High-Performance EV Battery on the Horizon

Also in this issue • Mercury and the Environment • Fly Ash Utilization • Carbonate Fuel Cells

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

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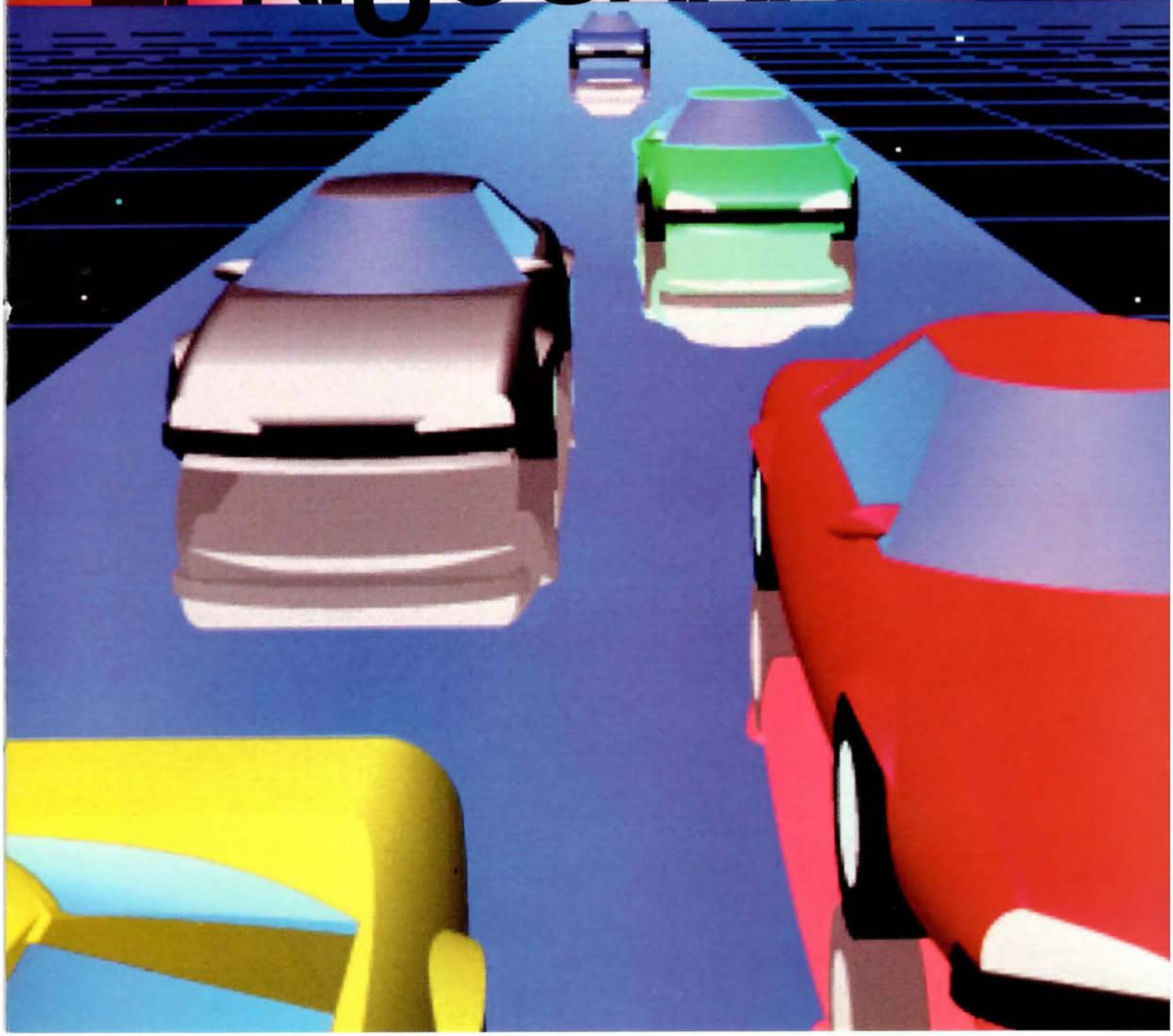

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Cover: The Horizon® advanced lead-acid battery, developed with EPRI funding, has the performance specifications needed to put the first generation of mass-produced electric vehicles on the highway. (Art reprinted by permission. © by Orion Press/Westlight.)

EPRI JOURNAL

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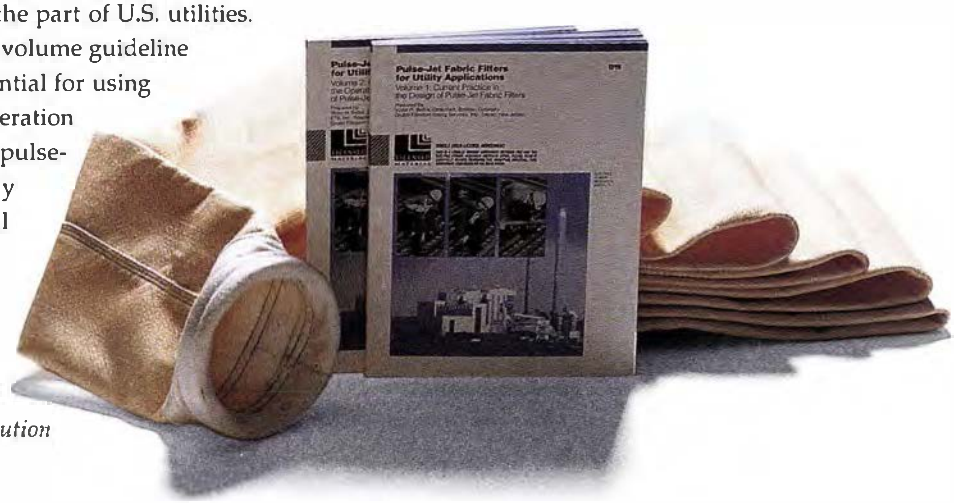
PRODUCTS

EPRI-sponsored deliverables now available to utilities and their customers

Pulse-Jet-Baghouse Resource

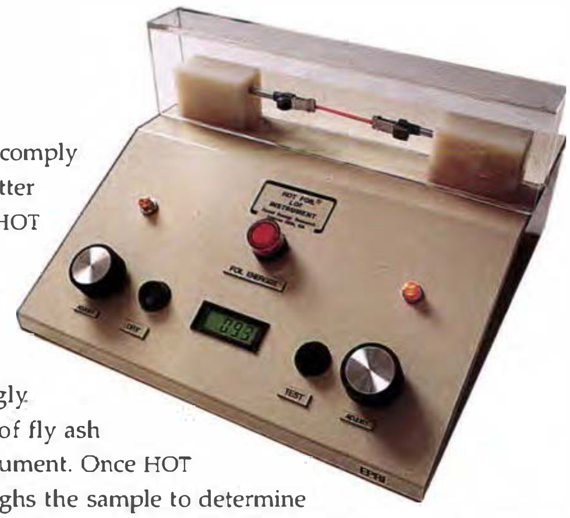
The successful application and improved design of pulse-jet fabric filter technology have stimulated increased interest on the part of U.S. utilities. EPRI has responded by preparing this two-volume guideline (TR-102978) to help utilities assess the potential for using the technology in their fossil-fuel-fired generation systems. Economic analyses show that the pulse-jet method of particulate removal is roughly 30% lower in capital cost than conventional baghouse technology and requires about half the space. The guideline offers practical information on the design, operation, and maintenance of pulse-jet systems.
For more information, contact Ramsay Chang, (415) 855-2535. To order, call the EPRI Distribution Center, (510) 934-4212.



ORAM for Safe and Efficient Outages

An improperly planned nuclear plant outage not only can cost a utility extra time and money but also may pose a significant risk to power plant personnel and equipment. EPRI's Outage Risk Assessment and Management (ORAM) software, Version 1.5, helps utilities optimize outage procedures and thus enhance both safety and efficiency. Whether it's a refueling outage or an unanticipated event, ORAM offers a comprehensive analysis of the various options available. The software can be used to plan an outage, to guide power plant personnel through outage procedures, or to analyze an outage after the fact. ORAM interfaces with utility maintenance and refueling scheduling programs and is flexible enough to accommodate virtually any plant configuration.
For more information, contact S. Pal Kalra, (415) 855-2414. To order, call the Electric Power Software Center, (214) 655-8883.

HOT FOIL Tools for Carbon Testing



Utilities installing low-nitrogen oxide burners to comply with the 1990 Clean Air Act Amendments can better optimize their NO_x control systems by using the HOT FOIL® LOI instrument. Low-NO_x burners typically increase the carbon content of fly ash, generating more particulate emissions. With HOT FOIL LOI, utilities can regularly assess the carbon content of their fly ash and adjust their burners accordingly. A power plant operator simply weighs a sample of fly ash and drops it onto the foil provided with the instrument. Once HOT FOIL LOI burns off the carbon, the operator reweighs the sample to determine the weight loss, which indicates the carbon content. (LOI stands for loss on ignition.) The whole process takes about 20 minutes, compared with 2 hours for conventional testing methods. HOT FOIL LOI is useful not only for optimizing NO_x control systems but also for increasing plant efficiency and monitoring boiler conditions. A separate instrument, HOT FOIL CI (for coking index), offers a similar testing method to determine the potential for carbon particulate formation during the combustion of residual fuel oil. It provides utilities with the first effective means of characterizing oil quality.

For more information, contact William Rovesti, (202) 293-7518. To order, call Richard Hack at Fossil Energy Research Corporation, (714) 859-4466.

Building an Energy-Efficient Home

With the help of this 15-minute video (VT-102878), contractors, do-it-yourself homeowners, and other utility customers will be well on their way to building more energy-efficient houses. Showing footage of the actual construction, from the ground up, of a new home in Dallas, Texas, the video demonstrates the use of environmentally friendly materials and techniques for creating an air-tight thermal envelope that can save up to 25% on heating and cooling costs. Soleplate caulking, exterior foam sheathing, and a variety of indoor insulation products are just some of the new-home construction materials discussed. Also covered are techniques for maintaining good indoor air quality.

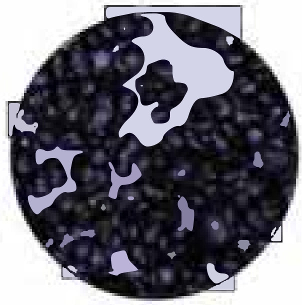
For more information, contact John Kesselring, (415) 855-2902. To order, call the EPRI Distribution Center, (510) 934-4212.

Cleaning Soil With Coal

Most manufactured gas plants (MGPs) closed down in the 1950s with the introduction of interstate gas pipelines, but they left a legacy of by-product residues that now contaminate potentially valuable real estate throughout the United States. A major engineering problem in cleaning up these sites is that the wastes are extremely heterogeneous and sometimes virtually impossible to handle, being a sticky mess of tar, soil, oil-water emulsion, and general debris. Now a process has been developed that is uniquely suited for remediating MGP sites: it includes separation of the various constituents and disposal of the nonhazardous residues by combustion in a utility power plant.

This new Clean Soil Process, developed by EPRI and Canada's Alberta Research Council (ARC) with 20 cofunders, is based on the principle that when fine coal contained in a hot water slurry is mixed in a tumbler with contaminated soil containing organic compounds, the contaminants are adsorbed by the coal and the coal tends to agglomerate, leaving the soil clean. In the complete version of the process, which has been tested successfully in a 250-kg/h pilot unit, coarse solids (more than 3.3 mm in diameter)—including clean coarse soil (pea gravel), coke, slag, and wood chips—are screened out of the slurry as it emerges from the heated tumbler for separation of the pea gravel from the carbonaceous materials. The slurry of fine solids (less than 3.3 mm in diameter), containing the contaminated agglomerated coal and fine clean soil, is routed to a flotation unit. Since the coal floats and the soil sinks, the flotation process separates the contaminated coal from the fine clean soil. The coarse and fine clean soil can then be combined and made ready for disposition. The agglomerated coal can be handled easily and makes an excellent fuel, providing 10,000–15,000 Btu of heat energy per pound on a dry basis.

Contaminated soil



Agglomerated coal

Clean pea gravel

Now a simplified version of the EPRI-ARC Clean Soil Process is being prepared for demonstration in a 200-t/d plant by New York State Electric & Gas Corporation. In this version, to be built by Thermo Design Engineering of Alberta, the fine-solids-slurry separation circuit is eliminated, and the final product is a nonhazardous mixture of coal, tar, and fine soil particles that can be burned directly in a utility boiler. The coarse soil can be returned to the site. The simplified plant, scheduled to begin operation in the fall of 1994, is expected to cost only about half as much as one based on the complete process and will be technologically and economically competitive with other remediation technologies.

■ *For more information, contact Conrad Kulik, (415) 855-2818.*

Analysis of Nickel in Fly Ash

Under the Clean Air Act Amendments of 1990, nickel compounds are designated as hazardous air pollutants. Although this designation resulted primarily from studies of smelter workers, it raises issues about possible effects due to nickel in fly ash from oil-burning power plants. At present, little is known about the nickel compounds found in power plant emissions, so EPRI is conducting research to characterize these compounds and determine whether they pose a health risk.

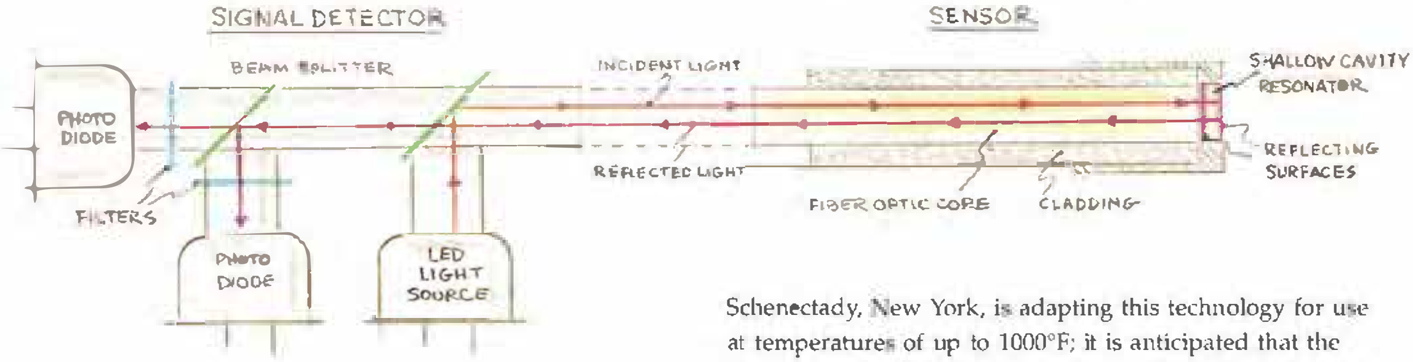
A major problem in determining which compounds of nickel are found in oil ash particles is the heterogeneity of these particles. On small, dense particles the nickel compounds are located primarily near the surface and are thus readily available for extraction and analysis. Large, frothy particles, however, may sequester nickel deep inside, making it difficult to determine the solubility of any nickel compounds that may be present. Solubility is a key factor in determining potential health risk, since the less soluble nickel sulfides are likely to have a higher carcinogenic potency than other, more-soluble nickel compounds.

One method of analysis has been developed by University of Louisville researcher John Wong, who uses sequential extraction—dissolving particles in a series of increasingly acidic solvents—to determine the chemical forms of nickel present. The results of these experiments indicate that nickel sulfides constitute only about 11–15% of the total nickel in oil ash from power plants—a conclusion that could significantly reduce the level of emissions control that might be placed on oil-burning plants. The technologies developed in this project are also being applied to the study of arsenic in coal fly ash.

■ *For more information, contact Larry Goldstein, (415) 855-2725.*

Power Plant Fiber-Optic Sensors Being Developed

Pressure and temperature sensors play a critical role in power plant operation. A typical plant may have 1000 such sensors that provide input to control and protection systems. As plant control systems become digitized, much more precise regulation is possible: a digital distributed control system (DCS) can regulate processes with 0.25% uncertainty, compared with 2–3% uncertainty for analog control systems. Unfortunately, the conventional mechanical sensors now used in power plants cannot provide the accuracy needed by a sophisticated DCS without frequent calibration. Moreover, maintaining the old sensors has become increasingly expensive. At one nuclear plant, for example, 26,000 man-hours were spent in instrumentation surveillance and testing during one 18-month fuel cycle and the subsequent refueling outage.



In 1992, EPRI funded exploratory research at Oak Ridge National Laboratory to identify and assess advanced concepts for pressure-sensing instruments. After analyzing 16 candidate technologies, the scientists concluded that only fiber-optic sensors have the potential both to increase accuracy and to reduce maintenance costs. Among their advantages are sensitivity to changes in temperature and pressure over wide ranges, absence of mechanical components, immunity to electromagnetic interference, small size, and ability to monitor multiple parameters simultaneously at various sites along their length. Fiber-optic instrument technology has not matured, however, so EPRI is currently funding development work for specific electric power plant applications.

One promising concept involves creating a tuned resonance cavity—called a Fabry-Perot interferometer—at the end of a fiber. The interferometer registers changes in pressure by reflecting a different frequency of light than that transmitted to it through the fiber from a light-emitting diode. Although commercial versions of such sensors are now available for special applications, they are not designed for the high temperatures of power plant environments. Under EPRI sponsorship, Mechanical Technology Inc. of Schenectady, New York, is adapting this technology for use at temperatures of up to 1000°F; it is anticipated that the Tennessee Valley Authority will demonstrate the technology in 1995 at EPRI's Instrumentation and Control Technology Center, located at TVA's Kingston power plant.

A potentially more flexible concept, being explored for EPRI by the United Technologies Research Center of East Hartford, Connecticut, involves the creation of sites along a fiber that will each reflect a different frequency of light. During manufacture, two beams of ultraviolet light are focused on a site, producing a pattern of variations in the index of refraction, called a Bragg grating, at that location. Later, when ordinary light is directed through the fiber, each Bragg grating reflects a characteristic wavelength, which changes with shifts in temperature and strain (pressure).

■ *For more information, contact Joe Weiss, (415) 855-2751.*

Producing the Near-EV

HORIZON 12-VOLT BATTERY MODULE

Strands of lead-fiberglass wire enter a continuous loom to be woven into bipolar mesh grids that become the electrodes in the Horizon advanced lead-acid battery. (Photos by J. Carl Ganter)

by Taylor Moore

THE STORY IN BRIEF Advanced, affordable batteries will be essential for making electric vehicles practical, and the utility industry, through EPRI, is a participant in the U.S. Advanced Battery Consortium, which is pursuing mid- and long-term battery technologies. For the near term, EPRI is in a strategic alliance with a recently formed joint venture to manufacture an advanced lead-acid battery that could be the first on the market. Expected to be in commercial production by next year, the Horizon® battery promises to deliver substantially greater range and acceleration than today's lead-acid batteries and to offer the capability for quick charging.

Term BATTERY

Forget all the negatives you may have heard up to now about lead-acid batteries for electric vehicles: that they're too heavy, have too little power, provide too limited a driving range, take too long to charge, and are too expensive to allow EVs to compete with conventional vehicles in the consumer market. A joint venture between a high-technology company and a Texas firm that has developed several key improvements in the technology with support from EPRI is about to erase those negatives. At a factory in San Marcos, Texas, near Austin, the venture partners are gearing up to produce an advanced lead-acid battery that could dramatically alter perceptions about the near-term viability of battery-powered electric transportation.

This new high-performance lead-acid battery is called the Horizon®. It promises to deliver 50% to 80% more specific energy (for greater range) than conventional lead-acid units and to provide two to three times more power (for acceleration). It also promises to last for perhaps 1000 charge-discharge cycles, or up to 80,000 miles, of maintenance-free use—three to four times longer than conventional lead-acid batteries. With the right equipment, it can be recharged to 50% of capacity in 8 minutes and to 99% in 30 minutes. And when manufactured in large volume, a Horizon vehicle battery pack could eventually cost as little as $3000—a fraction of the cost of today's units, which offer far less performance.

According to developers and proponents, the Horizon is the only advanced battery likely to be commercially available in time for use in EVs that auto manufacturers may introduce in 1998 if air quality regulatory mandates requiring production quotas for low- and zero-emission vehicles remain in effect in California and as many as a dozen eastern states. More-exotic and potentially more-powerful battery technologies are being pursued for midterm and long-term development by the U.S. Advanced Battery Consortium (USABC), formed in 1991 by the Big Three U.S. automobile manufacturers (Chrysler, Ford, and General Motors), the U.S. Department of Energy, and EPRI. Most of these electrochemical combinations, however, are not expected to reach commercial development until after the year 2000. Meanwhile, other battery technologies that may be nearer commercial readiness remain plagued by very high costs.

The Horizon, slated to begin limited commercial production next year, is the result of independent development by Austin-based Electrosource, Inc., with support from EPRI and nearly a dozen utilities. Through the end of this year, utility and EPRI funding will account for about $7 million of the more than $40 million in private investment supporting the overall product commercialization program.

"This battery is the only near-term technology currently identified that has the performance and low cost necessary to make electric vehicles more practical and affordable," says Jack Guy, manager of technology commercialization in EPRI's Customer Systems Division. "And there are several thousand EVs already in use that are potential customers for an improved battery." Guy was instrumental in establishing EPRI's involvement with Electrosource and its support of efforts to commercialize and patent Horizon battery technology for EV applications.

Not only has the Horizon battery project set a new standard of performance by lead-acid batteries—for which, until now, the basic materials and manufacturing technology had changed little in over a hundred years—it also represents a first for EPRI and its utility partners in terms of the strategic business alliance they have made with a public company. The utilities and EPRI are funding premanufacturing R&D that is refining and optimizing technical features of the Horizon battery right up to the point of commercial production.

"Our financial backing and commitment clearly demonstrate our belief that the development of the Horizon battery is a significant step toward the commercialization of electric-powered automobiles," says Clark Gellings, EPRI vice president for customer systems. "We believe that currently the long-life, lightweight Horizon battery has the greatest potential to become the most economically feasible

PATENTED FEATURES OF THE HORIZON ADVANCED BATTERY

Photos by J. Carl Ganter

High-Tensile-Strength Material

- Stabilizes plate dimensions and prevents grid growth.
- Use of low-tin lead alloys minimizes charge gassing.
- Use of fiberglass core eliminates need for antimony, calcium, or other alloys to add strength.
- Coextrusion of lead-fiberglass wire produces extremely fine grain structure that is highly resistant to grid corrosion.

Bipolar Grid Construction

- Provides low-resistance path for electron conduction between cells.
- Reduces internal resistance to less than 1 milli-ohm.
- Simplifies high-reliability cell connections.

Horizontal Plate Orientation

- Eliminates shedding of active plate material from grids.
- Eliminates stratification of electrolyte.
- Improves thermal dissipation and oxygen recombination.

Compression Cage Assembly

- Provides consistent contact between grids during charge and discharge.
- Maintains structural integrity.

solution for powering electric vehicles in the near term and well into the future."

Origin in defense aerospace technology

The story of the Horizon battery began in the early 1980s, when the development of an advanced composite material from one of the most mundane of industrial metals grew out of a fundamental advance in strategic defense aerospace technology. The new material survived the near death of its corporate parent and then underwent the key technology and manufacturing improvements that now make it the best bet for a near-term EV battery. The story is also about a technology that languished in obscurity for a while without an application.

In 1980, Austin-based Tracor, Inc., a high-technology firm working on such defense systems as the Minuteman II missile, developed an advanced composite aluminum alloy for use in certain components of atmospheric and space-based countermeasure devices. The new material gave researchers the idea for a similar lead alloy whose combination of high tensile strength and desirable electrochemical characteristics would make it potentially applicable in a lightweight, long-life lead-acid battery.

The lead alloy's composition and grain structure minimize the charge gassing and positive-plate corrosion that usually shorten the cycle life of a battery. Richard Blanyer and Charles Mathews invented and patented a technology for coextruding this lead composite onto a small-diameter graphite or fiberglass core to make a flexible but strong wire that can be woven into lightweight, bipolar mesh grids. In 1981, with their employer's blessing, Blanyer and Mathews formed their own company to develop a machine and a basic process for making coextruded lead-fiberglass wire.

In today's Horizon battery, the wire grids are woven by a continuous loom, are coated with a proprietary paste, and—in the form of horizontal plates—are assembled into cells. The battery's horizontal orientation distinguishes it from virtually all conventional lead-acid batteries, which employ vertical plates, and is said to eliminate the shedding of active material and the intraplate electrolyte concentration gradients that contribute to loss of cycle life in most lead-acid batteries. The configuration also improves heat distribution and oxygen recombination.

These technical features of the core technology enable the Horizon battery to deliver many more charge-discharge cycles with significantly greater energy and power per pound than conventional lead-acid batteries. But back in the 1980s, to commercially produce such an advanced battery at low cost and with consistent quality required still more innovations in the manufacturing process.

Blanyer and Mathews returned to Tracor around 1984 for help in applying their materials and process technology in the development of a commercial product. Tracor formed a team that included those two, the eminent electrochemist Norman Hackerman (then president of Rice University and a member of Tracor's board of directors), and Benny Jay (a senior Tracor aerospace executive in marketing and commercialization).

"The question for us was, is there a place for this stuff?" recalls Hackerman. "My response was that I thought they had a 20-year window in which to create a business producing lead storage batteries before any competing battery technologies could be developed and brought on-line. That was 10 years ago, and today I think they still have a 20-year window."

Three years of laboratory and process development work by the team followed at Tracor. Then, in 1987, Blanyer, Mathews, Hackerman, and Jay launched Electrosource, again with Tracor's blessing. Tracor also made available some of its R&D facilities, management personnel, and $7 million in startup funding. But while Electrosource's scientists and engineers continued work on the technology in the laboratory, the company's business development experts were getting nowhere in their search for a battery manufacturing company that could contribute its own expertise and implement the Horizon technology on a commercial scale.

The outlook became so bleak, recalls Benny Jay, who is today the president and CEO of Electrosource, that in 1991 the company's board of directors voted to cease operations and put the enterprise up for sale. Then they were contacted by EPRI. "At that time, we had concluded that we were way ahead of any commercial interest in an improved lead-acid battery, and we were ready to find something else to do with our time," remembers Jay. "We didn't know what EPRI was or that it had been building interest in the electric utility industry for a better battery to get EVs going."

By the spring of 1992, Electrosource was working under an EPRI R&D contract to verify its performance predictions and to develop the Horizon battery to the engineering prototype stage. The goal was to produce a limited number of batteries for testing in various EV development efforts with which EPRI was becoming involved.

Before long, EPRI and the utility industry's involvement with the Horizon program attracted another major partner—one that had precisely the background in precision, high-technology, quality-controlled manufacturing that the Horizon battery required. The company was BDM Technologies of McLean, Virginia, a subsidiary of BDM International (a member of the Carlyle Companies).

BDM Technologies is a leader in industrial automation, information systems design and integration, robotic manufacturing, and advanced quality control methods. Electrosource's Jay remembers, "BDM said, 'What you guys need is what we're good at, so let us join your team. We'll start concurrent work on a pilot production facility while you finish development work on the battery.' They were confident enough of our technology that they felt they could build flexibility into the factory design and adapt the manufacturing steps to account for the product's final features upon completion of the design optimization work."

Adds Jay, "But more than anything else, it was EPRI's participation and willingness to carry the technology forward that convinced BDM that, among all the new business opportunities they were aware of, this was the best."

BDM Technologies and Electrosource formed a strategic alliance in 1992, and last year that alliance evolved into a full-blown commercialization joint venture—Horizon Battery Technologies, Inc. HBTI's 88,000-square-foot factory in San Marcos was built by BDM, which is also contributing worldwide marketing support to the joint venture.

The San Marcos factory has already begun limited production of batteries, and plans call for producing a sufficient number of Horizon modules this year to support in-vehicle testing by a broad range of third parties. Considered a single production line of a commercial plant, the facility will be capable of producing 5000 kWh of Horizon battery modules a month, or enough for about 250 small-vehicle battery packs, when it is fully operational. Expanding capacity would require only straightforward replication of the existing production line. The factory is designed for zero environmental discharge, and the Horizon battery is fully recyclable through the existing lead-recycling industry.

The HBTI factory will also be a showcase for software-controlled, flexible manufacturing systems. It includes computer-integrated robotic manufacturing stages and just-in-time conversion of raw materials (pig lead, fiberglass, and bulk acid) into battery components. The multimillion-dollar plant was designed to incorporate ISO-9000-series standards for quality control.

"We envision eventually being able to make software-controlled design changes on the fly, changing to different designs and rotating stations automatically," says Jay. "Our long-term goal is to have mixed products—batteries for different applications—coming down the same production line. Eventually we also want to be able to produce packaged product ready for initial charge within 4 hours of its constituent materials' coming off the loading dock. Making lead-acid batteries for electric traction today in the best of factories involves a multiday, multishift operation."

A not-so-long-term goal of the enterprise is for HBTI—the principal commercialization entity—to produce equipment for siting Horizon battery manufacturing plants worldwide, most likely in joint ventures with overseas partners. These plants might take the form of final-assembly points for U.S.-made basic components. Both Electrosource and BDM would continue to provide their respective services to HBTI and its manufacturing partners.

"We're finding an enormous amount of interest in the Horizon battery around the world," adds Jay, "particularly in Europe, where planning for EVs is much further along, and also in the Pacific Rim, where we see opportunities for applying this battery in a whole different class of commuting vehicles that are of little interest to most people in North America."

Performance close to midterm goals

Experts at Electrosource and at EPRI say that the Horizon battery already exceeds some of the performance criteria estab-

Wire loom

Woven grid material

VISIT THE WORLD'S GREENEST, MOST ADVANCED BATTERY FACTORY **Limited production of Horizon advanced lead-acid batteries for electric vehicles has begun at this 88,000-square-foot manufacturing facility in San Marcos, Texas, near Austin. The factory is operated by Horizon Battery Technologies, Inc. (HBTI)—a joint venture between Electrosource, Inc. (the original developer of much of the Horizon technology) and BDM Technologies, a subsidiary of BDM International. The HBTI factory, built by BDM Technologies, features state-of-the-art computer-integrated, flexible manufacturing systems, including fully automated robotic assembly, and is designed for zero environmental discharge. Considered a pilot commercial plant, its initial production capacity is expected to reach about 5000 kWh of batteries a month in full operation.**

Battery testing

Photos by OZZ Research; J. Carl Ganter

Computer-controlled robotic assembly

lished for midterm batteries by the USABC and is close to meeting others. When initial design optimization is completed by the end of this year, the Horizon program expects to be commercially producing batteries with a nominal specific energy of 45 Wh/kg. That is short of the USABC goal of 80–100 Wh/kg, but the Horizon's developers expect to reach 50 Wh/kg in production in 1995. In any event, the energy capacity of a full-size Horizon battery pack is expected to give a typical passenger EV a driving range of up to 120 miles on a single charge.

The Horizon should also provide enough kick to allow an EV owner to confidently pull onto a freeway. Its specific power, expected to be 450–500 W/kg, exceeds the USABC goal by a factor of three or more, although its energy density, at 90 Wh per liter of volume, must be improved by about 50% to meet the midterm goal.

The Horizon battery's cycle life already beats the USABC midterm goal by 50%, if not more. "I fully believe that, at a moderate depth (36%) of discharge, the initial iteration of the Horizon battery will have close to 1000 cycles of life," says Jay of Electrosource. The Horizon battery pack should last for more than five years in an EV driven 15,000 miles a year. The battery's normal-rate recharge time is already half that of the USABC's 6-hour goal, while fast charging to full capacity with a high-power electronic charger is expected, at this stage of technology development, to take about twice as long as the 15-minute midterm goal.

The USABC's cost goal for a midterm battery that would be able to play a role in meeting the 1998 air quality mandates is $150/kWh. HBTI is striving to produce the Horizon battery for $400/kWh or less this year. As mass production progresses, HBTI expects the cost to fall below $150/kWh.

Regarding all the cost and performance criteria, says Jay, "there remains significant opportunity for improvement beyond what we will go into initial production with. For example, we haven't begun to exhaust our options for improvements that we know from laboratory work will increase the quality and reduce the cost of the electrode material." Such further improvements open up the possibility of an even-higher-performing Horizon battery for use in hybrid EVs featuring a small onboard generator to supplement and charge a battery.

All of the principals and most others familiar with the Horizon battery are equally enthusiastic about the many potential non-EV applications for the technology, although EPRI's support of R&D is maintaining the near-term commercialization focus on batteries for EVs. There is little doubt that if a lightweight, long-life, and affordable Horizon lead-acid battery for EVs is a commercial success, versions designed for other applications can't be far off. These range from most existing stationary applications of lead-acid batteries as backup or remote power sources to new, rechargeable applications for which lead-acid would not previously have been considered (such as power tools, lawn mowers, and cellular telephones). Automakers are even interested in using Horizon batteries in conventional vehicles because of the opportunities for vehicle redesign that their low profile affords.

"The Horizon battery will be a commercial success whether there is electric vehicle transportation or not," says EPRI's Guy. "Because it can be made as a sealed, maintenance-free package, I can see modules someday being used in portable computers. It performs as well as a nickel-cadmium battery right now but for one-fifth the cost. This battery is going to find its way into a variety of energy storage applications."

Norman Hackerman (who is now a member of Electrosource's board of directors and who in 1993 received the National Medal of Science, the nation's top honor for scientific achievement) says that he believes the Horizon battery technology "opens up a whole new ball game. This battery can perhaps double what current industrial-type lead-acid batteries can do. That is well within the theoretical limit for lead, and we should be able to go beyond 46 Wh/kg." He says that Horizon units able to propel an EV up to 130 miles on a charge are "certainly feasible."

Hackerman, who drops in on the researchers at Electrosource and HBTI once or twice a week, believes that the Horizon's improved capacity, fast-charge capability, and high-power characteristics give it "all the features the EV community has been looking for." He points out that although lead-acid theoretically can never approach the potential performance of, say, lithium or sodium battery chemistries, "the industry is not even close to starting along the road to producing such batteries."

Hackerman concludes, "The Horizon exists today. We're pretty sure these batteries can be made at reasonable expense. We're quite sure that they can be manufactured in quantity and with high quality, and we have a pilot plant that is starting to do that. The possibilities for improvements over time are not infinite, but they are great. So it's an exciting prospect. Even very old technology, which to most people means low technology, can become high technology. Certainly the manufacturing process will not be low tech; it will be highly automated. It has the potential for being a revolutionary kind of change."

Coming soon to a utility near you

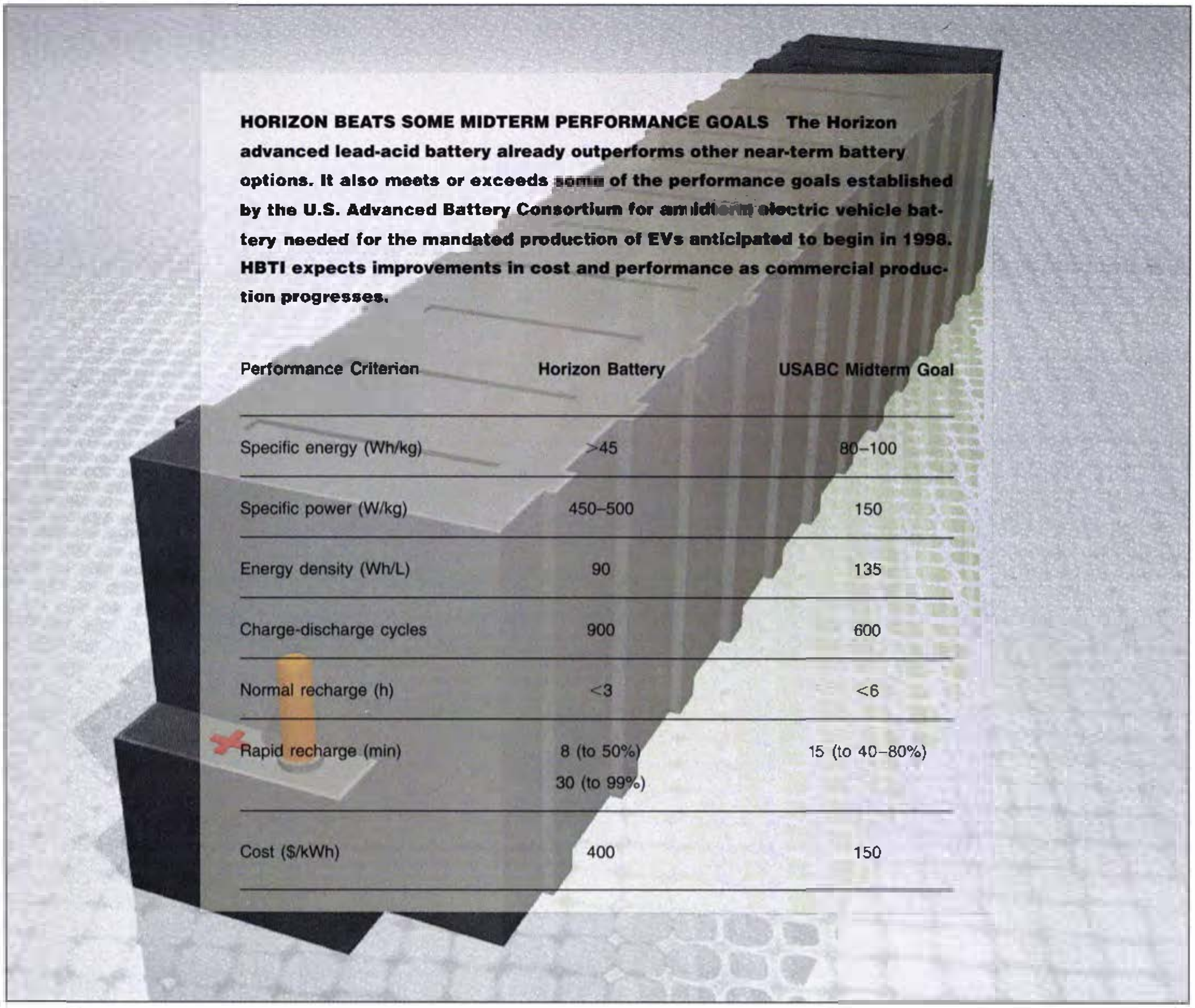
Utilities that have joined EPRI in supporting the development of the Horizon battery technology at Electrosource are excited not only about the prospects the product offers for an embryonic EV market but also in some cases about their potential business opportunities as distributors of Horizon batteries (perhaps as part of a package of energy services for remote or backup power). Electrosource says that several utilities have expressed interest in battery sales and leasing.

The utilities providing supplemental funding for the Horizon project are eagerly awaiting receipt of their initial battery packs for vehicle testing this year. Most plan to retrofit them into EVs they already operate as part of company fleets or for demonstration, such as the EPRI-developed G-Van. At least one utility—Centerior Energy's Toledo Edison Company—is planning to use Horizon batteries in pickup trucks that it intends to convert to battery power.

Jack Compton, manager of transportation at Houston Lighting & Power Company, says that his utility will retrofit a Horizon pack into one of its G-Vans. "We think the future of electric transportation hinges very strongly on battery technology, and we decided to get involved with the Horizon battery program because we think the technology might be the next step in making EVs successful."

HL&P is not alone. Says Bill Scribner, the commercial-marketing manager at Oklahoma Gas and Electric Company: "We think the Horizon battery's expected long life, quick-charge capability, and zero-maintenance operation resolve the problems of currently available batteries. The Horizon can make commercial EVs practical today until a truly advanced, long-term battery solution becomes available."

A California utility awaiting Horizon batteries for vehicle testing is Pacific Gas and Electric Company. "PG&E is pleased to be a partner with EPRI on such a promising energy storage technology," says Roland Risser, the utility's manager of advanced transportation. Risser says that the Horizon "has the potential to exceed all other lead-acid batteries in energy density, specific energy, and cycle life. The battery's positive characteristics are due not only to its unique design but also to the state-of-the-art manufacturing concept, using clean-room technologies, that



HORIZON BEATS SOME MIDTERM PERFORMANCE GOALS **The Horizon advanced lead-acid battery already outperforms other near-term battery options. It also meets or exceeds some of the performance goals established by the U.S. Advanced Battery Consortium for a midterm electric vehicle battery needed for the mandated production of EVs anticipated to begin in 1998. HBTI expects improvements in cost and performance as commercial production progresses.**

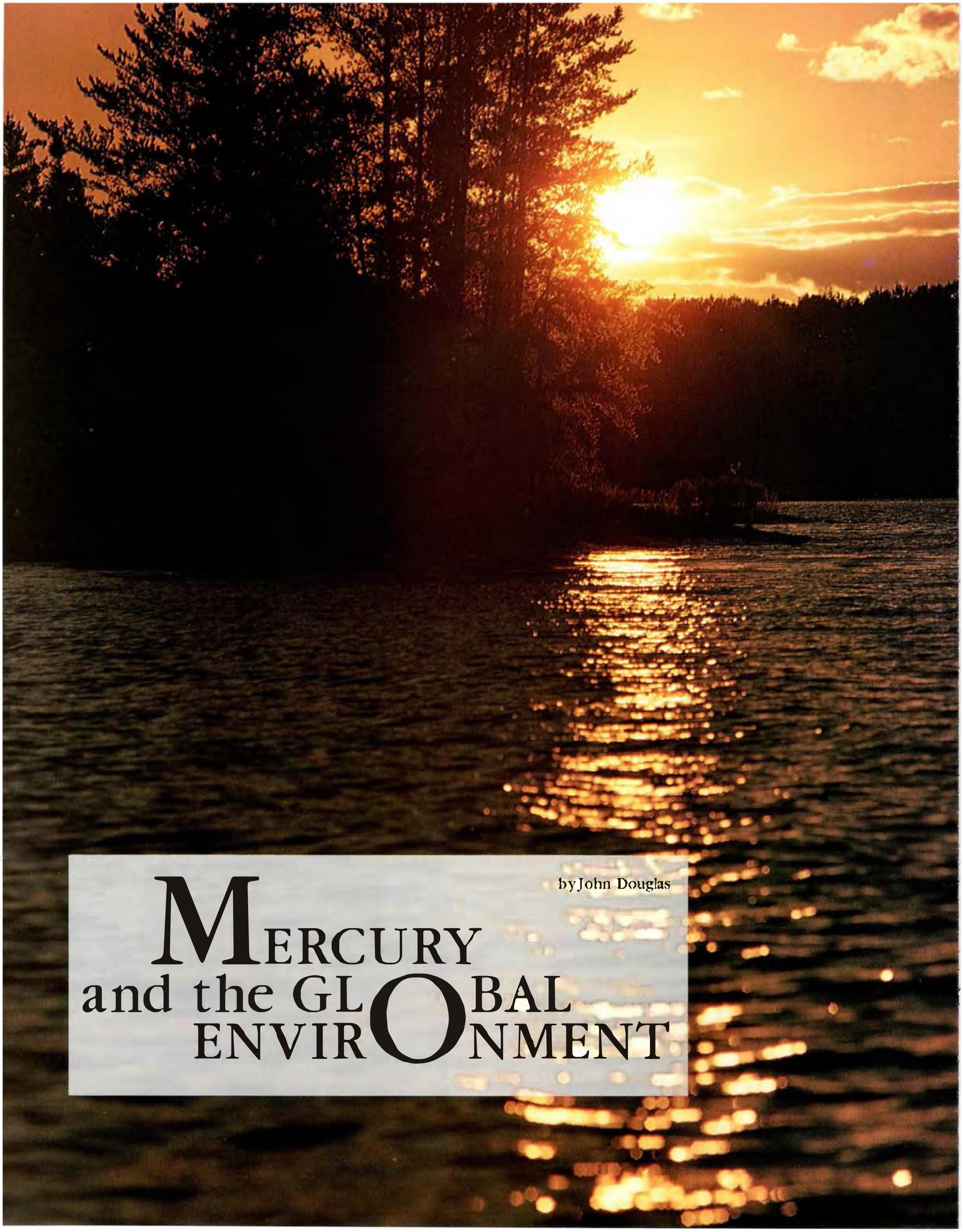
Performance Criterion	Horizon Battery	USABC Midterm Goal
Specific energy (Wh/kg)	>45	80–100
Specific power (W/kg)	450–500	150
Energy density (Wh/L)	90	135
Charge-discharge cycles	900	600
Normal recharge (h)	<3	<6
Rapid recharge (min)	8 (to 50%) 30 (to 99%)	15 (to 40–80%)
Cost ($/kWh)	400	150

HBTI is demonstrating. Combining this advanced, maintenance-free battery with a low sales price will ensure commercial success."

Also planning to retrofit G-Vans with Horizon batteries is Consolidated Edison Company of New York. Robert Bell, Con Edison's vice president for research and development, calls the Horizon program an example of utility investment in an electrotechnology that is expected to have broad application across many markets. He says it is conceivable that advanced batteries like the Horizon could be used in stationary, nonvehicular energy storage applications even in a utility service area as urbanized (but with as poor a load factor) as Con Edison's. "Because our load is principally commercial and mainly occurs during the day, we have some opportunity for energy storage. Distributed sources of power and storage are among the ways our system could develop in the future. Advanced storage batteries might enable us to defer reinforcing our transmission and distribution systems to meet load growth in some areas."

Bell, a member of EPRI's Research Advisory Committee and the USABC's management committee, notes that "among the research projects the USABC is supporting, there are some very interesting and important advanced battery technologies; but unfortunately it's going to take a long time to bring those to market, and they will probably not be ready for the 1998 mandates. To meet those mandates, we need a battery better than today's lead-acid battery as soon as we can get it, and the Electrosource battery is the only game in town. It's the only battery I see that can bridge the gap between today's lead-acid battery and the advanced batteries of the twenty-first century." ■

Background information for this article was provided by Jack Guy, Customer Systems Division.



MERCURY and the GLOBAL ENVIRONMENT

by John Douglas

THE STORY IN BRIEF EPRI research has produced the essential data and modeling capability to determine key relationships between human activities, such as power generation, and the presence of mercury in the environment. One of the most important results to emerge from this research is that atmospheric deposition is the primary source of mercury in remote seepage lakes of the northern United States, where contamination of the aquatic food chain is causing increasing concern. Deposition rates appear to be significantly lower now than they were some decades ago, and recent data imply that U.S. utilities emit substantially less mercury than previously thought. But emissions to the atmosphere may be increasing in some newly industrialized areas of the world, underscoring the fact that attempts to control mercury contamination in ecosystems will require an international focus.

Of the 189 substances designated "hazardous air pollutants," or HAPs, under Title III of the 1990 Clean Air Act Amendments, mercury was singled out for special study because of its potentially significant effects on human health. The main concern is that humans—especially fetuses and young children—could be harmed by the consumption of fish that have accumulated methylmercury from water and their own food. In addition, ecological damage could result as predatory mammals and birds receive high doses of mercury from their respective food chains.

As required by the Clean Air Act Amendments, the U.S. Environmental Protection Agency is conducting three major studies: one to assess the health risks to humans and wildlife of mercury emissions from all sources; another to investigate the deposition and effects of HAPs on large lakes and estuaries; and a third that focuses on electric utility emissions to determine whether there is a risk basis for concern over their release of toxic materials, including mercury. Results from the mercury study and the large lakes study are expected in late 1994, while those from the utility emissions study are expected by the end of 1995. These results could have a major impact on the operation of fossil-fired power plants.

Anticipating the industry's need for better information and analytical capability related to this issue, EPRI has sponsored the largest and longest-running research effort in the United States on mercury in the environment. The results show that mercury emissions from U.S. utilities are actually about half of previous estimates—accounting for less than 2% of the global emissions from human activities. In addition, EPRI researchers have developed a computerized model that simulates the cycling of mercury in surface waters. This model was recently incorporated by the EPA into one of its own environmental simulation programs.

"In order to assess the potential health risks from mercury emissions into the environment, we must be able to predict the relationship between human activities—such as power generation—and the accumulation of mercury in food chains," says Don Porcella, a research manager in EPRI's Environment Division. "Our work has provided essential data and modeling capability for determining such relationships. On the other hand, several important factors are still not well understood, and we have made some specific recommendations for further research by the scientific community."

A question of risk

Mercury is a labile, chemically active element that goes through a complex cycle of changes in the environment. The most toxic chemical form is monomethylmercury (CH_3Hg^+), which accounts for 95% or more of the mercury found in fish flesh. Monomethylmercury is a potent neurotoxin whose symptoms in humans range from tremors to—at high enough doses—death. Fetuses and young children are particularly vulnerable, since methylmercury poisoning can damage growing neural tissues. Consumption of game fish is the major source of mercury risk to humans, and the U.S. Food and Drug Administration has set an advisory limit of 1 part per million in fish flesh. Several states issue advisories against eating particular kinds of fish when their mercury content reaches 0.5 ppm.

Much of the current concern about mercury in the environment has arisen from the recent discovery of contaminated fish in remote lakes in several states. In most cases there was no obvious source of the mercury, since open dumping of mercury-containing waste had been prohibited for about two decades. Deposition from the atmosphere was suspected, but determining the amounts and the chemical forms of mercury involved was hampered by a lack of adequate sampling and analysis techniques.

In response, EPRI pioneered the development of ultraclean sampling procedures and more-sensitive analytical methods, which produced the first accurate inventory of mercury in a freshwater aquatic system. As part of this work, called the MTL (mercury in temperate lakes) project, EPRI researchers collected data on mercury concentrations in precipitation, lake water, groundwater, sediments, and organisms throughout the aquatic food chain.

In related work funded by the EPA, researchers partitioned Little Rock Lake in northern Wisconsin into two approximately equal basins, one that was treated with sulfuric acid and one that was left in its natural state as a control. An important purpose of this experiment was to test the effects of acidification on the production and biological accumulation of methylmercury in a lake. Previous studies had suggested that acidic deposition might be a contributing factor in the accumulation of mercury in fish.

Much of the MTL and related work, which at one point involved scientists from half a dozen organizations, has now been completed. Among other things, the researchers found that the mass of mercury deposited from the atmosphere appears to be large enough to account for the mercury discovered in remote lakes. Further, they determined that the methylmercury contamination of fish in the lakes results from chemical changes and bioaccumulation within the lakes themselves. In other words, the deposition of even small amounts of mercury can, over time, result in significant methylmercury accumulation in the flesh of the larger predatory fish likely to be eaten by humans. However, the amount of mercury that is methylated is controlled by site-specific water quality and is not directly connected to the amount deposited.

A global cycle

Most of the mercury in the atmosphere is in the vaporized elemental form. Deposition from the atmosphere to the earth's surface, however, involves oxidized mercury. Because mercury emissions from both natural and human sources are mainly in the elemental form, understanding the transport and oxidation of mercury in the atmosphere is important for predicting the impact of emissions on deposition.

One of the most important findings of EPRI's research is that the global mercury cycle is primarily responsible for the mercury pollution of remote seepage lakes—that is, lakes whose water comes mainly from rainfall. This conclusion is based largely on the observation that, at widely separated points around the world, mercury deposition rates and air concentrations are similar.

Given the significance of the global atmospheric mercury cycle, attempts to control mercury contamination in ecosystems will require an international focus. Particularly relevant are the estimates of mercury emissions from various sources around the world. The total mass of mercury in the atmosphere is currently thought to be about 6000 metric tons. Annual worldwide mercury emissions are also thought to be around 6000 metric tons. Of these annual emissions, some 2000 metric tons come from the ocean and another 600–2000 metric tons from natural terrestrial sources. The rest—2000–3400 metric tons—originates from human activities.

The largest component of anthropogenic emissions, about 1200 metric tons per year, is from fossil fuel combustion for nonutility industrial applications. Diffuse sources—such as paint volatilization, manufacturing processes, and disposal of batteries and fluorescent lamps—account for the second-largest contribution, 1000 metric tons per year. Next come waste incineration (600 metric tons per year) and electricity generation (300 metric tons per year).

The role of U.S. electric utilities has received particular scrutiny. Earlier estimates placed their contribution at 80–100 metric tons per year, but that figure was based on the analysis of the mercury content of coal seams. More-recent data, based on the analysis of the coal actually used by utilities, indicate that U.S. utilities emit less than 60 metric tons per year—only about 1% of the global total.

Changes over time

An important consideration is the possibility that the global mercury cycle has changed significantly in recent decades, as more rigorous controls on emissions have come into effect. A long-term perspective on the cycle has been provided by mercury samples from sediments and peat cores. The latter are particularly interesting because mosses—which dominate the formation of peat in bogs—tend to accumulate and retain more mercury than other plants. These core measurements indicate that modern mercury deposition rates have been two to five times greater than preindustrial rates.

Peat cores from Minnesota, for example, show that mercury deposition was highest in the 1950s, with levels about 10 times greater than those before 1900. By the 1980s, however, deposition had fallen to less than half of the 1950s levels. Emissions data from Sweden and measurements of liver mercury in a large number of raptors and herons in the United Kingdom also show a consistent pattern suggesting that mercury levels reached a peak around 1960. Similar trends have been observed in the eggs of fish-eating loons in New York and New Hampshire.

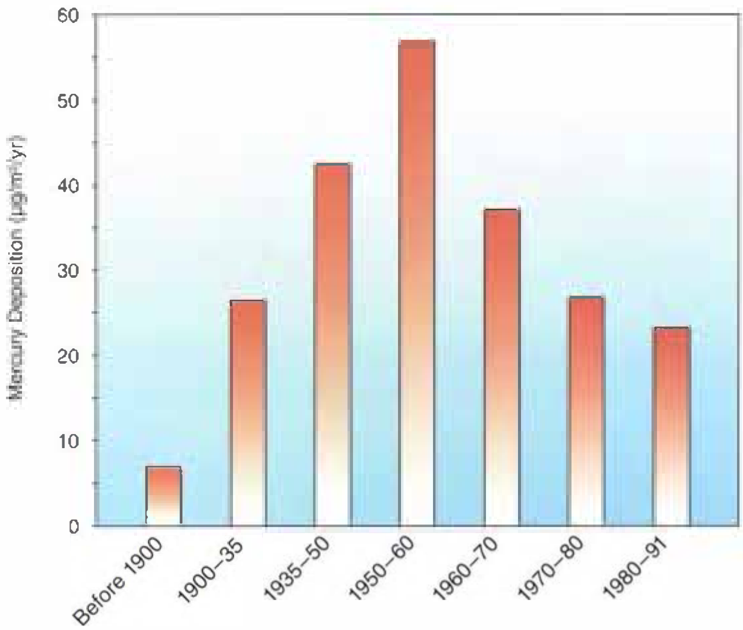
In addition, historical data indicate that some past uses of mercury may have introduced more of the element into the atmosphere than do present activities. For example, mining activities using mercury for gold and silver extraction from the middle of the sixteenth century to the end of the nineteenth century are thought to have put about 160,000 tons of mercury into the atmosphere. More recently, the decreased use of mercury in fungicides and paints and the restrictions on emissions from chlor-alkali plants have sharply reduced releases to the atmosphere from these sources. On the other hand, increased gold mining in the Amazon River basin and in other newly industrialized areas may become a major new source of mercury emissions.

Mercury cycling in lakes

The MTL project provided detailed information about mercury cycling in seepage lakes, which are isolated from all but atmospheric sources of mercury. The seven lakes examined in this study are located in northern Wisconsin, and the MTL work was coordinated with the EPA's National Acidic Precipitation Assessment Project, which funded the previously discussed acidification experiment at Little Rock Lake.

Measurements at Little Rock Lake revealed that atmospheric mercury concentrations were typical for remote locations (1.6 ng/m^3), with about 99% of the mercury in the elemental form. Almost all of

MERCURY DEPOSITION PEAKED A FEW DECADES AGO Historical mercury deposition from the atmosphere, inferred from analysis of peat cores collected in Minnesota, peaked in the 1950s. Since then, deposition rates have decreased steadily, presumably as a result of more-rigorous control of mercury emissions to the atmosphere from human activities. Current deposition rates in the Minnesota region, however, remain about three times higher than preindustrial rates.



PROBLEMS UP THE FOOD CHAIN Fish that have accumulated high levels of methylmercury in their flesh provide meals for predators like loons, minks, otters, and raccoons. Bioaccumulation in such fish eaters can sometimes lead to toxic effects, including increased mortality. Further up the food chain, at least one panther death in Florida has been blamed on the consumption of mercury-contaminated raccoons.

Ecosystem Effects

The biological effects of exposure to mercury at levels realistically found in ecosystems remain uncertain. Earlier, inaccurate measurements of mercury concentrations in lakes led to laboratory studies of toxic effects at levels far exceeding those generally found in the environment. The situation was further complicated by the fact that mercury tends to accumulate preferentially in the muscles of fish, with proportionately much less brain and neural exposure than in birds and mammals. Fish can therefore tolerate long-term exposure to small doses of methylmercury, which builds up in their flesh to levels that are potentially hazardous to the predators that eat them. (Once in muscle, methylmercury is only slowly excreted by a fish.)

To shed new light on this subject, EPRI and Florida utilities are cosponsoring a study of mercury cycling and its ecosystem effects (see text). After a review of previous laboratory experiments and studies of wild populations, the researchers concluded that predator species accumulate mercury at predictable rates and that concentrations of mercury in their tissues can thus be used as a reliable basis for predicting thresholds for health effects. Specifically, a 5-ppm concentration of mercury in the liver of waterbirds and a 1–3.6-ppm concentration in their eggs appear to represent a conservative threshold for toxic effects. Such effects include altered behavior—for example, reduced responsiveness to maternal calls and greater tendency to fright—as well as increased embryo and nestling mortality.

Predatory mammals are also sensitive to mercury poisoning, and their position at the top of a food chain may make them especially vulnerable in some contaminated locations. Few specific data are available, but mercury toxicosis has been suspected as the cause of death in wild populations of mink living in areas with mercury-polluted drainage. The death of at least one panther in the Florida Everglades has also been blamed on mercury, probably ingested when the panther ate raccoons that had fed on contaminated fish. Interestingly, an increase in the deer population in one region of the Everglades resulted in reduced mercury levels in local panthers, which apparently ate fewer raccoons because of the variation in available food.

The work by EPRI and the Florida utilities has led to the development of specific recommendations for future research aimed at reducing uncertainty about the ecological effects of mercury. In particular, there is a need for more site-specific research to build data sets on biological effects for various ecosystems, together with work to relate these data to laboratory experiments on vulnerable species. Further, the researchers recommend long-term monitoring of mercury residue levels in carefully chosen indicator species, such as fish-eating waterbirds, to determine changing levels of contamination. They point out that probably the easiest way to conduct such monitoring would be to periodically examine the mercury content of feathers taken from the indicator bird species, since these are readily obtainable without harm to the birds. □

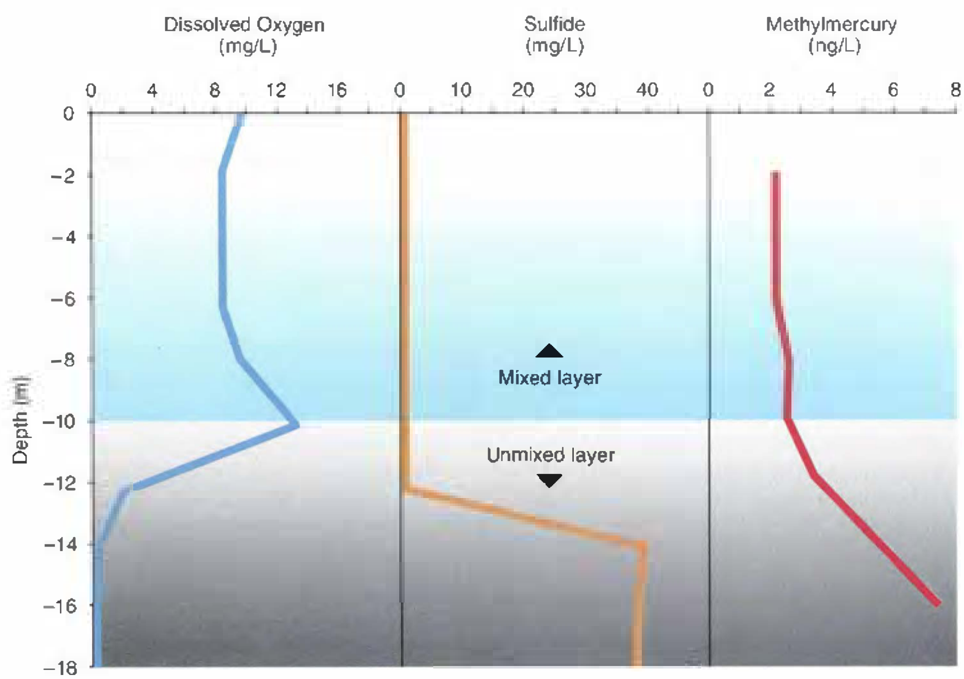
the mercury deposited in the lake, however, was in the oxidized form, with 0.7 g/yr entering the lake in rain and 0.4 g/yr entering as dry particles. The annual release of mercury back into the atmosphere was about 5% of the deposited amount.

The bulk of the deposited mercury eventually entered the sediments at the bottom of the lake. A total of only about 0.3 gram of mercury was found in the lake water at any one time, and about the same amount was present in the aquatic organisms. In contrast, fish were by far the greatest repository for methylmercury, which was 3 million times more concentrated in the fish than in the surrounding water. These results indicate that essentially all of the methylmercury is formed within the lake ecosystem. They also emphasize the importance of determining what factors affect the formation and accumulation of methylmercury in the food chain.

Previous research had suggested that acidity (low pH) and relatively large amounts of dissolved organic carbon in the water would increase methylmercury buildup in fish. Following up on that hypothesis, EPRI researchers compared fish from the seven MTL lakes and found a 10-fold variation in mercury contamination. Although the methylmercury levels in the fish clearly increased with a greater concentration of dissolved methylmercury in the water, it was not possible to explain the observed differences in bioaccumulation solely on the basis of pH and dissolved organic carbon. Other factors, such as the presence of chlorophyll, sulfate, chloride, and calcium in the lake, also appear to be at least partly responsible for the differences in bioaccumulation. In addition, more-abundant nutrients increase the biomass of fish and thus reduce their concentration of methylmercury, since a given amount of mercury is being spread among a larger mass of fish.

Such wide differences in methylmercury concentrations and the variety of possible factors involved imply that bioaccumulation in lakes needs to be considered on a site-specific basis and cannot be derived from a general formula that applies to a whole region. A better under-

SAMPLING AIRBORNE MERCURY
Although most of the mercury in northern U.S. lakes comes from atmospheric deposition, multiple sources appear to be involved in the contamination of Florida waterways. Monitoring stations for airborne mercury are helping EPRI, Florida state agencies, and utilities learn more about the sources, transport, and deposition of mercury in this ecosystem.



STRATIFIED LAKE PROVIDES CLUES TO METHYLATION
Concentrations of methylmercury and sulfide rise sharply as dissolved-oxygen levels decline in the unmixed bottom layer of a thermally stratified Wisconsin lake. This result suggests that anaerobic, sulfate-reducing bacteria living in the layer are responsible for transforming inorganic mercury to the methylated form.

standing of the fundamental biochemical processes involved in the formation and subsequent breakdown of methylmercury in lakes is also needed.

Methylation and demethylation

The process of methylation—which transforms the oxidized inorganic form of mercury into organic methylmercury—is not well understood. In lakes it appears to be primarily a biological process involving the metabolic activity of bacteria. In wetlands, which have higher levels of suspended material that can apparently act as catalysts, nonbiological methylation is also important.

New insights into the methylation process in lakes were provided by the MTL project through detailed studies of the formation of methylmercury at various depths of Wisconsin's Pallette Lake. This seepage lake is thermally stratified in the summer, with a mixed layer in the top 10 meters that has a high level of dissolved oxygen. Below this depth, in the unmixed bottom layer, the amount of dissolved oxygen rapidly falls off to nearly zero.

The researchers found that concentrations of both sulfide ions and methylmercury increased significantly at depths great enough to have little dissolved oxygen. This result supports the argument that anaerobic, sulfate-reducing bacteria may be involved in the formation of both chemical species. Laboratory experiments have tended to confirm the hypothesis. The addition of sulfate to a slurry made from lake sediments, for example, enhanced the production of methylmercury in the laboratory. Conversely, when specific metabolic inhibitors were used to block sulfate reduction by the bacteria, methylation also ceased. Not all sulfate-reducing bacteria can produce methylmercury, however, and the methylation process appears to be incidental to the production of an intermediate metabolite in specific bacteria.

Interestingly enough, some of the same bacteria are also apparently involved in the competing process—demethylation—which changes methylmercury into the less toxic, elemental form of mercury. A net increase or decrease in methylmer-

Update: Cleaning Up Mercury With Genetic Ecology

In addition to information-gathering research on mercury in the environment, EPRI continues efforts to reduce—through natural detoxification processes—the amount of methylmercury available to the food chain in contaminated aquatic ecosystems. These detoxification processes involve the action of bacteria to convert methylmercury and its inorganic precursor, the mercuric ion, to the less harmful, elemental form of mercury. The current research program, which EPRI is cosponsoring with the U.S. Department of Energy and the U.S. Environmental Protection Agency, aims at stimulating desired bacterial activity through application of the principles of genetic ecology.

This new scientific discipline looks at how environmental factors influence microbial activity at the genetic level in the environment. Natural detoxification processes, such as the demethylation and subsequent reduction of mercury, usually involve many separate molecular reactions inside a bacterium. These reactions are catalyzed by enzymes, whose production is controlled by groups of genes—called operons—that are turned on and off as a unit. Genetic ecology attempts to identify and control the action of operons in bacteria in situ to stimulate detoxification.

The research program's first field trial of genetic ecology is under way in Oak Ridge, Tennessee, at an artificial body of water called Reality Lake, which received high doses of mercury from an underground drainage system at the Oak Ridge DOE facility. The goal of this field trial is, first of all, to conduct bioremediation experiments in laboratory containers filled with water and sediments from Reality Lake. If scientists can identify environmental factors that stimulate demethylation by bacteria in these microcosms, then the experiments could be repeated on a much larger scale in enclosures constructed along the inlet channel to Reality Lake.

To date, EPA researchers have succeeded in using the microcosms to simulate the ecological conditions in Reality Lake and to stimulate the reduction of inorganic mercuric oxide by adding indigenous bacteria. The addition of such nutrients as phosphate and glucose to aid bacterial growth has had little effect, however, and so far no other environmental factors have been identified that hasten bioremediation by the bacteria.

"We have learned a great deal about genetic activity related to mercury reduction in aquatic systems through the microcosm work," says EPRI research manager Robert Goldstein. "Getting the microcosms to successfully mimic the chemical and biological behavior of the pond is a significant achievement in establishing model systems for detoxification studies.

"Although the prospects for using genetic ecology to find a cost-effective, reliable way to remove mercury from Reality Lake do not look promising at this time, the mercury experiments can serve as a good model: they can help establish a foundation for manipulating indigenous microbial communities to detoxify other kinds of contamination in the environment. Specifically, bioremediation strategies based on genetic ecology appear to be more promising for use in degrading complex organic contaminants." □

cury in a lake thus appears to depend on environmental conditions that determine which bacterial process will dominate. One of the most important factors is temperature; experiments show that the rate of methylation increases faster than that of demethylation as temperature rises. Lower pH (more acidic conditions) also seems to tip the balance toward the increased net production of methylmercury.

Building a model

In the culmination of EPRI's mercury research of the last decade, a mathematical model has been developed that incorporates the best current understanding of mercury biogeochemistry in lake ecosystems. This model—the Mercury Cycling Model (MCM), Version 1.0—is available to EPRI members and to researchers and runs on an Apple Macintosh computer. It can simulate mercury dynamics in a specific lake and calculate methylmercury contamination in the large fish likely to be eaten by humans and large predatory mammals and birds. The model is designed to help decision makers evaluate options for assessing and managing risks associated with mercury contamination.

MCM simulates mercury reactions in a lake from initial conditions at its boundaries and tracks changes at monthly intervals. Reactions in the watershed and the atmosphere are not modeled. Concentrations of the three major chemical forms of mercury are calculated for the mixed upper layer of a lake, its anoxic lower layer, and its sediments. Bioaccumulation is followed through four stages of the aquatic food chain: phytoplankton (photosynthetic microorganisms), zooplankton, foraging fish, and predatory fish.

In calibration tests, the model has successfully simulated mercury concentrations in the physical compartments of the seven seepage lakes examined in the MTL project and has accurately predicted contamination of their food chains. MCM has also been applied to major drainage lakes, such as Lake Superior and Lake Ontario. Recently, the model was incorporated into the EPA's Water Analysis Simulation Program, or WASP4, which is used for the assessment of water quality problems in surface waters of various types. Called MERC4 in this form, the EPRI model is being used to study Onondaga Lake in upstate New York, as well as two EPA Superfund sites.

Two important conclusions have come out of the risk management scenarios simulated to date with MCM. The first is that the effects of even dramatic changes in methylation and demethylation rates in a lake do not become apparent until 8–10 years after they occur. This lag time reflects the turnover rate of the predatory fish population, which has a long life span. The second major conclusion is that a 5% decrease in atmospheric mercury deposition—more than could likely be achieved by removing the entire contribution of U.S. electric utilities—would result in only negligible changes in fish methylmercury concentrations in remote seepage lakes.

Collaborative mercury research in Florida

Unlike the northern lakes previously studied, which receive virtually all their mercury from atmospheric deposition, Florida waterways may have other important paths of mercury transport and contamination. More than 2 million acres of Florida fresh water, including 1 million acres of the Everglades, are now covered by state advisories against the consumption of several species of game fish because of mercury contamination. To learn more about the sources and transport of this mercury, EPRI has launched the FRAME (Florida research to assess mercury in the environment) project in collaboration with the Florida Electric Utility Coordinating Group. This project will be coordinated with related studies being carried out by the EPA and Florida state agencies.

Florida's geology includes a considerable amount of limestone, the weathering of which results in rapid groundwater flow, possibly transporting mercury from localized sources to remote bodies of water. Also, in the Everglades, development and agricultural activities may be remobilizing mercury deposited in the past. The FRAME project will focus on four aspects of the mercury problem: measuring atmospheric deposition, modeling the mercury cycle in freshwater ecosystems, synthesizing information about mercury emissions and transport through the atmosphere, and developing an integrating model to determine risks from mercury in Florida.

Specific activities will include the establishment of a mercury deposition monitoring site in northern Florida to complement existing sites in the southern part of the state. The distribution and movement of mercury in freshwater ecosystems will be simulated with EPRI's MCM. Finally, mercury exposures and health risks will be calculated by using an integrating model developed under the management of Leonard Levin of EPRI's Environment Division.

The payoff

"EPRI's long-term commitment to study mercury in the environment is now paying off in a big way," Don Porcella concludes. "We developed ways of measuring lake contamination that corrected earlier mistakes. That led to the establishment of the first accurate mass balances of mercury in remote lakes and the development of a state-of-the-art model for predicting the bioaccumulation of mercury through an aquatic ecosystem. Now we're pressing ahead with work on mercury cycling in particularly vulnerable areas, in cooperation with specific member utilities."

Detailed results of EPRI's research on mercury will be presented at the International Conference on Mercury as a Global Pollutant in Whistler, British Columbia, July 10–14, 1994. Speaking of these results, John Huckabee, EPRI program manager for ecological studies, says: "As a result of the Institute's mercury research, which began over a decade ago, decision makers have better information and more-reliable tools to assess and manage risk. In particular, it has become clear that the problem of mercury contamination is global." ■

Background information for this article was provided by Don Porcella, John Huckabee, and Robert Goldstein, Environment Division.

BY LESLIE LAMARRE

BUILDING FROM ASH

THE STORY IN BRIEF Each year the electric utility industry generates some 48 million tons of fly ash. The cementlike characteristics of this combustion by-product make it useful in a variety of practical applications, and ratcheting disposal costs and environmental concerns are encouraging utilities to divert more of their fly ash toward such uses. The building-products market is particularly promising, offering a variety of high-volume, high-value uses. EPRI researchers and member utilities are working to develop building materials and products that incorporate a relatively high percentage of fly ash.

Go to any well-stocked building supply store in England and you're likely to find lightweight concrete blocks that you can cut with a saw and pound with nails. Some companies in Germany actually package the blocks in kits that make building a garage about as easy as playing with a set of Legos. The lightweight concrete blocks have not yet hit the construction market in this country, but EPRI is working on that. Why EPRI? Because roughly 75% of the material in the blocks is fly ash—by far the biggest by-product of coal-fired electricity production.

Known in the United States as autoclaved cellular concrete and in Europe as autoclaved aerated concrete, the building block material has made significant inroads in England and 39 other countries around the world. It is one among a handful of promising new building products that incorporate a relatively high volume of fly ash. Traditionally used in road construction, structural fill, and conventional concrete, fly ash is generating increased interest as an ingredient in practical building products like autoclaved cellular concrete. Not only do such large-volume applications result in high-quality products, they also entail no direct contact between raw fly ash and soil, thus avoiding an issue that has raised environmental concerns in some states.

Each year the electric utility industry generates some 48 million tons of fly ash. If piled into a space measuring 10,000 square feet, a common footprint for high-rise buildings, this quantity of ash would stretch 24.5 miles into the sky. Currently, the industry uses and sells a total of one-quarter of this fly ash. But experts speculate that this portion will dramatically increase within the next decade as the markets for the material continue to grow. Helping to encourage the use of ash is the steadily increasing cost of landfilling the substance, which is already as high as $30 a ton in some states. Also, disposal is increasingly frowned on by state environmental agencies, some of which have established regulations that promote beneficial uses for ash.

Dean Golden, manager of EPRI's research on high-volume by-products, notes that the use of fly ash in building products fits well with the "green" building philosophy of environmentally benign construction—construction that incorporates efficient energy systems and recycled building materials. "The green building concept is becoming more widespread among contractors, architects, and engineers," he says. "This movement will certainly encourage the use of fly ash in building products." Another form of encouragement came from the federal government last summer when the Environmental Protection Agency ruled that fly ash is not a hazardous waste. The ruling instantly sparked activity among industry groups like the American Coal Ash Association, which is working to open new possibilities for fly ash use.

Valuable commodity

The silica, aluminum, and calcium present in fly ash give it cementlike qualities that make it a functional ingredient for a variety of products ranging from kitty litter to auto parts. Its use as a substitute in concrete products is by far the largest market for the coal combustion by-product, accounting for more than half of the 13 million tons of fly ash used in this country.

The most obvious advantage fly ash offers over the cement materials it replaces is dollar savings. Typically, fly ash that meets national specifications for cement use will cost a contractor between $12 and $20 a ton, less than one-quarter the price of cement, which ranges from $50 to $90 a ton. Ash offers chemical and physical advantages as well. The spherical shape of individual ash particles, visible under a 30-power microscope, makes the material easier to pump and finish than cement, which is made up of angular particles. Also, fly ash's chemical makeup lowers the heat of hydration for concrete, thereby reducing the level of thermal cracking that occurs during the curing process. This is critical in large, structural applications, where cracks can allow water to seep in and erode steel reinforcing bars.

Humankind has appreciated ash's useful attributes for millennia. In fact, volcanic ash, which is very similar to fly ash, was used to build the Colosseum and the highways of ancient Rome. In this country, contractors have used ash from coal plants since the late 1940s, when the federal Bureau of Reclamation relied on it as a cost-cutting substitute for some cement in large dams in the West. The positive outcome of this early experience pushed fly ash into more widespread use.

Although EPRI sponsors work on specialty applications of fly ash—for example, its use in a promising class of metal matrix composites called Ashalloys (*EPRI Journal*, January/February 1994, p. 46)—the Institute has always kept its primary focus on large-volume applications. Earlier research projects included the use of fly ash in highway construction and structural fill. Within the past few years, EPRI's high-volume fly ash work has progressed to what Golden calls "the next hierarchy of uses," namely, building materials. "Not only are these high-volume markets, they are markets in which significant revenues can be returned," he says.

Ted Frady, fly ash program manager for South Carolina Electric & Gas Company, agrees that the building-products market can be lucrative. "The single best market we have today is the use of fly ash in concrete," he says. "It makes us money on the market and saves us money in that every ton we put to good use is a ton that does not have to go to the landfill." Frady stresses that "fly ash is not being used as a favor to the utility industry. Contractors use it for two reasons: it saves them money and it makes better products."

Indeed, William Gibson, manager of pozzolanic products for Holnam Inc., a manufacturer of cement and a marketer of fly ash and other construction materials, says, "Our educated buyers seek out fly ash for its advantages." He notes that the most attractive advantages include its ability to reduce cracking and shrinkage, particularly in hot weather, and its easy-to-finish nature. He says it is difficult to find a concrete structure being built today that does not contain some fly ash.

No matter how attractive fly ash may be, however, there is far too much of it to ever be entirely absorbed by the conventional building-products market. That is one reason EPRI is investigating new opportunities—such as that provided by autoclaved cellular concrete—to increase the use of ash in U.S. building products.

The cellular route

Invented in Sweden in the early 1900s, autoclaved cellular concrete (ACC) is now produced and used on every continent of the world. Although a patent on the material was issued early this century, it has expired and cannot be renewed, which leaves manufacturing opportunities open to just about anyone.

Manufacturing approaches vary from country to country. Generally, ACC is made by mixing portland cement, lime, aluminum powder, and water with a large proportion of silica-rich material. In most countries the silica is provided by sand, but manufacturers in the United Kingdom, China, India, and some parts of the former Soviet Union use fly ash as well. Both silica sources result in a product that has one-fourth the weight of conventional concrete. Studies have shown that ACC made with fly ash offers a product equal to or superior to ACC made with sand. The fly ash results in a product that has a high compressive strength and whose thermal efficiency, fire resistance, and capacity for sound absorption are comparable to those of ACC made with sand.

ACC proponents say the material has never caught on in the United States primarily because the construction industry has been dominated by timber products. Indeed, wood products have 95% of the U.S. market for building materials, with masonry making up the remaining 5%. The scenario in Europe is exactly the opposite, with masonry dominating the market. ACC proponents believe that the recent dramatic rise in U.S. lumber prices, combined with heightened environmental concerns about timber harvests, opens an opportunity for ACC to succeed in the U.S. market.

Golden notes that the recent interest in so-called green building products among professionals in the building trades will also help ACC succeed. "Aside from the advantages of saving natural resources and reducing the amount of material going to landfills, ACC made with fly ash is a great insulator," says Golden. Indeed, a typical 8-inch ACC block made with fly ash offers a thermal efficiency of R-13, more than three times the efficiency of the same size block made of conventional concrete. R-13 insulation meets the requirements for wall insulation in many states.

Also working in ACC's favor is the fact that conventional woodworking tools can be used with ACC blocks. Unlike traditional concrete, ACC can be cut with a handsaw or an electric saw. Nails and screws can be used to secure other materials, such as wallboard and fixtures, to the blocks.

While ACC may cost as much as 25% more than conventional concrete, use of the material is expected to cut labor costs. This is not only because the material is lighter in weight but also because a thin adhesive rather than a thick mortar is used between rows of blocks. With the thin adhesive, only the first row of blocks must be leveled. ACC experts estimate that a mason can lay two and a half times more ACC blocks than concrete blocks in a single day. These factors, combined with the insulation-related savings, translate into an overall decrease in the installed cost of ACC, making it as much as 20% lower than the installed cost of concrete, Golden says.

In an effort to get ACC on the U.S. market, EPRI has contracted with North American Cellular Concrete of Rhode Island to conduct extensive laboratory testing, market analysis, and product development. The company has built a mobile demonstration plant that is in the process of visiting nine coal-fired power plants across the country. The mobile plant spends about six weeks at each site, using each utility's ash to churn out about 1500 blocks. The utilities use the blocks to demonstrate the material to members of the local building industry by constructing small structures, such as walls or buildings. "The response of contractors in our area was quite positive," says Dave Odor, a research scientist with PSI Energy, which the mobile unit visited last spring. "They liked the fact that the material offers the advantages of concrete yet is much easier to work with."

About 50 blocks from each site are tested extensively to determine whether they meet existing structural and environmental standards for building materials in the United States. The data from these and other tests are being made available to the national code approval councils that regulate the use of such materials on the U.S. construction market. EPRI plans to cooperate with the American Coal Ash Association, government agencies, and utilities in obtaining approval from the councils. Approval is expected by early 1995.

Concrete pavement

Concrete matters

EPRI is also investigating more-familiar avenues for increasing the use of fly ash. Through a project with the Canada Centre for Mineral and Energy Technology (CANMET) that was completed last year, the Institute helped fine-tune and test formulas CANMET had developed for cement mixes containing 58% fly ash. This level is more than double the 25% allowed in cement under current guidelines established by the American Concrete Institute and nearly quadruple the 15% allowed in most cement mixes on the market today.

Past efforts to significantly increase the percentage of fly ash used in cement have resulted in a weaker material not fit for structural use. However, the work of CANMET and EPRI has shown that reducing the amount of water and adding superplasticizers to the mixture results in a workable product that meets the same strength and durability standards as conventional concrete. In fact, Golden reports, the new formulas containing 58% fly ash even offer advantages not found with standard cement formulas, such as a virtually crack-free concrete. The new formulas reduce the water-to-cementitious-agent ratio to 0.3, compared with the 0.5 ratio typical of portland cement mixes. The addition of superplasticizers helps keep the material workable rather than stiff, despite the reduction in water.

Tests of 128 concrete mixes incorporating 58% fly ash in the cement found that, after one day of curing, compressive strength was between 1000 and 1200 pounds per square inch, the level to which conventional structural concrete is typically designed. After 28 days, compressive strength increased to 5000–6000 psi, again within the range of structural-grade concrete. "What we wound up with was a material just as strong as conventional concrete but with superior durability characteristics," says Golden, noting that the new material demonstrated little cracking during the curing process. Even with the use of superplasticizers, which are relatively expensive, the final concrete mixes cost $5–$25 less per cubic yard than conventional concrete, Golden says.

No special facilities are needed for producing high-volume fly ash concrete. But like ACC, this material would have to be approved for introduction to the market. Although building code approval is not necessary because the material is not a building product in itself, existing standards established by the American Concrete Institute regarding the proportion of fly ash allowed in cement would have to be revised. Without such national approval, use of the material would have to be assessed at the state level on a case-by-case basis, which would certainly hinder widespread acceptance.

EPRI and CANMET are making data from their tests available to the standard-setting organizations. According to Golden, the approval process could take up to four years. But a favorable decision would be well worth the wait. "Concrete has been a strong market for fly ash, but with the conventional formulas, fly ash is only 4% of the final product," Golden says. "These new formulas could bring that proportion up to 12%, potentially tripling the size of the market for fly ash in concrete."

In the meantime, more-traditional uses for fly ash in the building trades are becoming increasingly popular. One of these is flowable fill, a fluid mixture consisting primarily of fly ash. Unlike structural fill, a granular material that requires compaction and does not flow or harden, flowable fill stiffens as it cures, and does not have to be compacted. Yet, once hardened, flowable fill can easily be excavated, if necessary. Often it is used to fill trenches. In building construction, flowable fill is used to add extra support between the ground and the floor of the first story. Although the use of flowable fill dates from the 1970s, it has grown significantly within the past five years. "It's our best market for fly ash," says Jim Sullivan, manager of ash utilization for Niagara Mohawk Power Corporation. Sullivan's utility sold 20,000 cubic yards of flowable fill last year, using up 22,000 tons of fly ash. The utility is now establishing its second flowable fill manufacturing plant.

Aggregate options

Like flowable fill, aggregate offers a significant opportunity to expand the market for fly ash. Traditionally made from stone and sand, aggregate constitutes nearly 80% of concrete, with the cement and wa-

Yellowtail Dam

A VERSATILE BY-PRODUCT It wasn't until the late 1940s that fly ash was first used as a construction material in the United States. Its strong resistance to cracking made it a successful substitute for cement in a number of large dams built in the West. Widespread use soon followed, and ash made its way into applications ranging from road construction materials to foundations for buildings. An important focus of EPRI's current fly ash research is high-volume applications in such building products as concrete.

Lightweight aggregate

Road construction

ter mixture accounting for the remaining 20%. Fly ash can be used to make a lightweight aggregate—more than 50% lighter than conventional aggregate—that works well in structural concrete, masonry, and decorative applications like landscaping. In building structures it can be used in a variety of applications, including floor slabs, beams, and columns.

Wisconsin Electric Power Company is among those interested in tapping the market for lightweight aggregate. The utility has a plant under construction that will produce the material by using about 85,000 tons of fly ash annually from its coal-fired Oak Creek plant in the Milwaukee area. The aggregate plant, scheduled to come on-line in August, is expected to produce 95,000 tons of aggregate per year, which will be sold to the construction industry throughout the Midwest.

Lightweight aggregate is manufactured in other parts of the country, but Wisconsin Electric holds a patent on both the formula and the process it will use to create its version of the material. The utility's formula combines fly ash with paper mill and municipal sludges. The mixture goes into a pelletizing pan, whose spinning motion causes the material to ball up into pellets, which can be sized for specific markets. The pellets are transferred into a rotary kiln, where volatile materials are burned out, giving the hardened pellets a cellular structure.

Tom Jansen, a senior specialist in ash marketing for Wisconsin Electric, says, "Pilot tests have shown that our material clearly meets existing standards, and it can be introduced to the market immediately." He notes that there are no other manufacturers of lightweight aggregate in the upper Midwest. "It will be very difficult for a conventional lightweight aggregate available in the area to beat our price." In the normal-weight-aggregate market, Wisconsin Electric will have to sell people on the advantages of lightweight aggregate. According to Jansen, it offers improved fire resistance and enhanced acoustic and insulating properties. Also, the lighter building materials made from it will be less expensive to handle and transport.

Jansen notes that the use of lightweight aggregate made with fly ash has environmental advantages too. "Since we are

A standard handsaw can be used to cut an ACC block.

AUTOCLAVED CELLULAR CONCRETE Manufactured and used on every continent of the world, autoclaved cellular concrete blocks go into all sorts of buildings, from high-rise condominiums to single-family homes. Unlike conventional concrete, ACC can be cut with handsaws, pounded with nails, and drilled with screws. The product's main ingredient is a silica-rich material. In most countries this material is sand. But manufacturers in some countries, including the United Kingdom and China, also use fly ash. EPRI is working to introduce ACC made with fly ash on the U.S. market.

ACC can be cut and shaped for architectural detail.

A brick veneer covers walls built from ACC blocks.

ACC is appropriate for high-rises as well as smaller structures.

Staff members of PSI Energy show off ACC blocks produced by the mobile plant.

The mobile plant is protected by a dome-shaped canopy during utility visits.

GOING MOBILE In an effort to get autoclaved cellular concrete on the U.S. market, North American Cellular Concrete, under contract to EPRI, has been taking its mobile ACC plant to utilities across the country. At each stop, the mobile plant uses ash from a utility coal plant to produce about 1500 blocks, which the utility then uses to demonstrate construction techniques to members of the local building industry. In all, the plant will visit nine utilities. Test data from block samples at each site will be provided to the national councils responsible for approving the use of such materials by the U.S. construction industry.

making use of utility and industry by-products, natural stone aggregate does not have to be quarried or mined." As for expanded aggregates made from clay, slate, and shale, he says, "These materials are very energy-intensive to produce. The process of making aggregate from fly ash consumes significantly less energy."

Wisconsin Electric's effort does not represent the first time fly ash has been used to make lightweight aggregate. Utilities in Florida and Virginia, for example, have developed systems to produce similar materials. Although lightweight aggregate currently represents less than 5% of the concrete market, it is a growing segment, says Golden. "Many parts of the country are already running short of conventional aggregates and will have to go to a synthetic aggregate anyway." He notes that aggregate made with fly ash offers a critical advantage in building construction: its lighter weight helps significantly reduce building loads.

Market factors

As the uses for fly ash continue to expand, utilities are focusing on making their ash more marketable. One key concern is quality. Standards set by the American Society for Testing and Materials (ASTM) classify fly ash in two categories—Class C and Class F. One significant characteristic setting the two classes apart is calcium oxide content. Because Class C fly ash has a relatively high level of calcium oxide, it sets up when water is added. By contrast, Class F fly ash has a very low level of calcium oxide, which means that it will not set up on its own but requires the addition of lime.

An important ASTM requirement for both classes of ash is carbon content. The carbon content of Class F fly ash is typically higher than that of Class C fly ash. Although the ASTM standard allows a maximum of 6% carbon for both classes, the marketplace generally demands levels no higher than 3% when the ash is sold to replace cement in concrete. A high carbon content can be a problem for concrete mixtures because, in Golden's words, carbon is an "oxygen scavenger." Oxygen is a necessary ingredient of concrete; it forms air bubbles as the material cures, allowing the finished product to expand and contract without cracking as the temperature changes. The carbon content issue is getting additional attention now that utilities are taking steps to comply with the provisions of the 1990 Clean Air Act Amendments concerning nitrogen oxides. To meet the required reductions in NO_x emissions, many utilities are retrofitting their coal plants with low-NO_x burners. The burners cause the plants to operate at lower, less efficient temperatures, which increases the carbon content of the fly ash. EPRI has developed a new technology that may address this issue. Called a fluid-bed processing plant, this patented technology is a spin-off from the fluidized-bed combustion concept. In a two-year project that got under way early this year, EPRI will demonstrate the use of this technology to reduce the carbon content of fly ash through carbon burnout. Several member utilities are participating in the demonstration. EPRI is conducting a scoping study to identify other approaches for reducing the carbon content of fly ash.

Quality isn't the only potential problem that can keep fly ash from reaching the market. As William Gibson of Holnam Inc. points out, location is an issue too. "It's a freight-sensitive product," he says. "There are a lot of markets wide open for the introduction of fly ash. But there are some areas where you've got a cement plant but no coal-fired power plant nearby." In such cases, the cost of hauling the fly ash to a buyer can overrun the market value of the material. In other cases, a market convenient to a utility might already be saturated with fly ash.

Above and beyond the concerns of quality and transportation cost is the issue of perception. Many utility representatives call it "the waste stigma." Frady of South Carolina Electric & Gas explains: "We're dealing with a product that, as a by-product of electricity generation, has the stigma of waste attached to it. This is not a good position to start with in a promotional business. People on the other side of the table can use that against you in a negotiation."

Until the recent EPA ruling that categorized fly ash as a nonhazardous waste, it was unclear how states should regulate the material. In fact, according to Diana Jagiella, an environmental lawyer with Howard & Howard who has compiled a report on the state regulation of fly ash, several states "either directly or effectively" regulate the material as hazardous, which significantly restricts its use. State regulations in place today vary dramatically across the country.

Among the groups interested in changing this scenario is the American Coal Ash Association. Sam Tyson, the association's executive director, says it is putting together a "model regulation" on fly ash use that could serve as a guide for states in updating their existing regulations. According to Tyson, the model regulation, which is expected to be drafted within the year, may vary for different regions of the country to account for differences in the ash produced.

Some utilities maintain that even under existing regulations there is ample opportunity to make productive use of fly ash. "It's just a matter of how long and how hard you are willing and able to work on these opportunities," says Frady. "Sometimes it takes years—literally two to three years—of working on a situation to accomplish your goals and get a product approved for use." Frady notes that this is true not only for large-volume uses involving direct contact between fly ash and soil but also for construction materials like ACC that face the obstacle of breaking into a new market. Nevertheless, says Joel Pattishall, senior ash marketing specialist with Pennsylvania Power & Light Company, it can be done. "The biggest barrier to increased use, in my mind, is lack of imagination," he says. EPRI researchers are confident that their work on product development, building code approvals, and commercialization will give more utilities cause to share this perspective. ■

Background information for this article was provided by Dean Golden, Environment Division.

THE ASH ADVANTAGE—THEN AND NOW

Humankind has long taken advantage of the cementlike properties of ash. For example, volcanic ash, which is similar to fly ash, was used in the Colosseum and the highways of ancient Rome. Below are just some advantages of concrete and other building materials using fly ash.

Crack resistant The chemical makeup of fly ash allows concrete to cure with little cracking.

Flowable Fly ash's spherical particles make concrete easier to pump and finish.

Less permeable Because fly ash particles are so fine, they are better able to fill the gaps between aggregate and other particles in concrete mixes, making the final product less permeable.

"Green" A combustion by-product that would otherwise sit in a landfill gets put to use. That also reduces energy consumption and emissions related to the cement and aggregate production processes.

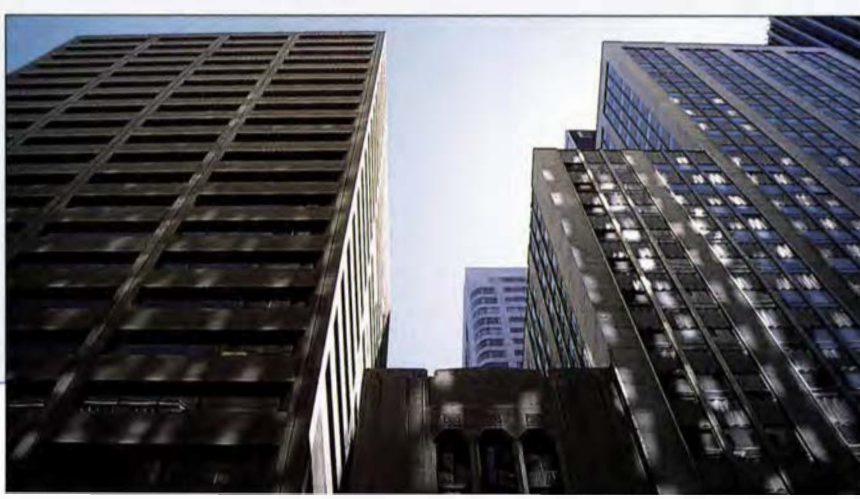
Light Large-volume fly ash applications result in relatively lightweight products that are easier to handle and transport.

Fire resistant By nature, fly ash is fire resistant (it is one of the few noncombustible materials that remain after coal is burned).

Sound absorbing Up to 75% of fly ash particles are hollow, giving them a good ability to absorb sound.

Insulating The air gaps in fly ash particles also make the material a good insulator against extreme temperatures.

Less expensive Fly ash is less than one-fourth the price of cement and similarly lower in cost than other materials it replaces.



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Producing the Near-Term EV Battery (page 6) was written by Taylor Moore, *Journal* senior feature writer, with assistance from **Jack Guy**, commercialization manager for EPRI's Customer Systems Division. Guy joined EPRI in 1974 after 18 years with General Electric Company, where he held various positions in engineering, marketing, manufacturing, and management. Guy graduated from the Advanced Marketing and Management School of Harvard University and studied electrical and metallurgical engineering at Villanova and Lehigh Universities. ■

Mercury and the Global Environment (page 14) was written by science writer John Douglas with technical information provided by three members of EPRI's Environment Division.

Don Porcella, manager of ecological studies, joined EPRI in 1984 after six years with Tetra Tech, a Honeywell R&D and consulting subsidiary. Previously he was a professor of civil and environmental engineering at Utah State University and the associate director of the Utah Water Research Laboratory. Porcella holds BA and MA degrees in zoology and a PhD in environmental health sciences, all from the University of California at Berkeley.

John Huckabee manages EPRI's Ecological Studies Program. He joined the Institute in 1979 and has also worked as a project manager on studies dealing with toxic substances, terrestrial and aquatic resources, and atmospheric deposition. Earlier he spent eight years in the Environmental Sciences Division at Oak Ridge National Laboratory. Huckabee earned a BS in biology at Sul Ross State University (Texas) and MS and PhD degrees in zoology and physiology at the University of Wyoming.

Robert Goldstein is manager of environmental risk analysis. He has been with the Institute since 1985, primarily focusing on atmospheric deposition effects, forest stress, and genetic ecology. Goldstein previously worked for more than five years as a systems ecologist at Oak Ridge National Laboratory. He has a BS in engineering and MS and PhD degrees in nuclear science and engineering from Columbia University. ■

Building From Ash (page 22) was written by Leslie Lamarre, *Journal* senior feature writer, with background information from **Dean Golden**, manager for high-volume by-products in EPRI's Environment Division. Golden joined the Institute in 1978 after six years with Southern California Edison Company, where he was a senior civil engineer. Before that, he was a senior engineering assistant for the city of Los Angeles. Golden holds BS and MS degrees in civil engineering from the University of California at Berkeley and Loyola University, respectively. He also has an MBA from the University of Southern California. ■

Progressive Flexibility Invitation Now in Members' Hands

Member utilities have received their 1995 EPRI membership invitation, which provides the first opportunity to select among the many options of the Institute's new Progressive Flexibility program. The new program, developed to respond to the changing needs of the electric power industry, combines the power of collaboration in R&D with an expanded power of investment choice.

Members are being urged to respond with their initial selection of funding options and allocation of dues among individual business units by June 3. EPRI will electronically post the summary of first-round results, and members will have the option to modify their choices before June 24. The overall results of members' funding decisions will be distributed on July 1. Each member's response is important because it will determine the member's access to EPRI RD&D program results, the member's eligibility to participate in the EPRI advisory structure, and the manner in which the member's funds will be apportioned to the separate elements of EPRI's technology program in 1995.

As previously announced, Progressive Flexibility organizes EPRI RD&D into a core program of research on vital and strategic issues that all members will help fund, plus a menu of 14 optional business units addressing specific technology areas. The Vital Issues core business unit covers research aimed at gaining a confident understanding of issues that pose a shared risk or opportunity for EPRI members or their customers. Among the research efforts included are air quality, health, and risk assessment work; EMF effects assessment; global climate risk and integrated environmental analysis; and land and water quality studies.

The Strategic R&D core business unit comprises exploratory research to overcome critical scientific barriers to fundamental advances in electricity production, delivery, and end use and environmental management; applied science to sustain and develop critical expertise in support of other EPRI R&D; and research into strategic innovations that other Institute business units could eventually pursue for commercial development.

The 14 optional business units span critical but independent elements of technology R&D, ranging from nuclear power, advanced fossil power systems, and environmental control to power quality, distribution systems, and electric transportation.

In addition to having the option to adjust their level of investment in the noncore business units, members may opt out of selected units, subject to a mininum overall investment. The membership invitation package describes each of the optional business units in detail, identifies the related targets in the 1994–1998 RD&D Plan, and provides a prioritized list of products to be developed, along with delivery dates and planned and cumulative expenditures for each product.

Membership options

For 1995, members may select any of three membership options: Traditional, Business Unit Flexibility, or Funding Flexibility. Traditional membership will be available with dues based on 100% of the current formula. Members who choose this option will have unlimited access to all EPRI RD&D results and may submit nominations for any advisory committee. Their dues will be allocated among the core and optional business units in proportion to the combined allocation of funds chosen by members under the other two options.

The Business Unit Flexibility option provides increased control over how a member's EPRI dues are invested. Total dues will continue at 100% of the current formula, and members must fund each of the two core business units at a minimum threshold percentage of the current dues formula. But they may allocate any remaining dues among the optional business units as they choose. Members who select Business Unit Flexibility will have access to all EPRI information but will be permitted to make advisory committee nominations only for those optional business units that they fund at or above a threshold level.

The Funding Flexibility option offers members a lower-cost form of EPRI membership, by which they may reduce their dues payments by up to 20%. But choosing this option will require members to decline participation in one or more optional business units; they will not have access to research results from unfunded business units and will not be eligible to nominate advisory committee members for those units. Members who choose Funding Flexibility must fund both core units and each selected optional business unit at a minimum threshold percentage of the current dues formula. The threshold is explained in more detail in the membership invitation package.

The decisions that members make in this first offering under Progressive Flexibility will be binding for 1995 only; all members will be free to change their choice of membership option or funding allocation for 1996. And under each of the three options, members will continue to be able to participate in Tailored Collaboration projects in amounts of up to 25% of their net 1995 EPRI dues. Those who select the Funding Flexibility option, however, will not be able to participate in TC projects related to business units they have not elected to fund. ■

HOTLINE

During May and June, EPRI is offering a special, toll-free telephone hotline service staffed by personnel who are knowledgeable about Progressive Flexibility and can answer member questions regarding the invitation. The number is 800-313-EPRI. The hotline will be staffed from 7 a.m. to 3 p.m. Pacific time, Monday through Friday. Questions may also be faxed to EPRI at 800-314-EPRI for a guaranteed response within 24 hours. Moreover, all of the 11 EPRI regional member relations executives are available to answer questions and help utilities evaluate their choices as EPRI nears the start of a new era of collaborative R&D ventures with its member companies and investment partners.

EPRI Officers to Speak at Technology Delivery Workshop

Three top EPRI executives will be featured in a panel discussion of various aspects of the Institute's redefinition and reorganization at the opening session of the 1994 Technology Delivery Workshop, to be held June 27–29 in San Francisco. "Delivering Value From Your EPRI Investment" is the theme of this year's event. Dick Balzhiser, EPRI president and CEO, will address the Institute's new vision and mission; Kurt Yeager, senior vice president for strategic development, will discuss mechanisms to help utilities obtain increased value from their EPRI investment; and Ric Rudman, senior vice president for corporate services, will outline the new ways utilities can invest in EPRI and the reorganization of EPRI business units.

"The discussion and the workshop in general will be of interest to everyone involved with the EPRI investment decision, including utility senior management and managers of EPRI technology transfer [METTs]," says Bob Noberini, the METT at Consolidated Edison Company of New York and cochairman of the now-annual event, sponsored by the Institute's Technology Delivery Committee. "In addition, corporate communicators and information technologists who are key to EPRI-utility communication and who influence the type of information systems, software, and hardware used for technology delivery would also benefit from the workshop."

The executive panel discussion will be followed by sessions at which EPRI representatives will describe how the Technology Delivery Committee and the METTs are working to improve technology delivery. Utility representatives will discuss their own experiences in ensuring the delivery of EPRI results. Various sessions will be devoted to giving attendees new ideas and suggestions on how to achieve technology delivery goals. The workshop will also offer a special orientation for METTs, demonstrations of EPRI software products and services, and a further update on the new EPRI business units. ■

For more information, contact Liz Gerhold, (415) 855-2477, or Susan Bisetti, (415) 855-7919.

Test Facilities and Guidelines Available for Transmission Cable Field Management

Until recently, electric and magnetic field (EMF) management efforts have been focused mainly on overhead transmission lines, but an increasing number of utilities are seeking information about reducing fields produced by underground cables. Member utilities can now get guidance in managing such fields and help in conducting tests of specific cables at the unique facilities of EPRI's Waltz Mill Underground Transmission Test Center in Pennsylvania.

In anticipation of the need for more information in this area, EPRI launched a series of studies in 1989 aimed at providing critical data about magnetic fields from underground transmission lines. Researchers at the Waltz Mill test center measured field strengths near different types of cable under many combinations of phase current magnitude, return current path, and structural variations. Details of the work have been published separately, and the resulting field reduction guidelines are presented in *Transmission Cable Magnetic Field Management* (TR-102003).

For those types of cable that may have modest to high field levels, 47 field reduction methods were compared with a base-case installation, and changes in field strength, cost, and ampacity were calculated for each method. It was found that most field reduction techniques increase the cost of a circuit or reduce its ampacity or both. A few fairly conventional configurations, however, were found to be cost-effective, as were some shielding options under specific circumstances, such as the use of steel pipe in urban areas.

"EPRI is offering to conduct customized cable tests for member utilities at the Waltz Mill facility," says John Shimshock, a project manager in the Electrical Systems Division. "It is difficult to generalize about many aspects of cable design and installation, but if a member utility needs further information about magnetic fields from a particular cable configuration, we can make the measurements quickly and very cost-competitively."

■ *For more information, contact John Shimshock, (412) 722-5781.*

EPRI, TVA Plan Instrumentation and Control Technology Center at Kingston

The Tennessee Valley Authority and EPRI are cosponsoring an $8.6 million center for instrumentation and control (I&C) technology, to be located at TVA's Kingston power plant near Knoxville, Tennessee. The center will become a focal point of EPRI's I&C research for utility power plant operations. TVA will construct a 6000-square-foot building to house the center, as well as install a distributed control system at Kingston's Unit 9. Using a plant simulator, the center will develop and demonstrate improved instruments, final elements, and control system algorithms, and it will also serve as a training facility. Additional funding for the center from other utilities is anticipated.

According to Joe Weiss, EPRI manager for fossil plant operations controls and automation, the formation of the I&C Technology Center is a response to increased utility demand for fossil plant productivity improvements. "Industry efficiency and reliability are more crucial than ever if utilities are to remain competitive in a deregulated environment," says Weiss. "Nearly two-thirds of utilities are targeting I&C upgrades or expenditures."

Early work at the center will be aimed at immediate productivity gains for utilities. It will include measurement of pulverized-coal flow; development of high-reliability temperature sensors suitable for application at up to 2000°F and capable of being calibrated on-line; high-temperature strain measurement for boiler tube headers; boiler flame temperature measurement for control of nitrogen oxides; and improvement of control valve operation. Researchers will also demonstrate state-of-the-art continuous emissions monitoring systems applicable to all fossil power plants. Documentation of cost savings will help utilities make more-informed retrofit decisions and will assist them in complying with recent emissions control legislation.

■ *For more information, contact Joe Weiss, (415) 855-2751, or Rob Frank at Kingston, (615) 376-1693.*

Software Gives Utilities a Closer Look at the Benefits of Energy Storage

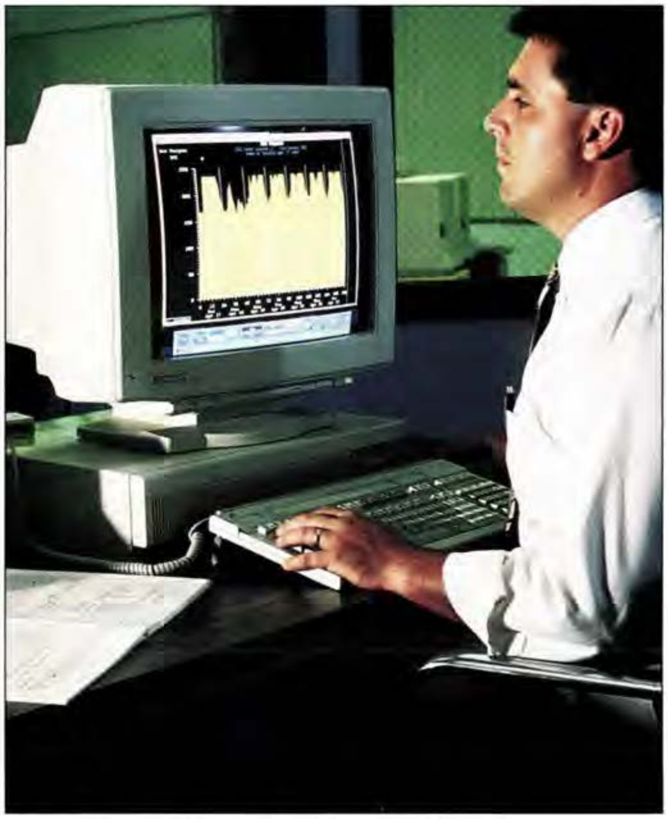
Many factors influencing U.S. utility operations encourage the increased use of energy storage, which according to EPRI estimates could reduce the need for additional generating capacity by as much as 15% through improved utilization of existing power plant assets. Two utilities recently documented the value of storage plants by using EPRI software to improve generation planning and power plant unit commitment and dispatch decisions. These software codes can help other utilities gain a clearer picture of the benefits of energy storage.

Previous methods of estimating benefits from storage have ignored or provided only an order-of-magnitude estimate of the dynamic benefits. These accrue from the use of storage plants for frequency regulation, rapid ramping up and down for load following, and emergency spinning reserve duty. The value of storage for these functions is virtually impossible to quantify without at least an hourly production cost model that accounts for real-world unit commitment and dispatch operations.

As part of scoping evaluations of emerging storage technologies, Bonneville Power Administration (BPA) used EPRI's DYNASTORE model to estimate the potential economics and system-specific benefits of alternative sizes of superconducting magnetic energy storage (SMES) systems in the Pacific Northwest. DYNASTORE is designed to simulate the least-cost dispatch of utility generating and storage resources, showing the differential value of storage options.

For a specific future planning scenario, BPA found that the most cost-effective SMES unit—one with a storage capacity of 1200 MWh—required less than one-sixth of the capacity originally considered applicable in that case. The modeling results allowed BPA to demonstrate that this size advantage can be worth millions of dollars in net benefits to the region. "The advantages of smaller SMES units were counterintuitive and probably would not have been discovered without the use of DYNASTORE," says BPA's John Haner.

Conventional economic benefit evaluations of energy storage plants have been unable to provide the optimized unit commitment and dispatch schedules that utilities need to efficiently coordinate power transactions with thermal and hydro generation schedules. In response, EPRI developed the DYNAMICS program for minicomputers and high-speed workstations, which uses more-advanced mathematical optimization techniques than are available elsewhere. DYNAMICS is the only software that indicates how close a particular schedule is to the true least-cost optimum and that provides the user with transaction break-even costs for power, energy, and emissions on an hourly basis.



DYNAMICS code in use at Alabama Electric Cooperative

Alabama Electric Cooperative, which operates the country's only compressed-air energy storage (CAES) unit, was closely involved in the design and testing of DYNAMICS. The generation and transmission cooperative uses the software to improve power system operations, particularly transaction and energy storage scheduling. It estimates that the use of DYNAMICS has led to a 1% reduction in power production costs, for annual savings of $850,000.

"DYNAMICS provides us with an optimized method for scheduling our thermal generating units, limited hydro power, limited energy purchases, and charging and expansion loads for the McIntosh CAES plant," notes the utility's John Smith. "We were unable to find this capability in any competing unit commitment program." Other utilities could expect to save 0.5–2% in power production costs through the use of DYNAMICS. For each 1000 MW of installed capacity, a 1% reduction in cost yields about $1 million in annual savings.

■ *For more information, contact Robert Schainker, (415) 855-2549.*

Advanced Fossil Power Systems

Molten Carbonate Fuel Cell Technology

by Ed Gillis, Generation & Storage Division

Most molten carbonate fuel cell (MCFC) developers in Europe, Japan, and the United States use similar materials for the various fuel cell components, and they also use similar manufacturing methods. For example, the fuel cell anode is generally porous nickel stabilized with chromia or alumina to inhibit sintering. The electrolyte is usually a mixture of lithium and potassium carbonate with a composition near the lithium eutectic point (62 mol%). It is made into a thick paste by adding lithium aluminate powder.

Most developers use a porous nickel cathode that oxidizes during initial stack heat-up and becomes a semiconductor as it is doped by lithium from the electrolyte. The notable exception is the use of cobalt by the Dutch development organization ECN (Energieonderzoek Centrum Nederland), which claims that cobalt increases cell durability. The cell separator plate is typically nickel-clad stainless steel sheet stock with a diffusion-bonded alumina border to mitigate corrosion in the different environments within a cell. The porous parts of the fuel cell (anode, cathode, and electrolyte) typically are manufactured by tape-casting processes.

Design approaches

In contrast to their use of similar materials and similar manufacturing processes, the MCFC developers differ in their approach to stack design. Energy Research Corporation (ERC), International Fuel Cells Corporation, and Mitsubishi Electric Corporation (MELCO) use external-manifold stacks, while M-C Power Corporation, ECN, Ishikawajima-Harima Heavy Industries (IHI), and Hitachi use internal-manifold stacks. There is no clear answer to the question of which stack design is better. The real issues are how well a power plant performs and whether it is cost-effective. EPRI believes that both types of stack can lead to desirable power plants. However, the different features of the two stack configurations do affect how the balance of the power plant is designed. Some of the differences are described below.

Figure 1 shows the assembling of an external-manifold stack by ERC's manufacturing subsidiary, Fuel Cell Manufacturing Corporation. Each cell is rectangular, with the approximately 5-square-foot active area producing about 0.5 kW of electricity. The individual cells are laid one on top of another and stacked to approximately 10 feet—as tall as the stack can be and still be shipped by truck. The stack resembles a crossflow plate-type heat exchanger. Full-length manifolds are later fixed to each face of the stack for providing the reactants to, and collecting the products from, the cells. The gaskets needed to seal the manifolds to the faces of the stack and to prevent electrical short-circuiting by the metal manifolds are critical for acceptable stack operation and are receiving much developmental attention. Completed stacks with the cell area shown produce 125 kW of dc power (although larger-area cells, which produce proportionately more power, are being or have been developed by the external-manifold stack manufacturers).

The external manifolds and the crossflow reactant-gas path create some design challenges. Gasket materials that can survive in the 650°C carbonate environment are limited, and those developed to date to seal the manifolds to the stack faces have very low pressure capability—only tenths of a pound per square inch. That, in turn, forces plant designers to use ultralow-pressure-drop equipment in the heat recovery systems that prepare the fuel and oxidant reactants for use in the stack. The reactants' crossflow pattern results in nonuniform production of electricity (and thus of heat) over the active area of a cell. The electric current produced in the cell's hot-

ABSTRACT *Molten carbonate fuel cells (MCFCs) are receiving a great deal of attention worldwide. EPRI is sponsoring MCFC development by two manufacturers, Energy Research Corporation (ERC) and M-C Power Corporation. Both manufacturers have contracts with utilities to construct demonstration MCFC power plants: ERC's 2-MW plant will be located on the municipal system of Santa Clara, California, and M-C Power's 250-kW plant will be located on San Diego Gas & Electric's system. Next year—1995—will be a milestone year, with both of these plants scheduled to be in operation and with other demonstrations planned by manufacturers in Europe and Japan. The goal of these demonstrations is to have commercially acceptable products on the market by the turn of the century.*

test quadrant, the fuel inlet/oxidant outlet quadrant, may be two or more times that produced in the cold quadrant diagonally across the cell; hence average cell performance is slightly lower than in a cell with counterflow reactant paths.

The fabrication of cell separator plates and reactant flow paths is generally less labor- and machine-intensive for external-manifold cells than for internal-manifold cells because metal-bending rather than metal-stretching processes predominate and no welding steps (and thus no elaborate fixturing) are required.

M-C Power, ECN, IHI, and Hitachi use the internal-manifold concept. M-C Power's cell and stack configuration is shown in Figure 2. As the cells are stacked, the triangular openings along their long edges create cavities that serve as the manifolds for distributing the reactants and collecting the products from the cells. In this configuration the reactant flow paths can be counterflow over most of a cell's active area. The cells shown are approximately 11 square feet in active area and produce over 1 kW each; a 10-foot-high stack will produce 250 kW.

Because the M-C Power stack configuration, like most other internal-manifold designs, has predominantly counterflow reactant paths, it has a uniform electric current distribution and temperature gradient over the active area of a cell. That keeps power production uniform and maximizes the amount of fuel that can be used electrochemically. The wide gas seals around the periphery of the triangular manifolds have some pressure-retention capability (still low, but on the order of 1 pound per square inch), so the heat recovery train design can be similar to that of combustion turbine heat recovery steam generators.

A system constraint in M-C Power's design, and in other internal-manifold designs except perhaps Hitachi's, is the use of pressed separator plates. Because of the low ductility of stainless steel, the depth of the corrugations in the reactant flow fields is limited. Since there is not sufficient cross-sectional area in the pressed corrugations to provide the necessary cooling air at atmospheric pressure without exceeding the pressure capabilities of the seals, M-C Power's system must operate at elevated pressure to reduce the flow volume of the reactant air. This pressure is not high (only 3 atmospheres absolute), so the air compressor requirements can be satisfied by a turbocharger. Hitachi uses a pressed separator plate with a corrugated metal insert under one electrode so that the anode and cathode flow field dimensions (and pressure drop) can be designed separately. However, this adds one more layer of stainless steel to the assembly and hence increases its cost.

Besides stack design, another main difference between MCFC systems is the approach to fuel reforming. The ERC stack has the ability to convert the natural gas fuel (largely methane) internally to hydrogen and carbon monoxide, which the cells then consume electrochemically. The reaction of methane with steam to form hydrogen and carbon monoxide is highly endothermic, requiring the equivalent of approximately 20% of the heating value of the methane. In ERC's internal-reforming stack, this heat is provided by the electrical resistance and electrochemical losses in the cells; hence no fuel is burned to provide the heat of reaction. This use of cell waste heat also reduces the airflow needed to remove waste heat by approximately 25%, thus reducing the system's parasitic power losses.

MELCO also takes this internal-reforming approach, and ECN is considering it. The other developers use a separate (i.e., external) reformer and use various methods of thermally integrating the reformer with the fuel cell stack. The advantage of an external reformer is that it can be maintained or replaced independently of the stack.

Figure 1 These workers are assembling an external-manifold fuel cell stack designed by Energy Research Corporation. Full-length manifolds for distributing the reactants to the cells and collecting the reaction products will later be fixed to each face of the stack.

MCFC demonstrations

A 2-MW plant developed by ERC will be demonstrated on the municipal power sys-

Figure 2 In this internal-manifold stack configuration designed by M-C Power Corporation, the channels created by the triangular openings along the cell edges serve as manifolds for distributing the reactants and collecting the reaction products.

tem of Santa Clara, California. This particular plant is not optimized for maximum efficiency; a compromise was made between system simplicity and efficiency, in the interest of reducing the plant's capital cost. The plant will operate at a lower-heating-value (LHV) efficiency of 50%, which is equal to that of most modern combined-cycle plants.

Some of the simplifications in the plant are related to how the reactants are conditioned for use in the stack. The reactants have to be heated to approximately 550°C before going to the stack, which operates at approximately 650°C. The sensible heat change in the reactants, principally the oxidant, cools the stack. The 2-MW system uses a simple heat recovery train to preheat the natural gas and steam. The oxidant is provided at over 10 times greater mass flow than the fuel to provide most of the stack cooling. It is produced by burning the residual fuel from the anode with a large amount of air; this combustion preheats the incoming air and lowers the temperature of the anode exhaust. The fuel cell could efficiently convert more of the fuel to electricity, but then there would not be sufficient residual fuel to preheat the air to the desired temperature.

If some or all of this preheating were performed by adding a heat exchanger (which, as a gas-to-gas heat exchanger operating at atmospheric pressure, would have to be large) or an air recycle loop, and if the fuel were recycled to maximize its utilization, the plant efficiency could be increased to 60% LHV; including a bottoming cycle would raise the efficiency even higher. However, the plant capital cost would increase.

A 250-kW plant based on M-C Power's design is being built by M-C Power, Bechtel, and Stewart & Stevenson at a hospital in San Diego Gas & Electric Company's service territory. Besides producing electricity, the plant will export steam to the hospital at the rate of approximately half a kilowatt thermal per kilowatt electric. In terms of electrical output, the plant's efficiency will be nearly 45% LHV; if the thermal energy is included, efficiency will be 67%. The natural gas reformer is separate from the fuel cell in this design. Some of the reformer reaction heat is supplied by recirculating a portion of the cathode exhaust over the reformer, and some comes from the combustion of the anode exhaust. Fresh air is added to this gas mixture, and its temperature is brought up to the desired level by adding more cathode exhaust as necessary. The cathode exhaust recycle compressor is a significant parasitic power drain on the system—over 10% of net power—so other recirculation approaches must be developed to achieve electrical efficiencies greater than 50%.

In the Netherlands, ECN has formed a consortium with utilities, a manufacturer, and the government to commercialize its MCFC technology. Two 250-kW demonstration units are scheduled to begin operation in 1995, one on natural gas and the other on coal-derived synthesis gas. The natural-gas-fueled unit will be demonstrated in a cogeneration application.

The MCFC development program sponsored by the Japanese government is aimed primarily at the use of coal gas. The demonstration program, therefore, focuses on pilot plant operation that simulates the integration of an MCFC with a coal gasifier and a steam bottoming cycle. A 1-MW central test facility has been constructed, and IHI and Hitachi have already tested nominal 100-kW stacks there. They are now constructing megawatt-scale stacks (probably two 500-kW stacks each) that will be tested on simulated coal gas and at elevated pressure in 1995. MELCO has also tested a 100-kW atmospheric-pressure, natural-gas-fueled stack, but it isn't clear from published reports what the company's next demonstration steps will be.

Clearly, MCFCs are receiving a great deal of R&D support and interest worldwide. Next year, at least five manufacturers on three continents will be conducting important power plant demonstrations, all aimed at having commercially acceptable products in the marketplace by the turn of the century.

Land and Water Quality

Wood Pole Preservatives: Study of In-Service Poles

by Ishwar Murarka and Adda Quinn, Environment Division

Electric utilities use wood poles treated with the preservatives pentachlorophenol (PCP), commonly referred to as penta, and creosote in their transmission and distribution systems. The U.S. Environmental Protection Agency is in the process of determining what level of these chemicals poses a threat to the environment and what action, if any, is required on the part of utilities. EPRI, in cooperation with 25 member utilities, the Utility Solid Waste Activities Group, and the Empire State Electric Energy Research Corporation, has undertaken a nationwide research effort to assess the nature and extent of soil and groundwater impacts of wood preservatives associated with in-service utility poles. The focus of this work is to develop reliable attenuation, biodegradation, and migration data through the testing and analysis of soil samples collected from several depths and distances around a broad spectrum of in-service U.S. electric utility poles.

Selected for study were 182 pole sites in 20 states in the northeastern, mid-Atlantic, southern, midwestern, southwestern, and northwestern United States. The sites in-

ABSTRACT *EPRI is participating in a cooperative effort to assess the nature and extent of soil and groundwater impacts of wood preservatives associated with in-service utility poles. Focusing on the preservatives pentachlorophenol and creosote, researchers are analyzing soil samples from a variety of pole sites across the United States. The goal is to provide a scientifically sound basis for the evaluation of the release, migration, and persistence of preservatives in soil.*

clude a range of climates; soils; and pole woods, sizes, and in-service ages. Several soil types have been encountered in the sampling so far, including clay, gravel, and sand. The poles covered in the study to date range from 30 to 95 feet in length and from 1 to 32 years in age. Slightly over half the sites have been sampled: 100 PCP pole sites and 7 creosote pole sites. A project overview and a summary of the preliminary results from the 107 pole sites follow.

Study design and methodology

Some 45–50 soil samples are collected from each wood pole site under study, using a radial sampling grid. Samples from PCP pole sites are analyzed for PCP and also for total petroleum hydrocarbons (TPHs), since PCP is applied in a diesel formulation; samples from creosote pole sites are analyzed for polycyclic aromatic hydrocarbons (PAHs). EPA and American Society for Testing and Materials methods were used for the analyses, with some modifications to enable the efficient analysis of the many samples with low concentrations of these chemicals—concentrations near the detection limits.

In addition, four soil samples near a pole and one background composite sample are collected for the analysis of physical and other chemical parameters. The background composite sample is also analyzed for moisture content and grain size. At PCP pole sites, a second composite sample from the background location is collected for biodegradation and attenuation studies. The Utah Water Research Laboratory at Utah State University is performing tests to determine the ability of native bacterial populations to degrade PCP in the site soils. The Utah researchers are also determining the retardation coefficients for PCP from site soils.

The sampling design calls for 16–20 soil borings to be made at each site along four evenly spaced radial spokes extending from the center of the pole. Soil samples for the analysis of preservative chemicals are collected along each spoke at four or five distances from the exterior of the pole (3, 8, 18, 30, and sometimes 48 inches) and at four depths—near the surface, 10 feet below the surface, and two intermediate depths (termed shallow and medium). Soil samples from the four depths in the two (or three) outer circumferences are composited into one sample per boring locus, thereby lowering by three-fourths the total number of samples for those distances. The background sample is collected as a depth composite from a location 7–10 feet from the pole in the assumed upgradient direction. Wood samples are collected from approximately 20% of the poles and analyzed for PCP or PAHs and cresols.

Chlorophenols (including PCP), TPHs, and PAHs are analyzed by standard EPA methods; a microscale solvent extraction modification developed for EPRI is used to significantly reduce the sample size and the volume of solvents required. The techniques used include sonication extraction of soils, followed by gas chromatography (with an electron capture detector or a flame ionization detector) or infrared detection.

All of the remaining chemical and physical parameter determinations are made by using standard EPA-approved analytical methods and instrumentation. These include determinations of cation exchange capacity, pH, grain size, percentage of moisture, and total organic carbon (TOC) content.

Microbial degradation studies are using specified procedures and involve adding radioactively labeled (carbon-14) PCP to soil samples and following the production of radioactive carbon dioxide. The PCP retardation coefficient for each soil sample is being calculated from 18 separate analyses, following standard EPA protocols.

PCP pole results

The PCP results, based on over 4000 samples from 100 pole sites, show a large variation in concentrations in the soils around utility poles, both at a given site and between sites. The average range of difference in PCP concentrations at a given site is about three orders of magnitude.

Figure 1 is a frequency histogram of the maximum PCP concentrations detected at the 100 pole sites. These ranged from 0.039 to 1500 mg/kg (dry weight). Nearly 40% of the sites had a maximum PCP con-

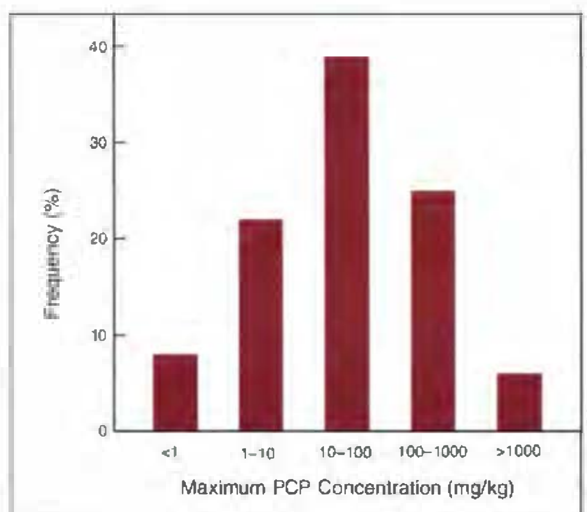
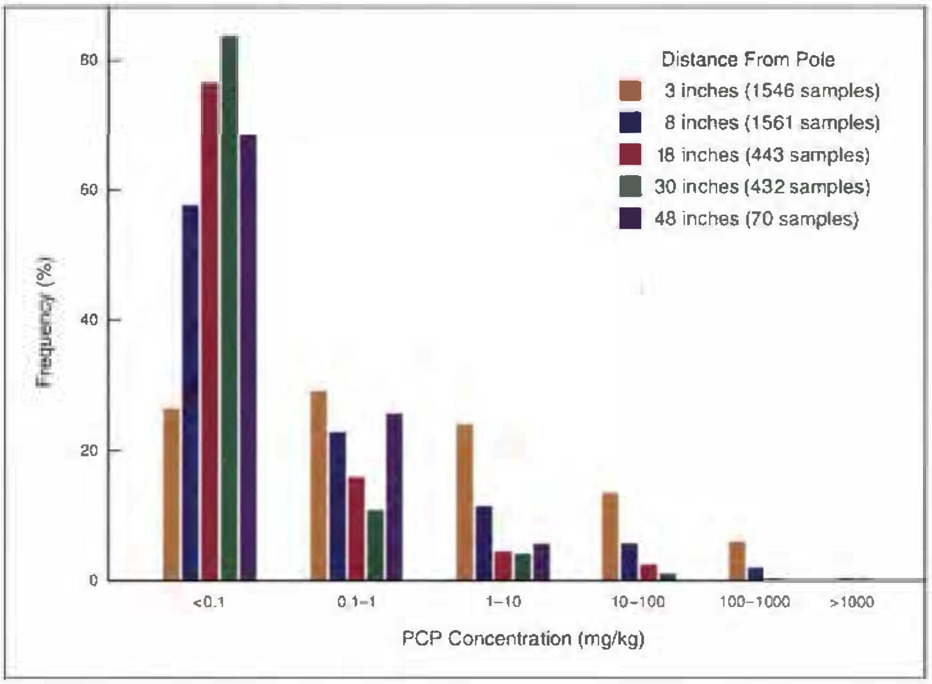


Figure 1 Frequency histogram of the maximum PCP concentrations measured at 100 utility wood pole sites. The maximum values ranged from 0.039 to 1500 mg/kg (dry weight), with nearly 40% of the sites having a maximum in the range of 10–100 mg/kg.

Figure 2 Frequency histogram for all PCP samples collected at the 100 pole sites, grouped by distance from a pole. For each group except the samples closest to a pole, the majority of the measured PCP concentrations were below 0.1 mg/kg.



centration in the range of 10–100 mg/kg, with smaller percentages of samples having higher and lower concentrations. Figure 2 is a frequency histogram of PCP concentrations for all the samples collected at the 100 pole sites, grouped according to distance from a pole. For each group except the samples collected 3 inches from a pole, the range in which most of the concentrations fell was <0.1 mg/kg; for all soil samples collected 3 inches from a pole, the range in which most concentrations fell was 0.1–1.0 mg/kg.

The average of the maximum PCP concentrations observed at the 100 pole sites is 190 mg/kg, with a standard deviation of 340 mg/kg; the median maximum concentration is 35 mg/kg. The data do not have a normal frequency distribution but instead are highly skewed toward lower concentrations, with the highest frequency of samples at or near the detection limit and with a "tail" that extends up to 1500 mg/kg.

The areas of maximum PCP concentration at individual pole sites varied by depth and distance from the pole. In general, the samples collected at ground surface 3 inches from a pole showed higher levels of PCP than samples taken at other depths or distances. For surface samples, maximum PCP concentrations ranged from 0.06 to 1500 mg/kg; for samples from increasing depths (shallow, medium, and deep), they ranged from below the detection limit (approximately 0.03 mg/kg) to 910, 1100, and 740 mg/kg, respectively. At most pole sites, PCP concentrations decreased rapidly with increasing distance from the pole. For each of the four sampling depths, average PCP concentrations decreased with distance.

The TPH results also show a large variation in concentrations around utility poles. Figure 3 is a frequency histogram of the maximum TPH values at the 100 pole sites. These values ranged over more than four orders of magnitude, from below the detection limit of approximately 60 mg/kg to 54,000 mg/kg (dry weight). The average of the maximum concentrations for the pole sites is 5000 mg/kg, with a standard deviation of 10,000; the median maximum concentration is 850 mg/kg. Like the PCP data, the TPH results do not have a normal frequency distribution but instead are highly skewed toward lower concentrations.

Creosote pole results

Soil samples from the seven creosote pole sites were analyzed for about 30 monocyclic and polycyclic aromatic hydrocarbons, the major ones being naphthalene, methylnaphthalene, acenaphthene, fluorene, phenanthrene, fluoranthene, pyrene, benz(a)anthracene, and chrysene. Total PAH concentration (the sum of 18 individual compounds) ranged over three orders of magnitude, with the maximum total PAH values for the seven pole sites ranging from below detectable limits (about 4.5 mg/kg for total PAHs) to 2300 mg/kg. The average of the maximum concentrations for the pole sites is 1500 mg/kg.

The concentration of total PAHs varied with depth, in some cases increasing and in others decreasing with increasing depth, depending on the particular location. Two-thirds of the borings 3 inches from a pole showed a pattern of higher total PAHs at the surface and medium depths than at the shallow and deep levels. A closer look at the distribution of PAHs in the soil samples collected at the various depths shows that the surface samples contain a greater rela-

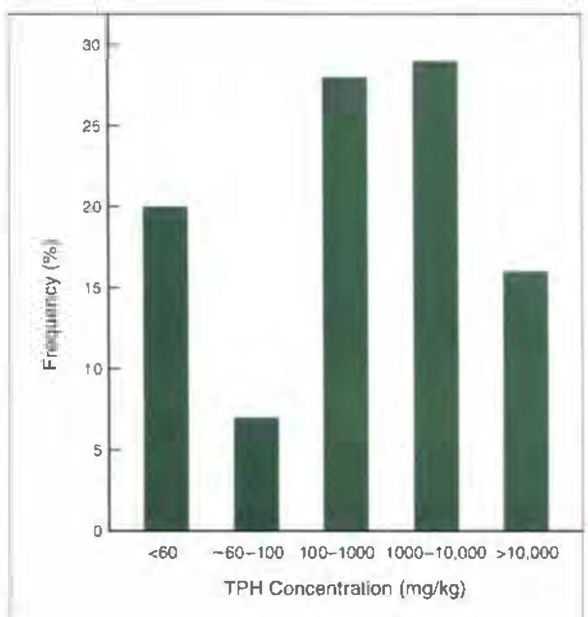


Figure 3 Frequency histogram of the maximum TPH concentrations measured at 100 pole sites. The maximum values ranged from below the detection limit of about 60 mg/kg to 54,000 mg/kg (dry weight).

tive amount of the higher-molecular-weight compounds (a pattern indicative of weathered creosote), while the deeper samples contain a greater relative amount of the lower-molecular-weight compounds.

Attenuation and biodegradation results

PCP retardation coefficients have been obtained for 83 pole sites, with values ranging from 3 to 270. These coefficients show a strong linear correlation with soil TOC content in two soil regimes defined by pH. For soils with a pH below 4.7, in which PCP is predominantly in the insoluble neutral form, the retardation coefficients are higher, reflecting the high adsorption of PCP to the organic carbon in the soil. For soils with a pH above 6.7, in which PCP is predominantly in the relatively soluble ionic form, the retardation coefficients are lower, reflecting diminished adsorption.

In the biodegradation work, 67 soil samples have been analyzed so far, and the results show that aerobic biodegradation of PCP is ubiquitous. However, the biodegradation rate constants have ranged between 0.037 and 5.8 per year.

Information for decision making

The variation in PCP concentrations at individual pole sites and between pole sites indicates that PCP migration is highly dependent on localized factors, such as soil type, local weather and topography, type of pole treatment, and age of pole. However, the researchers have discerned no linear correlation between any physical or site-specific characteristic and the measured concentrations of PCP. Indeed, even the PCP and TPH values appear to be independent of each other at most sites. This may be due in part to the abundance of petroleum compounds in the environment and to the many potential sources of TPH deposition in urban and suburban areas, especially in the case of poles near well-traveled paved roads.

One trend that does emerge from the data is the tendency for surface samples near a pole (3 inches away) to have higher PCP concentrations, and/or to exhibit more variation in PCP concentrations, than samples from other locations around a pole. In addition, the concentration of PCP decreases rapidly with distance from a pole (by as much as three orders of magnitude at 8 inches away). Finally, soil TOC shows a strong correlation with PCP retardation coefficients.

PAH concentrations, like PCP concentrations, vary greatly, with generally higher values at the ground surface. At each of the seven poles analyzed, the PAH results show a consistent pattern of more-weathered creosote at the soil surface and less-weathered creosote at increased depths.

The combination of field and laboratory data and modeling analysis in this project is intended to provide scientifically precise information to help regulatory agencies make sound decisions as they evaluate the potential threat to groundwater (for drinking purposes) from the release, migration, and persistence of PCP and PAHs in soil. Final results are expected to be available at the end of this year.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Industrial/Air Toxics Treatment (RP2662-36)	$200,000 24 months	Los Alamos National Laboratory/*M. Jones*
Development of an Active Series/Parallel Passive Hybrid Filter for Chiller Compressors With Adjustable-Speed Drives (RP3087-29)	$318,000 15 months	York International Corp./ *B. Banerjee*
Testing and Demonstration of Commercial/ Industrial Needs-Based Segmentation Framework (RP3825-1)	$400,400 14 months	National Analysts/ *T. Henneberger*
Integration and Demonstration of the Market Analysis Tools Commercial CLASSIFY-Plus and MarketTREK (RP3825-3)	$249,500 19 months	National Analysts/ *T. Henneberger*
Application of Quality Function Deployment to Demand-Side Management Program Design at PSI Energy (RP3825-4)	$97,200 16 months	Putnam, Hayes & Bartlett/ *T. Henneberger*
Customer Data and Communications Integration Demonstration (RP3855-1)	$1,221,100 26 months	Pacific Gas and Electric Co./*L. Carmichael*
Electrical Systems		
Distribution of STATCON Feasibility Study—Consolidated Edison (RP3389-16)	$104,700 8 months	General Electric Co./ *H. Mehta*
DYNAMICS: Technology Transfer Case Studies (RP3555-6)	$320,000 10 months	Decision Focus/ *G. Cauley*
Substation Insulators (RP3684-2)	$119,900 25 months	General Electric Co./ *J. Hall*
Study of Additional FACTS Technologies (RP3789-3)	$389,300 39 months	New York Power Authority/ *R. Adapa*
Low-Magnetic-Field Design for Transmission Lines (RP3798-1)	$399,700 18 months	General Electric Co./ *R. Lordan*
Research on Pole Foundations (RP3806-1)	$537,100 39 months	GAI Consultants/ *A. Hirany*
Advanced Techniques and Tools for the Removal of Jammed Cables (RP7910-31)	$601,000 11 months	Underground Research/ *T. Kendrew*
Gas-Pressurized Cross-Linked Polyethylene Cable (RP7920-1)	$549,000 13 months	Pirelli Cable Corp./ *F. Garcia*
Environment		
Study of Remediation Alternatives for an Oil Spill Site (RP2879-34, RP9015-12)	$300,600 16 months	Meta Environmental/ *I. Murarka*
Pentachlorophenol and Creosote Contamination at Utility Sites (RP2879-35, RP9024-2)	$387,600 17 months	Meta Environmental/ *I. Murarka*
Seasonal NO_x Control Assessment (RP2916-30)	$50,000 5 months	ICF Resources/*D. Eskinazi*
Global Mercury Model Development (RP3218-7)	$187,000 16 months	Tetra Tech/*D. Porcella*
Environmental Distribution of Petroleum Hydrocarbons at a Utility Fuel Storage Site With an Assessment of Remedial Options (RP9015-8)	$230,600 13 months	Atlantic Environmental Services/*A. Quinn*
Characterization and Fate of Non-PCB Dielectric Fluids (RP9015-11)	$215,700 24 months	Meta Environmental/ *I. Murarka*
Transportable Pulse-Jet-Baghouse Field Testing (RP9027-2)	$611,700 37 months	ADA Technologies/ *R. Chang*
Exploratory & Applied Research		
Instabilities in Multidimensional Nonlinear Plants (RP8014-4)	$453,600 61 months	University of Nevada, Reno/*M. Wildberger*
Electrochemical Reactions of Polymeric Insulation (RP8019-5)	$307,900 36 months	University of Connecticut/ *B. Bernstein*
Electrochemical Control of Stoichiometry in High-Temperature Superconductors (RP8060-7)	$87,800 20 months	Colorado State University/*R. Weaver*
Computer-Aided Design and Characterization for Copper Gallium Diselenide and Copper Indium Diselenide Solar Cell Development (RP8063-2)	$157,600 36 months	Pennsylvania State University/*T. Peterson*
Development of High-Critical-Current-Density High-Temperature Superconductors (RP8065-6)	$1,795,100 37 months	University of Wisconsin, Madison/*T. Schneider*
Generation & Storage		
Next-Generation Wind Turbine Feasibility Study (RP1590-17)	$220,000 11 months	U.S. Windpower/*E. Davis*
Compact Simulator Technology Development and Demonstration (RP3384-13)	$137,300 30 months	Automation Technology/ *R. Fray*
Measurement of Primary Airflow, Secondary Airflow, and Coal Flow to Pulverized-Coal Burners (RP3524-1)	$400,000 24 months	Alabama Power Co./ *E. Petrill*
Support of Wabash River Combined-Cycle Repowering Plant (RP3585-3)	$3,000,000 66 months	PSI Energy/*M. Epstein*
Next-Generation Geothermal Power Plant, Phase 1 Studies (RP3657-1)	$271,800 10 months	Ben Holt Co./*E. Hughes*
Assessment of Fuel Cells and Electric Vehicles at the Pittsburgh International Airport (RP3747-1, RP3859-1)	$568,500 25 months	Duquesne Light Co./ *J. O'Sullivan*
Integrated Energy Systems		
Decision Analysis for Utility Planning and Management (RP2631-3)	$103,100 12 months	Applied Decision Analysis/ *J. Bloom*
Power Quality Market Assessment (RP3273-9)	$169,600 4 months	Arthur D. Little/*V. Longo*
New Applications for the EPRI CONTRACTMIX Model (RP7604-2)	$92,500 13 months	Decision Focus/ *R. Goldberg*
Nuclear Power		
Ground Motion Guidelines Primer (RP3180-3)	$75,600 4 months	Risk Engineering/ *J. Schneider*
Upgrade Evaluation Methodology (RP3373-10)	$195,400 13 months	Queue Systems/ *C. Wilkinson*
Upgrade Evaluation Methodology (RP3373-11)	$241,500 17 months	Combustion Engineering/ *C. Wilkinson*
Thermo-Lag Fire Risk Methods: Development and Demonstration (RP3385-5)	$256,000 21 months	Science Applications International Corp./*R. Oehlberg*
Feedwater Particulate Filtration for a BWR System (RP3388-6)	$1,450,000 48 months	Public Service Electric & Gas Co./*P. Millett*
In-Situ Investigation by Surface-Enhanced Raman Spectroscopy of the Passive Films on 304 Stainless Steel in High-Temperature Water (RP3468-5)	$135,700 15 months	University of California, Berkeley/*W. Childs*
Risk-Based Regulation Support (RP3477-6)	$92,500 15 months	Yankee Atomic Electric Co./ *F. Rahn*
Comprehensive Approach to Safety-Grade System Replacements (RP3549-1)	$1,347,800 32 months	Bechtel Group/ *J. Naser*
Comprehensive Approach to Safety-Grade System Replacements (RP3549-2)	$489,400 20 months	Combustion Engineering/ *J. Naser*
Cost-Benefit Analysis of Alloy 600 Stress Corrosion Cracking Mitigation Methods (RP3580-2)	$76,900 7 months	Decision Focus/ *R. Pathania*
Irradiation-Assisted Stress Corrosion Cracking Database, Phase 2 (RP3844-1)	$260,300 24 months	Fourth Floor Databases/ *L. Nelson*

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CUSTOMER SYSTEMS

The Impact of Building Codes and Specifications on the Commercialization of Electric Vehicles, Vols. 1–3
TR-102739 Final Report (RP3272-5); Vol. 1, $200; Vol. 2, $300; Vol. 3, $300; $500 for set
Contractor: National Conference of States on Building Codes and Standards
EPRI Project Managers: J. Janasik, G. Purcell

First International EPRI/NSF Symposium on Advanced Oxidation, Vols. 1 and 2
TR-102927 Proceedings (RP2662-29); Vols. 1 and 2, $200 each volume
Contractor: CK & Associates
EPRI Project Manager: M. Jones

Performance Evaluation of the HydroTech 2000, Vol. 1: Heating Season
TR-103019-V1 Final Report (RP2892-20); $200
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Space-Conditioning System Selection Guide
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Contractors: Dorgan Associates, Inc.; Pacific Consulting Services
EPRI Project Manager: M. Blatt

Proceedings: 1994 Innovative Electricity Pricing
TR-103629 Proceedings; $200
EPRI Project Managers: P. Sioshansi, R. Siddiqi, L. Carmichael

ELECTRICAL SYSTEMS

Evaluation of Flexible AC Transmission System (FACTS) Technology to Improve First-Swing Stability: TVA's Cumberland Plant
TR-103164 Final Report (RP3022-2, -12, -91); $5000
Contractors: Ontario Hydro; General Electric Co.
EPRI Project Manager: R. Adapa

Assessment of FACTS Benefits Using Innovative Techniques
TR-103166 Final Report (RP4000-31); $5000
Contractor: CSA Energy Consultants
EPRI Project Manager: R. Adapa

Flexible AC Transmission System (FACTS): System Studies to Assess FACTS Device Requirements on the Florida Power & Light Co. System
TR-103167 Final Report (RP3022-19); $5000
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EPRI Project Manager: R. Adapa

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A Critical Review of the Genotoxic Potential of Electric and Magnetic Fields
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Contractors: ICF Kaiser Engineers, Inc.; Electric Research and Management, Inc.
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Laboratory Experiments to Measure the Rate of Hydrolysis of Pentachlorophenol
TR-102279 Final Report (RP2879-15); $200
Contractor: Colorado School of Mines
EPRI Project Manager: J. Goodrich-Mahoney

Continuous Emission Monitoring Guidelines: 1993 Update, Vols. 1 and 2
TR-102386-VI, TR-102386-V2 Final Report (RP1961-9); $1500 for set
Contractor: Kilkelly Environmental Associates
EPRI Project Manager: C. Dene

Retrofit NO_x Control Guidelines for Gas- and Oil-Fired Boilers
TR-102413 Final Report (RP2869-11); $1500
Contributors: Ben Carmine, Houston Lighting & Power Co.; Electric Power Technologies, Inc.; Carnot
EPRI Project Manager: G. Offen

The Effects of Electric and Magnetic Fields on Transcription in Cultured Human Cells
TR-102860 Interim Report (RP2965-5, -6); $200
Contractors: Columbia University Health Sciences; Hunter College, CUNY
EPRI Project Manager: C. Rafferty

FGD Mist Eliminator System Design and Specification Guide
TR-102864 Final Report (RP2250-3); $5000
Contractor: Radian Corp.
EPRI Project Manager: R. Rhudy

A Survey of Spray Dryer FGD Vendors and Spray Dryer FGD Installations Treating Flue Gas From Coal-Fired Boilers
TR-102865 Final Report (RP2880-2); $2000
Contractor: Radian Corp.
EPRI Project Manager: R. Rhudy

Pulse-Jet Fabric Filters for Utility Applications, Vols. 1 and 2
TR-102978-V1, TR-102978-V2 Final Report (RP3083-12); $1000 each volume
Contractors: Victor H. Belba; ETS, Inc.; Grubb Filtration Testing Services, Inc.
EPRI Project Manager: R. Chang

Compliance Monitoring Detection and Quantitation Levels for Utility Aqueous Discharges: EPRI Analytical Methods Qualification (AMQ) Studies I, II, and III
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Contractor: TRW Inc.
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EPRI Project Manager: K. Zammit

250-MW Demonstration of the Babcock & Wilcox Low-NO_x DRB-XCL Burners
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Whole Tree Energy Design, Vols. 1–3
TR-101564 Final Report (RP2612-15, RP3295-4, RP3407-3); Vol. 1, $200; Vol. 2, $200; Vol. 3 (forthcoming), license required
Contractors: Research Triangle Institute; Energy Performance Systems, Inc.; University of Wisconsin, Madison; Appel Consultants, Inc.
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TR-102094 Final Report (RP3404-1); $200
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EPRI Project Manager: E. Davis

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TR-102133 Proceedings (RP2531-2); $200
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EPRI Project Manager: R. Frischmuth

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Contractor: Ahlstrom Pyropower Corp.
EPRI Project Manager: R. Brown

Continuous Emission Monitoring System Procurement Specification Guidelines
TR-102430 Final Report (RP2936-1); $2500
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Demonstration of a Carbonate Fuel Cell on a Coal-Derived Gas
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Durability Testing of Ceramic Particulate Filters Under PFBC Conditions
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Gasification of Pittsburgh No. 8 Coal in Rheinbraun's Pressurized High-Temperature Winkler Pilot Plant
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EPRI Project Manager: E. Hughes

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Contractor: Foster Wheeler Development Corp.
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Central Appalachia: Production Potential of Low-Sulfur Coal, Vol. 2 (14-County Summary and Producer Survey)
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Contractors: Hill & Associates, Inc.; Pennsylvania State University
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User's Guide for the UNIRAM Availability Assessment Methodology: Version 4.0
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EPRI Project Manager: J. Platt

A Thousand Pieces: How Non-Utility Fossil Fuel Generation Adds Up (Series on Gas Demands for Power Generation)
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NUCLEAR POWER

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Boric Acid Corrosion Evaluation (BACE) Program Phase 1, Task 1 Report: Industry Experience Reference and Available Test Data Summary
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TR-102293-V5 Final Report; $200,000
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Generic Outage Risk Management Guidelines for PWRs: ORAM Technology
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EPRI Project Manager: P. Kalra

Residual Stress Measurements on Alloy 600 Pressurizer Nozzle and Heater Sleeve Weld Mockups
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EPRI Project Manager: R. Mahini

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Assessment of Existing Plant Instrumentation for Severe Accident Management
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THIRMAL-1 Computer Code for Analysis of Interactions Between a Stream of Molten Corium and a Water Pool, Vols. 1 and 2
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Contractor: Argonne National Laboratory
EPRI Project Manager: M. Merilo

Instrument Calibration and Monitoring Program, Vol. 1: Basis for the Method
TR-103436-V1 Final Report (RP2906-4); $200
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Instrument Calibration and Monitoring Program, Vol. 2: Failure Modes and Effects Analysis
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Process Data Network Architecture Plan for the Browns Ferry Nuclear Plants
TR-103445 Final Report (RP3332-4); $5000
Contractors: Capri Technology, Inc.; General Electric Co.; Tennessee Valley Authority
EPRI Project Manager: R. Torok

The June 28, 1992, Landers and Big Bear Earthquakes: Effects on Power and Industrial Facilities
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CONTRACTMIX: EPRI Fuel Contract Mix Model
Version 2.5 (PC-DOS)
Developer: Decision Focus Inc.
EPRI Project Manager: Richard Goldberg

DYNASTORE: Quantifying Dynamic Energy Storage Benefits
Version 4.0 (PC-DOS)
Developer: Electric Power Consulting, Inc.
EPRI Project Manager: Stephen Chapel

DYNRED: Dynamic Reduction Program
Version 2.1 (DEC-ULTRIX; DEC-VMS; RS6000-AIX; Sun-UNIX)
Developer: Ontario Hydro
EPRI Project Manager: Peter Hirsch

ESPM : Electrostatic Precipitator Performance Model
Version 1.0 (PC-DOS)
Developer: Research Triangle Institute
EPRI Project Manager: Ralph Altman

ETMSP: Extended Transient–Midterm Stability Package
Version 3.1 (DEC-ULTRIX; DEC-VMS; RS6000-AIX; Sun-UNIX)
Developer: Ontario Hydro
EPRI Project Manager: Peter Hirsch

GasPlan: A Gas Procurement and Operations Planning Tool
Version 1.0 (PC-DOS)
Developer: Applied Decision Analysis, Inc.
EPRI Project Manager: Charles Clark

GSHPM: Ground-Source Heat Pump Model
Version 1.0 (PC-DOS)
Developer: Quantum Consulting
EPRI Project Manager: Paul Meagher

IPFLOW: Interactive Power Flow
Version 2.1 (DEC-ULTRIX; DEC-VMS; PC-DOS; RS6000-AIX; Sun-UNIX)
Developer: Ontario Hydro
EPRI Project Manager: Peter Hirsch

LTSP: Long-Term Stability Program
Version 1.0 (DEC-ULTRIX; DEC-VMS; RS6000-AIX; Sun-UNIX)
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EPRI Project Manager: Peter Hirsch

POWERCOACH : Decision Analysis for Bulk Power Marketing Transactions
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Developer: Strategic Decisions Group
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Version 1.3 (PC-DOS)
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EPRI Project Manager: Robert Goldstein

RateManager
Version 1.0 (PC-DOS)
Developer: Electric Power Software
EPRI Project Manager: Perry Sioshansi

SARA : The Safety Review Advisor
Version 1.2 (PC-DOS)
Developer: Sargent & Lundy
EPRI Project Manager: John Gisclon

SCC/IGA-600 : Stress Corrosion Cracking and Intergranular Attack of Alloy 600 in Steam Generators
Version 1.0 (PC-DOS)
Developers: National Institute of Standards and Technology; National Association of Corrosion Engineers
EPRI Project Manager: Barry Syrett

SITES : Contaminated-Site Risk Management System
Version 3.0 (PC-DOS)
Developer: Decision Focus Inc.
EPRI Project Manager: Robert Goldstein

SSSP: Small Signal Stability Program
Version 3.1 (DEC-ULTRIX; DEC-VMS; RS6000-AIX; Sun-UNIX)
Developer: Ontario Hydro
EPRI Project Manager: Peter Hirsch

VSTAB: Voltage Stability
Version 2.2 (PC-DOS)
Developer: Ontario Hydro
EPRI Project Manager: Dominic Maratukulam

EPRI Events

JUNE

2–3
Integrated DSM/T&D
Lake George, New York
Contact: Phyllis Firebaugh, (214) 556-9545

6–8
Healthcare Initiative Project Meeting and Conference
San Francisco, California
Contact: Myron Jones, (415) 855-2993

6–8
ISA POWID/EPRI Controls and Instrumentation Conference
Orlando, Florida
Contact: Lori Adams, (415) 855-8763

13–15
Licensing Digital Upgrades for Nuclear Power Plants
Annapolis, Maryland
Contact: Pam Turner, (415) 855-2010

27–29
Technology Delivery Workshop
San Francisco, California
Contact: Susan Bisetti, (415) 855-7919

29–July 1
Service Water Systems Reliability Improvement
St. Louis, Missouri
Contact: Susan Otto, (704) 547-6072

JULY

10–14
Mercury as a Global Pollutant
Whistler, British Columbia
Contact: Pam Turner, (415) 855-2010

11–13
PWR Secondary Water Chemistry Training and Optimization Workshop
San Antonio, Texas
Contact: Barbara James or Gary Brobst, (707) 823-5237

12–13
Needs-Driven Program Design
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

25–27
International Conference on Low-Level Waste
Norfolk, Virginia
Contact: Linda Nelson, (415) 855-2127

27–29
ASME/EPRI Radwaste Workshop
Norfolk, Virginia
Contact: Linda Nelson, (415) 855-2127

AUGUST

2–4
Direct DSM Marketing
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

3–4
Nuclear Plant Performance Improvement Seminar
Charleston, South Carolina
Contact: Susan Otto, (704) 547-6072

9–12
Nondestructive Evaluation of Fossil Plants
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

17–19
Effects of Coal Quality on Power Plants
Charleston, South Carolina
Contact: Susan Bisetti, (415) 855-7919

24–26
4th International Symposium on Magnetic Bearings
Zurich, Switzerland
Contact: Tom McCloskey, (415) 855-2655

30–September 1
Cooling Towers and Advanced Cooling Systems
St. Petersburg, Florida
Contact: Lori Adams, (415) 855-8763

SEPTEMBER

7–9
4th Conference on Cycle Chemistry in Fossil Plants
Atlanta, Georgia
Contact: Linda Nelson, (415) 855-2127

7–9
4th International Conference on Rotor Dynamics
Chicago, Illinois
Contact: Tom McCloskey, (415) 855-2655

8–9
Decision Analysis for Environmental Risk Management
Palo Alto, California
Contact: Katrina Rolfes, (415) 926-9227

12–16
International Symposium: Resolution of Material Problems for PWRs
Fontevraud, France
Contact: Peter Paine, (415) 855-2076

14–15
11th Annual Operational Reactor Safety Engineering and Review Groups Workshop
Dallas, Texas
Contact: Susan Bisetti, (415) 855-7919

14–16
Fossil Plant Cycling
New Orleans, Louisiana
Contact: Lori Adams, (415) 855-8763

21–23
Healthcare Initiative Project Meeting and Conference
Location to be announced
Contact: Myron Jones, (415) 855-2993

25–30
Aerosols and Atmospheric Optics
Snowbird, Utah
Contact: Peter Mueller, (415) 855-2586

28–30
Magnetic Field Management Seminar
Lenox, Massachusetts
Contact: Rich Lordan, (214) 556-6520

OCTOBER

3–6
Pollution Prevention Seminar
Scottsdale, Arizona
Contact: Lori Adams, (415) 855-8763

4–6
Flexible AC Transmission Systems Conference
Baltimore, Maryland
Contact: Kathleen Lyons, (415) 855-2656

19–21
13th Conference on Coal Gasification Power Plants
San Francisco, California
Contact: Linda Nelson, (415) 855-2127

19–21
Fuel Supply Seminar
Chicago, Illinois
Contact: Susan Bisetti, (415) 855-7919

24–27
Power Quality Applications, 1994
Amsterdam, Netherlands
Contact: Carrie Koeturius, (510) 525-1205

28
Municipal Wastewater and Energy Conference
New York, New York
Contact: Keith Carns, (314) 935-8598

NOVEMBER

1–3
Substation Equipment Diagnostics Conference
New Orleans, Louisiana
Contact: Kathleen Lyons, (415) 855-2656

15–18
Market Research Symposium
Los Angeles, California
Contact: Susan Bisetti, (415) 855-7919

28–December 1
Fuel Cell Seminar
San Diego, California
Contact: Ed Gillis, (415) 855-2542

DECEMBER

5–7
12th International Electric Vehicle Symposium
Anaheim, California
Contact: Pam Turner, (415) 855-2010

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