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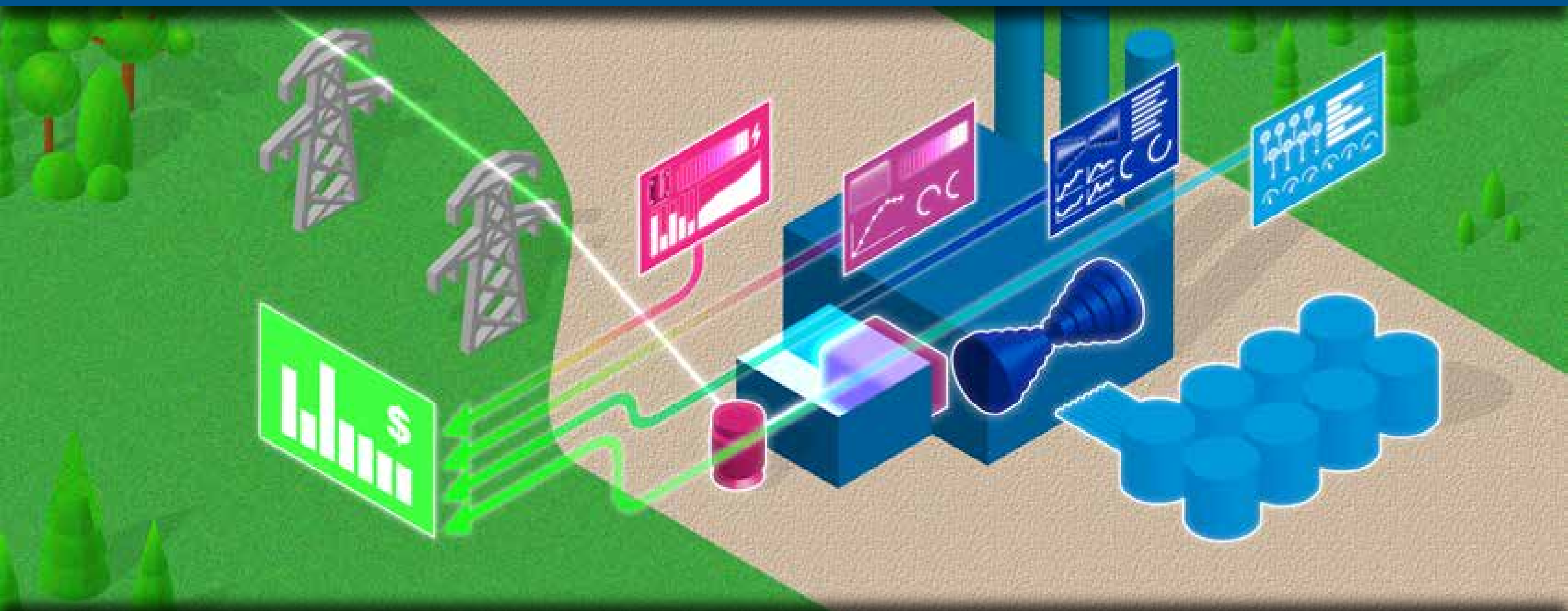
GETTING THE RIGHT INFORMATION TO THE RIGHT PERSON AT THE RIGHT TIME



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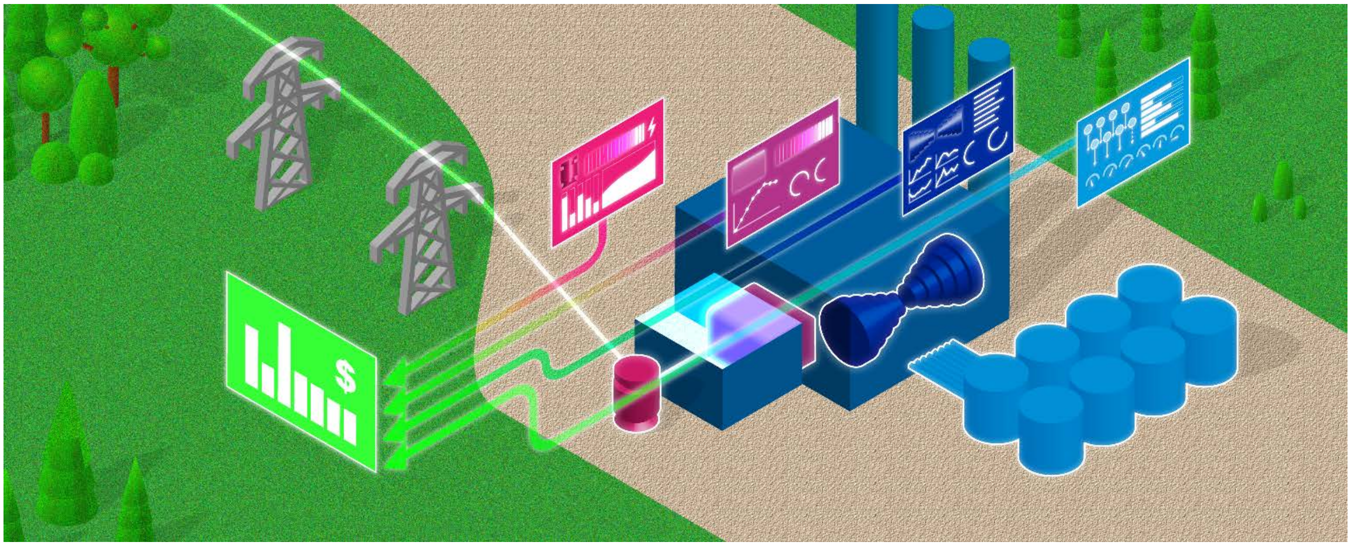


EPRI, Industry Collaborators Explore the Enormous Potential Value of Data for Power Plants

By Brent Barker

Staff at Duke Energy were remotely monitoring a recently rebuilt steam turbine when their advanced pattern recognition software picked up a very small "step-change" in vibration. The change was so slight that the plant operators did not see it, but staff at one of the utility's Monitoring and Diagnostic (M&D) Centers were concerned. Perhaps the new machine was just settling in. But a month later, after another small step-change in vibration, Duke Energy's evaluation team concluded something was wrong and worked with plant operators to take the machine offline for inspection.

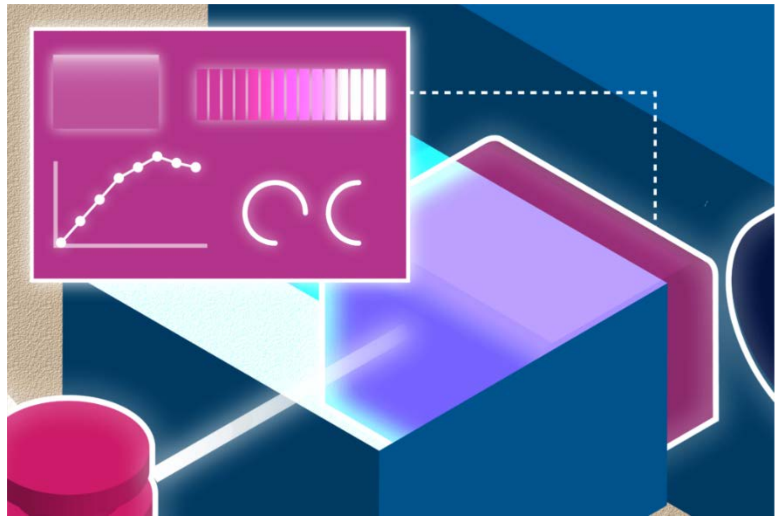
"What we found was that the turbine was throwing off little pieces of the turbine blades, which created a sudden change in the mass balance of the machine—and this was picked up as small changes in vibration," said Greg Augspurger, technical manager of Duke Energy's M&D Centers. "Had we not gone in, the machine probably would have torn itself apart, and we would have very likely had to replace the entire turbine at a cost of up to $35 million."

This story points to the enormous potential value of data analytics in power plant operations and maintenance.

"The value of information is based on the ability to take action," said EPRI Principal Project Manager Susan Maley. "Data in and of itself is worthless. Its value derives from getting the right information to the right person at the right time. This translates into good decisions that can help avert costly repairs or catastrophic equipment failures."

Maley manages EPRI's I4GEN initiative, which is helping utilities tap the value of data from digitized power plants. The vision is to deploy sensors on plant equipment, along with software tools to integrate and analyze sensor data, driving effective decision making.

Diagnostics are key to decision making. Today, this is achieved by teaming the best pattern recognition software with the diagnostic skills of technical experts with years of hands-on experience. Long term, I4GEN aims to advance technology that can learn diagnostic skills and offer predictive capabilities.



Extracting Value from Data at Duke Energy

Duke Energy has extensively deployed sensors to monitor components in its power plant fleet. At the utility's M&D Centers in North Carolina, Indiana, and Florida, IT infrastructure and software collects, organizes, and analyzes massive amounts of sensor data on hundreds of key components, looking for patterns indicative of problems. Technical experts sort through alarms, diagnosing the most significant problems and helping the software to learn.

"Only about 1% of the alarms lead to opening a 'case' to investigate further, and 70% of those cases are actionable," said Augspurger. "We have to cull the rest of the alarms and retrain the tool. A few years ago, for example, the cold from the Polar Vortex set off a storm of unexpected alarms. We had to go back and retrain the software to tell the equipment, 'It's okay if you're that cold.'"

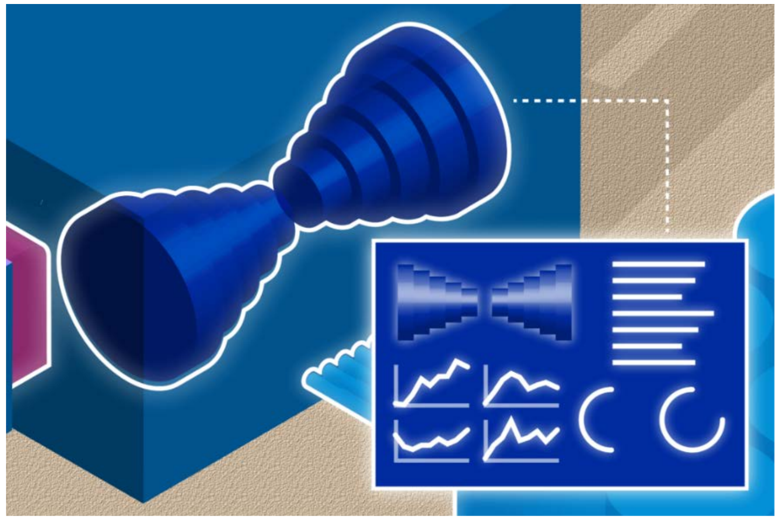
Recently, staff at an M&D Center noticed that an 11,000-horsepower air-cooled motor located outside a power plant was running warmer than expected, given the load and ambient temperature. They asked plant operators to check the air filter even though it was not due to be replaced for several months. The inspection revealed that the filter was clogged from dust kicked up on the dirt road serving a nearby construction project. The operators replaced the filter, avoiding expensive motor repairs.

"With the help of automated monitoring, we make these kinds of 'catches' several times a week in our fleet of power plants," said Augspurger. "In 2017, we made more than 400 of them."

Another important component being monitored is pumps. "We can remotely test pumps and assess their integrity," said Augspurger. "We can let operators know which ones are degrading and which are running fine so they don't take a good pump apart and break it." It costs between $20,000 and $400,000 to rebuild a pump.

"Investment in good data collection and analysis pays for itself many, many times over as long as they give you actionable information," said Augspurger. "We have structured our programs and business decisions to include this information."

The investment in capturing the right data is small compared with the potential savings.



"To instrument a major component like a turbine, for example, you are looking at half a million dollars or less," said Maley. "This can include sensors, software, and installation. Preventing a catastrophic failure of a turbine, generator, boiler, or feedwater pump can save tens of millions of dollars. Savings in routine, condition-based equipment inspections and repairs can add up to millions of dollars over the course of a year. Other EPRI utility members besides Duke Energy are making similar investments and embracing these advanced technologies."

Predicting Remaining Useful Life, Processing Terabytes of Data

With its I4GEN program, EPRI is helping develop industry-wide approaches to digital technologies, analytics, and artificial intelligence to maximize the value of information. I4GEN is driving development of diverse technologies to increase the flow and sensitivity of data, aggregate and interpret it, and link it to diagnoses by technical experts. More than 20 utilities, technology providers, and other companies are participating.

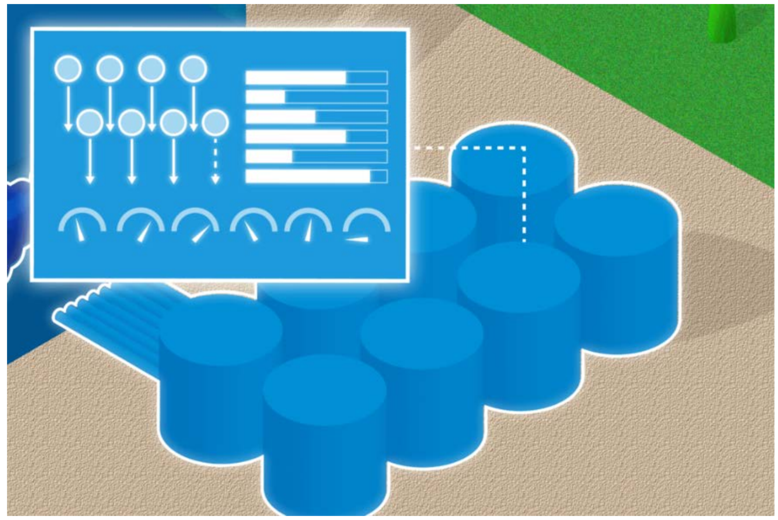
"Plants are moving more and more toward becoming digital plants," said Augspurger. "I4GEN exists to explore how far that can go, what it should look like, and what the path should be to get there. We're not exactly sure what a digital plant is going to look like because a lot of plants are already 40–50 years old."

One key interest is advancing diagnostic software. "Data is one thing, pattern recognition something else, but automated diagnosis and prediction are still a dream," said Maley. "In order to take action, it would be wonderful to use data and computation to predict the remaining useful life of equipment. If you knew that there was a high probability of equipment failure in the next 3 months or 6 months, you could make several decisions, including how you operate the equipment, when to take it offline, and how to plan the outage. This can save you time and money."

"What we'd like to do with I4GEN is take the digital power plant to the next level, to have the software do the diagnosis and quantify remaining useful life," said Augspurger. "That for us is the 'Holy Grail.'"

Augspurger says that Duke Energy is working with a new tool that uses neural networks to learn.

"Instead of training the software on normal pattern recognition, we are training it to use historical information of troublesome events and failures to uncover those unique fault signatures of impending failure."



Developing analytics to manage the deluge of data from sensors is another major objective. “We are collecting terabytes of data every year at our M&D Centers,” said Augspurger. “We need data analytics that can handle the growing volume and translate all this data into actionable information.”

I4GEN is exploring various architectures to collect, integrate, analyze, share, and display information. “We’re trying to understand what that optimal structure will look like,” said Augspurger.

One possible solution: Deploy enough computing power in the field to distill performance signatures from equipment data and send those to a central location for analysis.

“If you find a signature that raises concerns, you go back to the field, discuss the concern with operations and maintenance staff, log into the computer that found the signature, and interrogate the data,” said Augspurger.

Mitigating Risk

One company that recognizes the promise of producing actionable information from data is FM Global, one of the world’s largest commercial and industrial property insurers. The company works with utilities to mitigate risk through analytics and engineering.

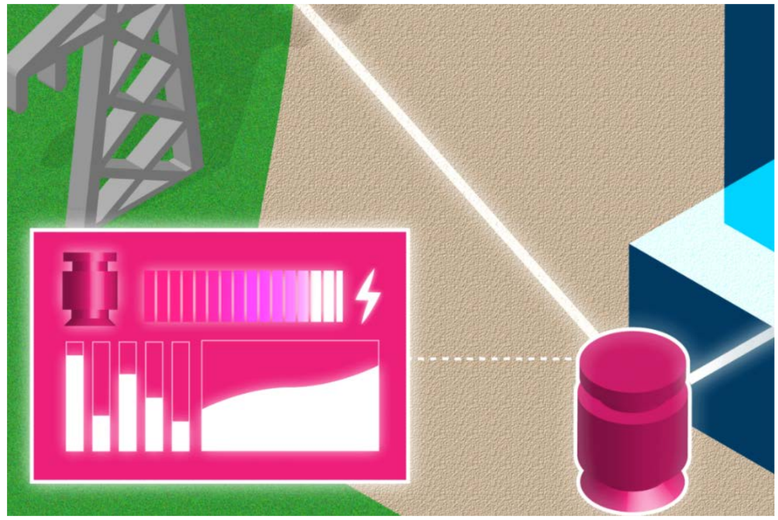
“FM Global is engaged in EPRI’s research and participates in our steam generator, maintenance, and combined-cycle programs to improve the availability and reliability of the plants and equipment it insures,” said Maley. “FM Global is a mutual insurance company, meaning that it is owned by its policyholders. Preventing property loss is as much to its benefit as it is to its clients. Insurance providers should be involved in the technologies EPRI is developing through I4GEN, not only to manage assets but to prevent losses.”

“We believe most losses are preventable through engineering,” said Erik Verloop, staff vice president and principal engineer for power generation at FM Global. “Our specialized property loss prevention engineers work with clients to reduce the risk of equipment failure. For the power industry, we have more than 50 boiler and machinery engineering specialists that visit power plants and work with plant management, operators, and engineers to identify vulnerabilities. Their recommendations help utility managers prioritize risk-reduction initiatives and help to set terms and conditions for the insurance policy, which includes coverage for equipment breakdown and forced outages.”

Using millions of data points collected by its loss prevention engineers along with extensive loss history data, FM Global makes predictions about what could go wrong for a property owner, where it could go wrong, and how bad it could be. “These predictive analytics allow our clients to understand which locations are most likely to suffer a loss and even identify which critical pieces of equipment are most at risk of breakdown,” said Verloop.

According to Verloop, automated monitoring of critical equipment and the data analytics to support rapid diagnostics further enhance risk management and property loss prevention and mitigation. “Real-time monitoring, diagnostics, and prognostics can help our clients pick up early warning signals or indications of problems in time to act, preventing escalation into a serious incident,” said Verloop.

Much of the risk is related to the major components. In dollar terms, according to Verloop, about 50% of the losses that occur in power generation are turbine related, and another 20% are generator related.



"Catastrophic losses, while infrequent, are often caused by rapidly deteriorating conditions, the failure of critical safety systems, and operators not responding appropriately to prevent the condition from escalating," he said.

Verloop adds that more common losses are often attributable to slowly progressing, undetected component degradation that leads to failure. This is where remote monitoring, diagnostics, and prognostics can have the biggest impact on loss prevention.

Well-established communications protocols and workplace procedures also are critical. "I recall instances in which a remote monitoring center picked up on something but because of a breakdown in communication or a lack of timely action by the operator, property losses ran into the tens of millions of dollars," said Verloop. "You want your processes and procedures to be so solid that an incident is a nuisance rather than a catastrophic event."

The Right Information, Person, and Time

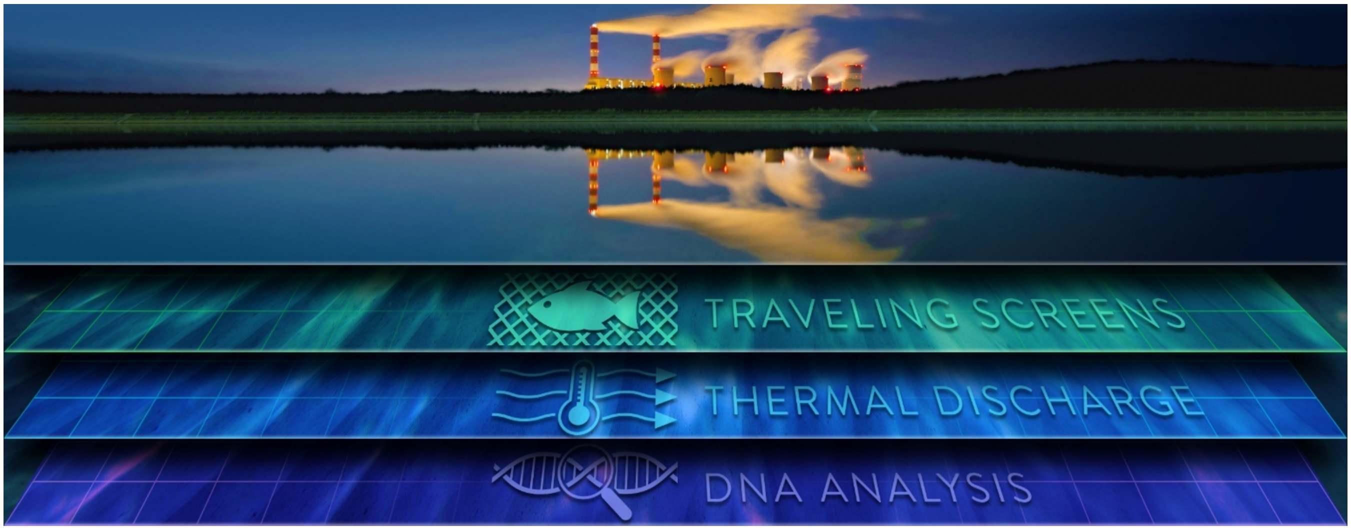
The value of information depends on its relevance and usefulness.

"Value comes down to getting the right information to the right person at the right time," said Maley. "In operational settings, the right information might be raw data, or integrated data, or an interpretation, evaluation, or diagnosis. The right person might be the maintenance technician, the technical expert, or the operator who takes decisive action, or even more likely the full chain of capable people leading to action. The right time could be an immediate shutdown or repair, or a near-term deviation from a preplanned maintenance schedule to replace a filter. Or it could be preventive, months or even years in advance for a major overhaul. Anytime you can effectively use data to take action, you are adding value."

Key EPRI Technical Experts

Susan Maley

A Deep Dive on Fish Protection



EPRI, Utilities Collaborate on Numerous Initiatives to Protect Aquatic Life

By Tom Shiel

In 2014, U.S. Environmental Protection Agency (EPA) issued its final 2014 rule to reduce mortality of aquatic life caused by cooling water intakes at power plants. Intakes can affect aquatic life by impingement, which occurs when large fish and shellfish get pinned against intake structures, and entrainment—when eggs and larvae are pulled into cooling systems and exposed to heat, physical stress, and chemicals.

The EPA rule requires plants to select and install an impingement reduction technology. Plants withdrawing water above a certain threshold must conduct additional studies to help state permitting authorities determine appropriate entrainment reduction technologies.

A primary question raised by this mandate: Which technologies are most effective in reducing impingement and entrainment?

"Research by EPRI and others indicates there is no single technology effective at protecting fish and other aquatic life at all power plants," said EPRI Technical Executive Doug Dixon. "Priorities and needs vary by the type of water body, configuration and operation of intakes, and species and life stage of fish and shellfish."

Recognizing these site-specific needs, the rule provides for flexibility in compliance. Selection and deployment of fish protection technologies are expected to occur between 2018 and 2025.

To inform its members, regulatory and resource agencies, and the public, EPRI's fish protection program assesses the impacts of cooling water intakes on aquatic life and conducts R&D on numerous technologies to reduce impingement and entrainment. EPRI technical research informs power companies as they conduct site-specific impingement and entrainment studies, evaluate the effectiveness of fish protection technologies, and implement solutions at their facilities.

In serving the broader public interest, EPRI research improves the technical basis for regulatory, permitting, and operating decisions. It also considers industry imperatives to control costs, achieve environmental compliance, manage business risks, and provide affordable electricity.

Lowering Potential Costs by Billions

During its rulemaking, EPA considered requiring all existing power plants with once-through cooling systems to retrofit closed-cycle cooling systems. However, EPRI research found that the nationwide cost for such retrofits would approach $100 billion, potentially forcing many plants to close and causing adverse environmental impacts such as increased particulate emissions.

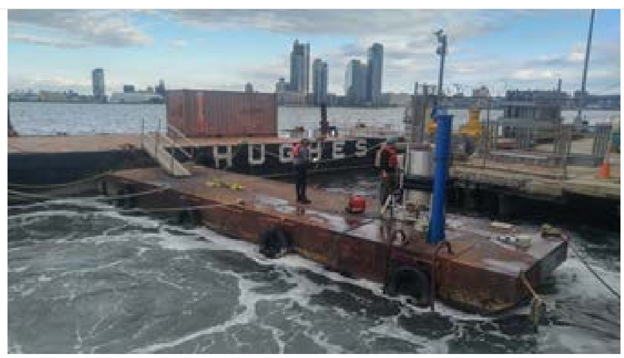
"We demonstrated that the national cost to society greatly exceeded the benefits," said Dixon. "The final rule allows for site-specific determination of the best technology available for fish protection. Our R&D supports that determination."

Traveling Screen Performance

To inform site-specific selections of the best technology available, EPRI has done extensive lab and field research on the performance of traveling water screens with fish-friendly modifications. Traveling screens are designed to prevent debris from blocking and reducing cooling water flow, which can cause a plant to reduce power output or go offline. They are also designed to stop debris from entering the cooling system and damaging equipment. In the 1970s, operators attempted to make the screens more fish-friendly by equipping them with fish-lifting buckets, gentle low-pressure sprays, and troughs to return organisms to the water source. In some cases, screens were modified with fine-mesh (less than 2 millimeters) screens to collect and return fish and shellfish eggs and larvae.

At Con Edison's East River Generating Station in Manhattan, EPRI tested a system of traveling screens modified to filter fish, fish eggs, and larvae from the intake. The screens' fine woven mesh was designed to be less abrasive to fish. Buckets on the screens collected fish, and continuous screen rotation facilitated rapid fish removal. The team found that eggs and larvae channeled through the cooling system and back into the river had higher survival rates compared with those that were removed by the screens.

Indeed, EPRI laboratory studies had previously demonstrated that survival of larvae on fine-mesh screens was generally poor. Preliminary results from similar ongoing studies at DTE Energy's Monroe Generating Station on Lake Erie also indicate that eggs and larvae collected by screens had lower survival rates, confirming laboratory observations.



Located on a barge near Con Edison's East River Plant, this equipment collects fish and shellfish eggs and larvae that are entrained in the plant's cooling system and exposed to physical and thermal stress. The silver cylindrical device is lowered into the water to collect aquatic life that exit the plant.

These findings could inform decisions by power plant operators to select screens with larger mesh that enables fragile early-stage organisms to pass through the cooling system and return to the water source. The effectiveness of this approach will depend on the attributes of each power plant and local aquatic species.

EPRI also partnered with Alabama Power to investigate the challenges involved with optimizing fish-friendly modified traveling screens. Plants that deploy screens for impingement reduction are required under the EPA rule to optimize them.

A traveling water screen and fish collection buckets made with molded polymer. Photo courtesy of Intralox, Inc.

Alabama Power equipped two facilities (Barry Electric Generating Plant and Plant Gorgas) with different state-of-the-art screen systems to address site-specific debris concerns. In the two-year study, the team identified equipment needs, preliminary methods for collecting optimization data, and the challenges with respect to gathering sufficient data to evaluate various parameters (such as screen rotation speed and spray pressure). Later in 2018, EPRI expects to publish a report with the results, along with other results from screen studies in a laboratory flume, helping other utilities perform screen optimization studies.

Protecting Fish from Thermal Discharge

In addition to protecting aquatic life at intake structures, power plants are required to mitigate discharge impacts. Many power plant cooling systems discharge heated water (generally less than 15°F warmer than ambient temperature) into rivers and other water bodies, and it is believed that the resulting heated plumes have the potential to adversely impact aquatic species. Identifying the extent of these plumes is an important first step in understanding their biological effects.

Traditionally, plumes are measured by boat surveys or estimated by computer modeling. However, boat surveys present worker safety concerns, especially during inclement weather. As an alternative, EPRI is researching the use of air and aquatic drones to map plumes.

Protecting fish from a plant's thermal discharge requires striking a fine balance. In some cases, plant operators must construct a costly, long return structure to help fish and other organisms avoid heated waters after entering an intake. At the same time, the longer the return structure, the greater the potential for injury or mortality and the greater the construction, operations, and maintenance costs.

Open-Access Database on Fish Larvae and Eggs

EPRI has created an updatable open-access web application to help identify fish larvae and eggs in freshwater, marine, estuarine ecosystems in North America—a necessary step in monitoring entrainment in cooling water intakes. EPRI provides the web application free to the public for use by power companies, resource agencies, private consultants, academia, and others.

To help operators assess the optimal return length and location, EPRI is considering field studies on thermal exposure effects. Researchers would tag fish and track how long they remain in the thermal plume and various temperature zones, comparing the results with those from similar laboratory tests.

Using Environmental DNA for Fish Protection

Tools to assess fish species composition and abundance can help utilities implement regulations. In 2018, EPRI will evaluate a new tool known as Environmental DNA (eDNA). To determine local biodiversity, researchers can collect and analyze DNA that fish and other organisms shed through blood, feces, mucous, and other tissues.

It's expected that eDNA will complement conventional sampling methods, given such potential drawbacks as sample contamination and difficulties distinguishing live and dead organisms. EPRI plans to inform the industry on eDNA's applications and limitations.

The Outlook for Fish Protection

Under the EPA rule, all plants must select and install impingement reduction technologies. These include fish protection–modified traveling water screens, barrier nets, and velocity caps. Evaluation of some plants may result in the installation and operation of entrainment reduction technologies. Examples include fine-mesh traveling screens, narrow slot wedge wire screens, and variable-frequency drives.

"Installing and operating these technologies between 2018 and 2025 will produce important and useful data on their performance, operations, and maintenance," said Dixon. "EPRI is ready to assist in gathering this information, identifying R&D gaps, and implementing research to fill those gaps and advance fish protection."

Monitoring Fish Populations in the Ohio River

Formed by 10 utilities in 1970, the Ohio River Ecological Research Program (ORERP) conducts fish, habitat, and water quality studies upstream and downstream of power plants. It's the largest and longest running power plant ecological monitoring program in the world and has consistently demonstrated that Ohio River fish populations have not been adversely impacted by plant operations. EPRI has managed the program since 2002. Insights from the research have helped plants meet federal and state requirements and inform the public, federal and state agencies, and nongovernmental organizations. By using consistent monitoring methods and equipment over many years, the program has enabled the collection of reliable data.

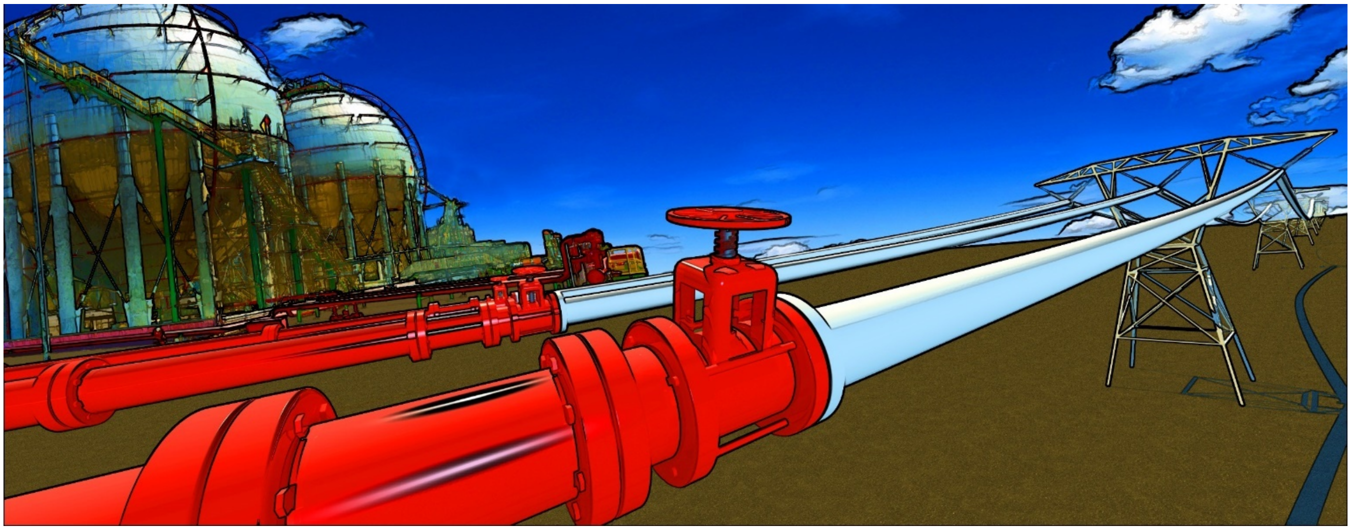
It also has made fish population sampling for regulatory purposes more efficient. "During implementation of the EPA rule, we found that facilities located within a few miles of each other typically performed the same biweekly sampling," said Tim Lohner, consulting environmental specialist at American Electric Power (AEP). "To streamline, we devised a plan in which each plant sampled less frequently, while ensuring that sampling was conducted at two or three facilities every week. Fewer samples were collected at each facility, but the overall assessment of Ohio River fish populations was more comprehensive."

"Data from the Ohio River program's collaborative studies, along with technology assessments and other analyses required by EPA, have resulted in a cost savings of up to $420,000 per facility," said Lohner. "We have used the results to justify the validity of certain regulatory variances. They confirmed that thermal discharges are not adversely impacting aquatic life, eliminating the need for more stringent temperature restrictions and saving us approximately $155,000 to $230,000 per facility."

Key EPRI Technical Experts

Doug Dixon, Jon Black

First Person—The Quest for Coordination

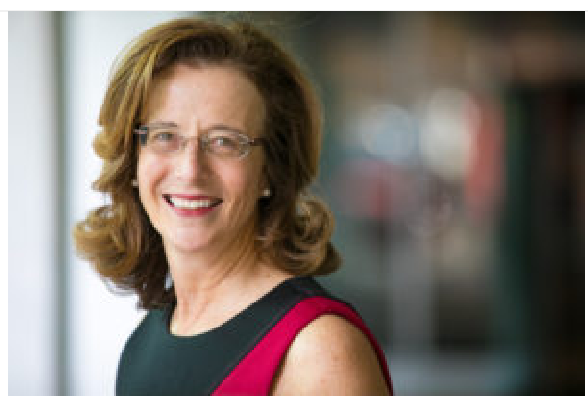


Interview: Natural Gas and Electricity Sectors Have Made Strides Toward Harmonization, But Challenges Remain

The Story in Brief

"We believe the key issue is reliability," says Lori Traweek, chief operating officer of the American Gas Association (AGA). Traweek speaks with *EPRI Journal* about coordinating the natural gas and electric systems—progress to date, challenges ahead, and the importance of planning, infrastructure, and R&D.

EJ: How have the electric and gas sectors become more interdependent?



Lori Traweek

Traweek: Over the last decade, natural gas has become much more abundant and affordable. That, along with environmental regulations and the cleaner attributes of natural gas relative to coal, has driven a significant increase in the use of natural gas for electric generation. In May 2017, the U.S. Energy Information Administration reported that natural gas has displaced coal as the leading fuel source in the Northeast's electric generation mix.

While natural-gas-fired generation is growing, it still represents only one-third of the total market for natural gas in the United States. The other two-thirds includes direct use of natural gas for space and water heating, cooking, and other uses in the residential, commercial, and industrial sectors. It is thus critically important that national policy considers the reliability of the natural gas and electric systems as interdependent, rather than address one system at the expense of the other. We must also consider regulatory requirements, safety, a clean environment, and affordability.

The direct use of natural gas and gas-to-power generation serve critical roles in the U.S. energy portfolio. Given this, we need to make sure that new processes or rules don't undermine what's already working well in these sectors.

EJ: What progress has been made in natural gas–electric coordination?

Traweek: Discussions about gas-electric coordination have been taking place for about six years, and great strides have been made. AGA has participated in these discussions and has provided detailed input to the Federal Energy Regulatory Commission (FERC) on various inquiries, conferences, and proposed rules on the natural gas side.

In 2012, FERC held a series of technical conferences to discuss natural gas–electric coordination in the different regions of the United States. In 2013, FERC issued Order No. 787, which authorizes interstate natural gas pipelines and electric transmission operators to share non-public, operational information to support the reliability of their systems. The order includes additional protections to ensure that shared information remains confidential. Some interstate pipeline operators are providing electric transmission operators with protocols for sharing non-public information.

> "With today's abundant supply of natural gas, we are at record levels of gas in storage. In some regions, new storage may not be needed. Rather, the solution may involve providing the incentives and cost recovery mechanisms so that electric generators can contract for existing storage services."

At a 2013 conference convened by FERC, natural gas and electric stakeholders identified several challenges related to different scheduling practices in the two industries. This prompted a rulemaking that led FERC in 2015 to issue Order No. 809 to help harmonize scheduling. The order extended the day-ahead deadline for scheduling natural gas transportation by an hour and a half and added another scheduling opportunity during the gas market's operating day.

In FERC electric dockets, grid operators have made certain tariff modifications to coordinate their day-ahead markets with the changes on the natural gas side.

In 2016, at FERC's request, the North American Energy Standards Board convened a natural gas–electric harmonization forum to explore the potential for faster, computerized scheduling for gas transportation, which includes nominations and confirmations.

Grid operators, such as PJM and ISO New England, are looking at ways to incent electric generators to procure firm natural gas services needed for reliability. For example, under PJM's "pay for performance" model, customers pay an additional cost to generators that commit to delivering power during weather extremes and other high demand periods. Generators must pay penalties if commitments are not met.

Enhanced natural gas pipeline services are available to generators, and new services are under development. For example, some interstate pipelines and natural gas utilities offer services that allow a generator to have natural gas transported with little or no advance notice. Natural gas transportation providers can be quite creative in designing these services and are happy to sit down with electric generators to customize them. However, we haven't seen a lot of interest from generators yet, possibly because they are unable to obtain cost recovery for such services.

Another area of natural gas and electric industry collaboration is cyber security—how to prevent and respond to cyber attacks. AGA has been working closely with the Edison Electric Institute in government-facilitated drills to enable exchange of information on cyber events.

"During the January 2014 'Polar Vortex' weather event, the natural gas industry honored firm fuel supply and transportation contracts. Natural-gas-fired generation units that experienced supply interruptions were not using firm services."

EJ: What is needed to improve coordination further?

Traweek: For the discussions to be constructive moving forward, it is important to first identify the issue that needs to be addressed. We believe the key issue is reliability for natural gas utilities and other pipeline shippers, such as gas-fired power generators. For reliability, electric generators may need to sign up for firm natural gas services, and pipeline systems may need to expand their infrastructure to provide these services. Organized electric markets should provide the appropriate incentives for electric generators to pay for the firm services. As I've mentioned, some grid operators are already working on this. In some regions, more natural gas infrastructure may not be necessary, and other approaches such as dual fuel requirements may offer a solution.

When generators sign up for interruptible natural gas transportation service, they must understand that this is a lower priority service and may not always be provided when capacity is needed for higher priority, firm customers. During the January 2014 "Polar Vortex" weather event, the natural gas industry honored firm fuel supply and transportation contracts. Natural-gas-fired generation units that experienced supply interruptions were not using firm services. If generators decide not to sign up for firm services or if such services are not available without a system expansion, they need to have backup fuel supplies or other alternative resources.

EJ: How can the two industries learn more about each other?

Traweek: Conferences are one way. Outreach is another, and the industry associations can help with that. Regulatory agencies such as FERC and the U.S. Department of Energy play important roles through proceedings and technical workshops. Some grid operators report that they have hired people who "speak gas" to help them better understand the details of natural gas operations. Most large utilities today provide both natural gas and electric services to retail customers, and that too has enabled a more holistic conversation.

"While natural-gas-fired generation is growing, it still represents only one-third of the total market for natural gas in the United States."

EJ: To what extent should gas infrastructure be expanded?

Traweek: Many of the coordination efforts underway or implemented have been helpful. That said, there will still be regions—and New England is one example—where increased pipeline capacity may be required to reliably meet the needs of both electric generators and direct-use natural gas customers. Additional infrastructure may be necessary in areas where electric generators need firm transportation capacity for reliability but no such capacity is available. This is typically an issue that the pipeline customer would discuss with the pipeline operator.

EJ: How can natural gas storage help?

Traweek: Natural gas storage is an important aspect of the reliability and resilience of the supply chain. It can provide vital operational flexibility when the pipeline and distribution network are constrained. Natural gas utilities conduct extensive planning so that they have enough gas to meet their obligations, and storage is often a key component of that. Electric generators may want to consider contracting for natural gas storage services to ensure reliability during peak demand. In organized electricity markets, generators may need to have the appropriate incentives to recover storage costs.

"With today's abundant supply of natural gas, we are at record levels of gas in storage. In some regions, new storage may not be needed. Rather, the solution may involve providing the incentives and cost recovery mechanisms so that electric generators can contract for existing storage services."

EJ: What is AGA's view about the potential development of organized wholesale natural gas markets, akin to the electricity sector's independent system operators?

Traweek: We think that the natural gas market already functions efficiently and that there are a lot of innovative natural gas products and services available to help electric generators meet their needs. We're not advocating for the creation of regional natural gas transmission organizations. Such a major restructuring may actually disrupt our ability to function effectively and affordably for our customers. There are regional differences in natural gas and electric operations, so we need to consider "one-size-fits-all" solutions carefully.

> "For reliability, electric generators may need to sign up for firm natural gas services, and pipeline systems may need to expand their infrastructure to provide these services. Organized electric markets should provide the appropriate incentives for electric generators to pay for the firm services."

EJ: How will growth in liquid natural gas exports and industrial demand for gas impact long-term prices for gas purchased by electric companies?

Traweek: Because of the abundance of natural gas supplies, the Energy Information Administration predicts that natural gas prices are going to remain low for many years, that liquid natural gas exports will increase, and that we can accommodate power generation needs and still not see significant price increases. We're not expecting the kind of volatility that we used to see with natural gas.

EJ: EPRI is conducting R&D on electrification of end-use technologies as part of its Integrated Energy Network analysis. What is AGA's perspective on these efforts, and how can the electric power and natural gas industries communicate better on this topic?

Traweek: I'll say first that our industries already have great communication. The fact that we're having this conversation is a tribute to EPRI and its efforts to connect stakeholders. Communication between EPRI and the Gas Technology Institute is as strong as ever, and communication between Edison Electric Institute and AGA is as strong as ever. We share board members and member companies, and there is a great synergy in that.

Our focus is on making sure that there's a fact-based discussion of the issues, including natural gas–electric coordination. Consumers win when they have energy choices and a full understanding of the implications and trade-offs of those choices. If consumers prefer cooking with natural gas—and we believe that there are a lot of people who do—then they should have the opportunity to use natural gas. And, if they want an electric heat pump and understand the implications of installing one in their house, then that should be an available choice.

To that end, R&D to advance a broad range of electric and natural gas end-use technologies is critical. This supports customer choice as well as emissions reductions and efficiency gains.

EJ: What other R&D can help improve natural gas–electric coordination?

Traweek: Cyber security is at the top of the list. We need more real-time cyber information and information sharing. Information technology research can help with demand forecasts and exchange of the data needed for natural gas and electric planning. Research on deploying pipeline infrastructure in a more environmentally sensitive way is important. These efforts are underway.

In Development

A Strategic Plan to Improve Management of Materials Aging in the Nuclear Industry

By Brent Barker

In 2002, maintenance workers at the Davis-Besse nuclear plant in Ohio discovered that corrosion had created a football-sized cavity in the reactor pressure vessel head. It did not lead to an accident, but the U.S. Nuclear Regulatory Commission (NRC) shut down the plant for two years to correct the problem. The fact that such extensive corrosion had gone undetected raised questions about aging management practices and procedures.

"It's paramount to have a strong understanding of aging of materials in nuclear reactors, where high temperatures, intense radiation, cyclic stress, and water chemistry accelerate degradation," said EPRI Senior Technical Executive Robin Dyle. "The discovery at Davis-Besse, along with observations at other plants in the 1990s and early 2000s of stress corrosion cracking, defects in dissimilar metal welds, and other degradation, had at times caught the industry by surprise and led to a call for action."

In 2003, U.S. nuclear owners and operators, working under the auspices of the Nuclear Energy Institute (NEI), established an initiative to improve materials management. Formally referred to as "NEI 03-08, Guideline for the Management of Materials Issues," the initiative established roles, responsibilities, and procedures for full industry cooperation, integration, and funding. A strategic plan called for:

- Proactive inspection
- Research priorities consistent with the most important gaps
- Consistent implementation of aging management guidance
- Coordination of activities and sharing of operating experience across the industry

"This was the industry saying, 'We're going to get ahead of materials challenges and resolve them quickly before they become problems. We're going to self-police our aging management practices,'" said EPRI Principal Technical Leader Wayne Lunceford. "All the U.S. nuclear utilities endorsed the initiative, committing to fully participate and comply with its requirements."

EPRI Programs Provide Industrywide Guidance and Rapid Response

The majority of the technical work was organized into six EPRI programs:

- Boiling Water Reactor Vessel and Internals Project
- Materials Reliability Program
- Steam Generator Management Program
- Nondestructive Evaluation Program
- Water Chemistry Control Program
- Primary Systems Corrosion Program

"Utility representatives collaborate with EPRI to identify the research needed to address key aging management needs," said Lunceford. "EPRI programs conduct the research and develop the appropriate aging management guidance, including maintenance and inspection criteria. Plant owners engage in the process and are responsible for managing the materials programs at their plants, including implementation of the guidance."

Rapid response mechanisms are built into the initiative. When plants find degradation that is novel, unique, or not sufficiently understood, the operators share that information with the appropriate EPRI research program, which in turn shares it with the entire fleet.

“We get all the right people on a conference call, talk through the issue, and take appropriate action,” said Lunceford. When existing EPRI guidance needs to be updated based on the new information, the EPRI programs will issue interim guidance that notifies the fleet of an aging management concern. These documents guide plants in looking for evidence of a particular type of degradation in certain components, often including detailed instructions on when, where, and how to inspect. The results of these activities, along with the associated research, will guide any necessary additional actions.

“With aging management, the challenge is to find the next material vulnerability and address it before any failures occur,” said Dyle. “One of the Material Initiative’s key accomplishments is that it has defined protocols for industry action upon discovery of new issues.”

Since the implementation of the Materials Initiative, there have been a number of cases in which degradation issues have been effectively managed. One recent example involves the boiling water reactor’s shroud, a protective shield that surrounds the reactor core and is subject to intense radiation. In the U.S. fleet in the late 1990s, unanticipated cracking was found in the welds used to hold the shroud assembly together. While operators had discovered cracks running parallel to the welds, other nonparallel cracks emanating from the welds went undetected.

“The inspection techniques being used were focused on finding cracking oriented parallel to the welds. They weren’t developed to detect cracks oriented perpendicular to the welds,” said Lunceford, who manages projects assessing core shroud cracking. “To better understand the significance of the cracking, we issued interim guidance asking all boiling water reactor owners to inspect their shrouds using techniques capable of finding these cracks. In the end, we concluded that this issue is not likely to be a significant aging management concern. The interim guidance helped us to gather the information needed to support this conclusion.”

In pressurized water reactors, a comparable assembly surrounds the core and directs coolant past the fuel bundles. The assembly is held together by “baffle bolts” that are highly irradiated and susceptible to cracking. Under stress they can shear off, causing alignment problems.

“The Materials Reliability Program anticipated that there would be problems with the bolts, but visual and ultrasonic inspections found that a few plants had more degraded bolts than expected,” said Dyle. “In response, the program issued interim guidance making inspection criteria more comprehensive and rigorous.”

As a part of the Materials Initiative, the EPRI programs keep the NRC fully informed of their work, including research plans, activities, and results. The NRC has indicated in public meetings that the initiative is effective and positive.

“As the industry implements EPRI’s aging management guidance, we gain a better understanding of materials degradation, occasionally prompting changes in inspection requirements,” said Dyle.

“A significant fraction of the EPRI guidance implemented by the utilities is above and beyond the regulatory requirements for these plants,” said Lunceford. “The Materials Initiative has made the fleet safer and more reliable.”

"The initiative has been, and continues to be, very successful at resolving materials challenges and filling knowledge gaps. There are now far fewer materials-related surprises and fewer outages negatively impacted by such surprises," said Dyle.

Key EPRI Technical Experts

Robin Dyle, Wayne Lunceford

In Development

Distributed and Fueled

New EPRI Program Explores the Environmental Aspects of Fueled Distributed Generation and Energy Storage

By Brent Barker

It's one of the big energy stories of the 21st century. Once largely powered by central power plants, electric grids in the United States and elsewhere are rapidly becoming powered by more distributed generation. While rooftop solar is significant in driving this transformation, fueled distributed energy resources are also playing a major role. Situated both behind the meter and in front of the meter, these resources include small gas-fired turbines, reciprocating internal combustion engines, and combined heat and power systems.

Based on data from the U.S. Energy Information Administration, EPRI estimated that the total U.S. capacity of small fossil generators (defined as units with a capacity of less than 25 megawatts) totaled 37 gigawatts in 2015. Most of this capacity is gas-fired turbines (including combined heat and power units) and internal combustion engines.

Exploring the environmental impacts of this growth is a primary objective of the new EPRI Program 197, Environmental Aspects of Fueled Distributed Generation and Energy Storage. The program was created through the expansion of several projects in EPRI's Technology Innovation program.

"Program 197 is designed to help us understand the challenges, benefits, and other environmental aspects of fossil distributed energy resources," said EPRI Program Manager Stephanie Shaw. "The research can inform utilities as they plan and site energy resources."

EPRI and the Houston Advanced Research Center (HARC) used a computational fluid dynamics model (developed by HARC) to simulate local air quality effects of distributed fossil units. EPRI studied differences between the HARC model and the fluid dynamics model developed by Cornell University and EPRI. Both models incorporate meteorological data and the effects of terrain and buildings on dispersal of air pollutant plumes. For example, certain buildings can draw a plume toward the ground—an effect known as building downwash.

Results of modeling gas-fired combined heat and power facilities showed minimal local air quality impacts. Increases in concentrations of nitrogen oxides (NO_x) were 1 part per billion (ppb), quite small relative to the U.S. Environmental Protection Agency's 100 ppb standard for nitrogen dioxide (NO_2).

Under meteorological conditions conducive to the biggest air quality impacts, the largest 1-hour increase in fine particulate matter ($PM_{2.5}$) was calculated at only 1 microgram per cubic meter. This is well below the 24-hour federal standard for $PM_{2.5}$, which is 35 micrograms per cubic meter.

Only one scenario resulted in significant local air pollution: 10 megawatts of backup diesel generation at a simulated data center produced 10–50 ppb of NO_2 and 5 micrograms per cubic meter of $PM_{2.5}$.

"With the exception of diesel backup generators, natural-gas-powered distributed resources have relatively low impacts on ground-level concentrations of nitrogen oxides, ozone, and particulate matter in local areas," said EPRI Principal Technical Leader Eladio Knipping.

However, using three-dimensional air quality models to evaluate larger geographical areas, EPRI and the University of California, Irvine, found that air quality impacts can increase significantly when distributed generation is aggregated or clustered regionally. Growth projections used in the modeling ranged from 6 to 24 gigawatts of additional fueled distributed generation capacity by 2030. In all scenarios, the air pollutant concentrations were greatest along the Pacific coast and in the Northeast.

"We found that the most aggressive scenario for penetration of fueled distributed generation could increase ozone concentrations by about 6 ppb," said Knipping. "In a region that already has more than 60 ppb of ozone, a 6 ppb increase could approach the 70 ppb 'non-attainment' threshold under the National Ambient Air Quality Standard. However, these impacts can in large part be mitigated with units that comply with more stringent emissions controls."

The new EPRI program will conduct additional emissions evaluations for new fueled distributed generation, enhance air quality models, and assess environmental impacts based on new distributed generation capacity projections.

Review of Lithium Ion Batteries

Program 197 also focuses on environmental aspects of energy storage technologies, particularly batteries.

GTM Research's *U.S. Energy Storage Monitor Q3 2017* estimates that 364 megawatts of utility-scale energy storage will be deployed in the United States in 2018.

Environmental impacts of batteries can vary by application. For example, the timing and frequency of the charge/discharge cycle can affect greenhouse gas emissions. EPRI is characterizing the impacts of lithium ion batteries in four utility-scale applications:

- Peak shaving and time shifting
- Frequency regulation
- Deferring investment in transmission and distribution infrastructure
- Voltage regulation

Researchers selected 11 storage systems in California with seven different designs using five common lithium ion chemistries. Preliminary results will be available in 2018.

Of particular concern are impacts at the end of a battery's life, when the device may be reused for a different application, dismantled and recycled, or disposed of in a landfill. Researchers are considering truck and ship transport and separation of battery components for recycling.

"Our new program focuses on storage and newer, smaller generation units making rapid inroads in the power system," said Shaw. "Our goal is to guide utilities in a sustainable direction as they deploy these technologies."

Key EPRI Technical Experts

Stephanie Shaw, Eladio Knipping

In the Field

EPRI Field-Tests New Approach for Optimizing Mercury Emissions Controls

By Tom Shiel

In field tests at six fossil power plants, EPRI advanced a new, more cost-effective process for evaluating the effectiveness of sorbents that capture mercury from flue gas.

EPRI developed the Rapid Sorbent Validation Protocol (RSVP) as a new technical approach to help electric utilities reduce stack mercury emissions. Many fossil plants may choose to inject sorbents and other chemicals into the flue gas stream at a cost of more than $1 million per year. To determine the correct amounts of these additives, plant operators must conduct expensive, time-intensive tests in which hundreds of pounds of sorbents are injected into the flue gas.

Using RSVP, operators can potentially reduce the cost of testing sorbents by more than 50%. A simple sampling system directs a small amount of flue gas across sorbent tubes. The amount of mercury adsorbed by the tubes is used to establish the sorbent's effectiveness, which may vary with different flue gas compositions.

EPRI applied RSVP to numerous sorbents in various flue gas conditions at six fossil plants operated by Great River Energy, American Electric Power, DTE Energy, Luminant, and Louisville Gas and Electric and Kentucky Utilities (LG&E and KU). Key findings:

- Four to twelve sorbents can be evaluated simultaneously.
- Using data from a reference sorbent, plant operators can compare the effectiveness of different sorbents for a specific flue gas composition and select the most promising ones for further evaluation.
- RSVP can be used to determine how changing flue gas conditions affect sorbent performance. For example, tests showed that increased sulfur trioxide and nitrogen dioxide emissions can significantly degrade the performance of the sorbent activated carbon.
- RSVP can provide quality control for different batches of a sorbent.
- Using RSVP, sorbent developers can assess new formulations and chemical additives quickly.
- For some applications (particularly in high-dust environments), improvements in flue gas sampling are needed.

EPRI plans additional RSVP field tests along with laboratory studies and full-scale tests on sorbent performance to refine the approach. RSVP is also being investigated for evaluating selenium sorbents.

"RSVP holds potential for reducing the time and cost of determining the most effective methods to reduce mercury emissions," said EPRI Principal Technical Executive Ramsay Chang. "We have another tool that will allow us to provide a cleaner environment for everyone."

Key EPRI Technical Experts

Ramsay Chang

Innovation

The Need for Speed

EPRI Examines How Best to Deploy Fast, Widespread Electric Vehicle Charging

By Chris Warren

Today's electric vehicles (EVs) can handle most of people's daily driving needs—relatively short commutes and trips to the store or school. But for EVs to go fully mainstream, some believe that they must meet demands for less frequent, long-distance driving, such as a 4-hour drive to grandma's for Thanksgiving or road trips to national parks.

"You don't just buy a car for your commute," said John Halliwell, a technical executive in EPRI's Electric Transportation Group. "If you want a broad base of customers, you need to meet more of their needs, including traveling long distances."

More public charging stations are needed so that drivers don't fret about getting stranded far from home. Charging must be fast enough to approximate the experience of filling up at a gas station. What constitutes "fast" charging may vary among customers, though a rule of thumb, based on a consensus of automakers, is charging 50–80% of a battery's capacity in 10 to 30 minutes—enough time to get a coffee and stretch.

With utilities, automakers, and charging equipment manufacturers, EPRI is leading discussion and collaborative research to develop charging that is fast, widespread, cost-effective, satisfies driver demands, and supports reliable grid operations. Three times a year, EPRI's Infrastructure Working Council convenes these stakeholders to address key questions and technical challenges. EPRI also coordinates working groups focused on electric bus and truck issues, direct current (DC) charging services, and utility vehicle fleets.

"We are looking to find the right balance between investment and driver perception. We have to get past the point where charging stations are so rare that you need a map to find them."

One question under discussion in the infrastructure group involves capacity. Today's public charging stations typically have a 50-kilowatt capacity, which can give a battery with a 100-mile range an 80% charge in 30 to 40 minutes. As EV batteries get larger, stations need much greater capacity for fast charging. EPRI is planning research over the next five years to address capacity requirements.

Even as significant investment will be required to expand high-power public charging infrastructure, it must be considered that most EV charging will likely be done overnight at home. "Because you can charge at home, and cars get more and more range, you don't need as much high-power public charging as you may initially assume," said Dan Bowermaster, program manager of EPRI's Electric Transportation Group. "That being said, what consumers need and what they want are two very different things."

Another question: how can charging stations supply the considerable load necessary to charge multiple vehicles simultaneously. For example, municipalities deploying electric bus fleets must plan ahead.

"Electric buses don't draw steady power. They need 300 kilowatts for 10 minutes a few times a day. It's a challenging load for a utility and impacts local power quality," said Halliwell. "Serving a municipal fleet of buses will require a large infrastructure capacity, but the total energy use is likely to be less than that of a typical commercial customer with the same capacity."

"Thanks to the collaborative infrastructure group, bus makers and other vehicle makers better understand that they can't come to a city and ask for one megawatt of power to be installed on this corner in two weeks," said Bowermaster. "They understand the need for upfront discussion with the utility about where and how to site charging capacity along bus routes."

A demonstration project with the New York Power Authority (NYPA) in New York City is underway to better understand these issues. NYPA and EPRI are installing enough on-route and depot chargers to keep 10 electric buses charged. Based on initial data on bus performance, energy consumption, and charger installation and operational costs, EPRI and NYPA will formulate a plan to deploy additional electric buses and charging infrastructure cost-effectively.

An overhead bus charger being monitored in the NYPA demonstration project.

New standards are needed to enable widespread, fast public charging stations. EPRI staff chair two Society of Automotive Engineers committees that are developing standards for the connectors that link EV batteries to sources of electricity.

"Certain brands of chargers may not work with certain brands of buses because of connector incompatibility," said Halliwell. "Standards can eliminate such scenarios."

In 2018, EPRI will survey utility customers to examine their motivations for EV purchases and expectations regarding public charging infrastructure. High-power charging stations are expensive, and most drivers will use them only occasionally. At the same time, the lack of a robust network could dampen EV demand.

"An expensive public charging infrastructure may be needed for people to buy EVs, but they might not use it much," said Halliwell. "We are looking to find the right balance between investment and driver perception. We have to get past the point where charging stations are so rare that you need a map to find them."

How Does Widespread EV Charging Affect Grid Operations?

To help utilities manage an influx of EVs, EPRI developed a "hotspotter" tool that can model the impacts of various EV penetration levels on distribution circuits down to the transformer level. It compares nameplate ratings of transformers against EV charging load over time.

"Contrary to what one might think, EVs won't impact the grid anytime soon," said Dan Bowermaster, program manager of EPRI's Electric Transportation Group. "Utilities are very good at maintaining a safe, reliable grid. In most cases, the challenge is more about how to integrate charging load into grid planning rather than how to maintain reliability."

Key EPRI Technical Experts

John Halliwell, Dan Bowermaster

Technology At Work

A Sunny Trend for Solar Energy in the Bluegrass State

Kentucky Utilities Use EPRI Research to Design and Build 10-Megawatt Solar Power Plant

By Sarah Stankorb

In Kentucky, one of the nation's largest coal-producing states, coal-fired power plants have long served as a primary source of electricity generation. While the Bluegrass State is one of only 21 states without a renewable energy standard or goal, deployment of renewables is growing here. With technical support from EPRI, Louisville Gas & Electric Company and Kentucky Utilities Company (LG&E and KU) recently designed, developed, and commissioned a 10-megawatt solar facility at the E.W. Brown Generating Station in Harrodsburg, Kentucky.

According to Dr. Nicholas Jewell, an R&D electrical engineer and scientist with LG&E and KU, changing environmental regulations and growing customer interest in renewables could increase solar's market share. These factors are driving the energy company to assess the technology through projects such as the Harrodsburg solar facility.

"While solar has been on our technology radar, we had very little practical experience with it," said Jewell. "As regulated utilities, LG&E and KU are required to provide reliable, safe energy at a reasonable cost to our customers. But solar energy generation in our service territory poses a challenge to that model."

Jewell adds that in Kentucky the levelized cost of electricity of a new solar facility is nearly double that of an existing coal-fired power plant, primarily as a result of differences in capacity factor and energy availability. (The cost of solar varies widely by location; there are areas in the United States where it is one of the lowest cost energy options.) The energy company relies on coal- and natural-gas-fired plants to provide backup capacity when the solar plant is not available, including times of intermittent generation as a result of passing clouds.

According to Jewell, approval of large solar projects in Kentucky can be time-intensive because requirements and processes for renewables are still emerging. For example, state law requires electricity utilities to charge "fair, just and reasonable rates for services rendered," and the Kentucky Public Service Commission (KPSC) only recently began expanding this requirement to consider higher cost renewable energy.

The 10-megawatt solar facility at the E.W. Brown Generating Station. Photo courtesy of Louisville Gas & Electric Company and Kentucky Utilities Company.

Jewell says that EPRI reports and technical guidance on solar technology options helped LG&E and KU inform its internal decisions and also inform the KPSC as it considered approval of the project.

"LG&E and KU's Research and Development team relied on EPRI research products and staff expertise to get up to speed on various solar project design and development considerations, as well as best practices for plant operations and maintenance," said EPRI Senior Technical Leader Cara Libby. "They participated in EPRI field testing projects, attended in-person meetings and webcasts, reached out to EPRI staff with technical questions, and incorporated relevant knowledge and insights into their project."

While seeking approval from the KPSC, LG&E and KU drew supporting information on technology options, solar irradiance in Kentucky, and power production profiles for different system configurations from EPRI's *Solar Power Fact Book*. The same resource helped inform their system design, including capacity and sizing, mounting structures, weather monitoring, and cables and conduits. LG&E and KU staff also gathered design information during EPRI meetings hosted at the Solar Technology Acceleration Center (SolarTAC), an outdoor test facility near Denver, Colorado.

From a design perspective, solar arrays with trackers produce more energy than fixed-tilt arrays, but typically have higher capital, operations, and maintenance costs. In most scenarios, EPRI research has shown trackers to be the most cost-effective option. However, LG&E and KU opted for a fixed-tilt array, concluding that maintenance of motors, linkages, and other tracker components would make their overall project less cost-effective.

To compensate for the lower output of fixed-tilt arrays, the utilities are applying a clever adaptation detailed in the *Solar Power Fact Book*. Developers often "overbuild" solar fields, installing extra direct current (DC) production capacity relative to the alternating current (AC) plant output. This makes up for conversion losses at the inverter, increasing energy production at minimal additional capital cost. Based on an internal analysis, the energy company found that aggressively overbuilding the plant with fixed-tilt arrays would sufficiently increase the plant's capacity factor and reduce operations and maintenance costs, yielding a lower levelized cost of electricity relative to a tracking system.

Practices for mounting panels onto racking systems were based on research results from EPRI solar performance testing at SolarTAC. LG&E and KU also adopted solar forecasting and performance monitoring tools, panel cleaning, detection of defective panels, and other aspects of operations and maintenance described in EPRI research results from SolarTAC.

Collaborative EPRI research at the Southeastern Solar Research Center helped to inform the utilities' decision to monitor solar energy production at the combiner boxes in addition to the inverters. According to Libby, combiner box–level monitoring can provide more granular production data and better insight into performance and maintenance needs.

LG&E and KU adopted EPRI best practices for monitoring weather and system conditions such as solar irradiation, back-of-module temperatures, and ambient temperature, pressure, and humidity.

"Production data from the combiners every second—along with data from on-site weather stations—help us to see how well this plant is operating," said Jewell.

The plant has attracted plenty of attention from customers, utilities, and other organizations requesting site visits to learn more about deploying solar. As a result of this interest, LG&E and KU have expanded their solar program offerings. Options for residential and business customers now include net metering for installations, a program allowing customers to buy renewable energy credits, and a community solar program called Solar Share.

The experience with the E.W. Brown solar facility informed a new business solar program, in which the utilities build and maintain solar facilities on customers' properties. Participants pay a fixed monthly fee and receive credits for renewable production.

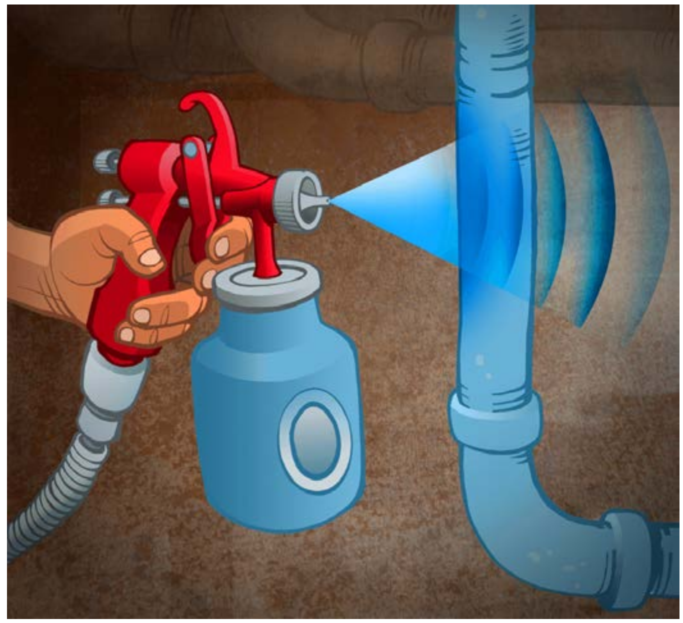
Key EPRI Technical Experts

Cara Libby

R&D Quick Hits

The Spray-On Sensor

'Sol-Gel' Technology Could Offer Lower Cost, More Rugged Solution for Component Monitoring



Soon, it may be possible to spray or paint an ultrasonic sensor on power plant components for tracking their degradation and structural health. An EPRI study reports that the "sol-gel" coating is ready for initial field testing.

Traditionally, workers scan plant components periodically with handheld ultrasonic sensors. This approach is costly, and comparing inspection results can be hampered by discrepancies in the sensor's position or orientation.

With sol-gel technology, a chemical slurry is applied and sintered onto a component, forming a film on its surface. An electric field is applied to align the dipoles in the film—a process similar to magnetizing a material. Electrodes in the film connect to a data acquisition system. When voltages are subsequently applied to the film, the dipoles elongate or contract, changing the film's shape and sending sound waves into the component. Sound waves reflected by the component's internal structures reshape the dipoles and film, resulting in a voltage across the sensor electrodes. The data acquisition system measures these voltages to construct an image of the component's interior. Unlike conventional sensors, sol-gel sensors can endure high temperatures (above 200°C) and radiation, be fabricated directly on a component, and conform to a component's geometry.

EPRI developed and lab-tested several sensor prototypes and found that there appear to be no "showstoppers" for field deployment. Researchers advanced the technology in several ways. When earlier prototypes caused corrosion of carbon steel, EPRI worked with Penn State University to identify a binder to mitigate that. The team investigated ways to improve the sensor's signal strength, such as optimizing sol-gel constituent proportions and stacking sensors. The technology can be customized for specific applications such as higher temperature environments. It is potentially applicable in any type of power plant, including nuclear, coal, natural gas, and wind.

Researchers report that more research is needed on the sensors' long-term performance at high temperatures as well as on "repoling."

R&D Quick Hits

How Can Forecasts Help Utilities Manage Solar's Variability?

Study: Leading Forecast Providers Have Average Error of 5–6%

The overall accuracy of solar power forecasts is improving, though performance varies among products and can diminish during periods with high variability in solar output, according to an EPRI study.

Grid operators use these forecasts for dispatching other system resources more effectively. But forecasting is still an emerging technology. Complex modeling must account for numerous factors, including historical weather, irradiance reaching solar panels, energy production data, solar panel efficiency, and weather forecasts.

In collaboration with Southern Company, EPRI conducted a six-month evaluation of 10 commercial forecast providers at four solar power plants across the United States. For comparison in this project, researchers used publicly available irradiance forecasts and irradiance-to-power transformation models to calculate baseline output forecasts. To ensure effective participation by the forecasters, EPRI established an anonymous submission process. EPRI also developed better mechanisms for storing and exchanging data, along with a suite of metrics, including average error and error at specific times of the day. The aim was to assess forecast effectiveness with respect to grid operational functions such as 1-hour and day-ahead scheduling of power deliveries.

Key findings:

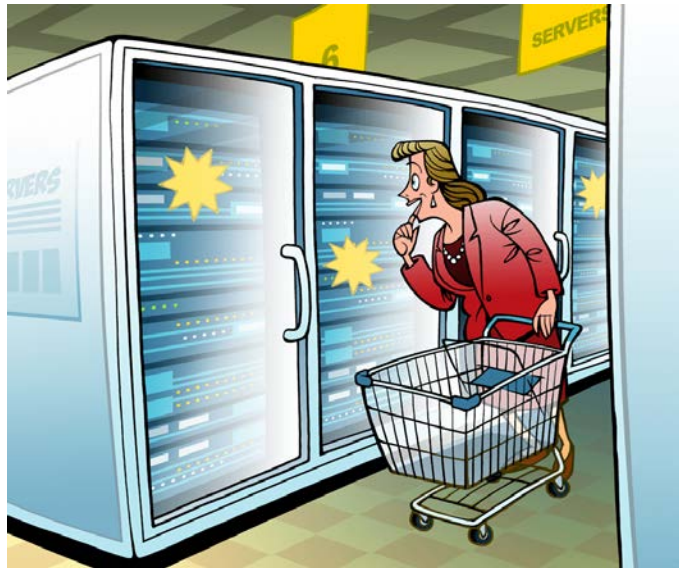
- Average error for the providers' day-ahead forecasts ranged from 5% to 10% of the solar power plants' installed capacity during daylight hours. Depending on the site, the best performers were 30–50% more accurate than the baseline output forecasts.
- No single provider was the most accurate in all scenarios, though a few emerged as the best overall performers based on a range of metrics.
- During periods of variable solar generation, the best performers' forecasts were occasionally wide of the mark, highlighting the need to look beyond average error at more detailed metrics. When facing such large disparities between forecast and event, operators must respond by dispatching other resources or carrying operating reserves.
- During solar ramping as a result of passing clouds, overall performance went down, with the lowest average errors at 20% of the solar power plants' installed capacity.
- Average errors for forecasts 7 to 10 days ahead were more than double those of day-ahead forecasts.
- Compared with a similar EPRI trial in 2014, overall performance improved, resulting in part from better technology.

EPRI is working with forecasters, national laboratories, and others to design better forecasting methods and to integrate them into grid operations. Demonstration projects in California and New York are evaluating the use of sky imagers, radiometers, ceilometers, and other advanced sensors to better understand meteorological phenomena and improve forecasts for both central and distributed solar power.

R&D Quick Hits

Chasing Away Server Room Heat

Study: Cooling Technology Can Tap Enormous Efficiency Potential of United States' 2.5 Million Small Data Centers



Variable refrigerant flow (VRF) heat pumps can reduce energy use in small data centers by up to 29%, according to an EPRI study.

While companies such as Google, Facebook, and Apple apply significant resources to reduce the massive energy consumption of their warehouse-scale data centers, the 2.5 million small data centers in the United States present enormous untapped efficiency potential. Representing about 1% of total U.S. electricity consumption, these network closets and server rooms are often located in commercial buildings—such as offices, hospitals, banks, and schools—that were not designed for data centers. Cooling typically accounts for about 40% of energy consumption in small data centers. Many best practices for cooling large data centers are not applicable because of space limitations.

As a potential energy savings solution, EPRI evaluated a VRF heat pump in its Innovations in Datacenter Efficiency Advances (IDEA) Laboratory in Knoxville, Tennessee. The system was configured to cool a server room while recovering server heat to condition an adjacent laboratory occupied by EPRI research staff. For 14 months, researchers compared its performance with that of a conventional heat pump system.

Key insights:

- In heat recovery mode, the VRF system yielded 10–12% energy savings.
- When cooling the server room and occupied space, energy savings were as high as 29%.
- At low outdoor temperatures, VRF indoor units may shut down to prevent freezing, limiting cooling capacity. This suggests that the technology may not be suitable for larger data centers in cold climates.

Utilities can use these results as a technical basis in considering the technology in energy efficiency programs.

R&D Quick Hits

A Rugged Rover in Search of Electromagnetic Interference

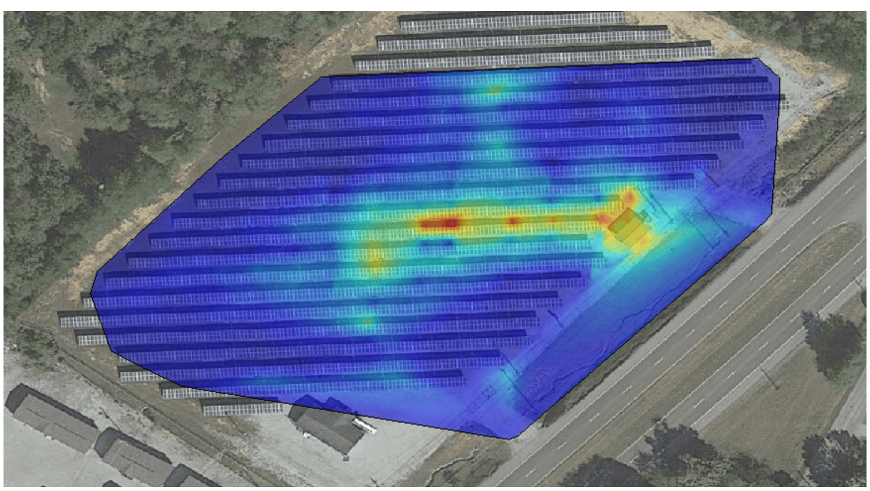
In field tests at the 1-megawatt Strawberry Plains solar power plant, an EPRI-developed robot demonstrated its ability to navigate rough terrain autonomously and collect accurate data on electromagnetic interference.

Interference radiating from power electronics in large solar arrays may violate Federal Communications Commission regulations. To assess its strength and source, it's necessary to gather, store, and analyze large amounts of data.

Known as the "Big, Autonomous, Mobile Measurement Platform" (BAMMP), the robot measures 42 inches by 33 inches by 20 inches, with four large wheels and a platform for various sensors (see photo above). Operators control it remotely via an onboard computer.

The robot collects electromagnetic spectrum data as it follows a programmed path, using a global positioning system to pinpoint the location of each measurement. To evaluate the effectiveness of corrective actions, the robot may gather data along the same path in the future. Researchers upgraded the robot prototype with the larger platform and wheelbase for smoother operation on rough terrain. New software enables the user to map interference levels throughout a facility (see photo below).

The robot measured the entire Strawberry Plains facility in one day.



A map, generated by EPRI software, showing the maximum elevated interference levels measured at the Strawberry Plains solar facility. The base image is from Google Maps.

R&D Quick Hits

Getting Creative with Water Use at Power Plants

Power plants are using alternative water supplies to meet a range of water needs reliably and cost-effectively, according to an [EPRI analysis] of 17 facilities across the United States.

Traditionally, power plants draw water from rivers, lakes, and other freshwater sources for use in cooling systems and other processes. In some areas, however, water scarcity or quality hinders or precludes their use.

Here are key findings for the diverse sources covered by EPRI's scientific literature review and staff interviews at power plants in different regions:

- Power plants have successfully used alternative water supplies for decades, in numerous applications and meeting up to 100% of their needs.
- Benefits of alternative water supplies include plant siting in a preferred location, regulatory compliance, lower costs, improved water quality, and reduced withdrawal of local freshwater supplies.
- The most promising, reliable alternative today is treated municipal wastewater effluent.
- Power plants are successfully using brackish inland water, stormwater, mine pool water, agricultural runoff, and interbasin transfers.
- Stormwater and agricultural runoff offer challenges with respect to quantity and quality but may be viable in some situations.
- Mine pool water, brackish water, and industrial effluent have variable water quality and require treatment but can be used successfully with careful planning, well-defined agreements with suppliers, and a backup source.
- Interbasin transfers and water produced from oil and natural gas reservoirs are the least promising alternatives.
- Successful use of alternative supplies is possible even if long-distance pipeline transport is needed.

Locations of the 17 case studies.

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