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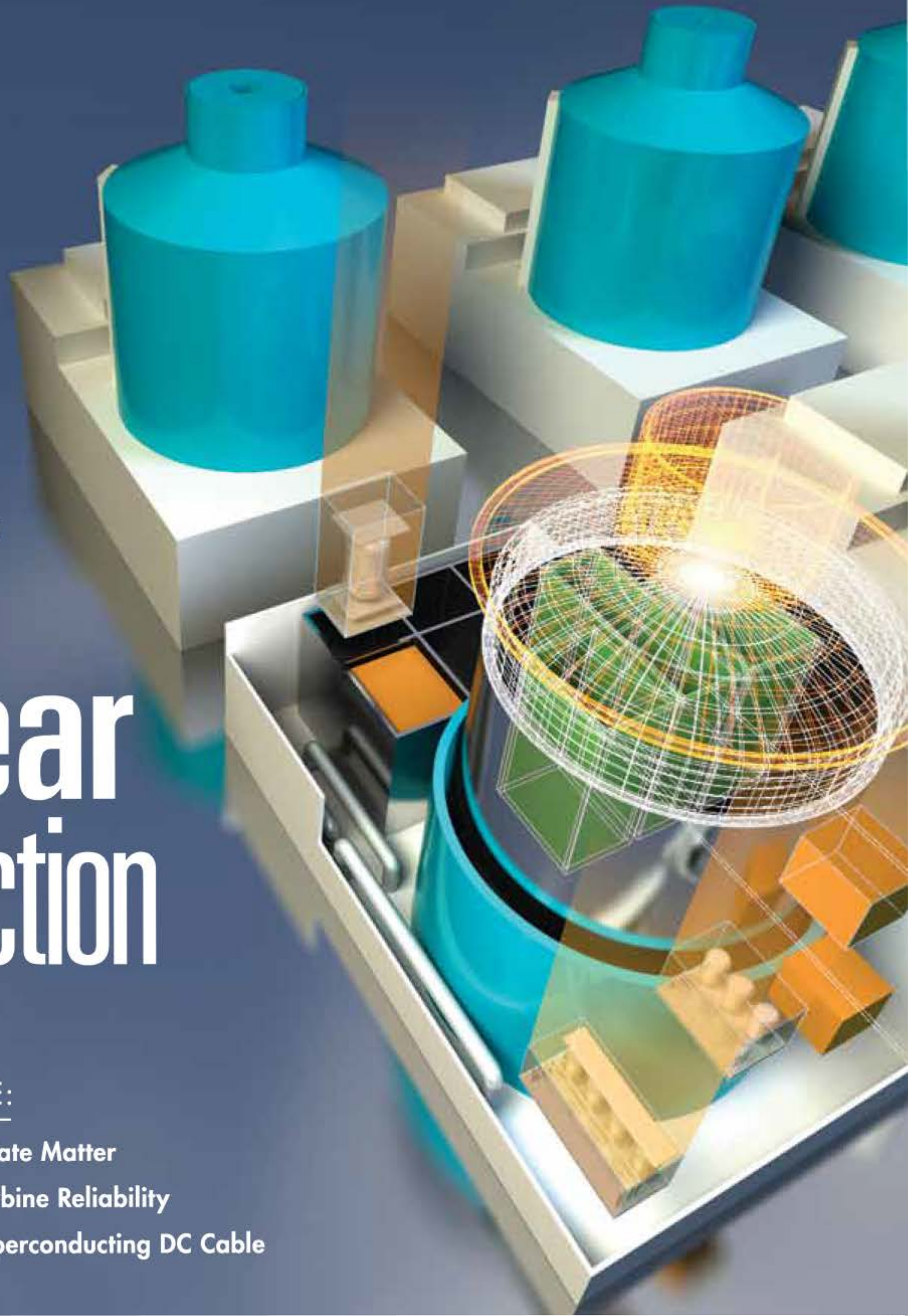

Modular **Nuclear** Construction

ALSO IN THIS ISSUE:

ELECTRIC POWER
RESEARCH INSTITUTE

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

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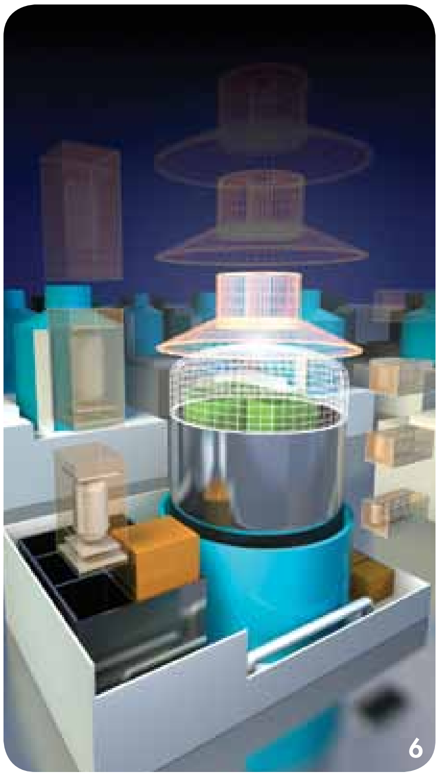

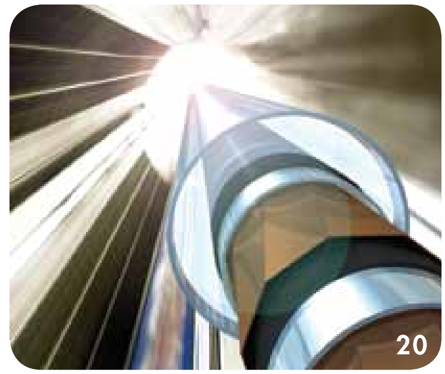

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VIEWPOINT

by Steve Specker, President and CEO, EPRI

Powering the Collaborative...The Inside Story

To fulfill EPRI's mission, we must continually increase the value our members derive from their participation in EPRI research and development programs. This requires that we focus on

- Simplifying our organization and operations;
- Broadening participation in our collaborative programs;
- Strengthening technical programs and staffing; and
- Enhancing the transfer of technology to our members.

The metrics to date indicate good progress in these areas, and member satisfaction surveys show a strong trend of increasing member value. But numbers tell only part of the story.

I wanted to make my own qualitative assessment of the health of the EPRI collaborative. To do this, I spent time during the past several months going "inside the collaborative" by participating in what I consider to be EPRI's most important and unique process—the semi-annual program advisory meetings. Here is the inside story on what I found.

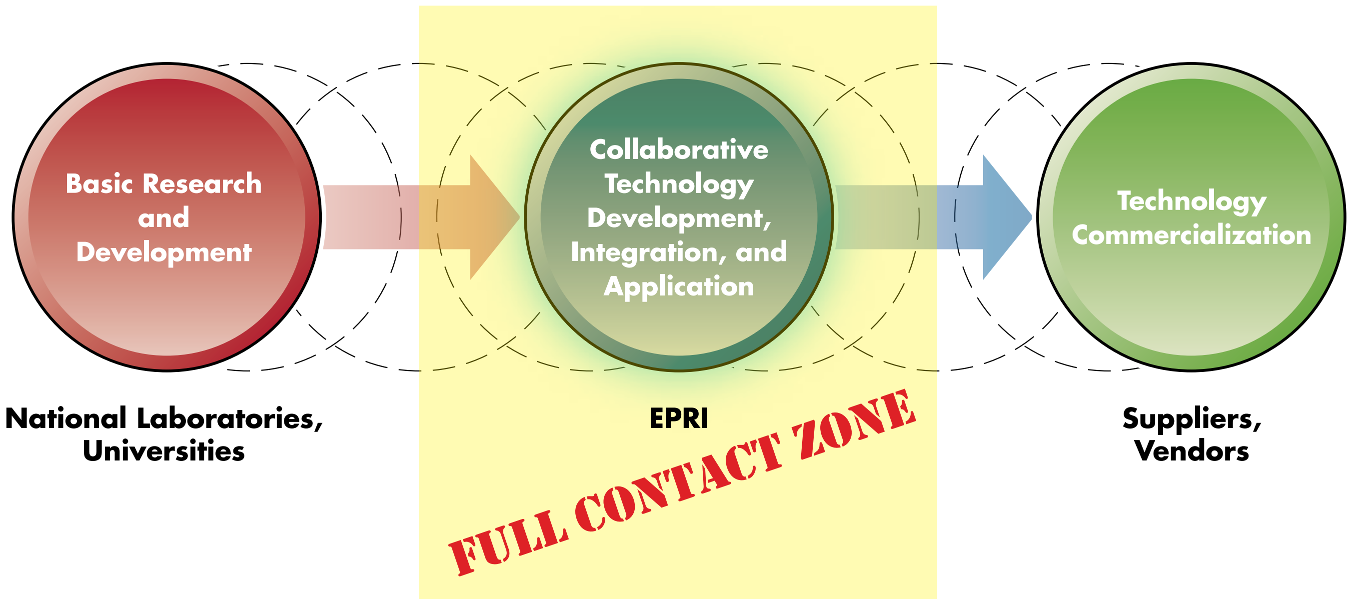
Successful collaborative R&D is a "full contact sport." Nowhere is this more evident than in the program advisory meetings. They bring together the institute's technical experts and experts from participating organizations in each of our approximately 70 R&D programs. (In the photo above, CoalFleet for Tomorrow® advisors help prioritize R&D projects. I encourage you to go to epri.com for a complete list of programs.)

For several days the experts in each program area engage in "full contact" as they review results, debate R&D priorities and needs, review and celebrate technology transfer best practices, and formulate the future R&D agenda for that program.

As I attended most of the winter 2010 program advisory meetings, I was pleased to see that their vital signs are stronger then ever. Collectively, more than 1500 people from around the world actively participated—a near record turnout made even more remarkable by these challenging economic times. Each program meeting had its own personality, but almost all were lively, highly interactive, and demonstrated various degrees of "messiness," indicative of an engaged and healthy collaborative.

As I participated in the meetings I kept thinking, "This is what it is all about—this is the power of the collaborative." These program advisory meetings are EPRI's core process and a key to what differentiates us from any other R&D organization in the world.

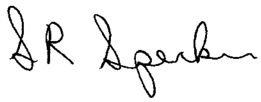
To better understand the importance of this core process, I



refer you to my Spring 2008 EPRI Journal column, where I discussed EPRI's role as a "technology accelerator." I characterized EPRI as the middle of three circles—with universities, national labs, and individual inventors on the left and technology suppliers on the right. It is the "full contact" taking place in EPRI's program advisory meetings that provides the focus and discipline to select the ideas and concepts from the left-hand circle that have the most potential to effectively address the needs of the electricity sector. It's then applied to design collaborative programs that accelerate the development of the technologies through to the right-hand circle, where they can be successfully put to work meeting the needs of the electricity sector and, ultimately, the public.

The toughest challenge of any R&D endeavor is moving good ideas and concepts from the laboratory to wide-scale implementation in the field. Occasionally success can spring from genius and/or good luck. However, consistent success results from effective, repeatable processes. Over the past 37 years EPRI has developed and refined such processes. At their core you'll find the program advisory meeting—uniquely powering the EPRI collaborative for the benefit of the electricity sector and the public.

That's the inside story.



Steve Specker
President and Chief Executive Officer

SHAPING THE FUTURE

Innovative approaches to upcoming challenges

Microalgae for Fuel Production and CO_2 Reuse

Recent public, government, and venture capital interest has accelerated research on using algae to produce biofuels, including transportation fuels, other biogenic liquid and gaseous fuels, and solid fuels for cofiring in power plants. Technically known as microalgae (and popularly referred to as pond scum), algae are microscopic plants that grow in aquatic environments, requiring water, sunlight, carbon dioxide (CO_2), and various nutrients for growth.

Industrial-scale algae production requires concentrations of CO_2 higher than those available from the atmosphere. Algae producers see concentrated CO_2 streams from power plant flue gas and other industrial facilities as promising sources of the high levels required for economic biofuel production. Such CO_2 reuse would benefit power producers facing the challenge of capturing and sequestering CO_2 under expected greenhouse gas abatement rules.

Scientists at NREL and other laboratories are working to breed, engineer, and grow algae optimized for biofuel production. (Photo courtesy of Warren Gretz, NREL)

To help assess the potential and requirements of algal biofuel development, and to identify co-benefit opportunities, EPRI has followed laboratory R&D and pilot-scale projects worldwide and provided utilities with technical assistance in evaluating project proposals from researchers and technology developers.

Much Potential, Substantial Challenges

Today, algae-based biofuel production remains at the stage of basic science, laboratory testing, and pilot-scale demonstration. Algae and algae-production systems are relatively versatile: depending on species and growth conditions, they may be used to produce biogenic diesel fuel, gasoline, kerosene, ethanol, methane, natural gas, and other fuels. In contrast with other biofuel-production organisms, algae have faster growth rates and higher productivity per acre than terrestrial plants, can grow in otherwise nonproductive areas, and can use saline water or wastewater from municipal, industrial, and agricultural sources.

Nevertheless, a recent workshop sponsored by the U.S. Department of Energy (DOE) and attended by researchers, representatives of the biofuels industry, and experts from EPRI, emphasized that algal biofuel production has not yet been proven affordable, scalable, and operationally robust for displacing significant amounts of fossil fuel. A key concern is requirements for land, water, and energy, which may make algae-based systems prohibitively costly. DOE's National Renewable Energy Laboratory estimates that it would require about 20,000 square miles of land (equal to the combined areas of Vermont and New Hampshire) to produce enough algal oils to displace 30% of the current annual U.S. consumption of conventional diesel fuel. Although algae are much more efficient at photosynthesis than other plants, they still convert only 2%–3% of total solar energy into biomass. Achieving higher-efficiency conversion may require genetic engineering.

R&D efforts include screening and engineering specific species of algae for high yields; improving open-pond and enclosed (i.e., photobioreactor) growth systems; increasing the efficiency of harvesting, drying, oil extraction, and processing techniques; and developing advanced fuel production technologies.

Assessing the Possibilities

In 2009, EPRI's Office of Technology Innovation initiated the first comprehensive industry-focused assessment of algae for biofuel generation, algal biofixation as a method for capturing CO_2 from fossil power plants, and other potential co-benefits for power plants (such as wastewater treatment). Under the Strategic Biotechnology program, EPRI is generating critical information on cost-performance potential, plant integration, and sustainability while identifying concepts that merit further R&D and demonstration.

EPRI has published a database compiling information from more than 80 vendors active in algae biofuels, CO_2 reuse, and related technologies (1020433). For 2010, EPRI is preparing technical updates that summarize initial findings from the industry-focused assessment—including a case study and a critical review of technical literature on utility-connected algae systems. Results are intended to support utility decision making, inform R&D planning, and ensure that technology developers address the needs and constraints associated with power plant applications in future process and technology designs.

For more information, contact Stephanie Shaw, sshaw@epri.com, 650.855.2353, or Brice Freeman, bfreeman@epri.com, 650.855.1050.





The Promise and Challenge of Wireless Power Transfer

From portable 3G smart phones to cordless peripherals, wireless technologies are driving the creation of new electronics, but for most such technologies, their batteries still require recharging from a power outlet through a cable. Wireless power transfer would remove this limitation, sending power directly to devices, much as a broadcast signal is sent to a television.

Wireless applications range from today's inductive charging of electric toothbrushes to utility concepts that sound like science fiction, including the use of lasers to deliver bulk power through the air without transmission lines. A recent EPRI analysis reports on envisioned uses and hurdles to adoption, making a mixed yet intriguing case for truly wireless power transfer.

Conceptual space solar power satellite (Art courtesy of NASA)

Possible Utility Applications: Starting Small, Thinking Big

The basic technology exists for cordlessly charging cell phones, iPods, and wireless computer peripherals. Commercially available charging pads employ inductive coupling to transfer power from a charger to a device when both are placed within the same electromagnetic field. Mats installed on garage floors may offer similar convenience for charging electric vehicle batteries. Purdue University, working with the U.S. Air Force, is testing tiny sensors powered through inductive coupling to detect failing jet engine bearings and transmit temperature data wirelessly. Combustion turbines, generators, and other rotating machinery also may benefit from this technology.

Most wireless power transfer utility concepts span longer distances, relying on radio-frequency or laser techniques rather than induction for power transfer. Several utilities are studying these wireless techniques for powering sensors and transducers to improve plant safety and efficiency. Radio-frequency transmission could transfer power to multiple devices in the same general area, regardless of location or accessibility. In contrast, laser beams can focus power transfer, hitting a small, discrete target. Large or small, wireless power transfer converters could deliver energy to special environments such as combustible atmospheres, where a hard-wired connection might generate a spark.

Perhaps the most radical, long-term vision lies in bulk power transmission. Point-to-point wireless transmission using high-energy lasers could yield tremendous savings by avoiding the cost of overhead lines and other infrastructure. It also may enable new power generation arrangements, such as solar power stations in geosynchronous orbit around the earth. Space-based solar power potentially offers a number of advantages over land-based systems, generating power 24 hours a day, avoiding insolation losses due to atmospheric reflection, and eliminating the terrestrial impacts of enormous solar arrays. Many technical difficulties make the practical application of such technologies speculative at best.

Recognizing Tradeoffs, Limitations, Demand Implications

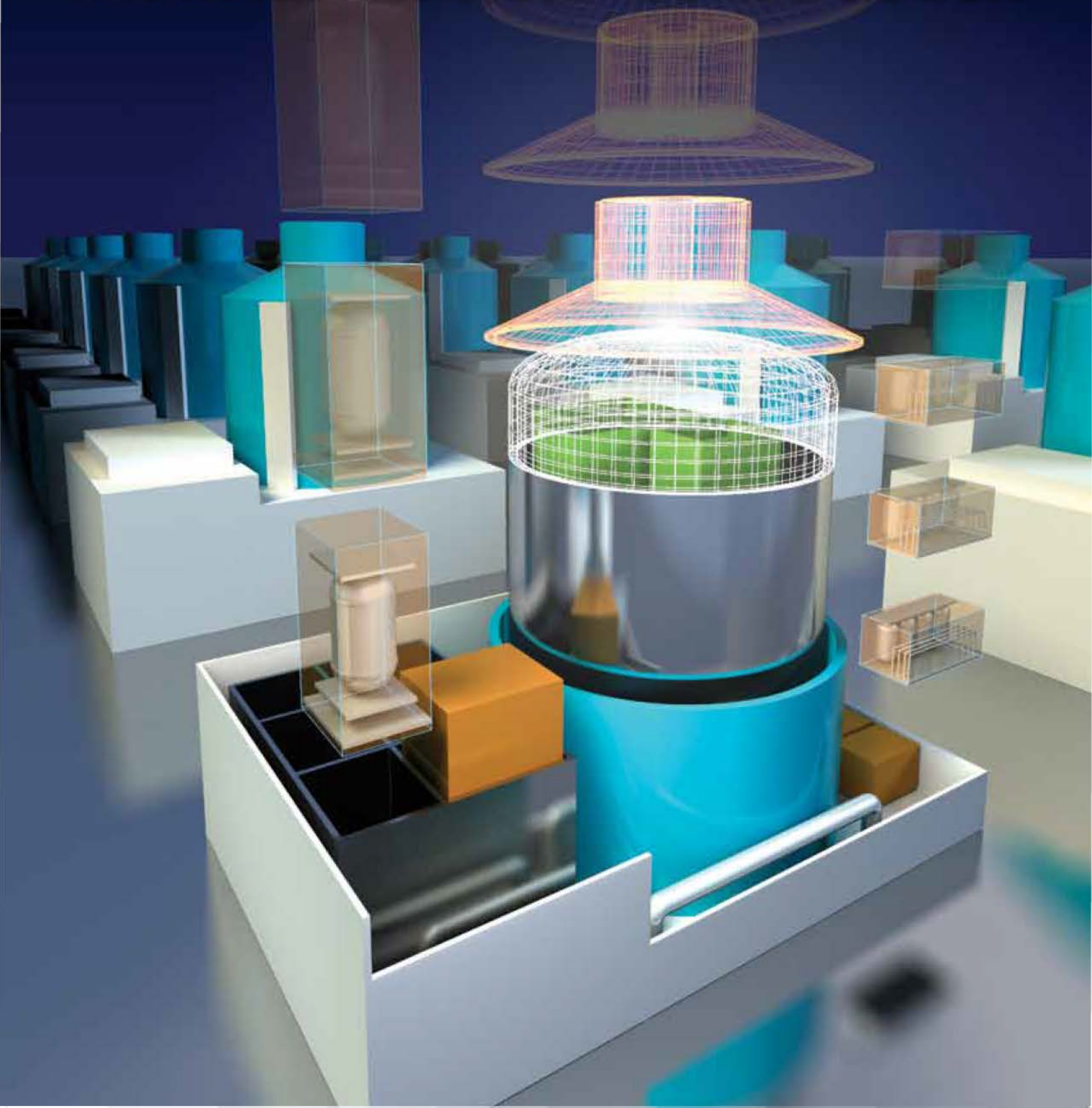
Convenience, improved functionality, safety, and productivity make wireless power transfer attractive in principle, but capabilities today are relatively limited. Efficiency is typically quite low—often less than 40%—restricting applications to relatively low power levels. Extensive engineering is needed to achieve broader application and to develop more effective wireless transmitters and receivers.

Other drawbacks may be equally problematic. Power fluctuations can compromise the reliability of wireless devices, and radio-frequency transmission might cause electromagnetic interference with medical equipment, create shock-inducing currents, or interfere with hard disk drives, credit cards, and related devices. As with any emerging technology, large-scale applications will pose challenges for developing standards and regulations.

But even if wireless power transfer continues to serve primarily niche applications, utilities will be wise to monitor its progress for at least one reason: the potential for increased power consumption. The wireless equivalent of a conventional 10-watt (W) cell phone charger might draw 40 W because of its lower efficiency. The effect on the individual consumer would be negligible—perhaps a couple of kilowatt-hours more per month. If 10 million people were to adopt such a charger, however, it would represent a potential increase in power demand of 300 MW and the need to provide hundreds of additional megawatt-hours per year in energy.

For more information, contact Haresh Kamath, hkamath@epri.com, 650.855.2268.

MAKING THE CASE FOR Modular Nuclear Construction



Interest in nuclear power is growing globally. A number of countries without any previous nuclear history—such as Egypt, Jordan, Turkey, Vietnam, Belarus, and the United Arab Emirates—are actively pursuing nuclear power plant development. Asia, which didn't experience the slowdown in nuclear power plant development that has gripped the West for the past 20–30 years, is rapidly adding to its nuclear fleet. New reactors are now under construction in Europe, and the United States will likely see the first new reactors built in three decades now that the U.S. Department of Energy (DOE) has offered conditional commitments for loan guarantees to Southern Company.

But the new generation of reactors will not be built the same way as those built decades ago. Modular construction techniques used in Japan and by the U.S. Navy are being adopted, with the result that plants can potentially be constructed much faster and at lower cost than if they were "stick-built" on site. Nuclear construction has always had modular aspects—at a minimum, the turbines, pumps, sensors, and control panels arrive on site assembled. The industry is now considering this approach for larger assemblies, which would arrive at the plant with piping, wiring, sensors, and other components already installed and tested. Nuclear submarine construction has used this process for decades.

A good part of the efficiency in modular construction lies in the possibility of doing comprehensive testing and certification of the modular components at the factory rather than in the busy, close quarters of a construction site. EPRI is working with utilities, manufacturers, and other interested parties to develop the methodology by which the Nuclear Regulatory Commission (NRC) can approve factory testing, eliminating the need for repeat testing after installation.

"The goal of the project is to provide a roadmap for the design and testing engineer," said EPRI senior project manager Ken Barry. "The roadmap reflects and compiles the world's experience with modules to ensure that inspections, tests, and qualifications conducted on the modules are not invalidated when the modules are shipped, stored, and installed."

THE STORY IN BRIEF

Builders of new nuclear plants will save substantial time and money with modular construction techniques—installing large, integrated component packages that have been tested at the factory rather than assembling and testing individual pieces at the construction site. EPRI is working with utilities and manufacturers to ensure that module inspections, tests, and qualifications will be robust and certifiable.

Benchmarking Procedures

EPRI's Advanced Nuclear Technology program is leading this work as part of its ongoing focus on the development of technologies and tools needed to deploy advanced nuclear plants. The program recently released a report that benchmarked successful applications of modularization and that can be used to guide further development.

The report, *Modularization of Equipment for New Nuclear Application—Benchmarking* (1019213), is based on visits to three companies that have been involved in modularization for years through U.S. Navy submarine construction or power plant projects in the Far East: General Dynamics Electric Boat, Hitachi-GE Nuclear Energy, and Mitsubishi Heavy Industries. The report details the types of modules each company makes, the testing procedures used, and how to make sure the modules arrive on site without damage.

Electric Boat and Hitachi-GE both report achieving significant time savings and reduced project risk by using modularization. Electric Boat reports that the first Virginia-class submarine took 18 million worker-hours to build; the fifth, 11 million hours. The target for the thirtieth is below 8 million. Hitachi-GE said that since 1990, construction time for its projects has been reduced by nearly 20%, and site construction worker-hours, by nearly 40%.

"The three companies that we benchmarked had more experience and knowledge with modules than we anticipated, and they readily shared this knowledge with the benchmarking team," said Barry. "Because they need to conduct design work much earlier in the project to support module construction, problems are also discovered earlier, at the fabrication facility. This eliminates issues later in the project that could impact costs and schedules."

Developers of next-generation plants are excited about these results: "I would anticipate almost all new construction being modular-type construction," said Leonard J. Azzarello, engineering manager at Duke Energy's Lee Nuclear Project, which is scheduled for completion in 2021. "You can get quality as good, if not better, by using modular construction, and you can get it much more efficiently."

"We need to make sure the NRC understands the efficiencies we hope to gain by doing much of the inspection and testing on the modules at the factory, before they come to the site," said Azzarello. "EPRI's activities help us understand how to maintain the qualification and testing that was done at the factory so that the inspection doesn't need to be redone. If we have to redo the inspections and tests with everything in place on site, then we won't achieve the benefits we had hoped for."

Modularization Benefits

While it is more complex and more expensive at the design stage, modularization can speed up the construction process and reduce overall costs. In the initial construction stages, modularization shortens the critical path on site, allowing the plant to begin commercial operation sooner.

Unlike stick-built plants, where each step requires the completion of the previous one, several modules can be assembled simultaneously in factories while concrete is being poured and other preparation work is being done at the site. This allows for better on-site resource leveling, since more work is being performed off site by vendors. Conducting work in the controlled factory environment enables a more systematic approach to safety and quality, with improved results.

"Regardless of how you construct, you must always achieve a quality product," said Azzarello. "There is simply no other option in the nuclear industry. It is just more difficult, more time-consuming, and therefore more costly to do that testing and inspection on site."

Other factors favor off-site fabrication facilities. Manufacturers can better control assembly by using crews that are specialized for specific tasks and that gain experience with multiple reactors. There is less need for scaffolding and temporary construction materials, and centralized fabrication offers a cleaner, better-lighted environment for assembling critical components. Factory workspaces also enable the use of more productive and efficient assembly techniques, such as down-hand welding. And off-site fabrication provides for more efficient testing and qualification, enabling earlier detection and correction of defects.

Finally, standard modules offer the potential for economies of scale in manufacturing, faster design, and easier permitting.

For very large modular structures, such as the CA-20 auxiliary building, submodules can be shipped to the site separately and assembled in an area close to the plant.

One of the world's largest cranes lifts the finished CA-20 module into place at the Sanmen AP1000 reactor site in China's Zhejiang province. (Photos: SNPTC)

Vendor Acceptance

Given these advantages, it is no surprise that nuclear plant vendors and suppliers are pursuing modularization. Duke Energy's proposed Lee Plant, for example, will use the Westinghouse AP1000 advanced light water reactor—the only Generation III+ reactor yet to receive design certification from the NRC. Westinghouse projects that an AP1000 plant can be built in 36 months from first concrete pour to fuel loading, in part because of its modular construction. The largest module is a four-story, 700-metric-ton (772-ton) unit that comes with rooms that are already piped, wired, and painted.

Other nuclear plant designs are being developed using modular engineering and design principles. Mitsubishi developed its advanced pressurized water reactor (APWR) design as part of Japan's Third Phase Improvement Standardization Program for Light Water Reactors. The first two plants based on this design are undergoing licensing in Japan and are scheduled to be built by 2016. A version for the U.S. market, the 1700-MWe US-APWR, is expected to achieve NRC design certification in 2011. Pending approval, the first two units will be installed at the Comanche Peak Nuclear Power Plant in Texas.

Hitachi-GE, meanwhile, has been building with modules since the 1980s. A plant built in 1985 used 18 modules, and the current plant design includes 193 modules, ranging from 5 metric tons (5.5 tons) to 650 metric tons (717 tons). Hitachi-GE uses seven types of modules in its plants: piping blocks, piping modules, platform modules, equipment modules, cable tray modules, special modules, and civil modules.

Addressing Unanswered Questions

While the advantages of modularization are clear, work remains to be done toward facilitating broader use. In the United States, where the NRC focuses primarily on safety and not on speed of construction, the nuclear power industry must make the case that items assembled and tested in the factory can be as safe and reliable as those built and tested on site. "The efficiency and effectiveness of modular submarine design and construction can be adapted to commercial nuclear power plants," said Tom Lyon, quality manager, commercial nuclear programs, for Electric Boat. "We design, build, test, and have sailors train on modules before we even integrate the modules into the submarine, saving millions of hours of construction time while improving quality and safety."

"We have found there is a 1-3-8 rule," said Lyon. "Something that would take me one hour to do on the factory bench would take me three hours to do on a module and eight hours if I had to do that same job on the ship. The more work I can push back to the bench or the module, the more man-hours I save."

One challenge is to maintain the integrity of the module after it leaves the fabrication facility so that it doesn't need to be inspected and tested again at the site. Fortunately, the past efforts of Electric Boat, Mitsubishi, and Hitachi-GE can be applied to other plants.

"We have experience in doing this for submarines, and that experience translates pretty directly into commercial nuclear work," said Lyon. Electric Boat does most of the hydrostatic and electrical continuity testing before shipping the modules, as well as some of the motor testing and flow balances on ventilation and piping systems. To make it easier to conduct hydrostatic testing, the systems are designed with isolation valves or mechanical joints so sections can be isolated and should not have to be retested after final assembly.

Electric Boat also uses environmental controls during shipping, such as placing an airtight blanket over the equipment and purging it with nitrogen, and uses humidity sensors to detect whether any moisture has gotten inside. When bolts are torqued, they are marked with tape or Torque-Seal—a lacquer put on the bolt after tightening. If the seal is cracked, the bolt must be retightened.

Because of the nuclear power industry's emphasis on quality control and assurance, rigorous procedures must be followed to ensure that testing information is transferred along with the work. An inspection is conducted after the module arrives at its destination, and if there is any evidence of damage, the testing is redone; otherwise the test results done in the factory are considered adequate.

"As the project team considered all the possible tests that could be performed and all the possible ways to invalidate these tests, the matrix became very large," said Barry. "This project makes the complexity manageable for the design engineer by distilling the relevant industry experience captured during the benchmarking visits."

The other issue is the size of the modules that can be shipped and lifted into position. While Electric Boat creates modules up to 2,500 tons (2,268 metric tons) for submarines, the modules can simply be loaded onto a barge at its factory on the Rhode Island coast for a 60-mile trip down to its shoreside assembly facility in Groton, Connecticut. For land-based power plants, the modules will have to be much smaller to facilitate transport and craning into position, but they can still be quite large. The AP1000 design, for example, has modules up to 700 metric tons (772 tons). The dome module on the Mitsubishi APWR weighs 500 metric tons (551 tons). Each module will have to be designed so that it can be transported and moved into position in one piece.

Modular Evolution

Modularization will continue to evolve and advance. "In the future, we will see hybrid modules combining civil/structural with mechanical/electrical modules," said Junichi Kawata, Hitachi-GE vice president and senior project manager. "This will result in shorter construction periods and better construction quality."

In order for modular fabrication and construction to be applied commercially, research will be required to gain industry buy-in and regulatory approval. The EPRI benchmarking report is one step in this direction. The final report provides the industry with details on what tests can be performed at the fabrication facility and how the chosen tests can be preserved during shipping, storage, and installation.

"The industry is not ready for full-out modularization yet in the testing area, which is why EPRI is involved," said Lyon. "Rather than focusing on what is allowed, EPRI is looking at where it can go in the future. This sets the bar high and lays the foundation for broader application."

This article was written by Drew Robb.
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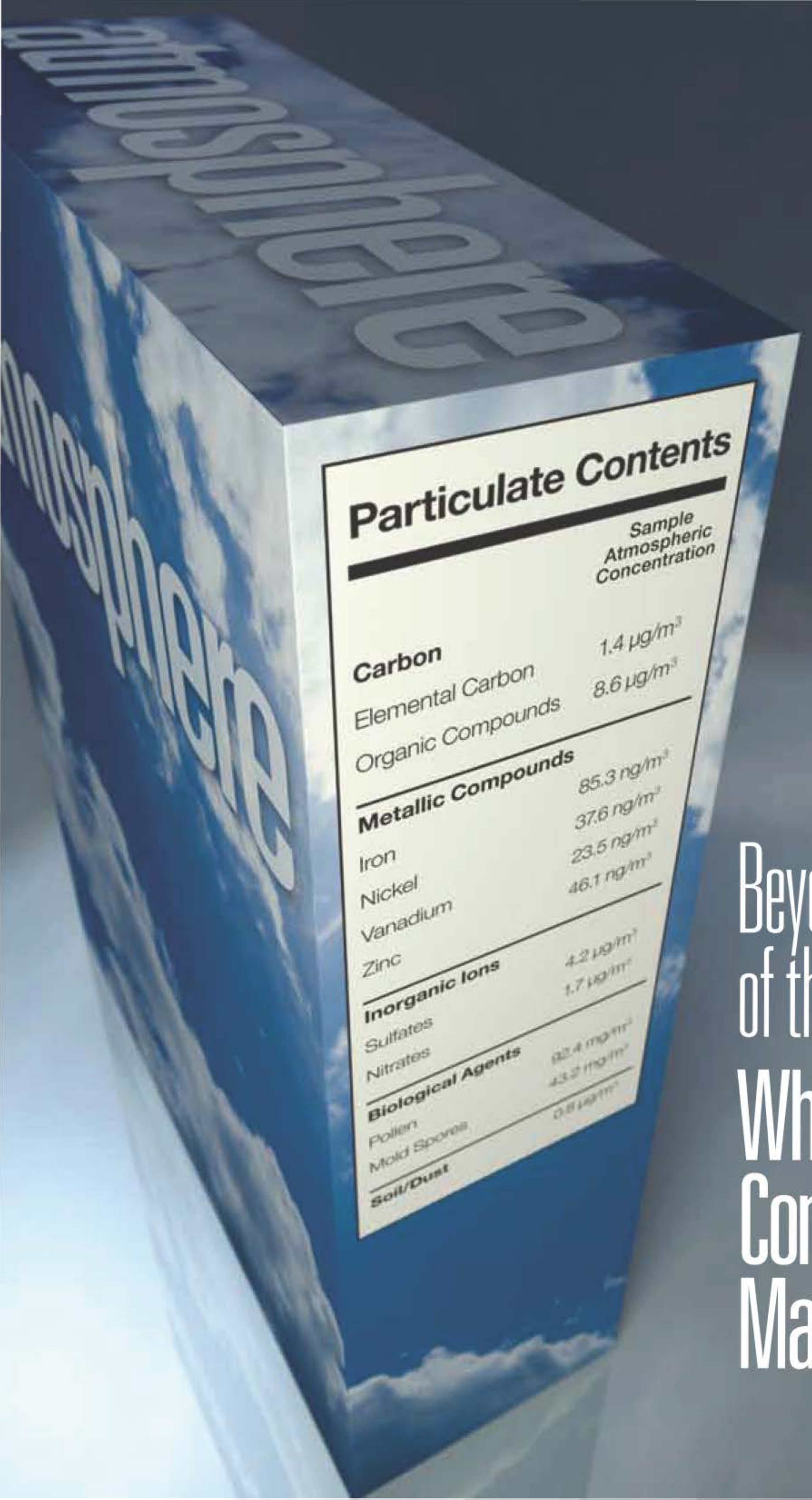
Kenneth Barry is a senior project manager in EPRI's Nuclear Sector, where his current activities focus on managing EPRI research in the Advanced Nuclear Technology group, which supports the nuclear renaissance. Since joining EPRI in 1991, he has managed the Nuclear Maintenance Applications Center (NMAC) program, was a manager of Nuclear Sector business operations, and served as an account executive for the Nuclear member services team. An ex—nuclear submariner with the U.S. Navy, he previously worked for Bechtel and for Tenera. Barry received a B.A. in mathematics and a B.S. in computer science from the University of Wisconsin at Madison and an M.B.A. from Saint Mary's College of California.



Beyond the Sum of the Parts: Why Particulate Components Matter

THE STORY IN BRIEF

What ingredients make up the mix of fine particulate matter in the atmosphere, and what risk does each component present to human health? EPRI's epidemiologic study of air quality effects in Atlanta and other metropolitan areas has already pointed to important distinctions, and the results may have a major impact on how particulates are regulated in the future.

Fine particulate air pollution is a complex mixture of many types of materials, among them metallic compounds, sulfates, nitrates, elemental carbon, and organic carbon (including hundreds of organic—or carbon-containing—compounds), as well as biological materials such as pollen fragments and mold spores. These components originate from a variety of sources, including diesel and gasoline engines, power plants, wood burning, industrial operations, and natural processes. The U.S. Environmental Protection Agency's (EPA's) current standards assume all particle types to be equally harmful. But the science no longer appears to support that assumption.

The EPA began regulating fine particulate matter—particles 2.5 micrometers in diameter or smaller—in 1997, after several epidemiological studies found a link between the microscopic particles and heart and lung problems. Even then, scientists understood that particulate matter is a complex mix of chemicals, but no one had systematically looked at the health effects of its individual components. Deliberating on what was known at the time, the EPA decided to regulate fine particulate matter as a single pollutant.

In January 1998, a group of air pollution experts gathered at a scientific meeting in Long Beach, California. During a coffee break, some of them got to talking. What was needed, they decided, was a study to determine which fine particles are toxic and which are benign. "We basically took out some napkins and outlined the type of study we needed to do," said Ron Wyzga, a senior technical executive and biostatistician at EPRI.

Ideas born on napkins tend to have a high mortality rate. Thanks to EPRI, however, this one survived. Just five months after that meeting in Long Beach, EPRI raised the necessary funds and launched the multimillion-dollar Aerosol Research and Inhalation Epidemiology Study (ARIES) in Atlanta. "When I think of what we did in that short period of time, I'm very impressed," said Wyzga, who now serves as the project's manager.

Today, ARIES encompasses a suite of studies in Atlanta and six other major cities. "It has turned out to be one of the largest, most comprehensive air pollution health studies ever done anywhere," Wyzga said. The investment in the study is beginning to pay off. The researchers now have solid evidence that fine particles aren't all created equal; some appear to be more toxic than others.

EPRI's research, together with other studies, suggests that the scientific framework for EPA's fine particle standard may be ready for reexamination. "We believe the emerging data are showing support for a shift in the current regulatory approach to protecting public health," said Annette Rohr, program manager for air quality, health, and risk assessment at EPRI.

A Decade of ARIES

Determining which types of fine particulate matter constitute a human health risk is no simple task. When EPRI tackled this question in the late 1990s, researchers settled on a type of epidemiological study known as a time-series study. "You're trying to find out what the health effects of air pollution are by comparing the health status of the population in different periods with pollution levels," Wyzga said. The results offer some information about the immediate impacts of air pollution.

The study design is relatively straightforward. Researchers collect comprehensive air quality data, and then they match those data with health data from the same period. The health data include deaths, hospital admissions, emergency room visits, and unscheduled physician visits.

Atlanta, like any large metropolitan area, has its share of air pollution concerns, including gridlocked traffic and a number of coal-fired power plants, which made it an excellent choice for ARIES. Fortunately, EPRI had already slated a comprehensive air pollution measurement study (Southeastern Aerosol Research and Characterization), which would provide the data needed for ARIES.

Air quality is monitored from a trailer located about two miles from downtown Atlanta. Rooftop instruments track concentrations of different components of particulate matter, as well as concentrations of pollutant gases such as carbon monoxide, sulfur dioxide, and gas-phase organic compounds. They also collect meteorological data. Computers inside the trailer process the data.

As the data pool has grown, trends have emerged. Organic particles (likely coming from mobile sources and biomass burning) seem to be more important from a health standpoint than inorganic particles. For example, organic carbon and elemental carbon are linked to an increased number of emergency room visits for cardiovascular disease. Researchers also have uncovered associations between adverse health outcomes and carbon monoxide, nitrogen dioxide, and ozone. "We see some evidence that metals may be important too," Wyzga said. When looking at sulfate, a particulate byproduct of power plant sulfur dioxide emissions (which accounts for a large portion of particulate matter in Atlanta), the associations with adverse health outcomes are largely negative, suggesting that, from a health perspective, this component may be less important than some other components.

Researchers aren't yet sure what all the results mean. "As with any study, the answers are relatively complex," said Wyzga. For example, research suggests that exposure to elemental carbon is associated with adverse health outcomes, but the mechanism is unclear. According to Rohr, the problem may not be the elemental carbon itself. Carbon can adsorb other pollutants like a sponge, so one possibility is that elemental carbon acts as a transport molecule, ferrying harmful hitchhikers into the lungs.

To see if the results obtained in Atlanta hold true for other cities, EPRI has launched smaller ARIES studies in St. Louis, Dallas, Birmingham, and Pittsburgh. Studies also are under way in Detroit and New York City to examine specific individuals and determine their residential exposures to air pollution and to take ambient air quality measurements. The goal is the same: to learn more about the health impacts of different types of particulate matter.

Results are not yet available for most of the cities, but researchers do have preliminary findings from St. Louis. Wyzga said that he and his colleagues are not finding as many positive associations in St. Louis as they did in Atlanta. That could be because of the smaller population, or perhaps because there aren't yet enough observations to indicate trends. "Where we are getting results," Wyzga said, "they are broadly consistent with those in Atlanta."

EPRI's Toxicological Evaluation of Realistic Emissions of Source Aerosols study uses field laboratories to examine the health impact of power plant emissions directly sampled at the stack through exposures to different combinations of simulated air quality. The study is important to EPRI's research on component-based standards for particulate matter.

Wyzga plans to have most of the ARIES studies wrapped up by 2012. As results from other cities become available, the associations will likely become clearer. Even without additional results, a consistent picture is emerging, said Naresh Kumar, senior program manager for air quality programs at EPRI: "We can't treat all components equally."

Beyond ARIES

ARIES isn't the only EPRI study to look at the components of fine particulate matter. Wyzga also oversees a study designed to look at the long-term health effects of different types of particulate matter on mortality in a group of approximately 70,000 veterans. "You're comparing the health status of veterans in different geographic areas with the pollution levels in those areas after adjusting for other factors that influence health, such as diet and exercise, age, and risk behaviors like smoking," he said.

Results from the veterans study—a collaborative effort between EPRI and Washington University in St. Louis—have been published in several scientific papers. In general, the findings are consistent with results from the Atlanta ARIES study. Pollutants associated with traffic appear to be important. For example, an individual's proximity to traffic was associated with an increased risk of death. After adjusting for traffic, researchers found strong associations between mortality and exposure to benzene, formaldehyde, diesel particles, nickel, nitrogen oxides, and elemental carbon. However, sulfate was not associated with greater mortality.

EPRI also is funding a suite of toxicological studies. One, called the Bi-City Concentrated Ambient Particle Study, looks at the effect of individual pollutants on cardiac function in rats. The rats are exposed to concentrated pollutants collected from the environment in Steubenville, Ohio, and Detroit. Results from the Bi-City study are generally consistent with the ARIES studies, although there are some differences. Metals, for example, seem to be more important to health impacts than organic compounds. Another toxicology study, TERESA (Toxicological Evaluation of Realistic Emissions of Source Aerosols), is examining the health impact of power plant emissions directly sampled at the stack by exposing rats to various air quality regimes that simulate those complex emissions. Generally, effects observed in the rats exposed to power plant emissions have been mild and of smaller magnitude than those observed in the rats exposed to concentrated urban particles.

Need for a New Regulatory Paradigm

Under the current mass-based EPA standard, average concentrations of fine particulate matter must not exceed 15 micrograms per cubic meter annually and 35 micrograms per cubic meter in a 24-hour period. The EPA monitors ambient air quality throughout the country. If a given area exceeds the standard, the state must develop a plan to lower emissions. Because the current regulatory paradigm assumes that all types of fine particulate matter are equal in terms of toxicity, states can comply with the standard by reducing emissions regardless of differences in health effects.

According to Bryan Baldwin, an EPRI advisor and manager of the environmental assessment department at Southern Company in Birmingham, that may not be the best way to protect public health. “Efforts should be focused on regulating the most toxic particles,” he said. “Unless you sort out that information, you won’t be able to focus control technologies on the particles that are producing the most harm to public health.”

Rohr added that the most effective and protective public health policy may not be focused on reducing overall particulate mass. “If we are going to improve public health, we need to focus on the most harmful particles and address those sources first, rather than reduce overall emissions. Doing so would allow us to more wisely use what limited resources we have today to address public health issues.”

A variety of alternatives to the mass-based standard exist. The EPA could instead regulate the most toxic components separately. States could take the lead by focusing their control strategies on the particles that research suggests are more harmful. “There’s a whole range of options,” Wyzga said.

Kumar noted that a precedent for component-based standards already exists at the EPA. Particulate matter also contributes to regional haze, as particles in the atmosphere absorb or scatter visible light. However, the various components of particulate matter contribute differently to visibility impairment. “The EPA in its regional haze rule has recognized that different components contribute differently to regional haze by assigning different weights or factors to different components,” Kumar said.

In May, EPRI will convene a meeting in Washington, D.C., to explore some of these regulatory alternatives. “We’re going to bring together a wide range of stakeholders,” Rohr said, including representatives from industry, legislators, regulators, and scientists. They will discuss different regulatory options, evaluate whether the science supports them, and outline directions to address gaps in knowledge.

The EPA revises its national ambient air quality standards every five years. The current review cycle for particulate matter is nearly complete, with new standards slated for publication in 2011. Wyzga and his colleagues don’t expect many changes in the 2011 standard but are focused on the revision that will begin in 2015. By then, more results from ARIES and other studies, including EPRI’s, should be reviewed and published. “Interest in this issue has been increasing,” Rohr said. The expectation is that the EPA will take those studies into account when it next revises its standard.

With respect to the health effects of particulate matter, many questions remain, and EPRI is continuing its efforts to advance the science. But, Baldwin said, “we’re getting close to the point where we can identify specific components that warrant either more or less attention.” Much of what brought scientists to this point exists in large part because of ARIES, a project that first took shape on the back of a napkin.

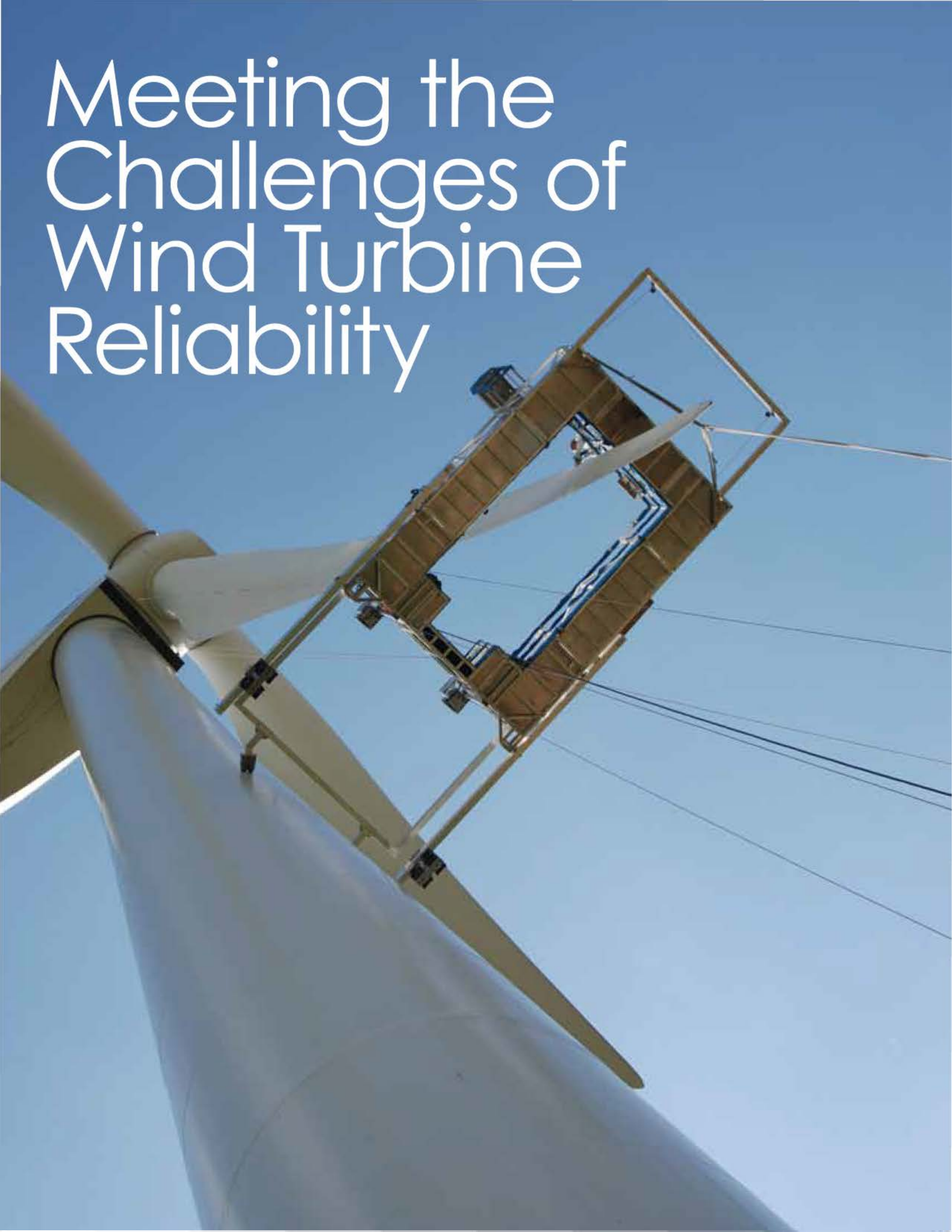
This article was written by Cassandra Willyard. For more information, contact Ron Wyzga, rwyzga@epri.com, 650.855.2577; Naresh Kumar, nkumar@epri.com, 650.855.2990; or Annette Rohr, arohr@epri.com, 650.855.2765.

Ronald Wyzga, an EPRI senior technical executive, specializes in the relationship between health effects and air pollution, with particular focus on the design, conduct, and interpretation of epidemiologic studies. Prior to joining EPRI in 1975, he worked at the Organization for Economic Cooperation and Development (OECD) in Paris. Wyzga has chaired several committees for the National Academy of Sciences and the EPA Science Advisory Board. He received an A.B. in mathematics from Harvard College, an M.S. in statistics from Florida State University, and an Sc.D. in biostatistics from Harvard University.

Naresh Kumar, a senior program manager, directs research related to the modeling and monitoring of ozone, particulate matter, atmospheric deposition, regional haze, and interactions between air quality and global climate change. Prior to joining EPRI in 1998, he was employed by Sonoma Technologies, Inc. Kumar received a B.Tech. in mechanical engineering from the Indian Institute of Technology, an M.S. in mechanical engineering from the University of California at Santa Barbara, a Ph.D. in mechanical engineering from Carnegie Mellon University, and an M.B.A. from the University of California Haas School of Business at Berkeley.

Annette Rohr, a senior technical manager in EPRI’s Air Quality program area, conducts epidemiological and toxicological research on the health effects of air pollution, including particulate matter and gaseous co-pollutants. 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. in microbiology and an M.S. in environmental engineering from the University of British Columbia in Vancouver and a Sc.D. in environmental health from Harvard University.

Meeting the Challenges of Wind Turbine Reliability



THE STORY IN BRIEF

Wind power represents the fastest-growing generation resource in the electric power industry, but premature failures of wind turbine components are significantly increasing maintenance costs and outages. To improve wind turbine reliability by reducing such failures, EPRI is spearheading an effort to apply various condition monitoring and nondestructive evaluation technologies now used in other applications.

Wind energy is by far the world's fastest growing source of electric power. Electricity generation from wind in the United States nearly doubled from 2006 to 2008, according to the U.S. Energy Information Administration, and installed wind capacity has been growing 20–30% per year worldwide. Two technical factors have driven much of this growth: today's significantly larger (and higher) wind turbines make more efficient use of available wind; and greater economies of scale and operating experience have helped reduce costs.

Modern wind facilities commonly use 1.5-megawatt turbines, but the trend toward larger size also makes failure of a critical component increasingly expensive. According to the National Renewable Energy Laboratory (NREL), most wind turbines require significant repair or overhaul of their gearboxes well before they reach their expected 20-year design life. And replacing a major component such as the gearbox or generator requires a large crane, costing tens of thousands of dollars. The cost of replacement parts over the lifetime of a turbine is projected to equal about 15% of its initial capital cost.

"Clearly this disturbing trend shows that we don't fully understand materials degradation issues and component failure mechanisms in the current generation of turbines," said Charles McGowin, EPRI senior project manager for wind power. "EPRI has considerable expertise in dealing with similar problems in fossil and nuclear plants—by means of advanced diagnostic technologies such as automated condition monitoring and nondestructive evaluation. We are now mobilizing an effort to apply the knowledge and tools developed from this experience to help improve wind turbine reliability."

Condition Monitoring

Part of the problem in maintaining wind turbines, compared with most central-station power plants, is that so many individual units are involved. So-called wind farms may include dozens or hundreds of units spread over a large, often remote area. Many turbines are accessible only by a ladder inside the supporting tower, requiring a typical technician crew of two to make a strenuous 15-minute climb, even for routine inspection and maintenance. The crew must haul tools and equipment up with a winch and work in cramped, often hazardous conditions.

One way to improve maintenance is to make it more predictive by using automated condition monitoring, which measures critical indicators of component health and performance. The objective is to identify incipient failures before catastrophic damage occurs. EPRI researchers have assessed condition monitoring technologies potentially applicable to wind turbines, prepared a cost-benefit analysis of a monitoring program, and identified promising technologies for further study.

EPRI's cost-benefit analysis found that successfully using a condition monitoring system to detect signs of failure at an early stage could save an estimated $75,000 to $225,000 for each major failure prevented in a megawatt-scale turbine. The cost of a "high-end" condition-monitoring system would be a fraction of that amount—about $20,000 per turbine. Nevertheless, the high initial cost of installing such systems on all the turbines at a major wind farm presents a major barrier to their adoption. Researchers concluded that field evaluations are needed to design and test lower-cost systems, and EPRI is working with member utilities to conduct such evaluations.

One monitoring technology chosen for early evaluation is vibration analysis, which is widely accepted for assessing the condition of rotating equipment in a variety of industries. This analysis detects abnormalities in the acoustic signature of a bearing or gear, which may indicate initiation of a defect. Recent advances in sensors and digital signal processing have helped create a new generation of relatively inexpensive vibration monitoring equipment that can provide valuable insight into the health of rotating equipment in real time. EPRI-sponsored laboratory tests of two vibration monitoring systems, using a turbine gearbox with a known defect, successfully demonstrated the ability of both systems to identify and locate the problem.

At the Tennessee Valley Authority's Buffalo Mountain Wind Project, EPRI and Southern Company are sponsoring field testing of another promising technology, which monitors the condition of lubricating oil. Preventing wear in a turbine gearbox requires maintaining a thin film of oil between the metal surfaces; any contaminants larger than the film thickness will initiate wear. Standard industry procedure is to remove and examine samples of oil from each turbine every six months, but this testing frequency may not be great enough to detect oil degradation in time to prevent gear damage. An alternative is to use an electronic sensor that detects metal particles in the oil as it circulates. Data collected over a year from three Buffalo Mountain turbines indicate that oil monitoring has the advantages of simplicity and minimal data interpretation. Researchers propose further testing to monitor oil in a system with a known defect or until a failure can be verified.

Other promising condition monitoring technologies also are in the demonstration pipeline: analysis of acoustic emissions, use of strain gauges on blades to detect imbalance due to icing, and "mining" of data already available from existing control systems.

Nondestructive Evaluation

Another concern in turbine maintenance is the lack of a robust, reliable inspection program for blades and other rotating components. Visual examination is currently the primary inspection method, and relatively few of these evaluations are performed. Among other challenges, such examination may require a technician to hang suspended from the turbine hub and inch downward along the surface of a blade looking for flaws. Most flaws in blades are fabrication-related, however, and may not become visually evident until relatively late in the flaw's development. A promising alternative is to use nondestructive evaluation techniques, which could improve flaw detection and reduce examination costs.

EPRI has long experience in applying nondestructive evaluation to fossil and nuclear plants and recently has launched a project to support the development of advanced nondestructive evaluation techniques and their application to renewable energy generation components. Specifically, EPRI is cooperating with Sandia National Laboratories and NREL to apply a noncontact nondestructive evaluation method for in-service inspection of turbine blades—locating potentially damaging flaws before they become visually evident. Called laser shearography, this technique is widely used in aerospace and aviation to examine rocket parts, airplane wings, and helicopter blades.

Laser shearography uses two light beams to illuminate a surface from different angles while the target material is stressed—for example, by vibration or pressure loading. A camera and image processor then combine the views produced by the two beams and reveal any surface deformations caused by the applied stress. The technique is particularly effective in detecting defects in fiberglass and carbon fiber composite materials such as those used in wind turbine blades, where internal flaws may be revealed by slight surface irregularities under stress. Laser shearography can quickly inspect a large area to identify defects such as wrinkles and delamination of composite materials.

EPRI's project successfully demonstrated laser shearography on a turbine blade in a test facility. In 2010, the technique will be refined for use during in-service inspection. Other visual and ultrasonic examination techniques will also be prepared for use on turbine blades and towers, both during fabrication and, later, in the field.

"The immediate impact of this work will be to improve the detection and characterization of flaws in turbine blades while lowering the cost and speeding up the process of inspection," said program manager John Lindberg. "Over the long term, application of nondestructive evaluation techniques can provide a solid basis for improving the reliability of renewable generation assets."

Standardizing Turbine Maintenance

A major reason for recent improvements in the reliability and performance of fossil and nuclear power plants is the widespread industry adoption of standard approaches to maintenance. These include maintenance guidelines and software, training in predictive and preventive maintenance, and databases that individual utilities can use to track performance of their equipment and compare it with industry best practices. Many of these tools have been developed with support from EPRI's Fossil Maintenance Applications Center, which has collaborated with EPRI's Renewable Generation program to launch the Wind Energy Initiative, which will encourage the application of these tools to wind turbines.

"Currently there is no standard maintenance basis for U.S. wind energy, and this lack has contributed to increasing failures," said senior project manager Ray Chambers. "What we hope to do with the Wind Energy Initiative is reduce premature turbine failures by applying well-established maintenance principles from other parts of the industry."

The first step toward standardization is to develop a broad inventory of major turbine components, together with failure models and effects analyses for each component. Wind farm owners can then use these analyses to determine what equipment conditions can be automatically monitored using instrumentation already installed, as well as what additional instrumentation should be considered. Existing preventive maintenance software will also be adapted to provide owners with an interactive tool for customizing their turbine maintenance programs according to specific operational considerations and risk tolerance.

EPRI also is developing wind-specific maintenance guidelines, which will provide recommendations on cyclic maintenance and condition-based maintenance routines developed from experience acquired by many companies. Further support will be provided by EPRI's Plant Maintenance Basis Database, which includes a vulnerability analysis to determine the impact of changes in maintenance procedures. This database is already used by EPRI's nuclear, fossil, and power delivery groups.

EPRI also is working with Strategic Power Systems, Inc., to adapt its Operational Reliability Analysis Program for use with wind turbines. This program is widely used with gas and steam turbines and could potentially provide wind system operators with the ability to identify reliability trends in their fleets while forecasting major maintenance and forced outages.

New Initiatives

As utilities rely more on wind turbines, new collaborative initiatives will be required to address emerging challenges in an integrated way. EPRI expects to launch two such initiatives in 2010.

The first of these, Field Performance Verification of New Wind Power Technology, will focus on developing a field test facility at a utility wind project to facilitate the development and commercial deployment of new technologies. Several innovative technologies are emerging that could improve the efficiency and reliability of wind power generation while lowering its cost. These include direct-drive generators and variable-speed hydraulic drives, which eliminate the need for gearboxes; air-cooled permanent magnet generators with full power conversion capability; and advanced rotor blades. The proposed facility would prepare test plans for each technology and perform field tests to verify their performance.

The second initiative, Improved Wind Turbine Operation and Maintenance Procedures, will mobilize EPRI's fossil and nuclear expertise to apply and test some of the condition monitoring and nondestructive evaluation technologies previously discussed, among others. The goal is to provide participants with hands-on experience with advanced operation and maintenance procedures and to develop an asset management guide for wind projects.

EPRI also is discussing with members how best to address various integration issues that may arise as wind penetration increases. These include concerns about effects of wind variability on generation system operations—especially impacts on the existing fleet's coal plants, gas turbines, and combined-cycle units, as well as on future advanced high-efficiency steam plants and carbon capture systems.

"We need to take a holistic approach in addressing these concerns," said Luis Cerezo, EPRI technical executive for renewable generation. "We need to make sure that changing one part of a generating fleet doesn't create new problems for the rest of the fleet. Improved flexibility to cycle and dispatch both existing and future advanced fossil plants will be key to accommodating the much higher penetration of renewable generation into the grid—anticipated by 2020 and beyond."

This article was written by John Douglas, science and technology writer. For more information, contact Charles McGowin, cmcgowin@epri.com, 650.855.2445; Luis Cerezo, lcerezo@epri.com, 704.595.2687; Ray Chambers, rchambers@epri.com, 704.595.2580; or John Lindberg, jlindberg@epri.com, 704.595.2625.

Charles McGowin is a senior project manager in the Wind Power program, focusing on wind turbine performance, system integration, and wind energy forecasting. He is also responsible for the annual update of the EPRI *Renewable Energy Technology Guide*. Since joining EPRI in 1976, he has worked on engineering and economic evaluations of coal, environmental control, waste-to-energy, biomass, and photovoltaics technologies. McGowin holds B.A. and B.S. degrees in chemical engineering from Lehigh University and M.S.E. and Ph.D. degrees in the same field from the University of Pennsylvania.

Luis Cerezo is a technical executive in the Renewables program, specializing in the transfer of fossil and nuclear plant experiences to renewable energy R&D projects. He joined EPRI in 2008 after a 35-year career with Iberdrola in a variety of operational and management positions. His most recent position was vice president of operations for Iberdrola Renewables USA. Cerezo earned an M.S. in mechanical and electrical engineering from ICAI Technical School (Madrid) and an M.B.A. from the University of Navarra's IESE Business School in Madrid.

Ray Chambers is the technical program manager for EPRI's Fossil Maintenance Application Center, which helps power producers target maintenance efforts to improve equipment and plant reliability while limiting costs. Before joining EPRI in 2001, he had 25 years of management experience at Pennsylvania Power and Light, Lockheed Martin Utilities Services, and Carolina Power & Light in the areas of maintenance, engineering, operations, site management, and assessment. Chambers holds a B.S. in nuclear engineering from North Carolina State University.

John Lindberg, a program manager in the Nuclear Sector, manages R&D on advanced nondestructive evaluation techniques to support both the long-term operation of the existing nuclear fleet and the construction of new plants. Before joining EPRI in 2007, he had more than 30 years of experience in nuclear generation at AREVA NP, GE Nuclear, and Pennsylvania Power and Light. Lindberg holds a B.S. in environmental science and resource management from Lehigh University.

DATELINE EPRI

News and events update

Switching Safety and Reliability Task Force Outlines Research and Deliverables for 2010

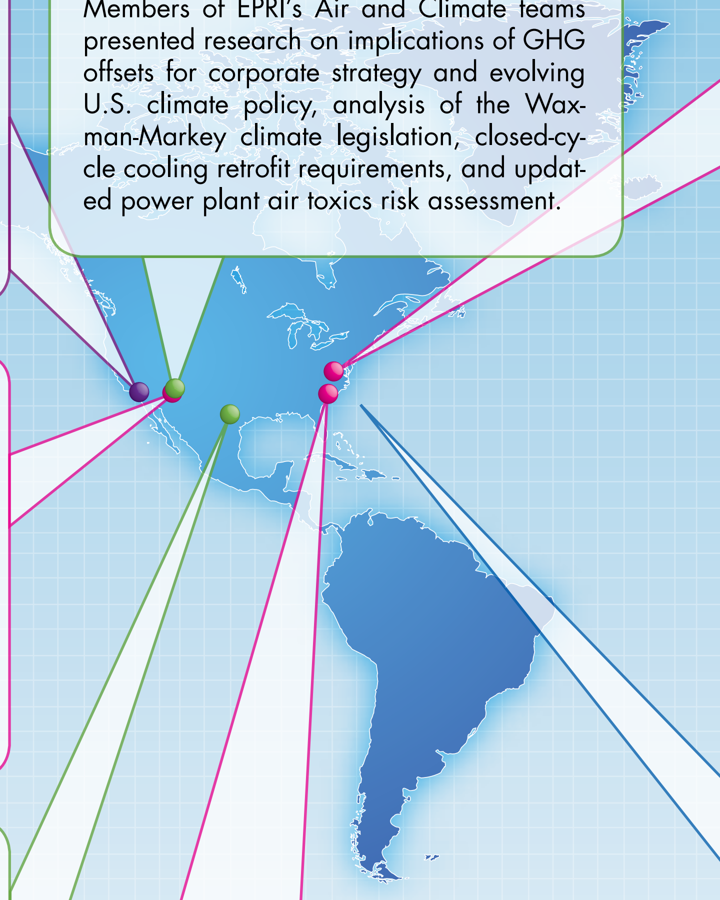
SAN DIEGO, Calif. – The EPRI Task Force on Switching Safety and Reliability finalized research plans and deliverables for 2010:

- Recommendations for certification of control room operators
- Incident-Based Training Modules for Power Switching, Edition 2
- Communication between field personnel and control center—utility practices
- Identifying error-likely situations in power switching
- Annual conference on switching safety and reliability.

The 2010 Switching Safety and Reliability Conference is scheduled for September 20–21, 2010, in San Diego, and the conference theme is "Switching Safety and Reliability for a Changing Grid." For more information, contact George Gela at 413.499.5710 or ggela@epri.com.

EPRI Contributes to EUEC Energy and Environment Conference on Climate, Cooling, and Air Toxics

PHOENIX, Ariz. – EPRI's Michael Miller's plenary session keynote covered 2009 updates to the Prism/MERGE analysis, reinforcing the findings that a full portfolio of energy technologies is critical to electricity sector carbon emission reductions and holding down electricity cost increases. Members of EPRI's Air and Climate teams presented research on implications of GHG offsets for corporate strategy and evolving U.S. climate policy, analysis of the Waxman-Markey climate legislation, closed-cycle cooling retrofit requirements, and updated power plant air toxics risk assessment.



Smart Grid Security Advisory Group Workshop Looks at Range of Grid Security Issues

PHOENIX, Ariz. – Arizona Public Service hosted the IntelliGrid Security Advisory Group Workshop, which focused on distributed network protocol security; best practices in control centers and substations; distribution system security requirements; the Advanced Security Acceleration Project—Smart Grid; the EPRI Smart Grid Labs under development; and status reports on security-related efforts at North American Electric Reliability Corporation and the U.S. departments of Energy and Homeland Security.

Manufactured Gas Plant Symposium Covers Advances in Clean-up and Investigation

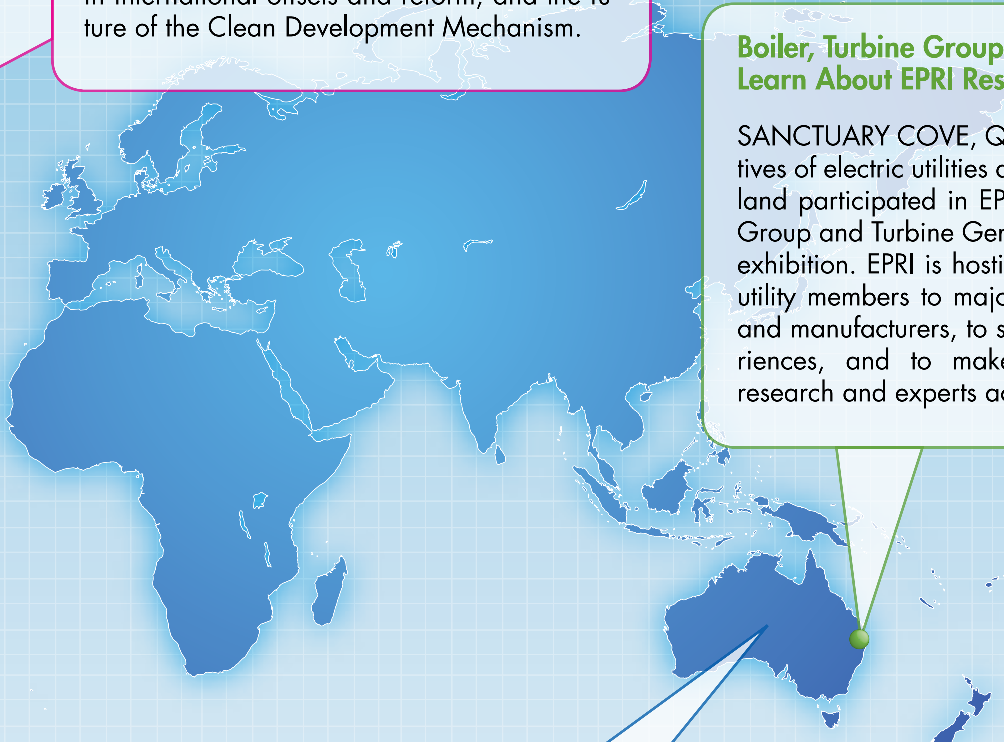
SAN ANTONIO, Tex. – EPRI's symposium in January covered a range of topics related to manufactured gas plant (MGP) site management and presented advances in the technologies used to investigate and clean up former MGP sites. Emphasis was on case studies, data, methods, and tools for the cost-effective and environmentally protective management of MGP sites. EPRI's land and groundwater research team led the event, and technical sessions covered air monitoring, soil vapor intrusion, remediation technologies, groundwater remediation, sediments, and human health/risk assessments.

Japanese Utilities Discuss U.S. Experience with On-line Maintenance

CHARLOTTE, N.C. – Representatives from six Japanese nuclear utilities attended a one-week workshop to discuss U.S. experience with on-line maintenance in terms of its interaction with risk and safety, work management, maintenance, licensing, and procurement.

EPRI Workshop Looks at GHG Offsets

WASHINGTON, D.C. – The seventh in a series of workshops on greenhouse gas emissions offsets in February focused on mechanisms to scale up offset supply and included representatives from the electricity, agriculture, and finance sectors; offset developers; federal agencies; congressional staff; non-governmental organizations; and academic and research institutes. Presentations examined carbon market fundamentals, proposals for sectoral crediting and trading, the role of the energy sector in international offsets and reform, and the future of the Clean Development Mechanism.



Boiler, Turbine Groups Share Experience, Meet Vendors, Learn About EPRI Research

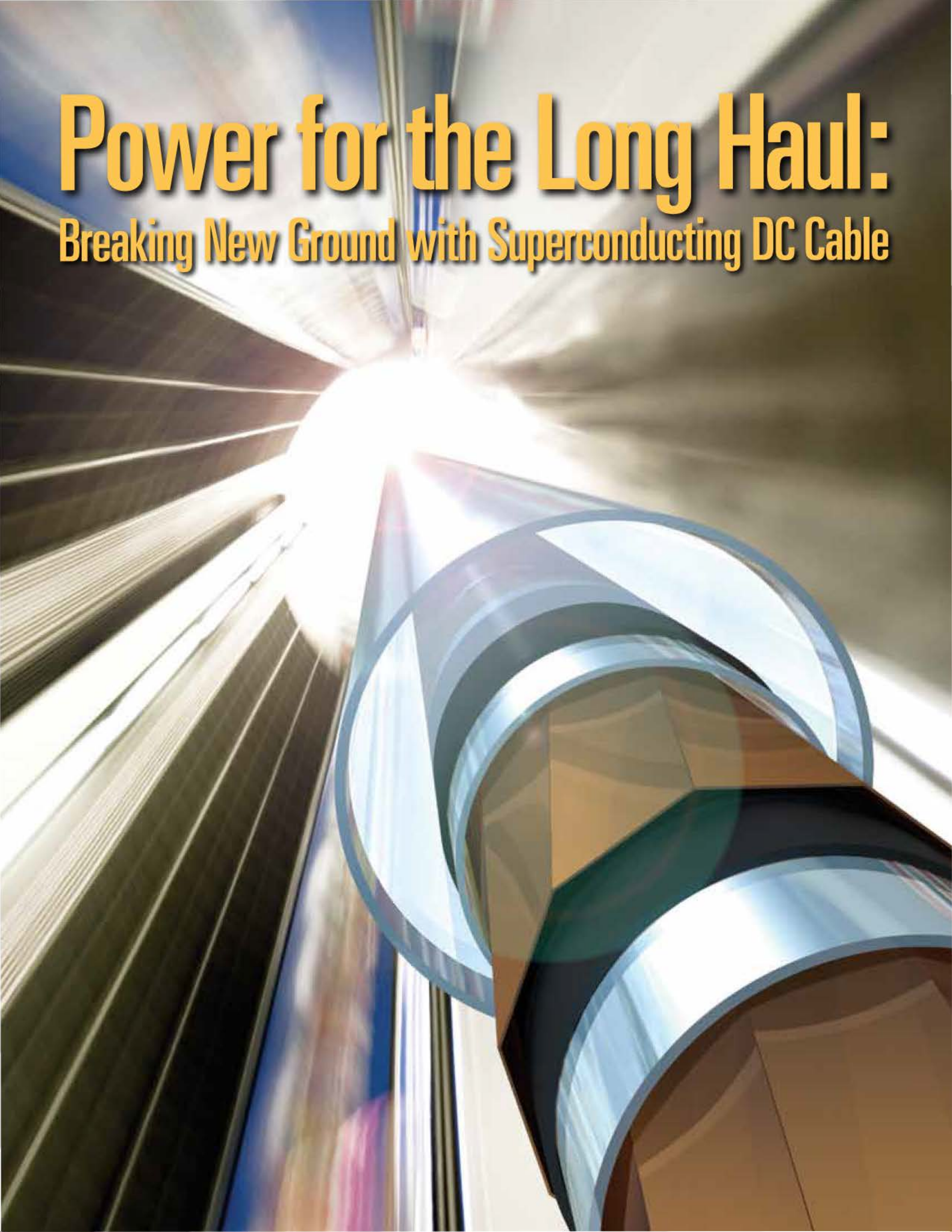
SANCTUARY COVE, Queensland – More than 160 representatives of electric utilities and suppliers in Australia and New Zealand participated in EPRI's Australian Boiler Reliability Interest Group and Turbine Generator User Group meeting and vendor exhibition. EPRI is hosting a series of such meetings to expose utility members to major boiler and turbine-generator vendors and manufacturers, to share plant failure/repair/replace experiences, and to make EPRI's major component reliability research and experts accessible to utilities worldwide.

New Members Focus on Smart Grid, Advanced Coal Technologies

U.S. & AUSTRALIA – Three Australian companies became EPRI members in the first quarter, funding clean coal technologies: Origin Energy, ZeroGen, and Energy Technology Innovation Strategy (ETIS). Also joining during this period were California Department of Water Resources, National Energy Technology Laboratory, Cisco Systems, Juniper Oxygen, and El Paso Electric.

Power for the Long Haul:

Breaking New Ground with Superconducting DC Cable



EPRI researchers have developed a conceptual design for a superconducting direct current (dc) cable that could carry 10 gigawatts (GW) of power over 1500 kilometers (km) with near-zero losses and could be built with today's technology. The next steps would be to optimize the design, develop prototypes, and then apply the cable in shorter-length applications such as interconnecting high-power, back-to-back dc converters. With further engineering, the cable could operate effectively as part of the existing grid—enhancing its safety, reliability, and efficiency and enabling a level of bulk power transfer that is not conceivable with today's conventional technology.

THE STORY IN BRIEF

Building on decades of ac superconductor R&D, EPRI has designed a first-of-its-kind dc superconducting cable that could be built with currently available materials. The new cable, which incorporates the best features of traditional and advanced bulk power transfer technologies, could be just what is needed to handle the changing transmission demands of the future.

Superconducting dc cable systems offer several potential advantages. They can:

- Move massive amounts of power over long distances with lower energy losses, greater reliability, and better stability and security than conventional high-voltage alternating current (ac) or dc systems, increasing the system's efficiency;
- Require smaller rights of way and fewer siting restrictions;
- Carry higher current at lower voltages; and
- Carry large amounts of remotely generated renewable energy over long distances.

"Should large, 5- to 10-GW generation facilities, such as large wind farms or nuclear facilities, become the norm in the next few decades for supplying energy to distant urban areas, new methods of transmitting this level of power over long distances will be needed," said Arshad Mansoor, vice president of Power Delivery and Utilization for EPRI. "On a long-range view, the superconducting dc cable is a promising means to that end."

A series of EPRI reports describe the cable design, further development options, and the practical issues of integrating cable into existing systems by using advanced power electronic converters. The EPRI reports are offered to increase awareness and understanding of the technology and its benefits, and to stimulate further engineering design and optimization.

Reinventing Transmission

A key challenge facing the North American transmission grid is the need to move power over longer distances, noted Steven Eckroad, EPRI program manager for underground transmission.

"Superconducting dc cable systems are inherently suitable for long-distance, high-power bulk energy transfer," said Eckroad. "Moreover, superconducting dc cable offers benefits that are simply not obtainable with the conventional transmission technologies—overhead high-voltage ac lines, overhead high-voltage dc lines, and underground high-voltage dc cables."

Each of the conventional transmission technologies has advantages and disadvantages.

Overhead high-voltage ac transmission is the backbone of today's grids. Increasing ac transmission voltage is the norm for increasing power flow in the near term. Overhead ac transmission accommodates multiple "local" connections but is less suitable for point-to-point, long-distance power transfers. Controlling power flows can be an issue, which may lead to the potential for serious voltage problems and system instability. For long lines, the need for reactive power compensation is a significant cost and operations burden.

Overhead high-voltage dc lines are generally more efficient than ac lines for long-distance, high-power point-to-point transmission and are increasingly used worldwide to carry remotely generated energy over long distances to population centers. To interconnect with the ac grid, high-voltage dc lines require power electronic converters, which add significant cost. As a result, dc lines become cost-competitive with ac only beyond a break-even distance, where the dc line's lower cost per unit length compensates for the converter cost. Unlike ac lines, overhead dc lines typically carry power along a single corridor without connections that deliver power to local loads.

Underground high-voltage dc cables avoid visibility and siting issues of overhead lines and offer greater reliability because they provide better protection from natural and man-made catastrophic events. High-voltage dc cables can deliver power at multiple off-ramps by using advanced voltage source converters, which make it possible to change the direction of power flow at many different nodes, providing the ability to feed power into and extract power from the system at many locations. However, voltage ratings for dc underground cables have not reached the levels of their overhead counterparts, and underground cables generally take longer

Building on Progress in AC Cable

The EPRI superconducting dc cable design builds on advances in superconductivity, innovative dc cable technology, and a series of demonstrations and in-grid projects with ac superconducting cables.

Superconductivity—the ability of some materials to carry electricity with zero resistance—was discovered in 1911. Although its potential for carrying power was recognized, the technology was uneconomical because materials had to be cooled with expensive liquid helium to extremely low temperatures (approximately –269°C) before they could superconduct. A lower-cost option emerged with the 1986 discovery of ceramic-based high-temperature superconductors, which are superconductive when cooled with liquid nitrogen to about –205°C.

Today, superconductivity is being put to use in power systems around the world. Projects to demonstrate ac superconducting cables in power grids have increased internationally as the technology improves and utilities seek to ease urban power congestion.

Superconducting cables provide three to five times the power capacity of conventional cables in the same physical space, enabling utilities to serve growing demand by using existing underground cable ducts. Superconducting cable systems also may be an effective option where rights of way are difficult to obtain.

In a pioneering 1999 demonstration project catalyzed by funding from EPRI and the U.S. Department of Energy (DOE), Detroit Edison installed the world's first high-temperature superconductor cables in a utility network to upgrade its downtown distribution system. Shortly before commissioning, project engineers discovered leaks in the system's vacuum thermal insulation, preventing the cable from operating as intended. Nevertheless, the project provided lessons for several additional in-grid demonstrations supported by DOE's Superconducting Power Equipment Program.

In one DOE-sponsored demonstration, American Electric Power has been operating a 200-meter high-temperature superconductor ac cable for more than three years. The 13.2-kilovolt (kV) cable provides a link between the secondary of a 138-kV/13.2-kV step-down transformer and the 13.2-kV bus. In a second demonstration, Long Island Power Authority in 2008 commissioned the world's first and only high-voltage transmission cable based on high-temperature superconductors. At 600 meters, the underground 138-kV system is the longest in-grid cable to date, linking a Long Island substation to overhead lines.

A proposed Entergy project in New Orleans, La., involves delivering power to growing residential and commercial areas where space constraints make new substation construction costly and problematic. Superconducting cable enables utilities to bring in transmission levels of power at distribution voltages, avoiding the need for substation transformers to step down voltage. The project will feature a 1.1-mile-long superconducting cable connecting a 230-kV/13.8-kV substation to a neighborhood site that is not large enough for high-voltage transformers.

Superconducting ac cable demonstrations also are planned or under way in Korea, China, Japan, Russia, and the Netherlands.

EPRI tracks these projects and reports on them in a series of annual Technology Watch reports that, like the superconducting cable reports, are available free as an educational service. The reports (1017792, 1015988, 1013990, and 1012430) offer tutorials on cable construction, technology, and operations, as well as status updates on cable demonstrations.

to repair because they require excavation.

"As with every other technology, the superconducting dc cable will have its pluses and minuses," said Eckroad. "But we think the design of the cable achieves some of the best features of all the options for moving bulk power."

Superconducting dc cable offers the following features:

- The massive power transmission capability of conventional high-voltage ac and dc lines;
- The efficiency and cost advantages of high-voltage dc lines, with even lower losses;
- The multiple off-ramp capability of high-voltage ac lines and of underground dc cables with voltage source converters;
- The unobtrusiveness and higher reliability of underground dc cables;
- The system control characteristics of dc transmission lines and links; and
- The potential to avoid electric and magnetic field (EMF) radiation.

"The key to the advantage of a superconducting dc cable is that the cable itself, excluding the converters, has no electrical losses," said Eckroad. "With other technologies, losses increase with the amount of power transmitted and with distance, especially with overhead ac. Of course, the superconducting cable must be kept cold, and the refrigerator power must be counted as a loss—but the loss is more or less constant and not proportional to the power transmitted on the cable. As a result, the percentage losses in a superconducting cable will be substantially lower than those with other transmission technologies. The more power transferred and the longer the distance, the more attractive this technology becomes."

The absence of electrical loss enables superconducting cables to carry high current at low voltage, in contrast to conventional aluminum or copper conductors, which require higher voltage to carry more current while minimizing losses.

"Superconducting cable changes the paradigm when it comes to increasing power," said Eckroad. "Instead of going to higher voltage to move more power, with superconducting cable you go to lower voltage and higher current—essentially providing transmission-level power at distribution voltages, which may reduce the need for large substation transformers to step down voltage to distribution levels."

Design Concepts and Grid Integration

EPRI researchers decided to pursue an interregional cable that would carry 10 GW over 1000 km or more, with nominal current and voltage of 100 kiloamperes and 100 kilovolts. Such a system could connect large power grids, transporting power from remote energy facilities to urban load centers with minimal environmental impact and without requiring transformation from transmission- to distribution-level voltages. This superconducting superhighway would serve multiple, distributed generators and loads, using voltage source converter technology for the power on- and off-ramps.

To ensure reliability and availability, EPRI designed for full redundancy in the cable system. Each circuit would have two cables in parallel, each with full 10-GW power capability. During normal operation, each would carry approximately half of the power. If there were a limitation of one cable, the other could carry the total load.

To address potential cable failure, modeling studies tested the assumption that loss of a dc transmission line carrying many gigawatts could cause voltage instability or frequency transients in the ac system. Results showed the ac system to be resilient to loss of the superconducting cables. Findings for long-distance cable routes in the eastern and western United States indicated that the eastern grid can accommodate the loss of a 10-GW superconducting dc cable and that the western grid can accommodate an 8.5-GW loss. These studies represent possible scenarios and are not necessarily prescriptive for all possible transmission paths.

Sharing Results, Reducing Costs

The three recently released EPRI reports are expected to stimulate interest and further development of the technology. American Superconductor, which manufactures high-temperature superconductor wire, is already using EPRI results to design a dc superconductor cable system for a proposed project to link the three U.S. electricity grids.

The three grids (the Western Electric Coordinating Council, the Eastern Interconnect, and the Electric Reliability Council of Texas) operate asynchronously, making it necessary to use back-to-back dc converters to move power from one region to another. The project, proposed by New Mexico startup company Tres Amigas, LLC, aims to link the three grids by means of three ac-dc-ac converter terminals linked by 5-GW superconducting dc cables.

"This project, if it goes forward, would help advance superconducting dc technology," said Eckroad. "Increased production of superconducting wire could help bring costs down and make long-distance superconducting cable more cost-competitive."

Next Steps and Future Work

Superconducting dc cable has been taken to a level of engineering design at which EPRI is confident of the concept's practicality and readiness for optimization and commercial development. Considerable work remains to be done before a final system can be fabricated and installed. EPRI researchers recommend a phased program to systematically develop the commercial prototype.

"The next step is to test the concept on a model cable system," said Eckroad. "A scalable model cable of approximately 60 to 100 meters, incorporating all the electrical and mechanical components, would provide a critical, early evaluation of a superconducting cable system. The model testing could be performed in a laboratory and then scaled up to a demonstration at a utility substation. This early testing and evaluation will provide information to guide future activities in design optimization and detailed engineering solutions."

This article was written by David Boutacoff. For more information, contact Steven Eckroad, seckroad@epri.com, 704.595.2717.

Further Reading

Program on Technology Innovation: A Superconducting DC Cable. EPRI. 2009. 1020458.

Program on Technology Innovation: Study on the Integration of High-Temperature Superconducting DC Cables Within the Eastern and Western North American Power Grids. EPRI. 2009. 1020330.

Program on Technology Innovation: Transient Response of a Superconducting DC Long-Length Cable System Using Voltage Source Converters. EPRI. 2009. 1020339.

Superconducting Power Cables: Technology Watch 2009. EPRI. 2009. 1017792.

Steven Eckroad is a senior technical manager and program manager for EPRI's Underground Transmission program. He also manages power delivery applications for superconductivity and supports the Institute's Energy Storage program. Before joining EPRI in 1992, he worked at EnerTech Energy Technology Consulting, which he founded, and earlier at Bechtel Group. Eckroad received a B.A. in physics from Antioch College and carried out postgraduate studies in electrical engineering at the University of Missouri at Rolla.

FIRST PERSON *with Michael Munroe and Bob Kipp*

People/Power:

THE HUMAN DIMENSION

Twice a year EPRI's Plant Managers Forum brings together power plant managers to discuss issues of common concern, practical problems and their solutions. Michael Munroe of PPL Corporation and Bob Kipp of Dynegy talk about the importance of these forums, especially as it pertains to the all-important human dimension of plant performance and safety.

EJ: What issues do you bring to the forum and what have you taken from the forum back to your plant?

Munroe: Plant managers get to talk about real problems, and share experiences. I get more out of this event than any other meeting I go to. We (PPL) brought back ideas for efficiency gains and a corrective action program in human performance. We are also interested in forced outage rates and the drivers that are causing people issues. We gain a lot of insight from listening to the experiences of other plants, because everybody is dealing with the same issues.

Perhaps the greatest benefit is building relationships so when we have an issue, we can pick up the phone and call someone we know. Things like our new scrubber operations, plant optimization, fuel-handling strategies, outages—the contacts we made at the forum resulted in direct benefits in these areas.

Kipp: We also get the chance to step out of the formal topics and have informal conversations—how people address the topics themselves, how they address the tangential issues that come up from the topics. That is the biggest benefit of the whole meeting—talking to people directly, listening to their stories, their experiences, and then applying it to my own facility.

EJ: Has either of you had one of those "light bulb" moments at these meetings, when you said to yourself, "Wow, I never thought of that!" and you were able to immediately apply it in your own plants?

Kipp: Oh, definitely I have. In our last meeting, Michael was talking about an EPRI human performance study. The first thing I did when I got back was download the study and read through it. Now I am looking at how I can implement some of the finer details of the study in my plant.

Munroe: Harry (Sideris) from Progress Energy talked in the last forum about "friendly eyes." They bring in a craft person, not a safety professional, during the scheduled maintenance outage and let him walk around and engage directly with the plant craft staff while they're working to get a dialogue going. We're going to implement this for our next scheduled outage. We already do a lot of exchanges and observations, but this is something very simple, very effective, and I would not have known about it had I not gone to the forum.

Kipp: You get another benefit I'll call the "snowball effect" in communication. You start talking in a group about a certain topic, and everybody is sharing their experiences, and suddenly somebody will say something that spurs another idea. Then the discussion expands on itself and before long you might have been talking about one subject and getting ideas and answers to problems there, and the next thing you know, you are talking about another issue.

Munroe: At every break, there is dialogue. There is very little time during the forum where you are not engaging somebody else. You can dive a little deeper into an area where you want to get some information. There's a lot of flexibility in the way the forum is set up.

Kipp: People also continue to communicate informally after the forum is over.

Munroe: I have benefited personally by establishing relationships with several people at the forums. We've shared plant visits between DTE's Monroe Plant and PPL's Montour Plant because we both were building scrubbers. I visited Monroe and looked at how they're doing coal handling. Frank Wszelaki, former Monroe Plant Manager, recently had a transformer go out and he was able to reach out through the network of forum members to try to find a spare transformer.

You may not get that kind of relationship the first time you come, but if you come to a couple of forums, you are going to find some people who you connect with well, and you stay in contact with them. Relationships are formed and are being sustained outside of the forums. You find out your plant, your project or the problems you are facing are similar to mine, and so you get those natural alliances. That is where I think the real benefit occurs.

Being able to talk to other plant managers and kind of bare your soul a little bit is a nice thing to have.

Kipp: That's right. It makes you feel like you are not out there all by yourself with the 3 o'clock in the morning calls.

EJ: A perennial issue is human performance, and Michael had asked a very interesting question at the most recent meeting: "How many mistakes does a human make in a day?" What do you see are some of the most effective ways to deal

with these human performance issues, and what you are learning from each other regarding human performance?

Munroe: We are making a big push at PPL, doing training specific to human performance—looking at how to keep people focused on their tasks. At the forum, we have gone into more detail. What mechanisms are you really using? How are you reinforcing behaviors? How are you getting contact with the people in the field? What are you doing to communicate? I think it's really valuable to discuss how plants have overcome human performance issues, hearing what works and what doesn't work. The key is to minimize the impacts of those mistakes and maximize the learning opportunities.

Kipp: We are doing the same types of things. We have increased our training, and we are trying to motivate and drive people to be alert and to be aware. I talk a lot about developing a culture, one that sustains itself in promoting improvement. There comes a point where you want that to take over for itself, you want your plant culture to support and drive improvement in the plant. You want your employees' normal behaviors to be those that are looking to do things right, looking to improve.

Munroe: We talk a lot about hazard recognition, trying to understand why a person does not see a hazard. If you can get someone to stop—and think—about problems and potential consequences, you'll see better results.

When employees don't see hazards, don't perceive risks, or when they proceed in the face of uncertainty, then we have to ask, what are you are thinking about when you do the job? What didn't you think about? Only when we understand those things can we build the necessary responses inside each individual.

EJ: You just used the terms "stop" and "think." In one recent forum, the managers focused on this point: "Plant managers must stop, think, and assess the impacts of their statements on employees' performance before they speak." Have you looked at the ways that you influence this culture to improve human performance?

Kipp: That really dives into leadership style. I want my supervisors and my leaders to do more than just direct. I want them to be out there reinforcing the good behaviors, encouraging people to be alert and to take responsibility for their actions. That behavior demonstrates leadership—encouraging people to ask "Why?" The human performance study I mentioned before has a whole section on questioning situations and asking why. I think that's exactly what we need to do and expect our people to do.

> **" I think it's really valuable to discuss how plants have overcome human performance issues… "** *~ Michael Munroe*

Munroe: I would agree. We as plant managers have to be careful about what we do and what we say because people are watching us. We need to be cognizant of where we show up, when we show up, and what messages we are sending. We need to go out with a purpose, with a message, even if the message is only, "Hey, I am just here to learn. I would like to see this pump taken apart. Are you guys getting the support you need?" That is a very different message than just walking up to a job and asking when it's going to be done.

EJ: Michael had made another comment about human performance at the most recent forum, saying we were advancing the technology, but the limiting factor is still human performance. Could you please talk more about that?

Munroe: You can never say you are "done" from the human performance standpoint. Getting the right process, the right coaching, and the right training is important. The big leap in the culture comes when people are self-policing. When it is 2 o'clock in the morning and the operations crew is out there, there is minimal supervision available. If they are talking to each other about doing it the right way, doing it safely, making sure we're on the right unit, we are going to take the appropriate action … that is when you get the incredible snowball effect, and it becomes part of the culture, part of the routine behavior.

Kipp: When do you ever get perfection? You are, or at least should be, continually improving, and from the leader's perspective that is the way we have to approach it. When you settle for less you start to have issues. You have got to keep moving forward, trying to find a better way, asking the questions, asking why, coming up with suggestions, solutions. We always talk about technical improvements. How do you think the technology advanced? It is from somebody asking the question, "How do we do it better?" and then going and finding a way.

EJ: A lot of our industry's most experienced plant people are edging closer to retirement. What is your perspective on differences between the generation that will be retiring and the generation coming up?

Munroe: It is interesting. We have done some training related to the differences in the generations and tried to understand them. A lot of people in the younger generation do not define themselves by their work, and they want flexibility. They are looking for challenge and the ability to contribute right away. We have been very pleased with our recent hires—some bright, capable people. We have enough flexibility to keep them challenged, and we find ways to give them experience.

I think there will be more opportunities for people to move. There are people who grew up at a plant and never left in 30 years. We are trying to change some of that, which is going to help us keep some of the bright new people we are hiring. In some cases we are not going to be able to retain the best people, no matter what we do, and we just have to understand that. We have identified when we expect to need people and have plans to address specific skills.

Kipp: I honestly don't see a real difference in the work ethic or anything else associated with the younger generation like you sometimes hear. It's strictly tied to experience, which is what you would expect. Along with experience comes confidence and comfort in the job and a sense of ownership in the facility. To promote this to the newer employees, I think we have to coach and teach them, try to bring them up to speed a little faster. Help them understand our plants and industry and the critical importance of what we do. We have done this through additional training programs and knowledge transfer programs, such as pairing more experienced and less experience employees.

"The younger crowd definitely is adaptable to the electronic technology. Nothing fazes them." *~ Bob Kipp*

EJ: EPRI is working to improve the interface between humans and machines. Given that the younger generation has been raised on video games and personal computers, do you see a difference in the way that the two groups receive and process information?

Kipp: I do think you see a difference. The younger generation is more comfortable with electronics. They've been doing it since they could walk up to a PlayStation and start playing. Someone with 25 to 30 years of experience, who hasn't had the same exposure to computers and gaming systems, may take a little more time to get familiar with it. The younger crowd definitely is adaptable to the electronic technology. Nothing fazes them. We change something and they are right there doing it, just like they adapt to the changing games and systems without slowing down. They have no fear with it.

Munroe: We can learn a lot from younger employees—for example, about getting input and how to display the data in distributed control systems. The current systems include a fair amount of graphics, and a lot of it tries to mimic what in the past would have been a simplified drawing. The younger workers are used to looking at a screen, interpreting and acting upon that information. How do we display that in ways that work best for them? That's an area where we can really grow in the future.

EJ: Safety is always and forever a big priority. What aspects of safety in human performance have the plant managers discussed recently?

Kipp: Safety comes up in pretty much all the topics we discuss at the forum. We have discussed all kinds of formal and informal safety programs. The conversation that I really liked was at our last meeting, where we discussed the development of a good safety culture—change behaviors, be responsible, slow down, think through problems, look the job over before you do it. Make sure things feel right, look right, that they even smell right. Make sure you are very comfortable that you are doing the right thing before you do it.

Munroe: Sometimes people want to separate human performance and safety. I don't think you can. We are working very hard to make sure that people don't perceive human performance and safety as two different things. They really are working toward the same goal.

The next Plant Managers Forum will be held August 24–25, 2010, in Allentown, Pa. For more information, contact Steve Hesler, shesler@epri.com, 704.595.2680.

Robotic Transmission Line Inspection

Overhead transmission lines are among the utility industry's most widely distributed assets, traversing tens of thousands of miles, often in remote locations. Reliability requirements, component aging, and right-of-way inspection compliance drive the need for thorough, timely inspections along the entire length of these lines. Such comprehensive assessments by maintenance personnel, working on the ground or in aircraft, currently entail significant expense.

To expand inspection capabilities and increase cost-effectiveness, EPRI is developing a transmission line inspection robot designed to traverse 80 miles of line at least twice a year, collecting high-fidelity information that utilities can act on in real time. As the robot crawls the transmission line, it identifies high-risk vegetation and right-of-way encroachment and assesses component conditions by means of various inspection technologies. The robot will be essentially self-sufficient, using its solar panels to recharge its batteries and power its motion, communications, and data gathering and processing.

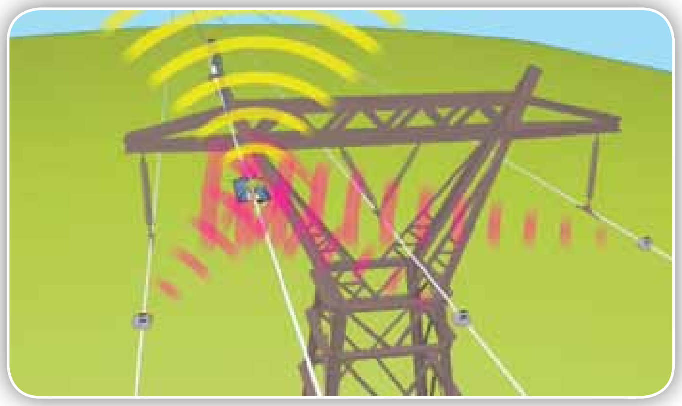
A Wealth of Inspection Equipment

One of the robot's main features will be a high-definition camera with advanced image processing to inspect the right-of-way and component conditions. Using images taken at two locations and factoring in precise parallax measurements, the robot will be able to determine clearances between conductors, trees, and other objects in the right-of-way. The camera also will be able to compare current and past images of specific components to identify high-risk conditions or degradation. As an alternative to the camera, the robot may be equipped with a Light Detection and Ranging (LiDAR) sensor to measure conductor position, vegetation, and nearby structures.

EPRI envisions that the robot will move at a pace that allows for detailed assessment. The objective will be to provide inspections that meet or exceed the quality of comprehensive examinations from a helicopter and that cover areas that are hazardous or difficult to access from the ground. The concepts and hardware that enable the robot to traverse transmission line structures are currently being patented, and the detailed design, implementation, and testing of these technologies are under way.

Connecting With Sensors

The robot will transmit key information to utility personnel, with a global positioning system accurately identifying its location and speed. Another system will collect data from remote sensors deployed along the line, and an electromagnetic interference detector will identify discharge activity, corona, or arcing. Where discharge is identified, field personnel may do further inspections using daytime discharge cameras.



The transmission line inspection robot will be able to gather information from line sensors of various types and relay information to maintenance personnel.

The conductor-crawling robot has been designed to work with a variety of EPRI-developed radio-frequency sensors that can be placed along transmission lines to provide real-time assessment of components such as insulators, conductors, and compression connectors. These sensors will likely be targeted for areas of environmental stress or where specific component types have been installed. For example, lightning sensors will be installed in high-lightning areas, vibration sensors will be used in high-wind areas, and leakage-current sensors will be deployed in coastal areas to detect salt contamination.

The deployed sensors will collect data continuously, develop histograms, and determine maximum values. Cached and current data will be transmitted to the robot when it is in close proximity and will then be transmitted to maintenance personnel. The inspection robots, when coupled with these sensors, will be able to provide comprehensive, accurate, and useful information to optimize line maintenance and improve transmission reliability. In some cases, the purchase of robots for use in place of maintenance crews could shift O&M expenses to capital costs, allowing a return on investment and depreciation.

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

New Technology Produces Activated Carbon On Site

Activated carbon injection is one of the most promising options for the control of mercury emissions from coal-fired power plants. Its promise is constrained by its expense. At $0.75–$2/lb, commercially available activated carbon could cost a plant millions of dollars a year.

To provide the industry with a lower-cost alternative, EPRI and the Illinois State Geological Survey developed and patented a technology for the on-site production of activated carbon. The sorbent activation process uses coal from the plant site to create activated carbon that can be injected directly into flue gas to adsorb mercury upstream of the particulate control device. Demonstrated to be effective with lignite, subbituminous coals, and bituminous coals, the process can prepare forms of activated carbon that have various surface areas, pore structures, and surface chemistries.

Tests have shown that the technology can produce activated carbon for less than half the cost of purchased carbon. A 500-megawatt plant could save $0.5 million–$2.5 million annually, and cost savings for the utility industry could exceed $500 million per year.

Field Tests Confirm Product Quality

Laboratory testing showed that the sorbent activation process can produce activated carbon with properties comparable to those of products sold commercially for mercury control. A unit producing 50 lb/hr was tested at Ameren's Meredosia power plant in Illinois. Two weeks of phase I testing showed the feasibility of generating activated carbon from pulverized coal and identified issues that could potentially result in low yields and carbon products with low surface area once the technology is scaled up. These issues were addressed in phase II testing.

While the samples produced in phase II were equal in adsorption capacity to commercial activated carbon, they received only limited testing in the flue gas at Meredosia because the boilers were off line for extended periods. Trials were continued in full-scale tests at Dynegy's Hennepin plant in Illinois.

Full-scale prototype sorbent activation unit, installed at a power plant.

Prototype Performs Well

The testing at Hennepin on a 75-megawatt (electric) unit equipped with a Toxecon fabric filter and firing Powder River Basin coal confirmed that activated carbon produced by the sorbent activation process performed comparably to commercial products. Both Powder River Basin coal and Illinois bituminous coal were used as feed for the test, with the products achieving ~85% mercury removal across the fabric filter when injected at 1.4–1.8 lb/MMacf (million actual cubic feet) of flue gas. A commercial activated carbon achieved only 75% at an injection rate of 1 lb/MMacf.

Researchers also experimented with adding calcium bromide to coal entering the boiler, a technique for enhancing mercury removal that EPRI is evaluating in related research (see "Southern Company Evaluates Mercury Control Technologies," page 30). This approach boosted removal levels to 92% in the case of Powder River Basin coal. Results from the Hennepin trials were considered very encouraging, given that the tests were performed with a prototype sorbent activation process unit that had not been refined for optimal performance.

Future Work

The next step is to build a full-scale unit for long-term performance and cost evaluation at a power plant. The new unit will build on the design experience gained from the prototype and recent test trials, and its refinement will be guided by a team that includes a commercial burner company and a collaborative of power-generating companies. Design, fabrication, and installation of the new unit are planned for 2010, and testing is expected to be conducted at two to three power plants for 3–6 months in 2011 and 2012.

For more information, contact Ramsay Chang, rchang@epri.com, 650.855.2082.

Near-Infrared Spectroscopy Technology for Conductor Inspection

As thousands of miles of transmission lines approach the end of their expected service life, utilities increasingly are concerned about conductor condition and reliability. Aluminum conductors reinforced with a steel-strand core (ACSR conductors) are of most concern because the outer layers of aluminum wire block visual detection of corrosion in the steel core.

Currently, most conductor inspection technologies require close access to the conductor, and a support team must move the inspection device from span to span or relocate the device to sections of the conductor where corrosion is suspected. To reduce costs, engineers have advocated limiting inspections to areas with a high probability of corrosion—areas around industrial or other pollution sources, near salt water, or where corrosion has already shown up as a problem.

To develop a more comprehensive and precise inspection system, EPRI has adapted near-infrared spectroscopy as a non-contact screening tool to quickly rule out areas with a low probability for corrosion. If a scan indicates that core corrosion may be present, a more precise inspection can assess the condition of the conductor. Sections can be removed for laboratory analyses, including measuring the remaining galvanized coating and testing tensile strength and linear polarization resistance.

Screening From a Distance

Migration of rust from strands of the conductor's steel core to the surface will change the spectra of reflected light. Near-infrared spectroscopy can measure these differences and identify sections of conductors that show signs of corrosion.

When 2003 laboratory study results showed the technology's feasibility as a practical inspection method, researchers built a beta version of a near-infrared spectroscopy apparatus that included a power supply, long-range optical elements, a spectrometer, and an integrated control system. EPRI tested and refined the unit at its outdoor environmental test bed in Charlotte, N.C. Built from relatively inexpensive off-the-shelf components, the apparatus is simple to deploy, has demonstrated repeatable results, and can be field-repaired.

In 2009, EPRI tested a prototype system at FirstEnergy and Manitoba Hydro to confirm in-the-field functionality and ruggedness and to establish effective operational procedures. While early EPRI testing had suggested that ambient light might be sufficient to produce effective readings, the field trials indicated that adding dual monochromatic light sources—most likely laser diodes—will be required for best results.

Next Steps

The use of near-infrared spectroscopy as a predictive tool would be of even greater value, and EPRI is pursuing one-year field trials of an improved prototype instrument by a half-dozen utilities. Spans identified by the device as corroded will be analyzed in the laboratory to measure conductor degradation. If the extent of corrosion detected by spectroscopy can be confirmed and correlated to remaining tensile strength, the system could be used to predict remaining service life while reducing the number of sections that need to be removed for laboratory analysis.

"Predictive use of the technology could save companies a tremendous amount of time and money and decrease the number of corrosion-related failures on their transmission circuits," said Neal Murray, senior project manager for the development work. "We may even be able to adapt the equipment and procedures for real-time scanning of entire spans by helicopter. That would be a real step forward."

For more information, contact Neal Murray, nmurray@epri.com, 704.595.2624.

Southern Company Evaluates Mercury Control Technologies—*Could prove valuable in addressing Maximum Achievable Control Technology standards*

The current leading control technology for mercury emissions is injection of a fine-powder sorbent material—typically activated carbon—into the power plant's flue gas stream. The resulting mercury-containing carbon is then collected by a downstream particulate control device along with the plant's fly ash. However, this process can cost $1 million–$10 million per plant per year. Carbon injection also can render fly ash unsuitable for use in concrete or, in some cases, increase emissions of particulate matter.

The U.S. Environmental Protection Agency is now developing Maximum Achievable Control Technology standards for U.S. coal- and oil-fired generating plants; the result will potentially be stringent mercury emission limits and the challenge of meeting them cost-effectively and without adversely affecting balance-of-plant operations and maintenance.

Southern Company has joined with EPRI to conduct demonstrations of three promising alternative mercury control methods—bromine addition, hydrogen chloride injection, and MercScreen technology.

Bromine Addition

Research has shown that adding calcium bromide to pulverized coal before it enters the boiler will oxidize elemental mercury, which can then be removed by a plant's wet scrubber unit. This oxidation is enhanced by selective catalytic reduction (SCR) systems when halogens, such as bromine or chlorine, are present at adequate levels.

Pilot-scale testing was conducted on Unit 4 of Alabama Power's Plant Miller to determine the effectiveness of an SCR system in oxidizing mercury in the presence of additional bromine and to evaluate the balance-of-plant impacts. Plant Miller is a 700-megawatt (MW) pulverized-coal unit that fires Powder River Basin coal in a wall-fired furnace. It is equipped with two parallel SCR chambers and a cold-side electrostatic precipitator.

Results showed that adding calcium bromide to the coal entering the boiler effectively achieves high mercury oxidation levels in SCR-equipped plants burning Powder River Basin coal. With the SCR in operation, mercury oxidation of the scrubber inlet gas increased from between 65% and 85% at the baseline to 97%. No increase in mercury adsorption by fly ash was observed. More than 98% of the oxidized mercury was removed by a pilot scrubber.

Chlorine Injection

Tests conducted at the Mercury Research Center at Gulf Power's Plant Crist evaluated mercury oxidation performance of four conventional SCR catalysts as a function of changes in flue gas, including chlorine levels, ammonia, flow rate, and temperature (1018072). For tests conducted with low-chlorine fuels, hydrogen chloride was injected into the flue gas upstream of a pilot SCR unit.

Results showed beneficial effects for mercury oxidation and capture when levels of chlorine are increased. On average, mercury oxidation across the SCR reactor improved from 50% to 90%, and capture by the electrostatic precipitator improved from 60% to 80+%. All catalysts tested showed a similar behavior with respect to chlorine levels. Project data will help full-scale facilities determine which methods can be used to improve mercury oxidation and capture primarily by capitalizing on equipment already in place.

Gulf Power's Mercury Research Center

MercScreen

MercScreen, developed by EPRI as an alternative to activated carbon injection, uses a fixed bed of activated carbon granules or pellets installed at the outlet of the electrostatic precipitator. In slipstream pilot-scale testing, a 1-MW MercScreen reactor was installed and tested at Alabama Power's Plant Miller to test its operation with five different commercial granular or pelleted activated carbons (1016176). Results showed mercury removal levels of 70%–90% for periods of up to 60 hours, with an acceptable pressure drop through the bed. The MercScreen technology promises to achieve high mercury removal, relatively low volumes of waste by-products, and possible regeneration and reuse of the activated carbon.

For more information, contact Ramsay Chang, rchang@epri.com, 650.855.2082; Chuck Dene, cdene@epri.com, 650.855.2425; or Alex Jimenez, ajimenez@epri.com, 650.855.2051.

EPRI Members Host Field Tests of Digital Radiography

A major factor in forced outages of fossil plants is the cracking mechanism in boiler waterwalls known as corrosion fatigue, which occurs in high-stress areas such as the tube attachment welds, the result of thermal cycling and water chemistry. Corrosion fatigue cracking presents a challenge for nondestructive evaluation because the mechanism involves multiple cracks that initiate and grow on the tubes' inside surfaces—at points where access may be impeded by insulation, structural components, and the building covering.

Looking for Better Tools

Conventional X-ray or gamma-ray film radiography, the standard technology for weld examination, is limited by a loss in sensitivity when the radiation beam passes through heavy components outside the boiler. Direct-digital radiographic detectors were proposed in the late 1990s as an alternative, but the technology's resolution was inadequate for crack visualization. Recent improvements have increased resolution to the point where digital detectors can now be used to identify and analyze corrosion fatigue cracking.

Laboratory tests have shown that digital detectors have image sensitivities at least equal to the sensitivity of radiographic film, plus a greater dynamic range to better address materials of various thicknesses. Requiring no film processing, they offer real-time viewing, and their remote positioning and alignment capabilities can improve accessibility and accuracy. Overall, digital detection represents a potentially more accurate, more cost-effective means for identifying and repairing damage in fossil plant boilers before damage leads to an unscheduled outage.

Field Tests at Conesville

American Electric Power (AEP) hosted the first field trials of the direct-digital radiographic system for corrosion fatigue cracking applications in the boiler of its retired Conesville Unit 1 in Ohio. The technology consists of two main components that work in parallel. On the outside of the boiler, a radiation source directs an X-ray beam toward the wall, and a photosensitive metal oxide detector on the inside of the wall receives the beam to create an image at a spatial resolution of 0.003 inch (80 microns). The two devices, mounted on wheeled frames that run on tracks, can travel horizontally or vertically along the boiler wall. A motion control system with integrated image-capture software keeps the X-ray beam and the detector aligned.

The first Conesville trial demonstrated that the system could be successfully deployed on horizontal tracks attached to scaffolding inside and outside the boiler, with the detector and source alignment correctly maintained throughout the scanning. The X-ray tube was placed approximately 40 inches (1 meter) from the boiler tube in order to allow maximum scanner travel around various obstacles exterior to the boiler. Personnel were able to operate the equipment safely from approximately 20 feet (6 meters) away—a significant reduction of the conventional radiation exclusion zone.

A motion control system keeps the X-ray tube (right) and the digital detector (left) in alignment as they scan boiler tubes for corrosion fatigue cracking.

Scanning at a rate of approximately 1 foot (0.3 meter) per minute, the system produced radiographic images of both walls of the tubes without interference from refractory materials, buckstays, insulation, the boiler casing, or the boiler's skin. A second field test verified an extension of the range of motion to include vertical travel and tilt of the detector, which would allow users to examine tube crowns, areas along the membrane, and corners of the boiler.

Tom Andress, senior engineer at AEP, is optimistic about the technology: "The issue with corrosion fatigue," he said, "is that there are so many different places it can occur. This technology would enable us to look at everything—very rapidly scan all the wall tie-ins, which is where the cracks start in one form of corrosion fatigue. We could do it in one outage."

Improvements Tested at Tyrone

Following the Conesville trials, a number of improvements were made to the equipment fixtures, and software features were added for off-axis imaging and fixed-source position scans. These improvements were successfully demonstrated at E.ON U.S.'s Tyrone Generating Station near Lexington, Kentucky. A videotape of the Tyrone demonstration is available on request.

For more information, contact Stan Walker, swalker@epri.com, 704.595.2581.

On-Site Assessments Help Reduce the Volume, Costs of Low-Level Waste

The closing of South Carolina's Barnwell regional disposal facility to states outside the Atlantic Compact leaves 85% of U.S. nuclear plants with no disposal site for Class B and C low-level waste (LLW). As a result, these plants must store this class of waste on site, leading to new challenges and higher costs. Nevertheless, nuclear utilities that apply the latest best practices in LLW management are slashing on-site storage and projected disposal costs by an estimated million dollars or more and reducing the volume of Class B and C waste by more than half. EPRI has compiled these proven techniques in a series of EPRI reports that have been applied to great effect with the support of on-site assessments.

Anticipating restrictions in disposal site access in the early 1990s, EPRI began working with nuclear utilities and industry experts to develop a series of guidance documents for LLW management. These guidelines cover the design of on-site storage facilities, optimal waste forms for extended storage (1016762, 1003436, 1007863), operation of on-site storage facilities (1018644), and waste reduction strategies (1015115). Each document synthesizes findings from years of research and presents techniques to help nuclear facilities implement and maintain safe, cost-effective, and technically sound LLW management programs.

On-Site Services

To help plant staff implement the guidelines more effectively, EPRI has conducted on-site storage and waste reduction assessments at seven sites, including both pressurized water reactors and boiling water reactors. During the assessments, a radwaste management expert identifies options to reduce the volume of Class B/C waste, develops on-site storage recommendations, analyzes each site's program relative to regulatory and industry guidance, and provides findings and recommendations in a detailed, comprehensive report.

The plant assessments have yielded an array of recommendations and benefits. One plant lacked both facilities for on-site storage and advanced practices to reduce waste generation. EPRI developed a matrix to help plant staff perform a detailed engineering evaluation of potential storage locations and develop a long-term strategy to reduce waste volume. A key element of the strategy was to segregate Class B/C resins from Class A resins. Up to that point, all the resins had been commingled in a single storage tank, with the result that the more voluminous but less radioactive Class A waste also became classified as Class B or C waste. Projected benefit: Reduce the volume of Class B/C resin by 51%. Projected savings: Reduce costs by 46%, saving $236,000 a year, or $5,670,000 over the life of the plant.

Liquid radwaste processing skid (Photo courtesy of Ameren)

The assessment for another plant, which already had an effective B/C waste reduction program in place, focused on optimizing storage. Recommendations included engaging management to resolve "ownership and use" of storage areas for radioactive materials and developing a long-term storage plan. Projected benefit: Reduce the number of shielded containers required for waste storage. Projected savings: Up to $200,000.

A third plant already practiced resin segregation, but low-activity Class A waste was occasionally commingled with Class B/C waste because of difficulties in resin classification. The assessment recommended using dose-to-curie conversion factors to determine resin classes more effectively and reduce resin commingling. The assessment team also helped plant staff develop plans to convert the existing radwaste staging facility to an interim LLW storage facility and provided options for life-of-plant waste segregation. Projected benefit: Avoided disposal costs. Projected savings: More than $5.25 million over the life of the plant.

"EPRI's on-site storage assessment gave us a comprehensive review of our preparedness for on-site storage," said Marlyn Anderson, radwaste supervisor at Omaha Public Power District's Fort Calhoun nuclear plant. "Their broad industry perspective and knowledge of best practices helped us to focus quickly on those things that would improve our program."

For more information, contact Lisa Edwards, ledwards@epri.com, 469.586.7468.

FirstEnergy Benefits From Standardized Task Evaluation Program

Supplemental workers perform more than half the outage maintenance tasks at U.S. nuclear power plants. These workers must be evaluated to ensure they possess the knowledge and skills required to perform specific tasks. Traditionally, each plant has trained and tested supplemental workers to establish proficiency, but the result has been duplicative, nonstandard training and testing for a pool of workers whose time could be more productively spent working at other plants.

Qualifying supplemental workers for specific tasks before they arrive on site can save plant operators considerable time, money, and effort. For example, reducing on-site orientation and qualification from six days to three could save 2,250 work hours for a single outage. To help companies achieve such savings, EPRI worked with nuclear plant training experts and work force providers to develop the Standardized Task Evaluation program, which provides standard advance qualification for supplemental workers.

Based on rigorous analysis of required capabilities, the program covers more than 50 common tasks and requires written tests and hands-on proficiency evaluations. In addition to reducing training costs, ensuring quality workmanship, and improving training-records management for utilities, the program helps work force providers streamline their qualification procedures and meet utilities' needs for skilled and available supplemental workers.

Putting the Program to Work

FirstEnergy Nuclear Operating Company (FENOC) was among the first utilities to implement the standard evaluations and has contributed to the development of the program through the program's steering committee and working group. The need for reliable, standard qualification was highlighted by FENOC's experience with a crew hired to service air-operated valves at its Beaver Valley pressurized water reactor.

"They had 12 air-operated-valve technicians and two supervisors to perform bench testing," said Archie Proffit, FENOC's program manager, fleet maintenance. "When we gave them a simple test to assess their qualifications, 11 of the 12 technicians failed it—and both of the supervisors. That really opened our eyes. We need good, qualified workers and we need to be able to determine that they're qualified, but training the workers ourselves takes a lot of money and time." As a member of the program's steering committee, Proffit saw the opportunity to cost-effectively improve the proficiency of the supplemental work force.

Collaborating with EPRI and work force providers DZ Atlantic and the United Association, FENOC helped develop and apply evaluation modules in key maintenance areas, including industrial rigging, foreign material exclusion, and valve maintenance. The effort paid off when the Institute of Nuclear Power Operations (INPO) issued a Significant Operating Experience Report on lifting and rigging in nuclear plants. The evaluations also significantly improved foreign material exclusion at the Beaver Valley, Davis-Besse, and Perry plants, as measured by an INPO maintenance evaluation.

"Instead of holding training classes on new requirements, we ask the supplemental personnel to come in already qualified, and we use the standardized task evaluation rigging modules to verify their qualifications," said Proffit. "When a worker has passed both the written exam and the hands-on proficiency evaluation, he or she is ready to go straight to work and complete the job safely. Using the Standardized Task Evaluation program for lifting and rigging has cut down our training time and costs by about 65%."

Easy Access

The standardized task evaluations are available to organizations that subscribe to this EPRI program. Selected evaluations have been made available through INPO's National Academy for Nuclear Training e-Learning system. Written tests can be administered via hard copy or electronically by utilities or work force providers. The practical evaluations are administered either in an accredited nuclear program or in accordance with criteria detailed in the EPRI-developed Administration Protocol for Portable Practicals.

EPRI's task evaluation program is not restricted to U.S. application. Nuclear plant owners in France, South Africa, and Canada have expressed interest in adapting the modules, and members of EPRI's nuclear program anywhere in the world can participate.

For more information, contact Patty Wade, pawade@epri.com, 704.595.2526.

PNM Resources Uses EPRI System to Evaluate Oil Spill Risks

The U.S. Environmental Protection Agency's Spill Prevention, Control, and Countermeasure (SPCC) regulations are designed to prevent oil discharges from reaching navigable waters or adjoining shorelines. Specifically, the rule requires utilities to draft plans that describe the equipment, work force, procedures, and training in place to deal effectively with a discharge of oil at any of their facilities. In 2005, PNM Resources revised the SPCC plans for its New Mexico facilities. The new plans recommended containment retrofits for more than half the company's substations and switching stations.

But PNM Resources' New Mexico stations are in arid regions with few bodies of water. In light of this reality, the company decided to reevaluate its 2005 assessment. In 2008, the company determined that it needed a better methodology to reassess the risk that oil from one of its facilities could reach water. Moreover, PNM had recently acquired stations in Texas that had to be evaluated, and the utility faced a compliance deadline under the SPCC rule, which was being reviewed and amended by the EPA.

A Quantitative Tool

John Acklen, manager of the SPCC project, turned to EPRI for guidance. "We thought of EPRI right away," he said. "We looked at its Mineral Oil Spill Evaluation System and realized that this was a way to really evaluate the risk quantitatively. That's what this tool is all about." The system's software program provides a method for predicting the likelihood that substation spills will reach groundwater or nearby surface water, how much oil will infiltrate the ground beneath electrical equipment, and soil saturation profiles at user-specified times. The program also creates a draft SPCC plan that automatically incorporates site characteristics and simulation results into an editable text file that can be customized to include utility-specific information.

Using data collected from field investigations at PNM facilities in Texas and New Mexico, the system was able to accurately predict the likelihood of oil spills reaching water. Ted McCarty, an SPCC team member, said, "EPRI's system took the guesswork out by giving us definitive and quantitative information that we could use as a guide."

Retrofit Plans Refined

After revising its SPCC evaluations, PNM Resources concluded that containment retrofits were warranted at only 28 of its 96 New Mexico stations. By determining that existing safeguards were sufficient at the majority of facilities, the new evaluation saved the company more than $800,000 that it would have spent under the 2005 SPCC plans. "EPRI's spill evaluation system was really important to our approach," Acklen said. "It gave us a way to measure, compare, and rank our substations, saving our company a substantial amount in retrofit costs."

The company also used the system to evaluate and help assess the risks at 127 stations owned by PNM subsidiary Texas–New Mexico Power. These stations are spread across a variety of physiographic and climatic zones, from arid desert to the Gulf Coast, so at some there is a greater likelihood of spilled oil reaching water. In addition to the SPCC plans for these stations, PNM Resources is developing multifacility plans to be posted on the company website, with each plan containing information about the SPCC rules, facility-specific information, and results of the Mineral Oil Spill Evaluation System analyses.

The SPCC evaluations helped PNM Resources determine that the evaluated facilities comply with both current and future SPCC rules.

For more information, contact Mary McLearn, mmclearn@epri.com, 650.855.2487.

REPORTS & SOFTWARE

Key deliverables now available

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

Solar Photovoltaics: Status, Costs, and Trends (1015804)

This white paper addresses the history, status, and trends of flat-plate solar photovoltaic (PV) power technologies in both crystalline silicon and thin-film forms. Perspectives are provided on the cost and performance of PV modules, as well as on the materials used to produce them. Looking back to the 1970s and forward to the next 30 years, the report describes major milestones and trends in PV power system development and incentives and policies that affect utility engagement. Recent trends suggest that power companies will have a significant role in both distributed and utility-scale applications. The white paper suggests some key evaluation parameters and includes a strategy checklist for utilities.

Best Practices for the Application of Handheld Computers to Operator Rounds (1017638)

Most generating companies have considered changing from clipboards and paper forms to the use of handheld computers for collecting of data during operator rounds. This report captures the experiences of several plants where this has been done, describes related industry experience, and provides guidance for those who are considering the transition. The report does not conclude that every plant should make this change; rather, it offers insights on performing thorough evaluations so utilities can make informed, quality decisions. It also offers guidance on making the transition in a manner that is as error-free, timely, and effective as possible.

Nuclear Maintenance Applications Center: Generator Maintenance Guide for Emergency Diesel Generators (1019146)

Routine and long-term generator maintenance is especially important as nuclear power plants prepare for life extension and the equipment ages past its original design life. Though the overall performance of emergency diesel generator systems has improved during the past 25 years, recent issues have indicated that increased attention to these generators is warranted. This report provides maintenance guidance for generators within nuclear plant emergency diesel generator systems, particularly focusing on stators and rotors. Bearing-drive trains, control systems, and lubrication systems are not discussed. The report, which combines expertise from industry generator experts with that of plant personnel, highlights generator maintenance tasks and practical maintenance strategies that can be performed to avoid generator degradation or failure.

Plant-Specific Recommendations for PWR Radiation Source Term Reduction (1019225)

EPRI's PWR Source Term Reduction program seeks to understand the causes of radioactivity generation and transport and—through data analysis, operations review, and technology evaluations—provide utilities with plant-specific recommendations for source term reduction. For this latest review, the project team segregated pressurized water reactor (PWR) plants by their design similarities and identified the plants that have implemented known source term reduction technologies. They then compared the performance of the technologies as a function of time for both activity releases and shutdown dose rates. As a result, the report provides recommendations for source term reduction that can be applied in general cases and notes the factors that are the primary considerations when benchmarking an individual unit for radiation field reduction.

Sensor Technologies for a Smart Transmission System (1020619)

EPRI researchers are pursuing a range of advanced, low-cost sensor technologies and associated infrastructure to help utilities deal with maintenance and reliability issues for an aging fleet of transmission lines and substations. New sensors also will be key to the emerging intelligent grid, which will incorporate automated smart diagnostics and condition assessment features that will enable a shift from resource-intensive, time-based maintenance to more cost-effective, condition-based maintenance. This white paper reviews the R&D efforts under way in the areas of sensor development, information application, communication and data collection, security, power harvesting, and algorithms and data visualization.

Combustion Turbine/Combined-Cycle (CTCC) Operations and Maintenance (O&M) Cost Analyzer, Version 7.21 (1020750)

The CTCC O&M Cost Analyzer is a spreadsheet software product that estimates lifetime O&M costs for plants using 28 specific gas turbine models, including D/E-, F-, and G-class heavy-duty and aero-derivative engines. The database includes initial component costs, and maintenance intervals are based on manufacturer algorithms. Unplanned maintenance costs are estimated from statistical experience for gas turbines. The software framework can be used to evaluate alternative approaches to satisfying maintenance requirements for both new and existing plants, including comparison of long-term maintenance contracts with self-directed maintenance.

Collaboration Is Key to Powering the Future of Transportation

Britta Gross *is director of Global Energy Systems & Infrastructure Commercialization at General Motors.*

For a lot of reasons, the time may be just right to introduce a new generation of electric vehicles to the market and change the way we commute: the battery technology's better, the country is weary of our overreliance on oil for transportation, and the environmental impact of emissions of all kinds is a growing concern to most everyone. As several major automakers—GM included—prepare to introduce an array of electric vehicles into the marketplace later this year, it's important to think through how these vehicles will interact with the electricity grid, especially as we move from hundreds to thousands to millions of plug-in vehicles on the road. Never has it been more important to get the launch of a new technology right—and never have strategic partnerships been so critical.

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We did a lot of really smart things in designing the Chevrolet Volt: we gave it a battery capable of powering about 40 miles of travel (most Americans commute less than 40 miles to/from work each day), and we gave it a small engine generator that runs on gasoline, which will provide another 300 miles or so of extended driving range. But one of the smartest things we did was to begin working with utilities from Day One.

Through a collaboration with EPRI, we formed a partnership initially with 30 utilities to help us do two things: (1) maximize the potential of our vehicle design and (2) define the right interface with the electricity grid for the first-generation Volt, as well as for subsequent generations of electric vehicles. The partnership has since grown to include more than 50 utilities in North America and continues to be a vibrant forum in which industry questions, standards issues, technology demonstrations, and market opportunities are discussed and strategized.

What's been the direct benefit of this collaboration? First and foremost, a single voice on all major issues related to electric vehicles and the electricity grid. If you listen to EPRI, the member utilities, or GM talk about plug-in vehicles, you will hear a consistent message on a broad range of subjects, from the ability of the grid to reliably handle millions of plug-in vehicles, to the potential for vehicle-to-grid technology.

"If you listen to EPRI, the member utilities, or GM talk about plug-in vehicles, you will hear a consistent message on a broad range of subjects…"

This close working relationship has brought together two major industries—automakers and utilities—and has brought clarity to efforts to develop industry standards for vehicle charging and communication protocols, as well as having prioritized the policies and incentives most helpful to early-adopter consumers.

GM's partnership with the utilities has also been strategically important in planning the new home charging experience for consumers and the efforts needed to get cities "ready" for plug-in vehicles. In many local communities, utilities will be working directly with dealers, consumers, permit providers, and others to ensure that the consumer experience of charging is as smooth and satisfying as possible.

This is the year of the Volt, and because of our collaboration with EPRI, we are confident that the Volt and its interaction with the grid have been thoroughly vetted with the expertise and active engagement of the utility industry. No doubt we still have a lot to learn about optimally supporting plug-in vehicles on the grid, but the opportunities to continuously improve grid interaction by leveraging the smartness of the car with the smartness of the grid currently appear limitless.

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