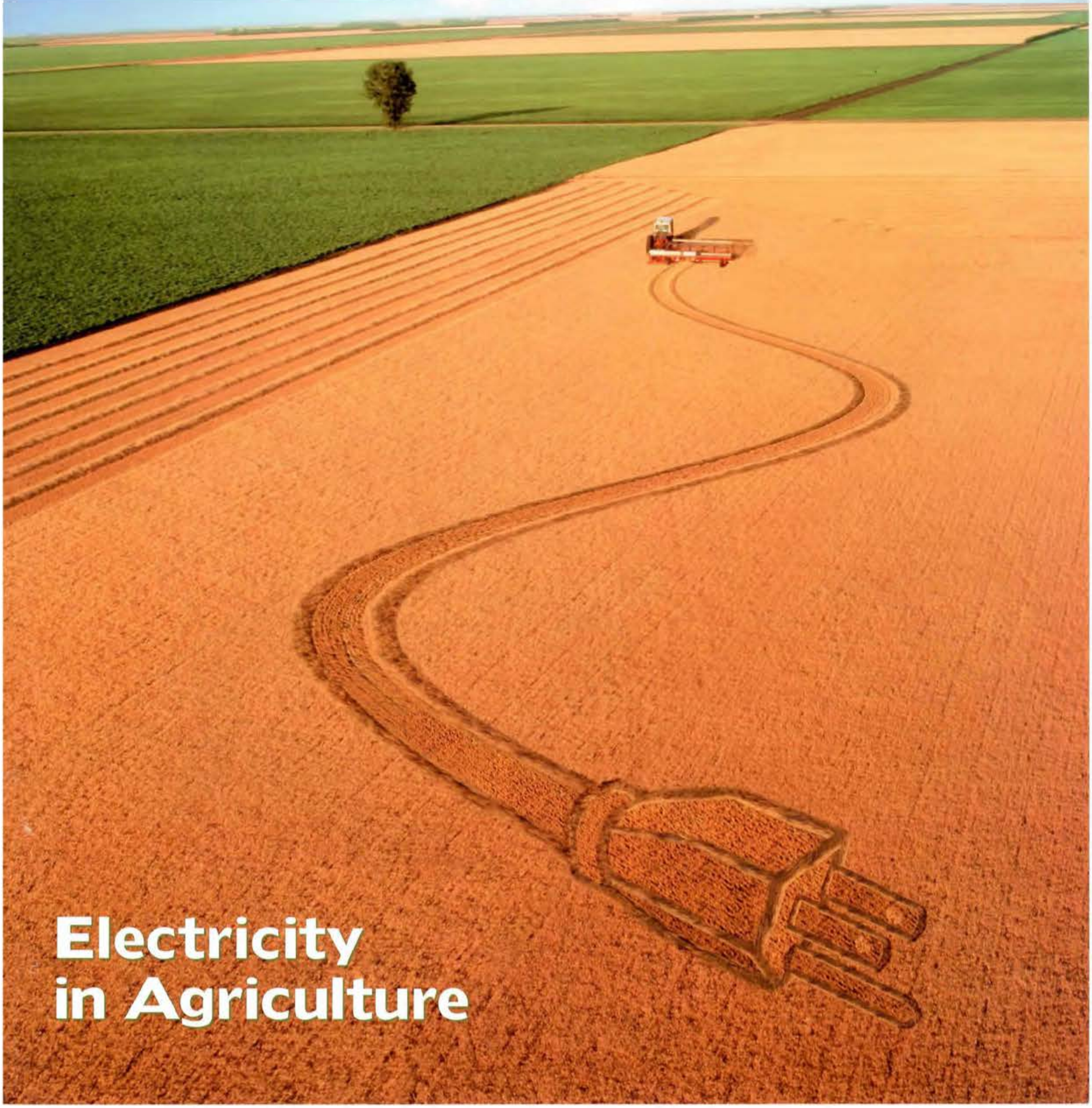
EPRI JOURNAL

MAY / JUNE 1998

Nitrate Contamination
Solutions That Work

Geothermal Heat Pumps
A Technology on the Rise



Electricity in Agriculture

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: In the field and the barnyard, farmers are finding that electricity can boost the efficiency of their operations while helping them respond to tightened environmental regulations. (Original field image by Andy Sachs/Tony Stone Images, photo manipulation by Weinberg & Clark.)

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Editorial

Cost Is Key for a Global Climate Agreement

The Kyoto Protocol, proposed last December under the United Nations Framework Convention on Climate Change, has the potential to fundamentally change the world's energy systems and to impose trillions of dollars of costs on the global economy. The technical aspects of such a sweeping plan are clearly crucial, and there is a significant scientific research program under way worldwide to determine what the target concentration level should be for each of the greenhouse gases. But other studies conducted by energy experts over the last decade have shown that economics are equally important and that adopting a least-cost approach to the achievement of these targets is an essential feature of a viable climate change mitigation policy. The global nature of the greenhouse gas issue and the focus on target atmospheric concentrations provide additional degrees of freedom for mitigation relative to more-localized environmental issues.

Certainly it is important, and economical, to take advantage of any so-called no-regrets options to reduce emissions of greenhouse gases. Once these low-hanging fruits are gone, the cost of further mitigation can be minimized by searching for the cheapest mitigation options worldwide. If it costs $30 to remove a ton of carbon in one country and $20 to remove it in another, the world can save $10 by making the reduction in the second country, regardless of who pays. It follows that such a least-cost strategy must include all nations.

Further, to meet an atmospheric concentration target over time, mitigation efforts can be relatively modest early on and should increase in intensity as we approach the target. This phased approach has the advantage of allowing for the cost-effective utilization of the existing capital stock until it is replaced by the next generation of more-efficient equipment. The approach also allows time for R&D to lower the costs of such promising technology alternatives as nuclear, solar, modern commercial biomass, energy conservation, and carbon dioxide capture and sequestration.

The Kyoto Protocol is one of the most far-reaching international agreements ever proposed. It aims to reduce greenhouse gas emissions in developed countries by approximately 5% below 1990 levels over the period 2008–2012 (a 35% cut from where emissions are expected to be at that time), with even greater reductions expected for succeeding periods. The protocol will be open for signature between March 1998 and March 1999 and will enter into force if ratified by at least 55 parties to the convention.

There is a good chance, however, that the Kyoto Protocol will fail to enter into force, largely because it does not encourage least-cost strategies. For example, the protocol does not include any targets for developing countries, thus making problematical their meaningful participation. In addition, by specifying high greenhouse gas reduction targets for the five years centered around 2010, it will magnify and accelerate the expensive turnover of capital stock.

For these reasons, the U.S. Senate—as well as legislative bodies in other nations—may find it difficult to endorse the protocol. Indeed, there was unanimous support last year for Senate Resolution 98, the Byrd-Hagel Resolution, which stipulated that the United States should not be a signatory to the Kyoto Protocol if the protocol did not mandate specific commitments for developing countries and if it would result in serious harm to the U.S. economy.

Many of the key details of the protocol remain ambiguous and hopefully will be clarified at the Fourth Conference of the Parties in Buenos Aires this November. In the meantime, it is important to pursue analyses and discussions of how to build a workable institutional framework—one that will encourage long-term, cost-effective worldwide commitment to reducing greenhouse gas emissions to achieve scientifically based target levels. And we must continue to conduct R&D that will provide the technological capability to do so with the smallest possible cost increase.

Stephen C. Peck
Vice President, Environment

Contributors

The Electric Farm (page 8) was written by freelance writer Judy Gerber, with technical information from Myron Jones of the Energy Delivery and Utilization Division.

MYRON JONES, project manager for advanced industrial systems, currently manages EPRI's food and agriculture targets. Earlier he initiated programs on advanced electrotechnologies for use in the health care industry and in municipal water and wastewater treatment. Before coming to EPRI in 1990, Jones was vice president of a subsidiary of Pacific Gas and Electric Company, where he was responsible for natural gas sales and corporate planning. Before that, he worked for Bechtel, Shell Development Corporation, United Technologies, and Rust Engineering, serving in a variety of process design and R&D capacities. Jones has BS and MS degrees in chemical engineering from the University of Maine.

Getting the Nitrate Out (page 18) was written by Leslie Lamarre, *Journal* senior feature writer, with technical information from Myron Jones (see above) and Keith Carns of the Energy Delivery and Utilization Division.

KEITH CARNS, director of EPRI's Community Environmental Center, oversees research on water and wastewater treatment electrotechnologies. Before joining EPRI in 1993, he ran an independent environmental consulting firm for two years. His earlier experience includes 24 years with the East Bay Municipal Utility District of Oakland, California—one of the country's largest water and wastewater utilities. Carns also served for more than 10 years as a member of and consultant to the drinking water committee of the U.S. Environmental Protection Agency's Science Advisory Board. He has a BS in civil engineering and an MS in environmental engineering from the University of California at Berkeley.

Heating and Cooling From the Ground Up (page 24) was written by Leslie Lamarre, *Journal* senior feature writer, with technical information from Mukesh Khattar and Carl Hiller of the Energy Delivery and Utilization Division.

MUKESH KHATTAR, team leader for HVAC, refrigeration, and thermal storage technologies, joined EPRI in 1989. Before that, he was a principal engineer with the Florida Solar Energy Center in Cape Canaveral, where he participated in key development, demonstration, and technology transfer work on the use of heat pipes for dehumidification. Earlier he was an assistant engineer in the Air Conditioning and Refrigeration Division of Voltas Limited in India, holding design, engineering, and project management responsibilities for HVAC and refrigeration systems for commercial, institutional, industrial, and other applications. Khattar received a BS degree in mechanical engineering from the Indian Institute of Technology in Kanpur, India. He also has MS and PhD degrees in the same subject from the Florida Institute of Technology.

CARL HILLER, senior project manager for residential and commercial systems, manages most of EPRI's residential air-source and ground-source heat pump work and all of its residential and commercial water heating work. Before joining EPRI in 1983, he spent two years with Acurex Corporation as a senior engineer in solar electric generating plant and cogeneration plant design. Earlier, at Sandia National Laboratories, he was involved in the thermal analysis of chemical heat pump systems and other technologies. He also worked at General Motors Corporation and served as a consultant to the U.S. Department of Energy on advanced heat pump concepts. Hiller holds three degrees in mechanical engineering—a BS from the University of Michigan and an MS and a PhD from the Massachusetts Institute of Technology.

Discovery

Basic science and innovative engineering at the cutting edge

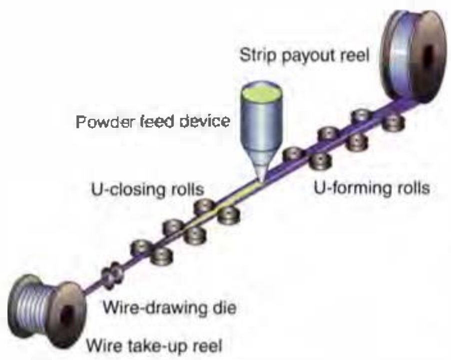
Continuous Manufacturing of Superconducting Wire

High-temperature superconducting (HTS) wire and multifilament conductors are now produced in a batch process. A powdered, rare-earth-containing ceramic copper oxide compound is used to fill silver wire sheathing, which is next heat-treated to render it superconducting, then rolled and drawn as wire or flat tape. But this oxide-powder-in-tube (OPIT) process can make continuous lengths of wire only about a kilometer long. For longer lengths, individual segments must be joined together, which may impair critical current conduction.

Recent EPRI-sponsored strategic R&D in advanced HTS materials and fabrication has produced a record length of HTS tape by using a low-cost, continuous method already employed in the commercial production of certain weld wires. The 2-km tape was made with Bi-2223, the same bismuth strontium calcium copper oxide compound used in commercial HTS wire produced by the OPIT method. The tape was successfully tested, attaining good superconducting current densities in elevated magnetic fields. This work was performed by researchers at Ohio State University, led by materials science and engineering professor Ted Collings, with materials fabricator Plastronic, Inc., as a subcontractor.

The continuous tube forming and filling (CTFF) process features rollers that form silver sheathing from a payout reel into a U-shape for continuous filling with powdered Bi-2223. U-closing rollers complete the sheathing of the wire, which is then drawn through a die and rolled onto a take-up reel. Multiple wire filaments may be stacked or bunched and ensheathed together to form a multicore tape.

Samples from the monocore tape fabricated by the researchers were heat-treated, and measurements of their superconducting properties were made at Ohio State, Plastronic, and the University of Wollongong in Australia. On the basis of these measurements, the researchers report that at 77 K (the boiling point of liquid nitrogen, which could serve as a relatively inexpensive coolant for HTS materials), the tape's transport critical current is fairly uniform throughout its full length. Although the critical current is lower than the values for specimens successfully produced by the OPIT method, the tape's irreversibility fields are as high as those of OPIT tapes. This suggests that there is no lack of magnetic flux-pinning strength and that high critical current should be attainable with further refinement.



Continuous tube forming and filling process

In addition, the ratio of the transport critical current at 4.2 K (the boiling point of liquid helium) to that at 77 K is three to five times greater for the CTFF tape than that claimed for commercial OPIT tape. This suggests that a substantial fraction of low-transition-temperature phase material is present, according to John Stringer, EPRI Executive Technical Fellow. "The results so far show that the CTFF strands are not attaining their full potential and that further process optimization is needed," says Stringer, who manages EPRI's work in advanced materials.

Another problem for the CTFF tape, as is also the case for OPIT tape, is that thermal cycling progressively degrades the material. This is because differences in the coefficients of thermal expansion of the ceramic superconductor and the silver sheathing lead to cracking of the ceramic compound.

Multicore CTFF tapes have been produced in short lengths, and upcoming work is aimed at producing a multicore ribbon of considerable length to further demonstrate the validity of the fabrication method. The original 2-km monocore tape was cut into six pieces of equal length, from which the researchers are fabricating a six-strand multicore tape. Later, they will turn to the optimization of superconducting properties. They also plan to pursue improvements in the powder filling material and in methods for heat-treating very long lengths of tape.

So far, all of the CTFF work has been done with the Bi-2223 compound, which loses superconductivity in moderate magnetic fields at 77 K. But many utility applications for high-temperature superconductors—for example, motors and generators—require an ability to operate in powerful, self-generated magnetic fields. Eventually, says Stringer, the CTFF method could be used to manufacture HTS wire from superconductor compounds (such as Bi-2212) that may perform better in high magnetic fields.

■ *For more information, contact John Stringer, (650) 855-2472.*

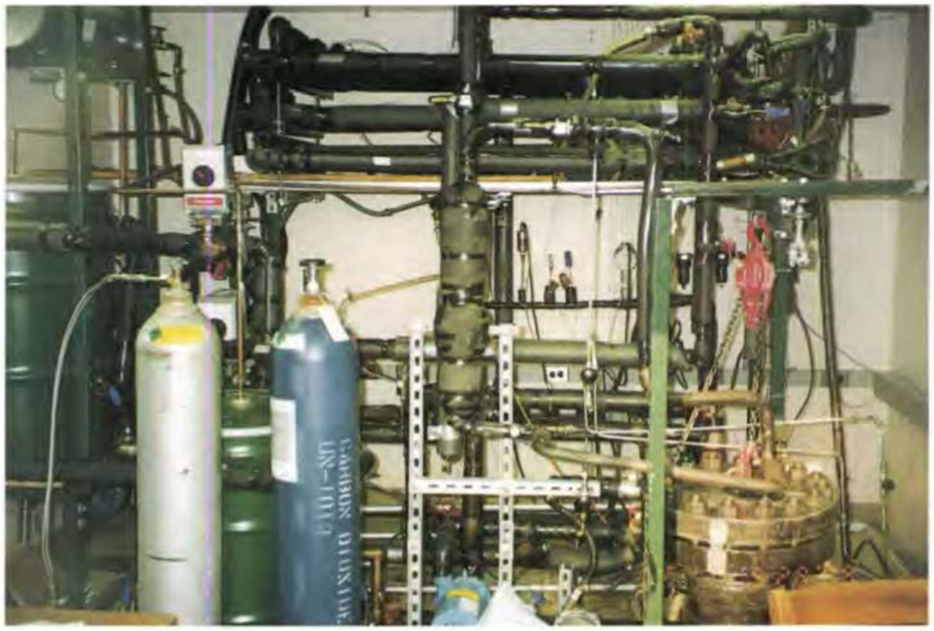
Ozone-Safe Refrigerants

Production of the chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants used in most electric vapor-compression equipment is being phased out under international agreements to help mitigate damage to the earth's stratospheric ozone layer. This phaseout is of particular concern to U.S. electric utilities because the refrigerant-dependent equipment used in air conditioners, heat pumps, and other space-conditioning systems accounts for about 20% of total utility revenues. Several ongoing EPRI projects are aimed at developing non-ozone-depleting alternatives to CFCs, whose production has been halted, and to HCFCs, whose production will be cut back, beginning in 2004, until a complete ban is achieved by 2030.

After nearly a decade of R&D, supported in part by EPRI, researchers are reporting significant progress toward the commercial availability of practical alternative refrigerants. Effective replacements must have zero ozone-depletion potential; that is, they must contain no chlorine or else have a very short atmospheric lifetime. They should also have boiling points, critical temperature (T_c) values, and other thermodynamic properties similar to those of existing refrigerants. Ideally, alternatives will require only minimal modifications to existing equipment.

Because it seems to be unlikely that a single substance will satisfy all these requirements, EPRI research is addressing compound mixtures and promising azeotropes—compound blends whose vapor and liquid phases have the same composition and whose boiling points therefore remain constant during evaporation. Also under investigation are new equipment designs for alternative refrigerants and new techniques for using natural ozone-safe refrigerants.

Clemson University researchers are exploring the potential of novel new chemicals as well as new mixtures of well-understood chemicals. The common HCFC R-22 has proved particularly difficult to replace because of its low boiling point (−40.8°C) and high T_c (96°C). Some compounds, including the propane-based HC-290 (*n*-propane) and HCFC-270 (cyclopropane), have boiling points and T_c values similar to those of R-22 but are unsuitably flammable. Certain sulfide compounds are inert and nonflammable and contain no chlorine, but their boiling points are too high for them to be suitable R-22 replacements. By blending these and similar candidates with other chemicals, Clemson researchers hope to minimize the compounds' negative characteristics while retaining their desirable ones.



COURTESY UNIVERSITY OF MARYLAND

Carbon dioxide test facility at the University of Maryland

"The Clemson work has identified five compounds in three different classes—sulfur-based compounds, ether-type compounds, and hydrofluorocarbons—that are probably not potential R-22 replacements themselves but that look very promising when blended," says Wayne Krill, a manager in EPRI's Energy Delivery and Utilization Division. "Several of these azeotropes have the right boiling point and critical temperature properties. This year, researchers are continuing to analyze a narrowing field of candidate mixtures in order to better understand their properties and to evaluate their prospects for commercial production."

Laboratory testing and characterization of promising replacement compounds and mixtures will be followed by vapor-compression-cycle modeling to assess how the refrigerants might behave in actual use. Applications development for some refrigerants could be under way by the end of this year.

Texas A&M University researchers are exploring solutions to practical design challenges posed by alternative refrigerants. Their work is focused on the use of R-410a—an azeotropic mixture of R-32 and R-125 that displays many of the physical properties of R-22—in plate-fin heat exchangers, a design of interest to many vapor-compression equipment manufacturers. If it is successful, the Texas A&M research could culminate in a new condenser design with potentially widespread application.

A different approach to avoiding many harmful effects of refrigerants is to use materials already present in nature. A refrigeration cycle that uses carbon dioxide as the working fluid was developed and tested by the University of Maryland's Department of Engineering. In studies comparing the effectiveness of CO_2 with that of R-22, high-pressure CO_2 exhibited a similar coefficient of performance. And because CO_2 is denser than R-22, equipment using it could be lighter and smaller than conventional units. The performance of CO_2 has been tested in a variety of heat exchanger configurations.

■ *For more information, contact Wayne Krill, (650) 855-1033.*

Around the World

Focus on international projects and alliances

EPRI International Launched

In an effort to focus more attention on the international market and further leverage its own unique collaborative advantage, this year EPRI launched a new division called EPRI International to manage projects involving markets outside North America.

"EPRI has done a great job of growing the business internationally," says Don Baker, who in January was appointed vice president in charge of the new division. "But now it's time to prepare EPRI for the transition from a U.S.-based company selling overseas to a business that is truly global in nature."

As Baker points out, EPRI's 34 international members and 128 international funders—which come from countries as diverse as South Korea and South Africa—have different needs than its domestic members. EPRI International will enable EPRI to give them the attention they deserve. "You can't put all of our international customers in the same basket," says Baker. "Aside from the obvious language and time differences, there are equipment and system differences. In addition, the countries of these customers are in various stages of economic development, which translates into different needs for EPRI products and services."

Unlike the United States and Canada, where electricity is transmitted at a frequency of 60 Hz, most countries rely on 50-Hz electric power. Even so, many areas of the world could benefit from the specific tools and expertise EPRI has developed over its 25 years of state-of-the-art, industrywide R&D work.

For instance, the demand-side management strategies EPRI has developed to help domestic utilities are now of critical interest to developing countries in Asia and Latin America, where power companies are pressed to serve spiraling demand with limited generating capacity. European utilities, meanwhile, could benefit considerably from EPRI's advanced technologies for coal-fired plants and other strategies for reducing environmental impacts.

EPRI has worked with international organizations from the start. But over the years, that involvement has become more significant. Today, as Baker points out, the more competitive electricity market in the United States is encouraging EPRI to be even more aggressive internationally, just as it has pushed EPRI's domestic members to set their sights overseas. This year, for the first time, two international members—Electricité de France and ESKOM of South Africa—are represented on EPRI's Board of Directors.

Together, contributors outside North America paid some $28 million to EPRI in 1997, which was about 7% of its total revenues. Baker's goal is to increase that figure to $100 million by 2001. The potential is certainly there. EPRI now draws its domestic revenues from a North American market with some $239 billion in annual electricity revenues. And that market is only about 40% of the size of the $608 billion market that includes Asia, Latin America, Europe, and Africa.

According to Baker, EPRI's strongest international market at this time is Europe, partly because the power companies there are more like U.S. utilities than are those in other parts of the world. Asia and Latin America are more challenging markets because many of their power companies aren't as interested in long-term collaboration as in obtaining solutions for specific problems at hand. Nevertheless, EPRI has made inroads with firms in these regions. Late in May, for example, EPRI officials signed an agreement with the Electricity Generating Authority of Thailand, kicking off a $2 million project that will use advanced metering technology developed by EPRI (see article, next page).

EPRI International currently has a staff of 24, most of whom work from EPRI's Palo Alto, California, headquarters. However, some are located in EPRI's eight international offices in Europe, Asia, Australia, and South America. In addition, 16 employees of international member companies are located on-site in Palo Alto to help transfer relevant technologies back to their home countries. Ultimately, Baker aims to have technical specialists from EPRI located throughout the world to help deliver solutions tailored to a region's specific interests and needs. "We want to establish a value-added presence on each continent," he says.

Before being appointed to head EPRI International, Baker was program general manager of marketing for General Electric's Power Systems Energy Consulting Group. In that position, he was responsible for leading marketing and sales efforts for the GE systems integration business, designed to help utility and industrial customers take advantage of pending deregulation in the United States and of privatization efforts worldwide. Earlier, beginning in 1993, Baker was program general manager for marketing and business development in GE's Power Systems Engineering Department, where he was responsible for developing global strategies and for interfacing with GE's worldwide sales force.

"Don Baker's proven skills in developing global networks and alliances will be very valuable as EPRI continues to expand its international activities," says chief operating officer Ric Rudman, to whom Baker reports.

■ *For more information, contact Don Baker, (650) 855-2995.*

Evaporative Cooler Boosts Turbine Output

Spray cooler water pump at the Jeeralang station

Ecogen's Jeeralang power station in the Australian state of Victoria is the site of the first overseas application of EPRI-developed spray evaporative cooler technology for combustion turbine plants. There the technology is increasing plant output by as much as 10% during the peak summer demand. On hot, dry summer days, when industries and households switch on their air conditioners, the station can be brought up to its peak capacity of 465 MW within half an hour.

In EPRI's technology, air passing through the compressors is sprayed with a fine mist of demineralized water, which lowers the inlet temperature and increases mass flow through the turbine, thereby increasing power output. Each unit is equipped with up to 2500 fine-spray nozzles at the inlet air duct, resulting in efficient operation.

"Increased power during peak periods is imperative in many parts of the world," says Tony Armor, director of generation development in EPRI's Energy Conversion Division. "Our studies show that direct-spray evaporative cooling is very effective for low-cost capacity improvement."

First used at UtiliCorp Energy Group's Ralph Green station in Missouri, the technology increased the plant rating by 15.5%. The EPRI spray cooler is more efficient than conventional evaporative coolers, and it controls overspray particle size to prevent compressor damage.

"With EPRI's help, we identified ways to raise our plant capacity at a fraction of the cost of our alternatives: building a new plant or buying expensive power," says Mike Jonagan, superintendent of gas turbines for UtiliCorp. The utility estimates savings of more than $3 million through the year 2010.

The experience at UtiliCorp served as a useful basis for the recent deployment at Jeeralang. EPRI contractor Fern Engineering worked with local firms in Victoria to install the system. Graham Dowers, manager of the Jeeralang station, explains: "The upgrade was a combined effort. We capitalized on the research done at EPRI and then used local expertise to redesign the system for our operation. We launched the system in January, just as large industries here began to switch on their air conditioners."

EPRI project manager Robert Frischmuth comments, "Where combustion turbines are kept in a state of operational readiness for short-duration demand periods and where rising peak demand calls for additional power, the evaporative cooler approach is frequently the technology of choice."

The spray cooler is available for licensing by generating companies in search of ways to quickly increase peak generating capacity at combustion turbine plants. ■ *For more information, contact Robert Frischmuth, (650) 855-2579.*

EPRI and EGAT to Study Electricity Use in Thailand

The Electricity Generating Authority of Thailand (EGAT) has signed an agreement with EPRI to study electricity use in Thailand as part of that country's demand-side management efforts. The study, which will use equipment developed by EPRI, is being financed by the World Bank through the Global Environment Facility. The findings will enable EGAT to understand electricity usage patterns throughout the country and, as a result, to design programs to increase efficiency and thus reduce greenhouse gas emissions.

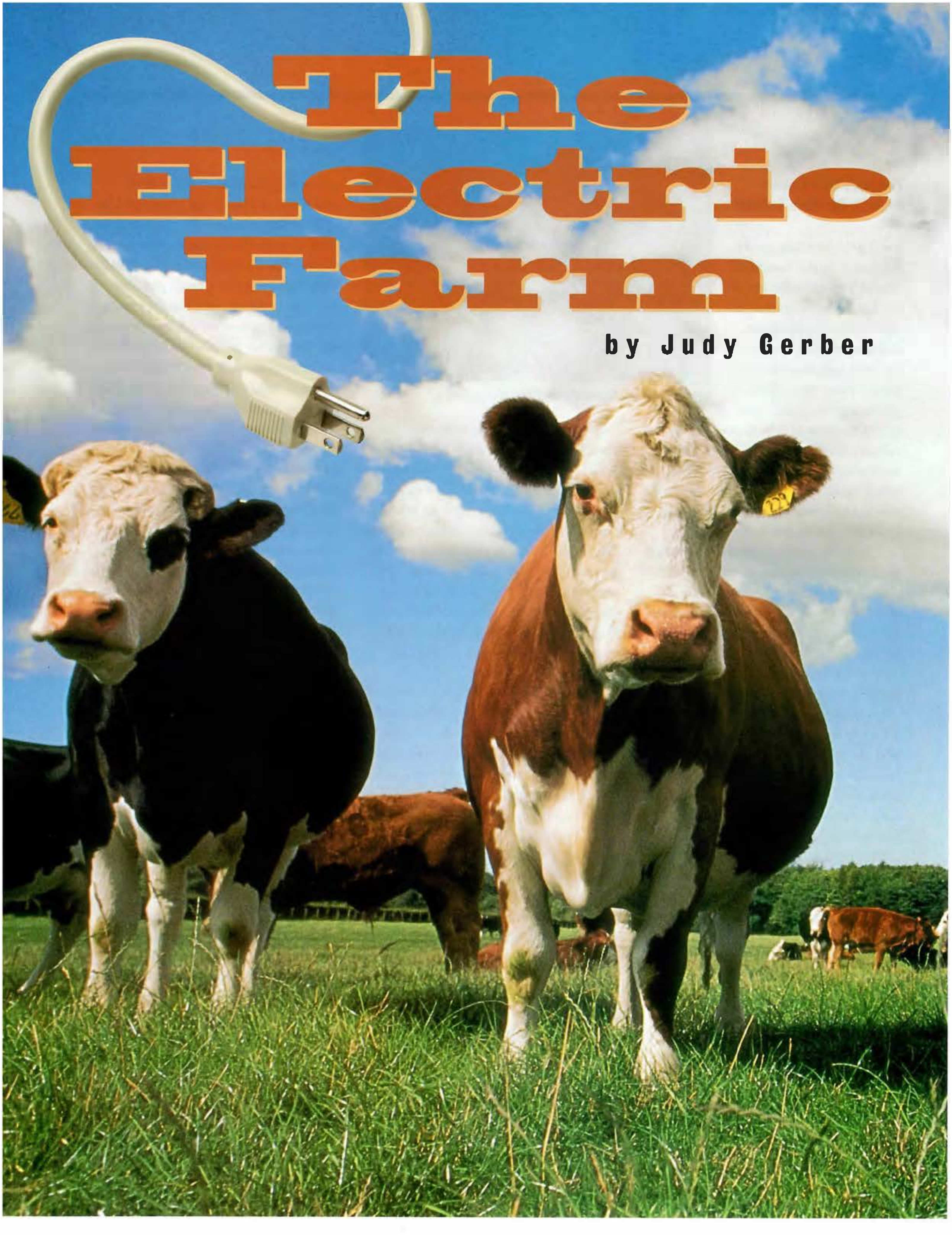
The project data will be collected by means of EPRI's patented NIALMS (Non-Intrusive Appliance Load-Monitoring System) technology, which features a small electronic data recorder that fits between a customer's watthour meter and the meter socket. This device determines the electricity being used by various appliances in a house and then transmits the information directly to the utility. With NIALMS, it is unnecessary for utility personnel to enter customers' homes to install equipment or to retrieve data. The system can identify power consumption patterns for an entire house or for an individual appliance without the need to meter each appliance separately.

Usage patterns will be studied in urban and rural environments, and monitoring will also extend to commercial settings. The resulting database on energy consumption will form a statistically representative foundation from which EGAT can both determine and forecast electricity demand, enabling the utility to evaluate existing energy efficiency programs as well as to design new ones.

Thailand leads Asia in embarking on such an extensive demand-side management program. With a national growth rate of 6%, EGAT is preparing to meet the increasing demand for electric power. Don Baker, vice president for EPRI International, comments, "We are pleased and honored to be strengthening our partnership with EGAT, and we look forward to demonstrating EPRI's state-of-the-art NIALMS technology in this first international application."

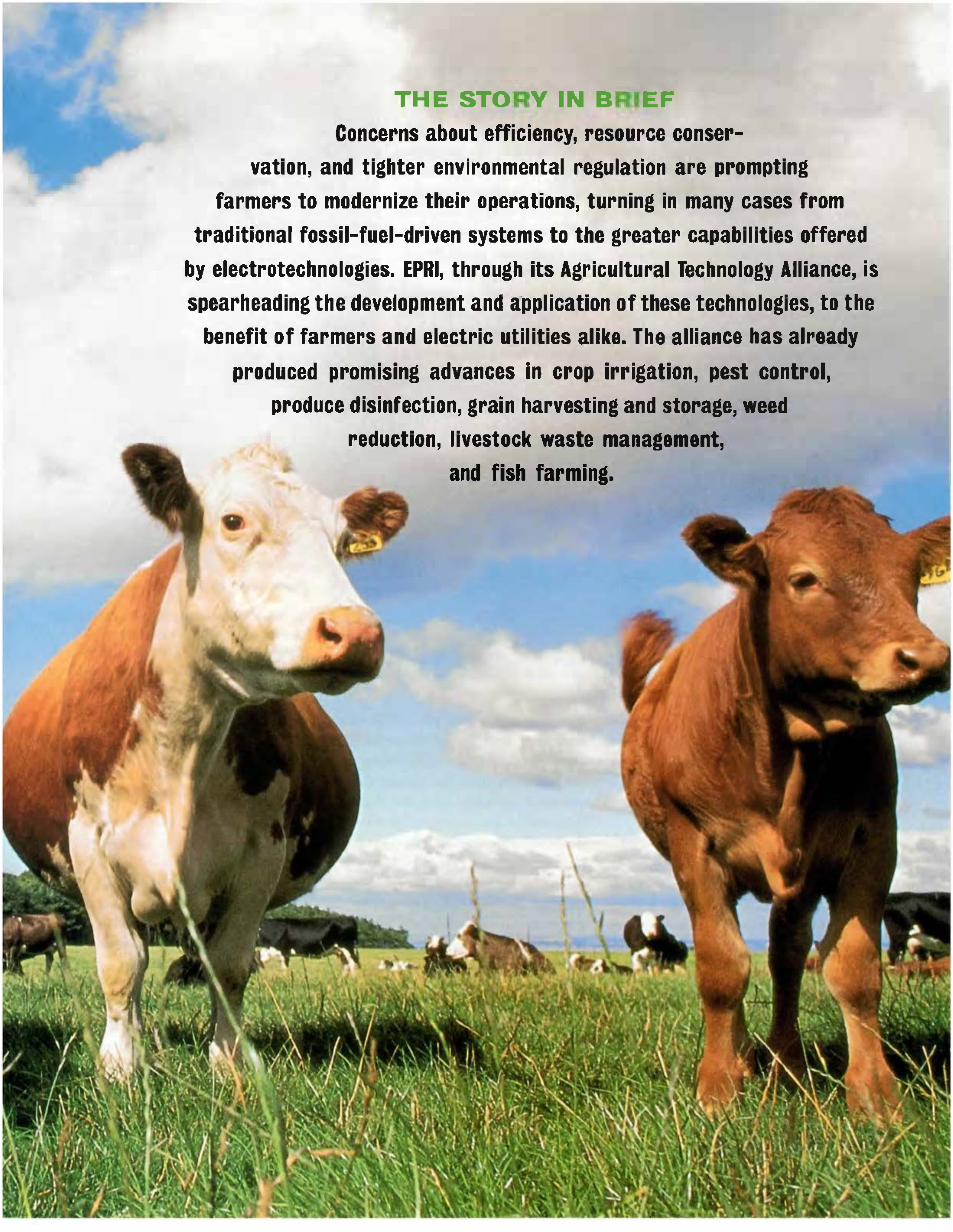
The Electric Farm

by Judy Gerber



THE STORY IN BRIEF

Concerns about efficiency, resource conservation, and tighter environmental regulation are prompting farmers to modernize their operations, turning in many cases from traditional fossil-fuel-driven systems to the greater capabilities offered by electrotechnologies. EPRI, through its Agricultural Technology Alliance, is spearheading the development and application of these technologies, to the benefit of farmers and electric utilities alike. The alliance has already produced promising advances in crop irrigation, pest control, produce disinfection, grain harvesting and storage, weed reduction, livestock waste management, and fish farming.



Food has captured its share of headlines in recent years. Reports of *E. coli* contamination in beef, strawberries, and raspberries have raised questions about the safety of fresh and processed foods in the United States. Key farm chemicals in use for decades, like methyl bromide, have come under scrutiny or been banned outright. Stricter enforcement of the Clean Air and Clean Water Acts is forcing livestock producers to install more-costly waste disposal systems. And the U.S. Food and Drug Administration (FDA) is currently soliciting public comments on its new definition of what constitutes organic produce.

Today's consumers are demanding an absolutely safe food supply. Responding to recent cases of food-borne illnesses, the Clinton administration requested an additional $71 million from Congress for food safety programs in 1999, and the president also proposed the banning of imported produce that does not meet U.S. inspection standards. Such measures are intended not only to protect individual American consumers but also to level the playing field for imported and domestic produce—an important issue, since the agriculture industry is responsible for a sixth of the U.S. gross national product.

In light of these developments, the agriculture industry is having to rethink its approaches to a number of farming operations, and farmers are increasingly looking to highly sophisticated electrotechnologies to solve new as well as old problems. Despite the importance of agricultural production to the nation, however, utilities have not fully recognized the sector's market potential. One reason is that farms are largely camouflaged in a utility's customer base. Because there are no SIC (standard industrial classification) codes for agriculture, it is difficult to track this load, and most farms purchase electricity at residential rather than business rates. In addition, largely because of the remote, spread-out nature of many agricultural operations, farmers have traditionally turned to fossil-fuel-fired energy options—including gasoline, propane, and diesel engines—rather than to electric motors, which are more efficient but require stringing three-phase power lines to far corners of the farm.

But times have changed. U.S. farming operations today bear little resemblance to the labor-intensive family farms of 50 or 100 years ago, which were tilled with a horse or a diesel tractor. Now, even small farms may gross over $100,000 in sales per year. Agriculture has become a major industrial operation, with the tilling of thousands of acres on a given farm and the factory-style production of livestock and poultry. The quaint perception of low-tech agriculture needs to catch up with modern realities, which include farmers who are computer literate, technically and commercially sophisticated, and interested in the efficiency and enhanced productivity offered by cutting-edge electrotechnologies.

To increase awareness of these realities and promote synergy between the agriculture and electric power industries, EPRI joined with some 40–50 member utilities and representatives of private, government, and nonprofit organizations to create the Agricultural Technology Alliance in 1994. The ATA's primary role is to facilitate its members' efforts to expand the use of electrotechnologies by their agricultural customers. To accomplish this goal, the ATA carries out research, development, and demonstration projects to enhance agricultural efficiency, reduce agricultural pollution, create new electricity markets, transfer technology from other industries, promote rural economic development, and shift loads from on-peak to off-peak hours. The ATA's market expansion work alone promises tremendous benefits for energy providers. The alliance has already identified electricity-based technologies that can substantially improve crop production, crop handling, livestock management, irrigation and pumping, and aquaculture

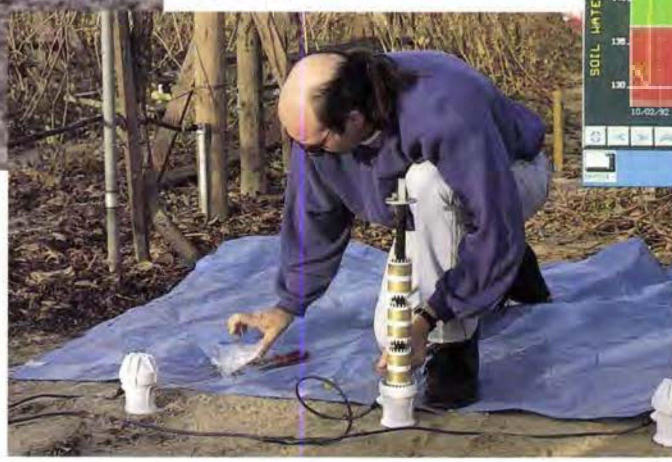
Peach trees with drip irrigation lines

Trunk diameter sensor

In crop irrigation research at the Agricultural Technology Application Center in Tulare, California, sophisticated sensors strapped to young peach trees measure daily changes in trunk diameter caused by water uptake. By correlating this information with data from soil moisture probes, researchers hope to develop a highly automated irrigation system that would be triggered by the trunk sensors a full day before soil probes would indicate a need for water.

and other forms of controlled-environment agriculture.

An ATA study based on information provided by the U.S. Departments of Agriculture, Energy, and Commerce indicates that there is a large potential customer base for these technologies. Currently, 45 states have 20,000–40,000 farming operations each, accounting for about 3% of the nation's electric power use. The study estimates that over the next five years, 80% of all new electricity revenues in this market will come from new electrotechnologies like advanced electric motors (including the single-phase Written-Pole motor), electric tractors, the McLeod harvester, and aquaculture systems. According to the study, if only 1% of U.S. farms took full advantage of these electrotechnologies, U.S. utilities would earn over a billion dollars in additional revenues each year. Other electricity-based applications with considerable potential for increasing load include chilled aeration of stored commodities, postharvest chilling of produce, and the use of ozone for disinfection and fumigation.



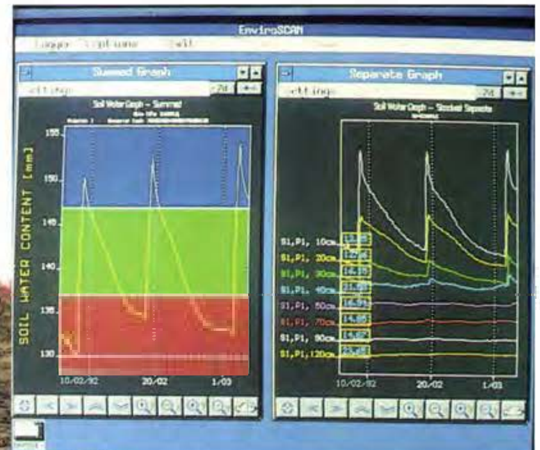
Soil moisture probe

After El Niño

Considering the El Niño–related rains that have inundated the western United States over the past several months, it's difficult to remember that water is a precious commodity there. But as the region's newspapers indicate periodically in screaming headlines about "water wars," water availability is a critical concern to the agriculture industry, with efficient irrigation practices a key to effective and economical production. And quantity is not the only concern. In California's San Joaquin Valley, as well as other parts of the country, carefully controlled irrigation is an absolute necessity for maintaining water quality. Government regulators are increasingly concerned about runoff, because of problems with microbial, nitrate, and herbicide and pesticide contamination of the water supply.

Scientists from the University of California at Davis and from Southern California Edison (SCE), in conjunction with the ATA, have launched a series of research projects bringing together the most advanced methods of irrigation with a refined understanding of when crops actually need water. The researchers are using trees and vines planted last fall at the SCE-EPRI Agricultural Technology Application Center (AgTAC) in Tulare, California, to study these processes.

When to water crops used to be a simple decision. If the soil was not wet enough to the touch or if the plants looked wilted, it was time to water. In the late 1950s, farmers used instruments inserted in the soil to measure moisture content and relied on weather forecasts and air measurements to estimate plant evaporation rates. More recently, scientists have developed ways to measure actual transpiration—the passage of water vapor through a leaf's surface membrane. A new study indicates that the diameter of a tree trunk or a vine's stem changes with moisture. The Tulare



Moisture probe data

project is studying ways to correlate all these factors, using sensors strapped to tree trunks. Eventually, such sensors could signal global satellites that would automatically turn on computer-controlled irrigation systems 24 hours before soil moisture levels or plant stress would indicate a need for water.

But maximizing crop production does not necessarily mean watering to avoid stress on a plant. Botanists at UC Davis have found that maximizing yield could involve stressing a plant early in its growth cycle. They have determined that some wines are better, for example, if water is withheld at certain times to shock the grapevines. Fruit trees can be stressed early in the growing season to increase flower buds the next year. The UC Davis project will help determine which watering schedule works best for which crops. Precise, computerized irrigation schedules will be critical to the successful implementation of these methods, since too much stress could kill the trees or vines.

PHOTOS BY: DAVID A. GOLDHAMER

A project at California State University at Fresno will determine how best to deliver water to a crop through a subsurface drip irrigation (SDI) system. Traditional flood irrigation spreads water all over the cultivated land, while conventional drip irrigation delivers small quantities of water slowly and frequently to each plant at the soil's surface. SDI, in contrast, uses buried lines to deliver water directly to a plant's roots.

Water lines are buried at root level in research on subsurface drip irrigation (SDI) at California State University at Fresno. Computer-controlled SDI systems with electric pumps are expected to use 25–50% less water than conventional irrigation approaches.

SDI is a computer-controlled, automated technology featuring electric pumps, which are more reliable for providing precise, stable water flow than are pumps driven by combustion engines. In experiments in the Midwest, SDI with electric pumps used 25–50% less water than surface or sprinkler irrigation, since evaporation, runoff, and drainage losses were greatly reduced. Just as water use goes down with more carefully timed and placed irrigation, systemic pesticide and fertilizer use can also be greatly reduced by this type of root-delivery system.

The demise of methyl bromide

In the United States, methyl bromide has long been considered the most effective broad-spectrum biocide available to control pathogens and insects in soil and storage facilities. But farmers will soon need to have new control methods in place. The Clean Air Act defines methyl bromide as an ozone-depleting chemical, and the government has mandated that its production cease as of January 1, 2001. As a result, the ATA is developing energy-efficient, cost-effective alternatives to methyl bromide.

At the AgTAC facility in Tulare, UC investigators and other scientists are using tomato and carrot plants to study the effects of injecting electrically generated ozone gas into soil as a preplanting treatment to control fungal and bacterial attack at the root level. They are also looking at how ozone can improve crop yield and reduce fertilizer use. EPRI project manager Gary Obenhof says that data from earlier studies elsewhere look good, and he expects further cultivation to show conclusive benefits.

Other researchers are looking at the feasibility of using ozone instead of methyl bromide to disinfect harvested fruit. Ozone has a long history of effectiveness as a disinfectant, having been used for decades in Europe to disinfect water supplies. In the United States, the FDA accepted ozone as a GRAS (generally recognized as safe) substance for disinfecting bottled water in 1982. EPRI sponsored the affirmation of GRAS status for ozone in food applications, which was accepted without comment by the FDA in 1997. Some regulatory hurdles remain before ozone is approved for use as a disinfectant on agricultural crops, but SCE scientists are already testing its effectiveness on citrus fruit, berries, and vegetables in expectation of regulatory approval.

Also under investigation is ozone's potential to control molds and insects in grain storage facilities that currently use methyl bromide. Final results are a few years away, but there are other electricity-driven options that have already proved effective for such storage applications: chilling and refrigeration technology, for example. Chemicals have been the method of choice in this country because methyl bromide has been less expensive than the electric power required for chilling. In Europe, South America, and some parts of Asia and the Middle East, however, storage facilities already use chilled aeration to store over a billion bushels of grain every year. ATA research indicates that, with the banning of methyl bromide and the advances being made in single-phase motors (discussed below), chilling will become a cost-effective choice for storage facilities here.

In chilled aeration technology, insect infestations in grain storage silos are eliminated without methyl bromide or other pesticides by blowing cold air through a silo at a temperature at which most insects will neither thrive nor reproduce—around 50–55°F. Because grain is an excellent insulator, only two treatments are needed, even in summer, and the portable chiller unit can be rotated among silos on a number of farms.

The current U.S. fumigation method for stored grain is both inefficient and wasteful, often requiring multiple applications of methyl bromide. After the grain is dried and fumigated, air at ambient temperature is blown through the bins to clear out the gas. In a warm climate, that air tends to heat the grain, allowing a reinfestation of insects, and the whole treatment cycle then has to be repeated. In warm, dry climates, ambient aeration also shrinks the size of the grain by removing moisture.

Chilled aeration can provide a safer, more economical process, particularly for high-value food grains like popcorn, rice, wheat, white corn, and other food staples. Most insects living in grains do not reproduce at temperatures below 55°F, and their growth rate drops exponentially for every degree from that temperature down to 50°F. Since grain is an excellent insulator, the crop remains at a low temperature once it is cooled; only the outer layers need to be recooled. In fact, at a depth of 4 feet into the grain container, temperatures vary by only a couple of degrees a year. Even in hot summer months, storage bins need only two chilling treatments before cooler fall temperatures set in; this is true even for bins holding 45,000 bushels of grain. Moreover, because the operator can control the amount of humidity in the air blown through the bin, grain shrinkage is reduced with chilled aeration.

DIRK E. MAIER/PURDUE UNIVERSITY

Purdue University scientists ran summer wheat-chilling trials to test the process. They found that it cost 0.5¢ to 1.0¢ per bushel to keep grain chilled at 50–55°F. The resulting savings from reduced shrinkage were 2.5¢ per bushel.

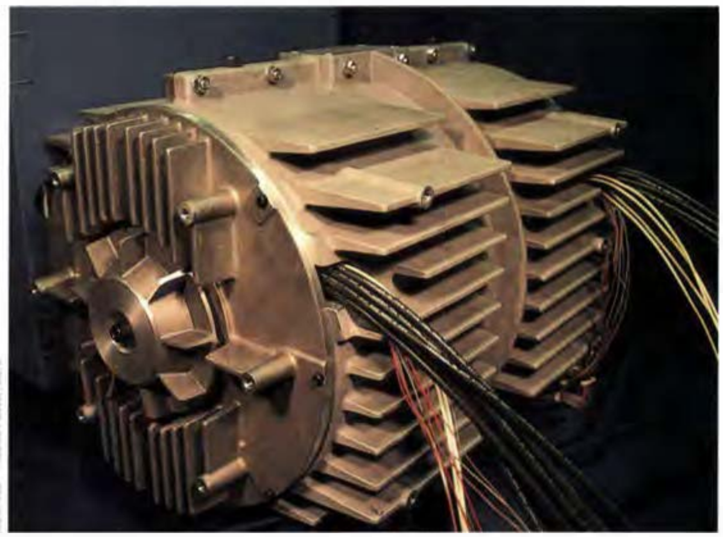
Grain chillers are already commercially available from one U.S. manufacturer—AAG Manufacturing of Milwaukee—and at least six European companies. The chillers are portable units, allowing a facility to invest in one chiller that can be rotated among a number of bins. Small facilities can even lease the units.

More capabilities from motors

Improvements in electric motors promise higher efficiencies and cost savings as well. The EPRI-developed Written-Pole motor, in particular, has the potential to overcome the most significant hurdle for electricity use in agriculture—the need to power large machinery.

Since they are located in rural areas, most farms have only single-phase electricity service. And single-phase power, while appropriate for modest needs like lighting, is not practical for running large motors and other high-power devices without the addition of costly phase converters. Bringing regular three-phase power to a new location can cost up to $30,000 per mile, essentially prohibitive for farmers and electric utilities. For this reason, farmers have relied primarily on diesel- and propane-driven engines, which are usually more expensive, less efficient, noisier, and less reliable than electric motors. They are also much more difficult to control remotely.

The Written-Pole motor, a large-horsepower motor designed to run on single-phase power, solves these problems. Its innovative design allows it to be activated with a much lower starting current than ordinary motors can be, so it can drive loads of up to 60 hp without straining single-phase distribution systems. The motor's low torque and starting current mean that it takes a relatively long time to come up to speed—1 to 5 minutes rather than seconds—but slow starts are not a problem for most agricultural equipment, including irrigation pumps and cooling fans. In fact, the leisurely startup can extend pump life by avoiding the water hammer effect common in irrigation and other pumping applications. The Written-Pole motor is rated at 94% efficiency; diesel engines, by comparison, are usually about 35–40% efficient.



COURTESY PRECISE POWER CORP.

The Written-Pole motor, developed by EPRI and Precise Power, opens up a tremendous range of electrotechnology applications in agriculture because it can run large machinery on the single-phase power typically provided to rural areas.

The Written-Pole motor's higher efficiency can translate into substantial savings for farmers and other users. For example, Precise Power Corporation, the motor's manufacturer, estimates that operating a 40-hp irrigation pump 2000 hours a year will cost over $1000 more with a three-phase motor and rotary phase converter than with a Written-Pole motor. An engine-driven pump would cost a whopping $10,000 more a year to operate, assuming fuel costs of $1.25 per gallon. Precise Power's claims have been verified by independent tests funded by EPRI and the National Rural Electric Cooperative Association at the University of Missouri. Clearly, the initial capital outlay of $300 per horsepower for a Written-Pole motor would be easily returned in savings on operating costs over the motor's estimated 25-year life.

The McLeod harvester

This past fall, inventor Bob McLeod took his prototype McLeod harvester out to the Ruttledge family farm in Manitoba, Canada, to harvest 300 acres of grain. In the process, he demonstrated a new electrotechnology that produces a cleaner grain product, reduces the need for herbicides, and helps feed resident livestock as well. Traditionally, farmers drive a combine through their fields that cuts the crop, separates the grain from the straw, and then spits the straw, chaff, and weed seeds out the back in a secondary process. In the next growing season, the weed seeds produce more weeds that must be destroyed through herbicide applications.

The McLeod harvester, which consists of a mobile unit and a stationary mill, eliminates most of the waste and improves the efficiency of harvesting. Pulled and powered by a tractor, the mobile unit cuts and threshes the crop just like a combine, then separates the straw from the grain, chaff, and weed seeds. Instead of spitting the weed seeds and the chaff back out into the field, however, the unit keeps it mixed with the grain (in a mixture McLeod calls graff) and carries it back to the stationary mill, located near the farm's storage bins. The mill, which is powered by a Written-Pole motor, automatically separates good grain from "savings" made up of chaff, weed seeds, and smaller grain kernels. The savings are then crushed and used for livestock feed without further processing.

McLeod says the new equipment has many advantages over a combine. First, he expects to be able to sell it for around $105,000. Current estimates are for the mobile field unit to sell for $50,000 to $55,000, and the cleaning mill, $50,000. A combine costs well over that amount, typically $150,000. Second, making productive use of the chaff mix reduces expenditures on livestock feed; the mix has an annual feed value of about $14 per acre. Third, McLeod's mill does a better job of processing, and the cleaner grain results in an estimated reduction of $1 per acre in the dockage fee the farmer pays for shipping and storage. The McLeod harvester makes good environmental sense as well. A farmer spends about $15 per acre on herbicide for a typical grain farm. Because the harvester leaves far fewer weed seeds in the field, there is significantly less need for herbicide. Farmers currently collecting weed seeds by other methods need only a quarter of the herbicide their neighbors use.

Grain and cattle farmer Garth Ruttledge says that the technology makes lots of sense. So did the

Livestock feed by-product

PHOTOS COURTESY BOB MCLEOD

Mobile field unit under construction

The McLeod harvester, an innovative two-part harvesting system, produces a cleaner grain product than conventional combines while reducing grain loss and the need for herbicides in subsequent planting cycles. The harvester's mobile field unit cuts and threshes wheat like a combine, but instead of discarding the chaff and weed seeds in the field, it retains these components with the grain. This mixture, called graff, is then processed by a stationary electric mill unit (powered by a Written-Pole motor), which cleans the grain and produces a high-value livestock feed from the crop residue formerly left in the field. The cost of the two-part harvester is less than that of a combine.

Stationary cleaning mill

PHOTOS COURTESY UNIVERSITY OF CALIFORNIA AT DAVIS

Wastewater pool with aerator

Large particles of manure flushed from livestock barns with water can be screened out physically by using a filter. In a relatively expensive second stage, the remaining effluent is sent to an aerated waste water pool where the smaller particles are treated in a bacterial process. Researchers at the University of California at Davis are experimenting with the use of chemicals like aluminum sulfate to coagulate the fine particles so that more of the solids can be removed in the filtering stage.

neighbors who came to his farm to watch McLeod test the harvester on a wide variety of crops—300 acres of spring wheat, barley, oats, rye, canola, and flax. The demonstration opened Ruttledge's eyes to the possibilities for electric power on his farm. He says that the combination of an electric motor with the McLeod harvester has "a potential that's really impressive," and he's already figured out that electricity would be much cheaper than diesel fuel on his 2500-plus acres.

Initial data show the mill costs \$0.75–\$1.00 per hour to run on a 20-hp Written-Pole motor. McLeod says there are other advantages to powering his mill with electricity. An electric motor lends itself to automation because it is so reliable and requires less supervision and maintenance than combustion engines. And the more automatic the operation, the more time available to the farmer to tend the crops.

Living with livestock

The industrialization of agriculture has brought changes that go far beyond the creation of larger, more efficient farms. Much like factory assembly lines, industrial farms tend to specialize in a particular product. In the world of livestock, that means raising tens of thousands of cattle, pigs or poultry in a relatively small space. But no matter how streamlined the operation, livestock are living creatures that produce enormous amounts of waste. In California, the leading dairy production state, cows create the waste equivalent of a city with 21 million people—and no sewage treatment plant. Since organic matter can be productively returned to the soil, animal lots are typically hosed down and the manure slurry collected to spread on adjacent fields. In small doses, that method works well. But in today's world of huge dairies and swine farms, water and air quality issues as well as public health concerns are driving the passage of regulations aimed at controlling livestock waste disposal.

In January of this year, the *New York Times* ran a front-page series about how the Centers for Disease Control traced *E. coli* bacteria on lettuce to contamination from cow manure on a California farm. And *E. coli* is not the only problem coming from livestock farms. According to the California Water Quality Control Board, too much waste runs off into groundwater and creeks, endangering California's most precious resource—water. When the land is overloaded with manure, nitrate and phosphorus leach into the water (see accompanying story, page 18). Ammonia and other volatile compounds escape into the air, creating a foul odor that is a nuisance to neighbors and reduces property values. The challenge to scientists and utilities is to come up with efficient ways to dispose of manure without hurting the environment or contaminating fresh food. Until now, the process has been expensive, but EPRI and SCE are sponsoring a demonstration project that may solve the problem with a relatively low cost system.

After farmers flush away solid waste in the farmyard with water, they have to separate the solid and liquid wastes—usually by screening out the solids with a filter. The filtered effluent is then subjected to an aeration process that promotes biological beneficiation of the waste. In the aeration process, air is introduced into the liquid waste fraction to enhance the growth of heterotrophic bacteria. The bacteria oxidize the fine manure particles to nitrate and nitrite, and sulfur compounds are reduced to elemental sulfur instead of to smelly sulfide. The more solids, the more oxygen it takes to support the waste-processing bacteria and the more expensive the treatment.

Unfortunately, in today's systems a large percentage of small solids pass through the filter in the first stage and remain in the water. Ruihong Zhang, assistant professor at UC Davis, says the key to reducing the cost of effective manure treatment is to reduce the amount of solid material in the water before it goes to the aeration stage. She is experimenting with chemicals—including aluminum sulfate, which is already found in soil—that can help coagulate the solids in the waste to make for more efficient separation. With much less solid material to process, the aeration step is expected to become more economical, largely because of decreases in compressor power consumption. The UC Davis and

SCE researchers plan demonstration tests in the field this year.

Halfway across the country at the University of Minnesota, researchers are looking specifically at livestock air pollution control. The federal government has established stringent new regulations to control odors from food processing operations—regulations that even make it an offense for bakeries to give off the aroma of fresh-baked bread. As urban areas expand outward into traditional farmlands and mechanized farming creates more of a factory environment, more complaints are being raised about offensive odors emanating from animal refuse.

Last fall, in a project principally funded by Northern States Power, University of Minnesota scientists worked with the ATA to test a pulsed-power process for odor control on a swine farm. Hogs are typically housed in a barn fitted with fans that draw air out of the confined space and disperse it outside the barn. In the process under investigation, a tubular reactor unit added to the airflow channel converts malodorous gases into more-acceptable chemicals. Basically, the reactor generates pulsed electricity, similar to small lightning strikes, in the tubes through which the barn air is blown. The electrical discharge produces highly reactive ions—charged particles that can destroy odor-bearing compounds like ammonia. The resulting volatile organic compounds, which can't be detected by smell, are then dispersed into the ambient air. After a three-week test on the hog farm, the project's leaders are optimistic about the reactor.

Principal investigator Roger Ruan sees potential in the technology, and not just for ammonia conversion. The chemicals generated by the reactor depend on what is in the air that passes through it, so the process has the flexibility to treat a wide variety of odor problems. The researchers are continuing to refine the process, and they plan to run more field demonstrations this year; the next one will take place on a potato farm.

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COURTESY UNIVERSITY OF MINNESOTA

Prototype pulsed-discharge reactor

Last fall, University of Minnesota scientists successfully tested a prototype odor control reactor on air drawn from a hog barn. The reactor unit's pulsed electricity—similar to small lightning strikes—creates highly reactive ions that destroy odor-bearing compounds like ammonia.

Farmers and fish

Other ATA researchers are refining the use of electricity-based technologies in controlled-environment operations—for example, greenhouse hydroponics and aquaculture, both of which present lucrative sideline opportunities for farmers. Aquaculture, also known as fish farming, shows particular promise, and EPRI has supported the development of several demonstration projects over the past three years to provide assistance to this growing electricity market.

Currently, no standard aquaculture system designs exist, and each operation is one of a kind. In the fall of 1997, however, the ATA put out a call for proposals to develop off-the-shelf designs, and three utilities were quick to sign up. In these projects, engineers are working with the utilities and commercial aquaculture operations in their service territories to develop off-the-shelf capabilities that will make fish farming more efficient and less risky.

In the first project, the North Carolina Fish Barn study, a research team from North Carolina State University and Carolina Power & Light is developing and testing a modular fish-farming system design that can be adapted to any environment in the United States. Alex Hobbs, a project engineer in CP&L's Concept Development section, describes such a system as an excellent opportunity for many farmers looking for other income to supplement their current farming operations. The automated system, which can be installed on a relatively small piece of land, includes instrumentation that monitors fish growth and signals the farmer (through a pager on the farmer's belt) if something needs attention. The result is a decent return on the investment with a limited amount of labor. In an earlier aquaculture scoping study, EPRI determined that it takes a minimum of 100,000 pounds of fish per year to reach profitability. At that scale, the Fish

Aquaculture, or fish farming, can be a lucrative side business for land farmers. The ATA is working with several utilities and aquaculture companies to develop standardized, automated designs that will make fish farms easier to build and run.

PHOTOS BY JIM SANCHEZ/THE ITHACA JOURNAL

Raising tilapia fry at Cayuga AquaFarms

Barn system could produce fish for $1.30 a pound and sell it on the current live market at $1.70 a pound. "After installation," Hobbs adds, "the operator needs to expend only a couple of hours each morning and afternoon in actual labor."

Cayuga AquaFarms, working with New York State Electric & Gas in upstate New York, has a commercial operation designed for the production of a half-million pounds of tilapia annually. This year, the farm is scheduled to produce 300,000 pounds of fish while the staff makes adjustments to the system, which includes a fish hatchery. Cayuga AquaFarms expects to be running at full capacity within 18 months.

In a third project, Great Bay Aquaculture and Public Service Company of New Hampshire have been testing equipment, primarily tank design and biological filters. They are completing a technical analysis of their system, which uses waste heat from a nearby power plant to warm water in the project's growing tanks. The present setup is expected to produce 300,000 pounds of summer flounder a year. The development team says their data will be applicable to any aquaculture system of comparable size, regardless of whether it is connected to a power plant. Great Bay Aquaculture plans to use these findings to build a 400,000-pound commercial fish farm this year.

The ATA is also involved with the regulatory side of aquaculture. The Department of Agriculture has been hesitant to recognize aquaculture as a form of agriculture. According to EPRI aquaculture consultant Jonne Berning, attitudes are slowly changing, and it will not be much longer before the agency gives full agricultural status to aquaculture. Once that happens, EPRI expects the industry to take off because projects will be eligible for federal grants.

By early 1999, EPRI staff members plan to have a practical manual available for utilities interested in promoting fish farming. The handbook will contain detailed information about the equipment needed, vendors, operational procedures, and disease control. A computer spreadsheet will be included to help utilities show their customers in a clear and simple way how they can apply the information to their particular needs.

Sharing opportunities and benefits

Agriculture is not the simple, straightforward business it was 50 years ago. As Myron Jones, EPRI project manager for the ATA, explains, "The farming industry these days is up against tremendous practical and institutional constraints in its quest to provide affordable, safe, and nutritious food to a health-conscious population while minimizing or controlling environmental impacts. Regulations are tough, but when it's a matter of public health, food safety, or water pollution, everyone has to comply."

From the fields to the processing plant, new technologies researched and refined by the ATA are providing solutions to agricultural concerns. Electric utilities have an important role to play in promoting these solutions, and electric power has enormous room for growth in agriculture. As Jones says, "Electrotechnologies clearly provide greater quality control, efficiency, and environmental compliance, and if they are aggressively and successfully marketed, they will definitely improve the farmer's bottom line." The ATA's goal is to make sure that this potential is realized, to the benefit of farmers and utilities alike. ■

Further reading

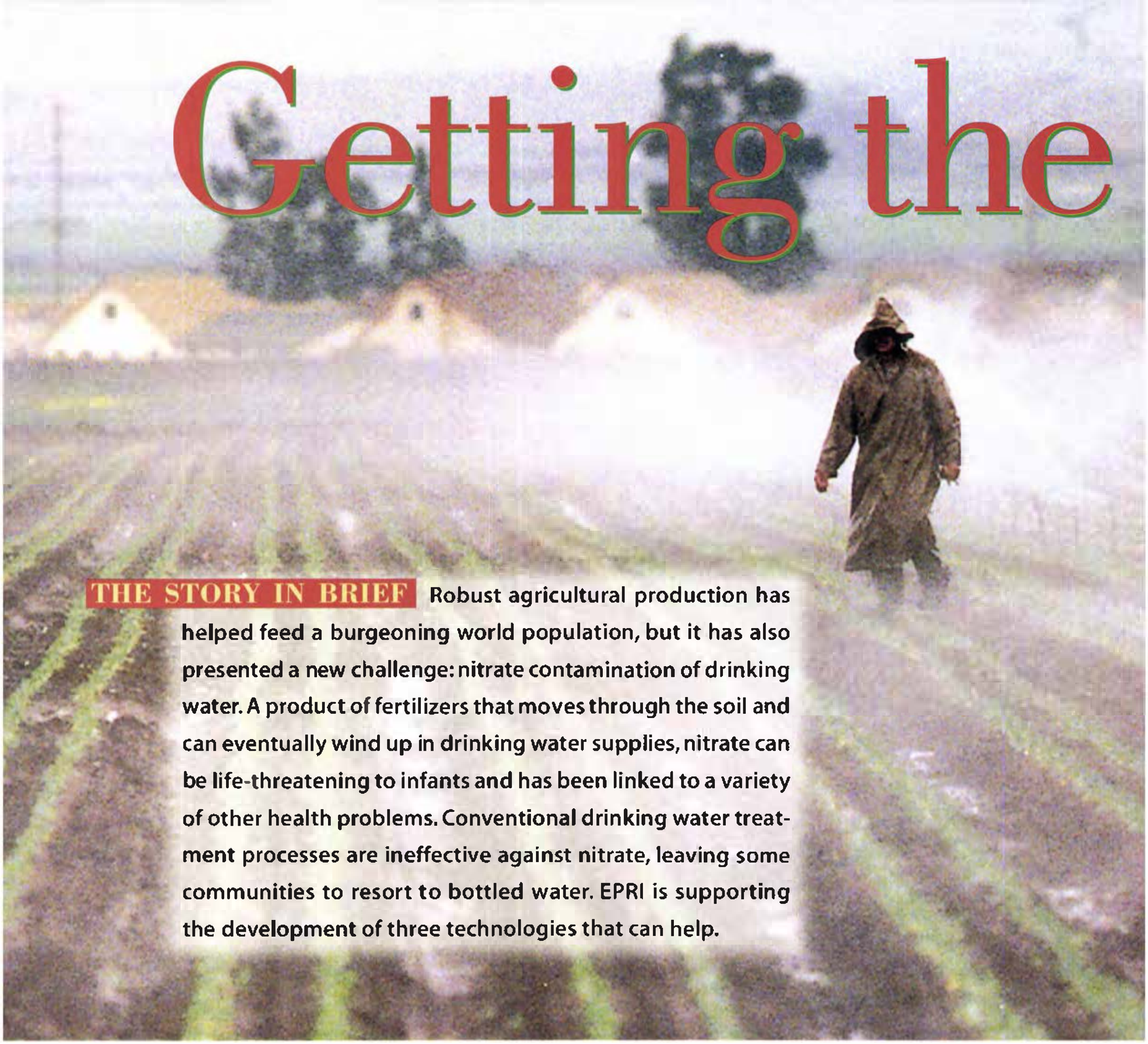
"A Fresh Look at Ozone." *EPRI Journal*, Vol. 22, No. 4 (July/August 1997), pp. 6–15.

"The Written-Pole Revolution." *EPRI Journal*, Vol. 22, No. 3 (May/June 1997), pp. 26–34.

"Fish Market Lures Utilities." *EPRI Journal*, Vol. 21, No. 4 (July/August 1996), pp. 16–23.

Background information for this article was provided by Myron Jones, Energy Delivery and Utilization Division.

Getting the



THE STORY IN BRIEF **Robust agricultural production has helped feed a burgeoning world population, but it has also presented a new challenge: nitrate contamination of drinking water. A product of fertilizers that moves through the soil and can eventually wind up in drinking water supplies, nitrate can be life-threatening to infants and has been linked to a variety of other health problems. Conventional drinking water treatment processes are ineffective against nitrate, leaving some communities to resort to bottled water. EPRI is supporting the development of three technologies that can help.**

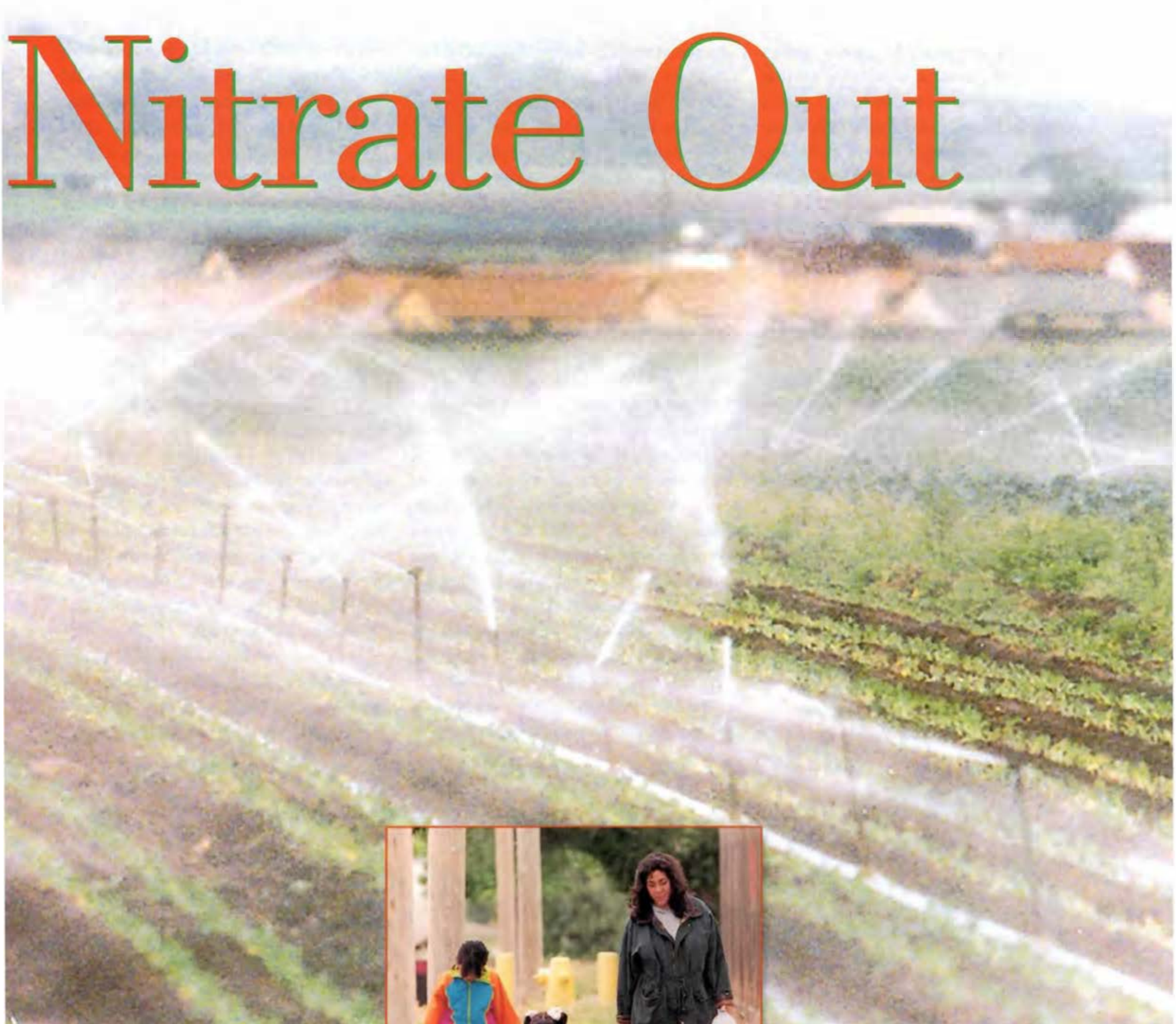
by Leslie Lamarre

Every year as spring approaches, parents of infants in the central Illinois city of Decatur line up to get free bottled water from their community. The practice isn't a goodwill gesture. It's required by the state's Environmental Protection Agency.

Like some 1100 other communities across the country, Decatur is grappling with the issue of nitrate contamination of its drinking water. A product of nitrogen-rich fertilizers and manure that accumulate on agricultural land, nitrate can seep into both underground drinking water sources like aquifers and surface sources like lakes and rivers. (Other, less significant sources of nitrate include septic tanks and wastewater treatment plants.) Nitrate-contaminated water presents a serious, potentially fatal health threat to children under 6 months old; studies have shown that infants who ingest it can develop methemoglobinemia, or blue baby disease, in which the blood's ability to carry oxygen is impaired. Less-conclusive studies have also linked nitrate to miscarriages and certain cancers.

Recognizing the problem in 1975, the U.S. Environmental Protection Agency began to limit the nitrate level in drinking water, specifying in the National Primary Drinking Water Regulations that it may not surpass 10 milligrams per liter of water. Individual states vary in their enforcement approach. In Illinois, the state EPA and Decatur officials agreed that once nitrate contamination climbs to 8.5 mg/L, the city must make bottled water available to residents at risk.

Nitrate Out



As agricultural production has increased tremendously to feed a burgeoning world population, the problem of nitrate contamination is growing rapidly not only in the United States but globally. It is of concern, for example, in many parts of Europe, Africa, the Middle East, and Australia. Although the issue is most common in rural areas, it also affects a number of urban communities that abut or incorporate farmland, including densely populated regions like the Los Angeles Basin.

In 1992, the U.S. EPA estimated that 4.5 million people in this country, including 66,000 at-risk infants, used drinking water from either community supplies or domestic wells exceeding the federal nitrate limit. In arid southern California, each year an estimated 4% of the region's domestic groundwater supply cannot be used for drinking water because of nitrate contamination.

Big or small, urban or rural—communities afflicted with nitrate contamination are scrambling to find a good solution. The difficulty is that nitrate compounds are very soluble chemicals and are not removed or destroyed by conventional drinking water treatment processes (such as filtration, disinfection, and coagulation and settling), which are aimed at eliminating bacteria and sediment. Thus the way communities most commonly deal with the nitrate problem is by dilution, mixing contaminated water with

PHOTOS BY CARLOS AVILA GONZALEZ/SAN FRANCISCO CHRONICLE higher-quality water. "At present, there's basically no nitrate removal method that is both effective and affordable," points out Keith Carns, director of EPRI's Community Environmental Center. That's why EPRI is supporting the development of three promising removal techniques, including a membrane-based technology now being tested in Decatur.

Seasonal problem

Seventy-six years ago, Decatur erected a dam to create Decatur Lake, which supplies 100% of the city's drinking water as well as water for the region's significant farming and grain processing industries. Over the decades, corn and soybean fields have expanded to cover more than 90% of the reservoir's 925 square miles of watershed.

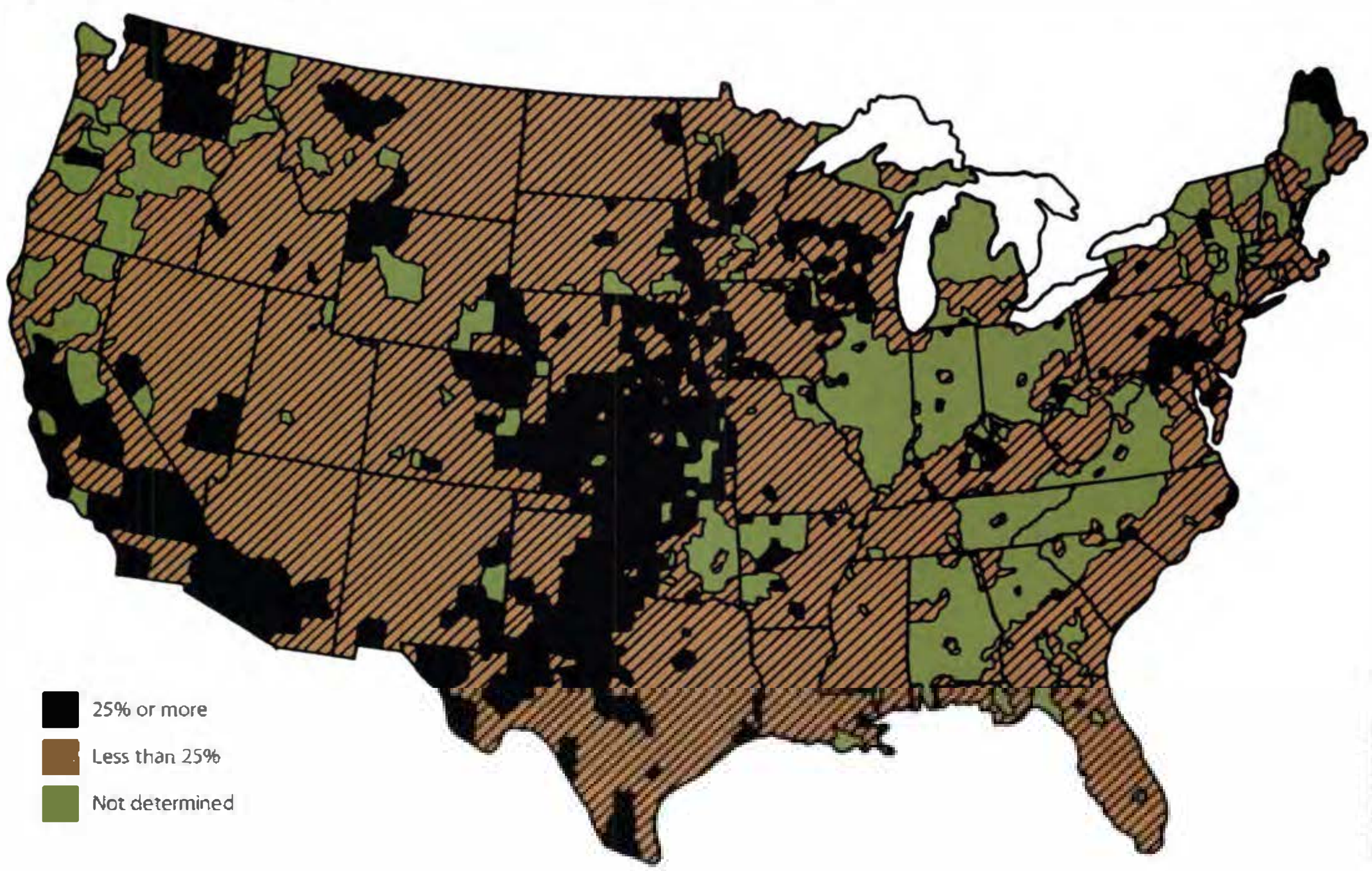
Every fall the region's farmers apply fertilizer to their fields, and every winter a good dousing of rain flushes the fertilizer through the soil and eventually into Decatur Lake. "Nitrate contamination has been a problem in our water for quite a number of years," says John A. Smith, Decatur's water production manager, noting that the level usually reaches 8.5 mg/L by March and doesn't subside until late June. "This year, due to El Niño, we've gotten a lot of rain and hit the 8.5 trigger level in January."

When nitrate contamination reaches the trigger level, Smith notifies local physicians, hospitals, the county health department, and the media that eligible residents can pick up free bottled water at two locations in the city. Parents of infants up to six months old are eligible, as are pregnant women who have a note from their doctor. Each household is entitled to two 1-gallon jugs a week per child. According to Smith, Decatur handed out 4500 jugs in the fiscal year that ended on April 30 of this year.

Decatur's annual water distribution process should come to an end soon, however. In a 1992 letter of agreement with the Illinois EPA, the city said it would bring its drinking water into compliance with federal standards by April 15, 2001. As part of this effort, Decatur has teamed up with EPRI and others—Illinois Power (headquartered in the city), the Illinois Department of Natural Resources' Waste Management and Research Center, and the U.S. EPA's National Risk Management Research Laboratory in Cincinnati—to test a technology developed by researchers at the University of Illinois.

Based on reverse osmosis, the technology involves pumping water at high pressure through membranes made of a synthetic polymer so that the membranes physically filter out the targeted pollutants while allowing clean water to pass through. Electricity plays an important role, powering the pumps that generate the necessary water pressure and the backwash that prevents residues from accumulating and blocking the membranes.

Most commonly used in the United States for desalinating drinking water, reverse-osmosis membranes have also been used to remove such other contaminants as



Nitrate contamination of drinking water is a concern across the United States, as well as in virtually every other country around the world. This map, developed in 1984, shows the percentage of an area's water samples in which the nitrate concentration exceeded 3 mg/L. This concentration is a rough guide to the amount of nitrate that could be present naturally; the U.S. EPA regulatory limit for nitrate is 10 mg/L.

Cryptosporidium, *Giardia*, bacteria, and viruses. Since in the case of nitrate compounds, the contaminant is dissolved, the pores of the membranes used must be much smaller than those of membranes for removing other types of contaminants. In fact, the pores of nitrate-removing membranes are a millionth of a millimeter or less in diameter—so small that researchers have to use a very powerful microscope to see them.

CARLOS AVILA GONZALEZ/SAN FRANCISCO CHRONICLE

Residents of Chualar, California, get their drinking water from a tank truck when nitrate contamination reaches dangerous levels.

Researchers headed by Mark Clark at the University of Illinois began testing a pilot-scale membrane filtration system in Decatur last February. Clark says that the results so far are promising, with nitrate rejection rates in the range of 93–97%. Further testing will continue through the summer, and an economic analysis of the process will be performed. Final results should be available in the fall.

At this time, only one or two other membrane filtration systems in the country are being used for nitrate removal. One drawback to this approach is that it results in a relatively large amount of wastewater, equal to some 20% of the original water volume flowing into the system. Disposing of this contaminated water can present an entirely new challenge for communities that rely on the membrane technology. The University of Illinois researchers are exploring the possibility of reapplying this water to agricultural land as fertilizer.

Bugs and syrup

Another EPRI-sponsored technology for nitrate removal avoids the issue of waste by approaching the problem from an entirely different perspective—a biological one. Developed and patented by researchers at the University of Colorado at Boulder, this process involves the use of denitrifying bacteria.

Several species of these nonpathogenic bacteria naturally reside in small quantities in soil and water. Although such bacteria have been used to denitrify wastewater for 30 years, they have never been used in this country to clean up drinking water—until now.

In a demonstration project sponsored by EPRI, the National Rural Electric Cooperative Association, Morgan County Rural Electric Association, and Tri-State Generation and Transmission Association, the University of Colorado researchers have shown their process to be effective, reliable, and safe. Results from the yearlong demonstration, conducted in the farming community of Wiggins, Colorado, indicate that the technology consistently removed more than 85% of the incoming nitrate contaminant, which was augmented to 20 mg/L for testing purposes. The estimated cost is 50¢ per 1000 gallons—a cost considered affordable for small communities.

Located 75 miles northeast of Denver in Colorado's eastern plains, Wiggins (population 650) is a place where farming is a way of life. Dairy farms and crop farms producing corn and wheat are the basis of much of the community's economic activity. According to the town manager, John Holdren, nitrate levels have climbed as high as 7.8 mg/L in recent years. Holdren says the demonstration, which concluded last fall, indicates that the process is a possibility for Wiggins. But the community is awaiting final project data before making a decision on whether to implement the technology.

Here's how the process works. First, it is necessary to create an oxygen-depleted environment because, in such an environment, denitrifying bacteria can use nitrate as a source of oxygen. For the demonstration, the researchers packed two 10-foot-tall, 3-foot-diameter reactor towers with a highly porous packing material (polypropylene) for the bacteria to populate and then flooded it to minimize dissolved oxygen. In order to grow, the bacteria require a carbon source. In the case of wastewater treatment, the source is raw sewage, which is obviously not acceptable in drinking water. Instead, the researchers opted for food-grade corn syrup, a common sweetener in processed foods and a substance many people associate with homemade treats ranging from candied apples to pecan pie. As the bacteria grow, they convert nitrate from the contaminated water into nitrogen gas, which is released harmlessly into the atmosphere. After denitrification, the water trickles through a filter packed with polypropylene, which removes dissolved organic carbon and particulate matter from the water and adjusts its pH. Finally, the water flows through a sand bed to remove any residual bacteria and fine particles.

Because corn syrup is 40% carbon by weight and is already approved for human consumption, it is an ideal food source for the bacteria. Another advantage is that the water content of the syrup is very low, minimizing the possibility of contamination by other bacteria. Although corn syrup will crystallize at low temperatures, this problem can be easily prevented by using an inexpensive heater. Vinegars with high levels of acetic acid are another possible food source for the bacteria, but they are typically more expensive than corn syrup.

Data from the Wiggins demonstration enabled the town of Coyle, Oklahoma, to win state approval for the first commercial application of the technology. This system is being installed by Nitrate Removal Technologies of Golden, Colorado, which licensed the technology from the University

Pilot-scale membrane filtration system in Decatur, Illinois

Inside EPRI's ion-exchange trailer

EPRI is supporting the development of three very different approaches to removing nitrate from drinking water—one physical, one chemical, and one biological.

of Colorado. It is expected to be operational this summer.

JoAnn Silverstein, the lead researcher in the university's development work, points out that the system was designed specifically for use by small communities with limited economic resources. "The entire system can be maintained by a part-time operator with a basic level of technical training," she says.

It may seem odd that electric utilities would participate in a project that doesn't involve much electricity. But as Steve Lindenberg, administrator of the Cooperative Research Network at the National Rural Electric Cooperative Association, points out, there are other motives for sponsorship. "Clean water allows for economic development in rural areas," he says. "As these communities grow and prosper, their utilities benefit too."

Ion exchange

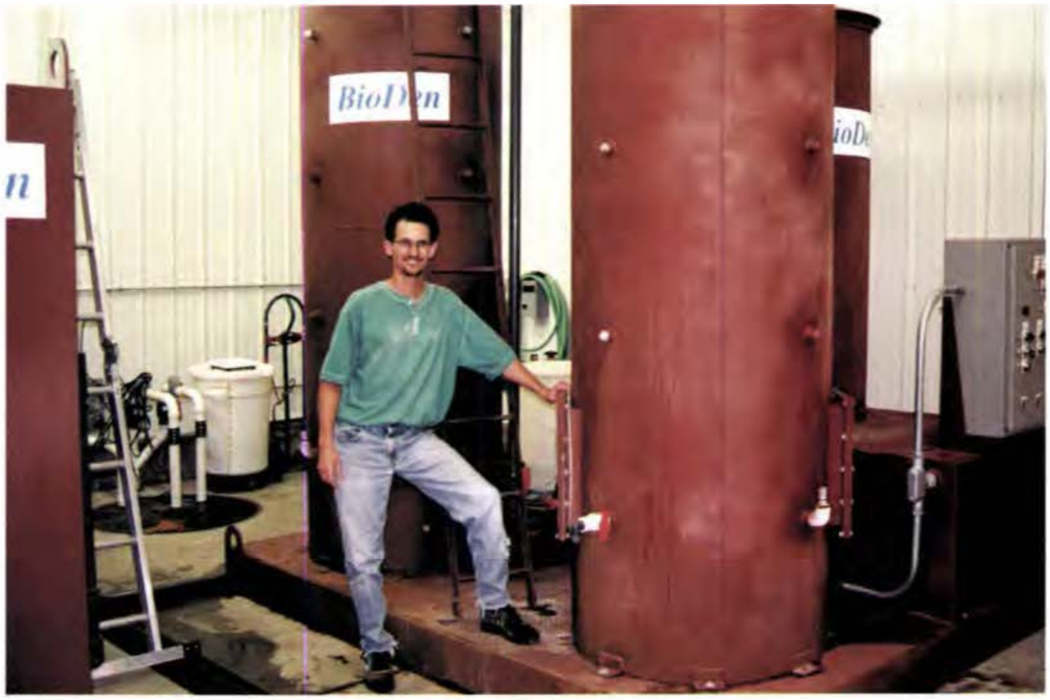
The only technology for nitrate removal that has advanced to the point of being used on a commercial scale by water utilities is the ion-exchange process. Long used in a variety of other water treatment applications—such as making ultrapure water, producing boiler feedwater, and removing heavy metals from industrial waste—the ion-exchange process involves a chemical reaction that removes the unwanted substance.

In nitrate removal, for which ion exchange is currently employed in some two dozen U.S. communities, the process uses an exchange bed made up of polystyrene pellets that are about the size of sand grains and have been treated with chloride or a similar substance. As the nitrate-laden water runs through this chloride resin, nitrate ions are exchanged for chloride ions, which are carried out in the water stream. Once the bed is saturated with nitrate, it must be flushed out for reuse. A chloride solution is run through the bed and picks up virtually all the remaining nitrate while regenerating the bed with chloride ions. The process results in a waste stream chock full of chloride and virtually all of the nitrate from the original water stream.

Although not considered hazardous, this waste stream typically represents about 3% of the original water input and can be costly to dispose of. In fact, the disposal issue has deterred some communities from using the ion-exchange method for nitrate removal. Research sponsored by EPRI and Southern California Edison is now developing an electrochemical process that promises to resolve the disposal problem.

In this new process, the waste stream from the ion-exchange unit passes through the cathode compartment of an electrochemical cell, where nitrate ions are reduced to ammonium ions. (The anode compartment, a necessary component of the electrochemical cell, generates oxygen, which can be harmlessly discharged into the atmosphere.) Since the ammonium ions in the resulting stream will not adhere to the exchange resin and since the chloride ions are several orders of magnitude more concentrated than the ammonium ions, the stream is still useful for nitrate removal and can be circulated back to the ion-exchange bed. In a variation of the process, the cell's anode compartment can be used to convert the ammonium in the circulating stream to nitrogen for release into the atmosphere.

"The advantage is that the water stream can be used many times over, with total nitrate removal reaching 99%," says Myron Jones, who oversees EPRI's ion-exchange research. And for large water utilities, it may make economic sense to further improve the process's efficiency by treating the resulting waste stream with caustic



COURTESY EDA INC

Biological denitrification demonstration system in Wiggins, Colorado

soda to remove ammonia. The ammonia can then be sold for fertilizer or some other application.

The researchers sponsored by EPRI and Southern California Edison have developed a demonstration-scale model of an ion-exchange system that incorporates the electrochemical process. The system is housed in a trailer that is scheduled to be delivered to Tulare, California, for a field test this summer. The system is designed to be flexible and is adaptable to a broad range of feed rates. Says Jones, "The process can be retrofitted to existing, full-scale nitrate removal systems."

Searching for solutions

As communities searching for the perfect solution to the nitrate contamination problem will discover, there are many factors to consider in deciding which technology to deploy. Carns of the Community Environmental Center, which is coordinating EPRI's nitrate removal research, notes that the size of a given water treatment system, the contaminants other than nitrate present in the water supply, the volume of water passing through the system, and economics will all play a role in the treatment decision.

Because the ion-exchange process has already been approved for denitrification by a number of state environmental regulatory agencies, it may be an attractive option for water utilities looking for a quick solution. But other factors may hinder its use in certain areas. For instance, some common groundwater constituents like dissolved iron can foul the exchange bed and interfere with the ion-exchange process. And disposing of the nitrate-laden wastewater resulting from the process can also pose a challenge for small communities with limited economic resources.

The membrane filtration process presents an even bigger disposal challenge. The waste stream is much larger than that resulting from ion exchange, and it contains not only nitrate but such other contaminants as sediment, bacteria, and possibly even pesticides. Although EPRI's economic analysis of the membrane approach has not been completed, the results are expected to show that it is more expensive than either the ion-exchange or the biological technique. Nevertheless, for communities aiming to eradicate a number of contaminants from their drinking water supplies, a membrane system might be the most attractive option. Another advantage is that such a system requires very little maintenance and can even be operated remotely.

With regard to waste, the biological solution is the most environmentally friendly of the three options at this time. And Carns believes that the economic comparisons under way might find it to be the most cost-effective as well. One drawback of the approach, however, is that the existing technology was developed specifically for small systems and was not designed to handle rapid flow rates. Although the biological concept could be applied to larger systems, the technology itself has not yet been scaled up.

As communities across the country deliberate on the nitrate removal issue, an increasing number of power companies are getting involved. "We see it as an opportunity to help the local water utility with an environmental problem," says Jim May, project coordinator for Illinois Power. "Water supply is a key issue in Decatur because we have a fairly large industrial base here whose facilities use water. And a good water source for them can also attract other businesses to our area." Besides, he says, "supporting a nitrate removal technology like this gives us a great opportunity to demonstrate one of the many positive roles electricity can play in a community." ■

Background information for this article was provided by Keith Carns and Myron Jones, Energy Delivery and Utilization Division.

Heating and Cooling

The Story in Brief Why pay for energy when there's a free stockpile of it right under your feet? With the help of a geothermal heat pump system, you can extract that energy from the ground and put it to good use, lowering heating and cooling costs. From private homes to public schools and fast-food restaurants, an increasing number of establishments are turning to geothermal heat pump systems for space conditioning. Experts say 1998 is already proving to be the best year yet for the technology, and they foresee an even more promising future. **by Leslie Lamarre**

The energy crisis of the mid-1970s dealt a harsh blow to St. Joseph's Indian School in Chamberlain, South Dakota. Heated with oil, this elementary school for disadvantaged Native Americans was sometimes left in the lurch when fuel trucks got snowbound or simply didn't show up on frigid winter mornings. Teachers resorted to wrapping their shivering students in blankets.

"The situation just brought tears to your eyes," recalls Richard Niess, a consulting engineer who worked for Westinghouse at the time. He had learned of the school's plight during a telephone conversation with a brother of the Jesuit order, which runs the school. The brother had called to inquire about a heat pump technology he thought might be able to extract warmth from the ground and use it to heat the school building. Niess confirmed that indeed his company had developed an electric heat pump that was being used in some industries to raise the temperature of hot water for cleaning and process purposes. And he didn't see any reason why the technology couldn't also be used to extract thermal energy from tepid underground water and use it to heat the school.

From the Ground Up

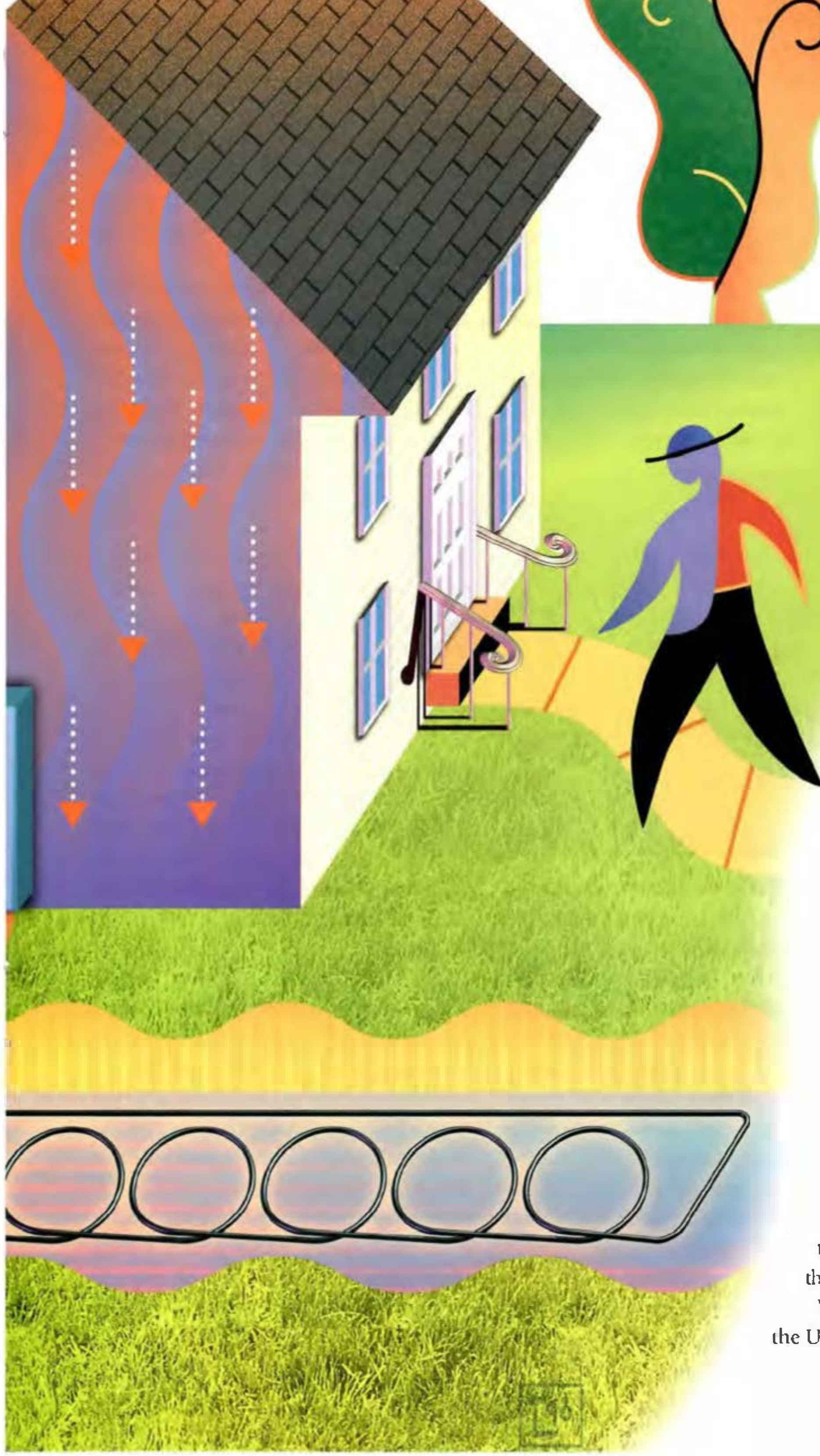


ILLUSTRATION BY BRYAN LEISTER

And so it was that, with some modifications to the technology, St. Joseph's Indian School became the proud owner of a geothermal heat pump system, which began operating in 1980. "Sure enough, it heated the school just fine, and the brother was the happiest camper you can imagine," says Niess. According to Harold Juhnke, the school's facility manager, the geothermal heat pump is still running strong. Operating it costs about half as much as heating with oil, he says, and it's a lot more reliable.

Geothermal heat pump systems (also called ground-source heat pumps or geoexchange systems) capitalize on a fundamental fact of nature: as little as 6 feet underground, the temperature remains stable year-round—generally about equal to the average annual air temperature of a region (typically somewhere between 40 and 70°F). By taking advantage of this free energy, a geothermal heat pump system reduces the amount of electricity required for space conditioning. The system has an underground piping network (technically called a ground loop) that serves as a heat exchanger. In the heating mode, thermal energy from the ground is transferred to a water mixture circulating in the loop. The mixture travels to the system's heat pump unit, which is quiet enough to be located inside the building. There, a compressor is used to raise the heat to a useful temperature. In the summer months, the process can be reversed, extracting heat from the building and dumping it into the ground to provide efficient cooling.

When geothermal heat pump technology emerged in the United States half a century ago, it was primarily a residential technology. Now there are hundreds of thousands of geothermal heat pumps across the country, operating not only in homes but also in schools, government buildings, office complexes, and a variety of commercial establishments. Interest in the technology is rising steadily, particularly in the commercial market segment, says Mukesh Khattar, who manages EPRI's research on systems for commercial applications.

This statement is supported by statistics from the GeoExchange Information Center, which is funded by EPRI, the U.S. Department of Energy, the U.S. Environmental Protection Agency, electric utilities, and the geothermal heat pump industry. The information center is part of the Geothermal Heat Pump Consortium, a nonprofit organization established to promote the technology. The center reports that installations have been numbering more than 50,000 annually and estimates that this figure may increase as much as 50% this year. "Interest is really shooting up right now," says Paul Liepe, executive director of the consortium.

PHOTOS COURTESY ST. JOSEPH'S INDIAN SCHOOL

Students at St. Joseph's Indian School in Chamberlain, South Dakota, enjoy a comfortable indoor environment even during the region's harsh winters, thanks to a geothermal heat pump system installed at the school in 1980.

Liepe recalls that three and a half years ago, when the consortium was founded, it received three or four inquiries a week. These days, the information center fields hundreds of inquiries daily from consumers, power companies, architects, the media, and others. "This is definitely the most interest we've seen," he says, noting that the enthusiasm was reflected in an excellent turnout at the National Association of Home Builders' annual conference in Dallas this January. "We had a traffic jam in front of our booth."

Contributing to the technology's burgeoning popularity are its environmental advantages, especially its energy efficiency. This efficiency was documented in a 1993 EPA study on residential space conditioning, which compared emerging ground-source heat pumps with other available options—including a system combining a standard gas furnace and a standard air conditioner and a system combining an advanced oil furnace and an efficient air conditioner. The study declared geothermal heat pump systems to be the most energy-efficient and cost-effective residential heating and cooling technology available. And experts believe that geothermal systems offer similar benefits in commercial applications. At a White House conference on climate change last fall, President Clinton praised the power companies involved in promoting geothermal heat pump technology, saying that their efforts will "reduce the threat of global warming."

James Bose, executive director of the International Ground Source Heat Pump Association (IGSHPA), based at Oklahoma State University, agrees with others who think that 1998 just might be the year for geothermal heat pumps: "For 20 years I've been saying the technology is just around the corner; now I believe it's here."

Down under

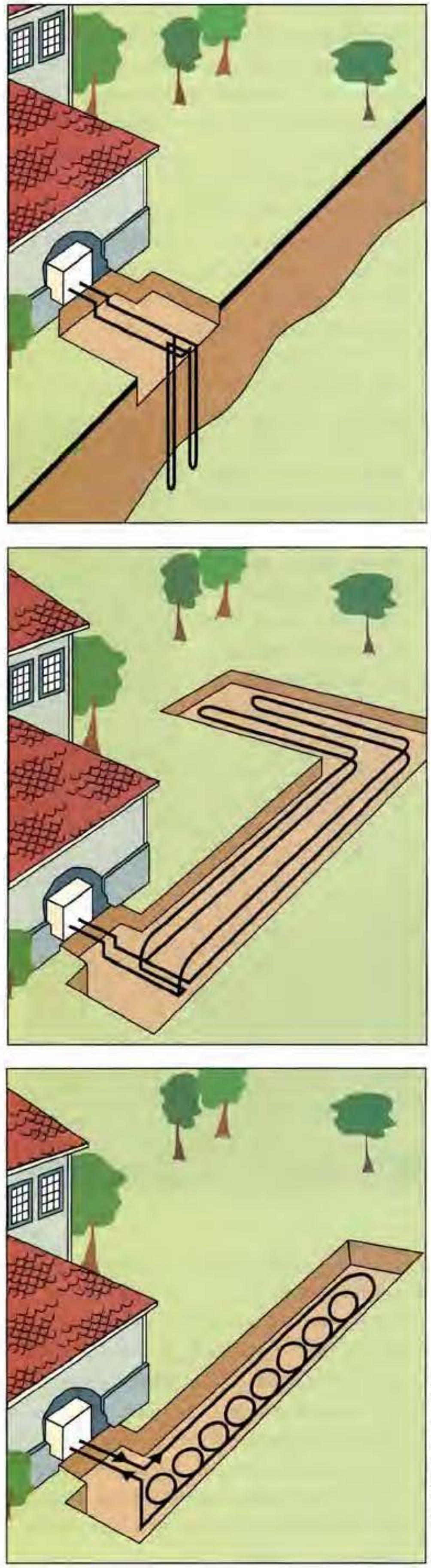
Like the earth in which they are placed, the ground loops of geothermal heat pump systems can vary dramatically. Generally, the configurations fall into two categories: open and closed loop. In an open-loop system, such as the one installed at St. Joseph's Indian School, the water tapped from an underground source travels through the system once and then is discharged (in some cases directly back into the aquifer). This design is more common in earlier installations and is now used mainly where water supplies are plentiful.

By contrast, closed-loop systems have an extensive underground piping network through which a water mixture circulates. Typically, this solution contains corrosion inhibitors to protect a system's metal components; in colder regions, antifreeze is added as well. The closed-loop configuration—in which hundreds of feet of piping snake through the ground—emerged as a practical option with the advent of high-density polyethylene pipes. These are far less expensive than copper pipes, and they don't experience the problems with corrosion that metal pipes do. Today, experts say, some 75% of new geothermal heat pump installations are of the closed-loop variety.

The ground loop of closed-loop systems can be installed in either a horizontal or a vertical position. In typical horizontal systems, two or more parallel pipes lie only about 6 feet below the earth's surface. Horizontal loops are usually cheaper to install because the earth can be dug with a backhoe or a trencher, whereas vertical installations require a well-drilling rig. On the other hand, horizontal loops need a much larger surface area than vertical ones, as well as soil that's malleable enough to be trenched.

One space-saving design for horizontal systems---a spiraling loop shaped something like a Slinky toy—was refined in the late 1980s by Oklahoma State University researchers, with funding from EPRI and the National Rural Electric Cooperative Association. Since it requires a much smaller excavation area, this design also saves on trenching costs. "It's a way of cost-effectively packing more heat exchanger into a given amount of trench," says EPRI's Carl Hiller, who oversees research on residential geothermal heat pumps and ground thermal properties. However, as Hiller notes, trenching is not always required for horizontal ground loops; if there is a pond or a lake on a given site, the loop can lie in the water rather than in the ground. This option is feasible only in water that maintains a depth of at least 6 feet, even during the driest months of the year.

Vertically oriented ground loops are the common preference for sites with limited space. In a vertical system, the parallel pipes stand upright underground in a series of U-bends. For these installations, well drillers bore down to a depth of 150 to 450 feet—and sometimes even deeper. A single hole is drilled to accommodate each U-bend. Vertical ground loops are common at commercial sites, which require a much bigger cooling capacity than do residential systems. As Hiller explains, "The cost of bringing a drilling rig out to make a couple of holes for a residential system can be prohibitive. But the same rig might drill hundreds of holes for a commercial project." The number of U-bend pipes and boreholes required for a vertical-loop system will be dictated not only by the desired cooling capacity but also by the depth of the holes—that is, the deeper the holes, the longer the J-bends and the fewer required for a given capacity.



The ground loop of a geothermal heat pump system varies according to a building's heating and cooling needs and the space available at the site. A vertically oriented ground loop is best for packing lots of cooling capacity into a limited space, while horizontal loops are favored where land is plentiful and heating and cooling needs are smaller. One space-saving horizontal design that features a spiraling loop was refined with funding from EPRI and the National Rural Electric Cooperative Association.

A relatively new development in ground-loop designs is the standing-column well. Such a system involves drilling a single borehole about 6 inches in diameter, into which a 2-inch-wide pipe is inserted. In one project on East 64th Street in Manhattan, for instance, drillers bored down 1500 feet into bedrock for the pipe. This approach offers a large cooling capacity for a very small amount of surface area. Another advantage is that in extremely cold or hot weather, water in the borehole can be pumped away so that it is displaced by fresh water from the ground, offering additional heating or cooling capacity.

Once the piping of a standard vertical system is installed, contractors close the air gap between the piping and the earth either by backfilling the space with soil or by injecting grout. EPRI has developed thermally enhanced versions of the two most popular grouts—one a bentonite-based formula and the other a cement-based formula. Now widely available, these two improved grouts have demonstrated thermal conductivity increases of as much as 100% over their conventional counterparts. As Hiller points out, however, the benefits of using thermally enhanced grout depend on the soil conditions at a given site; if the soil has a high thermal conductivity, such grout is very useful, but its benefits are reduced if the soil's thermal conductivity is low.

Hybrids

Even sites that don't lend themselves to full-fledged geothermal systems might still be able to take advantage of the technology. That was the case with a commercial project involving EPRI and Pennsylvania Power & Light (PP&L). Originally, the project called for a geothermal heat pump system that would meet the entire heating and cooling needs of a four-story office building to be constructed in Allentown, Pennsylvania.

The plan was to drill 55 holes, each 500 feet deep, for a total borehole depth of 27,500 linear feet and a system cooling capacity of 200 tons. A test well at the front of the property showed no problems at a depth of up to 500 feet. However, the well-drilling contractor soon learned that the geology at the rear of the site, where the ground loop was to be installed, was different. Excessive underground water flow in this area made drilling conditions very difficult; it was going to be impossible to install the ground loop without casing each borehole—an expensive procedure the developer had not anticipated.

PP&L suggested that the developer opt instead for a system with a smaller ground loop sized to meet the building's entire heating load and its cooling requirements for all but the hottest, most humid days. For those days, a conventional cooling tower would be installed to provide supplemental cooling. The developer agreed to this modification, and the contractor proceeded to install one of the country's first combination systems, known in the industry as hybrids.

The modified system has 88 boreholes, each 125 feet deep—for a total of 80 tons of cooling capacity—and a supplemental cooling tower with a 120-ton capacity. The 80,000-square-foot office building, called the Paragon Centre, opened in 1994. Data from EPRI-installed monitoring equipment indicate that, with a building occupancy rate of 80%, total annual energy consumption has been just 11.7 kWh per square foot. This represents an annual cost of $0.94 per square foot, compared with $1.60 for a building of the same size having a gas-fired boiler and an air conditioning system with a cooling tower.

EPRI's Khattar says the hybrid solution makes sense not just for sites with difficult drilling conditions but also for projects with large cooling loads or long cooling seasons. If a much larger ground loop is required for summer cooling than for winter heating—which is often the case in commercial buildings, especially those in climates with hot summers—it is less expensive to size the geothermal system for winter heating needs and supplement it with a fluid cooler or a cooling tower. This reduces initial construction costs and can overcome space limitations. Hybrid systems might also provide a practical approach in states where regulations restrict boring depth and grouting materials or where labor rates are very high.

Because of their energy efficiency and their design and sizing flexibility, geothermal heat pump systems are an increasingly popular choice for space conditioning at a variety of facilities, as illustrated by these user sites.

Cambridge-Isanti ice arena in Minnesota

COURTESY DETROIT EDISON

McDonald's restaurant in Detroit

Going commercial

One niche market for geothermal heat pumps that has emerged among commercial utility customers is fast-food establishments. Just within the past year, EPRI has participated in installations at a McDonald's in Detroit with Detroit Edison and a Wendy's in New York state with Central Hudson Gas & Electric; it is now involved with OG&E Electric Services in planning a geothermal heat pump for a Hardee's in Oklahoma.

As Khattar explains, many of these establishments are attracted by the low maintenance costs of geothermal heat pump systems. Unlike large commercial enterprises, which can afford to employ maintenance workers to tend to conventional central systems or rooftop equipment that is exposed to the elements, the relatively small fast-food establishments usually don't employ such personnel. "Since your heat exchanger is buried in

COURTESY BOB BUCKNER HOMES

Single-family residence in Oklahoma City

School in Lincoln, Nebraska

the ground, you don't have to worry about it clogging up with leaves or snow," Khattar says. "Virtually all maintenance issues are eliminated." Just about the only maintenance required for such systems, in fact, is a periodic changing of the air filter.

Contributing to the efficiency of these systems at commercial sites is their potential for using waste heat (from refrigeration equipment, for example). Such is the case at a new, all-electric ice-skating rink in Isanti, Minnesota, that features a geothermal system for heating, cooling, and ice making. There, waste heat from the ice-making equipment is being used to help warm the building and heat water. The Cambridge-Isanti Arena Corporation, which opened the facility in January, estimates that ice-making and space-conditioning costs will be as little as half what other Minnesota arenas of comparable size are spending.

Similarly, a combination gas station–fast-food restaurant built by Texaco in Oklahoma City uses heat expelled by refrigeration and ice-making equipment to supplement thermal energy from the ground for heating during the winter months. Operating since the station opened in July 1996, the heat pump system is also integrated with the car-wash water, which complements the earth as a sink for summertime heat, thereby improving efficiency in the cooling mode. This design allowed for some downsizing of the ground loop. OG&E Electric Services, the local power company, worked with Texaco, EPRI, and the Oklahoma energy consulting firm EPC, Inc., to design and install the system at the all-electric station.

A second new Texaco Star Mart station, built only 5 miles away, serves as a good comparison facility because it is identical in construction except for its heating, cooling, and refrigeration systems. It has conventional equipment—a rooftop electric air conditioner, a natural-gas-powered heating system, and an air-cooled refrigerator. Energy monitors installed at both sites show that for the past year and a half of operation, the energy bills of the station with the geothermal heat pump system have been, on average, 27% lower than those of the comparison station.

"The savings would have been even higher, but last year the station with the conventional system closed the restaurant portion of its convenience store," says Morris Lovett, vice president of Geothermal Design and Engineering—which, after the all-electric station opened, was established as the first unregulated subsidiary of OG&E's parent company. The new firm offers a wide range of geothermal heat pump services, including design engineering, project management, and system maintenance.

Although the station with the geothermal heat pump cost about $46,000 more to build than the comparable conventional station, its annual energy savings (which top $10,000 even without the fast-food operation running in the conventional station) are expected to more than cover the cost of the system in four years. "I think the system has done really well," says Bob Burkman, manager of marketing and engineering for Texaco. Burkman says his company is now considering installing geothermal systems at stations in other parts of the country.

Texaco isn't the only company that likes the technology. OG&E is benefiting from the increased revenues of a bigger electrical load in the winter and from the savings that make an important customer happy. "This is a technology that's going to take off," says Steve Ganzer, formerly president of EPC and now with Geothermal Design and Engineering, which is already involved in commercial and government projects in other areas of the country. "It's a real business opportunity," he says. EPRI is currently assisting in two of the firm's

COURTESY DONALD FREDERICK, DEVELOPER

Paragon Centre in Allentown, Pennsylvania local projects, the Hardee's restaurant mentioned earlier and a Conoco station, both in Norman, Oklahoma.

Spreading the word

As the use of geothermal heat pumps becomes more widespread, EPRI continues its efforts to improve the technology. Last year, it published a series of reports (TR-109160 through TR-109169) to assist installers of geothermal systems. For example, the reports offer guidance on the proper use of grouts in vertical systems.

Equipped with a geothermal heat pump system for heating, cooling, and refrigeration, this Texaco Star Mart station in Oklahoma City uses 27% less energy than a comparable station 5 miles away that has conventional equipment.

EPRI and the Geothermal Heat Pump Consortium are now working on a soil database to help contractors, engineers, architects, and others involved in planning geothermal heat pump systems determine the ideal loop design for a system, given a particular soil type. The database will use extensive soil maps that the U.S. Geological Survey has developed for localities across the United States. A user would first look up a locality on the USGS soil map to determine its soil conditions. The user could then plug this information into EPRI's database to determine the thermal properties of this type of soil. The database is expected to be available next year.

Meanwhile, an environmentally friendly antifreeze for ground-loop systems—developed with funding from EPRI, the National Rural Electric Cooperative Association, and others—is gaining in popularity. Called GS-4, the antifreeze is based on potassium acetate, which was originally used as a runway deicing fluid and is readily biodegradable. EPRI, working with researchers at Oklahoma State University and manufacturers, adapted the chemical for use in geothermal heat pumps, in part by adding corrosion inhibitors. The resulting fluid, which became commercially available about five years ago, is nontoxic. Moreover, it requires less pumping power than most other antifreeze solutions because, unlike them, it maintains a low viscosity at low temperatures. This characteristic also means, however, that GS-4 can leak more easily through the pipe fittings. Installers using it must apply special thread sealants and take other precautions to prevent leakage.

Other technological developments in the planning stages should encourage the use of geothermal heat pump systems, Khattar notes. One example is a methodology that EPRI intends to develop for sizing hybrid systems. These systems offer planners more site flexibility, since a site that is too small or otherwise unsuitable for a full-scale geothermal system—as was the case at the Paragon Centre—could accommodate a smaller-scale system supplemented by a conventional energy source. The planned sizing methodology could greatly increase the use of hybrid systems by helping designers determine what portion of the cooling load at a given site should be handled by the geothermal system and what portion should be handled by the conventional equipment. The ideal percentage of each would vary from site to site and climate to climate.

Another area of effort is control technology for geothermal heat pump systems. Recently, EPRI partnered with GC Controls of Greene, New York, to develop a low-cost, reliable microprocessor-based controller to efficiently control water-loop heat pump systems. The technology, called Smart Loop 2000, uses EPRI-developed control algorithms to maximize efficiency and performance. The controller is expected to be commercially available later this year. Khattar would like to extend the capabilities of this technology so that it can be used with geothermal heat pumps and ultimately with hybrid geothermal systems.

Such technological advances are among the subjects discussed at live satellite conferences cosponsored by EPRI, the Geothermal Heat Pump Consortium, and others at least once a year. These conferences provide a forum in which engineers, contractors, researchers, and others involved with geothermal heat pump technology can share their experiences.

Richard Stockton College in Pomona, New Jersey, is home to what is believed to be the world's largest single closed-loop piping network, which provides a cooling capacity of 1600 tons.

According to EPRI's Hiller and others, an increasing number of heating and cooling professionals are becoming familiar with geothermal heat pump systems. Contributing to the growing level of geothermal heat pump expertise in the field is an IGSHPA-sponsored certification program

Buried Appeal

Ironically, part of what makes geothermal heat pump systems so attractive is that there's nothing to look at. In fact, a number of buildings of architectural significance deploy the technology specifically for that reason. As Carl Hiller of EPRI puts it, "There's nothing like an air conditioner hanging out of a window to take the romance away from a centuries-old building."

Another advantage of the systems' invisibility is that, with the piping network underground and the heat pump inside a building, vandals cannot gain access to the equipment. This feature has proved to be a key attraction for schools, government buildings, and prisons, which suffer big equipment losses due to vandalism.

Among those taking advantage of the technology's aesthetic and other benefits is the Colonial Williamsburg Foundation. According to Clyde D. Kestner, director of engineering for the foundation, all of the more than 60 exhibition buildings in Williamsburg's eighteenth-century historical district—including the Capitol, the Governor's Palace, and the Wythe House—have space-conditioning systems that tap into a 65°F aquifer lying 400 feet underground. Most of these systems have an open-loop design and provide only cooling, using the water once and then discharging it for a range of other applications, from irrigation to waterfalls. However, over 10 of the open-loop systems also employ heat pumps, thereby providing heating as well as cooling.

PHOTOS COURTESY COLONIAL WILLIAMSBURG FOUNDATION

Wythe House

Three of the approximately 60 exhibition buildings use closed-loop geothermal heat pump systems to provide both heating and cooling. The largest of these systems was installed in 1989 at Shields Tavern, a reconstruction of a tavern originally built in the early 1700s. The new tavern is a functioning restaurant that operates seven days a week and accommodates up to 250 diners at a time. In the winter, its geothermal system draws heat from 250 feet underground to maintain a comfortable indoor temperature of 68°F, even on the coldest nights. In the summer, the system transfers heat to the ground, cooling the tavern to an average of 72°F.

"It's an ideal technology for a historical district, where you can't afford to have any outdoor air-source cooling equipment humming," says Kestner. "The overriding concern is authenticity. You don't want to see these modern systems, hear them, or even know that they are there. You just want them to do their jobs quietly behind the scenes." Kestner notes that as the aging boilers in the other exhibition buildings are replaced, an increasing number of the buildings will come to rely on geothermal heat pumps for heating and cooling. □

for installers. Established six years ago with EPRI support, the program certifies close to 1000 installers each year, says IGSHPA's James Bose. In fact, the program, which was first held at IGSHPA's headquarters at Oklahoma State University, has become so popular that the association now offers it in various locations across the country, including New York, New Jersey, Alabama, and Pennsylvania. Although state regulations at this time do not call for loop installers to be certified to perform their work, an increasing number of local governments, schools, and architectural firms are requiring certification, Bose says.

"We've got a better network of trade allies now," says Hiller, noting that a variety of other building professionals have also become familiar with geothermal heat pump technology in recent years. In fact, Paul Liepe of the Geothermal Heat Pump Consortium says that even residential real estate appraisers in many areas of the country are now recognizing the systems' value in significantly reducing heating and cooling bills. The consortium aims to increase the number of annual geothermal heat pump installations from 50,000 today to 400,000 within the next decade. Achieving this goal would reduce annual carbon emissions by more than 1 million metric tons.

What do the experts think? "Theoretically it's possible, but the industry will have to be creative to reach that goal," says EPRI's Mort Blatt, Energy Delivery and Utilization Division director. "Success will depend not only on technological developments, which EPRI is pursuing, but also on the marketing efforts spearheaded by the GeoExchange Information Center." ■

Background information for this article was provided by Mukesh Khattar and Carl Hiller, Energy Delivery and Utilization Division. The GeoExchange Information Center has a Web site at www.geoexchange.org.

Inside EPRI

News and information highlighting EPRI staff and operations

New Chairman and Board Members Elected

American Electric Power Company's E. Linn Draper, Jr., was elected to a two-year term as chairman of EPRI's Board of Directors at the annual meeting held in April in Washington, D.C. Draper is chairman, president, and CEO of both AEP and its management and technology arm, American Electric Power Service Corporation. Before joining AEP in 1992, he spent 13 years with Gulf States Utilities Company, where he also served as chairman, president, and CEO. Earlier he was an associate professor at the University of Texas and directed the school's nuclear engineering program. Draper currently sits on the boards of the Edison Electric Institute, the Nuclear Energy Institute, and the Institute of Nuclear Power Operations, as well as on the executive committee of the National Coal Council. Formerly, he chaired the EEI board and served as president and board member of the American Nuclear Society. In 1992, he was elected a member of the National Academy of Engineering.

Two vice chairmen and seven new members were also elected to the EPRI board at the April meeting. Christian H. Poindexter, chairman and CEO of Baltimore Gas and Electric Company, will serve as first vice chairman, and Craven Crowell, chairman of the Tennessee Valley Authority, as second vice chairman. The new board members are William A. Coley, president of Duke Power; Pierre Daures, CEO of Electricité de France; Richard R. Grigg, president and COO of Wisconsin Electric Power; Roger W. Hale, chairman and CEO of LG&E Energy Corporation; James J. Jura, general manager and CEO of Associated Electric Cooperative; Allen Morgan, CEO of ESKOM; and Jack Robertson, acting administrator and CEO of the Bonneville Power Administration.

Smithsonian Hosts EPRI's 25th Anniversary Symposium

To commemorate its twenty-fifth anniversary as the nation's leading provider of collaborative energy science and technology, EPRI sponsored a symposium on electricity innovation for the twenty-first century at the Smithsonian Institution in Washington, D.C., on April 29. The symposium's panel members and attendees—who included senior government officials, congressional staff members, chief executives of EPRI member companies, and other energy leaders—joined in a discussion about the future of electricity and about the way research will be conducted in the emerging competitive electricity industry.

"Electricity is the only form of energy that can simultaneously provide economic growth, environmental protection, and natural resource conservation," said Kurt Yeager, president and CEO of EPRI. "With proper incentives for further development of and investment in electricity-based technology, we could improve the nation's energy efficiency by 20% and add a trillion dollars to the economy over the next 25 years."

Bernard Finn, curator for electrical collections at the Smithsonian's National Museum of American History, provided historical perspective for Yeager's predictions. "The essential technologies for electric power were available by the end of the nineteenth century," Finn noted. "In the twentieth century, we built them into systems that made electricity cheaply available to virtually every part of the country. The consequences have been an incredible expansion of our capabilities, both at home and in the workplace."

According to Yeager, electricity's historical benefits will be dwarfed by those to come. "The future will be driven by new industries created by revolutions in information technology, advanced materials, biology and genetics, electrotechnology, and ecological management. These technological megatrends present new challenges to global economic and environmental sustainability. Energy provided by electricity has a major role to play.

"For a sustainable future, we need to sort out the best opportunities for electricity, define the technological gaps, set the research agenda, and promote public-private partnerships to invest in the work that will find the answers," Yeager said. EPRI is leading this effort by facilitating the development of the Electricity Technology Roadmap, a highly collaborative project of diverse stakeholders that will help guide science and technology in the coming decades to achieve maximum value for stakeholders and society. A series of workshops will take place this summer, with a goal of unrolling the roadmap in the fall.

The symposium also featured a panel discussion on the future of publicly funded research and the challenges of providing for critical R&D in a deregulated, competitive electricity industry. Robert Fri, director of the National Museum of Natural History, moderated the panel, which included Dan Adamson, special assistant, Office of the Secretary, U.S. Department of Energy; Susan Clark, commissioner, Florida Public Service Commission, and chair of the NARUC Subcommittee on Electricity; Catherine Van Way, majority counsel, House Committee on Commerce; and Howard Useem, Senate Committee on Energy and Natural Resources.

"Deregulation of the industry demands that leaders deal seriously with the scope of and funding mechanisms for publicly

Panel (left to right): Fri, Adamson, Clark, Van Way, Useem

funded R&D. We can't afford to leave this to chance," said Fri, formerly president of Resources for the Future. "A key question is whether increased competition and restructuring are likely to encourage the best use of future technologies."

Adamson pointed out that while increased competition and restructuring could result in greater pressure for companies to invest in innovative technologies and related R&D, there is concern that such pressure could also mean less support for longer-range, public-benefit R&D that does not promise a near-term payoff.

Clark shared this concern: "The importance of R&D to our future means we will look for opportunities to sustain its funding in a deregulated environment." She said the NARUC electricity subcommittee is carefully considering how to address the potential market failure of competition to ensure support for basic and long-term research. "State public service commissions will continue to play a role in encouraging collaborative, public-benefit research," she added.

Competition in wholesale power markets is already influencing the choice of technologies for efficient and low-cost electricity generation at emerging new merchant power plants, according to Van Way. "There are incentives for companies to invest in technologies that give consumers power that is cheaper and more reliable. We also see more utilities looking at distributed generation as a way to give consumers the added value that differentiates a company in a competitive market," Van Way noted. She added that new entrants in the electricity enterprise should also invest in R&D.

Useem encouraged the power industry to be vocal as Congress considers various legislative proposals to facilitate electricity deregulation and restructuring over the next couple of years. "Lawmakers will be receptive to consensus suggestions from the industry on how to ensure support for collaborative R&D, but you must speak loudly and clearly, with so many other issues on the congressional agenda."

Journal Wins Top Magazine Award

The *EPRI Journal* was judged the grand winner for magazines in the 1997 International Mercury Awards competition. Presented by the International Academy of Communications Arts and Sciences, the Mercury Awards recognize outstanding achievement in business communications and are considered one of the most prestigious awards in this field. The competition draws some 1000 entries each year from over 20 countries. This year's winners in other categories included AT&T, Microsoft, Consumers Power, the U.S. Postal Service, Genentec, ESPN, and IBM.

Charter Members Honored

Among EPRI's current members are 43 utilities that have continuously supported the organization since its inception in 1973. These charter members were recognized by president and CEO Kurt Yeager in a special awards ceremony at EPRI's twenty-fifth anniversary symposium in April. "I'd like to thank these farseeing companies for their leadership in helping found our organization and for their constancy in promoting innovation in our industry," said Yeager. "They have made it possible for EPRI to truly make a difference." The following utilities were honored:

Baltimore Gas and Electric Co.
Bonneville Power Administration
Buckeye Power, Inc.
Carolina Power & Light Co.
Centerior Energy Corp.
Central Hudson Gas & Electric Corp.
Central Illinois Public Service Co.
Commonwealth Energy System
Consolidated Edison Co. of New York, Inc.
Duke Power Co.
Duquesne Light Co.
Empire District Electric Co.
Houston Lighting & Power Co.
IES Utilities, Inc.
Interstate Power Co.
Kansas City Power & Light Co.
Kentucky Utilities Co.
Madison Gas and Electric Co.
MidAmerican Energy Co.
Nevada Power Co.
New England Electric System
New York State Electric & Gas Corp.
Northeast Utilities
Oklahoma Gas and Electric Co.
Orange and Rockland Utilities, Inc.
PECO Energy Co.
Pennsylvania Power & Light Co.
Public Service Co. of Colorado
Public Service Electric and Gas Co.
Puget Sound Energy
Rochester Gas and Electric Corp.
Salt River Project
Sierra Pacific Power Co.
Southern Company
Southern Indiana Gas and Electric Co.
Tennessee Valley Authority
TU Electric
Union Electric Co.
UtiliCorp United, Inc.
Western Resources, Inc.
Wisconsin Electric Power Co.
Wisconsin Power and Light Co.
Wisconsin Public Service Corp.

In the Field

Demonstration and application of EPRI science and technology

Advanced Particle Collector Tested, Ready for Demonstration

A novel, high-efficiency particle collection system that can take over where underperforming electrostatic precipitators (ESPs) leave off is ready for full-scale demonstration, following successful field tests at a coal-fired power plant in Alabama. ElectroCore—an electrostatically enhanced core separator system developed by EPRI and LSR Technologies with support from the U.S. Department of Energy—combines centrifugal and electrostatic forces for collection efficiencies as high as 98%.

"ElectroCore is the most innovative device I've seen in 22 years in particulate

control," says Wallis Harrison, a research specialist in charge of Southern Company's particle control research. The system's design is based on a centrifugal core separator originally developed by LSR. Ralph Altman, a project manager in EPRI's Energy Conversion Division, proposed adding a particle-charging device and an electrostatic field to remove submicrometer-range particles that would otherwise elude the centrifuge.

ElectroCore works by separating the flue gas from a plant ESP into clean and dirty gas streams. The flue gas is spun in ElectroCore's cylindrical separator, which causes particles to migrate to the outer wall of the cylinder. An electrostatic field in the cylinder ensures the separation of even the smallest particles from the precharged gas, boosting the system's collection efficiency. The clean gas, about 90% of the flow, is routed to the plant stack, while the particles and about 10% of the gas flow are returned to the ESP for recirculation and eventual collection.

In laboratory tests using a simulated exhaust gas stream with plant fly ash, a prototype system demonstrated a collection efficiency of 99%. That attracted the interest of DOE and of Harrison of Southern Company Services, which offered the use of Alabama Power Company's J. H. Miller, Jr., plant for field-testing a 1-MW prototype. DOE provided funding for the tests.

Conducted last year on an exhaust gas slipstream from Miller unit 3, the field tests confirmed ElectroCore can collect 95–98% of the particulate matter remaining in gas that has passed through an ESP. An economic assessment by Sargent & Lundy projected that the system could be retrofitted to a 250-MW coal-fired unit for about $25/kW. The system contains no fabric filters and takes up little space.

"ElectroCore is a highly practical solution for underperforming ESPs," says EPRI's Altman. "It can improve the performance of almost any ESP." The system can increase collection efficiency at units that are currently burning low-sulfur coal but have ESPs designed for high-sulfur coal. It can also be effective at units with small ESPs designed for high-sulfur coal.

The next step for the ElectroCore system is either a large-scale (10–20-MW) pilot demonstration or a full-scale (30–50-MW) retrofit. Either scale will give utilities the opportunity to confirm the system's costs, long-term performance, and reliability.

■ *For more information, contact Ralph Altman, (423) 899-0072.*

Digital Meter Measures Ground Impedance On-Line

Now available in a digital version is the Smart Ground Multimeter (SGM), a device for measuring substation ground impedance and providing other information that substation owners need to confirm grounding system design specifications and ensure worker safety. Developed with support from EPRI and manufactured by Hood-Patterson & Dewar, Inc., of Decatur, Georgia, the SGM measures substation ground impedance faster and more accurately than the conventional fall-of-potential method.

"Both the original version and the new digital version have provided us with excellent results in testing substation ground mat resistivity and touch voltages," says Rowland James of Entergy Corporation. "The SGM helps us make sure that our new and existing substations are performing as designed."

With the fall-of-potential method, measurements must be made on de-energized, isolated grounding systems—a task that is nearly impossible at existing facilities without interrupting the customers' power supply. In addition, this labor-intensive method requires running long lengths of cable to points far outside the substation property.

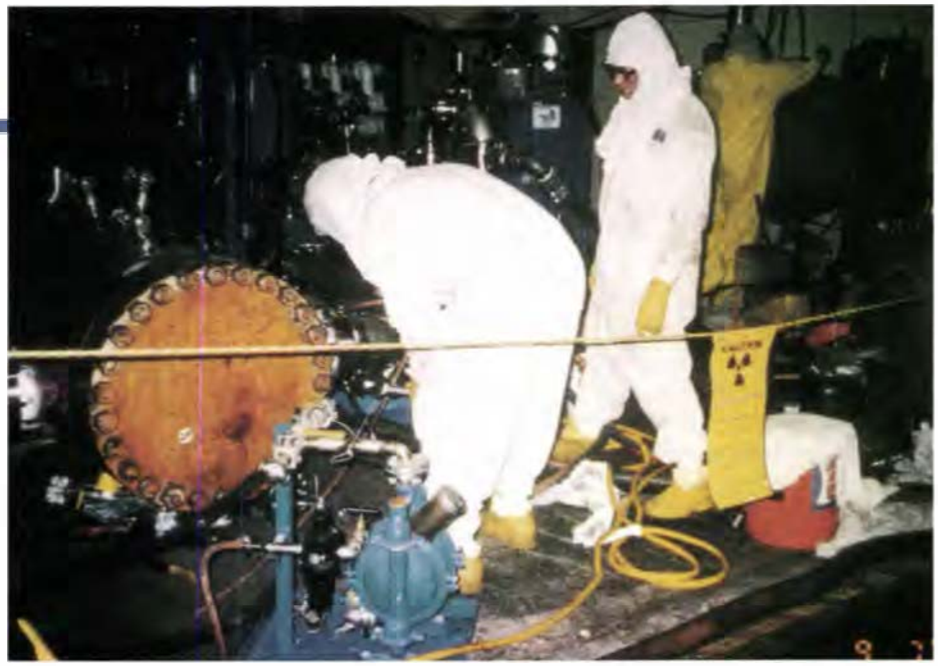
In contrast, the SGM can quickly and easily measure the ground impedance on both energized and de-energized substation grounding systems. It injects a transient electric current at the grounding system under test and measures transient ground potential differences around the system, as well as the injected current. It measures the ground potential with respect to several points on the earth's surface at relatively small distances from the test system, thus determining ground potential differences.

The measurements are then processed by computer software that filters out electronic noise, corrects for errors resulting from cable capacitance and the high ground resistance of the voltage probes, and estimates the substation ground mat impedance. The SGM can also measure other key parameters, including touch voltage, step voltage, soil resistivity, tower ground resistance, transfer voltage, and low impedance/continuity.

Consolidated Edison Company of New York was instrumental in the field evaluation and design enhancement of the SGM. Utility personnel tested the ground resistance at 27 substations and one 345-kV tower while evaluating the device. "The enhanced information from the SGM enabled us to save over $450,000 in ground grid improvements—improvements that had been considered necessary on the basis of measurements made with a conventional test instrument," says Consolidated Edison's Dan Marks.

An increase in competitive activities has led to a rise in the sale and purchase of substations. Says Jerry Melcher, EPRI project manager, "The Smart Ground Multimeter offers utilities a fast, accurate way to test the design and integrity of these systems, thus ensuring the safety of their workers and their investment."

■ *For more information, contact Lyn Cosby or J. B. Franklin at Hood-Patterson & Dewar, (404) 296-5990; fax (404) 299-3542.*



DFD Process Applied at Nuclear Plants

An EPRI-developed dilute chemical process that can achieve radioactive decontamination factors exceeding 1000 was applied to the reactor coolant systems of two nuclear plants—Big Rock Point and Maine Yankee—earlier this year, shortly after the plants were permanently shut down. The high decontamination factors achievable with this process will permit the unrestricted release of stainless steel and alloy 600 components at retired plants and will minimize personnel radiation exposures during decommissioning work.

The EPRI process, called the Decontamination for Decommissioning (DFD) process, can also be applied to steam generators and other components removed from service at operating plants. Earlier it was demonstrated on retired heat exchangers from two Commonwealth Edison plants—Quad Cities and Dresden. Three vendors in the United States and one in the United Kingdom are now licensed to use the DFD process.

Other currently available dilute chemical processes, designed for use at operating plants, generally do not achieve the degree of decontamination required for the unrestricted release or recycling of radioactive components. Processes for components retired from service can use more-aggressive solvents than processes for operating plants, where avoiding corrosion is a key concern. Most solvents that can achieve a high degree of decontamination, however, produce radioactive waste in an intractable form that is difficult to manage and dispose of.

The DFD process completely removes contamination by dissolving a thin layer of the base metal from the surface of a retired component. The dissolved contamination is then collected via established ion-exchange technology. A recent EPRI technical report (TR-107707) describes the decontamination and recycling of stainless steel from regenerative heat exchangers from water cleanup systems at the Quad Cities and Dresden BWRs.

The first full reactor coolant system decontamination using the DFD process was conducted at Consumers Energy's Big Rock Point BWR in Michigan, which shut down permanently last August after 35 years of successful operation. Applied in six cycles, the DFD process removed more than 96% of the radioactivity—amounting to over 400 curies and approximately 1000 pounds of corrosion products—for an overall dose-reduction factor of 15.

At the Maine Yankee PWR, 11 DFD cycles were conducted in two campaigns, reducing area radiation fields by factors of up to 37 and average contact fields to an average of 1% of predecontamination levels. The decontamination factor achieved for radiologically significant sources (the sources most important for personnel exposure) was 89. At both Big Rock Point and Maine Yankee, use of the DFD process means substantial dose savings for current and future decommissioning work. Further decontamination of some components may be required, however, to enable recycling rather than disposal as radioactive waste.

The patented EPRI DFD process is available under license from Alaron Corporation, Bradtec Ltd. (UK), Framatome Technologies, and PN Services.

■ *For more information, contact Chris Wood, (650) 855-2379.*

Technical Reports & Software

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

Energy Conversion

CHECWORKS™ Flow-Accelerated Corrosion: User Guide
TR-103198-P1
Target: Nuclear Power
EPRI Project Manager: B. Chexal

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

Valve/Steam Trap Leakage Quantification User Guide
TR-103198-P4
Target: Nuclear Power
EPRI Project Manager: N. Hirota

PWR Primary-to-Secondary Leak Guidelines, Revision 1
TR-104788-R1
Target: Nuclear Power
EPRI Project Manager: R. Thomas

PWR Steam Generator Sleeving Assessment Document, Revision 1
TR-105960-R1
Target: Nuclear Power
EPRI Project Manager: A. McIlree

Inhibition of IGA/SCC on Alloy 600 Surfaces Exposed to PWR Secondary Water, Vol. 1
TR-106212-V1
Target: Nuclear Power
EPRI Project Manager: A. McIlree

Depth-Based Structural Analysis Methods for SG Circumferential Indications
TR-107197
Target: Nuclear Power
EPRI Project Manager: D. Steininger

Hydro Stakeholder Education Resource Catalog
TR-107298-R1
Target: Hydro Relicensing and O&M Cost Reduction
EPRI Project Manager: C. McGowin

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

Advanced Mixed-Waste Treatment: Results of Mixed-Waste Treatment at the M-4 Facility
TR-107974
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Radioactive Liquid Processing Guidelines
TR-107976
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Advanced Resin Cleaning System (ARCS) Field Test: Demonstration at Grand Gulf Nuclear Station
TR-107988
Target: Nuclear Power
EPRI Project Managers: P. Millett, P. Frattini

Technical Issues and Low-Level-Waste Performance Assessment: ^{14}C in Disposal Facilities
TR-107995
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Titanium Dioxide Application Guidelines
TR-108002
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

The Effect of Alternative Amines on the Rate of Boiler Tube Fouling
TR-108004
Target: Nuclear Power
EPRI Project Manager: P. Frattini

Oil-Fired Combustion Turbine SCR NO_x Control Testing and Evaluation
TR-108169
Targets: NO_x Control; Combustion Turbines, Repowering, and Dispersed Generation
EPRI Project Manager: R. Frischmuth

Cesium Removal From High-Conductivity Waste Using Selective Ion-Exchange Media
TR-108262
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Assessment of Magnetostrictive Sensor Technique: Detecting Flow-Accelerated Corrosion in Feedwater Piping (Revision 1)
TR-108449-R1
Target: Fossil Steam Boiler O&M Cost Reduction
EPRI Project Manager: C. Brett

NDE Guidelines for Fossil Power Plants
TR-108450
Target: Fossil Steam Boiler O&M Cost Reduction
EPRI Project Managers: C. Brett, R. Tilley

Startup and Testing of the ABB GT24 Gas Turbine in Peaking Service at the Gilbert Station of GPU Energy
TR-108608
Target: Combustion Turbines, Repowering, and Dispersed Generation
EPRI Project Manager: G. Quentin

Advanced Gas Turbine Guidelines: Startup and Operations of the Siemens 84.3A in Peaking Service
TR-108609
Target: Combustion Turbines, Repowering, and Dispersed Generation
EPRI Project Manager: G. Quentin

Utility Responses to Railroad Market Power: Assessment of Options
TR-108653
Target: Fuel Supply Cost Management
EPRI Project Manager: J. Platt

Thermal-Hydraulic Bases for Fuel-Cycle Designs to Prevent Axial Offset Anomalies
TR-108781
Target: Nuclear Power
EPRI Project Manager: B. Cheng

Battery Performance Monitoring by Internal Ohmic Measurements: Application Guidelines for Stationary Batteries
TR-108826
Target: Nuclear Power
EPRI Project Managers: N. Hirota, W. Johnson

Improved Steam Generator Upper Bundle Hydraulic Cleaning System
TR-108856
Target: Nuclear Power
EPRI Project Manager: R. Thomas

Guidelines for Controlling Flow-Accelerated Corrosion in Fossil Plants
TR-108859
Target: Fossil Steam Boiler O&M Cost Reduction
EPRI Project Manager: R. Tilley

Clean Coal Demonstration Projects: Operation Experience and Risk Assessment Through September 1997
TR-108865
Target: New and Repowered Plants (Coal and Opportunity Fuels)
EPRI Project Manager: M. Epstein

Updated Cost and Performance Estimates for PFBC and Hybrid Gasification/FBC Power Plants
TR-108866
Target: New and Repowered Plants (Coal and Opportunity Fuels)
EPRI Project Manager: M. Epstein

CMMS Selection at Wisconsin Public Service: Computerized Maintenance Management System
TR-108938
Target: Plant Maintenance Optimization
EPRI Project Manager: R. Pflasterer

SENTINEL™ Technical Basis Report for Limerick
TR-108953
Target: Nuclear Power
EPRI Project Manager: S. Kalra

Outage Risk Assessment and Management Implementation at Fermi 2
TR-109013
Target: Safety and Reliability Assessment
EPRI Project Manager: S. Kalra

Dry Triboelectric Separation of Carbon From Fly Ash: Proof-of-Concept Testing
TR-109016
Target: Combustion By-Product Management and Use
EPRI Project Manager: R. Chang

Hydro Stakeholder Collaboration and Public Involvement Planning Case Studies
TR-109060
Target: Hydro Relicensing and O&M Cost Reduction
EPRI Project Manager: C. McGowin

Green Mountain Power Wind Power Project Development: DOE-EPRI Wind Program
TR-109061
Target: Renewable Energy Business Intelligence
EPRI Project Manager: C. McGowin

Central and South West Wind Power Project First-Year Operating Experience, 1996-97: DOE-EPRI Wind Program
TR-109062
Target: Renewable Energy Business Intelligence
EPRI Project Manager: C. McGowin

Development and Demonstration of 250-kW Molten Carbonate Fuel Cell Power Plant: Miramar Naval Air Station
TR-109083
Target: Combustion Turbines, Repowering, and Dispersed Generation
EPRI Project Manager: R. Goldstein

Mobile Generation Options to Enhance Customer Service Reliability: Case Study for the New York Power Authority
TR-109118
Target: Combustion Turbines, Repowering, and Dispersed Generation
EPRI Project Manager: D. Herman

CANMET/Industry Research Consortium on Alkali-Aggregate Reactivity
TR-109132
Target: Combustion By-Product Management and Use
EPRI Project Manager: D. Golden

Crack Growth and Microstructural Characterization of Alloy 600 Vessel Head Penetration Materials
TR-109136
Target: Nuclear Power
EPRI Project Manager: R. Pathania

Modeling for Assessment of SCC Initiation Time in Alloy 600
TR-109137
Target: Nuclear Power
EPRI Project Manager: R. Pathania

Assessment of the Pulsed Eddy Current Technique: Detecting Flow-Accelerated Corrosion in Feedwater Piping
TR-109146
Target: Fossil Steam Boiler O&M Cost Reduction
EPRI Project Manager: C. Brett

Assessment of a Transportable 200-kW Fuel Cell in Rural Applications, Site 1: Central Georgia EMC/Oglethorpe Power Corp., Jackson, Georgia
TR-109154
Target: Distributed Resources for Energy Services and Delivery Enhancement
EPRI Project Manager: J. O'Sullivan

Second National Green Pricing and Green Power Marketing Conference: Summary Report
TR-109179
Target: Renewable Energy Business Intelligence
EPRI Project Manager: T. Peterson

Green Pricing: Experience and Technology Options Assessment
TR-109204
Target: Renewable Energy Business Intelligence
EPRI Project Manager: T. Peterson

NO_x LOI Predictor: User Guide and Tutorial
TR-109208
Target: NO_x Control
EPRI Project Manager: J. Stallings

Assessment of Low-Pressure Turbine Exhaust System Improvements at Mayo Generating Station
TR-109225
Target: Steam Turbine Generator and Balance-of-Plant O&M Cost Reduction
EPRI Project Manager: T. McCloskey

Predictive Maintenance Assessment Guidelines
TR-109241
Target: Steam Turbine Generator and Balance-of-Plant O&M Cost Reduction
EPRI Project Manager: R. Pflasterer

Proceedings: Effects of Coal Quality on Power Plants—Fifth International Conference
TR-109340
Target: Fossil Steam Boiler O&M Cost Reduction
EPRI Project Manager: A. Mehta

Proceedings: Integrating Natural Gas Technologies Into Coal- and Oil-Designed Boilers—Second Utility Workshop
TR-109341
Target: Fossil Steam Boiler O&M Cost Reduction
EPRI Project Manager: A. Mehta

Design Description of a Prototype Implementation of Three Reactor Protection System Channels Using Field-Programmable Gate Arrays
TR-109390
Target: Nuclear Power
EPRI Project Manager: J. Naser

Small CHAT Plant
TR-109434
Target: Combustion Turbines, Repowering, and Dispersed Generation
EPRI Project Manager: A. Cohn

Calculating Cycling Wear-and-Tear Costs: Methodology and Data Requirements
TR-109470
Target: Generation Assets Management
EPRI Project Manager: D. Broske

A Comparison of Canadian and U.S. Hydro Operations and Maintenance Practices
TR-109484
Target: Hydro Relicensing and O&M Cost Reduction
EPRI Project Manager: C. Sullivan

PWR Steam Generator Tube Plug Assessment Document
TR-109495
Target: Nuclear Power
EPRI Project Manager: A. McIlree

Renewable Energy Technology Characterizations
TR-109496
Target: Renewable Energy Business Intelligence
EPRI Project Manager: E. DeMeo

EPRI M&D Center Course Catalog
TR-109511
Target: Steam Turbine Generator and Balance-of-Plant O&M Cost Reduction
EPRI Project Manager: R. Pflasterer

Infrared Thermography Developments for Boiler, Condenser, and Steam Cycle
TR-109529
Target: Steam Turbine Generator and Balance-of-Plant O&M Cost Reduction
EPRI Project Manager: R. Pflasterer

Distributed Generation Case Study: Industrial Process Heating (Cogeneration)
TR-109554
Target: Combustion Turbines, Repowering, and Dispersed Generation
EPRI Project Manager: D. Herman

GOTHIC Analysis of Containment Fan Cooler Unit (CFCU) Cooling Water Response Following a LOCA With Loss of Off-Site Power
TR-109612
Target: Nuclear Power
EPRI Project Manager: A. Singh

Energy Delivery and Utilization

CLASSIFY-Applications, Vol. 3: Moving From Customer Needs to Customer Solutions
TR-104568-V3
Target: Enhancing the Market Success of Emerging Electrotechnologies
EPRI Project Manager: T. Henneberger

Portfolio Management: Finding Growth Opportunities in a Restructured Marketplace
TR-108106
Target: Producing Successful Product and Service Portfolios
EPRI Project Manager: P. Meagher

Stock Characterization and Energy Savings Potential of Forced-Air Systems in Frostbelt Homes
TR-108408
Target: Residential Heat Pump Technology
EPRI Project Managers: S. Kondepudi, J. Kesselring

Inventory of Available Methods and Processes for Assessing the Benefits, Costs, and Impacts of Demand-Side Options, Vol. 1: Overview of Methods, Models, and Techniques
TR-108506-V1
Target: Producing Successful Product and Service Portfolios
EPRI Project Manager: G. Heffner

Inventory of Available Methods and Processes for Assessing the Benefits, Costs, and Impacts of Demand-Side Options, Vol. 2: Country Survey of Integrated Planning Approaches
TR-108506-V2
Target: Producing Successful Product and Service Portfolios
EPRI Project Manager: G. Heffner

Proceedings: Strategic Research Meeting on Electrotechnologies in the Chemicals and Petroleum Industries
TR-108908
Targets: Chemicals and Petroleum Industries; Strategic R&D
EPRI Project Manager: A. Amarnath

Costing and Pricing Electric Power Reserve Services
TR-108916
Target: Power Markets and Resource Management
EPRI Project Manager: C. Clark

Product Life-Cycle Management: Adapting the Best Practices of Other Industries
TR-108984
Target: Producing Successful Product and Service Portfolios
EPRI Project Manager: P. Meagher

Bundling of Products and Services in the Energy Services Industry
TR-108985
Target: Producing Successful Product and Service Portfolios
EPRI Project Manager: P. Meagher

Market Profiles and Market Entry Strategies for New Electricity-Driven Chemical Process Technologies
TR-109005
Target: Enhancing the Market Success of Emerging Electrotechnologies
EPRI Project Managers: T. Henneberger, A. Amarnath

Conductor and Associated Hardware Impacts During High-Temperature Operations: Issues and Problems
TR-109044
Target: Overhead Transmission
EPRI Project Manager: B. Clairmont

Cable Oil Monitor and Tester (COMAT)
TR-109071
Target: Underground Transmission
EPRI Project Manager: T. Rodenbaugh

HPFF Cable Leak Location Using Perfluorocarbon Tracers
TR-109086
Target: Underground Transmission
EPRI Project Manager: T. Rodenbaugh

Strategies for Marketing Electrotechnologies and Energy Services to Small Businesses: Metal Finishers and Electronics Fabricators
TR-109134
Target: Small Businesses
EPRI Project Manager: W. Krill

Customer Load Response to Spot Prices in England: Implications for Retail Service Design
TR-109143
Target: Power Markets and Resource Management
EPRI Project Manager: A. Faruqui

The High-Efficiency Laundry Metering and Marketing Analysis (THELMA) Project, Vol. 2: Laboratory Testing of Clothes Washers
TR-109147-V2
Target: Residential Appliances
EPRI Project Managers: R. Gillman, J. Kesselring

Physical, Thermal, and Hydraulic Properties of Bentonite-Based Grouts
TR-109160
Target: Residential Heat Pump Technology
EPRI Project Manager: C. Hiller

Soil Classification Systems Review
TR-109161
Target: Residential Heat Pump Technology
EPRI Project Manager: C. Hiller

Design, Testing, and Evaluation of a Water Injection Grouting System
TR-109162
Target: Residential Heat Pump Technology
EPRI Project Manager: C. Hiller

Evaluation of the Pumpability of Bentonite-Based Grouts
TR-109163
Target: Residential Heat Pump Technology
EPRI Project Manager: C. Hiller

Thermal, Physical, Hydraulic, and Heat-of-Hydration Properties of Cement-Based Grouts
TR-109165
Target: Residential Heat Pump Technology
EPRI Project Manager: C. Hiller

Ground-Source Heat Pump Cement-Based Grout Literature Review
TR-109166
Target: Residential Heat Pump Technology
EPRI Project Manager: C. Hiller

Grouting for Vertical Geothermal Heat Pump Systems: Engineering Design and Field Procedures Manual
TR-109169
Target: Residential Heat Pump Technology
EPRI Project Manager: C. Hiller

Electric Vehicle Vision 2007
TR-109194
Target: Electric Transportation Information Package
EPRI Project Manager: L. Sandell

Heat Pump Manual, Second Edition
TR-109222
Target: Residential Heat Pump Technology
EPRI Project Manager: M. Blatt

EPRI Freezing-Rain Ice Mapping Project: Region 4
TR-109440
Target: Overhead Transmission
EPRI Project Manager: P. Lyons

Office Complexes Guidebook: Innovative Electric Solutions
TR-109450
Target: Office Complexes
EPRI Project Manager: K. Johnson

■ **PROBE: Product Benefits Estimator**
Version1.0 (Windows)
Available to all EPRI targets
EPRI Project Manager: L. Holy

■ **ProfitManager**
Version 3.73 (Windows)
Target: Producing Successful Product and Service Portfolios
EPRI Project Manager: P. Meagher

■ **TRELSS: Transmission Reliability Evaluation for Large-Scale Systems**
Version 4.0 (Windows 95/NT)
Target: Grid Operations and Planning
EPRI Project Managers: R. Adapa, N. Abi-Samra

■ **UTWorkstation™ (Underground Transmission Workstation): PTMF (Pipe-Type Cable Magnetic Fields)**
Version 1.0 (Windows)
Target: Underground Transmission
EPRI Project Manager: T. Rodenbaugh

■ **UTWorkstation™: TOAD (Trench Optimization and Design)**
Version 3.0 (Windows)
Target: Underground Transmission
EPRI Project Manager: T. Rodenbaugh

■ **VIBRATION: Damper Placement for Aeolian Vibration**
Version 1.0 (Windows)
Target: Overhead Transmission
EPRI Project Manager: A. Hirany

Environment

Relation Between Residential Magnetic Fields, Light at Night, and Nocturnal Urine Melatonin Levels in Women, Vols. 1–2
TR-107242-V1–V2
Target: EMF Health Assessment
EPRI Project Manager: L. Kheifets

Coal Combustion By-Products and Low-Volume Wastes Comanagement Survey
TR-108369
Target: Combustion Wastes and Groundwater Protection
EPRI Project Manager: I. Murarka

Pole Preservatives in Soils Adjacent to In-Service Utility Poles in the United States
TR-108598
Target: T&D Soil and Water Issues
EPRI Project Managers: I. Murarka, A. Quinn

PISCES Water Toxics Field Study Report, Site C
TR-108891-V1–V2
Target: Water Toxics Measurement and Control
EPRI Project Manager: P. Chu

A Pilot Study for the Extraction and Treatment of Groundwater From a Manufactured Gas Plant Site
TR-108914
Target: MGP Site Remediation and Health Risk
EPRI Project Manager: I. Murarka

Round-Robin Study of Methods for Trace Metal Analysis: Graphite Furnace Atomic Absorption Spectroscopy—Cadmium, Arsenic, and Chromium
TR-108989
Target: Water Toxics Measurement and Control
EPRI Project Manager: B. Nott

Modeling of Mercury Deposition to Ecosystems
TR-109235
Target: Air Toxics Health and Risk Assessment
EPRI Project Managers: L. Levin, M. Allan

Magnetic Field Shielding Design Guide
TR-109271
Target: EMF Management
EPRI Project Manager: F. Young

Study of Ground Currents in Proximity of Substations
TR-109272
Target: EMF Management
EPRI Project Manager: F. Young

Power Plant Intake Systems Database Bibliography
TR-109273-DK
Target: Water Toxics Measurement and Control
EPRI Project Manager: K. Zammit

Magnetic Field Management: Active Loop Shielding—A Scoping Study
TR-109415
Target: EMF Management
EPRI Project Manager: F. Young

Large Granular Lymphocytic (LGL) Leukemia in Rats Exposed to 60-Hz Magnetic Fields: Results of the Second Study Using Continuous and Intermittent Fields
TR-109469
Target: EMF Health Assessment
EPRI Project Managers: C. Rafferty, K. Ebi

■ **RAMAS Ecotoxicology: Population-Level Ecotoxicology Risk Assessment**
Version 1.0 (PC-DOS)
Target: Water Toxics Assessment
EPRI Project Manager: R. Goldstein

Strategic Science and Technology

Research and Development Opportunities in Electrosynthesis and Electrochemical Manufacturing Processes
TR-107022
Target: Strategic R&D
EPRI Project Manager: A. Amarnath

Application of the Case-Specular Method to the Savitz Denver Study Residences
TR-107751
Target: Strategic R&D
EPRI Project Manager: K. Ebi

Effects of Magnetic Fields on Cardiac Control Mechanisms
TR-108251
Target: Strategic R&D
EPRI Project Manager: R. Kavet

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

Smart Materials and Structures: An Overview, With Implications for the Power Industry
TR-108377
Targets: Exploratory Research; Strategic R&D
EPRI Project Manager: J. Stringer

Superior Perovskite Oxide Ion Conductor: Strontium- and Magnesium-Doped $LaGaO_3$
TR-108742
Target: Strategic R&D
EPRI Project Manager: W. Bakker

Proceedings: Strategic Research Meeting on Electrotechnologies in the Chemicals and Petroleum Industries
TR-108908 (see listing under Energy Delivery and Utilization)

Development and Demonstration of an Agent-Oriented Integration Methodology
TR-108976
Target: Strategic Science and Technology
EPRI Project Managers: R. Pflasterer, M. Wildberger

The Future State of End-Use Technologies in the United States
TR-109070
Target: Strategic R&D
EPRI Project Manager: T. Henneberger

Experimental Development of Power Reactor Intelligent Control: Advanced Direct-Control Experiments
TR-109181-V1–V4
Target: Strategic R&D
EPRI Project Manager: J. Naser

Ceria Electrolyte for Solid Oxide Fuel Cell Applications
TR-109199
Target: Strategic R&D
EPRI Project Manager: W. Bakker

Residential Information Technologies and Energy Management: A Customer's Perspective
TR-109452
Target: Strategic R&D
EPRI Project Managers: S. Kondepudi, T. Henneberger

EPRI Events

July

6–7
Service Water Assistance Program Coordinators Meeting
Williamsburg, Virginia
Contact: Brent Lancaster, (704) 547-6017

7
Year 2000 Web Site and Knowledge Base Training
Palo Alto, California
Contact: Susan Marsland, (650) 855-2946

8
Year 2000 Web Site and Knowledge Base Training
Palo Alto, California
Contact: Susan Marsland, (650) 855-2946

8–9
Improving Service Water System Reliability
Williamsburg, Virginia
Contact: Brent Lancaster, (704) 547-6017

13–14
3d International Conference on Arsenic Exposure
San Diego, California
Contact: Janice Yager, (650) 855-2724

13–15
EPRI/ASME Radwaste Workshop
Orlando, Florida
Contact: Michele Samoulides, (650) 855-2127

13–17
Boiler Operating Theory Fundamentals
Castine, Maine
Contact: Sarah Vanberg, (816) 235-5623

14–16
Workshop on In-Service Inspection and Nondestructive Evaluation
Manitowoc, Wisconsin
Contact: Sherryl Stogner, (704) 547-6174

14–17
Basic Vibration Testing and Analysis
Long Beach, California
Contact: Edie McFall, (800) 745-9982

14–17
Machinery Alignment
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

14–17
Purdue Compressor Technology Conference
Purdue, Indiana
Contact: Cindy Quillen, (765) 494-6078

15–17
1998 International Low-Level-Waste Conference and Exhibit
Orlando, Florida
Contact: Michele Samoulides, (650) 855-2127

15–17
Nuclear Maintenance Applications Center Safety/Relief Valve Workshop
Wrentham, Massachusetts
Contact: Linda Suddreth, (704) 547-6061

16–17
Introduction to Computer-Aided Power Plant Analysis
Kingston, Tennessee
Contact: Eric Tolime, (423) 717-2016

20–22
Steam Turbine Performance Monitoring and Diagnostics Course
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

20–22
Technology Delivery Workshop
Denver, Colorado
Contact: Megan Boyd, (650) 855-7919

20–24
Drum Boiler Unit Operations
Castine, Maine
Contact: Sarah Vanberg, (816) 235-5623

21
Extending Time Between Generator Inspections
Philadelphia, Pennsylvania
Contact: Jan Stein, (650) 855-2390

21–23
Lubrication Oil Analysis
Long Beach, California
Contact: Esther Blanco, (562) 493-7741

22–24
Power Plant Pumps Short Course
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

23–24
Neural Network Theory and Engineering Applications
Kingston, Tennessee
Contact: Eric Tolime, (423) 717-2016

27
Year 2000 Web Site and Knowledge Base Training
Palo Alto, California
Contact: Susan Marsland, (650) 855-2946

27–31
Infrared Thermography: Level 1
Long Beach, California
Contact: Esther Blanco, (562) 493-7741

27–31
Supercritical Boiler Unit Operations
Kansas City, Missouri
Contact: Sarah Vanberg, (816) 235-5623

28
Year 2000 Web Site and Knowledge Base Training
Palo Alto, California
Contact: Susan Marsland, (650) 855-2946

28–30
Fluid-Film Bearing Diagnostics
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

28–31
Infrared Thermography Training and Users Group Meeting
Atlanta, Georgia
Contact: Edie McFall, (800) 745-9982

August

3–7
Combined-Cycle Unit Operations
Kansas City, Missouri
Contact: Sarah Vanberg, (816) 235-5623

4–6
Turbine-Generator Troubleshooting Short Course
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

5–7
Lubrication Workshop
Charlotte, North Carolina
Contact: Linda Suddreth, (704) 547-6061

10–11
Nuclear Plant Performance Improvement Seminar
Toronto, Canada
Contact: Brent Lancaster, (704) 547-6017

11–12
Manhole Event Workshop
Lenox, Massachusetts
Contact: Judy MacPherson, (413) 499-5701

11–13
Plant Performance Enhancement Program Coordinators Meeting
Toronto, Canada
Contact: Brent Lancaster, (704) 547-6017

11–14
Generator Monitoring and Diagnostics Course
Philadelphia, Pennsylvania
Contact: Edie McFall, (800) 745-9982

17–19
Advanced Power Quality Workshop
Knoxville, Tennessee
Contact: Martha Powers, (423) 974-8288

17–19
17th Annual Workshop on Steam Generator Nondestructive Evaluation
Breckenridge, Colorado
Contact: Ulla Gustafsson, (650) 855-2388

17–21
Designing, Developing, and Evaluating Training Programs: Power Plants
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

17–21
Feedwater Heater Technology Symposium
Seattle, Washington
Contact: Cindy Layman, (650) 855-8763

17–21
Steam Plant Operations for Utility Engineers
Castine, Maine
Contact: Sarah Vanberg, (816) 235-5623

18–21
Pressure Relief Valve Application, Maintenance, and Testing
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

19–21
Root-Cause Analysis
San Antonio, Texas
Contact: Edie McFall, (800) 745-9982

20–21
Nonroad Electric Vehicle Conference
Orlando, Florida
Contact: Michele Samoulides, (650) 855-2127

23–28
Year 2000 Web Site and Knowledge Base Training
San Diego, California
Contact: Peggy Amann, (650) 855-2259

24–25
Westinghouse DB and DS Circuit Breaker Users Group Meeting
Pittsburgh, Pennsylvania
Contact: Brent Lancaster, (704) 547-6017

25–27
NO_x Controls for Utility Boilers
Baltimore, Maryland
Contact: Megan Boyd, (650) 855-7919

25–28
Air-Operated Control Valve Applications
Eddystone, Pennsylvania
Contact: Edie McFall, (800) 745-9982

26–28
Westinghouse DH and DHP Circuit Breaker Users Group Meeting
Pittsburgh, Pennsylvania
Contact: Brent Lancaster, (704) 547-6017

31–Sept. 2
1998 EPRIweb Conference
Orlando, Florida
Contact: Michele Samoulides, (650) 855-2127

September

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

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

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

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

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

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

16–18
Forward Price Curve in Competitive Markets
Orlando, Florida
Contact: Peggy Amann, (650) 855-2259

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

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

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

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

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

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

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

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

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

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

October

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

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

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

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

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May/June 1998

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