SUMMER 2009

EPRI JOURNAL

ELECTRIC POWER RESEARCH INSTITUTE

Retrofitting CO_2 Capture

ALSO IN THIS ISSUE:

2009 Update: CO_2 Reduction Analyses

Electric Transportation Beyond the Road

Fish Protection on the Ohio

What Lies Beneath: Buried Nuclear Piping

The Water Resource—Uncertainty for Power Plants

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

Together. . . Shaping the Future of Electricity®

EPRI Journal Staff and Contributors
Dennis Murphy, *Publisher/Vice President, Marketing and Information Technology*
Jeremy Dreier, *Editor-in-Chief/Senior Communications Manager*
David Dietrich, *Managing Editor*
Jeannine Howatt, *Business Manager*
Josette LaCaria, *Graphic Designer*

Henry A. (Hank) Courtright, *Senior Vice President, Member and External Relations*

Contact Information
Editor-in-Chief
EPRI Journal
PO Box 10412
Palo Alto, CA 94303-0813

For information on subscriptions and permissions, call the EPRI Customer Assistance Center at 800.313.3774 and press 4, or e-mail journal@epri.com. Please include the code number from your mailing label with inquiries about your subscription.

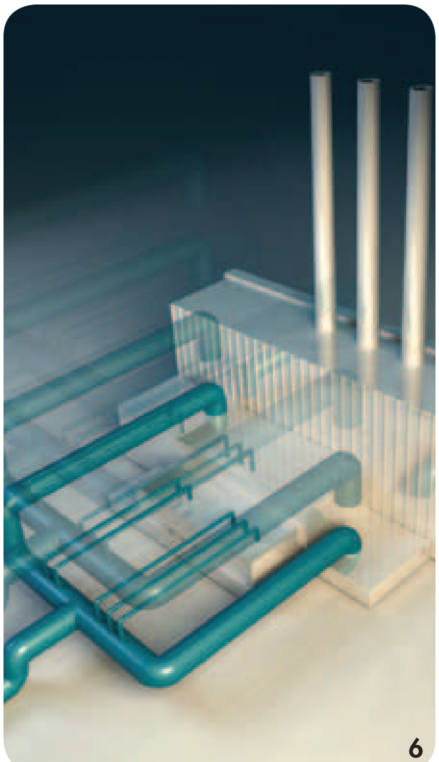
Current and recent editions of the EPRI Journal may be viewed online at www.epri.com/eprijournal.

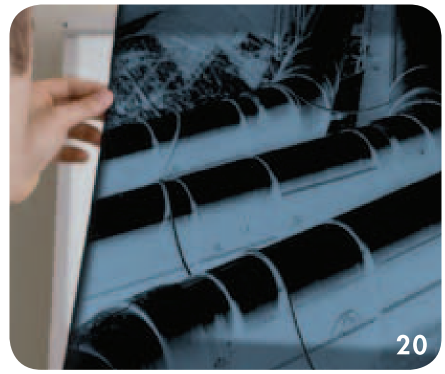
Visit EPRI's web site at www.epri.com.

Art: Cover and pages 6, 10, 14, and 20 by Craig Diskowski/Edge Design.

EPRI JOURNAL

SUMMER 2009





SPECIAL INSERT

Prism/MERGE Analyses 2009 Update

VIEWPOINT

2 Creating the Future

FEATURES

6 Retrofitting CO_2 Capture
EPRI research is providing a better understanding of the challenges and consequences of retrofitting existing fossil-fueled plants with CO_2 capture technologies.

10 Electric Transportation Beyond the Road
Non-road electric transportation technologies are helping utilities and their customers reduce emissions and fuel consumption while improving operating efficiencies.

14 The Ohio River Ecological Research Project
A utility-sponsored program for the study of fish and aquatic invertebrates near generating facilities along the Ohio River provides key long-term data.

20 What Lies Beneath: Finding Solutions to Buried Piping Problems
Interest in nuclear plant life extension has directed attention to the miles of decades-old service piping buried beneath generating stations. EPRI offers support to ensure the continued integrity of such systems.

24 First Person with Russell Noble
A long-time utility researcher points up the issues and growing uncertainties related to water resources for generating plants.

DEPARTMENTS

4 Shaping the Future

18 Dateline EPRI

28 Innovation

30 In Development

32 In the Field

34 Technology at Work

36 Reports and Software

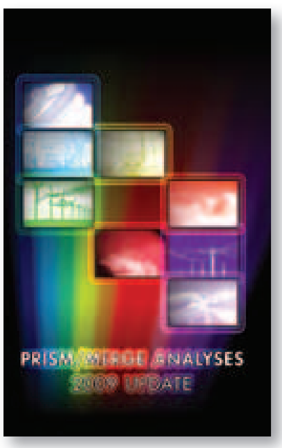
37 Wired In

VIEWPOINT

by Steve Specker, President and CEO, EPRI

Creating the Future

In 2007 EPRI published the findings of its first Prism and MERGE analyses. In Prism we performed a bottoms-up analysis of the U.S. electricity sector's technical potential for reducing CO_2 emissions through an aggressive, but technically feasible, deployment of a full portfolio of advanced technologies. In MERGE we modeled the economically optimum deployment of these technologies to determine the economic impacts of meeting a CO_2 constraint derived from the Prism technical potential.



In 2009 we have updated these analyses, the results of which are summarized in a special insert of this *EPRI Journal*.

The new Prism findings show that the U.S. electricity sector has the technical potential to reduce CO_2 emissions in 2030 to a level 40% below 2005. To achieve this will require sustained R&D, accelerated demonstrations, and rapid commercial deployment of a full portfolio of advanced technologies.

The new MERGE findings show that reducing CO_2 emissions to 40% below 2005 levels by 2030 and 80% below 2005 levels by 2050 will come at a substantial cost to consumers and the economy. The modeling indicates that even with an economically optimum deployment of a full portfolio of advanced technologies there would be an 80% increase in the real wholesale price of electricity by 2050 relative to a future with no constraints on CO_2 emissions. Achieving these same CO_2 reductions *without* expanding nuclear generation and *without* deploying CO_2 technology would result in a 170% increase in electricity price.

As I ponder these latest findings and the challenges of meeting significant emissions reduction targets between now and 2050, I find myself contrasting the challenges of the next 40 years with those of the past 40 years. Two key differences stand out.

During the past 40 years the U.S. electricity sector had a degree of freedom (unlimited, no-cost CO_2 emissions) that enabled stakeholders to select among several cost-effective generation technologies – nuclear, coal, and natural gas combined-cycle – to meet reliability and least-cost planning requirements. This latitude enabled us to move away from nuclear when the going got tough, drag our feet on energy efficiency, and invest too little attention and resources in renewable technologies. As a consequence, the U.S. is heading into a carbon constrained future with an electricity generation mix that is 70% fossil-fueled and that does not capture and store any of its CO_2 emissions.

That degree of freedom is now gone. To meet an 80% CO_2 emissions reduction target by 2050 we must use low- or zero-carbon generation technologies – renewables, nuclear, and fossil with CCS. Those who would choose only their favorites from this list are out of luck – there is no silver bullet. We need all of them, and we need them soon.

The second key difference is the nature of the electric grid. Over the past 40 years grid operation can be characterized as meeting predictable demand with dispatchable generation. As we deploy the full portfolio of advanced technologies, grid operation will increasingly be characterized as a dynamic balancing of a widely diverse set of supply-side and demand-side resources. The consequences are profound and are the driving force behind the smart grid. This smart grid, or as we call it the electricity network of the future (ElectriNet), will be an enabler of energy efficiency, renewables, energy storage, electric transportation, and new end-use electro-technologies.

In contrasting the challenges of the next 40 years and those of

the past 40 there is one thing that I hope will not change: the relentless focus on affordability of electricity. In the previous edition of *EPRI Journal* I discussed the "law of constant real electricity prices." The real price of electricity will almost certainly increase substantially as we transition from a high carbon to a low carbon electricity infrastructure. Does this mean that we must throw out "the law" over the long-term? No. It defines the cost gap that must be closed through continued innovation in electricity technologies.

Finally, this point for those who are just beginning your careers as technologists in the electricity sector: The Prism and MERGE findings and the law of constant real electricity prices make very clear the scope of your challenge between now and 2050 – provide society with the technology options to (1) de-carbonize the electricity infrastructure; and (2) to bring the real cost of electricity in 2050 back down to where it is today. If you succeed, you will have created a great future, for people and the planet.

Steve Specker
President and Chief Executive Officer

SHAPING THE FUTURE

Innovative approaches to upcoming challenges

The Societal Benefits of Smart Metering

In collaboration with four Ohio utilities, EPRI has completed a study that indentifies a wide range of potential benefits to utilities, consumers, and society that could result from deploying smart meter technologies. The study concluded that these potential benefits may produce enhanced service, a more responsive and efficient delivery system, more effective demand response systems, environmental benefits, and new products and services. A report on this work (1017006) describes methods to evaluate the deployment of these benefits in monetary terms.

The study, prepared with funding from American Electric Power, Dayton Power and Light, Duke Energy, and FirstEnergy, shows that smart metering is an enabler that has the potential to change how electricity is provided and used to the benefit of consumers, although it does not ensure that these benefits will actually be realized. It further concludes that consumers must be induced to change the way in which they use electricity, which may require utility incentives and other infrastructure investment beyond that directly associated with smart metering.

According to Arshad Mansoor, vice president of Power Delivery and Utilization for EPRI, “previously, there was not a consistent framework or methodology to quantify the societal benefits of an advanced metering infrastructure (AMI). This report addresses that challenge.” As Mansoor pointed out, “the value of these benefits could significantly differ from one utility to another based on customer demographics, types of programs associated with AMI, characteristics of the AMI system, and legacy systems that may already have been deployed by the utility.”

Establishing an Evaluative Framework

Because AMI primarily serves an enabling role, it can be a challenge to quantify broader social benefits attributable to smart metering. Currently there is no universal agreement on what constitutes such benefits or how to measure them. To build an effective evaluative framework, the EPRI investigators reviewed past business cases for smart metering filed with state public service commissions, characterized how societal benefits can be classified, and investigated alternative ways to quantify and monetize these benefits.

While quantification can be straightforward, it will often require specific utility data on customers and system operations. For example, the communication and control capabilities of smart metering can facilitate consumer participation in demand response programs, but the value to the public will depend on their level of participation and their likely savings; quantification will require modeling how load changes will affect prices.

Similarly, mass deployment of smart metering could increase service reliability by reducing the frequency and duration of outages. But to quantify this benefit, utilities will need to demonstrate the linkage between the metering infrastructure and the improvement in reliability, provide a credible estimate of the change in outage frequency and duration, and calculate the value of lost load for actual customer sectors.

Indirect benefits of smart metering, such as reduced environmental impacts and possible changes in regional employment and wage patterns, are more difficult to quantify and would involve more-extensive modeling and calculation efforts.

To further assist utilities in developing successful smart metering programs, the EPRI study describes basic approaches and specific mathematical tools that can be used to convert the value of each benefit into monetary terms. EPRI anticipates that this framework will prove useful to a variety of stakeholders evaluating smart metering proposals.

For more information, contact Bernard Neenan, bneenan@epri.com, 865.218.8133.

From Fuel to Consumer: Developing a Holistic Vision of Tomorrow’s Power System

Utility industry planners foresee a great deal of change for the power supply and delivery chain in the decades ahead. Concern over climate change will likely alter the mix of generation technologies and the availability of fuels. The expected increase in bulk renewable generation will require balancing resources and advanced power conditioning technology to deal with the variability of sun and wind. Demand response, rooftop solar units, microturbines, and other emerging distributed generation technologies must be efficiently integrated into the grid for two-way power flow between the customer and the service provider.





One result of these developments will be a move from the standard central-station, generation-to-load grid model to a holistic end-to-end conceptual approach that includes fuel supplies, renewable resources, distributed generation, storage, and consumers. In addition to these changes, the expected availability of plug-in hybrid electric vehicles and consumer-programmable smart appliances will present new challenges.

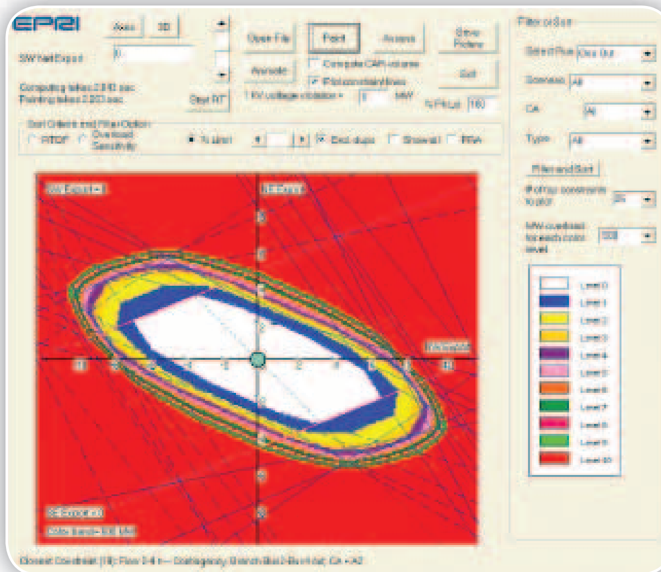
The current power delivery infrastructure, based partly on technology developed in the 1970s, will need to be upgraded and made smarter for dealing with these future challenges. A new EPRI report, *Vision for a Holistic Power Supply and Delivery Chain* (1018587), outlines a holistic view of the power system that incorporates everything from fuel supplies to consumer demand. The report also identifies the tools and technology advances that planners and operators will need to keep the system flexible and robust.

Upgrading the Grid

Central to this vision is the development of monitoring, modeling, analysis, coordination, and control capabilities that are in sync with the demands of future power systems. Comprehensive, real-time data will be critical, especially with regard to system disturbances and grid stability. Devices called synchrophasors can provide high-speed data on voltages and phase angles, helping system operators monitor the grid. Once deployed, such devices will allow operators to diagnose a problem and address it before it spreads, thereby avoiding blackouts. The grid of the future may even be able to monitor its own condition and to restore itself rapidly when part of it breaks down. Programmers are developing "intelligent" software that will enable the grid to assess its condition and take appropriate actions without human intervention.

But access to more data won't be enough to keep the system working smoothly. Planners and operators also need models that allow them to analyze the data and make meaningful conclusions. Today's models of generators and loads are often inaccurate because they are not based on real-time data, necessitating operators' adoption of cautious safety margins. Models based on actual measurements can help operators and planners make full use of the system's capability.

New models are also needed to forecast when and where system bottlenecks will occur. Today's power market allows the purchase of bulk power from outside a geographic region. The grid was not designed to accommodate the resulting transmission congestion, which can harm reliability and increase costs. System operators will require a better capability to predict power flows and congestion so that they can anticipate problems.



Tomorrow's holistic power system will benefit from probabilistic congestion forecasting and advanced visualization tools that can define a "secure system space" under complicated power flow conditions.

When problems do arise, operators need to be informed. The current alarm system doesn't always provide useful data. For instance, a single event such as a lightning strike can lead to a cascading outage, which can flood control centers with alarms. Advanced systems should provide operators with more information on the root cause of the problem and with instructions on what to do.

Comprehensive, real-time data will be important on the demand side too. Houses of the future may be fitted with smart appliances that can be programmed to consume less when energy prices are high, changing demand patterns. Smart meters—devices that can provide detailed energy use data from individual homes—will allow operators to track changes in consumption in real time, including the charging of electric vehicles. And because smart meters will facilitate communication in both directions, customers will be better able to plan their energy use according to cost and convenience. Such customer involvement may be the most profound change in the system of the future, helping consumers see themselves as stakeholders in the power chain, not just as ratepayers.

For more information, contact Stephen Lee, slee@epri.com, 650.855.2486.

Retrofitting CO_2 Capture

THE STORY IN BRIEF

Retrofitting existing fossil-fueled plants with the first available carbon dioxide (CO_2) capture technologies could play an important role in paving the way for development of lower-cost, reliable carbon capture and storage (CCS) systems. EPRI research is helping utilities better understand the engineering challenges and economic consequences.

Recently, the U.S. Energy Information Administration and other analysts reduced the number and capacity of new U.S. coal-based units projected to be built by 2030. Factors include reduced demand growth, accelerated investment in efficiency, increasing and uncertain capital costs, less available financing, permitting challenges, anticipated CO_2 emissions policies, and renewable portfolio standards.

Fewer new plants are just one reason why the likelihood has increased that the industry will need to retrofit existing U.S. coal plants with post-combustion CO_2 capture (PCC) systems to meet anticipated greenhouse gas reduction targets.

Also, retrofits potentially could be implemented faster than installation of CCS on new units, providing near-term advances in CO_2 capture technologies.

Retrofit technology also may prove essential in reducing emissions in nations such as China, where recently built coal generation rivals the total installed capacity of North America or Europe. Unless these plants are retrofitted, effective global CO_2 reduction may never be achieved.

Retrofit also offers advantages related to risk. A new plant with advanced capabilities and technologies carries risk for the investing utility even before CCS is considered. However, with older plants, recovered capital costs and relatively low operating costs help limit the risk to the cost of the CCS system. Retrofit provides good opportunities to demonstrate a new technology at scale. Also, given the aggressive push to advance CCS, technology installed today may be obsolete in ten years.

Collectively, all these factors suggest a continued reliance on existing plants and the need to evaluate the potential for CCS retrofits to reduce their emissions.

Best Candidates for Retrofit

The U.S. has more than 330 GWe of installed capacity in pulverized-coal (PC) plants, but CCS retrofits will not be cost-effective for all plants. Economics generally favor larger (>300 MW) and newer (<30 years old) plants, depending on plant condition. Smaller, older plants may also be appropriate for retrofit if they are efficient, have low running costs, have been operated in baseload mode, and have been regularly upgraded.

Other considerations include:

- Expansion space for new CO_2 capture system and compression equipment (about 6 acres for a 500-MW unit), plus space within boiler and turbine islands for additional piping and ductwork;
- Cooling water supply to meet as much as 100% increased water demand;
- Controls to reduce NOx and SOx concentrations in the flue gas entering the CO_2 absorber (the NOx, SOx, and particulate content must be reduced below currently permitted values to protect the solvent used in the CO_2 capture plant);
- Ability to sustain reduction in net power output; and
- Access to geologic storage or the opportunity to sell or dispose of captured CO_2.

Unit CO_2 capture costs ($/kW investment costs and $/MWh levelized operating and maintenance costs) will vary considerably based on site-specific factors—for example, a coal-fired power plant seeking to serve the California or Washington markets would need to remove more than half the CO_2 generated by the power plant—and the volume of flue gas treated will determine both capital and operating costs. Other criteria could include the capabilities to extract significant quantities of low-pressure steam for solvent regeneration, to extract intermediate-pressure steam intermittently for solvent reclaiming, and to receive significantly increased quantities of hot condensate return. In all cases, plants will need to find electrical capacity to replace large quantities of power consumed by CO_2 solvent or sorbent regeneration, compressors, and capture system pumps.

EPRI CO_2 Capture Retrofit Studies

To help utilities understand the operational and cost consequences of CO_2 capture retrofitting, EPRI is conducting plant-specific studies to determine thermal and economic impacts of retrofitting a plant with an advanced amine PCC technology. The studies, currently sponsored by 27 utility organizations in the United States, Canada, and Australia, are being conducted at five plants:

- Edison Mission Group's 1536-MW Powerton Station, operated by Midwest Generation in Pekin, Illinois;
- FirstEnergy's 176-MW Unit 1 Bay Shore Plant in Oregon, Ohio;
- Great River Energy's 1100-MW Coal Creek Station in Underwood, North Dakota;
- Intermountain Power Agency's 950-MW Intermountain Generating Station in Delta, Utah; and

- Nova Scotia Power's two 160-MW units at the Lingan Generating Station in Lingan, Nova Scotia.

Unlike previous "one-off" studies, the EPRI study will investigate capture technologies at plants representing a range of plant types and sizes. The resulting data will have application to a wide variety of plant configurations.

The project team will model the process flow and the heat and mass balances to identify the most practical CO_2 capture configuration based on each site's constraints; determine the space required for the capture technology; estimate the performance and costs for the capture and compression systems; and identify the features of each plant that materially affect cost and feasibility of retrofitting.

"In the past, with flue gas desulfurization (FGD), we were essentially putting a black box at the end of the plant," said Des Dillon, EPRI manager of the carbon capture retrofit project. "CCS technology requires far more integration within the PC plant. The retrofit design needs to optimize the requirements for steam, waste heat, water, and electricity.

"For example, CCS systems need steam at a certain condition to regenerate the solvent," Dillon said. "But that might mean extracting 25–30% of the steam from the low-pressure turbine, which wasn't initially designed for that duty and will require modification. If you can optimize the CCS system to require less steam extraction, it might be within the limits of the existing turbine design."

Study results may identify different options at each site. "The results could identify an investment in a plant, such as a turbine upgrade, that would improve the economics of the retrofit," Dillon said. "The results will also indicate the optimal level of carbon capture for a specific plant configuration. For example, given the space constraints in a plant, the results may show that only 30% carbon capture is economically viable at that plant."

Results will provide the utility hosts some of the first plant-specific hard data on retrofit economics. "We're looking forward to receiving some definitive economics and efficiency impacts," said Charlie Bullinger, senior principal engineer at Great River Energy. "These results will help us to understand the potential of the capture technologies as they evolve and to make investments in them more wisely."

"CCS is not here and now in terms of commercial viability and application, but we want to make sure that we're at the front of the learning curve, especially for existing plants like Powerton," said Douglas McFarlan, senior vice president of public affairs at Edison Mission Group.

The study's results also may provide broader perspectives. "The results will give us a number of data points that identify which features of a base plant are adding costs," said Bryan Hannegan, EPRI vice president, Environment and Generation. "That will tell us for the first time which existing units are the best retrofit candidates, how much of the fleet has potential for CCS retrofit, and at what cost CCS retrofits can be delivered. That will be important information for operators and policymakers."

Related Carbon Capture Research with Implications for Retrofit Applications

EPRI is conducting other studies that will provide insight into carbon capture retrofit:

- **Process Optimization Studies.** EPRI's CoalFleet for Tomorrow® program is looking to improve the economics of PCC in a new reference design ultra-supercritical (USC) PC plant (750 MW, 4200 psia/1110°F/1150°F). Those findings may also suggest approaches to retrofitting older units with lower steam conditions and less advanced emission controls. The project is exploring three areas: (1) solvent systems, (2) thermal integration within the CO_2 capture plant and between CO_2 capture equipment and the power plant steam turbine and balance-of-plant systems, and (3) CO_2 compression technology.
- **Valuing Operating Flexibility.** EPRI research is exploring the value of turning off capture equipment and venting CO_2 during peak demand. Modeling of an integrated gasification–combined-cycle (IGCC) plant indicates that flexible operation is technically feasible and may be economically attractive when electricity prices are high and CO_2 prices are low. Similar opportunities for coal plants are also envisioned. Where regulators do not allow untreated fuel gas emissions, a plant with CO_2 capture equipment and additional solvent storage vessels may be able to maximize power output temporarily without CO_2 emissions.
- **CO_2 Capture for CTCC Plants.** EPRI is launching a technical and economic assessment of CO_2 capture in a combustion turbine combined-cycle (CTCC) power plant, in both new and retrofit applications. A design will be developed for retrofitting PCC to an existing CTCC plant. The study also aims to identify ways to improve CO_2 capture economics for future plants, where the potential is not tied to existing plant components.
- **Assessing the Impact of Climate Policy on Retrofit Investment.** An EPRI study will help utilities determine the potential value of coal plant retrofit investments, measured in $/kW. Participants will better understand how a unit's investment-worthiness may change with respect to different climate policies and natural gas prices. EPRI will work with participating utilities to specify their generation mix, candidate units for retrofit investment, regional power market, and key planning and financial analysis assumptions. EPRI will then apply its Regional Power Market Analysis to different climate policy and fuel price scenarios to identify retrofit investment prospects.

Research, development and demonstration (RD&D) are also under way on PCC technologies for new coal-fired plants. "CO_2 emissions reductions can be achieved by applying CCS technologies to advanced new coal-based plants as well as in retrofit applications," said Jeffrey Phillips, program technical lead for EPRI's CoalFleet for Tomorrow program. "The retrofit work is building on what we've already learned in studies for new plants, such as the process optimization studies, so going forward, I see the two areas working together to advance CCS technologies."

"Collectively, EPRI's engineering and economic research on CCS for new and retrofit plants represents the type of accelerated real-world RD&D that is urgently needed to ensure that CCS technologies can be applied to coal-fired power plants—whether new or existing—in the requisite numbers to achieve the technology's potential," said EPRI's Bryan Hannegan.

This article was written by Jonas Weisel. Background information was provided by Des Dillon (ddillon@epri.com). Brice Freeman, Revis James, George Offen, Jeffrey Phillips, John Wheeldon, and Tom Wilson also contributed to this article.

Des Dillon is a project manager in EPRI's CoalFleet for Tomorrow program. He came to EPRI in 2006, having previously worked in the UK with Mitsui Babcock Energy Ltd., the National Engineering Laboratory, and Rolls-Royce. Dillon holds a B.Eng. in design engineering from the University of Glasgow and an Industrial Ph.D. in mechanical engineering from the University of Strathclyde.

CCS Research Branching Out: Evaluation, Testing, and Demonstration

EPRI is involved in a broad range of carbon capture and storage research, development, and demonstration programs:

- **Chilled Ammonia Pilot at We Energies.** The Pleasant Prairie Power Plant 1.7-MWe RD&D pilot-scale program is testing Alstom's chilled ammonia CO_2 capture process.
- **Industry Technology Demonstrations.** EPRI is teaming with industry partners to integrate larger-scale carbon capture systems with storage technologies. Projects include: scale-up of Alstom's chilled ammonia process with a 20-MW pre-commercial facility at American Electric Power's Mountaineer Plant; and demonstration of Mitsubishi Heavy Industries' advanced amine CO_2 capture technology at Alabama Power's Plant Barry. Between 2013 and 2017, demonstrations of CCS technologies also are planned at three progressively larger IGCC plants.
- **CO_2 Sequestration Projects.** EPRI is collaborating with DOE in its nationwide Regional Carbon Sequestration Partnership, focusing on CO_2 injection into underground reservoirs. EPRI is also conducting basic research on CO_2 reactions with underground formations and potable aquifer waters, well integrity, and remediation techniques.
- **Search for Breakthrough PCC Processes.** EPRI is tracking research on technologies to reduce costs and energy penalties and is providing assistance with four processes deemed most promising. EPRI is also working with University of Kentucky's Carbon Management Research Group to enhance CO_2 uptake by solvents and reduce the energy required to strip the CO_2 from the solvent.
- **Review of CO_2 Capture Development Activities.** In March 2009, EPRI published its annual review of progress in pilot and demonstration plant activities for the two leading CO_2 capture technologies: post-combustion and oxyfuel combustion.
- **State of CCS Technology R&D.** EPRI is part of a group of companies analyzing the status of CCS research for the Australian-led Global Carbon Capture & Storage Institute (GCCSI), providing a comprehensive baseline report that will include technical, regulatory, economic, geographical, and research/development capabilities, and an assessment of ongoing project status worldwide.
- **National Carbon Capture Center.** EPRI has joined with DOE, Southern Company, and four other companies in developing the National Carbon Capture Center, offering a "drop in and test" site for new carbon capture technologies. Operational in 2010, it will facilitate testing and evaluation at a size large enough to provide meaningful performance data under real operating conditions and enable scale-up of the technologies.
- **Microalgae Cultivation for Biofixation of CO_2.** EPRI is supporting initiatives that explore the potential for microalgae cultivation to remediate power plant waste streams of CO_2. Efforts are expected to advance on two fronts with utility-hosted demonstrations of the two types of cultivation systems—open ponds and enclosed photobioreactors.
- **Heat Rate Improvement for CO_2 Reduction.** EPRI's Production Cost Optimization project is helping utilities to improve heat rate at their coal-fired plants—an operational enhancement that is commercially proven, cost-effective, and immediately available for lowering CO_2 on the margin. This strategy could deliver significant savings if new regulations permit trading of CO_2 credits or impose a fee on CO_2 emissions.
- **Advanced Ultra-Supercritical Steam Conditions.** An EPRI study investigating the performance of an advanced USC PC plant (750 MW, 5100 psia/1256°F/1292°F) showed that the CO_2 emissions were more than 10% lower in ultra-supercritical pulverized coal plants than from a supercritical plant. EPRI is supporting the development of advanced ultra-supercritical technology.

Electric Transportation BEYOND THE ROAD

THE STORY IN BRIEF

Non-road electric transportation technologies are helping reduce emissions and fuel consumption in locations off the beaten path—at seaport loading docks, on airport runways, and in warehouses and manufacturing plants. This specialized equipment can not only save customers money but improve their operating efficiencies and maintenance programs as well.

Diesel-powered terminal tractors are the workhorses of seaports. At major ports hundreds of such tractors operate around the clock, shuttling cargo trailers from point to point in the container terminals. Yet even at the busiest ports, terminal tractors spend up to 80% of their shift with engines idling as they wait to pick up their loads. Such idling results in unnecessary and avoidable emissions, fuel consumption, and expense.

At the Port of Long Beach, California, one tractor stands apart from the pack. Its plug-in hybrid engine allows it to travel ten miles or more on electric power and to shut down its diesel engine when idle to reduce emissions and save fuel. The hybrid is the product of an EPRI collaboration with CenterPoint Energy, New York Power Authority, Southern California Edison, and Southern Company. Following a three-month stint at Long Beach, the tractor will pull duty in Savannah, Mobile, Houston, and New York. At each port, the project team will collect data on the tractor's performance, including fuel consumption, emissions, service and maintenance, and operator acceptance. Findings will determine if the plug-in hybrid technology is suitable for widespread application at seaports.

The Non-Road Fast Track

The hybrid yard tractor is one example of a rapidly growing, yet low-profile, category of electric transportation. Although electric and plug-in hybrid passenger vehicles offer enormous promise for reducing emissions and petroleum dependence, they are emerging technologies whose benefits are just beginning to be realized. Non-road electric transportation, in contrast, includes an array of applications delivering substantial benefits *today* to electric utilities, their customers, and the environment. Yet many applications remain untapped, and many utilities and their customers remain unaware of the potential.

"Electricity is a cheaper transportation fuel than petroleum," said Andra Rogers, EPRI project manager for non-road electric transportation. "The electrification of non-road transportation systems that move materials, cargo, and people can help electric utilities increase revenues and manage load. They also help end-use customers reduce pollutant and greenhouse gas emissions, save money on fuel, and in many cases improve operational efficiency and productivity."

Encouraging the use of electric material-handling systems also helps utilities forge strong, mutually beneficial relationships with customers, said Cedric Daniels, product manager for electric transportation at Alabama Power, a Southern Company subsidiary. "We work as consultants to our customers to help them have higher earnings and save money by reducing fuel and maintenance costs and improving efficiency. Our customers are also concerned about the environment and want to be seen as green partners within their communities. And they want to be sure their employees have a safer and cleaner work environment. Electric technologies score touchdowns in all these areas. Electric equipment not only helps reduce emissions, but also minimizes maintenance, repairs, and equipment downtime because electric motor technology is more efficient and produces less wear and tear than internal combustion engines. There is less heat and vibration generated in comparison to internal combustion systems, and fewer moving parts."

Since 1994 EPRI's Non-Road Electric Transportation program has performed technology demonstrations, developed case studies and information to communicate benefits to utilities and their customers, and participated in developing standards to ensure the interoperability and safety of electrical connections and charging infrastructure. EPRI facilitates technology transfer by hosting meetings where utility staff, regulators, and industry experts discuss the latest research and demonstration successes, challenges, and opportunities. The program has focused on four key segments: seaports, airports, industrial material handling, and truck stop electrification.

Green Ports

Seaports are major economic hubs and are often the top sources of air pollutants—including NOx, SOx, volatile organic compounds, and particulate matter—that contribute to adverse air quality, as well as greenhouse gases. As a result, seaports across the nation face increasing pressures to reduce emissions and improve efficiency as they increase throughput and expand operations to accommodate growing global trade. Many ports are finding that replacing fossil-fueled equipment with electric alternatives is a feasible and successful strategy. In addition to electrifying cargo-handling equipment such as yard tractors, seaports offer other opportunities for electrification, including shore power, electric dredging, and electric cranes.

Shore power. Traditionally, cargo and passenger ships docked in port have used auxiliary diesel generators to run the ship's lighting, refrigeration, heating, and air conditioning systems. These engines consume considerable fuel and account for a significant fraction of port emissions. Shore power, also known as cold ironing, allows berthed ships to shut down their diesel generators and instead plug into dockside electric service to power onboard systems.

Shore power effectively eliminates at-berth emissions and fuel consumption and opens new business opportunities, as demonstrated by a shore power collaboration involving Seattle City Light, the Port of Seattle, the U.S. EPA, and the Holland America and Princess cruise ship lines. As documented in an EPRI case study (1013879), the Seattle shore power operations reduced NOx emissions by more than one ton per ship per day, saved 12.5 tons of fuel per call, and slashed annual CO_2 emissions by 3,525 tons. Ships using shore power consumed about 5 to 11 megawatt-hours (MWh) of electricity per port call.

As with other transportation applications, shore power opens opportunities for emissions trading. Seattle City Light purchases $10,000 in greenhouse gas offsets annually from each cruise line.

Shore power requires investment in shipboard and landside electrical infrastructure, including cabling, connections, and transformers. Despite the investment, shore power is gaining momentum, stimulated in part by new regulations mandating cold ironing in California ports. However, no standard exists for shore power cable, connectors, or transformers. EPRI, through the Infrastructure Working Council, is supporting standardized infrastructure to reduce costs and ensure interoperability and safety.

Electric dredging. Most ports perform regular dredging to maintain channel depths suitable for navigation. Dredging using electric motors instead of the standard diesel engines can offer environmental advantages and economic and operating efficiencies, including significant emission reductions and savings in equipment operations and maintenance. As a result, electric dredging is now the norm at ports such as Oakland, Long Beach, Los Angeles, and Houston.

The Port of Mobile, Alabama, recently joined their ranks. King Fisher Marine's electric dredge the Waymon Boyd recently completed the port's first electric dredge with support from Alabama Power in partnership with EPRI.

Using a series of electric pumps and motors, the Waymon Boyd loosens and sucks up mud and sediment, then discharges the material through a system of pipes to a site four miles away. The total electrical load for the dredge was 4.6–4.8 MW, with power delivered from shore via a 3-inch-diameter cable.

A 3,000-horsepower diesel engine–powered dredge, similar in size and capability to the Waymon Boyd, would use approximately 2,000 gallons of diesel fuel per day, assuming 24-hour operations, and produce about half a ton of NOx per day and almost 28 tons per day of CO_2. To put these emissions into perspective, a ton of NOx per day is equivalent to more than a million passenger vehicle miles, and an average passenger vehicle emits approximately 6 tons of CO_2 per year.

Noise abatement is another environmental benefit of electric dredging—a particular concern when dredges operate around the clock near neighborhoods.

The cost to operate an electric dredge compared to diesel depends on the price of electricity versus diesel. In many places electric dredging brings a distinct economic advantage. Daily fuel costs for a diesel dredge similar in size to the Waymon Boyd consuming 2,000 gallons of fuel per day at $3.00 per gallon would run $6,000. In comparison, an electric dredge drawing 36,510 kWh at Alabama Power commercial rates of approximately 9 cents per kWh would run at $3,286 per day.

Airport Electrification

Airlines face a challenging mix of competitive, regulatory, community, and environmental demands. In response to fuel costs and pressure to reduce emissions, airlines are electrifying equipment traditionally powered by fossil fuels.

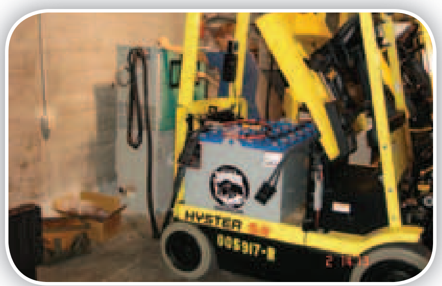
Electric ground support equipment. Airport ground support equipment, including baggage tugs, belt loaders, and pushback tractors, is a natural candidate for electrification. Research conducted by the New York Power Authority (NYPA) showed that a single internal combustion–powered tug emits 54 tons of greenhouse gases, burning 3,248 gallons of diesel per year.

In 2000 EPRI organized a project to electrify American Airlines' ground support equipment at Detroit Metro Airport. EPRI helped develop specifications for electric connectors to help provide infrastructure and ensure safety and reliability of fast charging. EPRI also helped develop methods to help users weigh the costs and benefits of electric ground support equipment.

Ground power. Aircraft parked at the gate need preconditioned air to ensure cabin comfort and electric power to operate onboard systems. Traditionally the air and power have been delivered through an auxiliary power unit, a small jet-fueled turbine in the back of the aircraft. Alternative power sources include a diesel generator on the ground or solid-state converters connected to the airport's main power.

An EPRI case study documents Southwest Airlines' procedures to minimize use of the auxiliary unit, saving fuel and money and reducing emissions. Southwest has electrified its gate operations in almost every city it serves.

Southwest estimates average fuel savings of 12 to 17 gallons for every turn at the gate. (A turn is estimated at 20 to 30 minutes. The average auxiliary power unit burns 34 gallons per hour under a normal load and up to 42 gallons per hour under a heavy load.) At 3,300 flights per day, the daily fuel savings can be as much as 56,100 gallons. Annual fuel savings are as much as 20,476,500 gallons. Fuel prices have varied dramatically recently, but even at a hedged price of approximately $1.80 a gallon, the savings are significant: $36,857,700.



Electric Forklifts Raise Revenues

In warehouses, manufacturing plants, and distribution centers, electric forklifts, cranes, and side loaders are boosting utility revenue while helping industrial customers reduce fuel and maintenance costs. Over the past 25 years, sales of electric forklifts (or lift trucks) have grown from less than one-third to more than half of annual lift truck sales. Most have been limited to indoor use, but several manufacturers now add features such as pneumatic tires and enclosed battery compartments that enable use outdoors. A recent EPRI–Southern Company–NYPA project demonstrated outdoor-capable forklifts to industrial customers, most of whom were unaware that such were available, even though they're widely used in Europe.

Based on EPRI technical data, Alabama Power's forklift incentive program has contributed millions of dollars to the utility's bottom line, as customers convert forklift fleets to electric power or add to existing electric fleets.

While building load isn't every utility's goal, increasing efficiency is. For some utilities, shifting load is even more important. In 2002, Southern California Edison launched an electric forklift peak-load-shifting program in response to the California energy crisis. Through state-provided incentives and time-of-use rates, SCE encouraged customers to shift battery charging off-peak, ultimately shifting 9,100 kW, 14% over its goal.

Truck Stop Electrification: Idle Reduction

Like ships in port, big rigs parked at truck stops sit with engines idling to provide electricity to protect refrigerated cargo and power air conditioning, heating, and appliances for drivers in truck cabs and sleeping berths. Idling engines consume more than a gallon of fuel per hour, and each of the 1.3 million long-haul trucks in the United States consumes about 2,400 gallons or more per year while idling.

New technologies enable drivers instead to rely on battery storage or electrical connections. EPRI projects with Alabama Power and Sacramento Municipal Utility District demonstrated potential cost savings and emission reductions that could be realized by using these alternatives.

Untapped Potential

EPRI and utility organizations are pursuing additional opportunities in non-road electric transportation. Southern Company is evaluating underground mines' material handling equipment that relies on internal combustion engines. Southern is also working with customers to implement electric overland conveyors to transport materials over distances of a few hundred yards to several miles, replacing loading and unloading now done by internal combustion vehicles.

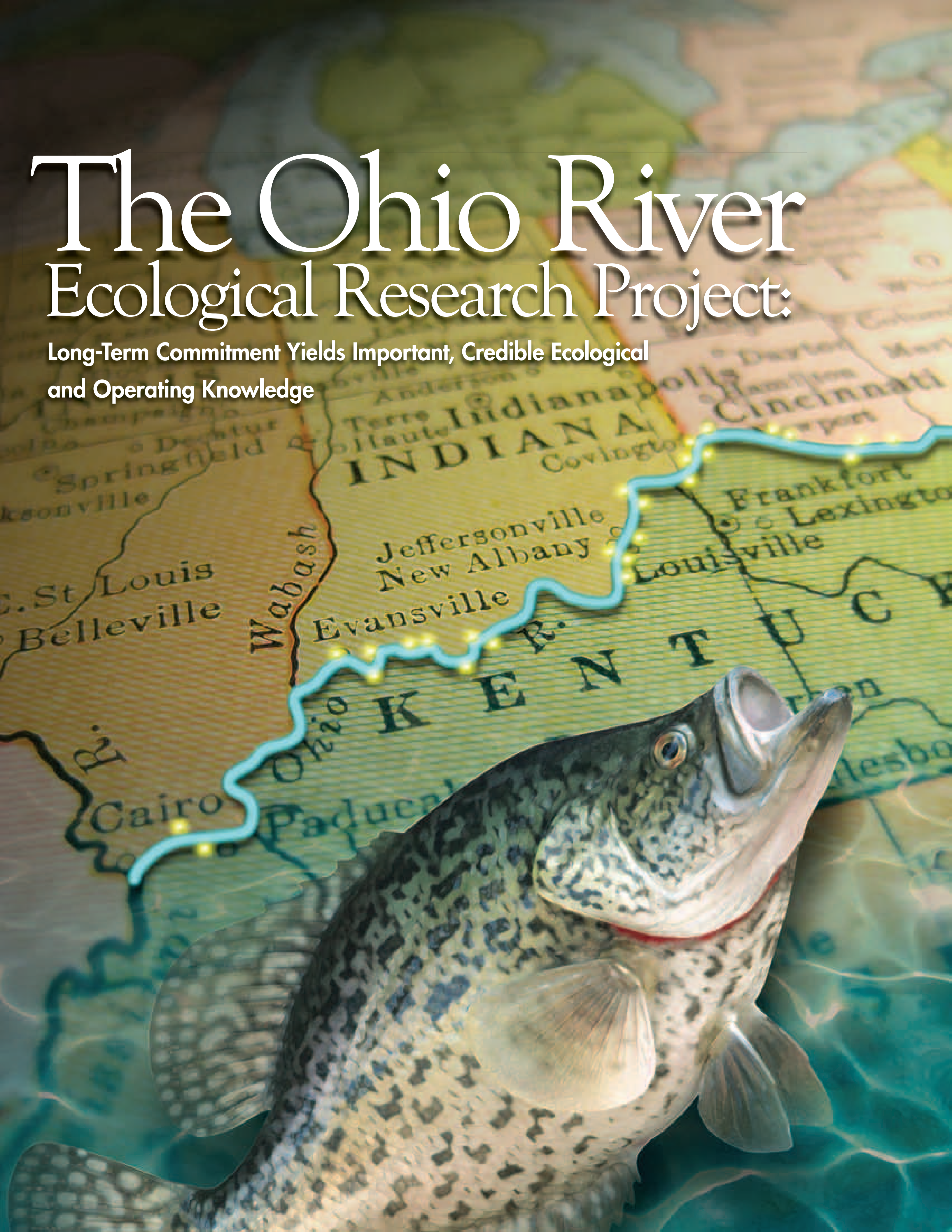
"We've learned not to assume that customers already know the value of using electricity to transport materials or products," said Alabama Power's Daniels. "Because we want to be a consultant for our customers' success, we strive to educate them using the best information available. EPRI's case studies and assessments are invaluable in this regard, because customers see EPRI as an objective and credible source of information. We consider EPRI as a partner in our development of technologies for electric transportation, and we see no end to the possibilities of working with EPRI to grow the value of our non-road electric transportation program at Southern Company."

This article was written by David Boutacoff. For more information, contact Andra Rogers, arogers@epri.com, 650.855.2101.

Andra Rogers is a project manager in EPRI's Power Delivery and Utilization sector, focusing on market enhancement and market expansion for non-road electric-drive vehicle technologies. She also manages EPRI collaborative programs with the federal government, including Department of Transportation joint partnership agreements for the development of plug-in hybrid and fuel cell vehicle technologies. Rogers joined EPRI in 2000 and managed projects in energy efficiency, advanced lighting, and industrial and agricultural electricity applications. She received a B.S. in business administration from California State University at Chico.

The Ohio River Ecological Research Project:

Long-Term Commitment Yields Important, Credible Ecological and Operating Knowledge



With more than 15,000 unique samples taken, 112 separate species collected, and nearly a million individual fish evaluated, the ongoing 37-year Ohio River Ecological Research Project (ORERP) is the world's largest and longest-maintained freshwater database on the potential effects of power plant thermal discharges. This comprehensive collaborative study, conducted adjacent to most of the 27 river-cooled power plants along the twists and turns of the 1,000-mile Ohio, has enabled utilities to show that thermal discharges do not significantly impact the spatial distribution of fish communities in the Ohio River near power plants.

Spawned by Section 316(a) of the Clean Water Act in the early 1970s and managed by EPRI since 2002, ORERP has yielded invaluable information for power plants and local communities while documenting important ecological changes in one of the nation's most important rivers. The 316(a) regulations require that power companies demonstrate the presence of a "balanced, indigenous community" of fish near a power plant's thermal discharge to establish that the plant is not harming or reducing populations of fish and aquatic invertebrates. When 316(a) became law, no one knew that it would usher in this one-of-a-kind collaboration, but after nearly four decades of sampling, the knowledge gained and the money saved clearly demonstrate the benefits of such a project.

"Through the wisdom and foresight of the companies that have participated off and on for almost 40 years, this project has generated scientific data that have allowed us to prove that there is minimal impact on fish populations and species due to thermal discharges," said Al Gaulke, an environmental specialist with American Electric Power (AEP) who has provided oversight and guidance for the project since 1974. "The bottom line is that regulators ask about the impact of your discharges on the water body. Everybody gets those questions, and you need reliable data to document impact."

THE STORY IN BRIEF

A utility-sponsored program for the study of fish and aquatic invertebrates near generating facilities along the Ohio River provides long-term data that help address questions raised by regulators and that help anticipate ecological issues that could arise in the future. This sustained and successful research serves as a model for programs that could monitor other major U.S. river systems and water bodies.

Gaulke has watched the project evolve over the years to reflect a broader regulatory oversight of utility operations and their potential effects on ecosystems, including the effects of toxic pollutants. While a focus on thermal discharges has always been the cornerstone of the project, ORERP has also addressed entrainment and impingement of aquatic species, regulated under Section 316(b). Entrainment occurs when small fish and other aquatic organisms pass through the intake screens and trash racks into the plant, sometimes suffering injury or death. Impingement occurs when larger fish and invertebrates are drawn to and trapped against the intakes' trash racks or screens. The 316(b) regulation for entrainment and impingement at existing power plants was recently updated but remanded to the Environmental Protection Agency in mid-2007 for revision.

"It's the long-term nature of the data that allows us to speak with great confidence about how power plants on the Ohio River impact aquatic life," Gaulke said.

Collection and Evaluation

The ORERP field studies assess the fish, habitat, and water quality near the 27 power plants that draw cooling water from the Ohio. Three times a year—in June, August, and October—researchers use seines and boats equipped with specialized collection gear, electric generators, and sampling probes to collect and study fish from the open waters of the river. Collection and tests are conducted at three sites upstream and three sites downstream of each participating facility. Each specimen is identified, categorized by species, weighed, and measured.

Sampling methods have been adapted through the years to be consistent with methods used by regulatory agencies. In earlier years, hoop nets, gill nets, and trawls were used to sample fish, invertebrates, ichthyoplankton (larval fish), zooplankton (water fleas), phytoplankton (algae), and freshwater mussels. Current methods emphasize seining and electrofishing, which stuns fish long enough to catch and analyze them. Electrofishing is now done at night to be consistent with sampling methods used by the Ohio River Valley Water Sanitation Commission (ORSANCO) and state agencies. Habitat measurements are also made according to ORSANCO procedures. Project scientists estimate that nearly 3,300 separate seining samples and more than 3,500 separate electrofishing samples have been taken in the Ohio during the project, making it comprehensive, current, and credible.

Power Plants on the River

The first coal-fired power plants were constructed in the Ohio River Valley during the late 1800s and early 1900s. There was little concern then about the effects on local fish populations. At the same time, locks and dams for navigation were changing the Ohio from a free-flowing, clear-water river to a series of impoundments in which industrial, coal-mining, and domestic wastewater discharges strongly affected water quality.

Studies have shown that certain fish species, such as mooneye, stonecat, and grass pickerel, which prefer clear water or clear water with aquatic vegetation, saw declining populations during the 1800s in response to the river modifications and increasing turbidity. Other species, such as black bullhead and channel catfish, which are more tolerant of degraded water quality, increased. Populations of skipjack herring and gizzard shad also increased during this period of declining river conditions. Since the Ohio's fossil-fuel-fired power plants withdraw up to 500 million gallons of water per day, it was only a matter of time before there was a concern about how these water withdrawals would affect fish populations in the river.

Water quality began to improve between 1950 and 1970, after greater regulation of industrial activities and the installation of sewage treatment facilities. There followed a corresponding increase in the abundance of numerous fish species. AEP researchers conducted fish collections from 1970 through 1985 and noted the increasing abundance of 22 species, such as largemouth and spotted bass, while catches of 7 typically pollution-tolerant species, such as black bullhead, had declined. Those findings indicated that the Ohio River fishery had improved, despite an increasing number of power plants along the river.

The Power of Broad Collaboration

Through the years, the project's scope and participant numbers have ebbed and flowed. Some facilities have been sampled nearly every year; others have been in the program only for a year or two; still others have been in and out of the program over the entire period. Ten companies currently fund the study: Allegheny Energy, AEP, American Municipal Power–Ohio, Buckeye Power, Duke Energy, Dayton Power & Light, FirstEnergy, E.ON US (Louisville Gas & Electric), Ohio Valley Electric Corporation/ Indiana Kentucky Electric Corporation, and Tennessee Valley Authority. With financial interest in 6 of the 27 power plants on the Ohio, AEP is the one company that has been involved throughout the life of the project.

Pooling funds has proved to be a more efficient way to conduct research, but each facility determines its participation annually, according to factors such as research budgets, economic conditions, and ecological questions from regulators. "As with any ecological research, companies are concerned about getting a return on their investment," said Tim Lohner, AEP's principal environmental specialist, who has worked with EPRI to expand the project since joining AEP 16 years ago. "With this project, companies have saved far more money—tenfold more, at least—than they have spent. This program has been very beneficial in terms of avoided costs, because the cost to participate doesn't come close to the cost of building a cooling tower."

Participants in the program say that while collaboration has not always been without its challenges, the cooperative effort has delivered compelling data essential to tracking the long-term effects of thermal discharge. Jim Stieritz, principal environmental scientist with Duke Energy, a participant since 1973 (including Duke's predecessor Cinergy), sees three primary benefits to the project: credibility, richness of data, and the ability to address regulatory questions with confidence.

"When you've got more than one utility involved, you've got more credibility," said Stieritz. "It's sort of a strength-in-numbers thing. And the richness and depth of the data can enhance sharing between companies, not just between individuals. Finally, the ORERP field data enable us to address questions when they first come up, rather than after laws have been passed."

In one example that Stieritz cites, the Thermal Working Group of ORSANCO had begun reassessing representative aquatic species for the Ohio River Thermal Model in 2006. ORSANCO had picked fish species that it felt were representative of the Ohio River, yet because of the ORERP database, environmental scientists at the utilities knew that some of the selected species were tributary species or were species that weren't well represented in the river. "We could only speak to this if we had the data," said Stieritz, "and we had the data in our field tests."

A Potential for Future Collaborations

Considering the clear success and value of the ORERP collaborative program, will utilities join to conduct similar projects elsewhere in the country? "I do believe there is potential for similar collaborations, although it's not always going to be easy," said Doug Dixon, senior project manager for water environmental projects at EPRI. Dixon and environmental specialists at some of the 11 utilities on the upper Mississippi River tried to organize a collaborative project there in 2004; they learned that one size may not fit all for such studies and that different rivers have fundamentally different characteristics. Each project will be unique simply because each water body is unique.

One major difference can be simple geography. While the Ohio River flows east to west, which means that water temperatures are relatively consistent throughout the length of the river, the Mississippi flows north to south, presenting more variables in thermal research because of natural temperature changes that can affect fish communities. The Mississippi also has greater distances between power plants and greater river traffic from both commercial and recreational sources.

John Thiel, Environmental Impact Group supervisor at Dairyland Power Cooperative in La Crosse, Wisconsin, has conducted fish impact studies at power plants for 30 years. Thiel believes that despite the inherent differences between the Mississippi and the Ohio, a collaborative research project for the upper Mississippi should be revisited.

"In the future, with some of the 316(a) ramifications, I think we may need to reconsider collaborative studies on a large scale in order to reduce cost," said Thiel. The Wisconsin Department of Natural Resources may require renewal of all 316(a) variances at every power plant in the state. Even now, Wisconsin is requiring re-evaluation of thermal caps, calculations, and mixing-zone limits. "There's no doubt that a collaborative effort will give us much

better information, and obviously the more data and the more sites you've got, the more valid your conclusions," Thiel said.

Whether collaboratives similar to ORERP emerge as a result of regulatory and environmental considerations remains to be seen, but Gaulke, the environmental scientist with AEP, has another take on why such collaborative projects are worthwhile. "As users of the water resource, you have a moral obligation to know and understand what your impact is, above and beyond the absolute regulatory requirement," Gaulke said. "That's a factor that may not have been part of our thinking when this started, but it is definitely part of our thinking now."

This article was written by Joe Gallehugh. For more information about establishing research collaborations with neighboring utilities, contact Doug Dixon, ddixon@epri.com, 804.642.1025.

Douglas Dixon is a senior project manager in EPRI's Environment Sector, specializing in a variety of fish protection–related issues. Before joining EPRI in 1997, he worked at ERM Inc., where he supported hydropower licensing efforts for the Federal Energy Regulatory Commission. Earlier he worked at the Virginia Institute of Marine Science, Versar Inc., and the Smithsonian Chesapeake Bay Center for Environmental Studies. Dixon holds a B.A. in biology from the State University of New York and a Ph.D. in marine fisheries science from the College of William and Mary.

Is Collaboration in Your Future?

Successful collaboration among utilities on shared water bodies requires effort, but if done right, it can return the time investment many times over in cost savings, reliable and credible data, and enhanced credibility on pertinent issues. Besides these benefits, participants in the Ohio River Ecological Research Project demonstrate a commitment to the understanding and stewardship of resources. As one member put it, "We have an obligation to know how our operations are affecting our natural resources."

Interviews with members of ORERP have identified the following key steps to a successful collaboration:

- Use independent environmental consultants.
- Consider using graduate students to gather and analyze results.
- Have a specific monitoring plan with specific objectives. For ORERP, it was the 316(a) requirements.
- Determine the type of sampling needed to attain your objectives.
- Sample a couple of sites every year; then sample every site in intervals of three, four, or five years. This approach saves money when using a statistical or ecological model.
- Design a five-year sampling plan. This saves money and encourages companies to plan their budgets in five-year increments to get a longer commitment for a more effective project.

DATELINE EPRI

News and events update

Hannegan Testifies on Water and Power

WASHINGTON, DC – Bryan Hannegan, vice president, Environment and Generation, testified before the U.S. House of Representatives Subcommittee on Energy and Environment on the subject of "Technology Research and Development Efforts Related to the Energy and Water Linkage." His testimony highlighted the following: power plant cooling accounts for approximately 40% of freshwater withdrawals in the U.S., but only 3% of total consumption; water use for power generation has declined steadily per unit of power produced; nuclear and coal-based power plants as well as renewable energy sources are significant users of water resources; advanced cooling technologies can reduce water use in power plants but at a significant increased cost; and EPRI research focuses on reducing the cost of existing cooling options and developing new technologies to reduce demand for freshwater resources.

Workshops Address Transmission Line Losses and Increase Efficiency

ALBANY, N.Y. – EPRI conducted six workshops in the United States and Europe to hear from industry leaders on research needs to realize higher transmission efficiency and reduced losses. Two themes, among others, emerged—reliability is still king, and smart technologies and new transmission hold the key to improving efficiency and maintaining reliability. The consensus was that efficient transmission, as well as integration of clean generation sources, has to be built on a foundation of a smart transmission system and new transmission. For more information, contact Karen Forsten, kforsten@epri.com.

Summit Looks at Wind Energy

MINNEAPOLIS, Minn. – A wind power summit, co-hosted by EPRI and Xcel Energy, convened in Minneapolis to focus on the state of wind power technology and research. Twelve utilities participated, identifying several issues, including costs, improving turbine performance, grid integration, and challenges facing offshore wind. For more information about the summit, contact Luis Cerezo, lcerezo@epri.com.

New Members Support Variety of Programs

PALO ALTO, Calif. – Ten new members have joined EPRI, supporting a variety of research, development, and demonstration collaboratives: Arch Coal, Inc., California Independent System Operator, Chevron USA Inc., City of Palo Alto Utilities, ESP Networks, Independent System Operator of New England, Midwest Independent Transmission System Operator Inc., Missouri River Energy Services, New York Independent System Operator, and North Carolina Electric Membership Corp. *(Locations shown on map in blue ● .)*

Meeting Focuses on Risks Posed by Counterfeits

WASHINGTON, DC – EPRI hosted a meeting to discuss ways for the nuclear industry to reduce risks associated with counterfeit and fraudulent parts and components. Participants represented utilities, the U.S. Department of Energy, the U.S. Nuclear Regulatory Commission, the U.S. Department of Commerce, National Aeronautics and Space Administration (NASA), the Nuclear Energy Institute, vendors, and academia. EPRI senior project manager Marc Tannenbaum described EPRI's work to develop practical tools to guard against counterfeit items, and participants discussed experience in other industries that could apply to the commercial nuclear industry.

Workshop Consensus: CCS Should Be Part of Solution

LONDON – EPRI director of generation Stu Dalton presented a carbon dioxide capture and storage (CCS) update at an international workshop at Chatham House that brought together policymakers, investors, financiers, and industry leaders to examine political, technical, and market trends affecting coal-fired generation. Opinions varied by region, but the general view was that CCS should be part of a broad low-carbon solution. In the UK there is more general support for CCS and a recent movement to install it at the outset for a significant portion of the plant.

Childhood Leukemia Workshop Considers Large-Scale Study

LONDON – Leading childhood leukemia experts from several countries met at an EPRI-organized workshop to discuss the feasibility of a leukemia study among children with Down syndrome. The increased incidence of leukemia in this genetically susceptible population should make it easier to study magnetic field exposure, early infection, and other possible risk factors. Participants discussed whether leukemia subtypes in children with Down syndrome are sufficiently similar to those in children without Down syndrome to serve as a model. Their conclusion that the subtypes are similar in the two populations opens the way for considering a large epidemiologic study. For more information, contact Gabor Mezei, gmezei@epri.com.

Epidemiologists Consider Variety of Pollutants

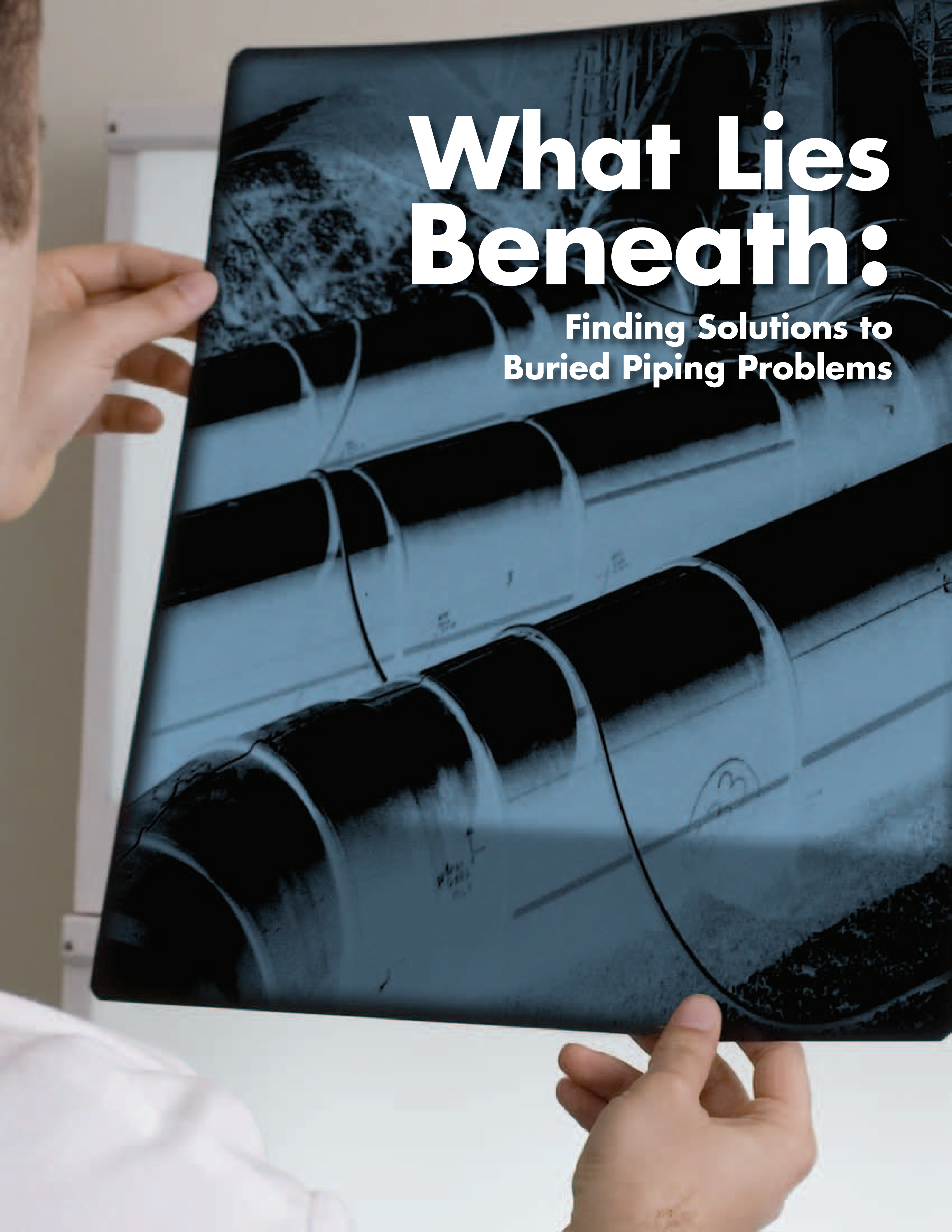
DUBLIN – Ron Wyzga, senior technical executive, has co-authored five papers that will be among those presented at the International Society for Environmental Epidemiology annual meeting. He is principal author of a paper suggesting that pollutants in addition to those from power plant emissions must be monitored to resolve air pollution health issues with epidemiological data. Other EPRI-sponsored research under discussion includes health responses over time as air quality changes; effects of living near major roadways on acute primary care visits of childhood asthmatics; and results from the Atlanta ARIES mortality–air pollution studies.

KHNP and EPRI Strengthen Ties and Exchange Knowledge, Experience

SOUTH KOREA – An EPRI team traveled to South Korea to meet with Korea Hydro & Nuclear Power Company (KHNP) to advance technology transfer, capture lessons learned from South Korea's extensive nuclear experience, and discuss opportunities for greater engagement. Workshops addressed topics such as flow-accelerated corrosion, risk and safety management, online maintenance, and plant support engineering. Participating KHNP subsidiaries included the Nuclear Engineering & Technology Center, Korea Electric Power Research Institute, and Korea Power Engineering Company.

Turbine-Generator Users Group Draws European Participation

MADRID – More than 130 people representing 20 European and three U.S. fossil and nuclear utilities participated in the first EPRI Turbine-Generator Users Group meeting held in Europe. The plenary session featured a presentation from Paulo Domingues Santos, Subdirector de Servicios Técnicos, ENDESA Generación, S.A. on "Major Steam Turbine-Generator Technical and Economic/Financial Challenges Facing European Utilities Today." EPRI, British Energy, ENDESA, ESB (Ireland), Iberdrola, PPC, ESKOM, ENEL, and Israel Electric also provided speakers. Two workshops covered turbine and generator condition assessment, maintenance, and refurbishment, and a tutorial on generator winding cooling water chemistry. Another TGUG meeting in Europe and one in Australia are slated in the next two years. For more information, contact Alan Grunsky, agrunsky@epri.com.



What Lies Beneath:

Finding Solutions to Buried Piping Problems

THE STORY IN BRIEF

Interest in nuclear plant life extension has directed attention to the miles of decades-old service piping buried beneath existing generating stations. As plant operators set up formal programs to ensure the continued integrity of such underground piping systems, EPRI is offering support with research, technology, and training.

When it comes to safety at nuclear plants, out of sight can't be out of mind. Pipes that were buried decades ago can degrade over time, leading to possible leakage and highlighting the need for vigilant monitoring.

While rare in the nuclear power industry, failures do occur. Recent instances include an estimated 100,000-gallon emergency cooling water leak at a northeastern U.S. nuclear plant and several instances of the discovery of ground water tritium, some resulting from buried piping leaks. None of these leaks posed a public threat or a safety risk, but perceptions matter, especially when firms are working to extend the operation of existing units or obtain permits to build new facilities.

"Buried systems are usually passive, out of sight, and have generally provided reliable service," said Maria Korsnick, Senior Vice President, Nuclear Operations, for Constellation Energy Group of Baltimore, Maryland, which operates three nuclear generating stations with nearly 4,000 MW capacity. "They usually only draw attention when a failure occurs."

Buried piping integrity is a significant issue in maintaining safe, reliable, and economical plant operation, and in addressing other industry drivers, such as meeting NRC requirements related to license extension and meeting internal industry performance expectations as evaluated by the Institute of Nuclear Power Operations.

To fully understand these issues and implement long-lasting solutions, more utilities are developing formal programs for buried pipe aging management and posting staff as buried pipe program managers. EPRI is supporting these efforts through research and development and training.

Attacks From Within and Without

A maze of buried pipes lies beneath most nuclear power plants. Depending on how close the plant is to the cooling water source, nuclear generating stations can have anywhere from a couple miles to more than ten miles of buried piping. These range from small instrument air lines to 16-foot-diameter recirculating water lines, with process fluids ranging from air to cooling water to fuel oil.

A plant can have as many as 30 separate buried piping systems traversing the property (see "Types of Buried Piping," page 23). While these pipes have generally held up well over the 30–40 years that many plants have operated, going beyond that requires the implementation of adequate aging management programs. "As nuclear plants age, leaks in some buried pipe systems have occurred, as might be expected given their age and service environment," said Korsnick.

"Our biggest single challenge is the inability to readily access the piping to determine its condition," said Shane Findlan, manager of EPRI's Balance-of-Plant Corrosion program. "A second significant challenge is that, rather than just worrying about the internal environment and how it affects the pipe, we have to be concerned about the external environment—the pH levels of the soils and different moisture levels."

Most buried piping is fabricated from coated carbon steel or stainless steel, which are both susceptible to a number of degradation mechanisms. Internally, the coating can break down and expose the steel to corrosion and erosion from the fluid and any associated contaminants. Tuberculation, the build-up of hard mounds of rust inside the pipes, increases friction and decreases water flow. Over time, the walls thin, eventually leading to a breach of the wall. Salt water, in particular, is a problem.

"We have one plant that uses salt water, and wherever internal coating flaws are present, we see greatly accelerated corrosion compared to what you would see in freshwater plants," said Greg Lupia, Corporate Buried Pipe Program Owner for Exelon Corporation (Chicago, Ill.). "But even among our freshwater plants, differing water chemistries result in varying corrosion rates."

While pipes are also coated on the outside to protect them from corrosion, problems still occur. Rocky L. Jones, a technical specialist at Entergy Corporation's Arkansas Nuclear One plant in Russellville, Ark., said that most buried pipe trenches were backfilled with sand, which has a low corrosivity factor. In some cases, however, rocks or other materials have gotten into the ditches, which can damage the coating. Jones also noted that the salt used at some plants to de-ice the roads in the winter winds up in the groundwater and corrodes the pipes.

To supplement coatings and reduce corrosion, therefore, nuclear plants use cathodic protection systems. These systems typically consist of a DC power source connected to anodes buried under the ground. Other wires connect to the pipes, which act as cathodes. Any breaches in the coating provide a path for the electricity to pass from the anodes through the ground and into the pipe, and then back through a cable to the power source. The flow of electricity into the pipe limits the corrosion.

None of these protective measures, however, are foolproof, and over time they tend to degrade.

"Regardless of the specific failure mechanism, the industry is concerned with preventing leakage from any buried system," said Korsnick. "In addition to immediate operational consequences, the industry is concerned with protecting the environment and the community that surrounds the plant."

Risk Ranking Assessment Software

Each nuclear plant may have several thousand segments of buried pipe at risk of failure. Since they can't all be inspected at once, this spring EPRI released BPWORKS—software that can help plant owners prioritize inspections of buried pipe systems. The software determines both the likelihood of a leak or break and the consequences of that leak or break. This information is plugged into a risk matrix to help prioritize the inspections.

"BPWORKS takes operational data and compares it to plant experience from NDE results, assessment results, and failure observations and allows operators to do some predictive modeling," said Findlan. "When you are talking about miles of buried piping in a single plant, software can help focus attention at the right location and help guide your assessment efforts."

BPWORKS (1019178) is available from the order center at 800.313.3774 or 650.855.2121 or by sending an email to orders@epri.com.

Leak Prevention

Preventing leaks in underground piping is a three-step process: evaluation, inspection, and repair or replacement.

Evaluation. The first step is to conduct a risk ranking assessment. Digging up and inspecting all those miles of piping for a direct inspection is simply not practical. It also isn't desirable, because digging could exacerbate any existing problems: a thin wall is more likely to burst if no longer surrounded by the backfill. Further, buildings and security fences may have been built on top of pipes over the decades.

"Exelon has developed a ranking system to help categorize all the piping so we can focus our resources for inspection," said Lupia. "We can't get all the piping inspections done in one year; our goal is to get all the high-risk piping inspected in some manner in three to four years."

Risk ranking involves first assessing the consequence of a leak for each pipe, based on factors such as whether the leak would compromise nuclear safety systems, reduce power production, or have measurable environmental impacts. For example, a tritium or fuel oil leak poses a greater environmental threat than a makeup water leak. The consequence is then multiplied by the susceptibility of that pipe to corrosion, which is affected by the type of pipe, local soil conditions, location, etc. Software such as EPRI's BPWORKS (see sidebar) can track the characteristics of each piping system and the relevant environmental characteristics to help set priorities.

Inspection. Several technologies are available to help determine the condition of pipes without having to dig them up. Ground-penetrating radar can be used to map their locations. Direct current voltage gradient (DCVG), which measures the voltage in the ground produced by the cathodic protection system, can locate faults in the coating. Guided-wave technology—using a collar that clamps onto a pipe and sends an ultrasonic signal down its length—allows inspection of 30 to 50 feet in either direction from a single location. EPRI is working to improve guided-wave techniques so that longer lengths of pipe can be inspected. Finally, there is internal inspection by robotic instruments that crawl through the pipes when they are out of service. EPRI has developed a crawler vehicle that uses transducers to interrogate a given pipe's condition.

None of these individual methods offer a complete solution, and they are often used together to provide a more complete understanding of current condition. DCVG, for example, can identify the general area where a coating breach and possible leak is present. Guided-wave technology can further narrow the search area, which would then be directly inspected using a crawler or by digging up the pipe.

Jones said that his firm is using DCVG, guided-wave technology, and crawlers to inspect the pipes at Arkansas Nuclear One. "DCVG is a fairly inexpensive way to investigate whether you have outside diameter corrosion due to lamination in your coating," he said. "In other cases, such as one pipe system at ANO where we can get inside for 2,000 feet, a crawl-through is more effective."

Repair or replacement. The third step in addressing pipe leakage involves repair or replacement of damaged piping, preferably using improved methods and materials that will prevent future corrosion. To ensure long-lasting repairs, EPRI is working to qualify non-metallic repairs such as sprayed resins and wraps for partial restoration of degraded pipe. Research into improved cathodic protection systems could lead to fewer instances where repair is needed.

"To further reduce the need for repair, the industry is carefully evaluating the use of corrosion-resistant materials as a long-term replacement for steel piping," said Lupia. "Those can include high-density polyethylene (HDPE), stainless steel, or other corrosion-resistant materials." HDPE pipe has been used by the waterworks and natural gas industries for nearly 40 years. In the United States alone, there are more than 700,000 miles of HDPE gas lines. HDPE is not susceptible to corrosion, doesn't need cleaning, has comparable installation costs to steel, and has lower maintenance costs.

HDPE has limited approval for use in the nuclear industry, especially for ASME Class 3 (safety-related) applications. That may soon be changing. Based in part on EPRI research, the American Society of Mechanical Engineers in 2007 approved Code Case N-755, which details rules for installing HDPE in Class 3 systems. The Nuclear Regulatory Commission (NRC), however, has not yet approved HDPE for broad application.

EPRI has also worked with two U.S. utilities on their Requests for Regulatory Relief (RRRs) for using HDPE in Class 3 applications. In October 2008, the NRC approved the RRRs for specific buried pipe installations at the Catawba and Callaway nuclear plants. Duke Energy's Catawba nuclear station has now become the first U.S. nuclear plant to use HDPE to replace a water system, changing out carbon steel buried piping used to supply water to and from the diesel generator jacket water coolers with 12-inch-diameter HDPE piping. AmerenUE's Callaway plant replaced 30-inch-diameter carbon steel buried piping in the Essential Service Water system with redundant 36-inch-diameter HDPE piping. The first two sets were installed in December 2008 and April 2009, respectively.

"I think the NRC has a positive perception of HDPE, but it is brand new," said Tim Eckert, EPRI program manager. "It has taken some time for people to accept that a highly engineered plastic can provide the high quality needed in these nuclear applications."

Buried Pipe Integrity Group

Recognizing the importance of buried pipe to long-term operational viability, many utilities have designated staff as buried pipe program managers. "If we do our job well, our plants can remain safe, cost-effective generation sources for decades to come," said Lupia. To help these individuals and their utilities address issues connected with buried piping, EPRI created the Buried Pipe Integrity Group (BPIG) in 2008. More than 80 nuclear reactors are represented by the members of BPIG.

The group shares operating experience on buried pipe and identifies opportunities for more-effective buried pipe management. One approach EPRI takes is to consult with representatives from the water and petrochemical industries to adapt the knowledge others have gained over the past century with respect to coatings and cathodic protection. For example, natural gas transport lines are commonly designed to accommodate internal inspection using devices called "pigs" that can be inserted into the pipe. The technology is not directly applicable to nuclear plant pipes, but there are important lessons to be learned.

"The gas pipeline industry is dealing with one pipe that runs for miles in a straight line," Eckert said. "We typically have a spaghetti bowl of buried pipes all intertwined within each other, so signals are easily confused. We are looking to see how well these techniques can be applied to multiple pipes together in one small, common area."

"As an industry, we need to be committed to ensuring the integrity of the buried piping at all our nuclear power sites," said Jones. "Collectively, we have more resources available to give engineers the tools needed to predict where there will be a problem and to upgrade the systems before leaks occur."

This article was written by Drew Robb. Background information was provided by Shane Findlan (sfindlan@epri.com) and Tim Eckert (teckert@epri.com).

Shane Findlan is a program manager in EPRI's Nuclear Sector, focusing on advanced repair technology for nuclear plant pressure systems, corrosion control and mitigation, and implementation of improved materials to enhance life extension. He joined EPRI in 1980, having previously worked at Battelle Memorial Institute as a research scientist. Findlan is a Registered Professional Engineer and an IIW International Welding Engineer. He received a B.S. in welding engineering from Ohio State University.

Timothy Eckert is a program manager in EPRI's Nuclear Sector, specializing in service water systems, secondary-side thermal efficiencies, and the aging effects of temperature and radiation on plant coatings. He joined EPRI in 1996, having previously worked in the nuclear energy division of General Electric and at TXU's Comanche Peak Steam Electric Station. Eckert received a B.S. degree in mechanical engineering from the University of Texas at Austin.

Types of Buried Piping

The 2007 NRC/Brookhaven National Laboratory paper *Risk-Informed Assessment of Degraded Buried Piping Systems in Nuclear Power Plants* lists the types of systems found at nuclear plants. The list was compiled through a survey conducted using data in *Welding Research Council Bulletin 446, Design and Repair of Buried Pipe*, as well as a review of 12 license renewal applications submitted to the NRC. The report identified 16 piping categories, including service water, diesel fuel oil, fire protection, emergency feedwater, and condenser recirculating water. Some categories had several subsystems. The service water category, for example, includes emergency service water, auxiliary salt water, salt water, nuclear service water, residual heat removal service water, plant service water, high-pressure service water, and intake cooling water.

The full 174-page report is available from the NRC at http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6876/cr6876.pdf. In addition to detailing the types of buried piping systems, it also discusses how to detect and evaluate pipe degradation.

FIRST PERSON *with Russell Noble*

'NOW IS A GOOD TIME'

Long-time utility researcher says power generators should work in common on diverse issues and technologies related to water

- Finite resources, growing demands
- Big unknowns – CO_2 technologies and water use

Russell Noble is a research manager in Southern Company's generation research and technology management department. He and his staff address research needs and power performance problems in a number of areas relating to power generation, including advanced power generation cycles, turbomachinery, and balance-of-plant. They are also responsible for improving performance and reliability of Southern's generation fleet, including instrumentation and controls, materials, and the entire plant, exclusive of emissions controls. Noble has 28 years of experience in power generation facilities research.

In this interview with the *EPRI Journal,* Noble discusses the electricity sector's issues related to water—its availability for power generation and the need to develop advanced technologies, especially for use in cooling water. Power companies are coming under increased pressure to reduce overall water withdrawal and consumption at a time when increasing electricity generation requirements compete with other demands for water, such as population increase, urban expansion, and agricultural requirements. To address these issues, EPRI launched its Advanced Cooling Technologies project. The project is developing a broad-based research plan to increase water use efficiency and conservation at fossil, nuclear, and renewable power plants through engineering and economic analysis, improved dry and hybrid cooling, reduced water losses from cooling towers, use of degraded water, and enhanced water resource management and forecasting. Among its research priorities, the project is examining cooling water availability impacts on power plant siting, meteorological impacts on air-cooled condensers, indirect dry cooling, hybrid tower designs, water-recovery options, wet-surface air coolers, advanced bottoming cycles, and preserving once-through cooling options.

EJ: Why are you concerned about water as a resource for power generation?

Noble: Southern Company operates in the Southeast U.S., where average rainfall is around 50 inches a year. That's a lot of rain, and typically we have plenty of water. However, looking forward we have fixed resources coupled with increasing demand—more people, more power, more food, more irrigation. Because I work in research and try to look ahead, I think now is a good time to be refining and developing our plan.

The other thing is metropolitan Atlanta, which now has more than 5 million people. We operate plants in the Chattahoochee and the Coosa river basins, from which Atlanta gets its water. Considering Atlanta's growth, the fixed resources, and increasing demand, we see a need to increase our efforts in terms of water sustainability.

EJ: And drought has played a role also?

Noble: The drought of 2007 really stressed us. I think we got about 25 inches of rain—less than half the normal rainfall. It affected everyone through crops, drinking water, restrictions on use—and we also had several power plants that had water-related problems.

EJ: How did it affect your operations?

Noble: We have about 8,000 megawatts of units with once-through cooling. When demand goes up in the summer, we need those units; but if thermal discharge compliance comes into play, we need to get a temporary variance or we must bring in temporary cooling, or back off on the load—or all of the above.

At a couple of sites in 2007 the river levels dropped and we were challenged with river water intake levels. So between thermal compliance and water levels we got a taste of how important water resources are.

EJ: Your company does not face an imminent or chronic water shortage, yet you have been a proponent for EPRI's Advanced Cooling Technologies project. Why?

Noble: In the meetings with EPRI and others in the Advanced Cooling Technologies project, I've met two groups. We're in the first group—the companies that are looking ahead and seeing that the water issue is an important concern. And our situation was exacerbated by the 2007 drought. But you've got this second group, for example these companies out west that are looking urgently at every source of water and every technology. They're looking at reclaimed water, dry cooling technologies, and every way to avoid using water. I wasn't sure we'd have much in common, but we really should all be looking at the same issues and technologies.

EJ: Given the difference between companies that have a "relative abundance of water" and those that face relative scarcity or even chronic to severe scarcity, is it possible to come up with a common agenda for advanced cooling?

Noble: Yes it is, because that increases our chance for collaboration and to do great things.

EJ: What would you place at the top of that common agenda?

Noble: I think it is condenser cooling—optimizing water use and optimizing performance for condenser cooling. That is the high water user, and if you are going to cut back, that is the place you can do it. It is not the easiest, and it is not the cheapest, but it is most of the consumption. For CO_2 emissions controls we're going to need water, but the parasitic loads for that equipment require you to generate that power somewhere else, and that's going to use even more water.

EJ: Climate and CO_2 could have a significant influence, then, on water?

Noble: In some obvious and not so obvious ways. In a nuclear plant, for example, you have lower temperature and lower pressure compared to coal or gas. Peak steam temperatures and pressures are lower, so for every megawatt-hour generated you have more heat rejected. The efficiency of any heat cycle is a function of the highest temperature and the lowest temperature, and nuclear plants have a lower high temperature. There's maybe a 10 percent difference in water usage. But when you factor in water demands added by future carbon capture technology, nuclear may come out ahead of fossil plants.

Also, we build plants for long-term operations and we must understand what our water availability is going to be. If carbon capture is in the plant's future, you are going to have to take that into consideration. All these things have to be factored in when you are looking at risk.

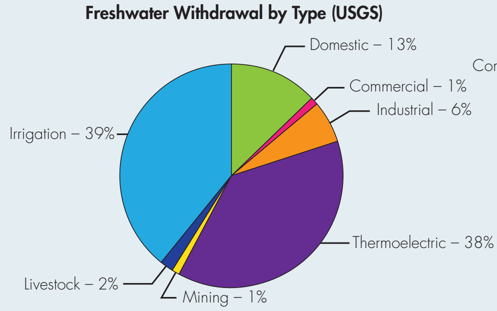
EJ: And efficiency comes into play in different ways?

Noble: Efficiency increases certainly reduce the consumption per megawatt-hour. In the end, if we are still using a Rankine steam cycle, we are going to use the atmosphere as the heat sink. For now, wet cooling is the way to go if you have the water to make it up. Right now we have the water.

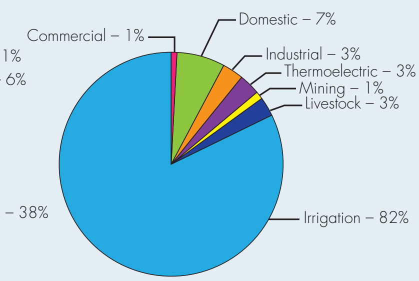
U.S. Freshwater Withdrawal and Consumption

- Power plants account for approximately 40% of freshwater withdrawal, return most of it to the water source, and account for only 3% of total consumption.
- Agricultural irrigation also accounts for approximately 40% of freshwater withdrawal, much of which is lost to evaporation, and accounts for 82% of total consumption.
- The total amount of freshwater withdrawn in arid regions is likely to be significantly less than in other regions due to use of:
  - cooling towers
  - non-traditional water sources
  - water recycling within the power plant
  - evaporation ponds

Freshwater Withdrawal by Type (USGS)



Freshwater Consumption (USGS)



"Looking forward, we have fixed water resources coupled with increasing demand—more people, more power, more food, more irrigation. I think now is a good time to be refining and developing our plan."

EJ: From a plant operations perspective, how do you view dry cooling? Good, bad, indifferent?

Noble: Well, it is expensive and it hurts the efficiency of your plant. It has high parasitic loads and high capital costs. I am not sure about the operations and maintenance, but I know there are more fans and more gear boxes, and whenever you have more rotating equipment, you are going to have more equipment failures and more forced outages.

EJ: What are some other fundamental issues?

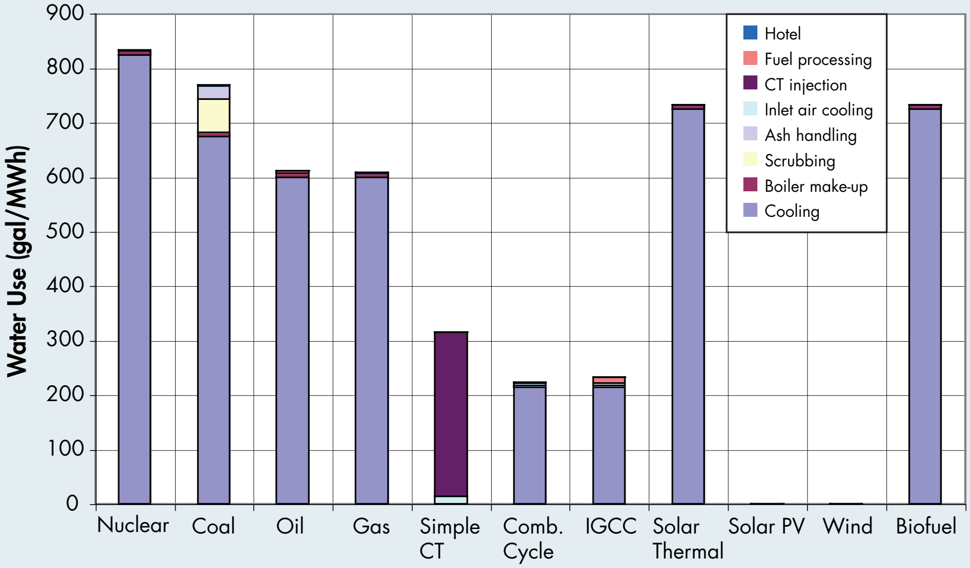
Noble: There is no doubt that water is essential to the way we do business now, using Rankine-cycle steam plants. And obviously water is critical for things other than power generation. In terms of our business, both new fossil and new nuclear are going to use water the way we are doing it now. Without a major change in the technology, we will continue to use lots of water.

The state of Georgia recently asked for a water usage plan, and it has been developed. The state recognizes that the region is growing and will need more water. If the area wants enough water to avoid economic stagnation, they need a plan.

EJ: Does Southern Company have a strategic plan for water?

Noble: Each plant has its own water emergency plan. We have drafted a strategic plan in terms of research, and it basically hinges on three obvious tracks. One, we optimize existing practices. Two, we focus on water recovery, whether it is from wet plumes, from stacks, or whatever. Three, we see what new technology is out there —for retrofit or for a new plant.

Water Use by Power Plants



Once-Through Cooling

- Historic process for condensing and cooling steam
- Cool water from a river, lake, ocean, or pond is pumped to the condenser, where it condenses the steam from the turbine
- After exiting the condenser, the heated cooling water is discharged back into the receiving water body

Recirculating Cooling

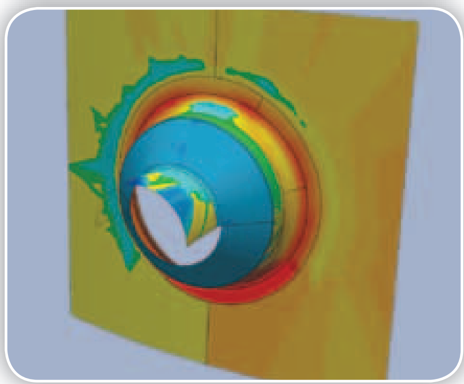
- Typically used in new electric power generation plants
- Minimizes impacts on fish and addresses thermal discharges
- Condenser water is cooled in either a cooling tower or cooling pond and then recycled back to the condenser

Strategies for Reducing Freshwater Use

- Dry/hybrid cooling substitutes air for water as the cooling medium.
- Non-traditional water sources substitute degraded waters such as sewage treatment effluent, agricultural runoff, produced water associated with the extraction of oil and gas, mine water, saline groundwater, and stormwater for freshwater.
- Water recycle strategies treat waste streams within the plant and reuse the water; e.g., remove salts from cooling tower blowdown and recycle it as make-up water.
- Increased thermal conversion efficiency, accomplished by using the waste heat of one plant process to drive another.

Three-Dimensional Profilometry Scanning in Nuclear Industry Promises Enhanced Ultrasonic Analysis

Being able to model the surface contours of in-service equipment offers many advantages for the inspection and maintenance of nuclear power plants. At present, maintenance personnel typically plan their activities from original manufacturing and design drawings, photos, select physical measurements, and a few pin-gauge contours taken at chosen locations. Such information often fails to capture the details and subtleties of surface conditions introduced during component installation or developed over years of operation and maintenance.



RapidForm XOV software allows scans of in-service components to be compared with design drawings, clearly highlighting deviations.

This can be particularly problematic for ultrasonic inspection techniques, where surface anomalies can either create false-positive indications or mask legitimate concerns. The availability of detailed, three-dimensional models of installed plant components would substantially improve ultrasonic inspection capabilities, as well as provide potential benefits in new plant construction, plant modification, and personnel safety.

In 2008, EPRI's Technology Innovation Program conducted laboratory and first-of-a-kind nuclear plant field trials of the 3D Profilometry Acquisition Scanning System (3D PASS), based on Z Corporation's commercially available ZScanner 700. Trial results show that this laser scanning device provides the most accurate capture of surface contour conditions of any technology employed to date in nuclear applications (EPRI Interim Report 1018520).

Portability, Versatility, and Accuracy

The 3D PASS is exceptionally portable, making it ideal for the limited-access conditions typical of nuclear facilities. The scanning system consists of a laser-head scanning unit, a laptop computer, a calibration target, and reflective dots that serve as positioning targets.

The target dots are manually applied in random, nonrepeating patterns, and the self-aligning ZScanner recognizes their positions to maintain its spatial reference from any position. After calibration, the operator points the scanning unit at the object and waves it back and forth, as if spray-painting. As the scanner beam passes over the object's surface, it collects data and builds a three-dimensional image on the computer screen in real time. Missed areas show up on-screen as "holes," which can be filled in by continuing the scan from another angle.

The 3D PASS software package includes ZScan acquisition software, which calibrates and configures the laser and facilitates the data acquisition; RapidForm XOR, which refines the scanned surface and creates a three-dimensional solid surface; and RapidForm XOV, which makes it possible to analyze this solid surface for deviations from a baseline three-dimensional model.

Successful Laboratory and Field Trials

Laboratory trials were performed at EPRI facilities in Charlotte, North Carolina. They included the scanning of two practice specimens: an N2 nozzle from a boiling water reactor and a charging inlet from a pressurized water reactor. Initial field trials were conducted at Florida Power & Light's St. Lucie Unit 1 in Florida and at BKW FMB Energie AG's KKM site in Mühlenberg, Switzerland. The quality of the data from these field trials exceeded expectations, resulting in procedures that will guide future field applications.

Potential Uses and Future Development

With further development, the 3D PASS system could produce three-dimensional models that embody the most accurate and complete as-built information ever recorded. When coupled with the analysis capabilities of RapidForm XOV, these models could not only significantly increase inspection accuracy but also spur unprecedented development of new ultrasonic techniques.

Another potential application of 3D PASS would be in new nuclear plant construction, where three-dimensional models of new plant components could be catalogued for comparison with those developed in future inspections. These models could also provide information for future plant modifications, including weld overlay and mechanical stress improvement process applications. For example, the three-dimensional model of the original surface condition underlying a weld overlay could help determine whether an ultrasonic signal represented a pre-existing surface condition or an anomaly resulting from the weld or overlay.

Future development of 3D PASS applications and of uses for its output data have the potential to benefit all aspects of the nuclear industry—resulting in decreased maintenance costs, compressed outage schedules, and enhanced plant operation and overall performance.

For more information, contact Robert Grizzi, rgrizzi@epri.com, 704.595.2011.

Capillary Electrophoresis Takes BWR Impurity Detection to a New Level, Brings Potential for Automated, Real-Time Detection

Successful nuclear plant operation requires careful monitoring of water chemistry, particularly in boiling water reactors (BWRs), where controlling contaminants in the reactor coolant is essential to fuel performance and corrosion mitigation. BWR plant chemists face a difficult challenge: how to accurately measure and analyze very low levels of ionic impurities and how to adjust water chemistry in response.

Ions of particular interest include positively charged cations such as sodium, potassium, calcium, magnesium, and lithium, and negatively charged anions such as chloride, sulfates, phosphates, and nitrates. Ion chromatography, the conventional method for monitoring ions in BWRs, is effective but suboptimal. It is time-consuming, adding to worker exposure and liquid radwaste generation, and it lacks the sensitivity plant chemists need to detect and measure ions at extremely low concentrations in high-purity coolant streams.

New Approach Shows Promise

EPRI researchers have worked for nearly a decade to develop a system for direct, on-line monitoring of water chemistry in high-purity BWR condensate. In recent years, the effort has focused on optimizing an analytical technique called capillary electrophoresis, which uses an electric field to separate ionic species according to their size/charge ratio as they pass through a capillary tube.

To increase the sensitivity of capillary electrophoresis, EPRI researchers developed chemical probes for use with indirect ultraviolet optical detection. Optical detection enables greater sensitivity because the ultraviolet absorption technique confers a higher charge to the analyte, accelerating the separation. With these refinements, the technique can measure high-mobility anions and cations at very low concentrations (below the parts-per-billion level), making it a promising alternative to ion chromatography, which measures parts per billion. Capillary electrophoresis also can analyze more than 10 samples in the time required for a single ion chromatography analysis, and it generates significantly less liquid radwaste.

Demonstrations at Cooper, Brunswick

Researchers demonstrated the method at Nebraska Public Power District's Cooper Nuclear Station in May 2007, where the project team consistently measured cations and anions at low parts-per-billion levels. In a 2007 plant test at Progress Energy's Brunswick Nuclear Plant, researchers used capillary electrophoresis to measure and determine the source of sulfate impurities detected in process water samples after condensate treatment. The analysis determined that the sulfates came from an organic source, not from the resin beds, enabling the utility to keep a condensate bed in service.

The Cooper and Brunswick demonstrations confirmed that capillary electrophoresis can be useful for detecting ionic species at very low concentrations. The technique and equipment performance were considered a success by both the developers and utility chemistry personnel. Results demonstrated that the technology offers the following potential advantages over ion chromatography:

- Improved sensitivity;
- Rapid analysis;
- Reduced equipment and operating costs;
- Reduced radwaste generation; and
- Reduced personnel exposure.

The demonstrations also showed that the technique can be used to track plant chemistry transient conditions rapidly and precisely. EPRI is working with a commercial equipment supplier to support the development of a fully automated system that will provide real-time analysis.

For more information, contact Susan Garcia, sgarcia@epri.com, 650.855.2731.

Biomass Pellets May Improve Utility Cofiring Prospects

Biomass combustion and gasification could contribute up to 20% of renewable energy produced in the United States by 2030, according to EPRI estimates. In particular, cofiring biomass in coal power plants is among the least expensive, lowest risk, shortest term options for generating power from renewable resources. A variety of technical challenges have limited the widespread use of biomass, however, and EPRI is investigating ways to overcome these difficulties.

Cofiring power plants can now typically use clean, high-quality biomass for 5–10% of the fuel load—a limit imposed largely by the high moisture content of raw biomass. In addition, the fuel quality of raw biomass may vary considerably, and a plant may experience increased corrosion and deposit formation. Most of these drawbacks can be reduced by pre-treating the biomass to reduce moisture and compress the material into pellets, but current processes are relatively expensive and cannot be used with some biomass feedstocks.


Biomass feedstock


Torrefied biomass


Biomass pellets

A promising alternative pretreatment, which is now approaching commercial demonstration, involves roasting raw biomass at 250–300°C in the absence of oxygen to drive off volatile components—a process called torrefaction, which has long been used to dry and roast coffee beans. The remaining char is then compressed into pellets that can be pulverized along with coal and have similar heat content. As a result, the fuel produced by the torrefaction and pelleting (ToP) process could potentially replace up to about 25% of a power plant's coal load. Energy for the torrefaction process itself can largely be provided by burning the volatile hydrocarbons driven off when the biomass is heated.

An additional advantage of ToP pretreatment is that it increases the uniformity of biomass fuel quality, since the pellets produced from wood cuttings, sawdust, and straw have similar physical and chemical properties after torrefaction. The pellets are also much easier to store and transport than raw biomass, which is usually harvested within a 25-mile radius of a power plant. Indeed, by sharply reducing the logistics costs involved, the ToP process will facilitate expansion of cheap energy crops on fallow lands and may even help open a global trade in sustainable biomass fuel. Torrefied pellets have about 30% higher energy content per unit of mass than raw feedstock and resist water penetration, which improves their durability. Beyond generating electricity, the pellets may also eventually be used in pellet stoves and steel production.

Results of a recent EPRI study of the ToP process have been published in a report, *Program on Technology Innovation: Utility Scale Use of Biomass* (1018661). An economic analysis performed as part of this study concluded that biomass cofiring, using torrefied pellets, may be a much cheaper alternative to post-combustion carbon capture and sequestration as a way to reduce greenhouse gas emissions from existing coal-fired plants. It may also provide a way for generators to meet state renewable portfolio standards at lower cost than other renewable generation technologies in many states. EPRI estimates that cofiring with torrefied pellets could provide greenhouse gas emission reductions at a cost of less than $30/ton of CO_2, which would make this a very competitive option for complying with anticipated future climate policies.

As generators in the United States, Canada, and Europe begin considering commercial demonstrations of cofiring torrefied pellets, EPRI is launching a project to build a pilot-scale testing facility that will provide critical technical information about the ToP process. Specifically, the project will allow participants to supply their own biomass raw materials for tests of torrefaction, pelletizing, and grinding. A broader goal is to provide the industry with key process parameters related to the pellets—including heating value, combustion nature, grindability, char composition, and handling characteristics —needed to support mass production. The test facility will also measure emissions profiles needed for the permitting of commercial-scale torrefaction units.

In addition to a torrefaction stage with a 3- to 6-kg batch reactor, the pilot plant will include feed-stock preparation facilities, a pelleting stage, and equipment for gas, liquid, and solid material analysis. Commissioning of the new test facility is scheduled for 2010.

For more information, contact Luis Cerezo, lcerezo@epri.com, 704.595.2190.

EPRI Helps the Industry Prepare for Lower Radiation Exposure Limits

In April 2009, the U.S. Nuclear Regulatory Commission (NRC) announced plans to develop a technical basis for potential rule-making that would effectively lower the allowed occupational whole-body radiation exposure dose to 2 rem/year, compared with the current limit of 5 rem/year. The proposed change is in response to recommendations by the International Commission on Radiation Protection. EPRI is working on a number of fronts to help the nuclear power industry prepare for the possible rule change, which could place substantial strain on the availability of some specialized nuclear workers.

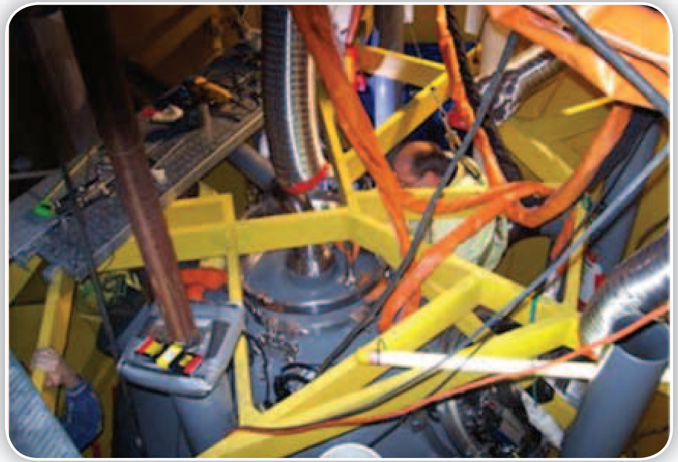
Even before the latest NRC activity, concerns had been rising about how to reduce the exposure of skilled craft, inspectors, and other critical-task staff, who often reach their annual dose limits during spring reactor outages and are thus unavailable to work during autumn outages. Another concern is that almost 25% of the current specialized workforce may retire within the next 10 years. But among the younger workers who could be expected to replace them, the turnover rate is high, partly because of competition from the medical industry for qualified radiation protection staff.

A Multifaceted Response

In response, EPRI has joined with the Nuclear Energy Institute and the Institute of Nuclear Power Operations to sponsor the RP2020 program to "reshape radiological protection at nuclear power plants to achieve significant improvements in safety performance and cost-effectiveness." EPRI is responsible for helping with the reduction of radiation fields in the work environment—known as source term reduction—and for promoting the development and use of new radiation protection technologies.

Recent work in EPRI's Radiation Source Term Reduction program focuses on collecting radiation field data, establishing benchmarks among the plants, and evaluating the efficacy of various technologies and operational strategies to reduce radiation fields. Emphasis has been placed on considering the plant as a whole, including the effects of core design, changes in water chemistry, and operating procedures for startup and shutdown. Results indicate that the most promising source term reduction technologies are zinc injection and electropolishing of component surfaces before installation.

The EPRI Radiation Protection Technology project identifies the tasks that contribute the most exposure and evaluates technologies that improve work practices or reduce general area dose rates—for example, by finding ways to reduce the time required for a task or by identifying areas for increased radiation shielding to protect workers.



Workers can practice their techniques in full-scale mockups of high-radiation areas, reducing their time in the reactor environment.

Developing Practical Solutions

One way to reduce the time required for a task in a high-radiation area, such as the area around a pressurizer nozzle, is to provide a remote mockup of the area, where welders and inspectors can practice their techniques before entering the reactor environment. Another time-saving method uses a new hydraulically tensioned fastener to replace certain bolts. Whereas tightening bolts by hand might require 10–15 minutes, the hydraulic system can lock the new fasteners into place in about a minute.

Shielding methods are also being improved. Traditionally, workers placed bags containing lead shot between themselves and a source of intense radiation. Now such sources can be wrapped in a custom-molded silicon matrix impregnated with tungsten.

To protect workers moving around in areas with varying fields, a real-time location sensor is being integrated with each worker's radiation dosimeter. Such devices can be used to survey radiation levels in three dimensions, to 3 centimeters resolution, and identify areas where unnecessary exposure may occur.

EPRI is investigating these and other new technologies while studying the correlation between source term reduction and workers' cumulative dose. Future efforts will focus on plant-specific recommendations for source term reduction and broad implementation of promising new radiation protection technologies.

For more information, contact Sean Bushart, sbushart@epri.com, 650.855.2978.

Dispersant Application Reduces Deposit Fouling in Steam Generators

Corrosion products entering the secondary side of pressurized water reactors (PWRs) via feedwater can deposit on steam generator tubes and other internal surfaces. These tenacious deposits inhibit heat transfer, block tube supports, and create crevices where corrosive impurities can accumulate. If not corrected, these deposits may lead to stress corrosion cracking and tube failure.

Nuclear utilities have attempted to counter the problem in several ways—by reducing the amount of corrosion products in the feedwater, for example, or by removing deposits through chemical cleaning or with high-pressure water jets. While often effective, these approaches can be costly and extend outages; ensuring that all problem areas are completely cleaned is also difficult. An alternative is to inject dispersants, which prevent corrosion products from depositing on steam generator surfaces so they can be eliminated in the blowdown stream.

Duke Energy recently performed a full-scale, long-term trial of a high-purity polyacrylic acid (PAA) dispersant at its McGuire Unit 2 PWR. Findings show that the dispersant application reduced the rate of steam generator fouling, corroborating results from previous proof-of-concept studies and short-term field tests.

Building on a Foundation of Collaborative R&D

The McGuire trial caps more than a decade of collaborative research and development involving EPRI, utilities, vendors, and consultants. In the 1990s, Commonwealth Edison (now Exelon) conducted corrosion tests to qualify a high-purity version of PAA dispersant and transferred details of the PAA program to the industry through EPRI. EPRI subsequently collaborated with Entergy on a three-month field trial at Arkansas Nuclear One Unit 2 just before steam generator replacement. The trial indicated that PAA can increase blowdown iron-removal efficiency by a factor of 10.

After the Arkansas trial, researchers completed additional qualification work to technically justify a six- to nine-month trial at a plant with replacement steam generators tubed with Alloy 690. This work demonstrated that such a long-term trial would not result in any adverse conditions in balance-of-plant or steam generator materials and that all candidate steam generator designs could accommodate a possible slight decrease in heat-transfer efficiency during the testing. In 2004, Duke Energy committed to conducting the full-scale, long-term trial at its McGuire Unit 2. Starting in 2005, plant personnel injected PAA into the feedwater piping upstream of the individual loop lines at concentrations of 0.25 parts per billion (ppb) to 4 ppb.

Results and Benefits

Researchers found that PAA dispersant injection at 2 to 4 ppb increased the corrosion product removal efficiency by an order of magnitude, from about 5% to 45–50%, and that McGuire Unit 2 actually exhibited a slight beneficial increase in thermal performance during the trial. Secondary chemistry parameters were not adversely affected, and demineralizer performance was not compromised.

Results of the McGuire trial are providing the basis for steam generator vendors' technical concurrence with industrywide long-term dispersant use. The findings are included in EPRI's recently published *Dispersant Applications Sourcebook* (1015020), which provides guidance and comprehensive information for utilities planning to use PAA dispersant. Several utilities are planning long-term dispersant applications. Exelon began PAA injection at Byron Unit 1 in April and plans to add dispersant at Byron Unit 2 and Braidwood Units 1 and 2 in 2009 and/or 2010.

Further Applications

EPRI is evaluating the use of dispersant for cleanup of feedwater systems prior to operation. Corrosion products carried from the secondary system to the steam generators during startup after outages can contribute up to 20% of the total corrosion product ingress during a fuel cycle. Dispersant use in the feedwater could enhance cleanup and increase the amount of corrosion product removed. Positive results will support qualification for a subsequent plant trial of this application.

EPRI has also begun an evaluation of dispersant application during steam generator wet layup, addressing a high-priority need to enhance deposit removal from steam generators during plant outages.

For more information, contact Keith Fruzzetti, kfruzzet@epri.com, 650.855.2211.

ITM Oxygen Technology for Advanced Clean Power Generation Systems

While much of the power industry's work on carbon capture and storage focuses on removing CO_2 from the post-combustion flue gas of conventional coal plants, two other options are expected to contribute substantially to a low-carbon energy future. Integrated gasification–combined-cycle (IGCC) systems remove CO_2 from the fuel before it is burned, and oxyfuel combustion systems, which use high-purity oxygen rather than air for combustion, produce flue gas with high CO_2 concentration that is much more efficient in direct capture.

Both of these advanced generation processes require large amounts of oxygen—a necessity that has worked against their competitive economics. Air Products, under a cooperative program with the U.S. Department of Energy (DOE), is working with EPRI and the electricity industry to develop an innovative ion transport membrane (ITM) technology for oxygen production that could significantly increase efficiency and reduce costs for advanced power generation applications.

Large-scale extraction of oxygen from air is currently accomplished by cryogenic air-separation units, which because they must be powered would represent a considerable parasitic load at generation plants and thereby reduce overall plant efficiency. The ITM process, which uses a ceramic material under temperature and pressure to ionize and separate oxygen molecules from the air, requires no electric power to operate. As a result, ITM technology could lower the cost of producing oxygen, reduce IGCC plant capital expenses by 7%, and reduce auxiliary power consumption by 6% of gross power production.

Air Products, which has been developing ITM technology since 1988, is already collecting data from the operation of a 5-ton/day (t/d) oxygen pilot plant unit near Baltimore as part of a cooperative program with DOE. The next step in the DOE program is to design, build, and test a 150-t/d unit and integrate it with 5- to 15-megawatt industrial turbomachinery. Commissioning of the 150-t/d intermediate-scale test unit is expected in 2010. EPRI will assist Air Products with the scale-up of the process and equipment and with the integration of ITM technology with advanced coal power systems. These efforts will focus closely on power industry–relevant design cases and on features and specific tests that will help advance the overall ITM program toward successful deployment in the power industry.

"EPRI's involvement is important, as this will directly involve the electric utility industry in integrating ITM technology for clean energy," said Ted Foster, director of business development for Advanced Gas Separation at Air Products. "This collaboration will

The Air Products Subscale Engineering Protoype.
Image courtesy of Air Products. © Air Products. All rights reserved.

give the industry a firsthand understanding of the technology."

Bryan Hannegan, vice president of Environment and Generation at EPRI, expanded on the value of the collaboration: "By reducing the cost of coal gasification and oxyfuel combustion, ITM technology will help enable a future generation of coal-fired power plants that will capture and store their CO_2 emissions while using less of the world's limited land and water resources. EPRI is pleased to bring together a collaborative of several utility companies in support of Air Products' and DOE's development of ITM technology for power applications, and we expect that our efforts will help accelerate the technology to market."

EPRI welcomes the participation of additional utilities and coal producers in the project collaborative.

This market could grow substantially in supporting advanced coal-based generation and integrated carbon capture technology. EPRI estimates the current U.S. power generation industry share of the oxygen market to be about 4%; if IGCC and oxyfuel combustion technologies are further developed as part of the industry's overall low-carbon power strategy, utility oxygen production needs could become the dominating market driver, accounting for more than 60% of the future market, or approximately 2 million t/d of oxygen by 2040.

For more information, contact Rob Steele, rsteele@epri.com, 704.595.2025.

TECHNOLOGY AT WORK

Member applications of EPRI science and technology

Diablo Canyon Uses EPRI Guide to Improve Work Planning

Diablo Canyon Nuclear Power Plant, just west of San Luis Obispo, California (Photo courtesy Jim Zimmerlin.)

Work management at nuclear plants involves more than just the efficient scheduling of maintenance activities. An effective process gives close consideration to task complexity, safety, plant conditions, human factors, cost-effectiveness, workforce skills and specialization, and plant-specific needs.

Doing it right is critical to the effective operation and maintenance of the plant. In recent years the Institute of Nuclear Power Operations (INPO) and World Association of Nuclear Operations (WANO) identified a trend: shortcomings in work instruction and procedures have contributed to maintenance errors, an increase in inoperable equipment, component failure, the need for rework, work backlogs, and injury.

The Challenge: Ensuring Work Package Quality

Central to work management is the preparation of a work package, which sequences maintenance tasks by compiling key documents—work orders, work instructions, and supporting materials such as drawings, vendor manuals, weld process sheets, information on operating experience, human performance details, and special work process permits.

In 2004, INPO and the EPRI Nuclear Maintenance Applications Center (NMAC) formed a working group to develop an industry guideline addressing work package quality. The resulting document, *Maintenance Work Package Planning Guidance* (1011903), provides an overview of regulatory and industry requirements for work package content, level of detail, and quality, as well as guidance on skills and performance attributes essential for work planners and the personnel implementing the work packages.

The document establishes the structure, format, and content for work instructions—the primary elements of a quality work package—and uses a graded approach to work planning. With graded work planning, work packages can be prepared to varying levels of detail, depending on factors such as task complexity, potential effect on plant nuclear safety, reliability, and skill of the craft. The report also provides examples for measuring and monitoring the quality of work packages.

Application at Diablo Canyon

Industry evaluators at INPO identified weaknesses in work planning at PG&E's Diablo Canyon Power Plant in California, and they formally designated work planning as an Area for Improvement. Plant staff turned to EPRI for help in taking corrective action and used the EPRI guideline document to implement improvements to the plant's planning programs. Plant staff also participated in the NMAC Work Planning Users Group, which meets twice a year to focus on continuous improvement of work packages.

The guideline document, combined with collaboration through the users group and the EPRI member network, helped Diablo Canyon staff identify and prioritize work planning issues and develop best practices. The staff established a work planning steering committee to monitor work package quality and assume responsibility for all work planning issues, including process, knowledge, safety, feedback, and human performance. Plant staff shared their experiences with the users group to further refine and develop solutions to their common issues.

Results: Measurable Success

Diablo Canyon made significant advances in its work package quality and planning processes, including a work planning training program, a computer-based feedback program, and enhanced metrics. INPO's most recent review recognized the substantial improvement and closed the previously issued Area for Improvement. Moreover, maintenance errors due to planning weakness have been substantially reduced, with success documented in independent evaluations, internal reviews, and positive plant condition reports. Maintenance workers surveyed have noted improved content, consistency, and completeness of recent work packages, and the organization continues to seek areas of continuous improvement.

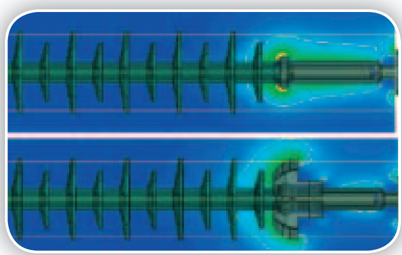
Effective work planning is an ongoing challenge at all nuclear power plants. Diablo Canyon expects to make further changes to its planning standards as a result of the electronic feedback process and continuous review and improvement of work package content and format. Adjustments will also be made to upgrade planning and work management computer software and to accommodate new workers who will replace retiring workers.

For more information, contact Lee Rogers, lrogers@epri.com, 704.595.2267.

EPRI Studies and Field Tools Find Weak Link in Polymer Insulators and Offer Fixes to Improve Reliability

Corona discharge caused by high electric fields can be a problem for polymer insulators, causing accelerated aging of rubber material on the high-voltage end of the insulators. To mitigate such deterioration and early failure, utilities have used corona rings to reduce the electric fields on lines operating at 161 kilovolts (kV) and above. In recent years, utilities have reported an increasing number of polymer insulation failures on 115-kV and 138-kV lines, suggesting that corona ring protection may be required also for these lower-voltage lines.

A recent EPRI study verified the problem by applying a variety of assessment tools, including advanced field inspection techniques, failure analysis techniques, electric field modeling, and equipment and failure databases. "The study was conclusive in finding that polymer insulator degradation can occur on 115- and 138-kV transmission lines in certain applications and that corona rings can eliminate the problem," said Andrew Phillips, director of transmission research for EPRI. "Since we have been doing related research at our Lenox test facility for many years, we already had the tools in place to deal with the issue."



The installation of corona rings (bottom) can reduce electric fields on the high-voltage ends of polymer insulators, preventing deterioration and early failure.

A 72-page report (1015917) on this work provides reference information and resources to address the premature aging of polymer insulators. The report also provides recommendations for assessing existing insulators, replacing or retrofitting at-risk equipment, and specifying insulators for new or replacement units. "We also have ongoing dialogue with insulator manufacturers and standards committee representatives to advise them of what we have learned," said Phillips.

Assessing Deterioration

Several EPRI members have already applied the research. "Because of our involvement in the EPRI insulators project, we were aware of these failures within the industry attributed to electrical discharge on lower-voltage insulators," said Raymond Ferraro, a specialist in emergent technology and transfer at Public Service Electric & Gas Company (PSE&G). "With this information, we felt it prudent to investigate the possibility of electrical discharge activity on our recently re-conductored and re-insulated 138-kV lines."

The assessment began with a review of insulators using the *EPRI Polymer Insulator Vintage Guide* (1012328), which tracks design and materials changes made by manufacturers over time. Next came discharge inspections of the insulators using the EPRI daytime corona camera.

"Once we verified electrical discharge with the daytime corona camera, EPRI worked closely with us to develop an approach to assess our level of risk for our installed insulators," said Ferraro. "They also helped us formulate a suitable remediation plan and instruct our workforce on condition assessment of field units, which included developing a customized field guide."

"Through early detection and intervention, we were able to reduce the risk of possible insulator failure by identifying which insulators should be removed from service and where corona rings could be retrofitted to provide protection," said Ferraro. "The results from this project allowed our re-conductoring project to continue, prevented polymer insulators from being installed without corona rings, avoided the need to replace a significant number of in-service polymer insulators, and established an approach for future assessments."

Advanced Modeling

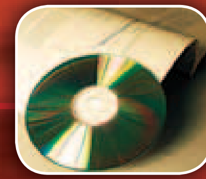
EPRI performed a similar assessment for Albuquerque-based PNM, which faces particular vulnerability at high altitudes, where corona problems are more likely. As a result, PNM removed units of a specific vintage and design, replacing them with units that have corona rings.

PNM's Emilie Dohleman found EPRI's advanced electric field modeling to be particularly valuable. "The three-dimensional modeling process really helped us in retrofitting existing insulators. This model showed precisely where the problem was, when a 2-D model probably would not have," said Dohleman.

"EPRI's long-term research in the area of corona effects and polymer insulator degradation was invaluable in assisting us in developing a cost-effective solution to this problem," said Dohleman. "EPRI developed a utility-specific guide for evaluating existing insulators for continued use on the system. This not only saved the cost of new insulators but also avoided the added expense of staff time, equipment, and line outages."

For more information, contact Andrew Phillips, aphillip@epri.com, 704.595.2234.

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 look under My Research Areas.

Tensions in Global Power and Fuel Sector Development (1015680)

This report offers detailed analysis of global long- and short-term developments in the oil, natural gas, and coal markets, closely examining market fundamentals, reviewing the recent dramatic swings in energy markets, and identifying critical considerations and constraints that explain market progression. The study builds on a foundation of EPRI studies conducted in 2007 and 2008 on global generation decisions and global natural gas and coal markets. In addition to timely reassessments of natural gas and coal, it adds discussions on world oil, the emergence of Russia as an important energy producer and exporter, and constraints on the global development of renewable power.

Review of CO_2 Capture Development Activities for Coal-Fired Power Generation Plants (1015700)

This report provides an up-to-date summary of the progress being made globally by power companies, vendors, and research institutes in development of the two leading CO_2 capture technologies: oxyfuel combustion and post-combustion capture. Some of the processes described are incremental improvements on existing CO_2 controls, while others anticipate new techniques, materials, and technologies that are not yet commercially available. This investigation includes a broad review of literature and proceedings from major U.S. and international conferences and also draws on information gathered from technology developers, manufacturers, and vendors. The information helps establish which approaches to CO_2 capture have the greatest chance of success and warrant increased development effort and funding.

Nuclear Maintenance Applications Center: Heat Exchanger Maintenance Guide (1018089)

This guide addresses various engineering, maintenance, and operations issues related to the preventive and corrective maintenance activities that are typically performed on nuclear plant heat exchangers and how to troubleshoot them. The report focuses on units that can be categorized as low energy, single phase, and water cooled; it expands maintenance guidance for both shell-and-tube heat exchangers and plate heat exchangers in one comprehensive report. Maintenance guidance for air-to-water heat exchangers is also included. Key heat exchanger suppliers were consulted in the production of this report to ensure that the guidance reflects the latest technologies available to the industry.

Program on Technology Innovation: Readiness of Existing and New U.S. Reactors for Mixed-Oxide Fuel (1018896)

Expanding interest in nuclear power and advanced fuel cycles indicates that use of mixed-oxide (MOX) fuel in the current and new U.S. reactor fleet could become an option for utilities in the coming decades. This review collects and distills the substantial knowledge and experience base derived from publicly available reports, manuscripts, and other documentation related to use of MOX fuel in light water reactors. The information was verified and augmented through consultations with experts from electric power utilities, reactor vendors, and other organizations, including those connected with the DOE plutonium disposition program. The report focuses on generic technical considerations and does not consider policy, economic, and social factors.

Fleet Management Analytics for 15-kV Distribution Cable (1019380)

Much of the industry's installed distribution cable fleet may be approaching the end of its service life. Balancing future failure costs against current replacement investments requires the ability to predict cable performance, but traditional modeling methods demand a significant amount of historical data that is often not available. This report describes a probabilistic modeling approach developed for Hawaiian Electric Company that utilized available data to project future cable failure performance. Various potential replacement strategies were modeled, and the results were used to investigate select business cases. The modeling methodology developed in this study for distribution cable can be modified to perform analyses of other power delivery components.

PRE-SW EMF Workstation 2009—BETA (1019411)

EMF Workstation 2009, a stand-alone software program for calculating electric and magnetic fields, was developed in response to continuing interest in the potential health effects of exposure to 60-Hz magnetic fields produced by power lines and substations. EMF Workstation 2009 models electric and magnetic fields from complex arrays of three-phase substation equipment, transmission and distribution lines, and single-phase custom conductors. The workstation also has the capability to calculate fields over uneven terrain and to compute induced currents in passive wire loops and lightning shield wires. As a 32-bit program, it will run under Windows 2000, Windows XP, and Windows Vista operating systems.

WIRED IN

Perspectives on electricity

Beyond Cap and Trade and Renewables Portfolio Standards

Jay Apt *is Executive Director of the Carnegie Mellon Electricity Industry Center at Carnegie Mellon University's Tepper School of Business and a member of the Department of Engineering and Public Policy, where he is a Distinguished Service Professor. He is an EPRI Board member.*

Congress is likely to labor mightily to pass legislation that will produce a carbon dioxide price of $10–$15 per ton. Although this will encourage some demand reduction and efficiency investments, it is far too low to affect investments in electric power production. Nor will the expected rise in price as the cap declines stimulate long-term investment: the net present value of a $65/ton price in 2030 is $10/ton, if a discount rate of 10% is used for investment decisions.

The present 2.1¢/kilowatt-hour production tax credit for certain renewables is the rough equivalent of $30/ton of avoided CO_2. That subsidy would likely be ineffective in stimulating new wind and other renewables without another mechanism—renewables portfolio standards (RPS). A 15% national RPS is part of the Waxman-Markey bill reported out of committee in May, and many state RPS targets will reach at least that level within a decade.

RPS goals of the sort contained in Waxman-Markey require more than a tenfold increase in renewables, which can be achieved, but with considerable effort. Wind, geothermal, and solar (if solar costs decline) can make substantial contributions. Biomass could also, but will be needed for transportation fuels in a carbon-constrained world.

But people won't stand for solutions that disrupt the economy when deployed at scales that make real contributions to solving the problem. Without considering the cost implications, Pennsylvania has mandated 800 megawatts of solar photovoltaics, despite the fact that cloud cover and latitude reduce the potential solar energy for the state.

Between now and 2020, meeting this requirement will cost Pennsylvania's ratepayers $1.8 billion more than the same amount of wind power and will cost $400 million per year thereafter. The lesson is that mandating technologies can be much more expensive than mandating performance by capping emissions at a level that declines over time.

Rather than telling power companies how to run their business—by instructing them to buy specific generation technologies or by setting the price of CO_2 permits at a level too low to induce them to invest now in new generation that does not emit CO_2—we should introduce a more direct strategy, one that can be dovetailed nicely with the likely national RPS in the 2020 time frame.

A carbon emissions portfolio standard can serve as a market signal and drive innovation toward a low-carbon economy, regardless of the strength and timing of cap-and-trade legislation.

Unlike state standards in California and Washington, which limit individual new power plants to a fixed amount of 1,100 pounds of CO_2 emissions per megawatt-hour, a carbon emissions portfolio standard should start at a higher level and be applied to the average generation mix of all the plants that serve a distribution company. Trading among companies would be allowed so that companies that have only coal plants could buy permits from companies whose power comes largely from hydroelectric, renewables, and nuclear plants. Perhaps most important, a carbon emissions portfolio standard would give power companies a certain and long-term signal to invest in renewables, low-carbon generation, and efficiency improvements in existing fossil-fired power plants.

As was done for the sulfur dioxide cap-and-trade program, the level of CO_2 emissions in a base period could be used to set the initial standard. It would then be ramped down over time, with all utilities eventually converging to a uniform national level. The average limit for the standard should ramp down in a clearly specified way over time so that power companies can see the higher standards coming and plan accordingly.

A carbon emissions portfolio standard that picks up where a national renewables portfolio standard leaves off will put the country on a sound and affordable path to low-carbon electricity.

More details are discussed in a Carnegie Mellon Electricity Industry Center briefing paper available at http://wpweb2.tepper.cmu.edu/ceic/pdfs_other/ClimatePolicy.pdf.

ELECTRIC POWER RESEARCH INSTITUTE

Post Office Box 10412
Palo Alto, California 94303-0813

ADDRESS SERVICE REQUESTED

NONPROFIT ORGANIZATION
U.S. POSTAGE
PAID
SALEM OR
PERMIT NUMBER 526

JOURNAL

ELECTRIC POWER RESEARCH INSTITUTE

SUMMER 2009

Printed on recycled paper in the United States of America

1019554