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EPRI JOURNAL

ELECTRIC POWER RESEARCH INSTITUTE

Managing the Smart Grid?

LOOKING AT APPS FOR THAT

ALSO IN THIS ISSUE:

Water + Chemistry = Solution

Oxy-Combustion for Carbon Capture

Smart Grid Demonstrations Focus on Integrating Distributed Energy Resources

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.

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Trust Is Our Foundation

"…from the beginning, the institute had to establish itself as a reliable technical resource, to both utilities and public bodies, through emphasis on objectivity, technical thoroughness, and intellectual integrity."

~ *Chauncey Starr, Founding President and Chief Executive of EPRI, quoted in* Science *magazine, 1983*

When EPRI issues a report, testifies before the U.S. Congress, or delivers its findings to its members, the regulatory community, environmentalists, and others, trust is the essential foundation for that work.

The energy questions we confront are imposing. Can we decarbonize the electricity sector and still burn coal? Can we rely on our middle-aged nuclear fleet while building new, advanced plants? Can we really achieve energy efficiency gains sufficient to offset significant new generation—and at lower cost? Can we test new technologies and rely on the findings? Each question can be answered "yes" or "no," depending on your ideology. EPRI's goal is to provide answers to such questions based on scientific and technical analysis.

To achieve this goal, EPRI's guiding principles are **objectivity, independence,** and **transparency**.

At EPRI, objectivity is a corporate and a personal responsibility. Each scientific and technical program, each report or white paper, and each interaction can either build trust or undermine it. For the individual, I think of objectivity as a "mental independence"—allowing a researcher or technical expert the freedom to aggressively peer into our world scientifically and speak the truth about technology.

Our independence is grounded in social responsibility and built into the way we conduct our business. The EPRI Advisory Council articulates the public interest as we develop the research agenda. Its members represent interests and viewpoints inside and outside the electricity business, and they help keep our focus on the public benefit and maintain our commitment to independence.

Two challenges make this independence more important than ever. We face the Herculean 21st-century task of expanding and re-engineering the 20th-century electricity infrastructure. Billions of customers will be added, and billions will depend on power produced at new levels of sustainability. Also, we expect to depend on electricity to do a great deal of work now done by petroleum, with transportation as a prime example.

The second challenge is the competition among technical innovations, which is especially apparent in the research and development stage. Technical innovations compete for attention, research funding, capital, and the public support that will help sustain and advance their development and ultimate commercialization. For EPRI, the challenge is to acknowledge the competition while basing research plans on addressing the overarching issues.

For example, EPRI is developing a multi-year research and development plan that focuses on six important issues:

- Energy efficiency
- Renewable resources and integration
- Smart grid
- Near-zero emissions
- Long-term nuclear operations
- Strategic water management

The role of these six important issues in structuring our research plans reflects a great deal of discussion and outreach with people at all levels, inside and outside the electricity sector. Many of these issues cross traditional boundaries in the electricity sector. Energy efficiency and renewable energy address power generation, transmission, distribution, and end use. If we look at water management, it is a boundary-crossing collection of challenges associated with water quality, availability, and sustainable use.

In addressing any issue, transparency is essential for EPRI. If the public clearly understands how we do our work and clearly sees that our actions match our words, they will trust our results. Ultimately, the results of our work must be testable and reproducible, and we must communicate them effectively to our members, industry stakeholders, and the public.

The electricity sector provides much of EPRI's funding, which can, on occasion, prompt questions about the objectivity and independence of our results. The rigor of our advisory structures, the scrutiny of peer review, and our charter to provide benefit to the public drive us to earn and keep the trust of everyone who depends on affordable, reliable, and environmentally responsible electricity. As we approach our 40th year, that trust is still our foundation.

Mike Howard
President and Chief Executive Officer

SHAPING THE FUTURE

Innovative approaches to upcoming challenges

IGCCost Web Tool Enables Cost/Performance Evaluations

For years EPRI has performed cost and case studies of integrated gasification–combined-cycle power plants in various configurations. A new web tool builds on these studies to provide an interactive presentation of the research results, allowing users to manipulate key assumptions that factor into the desired engineering and economic evaluations.

Developed by EPRI's CoalFleet for Tomorrow® program 66B, "IGCCost" is available to program sponsors on the CoalFleet Knowledge Base B website and covers results for multiple coal types, gasifier technologies, power system frequencies (50/60 Hz), gas turbines, and CO_2 capture configurations. The user also can specify assumptions related to engineering costs, coal prices, capacity factor for a plant, and the projected cost of CO_2 transport and storage.

Summary-level output from the program for each case includes power output from a plant, capital costs, levelized cost of electricity, and CO_2 emissions rates. The user also can make side-by-side comparisons of up to four cases. At a more detailed level for individual cases, the user can specify further variables, such as labor rates and fixed and variable costs for operations and maintenance.

"Understanding the cost and performance of currently available IGCC configurations will be critical for utilities when they begin work on new coal-fired power plants," said Ron Schoff, senior project manager. "In the future, we expect to add pulverized coal with post-combustion CO_2 capture and oxy-combustion options to the tool so that users can compare the main alternative coal technologies head-to-head for specific configurations."

CoalFleet has set a goal of driving down IGCC capital costs by 30% by 2025, while at the same time improving thermal efficiency with CO_2 capture from the current level of about 30% to almost 40% by 2025. Orders for new power plants of all kinds now are lagging because of the recession and regulatory uncertainty, but when demand picks up, it will be critical that utilities be able to calculate the cost and performance of various generation technologies and choose the best for the particular situation.

"Utilities are in a technology surveillance mode now," concluded Schoff. "IGCCost will help them better prepare for the time when orders pick up. Recognizing that, we plan to add new features to the software, such as a price on carbon, which will help them judge the likely impact of future policies on plant competitiveness. To make the tool even more generally useful, we also hope to provide it on some of the newer, more portable platforms, such as the iPad."

For more information, contact Ron Schoff, rschoff@epri.com, 704.595.2554.





New Research Looks at Emissions from Advanced Generation Technologies—In Advance

Emerging technologies such as integrated gasification–combined-cycle (IGCC) systems, oxygen-fired combustion, and various carbon dioxide capture technologies are undergoing emissions testing in anticipation of new environmental regulations. Before these advanced generation and emission control technologies are fully deployed, it is important to understand the chemical composition of emissions; investigate their fate in air, water, and solids streams; and conduct detailed studies of potential health and environmental impacts. These efforts can help stakeholders address potential environmental and health issues as early as possible. Developers then may be able to integrate solutions more effectively and economically and avoid costly re-engineering or retrofit measures.

New Rules Demand New Knowledge

Regulatory agencies continually review the need for reductions in air, water, and solid waste discharges to protect human health and the environment. These reviews focus on emissions such as sulfur dioxide, nitrogen oxides, and particulate matter, and on metals such as mercury, arsenic, and selenium. New technologies that are being tested to meet emerging regulatory requirements may produce unique air pollutants, wastewater streams, and solid by-products for which there is little information. Also, the changing mix of power plant emissions may interact in new ways with emissions from other sources, potentially producing new materials and compounds.

To date, only limited effort has been devoted to examining potential health and environmental impacts of IGCC plants, biomass fuels, carbon dioxide capture systems, and other emerging technologies. EPRI's Technology Innovation program is funding a multidisciplinary team with expertise in toxicology, risk assessment, measurements, atmospheric chemistry, air quality modeling, emissions controls, and occupational health and safety to investigate these critical issues strategically.

Modeling, Laboratory Science, and Field Studies

Work began in 2009, with multiple activities now under way. So far EPRI has:

- characterized emissions at a biomass-cofired plant and collected particulate matter samples for toxicology analysis;
- completed a comprehensive survey of existing and novel electric power generation technologies, air pollution controls, and fuels, and identified power plant configurations projected to contribute significantly to the U.S. generation mix in 2030;
- refined results from the survey to develop a "short list" of 20 representative configurations for more detailed analyses;
- gathered data on the chemical characteristics of the stack gas, liquid discharge, and solid waste composition of each technology and estimated their emissions; and
- begun incorporating the data into an emissions database that will be used in health and environmental risk evaluations, now under way.

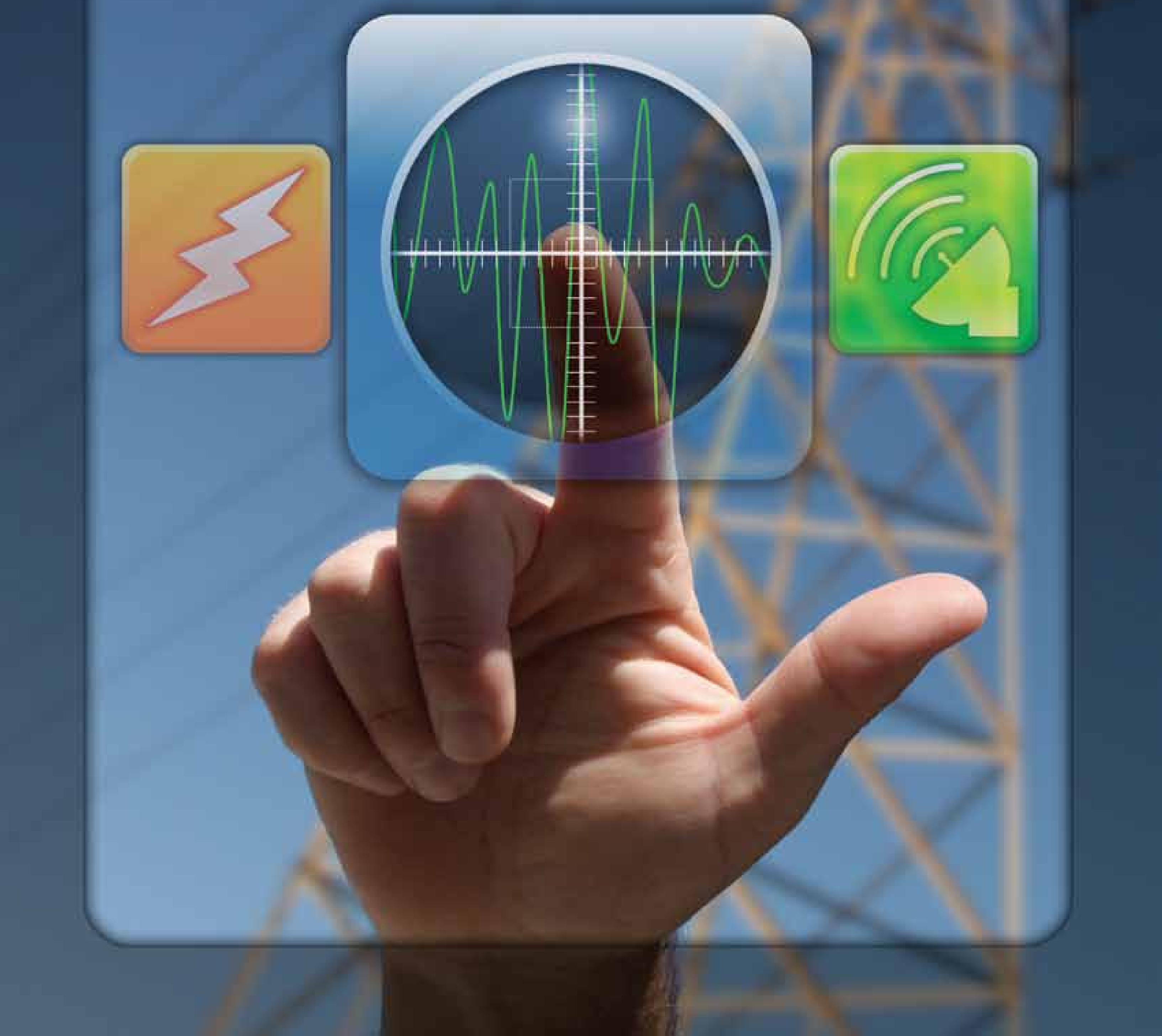
Basic research also is addressing priority issues related to the chemistry and toxicity of emerging pollutants. A first-of-its-kind laboratory study is looking at the biological effects of amines and their degradation products, with modeling activities related both to amines and to the formation of ultrafine particles in power plant plumes. For technologies and fuels meriting closer examination, the research will include field measurement and toxicology studies at pilot- or full-scale plant sites. Field research also will include occupational health and safety assessment.

If the research indicates that advanced plant configurations have significant potential for adverse impacts, more sophisticated testing will be conducted to understand potential implications. Results will be communicated to technology development teams inside and outside EPRI to guide process refinement and testing focused on impact mitigation.

For more information, contact Annette Rohr, arohr@epri.com, 425.298.4374.

MANAGING THE Smart Grid?

LOOKING AT APPS FOR THAT



THE STORY IN BRIEF

The revolution that is bringing the digital world to the palm of your hand is also handing utilities the opportunity to solve some traditional problems with some nontraditional thinking and applications that may prove surprisingly easy and affordable. Bottom line: some app-solutely amazing prospects for workers, consumers, and "the edge of the grid."

Consumers buy more than a half million smart phones each day. Used for making calls and checking e-mail, these pocket-sized devices also serve as powerful computers. Consumers can customize their smart phones and other smart devices by adding applications—"apps." These days, there's an app for almost everything. You can browse the *New York Times*, track your workouts, play Scrabble with a friend, count calories, follow Facebook, or even scan bar codes at the store to compare prices.

Smart devices, with their fast processors, high-resolution screens, and high-quality audio, are designed to entertain, but they hold promise for the power industry as well. "I really view these as a simple way to get laptop computing and communications capabilities out into the field," said Doug Dorr, a senior project manager at EPRI who leads a team working to design new applications for portable electronic devices. "If you want to acquire data, information or even look at training videos, it's a wonderful way to do it."

Dorr and others at EPRI are investigating how the industry might employ these devices and have found several possible uses. Need help locating contact voltage hot spots? Thanks to EPRI, there may soon be an app for that.

Mad Scientist

The idea to use smart devices to acquire and analyze data for the power industry started with a noisy air conditioner. In the summer of 2009, Norm McCollough, a project manager with EPRI, moved into a new house. The first time he turned on the air conditioner, he heard a terrible noise. "You could tell there was something wrong, but you really didn't know exactly what," he said. Lesser men might have called a repairman. McCollough—some call him the mad scientist—took matters into his own hands. He downloaded an app onto his iPhone to detect vibrations, and another to analyze the audio signal. Then he headed into the back yard to diagnose the problem. When he placed his iPhone near the air conditioner, the defect became "pretty apparent." The fan wasn't properly balanced. "You could see it in the big spike in the frequency band on the sound analyzer," he said.

A couple of months later, McCollough recounted the story to Arshad Mansoor, EPRI's senior vice president of research and development. Mansoor was impressed. McCollough told him the iPhone could do much more—perhaps even help the power industry keep tabs on the grid. Mansoor encouraged McCollough to seek funding to find out more about the capabilities of these devices.

This past March, McCollough received seed money from EPRI's Polaris Initiative, which funds high-risk research with the potential for innovative breakthroughs—"far-out ideas," McCollough calls them. Together with Dorr, McCollough has spent the past six months developing and testing five different applications on Apple's iPod touch, a device that has nearly all the capabilities of smart phones, except the ability to make calls. Eventually the pair hopes to have hardware and apps that work with every kind of smart device, including the Droid, the Palm Pre, the Sony Instinct, the Zune HD, and many more.

Tracking the Grid

After McCollough used his iPhone to diagnose the broken air conditioner, he couldn't help but wonder what else it could do. Although smart devices weren't designed for the power industry, their audio capabilities make them well-suited to measuring power frequencies. "The things that the power companies are interested in are in the same frequency band as audio," McCollough said. "An iPhone or an iPod can record, in stereo, about 48,000 samples of audio per second. That's in the hearing range of about 20 Hz to 20 kHz. The 60-Hz power line frequency is right smack on the low end of the audio range."

Keeping tabs on the grid is a complicated and costly job. The meters that enable field engineers to monitor power quality and measure electric and magnetic fields can cost thousands of dollars. And for each task, the crew needs a different meter. What if, McCollough thought, he could design applications that would allow a single smart phone to take the place of many meters?

Smart phones have incredible capabilities, but today's models don't come with the sensors required to measure voltages and currents. They also don't include an interface that would allow the device to connect safely to the grid. Fortunately, according to Dorr, "the sensors are already out there." The bigger challenge was to build an interface that could turn the signal coming from the sensor into something the smart device could handle and understand. A field crew might need to measure the current on a 13,000-volt power line. But when that signal comes into the smart phone, it needs to be less than a volt. "If it's more than that, it could damage the phone," Dorr said.

For the initial concept, Dorr and McCollough are using an off-the-shelf iPod microphone as an interface. Microphones already convert sound into voltage, so it's no great leap to get them to accept voltage from the outset. Eventually, Dorr and McCollough hope to build an interface that will work with any smart phone or smart device. Dorr envisions a rugged, weatherproof interface that would enable people to connect to the docking port on an iPhone or the USB port on Android-based devices. Alternatively, the interface could be wireless—the sensor would collect the information and transmit it directly to the device.

Using the microphone interface, Dorr and McCollough already have developed applications to measure power quality and log the data over time, find inadvertently energized objects, and measure magnetic fields.

Their iPQ Analyzer detects power quality problems. Sensors track the voltage and current and transmit that information through the interface to the smart phone. "We do a little bit of mathematics on that signal and waveform," McCollough said, "and what we get back are the different frequency components, or harmonics, that are in that line." That information allows engineers to spot problems early on.

"There are some power harmonic analyzers already out there, but they're very expensive," McCollough said—on the order of $5,000 to $25,000. "You can get the iPod touch and some smart phones now for about 100 bucks," he added. The sensor and interface might add a few hundred more dollars to the price, and it would still be a bargain. "It's an order of magnitude less," he said. The low cost means that "if we can make them rugged and weatherproof, you can have a lot more of these things in the field."

Juan Menendez, a manager at Southern California Edison, sees the value of such applications. If Menendez or his colleagues want to analyze power quality, they have to remove metal panel covers and connect to the power quality meter. If the data could

be transferred wirelessly to a smart phone—or better yet, he says, an iPad—their jobs would be much easier and safer. "We're slow in adopting new technology like this," he said. "But it may be something that we can sell in the long term."

For utilities that want longer-term data, the team developed a prototype application that allows smart devices to track power quality over time. In theory, a utility could provide these devices to customers with the request that they be plugged into a wall socket; the utility could then pick them up a month later. "You would have a pretty accurate picture of what goes on as far as the quality of the power," McCollough said.

Another problem facing utilities is contact voltage. Contact voltage occurs when a metal object, such as a streetlight or a manhole cover, inadvertently becomes energized. In wet weather, people or animals that come in contact with these objects can receive a shock. Dorr and McCollough have been working with Consolidated Edison of New York on a handheld meter for contact voltage detection and diagnostics and thought it would be neat to see if a smart phone could do the same thing. Contact voltage meters already exist, but they don't have GPS capability. "The iPod or any smart phone can map the energized object on a GPS grid," McCollough said. "That makes it a more useful tool."

Diane Blankenhorn, manager of research and development at National Grid in New York, says a contact voltage app could be very useful. She envisions meter readers carrying smart phones and sensors on their daily routes. As readers make their rounds, the sensor would detect any contact voltage, and the app would mark the location. "So then you just have to go back to the GPS coordinates," she said.

Fill 'er Up

Perhaps the lowest-hanging fruit on the industry app tree are programs that don't require any additional hardware. iPod touches, iPhones, and many other smart devices come equipped with a GPS, which makes mapping a breeze. McCollough created a prototype application that enables drivers to find charging stations for their electric vehicles. Also, the app can locate fueling stations that stock hydrogen, biodiesel, compressed gas, ethanol, and other fuels. Utilities could upload information about these locations and fuel or electricity prices. They could even use the application to dispatch crews to repair out-of-service charging and filling sta-

tions. Then it's simply a matter of keeping the master database up to date. "It's a simple mapping application that everybody can use to find these alternative fuel locations," Dorr said.

Similarly, other information stored in databases can be made available on smart phones so that field workers have the latest information. For instance, a utility might want field engineers to have a list of all its transformers. GPS capability gives utility workers even more power. Imagine, Dorr says, that a hurricane had hit the Gulf Coast and knocked down a number of distribution poles. With GPS-equipped smart phones, "we'd know exactly where poles needed to be replaced, even if the whole area was just devastated," he said. Smart devices also are a handy place to store training booklets or videos for trouble crews to reference in the field. "These kinds of apps are already happening," Dorr said. All that's needed is a smart phone or a tablet PC and some creativity.

The Grid's New Edge

Some information has been difficult for the power industry to retrieve. For instance, utilities know how much power a customer uses, but not precisely how he or she uses it. Dorr calls this "the edge of the grid." Smart phones may give utilities the ability to extend the edge. Dorr envisions future applications that can enable smart phones to receive basic power data or even pricing data from smart meters and allow customers to remotely adjust their thermostats or turn off appliances and lights. With a combination of smart phones and smart meters, utilities could get a more accurate load profile and obtain a much broader picture of energy management potential.

On the power generation side, smart devices could be cost-effective in better understanding how power output from a block of solar panels fluctuates. Imagine solar panels on thousands of houses. On any given day, clouds may block some of these panels, partially reducing their output. "Without significant monitoring costs, the utility has no way to look at these variations in real time," Dorr said. "If we had smart phones wirelessly logging the output from these panels and transmitting the data, we could gain a much better understanding of solar panel variability. It's one more way smart devices could help extend the edge of the grid," he said. "They bring about this potential to do things that we just never thought were cost-effective."

In September, Dorr and McCollough received additional Polaris funding to continue their work in 2011. They plan to run more tests to determine whether the phones will work in extreme heat or cold. "We want to make sure they are fail-safe," Dorr said. They also plan to develop a prototype universal interface and draft standards for how to acquire, display, and store the data.

Even at this early stage, Dorr sees a bright future for smart phones in the power industry. "This is really one of the enabling technologies that we've been looking for," he said. "It's potentially a game changer."

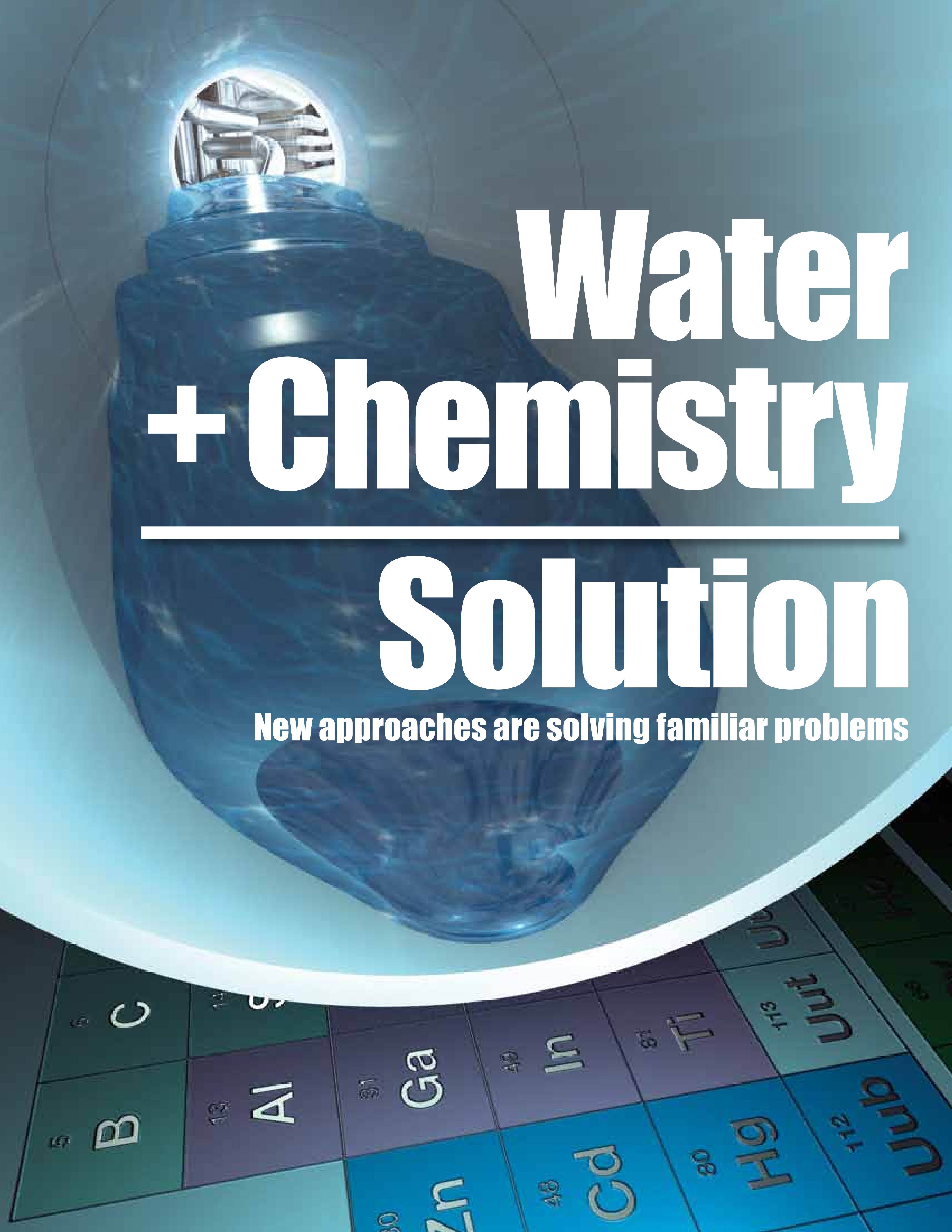
This article was written by Cassandra Willyard. For more information, contact Doug Dorr, ddorr@epri.com, 352.343.7088, or Norm McCollough, nmccollough@epri.com, 865.218.8089.

Doug Dorr is a senior project manager in EPRI's Power Delivery and Utilization Sector, specializing in data acquisition, analysis, and monitoring. He leads a team that is developing new measurement and analysis technologies for electric power distribution applications. Prior to joining EPRI, he held various project, program, and laboratory management positions with EPRI Solutions and EPRI's Power Electronics Applications Center (PEAC). He received a B.S. in engineering from Indiana Institute of Technology, in Fort Wayne, Indiana.

Norm McCollough, project manager in the Power Delivery and Utilization Distribution area, manages the underground distribution sensor research work. His current research activities focus on sensor technologies and sensor deployment on overhead and underground distribution lines. Before joining EPRI, he worked at Hendrix Wire and Cable as director of technology, Molded Division. He was responsible for developing advanced insulator-mounted electrical power line monitoring devices, advanced polymer materials, and injection molding strategies for new insulator types. McCollough attended the University of Tennessee and is a member of the IEEE Power Engineering Society. He currently holds seven Letters Patent.

Water + Chemistry / Solution

New approaches are solving familiar problems



THE STORY IN BRIEF

In a power plant, controlling the water chemistry is fundamental to plant operation—to availability and the reliability of components. The problems are as old as rust itself, but new solutions continually result from research, innovation, shared experience, and old-fashioned vigilance. Together, these lead to more effective chemical treatments and guidelines that reflect the state of the art.

Small problems with water chemistry and small deviations in water purity, if not addressed, eventually cause big problems and rack up big costs. An unscheduled shutdown of a baseload unit, depending on the cost of supplemental power, can result in economic impacts of $1 million or more per day.

For both fossil-fueled and nuclear units, the best water chemistry programs adapt to new technologies and take advantage of accumulated operational experiences. It is a long-term journey, not a destination. Maintaining proper water chemistry is a balancing act that requires monitoring, precise evaluation, and attention to each unit's idiosyncrasies. As one senior chemistry specialist said, "Each unit has its own personality."

Competitive pressures drive the need to maximize production, reduce operation and maintenance costs, and extend major component life. Solutions depend on the combined, cumulative knowledge of chemists, maintenance engineers, plant managers, technical services managers, production managers, operations managers, and materials specialists.

"When the critical elements of power generation clash, all parties should immediately launch a condition-based risk assessment," said Jim Mathews, EPRI's fossil fuel water chemistry R&D program manager. "An alarm from water chemistry instrumentation might mean adjustments can be made in the chemistry control or operating condition that enable the unit to extend operation to a period of lower demand. Or the unit could require shutdown, despite a very profitable operating environment. Shutdown is a consideration that impacts everyone, and that's why education should extend to everyone."

Water Chemistry Basics

A primary goal of water chemistry control in fossil and nuclear plants is to prevent deposition and corrosion. Deposition is the buildup of foreign substances or corrosion products on power plant heat exchangers or other component surfaces. It can be traced to impurities such as sodium, chlorides, sulfates, phosphates, lead, and iron. Naturally occurring organic material, hardness compounds such as calcium and magnesium, any acidic constituents entering the system, and dissolved gases such as excessive oxygen or carbon dioxide also contribute to corrosion and subsequent deposition or fouling.

With corrosion, metal is dissolved by chemical action resulting from low pH, acidic impurities, temperature, and stress. Exposed metal resulting from abrasion, corrosion, and thermal or physical effects promotes more rapid corrosion. Proper chemistry facilitates development of a stable or passive oxide on the metal surface that inhibits further corrosion. Conditions that weaken or destabilize the protective oxide can lead to flow-accelerated corrosion, corrosion fatigue, stress corrosion cracking, reduced component life, and downtime. Poor water chemistry control promotes corrosion and deposition of corrosion products, which can reduce heat transfer rates, increase resistance to steam and water flow, and reduce turbine efficiency.

At fossil plants, which operate at high temperatures and pressures, water purity is the primary consideration. Fossil plant chemists focus intensely on maintaining high-purity water and steam to protect turbines, condensing systems, feedwater heater trains, and condensate polishing systems.

"Our goal is no impurities in the water," said Mathews. "That requires vigilance and can be difficult to maintain, but that's our goal."

At nuclear plants, which operate at lower temperatures and pressures, a primary goal is to reduce impurities to concentrations "as low as reasonably achievable" (ALARA), but there are other considerations as well. Water chemistry, for example, can impact nuclear fuel operation and reliability, the generation of corrosion products that contribute to plant radiation fields, and the production of radioactive species such as liquid and airborne iodine.

The most common contamination sources include condenser leaks caused by a microscopic hole or a poor seal in a joint; makeup water; adverse operating conditions; and condensate polisher resins, which are used primarily in nuclear units and in supercritical fossil units that operate at high temperatures and pressures.

New Trends in Water Chemistry

Effective water chemistry programs incorporate new science, lessons learned in the field, and changing operational and safety requirements. The four techniques summarized below illustrate how "water + chemistry = solutions."

Filming Amine to Abate Damage from Frequent Cycling

Cycling standby and baseload fossil units has become more common as electricity demand has slackened in recent years and as more renewable resources have come on line. Cycled units operate at an increased risk of corrosion, especially when they are taken out of service for as little as 48 hours or for as long as three months. The equipment must be protected but also must be available to come on line within minutes.

FirstEnergy Generation Corporation, based in Akron, Ohio, has tried standard procedures to store frequently cycled units, including eliminating oxygen with nitrogen "blanketing" and draining boiler water. Nitrogen blanketing can have safety issues with repair and maintenance work, and draining boiler water is time consuming.

In 2010, FirstEnergy looked for other options. Cycle chemistry consultant George Verib, with technical assistance from EPRI's program, evaluated a filming amine in a six-month trial, and FirstEnergy was impressed enough with the results to implement the technology at six frequently cycled 110–250-megawatt subcritical boiler coal units. About 48 to 72 hours before shutdown, a filming amine is injected, producing a hydrophobic film on wetted metal surfaces. "It works kind of like car wax," Verib said. "Any water in the system beads up like it does on a well-waxed car, so the water never even touches the metal. That's how it inhibits corrosion."

The filming amine has attracted growing interest among water chemistry specialists. Several utilities, including American Electric Power and PPL Corporation, will begin testing it in January 2011. EPRI is promoting a project to conduct field and laboratory research into use of the amine as an alternative to current lay-up practices.

Reducing Agents Out, Oxygen Treatments In

In the 1990s, the fossil generation industry began to move away from using reducing agents to change the electrochemical potential of water from reducing to oxidizing. It's estimated that more than 75% of supercritical units operated by EPRI member utilities worldwide have switched from reducing agents to oxygenated treatments.

Changing the oxidation-reduction potential results in a hematite-based oxide that is much denser, more stable, and less subject to dissolution. The net result is lower dissolution, which translates into lower corrosion rates and less corrosion transport and deposition in boiler water. The only exception to using oxidizing treatment is when there is mixed metallurgy containing copper alloys. (Copper's corrosion potential is excessive in oxidizing environments.)

Southern Company was the first North American utility to convert a supercritical coal unit to oxygenated treatment. Senior chemistry specialist Randy Turner has been impressed with the reduced frequency of chemical cleaning and the reduction in flow-accelerated corrosion and iron transport.

"Before we switched to oxygen treatment, we were doing chemical cleaning every 18 to 48 months, depending on the unit design," Turner said. "Now we're doing it every 10-plus years. In fact, the unit that was converted in November 1991 has not required a chemical cleaning since."

Dispersants Boost Performance in Nuclear Units

Exelon senior chemistry specialist Dave Morey was intrigued by the results of field tests conducted at two EPRI members' nuclear plants to inject dispersants to reduce steam generator tube fouling. Such fouling can occur when corrosion products entering the secondary side of pressurized water reactors via feedwater settle on steam generator tubes and other internal surfaces. The deposits inhibit heat transfer, block tube supports, and create crevices where corrosive impurities can accumulate. These deposits can lead to stress corrosion cracking and tube failure.

Morey had tried chemical and mechanical methods to reduce corrosion products in the feedwater. These were effective but costly and carried risks related to extended outages and incomplete cleaning.

He read about a three-month trial at Unit 2 of Entergy's Arkansas Nuclear One that had reduced corrosion by using the dispersant polyacrylic acid. A subsequent 14-month field test at Duke Energy's McGuire Nuclear Station yielded improvements significant enough for Morey to pursue his own program. The research demonstrated that the dispersant prevented corrosion products from depositing on steam generator surfaces, so they could be removed via blowdown.

"The dispersant attached to iron oxide particles, giving them a net charge, so they repelled each other," said Morey. "The particles stayed suspended in the bulk water rather than settling out or depositing on heat transfer surfaces and were easier to remove in a system blowdown."

In April 2009, the first Exelon unit, Byron I, went on line with dispersant injection. "The results were remarkable," Morey said. "We picked up five to six pounds of main steam pressure, and the number four turbine governor valve gained 7% of travel, so we're basically de-fouling the steam generators."

That led to dispersant injection at Byron II and Braidwood I, which have consistently maintained a 50% gain in iron deposit removal efficiency. Six other U.S. utilities are evaluating or implementing the technology. The South Texas Project Electric Generating Station, owned by CPS Energy, NRG Energy, and the City of Austin, is set to begin injection by year's end.

Zinc Injection—Fast Track to Success

Zinc injection, which progressed from initial research through trials, field testing, and full-scale deployment in just five years, has been widely endorsed by EPRI's nuclear membership because of three main benefits: radiation dose reduction, mitigation of primary water stress corrosion cracking, and maintenance of fuel performance and integrity. One initial concern was that zinc-enriched deposits could impede heat transfer between the fuel cladding and coolant, leading to cladding failures. Detailed evaluations found no significant heat transfer problems.

Real Time and Ahead of Time—Software Tools Provide Crucial Support

EPRI's desktop ChemWorks™ and web-based SMART ChemWorks™ tools are used to monitor changes in water chemistry that can affect availability and reliability, providing early warnings of potential problems. They enable plant personnel to model effects of planned water chemistry changes and assess resulting chemistry changes across the system—in steam generators, main steam, condensate, feedwater, and heater drains. Specialists can then evaluate the data and optimize secondary pH controls, improving confidence in changes when implemented. Additionally, SMART ChemWorks can be configured to calculate plant-specific parameters such as crack growth rates for boiling water reactors and a fuel reliability index to gauge the performance of nuclear fuel.

SMART ChemWorks provides authorized users 24/7 access to their plant's performance data. "With SMART ChemWorks, you can keep tabs on water chemistry at any time from anywhere via a web browser," said David Perkins, EPRI program manager. "Users can also set the program up to send alerts via e-mail, a page, or a text."

ChemWorks is available to all EPRI nuclear members and is used in 13 countries. SMART ChemWorks is used in 22 U.S. plants.

"The EPRI data on the use of zinc for both radiation reduction and stress corrosion cracking mitigation is quite robust," said Morey. "All the lab and field data supporting the benefits of zinc in material reliability and radiation reduction enabled us to move forward with the technology fairly quickly." Over multiple cycles, Exelon's dose rates were reduced 50% in comparison with original measurements.

Today, 71 pressurized water reactor units worldwide inject zinc into the reactor coolant system.

Guideline Development

EPRI guidelines address water chemistry issues at both fossil and nuclear stations. They reflect the operating experience and expertise of diverse industry specialists.

"Our guidelines provide a framework for utilities to create water chemistry programs that help minimize materials degradation, optimize fuel performance, and minimize dose fields around the plant," said Keith Fruzzetti, EPRI technical executive. "They've basically become the technical bible for plant chemists."

Nuclear guidelines encompass water chemistry guidelines for boiling water reactors, primary- and secondary-side guidelines for pressurized water reactors, and new guidelines planned for service water system chemical addition and closed-cycle cooling-water chemistry. They provide specific recommendations for plant water chemistry changes. EPRI's recent update of its *Secondary Water Chemistry Guidelines*, for example, reviewed a significant body of laboratory work and plant experience to re-evaluate chemistry impacts on steam generator wet layup during outages. Modifications to the steam generator wet layup guidelines will allow plants improved flexibility without compromising corrosion protection.

Fossil plant water chemistry guidelines address all aspects of plant operation, including different steam generator designs and cycles such as supercritical once-through boilers, subcritical drum boilers, and multipressure heat recovery steam generators. The guidelines also address complications from cycling plants.

The guidelines are reviewed annually by a technical utility committee and updated as necessary to reflect industry operating experience and emerging concerns.

"We have also begun to examine water chemistry guidelines in the context of newer nuclear plant designs," said Fruzzetti. "We expect many guidelines to remain valid for the new designs, but we're working to identify technical gaps in understanding how water chemistry will affect the new plants."

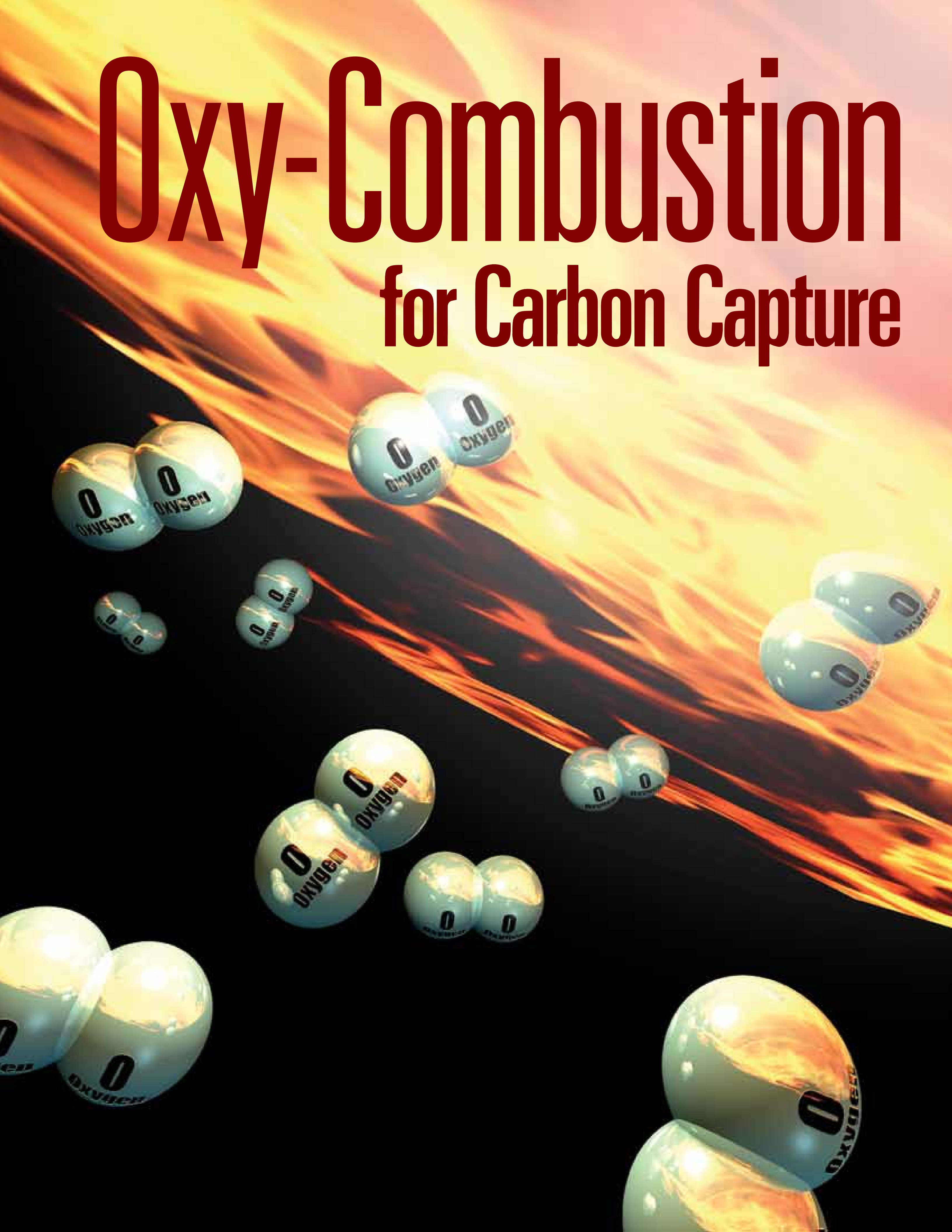
This article was written by Joe Gallehugh. For more information, contact Keith Fruzzetti, kfruzzet@epri.com, 650.855.2211; Jim Mathews, jmathews@epri.com, 704.595.2544; or Dave Perkins, dperkins@epri.com, 817.691.6494.

Keith Fruzzetti, technical executive in the Materials and Chemistry program area, focuses on chemistry optimization. Prior to joining EPRI in 2001, he worked at NWT Corporation as a senior consultant involved in PWR primary and secondary water chemistry. He received a B.S. in chemical engineering from San Jose State University and an M.S. and Ph.D. in chemical engineering from the University of California, Davis.

James A. (Jim) Mathews is a program manager for the Boiler and Turbine Steam and Cycle Chemistry Program. Before joining EPRI, he was the corporate consulting chemist for fossil generation at Duke Energy. He has published numerous papers on ion exchange, biofouling, chemical cleaning, and cycle chemistry. He received a B.A. in zoology and chemistry from Indiana University and completed postgraduate work in nuclear and corrosion engineering at North Carolina State University.

David Perkins, senior project manager in the Chemistry and Low Level Waste program area, focuses on pressurized water reactor primary chemistry controls, evaluation of primary-side zinc injection in pressurized water reactors, chemistry software development and support activities, and chemistry services. Previously, he served as manager of chemistry services at EPRI Solutions and was involved in developing and implementing chemistry services supporting EPRI technologies. He completed the United States Navy nuclear power program, as well as numerous training programs including the INPO-accredited chemistry technician and supervisor courses.

Oxy-Combustion for Carbon Capture



THE STORY IN BRIEF

New light was focused on oxy-combustion technology in September 2010, when Ameren Energy Resources signed a cooperative agreement with the U. S. Department of Energy to receive $1 billion, as part of the FutureGen 2.0 Industrial Alliance, to repower a 1970s-vintage steam-electric plant with oxy-combustion to capture and subsequently store CO_2. EPRI is helping utilities better understand the engineering challenges and is supporting efforts to solve key issues.

Three technology approaches are available for capturing carbon dioxide (CO_2) from coal-fired electric power generation. Postcombustion capture (PCC) technology uses a solvent to remove CO_2 from the flue gas released by conventional air-fired combustion. Precombustion CO_2 capture technology can be applied to an integrated gasification–combined-cycle (IGCC) plant, which gasifies the coal fuel and uses a solvent to remove CO_2 from the coal gas before firing in a gas turbine.

The third technology approach—oxygen-fired combustion, or oxy-combustion—separates oxygen from air and combines it with recycled flue gas so that combustion occurs in the presence of oxygen and CO_2, producing a flue gas rich in CO_2 (70%–90%, dry basis). This combustion process allows the CO_2 produced during coal combustion to be more easily purified and compressed before transport and storage.

Oxy-combustion is common in industrial processes that require very high temperatures. It has not, however, been employed for CO_2 capture applications. To date, no commercial-scale oxy-combustion power plants have been put into operation. Pilot plants, from 5 to 40 MWth, have been tested in Europe and the United States, and commercial plants are planned in Germany, the United States, and Spain.

The FutureGen 2.0 project plans to deploy the technology in a 200-MWe oxy-fired boiler, adding an important new element to the CO_2 capture scene. The project will repower an oil-fired steam-electric power plant in Meredosia, Illinois. Participants include Ameren Energy Resources, which owns the plant; Babcock & Wilcox (B&W), which will build the boiler and environmental equipment; and Air Liquide, which will supply the air separation unit and CO_2 purification unit. The project includes the plant repowering and the construction of a CO_2 pipeline and geological storage facility. Construction will begin in 2012 and be completed by 2015.

The FutureGen 2.0 project replaces plans for a new IGCC plant included in the earlier FutureGen project. "Until now, DOE had not selected any oxy-combustion project for funding," said Jeff Phillips, EPRI senior program manager. "We were struggling to see how oxy-combustion could move forward without government-supported demonstration. This definitely meets that need."

Technology Advantages, Risks

Compared with the other carbon capture technologies, oxy-combustion offers several advantages. First, according to the few "apples-to-apples" economic studies conducted to date, the technology appears to be at least competitive economically. Second, for plant operators, much of the technology would be familiar. Oxy-combustion differs from IGCC and PCC in that all its major systems are physical and do not involve critical chemical processes or inventorying large amounts of chemicals.

Third, the energy penalty with oxy-combustion is essentially electricity, and unlike PCC, the technology does not require major disruption of the steam power cycle. Last, oxy-combustion can be used in repowering and, potentially, retrofit applications, which could help the large installed base of coal-fired plants meet future carbon emission requirements.

An oxy-coal plant with CO_2 capture consists of five systems:

- Air separation unit (ASU)
- Steam generator / air quality control system (AQCS)
- Steam turbine cycle island
- CO_2 purification unit (CPU)
- Balance of plant

Three of these systems—the steam generator/AQCS, steam turbine, and balance of plant—will, with a few minor exceptions, look and operate like those in an air-fired coal plant. Recycled flue gas is combined with oxygen to produce a "synthetic air" mixture that approximates air-fired combustion and heat transfer and allows use of existing steam generator designs. (Indeed, the first-generation oxy-coal power plants also will be capable of operating in air-fired mode.)

For ASUs, cryogenic air separation is the only technology sufficiently mature to serve a commercial oxy-coal plant. The technology has been used for many years in industrial applications, and single trains as large as 4,000 tons per day are available. Because oxy-coal plants don't require the high-purity and high-pressure oxygen that industrial applications do, opportunities exist to minimize power usage and capital cost. For the same reason, ASUs designed for optimal power generation have not been built, but suppliers' experience suggests the technology risk is relatively low.

The power required by cryogenic ASUs represents the bulk of the energy penalty for CO_2 capture with oxy-combustion. For the future, ceramic membrane–based oxygen production promises to reduce capital costs and power consumption. EPRI has teamed with DOE and Air Products on the ongoing development of a novel oxygen production technology called ion transport membrane, or ITM.

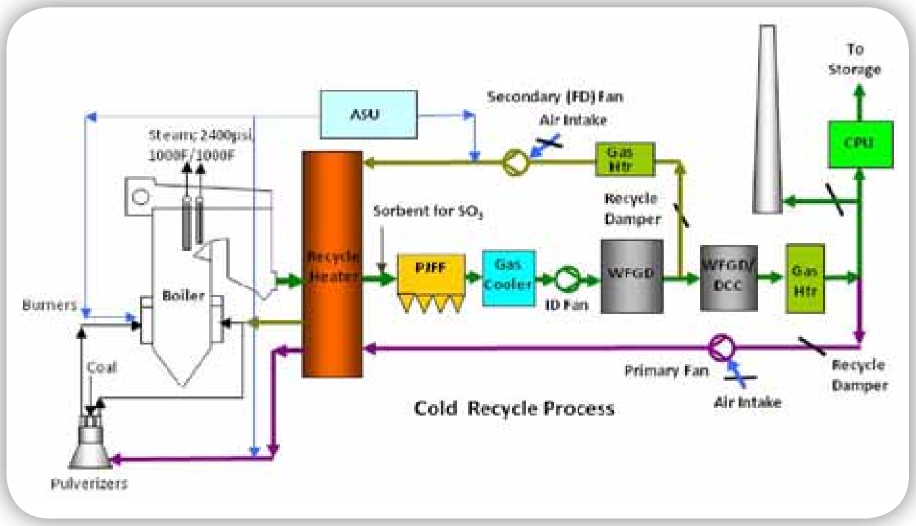
"The greatest uncertainty in overall cost and performance for an oxy-coal plant is in the CPU design," said David Thimsen, EPRI project manager of the oxy-combustion program. "The CPU proposed for the oxy-coal plants leverages experience in producing purified liquid CO_2 for the food and beverage industry as well as experience in cryogenic industrial gas processes. But the CPU process for oxy-coal power plants differs from the industrial process with respect to production capacity, nature of impurities, product quality specifications, and final state of product."

Indeed no common specification is available for CO_2 purity delivered by an oxy-coal power plant to a pipeline or storage site. In addition, while industrial CPUs use ammonia as the refrigerant, it is commonly assumed that CPUs in oxy plants will use the liquefied CO_2. Such "auto-refrigeration" CPUs have never been built at the scale required for an oxy-combustion plant.

"For both the ASU and the CPU," said Thimsen, "an additional challenge is that, unlike PCC development, the technologies associated with oxy-coal cannot be tested individually in slipstreams, but require the significant investment of building a full oxy-coal power plant."

EPRI Oxy-combustion Research

EPRI has sponsored studies and collaborations to better understand oxy-combustion technology:



Graphic courtesy Babcock & Wilcox

- *Preliminary Project Designs.* For two utilities, EPRI co-funded studies that developed a preliminary technical design and determined plant performance and costs for an oxy-coal plant. The first study outlined the design for a 50-MWe (gross) oxy-fired circulating fluidized-bed (CFB) plant with geological storage for the Jamestown (New York) Board of Public Utilities. The second study developed a design for a 78-MWe (gross) CFB plant for the Holland (Michigan) Board of Public Works and went a step beyond the Jamestown study to define the material and energy balances. EPRI also extrapolated information from both studies to assess the extent to which oxy-coal power plants might achieve near-zero emissions and qualify as a "minor source" for purposes of permitting.
- *Pilot Test.* EPRI participated in a utility advisory group for a project conducted by B&W and Air Liquide to test a 30-MWth oxy-combustion pilot plant. "At the time, in 2007, the test program was the largest oxy-combustion test in the world," said Steve Moorman, manager of business development for advanced technologies at B&W. The project provided critical experience with burner operation, transition from air- to oxy-firing, and environmental performance, and it proved Air Liquide's Floxynator™ concept for mixing oxygen with flue gas. Bituminous, subbituminous, and lignite coals were all successfully tested under oxy-firing conditions.
- *Working Group/Technology Development Roadmap.* EPRI took the lead in forming an oxy-combustion working group with two dozen vendors and utilities. With this group's support, EPRI is creating a technology development roadmap to assess the readiness of component technologies, identify technology risks, and establish a timeline for scale-up to full-scale deployment by 2020.
- *Economic Comparison.* EPRI conducted a literature review of studies comparing the economics of oxy-combustion with the economics of PCC and IGCC plants on a common baseline. The results indicate that under certain conditions (e.g., with lower-purity CO_2) the levelized cost of electricity for the oxy-coal cases is approximately 7% lower than for PCC and approximately 5% lower than for IGCC. Although these estimates cannot be conclusive, they indicate that the technology is viable and likely to be competitive.
- *Engineering and Economic Assessment.* EPRI is supporting development of a detailed engineering and economic assessment of an oxy-combustion plant, which will be comparable to studies of PCC and IGCC technologies conducted for the CoalFleet for Tomorrow® program. The assessment will address

plant design, equipment specifications, plant performance, and cost estimates. It will also evaluate the impacts on capital and operating costs of relaxing CO_2 purity requirements.

- ***Pressurized Oxy Technology.*** In a study for EPRI's Industrial Technology Demonstration program, EPRI is evaluating the performance and economic benefits of conducting oxy-combustion under pressure, the maturity of this technology, and how it might be further developed by demonstration. Pressurized combustion allows boiler and heat recovery process designs that increase boiler efficiency by recovering latent heat in the flue gas not available from flue gas near atmospheric pressure.

Commercial-Scale Demonstrations

Public policy discussions commonly set a target of making commercial CCS options available by 2020. Achieving this goal with oxy-combustion will require reducing performance uncertainties through operation of one or more plants at full scale (500–800 MW). The next critical step toward that end is demonstration of new-build and retrofit projects at 50–200 MWe.

FutureGen 2.0 is now the most prominent project in the pipeline. "What makes FutureGen 2.0 different from all the rest is that it has $1 billion already approved," said Jeff Phillips. "That is nearly 80% of the cost of the project. I don't think there is any other CCS project in the world that involves a coal power plant storing 1.3 million tons of CO_2 each year that has nearly 80% lined up." The 80% cost share will cover only the capital expense. The ongoing operation, maintenance, and fuel costs will be recovered through the commercial sale of electricity in a competitive market.

"FutureGen 2.0 will offer the industry the first opportunity to test the oxy technology at scale," said B&W's Moorman. "The key thing we need to learn is whether the ASU, boiler, and CPU can work together as a system. It hasn't been done before at this scale."

Several European pilot oxy plants are also planned for scale-up. In Germany, the 30-MWth Schwarze Pumpe plant, built in 2009 by the utility Vattenfall, has achieved thousands of hours of operation, and the plan is to scale it up to 250 MW by 2015. In Spain, CIUDEN is building a two-unit oxy pilot plant with a 20-MW pulverized-coal boiler and a 30-MW CFB boiler. The Spanish utility Endesa plans to build a 300-MW oxy plant by 2015.

While the first generation of oxy-coal plants will be designed with currently available technology for the ASU, boiler, and AQCS, longer-term research may enable further cost reduction and performance improvement.

> *"FutureGen 2.0 will offer the industry the first opportunity to test the oxy technology at scale."*
> *~ Steve Moorman*

For air separation, a process called *chemical looping* would separate oxygen from air by capturing it with a solid "carrier" material, which would be physically transferred to a second reactor, where the oxygen would be used to burn coal. This technology eliminates the large auxiliary power requirement of cryogenic air separation units.

For boilers, research is under way to reduce flue gas recycling, which would result in more compact boiler designs. Foster Wheeler is evaluating a new-build oxy-combustion CFB boiler that would require only 65% of the surface area and 45% of the volume of air-fired boilers, with associated cost reductions.

For the AQCS, technologies are under investigation for incorporating bulk removal of sulfur oxides (SOx) and nitrogen oxides (NOx) into the CO_2 purification process. This capability could replace conventional flue gas desulfurization and NOx control equipment, with a commensurate reduction in capital costs.

For Thimsen, the oxy-combustion demonstration plants and the longer-term research will help broaden CCS options. "Oxy-combustion gives us more choices," said Thimsen. "In the future, we may find that each CCS technology meets a different particular need. The oxy research under way now will help us better understand this technology's potential and limits, and where it might best be used."

This article was written by Jonas Weisel. Background information was provided by David Thimsen (dthimsen@epri.com). Jeffrey Phillips and Rob Steele of EPRI and Steve Moorman of Babcock & Wilcox (samoorman@babcock.com) also contributed to the article.

David Thimsen is a senior project manager in EPRI's CoalFleet for Tomorrow® program. He worked closely with EPRI in the late 1980s and 1990s to facilitate the field deployment of fluidized-bed combustion technology for utility-scale power generation. More recently, he has managed small-generator installation projects for the Distributed Resources program at EPRI, as well as advanced coal-fired power generation projects and field deployment of postcombustion CO_2 capture.

Steve Moorman is manager of business development for B&W's Advanced Technology Group. He is responsible for developing business and sales strategies to move B&W's R&D and advanced technology products from the lab and pilot scale to field demonstration and commercial application.

DATELINE EPRI

News and events update

Ireland Takes Aim at the Smart Grid

IRELAND—Irish utility Electricity Supply Board (ESB) and the Irish government are developing a comprehensive smart grid initiative to support the government's targets for wind integration, energy efficiency, and electric vehicle integration. In support of this, ESB Networks has joined EPRI's Smart Grid Demonstration Initiative.

The Electricity Research Centre of Ireland, with 16 industrial partners, is conducting smart grid research along with the government's Sustainable Energy Authority of Ireland and the Commission for Energy Regulation. The national target is nearly 40% of its total electricity production through wind energy by 2020.

This ESB Networks smart grid project will explore the further development of wind farm connections, assess the effectiveness of customer response and interest in demand and consumption management, investigate the readiness of secondary networks for high penetration levels of electric vehicles, and maximize existing electricity distribution networks.

This EPRI/ESB Networks smart grid project has four primary elements:

- Renewables integration
- Electric transportation
- Energy efficiency
- Flexible grid

New Nuclear Sector Members

PALO ALTO—Two new utilities joined the EPRI Nuclear Sector. Nucleoeléctrica Argentina SA became a full member in July. The company operates reactors at Atucha and Embalse, and a third unit is under construction at Atucha, scheduled for commercial operation in 2011. Czech Republic power company, CEZ a.s., signed a membership agreement and will become a full member in January 2011. CEZ owns and operates six reactors at Dukovany and Temelin, with additional units planned for Temelin.

Duvall Participates in Electric Vehicle Discussion

WASHINGTON, D.C.—Mark Duvall, EPRI director of transportation research, provided results of EPRI's research on grid readiness, battery storage, and the environmental benefits of electric transportation in a panel discussion at the Newseum October 19 sponsored by Business Forward, Ford Motor Company, and Microsoft Corporation. He addressed concerns about the adequacy of supply to meet charging requirements, safe recycling and reuse of lithium ion batteries, and the CO_2 benefit of plug-in vehicles—even when coal is part of the generation mix.

Other panelists were David Sandalow, assistant secretary for policy and international affairs for the U.S. Department of Energy; Sue Cischke, group vice president of sustainability, environment, and safety engineering at Ford; and Brian Schultz, director of business development and strategy for Microsoft.

Experts Gather to Discuss Gas Turbine Repairs

MADRID—EPRI program manager John Scheibel participated in a workshop hosted by Gas Natural/Unión Fenosa, in which participants focused on repair procedures for the combustor and airfoils of F-class gas turbines. Other participants included Endesa, Iberdrola, and EDF.

Mercury in Contaminated Sites: Characterization, Impacts, and Remediation

PIRAN, Slovenia—Sharan Campleman, an EPRI environmental health scientist, delivered a presentation titled "Mercury Emissions from Coal-Fired Power Plants: Evidence for Chemical Reduction" at a conference focusing on research related to mercury-contaminated sites in six areas: global mercury budget, site characterization, biogeochemical cycling, modeling, public and environmental health, and mitigation strategies. She also presented findings from the conference working group addressing risks to public and environmental health of mercury compound releases from contaminated sites.

Getting a Global Perspective on Smart Grid

PARIS—As part of meetings hosted by EDF this past summer, EPRI coordinated a discussion of international activities related to integrating distributed energy resources. Representatives from several European and Asian countries discussed their unique and common challenges in this area. The discussions were jointly coordinated with the First International Workshop for ADDRESS, a group of European distribution companies focused on demand response and distributed energy resources. Participants learned more about EPRI's Smart Grid Demonstration project, German smart grid projects, four European scenarios for ADDRESS applications, EDF smart grid activities related to ADDRESS, an AEP project looking at modeling and simulating community energy storage, and Southern Company smart grid demonstration projects.

Presentations are available at EPRI's smart grid demonstration website: http://www.smartgrid.epri.com/Presentations/PresentationsAdvisory.aspx. For more information, please contact Matt Wakefield at mwakefield@epri.com.

Blue Ribbon Commission on America's Nuclear Future

WASHINGTON, D.C.—EPRI program manager John Kessler and senior project manager Andrew Sowder briefed the Blue Ribbon Commission established by President Obama to examine America's nuclear future. In August, Kessler briefed the Transportation and Storage Subcommittee on used nuclear fuel inventories and extended used fuel storage on site at nuclear plants. In October, Sowder briefed the Reactor and Fuel Cycle Technology Subcommittee on advanced fuel cycles and the performance criteria by which options should be compared.

Smart Grid Demonstrations
Focus on Integrating Distributed Energy Resources

THE STORY IN BRIEF

EPRI's Smart Grid Demonstration Initiative is a seven-year international collaborative effort that addresses the major challenges to integrating distributed energy resources with utility distribution systems. Now in its third year, the initiative involves 11 host sites, with individual projects focused on integrating such resources as rooftop photovoltaics, smart charging of electric vehicles, and demand response.

As utilities pursue innovative approaches to improve power factor, manage voltage, and connect distributed energy resources to the grid, the adoption of advanced metering, new sensors, and communications infrastructure is moving the concept of a smart grid toward reality. These technologies enable such intermittent energy resources as solar photovoltaics and wind to be integrated into the grid. A key challenge will be to incorporate growing numbers of these resources, along with demand response and storage, into the distribution systems and their operations.

Electric vehicle charging, for example, may change power profiles along the distribution feeder for some utilities, which are trying to understand the options and impacts of charging at various times and locations. Charging when variable resources such as wind and photovoltaic generation are available may help balance demand and supply on the grid. Grid-connected photovoltaics have increased significantly for more than a decade, raising operational issues ranging from safety to maintaining the voltage within specific limits along the feeder. Using smart inverter technology, utilities may have the opportunity to use the distributed electric vehicle resource to manage power quality in the distribution system.

Information and communications technologies in smart grids are required for integrating distributed energy resources. Deploying automated meters and distribution automation systems supports those infrastructure requirements and may be more cost-effective for utilities than adding new central generation plants and related power delivery facilities, but questions remain about how best to deploy these resources. To help answering these questions, EPRI in 2008 launched the seven-year Smart Grid Demonstration Initiative, which now involves 19 international utilities and includes 11 large-scale smart grid demonstration projects. One goal is to share the best information and lessons learned on integrating distributed energy resources and specific technical issues of various distribution systems. These issues include how to achieve better voltage/VAR (volt-ampere-reactive) control when accommodating more renewable resources.

Growing industry interest and the many new smart grid projects around the world have prompted EPRI to extend the initiative through 2014, and it is again accepting new members in the international collaborative research project.

"The Smart Grid Demonstration Initiative provides a unique opportunity to develop ways of coordinating the operation of a large number of distributed energy resources with two-way communications, while giving participants hands-on experience with the integration process," said EPRI program manager Matt Wakefield. "At the same time, the interoperability standards will allow higher penetration of distributed energy resources so that they can achieve their full potential."

Operations Improvements

Even before work began at the utility host sites, EPRI had been working with participants to develop a foundation of tools and references to support the design of smart grid implementation. Host-site projects are applying EPRI's IntelliGrid℠ methodology to define the applications and identify the communication, information, and control infrastructures required to facilitate integration of distributed energy resources. Applications include distribution system planning and operations, integration into existing distribution automation approaches, and the capabilities required for these resources to be monitored and dispatched by the utilities' operations control centers and included in market operations.

One major result is the Distributed Resource Integration Framework, which stakeholders can use in planning and comparing integration projects.

For example, Kansas City Power & Light (KCP&L) adopted a design model that centers on the SmartSubstation concept. Using this design, KCP&L is working with select partners to integrate distributed energy resources to benefit an underserved population in a designated "Green Impact Zone" and in the surrounding urban area. Smart grid elements in this demonstration include rooftop photovoltaics, grid-connected battery storage, distribution voltage control, and demand-response thermostats and other devices on customers' premises.

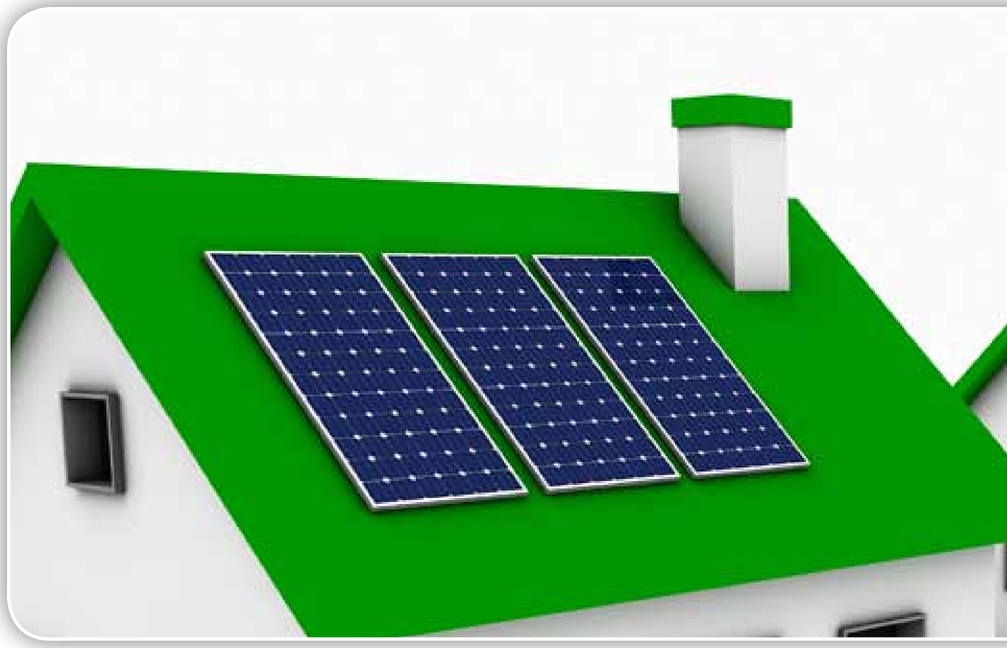
FirstEnergy is focusing on demand management for its design. The company has programs that use a two-way communications system to provide 23 megawatts of direct load control on equipment at 20,000 residential customer locations. The plan also includes installing permanent peak load shifting equipment, energy storage units, and distribution line sensors. The Integrated Distributed Energy Resource (IDER) load management platform will integrate these technologies to deliver distribution system operational benefits.

Surge of Distributed Photovoltaics

Thanks to favorable policies and the steady improvement in the efficiency and cost of photovoltaics, the deployment of distributed photovoltaic systems has grown 25%–40% over the past decade. At the same time, there has been a shift from stand-alone installations in remote areas to grid-connected systems, which now account for about 90% of capacity additions. As a result, distributed photovoltaic systems are affecting distribution networks, requiring additional controls for operating feeders with a high penetration of these devices. Smart grid technologies will provide distribution companies with the monitoring and control functions necessary to effectively manage the power generated by the new systems while maintaining the voltage profile along the feeder.

Renewable portfolio standards and other regulations are driving photovoltaics' deployment in ways that point to a future with greater reliance on distributed resources. For example, photovoltaic systems can be owned by consumers and can be connected to the grid. Utilities own and install photovoltaic systems on their property or on leased rooftops and connect them to the distribution system as an energy resource. These can be treated the same as other regulated assets within the utility's control. Of the 11 smart grid demonstrations, 8 involve photovoltaic-related projects.

PNM Resources is exploring ways to integrate high-penetration distributed photovoltaic systems at customer sites and utility substations with storage capability. This project will evaluate smart inverter interface technologies to enhance system



benefits and identify rate structures and storage control algorithms to help resolve time-related issues associated with a high penetration of renewable generation. PNM also is studying ways to use buildings' energy management systems to smooth some of the intermittency of photovoltaic generation. For example, adjusting the speed of ventilation fans in a large building can help compensate for fluctuations in the power output without affecting building temperature.

"When distributed energy resources such as photovoltaics begin to challenge voltage regulation, coordination of protection, and eventually energy balance, utilities can utilize their smart grid technologies to control the impact," said EPRI program manager Tom Key. "The current demonstration projects will provide critical insights on how to manage this process, as well as reveal new opportunities for utilities to take advantage of increased photovoltaic use to meet their own technical and business needs."

Preparing for Electric Vehicles

The smart grid demonstrations address another major utility concern: coping with an expected increase in electricity use resulting from widespread use of plug-in electric vehicles (PEVs). Charging PEVs may create new patterns of electricity use and require utilities to assess the distribution system impact of various charging options.

Duke Energy's smart grid demonstration project examines how residential photovoltaic systems can be used to help the utility prepare for widespread adoption of PEVs and stationary energy storage. The utility will equip several homes with 2.5-kilowatt photovoltaic units, which can be used to charge electric vehicles in conjunction with a home energy management system. Duke expects 300–500 PEVs will be on the roads and using its grid for charging by the end of 2011. The project also involves installing some 40,000 advanced meters and the use of dynamic pricing for load control.

The demonstration project of Ireland's ESB Networks will examine charging levels and times for PEVs and investigate optimizing rates and controls in order to maximize the ability of secondary networks to accommodate them. ESB plans to install some 2,000 residential charging points across its service territory by 2011. By testing time-of-use rates, it plans to gauge the impacts of smart meters and dynamic pricing on customer behavior. With significant wind generation already in service, the utility targets 40%

of electricity provided from renewables by 2020 and expects about half of that will be connected to the distribution system. It is evaluating optimal scenarios for large penetration of distribution-connected wind generators and the potential for electric vehicle charging as a ballast load for wind generation.

Standards Development

Another objective of the Smart Grid Demonstration Initiative is to identify the most effective approaches for integrating distributed resources and the best ways to provide these insights to the standards-making process for the interoperability of equipment used in smart grids. EPRI is taking the lead for creating a common set of semantics for two important standards promulgated by the International Electrotechnical Commission (EIC): the IEC Common Information Model, widely used to support real-time power system operations, and the IEC 61850 series of standards, which apply primarily to substation automation. Individual demonstration projects will identify additional gaps in existing standards and help coordinate standards implementation with the National Institute of Standards and Technology.

Assessing Benefits

Smart grids are expected to provide numerous benefits for consumers, utilities, and other stakeholders. These include reducing peak load, increasing utilities' operating efficiency, facilitating greater penetration of distributed renewable resources, and providing for smart charging of PEVs. It can be difficult, however, to estimate specific costs and benefits from individual smart grid functions for each stakeholder. EPRI and the U.S. Department of Energy are jointly developing a methodological framework for estimating these benefits.

The framework sets out a 10-step process for identifying smart grid functions, mapping those functions to potential benefits, and quantifying the monetized value of the benefits. It also provides the basis for further assessment, including developing a computational tool. It will be used to estimate costs and benefits of demonstration projects already under way and to estimate potential benefits of proposed projects.

"One of the most beneficial applications will be integrating distributed energy resources into utility applications," said Wakefield. "Ultimately, the goal is to create a way of coordinating the operation of large numbers of distributed energy resources so that they can be dispatched as a virtual power plant. Such interoperability is critical if these resources are to reach the level of penetration needed to have this major impact."

Tom Key added: "Smart grid technologies will be critical for introducing more renewable resources at the distribution system level. The current demonstrations allow utilities to get hands-on experience with a range of distributed energy technologies, evaluate new applications, and identify best practices and opportunities for grid modernization."

This article was written by John Douglas. For more information, contact Matt Wakefield, mwakefield@epri.com, 865.218.8087, or Tom Key, tkey@epri.com, 865.218.8082.

Tom Key, technical leader for renewable and hydropower generation, started in 1989 at EPRI PEAC, which became part of EPRI in 2005 with the restructuring of the Institute's subsidiaries. Previously he worked at Sandia National Laboratory, specializing in the compatible interface of end-use equipment and distributed power systems. Key earned a B.S. in electrical engineering from the University of New Mexico and an MS in electrical power engineering and management from Rensselaer Polytechnic Institute.

Matt Wakefield, program manager of Smart Grid Demonstrations, oversees the development of the smart grid with a focus on emerging information and communication technologies that can be applied to electric grid infrastructure. Prior to joining EPRI, he worked at Wisconsin Public Service Corp. (WPS) in the Instrumentation and Control group of the Kewaunee Nuclear Plant before becoming manager of the Applied Technology group at Integrys Energy group, the holding company of WPS. Wakefield received his B.S. in technology management from the University of Maryland University College.

FIRST PERSON *with Bill McCollum*

Leading with Authority

TVA building more than U.S. confidence in nuclear power

Watts Bar Nuclear Plant. Photo courtesy of TVA. © All rights reserved.

The Tennessee Valley Authority (TVA) is restoring one idled nuclear unit to service, completing construction of a mothballed unit, considering completion of a second mothballed unit, and establishing itself as a leader in deploying the next generation of reactors, including AP1000 and modular reactor technology. TVA Chief Operating Officer Bill McCollum talks about the business case for nuclear, the technology, and TVA's slate of activities.

EJ: How does TVA factor nuclear power into its integrated resource plan?

McCollum: We plan to rely more on nuclear generation and less on coal, while significantly increasing our work in energy efficiency. Nuclear offers reliable, low-cost, and low-carbon generation for our baseload needs. In the integrated resource plan, we use extensive modeling to look at the different supply sources we can use—or, in the case of energy efficiency, to avoid demand. The modeling results show that nuclear fits very well into virtually all future generation portfolios. TVA and the industry also face challenges with fossil fuels, especially coal: emissions of nitrous oxides, sulfur dioxide, mercury, particulates, and the challenge of coal combustion products. When you put those things together with the ability of nuclear to supply reliable, carbon-free baseload generation, it's not surprising that the integrated resource plan supports solutions where nuclear provides greater amounts of energy, with less reliance on coal and greater reliance on energy efficiency.

EJ: Do you see, then, nuclear specifically serving load now served by coal plants?

McCollum: We've already committed to idle approximately 1,000 megawatts of our current coal-fired generation, and we are evaluating other coal plants in our fossil fleet that don't currently have state-of-the-art emissions controls. It's quite possible that some of those could be idled as well, and nuclear would have to serve that load.

EJ: TVA is the only U.S. utility with recent experience building nuclear plants—at Browns Ferry in Alabama and Watts Bar in Tennessee. What are TVA's chief business and technical reasons for returning or bringing those units into service?

McCollum: As we looked at the option to restore Browns Ferry Unit 1 to service and to complete Watts Bar Unit 2, there were some key considerations. The infrastructure already in place offered significant advantages. We were able to complete the work required to refurbish Browns Ferry Unit 1 and restore it to operations at a very reasonable cost to our customers. Likewise for Watts Bar Unit 2.

EJ: What about the Bellefonte site in Alabama, where TVA halted construction back in 1988?

McCollum: Similar to Browns Ferry and Watts Bar, the infrastructure in place at Bellefonte Unit 1 appears to make that an attractive option. At their last meeting, the TVA board voted to fund more engineering to lay out the details of the work necessary to complete Bellefonte Unit 1. These details will help establish confidence in an estimate on which to base a future decision. But the broader point here is that the options available at Browns Ferry, Watts Bar, and Bellefonte really offered an advantage to our customers.

EJ: They compare favorably with the option to build new plants?

McCollum: The budget for Watts Bar Unit 2 is about $2.5 billion. The estimate for Bellefonte would be $4 billion to $5 billion.

EJ: Considerably better than new plant options, which are coming in at $10 billion per unit or so?

McCollum: Yes.

EJ: What lessons have you learned in recent years to help you stay on time and on budget?

McCollum: The technology associated with these projects is proven. They have a solid track record of performance in the industry. We already have an operating unit on site at Watts Bar and will be leveraging that experience when we bring Watts Bar Unit 2 into service. At Browns Ferry, bringing a third unit back into operation after 20-plus years out of service provided a number of lessons learned that we are incorporating into plans at Watts Bar Unit 2. And if we go forward with Bellefonte, the lessons learned from Watts Bar Unit 2 will feed into that construction activity. One of the key lessons: we need thorough planning and preparation in advance. We've gotten tremendous value from our detailed scoping, estimating, and planning studies. And we've built on studies from one project to the next, making those processes more robust, more detailed. This gives us high confidence in our schedule and budget estimates, allowing us to do a detailed risk analysis of the project before proceeding on a construction decision. We now complete more of the engineering before starting construction. In the previous nuclear building boom in the United States, it was common to fast-track projects and minimize their length by doing engineering essentially in parallel with construction. We're learning that there's

Bill McCollum. Photo courtesy of TVA. © All rights reserved.

"At Browns Ferry, bringing a third unit back into operation after 20-plus years out of service provided a number of lessons learned that we are incorporating into plans at Watts Bar Unit 2." *~ Bill McCollum*

tremendous value in getting the engineering as complete as possible prior to construction so that you understand the designs, you understand the issues. You are able to really lay out in detail the work to be done to complete the project and then focus on executing that plan, rather than having to deal with changes that come up as engineering is completed during construction.

EJ: So how complete does engineering need to be to realize these benefits?

McCollum: There are always site-specific considerations, and you would like to be 100 percent complete, but somewhere in the high 80s or in the 90s is typically sufficient to provide a high level of certainty for such construction.

EJ: Are you using any modular construction techniques, or just newer construction techniques?

McCollum: For these projects, it's not so much about changing the basic construction techniques, it's more about having detailed plans and executing those plans to improve productivity. However, we have used contract arrangements with vendors that help in terms of coordinating the work on the project. We have used some new technologies, particularly at the component level, such as motor technology to get improved efficiencies and in new control systems. Some of those have helped us in construction space, as well as ultimate operating benefits.

EJ: What about the new nuclear designs?

McCollum: We are continuing to work with NuStart to pursue our combined construction operating licenses for AP1000 reactors at the Bellefonte site, and we're working with Babcock & Wilcox on a lead project for application of their small modular reactor technology. We think that is a promising technology that offers a great option for the future.

EJ: What is driving your work with Babcock & Wilcox on small modular reactors, and when do you see deployment coming?

McCollum: The ability to add capacity in smaller increments might make financing easier for some nuclear projects. It could also enable a power provider to increase generation capacity in a way that more closely matches demand growth, rather than adding larger increments of "chunky" generation at one time. The components in small modular reactors could be built under factory conditions and then transported to the site. That should provide more certainty in cost and schedule for these projects. There are also options for cooling small modular reactors that could reduce water needs, and water is a big topic of discussion these days and will be even more so going forward. A potential for underground installation offers improvements in security. Potentially, you could locate small modular reactors closer to load centers, and that would reduce some of the transmission impact or need for transition upgrades for these projects. Finally, they're designed with longer operating cycles, so we could benefit from improved capacity factors.

We're currently working with the Department of Energy to evaluate bringing small modular reactor technology to power the Oak Ridge National Laboratory, in Tennessee. We think it's realistic that a small modular reactor could be brought on line around 2020 or shortly thereafter. It's a little early right now, but there's a potential for repowering some sites that are currently using coal-based generation.

EJ: Is it fair to say that TVA is establishing itself as a leader in the development of this technology?

McCollum: I think it is. We're strongly evaluating small modular reactor technology, and we set a goal of working toward being the first to deploy a small modular reactor. There's a lot to be done between now and then, but we're looking internally at what it would take to make that happen.

EJ: What do you think the levelized cost of electricity might be for small modular reactors? Or is it too early to say?

McCollum: Engineering and details of the construction process aren't really fleshed out enough right now for us to have confidence in a cost-of-electricity number. However, looking at our experience with NuStart, our projects to date, and what we've seen with Babcock & Wilcox's mPower technology, small modular reactors certainly have the potential to be competitive in terms of overall costs.

EJ: What opportunities to do you see in working with EPRI?

McCollum: There are opportunities to move ahead with modeling. A lot of our current large reactor designs were built and proven based either on naval reactor technology or demonstration plants built years and years ago. These demonstration plants provided the data still used today for nuclear and thermal hydraulic analysis. With small modular reactors, there's an opportunity to use advanced modeling techniques and alleviate the need for as much demonstration work as we had with the previous generation of reactors. I'm not saying you wouldn't have any demonstrations, but I think the use of advanced computer modeling and simulation offers some real advances that, in terms of time and cost, could move these designs forward.

Another area for focus is the fuel cycle and fuel-cycle costs going forward, including ways to close the nuclear fuel cycle. This is not just limited to small modular reactors.

EJ: Where is TVA focusing its R&D for nuclear?

McCollum: In general we're focusing our R&D to have impact in a few key areas, rather than engaging more broadly in areas where perhaps we don't have as great an impact. In nuclear, our focus will be on issues related to deploying small modular reactors. Where can we use advanced computer modeling and simulation to help with design certification or licensing of nuclear technologies? What can we do to help move fuel-cycle efforts forward? We are working with Babcock & Wilcox and others to move those ahead and looking at the Department of Energy's nuclear reactor modeling and simulation hub efforts to try to marry those together to keep moving things forward. And we're supporting the Blue Ribbon Commission's efforts to define the national solution for the nuclear fuel cycle. I think whatever that commission may come up with will require some amount of R&D work to try to move into implementation.

Browns Ferry Nuclear Plant. Photo courtesy of TVA. © All rights reserved.

EJ: With respect to the lead time for licensing and constructing nuclear plants, what do you think would be required to result in a more aggressive deployment of new nuclear plants in the United States?

McCollum: The licensing processes and licensing lead time are much better now than during the last building cycle for nuclear plants in this country. But we can continue to make further improvements to gain better certainty of schedule with licensing. And continuing to move ahead with standardized designs and improved construction techniques will help us reduce deployment times for standardized designs going forward.

EJ: How does TVA view the future of nuclear fuel management, fuel-cycle technologies, and the closing of the fuel cycle?

McCollum: We have to establish some level of certainty about how we intend to manage used nuclear fuel. We hope the Blue Ribbon Commission can achieve its objectives and set the course for the country once and for all because it takes a very long time to develop and implement a used nuclear fuel strategy. TVA in the past has teamed up with the Department of Energy to evaluate options. We, of course, are ready to continue to look at partnerships and demonstrations that can help move this forward.

There's also been discussion about establishing an independent, quasi-governmental organization to manage whatever program is ultimately chosen. We think having an organization with a singular mission to manage this program on behalf of the country would be beneficial in providing continuity and the emphasis to move a program to completion.

"…we set a goal of working toward being the first to deploy a small modular reactor." ~ *Bill McCollum*

Get the Iron Out: Oyster Creek Pioneers Fiber Technology for Feedwater

Exelon Corporation's Oyster Creek Generating Station has pioneered in the United States a Japanese hollow fiber filtration technology that reduces feedwater iron concentrations to previously unattainable levels.

EPRI's *Boiling Water Reactor Water Chemistry Guidelines* (1016579) identifies the following benefits associated with reducing feedwater iron:

- Prevents excessive buildup of tenacious crud on the fuel, which can contribute to fuel failures
- Minimizes cobalt 60 transport and corresponding radiation dose rates
- Optimizes zinc injection to suppress radiation field buildup

Photo courtesy of Exelon Nuclear. © All rights reserved.

Recognizing these benefits, North American boiling water reactor (BWR) operators reduced the fleet's average feedwater iron level from 2.54 parts per billion (ppb) in 1997 to 0.7 ppb in 2008, primarily through high-efficiency iron filtration technologies.

Oyster Creek had reduced feedwater iron from more than 5 ppb in the 1980s to 2–3 ppb in the late 1990s—levels that did not meet EPRI guidelines of 0.1–1 ppb or Exelon's long-term chemistry goals for asset protection. Moreover, maintaining the plant's reactor water chemistry with the existing condensate polishing system presented a significant operating cost.

Studies in 2001 showed that retrofitting a condensate filtration system upstream of the plant's deep-bed demineralizers would reduce operating and maintenance costs and lead to lower drywell radiation dose rates through more effective use of depleted zinc oxide.

Selecting Hollow Fiber Filtration

Retrofits of condensate prefilters upstream of deep-bed demineralizers in North American BWRs have exclusively employed pleated-filter technology. In Japan, however, hollow fiber filter technology has been used extensively and successfully in both nuclear and fossil condensate filtration applications.

EPRI tested the technology in the 1990s at PSEG's Hope Creek Generating Station and determined it to be technically superior. At that time it was considered uneconomical, compared with pleated-filter technology, and it had not been demonstrated in full-scale condensate applications in the United States. Subsequent design improvements have enhanced the economics, and the costs for U.S. plants can be further reduced by manufacturing the vessels domestically.

After its own analysis, Exelon installed hollow fiber filters in the main condensate flow path by means of piping tie-ins to the condensate header between the condensate pumps and the deep-bed condensate polishing system. Within days, the prefilter effluent iron was less than 0.1 ppb, and feedwater iron dropped from 3–4 ppb to less than 1 ppb. Feedwater iron levels continued to decrease as condensate demineralizer resin beds were cleaned or replaced.

After a mid-cycle maintenance outage in 2008, the first feedwater iron sample showed an iron concentration of 0.84 ppb—the lowest value ever measured during a startup at Oyster Creek. Reduced feedwater iron will allow Oyster Creek to achieve goals for the reactor coolant cobalt 60 (soluble)/zinc (soluble) ratio while maintaining feedwater zinc at less than 0.4 ppb, as recommended in the EPRI guidelines.

Hollow fiber filtration offers the following features and benefits:

- ***Long life***—Pleated-filter septa have an average useful life of 3–4 years, whereas hollow fiber filters at Fukushima Unit 4 have demonstrated module life of more than 14 years, with no indication of failure. (The unit's inlet iron, temperature, and flow conditions are comparable to those at Oyster Creek.)
- ***Minimal ancillary equipment***—Hollow fiber filter technology does not require an air receiver tank, air compressor, or backwash receiving tank to support filter backwash.
- ***Radwaste reduction***—Liquid radwaste from condensate operations is reduced by 98%. During the first year, Oyster Creek reduced liquid radwaste by 1.25 million gallons.
- ***High (99.8%) availability***—An 80-day interval between hollow fiber filter cleaning operations provides an extended system on-line period without inputs to the radwaste plant, facilitating radwaste maintenance planning and thus improving radwaste plant reliability.

Further Work

EPRI and Exelon continue to monitor the system, and EPRI is helping other utilities with evaluations. An EPRI report, *Evaluation of Hollow Fiber Filtration for Condensate Polishing Application* (1014714), provides an overview of hollow fiber filtration in nuclear applications and is available to all EPRI members.

For more information, contact Susan Garcia, sgarcia@epri.com, 650.855.2239.

Developing a Sustainable Nuclear Fuel Strategy

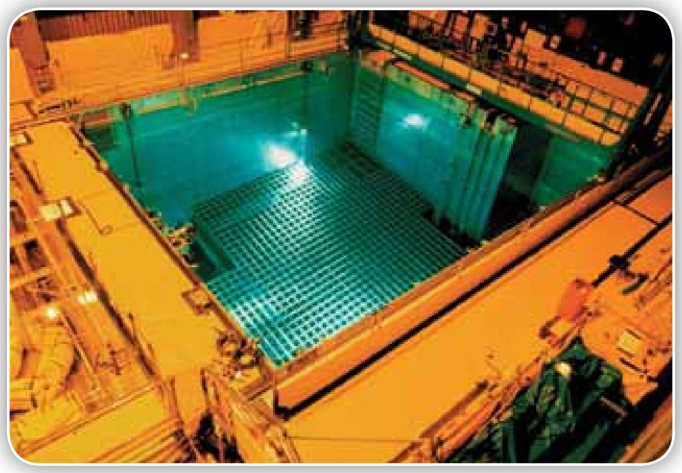
The success of nuclear power depends in part on a long-term commitment to the safe handling and disposition of used nuclear fuel and other waste streams. Countries with nuclear power programs—or with aspirations to nuclear power programs—should understand that the sustainability of these programs depends on effectively addressing technical, security, economic, public relations, and political issues regarding used fuel.

"Nuclear power plant operators have a near-term responsibility for managing the spent fuel that is produced by their operations, but operators in the United Stated currently have little choice but to store the spent fuel at the reactor site," said EPRI senior technical executive Albert Machiels. "There is no other outlet for this material: no central storage facility, no repository, and no place where the spent fuel could eventually be reprocessed and refabricated into new fuel elements."

In September, EPRI released *Advanced Nuclear Fuel Cycles—Main Challenges and Strategic Choices* (1020307). The report discusses four main areas that must be considered in developing a sustainable nuclear fuel program: sustainability of natural resources, waste management, nonproliferation, and economic competitiveness. The relative importance of these issues is different for each country, and the report looks in depth at how they are addressed in the two largest nuclear power producers: France and the United States.

"There is a marked difference between how the two countries are proceeding," said Machiels. "In the U.S. we have an economy that is mostly market driven, while in France the nuclear policy is driven by the government." The market-driven nature of the U.S. situation has reduced the value of reprocessing because it has been cheaper to acquire new fuel for reactors than to reprocess used fuel. France's emphasis on energy security emphasizes fuel independence, making fuel reprocessing more viable.

The report concludes that, while the strategies of countries or regions will differ, a sustainable nuclear fuel cycle should have three fundamental attributes:



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1. It should rely on the energy content of U-238, which represents more than 99% of natural uranium. A partially closed fuel cycle with fast reactors, in which fertile U-238 is converted into fissile Pu-239, is currently the most attractive advanced option. Another possibility is the thorium fuel cycle, in which fertile Th-232 is converted into fissile U-233. However, much less work has been conducted on the thorium fuel cycle, and its supporting infrastructure is still in its infancy.
2. It has to be as simple as possible. Simplicity is critical for operational, economic, licensing, and public acceptance reasons. Many options are on the table, and many represent dramatic departures from the current situation. What works on paper, however, does not necessarily work at an industrial scale.
3. It must remain focused on cost-competitive power generation. Certain options may become unrealistic if they prescribe the transmutation of all transuranics and fission products or excessive steps to make nuclear materials proliferation-resistant. Waste disposition and proliferation risks must be addressed in ways that are safe, secure, and pragmatic.

"Any rational fuel-cycle policy has to be focused on the fact that we are in the power generation business, and the goal is to produce power," said Machiels. "There are many technologies that could be used, but you want to make sure you choose an option that will be reliable and economically provide the power that is required."

For more information, contact Albert Machiels, amachiel@epri.com, 650.855.2054.

Hydropower Reservoirs: A Question of Emissions

Hydropower is a key element in renewable energy planning. It is dispatchable and can be used to balance other variable resources, such as wind and solar. For industry to continue using hydropower (existing and new installations) as a renewable resource, it will be critical to understand and quantify potential environmental impacts.

Hydropower reservoirs have come under criticism for net greenhouse gas emissions. The EPRI report *The Role of Hydropower Reservoirs in Greenhouse Gas Emissions* (1017971) reviews available information on the subject and examines the potential for U.S. reservoirs to be net emitters. The key finding: actual or potential reservoir greenhouse gas emissions are undetermined at present.

The U.S. Department of Energy (DOE) is funding a three-year study through the Oak Ridge National Laboratory to investigate these emissions from seven to eight reservoirs primarily in the southeastern United States and three reservoirs in the Pacific Northwest. EPRI will participate in the study, and funding from the hydropower industry could expand it to reservoirs in other climatic regions and reservoirs of varying sizes and depths.

Addressing hydropower's emissions was ranked fourth on a list of industry needs established at the 2008 EPRI/DOE Waterpower Industry R&D Prioritization Workshop. The National Hydro Association's staff recognizes the study's value and is urging its members to consider supporting this research.

The International Hydropower Association (IHA) is collaborating with the United Nations Educational, Scientific and Cultural Organization (UNESCO) to address the "possible role and contribution of hydropower to climate change mitigation and adaptation." Researchers from multiple continents will examine a representative set of reservoirs. Combined with the U.S. study, these results will provide robust answers.

The Need for Expanded Studies

The first studies suggesting reservoir greenhouse gas emissions as a potential environmental concern appeared in the mid-1990s. Most focused on South American tropical reservoirs. The data indicated that reservoir gross emissions are not zero. Because few studies had measured carbon cycling before impoundment, it is less clear whether there are net emissions. Most U.S. reservoirs have been in place for many years, and it will be necessary to measure emissions from reference sites comparable to pre-impoundment conditions to resolve the uncertainty.

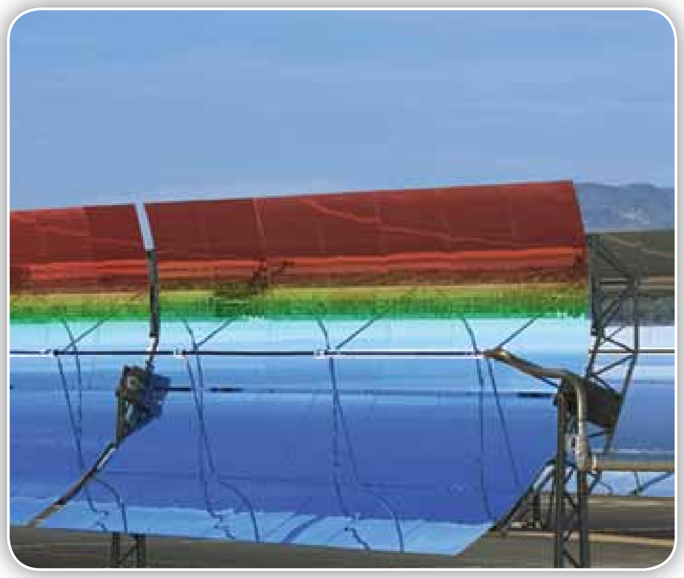
Unless the uncertainty is resolved, hydropower could be classified as carbon-emitting and possibly excluded from economic incentives for renewable energy development. Development of hydropower for energy storage and load management also may be precluded because of emissions concerns.

The need for comprehensive research was underscored by a recent study of the 90-year-old Lake Wohlen, in Switzerland. Published in the U.S. journal *Environmental Science and Technology*, the study found high emissions of methane, although one author emphasized that the complex process associated with the methane emissions was highly dependent on temperature, depth, and the amount of carbon-rich organic material accumulated on the reservoir floor. He indicated that a study of high Alpine reservoirs, generally in colder, more rocky, and more sparsely vegetated surroundings, yielded better results with regard to methane emissions. The variability of emissions based on altitude, climate, and other ecosystem characteristics demonstrates the vital need for a more diverse study.

The Risk of Not Answering the Question

In questioning hydropower as a renewable resource, critics cite the possibility of net greenhouse gas emission from reservoirs. Without sound data based on scientific investigation, regulators will lack a solid basis for decisions regarding the expansion of hydroelectric projects and continued operation of existing facilities. Comprehensive reservoir studies that factor size, depth, and climate will make the future of this important resource more clear.

For more information about participating in the DOE study, contact Doug Dixon, ddixon@epri.com, 804.642.1025.



New Storage System Could Lower Cost of Solar Thermal Power

More than a dozen new concentrating solar power plants are expected to be developed in the southwestern United States over the next few years, including a few that will use thermal energy storage to smooth production and allow them to generate electricity through intermittent cloud cover and into the evening. Thermal energy storage can increase a facility's annual capacity factor and potentially reduce the cost of electricity generated. A design developed by EPRI has the potential to lower the capital cost and make concentrating solar power more widely applicable.

The only operating utility-scale solar thermal storage units use two tanks to hold molten nitrate salt that has been heated by a solar field. When power is needed, salt from the "hot tank" is used to produce steam for a steam turbine generator and then returned to the "cold tank." In the new design, heated molten salt enters the top of a single tank containing a packed bed of quartzite rock and silica sand. After being discharged to produce power, the cooler salt is returned to the bottom of the tank.

The result is a sharp temperature gradient, or thermocline, inside the tank—with the hot salt on top and cooler salt on the bottom. For the same energy storage capacity, the thermocline storage system is expected to use about half the expensive salt required by two-tank systems.

Looking at potential benefits, EPRI conducted a study that included detailed process diagrams, heat and material balances, equipment lists, and cost estimates to provide a starting point for building a pilot or full-scale facility. Black & Veatch developed basic structural and engineering designs. To determine thermal stability and evaluate performance under different operating conditions, detailed thermal and operational models were used by Sandia National Laboratories, the National Renewable Energy Laboratory, and Purdue University.

The study found that a thermocline system offers significantly lower installed capital costs than a two-tank storage system at each design capacity. It compared costs for systems that receive energy indirectly from a parabolic-trough solar collector, by means of a heat exchanger, and systems that receive heat directly from a central-receiver solar collector that uses molten salt as the working fluid. The study confirmed the feasibility of achieving total (direct and indirect) capital costs below $35 per kilowatt-hour thermal (kWhth) and $70/kWhth for direct and indirect systems, respectively, compared with $50/kWhth and $90/kWhth for equivalent two-tank designs.

In general, the installed cost of a thermal storage unit decreases as capacity increases. For the largest single-tank direct facilities with 3,500-megawatt-hour thermal (MWhth) storage capacity, the system costs 33% less than a two-tank system. The maximum single-tank size for the indirect trough is 1,500 MWhth because of the lower operating temperature, and this system has a 37% cost advantage over the equivalent two-tank system. The study concluded that higher-temperature parabolic-trough collectors with direct storage systems would make thermal energy storage more cost-effective. This remains a significant R&D challenge.

A logical next step is to build a pilot plant or small commercial unit that can validate operation and costs. Salt-based thermocline storage has been demonstrated only on a small scale, at Sandia National Laboratories, using a gas-fired heater instead of a solar energy collection system. A potential technical issue for higher-temperature thermoclines involves the phenomenon of thermal ratcheting, in which thermal cycling gradually makes the quartzite filler compact at the bottom of the tank. The concern is that the compacted quartzite could then expand when heated, putting potentially damaging pressure on the lower tank wall. This could be resolved in pilot-plant tests. EPRI's Generation Technology Industry Demonstration program is exploring ways to encourage further development in collaboration with industry partners.

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

Not Your Father's Filling Station: TVA and EPRI Unveil SMART™ Station for EVs

EPRI, the Tennessee Valley Authority (TVA), and Eaton Corporation, with consultation from the Oak Ridge National Laboratory, this year designed and built the first of a new kind of electric vehicle charging station—one that incorporates solar and battery technology to test some important new aspects of vehicle charging and its interactions with grid operations.

The test station is part of EPRI's Knoxville, Tennessee, laboratories, in TVA's service territory. The Smart Modal Area Recharge Terminal, or SMART™ station, will be integral to EPRI's research on charging behavior and performance, providing information on energy use, the time when the equipment is used, the amount of solar-generated electricity produced and stored, and the potential impact on distribution system reliability when several vehicles are recharged at the same time.

Artist's renderings of the SMART™ station in Knoxville, Tenn.

The new charging station includes:

- Ten parking spaces, each with electric vehicle supply equipment rated at 30 A, 240 V (7.2 kW capacity).
- Approximately 2 kW of solar array photovoltaic panels per charge space. This grid-tied solar will assist vehicle charging, offsetting a portion of the energy consumed.
- Approximately 5 kWh of dispatchable, grid-tied battery storage per charge space to assist vehicle charging. This will enable evaluation of battery energy dispatch methodologies, including compensation for variable output of the solar array, dispatch during system peak time, compensation for peak system loads during daytime charging, and ancillary services.

The design's subsystems are grid-tied. The design encompasses everything from the distribution service transformer through the charge station and provides for advanced metering. It also provides for comprehensive data collection capabilities for energy flows between the subsystems.

As utilities adapt the grid to support electric vehicles, their strategies to mitigate peak demand can be supported by SMART stations, especially for daytime charging. In its simplest form, demand response can be implemented as on/off control of vehicle charging. In the future, enhanced communications capabilities for both supply equipment and the vehicle will enable sophisticated control, such as dynamically controlling the vehicle charge power in real time. The SMART station design incorporates features to enable the exploration of these possibilities.

This design will serve as a baseline for SMART stations in the TVA service territory and potentially nationwide. Additional Tennessee stations are planned for Knoxville, Nashville, and Chattanooga. They will be used for researching consumer behavior and its impact on the electricity system and for improving future stations.

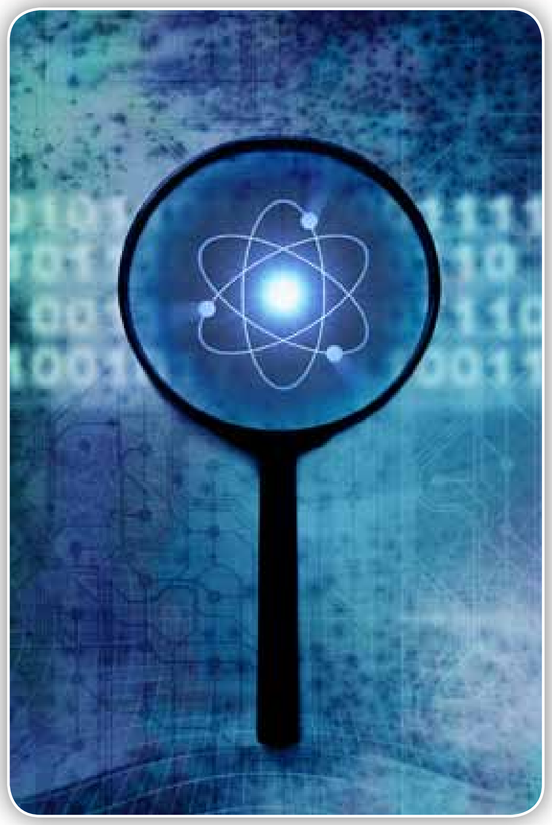
Future SMART stations may be used to test lithium ion batteries, which are smaller and lighter than the lead-acid system used in this first station. Station designers had to factor in climate control requirements for battery systems to ensure their capacity, longevity, and reliability. The lead-acid batteries also require ventilation and spill control within the station.

The SMART station is being deployed in conjunction with the EV Project, managed by ECOtality North America and including EPRI; TVA; the U.S. Department of Energy; the state of Tennessee; Oak Ridge National Laboratory; the cities of Knoxville, Chattanooga, and Nashville; and regional utility partners.

EPRI has published *Tennessee Valley Authority Smart Modal Area Recharge Terminal (SMART) Station Project: Volume 1—Base Design Report* (1020782), which provides details of the station design. It is available for download at www.epri.com.

For more information, contact John Halliwell, jhalliwell@epri.com, 865.218.8149.

Simplifying Cyber Security



Cyber security at nuclear plants attracted attention recently with the news that the complex Stuxnet computer worm was apparently targeted at control systems in Iran's Natanz enrichment facility and Bushehr reactor. The news highlighted the vigilance necessary to protect digital instrumentation and control systems in power generation and other critical infrastructure.

"Stuxnet is the exclamation point on the sentence, but is not a driver in and of itself," said EPRI Instrumentation and Control program manager Robert Austin. "The nuclear industry began to implement cyber security long before Stuxnet."

Two areas of concern are radiological releases (which drew attention after September 11) and the question of grid reliability (spotlighted after the great Northeast blackout of August 2003). For plant operators, complex challenges arose in establishing effective security policies and procedures for their plants' various information technology systems. Operators needed cyber-security guidelines for new digital equipment.

To address this need, EPRI developed *Technical Guideline for Cyber Security Requirements and Life-Cycle Implementation Guidelines for Nuclear Plant Digital Systems* (1019187). These guidelines detail 138 areas of security, covering everything from passwords and wireless connections to encryption and intrusion detection. The security areas were first defined by a Nuclear Energy Institute working group. Using the EPRI report, plant personnel can implement the guidelines.

"Plant operators don't have to go digging through the report with a highlighter to glean the steps they need to take," said Austin. "We have provided a written procedure, with our recommendations, that can be immediately incorporated into a plant's documentation systems."

A Step-by-Step Approach

The report details the types of threats that plants face and the applicable standards established by regulatory and standards-setting organizations. The report's appendices lay out exact steps to follow to address cyber security when designing and installing a new digital instrumentation and control system.

The first appendix provides a plant procedure and life-cycle checklist that can be applied to technical and regulatory issues associated with plant digital systems and devices that come under regulatory oversight. Each of the controls in the checklist references applicable regulations and recommends steps to take in each phase: requirements/specification, design, and post-design.

The second appendix shows how the plant procedure is applied in practice, using four plant modifications as examples. The first and simplest of these is a single, stand-alone firmware-based digital motor protective relay that protects safety-significant equipment on a 22-kilovolt bus. Next is a safety-related solid-state load sequencer that is more complex than the protective relay, but still has limited function and limited access control capabilities. The third example is a digital radiation monitoring system that provides information to the main control room and displays radiation monitor levels and status information. The final and most complex example is a main turbine-generator digital electrohydraulic control system. EPRI adapted these examples from actual plant modifications, so they reflect actual equipment and techniques that plant personnel would need to use.

Into Action

The guidelines' purpose is not simply to provide information but to equip companies and their personnel to put them into practice. Additionally, EPRI is producing a computer-based training module for the procedures. The guidelines and training can be used for nonnuclear plants.

"This is a novel way of delivering the EPRI results," said Austin. "Our utility advisors suggested this, and several advisors and cyber-security team members have said that this format will greatly shorten the time required for them to adopt and implement these EPRI results."

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TECHNOLOGY AT WORK

Member applications of EPRI science and technology

EPRI Assists Watts Bar with Dissimilar Metal Safe-End Weld Examination

Due Diligence Leads to Discovery

Prior to Watts Bar Nuclear Plant's fall 2009 refueling outage, the inspection team was preparing to conduct a remote inspection of the hot leg nozzle dissimilar metal safe-end welds on the reactor pressure vessel.

In reviewing vendor plans for examining the welds, the team discovered that the weld volume values relating to the weld locations did not match values from the 2005 exam, performed by a different vendor.

The team further determined that the positional data in the previous hot leg and cold leg exams were inconsistent, meaning that the required examination volume might not have been covered. TVA needed to ascertain how much of the required weld volume had been examined previously, identify any areas that had been missed, and, if possible, establish a plan to obtain coverage from the outside surface.

If the team's efforts at assessment were to prove unsuccessful, Watts Bar would have to extend the outage to remove the reactor core barrel in order to perform an inside surface examination that fully covered all susceptible weld areas. TVA turned to EPRI's Nondestructive Evaluation Program for assistance. Frank Leonard of TVA's inspection services organization provided the examination data to an EPRI senior program manager, who downloaded the data during the night, overlaid it on TVA Auto-CAD drawings, and by the next morning provided TVA confirmation that the weld coverage had been obtained during the previous exams. Further analysis with specialized EPRI software and comparison of the ultrasonic data with TVA's AutoCAD drawings identified the areas that had been missed in the previous exam.

TVA then planned and performed an outside surface manual examination to obtain additional coverage in those areas. The resulting graphical illustration of the examination coverage was incorporated into the technical justification to document the dissimilar metal weld examination volumes covered during the inspections.

Value of Collaboration

The Watts Bar and EPRI collaboration enabled TVA to avoid an extended outage, saving significant radiation exposure while maintaining plant safety and reliability and complying with regulatory requirements.

"Our inspection organization's prompt actions in assembling a team developing a solution, and flawless implementation prevented Watts Bar from having to pull the core barrel," said Michael Skaggs, vice president of nuclear operations support and former vice president, Watts Bar Nuclear Plant. "Including EPRI on the team showed a healthy nuclear culture, demonstrating that TVA is determined to 'do it right' by taking advantage of available resources to ensure success. Had the issue not been self-identified by the team and quickly resolved, there would, no doubt, have been serious regulatory consequences."

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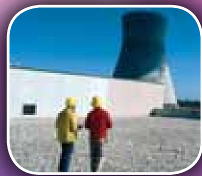
Photo courtesy of TVA. © All rights reserved.

Improving Plant Operator Performance with Better Graphic Displays

Older graphic displays still used in many power plant control rooms have been found to encourage poor operating techniques, such as "running by alarms," and actually impede proper situational awareness by operators. Significant improvements in these human-machine interfaces (also known as HMIs) have been made in recent years that allow operators to detect abnormal situations more consistently in advance of alarms. To explore the benefits of using high-performance graphics in control rooms, EPRI ran side-by-side comparisons with traditional interfaces. Results are available in the report *Operator Human-Machine Interface Case Study* (1017637).

A major problem with older control room displays is that they often overemphasize numeric data, rather than providing an operator with broader information in a useful context. New, high-performance operating displays can now show process values in a situational context, rather than as simple numbers on


a screen, and present key performance indicators as embedded trends in the graphics themselves. In addition, a hierarchical structure for the interface enables an operator to quickly access increasingly more detailed information. Display elements are scenario-based, with consistent images and color coding and with animation highlighting abnormal situations.

Control room tests of operating graphics developed by PAS, Inc., were conducted with EPRI support in 2009 at the Gerald Gentleman Station of the Nebraska Public Power District. The project tested operator effectiveness in using both new and traditional human-machine interface systems. Eight experienced operators tested both sets in four scenarios, using the station's control room simulator. The scenarios included pulverizer swap under load, pulverizer trip and load reduction, manual load drop with malfunctions, and circulating water pump failure and load runback.

Although the operators had only a few hours of experience with the high-performance graphics, they encountered few difficulties in using them to operate the unit in the simulated scenarios. The trials showed that operators made significant improvements in scenario performance and accomplishment with the new graphics. They recognized abnormal situations earlier and dealt with them more easily. They also noticed, because of clear and effective data displays, changes in operating values that indicated the unit was moving toward a trip.

After the trials, each operator was asked about using the improved interface to train new operators. This will be important, as many companies will replace a large group of experienced operators who are expected to retire over the next decade. All agreed that the high-performance depiction of normal operating range, abnormal range, and alarm ranges would make it far easier for a new person to learn how to operate the unit.

The study concluded that by applying high-performance human-machine interface display design elements, companies can significantly improve operators' situational awareness, their understanding of plant conditions, and their response time and accuracy. These design elements include:

- a hierarchical display structure, with distinct levels that provide progressive exposure of detailed data,
- consistent application of color on displays, and
- embedded trends of critical information that include expected ranges and interlocked actions.

As a result, units can be operated with fewer off-normal events and more timely correction of process upsets due to equipment failures or degradation.

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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.

Advanced Nuclear Fuel Cycles—Main Challenges and Strategic Choices (1020307)

U.S. civilian nuclear power uses are based on a once-through fuel cycle involving the irradiation of low-enriched uranium fuel in light water reactors and the subsequent storage and eventual disposal of spent fuel. This report provides a critical review of technological challenges to the growth of nuclear energy, emerging advanced technologies that would have to be deployed, and fuel-cycle strategies that would have to be considered before eventual disposal of residual wastes. The research team reviewed the main challenges to the growth of nuclear energy and evaluated several paths forward that appear to be industrially feasible for stepwise deployment in the 21st century.

Program on Technology Innovation: Drying of Low-Rank Coal with Supercritical Carbon Dioxide (CO_2) in Integrated Gasification—Combined-Cycle (IGCC) Plants (1020364)

Drying low-rank coal for use in IGCC power plants consumes substantial energy and reduces the technology's cost competitiveness. This study compares a dry coal-fed IGCC plant using commercially available coal-drying technology with a plant using an advanced coal-drying concept that applies supercritical carbon dioxide to extract water from the coal. Study results can be used to assess the thermodynamics and cost-effectiveness of this coal-drying concept. The primary application is for coal-fired power plants that include CO_2 capture, particularly IGCC plants using dry coal-fed gasifiers.

Standard Language Protocols for Photovoltaics and Storage Grid Integration (1020906)

Widespread deployment of distributed generators at some point will require monitoring and management by grid operators. Solar photovoltaic systems likely will be the first to challenge distribution operators, followed by plug-in electric vehicles and battery systems. This paper describes efforts to identify the basic inverter/charger capabilities and develop a standard communication protocol to enable distributed grid support. A standard protocol will enable utilities to support higher grid penetration and to derive greater value from distributed assets such as grid-tied photovoltaics and energy storage.

Routine Performance Test Guidelines for Steam Turbines (1021483)

Rising fuel costs and the possibility of CO_2 emissions regulations are prompting utilities and power generation companies to focus on power plant heat rate and performance. This report provides a significant collection of information and instructions related to performance testing of power plant steam turbines that can be conducted without major financial or time investments. The tests require a minimal number of personnel and produce results that can be used for trending, analyzing, troubleshooting, and optimizing the performance of individual pieces of power plant equipment. In using these guidelines, EPRI members should be able to conduct routine tests more frequently, improve test results, and improve component performance and unit heat rate.

Inspection Methodologies for Buried Pipes and Tanks (1021561)

The inspection of buried pipes and tanks has received heightened attention recently because of the finding of tritium in monitoring wells at some plants. This report presents techniques for inspecting buried pipes and tanks from a user's point of view. The report's objective is to assist utilities in selecting inspection methods and to provide perspective on the inspection capabilities of the various options. Technologies discussed include in-line buried pipe examination, indirect buried pipe assessment, and inspection of plates and welds in tanks.

Power Plant Closure Guidebook (1022263)

It is expected that many fossil-fueled power plants will be retired and decommissioned in the next decade. Drawing on the experiences of utilities, vendors, brokers, and contractors, this report details the components of decommissioning and discusses various solutions to expected problems. A carefully planned, well-executed project can save hundreds of thousands of dollars and months of reduced schedule time.

Approaches for Minimizing Risks to Power System Infrastructure Due to Geomagnetic Disturbances (1022269)

This white paper presents an overview of the state of the science in methodologies for and approaches to predicting and reducing the impact of geomagnetic disturbances on the grid. It presents the background and context of the issue and identifies open research areas. The overall goal is to develop and validate a risk assessment and mitigation methodology that allows for an appropriate balance of actions in forecasting, system and equipment hardening, and rapid system restoration.

It Will Pay to Be Clean

John W. Rowe *is chairman and chief executive officer of Exelon Corporation.*

Electric utilities face tough and challenging times—a relatively stagnant economy, growing regulatory pressures, and very large capital requirements. Technological change and environmental requirements have not hit us so thoroughly since at least the early 1970s.

While some scientists have embarrassed themselves with respect to climate science, the weight of authority regarding problems of increasing carbon in the atmosphere remains overwhelming. Even without a climate bill, nearly 30 states have enacted renewable electricity standards. The climate issue is real and will not go away.

But the key issue facing us right now is more conventional regulation: U.S. Environmental Protection Agency regulations for coal ash; transport rules for sulfur oxides and nitrogen oxides; hazardous air pollutant rules covering mercury, heavy metals, and acid gases; and source performance standards for carbon. We do not yet know the magnitude of their impact on coal-based generation. One estimate is that just the transport and hazardous air pollutant regulations could result in the retirement of 20% of the U.S. coal fleet.

"So we face this difficult issue of how to plan major investment in clean coal or new nuclear in a decade in which gas is queen and wind and solar are her handmaidens." ~ *John W. Rowe*

Large coal plants will continue to have a long economic life. It just will be less enjoyable—a little more like running a nuclear plant. But how many smaller coal plants will disappear, and how much of this generation will be replaced by natural gas–fired generation, solar, and wind, or combinations of the three? How fast will it be replaced, and under what terms? These are vital questions for our industry.

At Exelon, we have been thinking about the carbon problem for quite some time. In 2008, we announced our plan, "Exelon 2020," to eliminate our carbon footprint by 2020. We analyzed the relative economic merits of alternatives to abate greenhouse gases in the electricity sector, as measured in dollars per ton of carbon dioxide. Many factors that drove our original "supply curve" have changed since we first released it in 2008, when prices for electricity were climbing as a result of high natural gas prices and rising electricity demand.

The 2010 update of our analysis includes revised economic assumptions. The option of uprating Exelon's nuclear plants continues to look good. Shutting down our older coal plants has become a compelling option, and we plan to do so. But costs of new nuclear and wind have gone up, and they remain uneconomic in our markets. The cost of solar has come down, but it still is among the most expensive of options. Coal with carbon sequestration continues to look very expensive.

Two things dominate in the near term: low load growth and cheap gas. And they have important implications: One, don't build or buy too much of anything big too soon. Two, try very hard to get each piece right over the next decade, or you will create a large amount of investment that is stranded, either by economics or by regulations—or by both. The most important lesson Exelon has learned from the analysis underlying "Exelon 2020" is that we can effectively abate greenhouse gases by doing the cheap things first. We do not need mandates or substantial incentives to be "smart and clean." None of us knows how the future supply curve will morph. We need a system that rewards companies for reducing their emissions in the cheapest way possible, and we need a market-based solution to give us feedback.

There's a lot of work for EPRI to do in finding ways for us all to be cleaner without massive capital expenditures or subsidies. These include carbon sequestration, getting more years and megawatts from our nuclear plants, making solar more economical; and providing storage for wind.

We talk about "the dash to gas." I don't know any utility CEOs who are comfortable placing all our bets on one fuel. And yet, everything we see at Exelon says gas will have a big role for at least a decade. So we face this difficult issue of how to plan major investment in clean coal or new nuclear in a decade in which gas is queen and wind and solar are her handmaidens.

EPRI's challenge is to help utilities meet our challenges in ways that don't cost the shareholders, the customers, or the economy too much. Changes in environmental regulation and technology will be greater than we have seen before. In this context, innovation is terribly important. And in this context, the best advice I can give my fellow CEOs is that it will pay to be clean.

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