ELECTRIC POWER RESEARCH INSTITUTE

STATE OF THE TECHNOLOGY | 2016

SEEING ELECTRICITY THROUGH

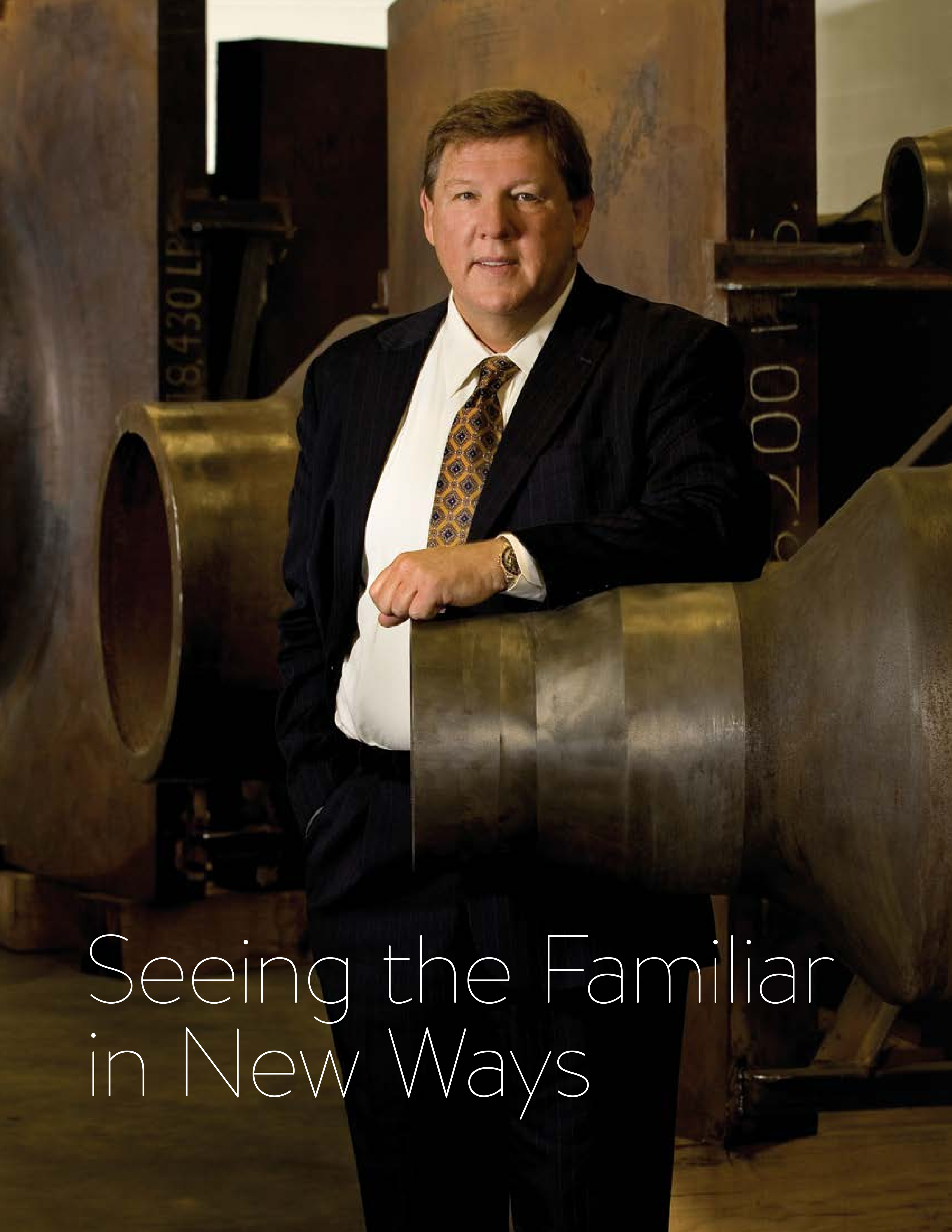
NUCLEAR

POWER DELIVERY & UTILIZATION

RESEARCH AND DEVELOPMENT

ENVIRONMENT

GENERATION



Seeing the Familiar in New Ways

As you read EPRI's *2016 State of the Technology Report*, I invite you to see today's global electricity sector in the context of climate policy, digital technologies, the workforce, and the world's growing dependence on electricity (to name a few big aspects). I encourage you to examine today's familiar power system and EPRI's work in a broad trajectory of change, and to see electricity in new ways.

See new ways for traditional assets. Fossil-fueled power plants are taking on new, more demanding operating missions. Increasingly they must ramp through cycles from idle to full production, with new demands and calls for new approaches for materials, systems, and the workforce. We are investigating ways to reduce emissions and to manage discharges and by-products more effectively. We're engaged in the fundamental transformation of distribution circuits from passive delivery systems to dynamic interchanges of electricity, services, and customer transactions.

See traditional assets more clearly—even up close. For the nuclear fleet, we are looking at virtually every aspect of the plants, inside and out. We are honing skills and techniques to evaluate plants' materials, which must operate to exacting standards under demanding conditions. We're looking at familiar power poles in new ways, and understanding how relatively simple changes can make these and other distribution structures more resilient. In the United States, we must see how best to modernize a transmission system with a quarter-million miles of lines.

See new connections and relationships. Distributed energy resources, such as customer-owned rooftop solar, are literally redrawing the traditional utility map and changing the business model. Information and communication technologies are changing the business from the back office through the wholesale and retail markets, and impacting customers directly.

See what we've never seen before. Augmented reality through wearable computer devices can overlay data and images on workers' views of power system hardware and components. This equips them to see or locate underground components or to locate and identify individual components damaged by weather or other causes. Read about a technology that enables plant personnel to see inside heat recovery steam generators to make the critical determination of the presence of water or steam. One program is investigating spray-on sensors to monitor the health of power plant components.

See the human dimension. Ergonomics research, including the possible application of augmented reality, equips people to perform work more safely and to reduce the risk of wear-and-tear leading to injury. New survey methods may provide a better view of customer preferences.

See threats more clearly. What risks do power plant owners and operators face from earthquakes and other potentially catastrophic events? Electromagnetic pulses resulting from high-altitude detonation of thermonuclear bombs pose a threat, and while it is difficult to determine the likelihood, it is important to characterize the risks and consequences carefully.

See the long term. This applies across the board, but to flag a couple of particulars, I invite you to read about the work we're doing with respect to aligning nearer term investment with long-term goals related to emissions reductions. Also, in most contexts "sustainability" implies a view beyond the horizon. Bringing a sharper, focused definition to the concept is proving helpful for the electricity sector and beyond that to encompass the broader energy sector. Also, we're looking at emerging technologies to understand their full environmental impacts over the entire life cycle—from manufacture and use to disposal and recycling.

Michael W. Howard

President and Chief Executive Officer,
Electric Power Research Institute

EPRI Research: No Show Stoppers for Plant License Renewal

SHERRY BERNHOFT
EPRI Senior Program Manager

As more nuclear plants operate beyond their original, licensed life, EPRI's Long-Term Operations (LTO) initiative is researching many issues associated with even longer term service. In the United States, most of the nation's 100 power plants are approved for renewal to 60 years. Utilities are interested in a second renewal out to 80 years, and the LTO program—established in 2010—is helping to substantiate the technical basis for longer term operations. For their part, the utilities are implementing aging management programs to prescribe actions needed to identify and address the degradation that occurs as components age through normal wear-and-tear and/or increased neutron—and temperature—exposure.

These programs provide the technical basis that the plants can use to continue to operate safely, while the significant body of previous research informs those actions necessary to support the long-term viability of the nuclear fleet—which produces about 20% of all the electricity generated in the U.S.

EPRI Senior Program Manager Sherry Bernhoft said neither recent nor historical research on nuclear plant operations has identified any technical or generic "show stoppers." But a great deal of work continues as EPRI and its LTO collaborators (which include the U.S. Department of Energy, federal laboratories, and the International Atomic Energy Agency [IAEA]) maintain their "living research continuum" in which "we perform technical studies and gather inspection data from U.S. plants and others around the world," Bernhoft said.

The technical basis for the LTO initiative, Bernhoft pointed out, was established based on decades of earlier research. Much of it has been published in EPRI reports. Utilities' aging management guidelines rely on more than 125 guidelines for inspecting, repairing, and replacing components.

In 2016 a number of LTO milestones will be achieved. For example, after years of preparation, EPRI is testing an experimental welding technique ("laser hybrid") in a cubicle at Oak Ridge National Laboratory. Researchers will demonstrate the efficacy of the robotic welding technique for *in situ* repairs on stainless steel "internals" of a pressure vessel's irradiated, and potentially embrittled, materials.

For the pressure vessel itself, the key to gauging embrittlement is to test a "capsule" of identical material positioned within the vessel for subsequent harvesting and analysis. "We have some of the previously harvested capsules, and we're in the midst of preparations to re-introduce them at a couple of host plants to extend the database," Bernhoft said.

EPRI is preparing to publish more research reports, including one that will present "the structural evaluation of irradiated concrete supporting the reactor vessel, and one for the inspection and evaluation of civil structures subject to environmental degradation," Bernhoft said.

Analytical research supporting long-term plant viability, she added, "will also help preserve an important source of carbon-free electrical generation. So, the work we're doing is very important as well as exciting and challenging."

Sensor Research to Transform Nuclear Plants into "Fully Informed" Facilities

EPRI is testing "intelligent" sensors and communications protocols to enable nuclear plant staff to access and analyze sensor data in real time. The research is part of EPRI's Instrumentation and Controls Program, and supports the Wireless Health & Asset Management project. Progress in resolving technical issues has been driven in large part by dramatic declines in the size and cost of computing.

Sensors traditionally converted physical parameters, such as heat or pressure, into electrical signals. Now compact and inexpensive computing capabilities can produce digital signals, and manufacturers are incorporating computer-processing capability into the sensors themselves.

But readings from "intelligent sensors" still must reach gauges, warning lights, and computer screens. EPRI Senior Program Manager Rob Austin says that hard-wiring sensors in nuclear power plants is extremely expensive in many cases, so EPRI is researching solutions that rely on wireless protocols.

"Most plants have installed, or plan to install, Wi-Fi access points—which raises issues," said EPRI Senior Technical Leader Nick Camilli. "First, the high frequencies aren't good at penetrating the thick concrete walls in the plants, so you need a lot of access points. And, each access point requires a power cable and an Ethernet cable—and each additional cable adds costs."

Camili says that EPRI has been experimenting with "distributed antennae systems at lower frequencies—basically cellular frequencies that don't need as many access points as Wi-Fi." EPRI and Exelon are piloting the use of this distributed antenna system (DAS) in a nuclear plant. "It's a common technology to bring cellular signals into buildings, but it has never been done at a nuclear plant," Camilli said.

Also, EPRI is testing several advanced sensors. An example is a fast-response, nanostructure hydrogen sensor that senses changes in the electrical characteristics of a microchip in the presence of hydrogen. Because some nuclear reactions can produce explosive hydrogen gas, nuclear plants must monitor atmospheric conditions inside containment to detect hydrogen. Initially the sensor will be tested outside of containment, but Austin points to a design concept being considered for use inside containment.

Whatever a sensor's function, converting the data into a "language" spoken by the different software programs can be achieved, Austin said, through the common information model. EPRI developed this model for transmission grid operations, and it has become an International Electrotechnical Commission standard, translating data into a common "vocabulary" allowing programs to exchange information.

"Our concept," said Austin, "is that the model works very well for communicating the status of their grid operations. We plan to demonstrate the feasibility of extending that model and bringing it into the plants."

EPRI conducted a workshop to further discuss and formulate these concepts. Participants identified many areas for inclusion in an industry roadmap being developed in 2016 to spell out the steps necessary to achieve EPRI's goals for project components, such as DAS, intelligent sensors, and common information models.

Ten-Year Study Investigates Dry Storage, High-Burnup Fuel

Photo courtesy: U.S. Nuclear Regulatory Commission

High-burnup fuel is defined by the U.S. Nuclear Regulatory Commission (NRC) as fuel that is discharged above the threshold of 45 gigawatt-days of power per ton of uranium (GWd/MTU). To improve reactor economics, the nuclear industry has been increasing its fuel burnup since the 1990s. Approximately two-thirds of fuel discharged from reactors today is above 45 GWd/MTU. With this increase in burnup, a question has been raised about the potential impact it could have on long-term storage. To address this question, EPRI and the U.S. Department of Energy have launched a demonstration project to confirm the behavior of high-burnup fuel during extended storage.

As part of this demonstration project, EPRI researchers are modifying a commercial storage cask with monitoring equipment. By 2017, the cask will be loaded with several types of high-burnup fuel at Dominion's North Anna Power Station, and key parameters will be monitored over a 10-year period at the plant's cask storage facility. The cask lid will be modified to allow thermocouples to be inserted so that temperature inside the cask can be routinely monitored. Pending NRC approval, there will also be intermittent gas sampling over the 10-year period to look for any indications of degradation. At the end of 10 years, the fuel rods will be transported to a laboratory to undergo material testing to determine if any changes occurred from the dry storage process.

The demonstration project has reached several significant milestones, including transportation of "sister rods" to Oak Ridge National Laboratory where they will be used to provide baseline information about the fuel prior to dry storage. Fabrication of the cask lid has also begun. "We remain on track in all aspects of the project, including the licensing. Before Dominion can load this special high-burnup cask, they have to get approval from the NRC," said Keith Waldrop, principal technical leader, Fuel and Chemistry. "Dominion submitted the license amendment request to the NRC last summer, the NRC issued a formal set of questions in January, and Dominion has provided its responses to keep the review on schedule to load the cask next July. The cask is on schedule to be completed in time to ship to North Anna early next year."

Changing Landscape Prompts Utility Interest in Advanced Reactor Designs

The designs for advanced nuclear power plants are drawing greater utility interest as power companies contemplate uncertainties in their industry and future electrical demand. The issues include declining output from coal-fired plants and the intermittency of wind and photovoltaic generation. Will nuclear generation manage to fill the supply gaps that could start emerging by the middle of the century? Even if every U.S. nuclear plant extends its operation to 80 years, the power industry will need additional capacity—if only to replace retiring coal plants. But what do utilities need to inform their decisions on investments in new, nuclear plants?

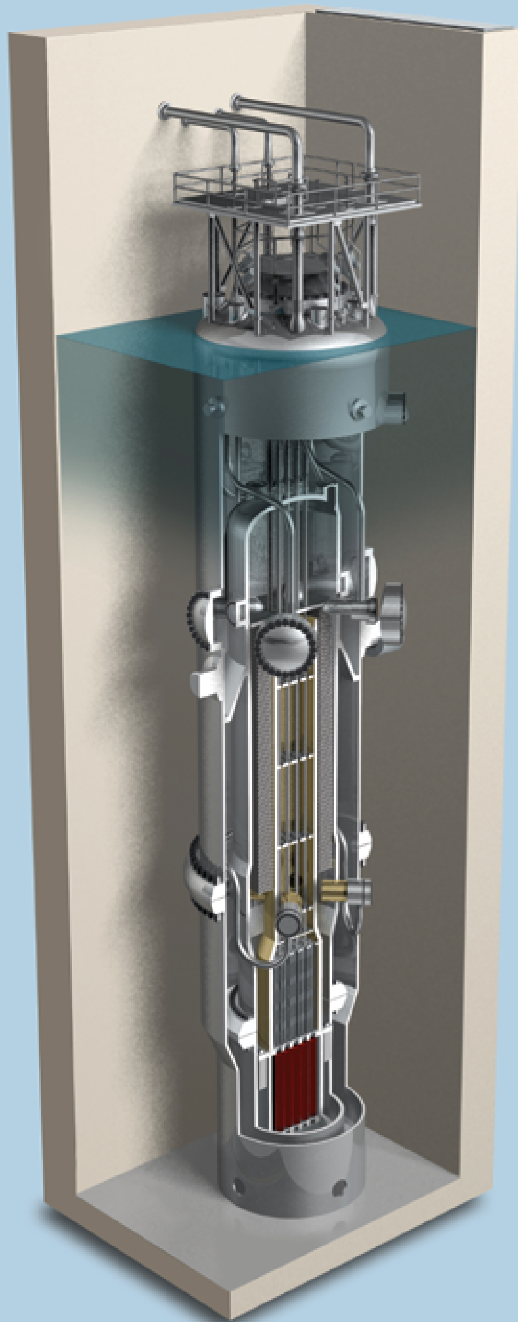


Photo courtesy: NuScale Power, July 2016

EPRI Principal Technical Leader Andrew Sowder observed that "no one has consistently engaged the utilities to find out what they want for their evaluations of these decisions, and this is a great opportunity for EPRI to step in and help research the potential options as we did with designs for advanced light water reactors."

"Ultimately," Sowder continued, "what the utilities need most are real options. We've reached a point where we need investment leading to demonstrations of advanced designs."

One option would be small, modular reactors (SMRs), which appear to be heading for commercial deployment. Designed as smaller, simpler versions of current light water reactors (LWRs) in the U.S. fleet, Sowder says they offer "additional safety margins by virtue of their smaller size, which reduces the amount of heat to dissipate and also the amount of radioactive material—or source term—that could be released following a severe accident."

Designers are hopeful, he adds, that operational SMRs will confirm the proposition that smaller reactors can compete economically in the marketplace, thereby paving the way for a new generation of advanced reactors offering similar benefits in terms of scaling, shrunken emergency planning zones, and modular construction.

More advanced, non-LWR designs (often dubbed "Generation IV") include those that offer enhanced safety from new physical properties and attributes associated with the use of new coolants and fuel systems. These include low (near ambient) operating pressures and an intrinsically robust fuel capable of withstanding the very high temperatures following complete loss of cooling.

The inherent safety of small, high-temperature gas reactors was demonstrated in Germany when one such reactor was used to simulate a worst-case loss-of-coolant accident. According to Sowder, the operators abruptly shut off the flow of helium coolant, and the reactor withstood the ensuing heat-up and cool-down without any emergency cooling.

He added that other advanced designs, such as fast breeder reactors, are based on technologies first developed during the mid-twentieth century but never fully commercialized. Breeder reactors and fuel recycling, he said, "would offer utilities the ultimate in security of fuel supply."

Sowder indicates that utilities and other owner-operators might also look for options advantageous in specific regions and markets. Examples include the flexibility to cycle reactors up and down (in areas with widespread renewables adoption); the ability to site dry-cooled reactors in areas with limited water availability; and even the option to produce commodities such as hydrogen or desalinated water as alternative forms of grid-scale energy storage.

Earthquakes and More: Reports Help Assess Major Events, Impacts

Early in 2017, EPRI will publish two reports on potential impacts of seismic events at nuclear power plants. One will report on insights gathered during 20 years of shake-table testing on components used in the plants. The second compiles component failures during earthquakes. But those reports don't represent the scope of EPRI's efforts to assess and predict the impacts of major external events, which include tornados, snow loads, transportation accidents, and severe flooding.

One ongoing initiative is to develop and refine software, guidelines, and technical methods for utility members to construct seismic probabilistic risk assessment (PRA) models. Stuart Lewis, the senior program manager in EPRI's Risk and Safety Management Program, said that modeling earthquake impacts in PRAs "continues to be our largest area of PRA research."

Lewis points to multiple projects aimed at representing seismic impacts on components and structures, but the "most significant project in terms of moving the process forward is the use of new data to inform our mathematical fragility model."

Fragility is the conditional probability that a component will fail as a function of the intensity of a force. "The model," Lewis said, "attempts to capture important elements of a very complex phenomenon, but we've been able to use data from industry experience and from the 20 years of shake-table testing that we have performed for the analytical report that EPRI is preparing for publication."

The second report will compile component failures during seismic events. It will include reports from industrial facilities because "nuclear plants haven't been affected by many earthquakes exceeding the plants' design basis, so we looked at nonnuclear facilities in Hawaii and in Japan and other countries to help us calibrate our analytical models," Lewis said.

He added, "we will be looking more closely at the risks from high winds and especially tornados because they have a possibility of affecting plants, especially older plants, where some of their equipment may not be as well-protected against wind loading or the "missiles," like the pipe and lumber stored at the plants, which tornados can launch against structures. EPRI did a lot of work in that area back in the '70s and '80s, and we developed a computer code to predict the impacts from tornado missiles, but we need to replace or at least upgrade that code."

EPRI has also initiated a project to characterize potential impacts from storm surges, and in the Tennessee River valley, it is exploring evidence of prehistoric floods in rock formations and other geologic sources. "We want to see whether we can use the same approach in the eastern United States that has worked well in the West," Lewis said.

He added, "Understanding the magnitude and frequency of a flood or an earthquake represents much of what we do, but one of our greatest challenges is understanding the impacts of those events. A flood might seem straightforward, but it's not just an issue of equipment under water. You may have water sweeping through your site with debris that can also have impacts, and it's a major challenge to represent those impacts in a logic model."

EPRI, ORNL to Validate Advanced Welding for Irradiated Alloys

As nuclear power plants age—and as more of them operate past their original licenses—repair technologies and other solutions will be required to extend their operational lives. In support of that goal, EPRI has joined forces with the U.S. Department of Energy to develop methods for repairing internal components using advanced welding techniques.

With no immediate need for welding repairs to the current fleet, EPRI is preparing for such repairs in the future, if they are needed to maintain a plant's integrity. In such cases, engineers and other experts will need to surmount an obstacle: the formation of cracks in the components' stainless steel alloys.

The cracking can occur when the alloys are subjected to the thermal welding cycle, which causes helium bubbles along grain boundaries to coalesce into much larger bubbles. The helium in the alloys results from "transmutation," in which elements in the alloys—particularly boron and nickel—are exposed to radiation (fast neutron fluence) from the reactor core.

In the past few years, EPRI and Oak Ridge National Laboratory (ORNL) have developed welding methods that may serve to repair irradiated components without creating helium-induced cracks. These methods will be tested in 2016, using a purpose-built hot cell at ORNL.

"Our experience tells us there could be some degradation issues with reactor internals in the future," said Greg Frederick, program manager for EPRI's Welding and Repair Technology Center. "Ideally, there will never be a situation where components will require welding repairs in the 'hottest' region of a plant. That would be the perfect situation. But the industry needs to be prepared."

In this stage of the preparations, the work has included the development of refined welding technologies: a low-force friction-stir welding process and auxiliary beam stress-improved laser welding. Each has trade-offs, but it's hoped that the methods will prevent helium-induced cracking.

"Our key goal for 2016 and 2017 is to launch the validation tests for the welding processes and methods developed at Oak Ridge," Frederick said, explaining that rather than using irradiated specimens from actual reactor internals (whose boron and helium content would be costly to ascertain), EPRI and ORNL have created a set of representative specimens with known levels of boron by subjecting them to high fluences in an Oak Ridge reactor.

Using a controlled set of specimens, researchers can expand the knowledge regarding cracking thresholds and overall weldability. "The comprehensive test matrix," Frederick said, "will cover the wide range of helium content and material types anticipated in nuclear power plants. And, as the validation testing progresses, if we see evidence of helium-induced cracking, we will have the opportunity to refine our welding techniques by adjusting the parameters for both processes."

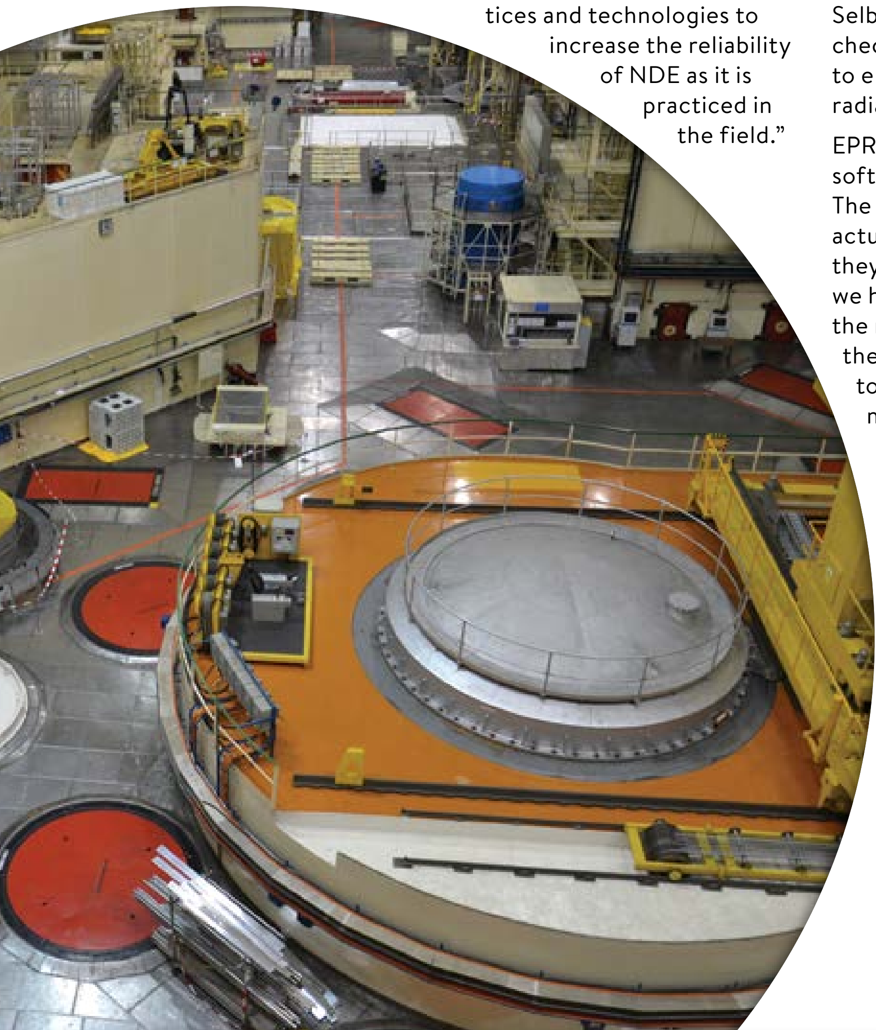
Welding parameters for the testing include the location and shape of the auxiliary beam, travel speed, wire-feed speed, primary laser power, focal length, spot size, and thermal profiles. All of those adjustments will be performed using welding equipment developed in conjunction with ORNL.

EPRI Is Leading Efforts to Increase the Reliability of Nondestructive Evaluation at Nuclear Power Plants

EPRI and the nuclear power industry are sharpening their focus on the reliability of nondestructive evaluation (NDE) performed on nuclear power plant components. EPRI surveyed its members regarding priorities for its 10 NDE research focus areas, finding that "workforce proficiency" and "improving NDE reliability" ranked first and second, respectively, in 2015 and 2016.

Specialists who inspect components with critical safety implications are qualified at EPRI, which designs and administers qualification exams at its NDE center in Charlotte, NC. The facility has the world's most sophisticated NDE mockups of nuclear components and serves as a global hub for NDE research.

EPRI Senior Technical Executive Greg Selby explained that years of "rigorous qualification of procedures, personnel, and equipment have been equated with NDE reliability, but a handful of operational experiences in the past three or four years have heightened our awareness that qualification alone is not the whole story. Qualification remains essential, and our tests—which require students to come in 'blind' and detect flaws in various components—are rigorous, but we and the industry are looking at practices and technologies to increase the reliability of NDE as it is practiced in the field."



Service companies' specialists perform about 90% of the more complex forms of NDE. Many of the key inspections deploy ultrasound, the same technology that is familiar to the public through its medical diagnostic implementations. The imaging technology is used to detect evidence of degradation mechanisms, surface cracks, or other anomalies in component structures.

The NDE center also is engaged in developing unique technologies to advance NDE beyond the basic application of ultrasound. The technology—along with five others—is part of the sensing and data analytics area of NDE technology innovation research. Known as *Sol-Gel spray-on sensors*, the "smart gel" could be applied to any component and remotely perform structural health monitoring through embedded wires that transmit monitoring results. Once perfected, Selby said, the technology will enable plant operators to check in real time on component integrity without the need to enter areas with accessibility challenges and/or high radiation levels.

EPRI also is evaluating mathematical models and simulation software to predict NDE capability in various scenarios. The models' performance is "being benchmarked against actual physical specimens to help us gain confidence that they will work within specific boundaries," Selby said. "Once we have proper procedures and we're seeing good results, the models and simulations will enable us to use fewer of the extremely expensive mockups that have been required to-date. Mockups can require a year to create, whereas a model can deliver answers to your questions in a week. It's just a faster, smarter way to do things." EPRI is performing its modeling and simulation in close collaboration with the U.S. Nuclear Regulatory Commission's Office of Nuclear Regulatory Research. "It's a multi-year project and very important for us as well as the industry and the regulators," Selby said.

But a truly paradigm-shifting research area for the future, he added, will be the creation of machine vision capabilities linked to image recognition software along the lines of Google's "Deep Learning" project. "We are very excited about its potential for NDE," Selby said.

EPRI Has Developed Guidance to Help Utilities Identify and Mitigate Cyber Vulnerabilities at Nuclear Power Plants

An EPRI project intended to close technical gaps in the deployment of cyber security measures at nuclear power plants has yielded robust guidance that's ready for publication in October 2016. The "Five Cyber Security Research Imperatives Assessment Optimization Project" was launched in response to the lack of technical criteria to precisely identify, evaluate, and manage vulnerabilities associated with attack surfaces and pathways. The initiative is only one piece of EPRI's Instrumentation and Control Program, which is addressing a wide range of issues raised by other technologies and methods. In the cyber security arena, the issues investigated by EPRI and its collaborators (which included a contingent of experts from fossil-fueled utilities) are foundational.

"Without a technical basis to implement cyber controls and methods," said Matt Gibson, a principal technical leader in EPRI's Plant Technology Nuclear Sector, "it's hard to tell if you're doing the right thing."

Computer systems have a wide range of potential vulnerabilities. "So, as the utilities look objectively at their systems to figure out how to protect them, their first step is performing a vulnerability analysis," said Gibson. "They would then perform technical assessments using the methods and guidelines, along with 'reference assessments,' that we have developed during this project."

Reference assessments of actual operational systems were developed during the project workshops held to develop standard assessment methods and guidelines (which will be detailed in the October report). The reference assessment work will continue into 2017. It involves "the application of particular methodologies to assess the vulnerabilities of a real system, a real piece of equipment, or a real group of components," Gibson said.

The assessments are being performed by experts from EPRI and the utilities, vendors, and contractors participating in the project. The reference assessment process "will provide feedback and insights on how well the assessment methodology works," said Gibson, adding that each assessment will be documented and entered into an EPRI library.

"One of our goals," Gibson continued, "is to have this methodology adopted by vendors as well as utilities. We would like them to include what we're calling 'cyber security data sheets' with their products the way other companies provide material safety data sheets. Their overall purpose would be describing potential attack surfaces and the methods that could mitigate those vulnerabilities."

The rigor of the nuclear cyber security project does not imply that nuclear plant management is anything but meticulous in its adherence to security and proper procedures. All of their configuration, engineering, and procurement controls exceed the scrutiny required at facilities in any other industry. That's in addition to the scrutiny applied to personnel, who are under continuous behavioral observation. These measures are due, in large part, to the thoroughness of the federal regulations applied to all of their procedures and operations whether it's replacing a wire or a turbine.

Nevertheless, the technical scholarship that EPRI is producing is filling gaps that the regulations don't address. And "we are making rapid progress," Gibson said. "The reference assessments and their underlying methodology are 'mature.' They have been thoroughly vetted in the workshops. So, their state of refinement can be characterized as moderate-to-high, and the work will continue."

What's Needed to Modernize U.S. Transmission Systems: Capital, Data, Analysis, and Insight

EPRI is leading a broad initiative to help utilities address monumental challenges posed by the aging of their transmission infrastructure. With an estimated quarter-million miles of U.S. high-voltage transmission lines (carrying 69 to 765 kilovolts of power), the enormity of the work required to keep the grid in good working order is self-evident. In response, EPRI is leading several projects to develop modern analytical tools, algorithms, and databases that will inform the utilities' capital investment decisions.

ANDREW PHILLIPS
EPRI Technical Director

"Our transmission system was built over many decades, and every design is different, with transformers manufactured by multiple companies to each system's specifications," said Andrew Phillips, EPRI's technical director of transmission and substations. "Any inferences about the health of components based on age alone in different systems and applications can be very misleading."

The systems are stressed daily by the peaks and valleys of their load. Temperature and humidity extremes in some regions can intensify corrosion—especially in areas with salt air.

"So, how do you reach your decision to refurbish a transformer instead of spending $3-to-$4 million to replace it when you probably don't have any detailed information about that type of transformer, its performance history, and the company that built it?" Phillips asked. "You wouldn't want to spend maintenance dollars on a transformer at the end of its working life. But how do you know for sure?"

To help answer such questions, EPRI is leading projects to:

- Help utilities develop asset data registries for their hardware, whether it's a transformer or an insulator, along with available details on component failures.
- Compile an industrywide database of transmission asset performance to develop failure rates and life expectancy estimations.
- Develop asset health algorithms to rank the relative risks for components using the asset registry data according to manufacturer, date of manufacture, use environments, and so on. An example is EPRI's Power Transformer Expert, or PTX, software, which predicts transformer failure probabilities based on factors such as dissolved gas analysis, oil quality, through faults, family, make, and model.
- Integrate asset health information by developing algorithms to rank the condition of components and aggregating those rankings to gauge the overall health of a circuit.
- Perform fundamental research on new sensors and new chemical markers to better predict equipment end-of-life.
- Promote (along with vendors) the creation of visualization software to display a utility's grid components with "alerts" and "alarms" where sensors indicate potential problems.

It is a broad effort, and Phillips points out that 48 utilities are participating—with $6 million in funding over the next three years.

The investment will pay dividends by providing utility executives with risk probabilities. "We've worked very hard on the probability side of these assessments, and we're now working hard on the condition side—because risk is basically 'condition times consequence,'" Phillips said. "The executives need a clear indication of risk to reach their decisions, so at its core this work is all about creating a very detailed picture of grid-asset health."

Platforms and Protocols Emerge as a Key for Grid Transformation

EPRI is leading an industrywide collaboration to develop information and communication technology platforms and protocols to support the effective integration of distributed energy resources (DER) and central generation. This will enable customers, vendors, and DER to interact with their utilities and vice versa. Known as *Architecture for an Integrated Grid*, the initiative will serve as a test bed for the technologies that will facilitate the Integrated Grid.

Matt Wakefield, EPRI's director of Information, Communication, and Cyber Security, said that individual projects, such as bridging the gaps in cyber security, will be important along with broad stakeholder adoption of the emerging technologies.

Among other breakthroughs, the technologies will facilitate the ability of utilities to upload apps into grid equipment, including those enabling smart meters to help utilities locate local outages.

Currently, virtually all advanced metering infrastructure (AMI) uses proprietary interfaces without any interoperability among brands. EPRI developed and last year unveiled baseline software for AMI in its "Open Application Platform" and is seeking additional support for its continuing refinement.

Meanwhile, the electrical output in areas with extensive DER penetration can pose significant challenges for utilities' power-balancing operations.

Wakefield pointed out that Japan has taken steps to curtail photovoltaic (PV) output during times of potential grid instability in areas where PV has been intensively adopted, but those steps require the ability to communicate with DER systems.

In the United States, most DER systems are being deployed without standardized protocols and communications capabilities. As part of its architecture project, EPRI is working with stakeholders to evaluate and enhance existing protocols through the use of open source software and tools to evaluate and enhance vendor technologies offering platforms for utility communications with PV inverters.

"The ability to upload software into existing hardware installations will encourage vendors to keep developing innovative apps," Wakefield said, adding, "The utilities will control the deployments, but—by realizing the architecture for the Integrated Grid—they will promote refinements in sensing and control technologies, as well."

Wakefield said the foundation of the Integrated Grid will comprise five "pillars," each with many elements that are in various stages of development:

- Open Enterprise Interoperability, in which utilities, researchers, and vendors will interact via the cloud to evaluate disparate utility back-office systems, allowing utilities to adapt to industry changes while preserving existing investments.
- Open Application Platform, in which smart grid equipment will enable development of innovative apps to enhance and expand the capabilities of AMI and other grid hardware.
- Open Telecommunications Architecture, in which communications software and protocols facilitate access to systems and sensors, and device-to-device communication.
- Distributed Energy Resources, whose outputs will be effectively aggregated and integrated with the grid using an open DER management software and tools such as OpenDERMS.
- Cyber Security, which will span the open interoperability and application platforms and associated systems and sensors.

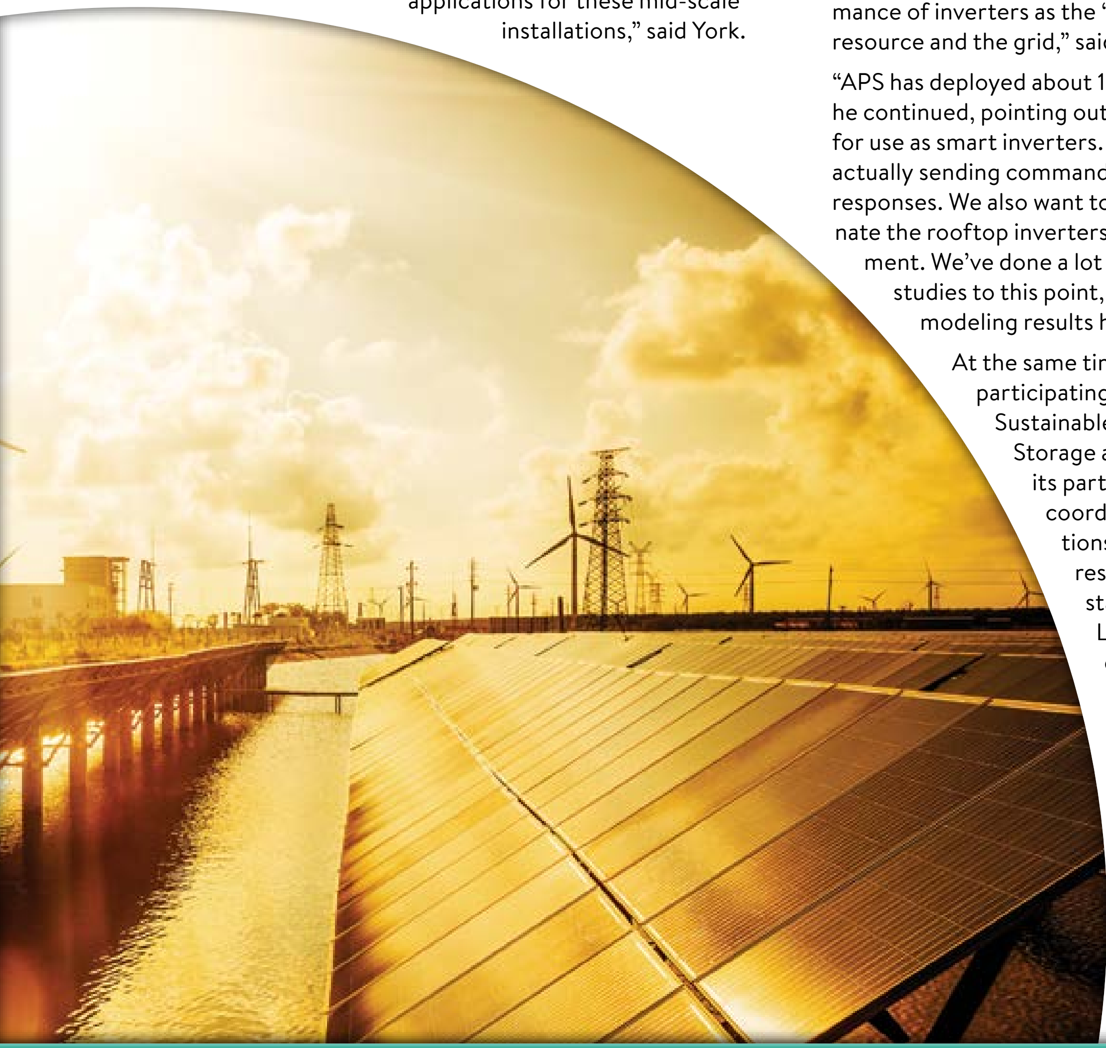
"If we deploy standard interfaces that can communicate securely across platforms," Wakefield said, "we'll see innovation we haven't even thought of before."

EPRI Research Keeps Pace with the Challenges Posed by Distributed Energy Resources

The challenges raised by steady growth in distributed energy resources (DER) range from improving hosting capacity—or a utility's ability to accommodate DER—to opportunities for greater efficiency in the interconnection application process. EPRI Senior Project Engineer Ben York says planning to host and manage DER will eventually become a normal operating procedure for utilities. Given the pace of growth, it's difficult for utilities to stay abreast of the various impacts. In response, EPRI has launched projects to investigate the changes, challenges, and opportunities that expanding DER bring to the grid.

"DER is expanding so much—and there are so many moving pieces—that it's difficult to pick out one or two projects to represent everything that's happening in this area. I think it's fair to say that solar is now expanding everywhere in the U.S. It's already well established in the Southwest, but it's also growing rapidly in North Carolina, which is now a major solar state, and other areas of the country as well."

York points out that photovoltaic arrays in the Southwest include enormous solar farms, but in other regions, "we're seeing growth in mid-scale resources." These arrays range in output from 500 kilowatts to 5 megawatts. "There has been considerable interest in the way utilities screen the applications for these mid-scale installations," said York.



For example, EPRI is working with New York utilities to find out if they are screening their larger DER applicants effectively or if there are extenuating circumstances that trigger, or should trigger, more-detailed reviews.

Screening is intended to determine if the additional output from a DER applicant would strain the local grid's hosting capacity. However, it's also possible that new technologies could increase hosting capacity. As a result, EPRI is working with Arizona Public Service (APS) to demonstrate the ability of inverters—which change direct current into alternating current—to regulate photovoltaic output in its service territory.

"A lot of EPRI's projects focus on helping improve the performance of inverters as the 'handshake' between a distributed resource and the grid," said York.

"APS has deployed about 1,500 inverters across their system," he continued, pointing out that the devices are UL-certified for use as smart inverters. "We're now in a phase where we're actually sending commands to inverters and cataloging their responses. We also want to work out the best way to coordinate the rooftop inverters with existing distribution equipment. We've done a lot of modeling and hosting-capacity studies to this point, and now we'll finally get to see if the modeling results hold up in real life."

At the same time, EPRI and other stakeholders are participating in the U.S. Department of Energy's Sustainable and Holistic Integration of Energy Storage and Solar PV (SHINES) program. For its part, said York, EPRI will evaluate the coordination of smaller scale PV installations with battery storage and demand response. At the same time, "we're starting a project with Entergy, in Louisiana, to study the same sort of coordination but with larger plants," said York. "So, it will be very interesting to see how the results of those two projects will differ."

After the Storms: Research Moves Forward on "Hardening" and Distribution Grid Resiliency

EPRI and 27 of its members last year completed a comprehensive evaluation of options to enhance the resiliency of electrical distribution grids. The three-year initiative was launched in response to widespread outages caused by a series of storms that included Hurricane Katrina and the 2011 Halloween Nor'easter. Experts from EPRI and the participating utilities researched the performance of existing and emerging technologies in severe weather while gathering a wealth of anecdotal information. The findings yielded options for improving the performance of the distribution system in major events and raised key questions that EPRI proposes to answer with supplemental research projects.

One such question involves utility pole materials. Distribution grid resiliency research established that wooden poles with a greater pole-top circumference are more likely to withstand destructive forces, such as those from trees falling across power lines. But "we looked at only limited batches of wooden poles in the project" said EPRI Technical Executive and Distribution Grid Resiliency Project Manager John Tripolitis. "So, the strength of wooden poles—with different preservative treatment types—along with their strength in comparison to composite and cement poles should be explored further."

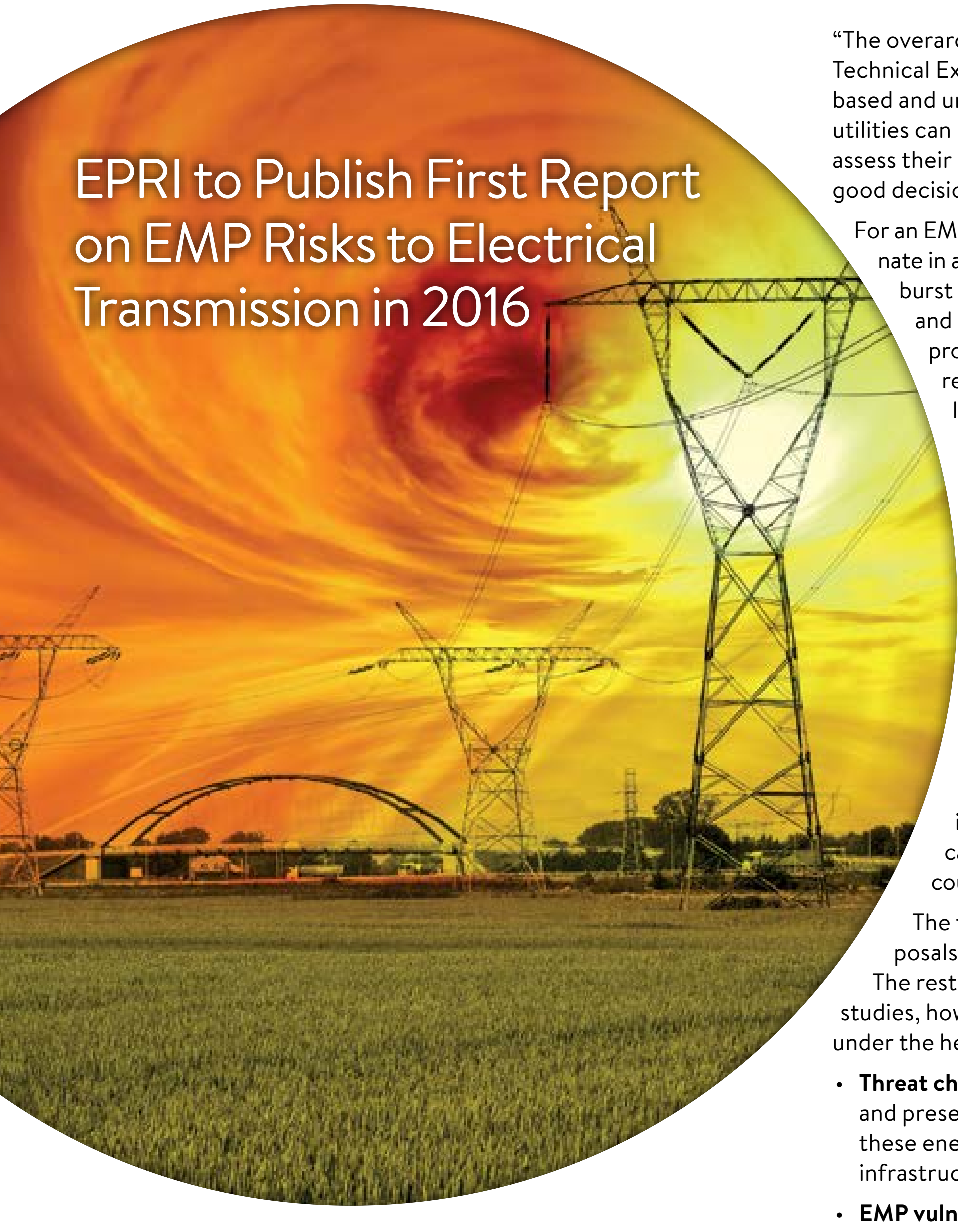
Tripolitis also pointed to alternative crossarm materials, such as fiberglass and composites, as candidates for more research. So, too, are emerging technologies for pole-top components, such as slipping conductor ties (designed to slip when subjected to forces from a tree impact, resulting in fewer broken poles) and breakaway components (which would "let go" of crossarms if enough force were applied to conductors).

Tripolitis said that such technologies are similar to vehicle components designed to help protect passengers during accidents by absorbing impact energy. But it's key, he said, "to know how much 'slip' and 'release' we need to dial into that hardware so we don't have conductors falling to the ground in normal conditions."

Another effort focuses on eliminating outages due to a phenomenon known as *conductor slap*. When a fault condition (such as a tree branch falling on a line and creating a short circuit) occurs on overhead wires, magnetic fields produce forces between conductors all along the circuit that cause them to swing. If they swing together, additional faults can occur, resulting in more customer outages. Said Tripolitis, "This condition may be exacerbated by the application of additional automated devices on the system. Consequently, we are investigating methods and designs to better predict and prevent conductor slap."

Looking ahead, Tripolitis said that utilities will remain focused on hardening their infrastructure but will want to know "which strategies will give them the most bang for their buck." EPRI developed a prototype cost-benefit model for evaluating resiliency options, but it needs to be refined to apply hardening options more selectively and to evaluate their efficacy across a system of circuits rather than just one circuit at a time. EPRI proposes to develop these enhancements through supplemental research.

EPRI to Publish First Report on EMP Risks to Electrical Transmission in 2016



EPRI will publish in 2016 the first in a series of reports on the threats to electric transmission systems from an electromagnetic pulse (EMP) released by a high-altitude thermonuclear detonation. As part of a broad study on the many impacts of EMP-induced failures within transmission systems, the first report will focus on potential risks to transformers. The broader research is titled "EMP Resiliency: Transmission Vulnerability and Mitigation."

"The overarching purpose of this research," said EPRI Senior Technical Executive Randy Horton, "is getting technically-based and unclassified information into the public domain so utilities can look 'under the hood' of our research and actually assess their own systems using reliable information to make good decisions."

For an EMP to impact the bulk power system, it has to originate in an altitude of 30-to-400 kilometers. From there, a burst of gamma rays strips electrons from air molecules and generates a wave of electromagnetic radiation that propagates to the earth's surface. This initial wave is referred to as *E1*, and it can damage electronics and lower-voltage transmission insulation.

The pulse's second component (E2) has characteristics similar to lightning. The third component (E3) is created by the interaction of the expanding fire ball and ionized debris from the blast with the earth's magnetic field.

The E3 pulse drives geomagnetically-induced currents (GIC) in the power system similar to those created during a geomagnetic disturbance. These quasi-DC currents can result in voltage collapse and additional hotspot heating in transformer windings and structural components. If severe enough, Horton said, "the resulting GIC could cause intense hotspots in those components, and that can cause bubbles to form in the insulating fluid, which could result in dielectric failure."

The transformer modeling and E3-mitigation proposals will account for about 30% of the EMP research. The rest will relate to the threats posed by E1 and E2. The studies, however, will mingle E1 and E3 issues; they will all fall under the headings of one (or more) of the following tasks:

- **Threat characterization**: Identify bounding EMP waveforms, and present the physics of EMP propagation as the basis for these energy fields to enter and damage transmission grid infrastructure.
- **EMP vulnerability**: Estimate the ability of grid components to withstand an EMP pulse.
- **Impacts**: Develop criteria and techniques for vulnerability assessments of bulk power systems (such as substations) and to account for the loss of a range of infrastructure supporting the grid, such as motor vehicles and communication systems.
- **Mitigation, hardening and recovery**: Identify and present various hardening approaches to mitigate EMP effects—along with potential plans to recover after an event.
- **Decision support and trial implementation**: Develop a framework for utilities to evaluate the relative benefits of mitigation options, and compile EPRI research results for distribution among utilities.

Horton stressed the importance of getting EPRI's work into the public domain: "We need stakeholders to have the ability to review our results—to see our assumptions and methodologies."

EPRI Helps Utilities Stay Tuned to New World of Telecommunications Technology

For a half-century, utilities have relied on telecommunications to control grid operations, but as they manage ever more complex data, traditional technologies for voice and data transmission are changing just as rapidly. EPRI's ongoing research helps utilities navigate the technological and operational uncertainties.

EPRI Technical Executive Tim Godfrey says the pace of change makes it difficult to keep telecommunications equipment up-to-date. "The utilities are used to having 30-year equipment life cycles in the field. Now, you're lucky to keep some things operating out there for five years," he said.

At the same time, telecom companies are changing their legacy, circuit-switching systems (referred to as *TDM*) over to voice-over-Internet Protocol (IP). Godfrey said utilities will be strongly affected by those decisions because many utilities have arrangements for hard-wired service to their substations, and that service is becoming more difficult to preserve.

That's because telecom carriers "want to retire the hardware and copper wires for TDM switching as replacement parts become harder and harder to find," Godfrey pointed out. "Utilities with internal TDM systems are facing the same maintenance issues, and those systems may be approaching the point where it won't be possible to maintain them."

EPRI and nine members have been engaged in a demonstration project to evaluate the technical feasibility of replacing TDM communications with Field Area Networks (FANs), which would provide wireless capability from substations out to feeders. FANs also could gather outage data from smart meters and support automatic reclosers by enabling high-impedance-fault sensors to communicate with the reclosers to cut power to fallen wires.

"We have now launched the Telecom Initiative," Godfrey said. "It has a much broader scope than the FAN project, and it will include an evaluation of the transition from legacy TDM circuits to IP circuits at substations. We'll also look at technologies to monitor communications network performance as a way of detecting unusual changes in throughput."

Other research tracks include:

- Wireless communications projects to evaluate the status of utility-owned cellular systems and the feasibility of utilities using commercial cellular systems
- A strategic fiber track to investigate the performance of the latest fiber technologies
- Evaluating telecom opportunities to control "smart inverters" for managing distributed generation

In 2010, municipal utility Electric Power Board of Chattanooga (EPB) offered an exceptional utility response to the telecommunications "revolution," expanding its product offerings to include 1-gigabit-per-second Internet service. In 2015, EPB offered 10 Gbit/s service to customers in its 600-square-mile service territory.

While embracing a consumer telecom business was revolutionary for a utility, "you have to remember that they had to deploy fiber-optic cable for each of their customers to deliver Internet that fast," Godfrey said. "But it's worked out well, and a side benefit is that they've improved their reliability because they now know what's going on at every single point in their grid."

The EPB paradigm won't soon be duplicated across the huge service areas served by investor-owned utilities, but it's one indication of the rapidly changing world in which utilities operate.

Augmented Reality: Utilities Look at a World with Overlays of Data and Images

Augmented reality offers utility personnel significant potential to increase the efficiency of everyday and emergency tasks. Unlike "virtual reality," in which people are immersed in artificial sights and sounds, users of augmented reality remain grounded in reality—but with an overlay of data, images, or both. It can be used with smart phones, tablets, or wearable technology, such as smart glasses. EPRI has launched various experiments to determine if augmented reality in phones and tablets and eventually wearables can increase productivity and reduce errors.

Variants of the technology include "assisted reality," which doesn't depend on a user's position or location, and "mixed reality," which offers elements of both. Given augmented reality's successful deployment in other industries, EPRI Technical Executive John Simmins says, "We would be negligent if we didn't investigate these technologies and develop firm assessments of their potential. We're where cell phones were in the late '90s—and look at where the phones are now."

EPRI is also researching improvements in data quality, as exemplified by a project in which EPRI worked with a utility to merge its silos of geographic information system data for gas and electrical assets so that field workers could see underground views of gas lines and electrical conduits on tablets while standing on a sidewalk.

Pinpointing the location of underground assets with such images could save maintenance crews a great deal of time. Similarly, field workers can use views of above-ground assets to assess storm damage. Currently, crews must walk block by block to determine what structures are down or damaged.

"With the right augmented reality," Simmins said, "workers standing on a street can see which components survived a storm by 'drawing a circle' in the air with their fingers and looking at a tablet to see what the power lines looked like before the storm." He projects that such imagery may one day appear in a product similar to Google Glass.

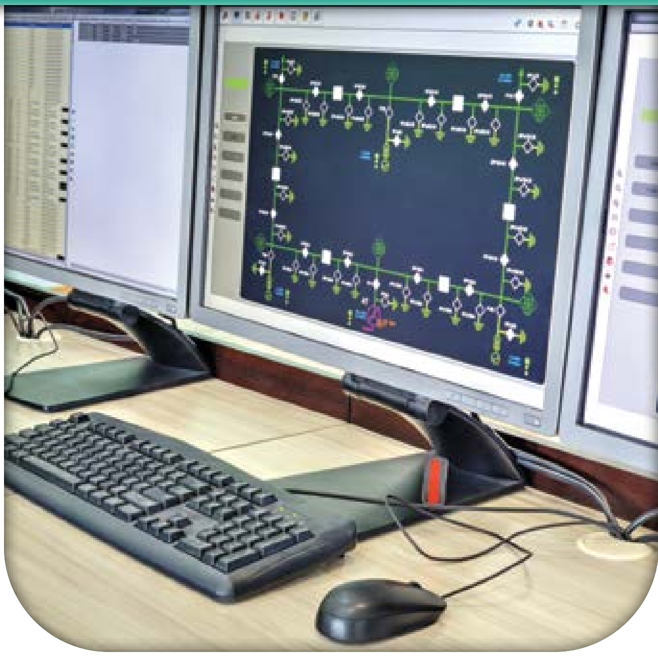
EPRI has launched a use-case experiment to determine if augmented reality could speed the warehousing processes assessing the feasibility of enhancing repair work by enabling crews to download blueprints and manuals into a tablet while repairing substations.

In another maintenance project, EPRI will test the feasibility of using tablets equipped with microphones to investigate anomalous mechanical noises, with results offered as troubleshooting explanations and recommendations to appear on the tablets.

Simmins describes another potential application in which workers' motions and exertions could be monitored to examine strain of muscles and joints, followed by advice to modify their tendencies. Live monitoring of stress- or heat-related problems could enhance safe job performance.

Although tablets and phones are currently the preferred platforms for augmented reality applications, wearable technology would offer the best solution for utility field workers because "your hands are free to perform your tasks and you don't have to keep looking down at a screen," Simmins said.

EPRI will publish its preliminary findings by the end of 2016.



Refined Metrics and Models Help Utilities Plan for Flexible Operations

Utilities are operating more flexibly to balance variation in customers' loads with variations in the power from wind turbines and photovoltaic arrays. System operators draw upon a range of resources to ramp up or down, but as variability increases, balancing challenges are likely to become more significant. In response, EPRI is leading or coordinating projects that will help utilities and ISOs plan for flexibility demands.

One such effort is the development of metrics for quantifying a power system's required flexibility. These include the periods in which flexibility resource deficits are likely—and an assessment of "flexibility well-being" to warn a utility of inadequacies in its suite of flexibility resources.

"We are still researching our proposed metrics, but we're at the stage where we're applying them to case studies and refining them with input from utilities and ISOs," said EPRI Senior Project Manager Aidan Tuohy.

At the same time, EPRI continues to update its InFLEXion flexibility assessment tool, which can be used for initial, screening-level evaluations of flexibility requirements and higher-tiered system assessments using adequacy metrics.

InFLEXion "is designed to sit on top of existing planning processes, and it works with existing simulation tools that utilities and ISOs would already be running," Tuohy said—adding that EPRI is developing application guidelines for the tool and is launching workshops for participating members to test the draft guidelines.

Surveys Assess Residential Utility Customers on PV, EV, and Technology Preferences

Can utilities gauge their customers' preferences among current and future products? EPRI has taken a first step in answering that question by adapting for utilities a survey approach used by other consumer industries. A proof-of-concept application in collaboration with three utilities was designed to determine the preferences of their residential customers for two new rate structures: time-of-use and fixed-bill.

Using models developed from the survey results, utilities can estimate how preferences and potential market size vary throughout their service territories.

EPRI is building on this work with three more projects. One will expand the initial work to include other rate structures, potentially coupled with consumer technologies such as connected thermostats.

Utilities in some areas are interested in their customers' likely preferences for rooftop and community solar, and this will be the focus of the second EPRI project in 2016.

EPRI Senior Technical Leader Jennifer Robinson says that the project "will try—among other things—to map out likely customer adoption of rooftop solar, which can be overlaid with distribution system assessments to help prioritize infrastructure upgrades." The third survey, which hasn't quite reached the drawing board, will examine customers' interest in electric vehicles.

Significant Steps Beyond COP21 Pledges Needed for Global Carbon Reduction Goals

BILL GOULD
EPRI Director of Strategic Analysis, Safety and Sustainability

The December 2015 Paris Agreement on climate change, completed at the United Nations Framework Convention on Climate Change twenty-first session of the Conference of the Parties (COP21), confirmed broad global consensus for greenhouse gas (GHG) reductions. Nearly all signatories agreed to reduce or cap GHG emissions through 2030 and supported a more aggressive long-term goal of "holding the increase in the global average temperature to well below 2°C above preindustrial levels" while pursuing a more stringent aspirational goal to limit global warming to 1.5°C.

"The agreement represents unprecedented global cooperation in trying to achieve an environmental goal, with almost 190 countries committing to reduce GHGs," says Bill Gould, EPRI director of strategic analysis, safety and sustainability. "While the pledges represent an initial stake in the ground, collectively they fall far short of reducing emissions to the levels associated with the stated goals."

To that end, EPRI analysis suggests that countries' near-term commitments, if achieved, will slow the growth in global emissions, but additional commitments will be needed to halt emissions growth—and much more stringent reductions globally will likely be required to meet the longer term goal. Gould notes, "All of the combined pledges through 2030, coupled with more optimistic reductions projections through 2050, effectively leave us about where we were in 2005. Continued cooperation through the end of the century will be required before we begin to see the reductions needed to achieve the goals."

Gould points to broad economic and technical considerations. "In the United States and elsewhere there's been a targeted focus on fossil-based electric generation," he said. "While decarbonizing the generation fleet is important and needed for success, most global emissions are from other sources. Global reductions require an all-encompassing, economy-wide strategy. The associated innovation, investment, and infrastructure transformation will be difficult to achieve in just a few decades."

Gould points to a variety of decarbonizing generation technologies, including nuclear and renewables, as the basis for decarbonizing the rest of the economy. But he cautions that much of the global generation fleet continues to grow around fossil-based generation (coal and natural gas), which will be in service for years to come. Research will be critical for decarbonizing these assets, including advances in carbon capture and sequestration and biomass utilization.

A progressively carbon-free global generation system can become the engine for decarbonizing energy used in transportation, industry, and buildings. But it will be critical to align short-term investments with longer term carbon reduction goals because any carbon-producing end use becomes embedded for decades in the economy.

Big Environmental Monitoring: Can Microsensors Fill Some Big Shoes?

Miniature sensors to measure physical and chemical parameters in air, surface water, and groundwater are appearing in the marketplace in ever-increasing numbers. Some of these devices are so small—just a square inch in some cases—that they could be incorporated into clothing or personal protective equipment. Manufacturers claim that the devices can measure airborne pollutants such as particulates, ozone, sulfur dioxide, carbon monoxide, and nitrogen oxides. Other microsensors are said to measure nitrates, organics, and other substances dissolved or suspended in water.

The devices have drawn scientists' and regulators' attention, including the U.S. Environmental Protection Agency, based on low cost and technological potential. EPA also has focused on the sensors' potential to spark unwarranted concerns among consumers who might not know how to properly interpret data from the sensors. EPRI's interest in environmental microsensors has resulted in three projects to evaluate their capabilities.

EPRI Principal Technical Leader Stephanie Shaw notes that the largest of the three studies will be a year long field test in which microsensor performance is compared with that of traditional monitoring approaches in real-world situations. The first of the side-by-side tests is expected at the site of a coal-fired power plant. The field testing will help EPRI substantiate the subject sensors' asserted attributes while identifying concerns. The work is essential, Shaw said, because "there is limited information on these sensors' performance outside of laboratory settings."

Parameters selected for initial sensor testing may include salinity, dissolved oxygen, hydrogen sulfide (which can be released by ash ponds and biological treatment facilities), along with fugitive dust.

Assuming that a given microsensor is proven to be sufficiently accurate for screening or benchmarking purposes, the device could offer utilities substantial cost savings.

For example, a microsensor measuring a single, gas-phase pollutant could cost hundreds of dollars compared with a traditional monitor costing $20,000 or more. Such inexpensive sensors could be deployed much more quickly and in far greater numbers.

The field-testing will go a long way toward establishing the accuracy of specific sensors, but EPRI also is tracking the state of the technology by monitoring scientific literature about air sensors and the technologies they employ. Shaw points to a collaborative surface water study at the University of Georgia that will use a wireless sensor network to monitor mine drainage. The project is currently in test phase. Once hardware and software testing is complete, the network will be deployed at a former mine in Kentucky.

Confirming the accuracy of surface water sensors would be particularly important for utilities that maintain waste lagoons for coal-ash impoundment or that plan to use alternative intake-water sources—among many other potential monitoring scenarios.

Beyond this, Shaw says, EPA is "committing substantial effort to evaluate communications options to help consumers and citizen scientists understand the information they receive from environmental sensors."

The agency's focus on microsensors is one component of its Next Generation Compliance strategy, which could potentially include novel monitoring methods such as microsensors and mobile monitoring.

Photos courtesy: Sonoma Technology, Inc.

For the Crews in the Bucket Truck: New Ergonomic Tools

EPRI's occupational health and safety ergonomics research over the past 20 years has provided design and process recommendations in nine handbooks used by a variety of electric utility teams in the field.

They include design specifications and best practices for preventing musculoskeletal injuries in diverse tasks. EPRI's newest ergonomic research focuses on the repetitive stress experienced by bucket-truck workers using pistol-grip controls. EPRI also is developing a technology transfer process to help utilities evaluate and implement the 112 ergonomic recommendations in the handbooks.

"We are looking to develop a decision tool to help users of our ergonomics handbooks prioritize intervention options for their workforce," said EPRI's Health and Safety Program Manager Dr. Lovely Krishen.

Krishen pointed out that the handbooks draw on analysis of an enormous, ongoing collection of illness and injury data, dating back to the mid-1990s. It was around this time that EPRI began detailed surveillance on musculoskeletal injuries, among other workforce injuries, from electric utility members. In 1998, it was determined that the Occupational Health and Safety Database trend analysis was sufficiently robust to launch a stand-alone ergonomics research program.

An important example of this research is the reconstruction, in a Marquette University engineering laboratory, of a "mockup" of working environments experienced by utility line workers. This mockup was necessary, Krishen said, because "close-up observations weren't possible when line workers were working on energized wires, but the mockups enabled the EPRI-Marquette research team to perform meticulous observations and biomechanical analysis of the tasks to identify options for engineering fixes."

Bucket-truck-based line workers, she added, "perform combinations of tasks unique to their profession. At times they may over-extend and strain their arms and shoulders and/or perform fine motor tasks with forearms and hands—all while maintaining muscle contractions, continuously, in a limited amount of time. It's an over-simplification, but the unique nature of these tasks indicates why abstract research models aren't nearly specific enough for an analysis of our workers' strains and injuries."

Other workers whose tasks are dissected in EPRI handbooks for best practices include fossil-plant operators, mechanics, and electricians as well as substation operators and maintenance workers. Handbooks also recommend ergonomic design elements for fleet vehicles and fossil plants.

Researchers also have placeholders for future research around certain tasks, Krishen said. "We're looking to deliver the information in formats that appeal to the changing workforce. They want to download and find the information they need quickly instead of paging through a handbook, so we're looking at technological options to deliver ergonomic information directly to workers' devices—including 'augmented reality.' We assume that supervisors are familiar with the handbooks, but we want to ensure that they—or the crews—can access information without significantly delaying their work."

The next ergonomic handbook addressing bucket-truck control tasks is slated to be published in 2017.

Tapping New Research Opportunities to Reduce Water Use

Most power plants (including those generating steam with biomass, solar, or geothermal energy) rely heavily on water for cooling. However, a U.S. Geological Survey statistic identifying freshwater withdrawals by thermoelectric plants as the nation's largest is often misinterpreted because they consume only 3% of the withdrawn water, returning about 97% to the water environment. Nevertheless, EPRI continues to research a range of approaches to reduce industry's "water footprint," including technologies through efficiency gains.

"It's a complex puzzle," said EPRI Senior Technical Executive Kent Zammit. "For a long time we've been working to conserve water at new and existing power plants, but the industry is moving beyond that. We're going to see more renewable energy, which reduces overall water consumption. We'll see more combined-cycle gas plants, which consume 50% less water than traditional Rankine cycle plants. But there are also possibilities for indirect savings by reducing electricity demand, so the more we integrate energy and water networks, the more opportunities we'll have to conserve both resources."

Where feasible, some plants with wet cooling systems use degraded water, such as wastewater treatment plant effluent, but in drought-prone areas degraded water has become more valuable for uses such as irrigation and groundwater recharge.

"California," he added, "has mandated the use of dry cooling systems at all new plants—unless the utilities can demonstrate that the cost of dry cooling would result in serious economic hardships. It is unlikely that companies would retrofit existing plants' dry cooling technologies with wet cooling systems," Zammit said, pointing out that the economics "would favor retirement of those plants and replacement with modern combined-cycle plants."

EPRI has identified a range of research projects to support greater cooling efficiency and better water management. They include evaluating technologies to increase power production by reducing condensing temperatures, breakthroughs in membrane technology to increase the volume of water available for reuse, reducing or eliminating all wastewater discharges, and developing nutrient "trading programs" as a compliance option for power plants to offset water quality-based permit limits.

"We have a lot of research projects underway," Zammit said, "and some of them would indirectly reduce water withdrawals by reducing electrical consumption. For example, EPRI sponsors research to increase desalination plant efficiency. Other projects are looking at using waste heat to drive processes, and technologies to store energy in hot water systems. We also sponsor research to increase the efficiency of forward-osmosis and reverse-osmosis for wastewater treatment."

Besides the potential environmental benefits of this research, the technologies that might emerge to help conserve water may also benefit utility revenue by reducing operating costs. In addition, further electrification to reduce carbon emissions and meet increases in water treatment demands could generate additional load growth for the industry.

As Zammit describes the changing market value of water, "Blue is the new black."

EPRI Emphasizes Collaboration, Research to Define Sustainable Electricity

EPRI launched its sustainability research program in 2008 with seven member companies and a mission to better understand sustainability for the electric power industry. It has since grown into the largest sustainability-focused collaboration in the industry with more than 40 companies confronting some of today's most challenging business decisions.

It's not just electric power companies that see the value of a focus on sustainability—their stakeholders are beginning to demand it. "The business case for sustainability has changed significantly over the past five years," said Technical Leader Morgan Scott. "Whether it's customers, employees, investors…it's no longer the exception, but a growing expectation for a company to consider sustainability as a part of its day-to-day operations because stakeholders are better understanding how sustainability ties to the bottom line."

With these growing expectations, findings from EPRI's sustainability research become more important for utilities' decision-makers. "CEOs need tools and information to help them decide on potential investments regarding issues that go beyond what they are required to do by law, whether it's watershed protection, resiliency commitments, or employee education" said Scott. Also, they must consider trade-offs as companies balance potential conflicts among sustainability stakeholder demands, shareholder resolutions, public disclosures, and the fundamental mission—to produce and deliver electricity.

Today, EPRI continues to launch and coordinate projects to inform business decisions associated with corporate sustainability. Scott said that EPRI research identified 15 priority issues across the economic, environmental, and social "pillars of sustainability"—to EPRI's knowledge the first such assessment at the industry level.

"The materiality assessment served as the foundation of our sustainability research," said Scott. "We've built on those 15 issues to develop tools industry can use to evaluate their approach to sustainability integration. These include a maturity model that helps companies understand where they are and where they want to be in their sustainability journey; metrics to benchmark sustainability performance; and research to better understand sustainability reporting frequency, trends, and value."

Yet a shared understanding among electric power companies and their stakeholders as to what "sustainable electricity" means remains a challenge. "*Sustainability* continues to be a nebulous term with many definitions," said Scott. "Our research is designed to bring clarity around this idea of sustainability and give decision makers the tools they need to strategically manage sustainability issues."

EPRI also focuses on sharing leading practices from electric power companies that are driving sustainability at their own organizations. This effort culminated with the publication of *Sustainable Electricity*, the first compilation of industry-authored case studies candidly looking at recent efforts and insider stories about challenges and process.

"This is part of the next decade of sustainability science," said Senior Program Manager Jessica Fox, who edited the book and wrote a chapter looking ahead at research. "Advanced tools will help companies drive strategic decisions in consideration of the complex relationships among sustainability issues. This is what will move us toward a shared vision of sustainable electricity."

Coal-Fired Power Plants and Flexible Operations Present Challenges Regarding Multimedia Emissions

Coal-fired power plants were designed to run continuously, but their baseload operations are changing dramatically as more of them serve as "peaker plants," which are fired up primarily to serve peak load. EPRI is undertaking several studies to determine the impacts of cycling these former baseload plants up and down. Research will focus on potential changes in smokestack emissions and wastewater discharges and will explore potential multimedia impacts of substituting biomass for coal.

During plant startups, cooler temperatures in the furnace and in air pollution control equipment may result in greater releases of pollutants in flue gas. Varying percentages of those pollutants might be absorbed by the process water running through sulfur dioxide scrubbers, but this is not well understood for species such as selenium.

"As things stand," said EPRI Senior Technical Executive Babu Nott, "we have fairly limited information about multimedia emissions during cycling. We have focused much of our attention on mercury because it is a hazardous air pollutant [HAP], but we need to look at other HAPs as well, including selenium, which is drawing more regulatory attention from the water side."

Nott said that, collectively, EPRI has done more work on mercury than on other HAPs. "Coal plants try to change mercury into its oxidized form—which is efficiently captured in scrubbers—but we really don't know if scrubbers are as effective at capturing other trace metals," said Nott. "And there are other unknowns. For example, scrubbers seem to capture selenium in very different amounts in similarly configured systems, with similar coal sources and controls, which means there are wide variations in the amount of selenium ending up in wastewater released by the scrubbers and eventually in scrubber solids."

Nott added, "Based on what we're hearing from electric power companies, fuel-switching at coal plants is another aspect of flexible operations that presents multimedia challenges. We are particularly interested in the impacts of switching from coal to biomass, which could occur for economic reasons. We don't think there is much of that at this point, but if this switching starts to occur in greater volumes, we should help power companies find out if biomass will release more pollutants during combustion."

Nott, who has worked on mercury issues and measurements since the early 1990s, said he had foreseen that the U.S. Environmental Protection Agency's pollutant-specific regulations would shift to a more integrated view of emissions and discharge.

"So, with flexible operations, we want to evaluate the impacts to find out if there are potential problems that we need to address first by measuring the emissions and then by finding cost-effective approaches to potential modifications in flexible operations," he said.

For more on flexible operations, see the related Generation article entitled, "EPRI Provides Insights as Power Plants Change Their Missions."

Reduced Emissions Through Electrification? Research Points to Real Potential

Two key propositions combine as the basis for important EPRI research and offer a path forward for reducing greenhouse gas (GHG) emissions:

- While the electric power sector is currently the largest source of GHG in the United States, it offers the potential to effectively reduce emissions by deploying renewables, nuclear power, and advanced fossil power with carbon capture and storage.
- This, in turn, can support climate mitigation throughout the economy through electrification.

The idea of reducing emissions by relying more on electricity is being examined in different areas. EPRI defines electrification as the application of novel, energy-efficient electric technologies as alternatives to fossil-fueled processes. For the economy as a whole, electrification can lower emissions intensity per unit of energy by substituting more efficient energy conversion and consumption (electricity) for less (fossil fuels) across all sectors. While other economic sectors also can help reduce emissions, it is well understood in the field of climate economics that, unless there is continued and appreciable electrification throughout the economy, cost-effective emissions reductions may not be achievable.

"Generating electricity with a smaller volume of CO_2 emissions and using that electricity to gradually displace a greater volume of the fuels that account for much of the nation's CO_2 inventory has been a mainstay of climate economics for more than 25 years," said EPRI Senior Program Manager Francisco de la Chesnaye. "So, for long-term planning, we are evaluating how and when a variety of new technologies can be brought to bear for electrifying the economy."

Besides the more obvious opportunities for CO_2 emission reductions, such as electrifying cars and light duty trucks, EPRI is evaluating alternative and niche technologies such as induction heating and induction melting for metals—along with indirect induction heating for plastics and other nonconductive materials. Induction heating eliminates the carbon releases from conventional furnaces. And, as part of its electrification research, an EPRI member launched a feasibility study for installing an induction furnace at a foundry.

EPRI is evaluating the use of heat pumps—already widely used in residential and commercial applications—for waste heat recovery in industrial applications. Currently, industrial heat pumps cannot recover heat from exhaust gases exceeding 450°F. However, heat pumps with passive heat exchangers or combined heat-and-electrical-generation systems are emerging in the marketplace. And, by recovering and reusing waste heat, they represent the single greatest opportunity to reduce energy use in the industrial sector.

For residential energy users in colder and frequently overcast climates—where photovoltaic panels might be less cost-effective—switching from oil furnaces to heat pumps can be financially daunting. However, as de la Chesnaye points out, the cost to continue heating homes and small businesses with oil-fired furnaces is not necessarily in line with long-term clean energy goals.

"If a carbon price were associated with the cost of fossil fuels, their costs would become less competitive relative to decarbonized electricity and the cost of operating residential heat pumps. And the cost to generate electricity with fossil fuels—particularly natural gas—has declined substantially in recent years. But there isn't any reason to assume that natural gas prices will remain low. So we need to keep evaluating technologies that will make electrification options cost-competitive going forward."

Assessing the Life Cycle of Transmission Grid Batteries

In a first-of-its-kind study, EPRI is conducting a cradle-to-grave assessment of lithium-ion battery arrays deployed along transmission lines, gathering utility use data as well as peer-reviewed and other published literature. The project is timely because utilities are expected to install these arrays in increasing numbers.

According to the latest U.S. Department of Energy data, approximately 220 MW of lithium-ion battery arrays are in service at 83 U.S. installations. An additional 54 MW is announced and under construction. California has the most installations (37) while Illinois—with only a handful of installations—has the greatest capacity (71 MW).

The computer-managed arrays, which can fill most of a ship container for larger installations, serve many functions. These include providing power for peak-shaving (sparing utilities the need to fire up auxiliary power plants) and maintaining a 60-cycle frequency balance during fluctuations as distributed generation feeds power into the grid.

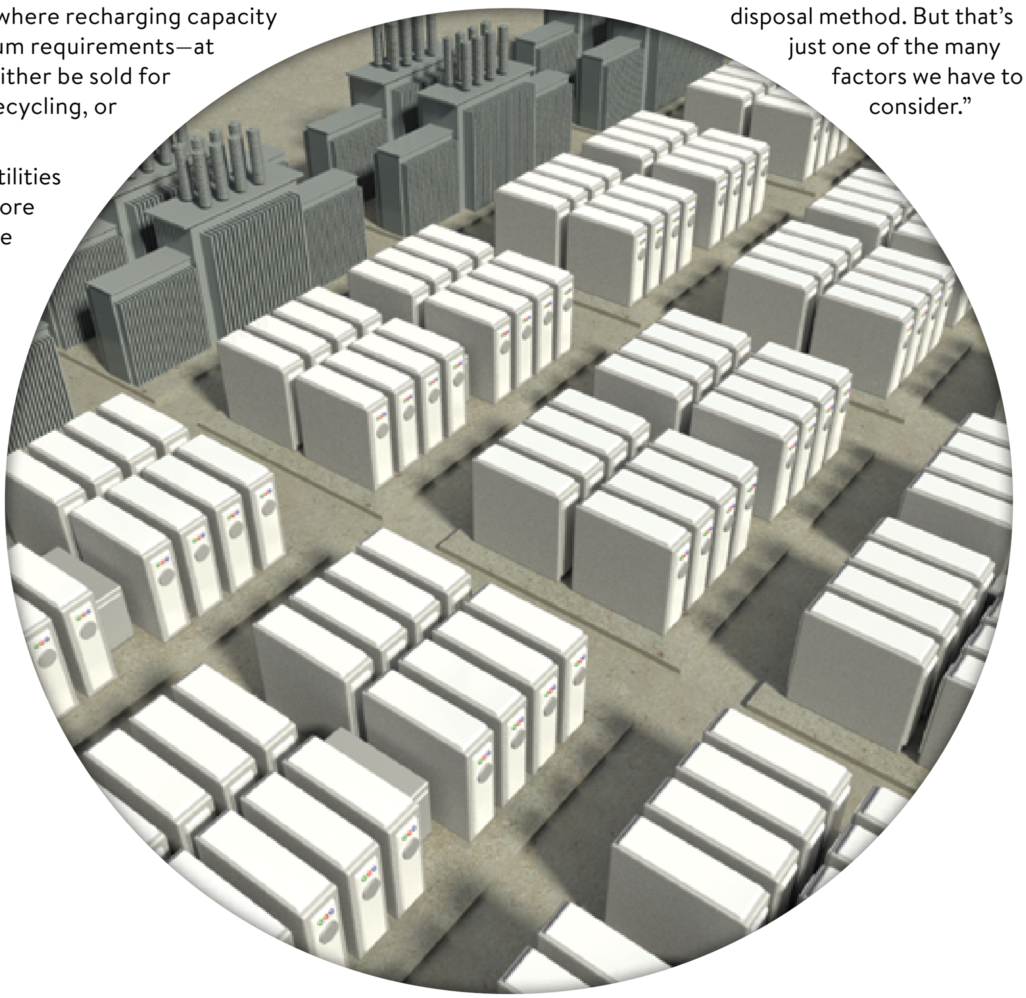
EPRI Technical Leader Arnout ter Schure pointed out that the lithium-ion battery arrays already deployed will start approaching the end of their useful life in the next 5 to 10 years. "No one has looked at their life cycle environmental impacts from the time their constituents are mined until the batteries reach a point where recharging capacity falls below a utility's minimum requirements—at which point they can then either be sold for second hand use, sent for recycling, or disposed of."

He points out that even as utilities work to achieve "greener, more sustainable grids," there's the need to look "at the whole picture. So, for example, we're also trying to work with vendors to find out what the batteries' constituents are," he said, "because lithium is only a small percentage of the entire battery, which contains many other materials as well—such as copper, iron, aluminum, and manganese."

Those other materials, ter Schure pointed out, are known to have greater environmental impacts than lithium. He added that the life cycle analysis—launched with EPRI funding last year—will also evaluate the batteries' balance-of-system, including air conditioning, because batteries generate a great deal of heat throughout their charging/discharging cycles.

The life cycle data will equip utilities to factor "green" benefits along with grid-management benefits into their procurement decisions if EPRI's analysis demonstrates net environmental benefits from deploying the arrays. "Those data could then be used to educate the public," ter Schure said.

"The assessment," he added, "might also show regulators that the batteries could be more environmentally beneficial with recycling mandates in place to ensure that the batteries are properly taken care of throughout their life cycles, preventing them from ending up in landfills—which might turn out to be the most environmentally appropriate disposal method. But that's just one of the many factors we have to consider."



EPRI Provides Insights as Power Plants Change Their Missions

NORRIS HIROTA
EPRI Senior Technical Executive

Declining gas prices, renewables output, and pending CO_2 limits are driving significant change in the missions assigned to fossil generation assets. For example, coal-fired plants designed for baseload operations are increasingly asked to perform as flexibly as gas-fired "peakers," laying up for weeks or months until they're suddenly needed. EPRI is assembling a database of approaches that utilities have deployed to address the issues raised by these changes.

"We used to work on ideas in which the plant design matched its operating regime, and the plant's economic viability was more certain," said EPRI Senior Technical Executive Norris Hirota. "But now, members want alternatives to 'gold-plated' solutions. So we want the database we're building to include 'silver' and 'bronze' alternatives—whether they're anecdotal workarounds or emerging technical breakthroughs, such as the latest generation of film-forming products that may protect metal surfaces from corrosion during layups at a much lower cost."

The consequences of mission changes are far from fully evident. "If you 'peel the onion,' you will find an unprecedented richness of technical issues that come up," Hirota said. "But, to use the analogy of antique cars, it isn't really feasible to completely retrofit them with technologies that would enable them to perform like today's ultra-low emission automobiles. And that's the problem with older plants—they weren't designed to meet today's environmental and efficiency goals."

Moreover, Hirota asks, "What impacts does the new mission have on staffing and on the sustainability of the solutions that you do implement? How do you balance the economics of different assets in your fleet as you adapt to mission changes?"

In 2016, EPRI completed its Mission Profiles Pilot Project, which took a "deep dive" in to emerging issues through visits to seven generating units (coal, gas, and hydro) and technical meetings with plant/corporate technical experts. Discussions included component fatigue, combustion, environmental controls, and others. Hirota, who is writing a report on the pilot project, said that plant visits with various technical experts are essential because much of the original design and engineering isn't accessible.

The pilot has been expanded to an ongoing project—the Mission Profiles Working Group—consisting of industry experts from more than a dozen EPRI members. Hirota says that a key task will be "precisely defining research issues, which is probably the most difficult thing we can ever do as R&D managers."

The working group's meetings through the summer of 2017 will expand on and address challenges identified during the pilot, and produce a number of field-proven technical resources to support the industry.

EPRI Program Manager Mike Caravaggio, who is leading the working group, said that the key outcome will be "the development of a digital knowledge sharing platform that can be used to rapidly share new learnings—be they R&D findings, operational best practices, or relevant case studies—as plants struggle with new operating regimes."

Encapsulation: One Piece of a Holistic Approach to Managing Wastewater and Waste Solids at Coal Plants

Emissions controls have diverted into wastewater the pollutants and particulates once released by coal-fired plants through their smokestacks. Previously, some of that water was treated sufficiently for discharge into waterways, while any wastewater streams containing ash (which is otherwise sold for beneficial reuse) had to be impounded in carefully engineered ponds and lagoons. In 2015, the regulatory landscape for coal plants changed when EPA revised its 33-year-old Effluent Limitations Guidelines and Standards Rule. Under the new rule, coal plants will be prohibited from discharging wastewater containing pollutants from ash-transport waters by the end of 2023—the same year that tougher limits for pollutants in flue-gas desulfurization (FGD) wastewater become final.

One promising option for compliance is encapsulation. This multifaceted process supports "the combination of semi-solid material extracted from wastewater through evaporative or membrane technologies with ash to create a cement-like material," said EPRI Project Manager Jeffery Preece. "We chose the word 'encapsulation' for this process because it combines the notion of 'pollutant fixation' with 'sequestration,' which occurs when encapsulated materials are landfilled."

Encapsulation, however, will require the successful adaptation of other technologies that EPRI and a number of its members are still evaluating for "cradle-to-grave" wastewater management.

Encapsulation, Preece pointed out, is as much about solids and landfill management as it is about wastewater management. That's why the approach to environmental controls has to be holistic. It's impossible to silo the steps that lead to encapsulation because they're interrelated—especially considering that wastewater constituents vary according to the source of the coal, the operation of air-emissions control equipment, and the operation of the wastewater treatment equipment.

Those variations might require the addition of chemical reagents—along with advanced process controls—to facilitate a cementitious reaction with ash, which may not have the requisite chemical and physical properties for sequestering the targeted pollutants.

"Some plants might be able to take their FGD stream and mix it with their ash and reagent, or reagents, right away," said Preece, "and we're looking at ways to enable plants to save some of their ash" so that they can continue selling it to cement producers.

Among the many economic considerations is the cost of running brine concentrators (also called *evaporators*), which will remove most of the water from the FGD waste stream. It's possible that the remaining slurry can be turned into a cement-like product for landfill disposal, but that's just one of many approaches—along with economic impacts—that EPRI is investigating.

"Our goal is to develop an understanding of the fundamental physical and chemical properties of encapsulation in 2017, and to then start pilot studies that will build on demonstration projects already underway," said Preece.

He points to some urgency with respect to these efforts because, even though final compliance is slated for 2023, new limitations will apply "as soon as possible—beginning November 1, 2018."

Will Connected Devices and Real-Time Information Improve Utilities' Diagnostic Capabilities?

No, but connected electronic media and advanced analytics may facilitate the transition of retiring power plant experts and limit the loss of institutional knowledge. Utilities may well use this loss to embrace connectivity that's driving a sea change in other industries. The needed tools, such as tablets and smart phones, are ubiquitous—but EPRI recognizes the daunting aspects of the transition as the industry also copes with major changes to its generation portfolio.

That's why an EPRI team in 2015 unveiled a plan to map a holistic approach to digitally connect plant assets and operations to address the challenges of the changing workforce, flexible operations, reliability, and overall plant efficiency. The team is selecting a handful of small, but "winnable," projects to prepare and build momentum for an inevitable shift toward digitally based and connected power plants.

The initiative is known as *I4Gen*, which stands for "Insight through the Integration of Information for Intelligent Generation." Susan Maley, Principal Project Manager for Instrumentation, Controls and Automation, said that many utilities have already begun working on pieces of the transformation, particularly in asset management and monitoring.

I4Gen offers a progression toward "actionable intelligence" through an accumulation of inputs: 1) signals, from sensors and other instruments; 2) data, which includes all other performance measurements; 3) information, which is data "in context"; 4) insights, which are predictions derived from computer simulations; and 5) actionable intelligence, which is the "right information" for plant personnel to make decisions or for computers to make recommendations.

Veteran plant managers can skillfully steer a baseload plant through the "chicane" of unexpected demands for operational flexibility. However, Maley said, "As this type of experience fades, the incoming workforce will likely be less comfortable with hands-on operations and maintenance and more comfortable with digitally based asset management and troubleshooting."

For example, handheld devices will enable personnel to download information while standing beside the equipment they're inspecting. The question for the industry then becomes: Can plant personnel access the data they'll need to make decisions without the benefit of institutional knowledge?

"Those decisions," Maley said, "can be financial as well as operational. They might involve elaborate scoping for resource planning, or they might be more maintenance-related, such as changing a pump that's predicted to fail by a computer program searching for abnormalities in operational patterns."

Other benefits of the shift will include more effective planning for maintenance outages. Such proactive asset management and advanced process control can directly contribute to a plant's cost competitiveness.

"The power industry will eventually have to go down the 'connected' road," Maley said. "So, we are challenging them to think about when, where, and how they'll do it so that it provides benefit, security, reliability, flexibility, efficiency, and sustainability for a diverse generating portfolio."

New Alloys and Carbon Capture Technologies May Pay a Generation Dividend

Photo courtesy: National Energy Technology Laborato

Can a power plant burning coal or gasified coal meet the U.S. Environmental Protection Agency's pending carbon-emissions standard without deploying capture and sequestration technologies? EPRI studies on new alloys necessary to increase thermal efficiency of such plants could help, but EPRI and its members are hedging such a bet by sponsoring or participating in evaluations of carbon capture technologies.

That said, interest in carbon capture research continues to fluctuate with uncertainty in policy and regulation. "Capture and sequestration technologies haven't reached a plateau, but the interest in them is not as high as it needs to be," said Jeffrey Phillips, EPRI's senior program manager for advanced fossil generation.

Meanwhile, a consortium of EPRI's members and research collaborators last year completed 14 years of metallurgical studies sponsored by the U.S. Department of Energy (DOE) and the Ohio Coal Development Office (OCDO). The studies examined the performance of an alloy that, unlike iron-based steel, can withstand temperatures exceeding 1,150°F. Components fabricated from that nickel alloy were tested in a commercial steam loop, and Phillips reports that a subsequent analysis indicates that they are ready for 30 years of use.

Installing these components in coal-fired plants with superheaters would increase plants' average 33% efficiency to 42%, enabling them to burn significantly less coal and come much closer to meeting EPA's pending 1,400 pounds-per-megawatt-hour standard for new sources of carbon emissions from coal-fueled utility boilers.

However, more work is needed before a power plant owner is likely to invest in this technology, prompting DOE and OCDO to fund the Advanced Ultra-Supercritical (A-USC) Plant Component Test (ComTest) Facility—a miniature coal plant featuring a superheater and a boiler with nickel alloy components producing 1,400°F steam to feed a 7-MW turbine.

Design is progressing for ComTest, which will be built in Youngstown, Ohio. Besides the DOE (which will set performance goals), other participants include EPRI, Babcock & Wilcox (superheater design), General Electric (turbine design and construction), and GE's newly acquired Alstom subsidiary (nickel alloy piping design).

In other carbon-focused research among EPRI's priorities, DOE's Wilsonville, Alabama National Carbon Capture Center is testing the performance of a preferential, membrane-based carbon capture technology. "This will be followed by an economic evaluation to determine what it would cost to scale up the technology," Phillips said.

He added that EPRI is also testing a patented, CO_2-adsorption technology in a private lab to study the performance of different techniques in releasing the carbon dioxide captured from flue gas. The study is intended to measure the efficacy of heat and vacuums to "nudge" CO_2 out of the adsorption solids to regenerate them.

"Given the number of developing nations that will continue to burn huge amounts of coal," Phillips said, "we are really behind the eight ball in terms of finding ways to reduce global CO_2 emissions. That's why we are calling for an 'all-of-the-above' strategy—including CO_2 capture and storage—and for going all-out in their development."

Supercritical CO_2—The Next Big Thing in Advanced Power Cycles?

Replacing steam with supercritical carbon dioxide (sCO_2) in a closed-loop power plant promises to increase thermal efficiency regardless of the plant's heat source—whether it's coal, solar, or enriched uranium. For fossil-fueled plants, spinning turbines with high-pressure CO_2 instead of steam could reduce carbon emissions through efficiency gains.

Although driving turbines with sCO_2 has been proposed for other power cycles, it is the closed-loop Brayton cycle that has attracted the interest of the U.S. Department of Energy, which has offered \$80 million for the design and construction of a 10-megawatt sCO_2 pilot plant. EPRI has been heavily involved in much of the research leading up to this evolutionary stage.

"We're right in the middle of all this work to advance the use of supercritical CO_2 in different cycles," said Jeffrey Phillips, EPRI senior program manager for advanced fossil generation. "One thing that's not yet known, however, is how nickel alloys will react to CO_2 exposure at high temperature and pressure."

Nickel alloys have emerged from EPRI-led research as the material of choice for components exposed to steam at temperatures up to 1,400°F. Currently, Rankine cycle plants (which exemplify the coal-fired fleet) heat steam as high as 1,100°F.

In a closed-loop Brayton cycle, the gas or vapor driving the turbine is never vented to the atmosphere. In this type of Brayton cycle, Phillips pointed out, "You can pick many different fluids to drive a turbine—but CO_2 has thermodynamic properties that support higher operating efficiencies."

Using sCO_2 instead of steam will raise the efficiency of a coal-fired, closed-loop Brayton cycle plant by 3 percentage points or more, trimming CO_2 emissions by 5-10%. Raising the sCO_2 to 1,400°F could increase thermal efficiency by an additional 3 percentage points, and "that will bring your total CO_2 emissions down by 15-20%," Phillips said.

So far, one sCO_2-based plant has been built and run in a factory test-stand as a small demonstration project. But NET Power LLC this year announced that it has broken ground for the construction of a 50-megawatt thermal, natural-gas-fueled plant with advanced "oxy-fuel" combustion and sCO_2 as its working fluid.

When asked about the status of sCO_2 cycles, Phillips said that if solid oxide fuel cells are the equivalent of "toddlers," closed Brayton cycle, sCO_2-based plants "are ready for kindergarten."

To advance this "kindergarten technology" to "college graduation," EPRI is also involved in a project with Babcock & Wilcox to design the first-ever coal-fired CO_2 heater, and to conceptualize designs for integrating sCO_2 with Brayton-cycle, solar-thermal plants. "It's all about producing more power with the same amount of energy—regardless of the source," Phillips said.

Research in Southeast United States Works to Optimize Photovoltaic Performance

As more utilities invest in photovoltaic (PV) assets, EPRI has launched research at Southern Research Institute's Southeastern Solar Research Center (SSRC) in Birmingham, Alabama to broaden the industry's understanding of PV system performance in regions lacking continuously clear skies and dry air.

In the U.S. Southeast, utilities are rapidly developing new PV farms and offering rooftop solar programs to their customers. With its service extending across the region, Southern Company is funding much of the work at SSRC, but the multifaceted research is expected to benefit all utilities with solar assets.

"In the last 10 years, there's been quite a shift from utilities watching the solar industry from the sidelines to figuring out the best way to integrate solar into their portfolios," said EPRI Senior Technical Leader Cara Libby.

Libby points out that, from 2005 through 2015, U.S. photovoltaic capacity grew from 0.25 to 25 gigawatts (GW). However, utilities want to be sure that their solar investments are sound, so EPRI is launching an accelerated aging study to gauge the working life of PV modules—the one-to-two-square-meter PV panels that make up PV arrays.

The study is necessary, Libby explained, because "there has been a lot of innovation in the design of PV modules as production ramped up over the past 10 years, and there are many uncertainties about their longevity. Will they really reach their 20- to 25-year service life? And how will they perform throughout those 25 years?"

For this study, which the U.S. Department of Energy is funding through its PREDICTS2 program, EPRI will expose unused modules to temperature and humidity extremes, dynamic mechanical loads, and other stresses in a controlled, accelerated aging process. Their performance will be compared to that of modules with several years of natural aging at a PV power plant.

The research is also evaluating optimal PV orientation. While PV modules may produce the most energy when facing south, this orientation doesn't always afford optimal load balancing, Libby pointed out. Consequently, she says, "Some PV installations are now facing southwest, which shifts production toward the mid- and late afternoon."

EPRI also is evaluating single- and dual-axis tracking mechanisms to achieve optimal array orientation throughout the day. To examine another aspect of optimizing power output, researchers are coupling one of the PV arrays with a battery storage system and with sky imaging technology that could support optimal energy generation with its minutes-ahead forecasts of solar irradiance.

In addition, EPRI is conducting a soiling study at SSRC to evaluate the effectiveness of washing PV modules. Future work may include evaluating coatings to repel dust and help prevent performance degradation.

Finally, EPRI is looking at PV panel recycling. "There aren't any regulations or processes for recycling," Libby said, "so we are launching a study to learn from the Europeans and determine what's necessary to implement a recycling program here."

Ultrasonic Drain Sensors Could Rival Dolphin Sonar

If dolphin sonar is sensitive enough to distinguish among different metals, as some researchers say it is, could an ultrasonic sensor duplicate this feat by distinguishing water from steam in the drain pipes serving a heat recovery steam generator (HRSG)? EPRI testing has already determined that the ultrasonic sensor in a Flexim Americas flowmeter is precise enough for this extremely difficult detection. And it's hoped that this year's testing will yield enough performance data for EPRI to publish all of its eagerly awaited research on the breakthrough technology.

Why the keen interest in a drain sensor technology? The surge in electricity from renewable sources and falling natural gas prices has intensified market turbulence and competition to the extent that combined-cycle plants are shutting down and restarting baseload units with unprecedented frequency. All those restarts inevitably raise the odds that a HRSG will be restarted with water (as condensate) still in the system—with potentially serious consequences for components that suddenly must withstand steam pressures exceeding their design envelope.

Before selecting the Flexim sensor for its trials, EPRI had tested other moisture-sensing technologies and found them wanting—probes, because they didn't survive the pressure and temperatures (approaching 1,200°F) in an HRSG; and acoustic detection, because it didn't detect moisture fast enough.

"The Flexim sensor," says EPRI Senior Project Manager Bill Carson, "can detect condensate and signal a drain valve to close in milliseconds." Alternatively, the sensor can skip the "close" signal and alert plant operators, who would have to quickly decide if drain valves should be opened.

But, until ultrasonic sensors are installed in HRSG drains, most combined-cycle plants will continue to rely on elaborate "sump pump" systems known as *drain pots* to purge their HRSGs. However, drain pot systems come with enormous price tags and maintenance burdens—and the timing of their use for purging HRSGs remains an educated guess.

Consequently, it stands to reason that utilities would be eager to evaluate an ultrasonic sensor whose installation would cost a tiny fraction of the $1.3 to $1.6 million EPRI estimates it would cost to retrofit a plant with a single drain pot (and a typical combined-cycle plant would require several of them).

Flexim's sensor, which times the speed of signal returns to confirm the presence of moisture, is applicable to any system where water could condense from steam. More importantly, slashing the frequency of shutdowns for HRSG repairs can enable the world's 1,600 combined-cycle units to produce electricity more reliably and inexpensively, Carson says.

"The supplemental research EPRI is performing will go a long way towards confirming the Flexim sensor's reliability, which will be crucial for the industry to accept the technology," he adds. "So far, we have permanent installations in four units, and we want the industry to see all the praise and pitfalls our research is documenting. And, we want to publish the data as soon as possible—we hope in 2017."

Film-Forming Products Become Important in Combating Corrosion

As utilities accommodate changing power markets with increasingly frequent layups of fossil-fueled generation, concerns are increasing that greater corrosion in steam and water systems may result. The reason is simple: Every shutdown exposes steel, brass, and copper components to humidity and airborne oxygen. An EPRI report estimates annual corrosion costs to fossil generation at $1.9 billion.

EPRI and 55 of its members have intensified their seven-year effort to investigate the potential for film-forming products (FFPs) to protect metal surfaces when plants are idle or operating. It's hoped that amine-based FFPs can ease that burden; however, the chemistry comes with drawbacks that will have to be mitigated before these chemistries become viable corrosion solutions.

The newest generation of FFPs became available less than a decade ago. Amine-based FFPs were already used in industrial plants, but with their smaller boilers, operated at lower pressures and temperatures, the applicability of those FFPs in power plants was uncertain, at best.

It's also uncertain "if the newest products have been modified to ensure that they only film metal components and don't form 'gunk balls' around corrosion products suspended in feedwater, which were common problems with the older products," says EPRI Program Manager Mike Caravaggio.

Besides forming "gunk balls," which can plug up pump strainers, the older FFPs also could foul water treatment equipment and disable online instrumentation, such as probes. Concerns also focus on their potential to trap corrosive molecules. Nevertheless, it's thought that FFPs can protect steam/water cycle components during layups more effectively than traditional approaches—dehumidifying the systems and flooding them with nitrogen gas—alone.

"We don't know exactly how long a film would persist when exposed to air," Caravaggio says, "but we know they persist for a significant period unless they're flushed off with steam and/or water."

In an aqueous environment, the films don't just shield metal surfaces from water; their carbon chains include hydrophobic "tails" that repel water. "These filming technologies are great when they're protecting pieces of equipment," Caravaggio says, "but they're terrible in some cases, such as when they're filming over your sensors."

To monitor and control this chemistry, EPRI is pursuing the development of an electrochemical technique to measure the presence of FFPs on metal surfaces during online operations. In addition, the team hopes to develop a probe to measure FFPs in feedwater.

Among the many projects under way in 2016, a university lab is investigating FFP protection by evaluating boiler tubes from a plant that routinely uses the products. Corrosion testing will continue at an Ohio laboratory with a purpose-built feedwater loop, and EPRI will compile case histories of plant experience with FFPs while launching the development of an ion chromatography method to measure FFPs in water.

"There's a lot of work left to do," Caravaggio says, "but we would like to have research-based guidelines for treatment, monitoring, and control published by the end of 2018. I don't know if we'll get there, but we've been dedicating a lot of resources to this for several years—and we're all confident in our approach."

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