EPRI JOURNAL®

WINTER 2000

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COVER: Atmospheric mercury that ends up in lakes and other aquatic environments is passed up the food chain from plankton to small fish to larger fish, where it can accumulate. (Art by Rob Barber)

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EDITORIAL

COVER STORY

The EPA has identified critical uncertainties that must be resolved before the United States can adopt mercury management practices with predictable outcomes. EPRI is leading the effort to resolve these issues through multidisciplinary studies of mercury cycling in the environment.

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Although commercially available hybrid electric vehicles offer better fuel economy and lower emissions than conventional cars, EPRI has launched an initiative to develop grid-connected hybrids that will come much closer to the ideal of a true EV.

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Editorial

Closing in on "Living Silver"

It was known to the ancient Greeks as *hydrargyros,* "liquid silver," and to Imperial Rome as *argentum vivum,* "living silver." These days, mercury is perhaps best remembered as the silvery plaything of high school lab wonks—a substance extracted from mercuric oxide stored high on shelves in dark brown glass jars. But this fascinating element, which is found naturally and ubiquitously in the earth's crust, is a poison to the human nervous system and may alter other functions in both developing fetuses and mature adults. It most commonly finds its way into the human organism as monomethylmercury, formed by sulfur-reducing bacteria in some freshwater systems, taken up by plankton and then fish, and finally ingested by predator mammals, eagles and other raptors, or human anglers.

The scientific questions surrounding mercury and its effects on human health have been with us for centuries, but they were focused sharply with the discovery in the 1950s of severe poisoning among fishing villagers in Minamata, Japan, and later in the larger city of Niigata. Thousands died from the extreme amounts of mercury received in those cases. However, dose estimates for those high exposures were not made until years after the exposures occurred, leaving many uncertainties regarding the manifestation of mercury-induced effects among adults and particularly among children exposed to mercury while in their mothers' wombs. The exposed children who survived have been followed since the 1970s by physicians at the Institute for Minamata Disease. The physicians are looking for signs of adult-onset neurological or other effects as indications of the disease.

Mercury levels potentially faced by U.S. fish consumers are hundreds to thousands of times lower than those in the Japanese cases. However, there is still substantial uncertainty about what levels can be considered safe, as well as about the sources of atmospheric mercury and how the substance cycles through the environment. Researchers are now zeroing in on some quantitative answers to these questions. For example, measurements from aircraft by EPRI researchers this past summer demonstrated that forest fires and wildfires may be a significant pathway for mercury contained in surface deposits to enter the atmosphere. At the same time, an international field team in Ontario, jointly supported by EPRI and by Canadian and U.S. agencies, is following mercury tracers through a lake watershed to determine how long it might take the mercury levels in fish in such lakes to drop if mercury emissions from power plants or other sources were reduced significantly.

In the most important studies under way, EPRI and many other institutions are working to determine the true threshold levels at which mercury affects childhood development. Several long-term studies of mothers and children around the world who have been exposed to mercury via fish consumption are continuing or being reevaluated. In one such study, researchers are examining the validity of developmental tests used in international studies by assessing the test performance of U.S. children already known to be developmentally challenged. This work will make it possible to calibrate the sensitivity of the test instruments to yield consistent findings worldwide.

These and many other scientific studies are leading to a deeper understanding of where mercury in the environment originates, how it is released and then cycles among aquatic, terrestrial, and atmospheric settings, and how it reaches the fish and marine life we consume. The importance of this work will ultimately be judged by its contributions to clarifying key practical issues: how much of a threat to human health mercury poses, what populations are exposed at the levels of concern, and how mercury emissions management can be tailored to allow us to measure and assess any resulting benefits.

Leonard Levin, Program Manager
Air Toxics Health and Risk Assessment

Contributors

Mercury's Pathways to Fish (page 8) was written by Norva Shick, science writer, with technical assistance from Leonard Levin, Paul Chu, and Richard Carlton of EPRI's Science and Technology Development Division.

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PAUL CHU manages research on toxic substances, including field studies to characterize air toxics emissions from power plants. Before joining EPRI in 1992, he was a research engineer for five years at Babcock & Wilcox, where he was involved in various development projects related to the removal of sulfur dioxide, nitrogen oxides, and particulates from flue gas. Chu has a BS in chemical engineering from the University of Arkansas and an MS in chemical engineering from the University of Texas.

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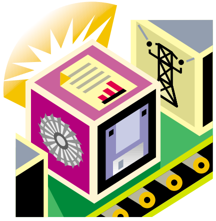

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COURTESY PACIFIC GAS AND ELECTRIC

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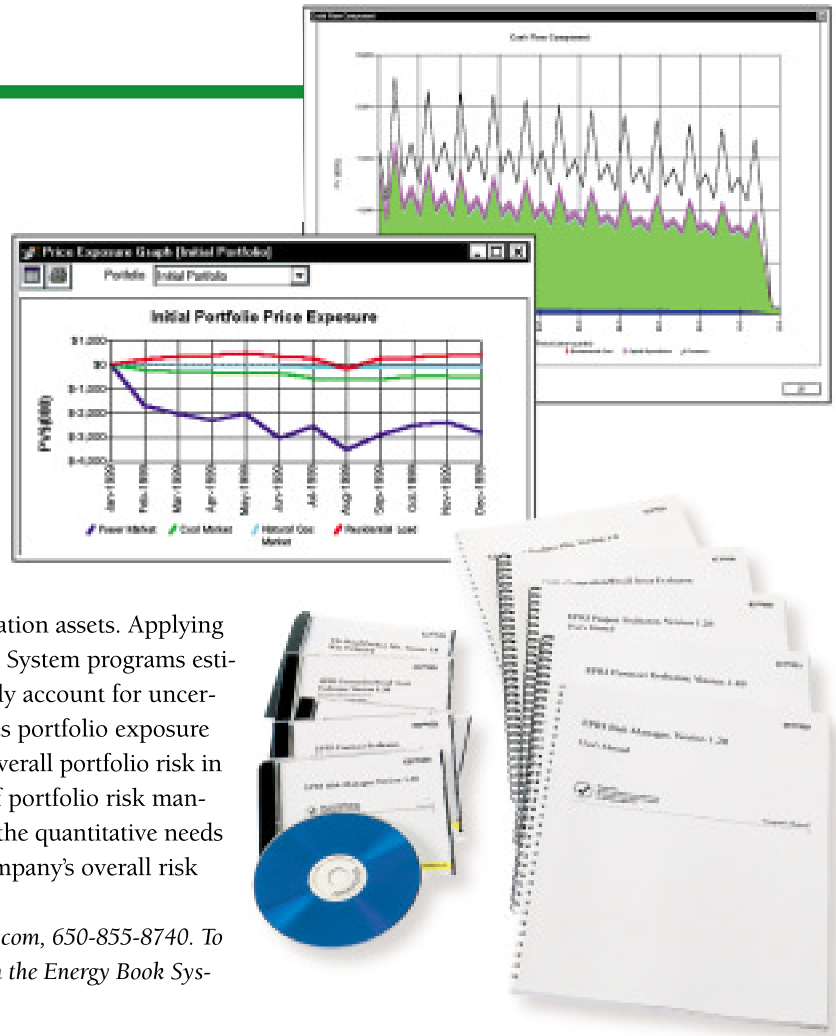
Risk Manager and Related Tools



Part of the EPRI Energy Book System, the Risk Manager software is designed to help users manage businesses in the power and energy markets. It is intended for use with one or more of the system's other software products: Contract Evaluator, a tool for valuing, pricing, and hedging contracts in wholesale energy markets; Retail Product Mix, a tool for designing profitable retail energy service offerings; and Generation Asset Evaluator and Project Evaluator, tools for managing fossil-fired generation assets. Applying methods of derivative asset valuation, the Energy Book System programs estimate the market value of energy resources and explicitly account for uncertainty in the underlying markets. Risk Manager assesses portfolio exposure to commodity markets and customer loads, evaluates overall portfolio risk in terms of cash flow or value, and assists in the design of portfolio risk management programs. The Energy Book System can meet the quantitative needs of individual units within a company as well as the company's overall risk assessment and management needs.

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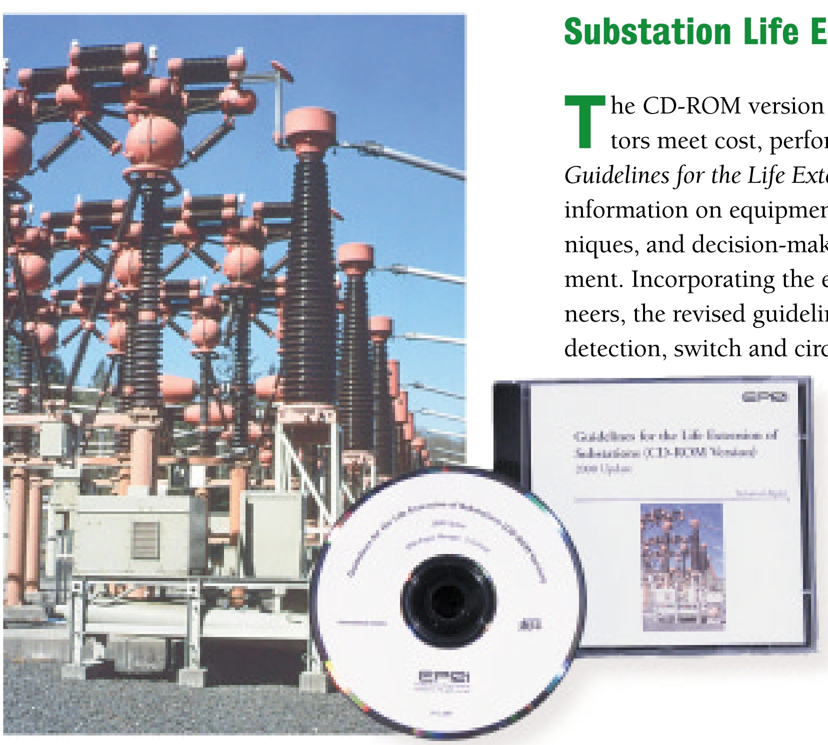

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■ *For more information, contact Steve Eckroad, seckroad@epri.com, 650-855-1066. To order the report on CD-ROM (1000032) or in a loose-leaf binder (1000031), call EPRI Customer Service, 800-313-3774.*

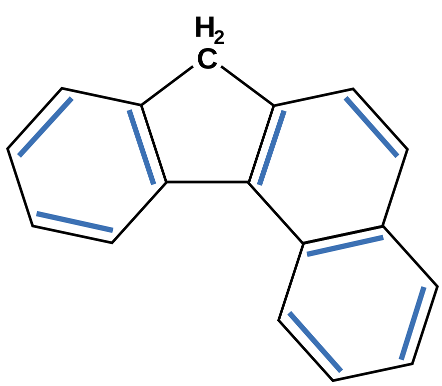
Discovery

Basic science and innovative engineering at the cutting edge

MGP Sites Yield Possible New Cancer Clues

Medical science has known for more than 200 years, from observations of chimney sweeps, that skin contact with coal soot and creosote is linked to a high incidence of skin cancers and other dermatological disorders. In the first quarter of the twentieth century, researchers found that coal tar and residues of other substances that had been heated to high temperatures induced skin tumors in animals. Scientists came to associate the tumor-causing activity with one or more members of the class of chemicals known as polycyclic aromatic hydrocarbons (PAHs). In the 1930s, a known skin tumor agent—benzo[*a*]pyrene (BaP)—was isolated from coal tar. Since then, hundreds of PAH compounds have been synthesized and tested.

The basic method of identifying cancer-causing chemicals has changed little from the time BaP was discovered. Data from mouse skin assays dominate the extensive scientific literature on cancer causation by PAHs. For regulatory purposes, however, the U.S. Environmental Protection Agency prefers the use of animal data from lifetime feeding studies to identify carcinogens and determine their potency (a measure of tumor incidence as a function of the dose of an administered carcinogen).



7H-benzo[*c*]fluorene

BaP plays an important role as a surrogate for estimating the potency of environmental PAHs, which are always found as complex mixtures. One such mixture is the coal tar and residue found at the former sites of some 1500 U.S. manufactured gas plants (MGPs), which produced gas from coal for lighting, heating, and cooking in the nineteenth and early twentieth centuries. EPRI and the utility industry have conducted extensive work over the past 20 years to assess and remediate environmental hazards at these sites and to better understand the toxicology of coal tar.

The EPA currently calculates BaP potency on the basis of data from two animal studies, neither of which was undertaken specifically to establish potency or made use of the lifetime feeding study protocol. One study combined data from groups of mice given different dose levels and assumed a linear increase in tumor incidence, and the other study combined unrelated tumors.

Because of the shortcomings in these studies for regulatory purposes, EPRI entered into a cooperative R&D agreement with the U.S. Food and Drug Administration (FDA) to develop new information about the potency of BaP. Using EPA-preferred methods, a team led by scientists at the National Center for Toxicological Research (NCTR) conducted a two-year feeding study. The study compared the tumorigenicity of two coal tar mixtures known to contain BaP—one a composite of tar from seven MGP sites—with that of BaP alone. This comparison made it possible to determine whether the tumor-causing potential of coal tar, a mixture in which up to 10,000 compounds may be present, could be predicted from the concentration of a single tumorigenic component.

The NCTR researchers, led by David Gaylor, calculated the BaP potency factor for humans to be 1.2 per milligram per kilogram of body weight, which is approximately one-sixth of the potency factor (7.3) listed in the EPA's Integrated Risk Information System, or IRIS, database. Values presented in this database are an integral element in human health risk assessments at both federal and state levels.

Larry Goldstein, who manages EPRI's contaminated sites health and risk target, points out that the potency factor for BaP influences the potency factors for other cancer-causing PAHs, since those factors were derived from studies in which the compounds' cancer-causing effects were compared directly with BaP's. "The potency factor for BaP derived from the FDA-EPRI study would reduce the potency factor for each of the seven priority cancer-causing PAH compounds by a factor of 6," says Goldstein. Because the cancer hazard risk of so many MGP sites is influenced by PAHs, it is particularly important that the risk be evaluated appropriately. Goldstein notes that on the basis of data from the FDA-EPRI study, a group of experts concluded that the "carcinogenicity of coal tars cannot be fully accounted for by BaP."

If not BaP, then what?

If BaP does not fully account for the carcinogenicity of coal tars, how can the risk that they pose to human health be estimated? A recent discovery by an EPRI-sponsored team of scientists led by Eric Weyand at Rutgers University suggests an alternative to BaP for evaluating the health risk of PAH compounds.

It is generally accepted that tumor formation by PAHs is due in part to the formation of DNA adducts, a specific type of cellular damage. The Rutgers researchers reported earlier this year that a PAH not on the EPA priority list is likely to be responsible for significant DNA adduct formation in the lung, the most sensitive organ for tumor induction in mice fed with coal tar. The compound is 7H-benzo[*c*]fluorene, which had not previously been implicated in cancer outcomes in mice or any other species. Weyand and his colleagues are currently attempting to determine whether 7H-benzo[*c*]fluorene—alone, in the presence of other PAH components of coal tar, or in the presence of coal tar itself—induces lung tumors in mice. "The results will have obvious implications for risk assessors now evaluating MGP sites on the basis of BaP," says Goldstein.

Recent work by Weyand and his Rutgers colleagues addressed the question of whether the lungs of mice fed different coal tars and coal tar–contaminated soils have damage caused by BaP and 7H-benzo[*c*]fluorene. Although the presence of 7H-benzo[*c*]fluorene in coal tar or coal tar–contaminated soils cannot be established by using conventional gas chromatography–mass spectrometry, its presence can be inferred from the formation of a DNA adduct specifically associated with it.

On this basis, 7H-benzo[*c*]fluorene was found in all the samples impacted by coal tar and in coal tar itself. The compound's presence in soil samples from actual sites indicates that natural processes that act to remove or degrade 7H-benzo[*c*]fluorene have not completely eliminated it. The presence of the 7H-benzo[*c*]fluorene-derived DNA adducts suggests that the compound is extracted from impacted soil following ingestion. In contrast, BaP in impacted soil and even in coal tar may not result in detectable adducts following ingestion. "Taken together, these data may indicate that 7H-benzo[*c*]fluorene may be more bioavailable and more important in health outcomes than BaP, whose role in coal tar–induced tumor formation is now in question," says Goldstein.

Implications for utilities and society

Results from EPRI's innovative, high-risk research on the role of BaP and 7H-benzo[*c*]fluorene in the potential cancer hazard at contaminated former MGP sites have major implications for utilities and for society in general. The results come at a time when increasing resources are being directed both at eliminating environmental sources of cancer risk and at achieving scientific breakthroughs in understanding the causes, formation, prevention, and treatment of cancer.

Former MGP site

At former MGP sites, soil accounts for the majority of impacted material. The concentration of PAHs in soil is likely to be much lower than the concentration of PAHs in source materials. But given the methods now used by federal and state regulators—methods based on BaP content—the estimated risk to human health for much of the impacted soil at these former MGP sites may exceed acceptable levels for residential and, occasionally, commercial land use.

In fact, the calculated allowable level of BaP is close to or sometimes lower than the background level in the area surrounding a site. Continuing to use BaP as the basis for site management decisions increases the likelihood that cleanups to or below ambient levels may be required even though BaP may contribute little to coal tar–induced cancers. "Continuing to rely on BaP as a basis for site management is, at best, questionable," says Goldstein.

"Although we still lack evidence that 7H-benzo[*c*]fluorene causes tumors, its capacity to effectively form DNA adducts is consistent with such a role," Goldstein points out. "Results from studies to address this directly are forthcoming, but the studies were not designed to derive a potency factor. Thus 7H-benzo[*c*]fluorene may provide an alternative to BaP for making site management decisions, but its actual role in risk assessment remains to be established."

Goldstein notes that the scientific community is only beginning to comprehend the potential role of 7H-benzo[*c*]fluorene in cancer incidence. If that PAH is found to cause tumors, it will be vital to establish how individuals may be exposed to it and what the relative contribution of such exposures is to overall PAH exposure. Although 7H-benzo[*c*]fluorene is in coal tar, it has also been detected in cigarette smoke and in cooked food, two sources that are likely to contribute significantly to overall body burdens. "A comprehensive program to fully understand the role of this new candidate carcinogen is warranted," concludes Goldstein.

Further reading

Identifying Potential Cancer Hazards at Contaminated Sites. EPRI. September 2000. Technical Brief 1000791.

Koganti, A., et al. "7H-benzo[*c*]fluorene: A Major DNA Adduct–Forming Component of Coal Tar." *Carcinogenesis,* Vol. 21, No. 8 (2000), pp. 1601–1609.

Culp, S. J., et al. "A Comparison of the Tumors Induced by Coal Tar and Benzo[*a*]pyrene in a 2-Year Bioassay." *Carcinogenesis,* Vol. 19, No. 1 (1998), pp. 117–124.

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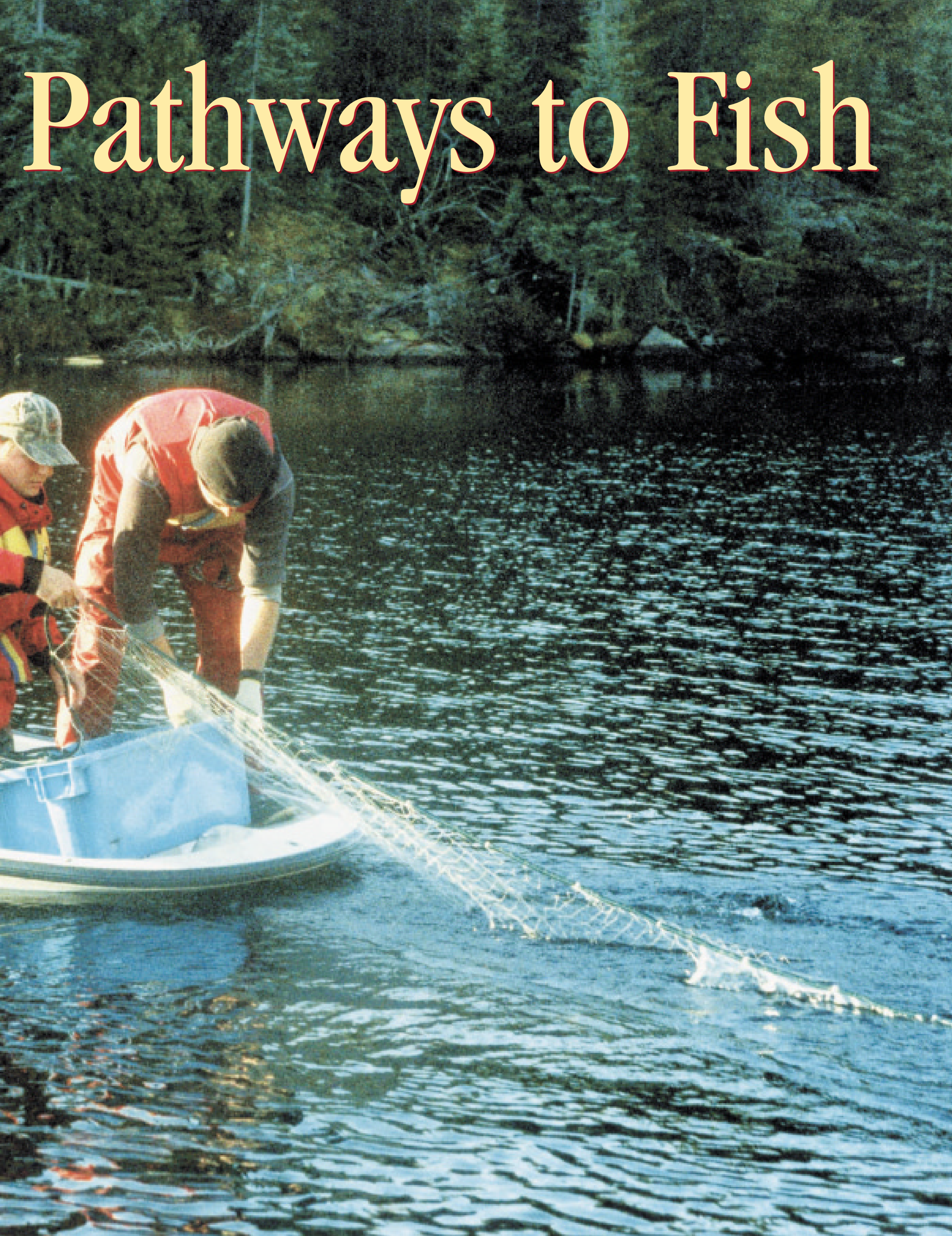
Mercury's

by Norva Shick

Pathways to Fish



The U.S. Environmental Protection Agency has stated that by December 15, 2000, it will decide whether to regulate hazardous air pollutant (HAP) emissions from electric utility steam-generating power plants. In essence, that date is decision day for mercury—one of the 189 substances listed as HAPs in the 1990 Clean Air Act Amendments. Congress determined that these so-called air toxics pose potential risks to public health and charged the EPA with further investigation. In 1997 the agency reported to Congress "a plausible link between anthropogenic releases of mercury from industrial and combustion sources in the U.S. and methylmercury in fish," and in 1998 it said, "Based on available information and current analyses, the EPA believes that mercury from coal-fired utilities is the HAP of greatest potential concern and merits additional research and monitoring." Regulations cutting mercury emissions from medical waste incinerators and from municipal and hazardous waste combustors are already in place.

The EPA is concerned about emissions from coal-fired generating plants because burning coal releases trace amounts of mercury that persist in the environment. Although mercury may transform from one chemical species to another, it does not degrade or disappear. In lakes and wetlands, it may transform to methylmercury—an organic form that is considered more toxic than other forms and that accumulates in fish muscle tissue and enters the bodies of people who eat the fish. Methylmercury is a neurotoxin, and those most at risk for brain and nervous system damage are fetuses whose mothers eat large amounts of high-methylmercury fish during pregnancy. Hence, mercury is on the EPA's list of persistent bioaccumulative toxic chemicals, and industries must report environmental releases of mercury above 10 pounds (4.5 kg) per year to the agency for its Toxics Release Inventory (TRI). Electric generating companies began this documentation for the TRI reporting year 1999.

The EPA's goal, if it decides to regulate utility mercury emissions, will be to lower the potential for human ingestion of mercury by reducing methylmercury concentrations in fish. But no one knows how these concentrations will be affected by emissions reductions or whether it is possible to achieve any significant public health benefit at reasonable cost to electric power generators who burn coal. If the relationship between mercury released by power plants and methylmercury in fish were a simple one, then decreasing plant emissions might solve the problem of too much methylmercury in fish. Unfortunately, the relationship appears to be highly complex. As noted by the EPA in its 1998 report to Congress, the quantitative nature of the relationship between power plant emissions and fish methylmercury remains a key uncertainty that must be resolved before the United States can adopt mercury management practices with predictable outcomes.

At stake are billions of dollars in mercury control costs annually, with estimates ranging from \$2 billion (EPA, 1999) to \$6 billion (Edison Electric Institute, 1997). Some industry observers predict that mercury emissions will decline without specific regulatory intervention as old coal-fired plants are retired, natural gas grows as a fuel of choice, and existing facilities install additional equipment to meet the current provisions of the Clean Air Act Amendments for controlling sulfur dioxide and nitrogen oxides. In the meantime, "what makes the most sense in this whole debate," says David Michaud, principal environmental scientist at Wisconsin Electric Power Company, "is to ask, how do we get from today to the future using coal and our other resources to the best practical advantage? We're in a global economy. Is it cost-effective to spend billions of dollars in the energy supply and services area for what may be small changes in methylmercury levels in fish?"

EPRI has provided input to the mercury debate from the beginning. In the 1980s, well before the passage of the Clean Air Act Amendments, EPRI realized the urgent need to study mercury in the environment and established a mercury research program. Before the EPA began preparing its reports to Congress on mercury and other HAPs from electric utility plants, EPRI was issuing comprehensive reports on work that applied consistent analytical procedures to collect accurate data sets (which were subsequently shared with the EPA). In several case studies, EPRI found that the amount of methylmercury in lake fish that might come from nearby power plants was well below the amount the EPA says people may take into their bodies without harming their health.

EPRI's reports supported the EPA's efforts to understand utility mercury releases in a context relevant to policymaking. Indeed, a hallmark of EPRI's program has been to share its results and cooperate with many other stakeholders. It participates in joint mercury studies with a number of agencies—including the EPA, the U.S. Department of Energy, and the U.S. Food and Drug Administration—as well as with Canada and other countries.

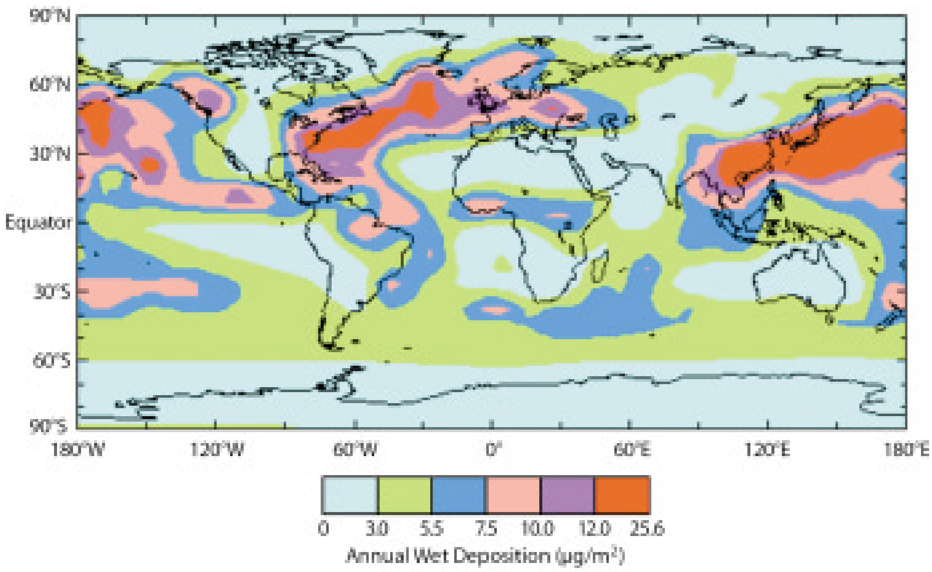
In its 1998 report to Congress, the EPA identified critical uncertainties that make it difficult to quantify health risks due to utility mercury emissions. The agency will be making its regulatory determination on or before December 15 with many of these uncertainties still unresolved. In its 1999 draft mercury research strategy, the EPA explicitly notes that EPRI work to be performed over the next several years is part of its plan to resolve these uncertainties.

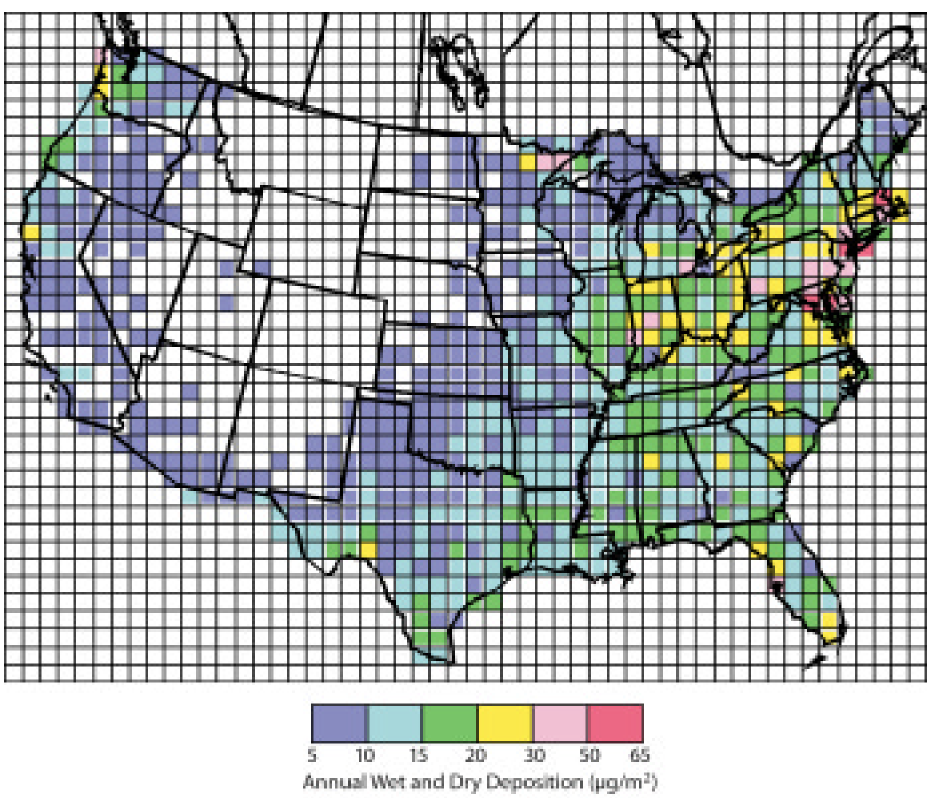
If the EPA decides to regulate utility mercury emissions, there will be several more years for power generators and other stakeholders to perform studies of mercury management, including detailed cost analyses. According to anticipated schedules, a proposed rulemaking would be due December 15, 2003, with a final rulemaking following a year later. Implementation of the regulations would begin in 2007.

Once the decision-making deadline has passed, two critical issues affecting the details of mercury management will remain, according to Leonard Levin, head of EPRI's air toxics health and risk assessment program. One critical issue is understanding mercury cycling through air and water so that it is possible to predict how quickly changes in mercury source emissions will appear in receiving waters and fish. This is important for discussions about strategies for managing mercury, says Levin, "since the results of any management strategy should be clear and demonstrable health benefits."

The second critical issue is understanding source attribution—that is, determining how well mercury in particular waterways and resident fish can be tied to particular sources and source categories. Here it is essential to study the background mercury that is already present in natural systems and continues to be mobilized in the environment. Background mercury—which is either a naturally occurring component of soil, water, and plants or a legacy of human activities like mining—apparently plays a large role in determining mercury concentrations and deposition rates in the United States. "It's critical to have a clear view of all the sources, including these background sources and other poorly quantified human sources of mercury. Trying to do source attribution without a thorough understanding of all the sources is impossible," Levin declares. Accurate source attribution will make effective mercury reduction feasible by identifying the right sources to control.

Work on the first critical issue, understanding mercury cycling in the environment, was a cornerstone of EPRI's original mercury research program and continues at a sophisticated level today. Over the past 20 years, EPRI has developed models to predict where mercury goes in the environment. These include three models that together describe mercury's movement through the air to its final destination on the ground: a global-scale chemical transport model (CTM), the regional-scale Trace Element Analysis Model (TEAM), and the local-scale Total Risk of Utility Emissions (TRUE) model. Another EPRI model, the Mercury Cycling Model (MCM), describes mercury's movement through water, including its methylation and the transfer of methylmercury through the food chain. In order to obtain accurate predictions from these models, EPRI has provided the most current and comprehensive input data. It also has made extensive measurements of mercury in the environment and of methylmercury in fish for comparison with model predictions.

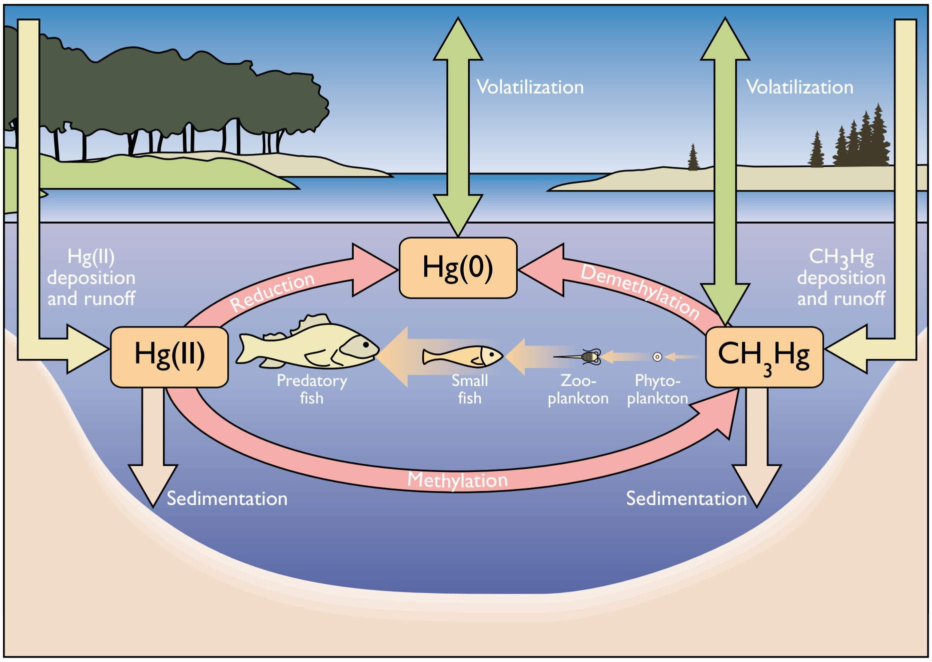




In EPRI modeling of mercury deposition for 1998, global-scale predictions (top) showed that the eastern half of the United States received a substantial amount of its mercury in rain and snow. This mercury came from all continents, with Asia contributing about half of the mercury released by human activities worldwide. Regional-scale predictions (bottom) showed the distribution of total deposition in detail. The regional-scale predictions were based on releases from North American sources—with boundary conditions set by global modeling—and agreed reasonably well with measurements taken at Mercury Deposition Network stations located across the country.

Mercury cycling in air

In its most comprehensive assessment of mercury cycling in air, EPRI modeled mercury deposition both on a global scale and on a regional scale. According to global-scale model predictions for 1998, eastern Asia and the northwestern Pacific Ocean received the most mercury returning to the earth in rain and snow (wet deposition). This mercury came from all continents, and the deposition pattern reflected the fact that emissions from Asia accounted for about half of all releases due to global



ROB FITZSIMMONS

Mercury entering lakes—by direct surface deposition or terrestrial runoff—typically includes elemental mercury, Hg(0); oxidized mercury, Hg(II); and extremely small amounts of methylmercury, CH_3Hg. Most lake methylmercury, however, is produced when anaerobic bacteria in the water and sediments methylate oxidized mercury through a metabolic process. Methylmercury is bioaccumulated by plankton and other organisms and then passed up the food chain to fish, where it also concentrates. While this diagram represents major processes in the aquatic mercury cycle, the overall cycle is complex and cannot be generalized for all lakes.

human activities. The eastern half of the United States also received a substantial amount of global mercury in rain and snow. It is apparent that sources outside the United States contribute to mercury deposition within the country. As for mercury returning to the earth by turbulence and gravity (dry deposition), the simulation found that mercury generally fell near areas where human activities released it in large amounts—for example, Asia, Europe, South Africa, and the eastern United States. The model predictions agreed reasonably well with actual measurements made by 11 laboratories at Mace Head on the western coast of Ireland during September 1998.

In an interesting test of the global CTM's sensitivity, EPRI reduced the modeled Asian industrial emissions of mercury by 50% and ran the simulation again. This time, areas in Wisconsin and Florida received about 10% less mercury, solely as a result of the Asian reductions; areas of Texas experienced a decrease in deposition of more than 20%. Deposition to well-studied lakes in these areas is important because it will be a key input to EPRI's MCM in future research to predict methylmercury levels in fish.

Since U.S. activities accounted for about a fifth of global emissions in the original simulation, it is clear that reducing mercury from U.S. industry solves only part of the mercury management problem. Indeed, some scientists think that considering natural releases must also be a part of any effective mercury reduction strategy.

To model mercury deposition on a finer scale within the continental United States, EPRI used TEAM inside boundaries defined by the global CTM. TEAM calculates mercury deposition inside the cells of a 100-kilometer grid, which is about eight times as fine as the grid used by the global model. TEAM's finer grid allows the influence of local and regional sources to be seen. In the EPRI simulation of 1998 deposition, the northeastern United States received the most mercury. Regions with heavy precipitation, such as the eastern states, northeastern Minnesota, and western Washington and Oregon, experienced considerable wet deposition—especially areas with local mercury sources, such as iron-roasting sites in Minnesota. Again, dry deposition followed the patterns of industrial activity.

TEAM predictions of atmospheric concentrations of mercury near the earth's surface agreed reasonably well with measurements taken at Mercury Deposition Network (MDN) stations, which are operated under the National Atmospheric Deposition Program. It is noteworthy that TEAM predicted a smaller range of surface concentrations in Florida than those measured at MDN stations there. Florida presents a unique problem for TEAM and other simulation tools because sources (such as waste incinerators and cement kilns) and receptors (such as lakes) are packed so closely together on the peninsula that the model's 100-kilometer resolution cannot reproduce local impacts. For this reason, researchers may need to turn to models with finer resolution, such as EPRI's TRUE model.

It is tempting to draw conclusions about areas of the United States experiencing the most mercury deposition and about sources contributing to that deposition. However, such conclusions would be premature. As Levin notes, modelers don't have all the input they need to attribute mercury deposition to particular sources or source categories. To acquire part of that information, EPRI is improving its inventory of natural releases by measuring mercury species lofted into the air when biomass burns in forest fires. Canadian and U.S. researchers are using an aircraft-borne analyzer that makes these measurements automatically.

Furthermore, the various-scale CTMs need refinement. The EPRI simulation assumed a uniform distribution of ozone across the United States, but scientists know that ozone is actually higher on the East Coast. Since ozone reacts with elemental mercury in the air to form oxidized mercury, which deposits to the ground, the East Coast may have more mercury deposition than this study showed.

Of course, the output of CTMs is only as good as their input. To improve modeling accuracy, EPRI made a thorough evaluation of 1999 mercury emissions from U.S. coal-fired power plants. Working closely with the EPA to analyze data submitted in response to the agency's mercury Information Collection Request (ICR), EPRI critically examined the results of some 40,000 coal analyses and numerous flue gas measurements from 84 representative plants.

To predict mercury emissions, it is important to know the chloride content of coal as well as its mercury content, since chlorine reacts with elemental mercury during combustion to form oxidized mercury—which, in units having sulfur dioxide scrubbers, is effectively removed by that equipment. It is also important to quantify the various mercury species emitted in flue gas because they take different deposition paths. Oxidized mercury dissolves in airborne moisture and deposits relatively close to its source in rain and snow, while most elemental mercury travels around the globe and remains aloft for about a year before it oxidizes and deposits to the ground over a wider region. Mercury also adsorbs to particles of ash or dust to become particulate mercury, which gravity or turbulence pulls down to the earth.

With the ICR data in hand, EPRI developed—for each of 12 categories of control technology—a set of correlations relating the mercury in power plant feed coal to the mercury leaving plant stacks. Using these correlations as well as information about power plant configurations and the total amount of coal burned in 1999, the researchers then calculated total and speciated mercury emissions for all 1128 coal-fired units in operation that year. Of the 41 metric tons of mercury released, they found that 58% was elemental, 41% was oxidized, and 1% was particulate. In other words, more than half of the mercury released by U.S. coal-fired power plants is the type—elemental mercury—that enters the global cycle and returns to the earth far from its source. "In general, what we're seeing for the 1999 emissions is relatively consistent with EPRI's 1990 estimates," notes Paul Chu, the EPRI manager who directed this phase of the work.

EPRI also updated its North American mercury emissions inventory to include releases from human activities and natural sources in the parts of Canada and Mexico that influence the United States, and it revised similar inventories for other continents when new information was available. All emissions were speciated on the basis of current knowledge, with those from natural sources considered to be elemental mercury. Of the calculated 2300 metric tons of mercury released annually by human activities around the globe, 49% came from Asia, and 6% came from the United States; 2% was attributed to U.S. coal-fired power plants.

Regional relationships

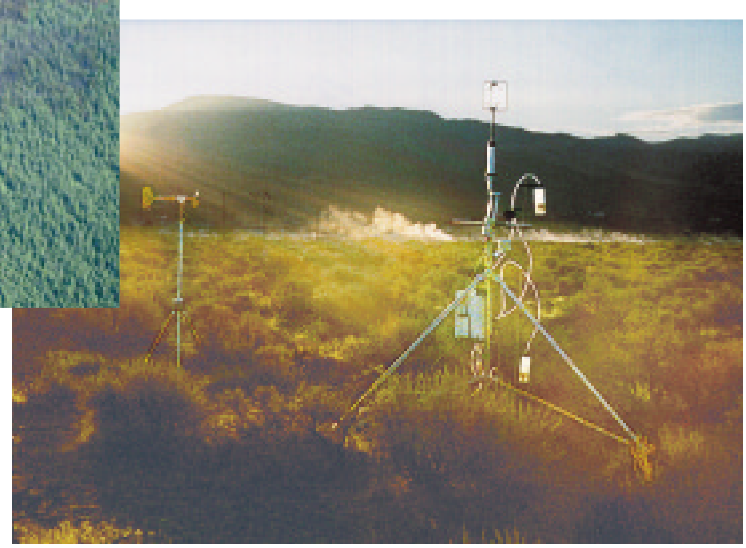
Although specifying the contribution of global mercury to deposition across the United States is essential, it is as important to focus on regional relationships. In 1997, for instance, EPRI coupled TEAM with a regional version of MCM to predict methylmercury levels in fish in eight lakes. On the basis of mercury deposition input from TEAM, MCM predicted methylmercury levels in six fish species. The predictions showed statistically significant agreement with measured levels of methylmercury in the fish.

Regional relationships are the subject of EPA pilot studies on total maximum daily load (TMDL) being conducted at Devil's Lake in Wisconsin and at Water Conservation Area 3A in the Florida Everglades. Both sites are classified by the EPA as impaired wa-

Mercury deposition is measured in the Everglades.

A controlled forest burn in northern Canada releases mercury from biomass.

Field measurements of actual mercury deposition are important for validating and refining models of mercury cycling in the environment. But tracing this deposition back to likely emissions sources is extremely complicated, requiring the consideration of background sources—releases from soil and plants, for example—as well as current industrial emissions.



The release of mercury from soils is monitored in Nevada.

How Much Is Too Much?

A number of national and international health advisory boards have established levels of exposure to methylmercury that they consider to be safe. These safe levels vary significantly among institutions. The EPA has set 0.1 microgram per kilogram of body weight per day as a safe level of exposure. This level, or reference dose, takes body weight into account to protect fetuses and children as well as adults. It is based on conservative assumptions designed to safeguard the health of society's most vulnerable members—fetuses whose mothers eat large amounts of high-methylmercury fish during pregnancy.

When the EPA set its current reference dose, the only scientific information available about methylmercury's effects came from poisoning episodes very unlike U.S. citizens' exposure to the chemical in fish in their diet. Now, results from two studies of island populations who eat substantial amounts of fish are available, and the EPA plans to redefine its reference dose on the basis of this new information. The studies looked at two groups of mothers and children—one group living in the Faroe Islands north of Scotland and the other in the Seychelles, a nation of islands off the coast of eastern Africa. In both studies, researchers monitored mercury levels in the mothers during pregnancy and tested the children for neurological problems and developmental delays after birth.

The mothers in the Faroe Islands study ate fish that were relatively low in methylmercury, and they periodically feasted on freshly caught pilot whales known to contain high levels of polychlorinated biphenyls (PCBs) in their blubber as well as methylmercury in their meat. The Faroese children were tested once at age seven. Those whose mothers had shown high levels of mercury at the time of birth scored lower than less-exposed children on language, attention, and memory tests; they also had higher blood pressure readings.

The mothers in the Seychelles study ate fish that, compared with U.S. fish, were very high in methylmercury, and their children have been tested at intervals beginning at six months of age. In the carefully chosen set of motor, sensory, and cognitive tests, the highly exposed children have shown no effects of methylmercury in comparison with their less-exposed peers. Results from the testing at 9 years of age will be available shortly. The children will continue to be tested through age 11.

In reviewing these studies at the EPA's request, the U.S. National Academy of Sciences found both to be methodologically sound, but it recommended that the EPA base its revised reference dose on results from the Faroe Islands study. If followed by the agency, this course of action will produce a reference dose identical to the one currently in place. However, concern persists that the Faroese mothers' feasting on pilot whales, which periodically exposes them to large doses of PCBs and other persistent organic pollutants, could be confounding the mercury results—especially since these pollutants and methylmercury are likely to have similar effects on developing nervous systems.

In its report, the academy commended an EPRI physiologically based pharmacokinetic (PBPK) model for reducing uncertainty about the methylmercury dose to important organs when mothers eat fish. The PBPK model accounts for individual differences in body response to methylmercury and calculates the dose to both mother and fetus. EPRI is using the model to determine the most accurate measure of methylmercury exposure during the critical phase of prenatal development. (Mercury concentrations in maternal hair and

ters and have advisories warning anglers about high levels of methylmercury in their fish. These sites and others like them must comply with state water quality standards, and the EPA wants to help states develop compliance procedures.

The standard compliance procedure defines an allowable TMDL for a given chemical in a body of water and then allocates that load (with a margin of safety) among the state-regulated sources—such as water treatment plants—that release chemicals directly into the water. However, trace chemicals like mercury may arrive mainly by air. The EPA hopes to use regional models to simulate a range of mercury deposition to waterways and MCM to show the impacts of the various levels of deposition on water quality and resident fish. With this information in hand, states will be able to predict the reductions in mercury deposition needed to meet their water quality standards. Learning how to achieve those reductions will depend on further investigation to identify distant sources that release mercury into the air. Basic technical support and a critical review of source-receptor modeling for these studies are being provided by EPRI, with funding from stakeholders in the coal, iron, and steel industries as well as from power generators.

EPRI also is helping plan an international study to determine the fate of mercury released by coal-fired power plants around Lake Superior and the effects of this mercury on the lake and surrounding watershed. Lake Superior, one of the world's largest freshwater lakes, covers nearly 3800 square miles (9840 km^2). In contrast, Devil's Lake covers 2.6 square miles (6.7 km^2) and Water Conservation Area 3A covers 700 square miles (1810 km^2). Yet for all three, researchers are asking the same basic questions about regional relationships.

Some parts of the ambitious Lake Superior basin program, which is funded by EPRI, the EPA, and DOE, are already in place. Power generators in Minnesota, Wisconsin, Michigan, and the Canadian province of Ontario have measured flue gas mercury released from their facilities. EPRI has collected speciated emissions data from Wisconsin Electric's Presque Isle plant on the south shore of Lake Superior and from Minnesota Power's Clay Boswell plant near Cohasset, Minnesota. Also, by monitoring mercury at a downwind sampling site in Isle Royale National Park, researchers have learned how stack emissions from Ontario Hydro's Thunder Bay plant disperse into the Lake Superior basin. Finally, EPRI has modified a dynamic version of MCM to fit the complex water circulation patterns of the lake.

Mercury cycling in water

"I think the big problems are understanding methylation and—particularly—linking deposition to methylation," says Don Porcella, international expert on mercury in the environment and retired manager of EPRI's mercury research program. "We're going to get at this linkage in EPRI's work on METAALICUS." He is referring to the Mercury Experiment to Assess Atmospheric Loading in Canada and the United States. This collaborative effort is the first direct test of the hypothesis that changing mercury input to a lake will proportionately change methylmercury levels in fish living there. According to Porcella, the key to investigating this issue was in finding an ingenious experimental approach.

The elegant design of METAALICUS depends on the fact that researchers can use several stable nonradioactive isotopes of oxidized mercury. These isotopes are forms of mercury with similar chemical behavior but different atomic weights. Three such isotopes will be used to trace mercury through the entire ecosystem of Lake 658, a small freshwater lake in an isolated region of southwestern Ontario province. One isotope will be deposited on the lake's surface, and researchers will determine how fast it appears in lake water, sediments, and food chain participants, including fish. Measuring levels of the isotope at various points along this pathway will show how much deposited mercury methylates and how much accumulates in fish. Depositing a second isotope on watershed wetlands and a third isotope on uplands away from the lake's surface will reveal the relative importance of these pathways in conveying deposited mercury to resident fish.

The isotopes will be deposited to the lake and its watershed packaged as seasonal rain or snow. All told, the amount of mercury added—about one-half teaspoon over the five-year study—will result in a deposition rate four to five times the background rate established for the lake. This elevated rate is approximately the rate of wet deposition in northeastern and north central U.S. watersheds. In two years of preliminary work, researchers have verified their ability to detect the isotopic mercury additions and have defined baseline levels of mercury and methylmercury throughout the watershed. The full-scale study will begin in 2001 and last three years.

One question METAALICUS will address is whether fish respond mainly to mercury of recent deposition ("new" mercury) or mercury stored in sediments and soils ("old" mercury). If the new isotopic mercury dominates, then changing mercury deposition rates should alter methylmercury concentrations in fish relatively quickly. Conversely, if the old mercury dominates, fish will respond slowly. In any event, it is difficult to predict the timescale of response.

The other, very important question METAALICUS will address is whether the relationship between mercury deposition and fish methylmercury is linear or more complex. The full-scale experiment will provide two points on the response curve—

Lake 658

Introducing mercury tracers into the watershed

Sampling fish for mercury analysis

METAALICUS, an international study cofunded by EPRI, is the first direct test of the hypothesis that changing mercury input to a lake will proportionately change methylmercury levels in fish living there. In the study, minute amounts of three nonradioactive mercury isotopes will be deposited on or near Lake 658, a small, isolated research lake in southwestern Ontario. Researchers will trace these isotopes through the lake's entire ecosystem—as well as conduct experiments in areas of a nearby lake, using structures called limnocorrals—to identify mercury's chemical and biological pathways and determine how quickly changes occur.

Limnocorrals

before and after increasing the rate of isotopic mercury deposition. An ingenious pilot experiment now in progress will add a few more points to the curve and increase certainty about its shape. For this pilot effort, researchers have installed four so-called limnocorrals in a nearby lake similar to Lake 658 and are applying intermediate amounts of a single mercury isotope inside three of them, reserving the fourth as a control.

Each limnocorral is an open cylindrical structure, made of flexible vinyl, whose top is above water and whose bottom is embedded in the lake sediments. Each creates an isolated minilake, 10 meters in diameter and about 2–3 meters deep, with the same characteristics as the surrounding lake water except that large fish are excluded. "There is no top carnivore that feeds on smaller fish. In such a limited space, carnivorous fish would consume all the other fish we need to measure," points out Rick Carlton, EPRI manager on the METAALICUS team. "Our top fish eats zooplankton." The limnocorrals are isolated from watershed influences, so the experiment will reveal only the effects of direct deposition to the lake's surface.

The version of MCM currently being used to analyze data from Lake 658 assumes a linear relationship between mercury deposition and fish methylmercury. EPRI will apply results from METAALICUS to refine the model and improve its power to predict methylmercury levels in fish under mercury reduction scenarios.

The METAALICUS study team includes leading mercury researchers from the United States and Canada. Funding for the $6 million project is being provided by EPRI, the EPA, DOE, the U.S. Geological Survey, the Wisconsin Department of Natural Resources, and Canadian government agencies.

Answers in the near term

Tracing mercury's pathways to fish is a complex problem, and EPRI is attacking it with parallel, multidisciplinary studies for a faster solution. Within two to three years, EPRI's work will provide key information needed to quantify the relationship between U.S. coal-fired power plant mercury emissions and methylmercury levels in fish in North American lakes.

Commenting on EPRI's use of models to make predictions and its complementary collection of mercury measurements to refine the models, David Michaud of Wisconsin Electric says, "I think the models and the approach EPRI is using provide us with the most reliable ideas of what the response to mercury reduction might look like." And in testimony before a subcommittee of the U.S. Senate Committee on Environment and Public Works, Leonard Levin stated, "It is clear that these studies, when complete, will better inform any deliberations about the need for, and focus of, mercury management decisions." ■

Options for Control

Prudent mercury management will balance the benefits of reducing emissions to target levels with the costs of the required control options. In compiling its 1999 emissions inventory for U.S. coal-fired power plants, EPRI found that existing sulfur dioxide scrubbers and particulate controls remove mercury: on average, the levels of mercury emitted by plants with this equipment were about 40% lower than the mercury levels in the plants' feed coal. However, reductions at individual plants may differ significantly from this average. EPRI is studying control technologies, their efficiencies, their costs, and their impact on combustion byproduct use and disposal for individual power plants with various operating characteristics and designs.

Measuring mercury in flue gas

A wide range of potential options for mercury management are under consideration. These options include enhancing existing technologies (for example, converting elemental mercury in flue gas to oxidized mercury for removal by sulfur dioxide scrubbers); adapting technologies used in other industries (for example, injecting activated carbon sorbent into the postcombustion pathway); and developing novel concepts for mercury control. EPRI is evaluating the performance and cost of commercially available sorbents for power plant flue gas and is experimenting with lower-cost sorbent materials.

Full-scale demonstrations of mercury control technologies at individual power plants are just getting under way, cosponsored by EPRI and DOE. "I would like to encourage EPRI's members to open their plants and their wallets over the next three years to help understand what it takes to control mercury," says David Michaud, principal environmental scientist at Wisconsin Electric Power Company. "Unless we see more and varied plants participating, we're not going to have the information we need to show the EPA the benefits of a flexible regulatory approach." □

Further reading

Assessment of Mercury Emissions, Transport, Fate, and Cycling for the Continental United States: Model Description and Evaluation. EPRI. December 2000. Report 1000522.

An Assessment of Mercury Emissions From U.S. Coal-Fired Power Plants. EPRI. October 2000. Report 1000608.

Toxicological Effects of Methylmercury. National Academy Press, Washington, D.C. July 2000.

Mercury Sorbent Effectiveness and Cost: An EPRI Synopsis. EPRI. 1999. Report SP-113805.

Study of Hazardous Air Pollutant Emissions From Electric Utility Steam Generating Units—Final Report to Congress. U.S. Environmental Protection Agency. February 1998. EPA-453/R-98-004.

Mercury Study Report to Congress. U.S. Environmental Protection Agency. 1997. EPA-452/R-97-005.

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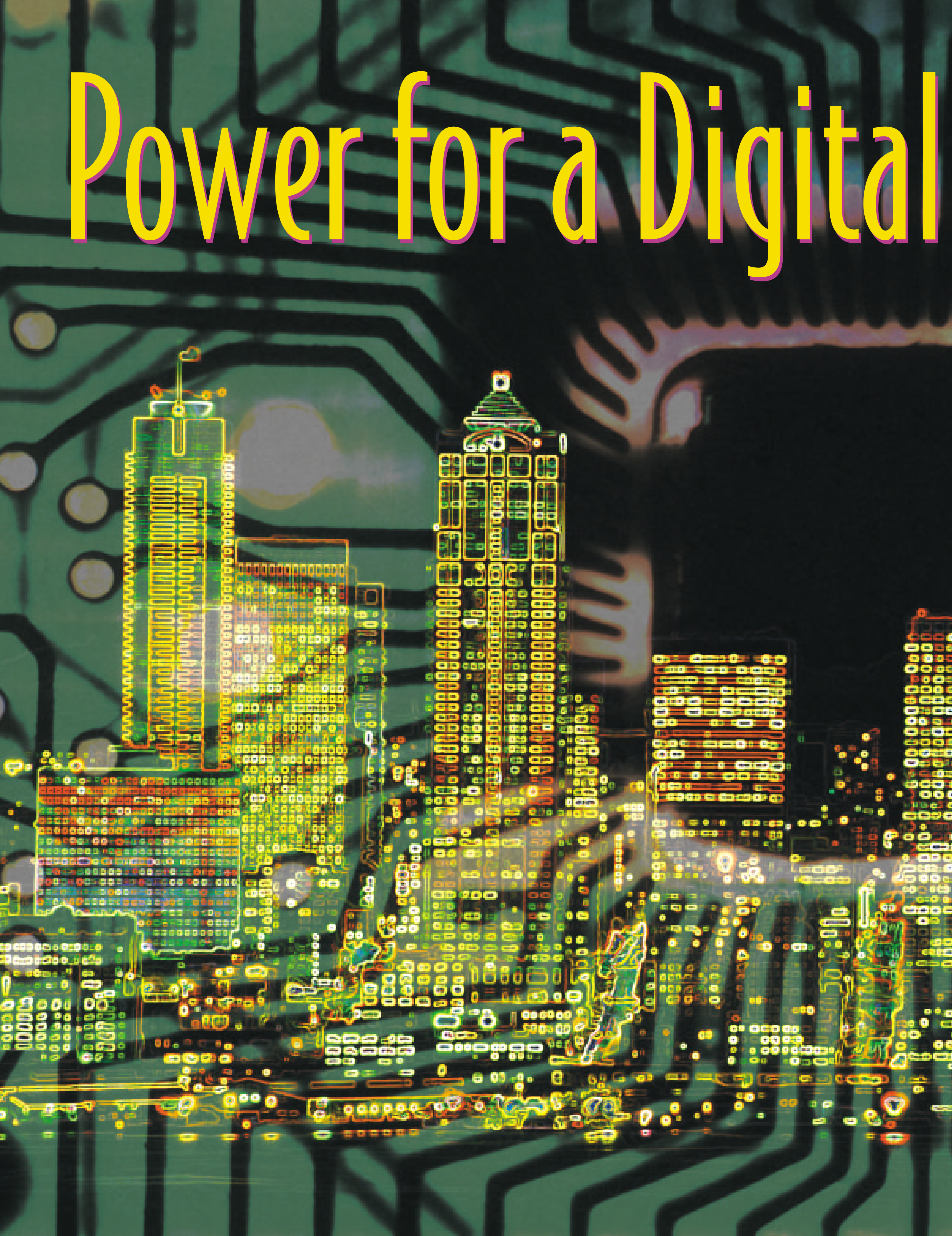
Power for a Digital



Society

The Story in Brief

The proliferation of power-sensitive digital technology poses new challenges for the planners and operators of the North American power delivery system: how to provide enough electricity to meet unexpectedly high demand, and how to ensure that the quality of power is adequate for a microprocessor-based economy. EPRI has responded to these challenges by launching two national programs. The Power Delivery Reliability Initiative, now finishing its first year, focuses on immediate steps that can be taken to improve the reliability of utility networks. The Consortium for Electric Infrastructure to Support a Digital Society, set to begin operation in January 2001, is concerned with finding long-range solutions to reliability problems and involves not only utilities but also equipment manufacturers and end-users.

by John Douglas

Just at a time when consumers are demanding a higher level of power reliability to keep their sensitive electronic equipment running smoothly, the ability to deliver the "digital quality" electricity they need is being severely challenged. Transmission line additions are not keeping up with the exponentially increasing volume of wholesale power transactions. Many urban distribution systems have aging infrastructures, whose vulnerability has been exposed by a series of expensive, highly publicized outages. Industry restructuring has not yet offered sufficient financial incentives to attract the capital investment necessary for improving the reliability of power delivery networks. Neither digital equipment manufacturers nor users are sure what level of reliability they can expect "at the plug" and whether there will be enough ride-through capability for the equipment. A variety of small power generation and energy storage units entering the market could help improve reliability for individual customers, but these units—known as distributed resources (DR)—could also create new problems for the utility grids to which they are connected.

Meeting these complex challenges requires a focused national research and development effort, one involving not only electric utilities but also major groups of customers and manufacturers and eventually government agencies. EPRI has responded to this situation by launching a bold, two-phase plan to mobilize all stakeholders in a unified effort to improve overall power delivery system reliability—from generator to end-user—in the most cost-effective manner. The plan's first phase, called the Power Delivery Reliability Initiative, is already under way and is focused on making immediate, clearly needed improvements in utility transmission and distribution systems. The plan's second phase will begin early in 2001 with the launching of the Consortium for Electric Infrastructure to Support a Digital Society (CEIDS), a broadly based effort to find long-term solutions to the challenges of reliability.

PHOTOILLUSTRATION PAGES 18–19 BY MARTHA LOVETTE

"Even at this early stage, one thing is abundantly clear: we can't solve all reliability problems by trying to gold-plate the grid," says Karl Stahlkopf, EPRI vice president for power delivery. "A combination of technologies, applied at various levels of the power system, will be needed. Some improvements are best made at the end-use level; for example, adding a large capacitor to a computer circuit board could enable the computer to ride through a momentary outage. Other improvements are best applied on power delivery systems, and we're already working on several of those. EPRI is providing the leadership necessary to coordinate reliability enhancement on a national scale by bringing together all the concerned parties."

The rise of the digital economy

The digitization of the global economy is rapidly entering its third phase. First came computers, which revolutionized information processing and fundamentally transformed the way most businesses operate. Next, as the cost of microprocessors plunged, individual silicon chips began to appear in all sorts of unexpected places—from phones to car brakes. This embedded-processor phase of digitization has progressed to the point that for every chip in a computer, 30 more are deployed in stand-alone applications.

In phase three, computers and microprocessors are being linked into networks, a trend seen most clearly in the explosive growth of electronic commerce. There are currently more than a million Web sites on the Internet, potentially available to some 200 million computers around the world. As a result, Internet-based commerce already represents about 2% of the American gross domestic product, and by the end of next year, the revenues from e-commerce are expected to exceed those of the entire U.S. electric power industry.

Networked information technology (IT) systems are believed to be exerting a highly leveraged influence on U.S. productivity growth as well. The United States has invested more than $1 trillion in IT equipment in the past 5 years, a period in which U.S. productivity surged after 30 years of subpar growth (about 1% a year). While productivity growth is still highly concentrated in the information industries, it is expected to continue to spread to other parts of the economy. For example, Alan Greenspan, chairman of the Federal Reserve Board, believes that the efficiency gains of electronic commerce could lead to a drop in overall product inventories of $250 billion to $300 billion a year—a reduction of as much as 30% in the country's inventory levels.

Computers, the Internet, fiber optics, and wireless communications—just some of the technologies underlying the digital revolution—will also transform the use of electricity in the new millennium. Advances will include Web-connected household appliances, smart houses, advanced automated manufacturing, self-diagnosing and self-repairing equipment, and real-time, off-site process control.

In the digital economy, there will be a new level of involvement in energy markets. Customers will have access to a network of information on energy availability, prices, and assets. Digital connections will enable all market players to be linked through instantaneous communications, opening up the possibility for new and more creative relationships between buyers and sellers. Consumers will use the Internet to select and pay for customized energy services in the new, deregulated energy markets.

Still, as inevitable as this emerging digital future seems, its success depends on the reliability of its power supply backbone. The proliferation of networked digital technology poses two challenges for those who must supply the necessary electric power—quantity and quality. Together, microprocessors and the equipment they control have helped stimulate growth in electricity demand well beyond previous expectations. Information technology itself now accounts for an estimated 13% of electricity consumption in the United States, and some industry observers believe the IT share may grow to as much as 50% by 2020. Even given the uncertainty in this extreme estimate, it is clear that IT-related electricity use is growing rapidly and could conceivably eclipse analog power needs in a few years.

Moreover, the amount of electricity used directly for computers and other digital devices represents only the tip of the iceberg: virtually all the commercial and industrial equipment controlled by microprocessors also requires electricity. Thus, digitization has increased the electrification of the economy. More than 80% of the growth in total U.S. energy demand since 1990 has been met by electric power, and within 25 years electricity is expected to account for more than half of the energy consumed in most industrial nations.

The demand for higher-quality electricity has also become critical. An unprotected microprocessor will malfunction if power is interrupted for even a single ac cycle—one-sixtieth of a second. On an annual basis, this means electricity must be available 99.9999999% of the time; that is, it must have what is called 9-nines reliability. Since the average reliability of delivered power is only about 3 nines (99.9%), additional measures are required to prevent malfunctions of computers and other microprocessor-based equipment. Such malfunctions can be expensive. At a steel-rolling mill, for example, plate thickness is controlled by microprocessors. Even a brief interruption can cause rollers to get out of alignment, making it necessary to remelt the product. Similarly, computer failure at a paper mill can create a mess that requires two work shifts to clean up.

Need for a national effort

The challenges just described come at a time of rapid change for the U.S. electric power industry—especially for the power delivery system. Federal deregulation has opened utility transmission networks for use by third parties, resulting in a greatly increased volume of bulk power transactions and a host of new wholesale market players. Meanwhile, most states are considering ways to increase competition in retail markets and provide customers with greater choice among electricity providers.

Grid expansion and upgrades, however, have not kept up with the new demands brought by deregulation. Most transmission and distribution systems were designed more than half a century ago, when long-distance power transfer was used mainly for economic exchange among a few utilities and when the reliability requirements of distribution systems were much less rigorous than in today's digital economy. So far, the needed improvements in both capacity and reliability have not been made. During the last decade, for example, total electricity demand in the U.S. rose by nearly 30%, but the nation's transmission network grew by only 15%. Over the same period, expenditures by investor-owned utilities for distribution system construction fell by about 10% in real terms. The outlook for the next decade is

A Race With the Digital Future

The urgency of the power reliability challenge is intensified by the unrelenting pace of the technologies driving the development of the digital society. These technologies—including microchips, networks, the Internet, and broadband communications—will increasingly require electric power reliability at the 9-nines (99.9999999%) level.

Microchips The computing power of microchips continues to double about every 18 months (as postulated in Moore's law), and there is no end in sight. Today's silicon chips are 1 billion times smaller, cheaper, and more powerful than their predecessors of the 1950s. Looking ahead, Arno Penzias, a Nobel Prize winner and the former chief scientist and vice president of Bell Labs, says, "We can expect a million-fold increase in the power of microprocessors in the next few decades, yielding computers more powerful than today's workstations for about the price of a postage stamp and in postage stamp quantities." Low-end, single-function microprocessors—already referred to as jelly beans in the trade because they can be produced as easily and cheaply as candy—will eventually be embedded into every appliance, tool, and product. The billions of microchips in operation around the world today are likely to become trillions within a few decades.

Networks A network is made up of two ingredients, nodes and interconnections, and its value grows in proportion to their number. In the case of digital networks, the individual nodes—the microprocessors—are exponentially shrinking in size and expanding in power, while the interconnections, both wired and wireless, are exploding in terms of connectivity, speed, and capacity. These developments are accelerating at such a rate that over the next few decades we will effectively be connecting everything to everything.

Internet Starting from scratch in the early 1990s, the Internet now boasts an estimated 200 million users, most of them in the high-tech regions of the world. Global Internet traffic is doubling about every three months, and by 2025 more than 3 billion people (nearly half the planet's population) are expected to be communicating and doing business via the Web.

Broadband communications Capabilities for interconnection and communication among microprocessors and computers are growing at least as fast as, if not faster than, computing power itself. The total bandwidth of communications systems is expected to triple every 12 months (Gilder's law). Global voice traffic—1000 times greater than global data traffic in 1998—is expected to be only one-tenth of data traffic by 2005. Some analysts predict that by 2008 two-thirds of all U.S. households will have high-speed data capacity. □

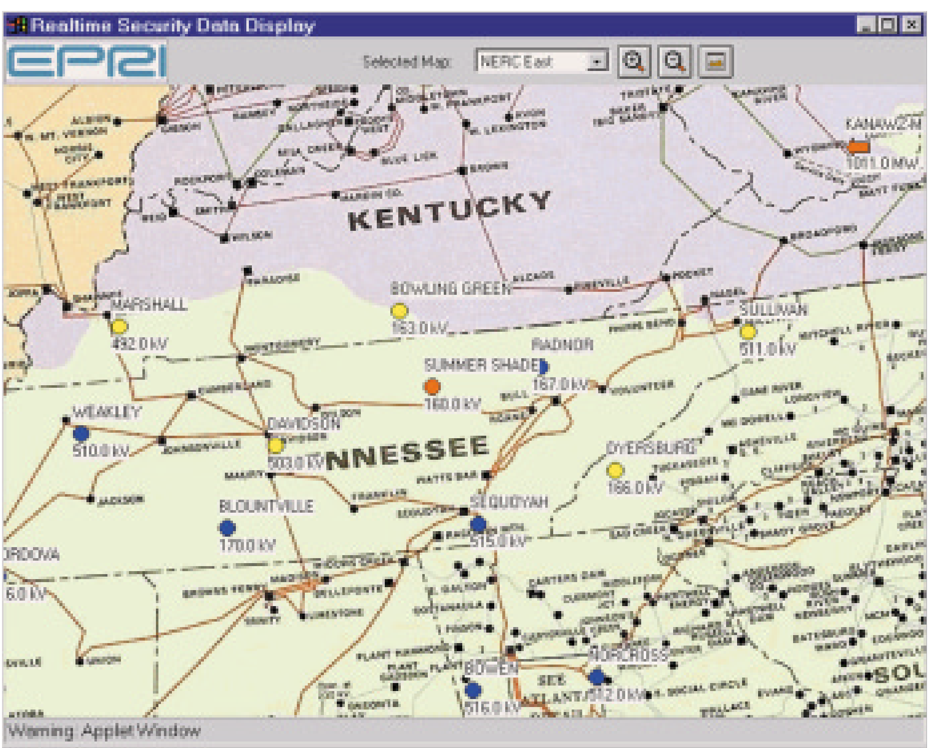
even worse: demand is expected to grow by 20%, but planned transmission system growth is only 3.5%.

The effects of the lag between demand and infrastructure investment are already being felt. In four of the past five years, the United States has faced serious reliability problems. In August 1996, voltage disturbances cascaded through the West Coast transmission system, causing widespread blackouts that cost California alone more than $1 billion. In June 1998, transmission system constraints disrupted the wholesale power market in the Midwest, with prices per megawatthour rising from an average of $30 to peaks as high as $10,000. Similar service curtailments and price spikes occurred in the summers of 1999 and 2000. Distribution system weaknesses have also become apparent, as major local blackouts have affected customers around the country—sometimes with long-term consequences. For example, the August 1999 outage that affected businesses and government offices in Chicago's downtown South Loop district prompted the city's utility, Commonwealth Edison, to launch a $1.5 billion distribution system upgrade program.

Clearly, the productivity of the American economy is more and more dependent on power reliability, but the delivery grid can no longer supply electricity that meets the reliability needs of a growing proportion of customers. Addressing this problem will require the concerted effort and commitment of resources from a variety of stakeholders, including the electric power industry, equipment manufacturers, government agencies, and major consumers of the highest-quality electricity.

Taking the initiative on reliability

The first step in creating such a national endeavor came in January 2000, with the formation of EPRI's Power Delivery Reliability Initiative. This two-year effort is focused on determining the root causes of recent reliability problems and on identifying ways to provide immediate improvement. The initiative is being conducted by EPRI in coordination with the North American Electric Reliability Council and is funded entirely by private participants, which currently include more than 40 utilities. In addition to helping improve the nation's power delivery system for the benefit of the whole industry, initiative participants gain access to information and technology they can use right away to strengthen their own networks.



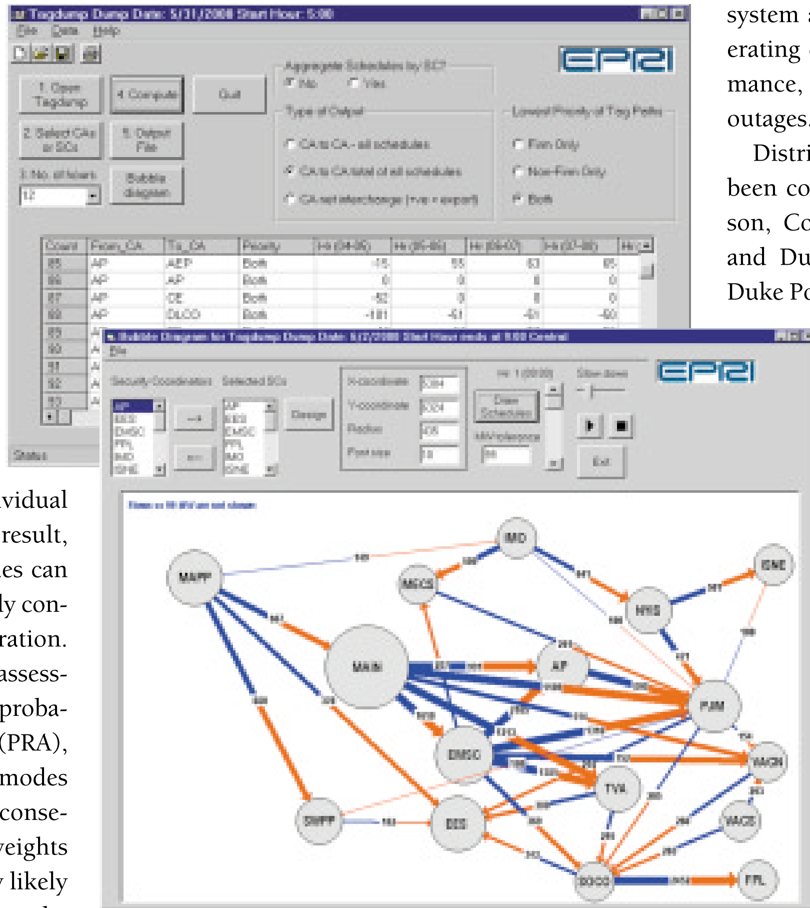
Developed in cooperation with NERC, EPRI's Real-Time Security Data Display software allows security coordinators and control area operators to view national transmission grid maps on which bus voltages and power flows on critical lines are superimposed.

One of the first tasks of the initiative's transmission portion has been to develop software tools that security coordinators and system operators can use immediately to reduce the probability and potential impact of regional power disturbances. Two of these tools were delivered in June 2000 and were used during the summer to enhance overall system reliability.

The Real-Time Security Data Display (RSDD) software provides operators with a bird's-eye view of transmission reliability over a large region—as large as the entire North American grid. Previously, security data were displayed mainly for individual control areas. RSDD shows voltage values and voltage limits for about 300 critical buses, selected from all three major interconnections (Eastern, Western, and Texas); a color code indicates whether any voltage is dropping below safe levels. In addition, the direction and amount of power flow in megawatts are displayed for about 50 so-called flowgates in the Eastern Interconnection. Each flowgate represents a critical line or set of lines needing close monitoring.

The Tag Dump software provides operators with aggregated schedules of wholesale power transactions between control areas. Regional security coordinators can use this information to determine more reliably whether particular flowgates are likely to become overloaded. If so, a coordinator can order certain transactions to be curtailed. Tag Dump automatically consolidates the data needed by a coordinator or an operator to optimize power flow throughout a region for the next several hours or the next day. Planners also can use the Tag Dump software to develop scenarios of severe transfer patterns for further study.

Another major task of the reliability initiative's transmission program is to conduct a new type of reliability analysis of the North American interconnections. Conventional reliability assessments use deterministic techniques that calculate the effects of losing critical transmission circuit elements. Each such potential loss is known as a contingency. The problem



EPRI's Tag Dump software displays aggregated schedules of wholesale power transactions between control areas, helping users to reliably determine whether particular flowgates are likely to become overloaded.

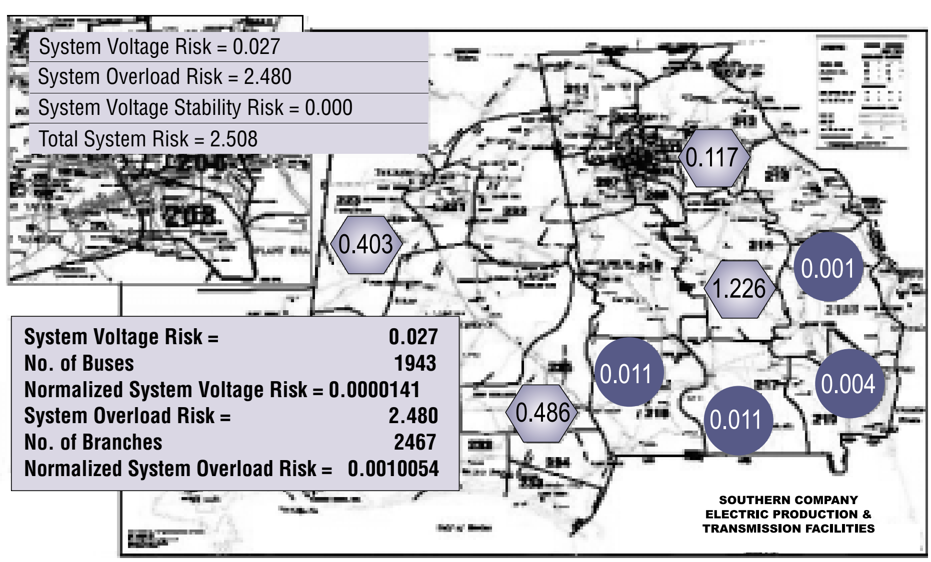
with this approach is that it does not take into account either the likelihood or the severity of individual contingencies. As a result, deterministic techniques can lead to inefficient, overly conservative system operation. The new reliability assessment method, called probabilistic risk assessment (PRA), identifies the failure modes with the most severe consequences and then weights them according to how likely they are to occur. Using the PRA approach, planners can explicitly determine the trade-offs involved in operating their system beyond certain limits. Such knowledge will eventually help operators understand how best to respond when a system starts to get overloaded.

The PRA methodology developed for the reliability initiative has so far undergone two beta tests, which have led to several enhancements. Currently, it is being applied to the Eastern Interconnection; a report on the results is due in February 2001. Analyses of the PRA results for all the interconnections will lead to recommendations for operational changes to improve overall system security and reliability. In addition, technical measures for strengthening specific transmission or generation systems may be proposed to eliminate or manage bottlenecks.

In contrast to transmission networks, individual utility distribution systems differ significantly from one another in architecture, equipment, and operating procedures. As a result, it is not cost-effective to apply probabilistic techniques to distribution system reliability analysis. Therefore, deterministic methods are being used to analyze representative distribution systems and identify generic weaknesses. Each distribution system assessment will address equipment conditions, available margins for load growth, maintenance techniques, system adequacy for meeting various operating conditions, human factors performance, and root causes of recent system outages.

Distribution system assessments have been completed for Commonwealth Edison, Consolidated Edison of New York, and Duquesne Light. An assessment at Duke Power is under way, and information gathered in a previously conducted assessment at Public Service Electric and Gas is being reviewed. Although the assessment results have varied widely from utility to utility, some general findings have emerged. For example, maintenance practices need to be revised, system monitoring and protection enhanced, and cable systems reinforced to withstand heavy loads during particular weather conditions.

The assessment results will be used to develop a self-assessment template that individual utilities can employ to determine the reliability of their own distribution systems. Specifically, the template will enable a utility to compare its system with systems having similar weather conditions and types of equipment. For example, if a utility is concerned about



Beta tests conducted by Southern Company Services and EPRI of a new probabilistic risk assessment methodology demonstrated how PRA can be used to compute relative risk values and identify transmission bottlenecks. This diagram shows the four zones with the highest annual voltage risk (circles) and the four zones with the highest overload risk (hexagons) in the Southern Control Area of the Southeastern Electric Reliability Council.

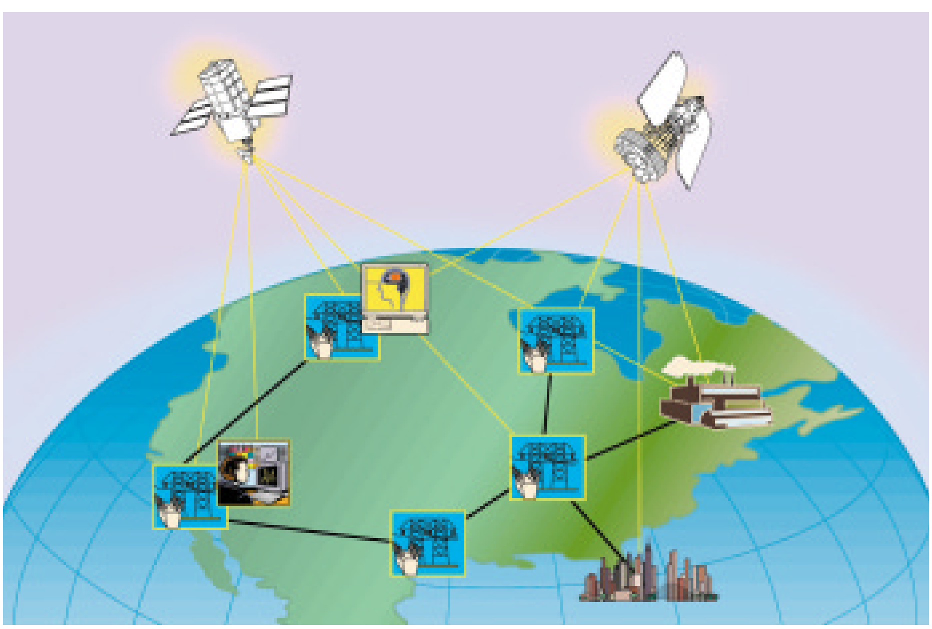
what relay settings to use for transformer loading in anticipation of four days of 90°F (32°C) temperatures and 80% humidity, it can see how other utilities set those parameters and learn what is considered best practice under such circumstances. The self-assessment template will be available to initiative participants in February 2001.

CEIDS: broadening the effort

The second phase of the national effort to ensure power for a digital society will officially begin in January 2001 with the launching of CEIDS. Already, however, a preliminary study of reliability needs is under way, and a tentative program to meet those needs through advanced technologies is being designed. CEIDS will have a much broader membership than the reliability initiative; as well as utilities, it will include equipment manufacturers and representatives of industrial groups (for example, high-tech companies) that are particularly sensitive to power reliability. CEIDS will also have broader goals, focusing not only on how to improve utility power delivery systems but also on how to integrate DR into the power grid and how to provide end-use equipment with an appropriate level of built-in protection.

Meeting these goals will require the adoption of separate strategies for improving the reliability of transmission systems, distribution systems, and end-use products. Each strategy will rely heavily on the use of new technologies, but there will be important choices to make about how best to apply the technologies. A major task of CEIDS will be to determine which combination of technologies is likely to be most cost-effective in optimizing reliability. Optimization planning must take into account the differing needs of diverse customers. For example, power quality can be significantly improved by adding backup generation or power-conditioning equipment at the site of use, and many large manufacturers with sensitive equipment have already invested in such customized solutions. However, these sophisticated add-ons are often too expensive for small and medium-size customers, who might be more interested in efforts to increase power quality at the distribution level.

"Unless the needs of diverse market segments are met through a combination of power delivery and end-use technologies, U.S. productivity growth and prosperity will increasingly be constrained," declares Stahlkopf. "It's important that CEIDS examine the impact of reliability on a wide spectrum of industries and determine the level of reliability each requires."



Grid reliability will be enhanced greatly by the widespread implementation of integrated network control, in which equipment operational data are collected from across the grid by distributed sensors and measurement devices. Gathered and time-stamped by global positioning system satellites, the data are then sent to control centers, analyzed, and used to make operating decisions that can be implemented through advanced power electronics control devices.

Participation in CEIDS

Once it officially begins operation in January 2001, the Consortium for Electric Infrastructure to Support a Digital Society will be open to utilities, equipment manufacturers, and major electricity consumers concerned about power reliability—and to the trade associations of all these groups. The goals of CEIDS are to better understand the link between power reliability and economic productivity and to demonstrate technological solutions to current problems that threaten this linkage. By joining, participants can help shape the consortium's research program to ensure that it meets the needs of their industries and can gain first access to the technologies developed in the program. For more information, contact Karl Stahlkopf (kstahlko@epri.com; 650-855-2073). □

To establish a firm basis for the CEIDS technology development and application program, the link between power reliability and economic productivity must be better understood. Lawrence Berkeley National Laboratory has been selected to conduct a three-month study to document the economic losses caused by power outages—losses for the U.S. economy as a whole and for vulnerable sectors of the economy and regions of the country. The researchers will also make documented, credible projections of the growth of digitization in the overall economy. Using these data, they will estimate the impact of improving—or neglecting—power reliability in the future. In addition, they will estimate the current level of investment in on-site backup generation and power-conditioning equipment.

Drawing on the results of this study and guided by the specific priorities of consortium members, CEIDS will launch a three-pronged technical program to identify improvements needed by the transmission, distribution, and end-use segments of the power system.

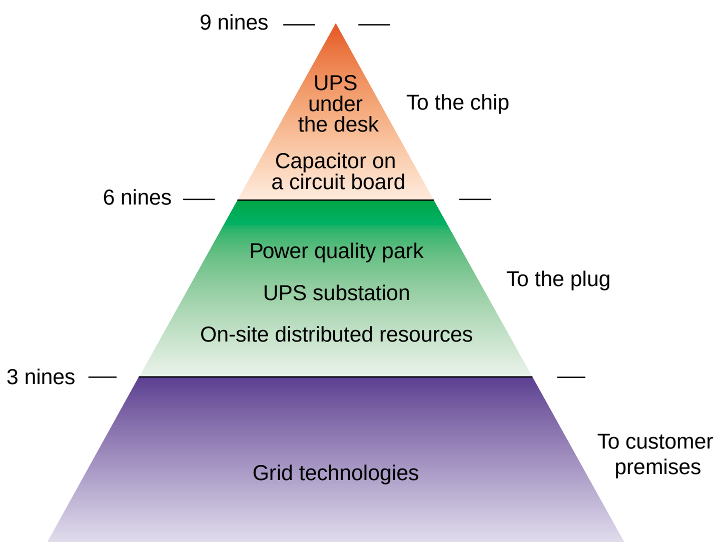
In the area of transmission, existing systems have about 4-nines (99.99%) reliability, but this respectable level is deteriorating as capacity growth lags behind demand. Given the current difficulty in obtaining permission to construct new high-voltages lines, the most promising strategy for quickly increasing transmission capacity is to upgrade existing systems by means of advanced technologies. Some of these technologies can be applied immediately on individual systems; the extent to which others are used will depend on how regional transmission groups are organized. A particularly urgent need is the widespread implementation of integrated network control (previously referred to as hierarchical FACTS control), in which the operation of multiple FACTS controllers is coordinated by using real-time information from a wide-area measurement system.

Distribution systems, where most of the power system disturbances that affect customers originate, have a reliability level of about 3 nines (99.9%). In many cases, as recent urban blackouts have dramatically illustrated, investment has not kept up with either load increases or customers' demands for higher-quality power. Now this situation is being further complicated by the introduction of DR units, such as backup diesel generators at industrial facilities, microturbines at small businesses, and various energy storage units.

A number of new technologies are available to help improve reliability throughout a distribution system—from substation to customer premises—but choosing the best implementation strategy will require careful assessment of specific local issues. One important factor affecting this choice is the trend in retail power markets to move from average-cost pricing to real-time pricing, which requires the use of electronic meters. These meters could also register sales of electricity from a customer's DR unit to the utility during periods of peak demand. Such arbitrage of power—buying from or selling to the grid as prices change—could help both the customer (by providing a return on the DR investment) and the utility (by leveling load).

Strategies for end-use equipment involve making up the difference between the reliability of delivered power and the reliability needed by the customer. Some industries are currently pushing for a 6-nines (99.9999%) reliability standard for "information-quality" power at the plug. That represents a total of about 30 seconds of outage a year. The gap between this standard and the 9-nines reliability required for an unprotected microprocessor would presumably be filled by on-site DR or storage capability. In the simplest case, a large capacitor built into end-use equipment itself could provide a few seconds of ride-through capability.

CEIDS will need to explore whether a 6-nines standard for delivered power is feasible as well as what options could further boost reliability to the 9-nines level needed by sensitive electronics. In particular, such studies could generate valuable information for manufacturers to use in designing equipment capable of performing effectively under the expected power reliability conditions.



Responding to the power quality needs of a digital society will require a combination of technologies deployed at different locations. The transmission and distribution system currently provides basic 3-nines (99.9%) reliability, although such advanced grid technologies as FACTS or Custom Power devices can improve on this average. Power quality parks or on-site distributed generation or storage equipment can boost reliability to the 6-nines, or information-quality, level. Achieving 9 nines may require an uninterruptible power supply (UPS) at the actual point of use or a large capacitor built into the end-use equipment itself. Which options are actually deployed will depend on the power quality needs of the individual customer.

Launching the consortium

A national endeavor to improve overall power system reliability will eventually need to involve a public-private partnership. As a first step, CEIDS is being established as an EPRI initiative to solicit private funds. Once sufficient private funds have been raised to mount a research effort that could at least make a credible study of current problems and propose viable solutions, EPRI would be in a position to seek public funds to demonstrate the technologies involved. In particular, federal funds may be sought through a separate entity, whose structure remains to be determined.

"EPRI is in a unique position to form a consortium that can bring together diverse public and private interests and conduct a research program touching all segments of the electricity enterprise," concludes Stahlkopf. "EPRI has pioneered many of the advanced technologies that are now being considered for widespread deployment on transmission and distribution networks and in end-use devices in order to increase overall system reliability. I believe that by promoting the judicious use of these technologies, CEIDS can make a significant contribution to power reliability in ways that could potentially translate into billions of dollars in increased productivity for the American economy." ■

Background information for this article was provided by Karl Stahlkopf (kstahlko@epri.com), Dejan Sobajic (dsobajic@epri.com), and Bernard Ziemianek (bziemian@epri.com).

by Taylor Moore

Hybrid EVs:

COURTESY ORION BUS INDUSTRIES

THE STORY IN BRIEF

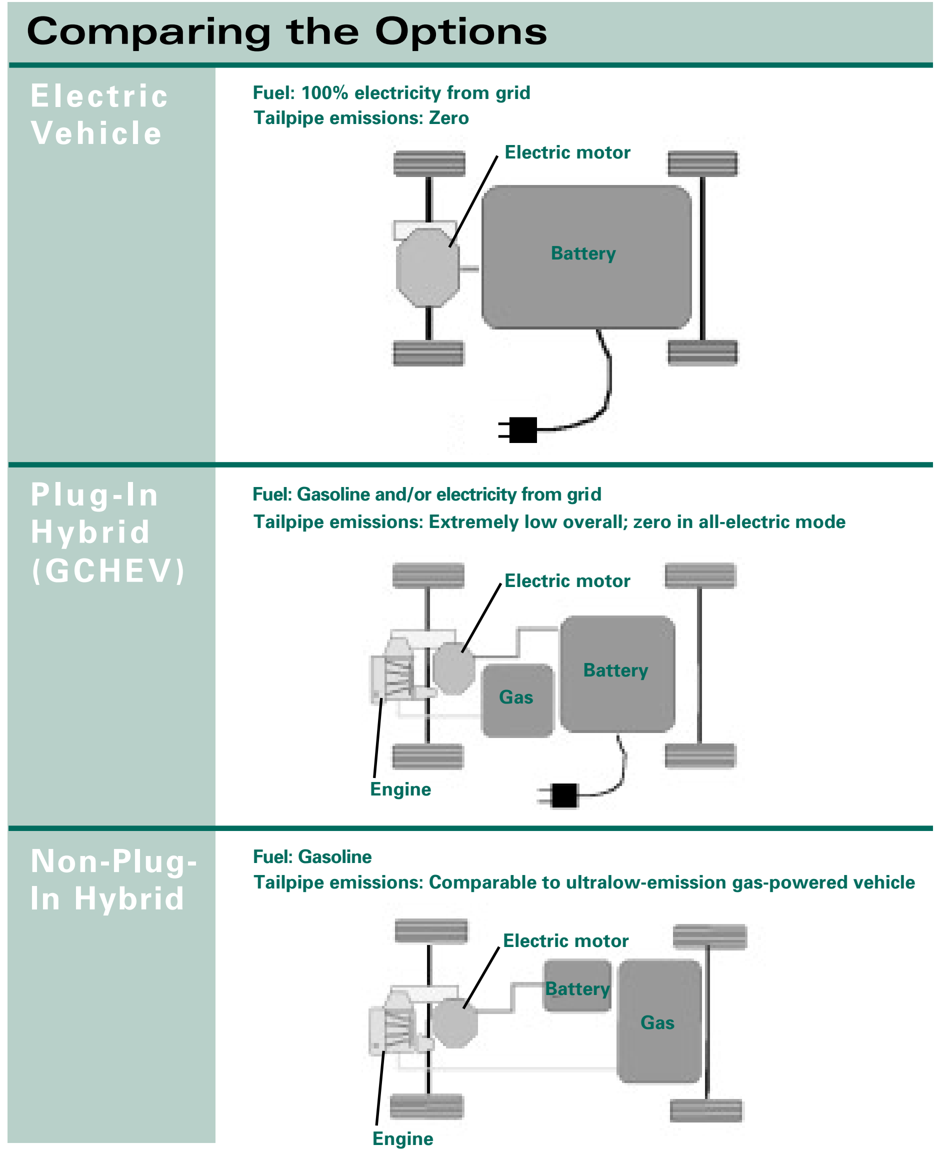
Hybrid electric vehicles, featuring both a gasoline engine and a battery storage system, became commercially available from two major auto manufacturers this year. While these hybrids offer better fuel economy and lower emissions than conventional cars, their battery packs are relatively small and are charged by the onboard gasoline engine-generator. In an effort to achieve efficiency and emissions levels closer to those of a true electric vehicle, EPRI is developing a grid-connected hybrid that operates the majority of the time in an all-electric mode, using its small gasoline engine only to extend driving range or to provide extra power. The development initiative—being pursued in alliance with General Electric, General Motors, Ford Motor, EPRI member utilities, and other key technology stakeholders—is at first focused on producing midsize hybrid buses and delivery vans and demonstrating their potential for cost savings to fleet vehicle operators. Expanded in the past year to put more emphasis on systems and components development, the initiative has as its ultimate goal the commercialization of grid-connected hybrid buses, vans, trucks, and automobiles.

Making the Grid Connection

The limited range and high cost of today's early-market, low-production electric vehicles (EVs)—drawbacks that are due almost entirely to the performance and cost of currently available batteries—are driving automakers to consider alternative approaches for environment-friendly vehicles. These include hybrid EVs (HEVs) with a drive system that combines an internal combustion engine with a modest amount of battery storage. Depending on the drive system design, the internal combustion engine can provide either primary propulsion or onboard battery recharging for electric drive. When operated at constant speed, the engine can be optimized for low emissions.

Toyota Motor Corporation's five-passenger Prius gasoline-electric HEV, which gets 52 miles per gallon (22 km/L) in city driving, went on sale in the United States earlier this year after a commercial debut in Japan. Honda Motor Company offers a two-seater HEV—the Insight—with a 61-mpg (26-km/L) city rating, and the automaker plans to introduce a four-passenger Civic HEV in 2001, first in Japan and then in the United States. Ford Motor Company has developed a 70-mpg (30-km/L) prototype hybrid electric family sedan called the Prodigy, and earlier this year it said it would begin selling a hybrid version of its Escape, a small sport utility vehicle, in 2003. Meanwhile, several bus manufacturers are developing diesel-electric hybrid transit buses.

Much of the rush to develop commercial HEVs is being driven—just as was the case earlier with EVs—by a looming regulatory mandate in California, whose Air Resources Board launched a zero-emission vehicle (ZEV) program a decade ago. Although the mandate has been revised twice since then to remove intermediate percentage requirements for ZEVs, it still requires that, starting in 2003, 10% of all new light-duty vehicles sold in the state by major manufacturers be ZEVs. In part because of the shortcomings of commercially available batteries for EVs, regulators are allowing vehicle makers considerable flexibility in meeting the ZEV requirements. The 6 largest manufacturers can satisfy three-fifths of the 10% requirement with low-emission vehicles, including future HEV models, while 11 other manufacturers will be permitted to meet their entire 10% obligation with such vehicles.



COURTESY SOUTHERN CALIFORNIA EDISON

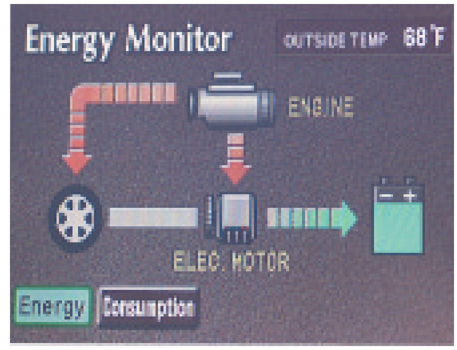
Hybrid electric vehicles (HEVs) can be divided into two basic types, depending on electricity source. Like an all-electric vehicle, a plug-in hybrid gets electricity for battery recharging from the utility grid. Such a grid-connected HEV (GCHEV) uses its small gasoline engine only when an extended driving range or extra power is required. A non-plug-in hybrid is fueled entirely by gasoline, with the engine-generator and regenerative brakes providing the electricity for battery recharging. GCHEVs are expected to be able to operate in the zero-emission (battery-only) mode for over 60% of the annual miles traveled by the average U.S. vehicle.

The push by vehicle manufacturers to develop commercial HEVs to satisfy much of the California 2003 ZEV mandate is no doubt somewhat of a disappointment to the state's electric utilities. The utilities have long championed electric transportation as a compelling solution to the vehicular emissions and petroleum dependency problems resulting from Californians' abiding love-hate relationship with the automobile and the freeway. Utilities have supported—and in some cases installed—thousands of public EV charging stations to accommodate the more than 2300 EVs now operating in California. But for the most part, today's HEVs and those anticipated in the near future have fuel-only designs that feature an internal combustion engine and a relatively small battery pack; all the electricity for recharging comes either from the engine-generator or

DAVID MORIN

Toyota Prius

Although they have the highest fuel economy ratings of all passenger cars sold in the United States, non-plug-in gasoline-electric hybrids like the two-seat Honda Insight and the five-passenger Toyota Prius rely exclusively on fuel derived from petroleum, most of which is imported.



COURTESY AMERICAN HONDA MOTOR CO.

Honda Insight

from regenerative brakes. These HEV designs continue to rely solely on petroleum-based fuels.

"With a few exceptions, the grid-connected, all-electric vehicle is being left by the wayside," says Robert Graham, EPRI's retail product sector leader for technology development. "The EV industry has lost much of its momentum, and the automotive industry is moving in the direction of hybrid vehicles that are not grid connected. EPRI and the utility industry still want to electrify transportation, however, and we're not ready to give up just yet. We've launched an initiative to try to salvage the pure EV market—an initiative that takes advantage of electricity's benefits as a transportation fuel and an alternative to the continued burning of fossil fuels in vehicles."

Next best to an EV

Graham says several studies suggest that even with a modest 40-mile (64-km) range in all-electric operation (that is, using only battery power), grid-connected HEVs, or GCHEVs, could handle more than 60% of the total annual miles traveled by the average U.S. vehicle. The percentage could be considerably larger for delivery trucks and smaller buses, given their typical driving cycles.

In GCHEVs, an electric motor and onboard batteries would propel the vehicle most of the time; at a set speed or during longer trips, a small internal combustion engine would begin operating to provide extra power or range. Although a GCHEV could include regenerative brakes, most battery recharging would be done while the vehicle is parked and plugged into a home, office, or public charging unit fed by a utility distribution system.

For many observers, GCHEVs directly address the two major commercialization hurdles—range and cost—facing pure EVs. A GCHEV needs a battery pack only about half the size of that of a pure EV to serve a daily driving cycle of approximately 20 miles (32 km), which is typical for millions of vehicles. Viewed from an operating and life-cycle perspective, GCHEVs have lower costs than pure EVs, even when battery replacement is considered.

"A grid-connected hybrid is the next best thing to an EV," says Ed Kjaer, director of electric transportation for Southern California Edison (SCE), a leading utility supporter of EVs and the operator of the nation's largest corporate EV fleet—150 vehicles of various types. "The attraction of a grid-connected hybrid is that for most of the duty cycle, it would basically operate as an electric, zero-emission vehicle."

In a bid to reverse the trend away from grid-connected vehicles, the EPRI-led initiative—whose participants include SCE, other utilities, and vehicle and component manufacturers—is aggressively pursuing the development of GCHEVs as midsize buses and delivery vans. "Our strategy is to determine whether GCHEVs serving as fleet vehicles that return to a base every night and are operated the majority of the time in all-electric mode will have lower operating costs than internal combustion vehicles or fuel-only HEVs," says Graham.

"We have extensively documented that electric drive systems are more efficient and reduce operating costs, but customers have a fear of insufficient range," Graham continues. "So the goal is to get enough GCHEVs into the fleet vehicle market to prove they actually reduce operating costs. We have to prove to fleet operators that range is no longer a problem and that there is value in the form of reduced operating costs. We know we cannot force a market or paradigm shift on environmental benefits alone."

To avoid reinventing the wheel, the initiative is focused on the use of commercially available components for GCHEV drivetrains. "All the components required for a GCHEV—control systems, motors, and batteries—are available today," notes Graham. "But whether an integrated package will be affordable is the question. The answer will still be driven primarily by the cost of the battery in relation to the required vehicle duty cycle."

EPRI continues to work with automakers and battery manufacturers through the U.S. Advanced Battery Consortium to develop next-generation batteries, and it sponsors ongoing efforts to develop markets for such batteries, both in transportation applications and in stationary, backup power applications. Advanced technologies include the nickel–metal hydride battery (now commercially available from two manufacturers) for use in the near term and the lithium-ion and lithium-polymer batteries (under development by several manufacturers) for use in the long term. "GCHEVs are likely to make it to the marketplace only if further battery development and cost reductions occur in concert with EPRI's and the utility industry's aggressive leadership of the GCHEV initiative," says Graham.

Adds SCE's Kjaer, "Any grid-connected technology could use these advanced batteries. To help bring down their cost, we want to start to create a volume base with various nonvehicle applications. We are hopeful that if advanced battery technology can successfully migrate into multiple applications, the cost will come down to the point that grid-connected vehicles will be more attractive, both from a consumer economics perspective and from a business perspective."

Kjaer says the fact that advanced batteries are still too expensive for affordable, mass-market EVs obscures the tremendous progress in cost reduction made over the past decade. Today the cost of advanced batteries per kilowatthour of capacity is one-sixth the cost in 1990. On the basis of projected demand for the 2003 California ZEV mandate, the cost can be expected to be reduced by another two-thirds—to around $350/kWh—in just a few years. Kjaer stresses that this cost projection assumes neither technology standardization nor any stationary application market demand.

"Although getting below $350/kWh may be difficult from a chemistry perspective, the business rationale seems clear," says Kjaer. "Even $200/kWh, which is not inconceivable, is still expensive. What we need to recognize, however, is that this is expensive only relative to a mature technology and to an industry that has had a century to refine its product. We need to be a little more patient. We're dealing not with an evolutionary technology but with a revolutionary one. We need to recognize that electric transportation represents a fundamental shift in what we consume in transportation and conveyance technology. That fundamental societal shift is going to take some time. But it's absolutely critical that we begin to make that shift today and not continue to wait for some better future technology."

Plug-in hybrid fleets on the street

The GCHEV initiative is pursuing several efforts to demonstrate the economic and environmental value of grid-connected hybrids in fleet applications. In one, EPRI and the New York Power Authority are cosponsoring work with General Electric to develop an advanced hybrid propulsion system for heavy-duty vehicles; the system features a battery pack combined with an ultracapacitor and an internal combustion engine-generator. In another effort, EPRI and SCE are exploring the market potential for GCHEVs as passenger shuttle vans or as step vans for express package delivery. Meanwhile, an alliance that includes EPRI, Ford Motor, GE, NYPA, other New York utilities, and service vehicle manufacturers is developing detailed business analyses of GCHEV van and shuttle fleets for key commercial applications. Ford already manufactures chassis for vehicles that are built and assembled by other companies—for example, Grumman Olson Industries in the case of vans and Diamond Coach Corporation in the case of shuttles.

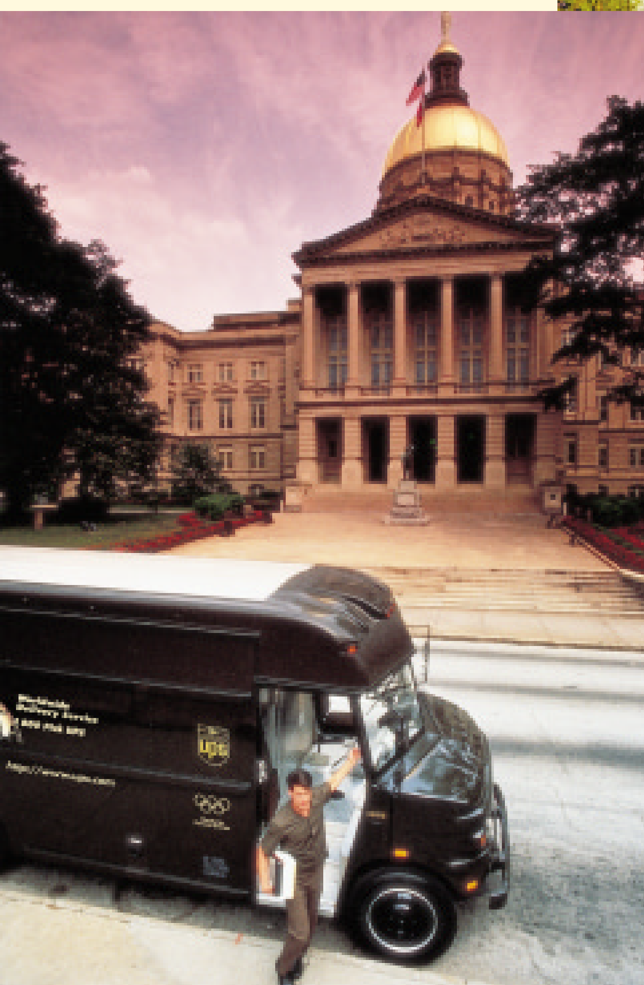
At a former U.S. Air Force base in New York, 500 long-life electric trucks for residential mail delivery are being built for the U.S. Postal Service in a joint venture between Baker Electromotive and Ford. Intended primarily for use in California, the short-range, aluminum-body trucks are equipped with lead-acid batteries and a drive system Ford developed for its electric Ranger pickup truck. The USPS has said it will order an additional 5500 delivery vehicles if the first 500 meet expectations. Although the initial lot are not hybrid EVs, this application could be well served by hybrids.

Another type of vehicle considered ideal for hybrids is the 2-ton delivery van widely used by the USPS, United Parcel Service, Federal Express, and other companies. NYPA has placed three 2-ton electric vans in service in New York City, where their successful operation encouraged the USPS to request bids for 20 more. Bart Chezar, electric transportation manager for NYPA, which is organizing a team of companies to bid for the contract, says hybrid versions of such delivery trucks could make electric van fleets more attractive in urban areas that are more spread out than New York. In such cities—for example, Atlanta and Los Angeles—the range of all-electric vans may be insufficient to meet typical daily driving cycles.

NYPA's near-term focus is to develop a 40-foot (12-m) hybrid electric transit bus. It is pursuing this goal in work with New York City Transit (NYCT), which, as an agency of the Metropolitan Transportation Authority (MTA), operates the largest fleet of transit buses in the country (more than 4000). Such vehicles represent possibly

Commercial, private, and government fleets are considered ideal early niche markets for GCHEVs because many fleet vehicles have fixed routes and return at day's end to a central location where they can be easily recharged. Potential GCHEV fleet applications include 2-ton delivery trucks, campus maintenance trucks, airport service vehicles, shuttle buses, and transit buses.

COURTESY SANTA BARBARA MTD, SANTA BARBARA ETI



COURTESY UNITED PARCEL SERVICE

DAVID MORIN

PHOTOS COURTESY SOUTHERN CALIFORNIA EDISON

A major supporter of electric transportation and of EPRI's GCHEV initiative, Southern California Edison has the largest corporate EV fleet in the country. It also operates an ISO-certified technical center where it conducts electric and hybrid propulsion system testing for cars, trucks, forklifts, buses, and other vehicles. With funding from the U.S. Department of Transportation, the center is converting a utility line truck to grid-connected hybrid operation, using an SCE-designed battery pack. SCE will field-test the truck to evaluate the electrical system and fleet-use impacts of large hybrid vehicles.

the most challenging application for any type of electric drive system. "Transit buses are tremendous energy hogs. They do a lot of acceleration and deceleration, put a lot of stress on the engine, and have huge heating and cooling systems and a lot of other electric components that add to the energy load," explains Chezar. "There are no batteries available that could supply the energy demand of an all-electric bus."

A prototype of the 40-foot hybrid bus was developed with GE and successfully operated. It had very low emissions, and compared with a conventional diesel bus, it offered significantly improved fuel economy and similar or better performance. The specifications developed in that effort were used by NYCT in a request for bids resulting in the production of 10 hybrid transit buses by Orion Bus Industries. These vehicles are currently in service, and another five buses are being manufactured by Nova Bus Corporation. Both the Orion and Nova buses use a drive system produced by Lockheed Martin Corporation. Meanwhile, NYCT awarded a contract to General Motors' Allison Transmission Division for retrofit hybrid electric drive systems to be installed as midlife replacement drives on diesel transit buses. The transit agency recently ordered 125 more hybrid electric buses from Orion, and its parent body, the MTA, has agreed to purchase another 250 in the future.

Chezar says that the 10 electric transit buses now in service, although built as grid-connected vehicles, are still primarily using their onboard generators to recharge their lead-acid batteries (designed mainly as power batteries to provide for frequent acceleration). In addition, every deceleration sends a surge of electricity back into the batteries from regenerative brakes. Use of the onboard generators has resulted in suboptimal, uneven charging that will shorten battery life. "If the batteries are properly charged overnight at the depot, they will last much longer," notes Chezar, adding that recharging infrastructure is being installed. The start-stop nature of urban bus driving generates heat in the batteries, which will also shorten their operating life.

Ultracapacitors provide a boost

NYCT's experience with hybrid electric buses has prompted the current effort involving GE, NYPA, and EPRI (as well as the New York State Energy Research and Development Authority) to develop an advanced hybrid energy storage system that includes an ultracapacitor. Says Chezar, "We've undertaken a comprehensive assessment of what can be done to make the next generation of hybrid electric buses better. We want them to be more efficient, and we want their emissions to be even lower. We also want to reduce the buses' overall weight so that passenger load does not have to be sacrificed to accommodate batteries and components. And finally, the buses need to be more cost-effective." Extensive analytical and laboratory test data on components were subjected to GE's highly regarded Six Sygma statistical analysis to identify the most cost-effective, efficient, and viable configuration.

Combining advanced batteries with an ultracapacitor, which can quickly store or discharge a substantial power pulse, makes it possible to design and size the batteries more for energy storage than for power, Chezar points out. "When a bus with this kind of system accelerates, power first comes from the ultracapacitor; once the bus gains speed, the battery takes over. The ultracapacitor acts as a buffer, allowing the flow of electricity into and out of the battery to be controlled. This prevents overheating and enables a smaller, more efficient engine with the potential for much lower emissions," he says.

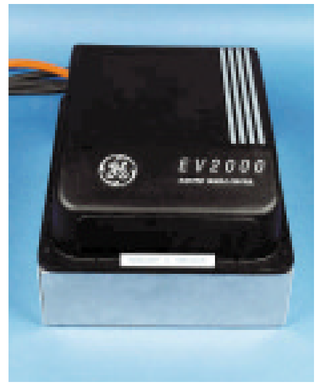
"Such an advanced hybrid energy storage system also enables the bus to operate in what we call stealth mode—that is, all-electrically in and around the depot and at stoplights and bus stops, without the engine," Chezar adds. "So most of the time, these advanced hybrid transit buses will be quiet and will have no emissions—not even hot air—coming from the back. They are a much better technology that people will be more inclined to use."

With the advanced hybrid drive program in its second phase, full-size components have been assembled in a 40-foot bus for testing, which is expected to be completed by early 2001. Chezar says that GE has made a commitment either to commercially produce the energy control system electronics or to license the technology to another manufacturer. Eventually, advanced battery technologies could be incorporated into the hybrid storage system, which also could be adapted for other fleet vehicle platforms.

Making grid-connected hybrids a reality

The 2003 mandate for zero-emission vehicles in California, which was forged by air quality regulators in political compromise with automakers and hence is unlikely to be further relaxed, has placed a short fuse on work by many companies to bring hybrid EVs to market. "Our plan with GE and NYPA is to have a 40-foot bus with the advanced propulsion system integrated and running by the summer of 2001, and we expect similar time frames for a grid-connected hybrid shuttle bus and a step van," says EPRI's Graham. "We believe that we can have grid-connected fleet vehicles in the marketplace around 2003 and that the grid-connected electric car market could evolve around 2007–2008."

The GCHEV initiative that EPRI is spearheading is leveraging approximately $2.5 million from its various cosponsors; EPRI itself has contributed about $350,000. Substantial participation from nonutility organizations—including GE, the California Air Resources Board, and the California South Coast Air Quality Management District—attests to the broad constituency that recognizes the importance of using electricity as a direct energy source, rather than as an intermediate form, to power transportation. For the long term, the substitution of electric drive and electricity storage technologies for petroleum-fueled, internal combustion–based vehicles is the only sustainable route to cleaner transportation for a substantially more crowded world in the future. It may also be a key solution in dealing with greenhouse gas emissions from vehicles.



COURTESY GENERAL ELECTRIC

This 100-kW energy management system, developed by General Electric, serves as the electronic interface between a set of ultracapacitors and a battery pack in an advanced hybrid energy storage system designed for use in transit buses and other heavy-duty vehicles. Testing of the hybrid system in a 40-foot (12-m) bus is expected to be completed by early 2001.

"You can't look at EVs, particularly the current generation, in isolation and say, 'Well, they're too expensive and you'll never get the cost down—they require too much technology,'" says SCE's Kjaer. "Today's technology is already migrating into the hybrids and fuel cell vehicles being developed for the future. You can't look at EVs as a one-model, one-cycle wonder. We need to be looking at this in terms of the next hundred years of electrodrive technology.

"There's a general consensus that about $2 billion to $2.5 billion has been spent on electrodrive technology for EVs thus far," he continues. "Although that is a lot of money, consider that one automaker alone has said it will spend $56 billion on advanced technology in the next three years. I don't think the $2.5 billion spent to this point has been wasted or been a failure. There are over 2000 EVs on the road that are amazing test beds. At SCE, we operate the largest EV fleet in the country. We know the technology works, and we know the investment to this point has also helped make hybrids a reality and will help make fuel cell vehicles a reality.

"The right philosophy is, the more EVs you get on the road today, the more hybrids and fuel cell vehicles you will sell in the future," Kjaer concludes. "That's because the more familiar people become with electrodrive in all the various applications, the more comfortable they will become with EVs as appliances that plug in and perform, thanks to the new fuel—electricity." ■

Background information for this article was provided by Robert Graham (rgraham@epri.com).

COURTESY ORION BUS INDUSTRIES

Ten diesel-electric hybrid transit buses produced by Orion Bus Industries are currently in service with New York City Transit, and the agency has ordered 125 more. The buses were built to specifications for a prototype developed earlier with support from the New York Power Authority.

In the Field

Demonstration and application of EPRI science and technology

Fuel Cell System Delivers for USPS in Alaska

The U.S. Postal Service and Alaska's Chugach Electric Association have given a stamp of approval to energy efficiency and environmental protection with the nation's first commercial fuel cell system operated as part of a utility grid. The 1-MW system, which EPRI cosponsored, is also the largest U.S. commercial fuel cell installation.

The fuel cell system ensures continuous power and heat at the Anchorage mail processing center, the major sorting and distribution point for mail sent into and out of Alaska. Operating 24 hours a day, 7 days a week, the center has approximately 425 employees and processes an average of 1.2 million pieces of mail a day.

Chugach Electric, a member-owned cooperative and Alaska's largest electric utility, installed and operates the fuel cell system for the USPS. Made up of five 200-kW fuel cells connected in parallel, the system is the primary source of power for the Anchorage postal facility. It is dispatched from Chugach's power control center, and any excess electricity it generates is fed into the utility grid. In addition to electricity, each of the fuel cells generates more than 700,000 Btu of heat per hour, which is used for heating the facility. This application increases the center's overall fuel efficiency.

New technology developed for the project by the Army Corps of Engineers' Construction Engineering Research Laboratory ensures that in the event of a grid outage, the fuel cells automatically switch to independent operation and continue to supply electricity to the facility. Thus the need for conventional uninterruptible power supplies and standby generators is eliminated.

The fuel cell system was inaugurated in a ceremony last August, at which U.S. Postmaster General Bill Henderson congratulated those involved in the project. "Clearly, this fuel cell installation will add to our ability to serve postal customers well throughout the great state of Alaska and also help us safeguard its unique environment," he said. Also attending the ceremony was U.S. Senator Ted Stevens of Alaska, who applauded both Chugach Electric and the USPS for a project that "opens the door to new and creative ways to produce energy in a cost-effective and clean manner." And Eugene Bjornstad, general manager of Chugach, noted that the project helps position the utility in the emerging competitive power industry because "fuel cells allow us to offer customers options."

The fuel cells are IFC PC25 units from International Fuel Cells, a subsidiary of United Technologies Corporation. In addition to Chugach, the USPS, and EPRI, funders of the $5.5 million system included the U.S. Department of Defense and the Cooperative Research Network of the National Rural Electric Cooperative Association.

■ *For more information, contact Ammi Amarnath, aamarnat@epri.com, 650-855-2548.*

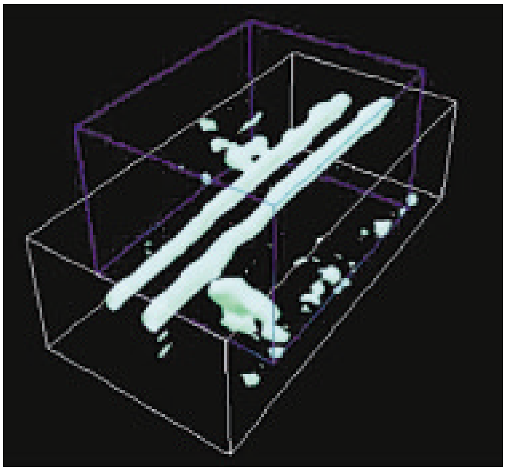
COURTESY INTERNATIONAL FUEL CELLS

Radar Produces 3-D Underground Images

An innovative radar system that can accurately locate underground objects and create three-dimensional images of them has been developed by scientists from Schlumberger Corporation and EPRI, with additional support from the Gas Technology Institute (formerly the Gas Research Institute).

A key enhancement of the new ground-penetrating radar system is advanced image-processing software. This software enables utilities, construction companies, and others involved with underground infrastructure to create precise 3-D maps of the complex array of electric, gas, water, and communications lines lying beneath today's busy city streets. Armed with this information, the companies can better manage, maintain, and build underground networks that serve downtown business centers and residential areas.

"The growing economy has placed new pressures on underground utility infrastructure," says Ralph Bernstein, an EPRI



CART image of a transmission line conduit system beneath a New York City street

technical leader in the distribution and metering area. "This system will help energy companies improve underground planning and maintenance as well as avoid disruptive construction accidents."

The system is based on existing ground-penetrating radar technology, which uses a transmitting antenna to send high-frequency radar pulses into the ground. When a pulse hits a buried object, such as a rock or a metal or plastic pipe, it is reflected back to the surface, where it is picked up by a receiving antenna. As a van moves the radar system along the ground surface, data on the timing of pulses and echoes are collected. The advanced image-processing software uses this information to create realistic 3-D images of underground objects.

In field demonstrations in New York City, San Diego, and other urban areas, the system—called the CART (Computer-Aided Radar Tomography) Imaging System—has demonstrated that it can create 3-D images of objects as deep as 10 feet (3 m) under most conditions. It can also acquire 3-D data 10 times faster than earlier systems.

The Schlumberger-EPRI team worked with two small companies, Witten Technologies and Malå Geoscience, in developing the new system. Schlumberger and Dycom Industries plan to offer utility mapping services with CART systems.

■ *For more information, contact Ralph Bernstein, rbernste@epri.com, 650-855-2023.*

SNCR Controls NO_x in Tests With High-Sulfur Coal

In a successful six-week demonstration program hosted by American Electric Power, selective noncatalytic reduction (SNCR)—a urea-based technology for controlling emissions of nitrogen oxides at fossil fuel plants—was tested on a large boiler firing high-sulfur coal.

SNCR, for which EPRI received the original patent, had achieved NO_x reduction levels of 30–50% on relatively small boilers, but before the testing at AEP, there had been no long-term operating experience with boilers larger than about 160 MW. Moreover, virtually all applications using medium- and high-sulfur coal had experienced troublesome impacts downstream of the reagent injection site, primarily plugging of air preheaters with ammonium bisulfate. Thus EPRI wanted to sponsor a test program to address both the scale-up of SNCR and the process's balance-of-plant impacts in operation with high-sulfur (>2.5%) coal.

COURTESY AMERICAN ELECTRIC POWER

The test program was conducted at AEP's Cardinal unit 1, a 600-MW cell-fired boiler retrofitted with low-NO_x burners and firing coal with a nominal sulfur content of 3.8%. During the tests, the SNCR system was operated in automatic mode under normal load dispatch conditions. It maintained NO_x levels corresponding to reductions of 25% at full load and 30% at low load, while maintaining ammonia slip at less than 5 parts per million. A modest increase in air preheater pressure drop resulted from ammonium bisulfate deposition during the demonstration; the pressure drop reverted to the baseline value after three weeks of operation without urea injection.

In addition to EPRI and AEP, the test program was supported by several other EPRI members, the Ohio Coal Development Office, the U.S. Department of Energy, and Fuel Tech, Inc. The program is documented in a recent EPRI technical report (1000154).

Says Jeff Stallings, EPRI manager for NO_x emissions control, "As a result of this work, it was concluded that for some large-scale coal-fired boilers, SNCR might be a candidate technology as a supplement or alternative to selective catalytic reduction, offering NO_x reductions in the range of 30%." But, he continues, "when firing medium- to high-sulfur coal, the need for periodic off-line water washing should be taken into account. SNCR remains a niche technology that can be used either separately or in conjunction with other approaches for reducing NO_x."

■ *For more information, contact Jeff Stallings, jstallin@epri.com, 650-855-2427. To order report 1000154, call EPRI Customer Service, 800-313-3774.*

Technical Reports & Software

To place an order, call EPRI Customer Service at 800-313-3774 or 650-855-2121, and press 1 for software or 2 for technical reports. Target funders can download an Acrobat PDF file of a technical report by searching for the report number on EPRI's Web site (www.epri.com).

Energy Delivery

UPS Substation™: Control System Feasibility Evaluation
1000002
Target: Substation Assets Utilization
EPRI Project Manager: R. Schainker

Guidelines for the Life Extension of Substations: 2000 Update
1000031
Target: Substation O&M
EPRI Project Manager: S. Eckroad

Guidelines for the Life Extension of Substations (CD-ROM Version): 2000 Update
1000032
Target: Substation O&M
EPRI Project Manager: S. Eckroad

Evaluation of Premolded and Field-Assembled Joints for Extruded Dielectric Medium-Voltage Cables
1000045
Target: Underground Distribution Infrastructure
EPRI Project Manager: B. Bernstein

Advanced Composites for Utility Applications, Phase 3: Polymer Composite Transformer Tank (500 kVa)
1000046
Target: Underground Distribution Infrastructure
EPRI Project Manager: B. Bernstein

Injection-Molded Lineworkers Gloves
1000047
Target: Distribution Systems
EPRI Project Manager: B. Bernstein

Controlled Release of Fungicides for Wood Pole Applications
1000048
Target: Distribution Systems
EPRI Project Manager: B. Bernstein

Five-Wire Distribution System Demonstration Project
1000074
Target: Distribution Systems
EPRI Project Manager: H. Ng

Switching Practices Survey: Toward Improved Safety and Reliability
1000123
Target: Substation O&M
EPRI Project Manager: P. Dessureau

Proceedings: Substation Equipment Diagnostics Conference VIII
1000124
Target: Substation O&M
EPRI Project Manager: S. Lindgren

SF_6 Gas Condition Assessment and Decontamination
1000131
Target: Substation O&M
EPRI Project Manager: B. Damsky

Nonintrusive Predictive Distribution Maintenance: Radio Frequency Interference/ Ultrasonic Surveys of Distribution Lines
1000194
Target: Distribution Systems
EPRI Project Manager: H. Ng

Rendering [Line Inspections] Nonhazardous: Unmanned Airborne Vehicle
1000712
Targets: Disaster Planning and Mitigation Technologies; Overhead Transmission
EPRI Project Managers: M. Ostendorp, R. Lings

LoadDynamics™: Model for Developing Probabilistic Forecasts of Load Conditions
Version 2.0 (Windows 95, 98, NT); AP-109732-R1
Targets: Distribution Systems; Underground Distribution Infrastructure
EPRI Project Manager: S. Chapel

Environment

Polycyclic Aromatic Hydrocarbons and the Immune System: A Review
TR-113375
Target: MGP Sites
EPRI Project Manager: L. Goldstein

Evaluation of Biocriteria as a Concept, Approach, and Tool for Assessing Impacts of Entrainment and Impingement Under Section 316(b) of the Clean Water Act
TR-114007
Target: Section 316(a) and (b) Fish Protection Issues
EPRI Project Manager: D. Dixon

Evaluation of Technologies to Remove Light Nonaqueous-Phase Liquids in the Subsurface
TR-114754
Target: MGP Site Management
EPRI Project Manager: A. Quinn

Female Breast Cancer Feasibility Study: A Comparison of Magnetic Field Exposures in a Garment Manufacturing Facility and Electric Utility Work Environments
TR-114845
Target: Occupational Health Assessment
EPRI Project Manager: K. Ebi

PISCES Water Characterization Field Study
TR-114966
Target: Plant Multimedia Toxics Characterization (PISCES)
EPRI Project Manager: P. Chu

Service Center Site Assessment
1000065
Target: T&D Soil and Water Issues
EPRI Project Manager: M. McLearn

Study of the Potential for Electric Power Facilities to Affect Use of the Global Positioning System
1000085
Target: Electromagnetic Compatibility
EPRI Project Manager: F. Young

Peer Review of the Watershed Analysis Risk Management Framework (WARMF)
1000252
Target: TMDL, Watershed, and Ecosystem Issues
EPRI Project Manager: R. Goldstein

PISCES Power Plant Chemical Assessment Model, Version 3.1: User Manual Addendum
1000335
Target: Plant Multimedia Toxics Characterization (PISCES)
EPRI Project Manager: P. Chu

Fossil and Renewable Generation

Hydro Life Extension Modernization Guides, Vol. 2: Hydromechanical Equipment
TR-112350-V2
Targets: Hydropower Operations and Asset Management; Relicensing Forum; Plant Maintenance and Life Management
EPRI Project Manager: D. Gray

Volatility of Aqueous Acetic Acid, Formic Acid, and Sodium Acetate
TR-113089
Target: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: B. Dooley

Steel Penstock Coating and Lining Rehabilitation (Hydropower Technology Roundup, Vol. 3)
TR-113584-V3
Target: Hydropower Operations and Asset Management
EPRI Project Manager: M. Blanco

Pulverizer Interest Group: Research Activities, June 1996 to December 1999
TR-113825
Target: Coal Boiler Performance/Combustion NO_x Control
EPRI Project Manager: R. Brown

Guidelines for Reducing the Time and Cost of Turbine Generator Maintenance Overhauls and Inspections, Vol. 3 (Balancing and Alignment) and Vol. 4 (Blade/Bucket Procurement and Refurbishment)
TR-114128-V3, -V4
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Manager: A. Grunsky

Productivity Improvement Handbook for Fossil Steam Power Plants, Second Edition
TR-114910
Targets: 16 fossil targets
EPRI Project Manager: A. Armor

Interim Guidelines for In Situ Visual Inspection of Inlet and Outlet Turbine Stages, Part 2: Remote Visual Inspection
TR-114961
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Manager: T. McCloskey

FERC/EPRI Tainter Gate Workshop
1000054
Target: Dam and Civil Works Issues
EPRI Project Manager: M. Bahleda

Conversion to Deaerated Stator Cooling Water in Generators Previously Cooled With Aerated Water: Interim Guidelines
1000069
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Manager: J. Stein

Association of State Dam Safety Officials (ASDSO)/EPRI Spillway Gate Workshop (January 2000)
1000101
Target: Hydropower Operations and Asset Management
EPRI Project Manager: M. Bahleda

Cardinal 1 Selective Noncatalytic Reduction (SNCR) Demonstration Test Program
1000154
Target: Postcombustion NO_x Control
EPRI Project Manager: J. Stallings

MERLIN Analysis of Leesville Dam
1000165
Target: Hydropower Operations and Asset Management
EPRI Project Manager: M. Bahleda

Testing of Stator Windings for Thermal Aging
1000376
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Manager: J. Stein

Nuclear Generation

PWR Secondary Water Chemistry Guidelines, Revision 5
TR-102134-R5
Target: Nuclear Power
EPRI Project Manager: P. Frattini

PWR Primary-to-Secondary Leak Guidelines, Revision 2
TR-104788-R2
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

Steam Generator Tube Integrity Risk Assessment, Vol. 1 (General Methodology) and Vol. 2 (Diablo Canyon Application)
TR-107623-V1, -V2
Target: Nuclear Power
EPRI Project Manager: M. Merilo

Cooperative IASCC Research Program: CIR-CD Version 0.06
AP-108557-R5CD
Target: Nuclear Power
EPRI Project Manager: L. Nelson

Time-Limited Aging Analysis Report for the Edwin I. Hatch Nuclear Power Plant
TR-110042
Target: Nuclear Power
EPRI Project Manager: J. Carey

Failure Root Cause of PCI Suspect Fuel Rods From Kernkraftwerk Leibstadt Reactor, Parts 1 and 2
TR-111065-P1, -P2
Target: Nuclear Power
EPRI Project Manager: S. Yagnik

Understanding of Thermal Diffusivity Recovery With Thermal Annealing: Addendum—Quantitative Electron Optical Characterizations of Fuel Samples
AD-111068
Target: Nuclear Power
EPRI Project Manager: S. Yagnik

Assessment of the Effects of Flow and Subcooling on Y-Pattern Unbalanced Globe Valve Thrust Requirements
TR-111595
Target: Nuclear Power
EPRI Project Manager: J. Hosler

Testing of Power Plant Cables in the Presence of an Ionizable Gas: Demonstration in a Simulated Plant Environment
TR-112235
Target: Nuclear Power
EPRI Project Manager: G. Toman

Optimum Discharge Burnup for Nuclear Fuel: A Comprehensive Study of Duke Power's Reactors
TR-112571
Target: Nuclear Power
EPRI Project Manager: O. Ozer

High-Range Radiation Monitor Cable Study: Phase 2
TR-112582
Target: Nuclear Power
EPRI Project Manager: G. Toman

Routine Preventive Maintenance Guidance for ABB K-Line Circuit Breakers
TR-113736 (revises NP-7410-V1P1)
Target: Nuclear Power
EPRI Project Manager: J. Sharkey

Pump Troubleshooting, Vol. 1
TR-114612-V1
Target: Nuclear Power
EPRI Project Manager: M. Pugh

Cracking in Vessel Head Adaptors: Analysis of Crack Growth Rate Reports (PWR Materials Reliability Project)
TR-114757
Target: Nuclear Power
EPRI Project Manager: R. Pathania

EPRI Baffle Bolt Project Summary
AP-114779-CD
Target: Nuclear Power
EPRI Project Manager: L. Nelson

Review of Phosphorous Segregation and Intergranular Embrittlement in Reactor Pressure Vessel Steels (PWR Materials Reliability Project)
TR-114783
Target: Nuclear Power
EPRI Project Manager: S. Rosinski

Welding and Repair Technology for Power Plants: Fourth RRAC International Conference
TR-114858-CD
Target: Repair and Replacement Applications Center Program
EPRI Project Managers: S. Findlan, D. Gandy, K. Coleman

Joint Owners Baffle Bolt Program
AP-114929-CD
Target: Nuclear Power
EPRI Project Manager: L. Nelson

Analytical Electron Microscopy Characterization of Upper Free Span IGA and SCC in Steam Generator Tubing From Oconee 1, 2, 3
TR-114980
Target: Nuclear Power
EPRI Project Manager: A. McIlree

Routine Preventive Maintenance Guidance for Westinghouse DHP Circuit Breakers
1000010 (revises NP-7410-V2P3)
Target: Nuclear Power
EPRI Project Manager: J. Sharkey

Evaluation of HCR Methodology Implementation in PSA and Control Room Human Factors Review for José Cabrera Nuclear Power Plant
1000028
Target: Nuclear Power
EPRI Project Manager: F. Rahn

Crack Growth of Alloy 182 Weld Metal in PWR Environments (PWR Materials Reliability Project)
1000037
Target: Nuclear Power
EPRI Project Manager: R. Pathania

Condensate Pump Application and Maintenance Guide
1000052
Target: Nuclear Power
EPRI Project Manager: M. Pugh

Bolt Preload Stress for ANSI Raised-Face Flanges Using Spiral-Wound Gaskets (Sealing Technology and Plant Leak Reduction Series)
1000066
Target: Nuclear Power
EPRI Project Manager: J. Jenco

Lessons Learned From Implementing RI-IST Programs
1000094
Target: Nuclear Power
EPRI Project Manager: F. Rahn

Dose Rate and Coolant Chemistry Data at PWRs Operating With Alternative Primary Coolant Chemistry
1000153
Target: Nuclear Power
EPRI Project Manager: H. Ocken

Losses of Off-Site Power at U.S. Nuclear Power Plants—Through 1999
1000158
Target: Nuclear Power
EPRI Project Manager: F. Rahn

Oconee Electrical Component Integrated Plant Assessment and Time-Limited Aging Analyses for License Renewal, Revision 1
1000174
Target: Nuclear Power
EPRI Project Manager: J. Carey

Zinc Addition at the Palisades PWR to Reduce Shutdown Dose Rates
1000190
Target: Nuclear Power
EPRI Project Manager: H. Ocken

Condensate Filter/Demineralizer Qualification and Testing in Precoat Application at Comanche Peak Steam Electric Station
1000199
Target: Nuclear Power
EPRI Project Manager: S. Bushart

Fire Barrier Penetration Seal Handbook
1000213
Target: Nuclear Power
EPRI Project Manager: R. Kassawara

Rod Bundle Heat Transfer for PWRs at Operating Conditions
1000215
Target: Nuclear Power
EPRI Project Manager: P. Frattini

Evaluation of Zinc Addition in Cycle 13 at Farley Unit 2
1000251
Target: Nuclear Power
EPRI Project Manager: R. Pathania

SysMon 2.0: Templates for System Monitoring by System Engineers
Version 2.0 (Windows 95, 98, NT); 1000261
Target: Nuclear Power
EPRI Project Manager: T. Eckert

Retail and Power Markets

Cool Storage Technology Guide
TR-111874
Target: Residential and Commercial Business Development
EPRI Project Manager: J. Kesselring

Strategic Overview of Distributed Resources
TR-114273
Targets: Distributed Resources Business Strategy Development; Using DR to Create Retail Business Strategic Advantage; Market Research and Tools for Retail Energy Services
EPRI Project Manager: D. Herman

Strategies for Providing Distributed Resource Services to Distribution Companies
TR-114275
Targets: Distributed Resources Business Strategy Development; Using DR to Create Retail Business Strategic Advantage; Market Research and Tools for Retail Energy Services
EPRI Project Manager: D. Herman

Light Trespass Research
TR-114914
Target: Residential and Commercial Business Development
EPRI Project Manager: J. Kesselring

Long-Term Performance of Screwbase Compact Fluorescent Lamps
TR-114923
Target: Residential and Commercial Business Development
EPRI Project Manager: J. Kesselring

Voltage Unbalance: Power Quality Issues, Related Standards, and Mitigation Techniques
1000092
Target: New Electric Motor/Drive Markets and Solutions
EPRI Project Manager: B. Banerjee

Residential Duct Sealing Cost-Benefit Analysis
1000102
Target: Residential and Commercial Business Development
EPRI Project Manager: J. Kesselring

Electrotechnologies in Metal Heat Treating Systems: Marketing Kit
1000136
Target: Materials Fabrication Industry
EPRI Project Manager: L. Svendsen

UV Curable Coatings: Marketing Kit
1000138
Target: Materials Fabrication Industry
EPRI Project Manager: L. Svendsen

Nonferrous Metal Melting: Marketing Kit
1000140
Target: Materials Production Industry
EPRI Project Manager: L. Svendsen

Contract Evaluator
Version 1.20 (Windows 95, 98, NT); AP-113198-P2R2
Target: Asset and Risk Management
EPRI Project Manager: A. Altman

Generation Asset Evaluator
Version 1.20 (Windows 95, 98, NT); AP-113198-P3R2
Target: Asset and Risk Management
EPRI Project Manager: A. Altman

Project Evaluator
Version 1.20 (Windows 95, 98, NT); AP-113198-P4R2
Target: Asset and Risk Management
EPRI Project Manager: A. Altman

Risk Manager
Version 1.20 (Windows 95, 98, NT); AP-113198-P1R2
Target: Asset and Risk Management
EPRI Project Manager: A. Altman

Strategic Science and Technology

In Situ Measurement of Residual Surface Stresses
TR-109717
Program: Strategic Science and Technology
EPRI Project Managers: A. McIlree, B. Syrett

Iron-Based Metallic Interconnects for Reduced-Temperature Solid Oxide Fuel Cells
TR-114131
Program: Strategic Science and Technology
EPRI Project Manager: W. Bakker

Corrosion Control Using Regenerative Biofilms That Secrete Antimicrobials and Corrosion Inhibitors
TR-114824
Program: Strategic Science and Technology
EPRI Project Manager: B. Syrett

Steam Chemistry: Interaction of Chemical Species With Water, Steam, and Materials During Evaporation, Superheating, and Condensation
TR-114837
Program: Strategic Science and Technology
EPRI Project Manager: B. Dooley

Measurement of Residual Stresses by Photothermal Method
1000156
Program: Strategic Science and Technology
EPRI Project Managers: R. Pathania, B. Syrett

Electrokinetic Removal of Arsenic From Contaminated Soil: Experimental Evaluation
1000203
Program: Strategic Science and Technology
EPRI Project Manager: M. McLearn

Advanced Coating Development for Gas Turbine Components
1000298
Program: Strategic Science and Technology
EPRI Project Manager: V. Viswanathan

EPRI Events

January 2001

10–12
PWR and BWR Plant Chemistry
San Antonio, Texas
Contact: Barbara James, 707-829-3500

15–17
Balance-of-Plant Heat Exchanger NDE and Condition Assessment for Engineers
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

15–19
Electrohydraulic Controls Workshop and Steam Turbine Generator Users Group
New Orleans, Louisiana
Contact: Linda Parrish, 704-547-6061

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

16–18
Modifying and Maintaining Structures and Conductors in Transmission Line Uprating
Haslet, Texas
Contact: Gayle Robertson, 817-439-5900

16–18
Utility Generator Predictive Maintenance and Refurbishment
New Orleans, Louisiana
Contact: Barbara McCarthy, 650-855-2127

22–24
Pressure Relief Device Users Group
Orlando, Florida
Contact: Linda Parrish, 704-547-6061

22–25
AK/AKR and Magne-Blast Circuit Breaker Users Group
New Orleans, Louisiana
Contact: Linda Parrish, 704-547-6061

30–February 1
Heat Rate Improvement in a Deregulated Environment
Dallas, Texas
Contact: Barbara McCarthy, 650-855-2127

February

5–9
Infrared Thermography: Level 1
Kingston, Tennessee
Contact: Sherryl Stogner, 704-547-6174

5–9
NDE Instructor Training
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

18–21
Substation Equipment Diagnostics Conference
New Orleans, Louisiana
Contact: Marjorie Morales, 650-855-2254

19–23
NDE of High-Energy Piping
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

21–22
Fluid Sealing Technology Working Group
Charlotte, North Carolina
Contact: John Jenco, 704-547-6054

March

5–9
Visual Examination: Level 1
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

12–16
Advanced Structural Analysis and Design Methods for Electric Power Lines
Haslet, Texas
Contact: Gayle Robertson, 817-439-5900

April

16–27
Ultrasonic Examination: Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

30–May 4
NDE for Engineers
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

May

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

16–18
CEM (Continuous Emissions Monitoring) Users Group
Charlotte, North Carolina
Contact: Barbara McCarthy, 650-855-2127

June

4–5
Containment Inspection: Visual Examination, Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

4–6
The Smart Solution: Conference on Industrial and Recreational Transportation
La Jolla, California
Contact: Laura Ramos, 650-855-7919

6–8
ASME Section XI Flaw Evaluation
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

11–15
Ultrasonic Examination: Level 3
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

12–14
PQA 2001 North America: Riding the Rivers of Change
Pittsburgh, Pennsylvania
Contact: Barbara McCarthy, 650-855-2127

18–22
NDE Technical Skills Training: Level 3 Basic/Specific
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

19–22
EPRI-IAEA Maintenance Optimization Technical Specialists Meeting
Charlotte, North Carolina
Contact: Martin Bridges, 704-547-6175

25–29
International Low Level Waste Conference and ASME-EPRI Workshop
Orlando, Florida
Contact: Barbara McCarthy, 650-855-2127

25–29
Visual Examination: Level 3
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

July

9–18
IGSCC Detection
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

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