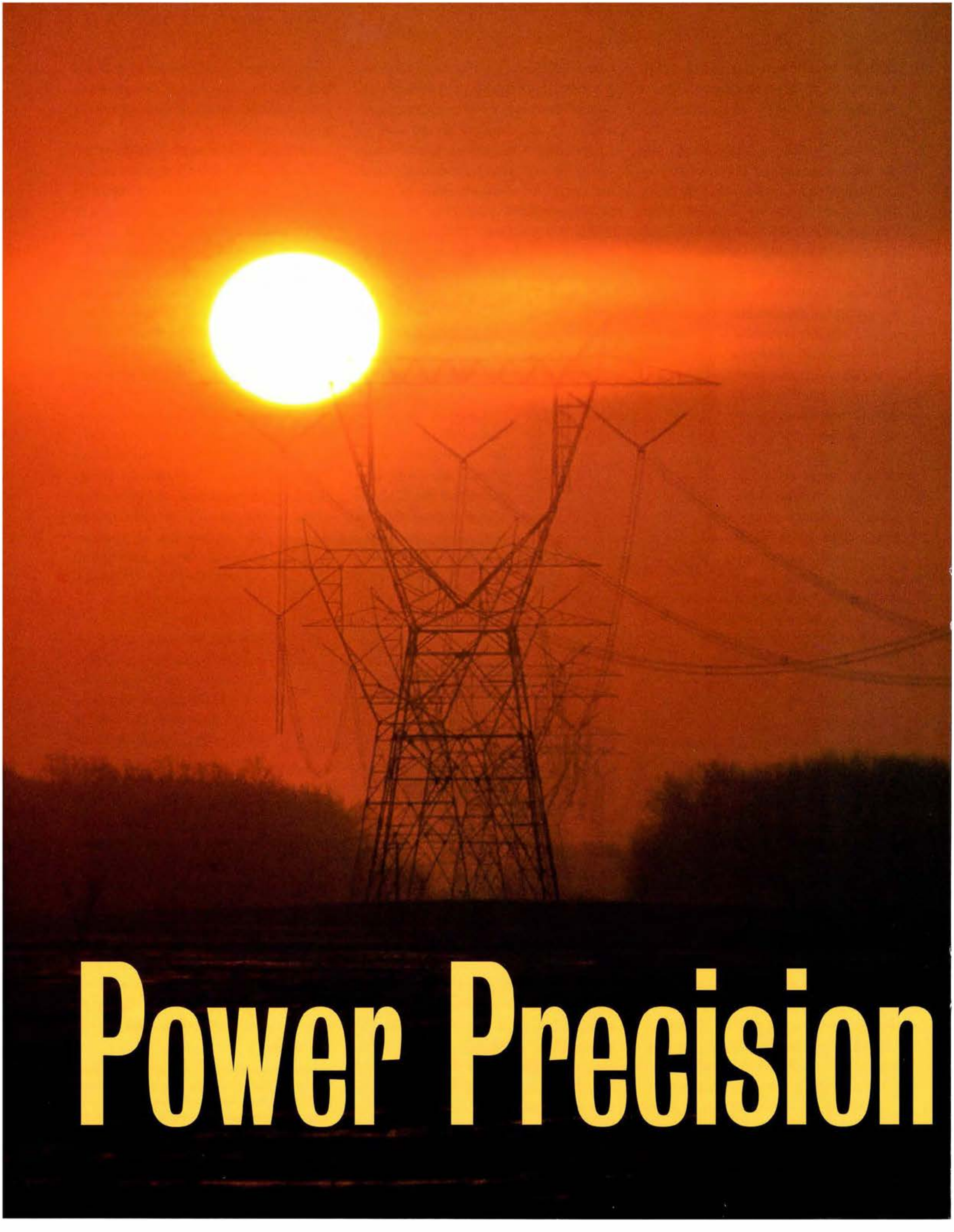
The Epic minivan was based on the Chrysler TEVan, one of several electric vehicles developed for niche applications with support from EPRI in the 1980s. When automakers showed renewed interest in EV development in the 1990s, EPRI shifted the bulk of its market transformation efforts to the advancement of battery and infrastructure technology, including vehicle charging stations.

Advanced nickel-metal hydride batteries that meet the USABC's midterm performance standards are now commercially available, and cost reductions continue to be pursued. Assuming that the current rates of technical progress and USABC funding are maintained, within the next five years lithium-ion and lithium-polymer batteries will be commercialized, enabling EVs to approach the performance of conventional gasoline-powered vehicles.

"The persistence required to transform the EV market might represent the extreme, but we recognized long ago that society is the ultimate customer for EV technology," says Riddell. "Although some significant barriers lie ahead, the energy efficiency, environmental, and national security benefits that will be realized from the reduced use of gasoline-powered vehicles and reduced dependence on foreign oil justify the intensive effort."

Adds Bloom, "Despite its advantages, increasing energy efficiency is never as straightforward as one might hope. Market transformation can take a long time, require multiple interventions, involve the entire value-added market infrastructure, and consume significant resources. What makes EPRI unique is its demonstrated ability to meet this challenge by analyzing all aspects of an opportunity for efficiency gains and then systematically integrating market research with technology development. By conceptualizing and implementing collaborative, coordinated intervention strategies, we can strongly influence the behavior of market actors—to the benefit of customers, industry, utilities, and society as a whole." ■

Background information for this article was provided by Morton Blatt, John Kesselring, Mukesh Khattar, Myron Jones, Keith Carns, and Ammi Amarnath of the Energy Delivery and Utilization Division and Jeremy Bloom and Ed Riddell of the Product Line Management Division.



Power Precision

THE STORY IN BRIEF

The promise of power electronics–based FACTS technology to transform transmission systems into high-speed, precision networks is being realized on a part of American Electric Power's grid, thanks to pioneering collaboration between the utility, EPRI, and Westinghouse. A third-generation FACTS device installed at an AEP substation is providing unprecedented levels of power flow control and operating flexibility. The device—the Unified Power Flow Controller—and other, even more advanced electronic controllers to come represent a technology solution for meeting the growing power transfer demands of emerging competitive electricity markets in the new millennium.

With UPFC

by Taylor Moore

In a remote corner of eastern Kentucky near the border with West Virginia, the world's most advanced electronic power transmission controller is helping American Electric Power use a new 138-kV line and other transmission assets to more reliably deliver more electricity to meet the demand of customers, including several underground coal mines. Called the Unified Power Flow Controller (UPFC), the equipment enables transmission operators at AEP's Inez substation to do something that is unprecedented in the electric utility industry worldwide: simultaneously, instantaneously, and independently control all three parameters—impedance, voltage, and phase angle—that determine the direction and magnitude of both real and reactive power flow on a transmission line.

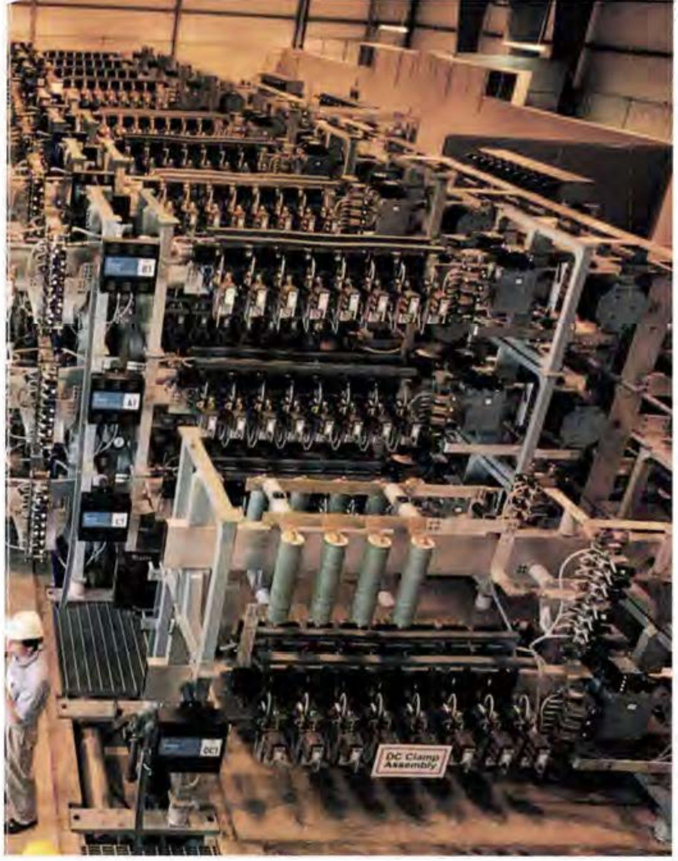
The world's first UPFC, installed at American Electric Power's Inez substation in eastern Kentucky, provides dynamic voltage support and flexible, independent control of the flow of real and reactive power on a new 32-mile (51-km) 138-kV transmission line between Inez and the utility's Big Sandy substation. Housed in a steel-frame building, the UPFC's two back-to-back ±160-MVA inverters can instantaneously control transmission voltage, impedance, and phase angle, the parameters that determine the direction and magnitude of real and reactive power flow.

AEP's Inez substation

The third-generation embodiment of EPRI's evolving vision for Flexible AC Transmission System (FACTS) technology, the UPFC heralds a sea change in the utility industry's ability to make electricity flow as desired. It represents a technology solution to a basic challenge raised by the increasingly competitive supply market: how to accommodate the growing demand for wheeling and open transmission access while preserving the stability and reliability of high-voltage grids that were not designed to serve as an integrated interstate highway system for electricity.

At the Inez UPFC's dedication last June, the significance of this advance in power transmission control capability and operating flexibility was evident in the remarks of executives from AEP, EPRI, and the former Westinghouse Electric Corporation division that manufactured the controller (now part of Siemens Power Transmission and Distribution). Nor did the importance of the moment or the device's stunning technical performance escape the attention of executives from other interested utilities in attendance, some of whom were already considering how the UPFC or a similar device could benefit their transmission systems. For some time to come, utility engineers from around the world will almost certainly be trooping to Inez to witness the future of power transmission in operation.

"Through the tailored collaboration of AEP, EPRI, and Westinghouse, we have successfully created the power technology of tomorrow, and we have it up and running today," said E. Linn Draper, AEP's chairman, president, and chief executive and the chairman of EPRI's Board of Directors. "The Unified Power Flow Controller is, without question, one of the most significant technological advances in the history of the electricity industry" and an example of "the advanced electronic tools that will take energy delivery into the new millennium," Draper told the dedication attendees. He added that, on a practical level, the UPFC is the realization of a decade-long dream of AEP engineers for "a black box device that would essentially allow us to dial in the desired flow of power on a transmission line."



Dedication guests view one of the UPFC's three-level, 48-pulse inverters.

The UPFC's successful operation at Inez is a milestone in the evolution of a robust, solid-state FACTS-based power delivery system—the focus of a broad initiative launched by EPRI in cooperation with member utilities nearly a decade ago. "FACTS technology will enable the delivery infrastructure to reliably and flexibly meet the needs of a competitive electricity market, which is demanding greater control and precision in response to an ever more complex marketing function and to a digital microprocessor–based end-use market that is increasingly sensitive to power quality issues," noted Kurt Yeager, EPRI's president and CEO, at the dedication ceremony.

"The UPFC represents a fundamental paradigm shift in power delivery technology from a mechanically controlled transmission system reflecting 1950s technology to an instantaneous, electronically controlled system providing speed and precision previously impossible," Yeager continued. "FACTS can literally transform today's power grid into a smart system capable of precisely moving power long distances among a diverse group of market participants."

Electronic valves control flow

The UPFC and other advanced FACTS controllers use high-power, silicon semiconductor–based switching devices called thyristors. Multiple thyristors, connected in series and coupled with related hardware and digital control systems, can switch megawatt levels of power within milliseconds to synthesize a smooth, sinusoidal voltage waveform—the electrical components of which are independently variable. The FACTS controllers employ various configurations and combinations of thyristor-based inverters for specific applications.

According to Bruce Renz, AEP's vice president for energy delivery support, today's emerging family of FACTS controllers function analogously to the control valves and variable-speed pumps in a water distribution system of reservoirs, pipes, and faucets. Along with surge-absorbing storage tanks, these valves and pumps enable improved overall control of water flow patterns. Power systems—in which voltage and electric current correspond to water pressure and rate of flow, respectively—need the electrical equivalents of valves, pumps, and storage. "Without such tools, it is not possible to fully utilize the inherent capacity of any complex electrical transmission system or to realize the financial gains associated with the increased throughput they may allow," concludes Renz.

On a transmission network, power flows according to the laws of physics and not necessarily along the shortest route between the points defined in a contractual transaction. Unintended loop flows of electricity beyond a contractual path are increasingly the cause of transmission bottlenecks that can limit power transfer capability, particularly if an area has too few transmission lines and hence is capacity constrained. Because, in most areas, new transmission corridors are difficult to site and costly to build, most utilities are focused on increasing the capability, controllability, and flexibility of existing transmission facilities.

In the case of the Inez substation, the surrounding rural area was dependent on long, heavily loaded 138-kV transmission lines serving a power demand of approximately 2000 MW. The voltage stability margin for system contingencies during normal operations was very small. Voltages at some locations could be 95% of nominal, which is considered the lowest acceptable level for supply reliability. A single contingency outage of a 765-kV line in the area would result in severe voltage drops and the thermal overloading of other lines. The loss of a second line could cause an areawide blackout.

AEP wanted to build a new 32-mile (51-km), high-capacity, double-circuit 138-kV line between its Big Sandy and Inez substations, but the amount of power that would actually flow on the new line was still going to be constrained by impedance and other ac transmission system parameters. Dynamic voltage support and reactive power compensation, along with high-speed control of power flow on the new line, were needed to enable use of the line at full capacity.

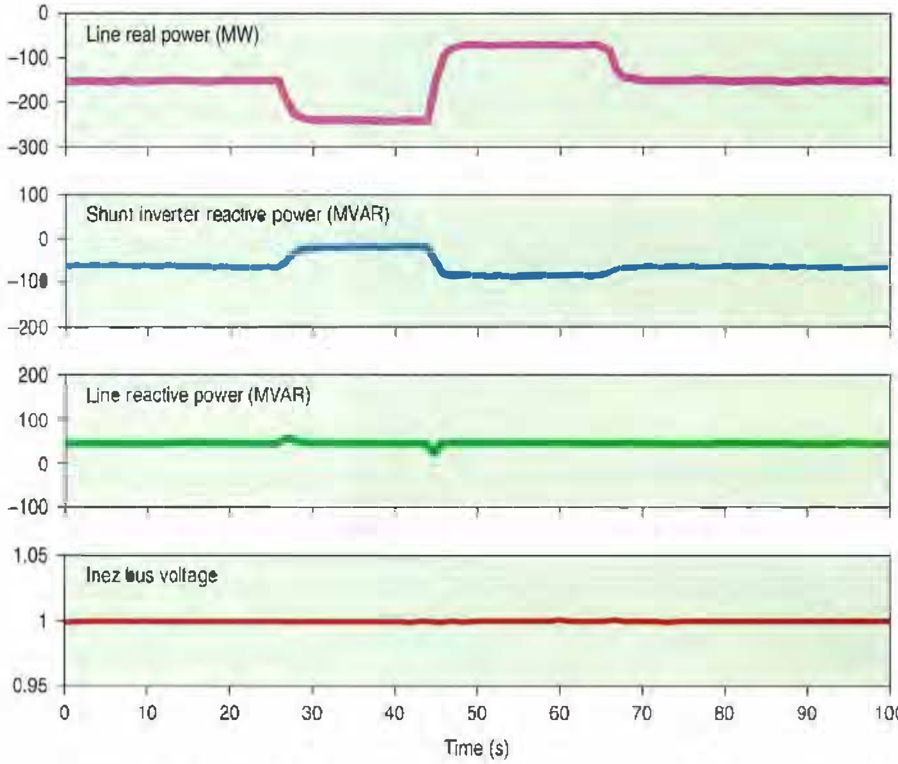
The $30 million UPFC is part of a comprehensive $90 million area-reinforcement plan implemented by AEP. The plan includes the new 138-kV line, series reactors to limit loadings on existing thermally loaded utility facilities, and a 345/138-kV, 600-MVA transformer at the Big Sandy substation. The UPFC regulates the Inez 138-kV bus voltages and controls six 138-kV shunt capacitor banks at Inez and three other substations.

In the UPFC, two identical ±160-MVA voltage-sourced inverters connected to two sets of dc capacitor banks provide a control range of ±320 MVA. These modular inverters, along with a spare shunt transformer installed at the substation, give AEP significant flexibility in configuring and operating the UPFC. The system can operate in full UPFC mode to control power flow with independent control of real and reactive loads, and the series inverter can be switched to double the shunt rating to ±320 MVAR. It is also possible to decouple the inverters at the common dc bus and operate them as independent shunt and series controllers. The UPFC's control logic is just as adaptable as the installed configuration.

During normal operation, one of the Inez inverters functions as a static compensator, or STATCOM, providing voltage support. In the event that either inverter is out of service, the other can be disconnected from the dc-bus switches and operated independently for reactive power support. The STATCOM component of the UPFC is the evolutionary link to the previous generation of FACTS devices. The first STATCOM, rated ±100 MVAR, has been operating successfully at the Tennessee Valley Authority's Sullivan substation since late 1995.

Located near Johnson City in northeastern Tennessee, on the edge of TVA's service territory, the Sullivan substation serves seven local distributors and one large industrial customer. Used in coordination with 84 MVAR of mechanically switched capacitor banks that extend its capacitive range, the STATCOM unit protects against unacceptable voltage drop on TVA's 161-kV and 500-kV network in the event that the substation's main transformer bank is lost during winter peak conditions.

The STATCOM unit has allowed TVA to save $14 million by deferring the costs of either installing a second transformer bank at Sullivan or constructing a fifth 161-kV line into the area. In addition, the unit has reduced TVA's need to use load tap changers to incrementally adjust voltages, thereby minimizing the potential for a transformer failure that would typically cost about $1 million to repair. And since load tap changer operations have dropped from 250 a month to 6 a month, maintenance costs for the tap changers are substantially lower. "STATCOM is an outstanding example of how new technology can help maximize the use of existing transmission facilities on a cost-effective basis," says TVA's W. J. Museler.



The UPFC's excellent dynamic performance is illustrated by these results from a 100-second test on the Big Sandy–Inez line. As the flow of real power was varied, the UPFC shunt inverter automatically compensated to maintain near-constant line reactive power and constant voltage at the Inez bus. The UPFC's voltage support capability protects against voltage collapse in case two transmission lines in the area are lost, and its power flow control capability enables optimal transmission system utilization.

Multiple functions multiply benefits

Abdel-Aty Edris, the manager for FACTS technology in EPRI's Energy Delivery and Utilization Division, notes the functional flexibility made possible by the UPFC's multiple compensation capabilities—its ability to control line impedance, phase angle, and transmission voltage—and concludes that the controller has "enormous potential for solving many of the system operations problems facing the utility industry."

In a draft of a paper prepared for publication in a professional journal, Edris summarizes the expected benefits of the Inez UPFC and quantifies its impact on power transfer capability and voltage quality. The bottom line: an increase of more than 100 MW in power transfer over the new 138-kV Big Sandy–Inez line and excellent voltage support at the Inez bus. This dynamic voltage support is expected to avert an area blackout in the event of double-contingency conditions (the loss of two lines) and to provide superior power quality throughout the area.

The flexible, independent control of real and reactive power flow on the new line enables optimal utilization of the existing transmission facilities in the area. Moreover, says Edris, referring to information provided by AEP, the overall system reinforcement frees up previously unusable transmission capacity, which is expected to accommodate years of load growth. And the UPFC's reduction—by more than 24 MW—of real power losses on AEP facilities in the region is the equivalent of reducing carbon dioxide emissions at generating plants by more than 85,000 tons a year.

Evolution of innovation

Conceptual development of the UPFC, as well as demonstration of its technical and economic feasibility, began in late 1991 in work jointly sponsored by EPRI, the Western Area Power Administration, and Westinghouse. In that R&D, researchers at the Westinghouse Science & Technology Center near Pittsburgh conducted demonstration tests and analysis using a Transient Network Analyzer scale model. More recently, the UPFC's impact on power systems has been extensively studied with

EPRI's comprehensive stability simulation software—PSAPAC (Power Systems Analysis Package). This software provides for several types of steady-state and dynamic analyses of systemwide phenomena, including the effects on power flow patterns.

Now, as part of Siemens Power T&D, the former Westinghouse energy management division is gearing up to market the UPFC and similar FACTS devices to utilities and transmission system operators everywhere. "The UPFC installation at the Inez substation is the first application of a device that will be marketed to power companies worldwide. There is already much interest overseas in FACTS," says John Kessinger, general manager of the Siemens Power T&D FACTS and Power Quality Division.

"As the most advanced high-power controller ever devised, the UPFC opens up enormous possibilities—so enormous that utility operators are abandoning much of what they've historically used as guidelines and are embracing a new era in transmission control. Once again, technology has provided a solution at a time when it's needed most," adds Kessinger. "The corporate commitment to FACTS will be sustained at Siemens, and as part of Siemens Power T&D, we expect to be able to offer the utility industry an even broader set of solutions because we will have access to additional power delivery technologies that can be integrated with power electronics like FACTS."

In the North American market alone, Kessinger estimates, every major utility that operates a transmission grid has at least one bottleneck that could immediately be improved with a UPFC. "A high percentage of these bottlenecks will likely be dealt with over the next 5 to 10 years as wholesale bulk power flows increase. That's a big market for the UPFC and other FACTS devices right there," says Kessinger.

At the Inez dedication, AEP's Draper noted that the UPFC and other FACTS devices are likely to play a critical role as new electricity market mechanisms and transmission system operators assume greater prominence in transmission planning and oversight, cost control, and delivery system reliability. "It may be in the context of the independent system operator [ISO] that the UPFC and other advanced technologies will make especially significant contributions in the new era of power delivery," he said.

"Ensuring the transmission flexibility to meet new and less-predictable supply and demand conditions in the competitive marketplace will be a very real challenge," Draper pointed out. "Advanced power electronics will be a big part of the solution. Highly automated transmission—with centralized control, greater speed, and more flexibility—will be essential to address the increased demand, the need for greater access and expanded choice, and the intense competition in the new electricity market."

AEP's Renz added, "In the ISO-based world of the twenty-first century, the broad and integrated application of UPFC and related FACTS technology will allow maximum use of transmission grids and provide the new control tools critically important to reliable operation in a much less predictable future." Renz parenthetically noted that AEP is considering as an addition to the Inez UPFC a large superconducting magnetic energy storage device that would collect, store, and release electricity on the grid, much as a surge tank does with water.

The next generation of FACTS

The substantial existing utility market for the UPFC notwithstanding, plans are being laid to take the next step in developing FACTS technology. Last September, the New York Power Authority approved $35 million for an EPRI-managed project with Siemens Power T&D to build and install a first-of-a-kind convertible static compensator (CSC) at the Marcy substation near Utica, New York. The $48 million NYPA project, which is being cofunded by EPRI, Siemens, and 13 other utilities (including AEP), will proceed in two phases, with completion by the end of 2002. NYPA expects the CSC to increase by 240 MW the flow of electricity from upstate New York, where most of its generation plants are located, to the downstate areas of heaviest use.

NYPA and EPRI have evaluated the conditions and limits of the two major interfaces of the New York state transmission system to identify the capabilities needed by the CSC FACTS controller. The controller is to serve initially as a shunt device for voltage support and eventually as a series device for power flow management as well. To be composed of several 100-MVA inverter blocks, the CSC offers even greater flexibility in configuration and operation than the UPFC. It will be able to control power flow simultaneously on two or more transmission lines at the Marcy substation and to run in at least five modes, including as a STATCOM or a UPFC.

EPRI's Edris estimates that the shunt portion of the CSC will increase the power transfer capability of New York state's Total-East interface by 120 MW and that of the Central-East interface by 60 MW. Using the series and shunt elements in combination could add another 120 MW of transfer capability to the Total-East interface and another 60 MW to the Central-East interface. The CSC will also improve voltage control, reduce system losses, and enable the maximum use of New York's transmission system.

"The CSC will help cost-effectively get power where it's needed in New York state," says Karl Stahlkopf, EPRI vice president for energy delivery and utilization. "Like AEP with the UPFC, NYPA is showing great leadership in applying this innovative technology for the benefit of its customers, and we are pleased to be of assistance. As industry restructuring makes new demands on power transmission systems, power electronic FACTS controllers like the UPFC and the CSC offer the most cost-effective way to increase the amount of power that can be transferred." ■

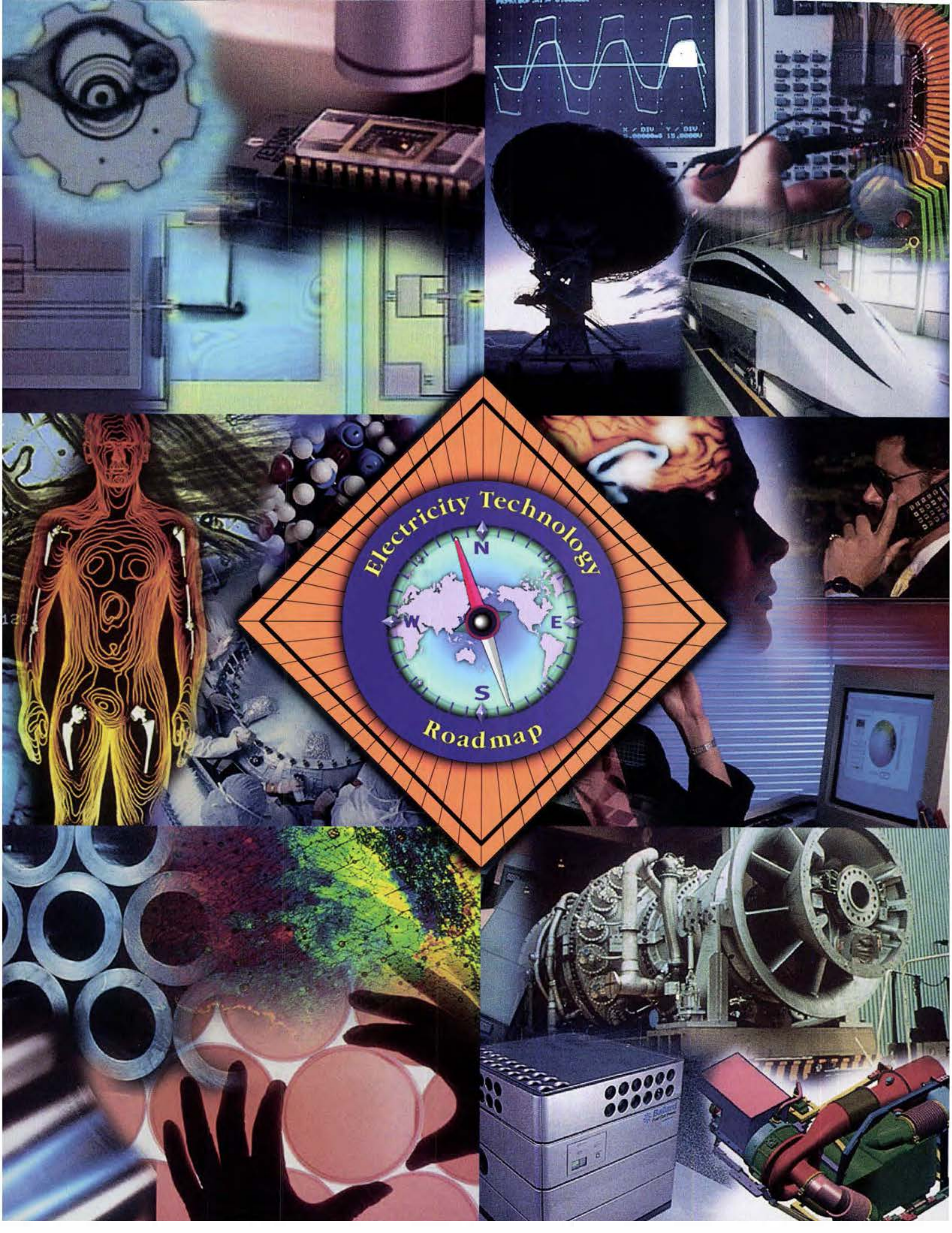
Further reading

Fardanesh, B., et al. "Convertible Static Compensator: Application to the New York State Transmission System." 1998 CIGRE Session, Paris, France, Paper No. 14-103.

Renz, B., et al. "World's First Unified Power Flow Controller on the AEP System." 1998 CIGRE Session, Paris, France, Paper No. 14-107.

Edris, A., et al. "Controlling the Flow of Real and Reactive Power," *IEEE Computer Applications in Power*, Vol. 11, No. 1 (January 1998), pp. 20–25.

Background information for this article was provided by Abdel-Aty Edris, Energy Delivery and Utilization Division.


Electricity Technology
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Roadmap

The Electricity Technology Roadmap

THE STORY IN BRIEF

With more than 150 participating organizations to date, the Electricity Technology Roadmap Initiative seeks to develop a comprehensive vision—through the middle of the next century—of opportunities for electricity-related innovation to benefit society and business. The roadmap will also translate that vision into a set of technology development milestones and identify the R&D pathways by which they can be reached. EPRI is leading this effort—intended to be an ongoing activity with broad participation—as an investment in the future and as guidance for broad-based public and private R&D investment. This article provides a brief overview of the initiative; detailed articles on the roadmap's progress and content will appear in subsequent issues of the Journal.

The role of electric power has grown steadily in both scope and importance over the past century. Developments in key technologies—including electric lighting, motors, computers, and telecommunications—have continuously reshaped American life and increased the productivity of its commercial and industrial foundation. Historically, as technology has advanced, electricity has accounted for a progressively larger share of total energy consumption. It is now nearly 40% of the total in the United States and in other countries with similar levels of economic development. This growth reflects the fact that electricity-based innovation lies at the heart of economic progress. It is also the key to sustainable economic growth and opportunity in the developing world.

Over the past year, EPRI has held workshops and individual discussions with representatives from more than 150 organizations in various stakeholder communities—including industry, government, the public interest and environmental areas, and the R&D community—to identify possibilities for increasing electricity's value to society. These activities, the beginning of the Electricity Technology Roadmap Initiative, have yielded a set of goals, or roadmap destinations, which include the following:

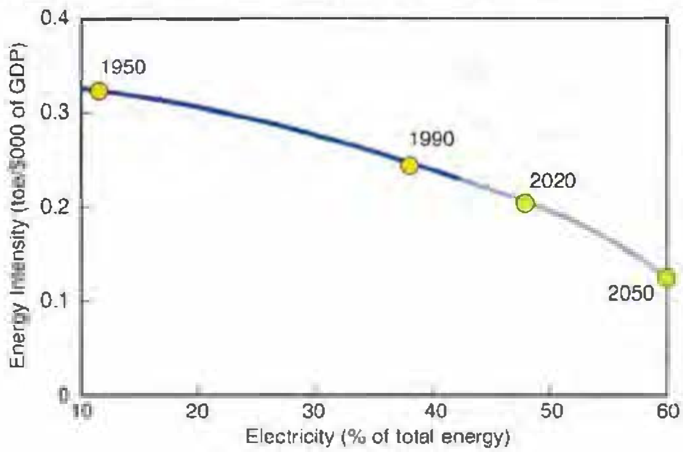
- Development of a more efficient, electronically controlled power delivery system to support the quality, security, and competitive market requirements of the twenty-first century
- Creation of integrated, customer-managed service networks to provide a growing array of customized options and intelligent end-use capabilities
- Maintenance of U.S. economic prosperity and leadership, sustained by innovation-based productivity growth
- Effective management of the coming century's global sustainability issues through technology that resolves conflicts between population growth, economic development, and resource availability, including environmental stewardship

Part of the roadmap initiative process has been to identify capability gaps that must be bridged if the desired destinations are to be reached. These gaps pose key R&D, investment, and policy challenges. A scientific and technological development roadmap is now being created to address these gaps and challenges. It will be continuously updated to keep pace with advancing knowledge and vision.

Transforming the power system

The roadmap's pathway to the future begins with one of the most fundamental electric utility functions: getting electricity from the point of generation to the point of use. Power delivery has been part of the utility industry for so long that it is hard to imagine that we have not already optimized the process. However, the power delivery function is becoming more complex with the onset of open power markets, the introduction of modern distributed generation and self-generation systems, and the saturation of the existing transmission and distribution grid. As a result, the reliability of power delivery may decrease, and losses due to transmission and distribution outages may far outweigh the hoped-for customer benefits of a competitive power industry.

In the United States, the focus is on new power delivery technologies that will enable integration of the North American power delivery grid under increasingly broad control capabilities and will also make possible major transfers of low-cost power over longer distances to meet the needs of customers. However, concern is growing that unless technologies to upgrade the power grid are deployed quickly, the increasing demand for transmission resources may threaten the network's reliability.



Electricity's unparalleled flexibility, precision, and end-use efficiency have a powerful effect on productivity. As electricity's share of total world energy increases, the amount of energy (tons of oil equivalent) required to generate a unit of gross domestic product will fall substantially.

The magnitude of bulk power transactions in the United States has increased fourfold in the last decade, with about one-half of all domestic generation now being sold on the wholesale market before it is delivered to customers. This growth occurs at a time when many parts of the North American transmission network are already operating close to stability limits, as illustrated by recent widespread outages in the western states. Traditionally, utilities would be adding new transmission facilities to handle the expected load increase, but because of the difficulty in obtaining permits and the uncertainty of realizing an adequate return on investment, the number of transmission circuit miles being added annually is declining.

The U.S. electric power system is one of the largest and most complex structures of the technological age. Its expansion will require a large increase in communications, control, and status-monitoring networks, thus creating further complexity and posing additional risk to the infrastructure. Improved models and tools will be needed to deal with this increasing system complexity because, unaided, operations staffs will not be able to respond quickly enough to detect and correct problems. The large-scale, real-time distributed control requirements of the power system will continue to challenge the state of the art in distributed system management.

An additional concern is that all other infrastructures—including transportation, telecommunications, oil and gas, and financial systems—depend on the electricity infrastructure to power and control their operations. The interdependence of the various infrastructures means that failures in one can easily propagate to others, multiplying the damages associated with system failures. Synergies among these infrastructures can also be exploited by innovations that create operating efficiencies through integration.

The new grid

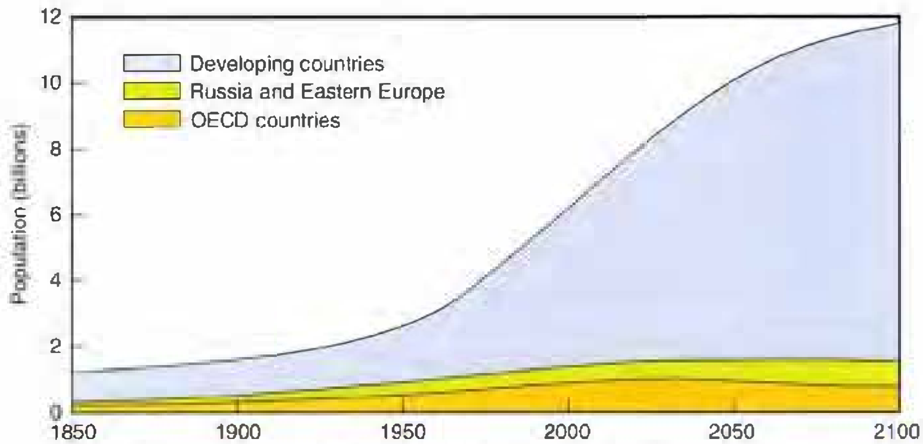
By 2010, a unified, digitally controlled transmission grid will be needed to move large amounts of power precisely and reliably throughout North America and to manage an exponentially growing number of commercial transactions. The backbone of the grid envisioned for 2010 will be high-temperature superconducting and advanced polymer cable systems; power flow management will be based on Flexible AC Transmission System (FACTS) technology and wide-area communications and control technologies capable of eliminating bottlenecks in the transmission system.

The new grid will link power generation to the customer over longer distances, thus contributing to supply flexibility. It will also be capable of providing customers access to more-diversified generation sources and to energy resources that would otherwise be wasted (for example, flare gas from Mexico and the Alaskan North Slope). With proper incentives and investments, all customers would have access to the power quantity and quality needed at any time of day. Moreover, increased undergrounding of the transmission infrastructure would reduce outages and vulnerability to hostile elements, reduce exposure to electric and magnetic fields, and limit the visual impact of the power system. A new equilibrium between ac and dc power transmission could also result from these technological advances.

In addition to transforming the U.S. grid, technological advances could spearhead the creation of all-new, less costly transmission systems in the developing nations, including both long-distance and urban delivery capabilities. These innovations would enable new business opportunities in power marketing, long-distance power transmission, and end-user services in the most rapidly growing regions of the world.

Improvements in the U.S. power delivery system will also become crucial in the coming decades. As industrial and commercial customers become more dependent on digital microprocessor systems, their power quality and reliability requirements are becoming more rigorous, and a market for high-quality, "premium" power is developing. By 2010, this demand is likely to pervade every sector of the economy and society. The roadmap therefore envisions a system able to deliver electric power of any waveform, quality, and reliability at a price that provides higher net value to the user.

This system must be able to function with a widely implemented, grid-connected array of distributed resources—fuel cells, microturbines, renewables, and energy storage systems. With adequate investment, technical innovations now on the horizon could make possible this entirely new level of system integration within 10 years. That in turn would allow the distribution system to become a comprehensive common carrier as retail competition expands and energy and telecommunications services continue to converge. The failure to develop such tools in parallel with the new sources of distributed generation will pose several threats: the disruption and possible fragmentation or stranding of the distribution system; higher infrastructure costs in pursuit of power quality and reliability; higher costs to the end-use customer; and significantly reduced economic productivity growth.



World population has doubled since 1950 and is expected to reach 10 billion by 2050. Population growth, driven almost entirely by increases in the developing world, is the single greatest threat to global sustainability in the coming century. (Source: World Energy Council and International Institute for Applied Systems Analysis, *Global Energy Perspectives to 2050 and Beyond*.)

Putting the customer in charge

The customer load is also undergoing a technological revolution. What's changing is the growing *intelligence* of this load and the need to adapt to this intelligence. As microprocessors become embedded in every appliance and as this distributed intelligence becomes increasingly linked to intelligent controllers that provide direct access to the Internet, the country's electricity and information systems will effectively be joined and, in time, will be able to function as a single integrated network. In the smart houses of the not-too-distant future, for example, controllers could automatically search the Internet for access to the lowest-cost power or seek power with other valued attributes (for example, green power or high-reliability power for critical applications). A controller could be programmed to take advantage of time-of-day pricing so that energy-intensive activities like clothes drying would be performed during off-peak periods. The system might also diagnose problems with household appliances and recommend service if needed.

The electricity industry is already expanding from its traditional generation, transmission, and distribution dimensions to include energy services, power marketing, and information technology–based services and products—all of which are designed to provide greater customer value. With greater investment, significant new business opportunities could be created by taking the next step: the complete transformation of the traditional power supply network into a truly customer-managed service network. Offering the customer control of electrons would be a powerful change, shifting the power provider from selling a cost-plus energy commodity to functioning as a flexible "virtual utility" that would ultimately provide a wide array of intelligent, individualized value-added services.

When electrons and intelligence are merged and controlled in a single flow, customers are in a position to build customized services that are closely tailored to their particular needs. The resulting supersmart electric energy would be completely flexible and controllable; it could be configured to any desired waveform throughout the electron path and optimized for specific end-use requirements. Moreover, it would automatically self-correct for any disturbances.

It is likely that this transformed network—based on the concept of a customer-managed virtual utility—would open the gateway to a flood of new intelligent electron services, or "intellectrics," that could place new levels of comfort, convenience, speed, efficiency, and adaptive intelligence at the customer's fingertips. But there are perhaps even larger economic benefits to be gained. To the extent that the network spreads throughout the economy and takes on the characteristics of an instantaneous economic "nervous system," it would become an important conduit for introducing new technologies both upstream and downstream of the customer load. It would also increase energy efficiency throughout by linking the larger systemwide intelligence with the intelligence embedded in the customer load.

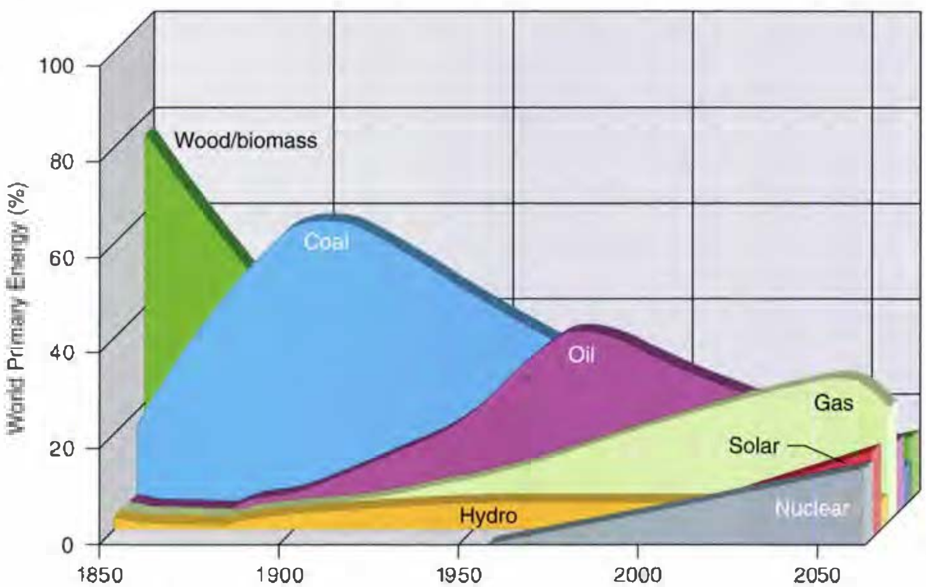
From commodities to services

The transformation to an intelligent, customer-managed service network would move the business dynamic of the electricity enterprise well beyond electricity as a commodity. This is in keeping with the paradigm shift in business toward rendering a service of far greater value than the original product. Du Pont, for example, is beginning to be paid for the painting of cars, rather than for the gallons of paint it delivers to the automaker's door. This puts Du Pont inside the factory, working with the auto company to improve the quality and cost of car painting. It shifts the work to the supplier and shifts the financial incentive of the supplier toward selling less paint rather than more. Similarly, a chemical company might make more money selling crop protection to farmers rather than more pesticides.

In the same vein, during the era of end-use planning, the electric utility industry was initially faced with the business irony of being asked to sell less of its product while receiving revenues only for selling more. The eventual resolution gave birth to the energy services industry, in which utilities were paid for provable savings in energy use. In the future, while electricity in bulk will still be needed at the wholesale level, the customers' value chain will shift the most lucrative energy business toward providing tailored services. The development of enhanced energy services within a customer-managed network will lead to substantially higher value for the energy consumer and society, increasing productivity and resource efficiency while reducing environmental effects and overall cost.

New possibilities for services may expand beyond the management of energy to the management of comfort, convenience, security, ambience, privacy, entertainment, education, and caretaking. But the vision will be shortchanged without a sufficient infusion of R&D to bring down the cost and increase the capability of the key interface technology—interactive metering. Advanced meters form the connection necessary for customers to make their needs and decisions known to the service community and for microprocessor-controlled processes and appliances to be linked to a growing variety of alternative service providers.

This is a chicken-and-egg situation not unlike that experienced with early television. The new meter will be of marginal benefit if there are no new services to be delivered, and new services won't emerge until the market density of meters can justify them. Service providers may have to subsidize advanced meters in the home to jump-start the residential market. It's in industrial and commercial environments, however, where the strategic advantages of advanced metering and the new integrated network will become most evident. There, they will result not only in the delivery of new intelligent services to the customer but also in the delivery of innovation, productivity, and efficiency from business to business and the interlinking of business processes into new webs of urban and industrial ecology.



World energy use has tended to be dominated by single fuels—in the twentieth century, coal, oil, and natural gas successively. While gas will continue to be the fuel of choice for the near future, the world will move toward a much more balanced portfolio of energy options over the next 50 years. (Source: World Energy Council and International Institute for Applied Systems Analysis, *Global Energy Perspectives to 2050 and Beyond*.)

The economic payoff

Economic growth and productivity have received strong boosts in the past from both short-term and long-term investments in R&D, and such payoffs are likely to increase with the advent of intellectrics and a greater customer orientation. With sufficient investment, new and emerging electricity-based technologies could revolutionize manufacturing and many service industries. The goal is to develop highly efficient enterprises—thinking factories and their counterparts in the service sector—with self-adapting processes to redesign and change products and services on demand, to minimize waste, to self-diagnose and self-repair, and to specify or create appropriate forms of energy input.

Such technology innovation could make possible some major stretch goals for the U.S. economy, including doubling labor productivity, cutting energy intensity in half (that is, halving the amount of energy needed to produce a dollar of gross domestic product, or GDP), and eliminating most waste streams.

The roadmap initiative participants have identified four enabling technology platforms that have the potential to significantly improve productivity in the next 20 years across a range of critical manufacturing and process industries. These technology platforms would also contribute to the comfort, convenience, and capability of the intelligent home of the future as well as the automated workplace. The four platforms are new materials, advanced sensors and controls, microminiaturization, and information systems. They are reflected in the Electricity Technology Roadmap because electricity is essential to their development and advancement and because they will become integral components of all future energy-consuming industries. As such, they are essential "infratechnologies" on which U.S. productivity and strategic competitive advantage depend.

Breakthroughs in these areas would significantly impact many sectors of the economy, including the electricity industry itself. For example, advances in carbon fullerene materials could lead to structures and systems with ultrahigh electric conductivity, high strength-to-weight ratios

(100 times the strength of steel at one-sixth the weight), and high resistance to corrosion. The same class of materials could be manufactured to have semiconducting behavior, excellent light-gathering capability, and other properties that would be useful in a variety of industrial applications in addition to the conduction of electricity. The potential payoff to industries as wide-reaching as aerospace, computers, and energy would justify at least a doubling of the R&D effort on advanced materials over the next decade.

Because of the widespread use of sensors, miniature machines, and information systems, advances in these technologies would yield extensive, compounding benefits to the U.S. economy—through increases in productivity and competitiveness, energy efficiency and resource utilization, GDP growth, and environmental protection. The failure to pursue these opportunities in an aggressive and timely R&D effort is likely to result in a number of penalties to the nation, including slower economic growth, loss of jobs, greater waste of natural resources, loss of technical leadership in areas highly significant to the future of the global economy, and reduced resilience in dealing with the uncertainties and threats of the future.

Key Technology Gaps

Power Delivery	
Superconducting cable	Cost reduction; cable length, insulation, and refrigeration requirements
FACTS technology	Cost reduction; nonsilicon devices
Advanced distribution automation	Sensors and software for rapidly detecting and correcting system problems
Superconducting magnetic energy storage	Increased storage capacity; reduced cost; grid integration
Stationary fuel cells	Scaling; thermal-cycling capability; electrolyte improvements
Dc distribution network	Dc/ac conversion; superconducting cable
Advanced metering	Meters and communication systems; multiple-utility "virtual meters"
Underground distribution construction	Polymer cables; underground corridors for integrated utility services
Power Supply	
Natural gas (central stations)	Reheat and intercooled turbine designs; high-temperature, high-pressure turbine designs; oxygen/methane and air/hydrogen turbines
Natural gas (distributed generation)	Ceramic blades and recuperators; solid oxide fuel cell systems; integration of combustion turbines and fuel cells
Coal (central stations)	High-temperature alloys; component development; carbon dioxide capture
Coal (coproduction)	Process development; systems development and integration
Nuclear energy systems	Modularization; advanced man-machine interface; hydrogen production; high-fuel-utilization cycles
Renewables (central stations)	Direct-drive, variable-speed wind turbine design and grid integration; low-cost photovoltaic materials and processing
Renewables (coproduction)	Biomass gasification process development; catalytic feedstock production
Economic Growth and Productivity	
Distributed controls and data analysis	Distributed intelligence; integration with sensor networks
Smart materials	Dynamic structures; integrated condition monitoring; biomedical systems; micromachine technology
In situ sensing	Miniaturization; throwaway designs; distributed computing
Expedited prototyping	Parallel processing and advanced computing; high-fidelity simulation
Smart sensors	On-board intelligence; optical, biological, and quantum computing

The challenge of global sustainability

Because it is difficult to see the global sustainability problem holistically, there has been a tendency to take a narrower point of view: food, family planning, structural reform, law, climate, business, energy, economic development, biodiversity. Unfortunately, difficulties in all these areas will be driven by the seemingly inexorable increase in a single variable—global population. The world is experiencing the greatest demographic expansion in history. Its population has doubled since 1950 and will double again by 2050 to about 10 billion people. Beyond that date, anything is possible: the population could stabilize or continue its rapid rise. Population growth is the greatest challenge facing the world today, the greatest economic opportunity in history, and society's greatest blind spot.

Population growth will spur a substantial need for economic and infrastructure development. To support a sustainable future, development must take place over the next century at a pace of at least 2% per year. This has been characterized as the 2% solution, a situation in which a number of factors—including productivity, energy efficiency, agricultural yield, emissions reduction, and water consumption—improve across the board at a rate of 2% per year or better. This will not be easy, but it is in line with the cumulative pace of advancement in the United States during the past century. If sustained on a global scale through the twenty-first century, these trends would allow robust economic development while sparing the earth. They should allow us to stabilize world population (to the extent that wealth is a primary determinant of population growth), avoid atmospheric levels of greenhouse gases above agreed-upon strategic limits, provide sufficient food for the bulk of the world's people, and return significant amounts of land and water to their natural states.

The implications for energy production and use are profound. As population and gross world product increase, the world will need more energy than we currently consume. How much more depends on the commitment to global electrification. Because of the efficiency and precision of electric end-use technologies, doubling electricity's fraction of the world's total energy consumption can reduce demand for new energy by one-third, and this new energy can be produced from increasingly carbon-lean sources.

At least 8–10 million MW of electric generating capacity will be needed by 2050 to realize this advantage, and even that will only provide global per capita electricity consumption equal to that of the United States after World War II. It would mean bringing on line the equivalent of a large (1000-MW) power plant every three or four days for the next 50 years. Moreover, to stabilize atmospheric carbon concentrations at the levels proposed by the United Nations Intergovernmental Panel on Climate Change, at least half of that new capacity will have to be carbon free, and the average efficiency of fossil power generation would have to rise to 50%, up from 35% today.

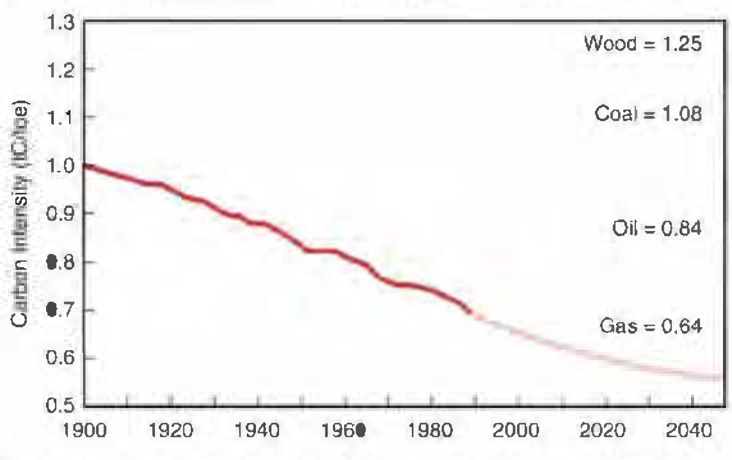
Power infrastructure development will be particularly important for the developing world, where large numbers of people are migrating from rural to urban areas in search of economic opportunity. The fraction of the world's population living in urban areas will grow from 50% today to about 75% by 2050, with most of the change occurring in the underdeveloped nations. This growth will substantially burden urban infrastructures and lead to worsened health and welfare problems unless personal and civic prosperity can be seeded through affordable electric power—nominally at 5¢/kWh or less.

The exploding global demand for electricity means that we will need all the practical electric generating options we can find, along with enormous increases in efficiency throughout the entire energy chain. A robust portfolio of advanced power generation options—fossil, renewable, and nuclear—will be essential to meet these growth requirements, both domestically and globally. While the task may seem daunting, the annual cost of achieving true global electrification over the next half-century is less than the world spends today on cigarette and alcohol consumption.

Over the next 20 years, the developed world will meet the need for additional capacity largely with gas-fired combustion turbines, while the developing world will continue to rely on indigenous resources, particularly coal in the case of China and India. Continuing to push the efficiency of combustion turbine technology is a high R&D priority because the turbines themselves will be key components in every advanced combustion system of the future, regardless of fuel.

The period from 2020 to 2050 will offer a critical window of opportunity for significant shifts in global energy supply, provided that urgently needed R&D investments are made in the near term. This longer time frame allows for large-scale, cost-effective turnover of capital equipment and for maximum utilization of technical breakthroughs, which will certainly occur if we make the R&D investments now. Advances in fuel cell technology, passive nuclear plants, and renewable generation options not only will increase fuel flexibility but will also yield substantial efficiency and environmental benefits. The end result could be an electricity-hydrogen global energy economy in the coming century, which would provide abundant, clean, sustainable energy while expanding the otherwise limited availability of freshwater worldwide.

The carbon-free portions of the power generation portfolio will become progressively larger—continuing the long-term trend of declining carbon concentration in the global fuel mix. Ensuring this is likely to require a 10-fold increase in R&D to develop noncarbon generation technologies as well as methods of removing carbon dioxide from power plant effluent and the atmosphere and sequestering it.



Minimizing the potential for global climate change requires a continued substitution of carbon-lean fuels, such as natural gas, for those high in carbon. (Carbon intensity is expressed in tons of carbon per ton of oil equivalent.) Achieving an electricity-hydrogen energy economy through the development of advanced, carbon-free power generation options is the ultimate goal. (Historical data from the National Academy of Engineering.)

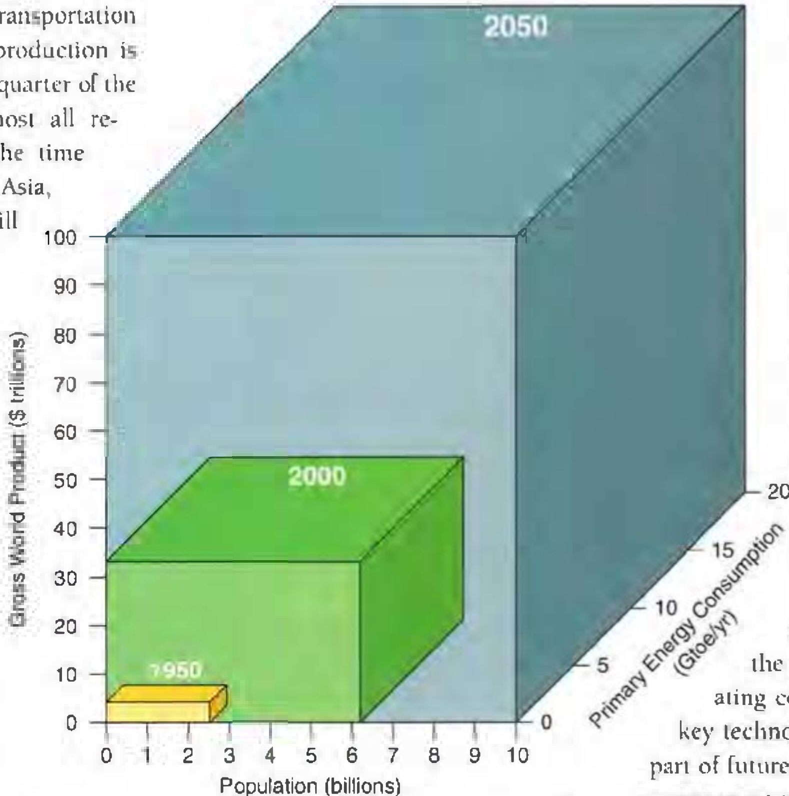
The central role of the environment

Environmental issues cut across almost all the roadmap discussions—an indication of their central role in energy development in the coming century and the need to accelerate work in the environmental sciences to guide both policy and technology strategies. The value of gaining a better scientific understanding of key environmental issues will grow as policy proposals with greater and greater economic consequences are debated.

The roadmap places the highest priority on coming to a better understanding of climate change. This understanding is important because of the long-term risks associated with an unconstrained rise in atmospheric greenhouse gas concentrations and because of the potential economic cost to society if large near-term reductions in greenhouse gas emissions are deemed urgent. Work is needed on the sciences related to climate change processes and effects, as well as on an integrated global analysis that weighs proposed control costs and their distribution against the costs of climate change effects. In addition, a technology strategy is needed to identify and evaluate specific options for moving away from CO_2-emitting power production systems and fossil fuel–based transportation systems.

The transportation issue is particularly important. In the context of demographics and environmental quality, electrified transportation is rapidly becoming a necessity, not just an option. And fuel diversification, which can be achieved primarily through the use of electricity, will help moderate the global competition for petroleum as developing countries build their transportation systems. Conventional oil production is likely to peak by the second quarter of the coming century under almost all resource scenarios—just at the time that emerging economies in Asia, Latin America, and Africa will be adding at least 40 million barrels a day to global demand. Competition for the world's highly geographically concentrated petroleum reserves could lead to increasing global instability, distorting global security and military policy to an ever-greater extent over the next several decades, unless alternatives are available.

In fact, the future of electricity's role in transportation looks particularly bright. Considering recent advances in vehicle and battery development, it is quite possible that emissionless electric, hybrid, and fuel cell–powered vehicles will compete aggressively in the market for personal transportation by 2020. Self-guided vehicles may also become available to free up transportation time for work or leisure activities. The relationship between transportation systems and the electric power industry could even be revolutionized by the development of self-generating electric (fuel cell–powered) vehicles that serve as mobile power sources, providing electricity to the grid during the 90% of the time that they, like most cars, are not on the road.



The magnitude of the global sustainability problem can be seen as the product of world population, economic development, and primary energy consumption. This sustainability "footprint" has grown by a factor of 100 in the last 50 years and by 2050 will be 1000 times as large as in 1950. Electricity can help moderate this growth.

Working for the future

The defining challenge of the coming century will be to balance the "trilemma" of interlocking sustainability issues—the economic aspirations of rapidly expanding populations in the developing world, environmental quality, and natural resource availability. Technology innovation is the best prospect for resolving conflicts between population, prosperity, and pollution. We have seen innovative technology development essentially make the fortunes of the world's great economic powers over the last century. With much advanced technology now mature and ready for application in other parts of the globe, the developing world can leapfrog the slow technology development process and enjoy a vastly improved quality of life—with much higher resource efficiency—while further advances are pursued.

In fact, the entire history of technology strongly supports this central premise of the Electricity Technology Roadmap Initiative: With aggressive R&D investment, future electricity-based technological innovations can contribute to much-needed improvements in virtually every aspect of life in the coming century. But merely identifying the destinations of our preferred future is only the beginning of the roadmapping process. Identifying and eliminating the technology gaps that are obstacles to our traveling the road successfully is a tougher problem—one that the initiative participants are now wrestling with.

Solving that problem will require even broader participation by public and private organizations, including federal and state legislative bodies, national laboratories, academic institutions, and private industry as well as the electricity enterprise. Funding and carrying out the R&D itself will require a strong extension of this collaboration, as neither the government nor industry can fulfill the roadmap's vision alone. Creating consortia to work on specific key technologies will be an important part of future work, as will working with government groups to create incentives for widespread involvement in technology development and application.

The results of this work promise to have a strong influence on the future. An integrated portfolio of innovations will fuel an unprecedented growth in global markets and economies, leading to a new era of human opportunity. Closely linked to this vision of economic and social progress will be a new era of global environmental and political stability arising from breakthroughs in global energy efficiency and conservation.

The roadmap proposes that a sustainable world can be achieved in the coming century, easing the great tensions between population growth and natural resource limits now predicted. The technological advances needed are within our grasp, and with commitments from industry and government, the R&D resources to produce them can be found. Regrettably, however, today this essential investment in innovation is being sacrificed. The roadmap initiative seeks to restore those commitments on the basis of destinations defined by the stakeholders themselves. ■

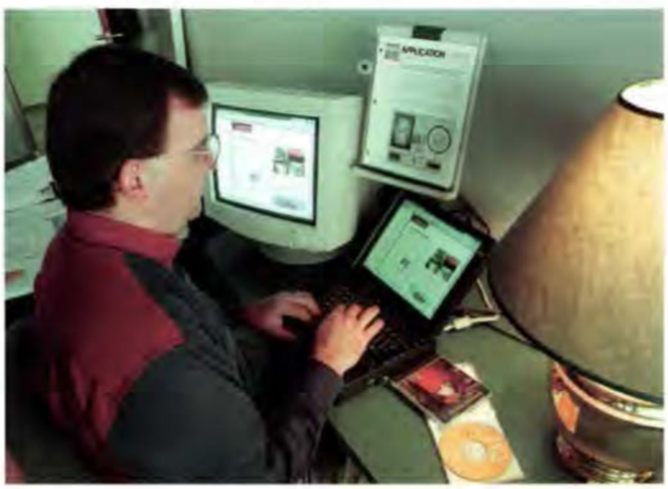
Background information for this article was provided by Brent Barker, Strategic and Executive Communications, and Steve Gehl, Strategic Technology Alliances.

In the Field

Demonstration and application of EPRI science and technology

Online Library of Power Quality Solutions

Electric utilities face a growing challenge in dealing with customer power quality problems created by electrical disturbances and system incompatibilities. In many cases, viable solutions and recommended practices for avoiding power quality problems have been documented and made available to individual utilities and their customers, but there is currently no general clearinghouse for such information. The result is that utility personnel sometimes spend needless time and effort researching power quality problems that have already been solved.



In response, EPRI's Power Electronics Applications Center (PEAC) has assembled a library of more than 65 technical documents that member utilities can access from personal computers to help customers apply the latest results of laboratory and field investigations to solve their power quality problems. The library includes documents from PEAC's series of publications on power quality problems and solutions and from a quarterly newsletter on system compatibility research. It is available on EPRI's electronic information network, EPRIweb, and also on CD-ROM for both Windows and Macintosh computers. Users can browse through the publications or search for a specific topic, using the Adobe software included on the Web site and the CD. Documents may be printed from a laptop computer—in the office or in the field—and distributed to customers at remote locations.

Utilities using the PEAC Online Library estimate that it saves 2 hours a month per person in a customer service or technical support group. The projected savings in customer support time range from $6000 to $60,000 a year, depending on the size of a utility's customer service group.

Utilities may customize the library to contain only the documents they want, and documents can be distributed to customers with utility-specific logos and graphics. The library can easily be included on a company's intranet, providing employee access from virtually anywhere. Utilities can also load the library onto the Internet, allowing customers direct access. "The customized library is exactly what we wanted," says Frank Sinicola of Consolidated Edison Company of New York. "We are offering it on Con Edison's intranet and have also included it on our Internet Web site."

The PEAC Online Library, including the most recent publications, can be accessed through the EPRIweb power quality page (www.epriweb.com/csg/pq). The CD-ROM is available from the EPRI Customer Assistance Center, (800) 313-3774.

New Surge Protection Measures for Appliances

Households are using an increasing number of microprocessor-based electronic appliances—from personal computers, entertainment centers, and microwave ovens to stoves, heat pumps, and security systems. Overvoltages caused by electrical switching transients and lightning strikes can damage or destroy these popular, high-value appliances. Even when the appliances survive a power surge, they may still be affected, such as in a computer lockup. Lightning alone is estimated to be responsible for half a billion dollars in U.S. property damage annually, according to the National Severe Storms Laboratory. Surge damage may account for 80% of claimed losses, with direct lightning strikes accounting for the rest.

Most property losses attributed to surges can be prevented by adding surge protection either at the appliance or in the power and communications wiring systems. Even appliances with several wiring systems can be protected from surges. For a growing number of cases, however, surge protection information and devices supported by a nationally recognized code or standard are not readily available.

In a first step toward minimizing surge damage and associated losses, State Farm Insurance Companies, Illinois Power, and the EPRI Power Electronics Applications Center (PEAC) joined forces to create a document called "Recommended Practice for Residential Surge Protection." After analyzing input from a variety of technical experts, the collaborators reached consensus on essential elements of surge protection, including wiring and grounding. Using practices developed in this project, Illinois Power is helping its residential and small commercial customers protect their electronic appliances and other valuable property from surges. In addition, results from the cooperative effort will enable EPRI and its members to promote better national and international standards related to end-use surge protection.

"With the help of our customer State Farm Insurance, we are now better able to respond to all customers' concerns about surge protection," says Jim May of Illinois Power. The insurance company, meanwhile, is exploring ways to educate policyholders, employees, and agents about this issue. Roger Witt of State Farm says that the results of the engineering effort with PEAC and Illinois Power "could help check the recent growth in damage loss claims for valuable electronic equipment."

The next step beyond the recommended-practice document is a consumer-oriented publication addressing specific methods of residential surge protection. The National Institute of Standards and Technology is working with the project team to develop this consumer guide.

■ *For more information, contact Marsha Grossman, (650) 855-2899.*

Benefits of Utility-Customer Collaboration Highlighted

To raise awareness of the benefits of active partnerships between utilities and their customers in solving common problems, EPRI's Community Environmental Center recently documented PECO Energy's development of a new operating strategy and other energy management measures for one of Philadelphia's major wastewater treatment plants. These measures have lowered peak demand, reduced pumping costs, and improved energy efficiency.

The Southeast Water Pollution Control Plant processes an average of 110 million gallons of wastewater per day (4800 L/s). Flow rates increase quickly during storms, since many sewers in older parts of the city carry both domestic wastewater and storm runoff. Peak flows may last for only short periods but must be pumped and processed at the treatment plant to meet discharge permit requirements.

During storms, as much as 70% of the treatment plant's 9200-hp equipment load is used to process wastewater and pump treated effluent into the Delaware River. Short intervals of high demand, especially during periods when on-peak rates apply, significantly increase billing charges to the city. In 1996 and 1997, PECO Energy partnered with the city to identify a plan for modifying the plant's operation to reduce its peak electricity demand and save the city money while maintaining effluent quality.

PECO Energy analyzed monthly demand profiles for the treatment plant to identify recurrent demand peaks and then produced a detailed outline of the plant's billing formula. Peak demand was correlated with rainfall events. Alternative operating strategies to reduce demand, electricity consumption, and operating costs emerged from a study of the billing formula.

Key features of the adopted strategy included an instruction program to improve plant operators' understanding of how energy management could be integrated into treatment procedures. Operators also learned how to use the plant process computer to monitor real-time operating data and predict when wetwell overflow levels would be reached so that they could fine-tune the timing of pump startup and shutdown.

In addition, a load-shedding schedule that covers various flow regimes during on- and off-peak periods was developed for the plant. Operators also instituted a plan for maximizing wetwell and influent sewer storage capacity to reduce pumping costs and cut power consumption.

The Southeast Water Pollution Control Plant is now in its second year of energy conservation operation. During the first five months of operation under the new strategy, the plant realized a 14% reduction in power demand charges. Electricity consumption decreased by 10%, and savings on the plant's electric bill averaged $16,000 per month.

"We could not have achieved these cost reductions without PECO Energy's assistance," says Andrew Sherman, operations supervisor at the treatment plant. "PECO identified the critical billing areas where maximum savings could be realized with minimum effort." The utility's Donahue Scott adds, "Modifying billing demand without affecting treatment performance paid big dividends for the city of Philadelphia and created a happy customer for PECO Energy."

EPRI's study documenting the energy monitoring and management effort is available from the EPRI Customer Assistance Center, (800) 313-3774.

■ *For more information, contact Keith Carns, (314) 935-8598.*

Technical Reports & Software

To order reports, contact the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, CA 94523; (925) 934-4212. To order software, contact the Electric Power Software Center, 11025 North Torrey Pines Road, La Jolla, CA 92037; (800) 763-3772.

Energy Conversion

Impact of Powder River Basin Coal on Power and Fuel Markets
TR-109000
Target: Fuel Supply Management
EPRI Project Manager: J. Platt

Guidelines for the Fluid Dynamic Design of Power Plant Ducts
TR-109380
Targets: Coal-Fired Boiler Performance Optimization and Combustion NO_x Control; Primary Particulate Control
EPRI Project Managers: J. Maulbetsch, G. Offen

CORETRAN Tech Transfer Workshop
TR-109621
Target: Nuclear Power
EPRI Project Manager: L. Agee

International RETRAN Conference, 1998
TR-109622
Target: Nuclear Power
EPRI Project Manager: L. Agee

Condenser Configuration and Performance Evaluation Using Computational Fluid Dynamics
TR-109725
Targets: Steam Turbines, Generators, and Balance of Plant; Repowering Strategies
EPRI Project Manager: J. Tsou

Streamlined Reliability-Centered Maintenance (SRCM) Program for Fossil-Fired Power Plants
TR-109795
Target: Plant Maintenance Optimization
EPRI Project Manager: R. Pflasterer

EPRI Report on Boraflex Seismic Assessment
TR-109927
Target: Nuclear Power
EPRI Project Manager: R. Mahini

Streamlined Reliability-Centered Maintenance at MidAmerican Energy's Council Bluffs Energy Center, Unit 3
TR-109989
Target: Plant Maintenance Optimization
EPRI Project Manager: R. Pflasterer

Streamlined Reliability-Centered Maintenance at Montana Power Co.'s Colstrip Unit 1
TR-109990
Target: Plant Maintenance Optimization
EPRI Project Manager: R. Pflasterer

Reactor Pressure Vessel Flaw Distribution Development: Inspection of Shoreham RPV—Progress Report
TR-110143
Target: Nuclear Power
EPRI Project Manager: S. Rosinski

The New Environmental Drivers: Challenges to Fossil Generation Planning and Investment
TR-110261
Target: Fuel Supply Management
EPRI Project Manager: J. Platt

Power Plant Tolling: Profits at the Point of Convergence?
TR-110262
Target: Fuel Supply Management
EPRI Project Manager: J. Platt

Computerized Maintenance Management System and Maintenance Work Process Integration
TR-110272
Target: Plant Maintenance Optimization
EPRI Project Manager: R. Pflasterer

Coal Quality Impact Model™, Version 2.0: User Manual
AP-110502
Target: Coal-Fired Boiler Performance Optimization and Combustion NO_x Control
EPRI Project Manager: D. O'Connor

Laboratory Investigation and Model Development of Flue Gas Mercury Adsorption Using Solid Sorbents
TR-110533
Target: Air Toxics Control
EPRI Project Manager: R. Chang

Assessment of Coal Handling for Fuel Flexibility
TR-110957
Target: Fuel Supply Management
EPRI Project Manager: D. O'Connor

Proceedings: 1998 Feedwater Heater Technology Symposium
TR-111046
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Manager: J. Tsou

Proceedings: 1998 Heat Rate Improvement Conference
TR-111047
Target: Coal-Fired Boiler Performance Optimization and Combustion NO_x Control
EPRI Project Manager: J. Tsou

Small CHAT Plant: Transient and Part-Load Characteristics
TR-111193
Targets: New Combustion Turbine/Combined-Cycle Design and Risk Mitigation; Atmospheric Particulates and Precursors
EPRI Project Manager: A. Cohn

Template for Submission of Risk-Informed In-Service Testing Program for Pumps and Valves
TR-111204
Target: Nuclear Power
EPRI Project Manager: F. Rahn

Hydro Operational Restrictions Forum: Agency and NGO Workshop Summary
TR-111248
Target: Hydro Performance Optimization and Asset Management
EPRI Project Manager: T. O'Shea

Proceedings: 2nd Annual EPRI Workshop on Power Plant Optimization (May 1998)
TR-111316
Target: Coal-Fired Boiler Performance Optimization and Combustion NO_x Control
EPRI Project Manager: J. Stallings

PISCIS: Processor and Interactive System for Core Intelligent Simulation
Version 1.0 (HP-UX)
Target: Nuclear Power
EPRI Project Manager: L. Agee

RPVDATA: Reactor Vessel Materials Database
Version 1.4 (Windows)
Target: Nuclear Power
EPRI Project Manager: S. Rosinski

wasteWORKS '98
Version 1.0 (Windows 3.1, 95, 98, NT)
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Energy Delivery and Utilization

The High-Efficiency Laundry Metering and Marketing Analysis (THELMA) Project, Vol. 7: Product Users—Field Monitoring
TR-109147-V7
Target: Residential Appliances
EPRI Project Managers: J. Kesselring, R. Gillman

Distribution Automation Pilot Project at Georgia Power Co.
TR-109486
Target: Distribution System
EPRI Project Manager: W. Blair

Add-On Heat Pumps: A New Marketing Perspective
TR-109735
Target: Residential Heat Pump Technology
EPRI Project Manager: C. Hiller

Near-Optimal Cool Storage Controller Development: Field Testing During the 1997 Cooling Season
TR-109767
Target: Commercial Building Thermal Storage
EPRI Project Manager: M. Khattar

San Diego Environmental Service Department's Ridgehaven Green Building Demonstration Project: Case Study
TR-109810
Target: Commercial Building Heat Pump Technology
EPRI Project Manager: M. Khattar

Unitary Cool Storage Field Demonstration
TR-109924
Target: Commercial Building Thermal Storage
EPRI Project Manager: M. Khattar

The Evolving Role of Marketers in the Restructured Electricity Market
TR-111004
Target: Power Markets and Resource Management
EPRI Project Manager: A. Altman

Ground-Source Heat Pump Bentonite-Based Grouting Research: Review of Literature on Existing Bentonite-Based Grouting
TR-111035
Target: Residential Heat Pump Technology
EPRI Project Manager: C. Hiller

Written-Pole Motor Generator Technologies Application Guide
TR-111036
Target: End-Use Power Quality Mitigation Systems
EPRI Project Manager: B. Banerjee

Modeling Development of Converter Topologies and Control for Back-to-Back Voltage Source Converters
TR-111182
Target: Substations
EPRI Project Manager: A. Edris

An Evaluation of Web-Based Residential Energy Bill Disaggregation Software
TR-111192
Targets: Residential Heat Pump Technology; Residential Water Heating Technology; Residential Appliances; Multifamily Housing; Manufactured Housing; Promoting Energy Products for Mass Markets
EPRI Project Manager: J. Kesselring

Proceedings: Substation Equipment Diagnostics Conference V
TR-111282
Target: Substations
EPRI Project Manager: S. Lindgren

Proceedings: Substation Equipment Diagnostics Conference VI
TR-111314
Target: Substations
EPRI Project Manager: S. Lindgren

■ EDC: Engineering Design and Costing Model
Version 1.0b (Windows 95)
Target: Distribution System
EPRI Project Manager: S. Chapel

■ Electricity Book
Version 0.75.1 (Windows 95, NT)
Target: Power Markets and Resource Management
EPRI Project Manager: A. Altman

■ PAD: TLWorkstation™ 3.0 Module
Version 3.0 (Windows 3.1, 95, NT)
Target: Overhead Transmission
EPRI Project Manager: A. Hirany

■ PQDS (Power Quality Diagnostic System): Simulation Module Production
Version 1.0 (Windows 95, NT)
Target: Power Quality
EPRI Project Manager: S. Bhatt

■ UTWorkstation: CABLEFUN (Cable Ampacity Fundamentals Program)
Version 3.0 (Windows)
Target: Underground Transmission
EPRI Project Manager: T. Rodenbaugh

■ UTWorkstation: CABLEREF (Cable Reference Database)
Version 2.1 (Windows)
Target: Underground Transmission
EPRI Project Manager: T. Rodenbaugh

■ UTWorkstation: PCFIELD
Version 3.0 (Windows)
Target: Underground Transmission
EPRI Project Manager: T. Rodenbaugh

■ UTWorkstation: PULLPLAN
Version 3.0 (Windows)
Target: Underground Transmission
EPRI Project Manager: T. Rodenbaugh

Environment

Site 24 Compact Disc Containing Environmental Data, Photographs, and Graphic Displays: User's Guide
TR-110830
Target: MGP Site Remediation and Health Risk
EPRI Project Manager: A. Quinn

Small CHAT Plant: Transient and Part-Load Characteristics
TR-111193 (see listing under Energy Conversion)

EPRICSG

National Accounts Manager: Design Study
TR-109726
Target: Information and Energy Management Services for Mass Markets
EPRI Project Manager: D. Cain

Assessments of Emerging Technologies for Wireless Communications
TR-110125
Target: Wireless Applications and Services
EPRI Project Manager: S. Drenker

Listening to Small and Medium Businesses: Opinions, Attitudes, and Decision Making in Open Energy Markets
TR-110406
Target: Understanding Energy Markets
EPRI Project Manager: R. Gillman

Getting Closer™: A New Way of Understanding the Cultural Values and Rituals Surrounding the Use of Energy
TR-110817
Target: Understanding Energy Markets
EPRI Project Manager: R. Gillman

Utility-Customer Communications Options for the "Last Mile"
TR-111023
Target: Information and Energy Management Services for Mass Markets
EPRI Project Manager: S. Drenker

Worldwide Satellite Communications for the Energy Utility Industry
TR-111052
Target: Wireless Applications and Services
EPRI Project Manager: S. Drenker

An Evaluation of Web-Based Residential Energy Bill Disaggregation Software
TR-111192 (see listing under Energy Delivery and Utilization)

Strategic Science and Technology

Internet Energy Management: A Security Analysis
TR-111015
Program: Strategic Science and Technology
EPRI Project Manager: S. Drenker

Value of the Small-Punch Test for Evaluating Fracture Toughness of Nuclear Pressure Vessels
TR-111142
Program: Strategic Science and Technology
EPRI Project Manager: V. Viswanathan

Influence of Silicon on the Corrosion Resistance of Stainless Steel in Coal Gasification Environments
TR-111181
Program: Strategic Science and Technology
EPRI Project Manager: W. Bakker

EPRI Events

February 1999

1–2
Containment Inspection: Visual Examination Training, Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

1–5
Supercritical Boiler Unit Operations
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

3–5
ASME Section XI Flaw Evaluation
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

8–10
Electric Motor Predictive Maintenance
Orlando, Florida
Contact: Megan Boyd, (650) 855-7919

8–12
Cyclone Boiler Unit Operations
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

8–12
NDE Instructor Training
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

9–10
Workshop on COSTAR (Concrete Structures Aging Reference) Manual
Charlotte, North Carolina
Contact: Brent Lancaster, (704) 547-6017

15–19
Magne-Blast Circuit Breaker Users Group
Clearwater Beach, Florida
Contact: Brent Lancaster, (704) 547-6017

16–17
Gas-Electric Partnership Meeting
Houston, Texas
Contact: Dick Schmeal, (713) 963-9307

16–17
Simulator Specification and Procurement
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

17–19
EPRI Healthcare Initiative
Denver, Colorado
Contact: Kelly Ciprian, (614) 855-1390

17–19
Service Water Engineer Training
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

21–24
7th Substation Equipment Diagnostics Conference
New Orleans, Louisiana
Contact: Michele Samoulides, (650) 855-2127

22–25
Microbiologically Influenced Corrosion
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

23–25
1999 Condensate Polishing Workshop
Santa Fe, New Mexico
Contact: James & Co., (707) 829-3500

23–25
Simulator Acceptance Test Procedure Workshop
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

24
Water and Energy Conference
Sarasota, Florida
Contact: Kim Shilling, (314) 935-8590

25–26
Municipal Water and Wastewater Program Meeting
Sarasota, Florida
Contact: Kim Shilling, (314) 935-8590

March

1–5
Boiler Operating Theory
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

8–12
Turbine Operating Theory
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

8–12
Visual Examination Technology: Level 1
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

11–12
Workshop on Ground-Penetrating Imaging Radar
Ridgefield, Connecticut
Contact: Andrea Duerr, (650) 855-2719

15–18
Advanced Structural Analysis and Design Methods for Power Line Upgrading
Haslet, Texas
Contact: Kathleen Lyons, (650) 855-2656

15–18
Generator Monitoring and Diagnostics
Orlando, Florida
Contact: Don Mason, (610) 490-3212

15–19
Basic Electrical Theory for Power Plants
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

15–26
Ultrasonic Examination Technology: Level 1
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

17–18
Health Facility Planning, Design, and Construction
Tampa, Florida
Contact: Kelly Ciprian, (614) 855-1390

22–26
Generator Operating Theory
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

28–31
1999 EMF Science Seminar
Denver, Colorado
Contact: Robert S. Banks Associates, (612) 623-4600

29–April 2
Designing, Developing, and Evaluating Fossil Plant Training Programs
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

April

5–9
Simulator Instructor Techniques
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

8–9
Workshop on AC Losses
Palo Alto, California
Contact: Kathleen Lyons, (650) 855-2656

12–14
Power Quality Challenges in the Semiconductor Industry
Tempe, Arizona
Contact: Karen Forsten, (423) 974-8291

12–14
Transmission Inspection and Maintenance (TIM) System Training Class
Las Vegas, Nevada
Contact: Kathleen Lyons, (650) 855-2656

12–15
Conference on Power Plant Impacts on Aquatic Resources
Atlanta, Georgia
Contact: Cindy Layman, (650) 855-8763

12–16
NDE for Engineers
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

12–16
Simulator Instructor Station Operations
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

13–14
Forecasting Symposium
Denver, Colorado
Contact: Paige Polishook, (650) 855-2010

15–16
TIM System Users Group Meeting
Las Vegas, Nevada
Contact: Kathleen Lyons, (650) 855-2656

20–23
Structured On-the-Job Training Program Design, Development, and Implementation
Kansas City, Missouri
Contact: Sarah Vanberg, (816) 235-5623

27–29
Preserving Equipment Qualification
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

May

3–7
Steam Plant Operations for Utility Engineers
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

10–11
Continuous Emissions Monitoring (CEM) Preconference Tutorial
Cincinnati, Ohio
Contact: Michele Samoulides, (650) 855-2127

10–13
Industrial Energy Technology Conference
Houston, Texas
Contact: Sam Woinsky, (713) 963-9336

10–14
Combined-Cycle Operations for Utility Engineers
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

10–21
Ultrasonic Examination Technology: Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

12–14
1999 CEM Users Group Meeting
Cincinnati, Ohio
Contact: Michele Samoulides, (650) 855-2127

17–21
Drum Boiler Unit Operations
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

19–21
Transformer Reliability: Management of Static Electrification
Monterey, California
Contact: Paige Polishook, (650) 855-2010

23–27
5th International Conference on Mercury as a Global Pollutant
Rio de Janeiro, Brazil
Contact: Ron Wyzga, (650) 855-2577

24–27
PQA '99: North America
Charlotte, North Carolina
Contact: Megan Boyd, (650) 855-7919

24–28
Supercritical Boiler Unit Operations
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

26–28
Valve Symposium
Lake Tahoe, Nevada
Contact: Linda Suddreth, (704) 547-6061

31–June 4
Cyclone Boiler Unit Operations
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

June

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

2–4
Corrosion and Degradation Conference
St. Pete Beach, Florida
Contact: Brent Lancaster, (704) 547-6017

7–11
Visual Examination Technology: Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

9
Retail and T&D Expo
Atlanta, Georgia
Contact: Lora Cocco, (650) 855-2620

10–11
Electromagnetic Interference Qualification of Digital Equipment
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

12–17
Joint ISA POWID/EPRI Controls and Instrumentation Conference
St. Petersburg, Florida
Contact: Paige Polishook, (650) 855-2010

14–18
ABB Circuit Breaker Users Group Meeting
Charlotte, North Carolina
Contact: Brent Lancaster, (704) 547-6017

14–18
Service Water Heat Exchanger Testing
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

14–23
Ultrasonic-Testing Operator Training for the Detection of IGSCC
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

15–17
3d Annual In-Service Inspection and Nondestructive Evaluation Workshop
Minneapolis, Minnesota
Contact: Sherryl Stogner, (704) 547-6174

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

17–18
CHUG Meeting
Portland, Maine
Contact: Eryn Schroeder, (650) 855-2259

21–23
1999 Plant Maintenance Conference
Atlanta, Georgia
Contact: Cindy Layman, (650) 855-8763

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

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

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

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

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

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