Ozone for Water Treatment

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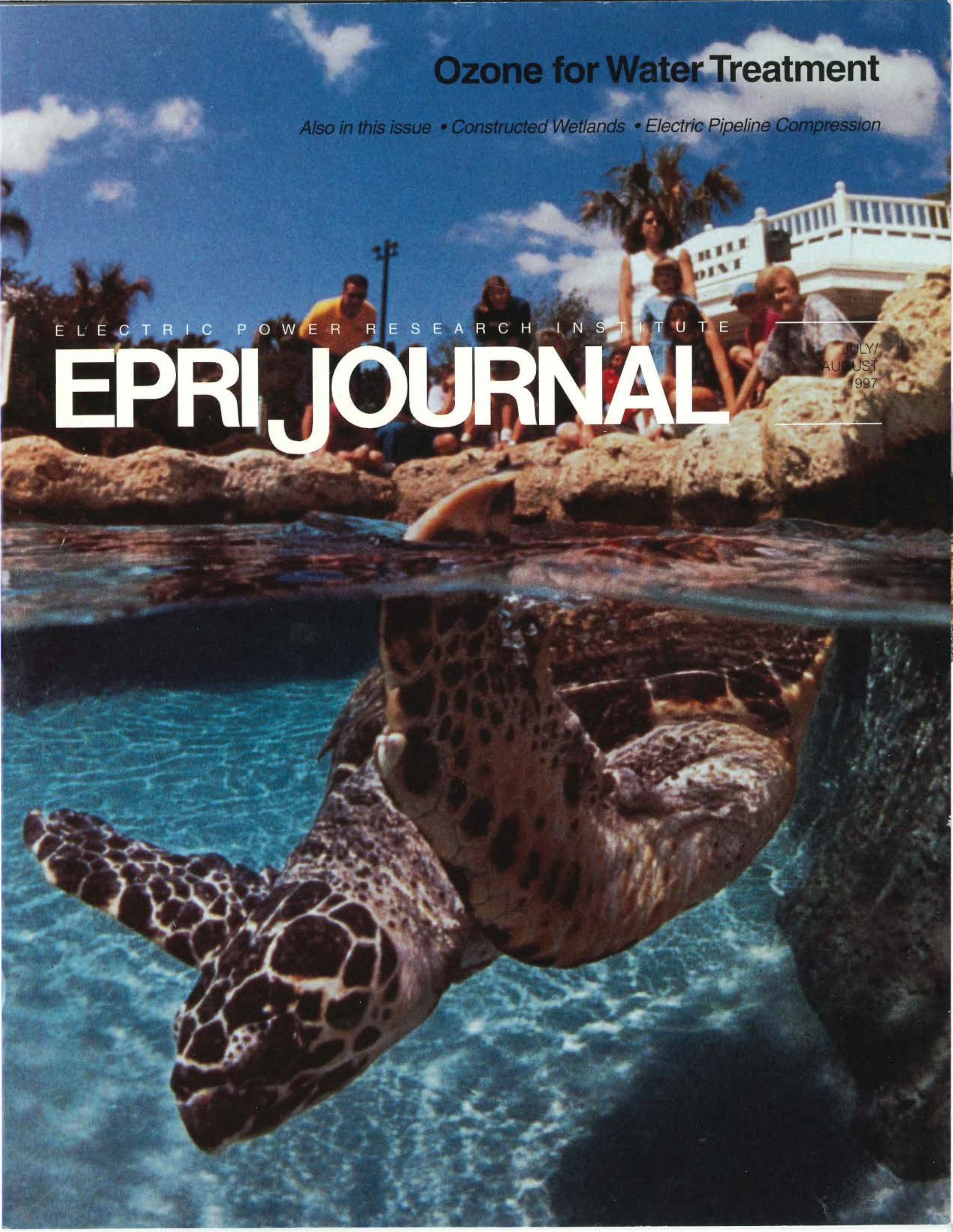
ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

JULY/AUGUST 1997



EPRI JOURNAL is published six times each year (January/February, March/April, May/June, July/August, September/October, November/December) by the Electric Power Research Institute.

EPRI was founded in 1972 by the nation's electric utilities to develop and manage a technology program for improving electric power production, distribution, and utilization.

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Cover: A loggerhead sea turtle plunges into crystal-clear water at Sea World's Orlando, Florida, theme park. Sea World is a pioneer in the use of ozonation for recycling saltwater in aquarium environments. (Photo ©1997 Sea World of Florida, all rights reserved)

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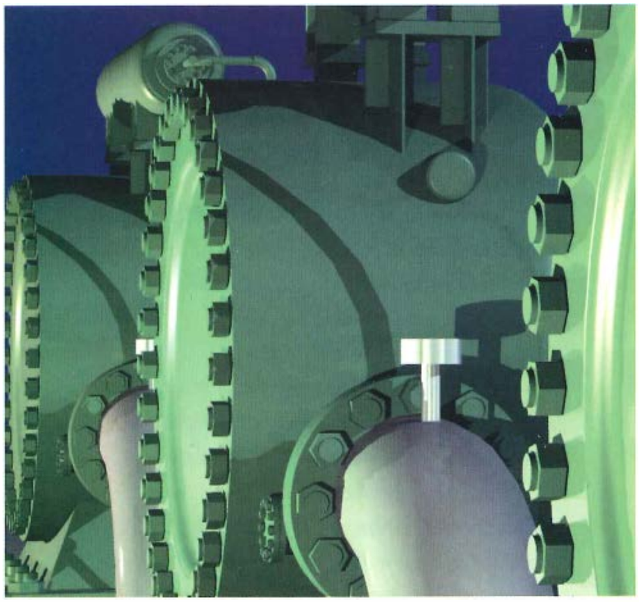

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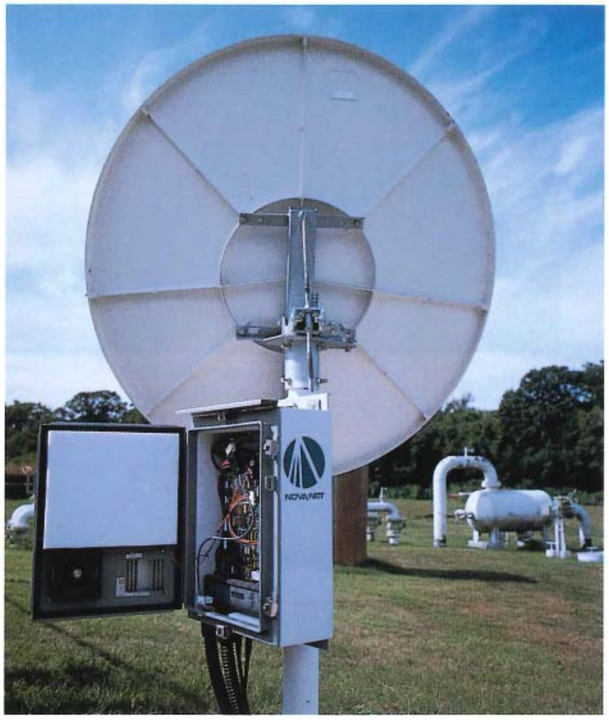

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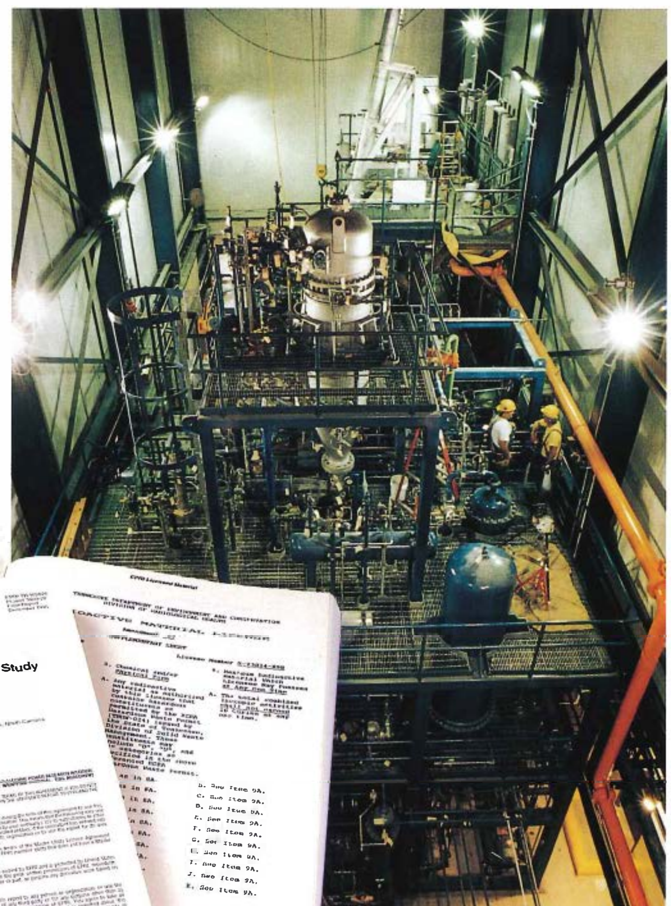
Today's cost-conscious power companies are looking for the most economical way to monitor substation equipment and read customer meters remotely. This new product, developed by EPRI and ICG Nova-Net, offers a more cost-effective alternative to options such as leased telephone lines. The electronics for this compact, 1.2-meter dish are mounted in an environmentally rugged enclosure. The entire unit can be installed quickly and easily, and it can be operated by either ac or dc power. Compliant with Utility Communications Architecture (UCA™) protocols, SCADA-SAT is suitable for outdoor installation and offers capital and operating costs significantly lower than those of alternative satellite systems. Power companies of all types—from those serving densely populated urban areas to those in remote locations---can use SCADA-SAT for around-the-clock surveillance of system operations.

For more information, contact Bill Blair, (650) 855-2173. To order, call Don Rowe at ICG Nova-Net, (303) 705-6915.



FRONT PHOTO BY RON MAY; BACK PHOTO COURTESY MOLTEN METAL TECHNOLOGIES

Mixed Waste Manual

Because mixed waste contains both radioactive wastes, which are regulated by the U.S. Nuclear Regulatory Commission, and hazardous wastes, which are regulated by the U.S. Environmental Protection Agency, managing such waste can be a significant challenge for nuclear utilities. This reference manual, *Mixed Waste Treatment Study* (TR-105826), offers for the first time a comprehensive analysis of all the options available for both on-site treatment and off-site treatment/disposal, including emerging technologies. The guide is designed to help utilities meet their multiple regulatory requirements in the most cost-effective manner possible.

For more information, contact Carol Hornibrook, (650) 855-2022. To order, call the EPRI Distribution Center, (510) 934-4212.

PQPager

Seemingly minor power quality disturbances can disrupt the electronic systems of large commercial and industrial customers, costing millions of dollars in downtime and lost products. Although tracking the quality of power at these facilities can help customers avoid such losses, most of the monitoring devices available today are very costly. PQPager offers power customers a low-cost alternative that makes monitoring affordable, even for small businesses. Mounted next to the customer's meter, PQPager automatically telephones both the utility account representative and the customer's engineer and explains in a synthesized voice the details of power quality problems as they occur.
For more information, contact Sid Bhatt, (650) 855-8751. To order, call BMI, (408) 970-3700.

PowerDOE

Power companies and their customers alike can use this state-of-the-art energy analysis program to conduct detailed assessments of energy use and cost in residential, commercial, industrial, and institutional buildings. The program incorporates an enhanced version of DOE-2—a program developed in collaboration with the U.S. Department of Energy that has served as the basis for many energy-related local, state, and federal building codes and standards. In analyzing energy use and cost, PowerDOE® accounts for all relevant aspects of a given building or campus of buildings, including architectural features, such as window types, wall structures, lighting systems, floor layouts, and space usage, mechanical systems for heating, ventilating, air conditioning, and refrigeration; and even complex engineered systems, such as on-site electric generators, thermal storage, and district heating and cooling systems.
For more information, contact Karl Johnson, (650) 855-2183. To order, call the Electric Power Software Center, (800) 763-3772.

Dynamic Voltage Restorer

Keeping customers happy is more important than ever in today's competitive business environment. That's why EPRI helped develop the Dynamic Voltage Restorer (DVR). A power electronic device that keeps sensitive customer equipment running smoothly during temporary voltage fluctuations (such as those that result from lightning strikes and tree contact), the DVR rapidly injects energy onto the distribution line to compensate for these disturbances. Developed by Westinghouse with funding from Duke Power and EPRI, the DVR is the most advanced of several electronic power controllers that EPRI has introduced to better serve commercial and industrial power customers.
For more information, contact Ashok Sundaram, (650) 855-2304. To order, call Neil Woodley at Westinghouse, (412) 256-2323.

Proton-Induced Fission Promotes Superconductivity

A challenge to many potential applications of high-temperature copper oxide superconductors is the easy motion of magnetic flux lines, which creates electrical resistance and suppresses the regime of desirable lossless conduction of current.

The intrinsic tendency to magnetic vortex motion can be strongly counteracted by the creation of columnar defects, which localize the vortices and expand the range of finite critical current density. This key measure of a superconductor's performance in high magnetic fields is marked by the irreversibility line in a field-temperature diagram, above which vortices are very mobile and which is ultimately limited by a high-temperature superconductor's transition temperature.

For mercury cuprates—the highest-temperature superconducting materials discovered to date—EPRI-cosponsored research indicates that fission of mercury nuclei with energetic protons can help stabilize magnetic vortices with large-diameter columnar defect tracks and thus maintain lossless current conduction. As a result of this process, the current-carrying capacity of the superconductor increases by orders of magnitude and the irreversibility line shifts upward to higher temperatures and field strengths.

Micrograph of columnar defects in Hg-1212

In ongoing work, the scientific and practical implications of the new process are being explored by the research team, which includes scientists from IBM, the University of Tennessee, Ohio State University, Los Alamos National Laboratory, and the Texas Center for Superconductivity.

Because protons penetrate great distances into the material, this novel mercury-fission process may be suitable for large-scale applications, such as irradiating wires wrapped around magnets.

■ *For more information, contact Paul Grant, (650) 855-2234.*

Pursuing the Promise of Zinc-Air Batteries

With four to five times the specific energy of lead-acid batteries and a low materials cost, batteries that use zinc as the negative electrode and air fed to a porous positive electrode are attractive candidates for powering portable equipment and electric vehicles.

Zinc electrodes are difficult to recharge over many cycles, however, because the metal tends to be deposited during charging in the form of dendrites that can short battery cells or as mossy or densified zinc—both of which are difficult to discharge. Another problem with electrically recharging zinc-air batteries is that the high potential applied to the air electrode during charging results in its relatively rapid corrosion and premature failure. As a result, practical zinc-air batteries capable of hundreds of deep cycles are not available, despite the fundamental attractiveness of this battery type and extensive past efforts to realize its potential.

To overcome the problems caused by electrical recharging, several zinc-air battery concepts that depend on mechanical recharging of the zinc electrode have emerged in recent years. In exchange for much-improved cycle life, these concepts require some type of system—an infrastructure—for the removal, collection, regeneration, and replacement of zinc electrodes. Electric Fuel Corporation, headquartered in Israel, has developed and demonstrated at the pilot-plant scale all of the infrastructure processes as well as the basic battery technology suitable for mechanical recharging of zinc-air batteries.

EPRI staff recently completed a preliminary evaluation—with positive findings—of the technical prospects for Electric Fuel's zinc-air battery system. For example, in ongoing field tests with vehicles of the German postal service, a 4-ton truck equipped with a 150-kWh Electric Fuel battery below the vehicle's loading surface demonstrated a practical range of more than 260 miles on a single battery charge—about five times the capability of a vehicle equipped with a lead-acid battery of comparable weight.

EPRI and Electric Fuel agreed in June to collaborate in a joint effort to evaluate, improve, and commercially introduce the company's zinc-air battery system (including the necessary infrastructure) in North America. Initial EPRI funding for the phased joint program comes from Strategic R&D, which conducted the technical assessment, including field visits to the demonstration site in Bremen, Germany, and a preliminary study of prospective battery and infrastructure costs.

COURTESY ELECTRIC FUEL CORP.

The first Deutsche Post delivery trucks equipped with Electric Fuel's zinc-air batteries make a simulated mail run in Bremen.

Strategic R&D and EPRI's Electric Transportation Business Area will comanage the collaboration with Electric Fuel. The program initially will assess the batteries' acceptability for use in fleet vehicle markets, determine the prospective costs of establishing zinc regeneration infrastructures on a scale compatible with regional U.S. fleet operations, assess the technology's environmental impact, and verify and test the performance of improved batteries under laboratory and actual-use conditions in the United States.

Favorable findings in these studies and tests could lead to the development of commercialization plans for the technology in this country, including the formation of strategic alliances with public and private organizations. "After reviewing the technology, we believe that the Electric Fuel battery system has excellent potential to give electric vehicles the improved performance and lower cost needed for fleet applications," says EPRI's Gail McCarthy, director of Strategic R&D. "We look forward to working with Electric Fuel and our member strategic partners toward realization of the technical and business potential of this promising technology."

In addition to the field tests with Deutsche Post, Electric Fuel has a license agreement with the Italian energy supplier Edison to commercialize the zinc-air battery in Italy, Spain, France, and Portugal. The Swedish utility Vattenfall has a license to commercialize Electric Fuel's battery and infrastructure in the Nordic countries and in St. Petersburg, Russia, and plans to demonstrate the battery and infrastructure technologies at the 200-vehicle level.

■ *For more information, contact Fritz Kalhammer, (650) 855-2547.*

Pushing the PV Efficiency Envelope

Photovoltaic flat-plate multijunction cells based on copper indium diselenide (CIS) and related alloys containing gallium or sulfur have the potential to reach sunlight-to-electricity conversion efficiencies exceeding 25%—far higher than the 15% goal previously established by EPRI as the threshold for PV technology to compete with conventional electricity-generating options in the sunniest locations. EPRI and the National Renewable Energy Laboratory (NREL) are cosponsoring the next phase of research on these promising PV materials.

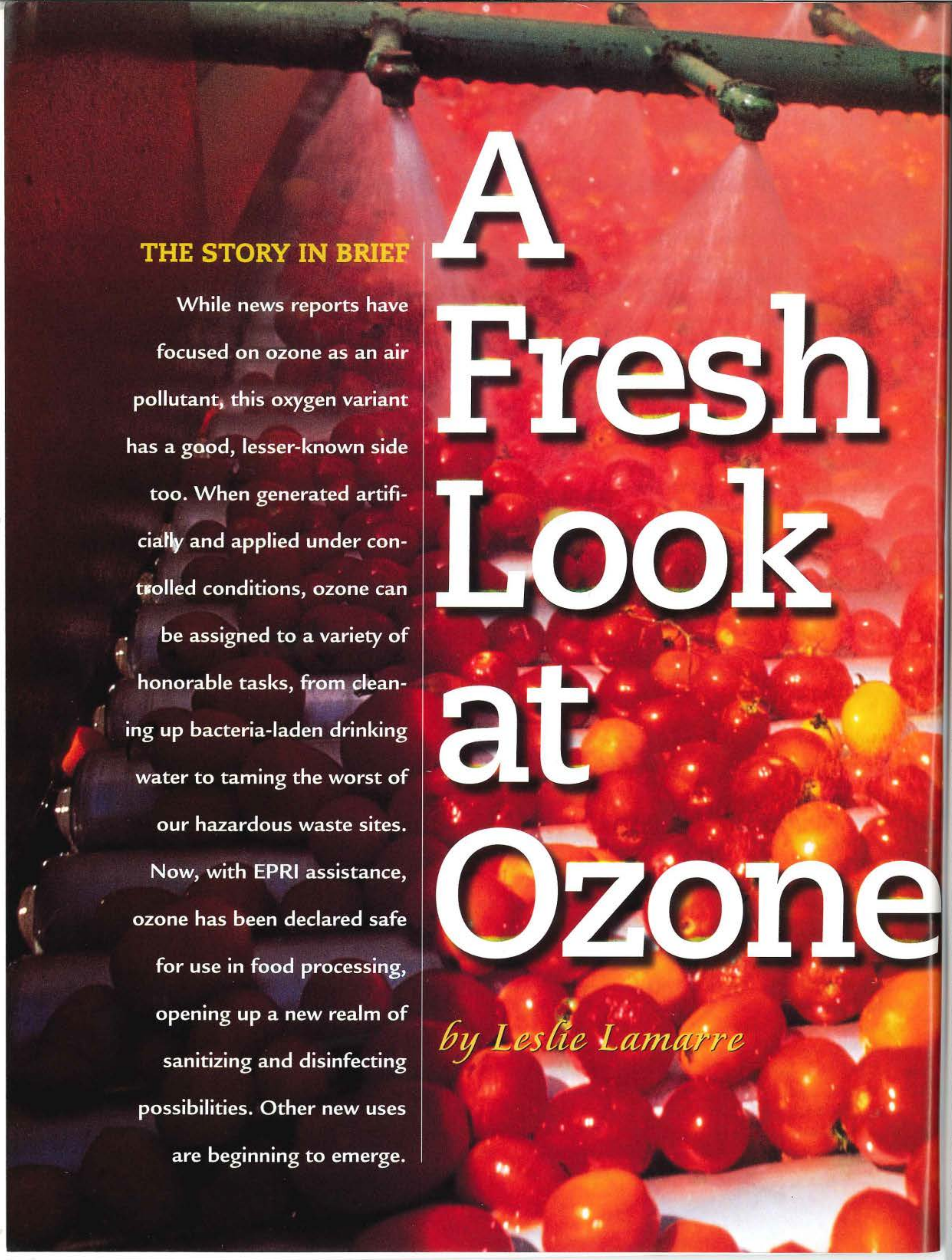
Previous NREL and EPRI research jointly focused on producing high-quality amorphous silicon (a-Si) and CIS materials, characterizing basic structural and physical properties, and developing safer and more environmentally friendly fabrication methods. The latest solicitation for the next phase of NREL's thin-film PV partnership program will build on the earlier findings to create super-high-efficiency multijunction PV devices that will greatly increase economic applicability.

Meanwhile, a new record of 13% stabilized efficiency for flat-plate, amorphous thin-film PV devices was recently established by United Solar Systems Corporation, using a-Si and a-Si-germanium materials in an advanced, triple-junction experimental PV cell. The alloy materials work in tandem to convert a larger portion of the solar spectrum to electricity than single-junction PV cells.

The stabilized efficiency breakthrough was based on a fundamental understanding of the relationship between PV materials properties and processing, derived in part through United Solar Systems' participation in the national effort funded by NREL and EPRI. The record efficiency was reported at the Materials Research Society spring meeting in San Francisco.

Commercial production is under way for a-Si-based modules using essentially the same technology as the record-breaking cell. The modules are warranted at 7.5% stabilized efficiency until more production experience is gained.

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



A Fresh Look at Ozone

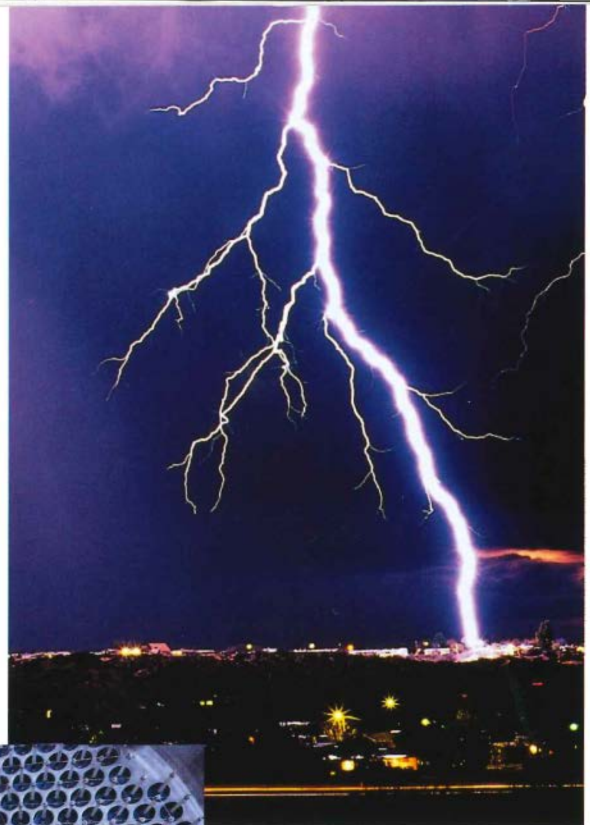
by Leslie Lamarre

THE STORY IN BRIEF

While news reports have focused on ozone as an air pollutant, this oxygen variant has a good, lesser-known side too. When generated artificially and applied under controlled conditions, ozone can be assigned to a variety of honorable tasks, from cleaning up bacteria-laden drinking water to taming the worst of our hazardous waste sites. Now, with EPRI assistance, ozone has been declared safe for use in food processing, opening up a new realm of sanitizing and disinfecting possibilities. Other new uses are beginning to emerge.

It sometimes happens that the best solutions to society's problems lie right before our eyes. In few cases is this more literally true than with ozone. Generated naturally when lightning bolts send electric charges through the air, ozone is one of the most powerful disinfectants and oxidants known. This explains why the air smells so fresh after a thunderstorm.

Ozone can also be generated artificially by passing air or oxygen through an electric discharge. And when ozone is used under controlled conditions, the same capabilities that effectively clean and freshen the ambient air during a storm can solve a number of other pressing environmental problems, from ensuring the safety of our drinking water to reducing the toxicity of our industrial wastes.



OZONE GENERATORS—NATURAL AND ARTIFICIAL **A gas generated naturally when lightning bolts rip through the air, ozone is responsible for that post-storm fresh-air scent. Although humankind's ozone generators are far less glamorous, they offer the same cleanup capabilities.**

A form of oxygen that has three atoms per molecule (O_3) rather than the usual two, ozone is an unstable gas that naturally decomposes into ordinary oxygen fairly quickly, especially in water. As the extra oxygen atoms split off from the ozone molecules, they can play one of two critical roles: disinfection or oxidation. As disinfectants, these atoms quickly destroy the bacteria they contact, leaving only common oxygen behind. As oxidants, the atoms adhere to existing chemical compounds, typically changing them to more-innocuous substances.

Artificially generated ozone is nothing new. In fact, Europeans have relied on the technology to treat drinking water for nearly a century. In contrast, the United States has been slow to adopt ozonation, largely because chlorination has been less costly to implement. Now, however, concerns about human health and the environment are convincing a variety of industries in this country—from drinking water treatment and food processing facilities to commercial laundries and zoos—to deploy ozonation. And it's no wonder. In 1991, the U.S. Environmental Protection Agency confirmed that ozone is the most effective primary disinfectant available for drinking water. In fact, ozone is far more effective than conventional disinfectants against the microbial contaminants—including *Escherichia coli*, *Salmonella*, *Giardia*, and *Cryptosporidium*—that have invaded our food and water supplies and claimed numerous lives in recent years. And consumer ingestion of ozone is virtually impossible, given its short half-life. Moreover, with an oxidation capacity 52% greater than chlorine's, ozone can address odor and color problems and can degrade harmful organic compounds, including some pesticides, and many impurities typically found in industrial waste streams.

"In an increasing number of applications that involve disinfection and oxidation, ozone is clearly the best next-generation technology—a far more effective approach than traditional methods involving extensive chemical applications that produce secondary pollutants," says Myron Jones of EPRI, which has studied and encouraged the use of ozonation for drinking water treatment for about seven years. "Ozone is like a good contractor. It gets the job done quickly and goes away without leaving a mess behind. When you're dealing with environmental issues, this is a great asset."

Over the years, EPRI's ozone research has branched into a variety of areas, exploring ozonation's effectiveness as a biocide replacement in cooling towers, as a bleach and detergent substitute in large-scale laundry facilities, and as a way to treat several kinds of industrial wastes. But perhaps the biggest single EPRI-instigated coup on the ozone front so far is an expert panel's recent affirmation of GRAS—generally recognized as safe—status for ozone as a sanitizer or disinfectant for foods. Allowed under a 1958 amendment to the federal Food, Drug, and Cosmetic Act, this GRAS affirmation was completed in February and delivered with supporting documentation to the Food and Drug Administration (FDA) in April. It clears the way for ozone's use in the $430 billion food processing industry.

Now and then

These days, most people associate the word *ozone* with the ozone layer in the stratosphere—the layer that protects us from the sun's harmful ultraviolet rays. News reports have also told us of ozone as a pollutant—a component of smog that results from a combination of other air pollutants, sunlight, and air. But artificially generated ozone was put to practical use well before these other aspects of the substance ever made newspaper headlines.

Ozone—whose name is derived from the Greek word *ozein,* which means "to smell"—was officially discovered in 1840 by the German scientist Christian F. Schönbein, who named the substance for its acrid scent. In 1893, the city of Oudshoorn in the Netherlands deployed the first commercial-scale ozone system for disinfecting drinking water. Gradually, ozonation became standard practice for water disinfection in a number of cities in the Netherlands, France, Austria, Germany, Switzerland, and other countries. Not until 1940, however, was the first drinking water treatment plant featuring the continuous use of ozone installed in the United States—in Whiting, Indiana, a suburb of Chicago.

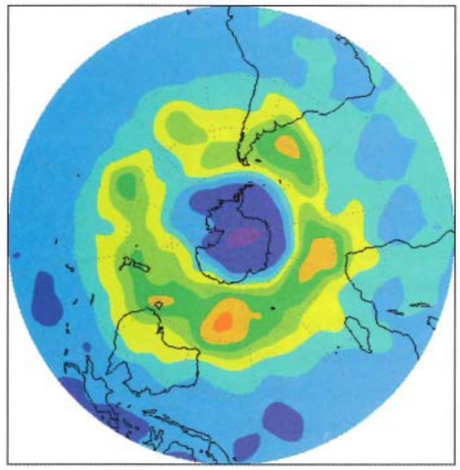
Produced by passing dry air or high-purity oxygen between two parallel electrodes (typically tubular or flat plated), ozone, like chlorine, is bubbled into water as a gas. The effectiveness of treating water with ozone is directly related to the water's temperature, its pH (hydroxide ions accelerate ozone's decomposition), and the size of the ozone bubbles generated. Because ozone is unstable and cannot be stored, it must be generated and applied on-site. Ozonation equipment must be carefully designed and operated to ensure that the gas is produced efficiently and used effectively—and safely. Indeed, while numerous toxicological studies show that ozone is neither mutagenic nor carcinogenic, it is a toxic gas and a respiratory irritant.

As evidenced by the GRAS affirmation effort, the food processing industry is the latest U.S. industry to embrace ozone. According to EPRI's Ammi Amarnath, who oversaw that effort, food processors across the country consume billions of gallons of water daily for washing foods and food equipment, for transporting various edibles through flumes, for cooking, and for mixing into foods that are bottled, jarred, or bagged. "Basically, wherever you've got water, you could use ozone," he says.

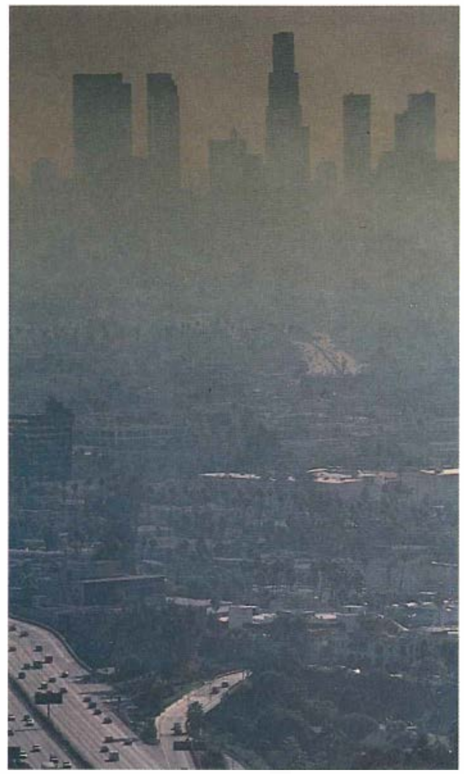
Traditionally, water for food processing is treated with chlorine. When reused, the water must be treated with chlorine again, and the buildup of toxic chlorine residuals becomes a concern. Not only can ozonation reduce the water's bacterial count and eliminate the discharge of harmful chlorine residuals, but it can also significantly reduce the amount of wastewater generated by the industry, since it can disinfect wastewater effectively without producing significant residuals. Common by-products of the ozonation process are acids, aldehydes, and ketones—biodegradable organic materials that also occur naturally as a result of bacterial decomposition. Studies indicate these by-products do not pose a health risk to consumers. However, if the bromide ion is present in water, ozone can, under certain conditions, oxidize it to the bromate ion, which has been shown to cause cancer in some animals. Technologies have been developed to minimize the formation of bromate during ozonation.

Before the GRAS affirmation, the use of ozone in food processing in this country was allowed in only two specific applications, despite the fact that elsewhere—France, Germany, Scandinavia, Japan, and Israel, for example—ozone has been widely used for as long as 75 years. In the United States, the Department of Agriculture approved the use of gaseous ozone for meat storage in 1957, specifying that the ozone must be dispensed at concentrations no greater than 0.1 ppm. And in 1982 the FDA affirmed GRAS status for ozone specifically for bottled water.

THE THREE FACES OF OZONE At its highest altitude, in the stratosphere, ozone exists in a layer that protects all life forms on earth from excess ultraviolet radiation. Closer to earth, in the troposphere, ozone is a major component of the photochemical smog that can invade urban areas and cause respiratory problems. Finally, the ozone we intentionally generate and apply under controlled conditions is a powerful disinfectant and oxidant that wipes out life-threatening microbial contaminants and cleans up industrial wastes.



Ozone layer over Antarctica



Smoggy morning in Los Angeles

Corona discharge from an ozone generator

PHOTOS (FROM TOP): COURTESY NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION; ULF E. WALLIN/IMAGE BANK; COURTESY OSMONICS, INC.

GRAS roots

To attain the GRAS affirmation for ozone for food processing, EPRI followed the FDA's guidelines and assembled a panel of six top experts in food science, food technology, nutrition, toxicology, and ozone chemistry. The Institute also undertook an extensive, worldwide search for scientific and historical documents describing the use of ozone in food processing. In reviewing these data, the experts carefully considered ozone's safety, toxicology, impact on nutrients, and efficacy in food processing. The panel members communicated regularly via conference calls and faxes and convened periodically in Washington, D.C., to review their findings. After 15 months of intensive investigation, they released and signed their assessment, concluding that ". . . the available information supports a Generally Recognized as Safe (GRAS) classification of ozone as a sanitizer or disinfectant for foods when used at levels and by methods of application consistent with Good Manufacturing Practices." This assessment, together with the supporting evidence, was published in an EPRI report (TR-108026) in May.

According to Dee Graham, an EPRI Food Technology Center expert who chaired the panel, it is not necessary for the FDA to reaffirm GRAS status; food processors are free to use ozone now. "GRAS status gives an additive legal approval," he explains, noting that such status is allowed only for substances that were widely used before 1958. "This is an expert affirmation that a particular substance is safe, and it is accepted as safe unless it is successfully challenged in court."

A CLEAN BOUNTY Thanks to the recent blessing of an expert panel, food processors across the country can now use ozone to disinfect and sanitize everything from peaches to poultry.

Officially announced to the food processing industry in this year's June issue of *Food Technology* magazine, the GRAS affirmation comes as great news to food processors. "Food processors are excited about ozone because it's a lot more versatile than chlorine," says Abel Balderrama, who manages a Dole citrus facility in Redlands, California. "You can use it as a gas to disinfect a room for food storage or add it to water to wash food. Other uses are just beginning to come out."

Some suppliers of the food processing industry are just as pleased. BOC Gases, a global supplier of industrial gases, recently announced the completion of a system that uses a mechanical filter and ozonation to disinfect water for poultry processing. This system is now being installed to help poultry processors meet new, stringent standards for food safety. "This is a new growth area for us," says Dennis Smithyman, vice president of BOC's global food marketing. "We anticipate great demand."

Louis Caracciolo, the inventor of the system being marketed by BOC Gases and the president of Louis/Tressler, a food science, safety, and engineering consulting firm, says his phone has been "ringing off the hook" since the GRAS status was affirmed. "GRAS status came at a critical time for the food processing industry," he says, noting that a new federal law went into effect last January that limits, for the first time, the presence of *E. coli* and *Salmonella* on meat and poultry processed in the United States. "This is really a new era in food safety in the United States."

Applications of ozone in the food processing industry are not limited to those involving water. For instance, gaseous ozone could be used to sanitize packaging materials in which food products are stored or to protect produce from rot and over-ripening during storage and transit. EPRI is also investigating the potential for using ozone to control insect infestation during food storage. This would provide an environmentally benign alternative to fumigants now being phased out—for example, the popular pesticide methyl bromide, which is one of only two fumigants still permitted for use on grain and which the federal government is banning as of 2001.

"The GRAS affirmation is going to have repercussions around the world," says Rip Rice, an ozone expert whom some call this country's father of ozone. He notes that other countries, including those that cannot afford their own food additive bureaucracies, are likely to take a cue from the United States and accept ozonation as safe for use in food processing.

DRINK UP **Ozone is widely recognized as the most effective disinfectant for drinking water. Municipal plants across the country, such as the one below in Fremont, California, are depending on it to meet more-stringent environmental regulations.**

Water ways

In the meantime, emerging environmental concerns have convinced a number of drinking water treatment plants in the United States to switch to ozone. Many of these facilities upgraded to ozonation in 1993 to comply with the EPA's 1991 surface water treatment rule, promulgated under the federal Safe Drinking Water Act. This rule required various contaminants to be reduced, including viruses (by 99.99%) and *Giardia lamblia* cysts (by 99.9%). In issuing the rule, the EPA listed chlorine, chlorine dioxide, chloramine, and ozone as candidates to accomplish the task and included data showing ozone to be the most effective option. (Ozonation can be up to 300 times more effective against *Giardia* than disinfection with chlorine, and it results in fewer disinfection by-products—substances that are also coming under increased regulatory scrutiny.)

Today more than 200 U.S. drinking water plants use ozonation, and the number is expected to climb rapidly. As a result of an information collection rule promulgated by the EPA in 1996, the country's largest treatment facilities are now required to gather data on microbes—including chlorine-resistant *Cryptosporidium,* which was linked to approximately 100 deaths and to over 300,000 cases of illness after getting into Milwaukee's drinking water supply in April 1993 and which has since triggered outbreaks in Nevada, Florida, British Columbia, and other regions. The large drinking water plants must also track levels of trihalomethanes and haloacetic acids (chlorination by-products) in their treated water supplies. The EPA will use the resulting data in developing two new drinking water regulations on microorganisms and by-products, to be promulgated by early 1999. According to Keith Carns—the head of EPRI's St. Louis–based Community Environmental Center, which manages the Institute's research on ozonation for drinking water—the upcoming requirements will cover the inactivation of *Cryptosporidium.* "This need will motivate many water utilities to install ozone," he says.

Ozone isn't always used as a disinfectant in water treatment. It can also be used as an oxidant. In fact, the city of Orlando, Florida, is building five full-scale plants to oxidize hydrogen sulfide, which causes taste and odor problems in the local water. EPRI research has also confirmed ozone's strength in this role. In a demonstration at Fort Walton Beach on the Gulf of Mexico, EPRI helped show that ozone could be used to oxidize the hydrogen sulfide that is naturally present in the region's underground waters and is responsible for their rotten-egg smell and sour taste. The city of Fort Walton Beach normally uses aerators to physically strip the hydrogen sulfide from the water. The month-long demonstration late last year showed that ozonation, by oxidizing sulfide to sulfate, was just as effective in eliminating the taste and odor problems. An economic evaluation is now being conducted to determine the cost of a full-scale ozonation system for the city.

Despite its advantages, ozonation is still a big consumer of electricity—big enough to turn away some potential users. Currently, it takes about 10 kWh of electricity to generate a pound of ozone. This compares with 1–2 kWh for the same amount of chlorine. Helping to make up for the higher cost of ozone generation are the transportation, packaging, storage, and safety-related costs for chlorine, which is not normally manufactured on-site. Still, there is ample opportunity to improve the efficiency of ozonation—especially in the way it is deployed.

According to Carns, drinking water treatment plants typically err on the side of conservatism with ozonation, treating water with too much ozone just to be safe. "There's not a very accurate understanding out there—in either municipal or industrial environments—about how much ozone is required to do a given job," he says. This is one finding EPRI has turned up in an ozone optimization study that is assessing ozone systems in drinking water treatment plants across the country.

Through this study, which has been under way for four years, EPRI is helping these plants define their disinfection and/or oxidation goals and develop specific dosage criteria that will enable them to meet those goals. The study is also identi-

PHOTOS (FROM TOP): BARROS & BARROS/IMAGE BANK; COURTESY ALAMEDA COUNTY WATER DISTRICT

IN THE SWIM **Ozone has been used for decades to treat the water in swimming pools and in fact kept pools sparkling clean at the 1996 Summer Olympics in Atlanta. Shown on the right is one manufacturer's equipment designed specifically for such applications.**

fying other ways to achieve efficiency improvements—for example, by varying the amount of ozone used according to the quantity and quality of the water flowing through a system at any given time, and by properly maintaining such equipment as ozone contactors, which may become clogged with dirt and other debris. EPRI has developed an operating protocol manual that drinking water plants can use to improve the energy efficiency of their ozone systems. The third and final phase of the ozone optimization study, which got under way this summer, is aimed at developing design standards for new plants deploying ozonation.

Another approach for increased efficiency—one that's in the early stages of research at EPRI—is to produce ozone from water through an electrolysis process rather than from air or oxygen. EPRI is also investigating the possibility of introducing an electrically charged spray nozzle into ozonation apparatus rather than bubbling the ozone up in a straight line. Called electrostatic ozonation, this approach would generate much smaller ozone bubbles, helping ensure that the ozone contacts the bacteria it needs to kill.

Other markets

Ozone's health and environmental benefits are working to secure it a place in a wide variety of other markets. When used in water in cooling towers, ozone prevents biological growth that stimulates corrosion and the proliferation of deadly bacteria like *Legionella pneumophila* (so named because it caused 34 deaths among those attending an American Legion convention in Philadelphia in 1976). Such bacteria thrive in the warm, damp conditions in cooling towers, humidifiers, and evaporative condensers. Ozone is more effective than chlorine and the other chemical biocides typically used in cooling towers to combat biological growth. And ozonation can offer much lower water consumption and disposal costs than biocides, whose use requires frequent blowdown—the flushing of water from the cooling tower to prevent the buildup of chemicals that can cause scale formation and reduce heat transfer efficiency.

Since the 1970s, when ozonation was first used in cooling towers, a number of cooling tower operators have switched to it from multichemical treatment and are satisfied with the results. Among the new facilities planning to use ozonation for this purpose is a so-called hospital of the future being built in Laredo, Texas, by Mercy Regional Medical Center. This facility will incorporate a number of other advanced electrotechnologies as well when it opens in the spring of 1998. EPRI and Central and South West Services have been working together to help Mercy plan for the facility.

In an entirely different water-based application, ozonation has been used to recycle saltwater in aquarium environments, where water discharge is laden with such concentrated wastes as brine, excess food, and animal waste. A pioneer of this application is Sea World, which first installed ozonation in the mid-1970s as part of a system for recycling water from the porpoise and whale exhibits at its Orlando theme park. Today Sea World uses ozonation—combined with ammonia scrubbing and biological filtration—to recycle the wastewater at all of its marine aquariums. In the two decades since Sea World's first system was installed, at least 50 other aquariums and zoos in the United States and Canada have adopted ozonation for recycling artificial brines. (Natural brines contain the bromide ion, whose oxidation results in hypobromous acid, a substance toxic to marine mammal eggs and juveniles.) In fact, experts say, without ozone there would be few marine aquariums located away from seawater sources.

To encourage the use of ozone in marine aquarium environments, EPRI and the New York Power Authority helped sponsor a demonstration of ozonation at the Central Park Wildlife Center in New York City. This system, which was used to purify the water habitat of polar bears, penguins, sea lions, and other animals, performed well during a year-long pilot. As a result, the center has opted to install a permanent ozonation system. The use of ozone at the facility has reduced the levels of parasites and other contaminants and has improved visibility in the exhibits. It has also enabled the addition of live fish to the exhibits so that the animals can hunt for food. In a related application, EPRI recently helped sponsor a successful demonstration of ozonation for reducing bacterial levels in a freshwater fish-farming facility in Iowa.

A more recent application of growing interest is the use of ozone in the commercial laundry industry. Benefits include reduced chemical and water use. Tri-O-Clean Systems of Fort Pierce, Florida, has installed about 20 ozone-based laundry systems around the country in the past six years. The company reports that these systems require, on average, about 25% less water and 60% less chemicals than conventional systems.

As Mike McKeever of Tri-O-Clean explains, conventional systems may require the addition of neutralizing chemicals to counteract the effect of detergents, alkalies, and softeners on the water's pH. In an ozone-based system, ozone and surfactants work together for stain removal. Because the surfactants are closer to neutral in terms of pH, the addition of neutralizing chemicals may not be necessary. As a result, three or more rinse cycles can be eliminated, cutting hot water costs by as much as 80% while reducing wear and tear on fabrics and potentially extending their life. Moreover, since ozone-based systems involve shorter wash cycles, they increase laundry production and reduce labor costs. Closed-loop systems, which recycle laundry water, can reduce water use even further—as much as 70%. Hospitals, nursing homes, prisons, and commercial laundries are among the facilities that are already realizing such benefits.

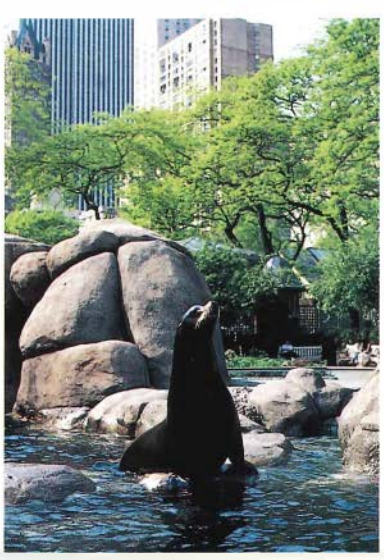
In December of last year, EPRI teamed up with Tri-O-Clean to introduce an ozone-based laundry system to the health care industry. (The country's 7300 hospitals generate some 5 billion pounds of soiled linen annually.) Through this program, EPRI members are helping install and monitor Tri-O-Clean's technology at health care facilities in their service territories. What these facilities are finding is that savings in chemicals, water, and the energy required for water heating can translate into significant reductions in operating costs.

One participant, Illinois Power Company, is working with Decatur Memorial Hospital, which processes over 2 million pounds of laundry annually. The hospital installed the new ozone-based system early this year and projects annual savings of $52,000. "Our hospital is typical of most in the health care industry in its efforts to maintain high levels of patient care, improve cost control, and adequately address environmental issues," says Tim Stone, Decatur Memorial's vice president. "EPRI and Illinois Power have offered us a positive alternative to our current laundry system to incorporate these objectives."

Industrial inroads

A major area of rising interest is the use of ozonation to treat the wastewaters of various industries—industries as diverse as electronic chip and aircraft manufacturing. "Ozone is the most powerful oxidizing agent available for the treatment of industrial wastewaters," says ozone authority Rip Rice, who published an extensive review of such applications early this year. The use of ozonation for this purpose has been rare, however, mainly because federal regulations have focused on the lowest-cost treatments rather than the most effective, he says. Nevertheless, Rice's review cites a number of successful full-scale applications, including the use of ozone to destroy organic contaminants in the groundwater at hazardous-waste sites.

At the Lorentz Barrel and Drum Superfund site in San Jose, California, ozone has been used in combination with ultraviolet radiation and hydrogen peroxide to remove volatile organic compounds (VOCs) from the groundwater. The process resulted in the removal of 90% of most VOCs, including trichlo-



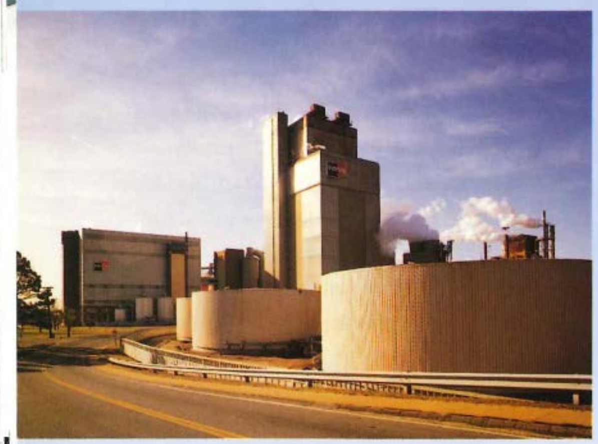
HEALTHY HABITATS
Aquariums and zoos across the country use ozonation to recycle saltwater in their exhibits. Advantages include reduced contaminants, improved visibility, and the ability to add live fish so animals can hunt for food.

PHOTOS (CLOCKWISE FROM TOP): RON GORDON GARRISON/COURTESY ZOOLOGICAL SOCIETY OF SAN DIEGO AND DEL INDUSTRIES; COURTESY MONTEREY BAY AQUARIUM; COURTESY NEW YORK ZOOLOGICAL SOCIETY roethylene, benzene, and acetone. Some of the VOCs were oxidized, while others were stripped from the water as a result of the physical agitation caused by the rapidly moving ozone bubbles. The resulting groundwater met discharge standards, and no harmful emissions were released.

In metal-finishing operations, ozone is being used to treat wastewater laden with cyanide. In this application, ozone works by oxidizing the cyanide ion, converting it to the less toxic cyanate ion, which gradually hydrolyzes to nitrogen, carbon dioxide, and water. At the Cadillac division of General Motors in Detroit, an ozone system ensures the complete destruction of cyanide-containing metal-finishing wastes. Cyanide-contaminated wastewaters at this facility go to a holding tank and then to two ozone reaction tanks. Ten minutes in the vessels is enough to accomplish the oxidation. From there, the water flows to a blending tank and clarifier for final settling, filtration, and discharge to the city

Ozone in Paper Making

One relatively new but significant commercial use of ozone is for pulp bleaching in the paper industry. As a chlorine replacement, ozone oxidizes the brown lignin in pulp, turning the pulp white enough to use in making office paper and other types of high-quality printing paper. Aside from the advantage of eliminating such cancer-causing by-products of chlorination as dioxins, mills that use ozone also require far less water than do plants with chlorine-based systems.



Union Camp Corporation's pulp and paper mill in Franklin, Virginia

PHOTO COURTESY UNION CAMP CORP.

Today ozone is used in 19 full-scale pulp-bleaching plants around the world, including three in the United States and others in South Africa and Brazil. According to ozone expert Rip Rice, ozonation was first used for this purpose in full-scale commercial settings in Europe and the United States in 1992 as a result of environmental pressures. Rice explains that paper companies in Germany, responding to local environmental concerns about chlorine bleaching, initially opted to purchase their pulp from Scandinavia and Austria. When the environmental organization Greenpeace learned of this practice, it confronted the German companies, accused them of exporting an environmental problem, and demanded that they require their pulp to be bleached without chlorine. The German industry complied, thereby spawning the installation of ozone-based bleaching systems in Scandinavia and Austria.

Reduced water use and improved water discharge quality were the primary incentives for the first U.S. application of ozone for pulp bleaching—at a plant in Franklin, Virginia. Owned by Union Camp Corporation, the mill is located on a small river where water use and discharge are strictly regulated. Before the implementation of the ozone-based system, nearly half of the mill's effluent pollutants resulted from the bleaching process, as is the case in most integrated pulp and paper mills.

More than 10 years of research went into developing this highly successful ozonation system, including four years of operation at a 25-ton-per-day pilot plant. (The capacity of the Franklin plant is 1000 tons per day.) In Union Camp's system, pulp is pressed to a high consistency before it is delignified by ozone under proprietary conditions in a patented reactor. Oxygen-rich gases exiting the reactor are economically recycled back to the ozone generators. Chlorine dioxide is used only in the final stage, to further brighten the pulp, and could be replaced by hydrogen peroxide for totally chlorine-free bleaching, says Rice.

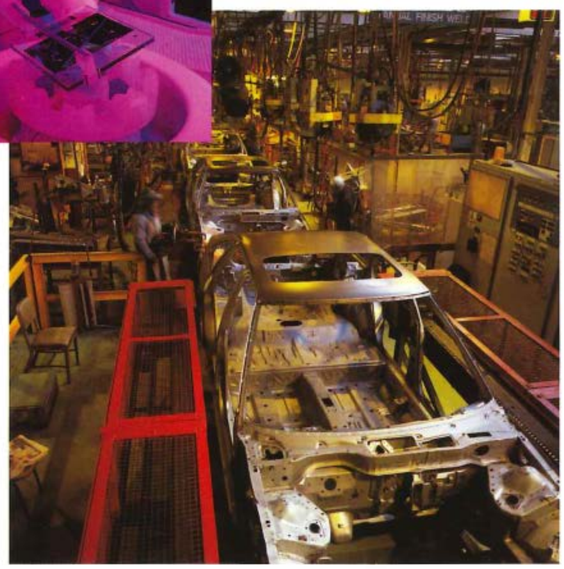
Compared with the conventional chlorine bleaching sequence it replaced, the Franklin plant's ozonation system has reduced levels of total chlorinated organics by more than 97%, oxidation-related byproducts by 70–90%, color by more than 98%, and effluent volume by 85%. The system's capital costs were 25–30% higher than those associated with a traditional chlorine system, but its operating costs are substantially lower. For instance, chemical bleaching costs alone have been reduced by 30–40%. Union Camp has licensed its technology to three other paper mills—one in Wisconsin, one in South Africa, and one in Sweden.

There is a clear movement away from the use of elemental chlorine for pulp bleaching in the paper industry. Already, many U.S. mills have voluntarily substituted chlorine dioxide for chlorine in this process. And this summer the U.S. Environmental Protection Agency will release its so-called cluster rules for the pulp and paper industry. These will include more-stringent regulations for air and water emissions and are expected to require a switch to chlorine dioxide.

Although ozonation systems may make sense for new pulp-bleaching facilities, existing plants may have little incentive to deploy them because the systems' capital costs are greater than the costs of shifting to chlorine dioxide. Still, environmental groups like Greenpeace are increasing pressure on pulp and paper facilities to switch to nonchlorine bleaching methods. Such pressure is coming from the facilities' customers as well, who want to tell increasingly environment-conscious consumers that the paper they're buying is the result of a chlorine-free process.

EPRI is currently investigating another ozone application for reducing the toxicity of paper industry effluents. In a project that got under way this spring, researchers at the Georgia Institute of Technology in Atlanta are testing the effectiveness and efficiency of using ozonation in combination with biological treatment to reduce the residual toxicity of paper mill wastewaters. Results are expected by the end of the year. □

INDUSTRIOUS OZONE **A wide variety of industries rely on ozone for cleanup tasks. While some, such as airplane and automobile manufacturers, use ozone to decontaminate wastewater, others, such as electronic chip and pharmaceutical manufacturers, use it to provide the high-quality water they need for their processes.**



sewer system. Installed in 1978, the ozone system has consistently reduced the concentration of cyanide in the wastewater from an initial 60 milligrams per liter to less than 1 milligram per liter. Boeing has had similar success with an ozone system it installed in 1957 to oxidize the cyanide in wastewater from its aircraft manufacturing plant in Wichita, Kansas.

In textile plants in Japan, Italy, England, and other countries, ozone is widely used to reduce the intensity of dye colors in the plant effluent. This application of ozone, which allows for the reuse of water, salts, and alkali, is only beginning to be considered in the United States. EPRI researchers are closely examining its potential and recently completed a successful demonstration of the process at a textile plant in Alabama.

Just as ozone can be used to treat the wastewater of various industries, it can be applied to produce the high-quality water that some industries require to make their products. Throughout the United States and Japan, for instance, electronic chip manufacturers deploy ozonation to recycle spent deionized water from their plants. Ozone is also widely used in the pharmaceutical industry to generate the ultrapure water needed in its manufacturing processes. Typically, water is purified by means of ion exchange and transferred to a storage tank until it is needed. As the water is circulated in the tank, ozone serves as a biocide to keep it free of bacteria. This task is critical, since a number of pharmaceuticals are made biochemically and the introduction of unwanted bacteria could result in unwanted chemical compounds.

In an even more established application, the pharmaceutical industry also uses ozone as an oxidant in its manufacturing processes. Unlike other available oxidants, ozone does the job without leaving behind residuals to disrupt the chemical reactions under way. It's also highly selective—that is, capable of targeting certain functional groups within a chemical compound without affecting the rest of the compound.

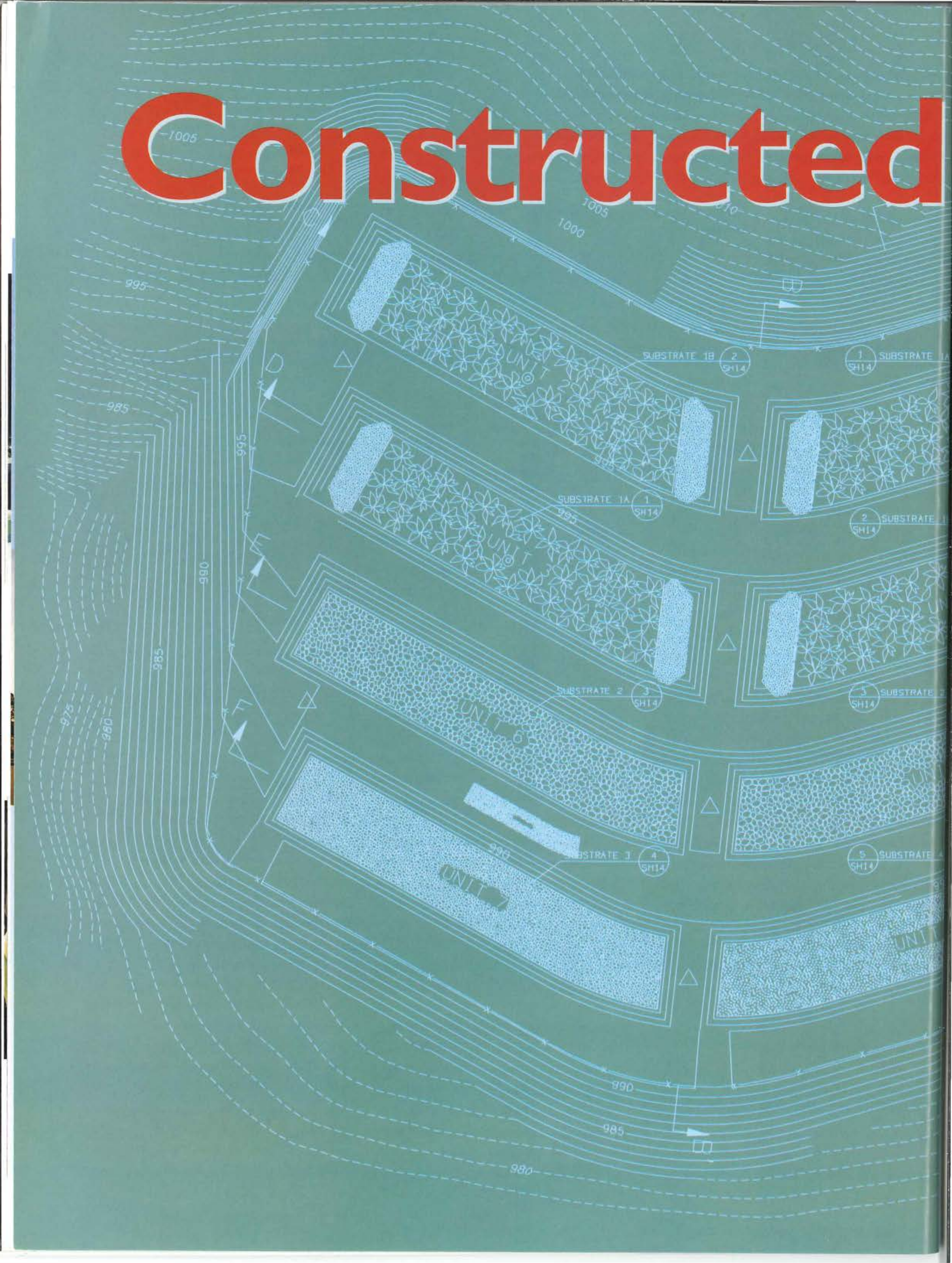
As EPRI's Myron Jones notes, there are scores of other possible applications of ozone still left to explore. Among those of interest are using it as a substitute for chemical soil fumigants, as an aid in agricultural drip irrigation systems (to prevent the clogging of emitters), and as a purifier for the high-quality water required for dialysis procedures. "Basically, any application that calls for purification or oxidation can potentially benefit from ozone," says Jones. "The sky's the limit." ■

WHITE WASH **Commercial-scale laundries, such as those in hospitals and prisons, are switching to ozone-based systems to reduce chemical and water use.**

Background information for this article was provided by Ammi Amarnath, Keith Carns, and Myron Jones of the Industrial & Agricultural Technologies & Services Business Area.

BOTTOM PHOTO VLADIMIR LANGE/IMAGE BANK; OTHER PHOTOS (CLOCKWISE FROM TOP): COURTESY BOEING COMMERCIAL AIRPLANE GROUP; JEFF SMITH/IMAGE BANK; DIGITAL VISION; COURTESY IBM

Constructed



Wetlands

Treat Wastewater Naturally

THE STORY IN BRIEF

By imitating and enhancing the natural cleansing functions performed by wetland ecosystems, constructed wetlands can successfully treat a variety of wastewaters. Through collaborative efforts at sites across the United States, EPRI is directing an applied research program to engineer and optimize constructed wetlands for treating leachate from coal combustion by-products, coal pile runoff, acid mine drainage, and other metal-bearing utility wastewaters. Meanwhile, in complementary laboratory research, the natural biological, chemical, and physical removal mechanisms that occur in wetland soils, microorganisms, and plants are being explored at unprecedented levels of detail, and genetic engineering and other innovative approaches are being applied to accelerate treatment processes.

BY CHRISTOPHER R. POWICKI

Wetlands are among the most productive of natural ecosystems, sharing the characteristics of terrestrial and aquatic environments and acting as buffers between them. In these transition zones, plants and microorganisms interact with water and sediments, reducing the biological, chemical, and physical impacts of the intersecting ecosystems on one another while fueling wetland productivity.

From ancient civilizations in China, Mexico, and Egypt all the way up to the present, human and other waste streams have been directed to wetlands. Wetland processes have thus been protecting surface waters from terrestrial discharges for thousands of years, but their purification potential was not formally recognized until the 1960s. Since then, intensive research and municipal, industrial, and agricultural experience indicate that filtering, flocculation, precipitation, nutrient uptake, photosynthesis, decomposition, volatilization, and other natural processes transform many pollutants—such as excess nitrogen, excess phosphorus, suspended solids, and heavy metals—into biomass, harmless byproducts, or useful nutrients.

Natural wetlands, however, do not always function in the predictable fashion critical to effective environmental control. Moreover, they have great value beyond their control capabilities: they offer unique ecological, aesthetic, and practical benefits, including wildlife habitat, recreational opportunities, groundwater recharging, flood control, and coastal protection. Constructed wetlands enable society to reproduce and exploit the treatment capabilities of natural wetlands while protecting and preserving those dwindling ecosystems.

In constructed wetlands, the processes intrinsic to natural systems occur in a highly engineered environment, with soils and other substrates, vegetation, microbial consortia, flow patterns, size, and other characteristics tightly controlled to reduce variability and increase treatment effectiveness. Many processes are decoupled and isolated in individual wetland cells that perform specific treatment functions or target specific contaminants. Wastewater flows by gravity—either above or below the ground—through these cells, which wetland designers select, sequence, and size on the basis of discharge characteristics and treatment goals.

"Properly designed wetlands greatly exceed the treatment capabilities of natural systems, even though they may look wholly unlike wetland ecosystems," says John Goodrich-Mahoney, EPRI project manager. "What appear to be lifeless ponds, mats of algae, or piles of rocks are actually highly engineered treatment cells; the cleansing processes occur in substrates, the water column, and aquatic plants and organisms, all of which are manipulated to optimize retention, absorption, transformation, and control of specific pollutants."

Technology drivers

Tighter restrictions are being considered for chemical releases to surface water bodies regulated under the National Pollutant Discharge Elimination System (NPDES). Although a number of states have adopted aggressive toxics control programs, the Great Lakes Water Quality Initiative, or GLI—an international effort to ensure long-term protection of North America's largest freshwater ecosystem—is the force behind many of the changes at the federal level.

Heavy metals commonly found in utility wastewaters are among the GLI's primary targets. Although typically found in discharges at very low levels, these metals can contaminate sediments and can bioconcentrate in aquatic food chains, posing potential risks to wildlife and humans. In the Great Lakes watershed and other basins, traditional discharge standards, which are based on the treatment capabilities of existing technologies, are proving inadequate to mitigate these risks. More-stringent water-quality-based effluent limits—possibly set at or below detection levels for trace elements—are under consideration. In addition, NPDES permits that do not currently incorporate limits on trace elements may be rewritten, and previously unregulated discharges are facing scrutiny.

Conventional chemical treatment technologies for metal-bearing utility discharges are resource-intensive, requiring chemi-

Intelligent design and engineering of constructed wetlands are the keys to cost-effective cleansing of utility wastewaters. The constructed wetland at Allegheny Power's closed ash management facility near Springdale, Pennsylvania, includes four vegetated aerobic cells. To create these cells, basins were excavated and lined, substrates were installed, and various species of aquatic vegetation were planted.

BLUEPRINTS AND PHOTOS COURTESY EES CONSULTANTS, INC., EXCEPT WHERE NOTED cal additions, energy inputs, human supervision, and regular maintenance. Hazardous by-products like chemical sludges can be generated, resulting in disposal costs. And these systems may not even be able to reduce trace element concentrations to the levels called for by emerging water quality criteria. Constructed wetlands, by contrast, are largely self-perpetuating. Resource inputs are minimal once a wetland is installed, and no undesirable by-products are generated. Gravity typically controls flow, and treatment is mediated by microbial processes, aquatic plant growth, and natural chemical and physical mechanisms. Fuel and manpower requirements are at an absolute minimum, resulting in significantly lower operating and maintenance (O&M) costs.

"In numerous municipal, agricultural, and industrial applications over the past 20 years, constructed wetlands have proved highly effective at reducing trace metal concentrations to extremely low levels," says Robert Brocksen, manager of EPRI's Water Toxics Assessment & Watershed Management Business Area. "Meanwhile, the rapid evolution of the electricity enterprise is creating a market incentive for transfer of the technology to the power industry. Constructed wetlands align with both cost reduction and environmental stewardship—near-ubiquitous business goals in the increasingly competitive marketplace."

In collaboration with utilities, environmental engineering firms, and the University of California at Berkeley, EPRI is directing a comprehensive program to develop design and engineering guidelines for the treatment of common metal-bearing waste streams. Ongoing activities include demonstration projects to broaden the experience base; field and laboratory work to increase mechanistic understanding of treatment processes; and experimental work to accelerate or otherwise enhance removal of specific contaminants.

"EPRI's program is introducing new dimensions to constructed-wetland technology," says Goodrich-Mahoney. "Never before have fundamental treatment mechanisms been explored at the levels of detail afforded by advanced analytical techniques, and our efforts to optimize these processes are on the leading edge of microbiology, plant physiology, genetic engineering, and other disciplines."

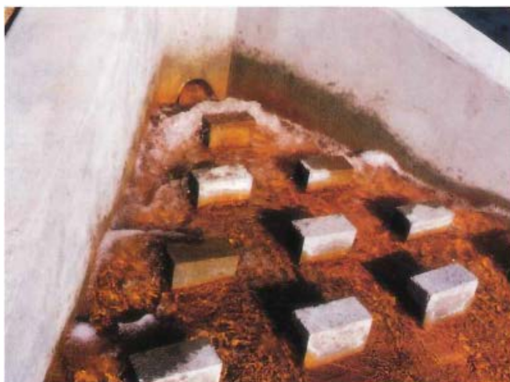
A brief history

The power industry's experience base with constructed wetlands is relatively limited. And results have been mixed. Most utility systems were designed and constructed in the middle to late 1980s on the basis of numerous successful applications by the coal mining industry. Acid mine drainage is similar to such metal-bearing utility wastewaters as runoff and seepage from coal storage and preparation areas and leachate from some combustion by-product disposal facilities. Common concerns include low pH; high acidity; high concentrations of iron, manganese, and aluminum; and trace concentrations of arsenic, boron, cadmium, chromium, copper, lead, nickel, selenium, zinc, and other chemicals.

In 1985, the Tennessee Valley Authority installed the industry's first constructed wetland—a system to treat acid seepage from an earthen dike surrounding a coal slurry pond at the utility's Fabius coal preparation plant in Jackson County, Alabama. This initial TVA system, an impoundment that is still operating today, has always produced compliance-quality discharges requiring no additional chemical treatment. "That's not to say we haven't had to climb a learning curve in terms of design, construction, and operation," says Greg Brodie, TVA program manager for water and wastewater. "The impoundment has succeeded only because of serendipity," he explains. "Seepage just happens to flow through a berm constructed largely of limestone; that introduces alkalinity, which results in efficient iron removal. It took us quite a while to figure out why the system worked. We know a lot more now than we did in the 1980s."

Other early utility systems have been plagued by problems. One example is a constructed wetland designed to treat highly acidic seepage from an ash pile in western Pennsylvania. Although the system reduces acidity levels and concentrations of iron, manganese, and aluminum, it produces a noncomplying discharge because it is undersized for the incoming mass loading and lacks the alkalinity-producing components now recognized as critical. In addition, the system has been overwhelmed by high flows during storms. As a result of these problems, the wetland is functioning only as a pretreatment unit; its effluent flows to a chemical system for additional acidity reduction and metals removal.

"The problems experienced at this wetland site are completely avoidable today,"



At the Springdale wetland, the leachate is pumped over a concrete aerator on its way to an equalization basin, where most of the iron removal occurs. The aerator introduces the oxygen necessary for the chemical reaction for iron removal.

Water, sediment, and vegetation samples from the Springdale wetland cells are being analyzed to increase understanding of treatment mechanisms.

says Goodrich-Mahoney. "The keys are increased knowledge of wetland processes and intelligent system design and engineering."

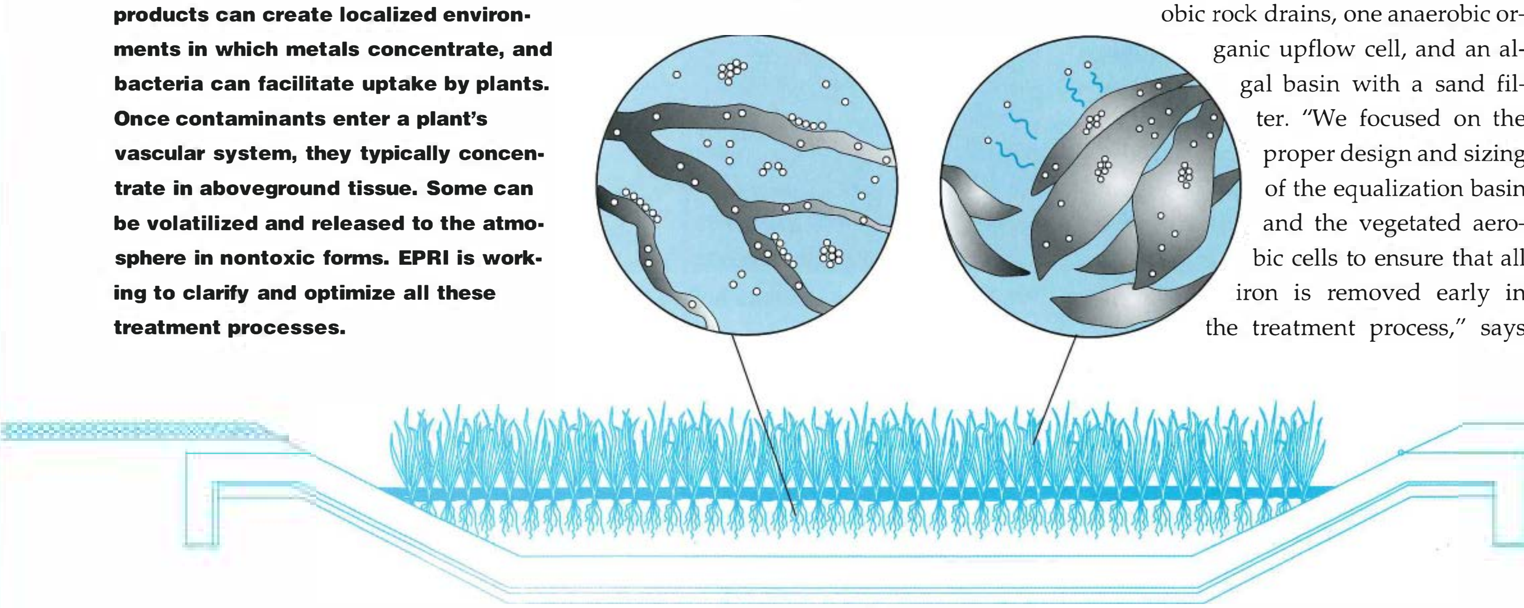
Intelligent engineering

A constructed wetland installed under tailored collaboration with Allegheny Power illustrates the detailed engineering process required to develop effective treatment systems. Located at a closed ash management facility near Springdale, Pennsylvania, the system was designed to treat an underdrain discharge from the facility into Riddle Run, a small tributary of the Allegheny River.

"Because the Springdale site is unmanned, we were looking for a passive, economical treatment technology with low O&M requirements and the ability to meet stringent NPDES limits for iron and other contaminants," says Rick Herd, strategic environmental management advisor at Allegheny Power. "Since 1988, we'd been operating a relatively primitive constructed wetland at our Albright ash disposal facility with mixed results: compliance with iron limits but less luck with manganese and a couple of other trace elements. We were confident that the lessons learned at Albright, along with the expertise and resources EPRI brought to the table, would result in a more intelligent and effective design for Springdale."

The Springdale system's design is based on PERT®—Phased Element Removal Technology. The PERT approach for identifying, ordering, and sizing treatment process steps has these underlying principles: to effect early removal of high-concentration contaminants or constituents that could cause operational problems downstream; to ensure compatible input and output conditions between cells as well as optimal treatment conditions within cells; to maintain close hydraulic control; and to provide conservative flow and treatment capacity margins. "These principles guide the engineering of site- and discharge-specific designs for constructed-wetland systems," says Terry Rightnour, president of EES Consultants, the design contractor. "Designs employing a series of treatment cells have proved to be most effective: each cell can be customized, and a compartmentalized layout enables individual cells to be maintained without disrupting the treatment process."

The Springdale leachate is characterized by a neutral pH and average total iron and manganese concentrations of 13.48 mg/L and 2.74 mg/L, respectively. The constructed wetland, installed in the summer of 1995, consists of an equalization basin followed by eight sequential treatment cells: four vegetated aerobic cells, two aerobic rock drains, one anaerobic organic upflow cell, and an algal basin with a sand filter. "We focused on the proper design and sizing of the equalization basin and the vegetated aerobic cells to ensure that all iron is removed early in the treatment process," says



In vegetated aerobic wetland cells, aquatic plants and soil microorganisms work together to remove heavy metals and other discharge constituents. In the root zone, roots and associated microbes can alter soil chemistry to sequester contaminants, root byproducts can create localized environments in which metals concentrate, and bacteria can facilitate uptake by plants. Once contaminants enter a plant's vascular system, they typically concentrate in aboveground tissue. Some can be volatilized and released to the atmosphere in nontoxic forms. EPRI is working to clarify and optimize all these treatment processes.

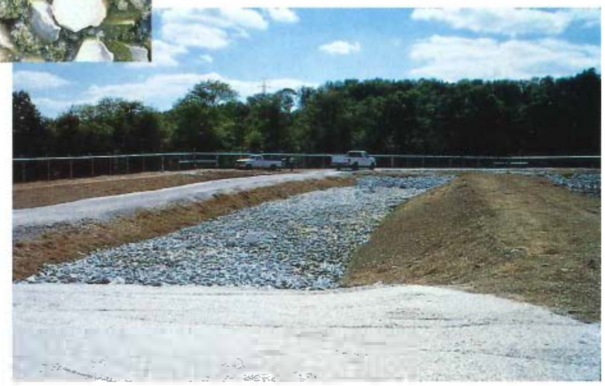
Goodrich-Mahoney. "Failure to remove sufficient iron can affect microbial processes that control downstream manganese removal and can also result in the clogging of sensitive substrates critical to the extraction of trace metals," he explains.

Leachate is pumped from the toe of the ash disposal facility over a concrete aerator and into the equalization basin. The basin, basically a concrete-lined pond, moderates flow to the downstream cells and removes most of the dissolved iron. The aerator introduces the oxygen necessary for hydrolysis of the dissolved iron and subsequent settling of iron precipitates. About 70% of total iron is removed by the basin. Some trace metals are also removed there, binding to and coprecipitating with the iron hydroxides.

After flowing by gravity through a rock-lined ditch where additional aeration and iron precipitation occur, the basin's effluent enters the first of the four vegetated aerobic cells. The system components that look and function most like natural wetlands, these cells support various species of aquatic vegetation—including cattails and several grasses—on a submerged, high-organic-content substrate. Numerous environmental control processes occur in the water column, in sediments, and in the root zone (rhizosphere) and vascular system of the aquatic plants.

On the basis of early studies of wetland processes, the dominant treatment mechanism for heavy metals was believed to be direct uptake and sequestration by aquatic plants. Now microbially mediated transformations are recognized as the most important mechanism, but wetland plants are essential, creating the oxidized rhizosphere that fosters the growth of specialized microbial communities. In the rhizosphere, these aerobic bacteria facilitate root system uptake of metals from the soil; plants transport these substances to aboveground biomass, where most concentrate but some volatilize to the atmosphere. Roots and their associated microorganisms also can alter soil chemistry, stabilizing and reducing the bioavailability of metals. In addition, roots can create chemical environments that promote the absorption and sequestration of pollutants and support microbial degradation.

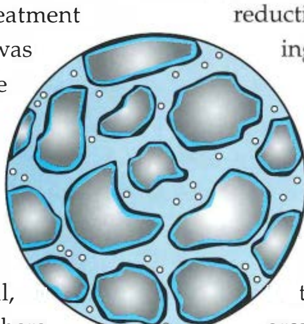
Two rock drains at the Springdale wetland harbor microorganisms that promote manganese removal. Because iron is known to impede manganese uptake and sequestration, the system was designed to remove all iron from the leachate before it enters these drains.

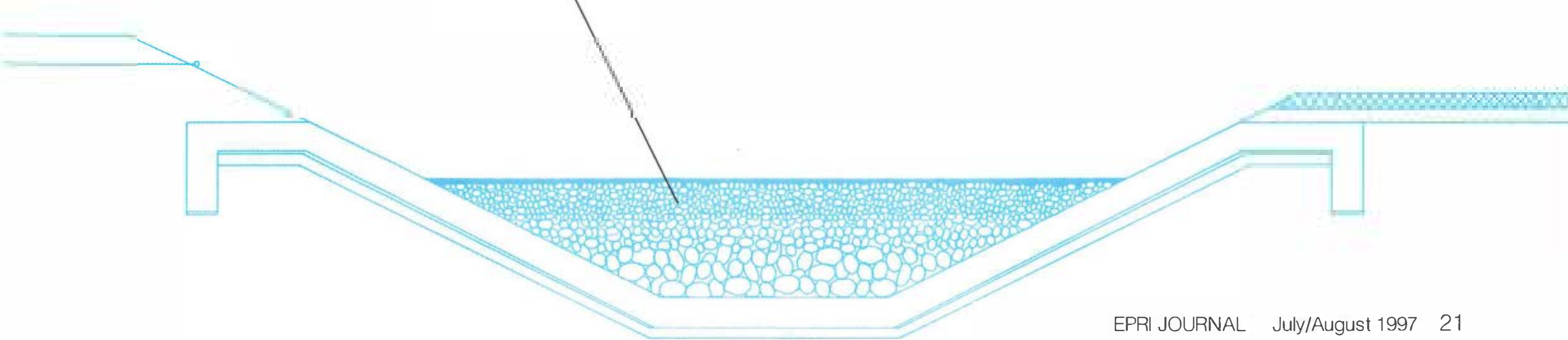


At the Springdale site, the four wetland cells remove residual iron, most of the dissolved manganese, and some trace metals. The initial cell removes most of the residual iron, lowering its concentration to 0.3 mg/L. This cell also removes approximately half the manganese, with further reductions occurring in the remaining three cells.

The first of two aerobic rock drains receives effluent from the final aerobic wetland cell. As the effluent flows over and between rocks of various sizes, the rock surfaces provide a growth substrate for "black slime" bacteria. Although the physiological treatment mechanisms have not yet been identified, these bacteria oxidize dissolved manganese and sequester it as manganese dioxide, reducing its concentration to less than 0.1 mg/L after the initial rock drain.

Effluent from the second rock drain enters an anaerobic organic upflow bed, which was installed to remove trace metals via bacterial sulfate reduction in an anoxic environment. The upflow configu-



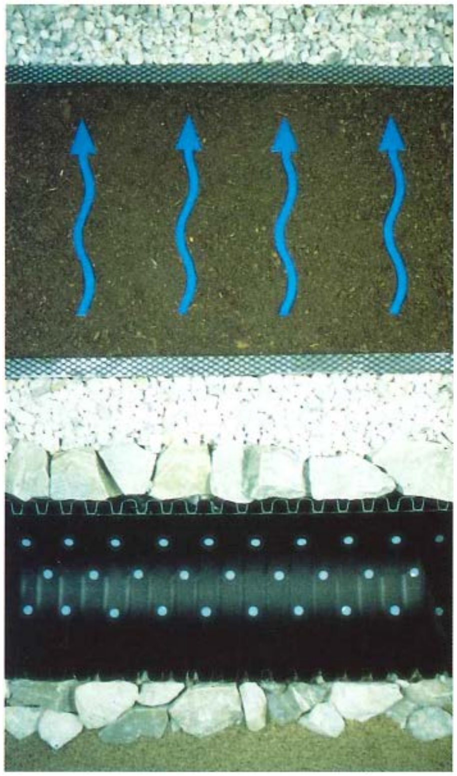


In rock drains, stacked layers of limestone riprap provide surfaces for the colonization and growth of biofilms composed of "black slime" bacteria. As the leachate flows around and between individual rocks, these microorganisms oxidize and sequester dissolved manganese. The biochemical reactions underlying this process are not fully understood, but the end result is that a manganese dioxide precipitate forms on the rock surfaces beneath the biofilm.

ration, in which the discharge flows through perforated pipes installed at the bottom of the bed and then upward through a spent mushroom compost substrate, maximizes hydraulic control. Bacteria in the anoxic substrate generate sulfide, thus promoting the scavenging of trace metals and the subsequent precipitation of metal sulfides.

The final cell is a combined algal basin and sand filter. It removes suspended solids, providing final polishing and clarification of the discharge before its release through a flow measurement flume and into the high-quality receiving-water stream.

Since being brought on-line in the fall of 1995, the Springdale system has removed an average of 97% of total iron and 98% of dissolved iron, bringing the 43-gal/min (average) discharge well under its NPDES limit for this constituent. Removal efficiencies of 89% for manganese and 79% for aluminum have been achieved. In addition, significant fractions of the trace elements arsenic, beryllium, molybdenum, nickel, and zinc are being extracted.



The Springdale discharge flows upward through an anaerobic organic bed where the removal of trace metals is facilitated by microorganisms. The upflow configuration maximizes hydraulic control.

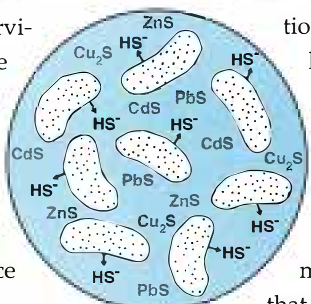
"Our constructed wetland not only achieves permit compliance but also is more cost-effective than conventional chemical systems," says Allegheny Power's Herd. According to the first detailed economic comparison of treatment alternatives, the total projected costs over the next 50 years are $2.5 million for the Springdale installation versus $4.8 to $8.8 million for comparably sized chemical systems. The wetland's advantages arise from low O&M costs: passive operation minimizes the need for supervision; no chemical additions are required; no sludge is generated; and the only regular maintenance task is to remove iron precipitate accumulations, which is expected to be necessary about once every 10 years.

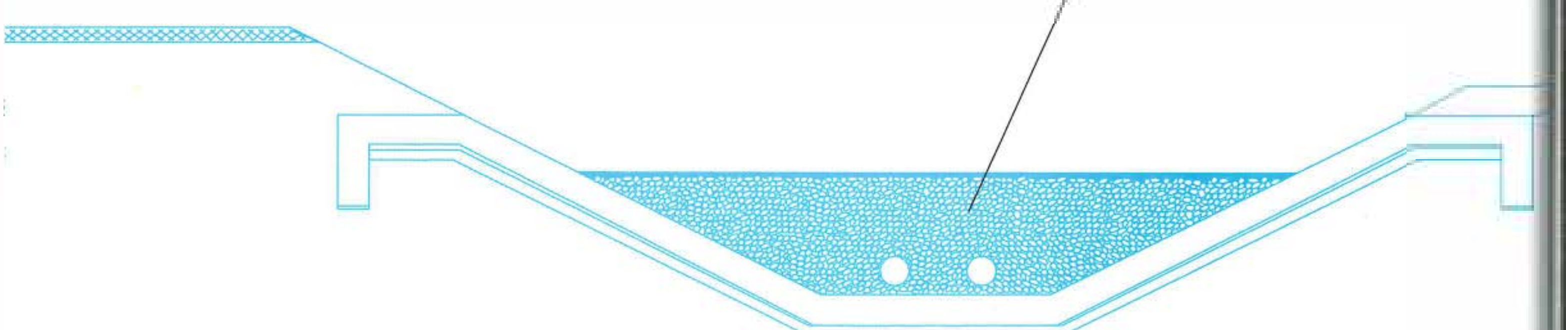
In recognition of these attributes, Allegheny Power received a 1996 Industrial Excellence Award from the Pennsylvania Water Environment Association for the most promising and cost-effective new wastewater treatment system constructed in Pennsylvania. According to Herd, the company plans to mentor the technology in partnership with the state's Department of Environmental Protection, working with citizens' groups, schools, and customers to promote industrial applications of constructed wetlands in its service territory.

The use of constructed wetlands at other Allegheny Power facilities is currently under evaluation. In addition, knowledge gained from the Springdale site is being applied to upgrade the utility's initial Albright system. A rock drain is being added to provide a final treatment cell that will increase the removal of manganese, a problem constituent since the wetland was first installed.

New application

Coal pile runoff is the treatment target for a wetland system being designed and constructed under tailored collaboration with Alabama Power. "Unlike the Springdale leachate, this storm water discharge is highly acidic and thus is similar to metal-bearing acid mine drainage," says Goodrich-Mahoney. "What makes the system unique is that it will be the first power in-





Because research has shown that trace metals can be effectively removed by sulfate-reducing bacteria in an anoxic organic environment, the Springdale designers included an anaerobic upflow bed in the system. The leachate, introduced through perforated pipes at the bottom of the bed, flows upward through spent mushroom compost. Bacteria in this anoxic compost produce hydrogen sulfide, which reacts with trace metals to result in the precipitation of metal sulfides. (A wetland being constructed by Alabama Power will also have an anaerobic bed, but for site-specific treatment reasons, flow in that bed will be downward, not upward.)

dustry application of constructed wetlands for treating this common nonpoint source of pollution."

The runoff has a pH of less than 3 and high concentrations of iron and aluminum—all characteristics known to create operational problems in constructed wetlands. Anoxic limestone drains (ALDs) are the conventional approach for producing the alkalinity required to neutralize acidic waste streams that have low levels of dissolved oxygen, such as coal mine drainage. As a surface discharge, however, the coal pile runoff has enough dissolved oxygen to oxidize dissolved iron. The resulting precipitate would form an armoring layer on the limestone surfaces, eliminating an ALD's buffering capacity.

Successive alkalinity-producing systems (SAPS) are an emerging buffering approach that will be a key component of the Alabama Power wetland. SAPS have a rich organic layer with an inherent oxygen demand; this layer, which is similar to anaerobic organic upflow beds like the one installed at Springdale, sits atop a conventional ALD. In the Alabama Power application, the acidic discharge will flow from a detention pond into the SAPS. The discharge will move downward through the organic layer, which will reduce its dissolved-oxygen content and thus prevent iron precipitation when the discharge flows through and is buffered by the limestone bed. Sulfate-reducing bacteria in the organic layer will provide additional buffering. At the SAPS outlet, the discharge will be characterized by near-neutral pH, and it thus will be ready to flow by gravity to an equalization basin for iron precipitation and then to other cells for manganese, aluminum, and trace element removal.

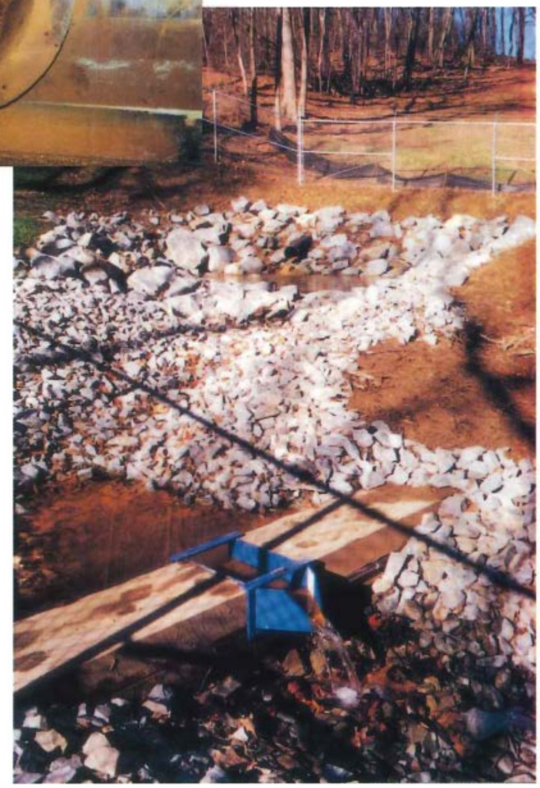
A storm water conveyance system and a detention pond are under construction. According to Bill Garrett, senior environmental engineer in Alabama Power's Environmental Affairs Department, pilot-scale tests will be conducted during the fall and winter to examine various ways to prevent the plugging of wetland cells, a common problem for discharges with a high aluminum content. Construction of the actual wetland system is planned for 1998.

"This project represents a unique opportunity for Alabama Power," says Garrett. "Because we are under no regulatory pressure to treat the coal pile runoff, we can be environmentally proactive while developing in-house expertise in constructed wetlands and exploring environmental control approaches that appear extremely promising for some of our other waste management challenges."

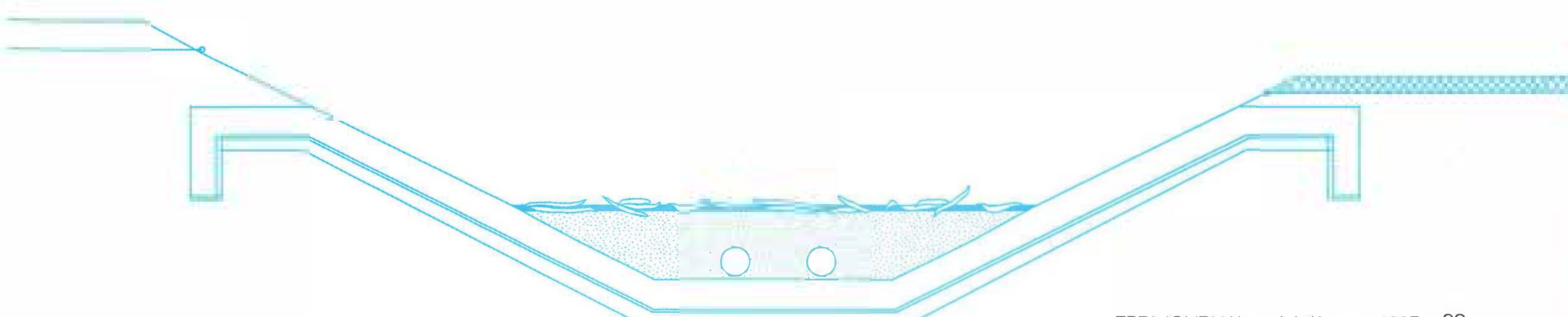
Treatment optimization

Complementing EPRI's constructed-wetland demonstrations are intensive field and laboratory studies that aim to increase mechanistic understanding of treatment processes and develop methods for maximizing the removal of specific trace elements. "Determining the fate of trace elements is critical to optimizing wetland

Allegheny Power's Springdale wetland is cost-effectively transforming a metal-bearing leachate (left) into a compliance-quality discharge (below).



A combined algal basin and sand filter provides final cleansing of the Springdale effluent before its release to Riddle Run, a tributary of the Allegheny River. Suspended solids introduced by the anaerobic upflow bed settle out of the effluent, and residual metals may be removed by wetland plants and microorganisms that have naturally colonized the basin. Additional plants and microbes may be introduced on the basis of laboratory and field studies at Springdale and at other wetlands being monitored in EPRI's constructed-wetland program.

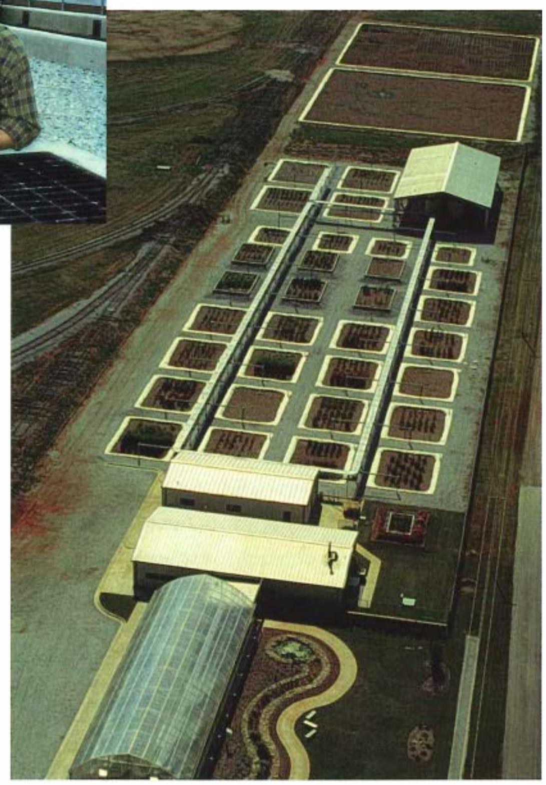


design and management and to minimizing risks," explains Goodrich-Mahoney. "We need to know how these elements are removed from a discharge, where they reside, how long they stay there, and what chemical form they take."

At present, the only data available are from preliminary analyses of a TVA wetland that has been used since the mid-1980s to comply with permit standards for a metal-bearing discharge. Core samples from this system, analyzed by using the U.S. Environmental Protection Agency's toxicity characteristic leaching procedure, indicate that after 10 years of operation, its sediments are nonhazardous. Toxicants are present but not at high concentrations, which suggests that metals are being removed from the discharge and transformed to nontoxic forms or sequestered in sediments, eliminating risks to downstream ecosystems.

Greenhouse-covered experimental cells at Springdale enable Allegheny Power and EPRI to field-test the treatment effectiveness of wetland plant species.

EPRI studies to determine precisely how trace elements cycle through constructed wetlands are being conducted by a multidisciplinary team of scientists from the University of California at Berkeley under the direction of Norman Terry, professor of plant biology. Surface water, sediment, pore water, and vegetation samples are being collected monthly from the Springdale site, TVA's Widows Creek installation, and the new Corcoran system in north central California. (The Corcoran wetland, designed and built by a team from Berkeley and other UC campuses and the Tulare Lake Drainage District, has 10 experimental cells for treating an agricultural waste stream containing selenium and other trace elements common to utility discharges.) Samples from all the wetlands are being analyzed to calculate the extent to which each of 26 trace elements is retained in sediments and waters or assimilated into the roots and shoots of vegetation. A primary goal is to better understand the role of various species in the cycling of these elements through wetland ecosystems.



Novel concepts for optimizing the removal of specific chemicals are being evaluated at TVA's constructed-wetland research laboratory.

An advanced analytical technique, high-energy X-ray absorption spectroscopy, is enabling the UC-Berkeley scientists to examine the chemical transformations that occur as aquatic plants absorb and process trace elements. "Conventional methods physically alter plant tissue in examining its chemistry, whereas this technique allows in vivo chemical analysis, providing a unique picture of what goes on inside plants," says Terry. "For the first time, we can track the valence state of trace elements to determine whether they are in toxic or nontoxic forms." To date, a variety of aquatic plants have been identified that absorb selenium and toxic metals and metabolize them to nontoxic chemical forms. For example, water hyacinths can convert toxic hexavalent chromium (Cr^{6+}) to nontoxic trivalent chromium (Cr^{3+}). From a practical perspective, the ability to identify whether a trace element is being converted to a nontoxic form or whether a particular plant can render a specific pollutant nontoxic is a major advance. A wetland could be vegetated with a species known to eliminate a contaminant's toxicity, for example; then, at the end of the growing season, the biomass could be harvested and used or discarded with no fear of future toxic effects.

Studies of trace element volatilization by aquatic vegetation have also generated significant results. Typically pollutants are absorbed and immobilized in plant tissues, but some plants can volatilize trace elements and release them to the atmosphere. "Volatilization is a particularly attractive treatment mechanism, since it removes pollutants from an aqueous medium and releases them in nontoxic form to the atmosphere," says Goodrich-Mahoney. For a constructed wetland in the San Francisco Bay Area, UC-Berkeley scientists have determined that volatilization plays a significant role in selenium removal. They have also identified controlling variables, including temperature, water levels, pollutant concentration, and plant growth stage. Shoot removal was found to stimulate volatilization in bulrush plants, suggesting that vegetation management could be employed to increase trace element removal efficiency in constructed wetlands.

In addition to studying process mechanisms, the other major thrust of the UC-Berkeley program is to develop ways to optimize wetland treatment. In one approach, wetland plants are being screened to identify species most effective at absorbing, immobilizing, and/or volatilizing specific trace elements. To date, 13 plant species have been screened for the uptake of 10 trace elements. Some species—including water zinnia, parrot feather, and umbrella plant—appear to be particularly effective for sequestering specific elements. Patent protection is being considered for another promising species never before considered for application in constructed wetlands.

The influence of rhizosphere microorganisms on trace element immobilization, transformation, and uptake by aquatic vegetation is also being investigated to identify and isolate particularly effective microbes. In studies of soil microbes at the San Francisco Bay Area constructed wetland mentioned earlier, bacteria located in the rhizosphere of aquatic plants showed higher selenium volatilization rates than those in the surrounding soil. "Surprisingly, they also enhance selenium uptake by the plants," says Terry. "These accelerated transformation capabilities almost certainly represent adaptations to a selenium-enriched environment. We have identified microbe-plant associations that exhibit enhanced removal, suggesting a possible management option: the introduction of the microbes to the water inlet of a constructed wetland to promote colonization and thereby increase treatment capabilities."

In controlled laboratory experiments at UC-Berkeley, modern molecular biology techniques are being applied to genetically engineer plant species with superior capabilities for trace element uptake, detoxification, and removal. Several promising transgenic Indian mustard lines have been developed. Some of these produce increased levels of the enzymes that mediate selenium uptake and volatilization. Others exhibit increased tolerance to heavy metals, such as cadmium. (If a plant species is to provide effective heavy metal treatment, its normal physiological functions must not be adversely affected by its metal uptake and storage capabilities.) Plans are to duplicate these modifications in wetland plants.

In addition, a gene known to control the detoxification of heavy metals in animal tissue has for the first time been isolated in the plant kingdom. By incorporating the gene into suitable wetland plant species, the UC-Berkeley researchers hope to increase the efficiency of heavy metal detoxification and sequestration by constructed wetlands.

"The preliminary results of our genetics program are extremely exciting," says Goodrich-Mahoney. "We've only scratched the surface, but already there are tantalizing indications that we could modify wetland plants to improve their physiological abilities for accumulating and detoxifying heavy metals and volatilizing selenium and other constituents."

Treatment optimization methods developed during the course of the EPRI program will be tested in four off-line cells installed solely for research purposes at Allegheny Power's Springdale site. Because these cells can be covered with a greenhouse, experiments are not limited to the normal growing season in the northeastern United States. Also, controlled studies can be conducted to determine the effectiveness of monocultures or mixed-species assemblages for immobilizing specific contaminants. The research cells are currently being used to examine plant species with an affinity for boron, a constituent of the Springdale leachate that is less amenable to biological uptake than are other trace elements.

EPRI is also monitoring ongoing work at TVA's state-of-the-art constructed-wetland research laboratory in Muscle Shoals, Alabama, as well as at other TVA treatment facilities. "There are a lot of novel treatment concepts that could further increase the cost-effectiveness of constructed wetlands," says Frank Sikora, a TVA research chemist. "Promising areas we are studying include new cell configurations for increasing trace metal removal efficiencies, rock biofilters for removing manganese, phosphate rock drains and downflow anaerobic systems for treating acid drainage, and methods for eliminating plugging problems in ALDs."

PHOTO COURTESY UNIVERSITY OF CALIFORNIA, BERKELEY

Indian mustard plants with potential for enhanced selenium uptake and volatilization have been genetically engineered in early EPRI work to develop superior wetland species.

On the basis of experience and information gained from coordinated field and laboratory studies, EPRI will issue a manual for designing and engineering constructed wetlands to comply with NPDES permit limits for metal-bearing discharges. In addition, the development of a model called TWED (Treatment Wetlands Evaluation and Design) is planned. TWED will simulate treatment processes in vegetated aerobic cells by building on an existing EPRI model for the management, restoration, and mitigation of natural wetlands and on that model's understanding of wetland hydrology, biogeochemistry, and vegetation. TWED will also incorporate new knowledge specific to treatment processes in rock drains, upflow beds, and other constructed cells. By inputting the chemical and physical characteristics of specific waste streams into TWED, utilities will be able not only to assess the feasibility of using constructed wetlands to meet specific discharge goals but also to gain preliminary system design and cost information.

"Constructed-wetland technology is really in its infancy, yet it has proved cost-effective and successful around the world for all types of wastewaters," says Goodrich-Mahoney. "I believe that natural biological, physical, and chemical treatment processes exist for every wastewater challenge; we need only identify, duplicate, amplify, and accelerate them. Our goal is to develop an industry-specific knowledge and experience base now, ensuring the intelligent design and engineering of passive, low-cost systems to meet future discharge restrictions—regardless of their stringency." ■

Background information for this article was provided by John Goodrich-Mahoney of the Water Toxics Assessment & Watershed Management Business Area.

Powering the Pipeline

THE STORY IN BRIEF

Competitive market forces are creating opportunities for electricity to play an increasing role in moving natural gas through interstate transmission pipelines. Electric compression, representing a potentially significant market for electricity, can offer gas pipeline companies important environmental and economic advantages over traditional gas-fired compression. Continued integration of gas and electric companies could lead to further synergy between therms and kilowatthours in the delivery and marketing of energy to consumers.

by Taylor Moore

The deregulation of the natural gas industry is helping to open a market for electricity that has long been virtually closed: powering the compressors that move huge volumes of gas from producing regions—such as the Gulf of Mexico and neighboring states and the Canadian province of Alberta—to major U.S. population centers like the Midwest and the Northeast. Along North America's 300,000-mile gas transmission pipeline network, at several locations where nearby high-voltage lines deliver low-cost electricity, pipeline companies are choosing electrically driven compressors over the traditional engines and turbines fired with gas from the pipeline itself.

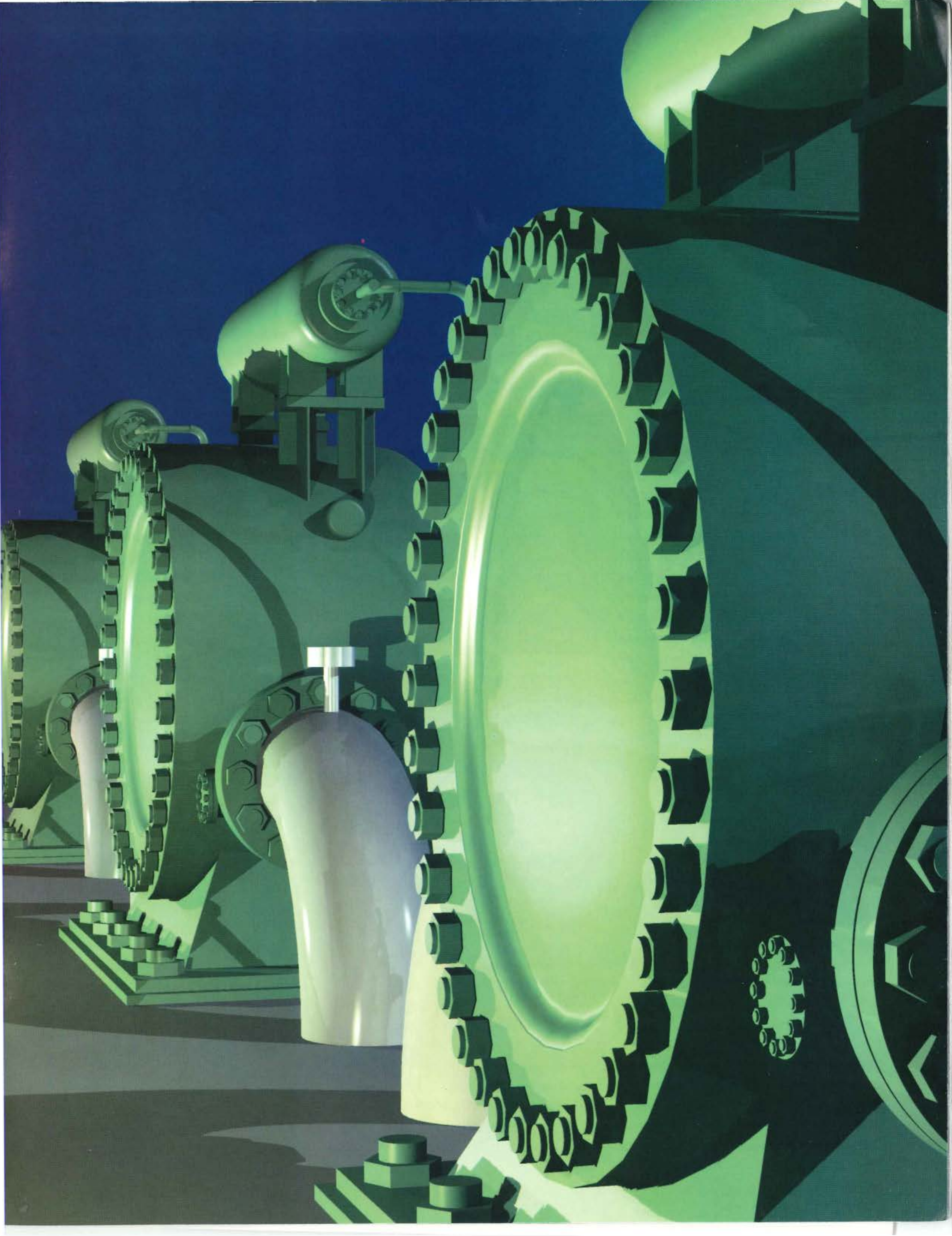
Although electric motor drives account for only a small fraction of installed compressor capacity on natural gas pipelines, their use in new installations and as replacements for older gas-fired equipment could increase substantially in the years ahead. Two key reasons are the approach of electric power industry deregulation—which is expected to lead to more-competitive power supply markets and lower electricity prices—and the rising costs of upgrading and retrofitting gas-fired equipment with controls to limit emissions of nitrogen oxides at compressor stations. NO_x emissions are a major contributor to ground-based ozone pollution, and industries in key areas that do not meet federal air quality standards are under pressure to reduce them.

The deregulation of the gas industry, which began nearly two decades ago, and the increased cost of reducing NO_x emissions are forcing interstate gas pipeline companies to consider all options for cutting operating costs in order to be competitive. Although electric compressor drives have been used to a limited extent for decades, some 98% of all pipeline compressor capacity is driven by gas-fired equipment. More than 6600 two- and four-cycle reciprocating engines drive slightly over half of that gas-fired compressor capacity. About 1200 newer, larger, and more efficient gas turbines drive the rest.

Typical compressor applications require 2500–3500 hp, and many compressor stations have multiple units. Located about every 50–60 miles along a pipeline to maintain pressure lost because of friction, the stations are often dispatched remotely from a control center. Interstate gas pipelines account for 80% of total installed compressor capacity. Compressors are also used on intrastate pipelines and gathering lines, in gas processing operations, and for pumping gas into underground storage in porous rock formations. Overall, installed compressor capacity in the gas industry represents the horsepower equivalent of more than 19,000 MW of electrical load.

Before the Federal Energy Regulatory Commission's landmark Order 636, which led to the unbundling of gas transmission services in 1991 and the spin-off of pipeline companies from integrated gas producers, economic and corporate cultural incentives favored gas-fired compression on pipelines. The costs were included in the cost of transmission service and were passed along to gas users. Moreover, as Ammi Amarnath of EPRI's Customer Systems Group notes, "Until recently, most gas pipeline and storage companies simply felt that it looked bad to gas customers if the pipelines used what was traditionally considered a rival energy form to pump their product to market." And gas executives continue to cite concerns about reliability, which they view somewhat differently than electric utilities, as a factor favoring gas over electric compression.

The long-standing preference for gas-fired compressors is giv-



ing way in the face of more-objective economic assessment, however, as pipeline companies weigh the cost of retrofitting NO_x controls on gas-fired equipment nearing replacement or of adding new compressor capacity to support pipeline expansion. Gas turbines at compressor stations often can be retrofitted with combustion and postcombustion NO_x control technologies, at a cost of about $60–$80 per horsepower. But increasingly, where it makes economic sense, pipeline companies are installing electric motor drives, often equipped with electronic adjustable-speed controls. Compressor system packagers also offer electric-drive units.

Fostering industry dialogue

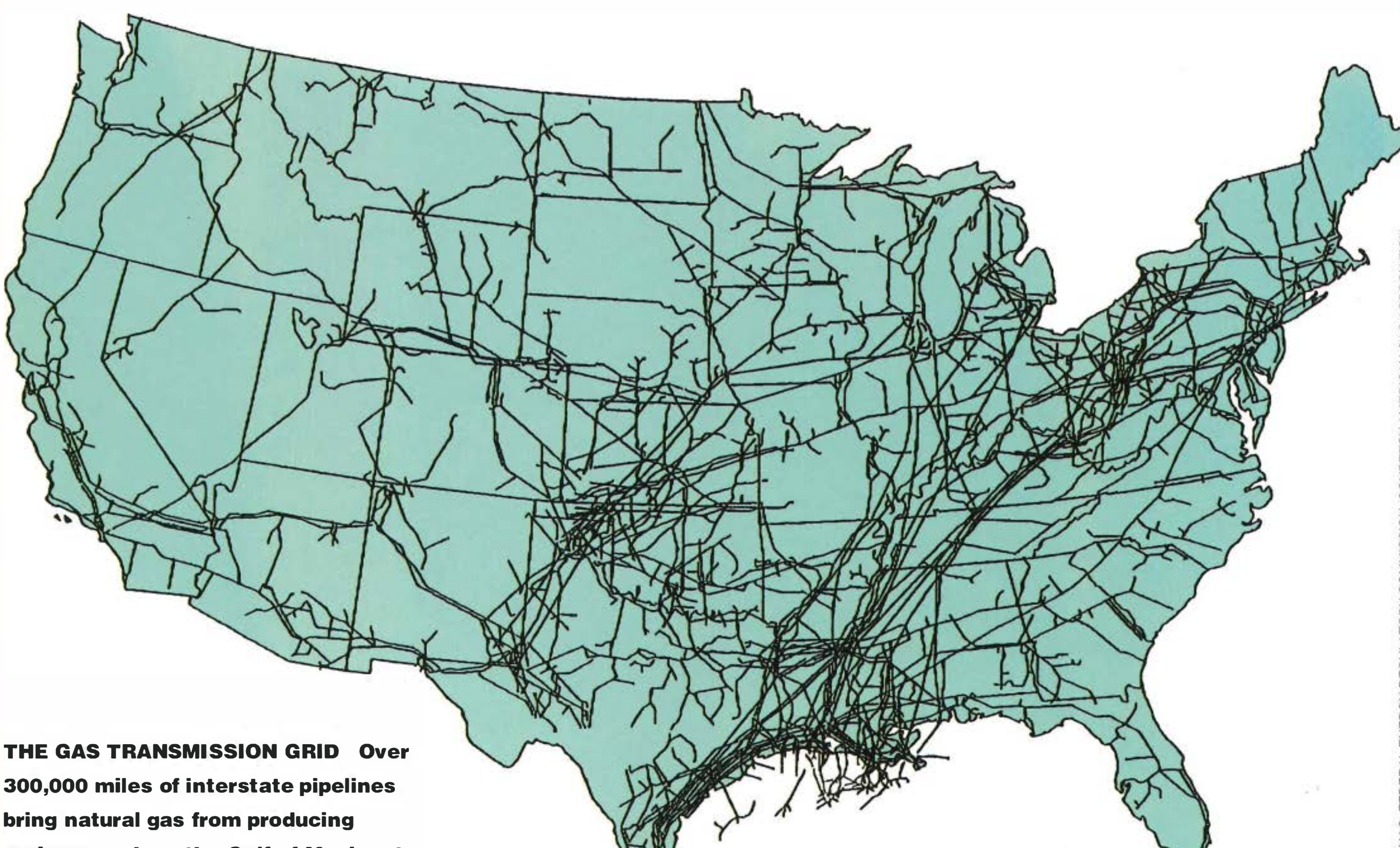
Perceiving a potentially large and largely undeveloped industrial market for electric-motor-driven gas pipeline compression, several years ago EPRI initiated a series of symposia that have regularly brought pipeline company executives and managers together with their electric utility counterparts. At these gatherings, the sharing of experiences and perspectives on the barriers to electrically driven compression has led to partnerships for specific studies and projects aimed at furthering prospects for the practice.

One utility that has long served several gas pipeline customers that use electric compressor drives is American Electric Power Company. AEP credits EPRI's recent efforts for catalyzing its own realization that substantial additional market potential exists for electric compression in its service area, which includes parts of Indiana, Kentucky, Michigan, Ohio, Tennessee, Virginia, and West Virginia. Many of the major interstate gas pipelines pass through the area on their way from the Gulf and Midwest regions to the Northeast.

"Until EPRI formed an electric compression working group, we had not focused on the gas industry as a growth market opportunity," says AEP national accounts executive Kent Flanery. He recalls that about the same time the EPRI working group was formed, Tenneco Energy (now part of El Paso Energy Corporation) upgraded over 14,000 hp of aging gas-fired compressor capacity with electric motor drives at its main-line station in Catlettsburg, Kentucky. "That really opened our eyes to the fact that there are many other opportunities out there."

But, as Flanery points out, electric utilities must understand the nature of the service needs of gas pipelines and the crucial role of pricing flexibility in order to influence pipeline companies' decision making in their choice of compressor options. "Utilities should realize that an electric compressor drive is of only incremental value to the gas company, since it has to pay for compressor station O&M whether a unit is driven by gas or electricity. The pipeline company is looking at a relatively small, incremental savings potential in contrast to a quantum leap in revenue for the electric company that serves the unit," Flanery explains.

"For a pipeline operator, the savings from an electric compressor drive have to be enough to warrant giving up direct control of the unit's fuel source, which is a risk factor for the operator," Flanery adds. "Overcoming that perception of risk is one of the greatest challenges electric utilities face in developing this market."



THE GAS TRANSMISSION GRID Over 300,000 miles of interstate pipelines bring natural gas from producing regions, such as the Gulf of Mexico, to population centers across the country.

MAP BY U.S. FEDERAL ENERGY REGULATORY COMMISSION, COURTESY AMERICAN GAS ASSOCIATION

Power costs, reliability critical

The Houston-based Chemicals & Petroleum Center (CPC), a technology application center of EPRI's Industrial & Agricultural Technologies & Services Business Area, has produced a wealth of information that offers member utilities strategic insights into the gas pipeline compressor market. EPRI's Retail Market Tools & Services Business Area conducts market assessments to identify new business opportunities and develops marketing strategies for introducing new technologies into competitive markets. Together, the two EPRI business areas produced a market assessment of the gas pipeline compression market that was published last year.

PHOTOS COURTESY TENNESSEE GAS PIPELINE CO./EL PASO ENERGY

An EPRI spreadsheet software product—MEGADRIVE™—is available to members for evaluating the comparative economics of electric and gas-fired compressor alternatives. Many assessments of specific electric compressor installations have been conducted in recent years by the CPC in cooperation with various utilities and gas pipeline companies. Most have involved the use of MEGADRIVE.

"Many utilities are successfully using the software to identify the most promising opportunities for applying electric compressor drives," says Amarnath, who manages the CPC. "MEGADRIVE's analysis is quite objective. In numerous cases, the software has confirmed gas-fired options as the more cost-effective."

Collectively, the studies have identified critical relationships among the key factors determining the economic advantages of electric and gas-driven options. Some of these factors relate to compressor location. For example, is the compressor in an ozone nonattainment area, and is there a market for NO_x allowances? Also, how close is the compressor to power transmission lines, and how much would a line extension cost? Fortunately, as Richard Schmeal, a program manager at the CPC, notes, "gas pipelines and power lines often run along the same corridors, so a power source is usually close to a gas pipeline."

COMPRESSOR UPGRADE LEADS TO ELECTRIC DRIVES El Paso Energy's Catlettsburg, Kentucky, main-line compressor station upgraded over 14,000 hp of aging gas-fired compressor equipment with three electric compressor packages like the one shown here. Equipped with synchronous adjustable-speed drives, these electric units have reduced station maintenance costs and personnel requirements and have cut emissions of nitrogen oxides.

Other important factors relate to the type of compressor installation. Although electric motor drives may cost as much as 40% less per horsepower than new gas turbines, electric retrofits for compressors typically operated at part load could still have high capital costs compared with the continued operation of older gas-fired equipment. Compressor installations of over 5000 hp are more likely to be cost-effective for electric drives because of life-cycle advantages in capital and maintenance costs at larger sizes. According to the CPC, maintenance costs for electric units can be less than one-fifth of those for compressors driven by reciprocating gas engines.

Electric compressors are considerably more efficient than gas-fired compressors because variable-frequency electronic controls enable an electric motor drive to maintain high efficiency over a wide range of speeds. The CPC calculates the net thermal efficiency of electric-drive compression (including electric power generation and transmission losses) to be 23–34% at the point of delivered pipeline compression, compared with 16–27% for a gas-turbine-driven compressor. Electric drives have an even greater efficiency advantage over reciprocating gas engines.

"It might sound like a long way around the barn, but it is more efficient to send gas to a combined-cycle power plant to generate electricity for transmission back to the pipeline compressor station than it is to burn natural gas directly in gas-fired compressors," says the CPC's Schmeal.

Perhaps the factor most critical to the economic appeal of electric compression is access to competitively priced power. Generally this means power that costs less than 3¢ a kilowatthour on average

A Quiet, Unobtrusive Neighbor

In at least one recent application documented by EPRI, electric-drive compressors were the key to an environmentally compatible siting solution. Columbia Gas Transmission Corporation needed to build a compressor station north of Baltimore on land that, since its purchase, had become surrounded by upscale residential development. The company's permit application to build a station on a 30-acre tract in what had previously been a rural area was challenged by neighboring residents, many of whom raise purebred horses. The residents voiced a number of environmental concerns, including noise, emissions, and aesthetic intrusion.

Columbia Gas Transmission solved its dilemma and won the intervenors' approval by selecting electric compression technology, which virtually eliminates vibration and noise problems, and by taking other steps to ensure that its Rutledge compressor station in Fallston, Maryland, would be a good neighbor. The station's buildings architecturally resemble the many equine stables in the area and fully enclose all gas piping that is not buried. Nearby wetlands were left undisturbed, and forest helps screen the station from view.

Inside the station are three 4000-hp Mopico integrated motor-centrifugal compressors from Pipeline Compressor Systems, installed in series to provide a range of compression ratios that maintain the station's discharge pressure at 1000 psi. Variable-frequency adjustable-speed drives allow the Mopico units to operate over a range of 6000 to 10,000 rpm. Because this type of electric motor-compressor features magnetic bearings and uses pipeline gas for motor cooling, there is no need for lube and seal oil systems and thus no potential for oil leaks.

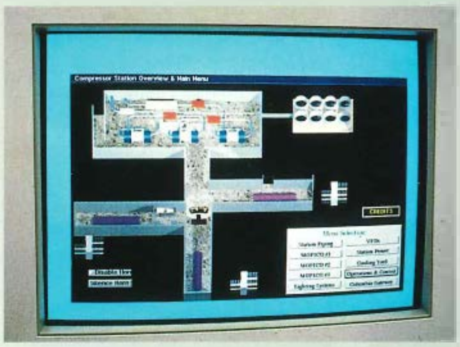
Power for the Rutledge compressor station is provided by Baltimore Gas and Electric Company, a summer-peaking utility that welcomed the winter-peaking compressor load. To serve the station, BG&E built a 2600-foot, 115-kV transmission line and a transformer substation, minimizing the environmental impact by using Columbia Gas Transmission's pipeline right-of-way. To minimize visual impact, the transmission poles were kept below treetop level, weathering steel was used, and other components were painted chocolate brown.

Fred Wrenn, field services vice president at Columbia Gas Transmission, says that the Rutledge station motor-compressors have met expectations for dependable, cost-competitive operation—offering significantly reduced environmental impact, lower operating and maintenance costs, and greater station flexibility, compared with the gas-driven reciprocating compressors the company had originally planned. The Mopico units are about 40% more energy-efficient than simple-cycle gas turbines, and because the magnetic bearings eliminate all moving parts except for the rotor, the units' operating life is expected to exceed 50 years.

Columbia Gas Transmission Corporation built its Rutledge compressor station in Maryland to conform to the architectural standards of the surrounding residential development. The company installed three integral electric motor-compressor units that don't disturb the neighbors or the environment.

—preferably available from a summer-peaking utility, since gas companies are overwhelmingly winter-peaking. The energy charge is only part of the cost of power, however. Industrial customers that potentially require large amounts of power also pay substantial demand charges. It is these charges that gas pipeline companies say can stop them from considering electric motor drives for compressor capacity used mainly for seasonal or peaking service.

"If we're asked by a customer to pump some extra gas toward the end of a month when demand is backed off and we have to start up one or several electric compressor units for just a few days, it can cost us a quarter of a million dollars in electricity demand charges just to push the button to start those units," says Jeff Wolfe, superintendent at Texas Eastern Transmission Corporation in Houston. (Texas Eastern was a unit of PanEnergy Corporation, which recently merged with Duke Power Company to form Duke Energy Corporation.) "If we were on a more commodity-based rate and had the flexibility to start and stop



Considered an advocate of electric compression in the gas pipeline industry, Wrenn agrees that opportunities for synergy between gas and electricity could increase if greater competition leads to lower electricity prices and more-innovative rate structures. "There is a solid relationship based on a thermodynamic and economic model in which the end point is the delivery of therms or kilowatthours in the most cost-effective manner," he says. "In addition, the environmental relationship between electricity and gas makes the case even stronger for using more electric compression on pipelines and using more gas to generate electricity."

Wrenn says that in promoting gas and electric partnerships, the EPRI Chemicals & Petroleum Center is disseminating cost and performance information on electric compression that is helping educate each industry about the other's technical and economic operating requirements, particularly in the area of reliability. But, he adds, "you can still get stuck trying to project future power costs. It's too early to say that electric compression is on everyone's heart and mind in the gas pipeline industry, but I believe acceptance of the technology is growing rapidly." □

the electric compressors as needed without the penalty of demand charges, we would probably run them more."

With operating experience going back to the 1940s, Texas Eastern is one of the oldest gas pipeline users of electric-drive compressors; it has over 500,000 hp of installed capacity, representing an aggregate electrical load of over 370 MW. Texas Eastern's 10,000 miles of pipeline extend from the Mexican border to the New York City metropolitan area.

"We're trying to negotiate with various power companies and make them aware of our needs as an interstate pipeline," says Wolfe. "For example, we'd like a combined contract that covers all our stations along a pipeline. We could pay higher energy costs for electricity and still use more electric compressors if we didn't have to pay so much in demand charges. My view is that electric compressor drives will continue to be a tough sell unless utilities understand the pipeline companies' needs and structure a rate that doesn't penalize a company for operating its system the way it needs to."

In some cases, electric utilities can offer gas pipeline customers time-of-use rates that give them greater flexibility to operate electric compressor units—often in conjunction with gas storage capacity—more economically. But as AEP's Flanery points out, utilities are generally restricted by the terms of regulated tariffs. "Within that limited scope of flexibility, however, we are trying to meet the needs of pipeline customers better than we have in the past," Flanery adds.

The situation could change dramatically in the next few years as more electricity markets are deregulated. Large industrial customers will be allowed to choose among electricity providers as individual states begin to loosen the regulatory reins on price and competition. Once that process begins and customers are free to shop around, the market price for electricity in areas with excess or underused generating capacity could decline substantially. At the same time, electric utilities could be free to structure service offerings that are more appealing and compelling to gas pipeline companies.

"In a deregulated market, gas pipeline customers are likely to have much greater influence over how electricity is priced," says Flanery. "Lower-cost electricity for these customers will not only improve the economic competitiveness of electric compression but also moderate anxieties about the loss of direct control over the fuel source for compression. Over the long run, these trends will benefit any pipeline company that is using electric drives."

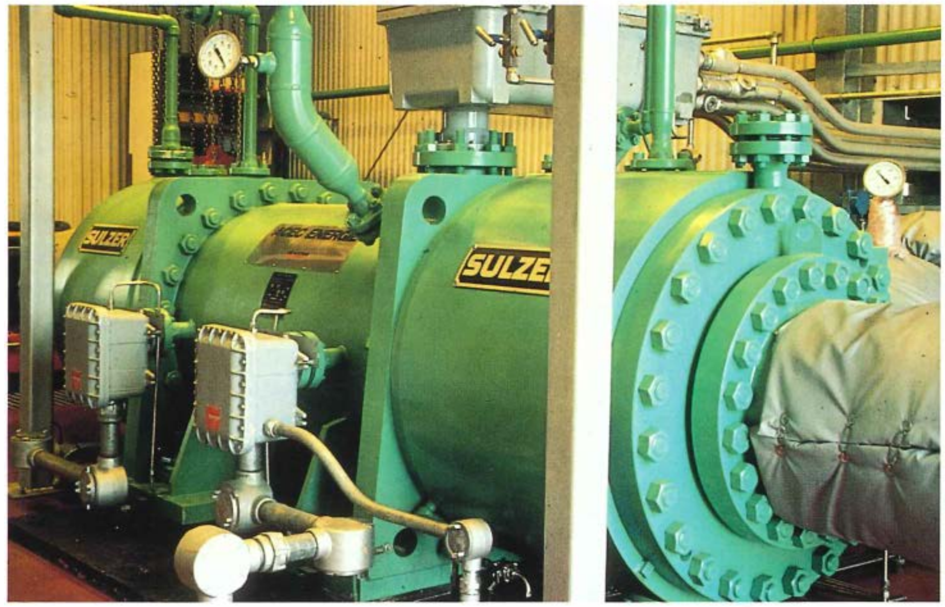
Various factors steer decisions

While the choice between electric and gas-fired compression is fundamentally an economic one, "there are nonquantitative factors that can enter into a business decision," notes Ian Ramsay, a business development manager at Houston Lighting & Power Company (HL&P), one of about 20 utilities in whose service areas the majority of U.S. interstate pipelines and storage facilities are located. A majority of the pipeline companies are also headquartered in Houston.

"Economics are certainly the determining factor, but under that umbrella are such costs as environmental regulatory compliance and preserving the public's goodwill," Ramsay explains. "That's where electric compression has real advantages over gas-fired equipment. It simultaneously solves several environmental problems that can be significant cost factors. These include NO_x emissions control and other siting constraints—like noise, which can be a significant negative factor for gas-fired compression in a populated area." (See sidebar.)

Noting the sensitivity of gas pipeline operators to the needs and concerns of the public, Ramsay says, "Pipeline companies are excellent corporate citizens and will do the right thing not just for themselves but also for the environment, whether that is motivated by emissions considerations, a noise component, or concerns about waste streams."

Beyond the environmental benefits of eliminating NO_x emissions at the point of compression and greatly reducing noise, another environmental concern—emissions of greenhouse gases, which are implicated in climate change—could motivate the increased use of electrically driven pipeline compression in the United States. (Per molecule, methane—the major component of natural gas—is a more potent heat-absorbing greenhouse gas than carbon dioxide.) This concern has already spurred some electric motor installations on TransCanada PipeLines Limited's 14,000-kilometer (8700-mile) main line from Al-



TRANSCO DEMONSTRATES INTEGRAL UNIT **Transcontinental Gas Pipe Line Corporation installed an 8000-hp integral electric motor-compressor with an adjustable-speed drive at an Alabama compressor station to improve operating flexibility, reduce capital and maintenance costs, and lower emissions and noise levels. The ASD enables the unit to maintain high efficiency under all load conditions.**

RONALD TONJES/PROWRITE

berta to Ontario, which transports 10% of the gas used in North America.

In support of Canada's commitment to voluntarily limit greenhouse gas emissions, Calgary-based TransCanada is implementing a variety of measures aimed at reducing natural gas emissions resulting from its operations. Among many operational changes designed to reduce the need for line purging and venting gas to the atmosphere, TransCanada plans to convert the starting engines for 33 reciprocating compressors at its Avon station to 75-hp electric motors by the year 2000, eventually cutting methane emissions equivalent to 3300 tons of carbon dioxide per year.

TransCanada also considers electric motor drives for new or upgraded compressor capacity for economic reasons unrelated to emissions control. The company recently announced plans for a major capacity expansion of its main-line system that includes 11 new compressors for installation in 1998.

Strictly economic considerations were behind Houston-based Transcontinental Gas Pipe Line Corporation's first application of electric compressors—the installation of three 12,500-hp General Electric motors at a North Carolina compressor station nearly 30 years ago. In more recent applications, Transco (one of the Williams Companies) has been motivated by environmental concerns. In 1994, for example, in the face of uncertainty about emissions limits, it replaced two gas-fired steam turbines at its Billingsley, Alabama, compressor station with two 7000-hp electric motors while retaining the station's existing centrifugal compressors. (This was the company's first true conversion of gas-fired equipment to electric drives; earlier electric compressor applications were new installations.)

More recently, noise control and the elimination of NO_x emissions were the principal factors behind Transco's installation of two new 7000-hp Ansaldo Ross Hill motors at a station in Princeton, New Jersey. In 1995 and 1996, the company installed two 12,000-hp electric motor drives at a compressor station near Atlanta, and it is evaluating an additional installation at the Princeton station. Transco's main-line system extends from Texas to New York—more than 10,000 miles—and includes 37 compressor stations.

Prelude to greater gas-electric synergy

Some experts point to the opportunities for cost-effective electric compression on gas pipelines and the increased use of gas in gas turbine combined-cycle power plants as the earliest, most tangible examples of the kinds of synergies that could result from the trend toward integrated service companies that provide comprehensive energy solutions to customers. Recent gas-electric business mergers are seen as signs that far greater opportunities for integrating and maximizing operating efficiencies may become possible. Such mergers include Portland General Electric Company with Enron Corporation, PanEnergy Corporation with Duke Power Company, NorAm Energy Corporation with HL&P's parent Houston Industries, Pacific Enterprises with Enova Corporation, ENSERCH Corporation with Texas Utilities Company, and Valero Energy Corporation with PG&E Corporation.

"These newly merged and merging companies will become even more integrated energy suppliers, and that could mean more use of electric pipeline compression," says HL&P's Ramsay, who chairs the EPRI Gas-Electric Partnership program. "The pipeline companies are always analyzing how to optimize their systems, just as electric utilities are constantly optimizing their transmission and distribution systems. The pipeline companies will decide what best fits their needs based on economic considerations, and I believe electric utilities will rise to the occasion and deliver the kinds of products and services the pipelines are looking for." ■

Further reading

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"Electric-Powered Pipeline Compressor Station." EPRI Chemicals & Petroleum Center TechApplication TA-105999. 1995.

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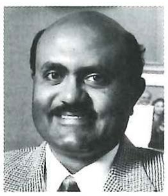
Background information for this article was provided by Ammi Amarnath of the Industrial & Agricultural Technologies & Services Business Area.

CONTRIBUTORS

Technical sources for Journal feature articles



AMARNATH

CARNS

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GOODRICH-MAHONEY

A Fresh Look at Ozone (page 6) was written by Leslie Lamarre, *Journal* senior feature writer, with information from three EPRI research managers in the Industrial & Agricultural Technologies & Services Business Area of the Customer Systems Group.

Ammi Amarnath, manager for process industries, joined the Institute in 1988. His previous experience includes seven years as a process engineer and supervisor for two manufacturers of process equipment, K-Sons Ltd. in India and Metito International in Houston. Amarnath has a BS in chemical engineering from the University of Mysore in India, an MS in the same area from the University of California at Santa Barbara, and an MBA from the University of Houston.

Keith Carns, director of EPRI's Community Environmental Center, oversees research in advanced electrotechnologies for water and wastewater treatment at Washington University in St. Louis, Manhattan College in New York, and the Mvula Trust in Johannesburg, South Africa. 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/wastewater utilities. He has a BS in civil engineering and an MS in environmental engineering from the University of California at Berkeley.

Myron Jones, manager for advanced industrial systems, came to EPRI in 1990. Before that he was vice president of a subsidiary of Pacific Gas and Electric, where he was responsible for natural gas sales and corporate planning. He also worked for Bechtel, Shell Development Corporation, United Technologies, and Rust Engineering in a variety of process design and R&D capacities. Jones has BS and MS degrees in chemical engineering from the University of Maine. ■

Constructed Wetlands Treat Wastewater Naturally (page 16) was written by science writer Christopher R. Powicki with background information provided by **John Goodrich-Mahoney** of EPRI's Environment Group.

Goodrich-Mahoney is manager for water quality R&D programs in the Water Toxics Assessment & Watershed Management Business Area. He also manages coal combustion by-product utilization projects in the Land & Groundwater Protection & Remediation Business Area. Prior to joining EPRI in 1990, he managed a regulatory development program at the U.S. Environmental Protection Agency in Washington, D.C. Goodrich-Mahoney received a BS in geology from St. Lawrence University and an MSc in geochemistry from Brown University. ■

Powering the Pipeline (page 26) was written by Taylor Moore, *Journal* senior feature writer. Background information was provided by **Ammi Amarnath** (see "A Fresh Look at Ozone"). ■

Passive-Loop Shield Performance Verified

The New York Power Authority (NYPA) and EPRI recently completed the development and initial testing of a passive two-loop shielding system for reducing magnetic fields along a 345-kV transmission line right-of-way, culminating several years of work at EPRI's Power Delivery Center. The New York tests, conducted in a tailored collaboration effort with the Environment Group's target on electric and magnetic fields management, demonstrated the technology's effectiveness in reducing 60-Hz magnetic fields.

Concerns about potential health effects of electric and magnetic fields have broadened in recent years to encompass electromagnetic interference issues, as computers and other electronic equipment have become more sensitive to this interference. Several useful techniques for reducing magnetic fields from electrical facilities, equipment, and appliances have emerged as a result of engineering research and are now being tested by utilities, government agencies, and businesses.


COURTESY NEW YORK POWER AUTHORITY

A corridor with two 345-kV transmission lines was the site for tests of a passive-loop shielding system for reducing magnetic fields.

Working with the staff of the Power Delivery Center, NYPA designed and built a passive-loop shield on a short section of its cross-state 345-kV transmission system in a corridor that contains two transmission lines. For this shield, wires were strung parallel to a section of the transmission lines to form two loops. The shield works on the principle that currents induced in passive-loop conductors produce a magnetic field that partially cancels the fields produced by a transmission line; the magnetic field at the edge of a right-of-way and beyond can be appropriately reduced along the line section employing the passive loop. For the NYPA tests, engineers designed a two-loop shield in order to reduce magnetic fields equally on both sides of the right-of-way.

The location of the conductors in a passive-loop shield governs the amount of current induced in the loop by transmission lines. Series capacitors are used to cancel loop inductive reactance and to permit postinstallation fine-tuning of loops. The capacitors must be able to withstand not only steady-state voltage under maximum line loading but also transients caused by faults on the main transmission system.

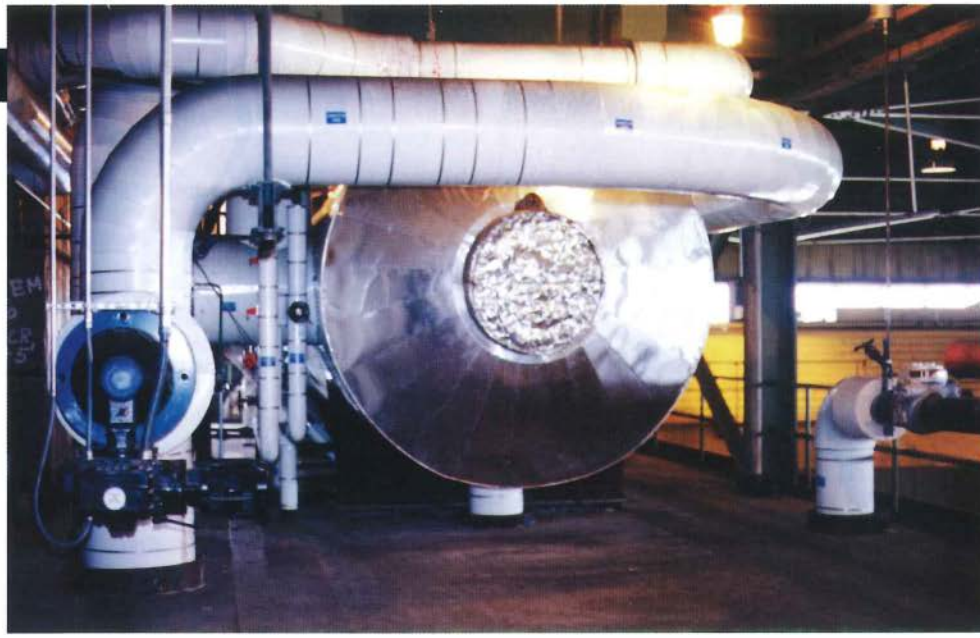
The NYPA design followed guidelines developed in earlier EPRI research, notes Frank Young of the Institute's Environment Group. "The measurement results verified both the accuracy of the design procedures and the effectiveness of passive loops in providing an economical means of reducing magnetic fields near selected portions of existing transmission lines."

■ *For more information, contact Frank Young, (650) 855-2815.*

Header Feedwater Heaters Improve Cycling Capability

The reliability and efficiency of fossil generating units designed for baseload operation are typically impaired when the units are used for cycling or peaking service, as many utilities are doing today to meet changing customer demand. The performance loss is primarily a result of design limitations of the units' conventional tubesheet-and-channel-type feedwater heaters (FWHs). A new header-type heater—developed in Europe and widely used there and in other parts of the world—offers several advantages that improve the performance of fossil plants in cycling operation and cut operating and maintenance costs while maintaining high reliability and availability.

Recently, when Union Electric (UE) needed to replace the FWHs on its Sioux unit 2, the St. Louis–based utility teamed up with EPRI in a project to maximize the life span of the new heaters and to optimize unit operation at the design heat rate. UE and EPRI cosponsored a retrofit of the 505-MW supercritical Sioux unit 2 with two new header-type FWHs, the first such U.S. retrofit demonstration involving a supercritical unit. EPRI documented the project in a technical report (TR-105994).


COURTESY ENCOR-AMERICA

One of the advantages of header-type FWHs is that their pressure-retaining parts consist of relatively thin cylindrical sections that are less susceptible to thermal stresses than the tubesheets of conventional heaters. The resulting longer life and greater reliability and availability of header FWHs more than compensate for their higher capital cost. Since the installation of the new heaters, UE has had lower heater maintenance costs, and Sioux unit 2 now operates at its design heat rate. The utility is retrofitting Sioux unit 1, another 505-MW supercritical unit, with the new heaters.

"With header feedwater heaters, we no longer anticipate the tube weld failures that were an unmanageable problem with the old tubesheet-type heaters," says UE's Glenn Tiffin. By eliminating future replacement costs and reducing maintenance expenses through the retrofit of header FWHs, the utility expects to save $3.2 million (present value) per heater over 30 years.

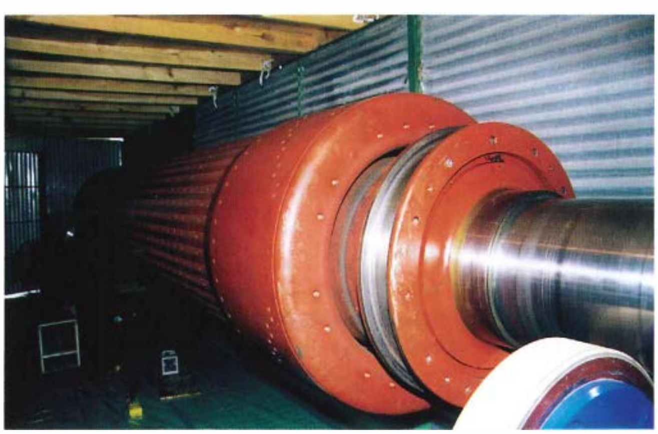
■ *For more information, contact John Tsou, (650) 855-2220.*

Software Helps Carolina Power & Light Avoid Retaining-Ring Replacement

Stress corrosion cracking can lead to the catastrophic failure of generator retaining rings and is the leading cause of their early retirement. Exposure to even small amounts of moisture makes 18-5 Mn-Cr rings susceptible to stress corrosion cracking. Generator manufacturers typically recommend that utilities replace these rings with 18-18 Mn-Cr steel, which is highly resistant to stress corrosion.

During a scheduled outage at Carolina Power & Light Company's Shearon Harris nuclear station, a nondestructive evaluation (NDE) inspector recommended that the utility remove the generator retaining ring for additional inspection and possible repair or replacement. Since extending the outage would have been expensive, entailing $12,000 per hour in replacement power and other costs, CP&L needed a way to evaluate the inspection results and develop a second opinion.

RRing-Life, PC-based EPRI software for assessing the life of retaining rings, is a product of efforts to develop NDE and analytical tools that can enable utilities to continue using 18-5 Mn-Cr rings. Taking into account such factors as stress, material properties, ring dimensions, geographic location, NDE results, and maintenance procedures, RRing-Life predicts crack initiation and growth rates and determines critical flaw sizes.



CP&L's detailed records of the dew point at the Shearon Harris station were a critical input to the RRing-Life analysis, which was performed quickly with help from EPRI's NDE Center in Charlotte, North Carolina. The analysis indicated that the level of cracking in the ring set at Shearon Harris was consistent with prior maintenance practices and known instances of moisture exposure. On the basis of these findings and past experience, CP&L decided to keep the ring in service while closely watching its condition and to repeat the RRing-Life analysis at the next scheduled outage. As a result of this decision, the utility avoided equipment costs of $250,000 as well as replacement power costs, for total savings of more than $5 million. "The use of RRing-Life allowed us to avoid a costly extension of the scheduled outage," says George Montgomery, a CP&L senior engineer.

RRing-Life is available from Structural Integrity Associates of San Jose, California, (408) 978-8200.

■ *For more information, contact Jan Stein, (650) 855-2390.*

New Technical Reports

Requests for copies of reports should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, California 94523; (510) 934-4212. Two-page summaries of the reports announced here are available, free of charge, by fax. To receive a summary, call EPRI's Fax on Demand service (800-239-4655) from a touch-tone phone and follow the recorded instructions, using the fax identification number given in the report listing.

CUSTOMER SYSTEMS

Commercial Kitchen Ventilation Performance Report: Six-Element Electric Range Top Under Wall-Mounted Canopy Hood
TR-106493-V9 Final Report (WO3563-6)
Contractors: Architectural Energy Corp.; International Facilities Management Association
EPRI Project Manager: W. Krill
Fax ID: 41589

Commercial Kitchen Ventilation Performance Report: Electric Underfired Broiler Under Wall-Mounted Canopy Hood
TR-106493-V10 Final Report (WO3563-6)
Contractors: Architectural Energy Corp.; International Facilities Management Association
EPRI Project Manager: W. Krill
Fax ID: 41590

A Small-Business Guide: Metal Finishing
TR-106676-V6 Final Report (WO4491)
Contractor: Resource Dynamics Corp.
EPRI Project Manager: W. Krill
Fax ID: 40968

A Small-Business Guide: Shopping Centers
TR-106676-V7 Final Report (WO3563-1)
Contractor: Resource Dynamics Corp.
EPRI Project Manager: W. Krill
Fax ID: 40969

A Small-Business Guide: Convenience and Grocery Stores
TR-106676-V8 Final Report (WO3563-1)
Contractor: Resource Dynamics Corp.
EPRI Project Managers: W. Krill, R. Wilhite
Fax ID: 40970

A Small-Business Guide: Office Buildings
TR-106676-V10 Final Report (WO3563-1)
Contractor: Resource Dynamics Corp.
EPRI Project Managers: W. Krill, R. Wilhite
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Improving Reliability of Class 1E Power Distribution to Instrumentation and Control Cabinets on Nuclear Power Plants in the U.S.A.
TR-107025 Final Report (WO3088)
Contractor: Westinghouse Science & Technology Center
EPRI Project Manager: B. Banerjee
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Lighting Retrofit Manual
TR-107130 Final Report (WO2285-26)
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EPRI Project Manager: K. Johnson
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Optimizing Energy Use in Industrial Freezing: Phase 1
TR-107171 Final Report (WO8060)
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EPRI Project Manager: A. Amarnath
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Fast Food Restaurant Computer Simulations: Akron, Ohio
TR-107205-V5 Final Report (WO3544-1)
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EPRI Project Manager: K. Johnson
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Full Menu Restaurant Computer Simulations: Phoenix, Arizona
TR-107282-V4 Final Report (WO3544)
Contractor: Architectural Energy Corp.
EPRI Project Manager: K. Johnson
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Full Menu Restaurant Computer Simulations: Akron, Ohio
TR-107282-V5 Final Report (WO3544-1)
Contractor: Architectural Energy Corp.
EPRI Project Manager: K. Johnson
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Full Menu Restaurant Computer Simulations: Flagstaff, Arizona
TR-107282-V6 Final Report (WO3544-1)
Contractor: Architectural Energy Corp.
EPRI Project Manager: K. Johnson
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Full Menu Restaurant Computer Simulations: Greenville, South Carolina
TR-107282-V8 Final Report (WO3544-1)
Contractor: Architectural Energy Corp.
EPRI Project Manager: K. Johnson
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Full Menu Restaurant Computer Simulations: Oklahoma City, Oklahoma
TR-107282-V9 Final Report (WO3544)
Contractor: Architectural Energy Corp.
EPRI Project Manager: K. Johnson
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Full Menu Restaurant Computer Simulations: Northern New Jersey
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Contractor: Architectural Energy Corp.
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Market Analysis for Natural Gas Compression Technologies
TR-107547 Final Report (WO4953-1)
Contractor: Hagler Bailly Consulting, Inc.
EPRI Project Managers: P. Meagher, T. Henneberger, A. Amarnath
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Proceedings: Second Annual Distributed Resources Conference
TR-107585 Proceedings (WO4952)
EPRI Project Manager: G. Heffner
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Energy Market Profiles, Vol. 2: 1995 Residential Buildings, Appliances, and Energy Use
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ENVIRONMENT

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GENERATION

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Selection and Optimization of Boiler Water and Feedwater Treatments for Fossil Plants
TR-105040 Final Report (WO9000, WO9003)
EPRI Project Manager: B. Dooley
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Advanced Gas Turbine Guidelines: Hot Gas Path Parts Condition and Remaining Life Assessment for GE 7FA in Baseload Operation
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Waste Accounting, Vols. 1–4
TR-106564-V1 V4 Final Report
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Generator Stability Parameter Identification Data Acquisition System (PIDAS), Vols. 1–3
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Contractor: GE Electrical Distribution and Control
EPRI Project Manager: J. Stein
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A Guide for Work Process Improvement and Best-in-Class Benchmarking in Fossil Power Plants
TR-107071 Final Report (WO3151-1, WO3854-1)
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EPRI Project Manager: R. Pflasterer
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Cost of Providing Ancillary Services From Power Plants, Vol. 1: A Primer
TR-107270-V1 Final Report
Contractor: T/Systems
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CHAT Plant Design Guide
TR-107287 Final Report (WO2620-14)
Contractor: Energy Storage and Power Consultants
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Proceedings: Second Annual Distributed Resources Conference
TR-107585 (see listing under Customer Systems)

Guidelines for the Procurement of On-Site Clip Replacement and Repairs of Water-Cooled Generators
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Contractor: JARSCO Engineering Corp.
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Large Air-Cooled Generators Driven by Combustion Turbines: Generic Issues
TR-107723 Final Report (WO3577-2)
Contractor: Electromechanical Engineering Associates, Inc.
EPRI Project Manager: J. Stein
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Development of an Advanced Corrosion Rate Monitor: The Harmonic Impedance Spectroscopy Method
TR-107867 (see listing under Strategic R&D)

Fuel Management for Competitive Power Generation: A Guide to Managing Change
TR-107890 Final Report (WO4122)
Contractor: Resource Dynamics Corp.
EPRI Project Manager: J. Platt
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SO_2 Compliance and Allowance Trading: Developments and Outlook
TR-107897 Final Report (WO4129)
Contractor: Keith D. White
EPRI Project Manager: J. Platt
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Regional Impacts of Electric Utility Restructuring on Fuel Markets, Vols. 1 and 2
TR-107900-V1–V2 Final Report (WO4122)
Contractor: The Brattle Group, Inc.
EPRI Project Manager: J. Platt
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NUCLEAR POWER

Indian Point 3 Retired Steam Generator Inspection
TR-103932 Final Report (WOS415-4)
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: G. Srikantiah
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Calvert Cliffs Nuclear Power Plant Integrated Plant Assessment Methodology
TR-104734 Final Report (WO3343-1)
Contractor: Baltimore Gas and Electric Co.
EPRI Project Manager: J. Carey
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Analysis of Steam Generator Tubing From Oconee Unit 1 Nuclear Station
TR-106484 Final Report (WOS413-12)
Contractor: Duke Power Co.
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Development of an Ultrasonic PWR Primary Coolant Temperature/Flow Measurement System (RCSM)
TR-106821-V1–V2 Final Report (WO3885-1)
Contractor: MPR Associates
EPRI Project Manager: R. James
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CECIL® Development Program for Combustion Engineering Steam Generators
TR-106854 Final Report (WO3877-1)
Contractor: Foster-Miller, Inc.
EPRI Project Manager: R. Thomas
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Demonstration of the Management of Aging Effects for Reactor Coolant System Piping
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Contractor: Framatome Technologies, Inc.
EPRI Project Manager: J. Carey
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Improving Reliability of Class 1E Power Distribution to Instrumentation and Control Cabinets on Nuclear Power Plants in the U.S.A.
TR-107025 (see listing under Customer Systems)

Guidelines for Managing Reactor Vessel Material Uncertainties: Part 1, General Approach; Part 2, Implementation Guide
TR-107110 Final Report (WO2975)
Contractor: ATI Consulting
EPRI Project Manager: S. Rosinski
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A Risk-Informed Flaw Tolerance Approach for Increasing ASME Section XI, Appendix G PT Limits
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Contractor: SARTREX Corp.
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Microstructural Characterization of RPV Steels: Phase 1 (Joint EPRI-CRIEPI RPV Embrittlement Studies)
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Effects of Protective Clothing on the Cardiorespiratory System of Workers at Elevated Temperatures

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Contractors: University of Massachusetts Medical Center; Yankee Atomic Electric Co.
EPRI Project Manager: C. Hornibrook
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Proceedings: Welding and Repair Technology for Power Plants (Second International Conference)

TR-107719 (see listing under Strategic R&D)

Condensate Filter Demineralizer Performance Improvement Program

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Contractor: CENTEC-XXI
EPRI Project Manager: C. Hornibrook
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Development of an Advanced Corrosion Rate Monitor: The Harmonic Impedance Spectroscopy Method

TR-107867 (see listing under Strategic R&D)

Dynamic Safety Systems for RPS Replacement, Phase 1: Cost-Benefit Analysis

TR-107967 Interim Report (WO4385)
Contractors: Duke Power Co.; Campbell Love Associates; Ohio State University; AEA Technology PLC
EPRI Project Manager: C. Wilkinson
Fax ID: 41714

POWER DELIVERY

Proceedings: Second Annual Distributed Resources Conference

TR-107585 (see listing under Customer Systems)

The Impact of Dispersed Generation on Electric Power Quality at the Central and South West Services Wind Farm

TR-107715 Final Report (WO7001-1)
Contractor: University of Arkansas
EPRI Project Manager: D. Richardson
Fax ID: 41253

The Impact of Dispersed Generation Upon the Quality of Electric Power: The Solar Park in the Ft. Davis Distribution System

TR-107725 Final Report (WO7001-1)
Contractor: University of Arkansas
EPRI Project Manager: D. Richardson
Fax ID: 41271

Implementation of an Auxiliary-Resonant Commutated-Pole Inverter

TR-107731 Final Report (WO7001-1)
Contractors: University of Arkansas; Central and South West Services
EPRI Project Manager: D. Richardson
Fax ID: 41279

Valuing Generation Assets in Uncertain Markets

AP-107748 Assembled Package (WO4024-1)
Contractors: The Brattle Group, Inc.; The Northbridge Group
EPRI Project Manager: R. Goldberg
Fax ID: 41317

Constrained Dynamic Dispatch

TR-107749 Final Report (WO3555-5)
Contractor: ESCA Corp.
EPRI Project Manager: D. Sobajic
Fax ID: 41309

Control Performance Standards and Procedures for Interconnected Operation

TR-107813 Final Report (WO3155-10)
Contractor: Priority-Based Control Engineering Co.
EPRI Project Manager: D. Maratukulam
Fax ID: 41448

TRACE User's Manual: A Beginner's Guide to the Use of the TRACE Program

TR-107846 Final Report (WO3140-7)
Contractor: University of Minnesota
EPRI Project Manager: P. Hirsch
Fax ID: 41496

Taiwan Power TCSC Evaluation Study

TR-107896 Final Report (WO3191-4)
Contractors: Taiwan Power Co.; Powertech Labs, Inc.
EPRI Project Manager: R. Adapa
Fax ID: 41573

Assessment of Applications and Benefits of Phasor Measurement Technology in Power Systems

TR-107903 Final Report (WO3789-5)
Contractor: GE Power Systems Engineering
EPRI Project Manager: R. Adapa
Fax ID: 41587

Synchronized Phasor Measurements for the Western Systems Coordinating Council (WSCC)

TR-107908 Final Report (WO3717-1)
Contractor: Virginia Polytechnic Institute and State University
EPRI Project Manager: R. Adapa
Fax ID: 41596

FACTS Assessment Study to Increase the Arizona-California Transfer Capability

TR-107934 Final Report (WO3789-4)
Contractor: San Diego Gas & Electric Co.
EPRI Project Manager: R. Adapa
Fax ID: 41671

Reliability Benchmarking Methodology

TR-107938 Final Report (WO4349-1)
Contractor: Electrotek Concepts, Inc.
EPRI Project Manager: A. Sundaram
Fax ID: 41679

San Diego Gas & Electric Company—Manufactured Pole Technology Assessment

TR-108016 Final Report (WO7017-2)
Contractors: San Diego Gas & Electric Co.; Engineering Data Management, Inc.
EPRI Project Manager: B. Bernstein
Fax ID: 41784

Proceedings: EPRI Corrosion-Resistant Coatings Technology Workshop

TR-108017 Final Report (WO4337-2)
Contractor: Foster Miller, Inc.
EPRI Project Manager: B. Bernstein
Fax ID: 41786

Testing of XLPE Transmission Cable Terminations at Three Utilities: Southern California Edison, Public Service Company of Colorado, and PECO Energy Company

TR-108073 Final Report (WO7937-4)
Contractor: KEMA Powertest, Inc.
EPRI Project Manager: W. Zenger
Fax ID: 41914

Defining Interconnected Operations Services Under Open Access

TR-108097 Final Report (WO5152-1)
Contractors: Operations Training Solutions; KEMA-ECC, Inc.; Power Technologies, Inc.
EPRI Project Manager: R. Adapa
Fax ID: 41944

STRATEGIC R&D

Accelerated Stress Rupture Testing Guidelines for Remaining Creep Life Prediction

TR-106171 Final Report (WO8046-4)
Contractor: Failure Analysis Associates, Inc.
EPRI Project Manager: V. Viswanathan
Fax ID: 25422

Mixed-Oxidant Corrosion in Nonequilibrium Syngas

TR-106717 Final Report (WO8041)
Contractors: J. A. Bonvallet; Lockheed Martin Missiles & Space
EPRI Project Manager: W. Bakker
Fax ID: 26360

Low-Pressure Rotor Rim Attachment Cracking: Survey of Utility Experience

TR-107088 Final Report (WO9005-1)
Contractor: Structural Integrity Associates, Inc.
EPRI Project Manager: V. Viswanathan
Fax ID: 40203

Optimizing Energy Use in Industrial Freezing: Phase 1

TR-107171 (see listing under Customer Systems)

Proceedings: Welding and Repair Technology for Power Plants (Second International Conference)

TR-107719 Proceedings (WO3887-1, WO9004-1)
Contractor: EPRI Repair and Replacement Applications Center
EPRI Project Manager: V. Viswanathan
Fax ID: 41259

Development of an Advanced Corrosion Rate Monitor: The Harmonic Impedance Spectroscopy Method

TR-107867 Final Report (WO1893-16)
Contractor: CC Technologies Laboratories, Inc.
EPRI Project Manager: B. Syrett
Fax ID: 41525

Input-Training Neural Networks for Error Detection

TR-107875 Final Report (WO8017-1)
Contractor: Northwestern University
EPRI Project Manager: M. Wildberger
Fax ID: 41533

Computer Simulation of Adaptive Agents for an Electric Power Auction

TR-107975 Final Report (WO8017)
Contractor: EPMT, Inc.
EPRI Project Manager: M. Wildberger
Fax ID: 41733

EPRI Events

SEPTEMBER

2
Brownfields Workshop
Kansas City, Missouri
Contact: Paul Radcliffe, (650) 855-2720

3–5
C-VALU Advanced Training and Users Group
Madison, Wisconsin
Contact: Rich Goldberg, (650) 855-2397

6–12
Power Quality Conference
Baltimore, Maryland
Contact: Karen Shover, (410) 265-4153

8–9
Electric Motor Predictive Maintenance
Chesterfield, Missouri
Contact: Melita Guellert, (650) 855-2010

8–10
Transmission Structure Coatings Workshop
Nashville, Tennessee
Contact: Kathleen Lyons, (650) 855-2656

9–12
Basic Vibration Testing and Analysis
Eddystone, Pennsylvania
Contact: Jeanne Harris, (800) 745-9982

10–12
4th Symposium on Electric Power for Compression
Houston, Texas
Contact: Dick Schmeal, (713) 963-9306

10–12
Value and Risk in Competitive Markets
Denver, Colorado
Contact: Art Altman, (650) 855-8740

11–12
1st Gas/Electric Partnership Symposium
Houston, Texas
Contact: Lynn Stone, (972) 556-6529

15–17
Lubrication and Bearing Workshop
Albuquerque, New Mexico
Contact: Linda Suddreth, (704) 547-6141

15–17
1997 Condensate Polishing Workshop
New Orleans, Louisiana
Contact: Barbara James, (707) 823-5237

16–18
Forward Price Curve Workshop
San Antonio, Texas
Contact: Vic Niemeyer, (650) 855-2744

16–18
Underground Transmission Technical Review
Philadelphia, Pennsylvania
Contact: Kathleen Lyons, (650) 855-2656

16–19
Transformer Performance, Monitoring, and Diagnostics
Long Beach, California
Contact: John Niemkiewicz, (800) 745-9982

17–18
Applications of Motors and Drives
St. Louis, Missouri
Contact: Carrie Koeturius, (510) 525-1205

18–19
Transmission, Reservation, and Scheduling Workshop
Burlingame, California
Contact: Julie Fennell, (650) 855-1009

21–24
International Ground-Source Heat Pump Conference
Baltimore, Maryland
Contact: Carl Hiller, (916) 758-3035

22–23
Industrial Minerals and Cement Workshop
St. Louis, Missouri
Contact: John Kollar, (412) 268-3435

22–26
Infrared Thermography: Level 1
Long Beach, California
Contact: Jeanne Harris, (800) 745-9982

23–25
Joint EPRI/GRI Seminar on the Management of Manufactured Gas Plant Sites
Washington, D.C.
Contact: Ishwar Murarka, (650) 855-2150

23–26
Price-Product Mix Workshop
Boston, Massachusetts
Contact: Peggy Prater, (650) 855-2951

24
Data-Mining Workshop
New York, New York
Contact: Arlene Garcia, (650) 855-2876

24
World Financial Center Real-Time Pricing Demonstration
New York, New York
Contact: Arlene Garcia, (650) 855-2876

24–25
Lightning Protection Design Workstation Version 4.0 Workshop
Dallas, Texas
Contact: Vito Longo, (650) 855-8586

25–26
Operational Reactor Safety Engineering and Review Group
La Jolla, California
Contact: Lori Adams, (650) 855-8763

26
Rough Sets and Fuzzy Logic Tutorial and Workshop
Palo Alto, California
Contact: Martin Wildberger, (650) 855-1043

29–October 1
Power Quality for the Semiconductor Fabrication Industry
Phoenix, Arizona
Contact: Karen Forsten, (423) 570-2418

30–October 3
Steam Turbine Performance Monitoring, Diagnostics, and Improvement
San Antonio, Texas
Contact: Jeanne Harris, (800) 745-9982

OCTOBER

1
Water and Energy Conference
Charleston, South Carolina
Contact: Kim Shilling, (314) 935-8590

6–7
Workshop on New Product and Service Development
Washington, D.C.
Contact: Lynn Stone, (972) 556-6529

6–7
Workshop on Nondestructive Evaluation for Damage Assessment
La Jolla, California
Contact: Susan Otto, (704) 547-6072

6–8
Gasification Technologies Conference
San Francisco, California
Contact: Michele Samoulides, (650) 855-2127

7–8
Motor Rewind Course
Wharton, New Jersey
Contact: Peggy Amann, (650) 855-2259

7–8
REEPS Software Training
San Diego, California
Contact: Paige Schaefer, (800) 398-0081

7–9
Infrared Thermography: Level 3
Long Beach, California
Contact: John Niemkiewicz, (800) 745-9982

7–9
Workshop on Simulator Acceptance Test Procedures
Kittanning, Pennsylvania
Contact: Sarah Vanberg, (816) 235-5623

8–10
Live Working 2000 Workshop
Lenox, Massachusetts
Contact: Kathleen Lyons, (650) 855-2656

8–10
Substation and Switchyard Predictive Maintenance
Eddystone, Pennsylvania
Contact: Jeanne Harris, (800) 745-9982

9–10
COMMEND Software Training
San Diego, California
Contact: Paige Schaefer, (800) 398-0081

13–14
INFORM Software Training
San Diego, California
Contact: Paige Schaefer, (800) 398-0081

14
Applications of Motors and Drives
Kansas City, Missouri
Contact: Carrie Koeturius, (510) 525-1205

14–17
Safety and Relief Valve Workshop
Huntsville, Alabama
Contact: Linda Suddreth, (704) 547-6141

16–17
EPRI-DOE Wind Turbine Verification Program Workshop
Green Bay, Wisconsin
Contact: Julie Fennell, (650) 855-1009

16–17
EPRI Partnership for Industrial Competitiveness
Allentown, Pennsylvania
Contact: Bill Smith, (650) 855-2415

20–21
Power Quality and the Plastics Industry
Charlotte, North Carolina
Contact: Carrie Koeturius, (510) 525-1205

20–24
Infrared Thermography: Level 2
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (800) 745-9982

20–24
Steam Plant Operations for Utility Engineers
Kansas City, Missouri
Contact: Sarah Vanberg, (816) 235-5623

20–24
3d Annual Distributed Resources Conference
Baltimore, Maryland
Contact: Lori Adams, (650) 855-8763

21–23
Transmission Inspection and Maintenance System Training
Atlanta, Georgia
Contact: Kathleen Lyons, (650) 855-2656

22–23
MANAGES and MOSES-MP Software Training
Charlotte, North Carolina
Contact: Adda Quinn, (650) 855-2478

23–24
HELM Software Training
Dallas, Texas
Contact: Paige Schaefer, (800) 398-0081

26–30
1997 EPRI Performance Measurement Workshop
Denver, Colorado
Contact: Lynn Stone, (972) 556-6529

27–28
OASIS Conference
Danvers, Massachusetts
Contact: Peggy Amann, (650) 855-2259

27–28
Power Quality Marketing Workshop
Knoxville, Tennessee
Contact: Lisa Nederhoff, (423) 570-8014

27–29
NMAC Workshop on Stationary Battery Maintenance
Atlanta, Georgia
Contact: Linda Suddreth, (704) 547-6141

27–31
Boiler Operating Theory Fundamentals
Kansas City, Missouri
Contact: Sarah Vanberg, (816) 235-5623

28–30
Achieving Success in Evolving Electricity Markets
Houston, Texas
Contact: Michele Samoulides, (650) 855-2127

29
Screening Industrial Power Generation Options
Pittsburgh, Pennsylvania
Contact: Margo Norman, (713) 963-9306

29–31
Fossil Plant Welding Workshop
Charlotte, North Carolina
Contact: Brent Lancaster, (704) 547-6041

29–31
Power Quality Advanced Training
Knoxville, Tennessee
Contact: Lisa Nederhoff, (423) 570-8014

30
Specialty Chemicals and Pharmaceutical Initiative
Philadelphia, Pennsylvania
Contact: Margo Norman, (713) 963-9306

NOVEMBER

3–5
Power Quality Interest Group
San Diego, California
Contact: Carrie Koeturius, (510) 525-1205

4–5
Applications of Motors and Drives
Omaha, Nebraska
Contact: Carrie Koeturius, (510) 525-1205

4–6
Fossil Plant Personnel Proficiency Evaluation Training
Charlotte, North Carolina
Contact: Brent Lancaster, (704) 547-6041

4–6
Transmission Inspection and Maintenance System Training
Dallas, Texas
Contact: Kathleen Lyons, (650) 855-2656

5
PQ-DeBUG Meeting
San Diego, California
Contact: Carrie Koeturius, (510) 525-1205

5–7
Fuel Supply Seminar
Chattanooga, Tennessee
Contact: Megan Boyd, (650) 855-7919

6
Electrosynthesis Symposium
Clearwater, Florida
Contact: Jigar Shah, (412) 826-3068

9–12
Electric Furnace Conference
Chicago, Illinois
Contact: Joe Goodwill, (412) 268-3435

10–11
Application and Development of Superconducting Cables
Columbia, South Carolina
Contact: Kathleen Lyons, (650) 855-2656

10–12
Workshop on Decision Analysis for Utility Planning and Management
San Diego, California
Contact: Peggy Prater, (650) 855-2951

11–12
Forecasting in a Competitive Electricity Market
Arlington, Virginia
Contact: Lynn Stone, (972) 556-6529

11–13
Boiler Tube Failure
Nashville, Tennessee
Contact: Michele Samoulides, (650) 855-2127

11–13
Lubrication Oil Analysis
Long Beach, California
Contact: Jeanne Harris, (800) 745-9982

12–14
Managing Hazardous Air Pollutants
Washington, D.C.
Contact: Lori Adams, (650) 855-8763

EPRI JOURNAL

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ADDRESS CORRECTION REQUESTED

July/August 1997

EJ-108516