WINTER 2012

EPRI JOURNAL

ELECTRIC POWER RESEARCH INSTITUTE

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Weighing the Risks and Benefits of Accelerated Spent Fuel Transfer

The Promise of Repowering

Emissions: Possible—Looking at Tomorrow's Power Plants Today

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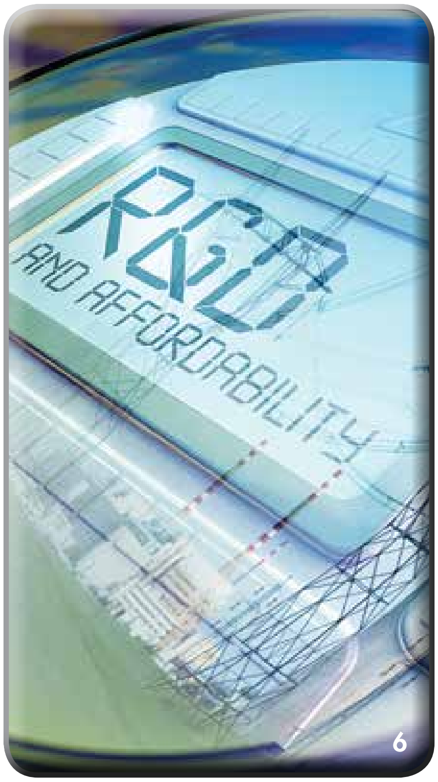


VIEWPOINT

FEATURES

DEPARTMENTS

VIEWPOINT

by Mike Howard, President and CEO, EPRI

Our Grid, Ourselves: Looking at Grid 3.0

Coming on the heels of this summer's unusual "derecho," Hurricane Isaac, and hurricane-turned-"Super Storm Sandy," big questions emerged regarding the grid's resiliency: How can we harden the grid and how can we recover more quickly to restore power? It also directed attention to "survivability"—the capacity for people to carry on some aspects of normal life when the grid is hit hard.

Today's information and communication technologies have dramatically changed the expectations of our connected-24/7 society regarding grid reliability. These technologies also serve as the foundation for a more resilient grid. EPRI is looking at. what we call Grid 3.0, an operating system that will seamlessly integrate these information and communication technologies.

Here's how a recent EPRI white paper summarized where we're headed: "The power system is revolutionizing at an exponential pace into a highly interconnected, complex, and interactive network of power systems, telecommunications, the Internet, and electronic commerce applications." Sound familiar? It should, because in general it also describes us—as individuals and as a society. So it is not surprising to realize that we, too, have changed and must change more. It is also not surprising that our expectations—like the grid itself—are already changing considerably.

It's important to note that this vision of the new grid encompasses much more than just disaster preparation or response. Sandy does provide us, however, with an opportunity to focus sharply on what we expect the grid to do and how we expect it to perform. In framing Grid 3.0, EPRI's job is to bring together the disparate trends in technology and society and help marshal the resources to make the new grid a reality.

Sensors, smart meters, phasor measurement units, and information/communication technologies will be the heart of Grid 3.0. The grid's brain will do the heavy lifting of data analysis and processing.

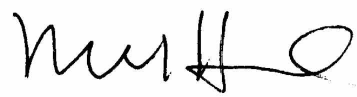
Let's imagine how the heart and the brain of Grid 3.0 can make the grid more resilient. As utility crews are deployed, they will take with them a mobile platform technology such as an iPad to do damage assessment. Linked with the utility asset database, crews will be able to generate work orders and transmit important information on damage assessment in real time.

Customers, meanwhile, will be using their mobile platforms to send pictures with GPS tags to inform utilities of the extent of the damage. Smart meters will have sent last-gasp signals before power was lost, helping pinpoint outages and prioritize where crews should be dispatched.

We do not have to imagine this anymore. EPRI is working with our members and national labs, universities, and technology providers to make Grid 3.0 a reality. I see growing indications that our communication technologies will help lead us toward Grid 3.0. A "killer app" may be just the bait to hook us on becoming more than passive consumers. And given our longstanding love affair with the automobile, it was not surprising in the wake of Sandy to see media interest in the concept that plug-in electric vehicles can play a role in resiliency and survivability for Grid 3.0. Currently we focus on simple things, such as charging phones from the car's battery. But for Grid 3.0, we're thinking big and looking at how such resources could be aggregated to support the grid and its customers.

As I write this, heroic and persistent utility crews are finishing rebuilding the grid in the U.S. Northeast. Here at EPRI, working collaboratively with our members, we are well down the road of rethinking the grid, with the ultimate goal of retooling and creating a more resilient grid. Read the column in this *EPRI Journal* by Mark Savoff, executive vice president and chief operating officer at Entergy Corporation. Entergy demonstrated important vision and leadership in commissioning a wide-ranging study of approaches for making the Gulf Coast infrastructure more resilient.

Together—researchers, utility executives, regulators, policy makers, and consumers—we will achieve the more flexible, resilient Grid 3.0 because our thinking, our expectations, and our innovations will themselves be more flexible and resilient.



Michael W. Howard
President and Chief Executive Officer

SHAPING THE FUTURE

Innovative approaches to upcoming challenges

Cyber Security Strategies for the Smart Grid

The emerging smart grid will offer capabilities and efficiencies unimagined before the digital age, from self-healing transmission system equipment to custom-tailoring consumer service and rate structures to using one's electric car as a home backup power source.

But the digital age has brought new vulnerabilities as well. The smart grid's advantages are enabled by its two-way communication and control linkages within a highly networked structure involving thousands of interconnected nodes. With such a system, the centralized, top-down approach to security will be insufficient to comprehensively deter cyber attacks. Hardening must be provided at many levels, as intruders could enter at virtually any point in the interconnected system.

There are also nonmalicious cyber security events, such as equipment failures and user/administrator errors, which currently cause the majority of cyber security problems. Natural phenomena such as hurricanes, tornadoes, floods, and solar activity can also result in security disruptions. Regardless of the source of the cyber security event, the impact is often the same.

Practical Guidance for Implementation

High-level guidance for the electricity industry has been provided in the three-volume National Institute of Standards and Technology Interagency Report (NISTIR) 7628, *Guidelines for Smart Grid Cyber Security*. The report addresses cyber security for all smart grid systems in all operational domains—generation, transmission, and distribution—and includes an approach for identifying cyber security threats and risks.

But while NISTIR 7628 provides a starting point for selecting and modifying security requirements, additional criteria must be used in selecting and implementing cyber security controls. These additional criteria include constraints and issues posed by device and network technologies, the existence of legacy components and devices, varying organizational structures, regulatory and legal policies, and cost criteria.

Under its Cyber Security and Privacy program, EPRI is providing utilities with practical guidance for setting up a smart grid cyber security program through a technical update report (1025672) that provides perspective and useful tips on issues broadly outlined in NISTIR 7628. The first phase of a cyber security strategy is to develop an overall cyber security risk management framework. The report outlines major concerns incorporated in such a framework, including the risk assessment process, security requirement specifications, and strategies for selecting and tailoring security control and countermeasure systems.

Experiment Setup and Initiation

The National Electric Sector Cybersecurity Organization Resource (NESCOR), a DOE public-private partnership led by EPRI, has drafted a report containing cyber security failure scenarios and impact analyses for the electricity sector. Expanded and refined by a technical working group from results of this summer's NESCOR Annual Summit Meeting, the report is expected to be a living document that will be updated continually.

The report includes a threat model, a template for detailed scenario write-ups, a method and criteria for prioritizing the failure scenarios, and an initial list of scenarios, covering both malicious and nonmalicious cyber security events. About 100 scenarios are included in the current document, which also includes a sample failure scenario write-up that uses the defined template. Going forward, the work plan includes further testing of the scenario prioritization method and development of detailed information for additional scenarios using the template and guided by the priority ranking.

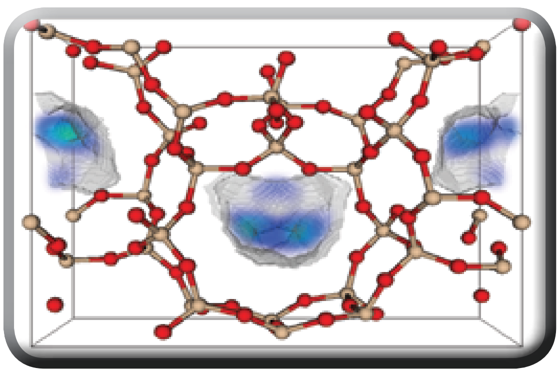
The failure scenarios, impacts, and mitigation strategies were developed from a bottom-up, rather than top-down, assessment of potential cyber security events. The failure scenarios included in this document are not intended to represent a complete catalog of all possible events. The write-ups are brief but commonly include some specific details to aid understanding. This is in contrast to a single, more general failure scenario that includes significant details to address all elements. The failure scenarios will be developed into tabletop exercises as part of a 2013 supplemental project, allowing utilities to assess their preparedness in responding to the impact of cyber incidents on power system operations.

For more information, contact Annabelle Lee, alee@epri.com, 202.293.6345.

Advanced Materials for Carbon Capture

Under its Technology Innovation program, EPRI is pursuing interdisciplinary efforts to identify and advance revolutionary carbon capture processes for postcombustion, gasification, and oxycombustion applications. While the work ranges from the modeling of CO_2 absorption, adsorption, and membrane processes to the testing and pilot-scale demonstration of emerging capture technologies, recent solvent-screening research has resulted in development of a particularly valuable tool—one that is expected to greatly accelerate identification of the most promising sorbent materials.

The materials-screening model, supported by the Department of Energy's Advanced Research Projects Agency—Energy (ARPA-E) program and developed in collaboration with the University of California at Berkeley, Lawrence Berkeley National Laboratory (LBNL), and Rice University, will help researchers find new, more effective carbon-grabbing materials to increase the efficiency and reduce the cost of the capture process.



With its innovative use of graphics processing units, the new analysis model quickly identifies sorbent structures that can remove carbon from flue gas more efficiently than amine solvents can.

Reducing Parasitic Losses

The few pilot plants currently investigating carbon capture use amine scrubbing—considered today's best technology. In this process, combustion emissions are funneled through a solution of nitrogen-based compounds called amines, which snare CO_2 from the flue gas. The amines are then boiled to release the captured CO_2, which can be compressed and prepared for injection in underground storage systems. Unfortunately, the capture, release, and compression process is energy intensive, costing a coal plant about a third of its potential electrical output.

Researchers seek to reduce these "parasitic" losses by finding new materials that can remove the carbon from flue gas more efficiently than amines. "There are potentially millions of materials that can capture carbon dioxide, but it's physically and economically impossible for scientists and engineers to synthesize and test them all," said U.C. Berkeley professor Berend Smit, who is also a faculty senior scientist in the Materials Sciences Division at LBNL.

The team has focused mainly on zeolites—crystalline porous materials made of silicon dioxide—and metal oxide frameworks (MOFs), which combine metals like iron with organic compounds to form a porous structure. Such solid materials are expected to be inherently more energy-efficient than amine scrubbing because the CO_2 can be driven off at lower temperatures.

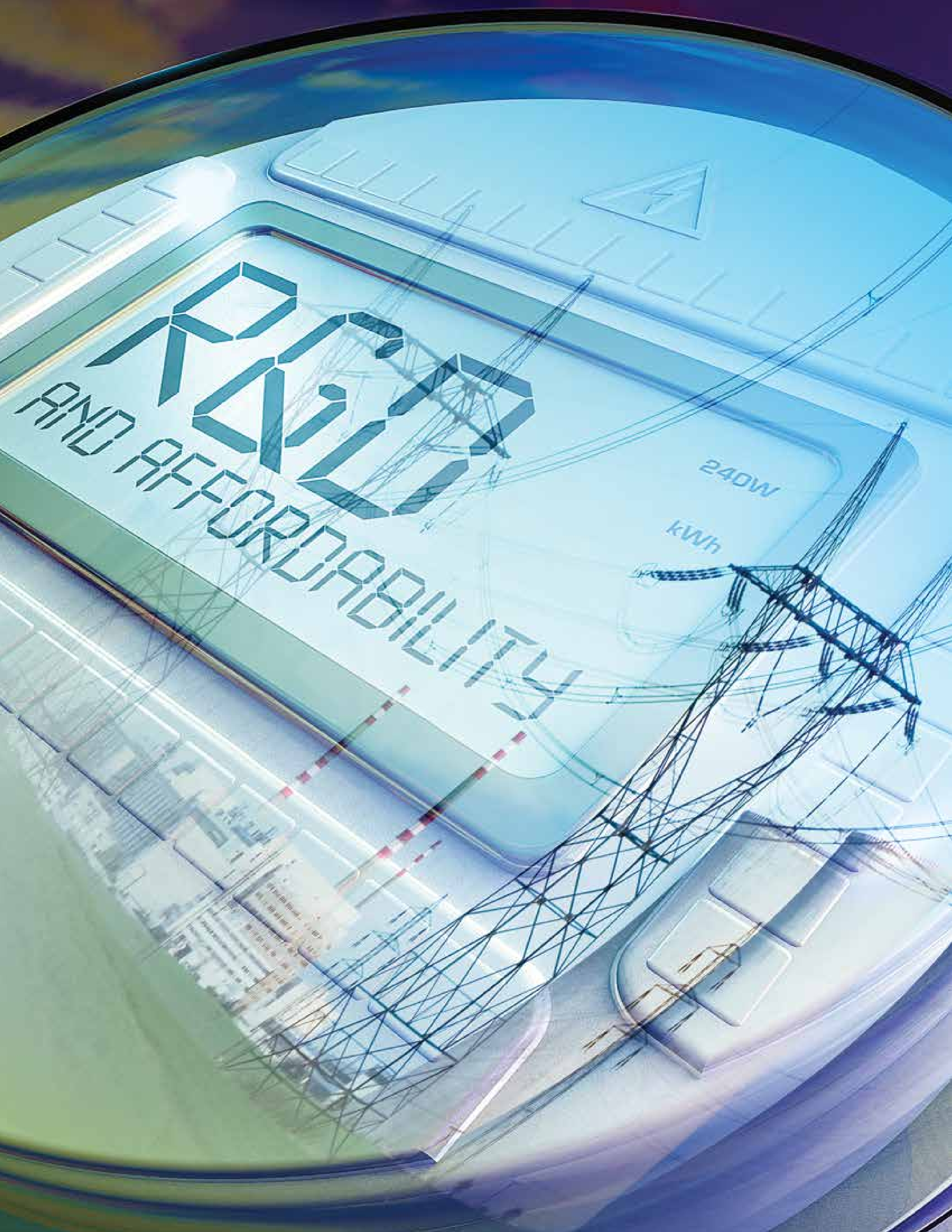
Modeling for Higher Efficiency

The Berkeley researchers worked with EPRI technical executive Abhoyjit Bhown and Adam Berger, a senior project scientist at EPRI, to establish criteria for carbon capture materials—focusing on the energy costs of capture, release, and compression—and developed a computer model to calculate this combined energy consumption for any material. The model then analyzed hundreds of thousands of representative structures from a database of more than 4 million zeolite structures compiled by Rice University scientists, as well as an additional 10,000 MOF structures. "The surprise was that we found many materials that could be synthesized and work more energy efficiently than amines," Smit said. The model showed that the best materials would use 30% less energy than the amine process.

"What is unique about this model," said Bhown, "is that, for the first time, we are able to guide the direction for materials research and say, here are the properties we want, even if we don't know what the ultimate material will look like. Before, people were trying to figure out what materials they should shoot for. Now, with the carbon capture model, a tremendous range of possibilities can be narrowed down quickly for more detailed investigation. The hope is that we can set up a system where, when someone comes up with a promising material, we can rapidly test it and get it to a readiness level pretty quickly."

This greater speed is facilitated by the model's use of graphics processing units rather than standard computer central processing units to perform complex quantum chemistry calculations—an innovation that cuts the analysis time for a candidate material from 10 days to 2 seconds. The database of carbon capture materials is being coupled with models of full power plants so that engineers can immediately see whether a material makes sense for an actual plant design.

For more information, contact Abhoyjit Bhown, abhown@epri.com, 650.855.2383.



R&D
AND AFFORDABILITY
240W
kWh

Boiler failures are the leading cause of unplanned outages in coal-fired power plants. Tubes that rupture and leak can force plants off line for days, and these outages can be costly. "If you lose a big, efficient unit in the middle of July and you've got to buy power now off the grid, it can be very expensive," said Tom Alley, vice president of the Generation Sector at EPRI. In 1985, EPRI launched a research program aimed at reducing boiler tube failures, which identified the causes and how to address them. The long-term program offers guidelines and technology for addressing problems and preventing tube failure.

The payoff for this research has been substantial. In 2007, Midwest Generation implemented EPRI's boiler tube failure reduction program at six Illinois plants. The program recommends that when failures do occur, plant managers investigate the causes and review the repairs, and that when tubes must be replaced or repairs modified, managers schedule these tasks during planned outages. By adopting these practices, Midwest Generation increased its annual available generation by 300,000 megawatt-hours between 2008 and 2010. The 80 utilities that have adopted this program in the past 25 years have improved boiler availability by as much as 4.5% and saved up to $37 million per year in reduced generation costs or lost opportunity sales. Reducing the overall cost of power generation translates into savings for customers.

Over the past six decades, the power grid has grown in size and complexity, yet the average cost of electricity is roughly the same today as it was in the late 1960s, when adjusted for inflation. "Electricity is still a bargain," said Mark McGranaghan, vice president of Power Delivery and Utilization at EPRI. The flat prices are due in part to industry advances made possible by research and development. Although research costs money, the investment comes with a significant return: low-cost electricity.

THE STORY IN BRIEF

Utility industry investments in R&D—especially in the areas of reliability, efficiency, and environmental compliance—have kept electricity prices low for 30 years. Continuing advancements and innovation promise even more benefits for the future.

Preventing Generation Outages

Plant operation and maintenance costs have a powerful influence on affordability. Long outages can be especially costly because of lost earnings and the need to rely on purchased or generated replacement power from more expensive sources. "An unplanned outage at a large nuclear or fossil plant can result in replacement power costs upwards of $1 million per day," said Neil Wilmshurst, vice president of EPRI's Nuclear Sector.

Fuel failures are one cause of outages in nuclear plants. Although the number of fuel failures has fallen dramatically since the 1980s, the problem has not yet been entirely eliminated. Fuel failures can cost utilities tens of millions of dollars in maintenance and downtime if the plant must shut down mid-cycle for an unplanned outage. In collaboration with utilities, fuel vendors, and industry organizations, EPRI published a series of reports on the best practices for eliminating fuel failures.

Although there was concern that striving for ever-shorter outages would compromise safety, "what has been proved over the last decade or so is that safety goes up," Wilmshurst said. "Shorter outage schedules have compelled plant owners to plan outage activities more carefully, with particular attention to plant and worker safety and reduced dose."

Outage length in a nuclear plant is dependent, in part, on cleaning up the cooling water. The plant's water must be scrubbed of radioactive materials to bring radiation levels down before plant workers can enter containment. EPRI has developed a new resin that may be able to capture three times more radioactive cobalt—the greatest source of exposure for plant workers—than traditional resins. "The sooner maintenance workers can safely get into containment, the sooner they can conduct the necessary inspection and maintenance activities," Wilmshurst said. "Keeping outages as short as safely possible results in reduced costs."

To keep plants reliable, power producers need to invest in new equipment. One key challenge is to determine which items to replace and when. Replacing a transformer too soon means wasted expenditures, but waiting too long might cause equipment to fail, precipitating costly outages. "We've done a considerable amount of work on life-cycle management—understanding when to replace equipment, what to replace it with, how to replace it," Wilmshurst said. Recently EPRI researchers used asset-management tools developed by French utility Electricité de France (EDF) to conduct life-cycle analyses for the main transformers at Constellation

Energy Nuclear Group's five nuclear power plants. The tools help determine the best schedule of refurbishment, spare parts procurement, and replacement to minimize costs while maintaining reliability.

Another simple way to curb costs is to increase plant efficiency. "We're looking at how we can tune the combustion process so that we get more energy conversion out of the coal," Alley said. "It's a pretty good bang for the buck." One way to improve efficiency is to increase the temperature and pressure inside boilers. EPRI has been working with boiler and steam turbine manufacturers to develop materials that can withstand temperatures up to 760 degrees Celsius, the temperatures needed for advanced ultrasupercritical steam cycles. The team's research focused on nickel-based alloys, examining long-term material strength, weldability, oxidation, corrosion, and more. In March 2012, the American Society of Mechanical Engineers Boiler and Pressure Vessel Code approved the best candidate, Inconel® Alloy 740, for use at temperatures up to 800° Celsius (1472°F).

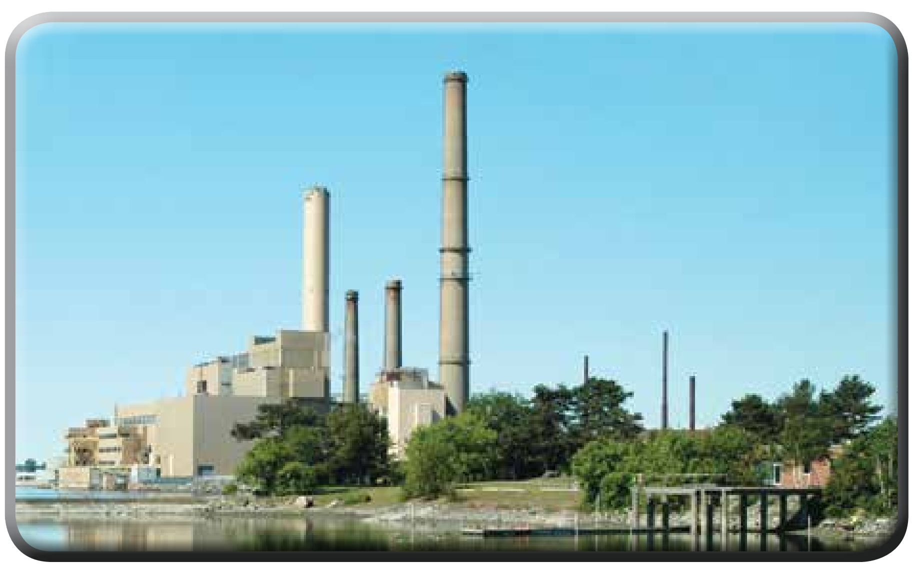
Toward a Smarter, More Efficient Grid

The grid that carries power from producers to customers is expected to play a larger, changing role in affordability. "Ensuring efficient operations on the distribution system keeps the customer cost down," said McGranaghan. That requires better planning, matching investments in the system to what's needed, and maintaining and replacing infrastructure in the most efficient way possible.

The emergence of smart grid technology promises huge efficiency gains, allowing the grid to become much more flexible and responsive. The smart grid's capacity for two-way communication will allow utilities and customers to take advantage of new options in managing and using energy. Utilities can offer demand response options to reduce load on the grid and to shift demand such as water heating and electric vehicle charging to off-peak times. Customers typically receive some financial incentive for participating in such programs. "Demand response is the least expensive approach for meeting capacity reserve requirements on the grid, but there are a lot of technological challenges in continuing to expand that option," McGranaghan said. One challenge is to develop communications standards so that grid operators' systems can communicate with customers' meters and appliances. EPRI is conducting a demonstration project involving a nonproprietary standard called OpenADR. "Through the demonstration, we identified the holes in the standard and where the standard needs to be adjusted," McGranaghan said. The researchers are now providing feedback for the protocol's next version.

Power companies also can help customers cut costs by helping them save energy. One way is to lower the voltage supplied to customers' homes. Engineers commonly think that motors on refrigerators and other appliances run hotter and draw more current when supplied with lower voltages, but they actually run more efficiently as long as the voltage stays within the appliance specifications. "The savings occur on the customer's side," said McGranaghan. Research conducted by EPRI and Pacific Northwest Laboratories suggests that utilities could cut energy use 3% nationwide by optimizing the voltage supplied to customers. Researchers are testing voltage control technologies and developing tools to determine where to implement these new technologies to get the maximum return on investment. The smart grid, with its advanced meters, will enable two-way communication between the utility and the consumer. "The advantage of having all those advanced meters there is that we can see every customer and make sure that the voltage is still acceptable in every case. That allows us to go right down to the limit in lowering the voltage," said McGranaghan. This voltage adjustment loop could eventually be automated by making use of continuous feedback from the meters.

Some studies show that simply supplying customers with more information can reduce energy use. For example, a study in Ireland found that 1,000 customers who received advanced meters reduced their energy consumption by 7%–12%. EPRI's research suggests that the awareness that comes from having an advanced meter helps customers reduce their energy consumption. "In Ireland the benefits were very clear," McGranaghan said. "It became the justification to go ahead with advanced metering throughout the country." Today EPRI has a whole research program focused on understanding customer behavior.



Cost-Efficient Compliance

Environmental regulations have a significant impact on power producers' bottom line. Retrofitting power plants with new equipment to comply with increasingly stringent regulations is expensive. "We can comply with the current regulations," said Alley. "The real issue is the cost of that compliance." To reduce costs, EPRI researchers look for more efficient ways to meet environmental requirements.

Future federal and state air quality regulations will likely require coal-fired power plants to slash mercury emissions. For many plants, injecting activated carbon into the flue gas stream to absorb mercury may be the most feasible option, but the reduction will come at a significant cost. A preliminary EPRI analysis suggests that the cost of producing sufficient activated carbon for the entire U.S. fleet could surpass a billion dollars. Power producers may be able to save money by producing the activated carbon on site, so EPRI, with the Illinois State Geological Survey, is developing the technology to manufacture it. The technology is projected to cut the cost of activated carbon by half, saving a 500-megawatt plant up to $2.5 million per year. The technology also would eliminate the need for handling and storage facilities.

EPRI research not only provides a better understanding of power production's environmental impacts, it also helps inform environmental regulations. In recent years, the U.S. Environmental Protection Agency (EPA) has been working to revise a rule with significant implications for the power industry. The rule, section 316(b) of the Clean Water Act, is aimed at preventing fish, shellfish, and their eggs from being harmed by cooling-water intake structures. Small organisms can be pulled into the plant and killed by heat, and larger fish can be trapped against the screens that cover these structures. The rule requires power plants to use the best available technology to minimize these impacts. The proposed rule considers two options that would require closed-cycle cooling (cooling towers). EPRI research estimated that retrofitting the U.S. fleet with this technology could cost more than $100 billion.

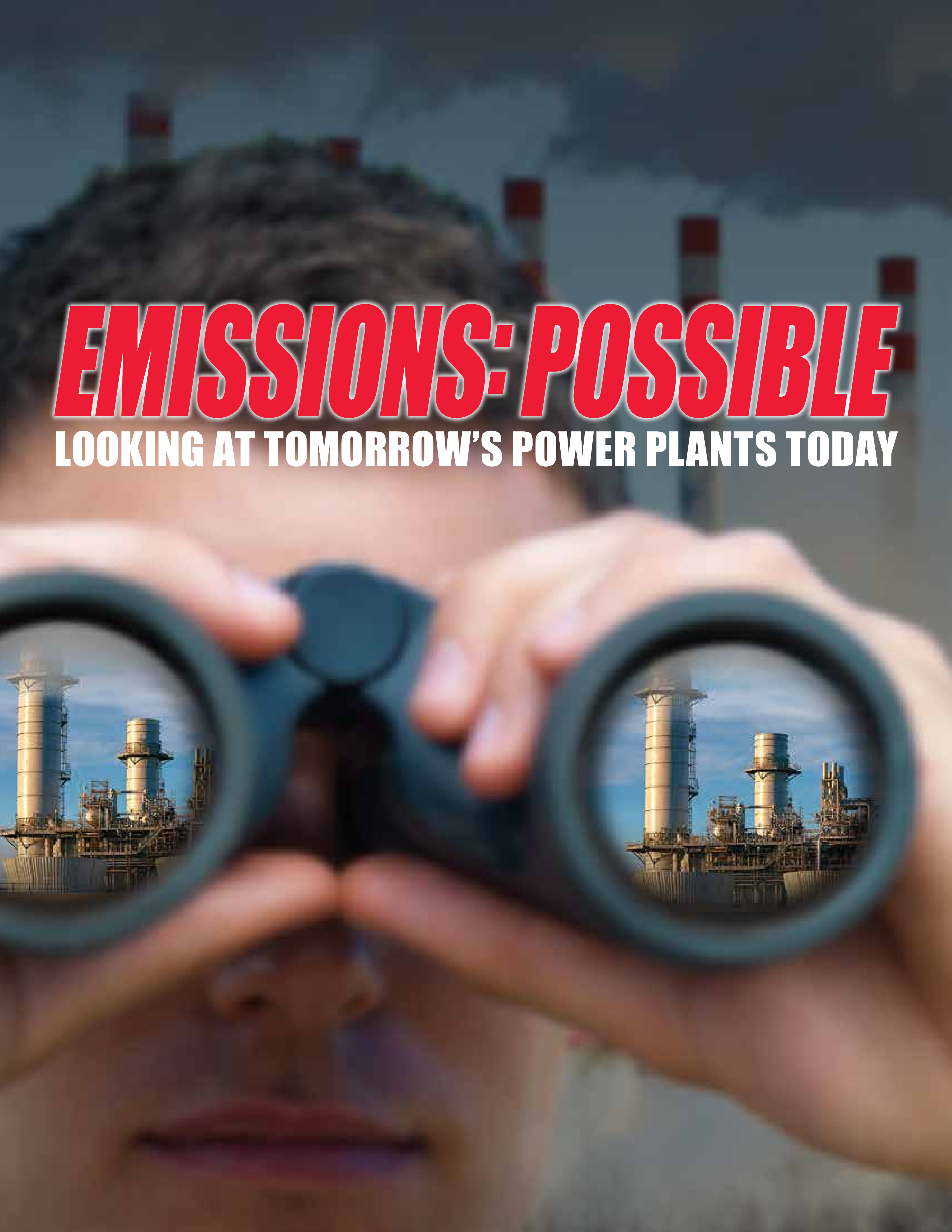
"We know that closed-cycle cooling could make a significant impact from a fish-protection standpoint, but is that the most efficient way to achieve the environmental outcome?" asked Bryan Hannegan, vice president of Environment and Renewable Energy at EPRI. EPRI's research suggests that fine-mesh screens provide similar protection for fish at a tenth the cost of a closed-cycle system. If the final EPA rule, set to be issued in June 2013, does not require closed-cycle cooling, the industry could potentially save approximately $90 billion in retrofit expenses.

The cost benefits of research aren't always easy to see. The payoffs of environmental studies, for example, may come years in the future. And rather than benefiting a single company, they may benefit the industry as a whole. But the value is real nonetheless. "There is an inherent and intrinsic value in maintaining an ongoing fundamental science and technology research program that you have at the ready, even though you might not use it every year," Hannegan said. "If we don't invest in the basic science, then when the industry faces a challenge, it's not going to have the tools it needs."

This article was written by Cassandra Willyard.

EMISSIONS: POSSIBLE

LOOKING AT TOMORROW'S POWER PLANTS TODAY



THE STORY IN BRIEF

A far-reaching, multidisciplinary research program is clarifying the potential environmental and health impacts of the next generation of power plants, allowing issues to be addressed as emerging technologies are being developed.

The smart technologist looks to the future to see what needs to be done today. One thing that's clear for the electric utility industry is that environmental concerns, energy economics, and technical innovation will change the generation portfolio by 2030 and alter the way new plants are designed, built, and operated.

The broad changes are fairly clear. Relatively clean-burning natural gas–fired plants will claim increasing portfolio share so long as the fuel is relatively cheap, but their emissions are receiving renewed regulatory scrutiny, and new fuel sources may prove problematic. Renewables are expected to claim a larger share, but environmental impacts of combustion-based options such as biomass have not been robustly investigated. If coal power plants continue to play a large role in a future concerned with greenhouse gas emissions, then carbon capture technology, and its environmental issues, will need to be understood and addressed.

The Big Picture

So how should new power plants change over the next 20 years, and how will they deal with growing environmental pressures? In 2009, EPRI zeroed in on this issue by launching groundbreaking multidisciplinary research to evaluate the environmental and health impacts of future generation technologies. It is a comprehensive undertaking to measure emissions, study new fuels and emission controls, understand the chemistry and toxicity of the resulting emissions, and determine the impacts of these technologies.

The aim is to provide power producers with robust science about possible health and environmental impacts during plant engineering, enabling smart decisions at the outset. Developing and adding equipment and processes after a power plant is built can prove difficult and very expensive.

EPRI is methodically characterizing, modeling, and assessing the properties and health risks of these fuels and compounds to address potential environmental issues. Currently, there are no regulations governing a number of materials or compounds because they are part of new technologies that are still undergoing laboratory research and field testing for wide deployment.

"We want to evaluate the technologies before widespread deployment," said Annette Rohr, a senior project manager in EPRI's Air Quality and Health program. "We want to avoid having to go back and retrofit facilities in the future."

The initial work identified 20 plant configurations likely to be operating by 2030, including different combinations of fuels, generation technologies, and pollutant-curbing processes. The study of natural gas combustion focused on advanced combined-cycle technology, while future coal plant configurations covered a range of technologies—conventional and advanced direct firing, oxyfuel combustion, circulating fluidized-bed (CFB) combustion, and integrated-gasification—combined-cycle technology—all with appropriate existing or emerging emission controls. CFB and direct firing of biomass were also included, as well as mass firing of municipal solid waste.

The list led to a preliminary screening impact assessment project to evaluate the health and environmental risks of the 20 configurations. This project has modeled emissions and quantified cancer and other health risks from different potential pathways of exposure, with results indicating low projected health risks overall.

The Rise of Natural Gas

A significant increase in natural gas extraction, coupled with the use of the controversial hydraulic fracturing, or "fracking," method to extract this fuel, has refocused a spotlight on natural gas. Demand and prices are projected to increase as power producers look for ways to reduce their generation fleets' emissions, given that natural gas combustion produces less greenhouse gases than coal combustion does.

In fact, natural gas power plants will likely be the dominant fuel source for new power plants in the near future. The U.S. Energy Information Agency (EIA) reports that in 2010, 23% of U.S. electricity was generated by natural gas power plants. The agency expects nearly half of the capacity added between 2009 and 2015 will come from natural gas. Even with relatively lower emissions, natural gas–fired plants still have significant impacts on the environment and human health. In 2010, according to the EIA, natural gas power plants generated 18% of the carbon dioxide and 10% of the nitrogen oxides that came from electricity generation plants in the United States.

EPRI recently reviewed key air quality issues associated with natural gas extraction and combustion, considering conventional pollutants such as particulate matter and volatile organic compounds (VOCs) as well as emerging concerns such as ultrafine particles (those less than 100 microns in diameter). The review identified missing data and assessment criteria that will help the electricity industry anticipate new regulations and make financial and operational decisions. For example, the review concluded that a closer look at emissions from the natural gas combustion cycle is needed. Several studies have offered conflicting evidence as to whether the process produces a greater number of ultrafine particles when a power plant increases its power output. There is speculation that ultrafine particles could cause greater harm to human health than larger particles, but no data exist on their emissions from grid-connected natural gas power plants. Similarly, emissions of VOCs, carbon monoxide, and nitrogen oxides have been shown to increase substantially during plant startup and shutdown.

The use of a high-pressure mix of water and chemicals in the fracking process to force natural gas from fractures generated in shale could have impacts on soil and water, as well as on emissions; none of these impacts are yet well understood. Research so far has focused on methane for calculating potential shale gas losses and on VOCs—including some hazardous air pollutants—that pose health risks to humans. Collecting both nitrogen oxide and VOC emission data from drilling and fracking would be another important undertaking, given these pollutants' significant impact on ozone creation.

The Green Fuel

Biomass is a renewable fuel that is under serious consideration by electric utilities. Using feedstock such as wood and agricultural wastes, biomass combustion generally produces lower emissions than fossil fuels. For example, the sulfur levels in biomass are lower than those in coal, and evidence shows that burning biomass along with coal reduces nitrogen oxide emissions. Net carbon dioxide emissions also should be lower with biomass, since the energy crops used for the feedstock take in carbon dioxide during their growth cycle. However, while some emissions data exist for pollutants such as ozone and lead, which are regulated by the ambient air quality standards, a good picture of the emissions composition of VOCs and other unregulated pollutants in a large-scale power plant is not available.

As part of EPRI's research program, emissions data were collected during test burns at a plant cofiring 20% biomass. Pollutants under the spotlight included particulate matter, elemental and organic carbon, semivolatile organic compounds, and mercury. A report on this work is forthcoming and will include results of toxicology studies that compared the emissions from cofiring with those from coal-only combustion at the same plant. EPRI is looking for additional opportunities to collect samples at a biomass-only plant and is conducting research on occupational exposure and health issues specific to biomass combustion, such as levels of biogenic dust.

Promising Technologies for Coal Plants

Research into understanding coal-fired generation emissions and ways to reduce them is farther along than such research for some other fuels. One of the most promising processes for capturing carbon from coal-fired plants relies on the use of a group of chemical compounds called amines; the process also could be applied to other carbon-based fuels, such as natural gas and biomass. As a result, EPRI focused on determining the impact of amines, as well as their degradation products, on environmental and human health.

Amines are organic compounds and derivatives of ammonia that are widely used in natural gas processing to remove impurities. As chemical absorbents, amines can bond with carbon dioxide in a solvent. After an amine compound captures carbon dioxide at the end the combustion cycle, it's then heated to separate it from the carbon dioxide before being returned to the absorber to perform the carbon capture process again. Unlike other emerging carbon capture technologies, which would require large-scale modifications to existing power plants, the use of amines would require the simpler addition of an absorber to the plant. Though there are a number of pilot projects worldwide, there has not yet been full-scale deployment of amines for carbon capture at a coal-fired power plant.

While the proven ability of amine technology makes it an attractive candidate for controlling carbon emissions, the approach does come with a significant shortcoming: the regeneration process can use 30% of the energy produced by the power plant, Rohr said. That inefficiency has prompted a search for solvents or sorbents that will lower the energy requirement (see "Advanced Materials for Carbon Capture," page 5).

Rohr and her team have evaluated the toxicity of three different amine solvents, the ways they might degrade during use, and their impact on air quality. Not only is it possible for the amines to escape into the atmosphere inadvertently, but the thermal and oxidation processes they undergo while capturing carbon dioxide also could lead to emission of compounds such as nitrosamines, nitramines, alkylamines, and amides. These emissions could then react

with other compounds in the atmosphere and create new compounds that could negatively affect air quality, the environment in general, and, potentially, human health.

Early toxicology results show that an acute exposure to amines at high doses didn't cause a strong reaction in the lung, but an exposure to a degraded amine compound did increase pulmonary inflammation. Work is under way to assess the toxicity of the amines after they undergo chemical reactions in a test chamber designed to simulate the atmosphere. Other projects include the evaluation of the genotoxicity of the amines and their degradation products and a focused evaluation of nitramines—a group of compounds that are not well understood from a health perspective.

Aside from toxicity concerns, another challenge related to studying amines and their degradation is the lack of standardized sampling and analytical methods for monitoring these compounds in flue gas. In early 2012, EPRI assembled an international working group to review the methods currently in use, test the methods at a pilot facility, and ultimately develop recommendations for a standardized approach. EPRI published a technical update on test methods for amines (1025020) in June of this year. In 2013 and 2014, the working group plans to carry out round-robin testing of different methods and create a standardized protocol based on those results.

Other activities related to amine research include modeling the thermodynamic and photochemical behavior of amines, modeling the formation of ultrafine particles in power plant plumes, and assessing potential occupational health and safety issues.

Another area of interest in the research program is the use of bromine in coal-fired power plants; research will address direct bromine injection and the use of bromine-activated carbon for mercury removal. Potential concerns exist with bromine reaching surface waters and forming potentially hazardous compounds. Research in this area will clarify whether, and to what extent, these risks exist.

Another emerging technology—oxyfuel combustion, which uses an oxygen-enriched atmosphere instead of air during coal firing—has not yet been widely deployed. EPRI has reviewed potential environmental and health impacts of emissions from oxyfuel combustion and will be submitting an article to the peer-reviewed literature shortly.

"We want to evaluate the technologies before widespread deployment . . . to avoid having to go back and retrofit facilities in the future."

Planning for the Future

The electricity industry anticipates new and/or tightening federal and state regulations on power plant emissions. Although there isn't a national climate policy, federal agencies have been moving steadily to set more emissions restrictions on power plants and invest in technologies for capturing pollutants. States such as California are tightening their emissions rules as well.

Responding effectively to such regulatory mandates requires a thorough understanding of complicated and interrelated scientific processes and health outcomes. EPRI's comprehensive approach, involving emissions monitoring, atmospheric chemistry and transport studies, measurements, and toxicological studies in both the laboratory and the field, offers needed information for making educated choices for generating electricity cleanly and economically in the future.

This article was written by Ucilia Wang. Background information was provided by Annette Rohr, arohr@epri.com, 425.298.4374.

Annette Rohr, a senior project manager in EPRI's Air Quality program area, conducts epidemiological and toxicological research on the health effects of air pollution. Before joining EPRI in 2001, she was an environmental scientist at Dames & Moore, where she conducted human health and ecological risk assessments. She received a B.S. degree in microbiology and an M.S. in environmental engineering from the University of British Columbia in Vancouver and an Sc.D. in environmental health from Harvard University.

Weighing the Risks and Benefits of

Accelerated Spent Fuel Transfer

THE STORY IN BRIEF

Should nuclear plants speed up the transfer of spent fuel from wet-storage pools to dry storage? To inform the discussion, EPRI has studied the costs, benefits, logistics, and safety issues involved.

Used fuel that is discharged from nuclear reactors—"spent" fuel—is initially placed into adjacent spent fuel pools. Because fuel assemblies continue to emit heat and radiation produced by radioactive decay after being removed from the reactor, they must stay in the spent fuel pools for a period of time to cool down and reach manageable levels of radiation before being transferred into dry storage. Spent fuel pools remove decay heat via active cooling systems; the pools maintain low radiation dose levels because the spent fuel is covered by approximately 20 feet of water.

The March 2011 earthquake and tsunami that damaged Japan's Fukushima Daiichi nuclear power plant knocked out power to the spent fuel pool cooling systems, resulting in pool water heating, evaporation, and a drop in water level. While this activity did not lead to serious consequences at Fukushima, it prompted renewed concerns over the safety of nuclear plant spent fuel pools damaged by accidents, terrorist attacks, or natural disasters.

To reduce potential risks due to decay heat and spent fuel radiation in storage pools, some policy makers, individuals, and organizations have called for moving spent fuel as rapidly as possible into dry storage. Advocates for accelerated transfer contend that spent fuel pools are already filled beyond their initial design capacity, are storing fuel much longer than originally intended, and contain substantially more radioactive material than the reactor cores themselves. In some scenarios, damage to or loss of the ability to actively cool spent fuel pools could lead to high radiation dose rates around the pools and a large release of radionuclides to the environment. Accelerated transfer could reduce such risks and decrease the heat load and radionuclide source term from materials in spent fuel pools.

In evaluating accelerated transfer, EPRI determined that the main benefits relate to reduced pool inventories and decay heat, while the main drawbacks relate to worker radiation exposure, equipment availability, and cost.

These benefits are receiving further consideration in light of Fukushima. To inform these discussions, EPRI has studied the costs, benefits, logistics, and safety issues pertaining to accelerated transfer. For the study, EPRI examined several representative nuclear power plants and generalized those findings to the U.S. industry. EPRI considered two scenarios for transferring all fuel cooled at least 5 years from pools to dry storage—a rapid, 10-year transfer schedule and a more modest, 15-year schedule—comparing them with a base case where spent fuel continued to be moved only as needed.

Wet and Dry Storage

Individual fuel assemblies remain in service for 4 to 6 years, and a typical plant shuts down every 18 to 24 months to replace about one-third of the fuel in the reactor and move the replaced fuel to the pools. In the United States, these pools were intended for short-term storage until the fuel could be reprocessed or moved into a permanent repository. Because neither option has materialized, most spent fuel has remained in pools far longer than expected.

"No regulations specify how long spent fuel can remain in wet storage before being transferred to dry storage," said John Kessler, manager of EPRI's Used Fuel and High-Level Waste Management program. "The current practice is to make space as needed for staging new fuel and for storing spent fuel."

Dry storage facilities will become more common in the years ahead. Even without an accelerated schedule, projections call for the amount of fuel in dry storage to nearly double by 2020. "As with spent fuel pools, dry storage was never intended to be a permanent waste-disposal solution, although facilities are projected to remain safe for many decades," said Kessler.

For dry storage, fuel assemblies are transferred into a steel cask in the spent fuel pool. A cask can hold 40 of the largest assemblies, which are 12 to 15 feet high and weigh about 1500 pounds each. The full cask is closed by bolting or welding a lid on top, after which water is evacuated and replaced with an inert gas. The cask is then enclosed in a concrete vault on an outdoor pad.

Study Findings

In evaluating accelerated transfer, EPRI determined that the main benefits relate to reduced pool inventories and decay heat, while the main drawbacks relate to worker radiation exposure, equipment availability, and cost.

Benefits: Smaller Pool Inventories, Less Decay Heat

Reducing the used fuel in pools would reduce the amount of material that could

The State of Dry Storage

No permanent used fuel repositories are yet in operation around the world. As a result, dry storage facilities will likely remain in use for at least 60 years. In the United States, the earliest sites from the mid-1980s have already exceeded their initial 20-year licensing term and are operating under license extensions. Many others will require extensions in the next few years.

Two different dry storage systems are used worldwide. One is a metal cask with a bolted metal lid; the metal cask provides the required radiation shielding for this system. The second type, more widely used in the United States, is a welded stainless steel canister holding the spent fuel, which is then placed inside a concrete "overpack" for shielding purposes.

One concern with extended dry storage is stress corrosion cracking of the stainless steel canister. Laboratory tests have shown that such cracking can occur in the steels used in casks when they are subjected to tensile stress and are in a corrosive environment (such as one with salt in the air and the right combination of temperature and humidity). The risk increases with time, not only because of aging and contamination of the materials, but also because the lower temperature of older fuel allows humidity to rise, creating conditions more favorable for salts on metal surfaces to absorb water and create corrosive, concentrated brine pockets.

"Experiments have shown it can occur, but that was under lab conditions," said John Kessler. "We need to know whether these conditions exist in the field in order to develop an aging management plan." EPRI worked with Constellation Energy Nuclear Group in inspecting two casks from the Calvert Cliffs Nuclear Plant's dry storage facility near Chesapeake Bay. Of the 60 dry storage casks in service, some for more than 15 years, the researchers inspected the cask with the highest radioactivity and thermal output and the cask that was the oldest and coolest on site.

The procedure involved video inspection of the casks and of the concrete overpack doorway and seismic restraint; temperature measurements on the bottom and upper shell of the coolest cask; and collection of dust and salt samples from the cask surface. EPRI will investigate whether correlations can be established between the internal and external salt concentrations and the risk of stress corrosion cracking.

Inspection at Calvert Cliffs revealed some rust stains on one of the canisters, but no signs of major corrosion on the casks' surface or on the welds. This is significant because the welds are more prone to stress corrosion cracking due to high tensile stresses.

"This inspection was our first attempt to do this sort of thing," said Keith Waldrop. "Just showing that we could do it was a great success, and we completed it with a radiation dose only half of the planned level. Our temperature measurements at the end of the cask were close to predictions, but we didn't get good enough contact with other parts of the cask for accurate readings. That was part of the learning process."

Plans call for two to three inspections at other sites in 2013. "Our goal is to use field data to develop models that predict temperature and humidity based on conditions that can be observed without going in to inspect every cask," said Kessler. "This involves predicting when and where the conditions conducive to stress corrosion cracking might warrant enhanced inspection or monitoring and determining what kind of monitoring is necessary."

contribute to health, safety, and environmental effects in the event of a serious nuclear plant accident. Removing assemblies would also have the benefit of reducing the density of the remaining assemblies in the pool, which could lower the risk of radioactive release in the event of pool drainage.

Removing fuel cooled five years or longer would reduce the inventory of spent fuel assemblies in the pool by 67%–73%. Because the youngest, hottest fuel must remain in the spent fuel pools until it can be placed into dry storage, the relative reduction of heat and radioactivity would be smaller than the reduction of assembly inventory in an accelerated transfer scenario. Decay heat would fall by 23%–32%, and radioactivity in the pool would be reduced by 43%–47%.

Drawbacks: Exposure and Equipment

Accelerated transfer would require workers to spend more time moving fuel, working with greater quantities of fuel, and work-

ing with hotter fuel, resulting in exposure to more radioactivity. The EPRI study estimates that the average worker dose would rise from the current level of 400 person-millirems per cask to 750 person-mrem. While the regulated limit for workers is 5,000 mrem per year, any increase in dose is a concern because of regulatory and industry efforts to drive exposure as low as reasonably achievable.

Transferring spent fuel requires one to two weeks to fill a single cask. Meanwhile, plant operations place competing demands on the cask crane. These tasks include repositioning spent fuel or control rods in the pool, receiving new fuel, identifying and removing foreign objects, and performing inspections and repairs.

In view of other scheduling demands, a typical plant might have only a few weeks per year available for dry storage transfer—or less, if reactors share a spent fuel pool and/or cask crane. Given these factors, a typical plant would need between 8 and 15 years to move all of its 5-year-cooled fuel into dry storage.

"We looked at the time line for a typical two-unit plant with one shared crane and spent fuel pool," said Keith Waldrop, EPRI senior project manager. "Normally this plant would load about four dry storage casks per year. At best, with all the other demands on cask crane scheduling, this site could manage about three additional casks per year."

Cask availability is another concern. EPRI calculated that annual demand for casks would be three times greater for the 10-year transfer scenario than for the base scenario. Also, given the higher decay heat and radiation source term from younger fuel, it may be necessary to design smaller casks or to load less fuel in existing cask designs. Thus, cask manufacturers would have to increase production significantly for the accelerated transfer period; once the existing inventory had been transferred, demand would return to current levels.

Costs of Accelerated Transfer

By 2060, nearly all spent fuel from nuclear plants currently in service will be in dry storage, regardless of the schedule followed. In comparing the cost of accelerated transfer with the cost of transfer at current rates, EPRI calculated the added cost (net present value) to be $3.5 billion, or 38% higher than the base case, for the 15-year schedule and $3.9 billion, or 42% higher, for the 10-year schedule. This includes up-front costs, such as purchasing additional transfer equipment; operational costs and risks related to loading more casks; and incremental costs resulting from the higher demand for dry storage casks and the possible need for cask redesign or recertification.

"Our study shows that it is feasible to move spent fuel into dry storage at an accelerated rate," said Waldrop. "However, it is not clear whether the potential risk reduction from doing so would be great enough to offset the increases in accident risks, occupational safety hazards, operational impacts, and costs that an accelerated transfer rate would bring about." The Nuclear Regulatory Commission will evaluate the pros and cons of accelerated transfer as part of its review of spent fuel safety post-Fukushima; EPRI's research is expected to inform these deliberations.

This article was written by Cliff Lewis. Background information was provided by John Kessler, jkessler@epri.com, 704.595.2737, and Keith Waldrop, kwaldrop@epri.com, 704.595.2887.

John Kessler is the program manager of EPRI's Used Fuel and High-Level Waste Management program. Before joining EPRI in 1993, he worked at Nutech and was a private consultant on dry spent fuel storage system design. In addition to developing cement-based nuclear waste forms at Oak Ridge National Laboratory, he worked with Sargent & Lundy on licensing of new nuclear plants. Kessler received B.S. and M.S. degrees in nuclear engineering from the University of Illinois, Urbana-Champaign, and a Ph.D. in mineral engineering from the University of California at Berkeley.

Keith Waldrop is a senior project manager, specializing in research related to the management, storage, and transportation of spent nuclear fuel. Before coming to EPRI in 2011, he was a senior engineer at Duke Energy, responsible for management of spent fuel at the McGuire Nuclear Station. He also performed core reload design analyses, including implementation of in-house core power distribution monitoring. Waldrop received a bachelor's degree in nuclear engineering from Georgia Institute of Technology.

DATELINE EPRI

News and events update

HANNEGAN MODERATES RETECH ROUNDTABLE

WASHINGTON, D.C. – EPRI environment and renewable energy vice president Bryan Hannegan moderated an executive-level generating-company roundtable as part of the opening plenary session of the Renewable Energy Technology Conference and Exhibition (RETECH) in October. RETECH, a global business conference, brings together business and utility leaders, investors, technology innovators, government officials, and university researchers from across the renewable energy industry. Hannegan also chaired a technical session on trends in utility-scale renewable energy power production and its integration with existing generating systems.

RESPONSE TO EPA NOTICE INFORMS FISH PROTECTION RULES

PALO ALTO, Calif. – In August, EPRI published technical comments that respond to an Environmental Protection Agency Notice of Data Availability (NODA) on the control requirements for fish mortality at power plant cooling water intake structures. The NODA process is intended to ensure that regulations are based on the best available scientific, economic, and engineering data, are protective of the environment, and are in the best interest of the public. The EPRI report (1025381) discusses the potential consequences, both positive and negative, if requirement components outlined in the NODA are included in EPA's final rule, expected in the summer of 2013.

WORKSHOP TARGETS GAPS IN DEMAND RESPONSE

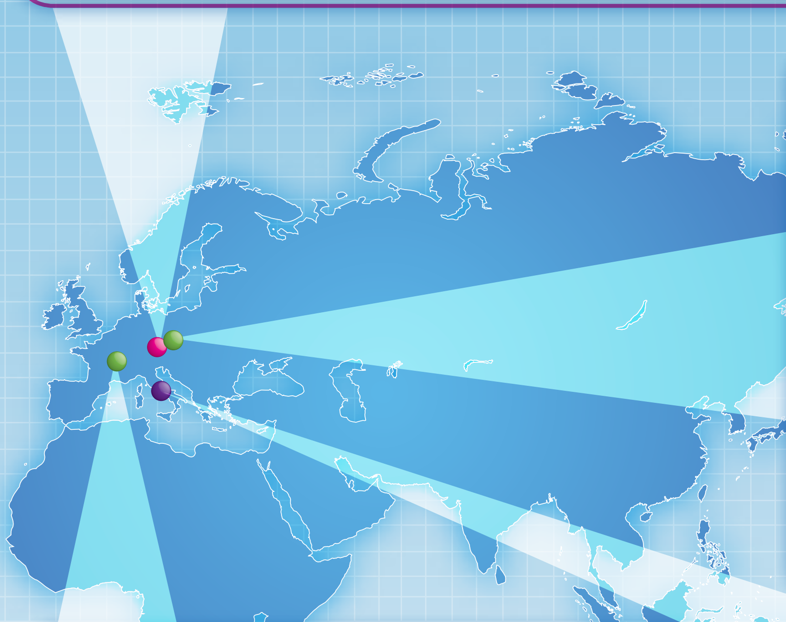
HOUSTON, Texas – CenterPoint Energy hosted an EPRI Demand Response 2.0 Roadmap Workshop to identify gaps in the state of demand response and develop recommendations for research, development, and demonstration to fill them. The workshop looked at bulk renewable integration using demand response; grid capacity and resource planning using demand response and distributed energy resources; and aligning wholesale and retail programs and rate structures.

EPRI HOSTS FUKUSHIMA FORUM

CHARLOTTE, N.C. – EPRI hosted the second Fukushima Forum in Charlotte in early October. This meeting, cosponsored with the Institute of Nuclear Power Operations and the World Association of Nuclear Operators, attracted almost 100 participants from 53 utilities and organizations in more than 15 countries. Presentations and discussion centered on the results of safety evaluations conducted at nuclear power plants around the world, actions taken or planned to upgrade safety at these plants, and implementation plans for the next five years, including expected resource requirements, availability of resources, and implementation costs.

AGREEMENT OUTLINES EPRI-IAEA COLLABORATION

VIENNA – EPRI and the International Atomic Energy Agency announced an agreement in September to promote public benefit research into nuclear power plant development, operation, decommissioning, and waste disposal. The collaboration enables technical engagement on issues regarding nuclear plant development in countries initiating commercial nuclear power programs. Technical areas of engagement will include risk and safety evaluation, power plant aging and materials degradation, nuclear waste disposal technologies, and capacity building for new owners and countries developing nuclear power programs. Key collaboration mechanisms will include sharing of information on commercial nuclear energy, organization of joint workshops and training seminars, and publication of joint reports and guidelines.



WORKSHOP PROVIDES GLOBAL TAKE ON ULTRA-SUPERCRITICAL TECHNOLOGY

VIENNA – Along with delegates from more than 17 countries, EPRI participated in the International Energy Agency Clean Coal Centre Workshop examining the status of research on the next generation of advanced ultrasupercritical power plants. EPRI senior project manager John Shingledecker served as the U.S. representative for the closing panel discussion. EPRI is the technical lead for the U.S. Department of Energy / Ohio Coal Development Office Advanced Ultrasupercritical Steam Boiler and Turbine Consortium.

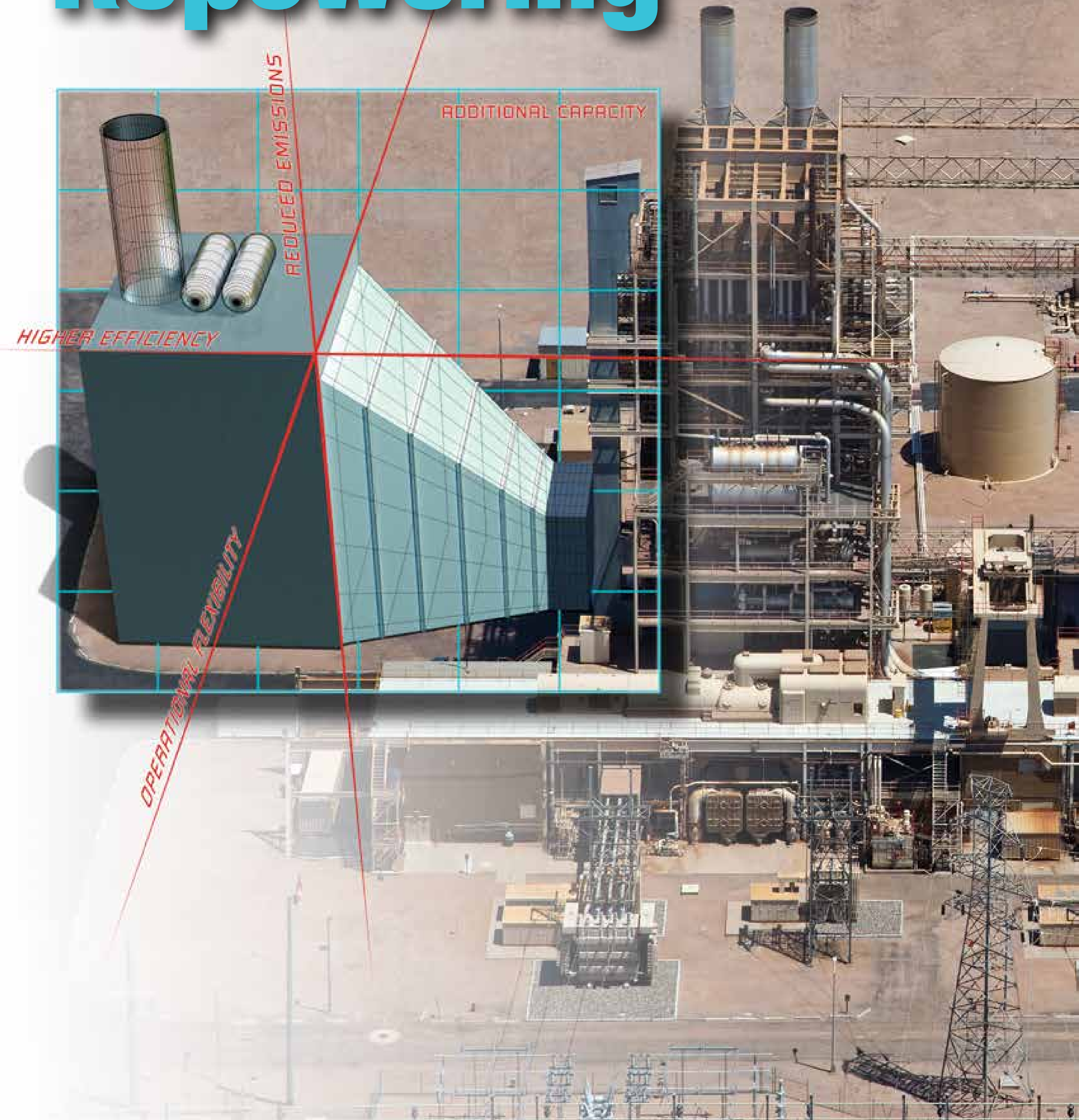
EPRI COSPONSORS INTERNATIONAL GHG EMISSIONS TRADING WORKSHOP

PARIS – The 12th Annual Workshop on Greenhouse Gas Emission Trading was held October 15–16, cosponsored by EPRI, the International Energy Agency, and the International Emissions Trading Association. This year's workshop focused on the evolution of national and subnational GHG trading programs, the linking of existing and evolving GHG trading programs, the role of emissions trading in international trade and potential trade wars, and the evolution of new market mechanisms as part of international negotiations under the United Nations Framework Convention on Climate Change. EPRI's Adam Diamant provided a presentation on California's forthcoming GHG cap-and-trade program, which is effective January 1, 2013.

EPRI INITIATES INTERNATIONAL SOLAR POWER PROJECT

SICILY – EPRI has launched a three-year field assessment and optimization project at the Archimede Concentrating Solar Power Plant, part of Enel's Priolo Gargallo Power Station in Sicily. Archimede, which contributes 4.9 MWe of equivalent solar capacity to an adjacent natural gas combined-cycle plant, is the first plant to use molten salt as the working fluid instead of synthetic oil. The EPRI study will help optimize, scale, and expand the use of concentrated solar technology by providing insights on preferred design configurations, components, and maintenance strategies.

The Promise of Repowering



Coal-fired power plants account for nearly half of total power generation capacity in the United States, and nearly three-fourths of those plants are now over 30 years old. They face a pincer action between new, more stringent environmental regulation on one side and age/technological obsolescence on the other. Whether an aging coal-fired power plant should be retired, converted to gas, upgraded environmentally, or repowered is one of the most challenging decisions facing power plant owners today. A recent EPRI analysis of current and potential Environmental Protection Agency (EPA) regulations estimates that under a reference case natural gas price (average of $6.50/MBtu), between 35 and 60 gigawatts (GW) of U.S. power generation may retire or refuel to natural gas by 2020. However, if low natural gas prices continue (average of $4.50/Mbtu), then up to 100 GW of existing coal capacity could retire or refuel by 2020.

Short-term options include retiring the plant or quick conversion to direct firing of the boiler with natural gas. The latter might buy a few years of extended life without imposing the economic burden of environmental retrofit. But increasingly, utilities are seeking a longer-term solution that bypasses expensive environmental controls yet brings additional benefits. They are seriously exploring repowering plants with combined-cycle technology for a number of reasons.

The most likely plant configuration involves replacing the coal boiler with a gas-fired turbine (GT) that feeds its exhaust into a heat recovery steam generator (HRSG), whose output is run through a steam turbine to increase both electricity production and overall plant efficiency. Where feasible, the existing steam turbine would be retained and refurbished to add another 20–30 years of operation. To reduce capital cost further, utilities would also attempt to retain as much as possible of the original balance-of-plant equipment, including the switchyard, administrative buildings, condenser, and source of cooling water.

THE STORY IN BRIEF

Repowering aging coal plants for gas-fired combined-cycle operation is a strategically important option for owners and operators that face expensive or problematic environmental upgrades. EPRI has studied the key factors involved in such conversions to clarify when they make the most practical, economic sense.

According to Dale Grace, EPRI senior project manager, "In the past 20 years, more than a dozen such repowering projects in the United States have utilized GT/HRSG technology." The popularity stems from the potential to create an essentially new unit at lower cost while gaining the benefits of higher efficiency, reduced emissions, increased operational flexibility, and additional capacity in comparison with the coal-fired predecessor.

The economics appear solid, even according to conservative assumptions. "Repowering saves about 20% of the capital cost compared with a brand new power plant, on a dollar-per-kilowatt basis," said Grace. "On a cost-of-electricity basis, it can save about 5%. Since fuel is still the lion's share (50%–60%) of this cost, the operational savings could be even greater if gas prices remain low."

Driving Forces

Two regulations recently promulgated by the EPA would require significant pollution control upgrades for many older plants: the Cross-State Air Pollution Rule (CSAPR) and the Mercury and Air Toxics Standards Rule. Although the CSAPR implementation schedule is working its way through the courts, the bottom line is that aging coal-fired plants will have to meet these new emissions standards or shut down.

Many plants are approaching the age at which it may no longer be economical to maintain them, with the equipment's age or technological obsolescence rendering it too costly to upgrade or to modify with new pollution controls. Emissions regulations may make it necessary to shut these units down earlier than planned or to retire them simply to make room for new units that are more efficient and environmentally compatible.

Even as this pincer action comes into play, new opportunities have been opened by the combination of advanced power-generation technology and low gas prices afforded by the boom in shale gas production. Grace points out that repowering with combined-cycle technology was examined in some detail in the 1990s, but it was not nearly as attractive as it is today. Environmental pressures at the time were mild in comparison, natural gas prices were volatile, and the domestic natural gas resource base was much smaller, with planners anticipating extensive imports of liquefied natural gas. Today, GT/HRSG repowering is a much more promising option for coal-based utilities looking to diversify their energy resource base.

Broad Benefits

The improvements made possible by repowering with GT/HRSG are quite broad. First and foremost is improved plant efficiency. Modern gas turbines operate with efficiencies in the range of 27%–36% (higher heating value, or HHV) in simple cycle. Adding an HRSG to convert the gas turbine's waste heat into steam to flow through the steam turbine raises overall plant efficiency to 40%–50% (HHV). The lower end of this combined-cycle range is typically above the higher end of the range for coal-fired plants (20%–40%).

Higher efficiency results in reduced fuel consumption and lower plant emissions. The improved low–nitrogen oxide (NOx) combustor technology of modern gas turbines, combined with selective catalytic reduction, can reduce NOx concentrations by a factor of 6 below the best-performing coal-fired units. With natural gas's negligible sulfur and ash content, repowering also reduces sulfur dioxide and particulate emissions significantly. Also, the switch from coal-fired operation to gas in combined-cycle mode dramatically reduces carbon dioxide emissions.

Operational flexibility is another key benefit. Increased reliance on renewable energy sources requires load-following plants capable of starting quickly. Renewable generation technologies, such as wind

The inventory of possible candidates for repowering is large. Worldwide, the number of potential candidates is estimated at 1,540 units, totaling some 273 GW of capacity. In North America, there is some 60 GW of coal-fired capacity over 30 years old for which repowering could be viable.

and solar, produce power under conditions that don't match fluctuations in demand. Wind power is particularly difficult to predict more than a hour or two in advance, so it's essential to have standby or quick-start power during peak demand.

Advances in gas turbines provide the capability to fast-start the engine, achieving full capacity from a cold start in about ten minutes, at least in simple-cycle operation. In combined-cycle mode, the rest of the power train becomes the determining factor. Start-up time increases substantially when an HRSG and steam turbine are added to the system, because these components require a more gradual start-up to match temperature and minimize thermal strain. However, newer HRSG designs will better accommodate fast-start cycling conditions. The steam turbine remains the primary component adversely affecting the overall start-up sequence. Even so, start-up duration and cycling ability should be much improved with a GT/HRSG unit in place of the original coal-fired plant.

An important aspect of combined-cycle repowering is the additional capacity resulting from gas turbine power trains. The existing coal plant uses a boiler to produce steam, which in turn drives the steam turbine—the only source of electric power generation. Replacing the boiler with one or more trains of GT/HRSG can double or triple plant capacity.

Absent the need for additional capacity, the economic case and impetus for repowering are diminished. "Repowering becomes particularly relevant in regions that need power," said Grace. "However, if there is excess capacity, due to wind and solar installation, for example, the additional capacity can be a drawback. This should be an early and central consideration for repowering. You can't turn a marginal coal plant into a profitable gas-fired plant if you don't have the market to begin with. Currently, a lot of regions in the country are right-sized. So if you generate excess power, you need to ask if there is transmission capacity to get it to a distant market."

Ideal Candidate

The ideal candidate for repowering, according to Grace, is relatively young—roughly 20–30 years old—with plenty of life left in the steam turbine, auxiliaries, and balance of plant. Promising candidates are often between 100 megawatts and 300 MW, with the steam conditions from the HRSG well matched to the capabilities of the steam turbine. Ideally, the steam turbine should be modern enough to handle subcritical conditions of 2,400 psi and 1,050°F steam. For every 100 MW of steam turbine capacity, Grace said, repowering will add about 100–200 MW of GT/HRSG capacity. Duct firing is often used to fill additional steam turbine capacity if the GT/HRSG steam output is not optimally matched to the steam turbine.

"Repowering of the type we are talking about assumes 20 to 30 years of service left in the steam turbine. Many owners will take an existing steam turbine and refurbish it to get a little more efficiency and extend its life. If it will last at least another 20 years, it is generally a good bet," said Grace.

Steam turbines generally hold up well if they are cared for. "Although nobody initially imagined they would get 50 years out of their steam turbines," said Grace, "in practice this is now happening. If you already have 40–50 years out of a steam turbine, a detailed condition assessment would determine whether you could get another 20-plus years."

Candidate sites would have the following assets:

- Critical subsystems, such as once-through cooling with sufficient margin to handle the additional heat rejection from the repowered plant and/or space to add cooling towers;
- A good natural gas supply;
- No transmission limitations;
- A spare bay in the switchyard or space to expand;
- Enough real estate to conveniently site the gas turbine and the HRSG; and
- An HRSG site close enough to the steam turbine to minimize piping runs.

Comparative Economics

A recent EPRI study considered the economics of a hypothetical redeveloped plant site, comparing the cost and performance of two repowering options. The objective was to provide a framework and methodology for utilities to use in a case-by-case assessment of options at various sites.

In the study, both options entailed repowering an old coal plant with a new GT/HRSG power train, but they differed in the extent to which original downstream equipment was replaced. The first option ("Brownfield") included procuring a new steam turbine, other process equipment, and auxiliaries, while the second ("Repowering") retained considerably more original equipment, including the steam turbine, auxiliaries, condenser and cooling system, electrical switchyard, foundations, and buildings.

As expected, Repowering offered considerable savings in capital investment. In aggregate, total project costs for this option were $461 million, versus $591 million for Brownfield. Net output was 2% lower with the Repowering project, reflecting the slightly lower efficiency of a system using older equipment. Capital costs were projected to be $763 per kilowatt (kW) for Repowering, versus $961/kW for Brownfield. The levelized cost of electricity was $77.91 per megawatt-hour for Repowering, versus $82.77/MWh for Brownfield.

In terms of project scheduling, Repowering was slightly faster. Elapsed time from the start of permitting to commercial operation was 39 months for Repowering, versus 42 months for Brownfield.

The study team, using sensitivity analyses, cautioned that initial project cost estimates are critical to the assessment outcome. For example, if the actual costs for the plant modifications were assumed to be 50% more than anticipated, the scale would tip, and the Repowering option would be projected to result in a total levelized cost of electricity $7/MWh more than the Brownfield option.

Vast Inventory

The inventory of candidates for repowering is large. Worldwide, the number is estimated at 1,540 units, totaling some 273 GW of capacity. In North America, there is some 60 GW of coal-fired capacity over 30 years old for which repowering could be viable.

Realistically, the opportunities are more modest. "A lot of utilities have already made the environmental investment in their bigger, more efficient coal plants. The ones under consideration for repowering tend to be the ones run on the margin," said Grace. "They come on line only at certain times of the year, and they don't represent as high a percentage of electricity production. They represent a large amount of capacity, but they are underutilized. The concern with these marginal plants is their environmental profile." The question facing utilities is whether the units' long-term value warrants upgrading environmental controls.

Each utility's situation is unique, but owners with aging coal plants face a set of near-term decisions. "The questions utilities are grappling with are not easy," said Grace. "The new regulations require them to decide whether to put a lot of investment into an old coal plant to clean up the stack, to retire it outright, to just run some natural gas into the boiler, or to repower. There is a significant upside to the repowering option, and fortunately there is enough experience out there among utilities and vendors to reduce the uncertainty about the investment. By consolidating some of the lessons learned and modeling the cost, performance, and scheduling of various repowering options, EPRI is easing the decision burden."

This article was written by Brent Barker. Background information was provided by Dale Grace, dgrace@epri.com, 650.855.2043.

Dale Grace is a senior project manager in EPRI's Generation Sector, specializing in research on gas turbine engines and combined-cycle power plants, including reliability and durability issues, technical risk mitigation, and operations and maintenance. Before joining EPRI in 1996, he worked at Combustion Power Company, performing process engineering and technical analyses for the design of fluidized–bed combustion boilers and associated environmental control systems. Grace received a B.S. degree from California State University at Fullerton and an M.S. in mechanical engineering from Stanford University.

THE PORT PLUGS IN

Innovations Help Savannah Move and Store Freight More Efficiently and Cleanly

Richard Cox, general manager of equipment and facilities for the Georgia Ports Authority, is a quiet, self-described "maintenance guy" who has led a quiet revolution at the authority's Port of Savannah Garden City Terminal. Since 2000, the facility's throughput of containers has grown rapidly, from less than 1 million twenty-foot-equivalent container units, or TEUs, to about 3 million. Its compound growth rate during that time has been more than 10%—nearly double the growth rate of other major U.S. ports. At the same time, the port is lowering its costs for energy and maintenance and reducing its emissions. The one-word answer to the question "How?" is "Electricity." For the details, *EPRI Journal* interviewed Richard Cox.

EJ: Let's start with your ship-to-shore cranes. With its boom up, your biggest crane is as tall as a 36-story building. Originally all of the cranes were diesel. Now you're switching to electricity. Please give us some background.

Cox: Diesel cranes provided that untethered ability for the gantry to move to wherever the ship needs to be berthed, but our first-generation cranes averaged 18 to 20 gallons of diesel fuel per hour, and then our second-generation cranes were 24 to 26 gallons per hour. About 1998, we began to research electric cranes. We bought our first two electric cranes as a test. Initially we agonized over how to provide this gantry crane with flexibility and travel, in view of the conductor size.

EJ: And by that you mean how best to provide an extension cord?

Cox: Yes. Typically at that time, cranes were powered with 4,160 volts and had travel of about 900 feet in either direction from wherever they were plugged in, given the cable reels then in use. During our research Georgia Power typically used 13,800-volt transformers. So I gambled and went with 13,800 to power our cranes. With a smaller conductor, which provided 2,300 feet of travel from the feed point.

EJ: That's a long extension cord. So you started with a couple of cranes, and how did they perform?

Cox: We discovered that for about $7 in diesel fuel cost back then, our electricity bill was only $1. So much energy with the diesels was wasted as heat. And any time we lowered a box or the spreader, we were loading the dynamic breaking resistors as heat. But with the electric cranes, we captured that energy when lowering the container and so "regenerated" electricity. For about 18 minutes of every hour of operation, the crane was actually feeding electricity back to the grid. We call that re-gen.

We also discovered we improved crane reliability. We went from 1.2% downtime to 0.5% downtime because we always had the cranes plugged in, the drives were always warm, and you're only using whatever power is needed for HVAC, lights, and so on. It really was a great decision.

EJ: And it was just plug-in power right off the grid.

Cox: One of our first challenges was to find a reasonably flexible and easy-to-handle 15,000-volt plug.

EJ: What other advantages did you see?

Cox: Since our cranes are on the river, we avoided diesel spills right on the water and we reduced maintenance. After about 35,000 hours, we'd need to replace a diesel, and it would run about $200,000 to $300,000 per crane—and that's not including the labor to install the replacement. Operators and everybody around the crane noticed the reduced fumes and how quiet it was—a much safer environment. Anybody who's ever worked around diesel knows that an emissions-free alternative is going to improve your work environment.

EJ: So that made the business case for repowering more cranes?

Cox: About 2003, 2004, we decided to convert seven of our existing diesel-powered cranes. Roughly 10 years ago, we were burning 7,500 gallons of diesel a day; today, as we've grown by a factor of three, and with a lot more mobile equipment, we're still at 7,500 gallons a day. When you think about the scale-up of our operation and being able to maintain fuel consumption, that's significant.

EJ: Talk about the role that Georgia Power has played in this.

Cox: They helped us get a dedicated power feed and a dedicated substation just for our cranes. Before, if someone out on the road hit a pole, we were out of business. We built a dedicated substation that had the flexibility for powering up to 27 cranes. Georgia Power provided us reliability, they provided us the foresight to plan ahead. Then, at our expense, they built a second, redundant feed. That's a huge advantage to us. We're typically the last port of call for a ship before

> **"We discovered that for about $7 in diesel fuel cost back then, our electricity bill was only $1."**

“But with the electric cranes, we captured that energy when lowering the container and so ‘regenerated’ electricity. For about 18 minutes of every hour of operation, the crane was actually feeding electricity back to the grid. We call that re-gen.”

the Panama Canal, and if it misses that window to go through the canal, it can mean a huge penalty.

EJ: In some respects, have the Ports Authority and Georgia Power come up the learning curve together?

Cox: Yes. With our business growing as fast as 16.6% a year, it put a real big demand on Georgia Power to be flexible and accommodating. Our single point of contact, Dale Holloway, he's been an excellent partner. He's the guy I call whenever we have a power issue—not necessarily power to the cranes, but to the whole terminal.

EJ: So you really do have a best friend at the power company.

Cox: Absolutely.

EJ: In addition to your big ship-to-shore cranes, you're looking to go electric with another kind of crane that is much more challenging to connect. Tell us about that.

Cox: They're called rubber-tired gantry cranes. Up to now they've been diesel powered, and they have the flexibility to go anywhere on the terminal. They're the cranes we use to stack the containers across the port. Because they can span across the containers stored on site, and because of their "digging ability" to reach containers down in the stacks, they're ideal for getting the maximum density of containers across the port. By the first quarter of next year, we'll have 116 of these RTGs, compared with the 11 we had when I started in '95. We're bringing in four electric-powered RTGs, or eRTGs, for our demonstration project.

EJ: What are the big questions you hope to answer with the demonstration project?

Cox: How to maintain our flexibility and yet go electric. A big question was how to connect these mobile cranes with the grid. We talked about using cable reels, but we never could figure out how to make it effective. Where you're crossing from one container stack to another, how do you protect the cable from being run over and damaged by the trucks navigating from one end of the terminal to the other?

It took a long time, but finally somebody came up with this demonstration bus bar. A stack of containers is typically 500 feet long, and then you've got a roadway, and then you've got another stack on the other side of the roadway, and so on across the terminal. The bus bar will extend the 500-foot length of a stack, and whenever you're in the stack, you're on utility power.

EJ: So instead of being tethered with an electric cable, each crane would need to maneuver to establish contact with a stack's mounted bus bar?

Cox: Yes. When you get to the end of the stack, the crane's diesel engine automatically turns itself on, syncs with the utility frequency, and then says, "I'm ready to transfer" and transfers from utility power to diesel. It has this attachment that drops down and retracts, and then the eRTG travels across the roadway. When it gets to the other stack, that attachment rises up and engages the bus bar and is back on utility power.

We're estimating that 95% of the time, the eRTG will be on utility power. The 5% of the time on diesel would be only when you need to move from stack to stack. But even better, you can also move from one row of containers to another row of containers, and that flexibility was the magic bullet.

EJ: So is the Georgia port here the first one to use these, or are there demonstrations elsewhere?

Cox: We will be the first one with this system in the U.S. Our finance people have said that if the eRTGs rely 70% on utility power, the payback could be less than six years. We should achieve the same benefits as electrifying the ship-to-shore cranes. We'll be able to regenerate electricity about 18 minutes out of the hour; we've got that same cost-benefit ratio, no diesel replacement, no diesel maintenance.

EJ: That's an electric vehicle like none other. But you're electrifying more than cranes.

Cox: Cranes are not our biggest utility cost. Last fiscal year we spent $1.6 million pro-

“We went from 1.2% downtime to 0.5% downtime. . . .”

Electric Cranes: Demonstration Project to Provide Data, Insights

The Georgia Ports Authority (GPA) and Georgia Power Company, a Southern Company, are engaged with EPRI's Non-Road Electric Transportation Program, which will collect and analyze energy data from four electric rubber-tired gantry cranes in regular operation at the Port of Savannah. These cranes are equipped with sensors and data-logging equipment that will operate simultaneously and continuously for 3–6 months, measuring engine performance, generator outputs, and GPS data to distinguish activity patterns. Researchers will evaluate the electricity needs and demand profiles of an expanded eRTG fleet and analyze costs and benefits of eRTGs versus diesel cranes.

In recent years, EPRI, GPA, and Georgia Power collaborated to demonstrate a prototype plug-in hybrid yard tractor and research the costs and benefits of electric ship-to-shore cranes and electric refrigerated racks in use in Savannah.

More information is available on epri.com, including these reports: *Electric Ship-to-Shore Cranes: Costs and Benefits* (enter product ID 1020510 in Search) and *Electric Refrigerated Container Racks: Technical Analysis* (product ID 1019926).
More on YouTube

Check out a brief video on EPRI's Non-Road Electric Transportation Research, featuring the Georgia Ports Authority and others. www.youtube.com/eprivideos

viding power to refrigerated containers, compared with the roughly $800,000 to power the cranes.

EJ: Which basically involves stacking containers in what you call reefer racks. Is this another area ripe for electrification?

Cox: Typically we'd have a 450-kilowatt diesel power pack that would plug in up to 30 containers. We're going to build 120 reefer racks across our terminal to plug those containers into the grid. We have 64 completed and another 20 being constructed this year.

EJ: You're looking across the operation, aren't you?

Cox: We looked at our high-mast lights, which used about $450,000 of power a year. We used to use high-pressure sodium, twelve 1,000-watt lamps per light pole. We're now converting to five metal halide lamps per pole, which will give us a 59% reduction.

EJ: Is all of this giving you a competitive edge among ports?

Cox: I've got to believe so. We are probably one of the most efficient terminals in the U.S.

EJ: And you're making life better for yourself. What's that called—enlightened self-interest?

Cox: As a maintenance guy who doesn't use all those fancy words—yeah, the idea was to eliminate every single point of failure, eliminate redundancy, and have different levels of protection, yet still be environmentally sensitive. We've got the ability to unplug our cranes and change the order of them, you know, and that's provided us with all this flexibility, all this ability to meet our customers' needs.

EJ: What's next?

Cox: We're going to need to use smart technology on our side of the meter—just as Georgia Power's doing on their infrastructure.

> **"Operators and everybody around the crane noticed the reduced fumes and how quiet it was—a much safer environment."**

Acoustic Mouse Targets High-Quality Imaging with Handheld Convenience

Nuclear and fossil power plants use periodic ultrasonic testing (UT) of plant components to conduct condition assessments, quantify service-induced degradation, and support run/repair/replace decisions. The technologies currently available to conduct such nondestructive evaluation generally fall into two categories: manual UT scanning, in which the examiner reports conclusions but may not record the ultrasonic data, and encoded (often robotic) scanning, which yields high-precision imaging and fully recorded ultrasonic results at a higher cost.

To provide the industry with a UT system that incorporates the advantages of both approaches, EPRI is developing a breakthrough "acoustic mouse" system that combines handheld convenience with high-quality imaging at reduced cost.

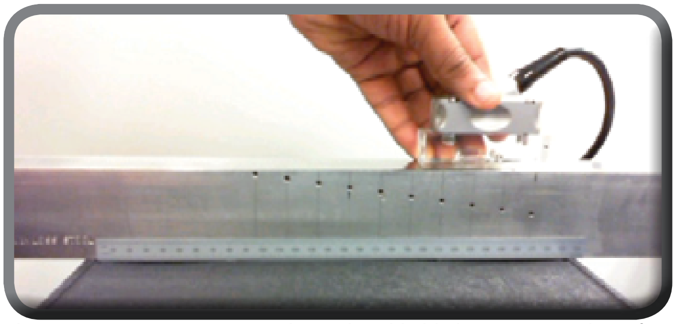
The Goal: Precise but Flexible

Conventional manual scans are qualified for detecting safety-significant cracking and other defects, but because they often provide no images for precise analysis and independent review, scan results are sometimes interpreted conservatively, which can lead to premature or unnecessary repairs and replacements.

Automated UT-based systems are generally more precise because they encode and record the exact position of the ultrasonic transducer as raw inspection data are collected. This technology allows accurate, 3-D data images to be constructed, manipulated, stored, and reviewed by independent analysts, often leading to better decision making. Unfortunately these systems require time-consuming setup, may experience mechanical breakdowns, can have difficulty encoding complex component geometries, and are sometimes too bulky to set up in parts of the plant where physical access is constrained. These factors may limit the scope of application and impact the timely completion of inspections during a planned outage.

Recent proof-of-concept experiments with the new acoustic mouse technology show that acoustic noise generated within a material may be used to track and uniquely identify an ultrasonic transducer's location at any specific time. This position-tracking capability will allow the manually applied sensor to match the accuracy of automated UT scanning systems without the need for a complicated stationary support structure. The system will allow an operator to manually pass an ultrasonic transducer over a component's surface and capture real-time computer-constructed 3-D images.

Researchers are developing advanced signal processing and recognition algorithms that are capable of identifying the unique ultrasonic reflectors associated with a component's internal features while accommodating the variations in their geometry. With these reference signals established, cracks and other types of degradation can be discerned, located, and measured. Synthetic focusing and de-noising algorithms are being developed to improve transducer placement and data reconstruction.



The acoustic mouse system employs a hand-held ultrasonic transducer for real-time 3-D imaging to detect, quantify, and monitor internal flaws with high precision.

EPRI is working to equip the acoustic mouse technology with an advanced probe that will allow it to attain optimal imaging precision without costly instrumentation. Achieving meaningful acoustic focusing in thick-section components requires the use of large probes; achieving maximum flexibility requires the use of phased-array probes with small elements. To respond to both needs, probes have generally called for a very high number of array elements and a high-end instrument to operate them. EPRI is developing a method for designing sparse-array configurations to produce equivalent results using a smaller number of array elements and less-costly instruments with a smaller number of channels.

Prototype Development

A fully functional acoustic mouse system prototype is now under development, with validation testing scheduled for early next year. By the end of 2013, acoustic mouse technology is slated to be ready for commercial licensing by ultrasonic equipment manufacturers through EPRI's Nuclear and Generation Sectors. Manufacturers are expected to use this ultrasonic tracking technology to integrate new nondestructive evaluation capabilities within their inspection product lines and conduct demonstrations and final qualification tests. EPRI will help coordinate the demonstrations and training and provide application-specific guidance for field-deployable acoustic mouse systems.

For more information, contact Mark Dennis, mdennis@epri.com, 704.595.2648; John Lindberg, jlindberg@epri.com, 704.595.2127; or Greg Selby, gselby@epri.com, 704.595.2595.

Advanced Coal Cleaning for Minimizing Plant Emissions

Environmental compliance for fossil-fired power plants has been achieved primarily with combustion- and postcombustion-based environmental control technologies such as low–nitrogen oxide (NOx) burners, selective catalytic reduction units, electrostatic precipitators, and flue gas desulfurization units. However, as regulators further ratchet down allowable levels for NOx, sulfur dioxide (SO_2), sulfur trioxide (SO_3), and hazardous air pollutants (HAPs), conventional solutions may have difficulty doing the job on their own.

Impending stringent water and solid residue regulations could also be a factor. For example, HAPs currently released into the flue gas stream during the combustion process are captured by sorbents injected into the gas and removed with the particulate control systems, or they are scrubbed out by wet flue gas desulfurization units downstream of the combustion process. In either case, the captured sorbent or process water may lead to potential issues with trace metals finding their way into aquatic environments.

EPRI believes that advanced coal-cleaning technology, when applied in concert with conventional environmental controls, could substantially improve pollution reduction capability, allowing plants to achieve near-zero emission levels. Current research is focusing on whether such systems could be both effective and practical for deployment at individual power plants.

Avoiding the Gas Phase

For decades, most bituminous coals used for steam production have undergone some level of cleaning to meet a power plant's fuel specification, which typically limits sulfur, ash, moisture, and sometimes chlorine content. This is achieved through a variety of physical and mechanical processes collectively referred to as washing: the raw coal is crushed, and impurities are separated out with screens, centrifuges, and flotation tanks to produce a dry fuel that is then transported to the plant. Burning such conventionally cleaned coal can modestly reduce a plant's sulfur emissions. Advanced coal-cleaning technologies go much further, using thermal, mechanical, magnetic, or chemical processes to remove organically bound sulfur and heavy metals such as mercury, selenium, and arsenic, which make up the HAP inventory.

Removing mineral matter and associated pollutant precursors before the coal is burned can make them easier to control. While the treatment of mercury with sodium-based sorbents provides an effective capture solution, for instance, the fate of the adsorbed mercury and related sodium species could be a potential future water quality concern. Precombustion coal cleaning to reduce the concentration of sulfur and heavy metals in the feedstock fuel reduces the conversion of these compounds from their stable solid forms to gases or liquids.

EPRI Research

Advanced coal cleaning currently is at an early to intermediate stage of development, where gaps in technology and barriers to implementation are numerous. For example, the flotation technologies widely used in coal-cleaning operations are typically too large to be sited at a power plant; additional work is needed to investigate their maximum efficiency and capacity constraints. While sulfur and ash removal is reasonably well understood, much more information is needed on the removal of HAP precursors, including effectiveness with different types and grades of coal. And generally, advanced options—including magnetic and triboelectric separation—will require additional development, with demonstration at pilot and full scale.

The objective of EPRI's work is to assess the technical and economic feasibility of implementing advanced coal-cleaning technologies at existing power plants. The project results will determine if this approach, when combined with existing postcombustion controls, can produce near-zero emission levels, provide plant efficiency gains, and improve overall system economics.

Research will first evaluate existing plant characteristics—such as design, equipment limitations, available space, and operating features—for adapting to a range of coal-cleaning concepts. A feasibility assessment will follow for retrofitting a selection of these concepts into existing and new facilities. The most promising designs will be further developed and tested at bench and pilot scale under EPRI's near-zero emissions effort, the NZE Technology Innovation Strategic Program. Full-scale demonstrations and technology commercialization will be pursued through strategic alliances with power producers and technology suppliers.

For more information, contact Jose Sanchez, josanche@epri.com, 650.855.2143.

Nanotech Coatings Reduce Ice on Transmission Equipment

Transmission lines face a weighty problem during winter storms. Ice formation on conductors makes them substantially heavier, causing them to sag and—in extreme cases—even break if buffeted by strong winds. Ice on insulators is problematic as well, potentially bridging out insulators when it melts, which can lead to flashovers.

To avoid contamination flashover of insulators under marine pollution conditions, utilities have for decades used hydrophobic (water-repelling) materials on insulation in harsh environments, including silicone rubber composite insulators and room-temperature vulcanized (RTV) silicone coatings for porcelain or glass. Such materials cause water to bead up on a surface rather than forming a continuous film that together with the contamination can create a conductive surface.

Research on nanostructured polymers has produced superhydrophobic and ice-phobic coatings that have already been applied in the aircraft, shipping, and building industries—for example, to prevent ice buildup on aerospace vehicles and to provide self-cleaning properties for windows. EPRI is now pursuing research to evaluate this new breed of coatings and determine their suitability for transmission and distribution applications.

Initial Testing

Researchers mapped out a three-tiered testing program to evaluate the coatings, first at small scale on coated material samples, then at full scale on coated components (actual conductors and insulators) in the laboratory, and finally in field demonstrations on systems at utility sites.

The Tier 1 insulator tests have now been completed at EPRI laboratories in Charlotte, North Carolina, and Lenox, Massachusetts. Coatings from different vendors were applied to flat samples of toughened glass, which was selected because its surface is similar to that of both glass insulators and the glaze on porcelain insulators. The samples were cut to different dimensions, depending on the tests being performed.

The Tier 1 program included 14 different tests to investigate the coatings' capabilities and durability over the life of an insulator. The tests addressed the following specific properties: scratch, abrasion, and impact resistance during storage, transport, and installation; ability to withstand degradation in the field caused by extreme sunlight, humidity, temperature, snow, and ice and by unusual electrical activity, such as corona effects and dry-band arcing; and ability to improve insulator performance by inhibiting ice and snow buildup on both the surface and the contamination layer or by conferring self-cleaning capability.

Each vendor used different technologies to achieve the samples' hydrophobic surface properties. The test subjects included two superhydrophobic coatings, two self-cleaning coatings, and three conventional RTV coatings. One uncoated sample and the samples with RTV coatings—commercial products currently used in substations—were included as controls.

Continuing Work

The test results indicated that the new coating technologies are feasible for utility application, but not all performed equally well. The Tier 1 insulator tests are being expanded to include coatings from seven vendors, with some test repetition to increase confidence in the results.

Tier 2 testing is being initiated on all of the seven vendors' insulator coatings, with coated insulator discs and spools undergoing high-voltage sparking and flashover tests, salt fog tests, and corona tests. Resistance to icing, ultraviolet exposure, and contamination is also being investigated, as well as mechanical damage related to handling, shipping, and installation.

In addition, Tier 1 tests are being initiated on conductor materials, with a focus on coating penetration, emissivity, dielectrics, expansion, mechanical strength, contact resistance, and wear resistance. The coated conductors will be tested under a variety of icing, wetting, ultraviolet, temperature, and corona conditions.

The potential benefits of ice-phobic coatings include increasing the reliability of both new and existing assets by reducing insulator flashovers and conductor failures. The coating technologies also promise to reduce the conductor and structure ice loadings that impose design limits on transmission line structures and foundations; lower loading requirements can reduce the cost per mile of construction.

For more information, contact Andrew Phillips, aphillip@epri.com, 704.595.2728.

New Tablet App for Valve Maintenance

Keeping nuclear plant maintenance crews up to date on equipment details and best practices is important to ensuring high levels of reliability—a task made more difficult by aging of the industry's workforce, continuing personnel turnover, and increased outsourcing of support staff. Plants have traditionally relied on Nuclear Maintenance Application Center (NMAC) guidelines that cover equipment disassembly/reassembly instructions, inspection criteria, troubleshooting procedures, and preventive maintenance tasks for common plant components. The NMAC guidelines, based on years of operating experience from around the world, have generally been delivered in the form of technical reports and maintenance workshops.

Responding to a cultural shift as the industry transitions from paper to digital technology solutions for day-to-day plant tasks, EPRI is looking beyond hard-copy reports, pdfs, and PowerPoint presentations to portable digital apps that can deliver information and guidance to maintenance workers when they most need it—while performing maintenance. The first of these new interactive products is based on the previously published *NMAC Air-Operated-Valve Maintenance Guide* (1016682) and *NMAC Valve Positioner Maintenance Guide* (1003091).

Versatile and Easy to Use

Designed for use with desktop, laptop, or tablet devices, the valve maintenance app can serve a variety of member needs.

The app's portability is expected to make it an unparalleled field support tool. Its contents include equipment details that can enhance familiarization with components and assist site workers with procedural protocols and component troubleshooting. Immersive, interactive task-based routines outline each step in a maintenance sequence, from component disassembly to inspection, repair, and reassembly. Animated, user-controlled views enable exploration and afford a realistic perspective on equipment as it is likely to be encountered in the field. Pop-up boxes that highlight important tasks and cautionary measures reinforce user knowledge and retention.

The app can assist in training and evaluating new maintenance personnel and provide a quick refresher on infrequently performed tasks for the seasoned worker. The highly interactive format allows personnel to assimilate knowledge at their own pace and from any location—no travel required. Any-time access allows workers to quickly orient themselves on the day's upcoming tasks and brush up on particulars beforehand. And because the guide is in digital form, the product can be quickly downloaded for immediate installation and use by members. The product is fully self-contained, and no additional software is needed.

The tablet app's 3-D equipment visualization helps familiarize maintenance workers with components, disassembly/reassembly, and troubleshooting.

First of a Series

While of immediate value to members, the air-operated-valve maintenance app will also provide a model for other guideline modules that will focus on equipment of high industry priority. Like the valve app, these new modules will draw on information contained in the existing NMAC library of maintenance guides and insight from industry experts. Advanced knowledge elicitation and capture techniques, combined with virtual reality 3-D presentation concepts, result in high-value products that can be accessed in real time, on site, using tablets and laptops.

Benefits to users include better job planning, improved worker efficiency and productivity, and cost reduction. In cases where maintenance must be done in irradiated zones, the better preparation and faster job completion can also result in significant radiation avoidance for workers.

The air-operated-valve maintenance app is available in both Windows (1025544) and Android (1025238) formats and can be downloaded by members from www.epri.com. Foreign language versions are also under development for use by international members.

For more information, contact Mike Pugh, mpugh@epri.com, 919.812.5162, or Nick Camilli, ncamilli@epri.com, 704.595.2594.

Advanced Modeling to Increase Bat Protection at Wind Sites

While bird fatalities were a big environmental concern in the early days of wind power development, a decade of research has shown that bats—which have an important role in the control of agricultural and health pests—represent another significant ecological risk. Of North America's 45 bat species, 11 have been documented in fatalities at wind sites, mostly in late summer and early autumn during migration. Bat fatalities are of growing concern to federal and state resource agencies, especially because of the spread of white-nose syndrome, a fungus that has caused death among cave-dwelling bats and may cause listing of additional species as endangered or threatened.

Concerns about bat mortality have put some wind power projects on hold, and the economic viability of some operating wind farms has been hobbled by broad-brush mitigation strategies, such as restricting wind operations during bat migration. For example, preliminary studies indicate that delaying the start of energy generation from the point where wind speeds reach 4.0 meters per second until they reach approximately 5.5 m/sec could reduce mortality by 50% or more during fall migration, but this approach may result in generation losses.

EPRI research is developing a more nuanced approach based on a bat detection system that allows turbines to be paused for short, defined periods rather than kept out of service through longer-term curtailments.

An Integrated System

The automated bat detection system uses an array of ultrasonic microphones mounted on the nacelle of the turbine to detect the calls that bats use to navigate and find prey. In 2010, EPRI tested a small array of microphones near the Cedar Creek Wind Resource Area in Colorado. The microphones were able to detect the bat calls and were not adversely affected by ambient or wind turbine noise. In a follow-up study at a Texas wind energy facility, four detectors mounted on two turbine nacelles detected bats within the entire sweep area of the wind turbine blades.

In the most recent field work, researchers installed ultrasonic microphones on four turbines at We Energies' Blue Sky Green Field Wind Energy Center in Wisconsin to record bat calls. Data from this phase are being used to develop the Bat Detection and Shutdown System, which will predict potential bat mortality by combining real-time bat activity with real-time meteorological data such as wind speed, temperature, humidity, precipitation, and visibility. By enabling operators to idle turbines more precisely, the detection system will potentially allow greater power generation than is possible with current shutdown protocols, with comparable levels of bat conservation.

Ultrasonic microphones coupled with sophisticated modeling software allow wind turbines to be automatically shut down when bat activity is detected.

Testing the Model

Researchers at the Blue Sky site will evaluate the effectiveness of the model as part of a bat mortality study involving 30 normally operating turbines and the 4 turbines instrumented for bat protection. "We'll monitor bat fatalities at those 30 turbines, as well as those from turbines using ultrasonic microphones to trigger turbine curtailment," said Sue Schumacher, senior ecologist at We Energies. "So we'll have two sets of data taken at the same time from the same wind farm. By comparing the results, we'll learn whether the controlled turbines offer better protection and will be able to fine-tune the predictive model for improved outcomes."

The primary goal is to reduce bat mortality at existing wind turbines and to address resource agency concerns regarding wind energy facilities. The system could also support effective ecological assessments before wind power projects are built and provide monitoring at new wind energy facilities.

For more information, contact John Goodrich-Mahoney, jmahoney@epri.com, 202.293.7516.

More on YouTube

Check out this brief video showing the installation of bat detection equipment on Wisconsin wind turbines.
www.youtube.com/eprivideos

Water Quality Trading Pilot Cleared for Launch

In August, representatives from Indiana, Kentucky, and Ohio signed a plan that will allow the first-ever trading of water quality credits under common interstate rules. Developed under EPRI's Ohio River basin water quality trading project, the plan provides a framework for these states to begin pilot trades through 2015. This will allow testing of different trading mechanisms in advance of new and potentially more stringent water quality criteria and permit limits.

Similar in concept to air emissions trading projects that helped resolve acid rain problems in the 1990s, water quality trading is a market-based approach that enables facilities facing high pollution control costs to buy reduction credits from entities that can achieve the same results at a lower cost. The goal is to achieve substantial water quality improvement in the most efficient way.

"The states in the Ohio River basin, working through the Ohio River Valley Water Sanitation Commission (ORSANCO), have a proud record of collaboration to improve water quality in the Ohio River and its interstate tributaries," said Peter Tennant, executive director of ORSANCO. "The initiation of a water quality trading program is the latest chapter in the effort to find innovative and cost-effective approaches to environmental improvement, and success here could serve as a model for interstate trading elsewhere."

Focus on Nutrient Loading

High concentrations of nutrients such as nitrogen and phosphorus can cause uncontrollable algal blooms in aquatic environments, consuming much of the oxygen needed by marine life for healthy growth. The nutrients that can impact water quality in the Ohio River basin come from many sources, including power plants, wastewater treatment plants, urban stormwater, agriculture, and even sources outside the basin. Because of the large number of sources and the high nutrient loading in some basins, improving water quality will require collaboration among many stakeholders. In addition, coordinated efforts among state, regional, and federal regulatory agencies are critical in addressing how interstate trading will occur.

EPRI launched its Ohio River basin project in 2009 as a comprehensive, scientific approach to developing reduction credit markets for nitrogen and phosphorus. The current pilot project focuses largely on farms to encourage agricultural conservation practices; such best practices, which reduce runoff of nitrogen and phosphorus generated by crop fertilization, offer one of the most effective and least costly ways to keep nutrient loads from ending up in the river basin.

"This trading plan is a win-win for utility companies, agriculture, and ultimately consumers and the environment," said American Farmland Trust president Jon Scholl. "For farmers, water quality trading creates opportunities to work within their communities to implement conservation practices that improve water quality and protect and enhance valuable farmland soils."

"For power producers, trading provides a cost-effective option for meeting nutrient reduction targets," added Jessica Fox, senior scientist for EPRI's Water and Ecosystems program. While these near-term benefits are attractive, Fox said, the longer view holds considerable gains as well: "In addition to improving water quality, the trading program and the practices it supports can help restore wildlife habitats, reduce greenhouse gas emissions, curb topsoil losses, and provide financial support for farmers and local counties."

Program Expansion

Pilot trades over the next few years are expected to involve at least three power plants or other participants and up to 30 farms implementing agricultural conservation best management practices on up to 20,000 acres. Nutrient reductions are expected to total approximately 45,000 pounds of nitrogen and 15,000 pounds of phosphorus annually. At full scale, the project could include up to eight states in the Ohio River basin and would potentially create credit markets for 46 power plants, thousands of wastewater facilities and other industries, and approximately 230,000 farms.

For more information, contact Jessica Fox, jfox@epri.com, 650.855.2138.

Representatives sign up Indiana, Kentucky, and Ohio for the first interstate water quality trading program at an August 9 ceremony in Cincinnati.

TECHNOLOGY AT WORK

Member applications of EPRI science and technology

EPRI Helps Chubu Electric Manage Seawater Intrusion Damage

Nuclear reactors situated in coastal areas typically use seawater for condenser cooling. The water chemistry of boiling water reactors is carefully monitored to ensure, among other things, that none of this seawater enters into the water of the reactor or spent fuel pool, as the presence of chloride and other impurities can quickly corrode internal reactor and fuel pool components. When Chubu Electric Power Company experienced a large-scale seawater intrusion event, EPRI was able to offer rapid-response technical expertise to successfully diagnose and manage water chemistry issues and avoid reactor damage.

Chubu Hamaoka Power Plant

Timely Technical Support

In May 2011, Japan's prime minister ordered Chubu to shut down its Hamaoka-5 plant as a precautionary measure in the wake of the devastating tsunami that damaged the Fukushima Daiichi nuclear complex. The shutdown was proceeding normally until a recirculation piping end cap failed from fatigue due to a manufacturing defect. The dislodged end cap struck and damaged condenser tubes, allowing seawater used for cooling to rapidly enter the reactor.

At the time of the end-cap failure, EPRI staff were visiting Hamaoka to review post-Fukushima safety enhancements. Chubu requested EPRI's assistance in evaluating technical options for responding to the seawater intrusion. EPRI was well positioned to offer assistance, as it tracks seawater and other intrusion events worldwide, documenting their severity and impacts on fuel and materials. EPRI's response drew from a vast collection of data on plant design, operating practices, chemistry control, corrosion mitigation, and dose rates—information that is included in EPRI's *BWR Water Chemistry Guidelines.*

EPRI Recommendations

Information from the Hamaoka event was sent back to the United States on the evening of the request, and a preliminary response was received less than 15 hours later.

Reducing levels of chloride in the reactor water was the most urgent task. EPRI provided recommendations for operating cleanup water filter demineralizers and resin mixtures to reduce levels, as specified in the water chemistry guidelines. When chloride levels unexpectedly increased again, EPRI identified the source as the residual heat removal/shutdown cooling system, whose piping contained some salt water from the suppression pool. Combining these recommendations with its own findings, Chubu was able to implement countermeasures to prevent further seawater intrusion to the reactor.

To reduce the levels of corrosion products (crud) in the reactor coolant, EPRI suggested using optimized resin mixtures that had been applied successfully for shutdown crud cleanup at U.S. nuclear plants experiencing seawater intrusions. EPRI also recommended that the cleanup water filter demineralizer system remain in service to clean up impurities in the reactor water and to gradually clean up the crud in the reactor coolant. As a result of these and other actions, Chubu successfully reduced reactor water impurities to levels within the chemistry specifications.

Further recommendations involved the temporary installation of a portable reverse osmosis system and a mixed-bed processing system to clean up the salt water inventory in the main condensers; suggested approaches for recycling or discharging the reverse osmosis permeate were also provided. EPRI advised that cleanup could be achieved in steps by pumping contaminated water from the event to the radwaste storage area and processing it there for either recycle or discharge.

"The seawater intrusion at Hamaoka-5 was unprecedented in Japanese nuclear history," said Yoshihiro Ichikawa, general manager of the operations and maintenance group at Chubu. "EPRI's rapid response helped us collect the necessary information so we could organize and implement appropriate countermeasures. Among other things, EPRI's practical recommendations on cleanup of chloride and other impurities in the reactor water were instrumental in verifying the relevance of our cleanup strategy."

EPRI is continuing to work with Chubu to monitor and assess the reactor chemistry and resolve remaining issues. The Hamaoka seawater intrusion response is expected to contribute significantly to the state of knowledge around the impacts of such events.

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

Life-Cycle Extension of F-Class Gas Turbine Components

Efforts to boost gas turbine efficiency in the 1990s involved higher firing temperatures, which led to durability problems in the hot-section components of F-class turbines. Problems with F-class units, primarily in the first row of blades, or buckets, have been systematically resolved over the last decade, but there is growing awareness that the criteria for establishing a component's usable life might now be overly conservative, leading to premature equipment retirement. The current recommendation for first-row blades is two 24,000-hour run intervals, with blade refurbishment between the intervals. EPRI is exploring this issue to determine whether the useful service for such F-class components could be confidently extended to a third run period.

Hot-section modifications have focused primarily on improved blade cooling. Some original first-row blade designs had a metallic coating, which tended to oxidize prematurely on the leading edge. This problem was corrected with the addition of cooling holes and later with the addition of a thermal barrier coating. The formation of cracks in the lowermost hole of the trailing edge was addressed with a platform undercut and adjustment of the holes to more effectively cool the surrounding material. Cracks and coating spallation on the platform were reduced by directing more cooling flow through the platform and by improvements in coating processing.

These modifications appear to have been effective, but it has not been established whether repair techniques and structural modifications can restore a significant portion of the original component life or enable additional operation cycles at low risk. EPRI's life-cycle extension study is using a broad spectrum of techniques to provide the answers.

Study Design

The evaluation involves a multidisciplinary approach to hot-section life management, which assesses the component condition and the possible risks involved with extending active service life. The assessment draws information from many sources: design analysis (durability, weak points, and limitations of materials and coatings), inspection parameters (frequency, location, limits, and tolerances), service history (baseload duty, cycling duty, turbine inlet temperature, and hours of operation), and repair techniques (welding, brazing, and heat treatments).

The study uses the Hot Section Life Management Platform (HSLMP), which was developed explicitly to handle the advanced design techniques and systems found on all F-class hot-section components. The HSLMP integrates aerothermal modeling, durability modeling, and test results. To obtain critical temperatures and stresses for any given design, the platform relies on finite-element analyses and computational fluid dynamics programs similar to those used by the original equipment manufacturers.

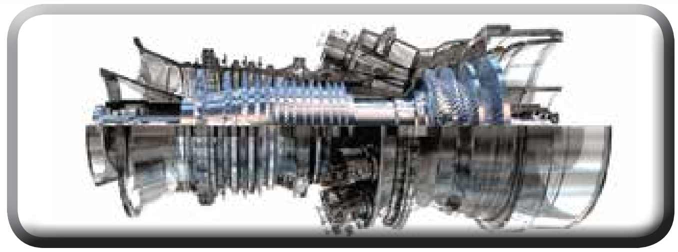


Photo courtesy of GE Energy. © All rights reserved. Flex Efficiency 60 & 7 F 7 Series Gas Turbines

The ongoing process of condition evaluation relies on several methods of assessment: visual inspection, nondestructive measurements of internal and external coatings and cracks, metallurgical analysis, and mechanical tests of fatigue and creep rupture. A key feature of this aggressive plan is to perform each of these tests and inspections at successive intervals, establishing a baseline that can be applied to other blade sets, stationary vanes, and turbine stages.

Early Results

The study is being conducted with the direct involvement and cooperation of an operator of a large fleet of F-class turbines. To date, the aerothermal modeling of original and modified rotating blades operating within the host fleet has been completed, as well as a similar analysis of the first-stage stationary-vane segment. An initial assessment of thermomechanical fatigue and creep damage has been made for all of the sets of first-row blades currently in service. Damage tracking is ongoing. Inspections and metallurgical examinations have been completed for blades that have seen a first and a second service interval.

The results have been positive and promising, indicating that a third interval of service is feasible through a combination of the following procedures: swapping blade sets between machines, upgrading earlier designs with additional cooling and stress-relief strategies, ensuring conformance to critical tolerances, and undertaking prescribed repairs. More details of the study are available in "Extending Useful Life of F-Class Gas Turbine Components," from the *Proceedings of ASME Turbo Expo 2012,* June 11–15, Copenhagen, Denmark.

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Perspectives on electricity

Entergy and the Gulf Coast: Big Picture Thinking—and Action—Required for Resilient Infrastructure

Mark Savoff, *Executive Vice President and Chief Operating Officer, Entergy Corporation*

Photo courtesy of Entergy Corporation

The damage and injury wrought by hurricanes Isaac and Sandy are heartbreaking reminders of the need to build more resilient coastal communities, to adopt a vision that emphasizes long-term sustainability in the face of rising seas and violent storms.

If a positive can be found amid these disasters, it is that the issue of coastal resiliency and adaptation has finally moved to the national stage after years of being dismissed as simply a parochial concern.

But from our perspective on the Gulf Coast, it has always been an issue with true national implications. The Gulf Coast is home to roughly $2 trillion in assets—which make up a large part of the nation's energy infrastructure—and the figure is expected to grow to $3 trillion by 2030. Nearly half of the nation's crude oil refining capability, two of the world's largest ports, and much of the nation's domestic oil and gas production are located in the region.

Entergy jump-started discussion of the issue more than two years ago by commissioning a $4 million study that was the first comprehensive analysis of climate risks and adaptation economics for the Gulf Coast.

The report, *Building a Resilient Energy Gulf Coast*, provides a roadmap for stakeholders on how best to address the risks posed by a changing environment and how to build a more resilient Gulf Coast. It spells out how the Gulf Coast economy could face approximately $350 billion in cumulative losses by 2030 from growing environmental risks. Put another way, the potential cumulative losses are enough to rebuild New Orleans six times over or build 700 Superdomes.

The region is already experiencing some of these losses. The study found that 77 coastal parishes and counties—stretching from Texas to the Florida Panhandle—currently suffer annualized losses of some $14 billion, an amount that could increase by 65% over the next two decades because of economic growth, subsidence, loss of coastal wetlands protection, and climate change.

The study identifies economically sensible adaptation investments that can stem the increase in annual losses between today and 2030 and keep the risk profile of the region constant. For example, an investment of $50 billion in cost-effective measures over the next two decades—including improved building codes, beach nourishment, and roof cover retrofits—can avoid about $135 billion in annual losses over the lifetime of the implemented measures. Economic analysis we've commissioned shows that given the impact these losses have on the overall economy, many of the proactive adaptation investments are highly cost-effective, with benefit-to-cost ratios exceeding five to one.

To help build political and community support, Entergy, America's Wetland Foundation, and its Blue Ribbon Resilient Communities task force held 11 community meetings over the course of nearly two years to gather input on how to move the issue forward.

Recommendations gathered during the meetings were compiled in a report, *Beyond Unintended Consequences*, presented September 12 to a congressional delegation in Washington, D.C.

You will never be able to manage a risk you don't see coming or that you deny exists. It's vital that we put ourselves into a risk management frame of thinking, test ourselves against future scenarios that consider environmental vulnerability, and see how prepared we are for managing these risks. There are cost-effective ways we can take risk off the table.

As Wayne Leonard, Entergy's chairman and chief executive officer, has said: "Doing nothing is not an acceptable plan. That's a plan to put Entergy out of business, a plan for misery and suffering for our customers, and a plan that would devastate a region already economically impaired."

It's past time for industry, government, and nonprofits, working together, to take action to protect the nation's economic assets and energy security.

REPORTS & SOFTWARE

Key deliverables now available

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

Guidelines for Nuclear Plant Response to Earthquake (1025288)

Incorporating the last 20 years of global experience with large earthquakes, these earthquake response guidelines update EPRI report NP-6695, issued in December of 1989. The new guidelines prescribe immediate actions to determine the need for plant shutdown after an earthquake, provide procedures for evaluating earthquake effects on the plant, and define criteria for timely plant restart. They also offer guidance on long-term evaluations, which, in most cases, can be performed after plant restart.

Full-Scale SCR Mercury Speciation Testing (1025349)

Understanding interlayer speciation effects is important for developing catalyst management strategies that maximize mercury oxidation. This report evaluates mercury speciation throughout a full-scale, commercially operating selective catalytic reduction (SCR) system at a unit burning a low-sulfur bituminous coal. The study measured speciation at the SCR inlet, outlet, and all interlayer locations. Preliminary data show that all four catalyst layers participate in mercury oxidation.

Solar Photovoltaics Market Update, Volume 3: Fall (1025411)

This report synthesizes data from multiple sources to highlight industry developments that are likely to impact utility solar PV investment and planning efforts. Specifically, it covers recent PV pricing and cost trends, an apparent rise in concerns over equipment and installation quality, and strategies for high-penetration PV management that are being used in Germany—the world's leading solar market. It concludes with a summary of emerging low-concentration PV technologies.

Applying an Integrated Risk Management Approach to Risks from Severe Geomagnetic Disturbances (1026427)

This white paper describes an equipment retrofit project—the installation of neutral resistors in the ground connection of high-voltage transformers—that could reduce the risk of equipment damage from a severe solar storm. The risk management approach illustrated in this case could be extended to examine a broader portfolio of retrofit projects for transformers and other equipment and could be useful for projects that incorporate power system operational strategies.

Evaluation of Methods for Characterization of Biomass Fuels (1026460)

Currently, there is no universally accepted suite of methods for biomass testing in the United States. This report identifies test methods for biomass characterization that are acceptable and reproducible. It reviews existing standard methods for determining combustion characteristics for biomass fuel and for characterizing the chemical composition of common biomass materials. Biomass properties that can cause slagging during combustion are highlighted.

Technology for the Examination of Boiler Tubing Dissimilar Metal Welds, Revision 1 (1026538)

This report documents an EPRI project that evaluated seven ultrasonic approaches for examining dissimilar metal welds in the high-temperature tubing of fossil-fuel-fired boilers, including welds fabricated with 300-series (austenitic) filler metal, welds fabricated by the induction pressure welding process (no filler metal), and welds joined with a nickel-based filler metal. These ultrasonic approaches were found to offer significant improvements over conventional examination techniques for detection of service damage prior to failure.

Investigation of Strategies for Mitigating Radiological Releases in Severe Accidents—BWR Mark I and Mark II Studies (1026539)

This report assesses strategies to maintain BWR Mark I and II containment systems as effective barriers to the release of radionuclides that contribute to land contamination following a beyond-design-basis accident; the assessments assume that reactor core damage has already occurred. The strategies evaluated include water injection by flooding or spraying, alternative containment heat removal, venting, controlled venting, filtered venting, and combinations of these actions.

Bulk System Reliability Assessment and the Evolving Smart Grid (1026544)

As smart grid implementation continues, reliability assessment models, metrics, and analysis methods will be vital in determining the benefits and impacts of potential system designs. This white paper provides a summary of insights and concerns expressed by utility, regulatory, vendor, and academic participants at two exploratory workshops focused on the evolution of these tools. A framework for advancing the development of new models, methods, and metrics is included.