SPRING 2012

EPRI JOURNAL

ELECTRIC POWER RESEARCH INSTITUTE

Power Plants

Preparing for Long Life—*or the Afterlife*

ALSO IN THIS ISSUE:

ELECTRIC POWER
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Art: Cover and pages 6, 10, and 20 by Craig Diskowski/Edge Design.

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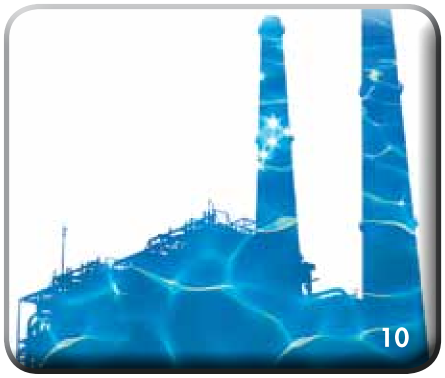

VIEWPOINT

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VIEWPOINT

by Mike Howard, President and CEO, EPRI

Scouting a World of Innovation

There's a world of innovation out there; only a small fraction of it begins and ends in the electricity sector. Some parts of it sit neglected in back alleys or dim corners of science and technology. Other parts are targeted for national defense or telecommunications, while applications in the world of electricity are overlooked.

The interconnected world is smaller than ever, and floods of information are available with a click or a keystroke. But the world of innovation is bigger, and it's moving faster. If EPRI is going to help drive innovation, we need to map it and understand it in a systematic way—a big challenge as more people pursue innovation in more places and in more ways than ever before.

But we must do more than put pins on a map. We must better connect innovations outside the electricity sector to our needs in technology, operations, and planning—and we must apply innovations effectively and creatively.

In 2011, as part of our Technology Innovation program, we took an earlier EPRI effort to scout innovation and launched a more integrated and more muscular initiative. In 2012, we are deploying 22 of our leading scientists and technologists as scouts—around the world, inside and outside the electricity sector—to accomplish several objectives:

- Help fill the pipeline of ideas that can become part of EPRI's research, development, and demonstration (RD&D) programs, including those in our Annual Research Portfolio, supplemental projects, and Technology Innovation areas.
- Identify innovative and novel concepts in science and technology that can be applied in addressing challenges, solving problems, and capitalizing on opportunities facing the electric power industry and its customers.
- Develop new collaboration opportunities to expand and enhance RD&D funding from diverse sources in government, academia, and industry. This can create greater opportunities for EPRI both to lead and to support broader RD&D.

- Help accelerate the development of technologies, up through commercialization.

The scouts will focus on innovations that have potentially high value to society, utilities, and their customers but that also have potential risks, including those associated with an innovation's commercial development and application. We are instructing the scouts not to shy away from risks but to choose innovations that combine the potential for both high value and high risk. The scouts are focused primarily on technologies at an early stage—ideas, concepts, and prototypes.

We often use two words to describe the kinds of innovations we're looking for: breakthrough and disruptive. Both point to the same idea—that the greatest potential value and greatest risks are tied to those innovations that can break through the limitations of today's technologies and systems, and that they can disrupt the status quo enough to bring us to new levels of performance, reliability, and efficiency.

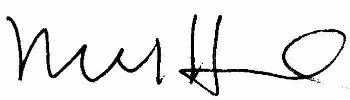
Currently, EPRI's innovation scouts are concentrating their work on more than 20 key areas of science and technology in our Technology Innovation program, as endorsed by EPRI's Research Advisory Committee. These areas include biotechnology; CO_2 capture; sensors and operations; grid transformation; renewable energy; nondestructive evaluation; emissions, health, and environment; materials for fossil and nuclear generation; materials for power delivery; and near-zero emissions.

The scouting will guide the development of white papers, reports, and technical briefs for EPRI members, our board of directors, our various advisory groups, and the public. This will spark the kinds of discussions that are needed to launch new work or to take innovations in one area and apply them to new areas.

We also seek opportunities for their work to broaden collaboration in exploring and funding innovation—opportunities for industry, national laboratories, universities, commercial interests, EPRI, and others to evaluate, test, demonstrate, and position technologies for commercialization. Our particular roles and our respective strengths—if effectively combined and channeled—may work together more effectively to move innovations from the lower to the higher end of the technology readiness scale.

"If we are 'good scouts,' I believe we can take silos of innovation and transform them into networks."

If we are "good scouts," I believe we can take silos of innovation and transform them into networks. We can help direct and channel innovation for the benefit of electricity consumers and society. There's a world of innovation out there, and not all innovations are looking for application in the electricity sector.



Michael W. Howard
President and Chief Executive Officer

SHAPING THE FUTURE

Innovative approaches to upcoming challenges

Smart Windows Near Demonstration

It's a sci-fi staple: The cyborg hero waves his hand in front of a small control panel, and the panoramic view from his mile-high penthouse above twenty-second-century Los Angeles disappears as the window goes opaque. In fact, the basic technology works today and is on the road to demonstration and commercialization by more than half a dozen companies. EPRI is collaborating with one of these, ITN Energy Systems, to develop a thin-film electrochromic (EC) coating on a flexible substrate that could be applied to retrofit conventional windows to "smart window" status.

The EC coating consists of several layers of materials, with the conductive outside layers acting as the anode and cathode for voltage applied across the layers. Application of voltage causes specific EC ions to move from an ion storage layer to the EC layer. This movement causes the window to darken when a small amount of voltage is applied in one direction and become transparent when the voltage is reversed. The transmission of light through the coating can vary from 5% to 80% and depends largely on the EC materials used—typically lithium or nickel ions and tungsten oxide. The switching speed is on the order of seconds to minutes, also depending on materials. Voltage need be applied only during the transition to or from the dark state, with no voltage required to maintain that state.

Costs and Benefits

Several companies are working on technology that could be incorporated in new window installations for around $100 per square foot of window area, without the capability for retrofit. Market assessments show that the cost would need to be less than $50 per square foot (an incremental coating cost of $10 per square foot) for widespread penetration of the technology. EPRI believes that a cost-effective retrofit could accelerate the technology's adoption. The ITN work focuses on developing roll-to-roll production of EC film on a flexible substrate, with the potential to reduce the cost to about $25 per square foot.

The payoff could be large. EPRI has estimated that EC windows could reduce a building's energy demand by up to 40% and save up to $300 billion over 20 years if implemented on a broad scale in the United States. Much of the savings would come from reduced cooling loads for commercial buildings and the ability to reduce the size of heating and air conditioning equipment in new construction. Adjustable transparency also could reduce lighting costs and provide more natural daylight illumination. Unlike currently available window modifications, such as low-emissivity (Low-E) coatings, EC technology provides dynamic response to changing weather conditions and can respond to pricing or event signals from the electric service provider as part of a smart grid system.

Roll-to-roll production unit for flexible electrochromic coatings

Continuing Research

The development work at ITN, assisted by EPRI and supported by a grant from the U.S. Department of Energy's Advanced Research Projects Agency—Energy (ARPA-E), has validated the roll-to-roll production process in the laboratory and tested samples in limited field applications. Recent efforts have focused on developing a larger production unit, optimizing the production controls for consistent quality, and improving the "clear" state transmittance of the EC coating. Results have been very encouraging, and new 500-cm^2 samples will be lab-tested by EPRI this year.

Utility energy-efficiency programs provide ideal platforms for large-scale demonstrations to assess performance in the real world. EPRI is working to establish a demonstration program when the technology is ready.

For more information, contact Ammi Amarnath, aamarnath@epri.com, 650.855.1007.

A Standard Plug-In Communications Interface for Grid-Connected Appliances

To enable demand response, individual devices (such as water heaters, thermostats, or other smart appliances) or the controls that manage the devices must be able to receive and respond to signals from the power system. Household appliances may then respond automatically to conditions on the system—for example, by moderating air conditioning during the hottest hours or delaying operation of the clothes washer during peak load periods. Governed by the homeowner's programmed preferences, this capability may provide consumers with important options to manage their power bills and help the grid through periods of high demand.

Different wireless or power line communications technologies and protocols can be used to communicate, depending on the utility's terrain, load density, and other factors. Several different approaches could be used—even within the same utility. Given the variety of communications technologies that must be supported, a practical way to accomplish connectivity is to provide consumers with a modular interface—a standardized socket like a USB port on a computer—that can link appliances with the utility system. A successful interface must be compatible with diverse utility systems, accommodate changing technologies, be practical for a variety of equipment manufacturers, and be economical and convenient for consumers. In a recent two-year cooperative project with manufacturers, communication system providers, and utilities, EPRI led an international effort to bring into common use an interface based on open standards.

The Modular Advantage

With consumer participation in load response programs still very low, the residential equipment industry has viewed smart grid–enabled appliances as a niche market and has been reluctant to provide mainstream products with these built-in capabilities. At the time of purchase, a consumer may not have interest in or access to utility load management programs. Products most likely to be included in utility programs, such as HVAC equipment and water heaters, typically are crisis buys, made with little time for thought. As a result, consumers are likely to choose lower-cost, non-communicating products that, once installed, will be excluded from smart grid participation for up to 30 years.

In the past, utilities have dealt with this by sending electricians to consumer homes to rewire the power feed to the conventional appliances. The result is high enrollment cost, load management behavior that is not user friendly, and responsibility for removing equipment if the consumer decides to leave the program.

Modular, plug-in interfaces avoid these problems, allowing manufacturers to produce smart grid-ready appliances at little additional up-front cost and ensuring that consumers can convert them easily when they are ready to participate in load management programs.

A Simple, Flexible Specification

EPRI led a collaboration of more than 65 companies that identified simple, easily extended design concepts that support existing standard protocols, including Internet Protocol (IP), OpenADR, and Smart Energy Profile. At the same time, mechanisms were identified to support basic demand-response functions directly in the module for appliances that do not have "intelligence" built in. The interface allows the use of more complex methods whenever higher-level functions are supported in the appliance.

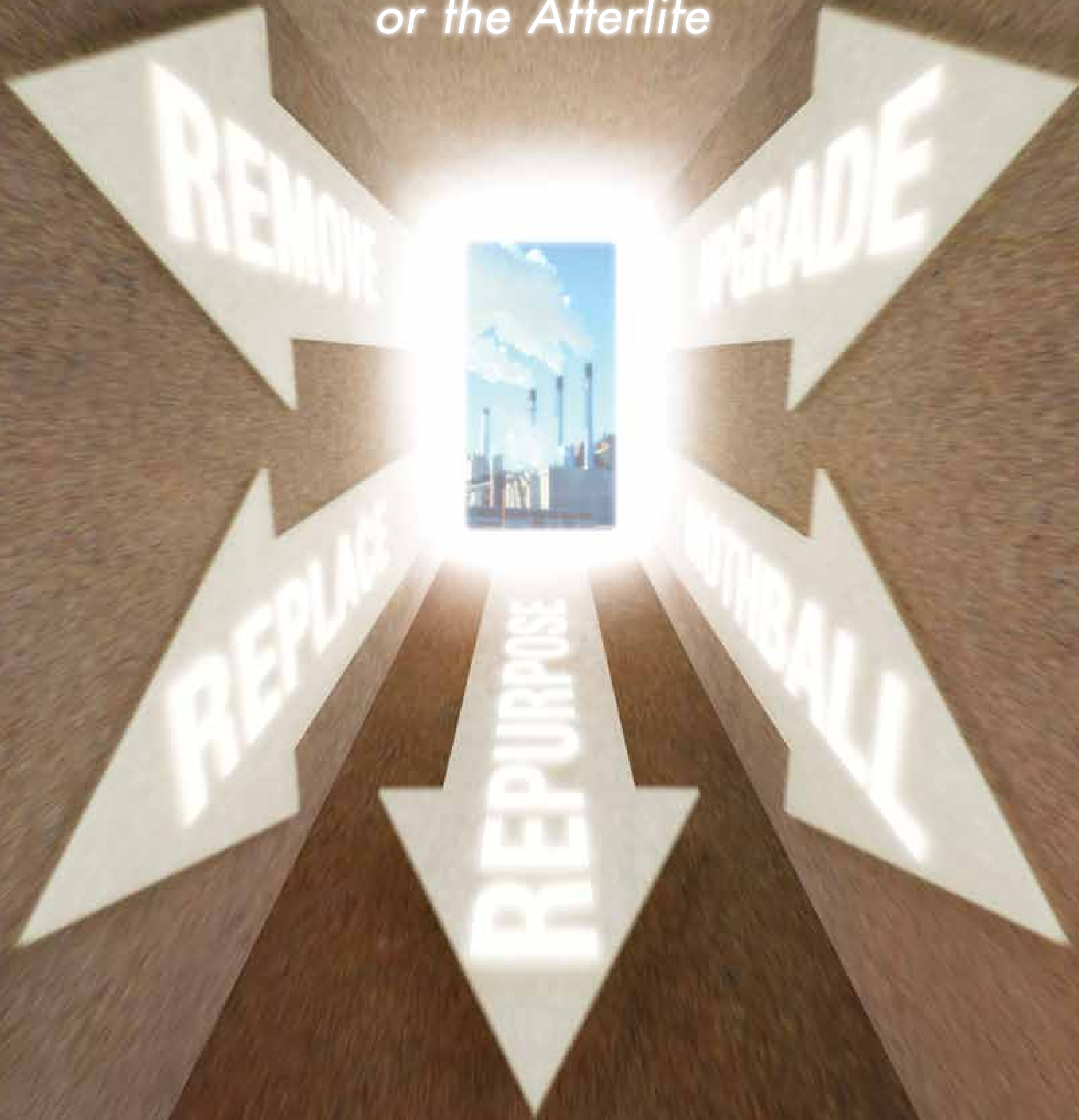
The modular interface can readily support a wide range of utility programs, including direct load control, time-of-use pricing, critical peak pricing, peak-time rebates, block rates, real-time pricing, and ancillary services. Further, the modules' functionality can be tailored to support the business drivers specific to a utility's region or service territory.

The project results were adopted by the National Institute of Standards and Technology (NIST) through the Home-to-Grid Domain Expert Working Group, which brought together contributions from EPRI and the Universal Smart Network Access Port (USNAP) Alliance to produce a single interface specification. EPRI helped lead this merging process, addressed public review comments, and produced final specification materials for the working group. In late 2011, NIST turned this work over to the Consumer Electronics Association to finalize an open standard, which will be designated ANSI/CEA-2045.

For more information, contact Brian Seal, bseal@epri.com, 865.218.8181.

POWER PLANTS

Preparing for Long Life
or the Afterlife



In January, Ohio-based power producer FirstEnergy announced that it would shutter six aging coal-fired power plants. The company said that bringing the plants into compliance with new environmental regulations, such as the U.S. Environmental Protection Agency's recently finalized mercury and air pollution rules, would be too costly.

FirstEnergy isn't alone. In the coming decade, many utilities will make tough decisions regarding their aging coal plants. "Power companies are facing pressures to consider the viability of these older plants," said Jeffrey Clock, a senior project manager in EPRI's Environment Sector. "Coal prices keep going up and gas prices keep coming down." What's more, new emission control requirements will drive up costs.

For a power plant, the lifespan is not always easy to foresee, and some plants may even have an "afterlife." The Pratt Street Power Plant, constructed in the early 1900s to run Baltimore's rail system, now houses restaurants, bars, and a bookstore. The building is a Baltimore tourist attraction, bringing new energy to the city's much-visited Inner Harbor.

Beyond bookstores or bars, the possibilities are many. Some plants will be torn down, while others may enter the afterlife to be sold, temporarily mothballed, or repowered. EPRI research is providing information that can be used to evaluate options and navigate the technical challenges that arise when a plant must be demolished or retooled.

THE STORY IN BRIEF

With changing generation economics and the adoption of new environmental regulations, many power companies are facing tough choices about what to do with their aging coal-fired power plants. EPRI is conducting new research to help electric utilities make these complex decisions.

Tough Choices

Revis James heads EPRI's Fleet Transition Initiative, launched in 2011 to provide members with insights and tools to help them decide how best to manage their generation fleets. A director in EPRI's Generation Sector, he has thought a lot about the factors that affect the viability of coal-fired power plants. Although EPRI has a great deal of experience addressing technology questions, research addressing fleet management is "a new area for us," James said.

For any business, economics is the driving factor. But determining a plant's economic viability is a complex calculation with many variables. For example, utilities need to examine the cost of coal compared with other fuels. "Because the world is electrifying quite quickly, there've been more and more exports of coal from the United States to other places," James said. That drives coal costs up. Natural gas, however, has remained relatively cheap.

Company executives also have to consider a plant's capabilities. Many older coal plants were designed to operate more or less continuously as "baseload" power generators. But with growing reliance on renewable energy sources such as wind, systems are having to become more flexible. When the wind stops blowing, power producers need to ramp up other generation units quickly to meet demand. Many older coal plants aren't able to respond rapidly. Those that can might require more maintenance than they would if they were run continuously, and such "cycling" operation can reduce a plant's efficiency.

Power companies must think beyond whether a plant is economically viable in today's market, factoring in future electricity demand and fuel costs as well. For example, if natural gas prices are projected to remain low, a coal plant that is only sporadically competitive may not be worth saving. However, if gas prices are expected to rise, a company may decide to mothball a plant, bringing it back on line when fuel prices warrant. Similarly, if future regulations are likely to make it more difficult to site, build, or finance new power plants, holding on to existing plants may be the more attractive option.

While mothballing a plant for years or even a decade can be costly, it may be less expensive than demolishing the existing structure and building a new plant in the future. "The mothballing costs have to be measured against future economic conditions and against the alternative of replacing the plant," James said.

Capability and balance across the fleet is another consideration. Electricity demand fluctuates by time of day and season, with daily peaks and valleys. If a company expects higher peaks or lower valleys, that could affect which plants are—or will be—economically viable. Just as hardware stores stock up on snow shovels in the winter, power companies may want to stock certain assets so they can provide solid baseload capacity but also serve peak demand in particular seasons. They can't close too many plant because they need to be able to keep up with demand. "Any decision has to take into account what is happening to the rest of the fleet," James said.

When is the right time to retire a coal plant? "You could get a lot of different answers, depending on when you ask that question and where you are in the United States," James said. The equation is complex and involves many uncertainties. Power producers will want to adopt a "least regrets" strategy, he added.

Upgrade Solutions

For older coal plants that can't meet new air pollution regulations, demolition may seem like an obvious choice. Older plants can't handle as much heat and pressure as new, advanced supercritical plants, so they are less efficient. But some plant components, such as the steam turbine, the cooling system, and the ash handling system, still may have value. For some utilities, retrofitting a plant may be a better choice than starting from scratch.

One way to increase the efficiency of a subcritical plant is to replace the boiler with one made of nickel alloys that can withstand higher temperatures and pressures. Rather than replacing the existing turbine, a supercritical "topping turbine" could be added. The topping turbine would lower the pressure to a level that the older turbine can handle, allowing its continued use. EPRI showed in a 2010 report (1019676) that this is theoretically possible. Although purchasing and installing a supercritical boiler and turbine isn't cheap, this option would make the plant more efficient and lower its emissions because less fuel would be burned and it would be possible to add emissions controls. "For some power plants, this could be a pretty good choice," said Jeffrey Phillips, a senior program manager in EPRI's Generation Sector.

A more radical retrofit would replace the entire plant with a higher-efficiency design; this could be a more attractive option than building a new plant on another site. The original site retains significant value. "A lot of assets that you would look for are already there," Phillips said, including transmission lines, cooling towers, coal delivery systems, and a trained workforce. What's more, the existing site already is licensed and permitted for power generation, and surrounding communities are used to having a power plant nearby, moderating the concern over community impacts that typically accompanies new sitings.

If natural gas prices stay low, however, replacing an existing coal plant with a natural gas combined-cycle plant may make more sense. This would involve replacing the coal boiler with a gas turbine and a heat recovery steam generator. Not every component would need to be replaced. The steam generator could feed into the existing steam turbine, and the plant could, of course, use the existing cooling towers and transmission lines.

End of the Line

Some power companies will decide, as FirstEnergy did, that a plant has reached the end of its usefulness. Clock pointed out that "nowadays, plant closure is not a straightforward demolition project." Significant technical and logistical challenges must be met, including environmental assessments, engineering challenges, health and safety issues, community outreach, and planning for the plant's workforce.

In 2010, EPRI formed the Power Plant Decommissioning and Site Closure Interest Group to provide a clearinghouse of information for power companies that may have to navigate these tricky waters. During the group's annual workshop and regular webcasts, members can discuss with experts and each other a variety of concerns. "Plant closings have been relatively rare, and there isn't a whole lot of experience in the industry," said Clock. "While there is a lot of experience with construction practices, there is much less that relates to demolition."

One group participant, Hawaiian Electric Company (HECO), has faced a particularly steep learning curve. "We had not dismantled and removed any generating units from our system in the last 40 years, and now we're dealing with four retired units," said Gary Hashiro, a project manager in HECO's power supply engineering department. "We're a small utility in the middle of the Pacific Ocean. The interest group has helped us use our limited funds effectively, increasing the likelihood of success in our generation removal projects."

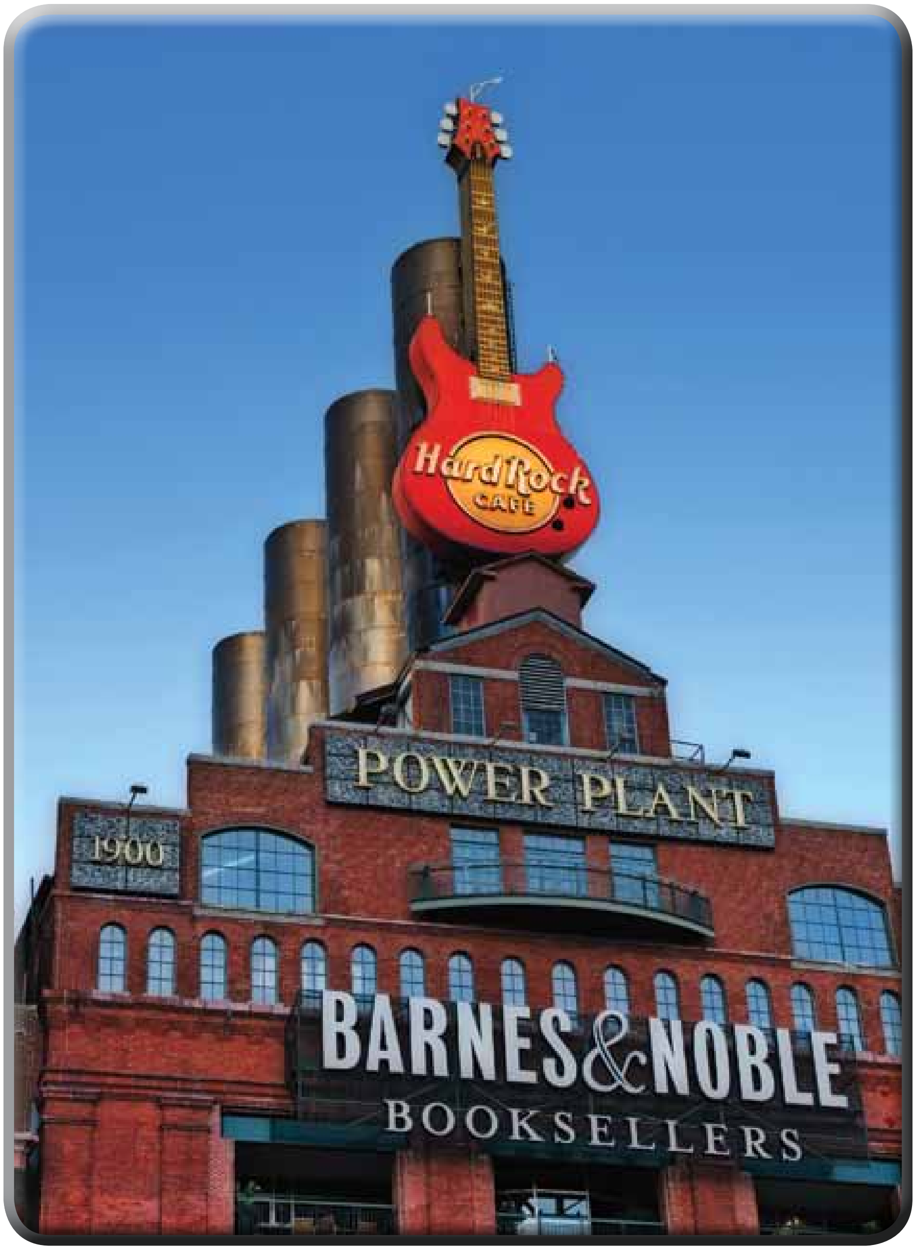
In 2010, Clock and his colleagues published a guidebook (1022263) that includes an annotated checklist of topics and issues that need to be addressed when closing a plant. While each project is unique, the report details common concerns and possible solutions regarding decommissioning. Because many coal plants are decades old, finding information on the plant's design and operation may prove challenging. "The people who built and operated these plants may not be around anymore," Clock said, "so engineers need to budget significant time to recreate plant construction, design, and operation information that may not have been retained within the corporate memory."

Employees' knowledge and familiarity with the plant are crucial, but keeping workers engaged also can prove challenging. "How do you continue to get productivity out of employees who know the plant is going to be shut down in a year or two? Will they start to jump ship, looking for other jobs or taking early retirement packages?" Clock asked. Another important issue is community outreach. "Community concerns are key, and it's not always easy to identify those up front," he said

Some decommissioning issues are less obvious. For example, a guest at a recent workshop discussed issues related to PCBs in solids—in everything from fiberglass insulation to paint—subjecting familiar compounds to fresh scrutiny. "Addressing PCBs in insulating oils has been accomplished by many members. But solid sources represent a new area of potential concern," Clock said.

Even a volatile scrap metals market can have a dramatic impact. "It turns out there's a lot of valuable material in these plants," Clock said. In some cases, the value of the scrap may nearly cover the demolition cost, but rushing a project or disposing of scrap metals at the wrong time can drastically reduce their value. "It's not unusual for a project to cost $15 million to $20 million," he said. "If you can offset a significant portion out of scrap metal, you really want to do it right."

"The future use of a site is really a key driver in how you go about the closure process," Clock said. For example, if a power company plans to construct a new power plant, less remediation and demolition will



Baltimore's Pratt Street Power Plant has a most unusual "afterlife." Built in the early 1900s to run the city's rail systems, the plant now houses restaurants, bars, and a bookstore.

be required than if it plans to sell the land for residential use. But deciding how to repurpose the site can be difficult. "It's the most significant issue that companies struggle with," Clock added. The decision can involve so many factors that a complete teardown often seems like the easiest option.

Clock's next project involves creating a database of plant closure projects that includes information from engineers and managers who have conducted decommissioning projects. Users will be able to reference plants similar to their own to get a better sense of what they should expect in terms of costs, regulatory issues, engineering concerns, and more.

As a result, while engineers and operators will face many decisions, the new forums, the growing banks of data, and the shared experiences can all be used to see more clearly how life can go on for some plants, how some plants will go away, and how some may live on in an afterlife their builders may never have imagined.

This article was written by Cassandra Willyard. Background information was provided by Revis James, rejames@epri.com, 202.293.6348; Jeffrey Phillips, jphillip@epri.com, 704.595.2738; and Jeffrey Clock, jclock@epri.com, 845.608.0642.

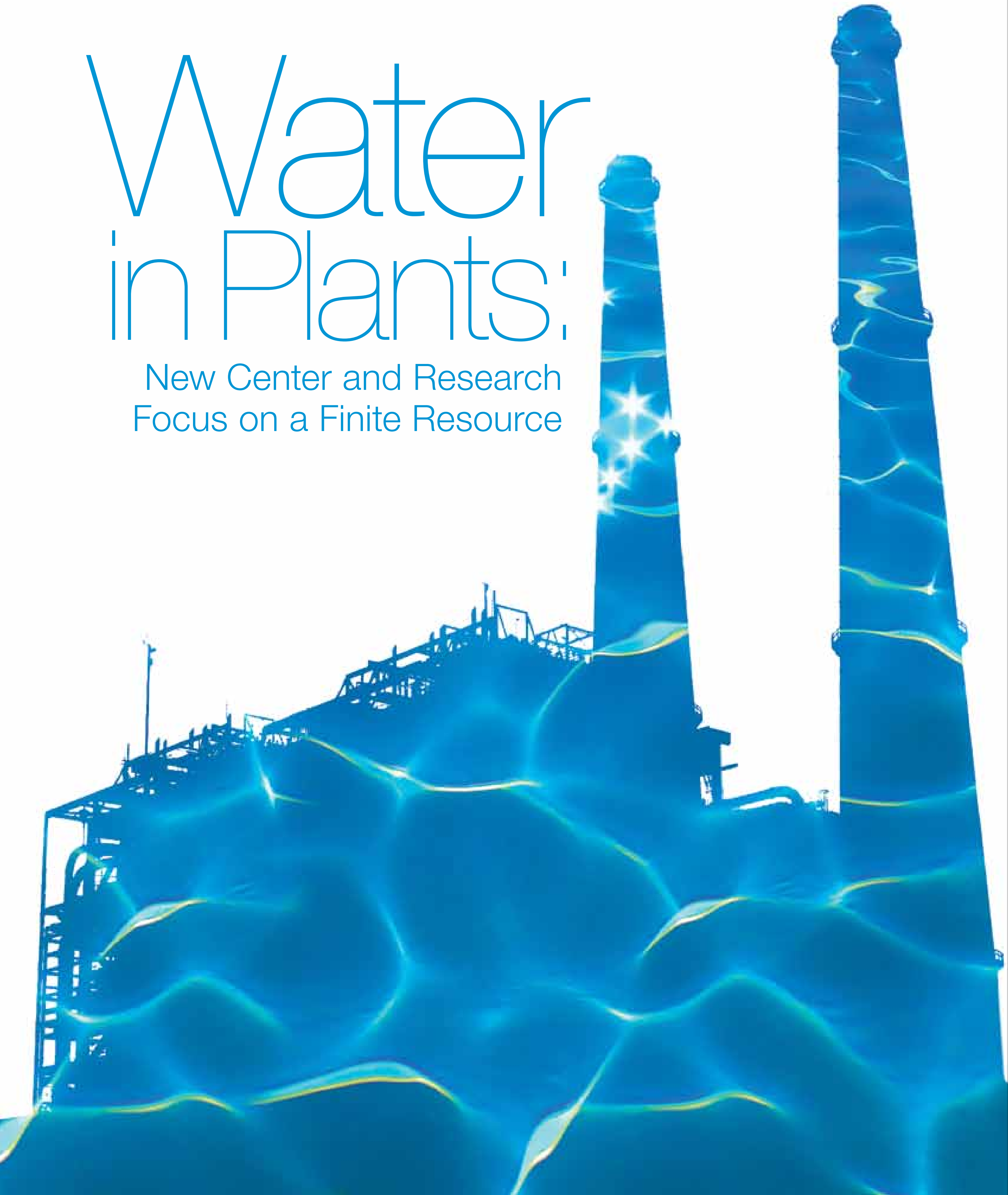
Revis James is a director in the Generation Sector. Before joining EPRI in 1992, he worked at ERIN Engineering & Research, Impell Corporation, and Bechtel Power Corporation. James earned B.S. degrees in nuclear engineering, electrical engineering, and computer science, and an M.S. in nuclear engineering from the University of California, Berkeley.

Jeffrey Phillips is a senior program manager in the Generation Sector, specializing in advanced generation research, including the CoalFleet for Tomorrow® program. Before joining EPRI in 2004, he worked on gasification plants for the Royal Dutch/Shell group, on hazardous waste gasification at Molten Metal Technology, and on combined-cycle plants at Fern Engineering. Phillips holds a B.A. in mathematics from Austin College, a B.S. in mechanical engineering from Washington University, and M.S. and Ph.D. degrees in mechanical engineering from Stanford University.

Jeffrey Clock is a senior project manager in the Environment Sector, focusing on investigation, remediation, and management of former manufactured gas plant (MGP) sites and on transmission and distribution environmental issues. He joined EPRI in 2008 after a 24-year career at Central Hudson Gas & Electric Corporation in environmental compliance, licensing, and site assessment and remediation. Clock received a B.S. degree in natural sciences from Bard College, an M.S. in biology from New York University, and an M.B.A. from Rensselaer Polytechnic Institute.

Water in Plants:

New Center and Research Focus on a Finite Resource



Electric power generation requires reliable access to large volumes of water, primarily for cooling of thermal power plants. This need comes at a time of declining supply, when even temperate climates are experiencing water constraints due to population growth, precipitation fluctuations, and changing demand patterns. A 2010 EPRI study found vulnerability to water shortages in all U.S. regions, with decreasing stream flows in some areas, declining groundwater levels, increasing surface water temperatures, and variable precipitation. Such water constraints could affect future generation technology selection, plant siting, and plant operation.

THE STORY IN BRIEF

Optimizing the consumption, use, and discharge of water represents a significant challenge for power generation facilities. A new research center and advanced research across several fronts are aimed at finding new technologies and methods to improve water use efficiency, lower withdrawal levels, and reduce pollutant discharges.

Water Research Center

A major focal point for future research will be the new Water Research Center, being developed by Georgia Power (a subsidiary of Southern Company) in collaboration with EPRI and supported by 12 electric generating companies. Located at Georgia Power's Plant Bowen, near Cartersville, Georgia, the center will provide insights on best practices for sustainable water management and meeting wastewater restrictions. It also will be used to evaluate technologies for reduced water consumption and improved wastewater treatment.

"The Water Research Center will be a first-of-its-kind, industrywide resource for conducting power company water research," said George Offen, EPRI project manager for the center. "Electric generating companies, research organizations, and vendors will have access to full-scale infrastructure, treatable water, monitoring and analysis facilities, and specialist staff to enable plant-based water research studies."

According to Offen, research projects will include advanced cooling-water technologies, biological and inorganic wastewater treatments, zero liquid discharge options, solid landfill water management, and water conservation (including moisture recovery from flue gas). The EPRI collaborative will guide facility development to ensure that it meets industry needs. EPRI is sponsoring a design and engineering study for the research infrastructure. Construction is scheduled to start in the spring, with the center expected to begin testing by midyear.

Water Reuse

Monitoring infrastructure already has been installed at Plant Bowen for water modeling and balancing research. "Older power generation facilities, which were built when water was not an issue, typically do not have instrumentation on different flow streams," said Jay Wos, Southern Company's manager for the Water Research Center. "We recently installed metering technology that gives us a more precise idea of how much water the plant is using, how the water is used, and what's in the water. Knowledge of all flows may enable us to develop plant-specific models for water balancing and identify reuse options at different levels of cleanliness."

Power plants today employ many practices to reuse water. Water typically is "cascaded" from one use to another, depending on the water quality needed for each process. For example, freshwater is treated and used for boiler feedwater, resulting in a wastewater stream. Wastewater from the water treatment system can be used as makeup in the flue gas desulfurization (FGD) system. Boiler blowdown can be used as makeup in cooling-water systems. Cooling tower blowdown also can be used as makeup in the FGD system. FGD blowdown can be used for ash sluicing. Ash pond runoff can be used for fly ash wetting (dust control). Wastewater treatment research might allow for even greater recycling and reuse.

A significant amount of water is lost through power plant stacks (flue gas from fossil plants contains 8%–13% moisture as a by-product of combustion) and cooling tower plumes. Moisture recovery from flue gas would be significant if proven to be economically viable. The recovered water can be used elsewhere in the plant, and the recovered heat can be used to reduce the plant's heat rate. Research at the center and elsewhere will evaluate new moisture recovery technologies, including flue gas coolers, water-selective membranes, condensing heat exchangers, and membrane wet electrostatic precipitators.

Water conservation and reuse efforts, together with future more stringent discharge limits, are spurring interest in zero liquid discharge systems for treating FGD wastewater. "Zero liquid discharge systems are the fallback when wastewater cannot be cost-effectively treated and discharged. Thermal zero liquid discharge systems use energy to evaporate the water in order to separate out dissolved solids, producing both solids for landfill disposal and high-quality reusable water, thereby discharging no liquid," said Paul Chu, EPRI project manager.

These systems begin with pretreatment, which includes dealkalization/metal removal and clarification, and often are followed by softening, which converts calcium chloride to the more easily handled sodium chloride. A brine concentrator reduces wastewater volume, and a crystallizer produces solids for disposal and reclaims the water.

Very few zero liquid discharge installations are operating to treat the complex and highly corrosive FGD scrubber blowdown; more applications are focused on other waters, such as cooling tower blowdown. In addition to the significant capital, energy, and chemical costs, many power companies are concerned with reliability issues related to scaling and corrosion. Because zero liquid discharge operations appear highly dependent on water chemistry and proper design, more independent research is needed to understand their operation on a range of water constituents and parameters. According to Chu, EPRI is documenting the operating experience of the limited number of plants with zero liquid discharge systems for FGD wastewaters and helping plan possible laboratory studies at the Water Research Center.

Reducing Cooling Water

A key to curtailing power plant water consumption is to reduce the largest single use: cooling water.

Power plants typically are cooled by using either once-through cooling or recirculating cooling. Once-through systems withdraw water from a natural source (typically a lake, river, or ocean), use it to extract waste heat from the steam cycle, and then return it to the water body at a slightly elevated temperature. In the United States today, more than 1,200 generating units (about 40% of U.S. capacity) use once-through cooling. Recirculating cooling (sometimes called wet cooling) cools water in a tower or pond and recirculates the water to the condenser. Cooling is accomplished by evaporation of a small fraction (1%–2%) of the water.

"EPRI's Advanced Cooling Technology project is investigating methods to reduce the efficiency penalty of switching from these conventional cooling approaches to systems that have lower water consumption and is evaluating their cost-effectiveness," said Richard Breckenridge, EPRI project manager.

One such alternative is dry cooling. It uses air rather than water to condense the steam, which is piped from the turbine to air-cooled condensers. Since 1999, nearly 20 GW of new U.S. capacity has come into service equipped with direct dry cooling. "Although dry cooling systems achieve large water savings," said Breckenridge, "their initial cost is three to five times that of wet cooling systems, their operating power requirements for cooling-system pumps and fans are 1.5 to 2.5 times higher than those of wet cooling systems, and they impose a 3%–15% thermal efficiency penalty on the power plant, depending on ambient conditions."

EPRI research is addressing operational and cost issues associated with air-cooled condensers. High and gusty winds can cause stalling of the airflow in leading-edge fans, creating a sudden drop in cooling capacity. A recent EPRI study, conducted with Électricité de France, performed wind tunnel tests on scale models of power plants with air-cooled condensers to determine how wind affects airflow around and within condenser cells. The study also evaluated mitigation approaches.

EPRI also is exploring hybrid cooling systems, which configure dry and wet loops in parallel, to cool the recirculating condenser water. These systems reduce cooling-water volume by using dry cooling during cooler periods and wet cooling during hotter periods, when dry systems cannot maintain low turbine-exhaust pressure. Eight hybrid systems are operating in the United States—three on coal-fired steam plants, two on gas-fired combined-cycle plants, and three on waste-to-energy plants.

"To date, little public information has been available on the design, cost, and performance of hybrid systems," said Breckenridge. "Results of a recent EPRI study that surveyed existing hybrid systems showed that they are typically sized to consume 30%–70% less water than a closed-cycle wet cooling system and can be expected to cost 75%–90% of an all-dry system with an air-cooled condenser." EPRI's Advanced Cooling Technology project recently developed software that allows utilities to project the operational impacts of installing hybrid cooling.

Another option for reducing freshwater consumption is to use degraded water sources. Power plants have used such sources for years, particularly sewage effluent. A recent study identified 57 U.S. facilities that use reclaimed municipal wastewater for cooling. If located close enough to a power plant, this source is attractive because of its year-round availability, relatively low treatment cost, and minimal plant impacts. To increase the use of degraded water from other sources, EPRI has identified needed research on better and cheaper treatment options, wastewater disposal options, and coatings to prevent scaling and fouling.

Potential Breakthrough Technologies

EPRI's Technology Innovation (TI) program is exploring early-stage technologies that could be alternatives to current wet cooling options. In early 2011, EPRI released a Request for Information to researchers and developers pursuing water-efficient technologies with potential power industry applications.

From more than 70 responses, EPRI selected four projects. One is a technology developed by Argonne National Laboratory for enhancing thermophysical properties of heat transfer fluids used in wet cooling towers. The process adds heat-absorptive nanoparticles to the coolant stream, enabling the same volume of coolant to absorb more heat in the condenser and to dissipate the increased heat in the cooling tower. The potential is there to reduce water use at both existing and new steam-electric plants by as much as 20% and decrease coolant flow rates by about 15%, lowering pumping loads and parasitic losses.

Also under investigation are an absorption chiller, which supplements a dry-cooling-type technology with a refrigerant cycle for evaporative cooling to temperatures lower than those attainable with dry cooling; dew point cooling, under development by the Gas Research Institute, which would cool water to the dew point, gaining cooling efficiency and using two-thirds less water; and a thermosiphon, developed by Johnson Controls, which employs a refrigerant in a gravity-feed cycle to reduce evaporative losses.

"The issue with current alternatives to water-based cooling, such as dry cooling, is that they're costly and have operational drawbacks," said Sean Bushart, EPRI program manager. "We know the technologies in the TI Program will take a lot of work to develop, but they also have huge potential. With these projects, we're pushing the envelope to find game-changing technologies that would achieve significant water reduction while also being operationally desirable."

This article was written by Jonas Weisel. Background information was provided by George Offen, goffen@epri.com, 650.855.8942; Richard Breckenridge, rbreckenridge@epri.com, 704.595.2792; Paul Chu, pchu@epri.com, 650.855.2362; and Sean Bushart, sbushart@epri.com, 650.855.8752.

George Offen is a senior technical executive, focused on the reduction of air pollutants from coal-fired power plants, including development and optimization of controls for mercury, CO_2, and SO_2. Before joining EPRI in 1985, he was manager of energy engineering at Acurex Corporation and earlier held teaching positions at Stanford and Santa Clara Universities and carried out research assignments at Chevron Research and the French Institute of Petroleum. Offen received B.S. and Ph.D.degrees from Stanford University and an M.S. from MIT, all in mechanical engineering.

Richard Breckenridge is a senior project manager in the Generation Sector, serving as the technical lead in water management technologies and in the development of the Water Research Center. Prior to joining EPRI, Breckenridge was the corporate chemist at Arizona Public Service Company and worked many years in the consulting field for specialty chemical companies, including Calgon Corporation, Nalco, and Applied Specialties, Inc. Breckenridge earned his B.S. degree from Northern Arizona University in earth science, chemistry, and mathematics.

Paul Chu is a senior project manager in the Environment Sector, with current research activities focused on air and water toxics issues. Before joining EPRI in 1992, he worked at Babcock & Wilcox, where he was involved in various development projects related to flue gas cleanup of SO_2, NOx, and particulates. Chu received a B.S. degree in chemical engineering from the University of Arkansas and an M.S., also in chemical engineering, from the University of Texas at Austin.

Sean Bushart is senior program manager for the Land and Groundwater program, with current activities focused on innovative applications related to power plant and transmission and distribution environmental issues. He also manages EPRI's Water Technical Innovation program and is the lead for EPRI's cross-sector water initiative. Prior to joining EPRI in 1999, Bushart was director of microbiology/chemistry laboratory services at CytoCulture. He holds B.S. and Ph.D. degrees in biology from Rensselaer Polytechnic Institute.

FGD Wastewater Treatment

Since 2008, EPRI's Environment and Generation sectors have been jointly evaluating technologies for the removal of mercury, selenium, and other trace elements from scrubber wastewater. A parallel focus has been to understand the fundamental chemistry in FGD systems.

Bench- and pilot-scale tests were conducted recently to determine factors that affect selenium behavior in the scrubber. "Although selenium chemistry in wet FGDs is highly complex and not well understood," said Paul Chu, EPRI project manager, "researchers know that selenium in FGD liquor forms both selenite, which is captured by conventional wastewater treatments, and selenate, which is not efficiently captured." Test results showed that the oxidation-reduction potential of the FGD liquor influences the oxidation of selenite to selenate and that decreasing oxidation air and/or using a scrubber additive, such as ferric chloride, may shift more selenium to scrubber slurry solids, away from the blowdown.

EPRI also is investigating biological options such as bioreactors and vertical-flow wetlands for capturing mercury and selenium from FGD wastewaters. Biological approaches use bacteria or microorganisms to chemically reduce and sequester selenium; these bioreactors also capture mercury, but the chemistry is not well understood. To better understand the mercury chemistry, and with the ultimate goal of optimizing mercury performance, EPRI now is conducting laboratory studies to examine how a bioreactor's trapping mechanisms and efficiency are affected by FGD water chemistry, microbial processes, and speciation of mercury. Results show mercury removal likely is due to adsorption onto carbon; however, much still is not known—such as the form or species of mercury in the wastewater, as well as the wastewater chemistry and conditions in the bioreactor columns.

EPRI is supporting pilot field tests of a hybrid zero-valent iron technology, developed by Texas A&M University, for removing selenium, mercury, and other trace metals from FGD wastewater. The process shows promise of higher removal levels, better reagent utilization, and less waste disposal than earlier iron-based water treatment technologies.

THE *Man* WHO NEVER STOPPED

When Chauncey Starr walked through the door of the Radiation Laboratory at UC Berkeley (UCRL) in 1942, he stepped into a destiny he could never have imagined. Inside was the buzzing center of the world's most closely guarded secret, the Manhattan Project, the feverish race to build an atomic weapon before the Nazis did. E.O. Lawrence, for whom the lab is now named (the Lawrence Berkeley National Laboratory), had invited Chauncey in. Lawrence, with an uncanny eye for talent, saw something in the young man that others, even Chauncey himself, had not realized was there—an ability to lead creative technical minds on an unrelenting march toward a single objective on a wartime schedule. Lawrence proved to be Chauncey's most important mentor, and many of the attributes that Chauncey so admired in Lawrence became his own.

"My previous work had been either solo or with a few associates, and on a very small scale with little funds," Chauncey said. "At UCRL, I was thrown into large-scale, 24-hour, 7-day, multiple-idea research, with performance, not cost, as the target. Lawrence presided over this creative chaos with a master's touch—discarding failures, pushing what worked, making decisions intuitively, and inspiring with his confidence."

THE STORY IN BRIEF

Chauncey Starr (1912–2007) emerged from the pressure cooker of war as a seasoned and inspirational leader of large-scale R&D. He helped pioneer commercial nuclear power, created the interdisciplinary field of risk assessment, and invented EPRI, adapting a wartime model to a new age and a new set of R&D challenges. On the 100th anniversary of his birth—and the 40th of EPRI's founding—the wisdom of his vision and the integrity of his approach have never been more apparent.

Savvy Engineer

Chauncey brought something besides leadership potential that Lawrence urgently needed—the ability to bridge science and engineering. Chauncey had been trained in both and before the war had been an experimental scientist at Harvard and MIT, known to be ingenious at making his own equipment. He had been recruited in 1939 by the U.S. Navy's Bureau of Ships to help it understand the shock waves produced by mines that were destroying British shipping. He had begun in typical fashion, building his own instruments to study the problem. Lawrence appreciated Starr's engineering savvy and saw him as a distinctly innovative engineer in a sea of top physicists.

After Chauncey received initial training on the principles of the calutron electromagnetic racetrack for separating U-235, Lawrence sent him as his emissary and troubleshooter to Oak Ridge, Tennessee, where workers were refining weapons-grade uranium—and falling behind on production quotas. Chauncey found himself in charge of hundreds of gifted engineers experimenting with ways to improve production. As UCRL's physicists advanced their knowledge, Chauncey's team turned theory into reality. By 1945, Oak Ridge had separated enough U-235 to provide the critical mass for a weapon.

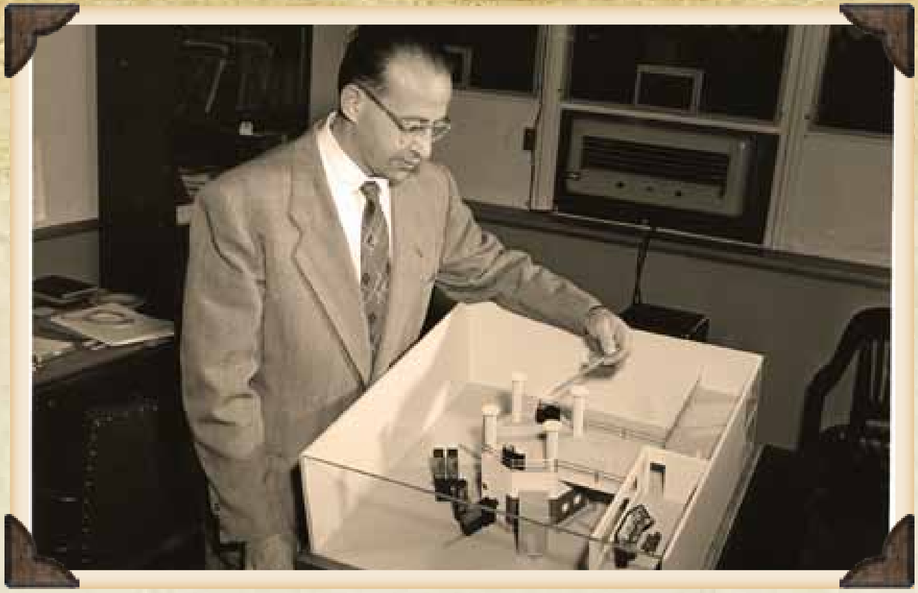
Inspirational Leader

Chauncey's wartime experience seasoned and matured him and transformed him from an isolated scientist to an inspirational leader. Attitudes, approaches, and the principles of leadership that would guide Chauncey for the rest of his life had germinated and taken root during those three-plus eventful years. Large-scale R&D was now in his blood, and the way to ensure its success was as ingrained in him as it had been in Lawrence. A leader is not the boss, he liked to say in later years; a boss directs, a leader inspires. This requires humility, Chauncey liked to point out, "because you can't do it alone and you can't do it by delegation." His rules for R&D were few: "Gather together the best people you can find and listen to their expertise. Know where you want them to go. Experiment with ideas and approaches, and realize that failure is a part of the equation, not something to get upset about or side-tracked by. As a leader, allow others to feel free to try and be free to fail. If an idea fails, just go on to the next thing."

Central to this ethos was the integrity to call it as you find it, not as you wish it. As the Oak Ridge staff disbanded after the war, Chauncey went off to explore nuclear power concepts for North American Aviation (NAA). The Air Force had asked NAA to study the possibility of nuclear propulsion for intercontinental rockets and ramjets. At the end of two years, Chauncey's team concluded that while nuclear propulsion was feasible, chemical rockets would be substantially better. He did what few military contractors are willing to do: he recommended cutting off funding for his own project.

Nuclear Pioneer

Chauncey then convinced NAA to turn his resources toward the greater promise of nuclear power. With this done, he gained



the attention, respect, and support of the new Atomic Energy Commission (AEC). It proved to be a fundamental career move into the frontiers of nuclear power, where the lessons of the nuclear rocket study remained paramount: pursue what works, not what doesn't; pursue the truth no matter where it leads you. In the end, his thinking had crystallized into the important clarifying role science plays in society. Speaking to colleagues on "The Soul of EPRI" in 2002, he reminded the researchers gathered around him to remain steadfast in their work. "Our credibility is priceless. Like freedom, it requires continuous defense."

NAA became North American Rockwell, and Chauncey assumed the presidency of its new Atomics International (AI) division, where he served for the next 20 years. The goal was to commercialize atomic power, and this effort prompted a competition among reactor designs that carried forward the momentum of the WWII weapons program. The principal issue was which of the many engineering paths to take. Debates ensued over the pros and cons of alternative combinations of fissionable fuels, moderators, and reactor configurations—the type of parallel-path R&D that appealed to Chauncey's fertile and flexible mind.

During those pioneering days, when the potential for nuclear power seemed a gift to the world, President Eisenhower proposed the Atoms for Peace program in his 1953 address to the United Nations. He proposed that the United States make nuclear power available to all nations through small experimental research reactors for teaching and experimentation. At his 95th birthday celebration, Chauncey remembered his reaction at the time. "It was earthshaking in its nobility. I was so very proud of my country." Chauncey had been asked to lead a five-person committee to decide whether the nation should, in fact, pursue Eisenhower's magnanimous offer. After careful consideration—and along with one other committee member—he nevertheless voted against it for security reasons. In the end, the idea was vetoed by the Russians and faded away as the Cold War solidified.

By the mid-1960s, Chauncey's leadership at AI was coming to an end. The AEC, faced with serious budget constraints, decided to concentrate its efforts on the already commercial light water reactor. To Chauncey's enduring disappointment, it withdrew support from the heavy water organic-cooled reactor that AI was bringing forward with the Canadians. As he stated in 1995 in the *Annual Review of Energy and the Environment*, "I am strongly of the opinion that organic cooling would have opened the door to simpler and safer reactors…permitting inspection and maintenance while the reactor was operating. I believe the importance of the simplicity of man-machine interactions for economic and safe reactor operation has been underrated by the AEC and its successors, by the regulators, and by the industry."

Father of Risk Analysis

The intertwined issues of safety, risk, and cost had become a central passion for Chauncey by 1966, when he became dean of the School of Engineering and Applied Science at UCLA. A paradox intrigued him: the mismatch between actual risk and perceived risk of large-scale technology in society. He noted that society had an odd tolerance for self-generated risk and a distinct intolerance for risks imposed by others. He noted that people would accept voluntary risks that were 1,000 times greater than those imposed from the outside. "We are loath to let others do unto us what we happily do to ourselves," he observed. He quantified risk in new ways, and his seminal paper in *Science* in 1969 served as the foundation for the new interdisciplinary field of risk analysis.

This guiding passion for interdisciplinary study harked back to his wartime experience. "I believed then, as I do now," he said, "that some of the most fruitful frontiers of engineering are interdisciplinary… [and that] these activities have a difficult time in the discipline-focused, professionally accredited engineering curricula." As a result, he introduced a new, interdisciplinary degree program in environmental

engineering at UCLA and, working with the dean of medicine, created the school's Institute of Medical Engineering.

Founder of EPRI

When asked at his 95th birthday celebration to identify the world's greatest technological achievements during his lifetime, he shook his head, pausing, his eyes alight with the possibilities. Finally, he said the two that stood out above all others were the electrification of the world and the communications revolution spawned by electricity, which flattened the world.

It was the enormous impact of electricity on society that led him to respond with such clarity and breadth of vision to the committee responsible for creating a new industrywide R&D organization for electric power in 1972. The electricity sector was under the gun—a one-year political deadline imposed by the Senate Commerce Committee. This deadline appealed to Chauncey's wartime can-do spirit with a scale of interdisciplinary R&D that he could only dream about. The committee wanted him for reasons of expediency, and he wanted the job for its potential to serve society. What other industry was this important to the world? What other industry had to plan in terms of decades? What other industry could break the cycle of poverty in the developing world? "A dinner cooked over a fire wastes 98% of its energy," he pointed out. "The same fuel used to generate electricity can cook 15 dinners."

The challenge was simply too great—and the possibilities were too profound—to decline. He'd give up his comfortable roost in academia and culminate his career with a dream script he could write himself. OK, he said to the new board, he'd accept, provided he could set up EPRI to fulfill its broader social purpose, bring in the best people, and run it his way, unimpeded, for five years.

It wasn't wartime, so Chauncey could not simply conscript the best and the brightest to come to Palo Alto. But he could do the next best thing—hire them through R&D contracts and put them together in unique combinations to get a job done. For example, Carnegie Mellon researchers could be joined with an engineering team from Stone and Webster, merging the specialized expertise of the two. It was a wartime model adapted for a new age. Chauncey established EPRI as the first industrywide virtual R&D organization. The intent was flexibility and speed. If one path doesn't work, go to the next. When cold fusion hit the headlines, a team was set up the next day at Texas A&M to investigate. When the experiment couldn't be replicated, EPRI disbanded the team.

No Stopping for Retirement

Chauncey formally retired at 65 as required—and then forged ahead informally at EPRI five days a week for the next 30 years. In 2007, EPRI hosted his 95th birthday celebration, where he was asked about his ongoing work. He mentioned three or four projects, including a continental super grid where hydrogen and electricity would be delivered through the same conduit. People who knew him from the early days were there in tribute. He waved away their accolades. He already had enough awards and tributes to fill a small museum, but the things that mattered were the work, the ideas, the creative ferment, the people, and the nobility of purpose. Young people there, about the same age Chauncey had been when Lawrence summoned him, admired the legend who was still alive and kicking, as feisty and gentle as a beloved grandfather, and contemptuous of rules that got in the way. His advice to them: "Disregard all organization charts." Truth should reign, he meant. Service to your country, to humanity, is your goal. He was an exemplary man, one of the greats of the greatest generation.

The day after this birthday celebration, he got up, had breakfast, then took a nap from which he never awoke. His office was stacked to the ceiling with unfinished work. *The man never stopped.*

This article was written by Brent Barker.

DATELINE EPRI

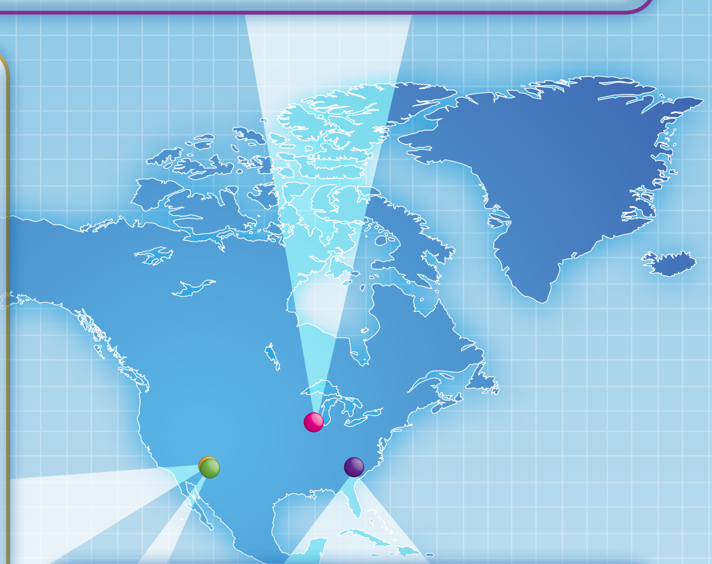
News and events update

MANUFACTURED GAS PLANT SYMPOSIA FOCUS ON INVESTIGATION, REMEDIATION, AND REDEVELOPMENT

CHICAGO — EPRI co-sponsored MGP 2012, the Fourth International Symposium and Exhibition on the Redevelopment of Manufactured Gas Plant Sites, in March. This conference series, along with EPRI's manufactured gas plant symposia, is a primary international source of comprehensive technical information on MGP site investigation, remediation, and redevelopment. Featured research included EPRI's surfactant-enhanced *in situ* chemical oxidation demonstration, a feasibility study on the application of *in situ* stabilization and solidification of contaminated sediments, the demonstration of reactive capping technology for affected sediments, and nonaqueous-phase liquid mobility research.

MIKE HOWARD KEYNOTES FIRST-OF-KIND RENEWABLE ENERGY FORUM

SCOTTSDALE, Ariz. — EPRI president and CEO Mike Howard delivered the keynote address on R&D gaps for renewable technologies and grid integration and business models for renewable electricity in the twenty-first century at the EPRI/American Council on Renewable Energy/National Renewable Energy Laboratory Forum on Renewable Energy in February. The forum examined potential realignment of business models to support accelerated clean energy development and focused on technologies, policies, and financing needs associated with any increase in renewable electricity. Environment and renewables vice president Bryan Hannegan moderated a panel discussion on the financial and operational complexity of increasing the amount of electricity produced from renewable energy, with emphasis on the regional nature of resources. It was a unique opportunity for financers, developers, regulators, and power companies to come together in a single forum and create a dialogue with the stated goal of a durable U.S. renewable energy industry that can stand without a policy mechanism or incentive.



EUEC CONFERENCE COVERS THE WATERFRONT

PHOENIX, Ariz. — At the 15th Annual Energy, Utility & Environment Conference, EPRI researchers presented 15 papers across six technical tracks, including climate/energy policy, sustainability, water, modeling, and renewable energy. EPRI hosted a session that examined water use and availability issues for the electric power industry. EPRI senior program manager Kent Zammit examined the physical, regulatory, reputational, and financial risks associated with water use by electric power generators—risks that will grow as competition for water increases.

SMART GRID INTEROPERABILITY PANEL GETS UPDATES ON STANDARDS, CIM

CHARLOTTE, N.C. — The U.S. National Institute of Standards and Technology's Smart Grid Interoperability Panel met in March to discuss its priority action plan. Participants were updated on progress with International Electrotechnical Commission (IEC) standards development under TC 57 Working Group 14. This work is based on prior use cases and requirements developed for advanced distribution automation. An update was provided on work related to the integration of MultiSpeak and the Common Information Model (CIM) standards. EPRI senior project manager John Simmins reported that the development of CIM is progressing. Said Simmins, "The industry is on a path to make the common information model a reality in the next few years. In fact, some parts of the model are functional today and could be incorporated into utility strategy plans."

WORKSHOP ADDRESSES BOILER AND HRSG EXFOLIATION

LONDON — EPRI and the National Physical Laboratory hosted a workshop in January in which more than 40 experts from the United States, UK, European Union, and Japan reviewed steam-side exfoliation in boilers and heat recovery steam generators. They reviewed recent experience, evaluated progress in understanding the phenomenon, explored development of mathematical models, and determined key next steps for the industry and researchers.

FORTY-FOUR COUNTRIES REPRESENTED AT MEETING FOCUSED ON NUCLEAR SAFETY

VIENNA — EPRI director Ken Canavan and senior project manager Andrew Sowder participated in an International Atomic Energy Agency meeting in March on reactor and spent fuel safety in light of the 2011 Fukushima Daiichi accident. More than 240 experts from 44 countries discussed lessons learned and plans to improve nuclear plant safety. One area of particular focus was the need for additional permanent—possibly portable—equipment that could add a layer of defense to existing plant safety systems.

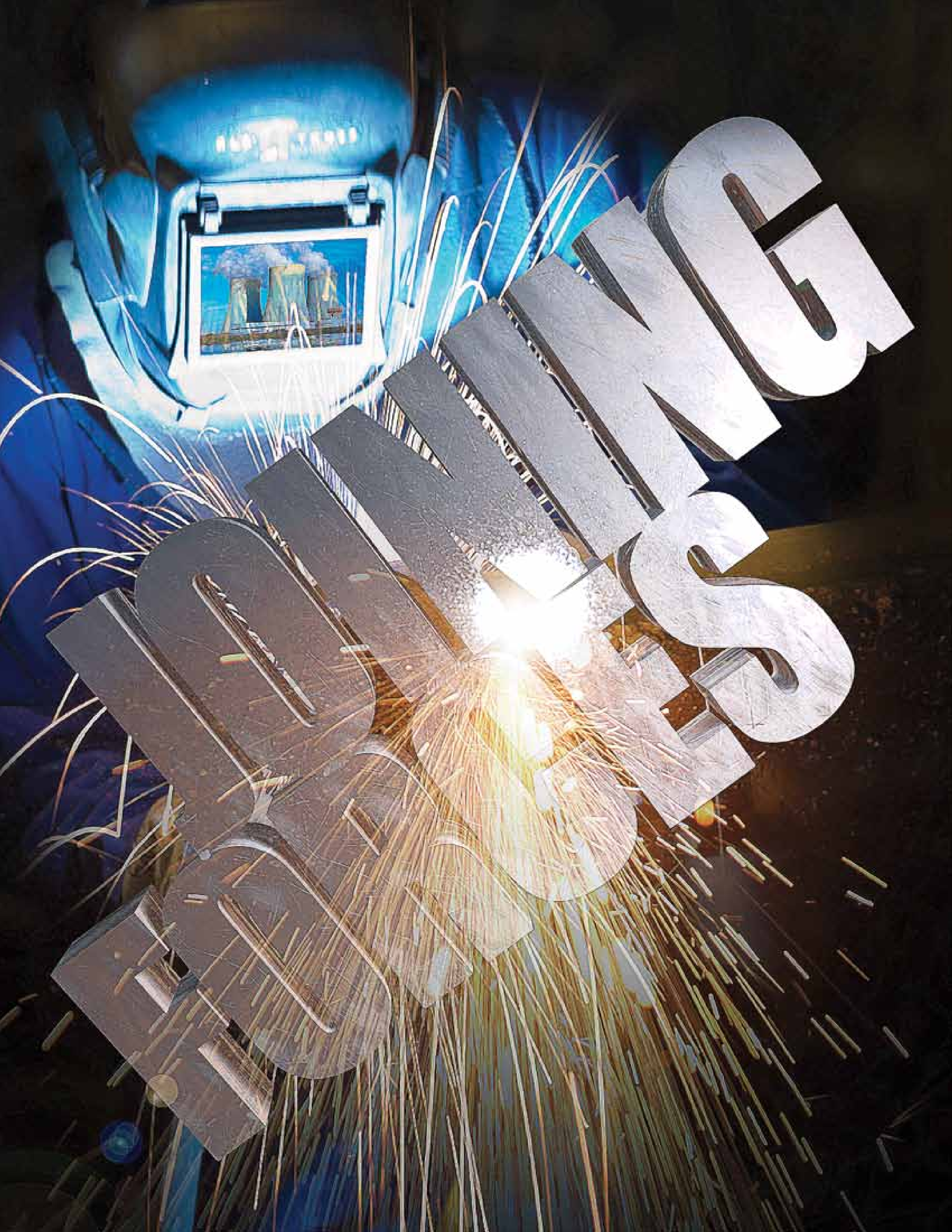
POST-FUKUSHIMA COOPERATION CONTINUES TO EXPAND

Tokyo Electric President Toshio Nishizawa met with EPRI President and CEO Mike Howard during EPRI's visit to Japan in February.

TOKYO — EPRI President and Chief Executive Officer Mike Howard, Nuclear vice president Neil Wilmshurst, and senior technical executive Rosa Yang met with several utilities, including Tokyo Electric Power Company, Chubu Electric Power Company, and Kansai Electric Power Company, to discuss further cooperation and collaboration. In addition to continuing various post-Fukushima activities with the Japanese nuclear industry, the senior management at the Japanese utilities asked EPRI to support an initiative by the Federation of Electric Power Companies to establish an independent organization for enhanced safety of nuclear power plant operation. Discussions of this proposal are under way.

TWO UTILITIES JOIN EPRI SMART GRID DEMO PROGRAM

BRISBANE, Australia, and HONOLULU, Hawaii — Australia's Ergon Energy joined the EPRI Smart Grid demonstration project as both a member and a host site candidate. The company is preparing to release its Energy Sense Communities Program and its program to integrate all of its smart grid initiatives. Hawaiian Electric Company (HECO) also joined the demonstration project as both a member and a host site. On Maui, HECO is integrating diverse renewable generation such as biomass, hydro, wind farms, wave generation (in development), and distributed photovoltaics. For Hawaii's grids, the company is addressing issues such as balancing and frequency regulation, ride-through and anti-islanding, reserve requirements, and periods of excess energy.


JOINING
FORCES

THE STORY IN BRIEF

Researchers at EPRI's Welding and Repair Technology Center are collaborating with national laboratories, universities, utilities, and code organizations to ensure the safe and reliable long-term operation of existing and future nuclear plants. From advanced weld repair using lasers to the computer-aided development of superior new alloys, EPRI is taking cutting-edge knowledge and tools out of the research lab and putting them to work inside power plants.

Nuclear power plants are held together by tens of thousands of welds. Joining sections of reactor pressure vessels and connecting piping and supporting structures, strong and durable welds have contributed to the existing nuclear fleet's record of safe and reliable operation. Welding experts are collaborating on the development of advanced welding processes, techniques, and new materials to maintain that performance and also ensure the integrity of the next generation of nuclear plants. EPRI's Welding and Repair Technology Center (WRTC) in Charlotte, North Carolina, serves as a hub of welding research and development, focused on practical solutions that support safe plant operation, extend plant life, reduce outage times, and cut costs.

Greg Frederick, WRTC program manager, emphasizes that the center's mission is to take research and put it to work in the field. "We turn research results into practical solutions to real-world problems in power plants," he said. "Examples include mitigating issues with dissimilar metal welds, optimizing weld techniques to reduce outage time, welding irradiated components, and developing new weld alloys that are easier to use and offer superior corrosion resistance. Much of this work will also apply directly to the construction and maintenance of new nuclear plants."

Frederick cites EPRI's "unique position to work with utilities, national laboratories, universities, regulatory agencies, and other organizations" to identify industry welding needs and develop solutions. "This collaborative approach allows the nuclear industry to tap into advanced knowledge and capabilities and get comprehensive solutions that are challenging for individual utilities to obtain on their own," said Frederick. "In turn, the collaboration offers guidance to universities and national labs to keep their research applied and relevant."

EPRI participates with the American Society of Mechanical Engineers (ASME) in developing new code cases related to welding and also produces technical results that may be useful in informing utility relief requests to the Nuclear Regulatory Commission (NRC). This combination of R&D and code case support has led to ASME codification and NRC approval of new weld processes, enabling nuclear plant owners to cost-effectively mitigate corrosion cracking in piping and larger components with more complex geometries.

Dissimilar Metal Welds

Many power plant components include different types of base and weld materials, including stainless steels, cast stainless steels, nickel alloys, low-alloy steel, carbon steel, and various weld metals used during fabrication and installation. Achieving a sound weld between dissimilar materials depends on the properties of the alloy used to fill the joint during welding. The original filler materials used to weld dissimilar metals in nuclear plants are subject to primary water stress corrosion cracking.

FirstEnergy Nuclear Operating Company (FENOC) has been working with EPRI for almost a decade to address long-standing challenges associated with the joining of dissimilar metals in reactor cooling systems. Recent work has focused on new techniques to apply corrosion-resistant alloys in weld overlays.

The overlay process deposits a corrosion-resistant alloy around the outside diameter of a dissimilar metal weld, much as a cast is wrapped around a broken arm. A full structural weld overlay is thick enough to take the entire loading and stress of the underlying weld, so it can be used to replace material that has cracked completely through as a result of corrosion or other degradation processes. An optimized weld overlay—thinner than a full structural overlay—can be used where the cracking in the underlying material is less than half the original wall thickness. With less weld volume, optimized overlays are faster to apply and to inspect, minimizing plant outages, which can cost more than a million dollars per day.

FENOC teamed with EPRI at the Davis-Besse plant in Ohio to pioneer the use of optimized overlays as a preemptive mitigation measure on large-diameter coolant piping susceptible to stress corrosion cracking. To support this first industry implementation, EPRI performed comprehensive testing and analyses using full-scale mockups of large-diameter piping connections to demonstrate that the optimized overlay technique was safe and effective. WRTC staff at EPRI worked with colleagues in EPRI's

Materials Reliability Program and Nondestructive Evaluation Center to ensure the inspectability of the optimized overlays. The application used the methodology of ASME Code Case N-740-2 and supported FENOC's relief request, which the NRC accepted, enabling the project to proceed.

The successful relief request speaks to NRC's confidence that the weld overlay can structurally enhance the integrity of the coolant piping. It can also provide economic benefits.

Applying four optimized weld overlays at Davis-Besse enabled FENOC to save approximately $1.5 million in welding and outage costs—based on savings of one-half day for each overlay at $375,000 per day. FENOC's pioneering application paves the way for other nuclear power plants to use optimized weld overlays to save time and money while improving safety and mitigating potentially deleterious cracking in primary systems.

"A key element of the optimized weld overlay project was the manner in which the EPRI Welding and Repair Technology Center, Materials Reliability Program, and Nondestructive Evaluation Center worked together to achieve this success," said Dan Patten, FENOC's fleet manager, programs and component engineering. "No project succeeds without teamwork. FENOC highly values these EPRI resources."

Resolving Alloy Issues

High-chromium nickel-based alloys (52 and 52M) are used extensively for weld mitigation, repair, and new fabrication because of their high corrosion resistance. However, they are difficult to weld and susceptible to cracking under some welding conditions. The necessity of repetitive repair and rework of alloy 52 and 52M welds has extended refueling outages and resulted in unexpected maintenance costs and lost electricity production. Although welding vendors have sought to optimize proprietary welding processes and equipment for 52/52M, the industry continues to face problems with these alloys.

The WRTC is using computational modeling and weld testing in laboratory mockups to develop new understanding of how weldability and crack susceptibility are influenced by base metal composition and welding process parameters such as temperature and delivered energy. Researchers also are evaluating alternative processes—gas metal arc welding, laser welding, friction stir welding, magnetic stir welding, and hybrid welding—to determine how successfully they can be used with high-chromium nickel-based alloys.

A related WRTC project is pursuing a longer-term solution: developing and testing a new, welder-friendly corrosion-resistant weld alloy as an alternative to Alloy 52. Researchers are using computational modeling and analyses in concert with newly developed small laboratory weldability testing techniques to evaluate alloy candidates for more consistent weld quality.

"In the past, developers produced new weld alloys by starting with the base metal composition and systematically adding minor alloying elements to achieve acceptable welding characteristics," explained Steven McCracken, WRTC project manager. Alloy 52/52M, for example, is based on Inconel™ 690, with only minor element additions. Instead of starting with the base metal composition, the WRTC researchers are using computational modeling to formulate an alloy composition that has superior welding performance from the outset, is compatible with the base materials to be joined, and maintains the mechanical and corrosion properties required for a nuclear plant's reactor cooling system environment. "The use of computational modeling provides a more cost-effective and expeditious path to a comprehensive solution than traditional empirical approaches," said McCracken.

Again, collaboration is the key to these efforts. EPRI is working with a consortium of universities—including Ohio State University, Lehigh, the University of Wisconsin, and the Colorado School of Mines—and tapping their metallurgical expertise to expand the modeling database.

Welding Irradiated Materials

Extending nuclear plant operations raises new challenges. As nuclear reactors age, exposure to radiation increases the helium level in the reactor pressure vessel and internal components. The base material becomes increasingly difficult to repair because conventional welding techniques make it vulnerable to helium-induced cracking, which is related to the concentration of helium in the material, the heat input used for welding, and other factors.

Helium-induced cracking is a complex phenomenon that is not completely understood, but its operational impacts are clear. Key structural components, such as core support lugs and jet pump riser leaves, are susceptible to such cracking, and conventional arc welding techniques can't be used. Because replacement of these internal components is a costly undertaking, involving cut-up and disposal as well as removal, repair may be the only option for extending life. EPRI is collaborating with the U.S. Department of Energy (DOE) to develop the knowledge and advanced technology for welding irradiated material.

One promising option is laser welding, which operates at lower energy levels than arc welding, provides precise heat input control to avoid helium-induced cracking, and can be deployed under water. In 2011, the WRTC acquired and installed a 2-kilowatt fiber laser system. The compact, high-powered solid-state device can deliver a laser beam to remote locations via optical fiber, making it potentially suited to repairing internal reactor components. Researchers are evaluating the laser's heat and process parameters, integrating its operation with positioning hardware to ensure accurate weld application, and developing an overall assessment of laser welding as a field-deployable technique.

Current laser welding technology is capable of successfully welding materials with helium concentrations of up to 10 atomic parts per million—a level generated in many reactor internal locations after about 40 years of operation. New welding technology will need to extend the weld-

A researcher uses the orbital gas tungsten arc welding process to demonstrate weld overlay application.

ability of irradiated materials out to 80 years of operation. Hybrid welding technologies, such as systems that use multiple laser beams to alter the residual stress, show significant promise for extending the weldability range of irradiated material, but extensive process development and testing will be needed before these technologies are ready for field implementation. EPRI and DOE are evaluating hybrid laser welding processes for repairing highly irradiated materials under EPRI's Long-Term Operations Program and DOE's Light Water Reactor Sustainability Program.

It will be essential to demonstrate the ability of laser welding to successfully repair irradiated material samples. To support that goal, EPRI and DOE are outfitting a "hot cell" at the Oak Ridge National Laboratory to perform welding experiments on irradiated materials used to construct reactor internals and vessels.

Advanced Nuclear: Building on Experience

The current fleet of nuclear power plants has an enviable record for reliability, with an average capacity factor exceeding 91% in 2010. As WRTC researchers work to extend the life of this existing fleet, they're also striving to ensure the reliability and longevity of future nuclear plants.

EPRI is working with utilities and equipment manufacturers to develop welding and fabrication best-practices guidelines for new nuclear plant construction. The guidelines will be based on lessons learned from the 104 nuclear units operating in the United States. Using this experience can help the industry identify practices that contribute to component degradation and materials failures and apply improved approaches that increase reliability and extend component life.

"The best-practices project is yet another collaborative effort to develop information and tools to preemptively build reliability into new nuclear power plants," said Frederick. "Working together, utilities, equipment manufacturers, vendors, and the welding community can ensure that new nuclear plants will operate reliably long into the future."

This article was written by David Boutacoff. Background information was provided by Greg Frederick, gfrederi@epri.com, 704.595.2571; Steven McCracken, smccracken@epri.com, 704.595.2627; Eric Willis, ewillis@epri.com, 650.855.2023; and Dana Couch, rcouch@epri.com, 704.595.2504.

Greg Frederick, program manager at EPRI's Welding and Repair Technology Center, provides oversight of strategic research on advanced joining and repair technologies and material evaluation. Before joining EPRI in 1995, he worked for J.A. Jones Applied Research Co. Frederick holds a B.S. in welding engineering from the Ohio State University and holds 15 patents for repair welding processes, applications, and materials development.

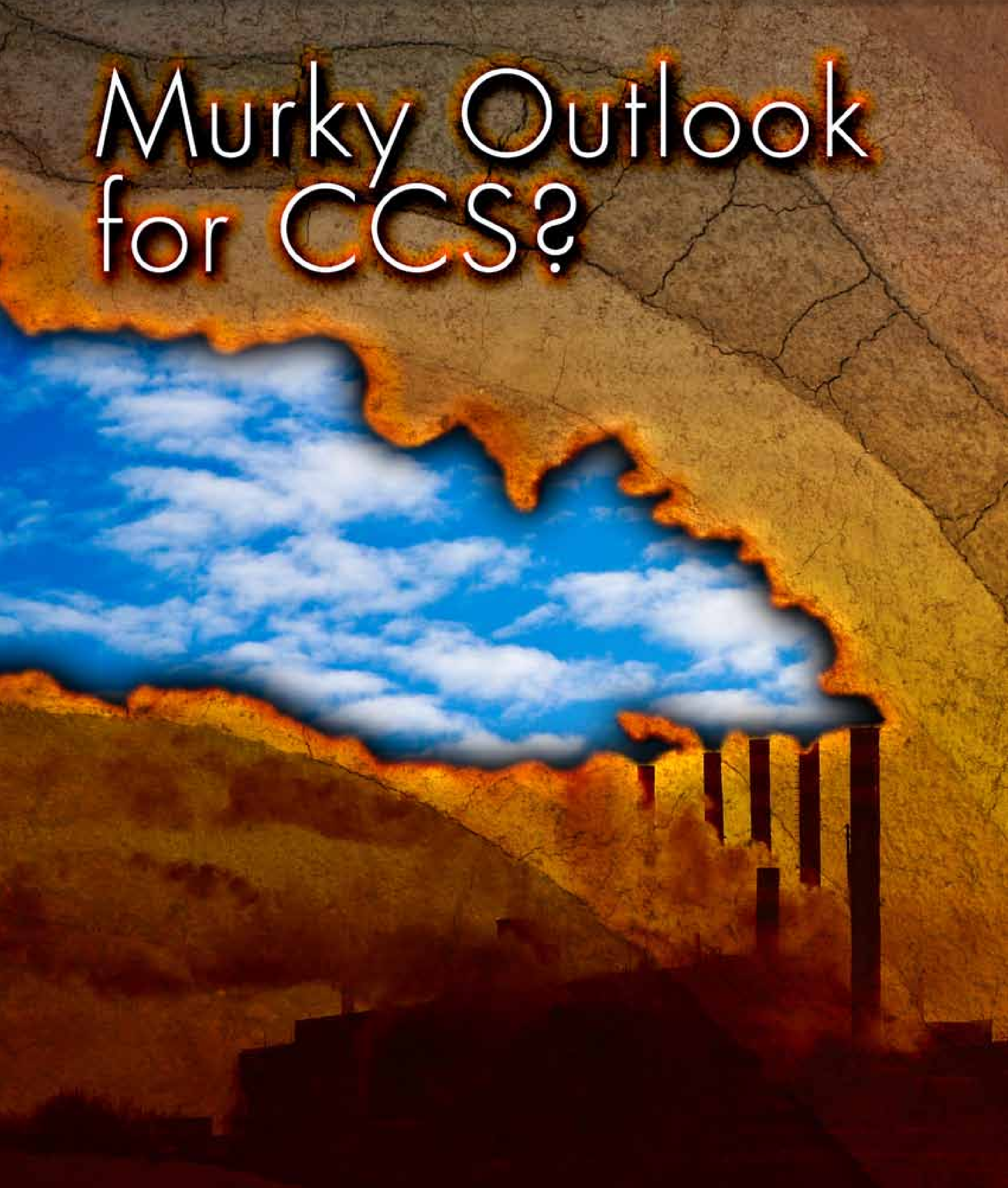
Steven McCracken, senior project manager in EPRI's Welding and Repair Technology Center, focuses on weldability issues with high-chromium nickel-based weld metals and on advanced welding and repair technologies for the nuclear power industry. Prior to joining EPRI in 2007, he worked as the welding and repair/replacement engineer at Ameren Missouri's Callaway Nuclear Plant. McCracken holds a B.S. in mechanical engineering from the University of Missouri and an M.S. in welding engineering from the Ohio State University.

Eric Willis, a senior project manager in the Nuclear Sector, has more than 25 years of experience in the construction and modification of conventional and nuclear power plants. He currently manages work on welding irradiated materials and recently facilitated NRC approval of the optimized weld overlay technology. Willis received a B.S. in welding engineering and an M.S. in materials engineering from California Polytechnic State University at San Luis Obispo.

Dana Couch is a senior project manager in the Nuclear Sector, with current research activities focused on welding and materials issues affecting long-term operation and maintenance of the nuclear fleet. Before joining EPRI in 2008, he worked at TVA, where he was the corporate nuclear welding engineer and was responsible for TVA's boric acid corrosion and alloy 600 programs. Couch received a B.S. degree in materials engineering from Auburn University.

To see more on the Welding and Repair Technology Center, please visit our YouTube channel at EPRIVideos.

Murky Outlook for CCS?



David Victor, a professor at the School of International Relations and Pacific Studies at the University of California, San Diego, leads the Laboratory on International Law and Regulation, which studies the relative effectiveness of international laws. Dr. Victor has for some time been tracking developments related to carbon capture and storage (CCS). In a recent discussion with *EPRI Journal*, he reviewed a number of factors that are influencing the development of CCS technology.

> "European utilities are doing a lot more on CCS than their U.S. counterparts because their governments are serious about long-term emissions cuts."
>
> *~ David Victor*

EJ: CCS has been viewed as integral to the overall strategy to reduce greenhouse gas emissions. In your view, has the status of CCS changed as a result of recent trends in policy and politics?

Victor: Yes, I think the star has waned, principally because there's less confidence that the United States will have a major program to eliminate greenhouse gas emissions. Polls broadly say that the public is worried about this issue, but I'm not sure the public is willing to pay a large cost to deal with it.

EJ: How have the recession, debt, and worries about escalating electricity costs affected the prospects?

Victor: I think all of those factors darken the prospects for CCS. Lower demand for electricity and shrinking public budgets reduce support for new technology, especially costly demonstration projects. The federal government isn't sending clear signals about the importance of CCS, but in theory the states could work closely with regulated utilities to allow the big expenditures needed for demonstration projects and full-scale deployment. In practice, though, the weak economy and lots of other pressures on power rates make state utility commissions skittish about adding still more expenses to the rate base. It's a tough sell today.

EJ: So will we see such projects appear in ones or twos? Will regulators continue to push for them, even in the absence of a political groundswell?

Victor: Yes, I think some large utilities and some regulators, especially in coal states, will be interested in testing elements and whole systems for CCS. A few U.S. utilities have invested in a handful of projects—mostly at demonstration scale. But it's only a start. The next phase will be a lot more expensive, and most U.S. companies are pushing that down on their priorities lists because they don't see credible federal rules related to carbon dioxide anytime soon. In this environment, we'll see just a few projects here and there—if that.

EJ: What are the implications of technological hurdles such as parasitic load and water consumption?

Victor: CCS faces a trifecta of hurdles. It's got regulatory hurdles relating to pipelining and injecting CO_2 underground. It's got fundamental questions around the business model, which itself hinges on regulation. And it faces technological hurdles—including how to reduce parasitic loads. The technological problems will prove manageable if we start building plants and testing different technologies at scale, but we're not doing that because of the first two hurdles.

The central problems are rooted in the business model. Very few private companies will commit billions of dollars for projects when costs and rate recovery are so uncertain. A lot of people are also worried about liability surrounding CO_2 injection, but my sense is the problem will prove manageable if real companies see real prospects for profitable projects, and that depends on business models. Whenever new technologies appear, there are many abstract problems and barriers that find a way of disappearing as the technology scales.

EJ: Carbon taxes, cap and trade, and the clean development mechanism seem to be vanishing from the public's radar. With the European emissions markets and their smaller American cousins working in relative obscurity, what does this mean for the future of CCS?

Victor: I think market mechanisms are overrated when it comes to testing and deploying expensive new technology. One of the biggest problems with cap and trade is the risk that prices will fall. In fact, prices have plummeted, making it even harder for companies to justify such big bets. We see lower prices for lots of reasons. The clean development mechanism has allowed bogus credits into the system, although new rules might be tightening up that problem. The biggest factor, though, is hard economic times, which have lowered demand for credits. Some markets, like RGGI [the Regional Greenhouse Gas Initiative] in the northeastern United States, have also been designed "long" so that prices would never be meaningful—today the RGGI price is barely different from zero. In Europe, the larger market and the stronger political commitment keep prices higher. But the $10 price typical in Europe today is perhaps one-fifth to one-tenth of what you need to justify CCS. No current emissions trading program creates, on its own, a strong enough price incentive for CCS.

And here's what's important about cap and trade. On its own, cap and trade won't create the necessary incentives for big technological innovation. For that you need a technology strategy—including government funding and industry consortia like EPRI. Market incentives such as cap and trade or carbon taxes help nudge industry in the right direction, but their biggest effect is to signal that government is serious about managing the climate problem. European utilities are doing a lot more on CCS than their U.S. counterparts because their governments are serious about long-term emissions cuts. In Europe, with some regulatory pressure and some help from government, a utility can justify large-scale demonstration projects for CCS. In the United States, the incentives just aren't that strong.

EJ: So to build a collaborative approach to CCS, is the best near-term approach to go global?

Victor: Absolutely. If you're a U.S. company looking at CCS, you'll get a bit of regulatory support along with some public funds, but overall, the incentives aren't strong. If you want to test CCS, you have to find partners in regulatory environments that are conducive to testing and building CCS. That means Europe, especially, but perhaps also Canada and Australia. Also, look for partners who are good at building large industrial engineering projects at low cost, which today means China. Chinese firms are building large chemical engineering projects and coal-fired power plants at one-third the cost of a project in the West.

> **"There's a tremendous risk that we will massively underinvest in CCS because of regulatory uncertainty around climate change and because natural gas prices make gas an easy default option."**
> *~ David Victor*

EJ: If some key players end up on the sidelines, what could be the effects on technology development?

Victor: The first movers in this space will be suppliers and companies in a regulatory environment that is both pressing them and helping them build plants. The U.S. environment today neither presses nor helps. That's terrible news for CCS. Some of the most visible side effects could be in rival technologies, such as nuclear power, natural gas, and efficiency. Without CCS, utilities will need to lean a lot harder on these alternatives. One thing we've learned about energy security over the years is that it comes from diversity and flexibility; I worry about a power system that tries to take on big challenges like cutting emissions without having all the options on the table.

EJ: So if the path to CCS technology is one of no pain, no gain, where do you think utilities will most feel some pain?

Victor: Finance and regulation. The technology is challenging, but you don't get the luxury of struggling with technological challenges until you've got a viable business model that lets companies invest massive amounts of capital with low regulatory risk. That's what utilities do: they raise huge amounts of money at low cost because bondholders expect that the regulatory environment won't change radically. We haven't been able to demonstrate that this is true for large CCS projects. Nonutility players may invest in a few projects here and there—such as enhanced oil recovery—but I don't see how you get CCS at scale without making this financially attractive to utilities.

EJ: Countries with coal reserves possess large untapped wealth. Do you think that their governments or other entities might support R&D to drive CCS, at least to the demonstration stage?

Victor: Having large coal resources tips the balance a little bit in favor of investing in CCS. Countries that depend heavily on coal are more likely to support CCS to generate jobs and so on. Those governments also face strong local coal-linked political lobbies that see CCS as a way to stay in business. Australia's keen interest in CCS is an example.

But the importance of this can be overstated, and coal has its competitors. If people think that coal might not be viable long term, they'll turn to resources such as gas and uranium. There's a tremendous amount of natural gas in the world, and as countries have had incentives to look for gas, they've found a lot of it. Even coal-rich countries, China and India most notably—with the right incentives, they'll find resources other than coal. Resources aren't destiny.

EJ: Given the variety of issues and players, it seems that a major challenge is to pull all the players together to orchestrate a more coherent approach. Do you see anybody in a position to make that happen?

Victor: A coherent overall approach would be ideal, but it's unlikely. Much more urgent is coherence around getting the first few individual projects started. Who is out there getting their regulators, their technologies, their suppliers, their managers organized around practical projects? We see U.S. utilities such as AEP, Duke, Southern, and others go several steps down the road, investing in projects. I think we'll see a handful of large European utilities—such as Vattenfall and E.ON—make big steps because they work in regulatory environments that create stronger incentives to devote capital and other resources to CCS. I would watch Europe closely. There are strong financial incentives and pressures that encourage CCS investment; at the same time, in some parts of Europe, notably Germany, local opposition to CCS is severe. I don't see how Germany will deliver on all the things it is promising—massive renewables, CCS at scale, and a phaseout of nuclear power—while keeping the lights on.

We might see a coherent strategy emerge in China. Chinese firms like Huaneng might do a few projects if they saw an export market or if they thought that China would put strict limits on CO_2 emissions in the foreseeable future. It's fashionable these days to see China vaulting to the top position in all kinds of innovation; I remain more skeptical they will do that in CCS because it's still really hard in China to create a viable business model to justify the massive investment.

EJ: So where do you rank CCS among the major areas of electricity sector R&D? In the top five? In the top 50?

Victor: I think it's a top five, in part because CCS is a cluster of technologies that the market, on its own, won't deliver. There's a tremendous risk that we will massively underinvest in CCS because of regulatory uncertainty around climate change and because natural gas prices make gas an easy default option. So my high ranking reflects not just the technological opportunity but also the need to be ready for massive deployment 10 to 20 years down the road.

It's important to remember that while CCS technologies are generally discussed with respect to coal, they could be crucial in a gas-intensive world as well. Is gas a bridge to really low emissions of CO_2, or is it just a bridge to nowhere? With CCS, natural gas could be a bridge to a much lower emissions future.

EJ: Looking beyond the state of the markets and the state of the technology, what's the collective state of mind that you see among those with a stake in CCS?

Victor: Five years ago, big CCS conferences were like rock concerts, and now they're like a convention of pathologists. In the old world, we kept seeing more, better, bigger options for CCS. (We also saw lots of wildly unrealistic claims.) We saw companies following with real investments in demonstration projects and plans for full-scale projects. Until five years ago, we saw people investing time and resources in solving problems. Today, we mostly see people investing a lot of time in making lists of problems.

EJ: So what's needed to reestablish momentum?

Victor: You want to use market incentives to encourage investment in a whole bunch of options. But if you rely on the market alone, companies won't invest much in something as big, expensive, and risky as CCS. You need some extra push, such as special funds for demonstration projects. We have those funds today, but they are cumbersome to use and are under threat in budget-cutting Washington. You need regulatory policies that create direct incentives for companies to test and build projects.

As a huge fan of markets, I'm extremely uneasy talking about this topic because, frankly, the markets on their own aren't going to get us to CCS. The Europeans are poised to move a lot faster on CCS because they have market incentives, strong regulatory pressure, and regulators who are going to keep companies financially whole when they make these bets. You can imagine financing a project in that environment.

> **"Until five years ago, we saw people investing time and resources in solving problems. Today, we mostly see people investing a lot of time in making lists of problems."** *– David Victor*

Advanced Technologies for Inspecting Concrete

Reinforced concrete is durable and inherently resistant to aging, making it well suited for use in nuclear plant containment structures. However, prolonged exposure to elevated temperatures, thermal cycling, chemical exposure, radiation, and applied loading can cause degradation in concrete's aggregate material, cement matrix, or embedded reinforcements. Extending the life of nuclear power plants will require more detailed knowledge of concrete condition and degradation mechanisms.

To address this gap in understanding, EPRI and Constellation Energy Nuclear Group (CENG) are collaborating to investigate concrete aging and nondestructive evaluation at the R. E. Ginna Nuclear Power Plant. Results are being shared with the industry to support decisions related to long-term operation of nuclear power plants and to improve condition assessment.

Monitoring Tendon Load with Fiber Optics

Like other pressurized water reactors, Ginna employs a series of steel cables called *tendons*, which are installed vertically through the containment concrete in conduits. The tendons, each composed of 90 wires, are anchored at both ends—at the bottom in bedrock and at the top by an adjustable anchor. The tendons supply a tension force to the concrete, giving it greater strength to withstand an increase in pressure from a potential breach of the primary system.

Fiber-optic strain gauge installed on a tendon anchor

To ensure that the tendons are functioning properly, nuclear plant owners perform periodic "lift-off" tests to determine the force required to lift the head plate at the top of the tendons. If the force required to lift the tendon head plate is lower than a predetermined level, tension adjustments are made at the top anchor using shims. The need for specialized heavy lifting equipment makes this test expensive and potentially problematic, and the periodic testing provides only limited information on tendon condition.

As an alternative, CENG and EPRI installed fiber-optic strain gauges on the main shim supporting the head plate at the top of the tendons. The gauges feed real-time data on tendon load, strain, and temperature to a computer to enable continuous monitoring of tendon condition, providing a wealth of information unobtainable from lift-off testing.

The fiber-optic system gives plant engineers baseline information on tendon condition and allows them to track changes over time. Moreover, the system tracks and quantifies strain variation resulting from seasonal or diurnal temperature cycles or other factors such as wire breakage in the tendon. In one structural integrity test, plant engineers pressurized the containment to simulate a loss-of-coolant accident, and the fiber-optic system measured the increased strain on the tendons.

Digital Image Correlation

In a first-of-a-kind application, the project team also evaluated the performance of a digital image correlation (DIC) system to monitor surface strain on the containment for enhanced condition assessment. The DIC technology uses twin high-resolution cameras to take photographs of a speckled pattern applied to a surface—in this case, the cylindrical exterior of the containment. A software system analyzes the camera images pixel by pixel and develops a map of the surface, providing a baseline measurement. Any subsequent stress or movement of the surface alters the speckled pattern and is detected by the cameras and analyzed by the software.

The project team applied the DIC system during the containment pressurization test and demonstrated its ability to detect and measure the increased stress on the concrete surface. Because the pattern markings are retained, future assessments can be made on the same areas to identify trends as the concrete ages.

Results and Benefits

The project team successfully demonstrated the ability of fiber-optic tendon load monitoring and DIC technologies to enhance information on the condition of the Ginna containment. These technologies enable plant engineers to more effectively track changes in condition over time and are potentially more robust and cost-effective than periodic sampling approaches. More in-depth understanding of aging effects can help inform aging-management programs and plant relicensing efforts and can help ensure continued safe and reliable long-term operation.

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LEDs for Street and Area Lighting

Light-emitting diodes (LEDs) produce light when electrons flow through semiconductor material rather than by heating a filament or discharging an electrical arc through a gas. For decades, LEDs were used in just a few low-power applications, first in automobile indicator lights and then in numerical readouts on calculators and home appliances.

With recent improvements in color balance and power levels, LEDs are being considered for broader lighting applications, most notably in flashlights, headlights for vehicles, and task lighting. EPRI believes they also have promise to replace the high-intensity discharge (HID) lighting currently used to illuminate streets and parking lots. Researchers are investigating this potential at demonstration sites suggested by participating utilities and municipalities.

Application Tradeoffs

One of the strongest advantages of LED lighting is application efficiency. Conventional street lamps and parking lot lamps radiate light in nearly all directions. Large reflectors above the lamps redirect some of the wasted light, but up to 30% of the light emitted still travels skyward or in other unintended directions, contributing to light pollution and wasted energy. LED lamps, on the other hand, emit light in a single direction, providing high task efficiency, uniformity of coverage, and very little light pollution. They can be operated at a reduced light output while achieving a result equal or superior to that of HIDs.

As solid-state devices, LEDs operate at low currents and low temperatures compared with incandescent or discharge bulbs, leading to longer lamp life—two to four times that of HID lamps—and lower maintenance costs. Because LEDs are small and encased in plastic, they are more rugged than large, fragile glass bulbs and less likely to be damaged or broken while being handled. They also can be set up for dimming, offering power providers a largely indiscernible load-reducing option.

LEDs carry drawbacks as well—primarily their initial cost, which can be five times that of conventional systems. Unlike HIDs, they will operate only with correct electrical polarity, requiring three-wire installation, and they are less immune to electrical disturbances.

Demonstration Results

EPRI launched its LED Energy Efficiency Demonstration project in 2009 to test high-power LED systems in the field. Data were collected by EPRI's Scotty remote-controlled robot at more than 20 demonstration sites, where a variety of street and parking lot lighting systems were retrofitted with commercially available LED lights. Researchers measured energy savings of 25%–70% for the retrofits, with equivalent or better lighting performance.

An important finding from the demonstration was the lack of maturity in the specifications for LED fixtures and drivers (the lamps' power electronics circuits). Each manufacturer's design is essentially unique. In fact, EPRI found variations of up to 5% in efficiency among nominally comparable fixtures. Simple energy consumption tests also showed substantial inconsistency among same-model fixtures—in one case, up to 8% variation in input power.

An overall failure rate of 15% confirmed that while the technology shows great promise, manufacturers still have some way to go in developing affordable, robust, highly reliable LED area lighting. EPRI recommends that the industry adopt a standard form factor for fixtures and develop detailed specifications, especially regarding manufacturing tolerances, driver efficiency, and design of control circuitry.

The tests and analyses also identified specific design refinements that could improve performance. One is the standard addition of ferrite beads to LED fixtures to filter out high-frequency signals, which may produce harmonics on the line. Another recommendation results from researchers' observation that the demo LEDs drew more power as the night temperatures cooled their fixtures; as a result, the lamps will waste energy by over-illuminating an area during early morning hours and especially during cold winter months. Adding a temperature sensor and compensation circuit would allow the driver to automatically adjust the LED current to maintain constant input power, regardless of ambient temperature.

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EPRI Provides Input to Cancer Study Design

The U.S. Nuclear Regulatory Commission, through the National Academy of Sciences (NAS), is updating a 1990 report prepared by the National Cancer Institute on cancer in populations living near nuclear facilities. The NAS study is focused on public exposures from routine operation of nuclear facilities, as opposed to exposures from emergency operations or accident events.

In light of the difficulties in developing a sound design for this type of study, EPRI formed a committee of scientists and professionals in the fields of epidemiology, radiation biology, nuclear plant effluents, and environmental risk assessment to offer suggestions to the NAS committee responsible for scoping the report update. The technical considerations are largely related to the data challenges that exist and the statistical limitations inherent in epidemiological studies. The EPRI input provides key recommendations on epidemiological approaches that may yield more meaningful study results.

Earlier Studies and Confounding Factors

The 1990 study considered the mortality risk in populations around 52 nuclear power plants and 10 Department of Energy nuclear facilities. The results concluded that deaths from cancer were not more frequent in counties near nuclear facilities than in control counties. While pointing out that results were limited by the approach used to correlate releases and mortality and by the large size of the counties, the report authors stated that "if nuclear facilities posed a risk to neighboring populations, the risk was too small to be detected by a survey such as this one."

Subsequent studies of childhood cancers in the United Kingdom, Germany, and France also faced the problem of statistical limitations, primarily related to the fact that the monitored emissions from nuclear facilities are far smaller than natural background levels. In both the German and French studies, it was estimated that the exposures were 1,000 to 100,000 times smaller than natural background. If incremental dose increases are in fact this small, it will not be possible to discern a statistically significant increase in cancer risk.

Other result-confounding issues for the NAS update include outdated dosimetry models and parameter values (some of which were first published in 1959) and the use of distance from a facility as a surrogate for received dose, which fails to make use of actual facility release data and ignores the effects of local terrain and meteorology on effluent migration. To ensure realistic dose values, the NAS will need to develop an improved approach for linking emission measurements to the public dose received, including consideration of dose-rate and dose-distribution effects.

EPRI Recommendations

The EPRI committee's key recommendations, presented to the NAS during a public meeting, focused mainly on the dose issues, pointing out that an epidemiological study based on a small dose relative to annual background and medical exposures increases the difficulty of providing a definitive answer on cancer risks in populations near nuclear facilities. In recognition of this fact, and to make it clear to outside stakeholders, the committee said the NAS should develop an appropriate risk communication plan that explains the challenges associated with low-dose epidemiological studies, clearly articulates the study expectations, and describes how the results will be used.

The committee also recommended that any new epidemiologic study should closely coordinate the dosimetric efforts with the epidemiologic efforts and develop a comprehensive and consistent exposure assessment methodology for dose evaluation.

With respect to epidemiological studies, the EPRI committee submitted the following specific suggestions:

- Estimate actual dose for the study populations instead of using distance from a facility as a surrogate for dose.
- Conduct an analytic study (perhaps of a case-control design) focused on childhood cancer, with special attention given to leukemia and non-Hodgkins lymphoma in children under age 5. Use information from a child's full life span (including time in utero) about family history, personal illnesses, siblings, day care, places of residence, and possible exposures to radiation or environmental toxins.

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EPRI Develops Prototype Medium-Voltage Utility Direct Fast Charger

While recently commercialized plug-in electric vehicles offer sufficient battery capacity for typical daily driving, fast charging technologies have near-term potential to extend the range and versatility of such vehicles. To enhance this capability, engineers from EPRI, with financial and technical support from the Tennessee Valley Authority, have developed a prototype for an advanced direct-current (DC) fast charger system. The Utility Direct Fast Charger is being tested at EPRI's Knoxville laboratory in preparation for field demonstrations.

Advanced Transformer Boosts Efficiency

DC fast charging technology is expected to enhance the commercial appeal of plug-in electric vehicles. But widespread deployment of today's commercially available 208- or 480-volt alternating-current (AC) fast chargers has been inhibited by the high costs of power delivery infrastructure and hardware: three primaries and three secondaries, a three-phase 13.8-kilovolt (kV) AC line-to-line medium-voltage distribution transformer, and in many cases, an additional dedicated 60-hertz low-voltage isolation transformer to meet safety codes. Siting requirements and labor further add to the infrastructure cost. With high input current, the system loss in these DC fast chargers typically is greater than 10%. Conventional DC fast charging systems can attain efficiencies of 90%–92%, but additional losses in a three-phase supply transformer may reduce overall efficiency to 89%–91%.

The 2.4-kV/45-kVA (kilovoltampere) solid-state Utility Direct Fast Charger has fewer components than fast chargers used today, and its simple design is expected to result in lower installation costs. The unit also is more efficient than commercially available chargers, with an overall system efficiency of 96%–97%.

The charger's efficiency advantage comes from its key component—a solid-state transformer that can output a wide range of DC and AC voltages to tailor power to specific needs. For vehicle charging, the charger replaces both the independent power conversion units and the conventional transformer with a single interface system. The Utility Direct Fast Charger underwent successful proof-of-concept testing with an earlier, 2.4-kV/10-kVA fast charger prototype in March 2011. In these tests, the utility charger achieved efficiency greater than 96% in the 10%–90% operating range, a saving of more than 6% over the conventional approach, or a loss reduction of more than 50%.

In addition to its use in vehicle charging, the system has been proposed as a replacement for conventional transformers in regular medium-voltage power distribution. If a business installed the fast charger as its building transformer, it could not only conveniently add fast charging service but also integrate on-site solar, energy storage, and building energy management systems. This could help manage the high peak loads of the DC charger and reduce demand charges.

Researchers at EPRI's Knoxville laboratory charge a Mitsubishi i-MiEV with the Utility Direct Fast Charger.

Utilities may consider providing fast charging capability directly from the distribution system—especially in cities, where fast chargers may not be hosted by a business. For such an application in which a DC-AC inverter function is not needed, the isolated DC-DC converter output can be used directly for fast charging, avoiding an additional 1.5% energy loss. Eliminating the conventional transformer also allows significant reduction in the size and weight of cabling and installation materials. A standard 50-kilowatt transformer weighs more than 800 pounds (363 kg)—more than 1,000 pounds (454 kg) with a charging station and low-voltage charger. The electronics for the entire EPRI Utility Direct Fast Charger weigh less than 150 pounds (68 kg).

Technology Demonstration

Recent testing at EPRI's Knoxville laboratory confirmed the 2.4-kV/45-kVA fast charger prototype's ability to provide a full charge to commercially available plug-in electric vehicles (two Nissan Leafs and one Mitsubishi i-MiEV). An important part of the demonstration was to confirm the communication compatibility of the fast charging technology with the electric vehicles' battery management systems by means of the industry standard CHAdeMO communication protocol. A user interface and web-based mobile data collection system were included in the Knoxville trials.

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EPRI Estimates Performance, Costs for Solar Thermal Plants

There are more than three dozen utility-scale concentrating solar thermal power (CSP) systems in operation worldwide (1,700 MW), with more than 60 additional systems planned or under construction (15,000 MW). Yet despite the surge of interest in solar thermal technology over the past decade, very little comparative cost and performance information has been available, owing in part to proprietary concerns of manufacturers and developers.

To create a snapshot of the current state of CSP projects and provide input for future utility generation asset planning, EPRI has collected information on the commercial status and potential costs of three CSP technologies for which validated cost and performance data are available: parabolic trough systems (with and without thermal storage), power tower systems (with thermal storage), and dish Stirling systems.

The report on this work (1025007) includes performance and cost estimates for four representative CSP configurations sited near Daggett, California, and in Queensland, Australia—locations considered favorable for solar thermal development. The performance estimates, including daily generation profile, monthly output, and annual capacity factor, were produced using the System Advisor Model, a publicly available tool developed by the National Renewable Energy Laboratory in conjunction with Sandia National Laboratories and the Department of Energy's Solar Energy Technologies Program.

System Designs

All three CSP technologies use mirrors to concentrate solar radiation onto receivers to produce heat for electricity production.

Parabolic trough systems use rows of long, trough-shaped mirrors to focus sunlight on insulated tubes positioned along the mirrors' focal line. An oil-based heat-transfer fluid circulating through the tubes carries the heat to steam generators at a central plant, where power is produced via a conventional steam turbine. The parabolic trough technology is commercially proven, and most of the world's CSP projects use this design. Transferring heat from the circulating fluid to molten salt rather than using it to immediately produce steam can provide several hours of thermal storage, which then can be used to supply power after sunset or during cloudy periods.

Power tower systems use a large field of flat mirrors to track and reflect sunlight onto a central tower receiver to heat a working fluid—usually molten salt—which is used to raise steam for power generation and also can provide significant amounts of thermal

storage. The first commercial molten salt power tower was commissioned in May 2011, and several projects are under development in Nevada, California, Arizona, and Spain.

Dish Stirling systems use a large parabolic dish to track and concentrate sunlight onto a receiver attached to the dish by a boom. A Stirling engine and a generator assembly are incorporated into the unit to convert the heat to electricity. The units are self-contained, highly efficient, and well suited for mass production, although they carry no thermal storage capability. The ability to generate electricity independently—without a central power block—makes this technology attractive for distributed generation or utility-scale projects. The technology faced a major setback in 2011 with the bankruptcy of the leading technology provider and cancellation of several industry projects, but large arrays of dish Stirling units are still planned and under construction.

Cost Estimates

Capital costs, operations and maintenance costs, and levelized cost of electricity were estimated for the four representative configurations in both locations. Capital costs for the California site were $4,070/kilowatt for a 250-MW parabolic trough plant with no storage; $7,020/kW for a 250-MW parabolic trough plant with 6 hours of storage; $7,550/kW for a 100-MW molten salt power tower with 10 hours of storage; and $4,540/kW for a 100-MW dish Stirling system. Levelized cost calculations were made both with and without a 30% investment tax credit for the California plants. No tax credits were considered in the costs for the Queensland plants.

The report appendices include a comparative table of plant cost and performance data; a table detailing the solar thermal plants currently operating, planned, or under construction; and additional information on important concepts related to solar thermal systems.

For more information, contact Cara Libby, clibby@epri.com, 650.855.2382.

Testing Damaged HVDC Glass Insulators

Improved converter technology and increased worldwide interest in smart grid projects have focused attention on high-voltage direct-current (HVDC) transmission systems, which offer a number of valuable capabilities—facilitating integration of distributed renewable resources, transferring bulk power over long distances, isolating power systems from disturbances, and enhancing system reliability. One recent study forecasts that annual global investment in HVDC will increase by 44% over the next five years—mostly in China and India, but with significant application in Europe and North America as well.

Of particular concern is ensuring that HVDC systems can be operated consistently at their full system voltage while managing to avoid flashover events and preparing for related maintenance issues. Such difficulties on an HVDC line linking two African nations spurred new experimental testing at EPRI's high-voltage laboratory in Lenox, Massachusetts.

Flashover with two broken discs at the live end

Shattered Insulator Discs

The Cahora Bassa HVDC transmission line delivers power from hydroelectric resources in the Republic of Mozambique to the Republic of South Africa. This resource is a critical asset in South African utility Eskom's power system, accounting for roughly 5% of its generation capacity.

The transmission line is configured as two monopole systems running parallel about a kilometer (0.6 mile) apart. Stretching 1,400 km (870 miles) south from the Cahora Bassa hydro dam to Pretoria, the lines are each supported by about 3,500 towers, which use both composite and glass (cap-and-pin) insulator strings. The glass insulators are prone to vandalism, and line inspections have shown that individual discs in some glass strings have been shattered. It is assumed that this condition may degrade the insulation strength of the string as a whole, depending on the number and position of the shattered discs.

Because of the uncertainties in insulation and air-gap integrity, live line work currently is not being conducted at full voltage and is limited to minor maintenance tasks. Also, the line's system voltage has been reduced to 400 kV, just 75% of the 533-kV rated voltage. At Eskom's request, researchers at the Lenox lab conducted tests to clarify how vulnerable the damaged insulators are to flashover events and help develop an effective approach to economical repair and maintenance of the line.

Study Findings

The Lenox engineers set up a two-part test program, first determining the breakdown strength of undamaged insulator strings composed of various numbers of discs (to better understand baseline capabilities) and then examining the effect of shattered discs in different positions on a string. The testing was conducted under positive polarity conditions. In the first series, tests on strings with 6, 10, and 13 discs showed a direct linear relationship between the number of discs used and the total flashover voltage under HVDC conditions; flashover occurred at 573 kV with 6 discs, 932 kV with 10 discs, and 1,216 kV with 13 discs.

The damaged insulator tests were carried out with 13-disc strings that had single and two adjacent shattered discs placed in four locations on the string—at the live and dead ends of the string and a third of the way from each end. The tests, which were recorded by a high-speed digital camera, showed that shattered discs at any location do indeed result in a decrease in insulation strength, with the greatest effect seen when the damage is at the live end of the string. Two broken disks at the live end resulted in the worst performance recorded: a 24% reduction in flashover voltage. The flashover voltage generally increased as the broken discs were moved away from the live end.

Further testing will be required to determine the linearity of a full insulator string of approximately 30 discs, and the tests must be repeated under negative polarity conditions. The effect of pollution contamination on the test strings should also be studied. The test results, which provide new understanding of the performance of broken glass insulators, will enable Eskom to establish effective insulator replacement and maintenance strategies.

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TECHNOLOGY AT WORK

Member applications of EPRI science and technology

Optimizing SCR for Mercury Oxidation

Late last year, the U.S. Environmental Protection Agency unveiled new standards that sharply limit mercury emissions from the nation's coal- and oil-burning power plants. Under the new regulations, utilities will have three years to install emission control equipment that ensures compliance with the new limits. One cost-effective approach may be to enhance the capabilities of air quality control systems already in service for other air pollutants—for example, selective catalytic reduction (SCR) systems, electrostatic precipitators, or wet flue gas desulfurization units.

SCR technology has long been the technology of choice for meeting stringent emission limits for nitrogen oxides (NOx) in coal-fired generating plants, and SCR catalysts also have the ability to oxidize mercury, making its capture easier in a downstream scrubber. But while SCR catalyst behavior is well understood for NOx reduction (deNOx) and SO_2 oxidation, mercury oxidation across catalysts is not well understood with respect to many common operational parameters and catalyst formulations.

Improving the performance of SCR systems for mercury oxidation could provide power plants with a highly effective, low-cost method of mercury removal using equipment already in place—an extremely attractive option compared with the prospect of installing new, dedicated mercury removal systems.

Investigations at the Mercury Research Center

To better understand mercury oxidation by SCR catalysts, Southern Company and EPRI conducted a test program at Gulf Power's Mercury Research Center (MRC) at Plant Crist, near Pensacola, Florida. The MRC operates as a 5-MW-equivalent slipstream facility, using flue gas extracted from points both upstream and downstream of the host unit's economizer.

The test was devised to determine mercury oxidation across five different catalysts as a function of chlorine and bromine levels, ammonia levels, temperature, and flow rate. Catalyst types included plate, honeycomb, and corrugated. Fuel was purchased from the spot market and included South American coal, western bituminous coal, and various fuel blends.

Test Program Results

Findings of the test program indicate that chlorine concentration in the flue gas has a strong effect on SCR mercury oxidation, with four of the catalysts tested demonstrating increased oxidation performance at higher chlorine levels. Flue gas highly depleted in chlorine—less than 50 parts per million by volume (ppmv)—will see very strong incremental improvements in SCR mercury oxidation as chlorine concentrations are increased.

Gulf Power's Mercury Research Center

While oxidation efficiency varied from catalyst to catalyst, tests conducted using two new catalyst layers at 90% deNOx and 700°F (371°C) showed that chlorine concentrations of up to 150 ppmv are necessary to achieve nominal 90% mercury oxidation.

Test results also indicated that ammonia inhibits mercury oxidation across the SCR system. Thus, the downstream catalyst layers will contribute more to mercury oxidation than will the upstream layers. SCR systems with higher deNOx reactor potential are expected to oxidize higher levels of mercury, and the mercury efficiency will decrease as the catalyst deactivates over time.

Increased temperature was shown to have a negative effect on SCR mercury oxidation—an effect opposite to that of the deNOx reaction, which increases as temperature increases. Accordingly, lower-temperature operation of the SCR system would help to maximize SCR mercury oxidation but at the cost of some NOx reduction efficiency. Flow rate appeared to have very little direct effect on mercury oxidation.

Overall, the MRC demonstration provides data-backed guidance on the expanded use of SCR, helping units with existing full-scale SCR systems to determine what changes in operating parameters could improve mercury oxidation while maintaining NOx reduction. For retrofits, the demonstration will help designers optimize new SCR systems for both NOx reduction and mercury oxidation.

In related work, EPRI is developing a comprehensive model for predicting SCR mercury oxidation according to flue gas conditions and reactor deNOx potential, providing assistance on beneficial flue gas modification and improved catalyst management strategies. Additional efforts involve the evaluation of new catalyst formulations designed to achieve higher oxidation levels and an investigation of mercury behavior across catalyst layers as they deactivate over time.

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SCS and EPRI Expand Groundwater Monitoring Capability

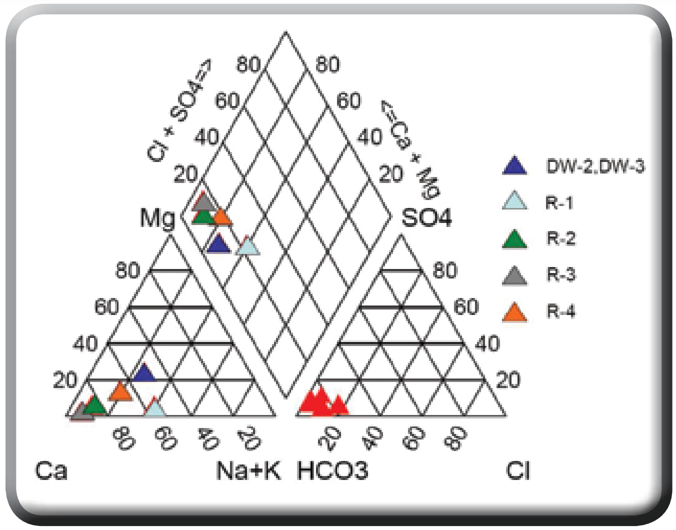
Companies that own or operate fossil-fueled power plants have had to monitor and report on groundwater concentrations of inorganic constituents for decades. For help in analyzing and reporting data on groundwater near its fossil power plants and ash by-product disposal sites, Southern Company Services (SCS) collaborated with EPRI in the early 1990s to produce a database called MANAGES, which interprets water quality, soil quality, and waste characterization data. The company found the software to be a consistent and reliable tool and has been using it for nearly two decades.

In recent years, regulatory and public interest in potential groundwater issues has expanded to include not only fossil plants but nuclear facilities and transmission and distribution sites, resulting in increased demands for collection and analysis of groundwater data. To meet the new regulatory requirements, SCS approached EPRI about expanding the capabilities of MANAGES to include radionuclide data from nuclear power plants so that the program could be used as a single repository of all the utility's groundwater data. According to SCS's David Morris, manager, earth science and environmental engineering, "Since we work in both the fossil and nuclear areas, we wanted to have a tool that meets both needs."

Greater Coverage, Easier Access

Integrating nuclear capabilities into the MANAGES platform added a significant degree of complexity to the software, and technical staff from EPRI's Environment and Nuclear sectors worked together to ensure that the program included the additional functionality. MANAGES 3.2, released in November 2010, was designed to collect and manage data for various constituent types, including 200 organic compounds, 100 inorganic constituents, and 140 radionuclides. The additional capability allows SCS to perform many kinds of data analyses, including time-series graphing, detecting changes in groundwater chemistry, and comparing groundwater concentrations with regulatory limits.

Ease of use was also enhanced. The program provides SCS a single, consistent database that can be accessed by all environmental professionals within the company. The MANAGES platform offers about 100 analyses, graphs, and statistical tests and can run reports that analyze groundwater concentration trends and automatically flag concentrations that are higher than regulatory limits. The software can either print data using a state-specific form or export data in a state-specified electronic



MANAGES calculates and exports stored data to a variety of specialty geochemistry platforms.

format, which is especially useful for the quarterly reports that Southern Company subsidiaries provide to various regulatory agencies.

Training and Support

EPRI conducted a training workshop in July 2011 to facilitate greater familiarity with the program at SCS and Southern Company's other operating subsidiaries and to bring the staff up to date on the software's new capabilities. In addition, EPRI's ongoing MANAGES Forum provides significant support, including training and webcasts, troubleshooting, and an annual workshop. In addition to helping SCS maintain expertise in using the software, the MANAGES Forum allows SCS and other companies the opportunity to shape the development of future versions of the software and to share experiences and insights.

SCS believes that MANAGES 3.2 will significantly help in managing the company's groundwater data and in meeting regulatory requirements. According to Steve Bearce, a senior geologist at SCS, "MANAGES now provides a seamless interface between fossil and nuclear uses. It ensures that our work is done in a consistent manner and that we have the same level of quality, regardless of who is working on the project. It's a wonderful tool."

For more information, contact James Lingle, jlingle@epri.com, 414.355.5559, or Karen Kim, kkim@epri.com, 650.855.2190.

REPORTS & SOFTWARE

Key deliverables now available

The following is a small selection of items recently published by EPRI. To view complete lists of your company-funded research reports, updates, software, training announcements, and other program deliverables, log in at www.epri.com and go to Program Cockpits.

Advanced Data Processing and Computing Technologies at Control Centers (1021752)

This report explores the applicability of advanced computing technologies and problem solution methodologies for providing more useful information to power system operators. After reviewing the shortcomings of commonplace tools, the report describes emerging computing technologies that may offer improvement, such as cloud computing, graphics processing units, the Semantic Web, and service-oriented architecture. New algorithmic and modeling techniques that could improve power system tool simulations are also presented.

Nuclear Maintenance Applications Center: Air-Operated Valve Diagnostic Testing Guide (1022954)

This report presents a thorough discussion of air-operated valve (AOV) diagnostic test equipment, the principles of equipment operation, and background information that personnel can apply when performing AOV tests and trace analyses. In addition to guidance on test equipment selection and setup, information is included on testing frequency, the use and benefits of strain gauges, and the use of traces and plots for detecting maintenance problems.

Failure Analysis of Digital Instrumentation and Control Equipment and Systems (1022985)

This interim report documents an investigation of digital system failure analysis techniques that may be of use in improving the effectiveness and efficiency of techniques currently being applied. Covering both top-down and bottom-up approaches, the report presents detailed breakdowns of failure modes and mechanisms for specific digital components and assesses the strengths of selected failure analysis methods, including the ability to identify vulnerabilities that would likely be missed by other methods.

Transformer Industrywide Database: Equipment Performance and Failure Database Analysis—Status Update (1023047)

This compilation of the EPRI Transformer Industrywide Database (IDB) is a collaborative effort to establish a statistically valid population of many types of power transformers and collect data on their operation and failure. Analysis of these data will guide asset managers and maintenance managers in their decision making by providing both information about historical performance and models for projecting future performance.

Field Guide: Turbine Steam Path Damage (1024593)

This new EPRI field reference guide compiles the most recent knowledge about turbine steam path damage in a handy pocket size to assist plant staff and field engineers in identifying and repairing damage during periodic inspections. The guide includes information on recognizing underlying mechanisms, determining the root cause, and choosing immediate and long-term actions to lessen or prevent recurrence of the problem.

Mapping and Assessment of the United States Ocean Wave Energy Resource (1024637)

This report describes a rigorous assessment of the U.S. ocean wave energy resource using a 51-month Wavewatch III hindcast database developed especially for this study by the National Oceanographic and Atmospheric Administration's National Centers for Environmental Prediction. The total available wave energy resource along the U.S. continental shelf edge was estimated to be 2,640 TWh/yr, with total recoverable resource estimated at 1,170 TWh/yr. Regional breakdowns of these estimates also are included.

Economic Evaluation of Alternative Cooling Technologies (1024805)

Different types of power plant cooling systems, including once-through cooling, wet closed-cycle cooling, dry cooling, and hybrid systems, can offer significant opportunity for water conservation, but these water savings often come at the cost of higher power requirements, reduced plant efficiency, and limited plant capacity. This report presents data, information, and methods that will enable decision makers to understand the trade-offs and to make the appropriate system choice for a variety of plant types and site locations.

Potential Effects of Electromagnetic Fields from Submerged Electrical Cables on Aquatic Life (1024943)

There is considerable interest in power generation based on waves, river currents, or tidal flows, but such projects will generate underwater electromagnetic fields (EMFs) when power is transmitted to shore. This resource paper provides a review of the scientific literature to date on EMF effects from submerged electrical cables on aquatic life and identifies gaps and further research needs for studies of physical characterization and biological response.

WIRED IN

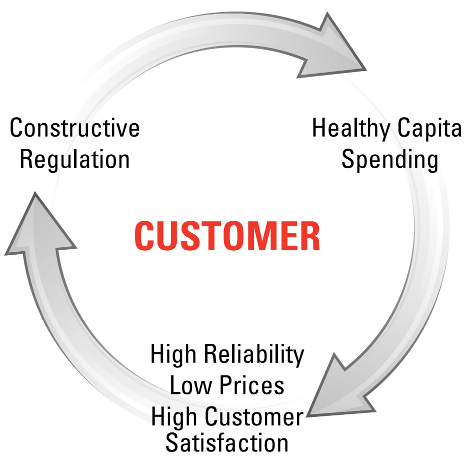
Perspectives on electricity

Research, Technology, and the Circle of Life

Chris Hobson,
Chief Environmental Officer, Southern Company

At Southern Company, the "Circle of Life" illustrates what is central to our business and where we focus our attention and resources.

Our customers are at the center of everything we do. As the graphic shows, we focus on the fundamentals of low prices, high reliability, and customer satisfaction. These in turn directly connect to constructive, effective regulatory relations and activities, which enable healthy capital spending. For a regulated, capital-intensive company that provides its customers with one of life's most essential services and products, we think this circle carries a big message in a small space.



Today, this circle is surrounded by big challenges. About half of Southern Company's 43,000-megawatt (MW) generation portfolio is coal fired. We expect that by 2021, new investment in our flagship coal-fired units will range from $13 billion to $18 billion, primarily for environmental controls. For as much as 8,000 MW of the fleet, we face significant decisions—including retrofitting with new controls, closing, or switching to natural gas.

As a result, we and our customers together are facing the fact that costs will increase. That's a certainty.

At the same time, we face significant uncertainty in several federal regulatory areas, including maximum achievable control technologies (MACT), criteria pollutants (that is, nitrogen oxides, sulfur dioxide, particulate matter, and ozone), coal combustion by-products (ash, etc.), water, and greenhouse gases. There's a world of details in each of these regulatory areas. There's also a world of potential interactions and side effects. And there's another world of higher costs. Wrapped up with all these variables are technical questions—including important ones about the point of diminishing returns for investment in incremental emissions reductions.

Because our customers are at the center of our business, we are obligated to raise fundamental questions about the costs and benefits of regulations. If we pass the point of diminishing returns on utility regulation, we are essentially diverting money, attention, and technical resources away from areas where society may be able to achieve more meaningful results.

That's why a constructive regulatory environment is so important. In working with regulators, it is important to be informed and open-minded and to be supported by good science and effective research. It's good business in general: Know the facts, know the people, know the costs and benefits, and keep the customer as your focus.

There's another, unstated yet vital, factor that supports the Circle of Life. It's research and development. R&D is not an afterthought or a bolt-on function at Southern Company. Through good economic times and bad, we have continued to build our R&D organization into one of the most diversified and robust among U.S. utilities. We've done this because the benefits are many, especially for our customers. As we have built, installed, and operated scrubbers and selective catalytic reduction equipment, we have achieved industry-leading performance in cost and operation. Now we are at the forefront of new energy technologies. We operate one of the nation's largest solar plants, and we're building the country's largest wood biomass generating plant. In addition, the world's largest operating utility carbon capture and storage system is removing up to 500 metric tons of carbon dioxide per day from our Plant Barry in Alabama. And our 582-MW twenty-first-century coal plant now under construction in Mississippi will have an emissions profile comparable to that of a natural gas plant. It also will be a zero discharge plant for water, with most of the industrial process wastewater recycled for various uses at the facility. We are further leading the industry in R&D at our innovative Mercury Research Center and soon-to-be-completed Water Research Center, in which EPRI is collaborating.

Ultimately, R&D is all about the customer. These technologies are crucial to the future of our industry, and they are fundamental to the Circle of Life—essential to constructive regulation, healthy capital spending, a clean and reliable energy supply, low prices, and customer satisfaction.

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ELECTRIC POWER RESEARCH INSTITUTE

SPRING 2012

Printed on recycled paper in the United States of America

1025049