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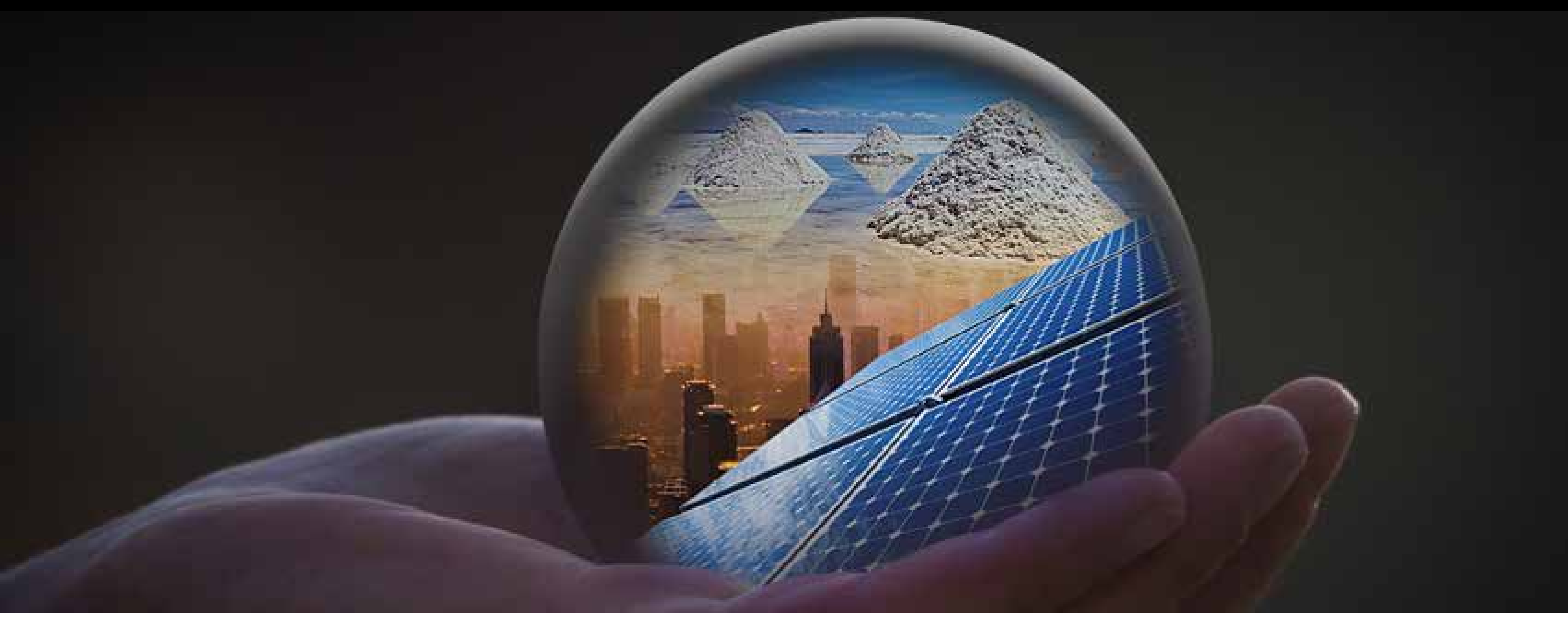
GETTING A HEAD START ON FUTURE ENVIRONMENTAL ISSUES



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Mike Howard, President and Chief Executive Officer, EPRI

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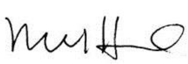
Mike Howard



President and Chief Executive Officer, EPRI

Feature—Getting a Head Start on Future Environmental Issues

By Chris Warren

The Story in Brief

It's tempting to assume that the widespread deployment of solar and wind will reduce or mitigate the future power system's environmental impacts. The reality is that new environmental challenges are emerging, and relatively little is known about them. EPRI has launched a multifaceted three-year initiative to anticipate and understand these challenges and inform solutions ahead of major impacts.

For millennia, sages and intellects have pondered the future and how to shape it in a positive way. Abraham Lincoln made such exercises seem realistic when he said, "The best thing about the future is that it comes one day at a time."

Lincoln's words point to the need to think and act each day in ways that shape better outcomes. As the power system incorporates more distributed energy resources (DER), including solar and wind, it can be tempting to assume that the transition will reduce environmental challenges.

While sustainability drives many changes across the power system, any potential transformation brings unanswered environmental questions and potential challenges. For example, what are the environmental challenges of solar panel degradation after a few decades of operation? What is the proper end-of-life use, if any, for the panels? Is it best to dispose them in a landfill? Can valuable materials such as gallium be recovered and reused?

Identifying Questions, Seeking Answers

Consider just a few of many emerging questions: What are the environmental impacts of lithium mining for battery manufacturing? How are emissions affected when coal and natural gas power plants are cycled more to balance intermittent solar and wind generation? What are the impacts of emissions from DER that use fossil fuels?

This article, the first in a series on environmental issues in the power system of the future, examines EPRI research on air quality effects of fossil DER connected to the grid as alternate and backup power sources. Fossil DER—which make up almost 60% of all DER today—include combined heat and power plants, diesel generators, small single-cycle turbines, microturbines, and fuel cells.

“Some people think that what you don’t know can’t hurt you, but that is often what hurts you in the end,” said Stephanie Shaw, an EPRI senior technical leader who leads the fossil DER air quality research. “If you don’t understand the landscape, then you will be unprepared if a challenge emerges later.”

To examine future environmental issues comprehensively, EPRI proposes seven factors to consider before any new generation or other infrastructure is added to the grid:

- Changing customer values and attitudes (such as those of the “Prosumers” who produce electricity at their businesses and residences)
- Power plant design
- Permitting
- Construction
- Operations and maintenance
- New and emerging technologies
- End-of-life questions

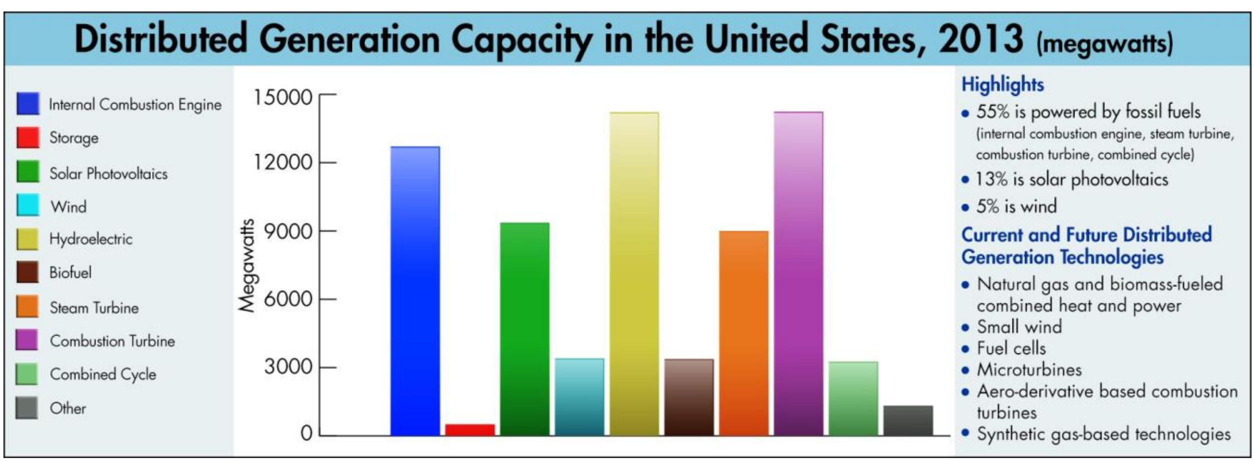
Seven Factors for a Big-Picture Perspective on the Environment

To comprehensively address environmental issues that arise in the future power system, EPRI has identified seven factors to analyze before any generation, distribution, or transmission infrastructure is deployed:

Customer attitudes
Design
Permitting
Construction
Operations and maintenance
New and emerging technologies
End-of-life

A thorough examination of these seven factors can identify multilayered environmental issues that emerge in an increasingly complex power system with two-way power flows. “All we did at the bulk generation level in the past was say that the load is 100 gigawatt-hours, and DER are producing 10 gigawatt-hours, and we would ignore the environmental impact of that 10 gigawatt-hours,” said EPRI Chief Sustainability Officer and Environment Vice President Anda Ray. “Now we have to pay attention to the characteristics of this two-way flow because it can mean building more distribution infrastructure, which can also have an environmental impact.”

“Electric power companies used to emphasize the principle that everything has to be least cost,” said Ray. “The emphasis has shifted as more consumers and investors have environmental sustainability as a value.”



Though much of the newly installed distributed generation is solar, fossil-powered distributed generation still accounts for the vast majority of the total. The data is for units less than or equal to 25 megawatts.
Source: U.S. Energy Information Administration

A grid that relies more on distributed resources demands an environmental paradigm shift for society and utilities alike. “The environment used to be considered a hurdle for the industry,” said Ray. “I want to build this new plant; just tell me what I have to do environmentally to ‘check the box’ and move forward. But now the environment is integral to the utility’s overall value proposition, which means that end-of-life and many other issues and costs need to be considered in the design phase of everything that touches the power system.”

EPRI’s multiyear initiative extends across its research sectors and includes a broad range of stakeholders in North America and globally, including power companies, customers, regulators, policymakers, and others. The intent is to pave the way to a cleaner, more robust power system and avoid unintended environmental consequences.

From Tall Stacks to Urban Canyons

Discussion of the changing power system often centers on the addition of renewable DER, especially solar and wind. But a large proportion of distributed generation is also coming from fossil-powered DER, primarily natural gas combined heat and power plants (see chart). Driving this is the desire by energy-intensive industries such as manufacturing and food processing for the most cost-effective energy. For emergency power, hospitals, businesses, residential customers, and others rely on diesel generators.

The spread of these relatively small fossil DER units, which EPRI has defined in its research as 25 megawatts or smaller, raises important air quality questions. The traditional power system has been dominated by large, central coal and natural gas-fired plants, usually located far from population centers, which can offer air quality benefits. “With central station coal or natural gas, you benefit from their tall stacks that release emissions at an elevation of 200 meters,” said Shaw. “Those emissions are going to dilute, react, and change before they reach the ground. Often, the environment can do its work to transform those emissions into something much less harmful, though that’s not always the case.” With continuous emissions monitoring and emissions control devices at these facilities, many impacts are well understood, and air quality has improved in recent years.

Fossil DER often operate at street level near or in cities and towns. Because such emissions can be released into urban canyons created by tall buildings and narrow streets, they are not always subject to the natural dilution that occurs high in the sky. Local and regional air quality impacts of such units are largely unknown, and EPRI launched the first comprehensive examination in 2014.

Shaw lists just a few of the unknowns. “Are fossil DER emissions sufficiently low that the environmental impacts are negligible? Are there emissions controls on these units, and are they needed? Do we have modeling tools to calculate impacts from individual sites? Do we have tools to calculate cumulative regional impacts?”

Generally, fossil DER units must be permitted before going into service. For emergency generators, permits restrict hours of operation and fuel types to minimize air pollution. Growing interest in using fossil DER for demand response—which may entail ramping up and down rapidly to help utilities meet peak demand—has led state and local regulators to reconsider permitting standards. This will require a better understanding of emissions.

In 2014, Shaw and EPRI Principal Technical Leader Eladio Knipping began the three-year initiative by determining what is known about emissions from fossil-fueled DER. These include particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, and carbon dioxide. “These devices are not regularly measured,” said Shaw. “So we scoured available emissions information from our utility members and other sources.” This legwork revealed important details about the types and levels of emissions.

Also in 2014, EPRI developed air quality models to characterize emissions within a half-mile of facilities, as well as regional models to predict impacts in areas the size of southern California or the northeastern United States.

Researchers are modeling various scenarios to determine current impacts, as well as impacts in 2035 based on projected deployment of fossil DER.

The Work Ahead

Building on this groundwork, Shaw, Knipping, and their team in 2015 will continue to evaluate model scenarios and begin emissions measurements in the field. The first field site is a 15-megawatt combined heat and power natural gas facility. Although this unit is small relative to a traditional power plant, monitoring it will yield valuable information because emissions tests were conducted when it was commissioned five years ago, and it has been operating regularly since then. “A big question is how these devices age,” said Shaw, adding that she plans to measure emissions at a fossil DER facility participating in a demand response program.

This work seeks to identify future research priorities and provide information to guide practical solutions. Scientifically sound insights on air quality impacts of increased fossil DER can inform regulators as they modify and implement emissions rules. The research can guide utilities as they consider where to install fossil DER units and how much capacity to add in specific locations to comply with air quality regulations. The results can also help inform other EPRI researchers and organizations developing new emissions control equipment for fossil DER.

The work that Shaw and her colleagues are doing today is aimed at guiding choices that lead to an improved future. “If the data show that increased fossil DER is a net positive for the environment, then that helps everyone involved make a better choice,” she said. “And if there are concerns about future air quality impacts, the research can help us provide recommendations to minimize them.”

Key EPRI Technical Experts

Stephanie Shaw, Eladio Knipping

Feature— Smarter on Smart Grids

Top 8 Takeaways of EPRI's 7-Year Demonstration Initiative

By Michael Matz

The Story in Brief

"Smart grid" has a new meaning today, thanks to hundreds of insights from an ambitious research undertaking with 17 utilities. Here's a selection in areas ranging from energy storage and voltage management to distribution automation and cybersecurity.

In an age of information excess, making lists is an instinctive way to make the overwhelming manageable. From today's "to-do lists" to corporate mergers, lists provide order and a starting point for more ideas… and more list items.

EPRI researcher Matt Wakefield must have been thinking along these lines in 2008, when he was charged with the monumental task of launching EPRI's seven-year Smart Grid Demonstration Initiative. The objectives were sweeping and ambitious: launch multiple field projects with utilities, test technologies to integrate distributed energy resources into the grid, and define standards to make all this equipment interoperable.

Wakefield started by engaging potential utility collaborators in conversations to define the initiative's scope. "We made a list of different types of distributed energy resources to integrate in the demonstrations," he recalled. "It included items like demand response, energy storage, electric vehicles, and renewables such as solar and wind."

Fast forward seven years to the completion of the initiative's 47 demonstration projects with 17 utilities, and a remarkable finding emerged. One of the most customer- and grid-friendly distributed energy resources wasn't on that original list. Demonstration participants discovered a few years into the initiative that *voltage management*—optimizing distribution system voltage to reduce energy demand—dramatically improved grid efficiency. "Back in 2008, no one viewed voltage management as an energy resource," said Wakefield. "Today, it's seen not only as a resource, but as a big potential energy saver."

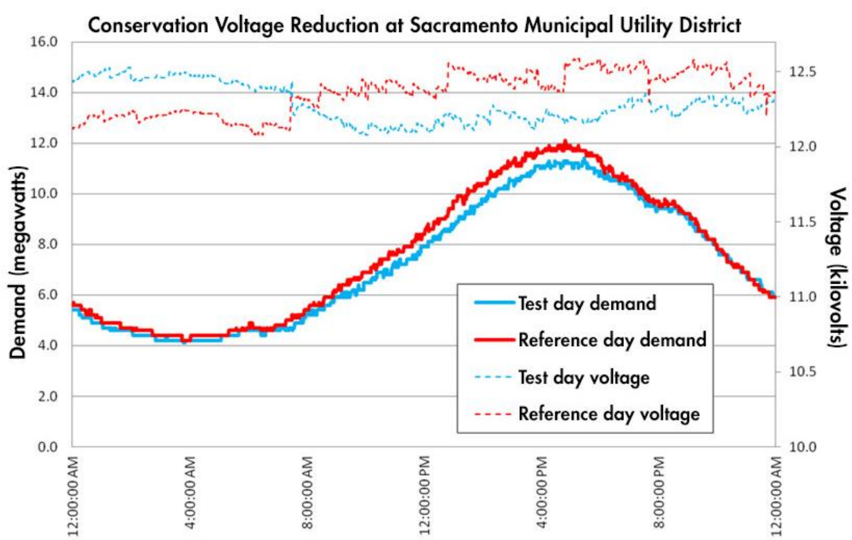
This is just one of hundreds of findings that together have supported the industry's smart grid progress and advanced its knowledge. And that brings us back to the value of list-making, with eight of the initiative's major insights.

1. Voltage management can reduce energy use by as much as 4%.

For decades, grid operators have managed distribution system voltage to lower energy losses in power lines, transformers, and end-user devices. Recent advances in sensor technology have enabled more effective voltage management, with potential for much greater energy savings.

Building on previous EPRI research that established the potential energy efficiency benefits of advanced voltage management, the demonstrations tested several voltage management technologies to provide essential details on savings—and where and when they work best. *Conservation voltage reduction* uses automated controls to reduce voltage delivered to residential appliances and industrial machines during high-demand times. With additional sensing and control technology, this approach yielded 1.5–4% reductions in energy use in various scenarios.

EPRI and its collaborators learned that the benefits of voltage management are greater in feeders serving residential and commercial customers, compared with those serving industrial facilities, as a result of load and feeder characteristics. Also, depending on the region, summer and winter electric peaks can influence the savings. Each utility will need to consider these factors when evaluating benefits and technology costs.



This graph shows the test results of conservation voltage reduction controls on a substation in Sacramento Municipal Utility District's service territory. The dotted blue curve shows the reduced voltage, and the solid blue curve shows how those reductions led to lower electricity demand. The analysis revealed an average peak demand reduction of 1.7%.

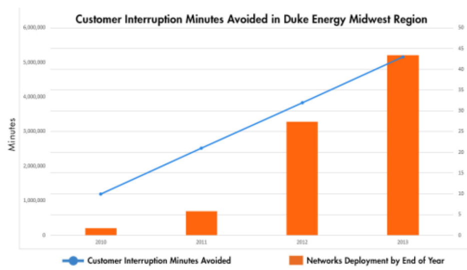
2. Distribution automation can speed outage restoration, but managing the data remains a challenge.

A central element of the smart grid is *distribution automation*, which allows for real-time, automatic adjustments of distribution system configuration in response to changing electricity supply and demand, outages, faults, and other failures. This self-healing capability involves equipping grid components with intelligent sensors, processing real-time data on grid conditions, and communicating with utility databases.

In 2008, some interoperability standards existed for distribution automation, but quite often components from different manufacturers did not interface seamlessly. Demonstration participants worked to improve these interfaces and interoperability standards.

The efforts paid off. Utilities applying distribution automation achieved faster pinpointing and restoration of outages. For example, 43 self-healing networks deployed in Duke Energy's Midwest region between 2010 and 2013 performed automatic restoration operations, preventing sustained outage for thousands of customers and saving 9.4 million customer interruption minutes (see chart).

Even with such impressive numbers, EPRI and its partners discovered that integrating the enormous volume of distribution field data from sensors and intelligent devices—and from new and old utility systems—can be messy. A key task ahead is to design communication systems and protocols that can handle the data, including cybersecurity requirements.



Duke Energy avoided more customer interruptions as it deployed more distribution automation.

3. Advanced metering infrastructure: Benefits extend well beyond meter reading.

In 2008, utilities used customer smart meters mainly for billing. EPRI's initiative examined new possibilities for smart meters and demonstrated new applications to support utility operations. These included identifying outage locations, managing power quality, measuring voltage for customer solar arrays, supporting conservation voltage reduction and demand management systems, and offering customers time-based electric rates and web portals.

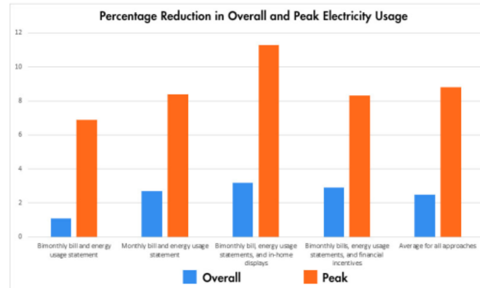
Through these applications, participants took critical steps to define standard communication interfaces and data for *advanced metering infrastructure*, which supports communication between utilities and customers through smart meters, communications networks, and data management software.

Southern Company demonstrated the use of smart meters for automated monitoring of *capacitor banks*—grid devices that help control voltage. Meters perform daily health checks on capacitor banks and relay the results to the utility's meter data management system, which in turn flags malfunctions and alerts field technicians to inspect. The monitoring system identified more than 650 problems in the first six months and allowed for repairs to be made within days, reducing line losses and improving distribution voltage management. The method replaces time-intensive manual monthly readings of existing feeder monitors in substations and annual visual inspections.

4. Solving mysteries: Tools to influence customer energy use have the potential to reduce demand, but understanding customer behavior is not easy.

A key aspect of a smarter grid is engaging smarter customers to reduce electricity use and peak demand. In 2008, industry's understanding of customer wants and needs—a prerequisite for successful customer engagement—was primarily anecdotal. EPRI's initiative advanced the statistical science and precision of customer behavior studies. Yet, many aspects of customer behavior remain somewhat mysterious.

Consider the results of the demonstration projects with two utilities: Ireland's ESB and Illinois' Commonwealth Edison. ESB offered 3,800 residential customers various combinations of engagement tools: electricity prices that vary by time of day, monthly and bimonthly bills, detailed energy use statements, financial rewards for reducing use, and in-home energy displays. On average, these reduced overall energy use by 2.5% and peak use by 8.8% (see chart). But ESB found no clear electricity price threshold above which customers changed their behavior. Commonwealth Edison's results were even more baffling: Customers did not alter electricity use in response to peak prices that were more than 15 times their normal rates.



ESB's demonstration project showed how various customer engagement tools affected energy usage.

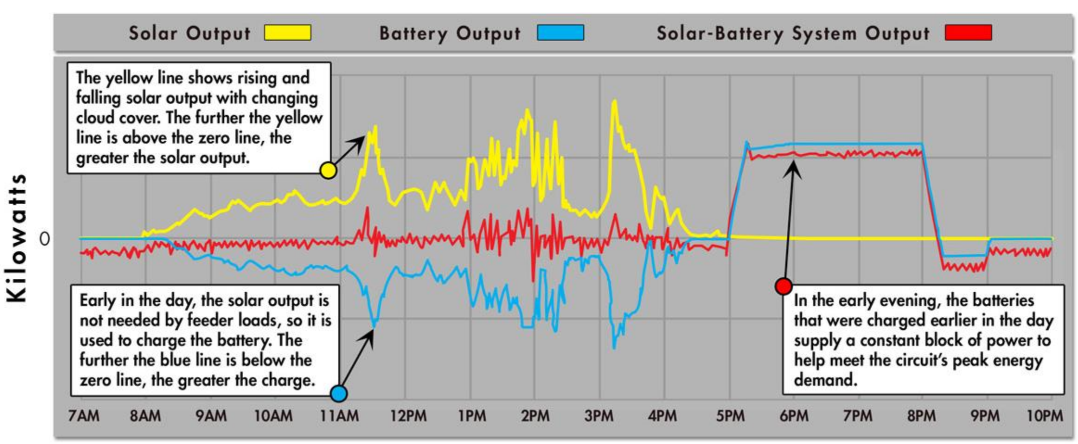
"Customers like the idea of price incentives, but more work is needed to make them effective," said EPRI's Gale Horst, who managed the demonstrations. "One problem is that most customers don't know what a kilowatt-hour is."

5. Integrated solar-battery systems can provide firm, dispatchable energy.

Much talk in the electric power industry these days focuses on the promise of combining batteries with solar—and with good reason. Batteries can smooth the rapid solar output shifts that can lead to fluctuations in customer service voltage. They can also help reduce a feeder's load during high-demand periods (a service called *peak shaving*) and provide *firming*—the guarantee of constant power output to the electricity market at a certain time. But making this work in practice is still not easy.

A demonstration project at the Public Service Company of New Mexico proved that solar-battery systems can provide these valuable services with the right combination of supporting infrastructure. The utility deployed a 500-kilowatt solar array with a 1-megawatt-hour lead-acid battery system at its Studio Substation distribution feeder, which serves residential, commercial, and industrial customers near Albuquerque. The solar-battery unit is integrated with a cyber-secure communications system that collects a set of data—such as solar array voltage, temperature, and battery output—every second. Supported by these data and modeling predictions of peak load and solar output, the solar-battery unit's algorithms successfully provided simultaneous voltage smoothing, peak shaving, and firming. It transformed extremely variable solar power into a block of energy that aligned with the utility's evening peak load (see chart below).

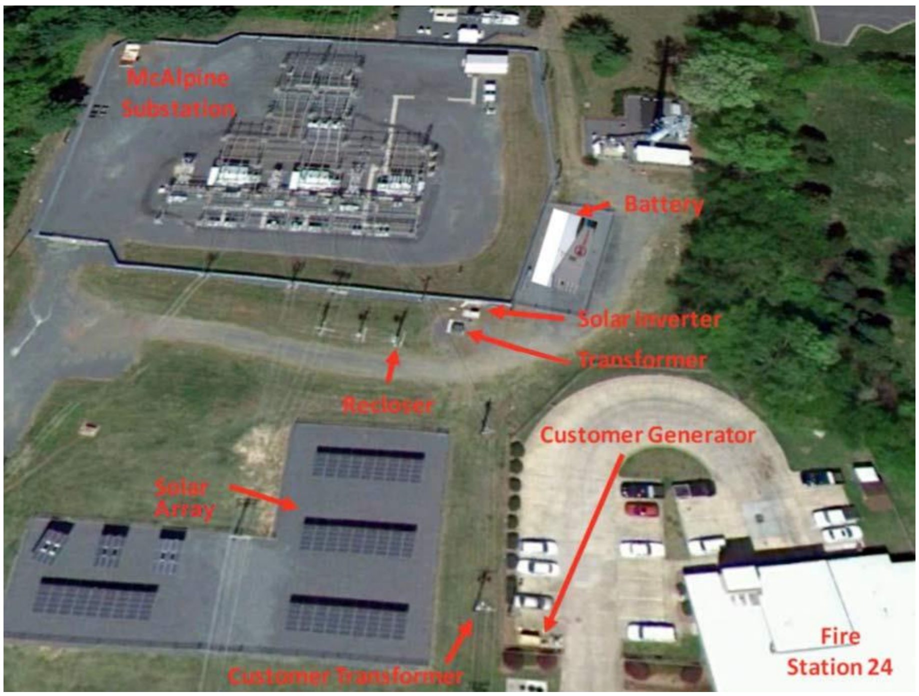
It is an important step in designing solar-battery systems with standard configurations and interfaces that can serve as building blocks for smart grids elsewhere. The goal is to avoid the need to design such units for each local application.



6. Off-the-shelf equipment can serve as building blocks for microgrids.

There is still much to learn about building and reliably operating *microgrids*—local grids usually connected to the traditional electric grid that disconnect if necessary to operate autonomously. If implemented well, they can provide backup electricity to customers during outages.

At a fire station near a distribution substation, Duke Energy demonstrated that a microgrid can be created from standard utility distribution equipment such as reclosers, transformers, and switches, coupled with a 50-kilowatt solar array and a 500-kilowatt-hour lithium-iron phosphate battery/inverter system. With a few modifications, the devices provided a seamless transition to and from grid connection. Duke determined that the capabilities of standard equipment must be fully investigated and understood in order to build microgrids.



A microgrid in Duke Energy's service territory

7. Utilities need a coordinated cybersecurity approach for all their interconnected systems.

The grid's 21st century evolution is being driven by the widespread use and networking of monitoring systems, distribution automation, smart inverters, smart meters, and other intelligent devices. Utilities increasingly depend on data communications and automated control among millions of devices for reliable grid operations, exposing the electric system to potential cybersecurity attacks.

Several utility participants in EPRI's initiative observed that achieving comprehensive cybersecurity protection for their operations and IT systems is no easy task. One challenge is that multiple systems and operators independently gather and analyze security information from different applications and vendors. The conclusion shared by the participants: Utilities need a coordinated cybersecurity approach that will enable them to support new applications and legacy systems and to comply with regulations and standards.

For its demonstration project, Southern California Edison demonstrated a technology known as Common Cybersecurity Services, with an architecture that supports different devices, current and next-generation networking, and all major communications protocols used in the grid. The technology assigns each grid device a unique key that enables secure communications with its control system. The utility expects that the technology will help to quickly identify cyber events and coordinate many aspects of its security awareness and response.

8. The greatest challenge to achieving a smarter grid: communications.

The demonstrations focused the industry on the paramount importance and challenge of communications technology. “Communications networks need to be as secure, reliable, and robust as the grid itself,” said EPRI’s Matt Wakefield. “This requires strategic infrastructure investments that enable communications across many different utility business units—from grid operations to planning to billing—that have traditionally been siloed.”

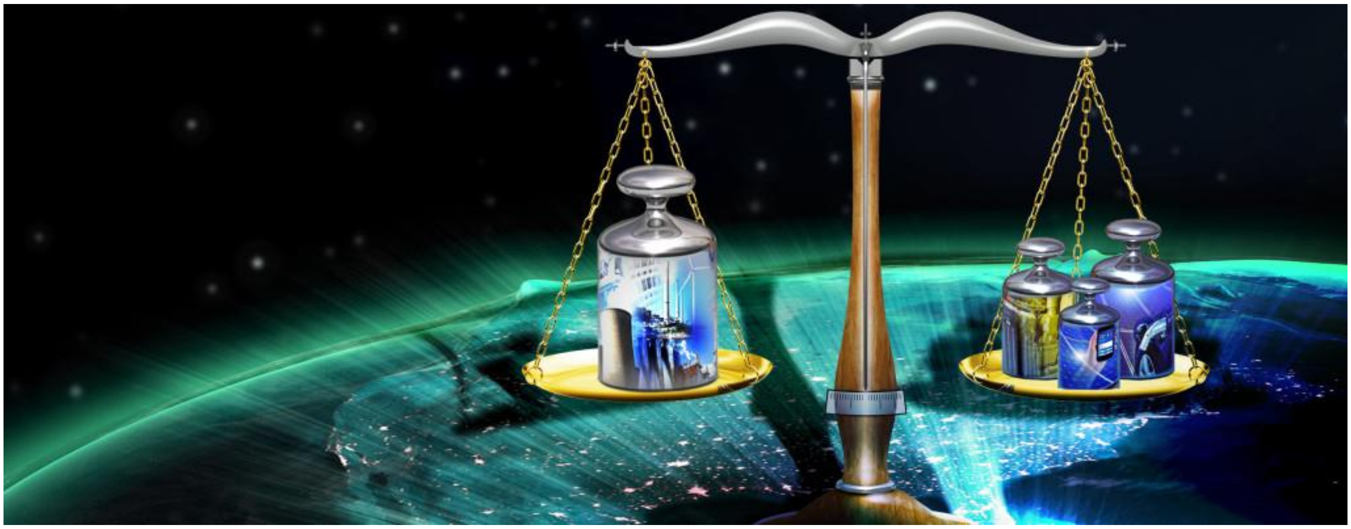
Participants experienced many setbacks resulting from communications failures. A common challenge was getting various utility systems to communicate with one another.

In one demonstration, Salt River Project tested a private *field area network*, a technology that places data systems and processing closer to electric infrastructure and customers and that can accommodate many smart grid applications. The utility found that while such a network requires a large initial investment, it has the potential for long-term payback if used for data-intensive applications.

Key EPRI Technical Experts

Matt Wakefield, Gale Horst

Feature—A Rigorous Framework for the Grid's Transformation



New Bottom-Up Methodology to Assess Benefits and Costs of Distributed Energy Resources Starts at Local Circuits and Builds to System Level

By Chris Warren

The Story in Brief

As the grid transforms from a one-way power delivery system to a far more complex system, utilities, regulators, and other interested stakeholders need a common language to understand and agree on the best future path. EPRI's new analytical framework provides this language, outlining an approach to comprehensively and transparently assess the benefits and costs of integrating new distributed energy resources into the grid.

In April 2014, the New York Public Service Commission launched Reforming the Energy Vision, a fundamental reimagining of how the state produces, consumes, and manages electricity. Utilities, grid operators, generation owners, and other stakeholders are working to guide the grid's transformation from a network of central power plants delivering electricity to homes and businesses to a more complex, dynamic system that includes extensive energy storage, demand management, rooftop solar, and other distributed energy resources (DER). New York's initiative relies on collaboration to ensure that the electric system remains as reliable and resilient as it has been historically while optimizing diverse emerging energy resources.

New York is not alone in its effort to establish rules, policies, technologies, and incentives to successfully guide these changes. In August 2014, the California Public Utilities Commission kicked off a rulemaking process requiring the state's investor-owned utilities to integrate distribution resource plans with DER into long-range grid planning. Also in 2014, the Tennessee Valley Authority launched an initiative to develop a methodology to assess the value DER bring to the grid, taking into account where solar and other resources are interconnected and the resulting costs. There is great diversity among the organizations working to ensure that DER connected to the distribution system benefit the grid and society, including utilities, grid operators, renewable energy developers, environmental nonprofit groups, regulators, policymakers, and consumers.

While the initiatives have different names and methodologies, they share a key objective that is neatly summarized in New York's proposal: "to make energy efficiency and other distributed resources a primary tool in the planning and operation of an interconnected modernized power grid."

Providing a Template: EPRI's Integrated Grid Benefit-Cost Framework

The need for a roadmap and tools to guide the grid's transformation spurred EPRI to launch its Integrated Grid initiative. EPRI's 2014 concept paper, The Integrated Grid: Realizing the Full Value of Central and Distributed Energy Resources, outlined key issues to address in moving toward a power system that maximizes the benefits of the existing grid and DER. Following up this initial work, EPRI unveiled the Integrated Grid Benefit-Cost Framework in February.

The Benefit-Cost Framework is not a one-size-fits-all analysis to determine exactly how to incorporate DER. Instead, utilities, regulators, and third-party stakeholders can use its methodology to more accurately and transparently assess the benefits and costs of adding DER in specific locations and for the power system as a whole. "This work shows that you have to take a system perspective and examine local and distribution issues and then aggregate those to assess impacts on transmission, generation, and overall resource planning," said Mark McGranaghan, vice president of EPRI's Power Delivery & Utilization research sector. "The kinds of studies that need to be done each step of the way are laid out, though we don't tell you how you have to do those studies."

This presents a new paradigm for utility planners, who have historically focused on the one-way delivery of energy from power plants through transmission and distribution systems to customers. With more DER feeding electricity into the distribution system, there's an acute need to understand and plan for two-way power flows. "Not that long ago, planners were basically able to separate the transmission and distribution systems," said Ben York, senior project engineer in EPRI's Distributed Energy Resources program area. "Now you have distributed resources on the distribution system potentially pushing power back onto the transmission grid. That is forcing tighter connection between bulk system planning and distribution planning, where bulk planners take into account generation resources on the distribution system."

To do that properly, EPRI's Benefit-Cost Framework accounts for the importance of the distribution system, down to individual feeders, or circuits. EPRI's approach is rooted in engineering and quantitative rigor, distinguishing it from studies such as value-of-solar analyses that seek to quantify the impact of additional DER on the entire grid. "One of the limitations of prior studies is that they take a top-down look, starting at the transmission level and relying on broad assumptions about how much distributed generation the distribution grid can handle and the impacts," said Jeff Smith, a senior project manager in EPRI's Power System Studies Group. "This can result in significant inaccuracies in assessing the costs and benefits."

By contrast, EPRI's methodology starts at individual distribution feeders, quantifying each feeder's DER hosting capacity and the resulting costs and benefits of adding DER within that feeder. Then, it aggregates these local costs and benefits and determines impacts at the transmission and overall system levels. "Our method is bottom-up, not top-down," said Smith. "Quantifying the value impacts where the DER are connecting is fundamental to any analysis."

The Basics of the Framework

The EPRI Benefit-Cost Framework outlines four steps for a comprehensive assessment of the implications of adding DER: core assumptions, distribution impacts, bulk power impacts, and benefit-cost analysis. Identifying core assumptions helps stakeholders account for the unique attributes of the power system, policies, and conditions in their state, region, or country. "The core assumptions step defines the scenarios to be evaluated and the questions that utilities, regulators, consumers, and others will need to answer as they determine how and where to deploy DER most effectively," said York.

An Overview of EPRI's Benefit-Cost Framework:

Core assumptions:
Because no two power systems are exactly alike, the starting point for utilities, consumers, regulators, and other stakeholders is to account for their unique market conditions and study objectives. Identifying the questions that must be answered helps to define potential scenarios to study and the assumptions behind them.

Distribution impacts:
Distributed energy resources connect at the distribution level. Understanding how they impact parameters such as voltage, safety, and reliability is key to determining the costs and benefits

Bulk power impacts:
Two-way electricity flows between the distribution and transmission systems can affect the capacity and flexibility required to serve demand. Assessing those impacts is vital

Benefit-cost analysis:
Quantifying the actual costs and benefits of integrating distributed energy resources in real dollars is the framework's final step. These costs and benefits don't accrue equally to society, utilities, and consumers.

For example, what level and what types of DER penetration are sought? Is the aim to deploy enough solar photovoltaic (PV) generation to supply 10, 15, or 30 percent of residential and commercial load? Is the goal to add one, two, or three gigawatts of storage? The range of scenarios is as wide as the varying market conditions and policies around the world. Once those scenarios are determined, a deeper look at the assumptions behind them is essential. Utilities and regulators planning for significant solar deployment should fully consider the costs of integration and ways to ensure that the grid remains resilient and flexible with added intermittent generation. "You are assuming things about the cost of PV and the amount, location, and timing of the adoption," said York. "These and other assumptions go into each scenario."

The next step is to examine the distribution impacts. "Any holistic assessment of the entire grid requires you to first consider where DER are connecting within the distribution system," said Smith, pointing to five parameters that must be measured to gauge the effects of new DER: voltage, safety, thermal capacity, energy, and reliability. "Investigating all five allows you to assess the potential impact that results in a cost or potential value," he said. One cost, for instance, may be incurred by the need to reconductor power lines to accommodate more DER. An offsetting benefit might be realized by delaying or avoiding the upgrade of a substation transformer because the added distributed generation can serve local peak demand.

A similar assessment of DER impacts is then applied to the bulk power system, with a primary focus on the system's ability to serve demand. The transmission system's performance, flexibility, and operations are examined to again determine potential costs and benefits yielded by additional DER.

The framework's final step involves quantifying in real dollars the costs and benefits at both the distribution and bulk power levels. Keep in mind here that costs and benefits don't accrue equally to every stakeholder. "If the utility wants to look at them from their perspective, they can do that," said McGranaghan. "But regulators and policymakers might want to look at them from a societal perspective, supporting decisions on incentives for applications with value streams that might not get realized by utilities."

Integrated Grid Pilot Projects

Though essential, EPRI's detailed framework is not sufficient by itself to guide the journey to the Integrated Grid. "It's great that it's written down, but what we need next is real-world application," said McGranaghan.

EPRI is doing this with utilities through dozens of pilot projects over the next several years to examine costs and benefits of a wide range of DER. These include microgrids, electric vehicle charging infrastructure, distributed energy storage, and utility-scale solar. In part, these pilot projects are designed to test the framework's effectiveness. For example, EPRI is helping Salt River Project develop and customize an automated tool to analyze its distribution system's hosting capacity.

These and other pilots will inform and refine the benefit-cost framework by providing system-specific data about the costs, benefits, and challenges of DER integration. "Many of these technologies are new, and all you have is what the manufacturers tell you is the cost," said York. "Deploying and scaling up these technologies give you a much better idea of the real costs, benefits, and impacts."

Along with the pilot projects and the framework, EPRI has organized a broader scope of work through "research imperatives" to guide the development of analytical tools and standards needed to make the Integrated Grid a reality. These include DER interconnection standards and improvements to smart inverters. "Even if the framework says something is worthwhile to do, we still have to have the technology, standards, and tools to actually do it," said McGranaghan.

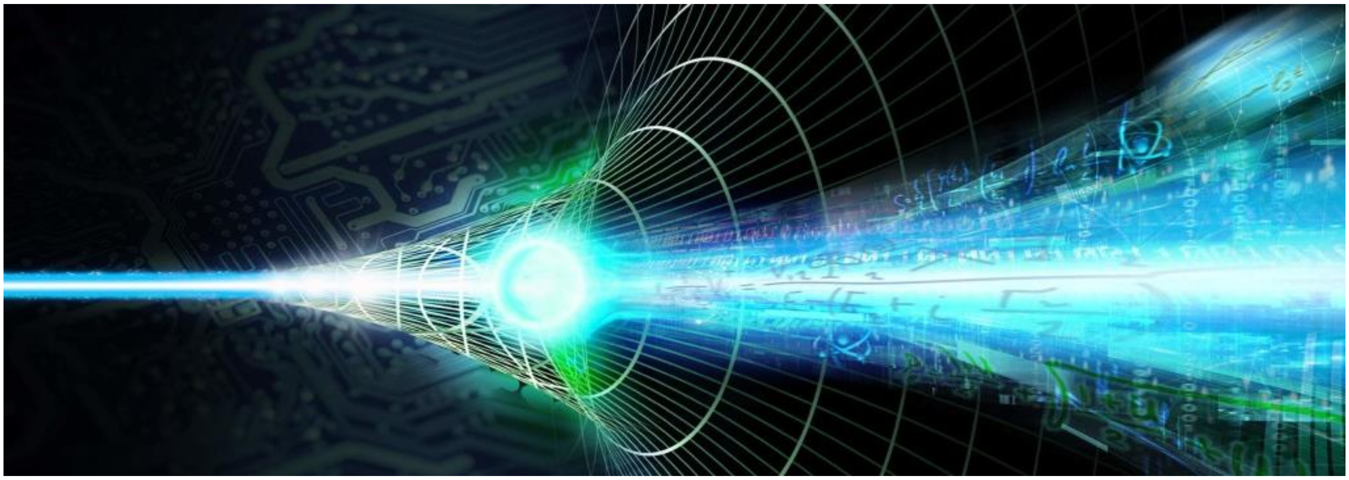
EPRI's Benefit-Cost Framework is intended to bolster trust and transparency among the many groups interested in the grid's evolution. "Integration of the grid impacts everyone—not only utilities and regulators, but also individuals and businesses that own solar power systems and other distributed energy resources and have a genuine interest in the power system," said York. "The framework provides a common language for all these people to understand and buy into the benefits and costs."

For more information, visit EPRI's Integrated Grid website.

Key EPRI Technical Experts

Jeff Smith, Ben York

Feature—Analysis in a Flash



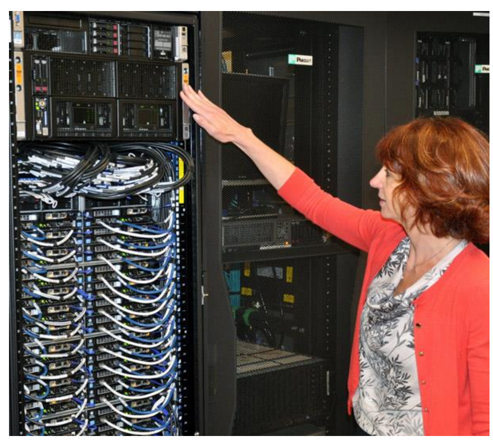
High-Performance Computers Provide Speed to Solve Complex Power Industry Challenges

By Robert Ito

The Story in Brief

Researchers increasingly use high-performance computers to tackle the power industry's diverse technical challenges, from grid operations to nuclear accident mitigation. Complex analyses that once required weeks or months now are possible in just minutes.

EPRI researcher Richard Wachowiak needed to evaluate multiple strategies and consider as many fixes as possible to minimize the impact of nuclear plant accidents. Examples of such fixes included adding water to the reactor pressure vessel and installing filters in the reactor's drywell vent. Working alongside Phoebe, he did this with computer simulations for more than 500 different scenarios in just a few hours. Phoebe is EPRI's high-performance computer, and before she joined the EPRI team Wachowiak would have spent nearly a month to run just 50 similar simulations.



EPRI's Heather Feldman with the high-performance computer Phoebe

If the electric power industry has contributed to the rise of high-performance computers by providing the energy to run them, these machines are now returning the favor, enabling new ways for researchers to examine and solve diverse technical challenges. With high-performance computing, scientists can run models and simulations that would otherwise be too expensive, complex, or dangerous. The key factor is speed, a direct result of parallel computing. By splitting tasks and running each part independently, parallel computing enables researchers to rapidly conduct thousands of simulations and run virtual experiments that would be impossible with regular computers.

Preparing for the Unlikely

Although nearly all nuclear power plants have operated safely and reliably over their lifetimes, many people associate nuclear power with images of Three Mile Island, Chernobyl, and Fukushima Daiichi. For Wachowiak, principal technical leader in EPRI's Risk and Safety Management Program, understanding how to limit the impact of such accidents inspires and drives his research.

Wachowiak works on modeling and simulation of severe accident mitigation strategies at nuclear plants. He looks for ways to mitigate accidents by evaluating many factors, such as the probability that a certain component fails during an earthquake.

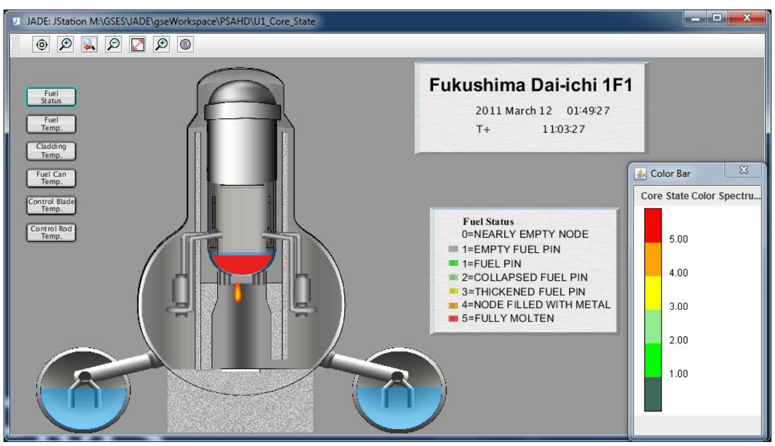
In a recent study, Wachowiak and his team used Phoebe and EPRI's Modular Accident Analysis Program software to run more than 120,000 simulations of nuclear accident scenarios. The simulations estimated each scenario's likelihood by generating event tree diagrams that show what happens after an initiating event. The diagrams were modified to reflect what occurs with a mitigating strategy, such as injecting water to cool the reactor.

Wachowiak's team investigated the ways each strategy could succeed and fail and calculated the potential effects of each scenario, such as the amount of radioactive material released. Then they used a code developed by the U.S. Nuclear Regulatory Commission (NRC) to model the accident's public health impacts, given factors such as weather patterns, wind direction and speed, and the nearby population.

After running and analyzing thousands of simulations, researchers determined that adding water to a damaged reactor core was essential to any mitigation strategy. Without it, containment of radioactive material is unlikely, regardless of any other steps taken.

With the results of these simulations, nuclear plant operators can more effectively identify necessary improvements and mitigation strategies at their facilities. "We work to help utilities make informed decisions about where they should invest their resources to mitigate these scenarios," said Wachowiak.

"The strategies that we are researching go over and above what is already in a plant's licensing basis," he said. "This work will lead to a set of actions at nuclear plants that address a broader range of accident scenarios, increasing industry safety."



Researchers ran thousands of simulations of severe nuclear accident scenarios on EPRI's Modular Accident Analysis Program. This snapshot of a simulation of one of the reactor units at Fukushima shows the predicted time (in the upper right box) of the failure of the reactor pressure vessel. The red drop signifies the fuel rods leaking into the containment area.

Helping Grid Operators Respond Adeptly to Disturbances

What happens when lightning hits a transmission line or a truck crashes into a transmission tower? Such disturbances can have devastating effects on the grid in minutes or even seconds. Grid operators need huge computational power to quickly analyze grid conditions and inform timely responses. The objective is to assess *transient stability*, the grid's ability to keep its equipment operational after disturbances. Unfortunately, performing hundreds of simulations in a matter of minutes is beyond the capabilities of most utility computer systems.

Enter high-performance computing. For two years, EPRI has worked with researchers at Lawrence Livermore National Laboratory to modify and upgrade the Extended Transient Midterm Simulation Program, a transient stability analysis tool that EPRI developed in the 1980s. Back then, when researchers relied on a single computer processor, simultaneously evaluating several grid scenarios required significant time.

This time, the work was done on Livermore's Cab, a 431-teraflop supercomputer capable of large parallel simulations of *contingencies*, or failures of various parts of the grid. Researchers ran simulations of thousands of contingencies in parallel, beginning with one or two triggering events, then simulating possible outcomes.

"We're building a program that grid operators can run every few minutes to process a large number of contingencies so that they can have a nearly real-time picture of the grid's security condition," said EPRI's Alberto Del Rosso, who led the project. "This leads to good, timely decisions on control actions to prevent adverse effects of grid disturbances."

The research demonstrated the advantage of parallel computing. One study ran 4,096 contingencies on 4,096 processors in just 200 seconds. Such an operation on a non-parallel computer system would require about 20 hours.

EPRI's upgraded transient stability analysis program operating on today's high-performance computers can help utilities prevent and respond in real-time to crises that threaten power supply. For example, during transmission line faults, the software might inform a quick decision to redirect power flow or start a new generator. In the next two years, EPRI plans to assess the viability of running an upgraded version of the tool on Phoebe, which could provide further research enhancements in this critical area.

From Falcon to BISON: Fuel Performance Software and "Virtual Reactors"

Most current software used by utilities to simulate the complex inner workings of nuclear reactor cores offer only a low-resolution, two-dimensional view of operations. Soon Phoebe will be joined by VERA (Virtual Environment for Reactor Applications). This large software suite will enable 3-D monitoring of any reactor core element at any time, with unprecedented clarity.

Under development at the Consortium for Advanced Simulation of Light Water Reactors, VERA will be used to simulate situations that would be impractical—and in some cases, catastrophic—to recreate in the real world. These include corrosion-related failures, coolant leaks, and fuel rod vibrations that can lead to dangerous fuel leaks. Running on a high-performance computer, VERA will complete complex simulations in a matter of hours that would require days or weeks with a single processor. VERA's higher-resolution view could help plant operators to better anticipate and respond to concerns.

EPRI Project Engineer Brenden Mervin used Phoebe to test BISON-CASL, the fuel performance component of VERA's virtual reactor. EPRI was well positioned for this task because it developed Falcon, a fuel performance analysis code used by the nuclear industry for the past four decades.

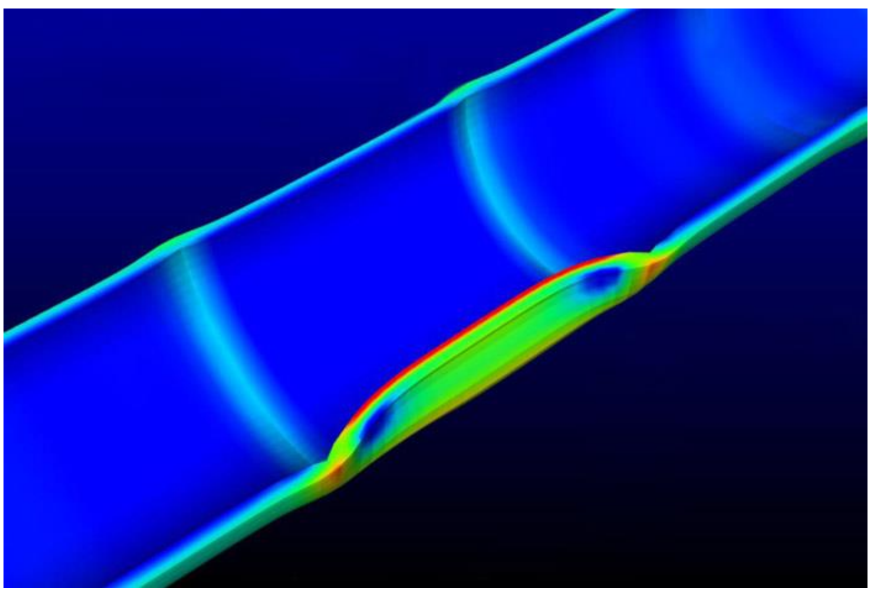
“…and the results come flowing out.”

Mervin tested simple simulations, such as ramping up power of a shortened fuel rod, as well as more complex scenarios—for example, ramping up a full-length rod to full power, shutting it down, and then ramping it back up again. “Ramping back up is when you get the peak stress and when certain failures usually occur,” said Mervin. “We do these simulations to help predict and prevent fuel failures that could cost the utility a million dollars or more.”

EPRI found that BISON-CASL’s calculations for certain cladding stresses in virtual fuel rods were within 0.5% of Falcon’s numbers, affirming the new code’s reliability. “It wasn’t practical to compare BISON-CASL with real-world reactor data because those numbers are not readily available,” said Mervin. “Falcon has been compared and validated against real reactor data for many years, so it’s a good benchmark.”

With BISON-CASL’s 3-D capabilities, researchers will gain a better understanding of what happens to fuel pellets during an accident. Because pellets are not always symmetrical, two-dimensional modeling may overlook some critical features. The 3-D simulations will give researchers a clearer picture of pellet imperfections that can lead to greater stress during power ramps.

EPRI is also tasked with ensuring that VERA is a product that the nuclear industry can use. A development version of VERA will be available this year under a testing and evaluation license. “Will utilities need a supercomputer with 200,000 processors to run VERA?” said Mervin. “That would not be practical. But if they can run it with a small industry-class high-performance computer, we will have succeeded.”



EPRI researchers used Phoebe to run tests on BISON-CASL, a new fuel performance analysis code. In this 3-D BISON-CASL image of a nuclear fuel rod section, the middle part of the section (colored red and green) has a defect known as missing pellet surface that can increase stress on the rod’s outer layer.

Phoebe's Future

EPRI is using high-performance computers for atmospheric modeling and to examine potential carbon capture technologies. Planned applications include the thermal-hydraulic response of containment systems in nuclear plants and software to characterize the degradation and performance of nuclear components.

For Mervin, access to Phoebe provides a huge step forward for simulation and modeling on large-scale projects. "In the past, you might want to run scenarios, but it would take two to four minutes a pop," he said. "If you've got 264 scenarios, that's something you're not going to do. With Phoebe at your fingertips, 264 scenarios is not a problem. You just throw them all in the computer cluster, and the results come flowing out."

Key EPRI Technical Experts

Richard Wachowiak, Alberto Del Rosso, Brenden Mervin

Feature—Solar's New Home on the Grid

New Tools and Methods Work to Integrate Solar on Local Circuits

By Garrett Hering

The Story in Brief

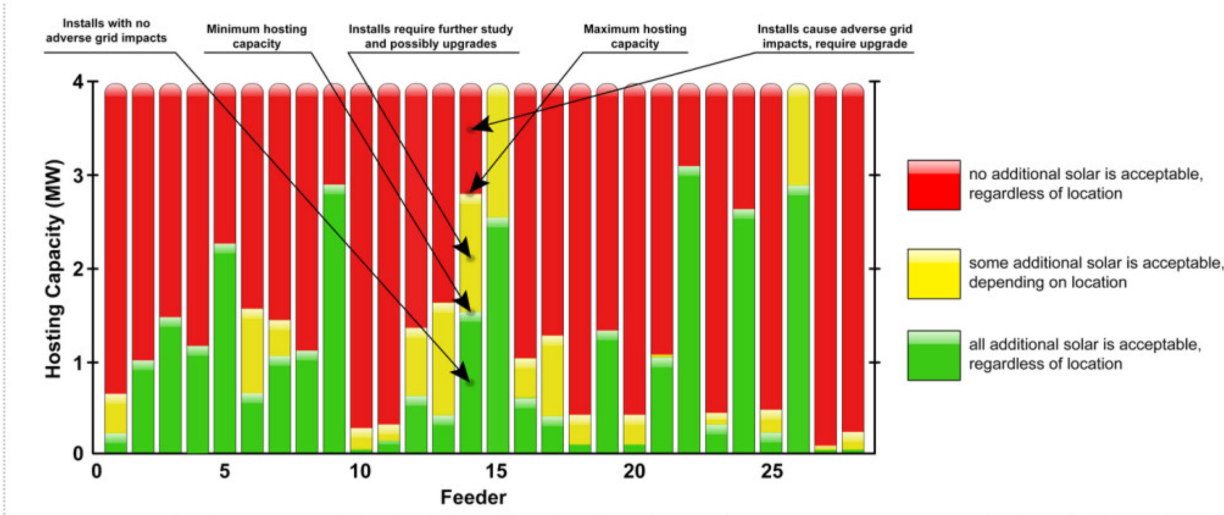
How much solar generation can the grid handle? Using new EPRI tools and methods, utilities can better understand and manage distributed solar—and navigate a changing grid landscape.

In 2015, the International Energy Agency (IEA) expects grid-connected photovoltaic (PV) generation to meet about 1% of annual global electricity demand. This may not seem like much progress since 1954, when scientists at Bell Laboratories demonstrated the world's first practical PV cell by harnessing sunlight to propel a miniature toy Ferris wheel. But that 1%, or 237 billion kilowatt-hours of intermittent solar electricity, is roughly equal to California's current power generation from all sources—and IEA projects this production to more than double by 2020.

Much of PV's rapid emergence occurred during the past decade. Of the 177 gigawatts of PV connected to global power grids at the start of this year, 98% came into service after 2004. Italy, Greece, and Germany relied on PV to meet between 7 and 8% of their electricity use in 2014, according to IEA. In the United States, PV's share nationally remains under 1%, but states such as California, Arizona, New Jersey, and Hawaii have crossed the 1% threshold.

Notwithstanding its gains, PV risks becoming a victim of its own success unless emerging technical challenges are addressed. Key concerns relate to small-scale PV connected to local distribution circuits, or feeders, originally configured for one-way power flow from central station power plants through substations to utility customers. Today, millions of customers with on-site PV systems send electrons in the other direction, requiring network operators to manage two-way power flows and associated impacts.

On certain feeders in Germany, California, and Hawaii, solar generation exceeds demand, prompting some utilities to limit new installations and curtail output from existing ones. Such actions—driven by concerns regarding the affected feeders' and the grid's technical ability to manage power flows from local concentrations of distributed solar installations—have led to conflicts among grid operators, solar development companies, and customers.



Using high-resolution data collected from 35 distribution feeders across the United States, EPRI analyzed each feeder's capacity to host PV. The graphic depicts the unique range of results for 28 of these feeders. In the green area, installations are within a minimum hosting capacity, with no adverse grid impacts. In the yellow region, impacts depend on PV size and location, requiring careful planning to reach a potential maximum hosting capacity—or possibly grid upgrades. In the red zone, grid impacts occur regardless of PV size and location, requiring upgrades. Feeder location, construction design and operating characteristics also influence the results. Overall hosting capacity for the feeders ranged from less than 10% of peak load to more than 100%.

Tools for the Grid's Cutting Edge

These developments raise important questions for the grid as a whole and for particular feeders: How much distributed solar can be integrated effectively? What are the optimal locations and configurations for this solar? Since 2009, EPRI has been developing advanced tools and methods to better understand and manage distributed PV, helping utilities meet the challenges of the distribution grid's changing landscape.

This research is a critical facet of EPRI's Integrated Grid concept, which seeks to tap the full potential of distributed energy resources by incorporating them into grid planning and operations. When distributed resources are integrated effectively, utilities should be able to improve distribution system efficiency and defer costly infrastructure upgrades.

"Many utilities are asking, 'When and where are we going to have problems? What penetration level can we support without issues?' This line of questioning drove the launch of this research," said Jeff Smith, EPRI program manager. "We want to help utilities determine how much PV their feeders and distribution systems can host, as well as the best locations and configurations for that solar to optimize its integration into the grid. These insights will enable them to improve their screening of PV interconnection requests."

Supported by more than a dozen utilities and the U.S. Department of Energy, EPRI's analysis of feeder hosting capacity for PV is built on an expanding pool of detailed solar and electrical data from feeders across the United States. EPRI developed and deployed remote monitoring systems to collect the data—such as solar irradiance, panel temperature, and power output—in one-second intervals. This captures much greater detail than existing hourly monitoring systems and provides a more accurate picture of solar power's characteristics, such as its variability due to moving clouds.

"With this high resolution, we are characterizing the details and the variability," said Smith, adding that the data have attracted the attention of utilities, solar companies, researchers, and the public. EPRI created a public website with continuously updated information on the project.

Several hundred monitoring systems are gathering data on 35 feeders in the geographically diverse service territories of Consolidated Edison, FirstEnergy, National Grid, Progress Energy, Salt River Project, San Diego Gas & Electric, Southern Company, and others. Many of the monitored PV sites are single-module systems installed on utility poles specifically for the research, while others are previously completed grid-connected systems.

In the Southeast, approximately 100 units are installed in the service territories of Southern Company subsidiaries Georgia Power and Alabama Power. Southern Company's interest in the project stems in part from the region's heat and humidity, which cause more clouds and variability in PV output than in other regions.

Detailed Feeder Analyses

Using these data and OpenDSS, EPRI's open-source distribution system software that simulates circuits, EPRI researchers and utility distribution planners and engineers have analyzed the hosting capacity of the 35 feeders. Each detailed analysis characterizes various potential impacts of distributed solar that could limit its reach on a feeder. "The most critical impacts are with voltage and system protection," said Smith.

Fluctuating solar output can change a feeder's voltage faster than regulation equipment can respond, shifting voltage above or below operating limits. In a related project, EPRI is examining the potential of smart inverters to regulate voltage and extend feeder hosting capacity (see sidebar). System protection impacts include disruptions in the coordination of protective devices as well as *unintentional islanding*—when distributed generators continue operating during a power outage, potentially endangering customers and utility workers.

Inverter Intelligence and PV Hosting Capacity

Regulatory authorities increasingly recognize the ability of smart inverters to mitigate feeder voltage variations caused by high levels of PV. In Germany, where more than 98% of the country's one-million-plus PV systems are connected to the distribution grid, system owners are required to retrofit their installations with smart inverters. Last December, California added a smart inverter requirement to its Electric Rule 21, a tariff that defines interconnection, operating, and metering rules for generating facilities on investor-owned utility distribution systems.

EPRI is investigating smart inverter settings that can most effectively increase feeder hosting capacity. An analysis of distribution feeders in New York identified a case in which smart inverters could increase capacity by up to 260%.

"Smart inverters can help when voltage problems are detected," said Jeff Smith, manager of EPRI's PV feeder hosting analysis project. "In most cases, we have found smart inverters to be the least expensive solution."

Each analysis factors those variables that can impact hosting capacity, such as the feeder's construction design and operating characteristics, and the location and type of PV systems, including small and large rooftop arrays and ground-mounted power plants. "In the 35 feeders we have examined to date, there is a wide disparity in hosting capacity, ranging from less than 10 percent of peak load in some cases to more than 100 percent in others," said Smith.

Depending on the PV-related variables, a given feeder can have a range of possible hosting capacities, with minimum and maximum values. As a result, there is no simple answer to the questions, how much distributed PV can the grid handle, and how much can individual feeders handle?

The PV variables also explain why feeders with similar characteristics may have different hosting capacities. For example, EPRI analyzed two similar feeders with minimum hosting capacities of 30% and 16% of peak load. If PV deployment on these feeders were to reach their minimum capacity thresholds, the feeders could still accommodate more PV, depending on the location, size, and configuration of the units.

For each grid impact under investigation, EPRI's detailed feeder analysis grouped millions of possible PV deployment scenarios into three categories:

- Deployments within a minimum hosting capacity, with no adverse grid impacts expected
- Deployments requiring further study and possibly system upgrades, depending on location, size, and configuration of PV units
- Deployments beyond maximum hosting capacity, with adverse grid impacts expected

The participating utilities are using the analyses to support PV interconnection studies and distributed resource mapping and modeling.

EPRI's analyses reveal that there is no simple rule of thumb for determining feeder hosting capacity. This conclusion calls into question the Federal Energy Regulatory Commission's so-called 15 percent rule, which says that PV systems can connect to the grid without interconnection studies as long as aggregrate distributed generation on a feeder does not exceed 15% of its annual peak demand. In 2014, this rule was updated to allow for projects sized 2 megawatts or smaller to connect to circuits without studies if aggregate distributed generation does not exceed 100% of peak demand. Such one-size-fits-all thresholds may not align with actual hosting capacities for specific feeders.

Streamlined Distribution System Analysis

Last year, EPRI developed a streamlined methodology to quickly analyze hosting capacity for an entire distribution system. By extrapolating key findings from detailed feeder analyses, such as optimal locations for PV, the streamlined method equips utilities to estimate hosting capacity for thousands of feeders in a distribution system. When incorporated into utility planning software, it can analyze a feeder's hosting capacity in just minutes, compared with weeks required for the detailed approach. It is meant to complement, rather than replace, detailed analysis, helping to identify when the latter is needed.

Video: Solar Impacts on a Distribution Feeder

Using EPRI's open-source distribution system software, OpenDSS, EPRI produced a video that shows the impact of distributed solar. The simulation portrays how one system variable—the distance of PV from a substation—can impact voltage control on a feeder.

Several utilities are using the streamlined method. For example, EPRI is customizing a streamlined approach for planning engineers at Salt River Project to evaluate all of the Arizona utility's feeders.

Given the growth of distributed solar, such plans may become the state-of-the-art in other states as these hosting capacity tools are used more widely. EPRI has launched a new initiative to help utilities apply the tools for system-wide analysis and incorporate them into their planning software.

Key EPRI Technical Experts

Jeff Smith, Tom Key

First Person—Of Oboes and the Public Interest

Viewing the Electric System as a National Asset… and a Finely Tuned Orchestra

For 35 years, Matthew L. Wald has written extensively about energy for *The New York Times*, *Scientific American*, and *MIT Technology Review*. In April, he began work at the Nuclear Energy Institute as a senior director, policy analysis and strategic planning. In this interview with *EPRI Journal*, Wald discusses how optimizing the power generation mix and taking a national perspective can support a robust grid.

EJ: Wind and solar are growing by leaps and bounds because of tax subsidies, state mandates, and improving technology. Where is this leading the grid?

Matthew Wald

Wald: There is a limit to how much is desirable. Consider this analogy. In February in Washington, the National Symphony Orchestra performed the Eroica Symphony. Just as Beethoven specified, there were two oboes, two flutes, two bassoons, three horns, and timpani. If the price of oboes dropped, would the symphony use more of them? Of course not, because the conductor isn't hiring on price. And as it turns out, the price of oboes is pretty stable, at least in relationship to flutes, bassoons, horns, and timpani.

Unlike the Eroica Symphony, the power grid has an oboe problem. Generation works largely on price in most of the country, and the grid is going through rapid price changes. Renewable energy sources are a bit like oboes; they are useful and distinctive. And they are getting cheaper. But how many can the system use? The grid is threatened by the "silver bullet syndrome." In the popular mind, mandated solar and wind will solve our climate woes. But that idea could lead to more intermittent power than the system can assimilate, as has occurred in Hawaii, and soon in parts of California.

When solar is cheaper than coal, coal will disappear without a trace, like the Soviet Union or Pokemon or disco music or some similar bad idea, right?

Well, maybe.

When the electric system runs well, it is like a symphony. You might really like oboes, but making up a whole orchestra of them is going to cause problems.

EJ: So how is the grid's oboe problem being addressed?

Wald: One answer is taking shape in California, though it's not a perfect answer by any means.

In California, renewable energy is part of the state religion. And because it is not dispatchable—that is, it comes when it wants to, not when you want it to—it is threatening to bump up against grid stability.

California might reorganize itself to handle the problem. At the moment it is taking two sensible steps that are opaque to the public.

One is a mandate for 1,300 megawatts of energy storage. Not megawatt-hours, just megawatts. In other words, not energy, just power. The popular conception is probably that these batteries will charge up at night from excess wind power, or at noon with excess solar power, and deliver the energy when the sun is down and the wind isn't blowing. In fact, they will do hardly any of that. Batteries would have to fall in price by two-thirds to three-quarters to be cost-effective for arbitrage—buying and storing power at off-peak prices and reselling it at higher prices.

Instead they're going to provide a quick jolt of power—what the industry calls "ramping"—when the sun sets and everybody comes home and turns on a flat-screen TV and microwave oven. Then the natural gas plants, which were squeezed off the grid in the sunny mid-day, wake up and get back to work.

"When the electric system runs well, it is like a symphony.
You might really like oboes, but making up a whole orchestra of them
is going to cause problems."

I haven't seen a good estimate of the costs of this approach, but they will be ascribed to all ratepayers. These oboes aren't quite as cheap as they look.

The other step California is taking is to coordinate with utilities in Nevada to adjust fossil generation up and down as renewable generation falls and rises. This is also perfectly sensible. But it guarantees that Nevada can't follow in California's renewable footsteps. Nevada will be the shock absorber for the rise and fall of wind and sun, the elephant jumping on the trampoline across the state line.

EJ: What are the risks?

Wald: If these approaches work, they won't cost anything except some money. If they don't work and outages occur, they will result in a few lost jobs at the top and very unhappy utility customers. As William Congreve, who was born 100 years before Beethoven, wrote, "Hell hath no fury like a voter scorned." Or something like that.

The problem with electricity is that it is generally noted only in its absence. People didn't focus on the particulars of the grid, such as transmission lines, state estimators, and tree trimming, until the great Eastern blackout of 2003. That event led the National Academy of Sciences to conclude that while the price of a kilowatt-hour was 11 cents, the value, when not available, was $5.00.

> "The problem with electricity is that it is generally noted only in its absence. People didn't focus on the particulars of the grid, such as transmission lines, state estimators, and tree trimming, until the great Eastern blackout of 2003."

When the electric system works, it's invisible, but to use a peculiarly literal analogy, it can be the third rail of American politics. In the entire history of the United States, half of the governors whom voters have removed from office were evicted for messing up the power grid. That was Gray Davis in California in 2003. The other was Lynn Frazier in North Dakota in 1921, when electricity was not a factor.

EJ: Aren't renewables essential for a low-carbon, low-emissions system?

Wald: Yes, but achieving lower emissions is not the only goal in our electric system. In fact, there are four goals in conflict, and we could use a better-informed national debate about reconciling them. The goals are a system that is reliable, cheap, clean, and politically appealing. Coal is cheap and reliable; nuclear is reliable and clean; solar and wind are clean and emotionally satisfying. Gas is cheap, sort of clean, and sort of reliable. Hydro is clean and a good dance partner for intermittent clean sources, like wind and sun, but it is not reliable by itself.

You can't draw a Venn diagram where all these things intersect.

> "We're not going to solve these problems until we think of the electric system as a national asset and a national issue, and we make decisions with a broader constituency in mind."

There is, however, an optimum mix. A mix is itself a virtue. In the last 30 years, the electric system has proved durable because it uses a mix. It has struggled through oil shortages, coal shortages, gas shortages, droughts, a generic question about nuclear design, and other blows that have hurt one sector or another of the system. But the system itself has been flexible enough to withstand challenges to its components. This flexibility may become more important as new factors, like carbon control, come into play.

EJ: What is EPRI's role in this conversation?

Wald: EPRI's research indicates that an integrated mix is the best path forward, but this is not high-visibility research.

EPRI, which knows more about the grid than anybody, could be doing more to make electricity visible in ordinary times, to help provide the nail that secures the shoe that saves the horse that saves the battle and keeps the kingdom cooking. EPRI can explain to the public in basic terms how the system works and what's needed to keep it working. Maybe we should re-incarnate Reddy Kilowatt and paint him green.

But talking about these things rationally is hard, because the electric system runs on ingredients that most people don't understand and that become important when you have a lot of renewables. Here's an example: With renewables, power and energy are no longer in tandem. The independent system operators have to cope with power and energy separately, and have to manage voltage support, frequency regulation, and ramping. This stuff is essential but obscure. All of it costs consumers money.

Some of the public ignorance is aided by interest groups. For example, Grid Alternatives, the name of the nonprofit organization that installs solar in low-income communities, implies that rooftop solar frees panel owners from the grid. In fact, debate would be enhanced by a public understanding that the grid is what enables the use of solar. And a robust grid is the only hope for tapping wind.

Expanding the grid will be hard. Most of the opponents are the people who call themselves environmentalists. A better description would be conservationists. They are not really environmentalists. What they favor is stasis. They do not like the industrialization of rural environments for any purpose, from fracking to coal mining to power plant building to transmission. They often show up at hearings on transmission projects as members of the interested public, but interested public can be the opposite of public interest.

EJ: How can power industry stakeholders reframe the conversation to support a robust grid?

Wald: We're not going to solve these problems until we think of the electric system as a national asset and a national issue, and we make decisions with a broader constituency in mind.

A big part of the problem is that if our federal and state governments succeed in their goals, we are guaranteed to fail.

"The industry has to explain that the grid is good for the health of the economy and the environment."

Consider the public service commissions, which are set up to minimize prices and benefit the people of the state. Meeting national goals takes a national perspective. The people who plan and approve power lines need to think like the people who designed the interstate highways, not like the people who build ships in bottles. If the best way to reduce fossil fuel use in New York is to build a windfarm in the Dakotas and a transmission system to move the energy, then stop erecting government structures that say that transmission lines are neighborhood projects, conceived locally for local goals. If public benefit means cutting carbon, then stop making decisions based on the idea that public benefit means minimizing electric rates. And if electricity industry institutions can't get this idea across directly, it may be time to look to all those organizations that purport to support the environment, and drag them to the table to talk about what's needed.

America has prospered so far partly because its layers of government have favored commerce, promoted stability, and allowed cheap transportation. It's time to do that in electricity.

EJ: What is the role of research?

Wald: There are at least four, and two of them contradict.

One is to build and deploy better hardware like phasor monitoring units that help grid operators run transmission lines closer to their limits without increasing the chance of failure. A second is developing software to help operators visualize the system in all its complexity. A third is to demonstrate the benefits of the grid. In 2000, we were hailing the grid as being the greatest invention of the 20th century. Now we have people saying they are virtuous because they are off the grid. The shift is so fast it can make your head spin. The industry has to explain that the grid is good for the health of the economy and the environment.

And the fourth, the contradictory part, is that research has to show that while improvements will come, we already have the technology to make the grid perform better, and we're paying for our reluctance to deploy that technology. From seatbelts to measles vaccines, sometimes the solution is staring us in the face.

The views and opinions in this interview with Matthew Wald do not necessarily reflect the views of the Electric Power Research Institute.

First Person—Building Strong Customer Engagement: More Fun and Less Expensive

Mark Bonsall is General Manager and CEO of Salt River Project (SRP), an Arizona utility that holds J.D. Power's highest ranking for customer satisfaction among utilities in the West. In this interview with *EPRI Journal*, Bonsall discusses how his company engages its customers, the benefits, and the future of customer-utility relationships.

EJ: What is driving SRP to engage more with customers?

Bonsall: It's our dedication to customer satisfaction. At SRP we have developed a culture of service, excellence, and customer respect. Engaging with our customers in this way is obviously better for them, and a lot more fun, rewarding, and interesting for our employees. Plus, we've found it to be substantially more productive and, frankly, less expensive. Lastly, our industry is draped in the public interest. A customer relationship built on excellence and respect makes for more rational dialogue with our customers about the many public issues we face together.


Mark Bonsall

About 20 years ago, we started to question the idea common in the utility business that the least amount of customer communication is the best communication. As we got more of a taste of customer engagement, the more we liked it and found it energizing for employees and customers alike. Over time, it has developed into the norm at SRP.

> "As we got more of a taste of customer engagement, the more we liked it and found it energizing for employees and customers alike."

Internally, we have spent a lot of time figuring out how to relate the many different employees' jobs to customer satisfaction, so that every employee can say, "That's what I do for the customer." One issue, for instance, was figuring out how to relate power plant personnel to customers. Addressing this involved redefining the product we provide to our customers. We consider reliability, rather than electricity, as our number one product. The link between plant personnel and reliability is obvious. So, the customer service metric for personnel in our power plants is the availability rate of their plant.

EJ: What do customers look for in service from SRP, and how do they measure value?

Bonsall: They look for reliability, choice, convenience, conservation opportunities, and information. Through focus groups, surveys, and other customer research, we have found that all these elements enhance the value equation for the customer, and we have developed many products and services in these various areas that customers appreciate.

"We consider reliability, rather than electricity, as our number one product. The link between plant personnel and reliability is obvious. So, the customer service metric for personnel in our power plants is the availability rate of their plant."

That's not the entirety of the value equation, however. There are two other important elements for SRP: our hearty community involvement and our obligation to provide water, because we secure and deliver much of the water supply to central Arizona. The more our customers understand and appreciate these activities, the more they value SRP. This leads to respect, loyalty, and the ability to have those conversations about matters of public interest.

EJ: You mentioned choice as a key element that customers are looking for. SRP offers time-of-use rate plans as well as a pay-as-you-go plan. Describe the rationale for these programs, how they work, and how many customers participate.

Bonsall: Our original Time-of-Use programs, introduced decades ago, had complex pricing structures. We now have about 160,000 customers on SRP's Time-of-Use Price Plan. In time, we realized that many of our one million customers don't want to deal with the complexity of those programs. They want to conserve, but don't want to be bogged down "doing the math." That led us to pilot our EZ-3 Price Plan in 2008. EZ-3 enables customers to save on bills by managing their consumption during three on-peak weekday hours. All they need to do is remember the same three hours year-round. These easier, more convenient programs attracted a whole new population of customers—roughly 125,000.

In-house display and smart cards for SRP's M-Power program

Currently, about 285,000 customers are enrolled in what we call our Time-of-Day Price Plans, which include both EZ-3 and Time-of Use.

In 1999, we launched our pre-pay program called M-Power. Customers decide how much energy to purchase in advance with a smart card and monitor their consumption on a display unit inside the house. The idea was born out of our desire to provide a way for customers to avoid credit problems. We knew that people want to manage their bills responsibly and avoid credit trouble. But with the traditional payment approach, the bill arrives weeks after consumption, and there is absolutely nothing the customer can do about it—the horse has left the barn. It was frustrating for our customers and frustrating for us.

“In all, almost half of our residential customers have chosen some kind of alternative price plan.”

With M-Power, we reversed this business model and found it to be very effective. The in-house display unit is like a gas gauge, but for electricity, so customers can see how much power they have left. This is key to the program’s success because it makes an invisible commodity visible. M-Power gives customers the ability to manage consumption in real time. It turned an entire population of customers—who were previously struggling in their relationship with us—into our most satisfied customers. Approximately 150,000 of our customers are on M-Power. In all, almost half of our residential customers have chosen some kind of alternative price plan.

Choice is a big driver of satisfaction, whether customers exercise it or not. If they don’t switch price plans, they’re happier simply because they made the conscious decision that they didn’t want to change. If they did change and liked it, they’re happier because they made the choice.

EJ: To what extent have these programs reduced peak demand and lowered customer bills?

Bonsall: SRP’s Time-of-Day residential customers see an average annual bill savings of about 4.5%, with many saving even more. Our pre-pay customers on average reduce their power consumption by 12% and their cost by 9%. They also avoid late fees. That is substantial energy conservation and meaningful savings for customers.

“Our research has shown that if customers select just one additional service—whether it’s M-Power, Time-of-Day, Custom Due Date, eBill, large print bills, various text messaging products, or something else—their satisfaction with SRP increases.”

The Time-of-Day Price Plans have reduced our peak demand by about 280–290 megawatts. We estimate that our pre-pay program has yielded an 80-megawatt reduction. Again, these are substantial numbers.

EJ: How have the programs affected or re-shaped customer satisfaction?

Bonsall: Quite dramatically. Customer satisfaction is as high as it’s ever been. Our research has shown that if customers select just one additional service—whether it’s M-Power, Time-of-Day, Custom Due Date, eBill, large print bills, various text messaging products, or something else—their satisfaction with SRP increases. It takes just one additional service to deepen their relationship with us. That’s powerful.

EJ: These programs cost money to develop and launch. How did research inform their design and support your confidence that customers would adopt them?

Bonsall: Research is key. Focus groups and other research mechanisms give us an initial idea of how well a program might be received. Our board has given us authority to create a pilot program on almost any pricing approach we want, and we tend to do that. Two of the three EZ-3 programs are still in the pilot stage, and we’re looking at how they satisfy or don’t satisfy customers.

Customer Engagement at Salt River Project: Key Figures

- Total electric customers: 1,000,000
- Number of customers on Time-of-Day Price Plans: 285,000
- Number of customers on pre-pay program (M-Power): 150,000
- Average annual bill savings, Time-of-Day residential customers: 4.5%
- Average bill savings, pre-pay customers: 9%
- Average reduction in electricity consumption, pre-pay customers: 12%
- Peak demand reduction from Time-of-Day price plans: 280–290 megawatts
- Peak demand reduction from pre-pay program: 80 megawatts

Pilot programs are not particularly expensive to implement. Our flexible billing system helps with that. If they get traction, we move them to full stage. If not, we end the pilot and move on. To overcome customer hesitation with new programs, we often guarantee the customers that they will not be harmed—meaning they won't pay any more than they would under their current price plan. That approach has worked beautifully.

Another example: SRP is working with EPRI on research to understand residential customer preferences for electricity service plans, which include various pricing structures and technologies. With this and other research, we can better understand preferences and market sizes for different types of plans. This helps us to design a diverse set of offerings so customers can choose plans that best fit their needs.

EJ: Most people lack either understanding of or interest in electricity. How has SRP overcome this to engage with customers and enlist them in these programs?

Bonsall: It's a major challenge for utilities to help customers understand electricity service. I've already mentioned one way we try to overcome customers' aversion to dipping their toes in a new pond: With SRP's 90-day risk-free guarantee, they can always return to their original program, if they want to, and we'll pay the difference if their bills increase. But change helps them learn about the service and how to save money in the process.

Providing useful, clear information helps. The most highly visited pages on our website are the customer's daily and hourly usage history on SRP's My Account. Soon we'll provide real-time usage information.

It's difficult but not impossible to explain the complexities of the modern grid. We produced a video that uses whiteboard animation to explain how the SRP grid is changing, why customers with solar still need the grid, and how our different price plans serve different kinds of customers. We found it to be highly effective for both our customers and employees. Customer education is an ongoing process. As you make good information available, customers look at it, become more interested, and their understanding increases.

EJ: What other programs are you considering or launching?

Bonsall: We're redesigning our website to be adaptive to various mobile devices. In addition to energy statistics on our My Account website, we plan to provide users with a cost per day metric, so they can get a better feel for their electricity costs as they go and what their bill will be at the end of each month. This is similar to how people understand their cars' miles per gallon and how much their road trip will cost. With our second generation of smart meters, which we're implementing now, the same meter will have the ability to handle the pre-pay program or any of our Time-of-Day programs. We'll be able to offer pre-pay options and functions across all price plans, along with some demand response capability.

EJ: SRP ranks highest in residential and business customer satisfaction in the West, according to J.D. Power. What are the business impacts?

Bonsall: For the most part, we don't use the J.D. Power awards for advertising. They are, however, wonderful drivers of employee morale because they validate the hard work everybody does to achieve good customer satisfaction. We have cabinets full of J.D. Power statuettes at 16 different locations around the company—including power plants and service centers—and those make a difference for employee morale. We have found the J.D. Power research to be very valuable as a complement to our own, and we use it regularly to inform our service offering decisions.

EJ: How are you advancing your relationships with customers who have rooftop solar?

Bonsall: We're working with EPRI to test advanced inverters, with a plan to put them on 900 to 1,000 houses in our service territory. We're going to test various communications protocols with different inverters to determine how to best integrate solar into our grid and maximize the benefits for both our customers and the grid. The possibilities are substantial. Smart inverters can enable us to dispatch these solar units for various system purposes just like you would a regular generating station.

EJ: What R&D is needed for a better understanding of customer preferences?

Bonsall: I'd like to see research on how to further differentiate, on a retail basis, the basic electricity commodity by reliability, fuel mix, or other variables. For example, customers in our M-Power program have the ability to self-disconnect from the grid and then reconnect. This is a different kind of service that these customers value. There may be other ways to provide that ability.

The same applies to fuel mix. Are you getting regular, high test, or premium? What proportions of solar, natural gas, and coal do you want in your mix? Having these choices could favorably impact customer satisfaction. But how would a power company implement this? It's an interesting question with profound operational implications, because it involves building a generation mix with variable costs driven by customer preferences, rather than a one-size-fits-all, least-cost generation mix.

EJ: With respect to customer service and engagement, what particular areas does SRP's long-term business strategy target?

Bonsall: Communications capabilities will be profoundly important in the future. Our smart meters can link with thermostats and other devices, and are connected in a radio network, backed up by an extensive fiber system. This combination enables substantial new product and service development, which is very exciting to me.

EJ: Your look in the crystal ball: Describe the utility-customer relationship in 10 years.

Bonsall: The customer relationship will be increasingly diverse and customized. Some will want least cost while others want premium. Some will want to pay as they go, while others want monthly bills. Some will be both buyers and sellers of electricity. Some will want access to all utility services while others want partial services. The ability to communicate well is going to be the key to navigating this transition.

Wired In—The Integrated Grid: A Regulator's Perspective

In 15 years, we may not recognize much about utility regulation as it is today. Innovative technologies that could revolutionize how we use and consume electricity are already in play. Because much of this modernization is taking place at the distribution level, state commissioners have taken a keen interest in EPRI's Integrated Grid research on tools to realize the full value of a transformed grid.

Lisa Edgar,
President, National Association
of Regulatory Utility Commissioners

At the last two winter meetings of the National Association of Regulatory Utility Commissioners (NARUC), EPRI officials presented their latest reports. Importantly, the Integrated Grid concept embraces the diversity of our nation's electricity industry. As state regulators are fond of saying, there is no one-size-fits-all solution to utility planning. Any efforts to modernize the system must take this into account.

The concept fits nicely with my theme as NARUC President—Coast to Coast: Consumers, Convergence, Change. As various states and regions address the many challenges ahead, different solutions and trends will emerge. At its core, though, the Integrated Grid must maintain and improve reliability and provide ample benefits for the customers served and costs incurred.

As utility regulators, our job is to help bring some certainty into this rapidly changing industry—to ensure safety, reliability, customer affordability, environmental sustainability, and financial viability. This applies to all customer types, from residential to large industrial, traditional utilities, and newly emerging technologies and enterprises.

Our unique reality is that we have to regulate in the public interest while our systems are in transformation. We must consider—and even encourage—the changes that are here and those that are coming. We must add value without adding undue risk.

And that's hard. But I know, coast to coast, we are up to the challenges. We must be adaptive in our processes, recognize and appreciate our regional differences, share ideas, and stay true to our state issues and mandates. This is why so many NARUC members are intrigued by EPRI's Integrated Grid project.

As the saying goes, "Timing is everything," and the EPRI Integrated Grid research could not be more timely. States across the country are asking questions about distributed generation and its potential impacts on the grid, consumers, and the utility business. Utilities continue to roll out smart meters to provide consumers with more control over their energy use. At the same time, interest in solar has surged, and many utilities are testing the impacts of widespread integration into the grid. Also, studies on microgrids, energy storage, and electric vehicles are ongoing—potentially resulting in new demands on the electricity system.

Clearly change is upon us, and regulators are eager to see the results of this ambitious EPRI program. It is important that these technologies, as promising as they appear, be utilized in a manner that both protects consumers from unexpected rate increases and improves service. In these days of social media and instant communication, consumers have more information about their electric service than ever before. Many want information and choices, and it is the regulator's job to make sure that consumers of all types benefit from these changes.

It is also incumbent upon EPRI and the utility industry to communicate with consumers throughout this project. We must all reach out and explain the benefits and costs associated with the changes we see. Consumers expect and deserve a two-way conversation.

State regulators are excited about the future. There is no better time to be involved in this sector than right now. The decisions we make over the next few years will have lasting implications. Let's use this opportunity to work together and focus on making the Integrated Grid work for all.

Technology At Work

Protecting City Fish and Country Fish

By Chris Warren

It would be difficult to imagine power plant locations more opposite than the East River in downtown Manhattan and the Mobile River in rural Alabama. Con Edison's East River Generating Station operates in one of the densest urban landscapes on the globe. In contrast, Alabama Power's James M. Barry Electric Generating Plant operates in a rural environment in the Deep South.

Although in vastly different settings, the two plants recently shared something important: the need to reduce potential harm to aquatic life from the use of river water for cooling while simultaneously protecting their cooling water intakes from clogging by waterborne debris and biofouling. Both plants are preparing to comply with new U.S. Environmental Protection Agency rules on intake structures for existing facilities, finalized last August. Con Edison also must comply with requirements of a state-issued permit allowing continued operations without a cost-prohibitive retrofit of a closed-cycle cooling system. Both utilities turned to EPRI, a research leader in the area, for assistance.

Manhattan-Style Fish Protection

For two decades starting in 1989, Con Edison's East River Generating Station relied on traveling water screens to prevent debris from being swept into its cooling water intake structure and potentially shutting down the plant. In 2009, the state required Con Edison to upgrade its screens to maintain its State Pollution Discharge Elimination System permit.

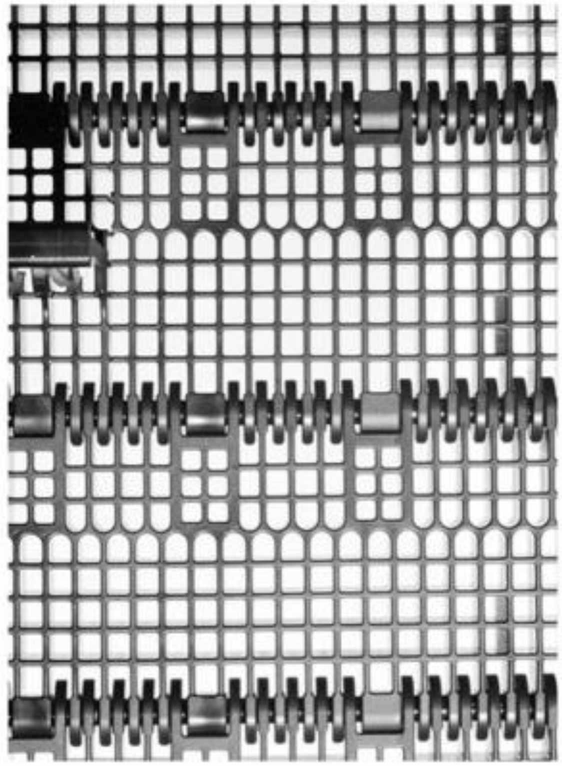
For years, EPRI has conducted collaborative fish protection research as part of its mission to make electricity more environmentally responsible. Building on knowledge from these efforts, EPRI worked on research with Con Edison to optimize the utility's new fish protection–modified traveling water screens and fish return system. Prior to modification, the screens rotated intermittently from underwater to the surface, where collected debris and fish were washed into a combined trough for return to the river. Through several iterations, Con Edison and EPRI worked together to make the screens more fish-friendly, including using woven mesh metal screens that are not as abrasive for the fish, collecting fish in buckets on the screens, and continuously rotating the screen so fish can be removed quickly. As the rotating system raises the fish, they are rinsed from the screens with a low-pressure wash system into a trough that returns them to the river. In addition, when fish eggs and larvae are present during spring and summer, finer mesh screens are used to prevent entry into the plant's cooling system. They are also rinsed from the screens and returned to the river to continue their growing phases. Because the system is significantly safer for aquatic life, Con Edison expects to achieve compliance with its permit after it completes a monitoring plan to demonstrate the new system's performance.

Southern-Style Fish Protection

As with Con Edison, optimizing fish protection was at the core of EPRI's collaboration with Alabama Power, which also installed fish protection–modified traveling water screens at its Barry Electric Generating Plant. Instead of metal screens, the utility opted for a version manufactured by Hydrolox and made with a much lighter molded polymer. The utility faced a severe debris problem, and the polymer screen's design and material offered the potential to shed sticks and protect aquatic life more effectively.

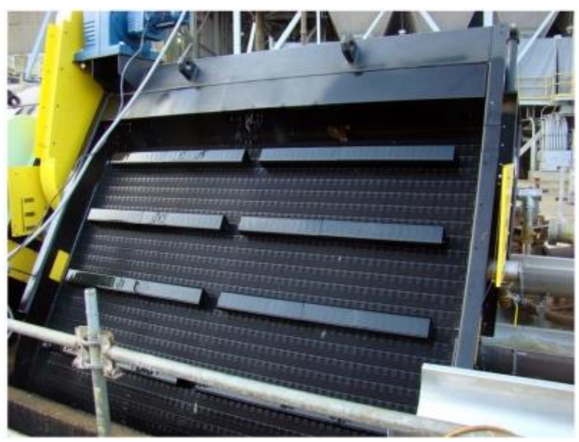
Barry's cooling water intake structure was the first to complete a retrofit using this technology. EPRI and Alabama Power conducted a research study to gauge the screen's debris-handling and fish protection performance, providing a model for future analyses. Alabama Power's parent Southern Company funded the study, along with Dairyland Power, Luminant, and Omaha Public Power District. "This was an excellent example of how EPRI's collaborative R&D model can demonstrate a new screening technology," said EPRI Technical Executive Doug Dixon.

Con Edison installs the first of five new fish protection–modified traveling water screens at its East River Generating Station in 2012.



A close-up shot of the polymer mesh screen used at Plant Barry. Photo courtesy of Intralox.

In this aquarium facility at the Barry plant, fish are held for 24 to 48 hours for survival testing.



A fish protection–modified traveling water screen at Alabama Power's Barry Electric Generating Plant. The long, narrow rectangular structures are buckets that help return fish to the river.

For their fish protection work, both Con Edison and Alabama Power received EPRI Technology Transfer awards.

Key EPRI Technical Experts

Doug Dixon

Technology At Work

MISO Taps EPRI Software to Envision the Future

By Chris Warren

Five years ago, John Lawhorn and his staff at the Midwest Independent System Operator (MISO) faced a challenging question: How would the U.S. Environmental Protection Agency's (EPA) proposed Mercury and Air Toxics Standards impact electric companies and other stakeholders in the 11 states where MISO was responsible for delivering reliable, cost-effective power? (The grid operator MISO has since expanded to 15 states, and is now called the Midcontinent Independent System Operator.) Their prediction that the rules would lead to the retirement of about 12,000 megawatts of coal-fired generation capacity was remarkably accurate. To date, about 10,000 megawatts have been retired.

Lawhorn isn't psychic. Rather, he relied on the EPRI software Electric Generation Expansion Analysis System, or EGEAS, which has become essential for his policy and economic analysis work at MISO. "We run it every day and have trained 15 people to use it since first obtaining it seven years ago," said Lawhorn, who received a 2014 EPRI Technology Transfer Award.

Electric system planners like EGEAS because it can analyze many complex, multi-year resource planning scenarios in just minutes—much faster than similar software.

EPRI first developed EGEAS in the early 1980s and has continually enhanced it with new features. Later this year EPRI will release version 11, funded in part by MISO. EPRI licenses third-party software firms to provide training and support for EGEAS users.

A Key Tool for Transmission Planning

EGEAS analysis is step one in MISO's annual seven-step planning process to ensure system reliability and compliance with state and federal requirements. MISO and its stakeholders typically identify four scenarios to reflect evolving policies by analyzing load forecasts, fuel prices, demand response, energy efficiency, renewable energy penetration, and other variables. They run the scenarios through EGEAS and use the results to support generation capacity planning, power plant siting, and assessing costs and power flows in the system.

For example, to help determine new power plants needed to meet electricity demand in five years, EGEAS can project future load, cost and performance of various generation technologies, and cost of environmental regulatory compliance—and then provide guidance on the most economically efficient power plant construction.

Without EGEAS, long-term generation planning would require MISO to gather information that electric companies would rather not supply. "Due to business confidentiality, the generators typically will not disclose their generation plans," said Lawhorn. "EGEAS allows MISO to set the needed generation forecast without that information."

With respect to state and federal policies, MISO uses EGEAS to analyze cost implications for stakeholders such as electric companies, regulators, independent power producers, and power marketers. A recent assessment of the potential impact of the EPA's Clean Power Plan, which seeks to limit carbon dioxide emissions from existing power plants, indicated the possible retirement of another 14,000 megawatts of coal plants.

Because of the tool's demonstrated value, MISO has suggested that regulators and electric companies in its territory use it for their own analyses. Doing so, said Lawhorn, will make communication easier. "When you start talking regulations, it's helpful if everyone speaks the same language," he said. Of the 15 state public utility commissions in MISO's territory, 10 currently use EGEAS.

Users Around the World

Electric companies and regulators in Egypt, Israel, Malaysia, Saudi Arabia, Taiwan, and Thailand have used EGEAS for analyses, and one Asian company used EGEAS to plan power plant construction to best support regional economic development.

While MISO has devoted substantial resources to train its personnel to use EGEAS, such investment is not always required for significant benefits. "We know of a small utility where one person is responsible for generation planning," said Adam Diamant, a technical executive in EPRI's Energy and Environmental Analysis Program. "And he has become a powerful EGEAS user, too."

Key EPRI Technical Experts

Adam Diamant

In The Field

Rise of the Robo-Houses

Machines Replace People to Provide Unprecedented Precision in Energy Efficiency Assessments

By Robert Ito

A six-year, first-of-its-kind study comparing the energy efficiency of three experimental houses has yielded valuable insights for utilities regarding the relative effectiveness of various technologies. EPRI, Tennessee Valley Authority (TVA), and Oak Ridge National Laboratory collaborated on the project in a suburb of Knoxville, Tennessee.

One of the experimental "robo-houses" in the energy efficiency study

Houses That Simulate Human Behavior… and Heat

In 2009, TVA built three houses, outfitting each to provide a different level of energy efficiency. The Builder house, the project's control, was constructed to standard local building codes and looked much like other Tennessee Valley houses. The Retrofit house was equipped with currently available energy-efficient technologies, such as programmable thermostats and Energy Star appliances. The High-Performance house incorporated the latest construction technologies, with elements such as rooftop solar, six-inch-thick walls, and triple-pane windows.

To ensure accurate comparison of the houses' energy efficiency, EPRI and Oak Ridge National Laboratory equipped them with automated systems to replicate human domestic behavior. Lights and TVs in the three houses were programmed to simultaneously switch on and off by themselves. Robotic arms opened and closed refrigerator doors at the same time in each house. An identical load of towels spun in each dryer. EPRI created a system to simulate the breathing, sweating, and heat output of three humans, replicating significant factors affecting energy consumption (see sidebar).

In contrast with previous residential energy efficiency demonstration projects in occupied residences with variable human behavior, the EPRI study created identical behaviors in each structure, enabling efficiency and cost comparisons with unprecedented accuracy.

Lessons for Utilities and Consumers

After three years of operation, the Retrofit house used 40% less energy per year than the Builder house, and the High-Performance house used 66% less than the Builder house. The Builder house's annual energy cost was $1,868, compared to just $320 a year for the High-Performance house.

Utilities can use performance results of various devices to determine if they are ready for deployment. Among the most effective energy savers was a variable-speed heat pump water heater, which proved more efficient and consistent than the solar thermal system for water heating. The use of ducts in unconditioned attics proved to be large energy drains.

A key lesson for builders: The biggest energy savings were provided by thicker walls and additional insulation. For residents, the biggest cost savings were provided by weather stripping and replacing incandescent bulbs with fluorescent bulbs.

The occupancy simulation protocol designed for the experiment will likely serve as a model for future energy efficiency research. By eliminating the variable of human behavior, researchers gained a much clearer picture of how various factors can impact efficiency of residential energy use. “You really couldn’t do this in a lab, because we’re testing the building materials, too,” said EPRI Engineer Chuck Thomas. “This research gives us a better picture not only of the efficiency of the equipment, but also the efficiency of the entire home.”

Simulating Body Heat and Human Sweat with Something He Built in His Garage

EPRI Engineer Chuck Thomas may have been inspired by the 1980s television series *MacGyver* as he considered how to ensure a precise comparison of the experimental houses’ energy efficiency. He recognized that even the relatively small amount of heat and humidity generated by humans impacts a structure’s interior and the energy required to heat and cool it. The solution: Build a device to simulate heat and sweat output for a family of three, and deploy it in the three houses.

This device, built by EPRI’s Chuck Thomas, simulates human heat and sweat.

After first considering a device constructed by a University of Central Florida laboratory built with a cast iron skillet and an electric hot plate, Thomas decided to build his own with elements purchased from a local Home Depot. Working in his garage, he equipped a two-and-a-half-gallon water heater with water level and flow rate sensors, wrapped it in insulation, and placed it inside a 50-gallon waste container. “It kind of looks like a garbage can, but there was a lot of work that went into it,” Thomas said.

By cycling the heating element at carefully controlled rates, the device can release through a pipe precise ratios of moisture and heat. In this way, it can simulate varying numbers of occupants over 24 hours. “Have you ever wondered what the sweat and breath of three average human beings would feel like if you pumped it through a 1.5-inch-diameter pipe?” said Thomas. “If you put your hand over the pipe, it would burn you.”

Key EPRI Technical Experts

Chuck Thomas

In The Field

A Magic Glove

Flexible Probe Lends Hand to Crack Detection in Heat Recovery Steam Generators

By Garrett Hering

During a meeting with a colleague from Southwest Research Institute (SwRI) in 2011, EPRI's Stan Walker was trying to imagine the perfect tool for detecting cracks in the most vulnerable, hardest-to-reach nooks and crannies at power plants.

A glove equipped with the flexible eddy current array probe is used to inspect tube-to-header welds in a heat recovery steam generator.

In heat recovery steam generators at combined-cycle–natural-gas plants, for instance, joints where steel tubes are welded to cylindrical headers have proven especially challenging to search for surface defects using conventional means. Many other power plant components and weld orientations with various surface geometries make it difficult to design a suitable inspection fixture.

Walker recalled how he and his colleague arrived at a solution: "I said, 'If we could just make a tool that moves like my finger, able to move around a weld joint and maintain contact the whole time.' And he added, 'Now, if we can just make a flexible probe and put it on the end of your finger or glove.'"

Glove-Mounted Probe for Manual Inspections

From this brainstorm, SwRI and EPRI developed the flexible eddy current probe, which attaches to the finger of a glove and is designed specifically—and literally—for manual screening. The probe is based on printed circuit board technology using spiral metal coils embedded in a flexible substrate. The coils identify cracks using magnetic current fields.

"The probe is like a thick piece of scotch tape, not hard," explained Walker. "At a power plant, you normally use gloves anyway, so we first placed the probe on a glove finger."

The examiner places the finger-mounted probe on an area to be inspected, and finger pressure conforms it to the surface geometry. For example, the operator can bend his finger to inspect the circumference of a weld joint. The flexible probe connects via a small, rigid printed circuit board interface in the glove's palm to a portable instrument that connects to a computer for viewing test results.

Typical eddy current probes are rigid, handheld devices shaped like a pencil or rectangular box. They are widely used to find defects in flat metal surfaces at power plants and in the aerospace, automotive, and chemical industries. But for weld joints and other complex geometries, such devices are often inadequate. Examinations are sometimes conducted with liquid penetrant, which can be messy in tight spaces.

Crack Detection in Field Demonstrations

Last year in field tests on heat recovery steam generators at four combined-cycle–natural-gas power plants, EPRI and SwRI demonstrated how the glove probe literally lends a hand in crack detection.

"In an examination at Southern Company's Rowan Plant in North Carolina, we found three cracks plant staff had already discovered and one additional crack they didn't see," said Walker. "They wanted to know about other applications, so we demonstrated it on combustion turbine buckets, compressor blades, and the turbine rotor."

Based on the field tests, improvements have been made ahead of the probe's planned 2015 commercial launch. The flexible probe and printed circuit board, originally placed in a pocket sewn into the glove, are now attached with Velcro. The commercial product—which SwRI has been licensed to sell—will include all components for portable use, including a rugged tablet computer.

In addition to the glove probe, SwRI is working under contract with EPRI to interface the flexible probe with other small, portable instruments. The two companies also are evaluating designs for a robotic probe with two extendable arms to examine areas where fingers cannot reach. Called the Mechanized Over/Under Slung ET, or MOUSE, this version will travel on magnetic, motor-driven wheels along the underside of headers.

"It's a low-cost tool, and we are still finding all these new things we can do with it," said Walker.

Key EPRI Technical Experts

Stan Walker

In Development

Computerizing Verification Tasks

A Promising New Way to Reduce Radiation Exposure to Nuclear Workers

By Robert Ito

EPRI is developing a prototype system using tablet computers equipped with camera or video connected to databases to verify the open-or-closed status of a valve or switch in a nuclear power plant. Testing began last June at the Tennessee Valley Authority's Bellefonte Nuclear Generating Station, and a second testing phase is in progress. If successful, the device will perform vital verification tasks now done by humans—saving time, reducing human error and radiation dose, and improving plant reliability.


A plant technician uses the tablet technology to verify the completion of a valve alignment.

Independent Verification in the Hands of Machines

Since the dawn of the nuclear power industry, plant workers have been tasked with double-checking the work of their colleagues. In a typical scenario, when a worker opens or closes a valve, an independent verifier follows and rechecks everything, ensuring that the first worker didn't make any mistakes. With roots in the U.S. nuclear navy, such independent verification has long been a core tenet of the industry's safety culture.

There are potential downsides to human verification. Every check pulls a worker away from another job, with possible radiation exposure. People are prone to attention lapses, particularly during repetitive verification tasks, and may be reluctant to question a trusted colleague's work.

But what if a handheld tablet computer could do the work of a human verifier? To investigate this question, EPRI developed a prototype. Here's how it works. The user performs a procedure—such as closing a valve—and at each step photographs the component with the tablet's digital camera. The tablet's software compares each photograph with a laser-scanned three-dimensional model of the component, recording and detecting whether the component is open or closed. As the software determines that a given step in the procedure is completed, it allows the user to move to the next step.

Embedded in the procedure is a fully independent verification that both avoids the need to dispatch a second person later and catches rare-but-inevitable human errors for better reliability. Because the procedure is driven by tablet software, no paperwork is required.

At the Bellefonte station, researchers tested procedures on gate valves, butterfly valves, lighting panel switches, and motor control center breakers. In each procedure, the prototype accurately verified the component's status.

Refining the Verifier

EPRI is conducting a second test phase at Duke Energy's Catawba Nuclear Station in 2015 to investigate the use of video. The verifier moves the tablet's video camera 360 degrees around a component and processes the video into a three-dimensional representation of the component. The software compares this image with the reference model to determine the component's open or closed status.

Also, researchers plan to make the system fully portable and self-contained, eliminating the need to be docked to a separate laptop to run the verification software. They want to investigate the economic feasibility of building a digital library of three-dimensional reference shapes of thousands of plant components potentially requiring verification.

If a workable device is commercialized, human verifiers will be among the key beneficiaries. "We respect radiation," said David Ziebell, EPRI senior technical leader. "If we send somebody out to containment to do a valve alignment, that person's going to absorb dose. If we send a second person out to verify, that person's also going to absorb dose. If we can reduce that, that's a win for all involved."

Key EPRI Technical Experts

David Ziebell

In Development

A New Approach to Predict Life of Corrosion-Pitted Turbine Blades

By Garrett Hering

During power plant shutdown and layup modes, steam turbines are exposed to oxygen, and the resulting corrosion can form tiny pits on turbine blades at random locations. Over years of operation, these pits can act as initiation sites for cracks that can destroy one or more blades or even entire turbines. In worst-case scenarios, such damage can force generation units out of service.


Corrosion on a turbine

Significant knowledge of corrosion-related risks has been compiled through decades of operational experience and research on turbine pitting and cracking. Yet until recently there has been no way to help predict the life expectancy of blades with pitting.

Since 2010, EPRI has led an international team of experts—including the UK's National Physical Laboratory, Austria's University of Natural Resources, and U.S.-based SimuTech Group—to develop the industry's first methodology for such predictions. EPRI's Technology Innovation Program funded the effort.

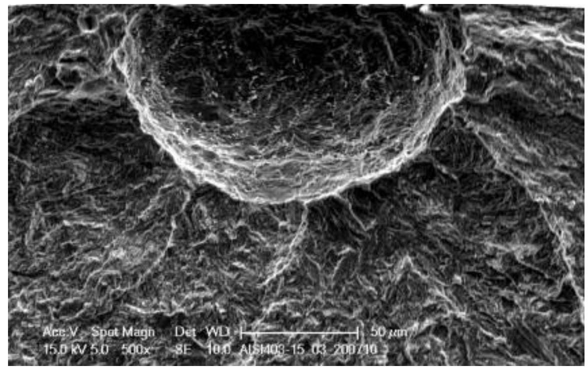
"While significant research has been undertaken on preventing corrosion damage and crack growth, we focused on crack initiation—when a pit morphs into a crack—because there has been very little work on this," said EPRI Technical Executive David Gandy. "The key question we were trying to answer was, when an operator discovers a turbine blade with pitting, how much life does it have left?"

Plotting Pits and Cracks

At the University of Natural Resources in Vienna, Austria, the research team conducted ultrasonic fatigue tests on turbine blade specimens with artificially generated pits and cracks. Using a special test chamber, the team accelerated the corrosion process so that it took less than 14 hours for the specimens to reach the end of their useful life. Compared to traditional field testing, this enabled researchers to more quickly compile and process data on how the material weakened. The tests allowed the team to understand the relationship between corrosion pits and subsequent cracking on two common types of steel blades when subjected to various operational conditions and stresses.

"These tests enabled a rapid assessment of fatigue damage," said Gandy. "Performing standard fatigue tests in a corrosive environment can take up to a year or longer. We were able to do our testing in less than a week in most cases."

Plotting pit size against the stress level reveals a definitive line indicating safe operation. “The research showed that if you are below the line, where pits and the stresses are small, then blade failure is not a concern,” said Gandy. “But above the line, the blade is in a more risky condition.”



This 85-micrometer pit in stainless steel turbine blade material was created in a laboratory.

Applying to Industry

Using the test results, the researchers devised a methodology that operators can use to help predict when blades are at risk of fatigue failure, given a specific size of corrosion pit. Key steps are:

- Inspecting blades for pitting by measuring and documenting the location of deep pits
- Calculating stresses
- Correlating stresses with the location of specific pits and diagramming the results
- Determining an appropriate safety margin for continued operation
- Scheduling blade replacements in advance

The team demonstrated the methodology on a 600-megawatt fossil-fuel turbine with pitted blades, predicting the risk of continued operation under different operating scenarios.

EPRI incorporated the methodology into a beta-version spreadsheet that operators can use to predict blade failure. In 2015, EPRI plans to expand this spreadsheet into a software program.

Key EPRI Technical Experts

David Gandy, Steve Hesler

Innovation

An Innovative Material for Nuclear Plants

EPRI Demonstrates Alloy That Could Reduce Plant Workers' Cobalt Radiation Exposure by up to 20%

By Michael Matz

Culminating almost 30 years of materials research, EPRI has demonstrated in the laboratory a new alloy for hardfacing select nuclear plant components to improve their resistance to wear and *galling*, a form of damage in which material is extracted from the component's surface. Use of this alloy, called NitroMaxx, will also help reduce worker radiation exposure. EPRI is seeking to patent NitroMaxx and in 2015 will continue to characterize its properties through laboratory and field testing.

A Tale of Three Hardfacing Alloys: Stellite, NOREM, and NitroMaxx

Power plant components are typically made by forging or casting metals and then applying surface treatments called *hardfacings* to provide resistance to wear and galling. In nuclear plants, cobalt-based hardfacing alloys, such as Stellite, have been used for many years because of their weldability and wear resistance. But breakdown of such materials releases elemental cobalt, which is transported through coolant flow streams into the fuel core where it is irradiated and converted to radioactive cobalt-60. This circulates back to other parts of the plant, resulting in a major source of worker radiation exposure.

Stainless steel–based hardfacing alloys have the potential to reduce cobalt-related radiation in nuclear plants by 15–20%. In the 1980s, EPRI developed such a material, called NOREM. But this and similar alloys are difficult to apply through welding and are susceptible to significant galling at temperatures above 200°C. When galling develops on the surface of a valve seat, for example, the valve may seize—potentially leading to plant safety risks. Since the 1980s, the nuclear industry has evaluated more than two dozen cobalt-free hardfacing alloys, but none has demonstrated adequate wear and galling resistance—until EPRI's stainless steel–based NitroMaxx.

NitroMaxx grew out of four years of research and development to characterize the structural properties and degradation mechanisms of existing cobalt- and stainless steel–based alloys. In particular, EPRI researchers gained a better understanding of how galling develops. Through this work, the team figured out how to create a durable alloy that could effectively resist galling and wear.

To design NitroMaxx, researchers super-saturated the matrix of a stainless steel alloy with nitrogen—an approach that has long been known to increase hardness. One key to NitroMaxx's galling resistance is its *high strain-hardening rate*—a property that allows the alloy to become harder at the surface when subjected to strain.

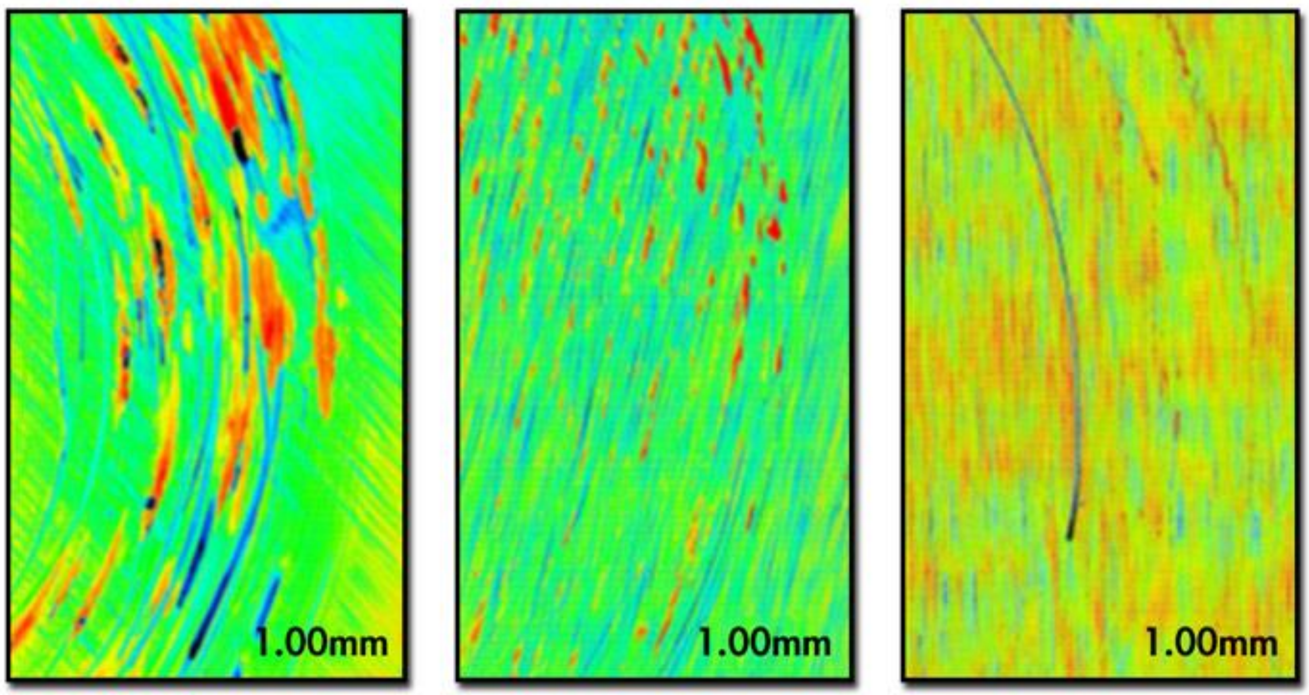
The manufacture of NitroMaxx is made possible through the use of powder metallurgy and hot isostatic pressing, which involve heating and consolidating metal powders. With powder metallurgy, manufacturers can optimize an alloy's composition and structure with great precision, allowing the application of hardfacing alloys to components without welding.

NitroMaxx has potential application on many nuclear plant components, including valves, gates, and certain reactor pressure vessel internals.

From the Laboratory to the Field

In laboratory tests, EPRI researchers subjected samples of NitroMaxx, Stellite, NOREM, and other alloys to various sliding wear and galling tests at a typical nuclear plant operating temperature (343°C). Using a laser microscope to examine the resulting degradation, they determined that NitroMaxx's resistance to galling and wear was much greater than NOREM's and similar to Stellite's (see images below).

In 2015, EPRI is performing additional tests in simulated nuclear plant environments to gauge NitroMaxx's durability, corrosion resistance, and performance during temperature and pressure cycles. The next step is to work with utilities and manufacturers to field-test components in noncritical plant applications.



Laser micrographs of NOREM (left), Stellite (center), and NitroMaxx (right) samples subjected to the same stresses at plant operating temperature reveal almost no galling (indicated by the thick streaks) for NitroMaxx and significant galling on NOREM.

Key EPRI Technical Experts

David Gandy

Innovation

Learning from Fukushima

Analyses with EPRI Software Yield Critical Lessons to Help Improve Nuclear Plant Design and Accident Response Guidelines

By Chris Warren

As the accident at Japan's Fukushima Daiichi nuclear power plant was still unfolding four years ago, EPRI technical staff turned to a familiar tool to better understand what was occurring. The Modular Accident Analysis Program, or MAAP, software is used to quickly analyze the progression of events during an accident. "Severe accidents are complicated, and it's helpful to have a code like MAAP that can capture the many possibilities without taking a long time to run," said EPRI Fellow Rosa Yang.

Unlike other codes, MAAP runs faster than accidents progress, so it can be used during an event to guide emergency responders. Originally developed after the 1979 Three Mile Island accident and now in its fifth version, the tool has informed changes to industry guidelines that plant operators use to respond to accidents. Operators also use MAAP to identify priority safety concerns to address, helping to prevent accidents.

Lessons for the Global Nuclear Industry

Because Fukushima lost power soon after the event started, there are virtually no plant data from the accident's early hours—which would be critical for understanding its progression. MAAP has filled in many of those gaps. In the years since the accident, EPRI has used MAAP to help plant operators and policymakers better understand what took place during those initial hours. These analyses have yielded critical lessons to help the global nuclear industry improve plant design and accident response guidelines.

Clean-up of rubble at Fukushima Unit No. 3 in preparation for future fuel debris removal

The loss of power during the accident made it impossible to deploy cooling measures to prevent reactor meltdowns and radioactive material releases. One lesson from MAAP: Plant operators need a detailed strategy for using portable equipment, such as pumps to inject cooling water into hot reactors. Such strategies should include procedures and guidelines that "buy time" for plant operators to retrieve the equipment. For boiling water reactor nuclear plants such as Fukushima, this might involve devising a way for the plant's existing reactor core isolation cooling system to function temporarily after a loss of power.

"You can reconfigure plants to make existing equipment available long enough so workers can go to a protected warehouse and get portable pumps or power supplies for a sustained recovery," said EPRI Principal Technical Leader Rick Wachowiak. "Nearly all nuclear utilities in the United States use MAAP analyses to develop the portable equipment plans they submit to regulators."

EPRI's MAAP analyses of Fukushima also bolstered the growing industry consensus that adding water to a damaged reactor core is essential to prevent the release of radioactive material.

Decommissioning and Lasting Change

Tokyo Electric Power Company is using MAAP results and data collected from the site to accurately estimate where the Fukushima reactor cores are physically located now and to determine how extensively they are damaged—vital information for plant decommissioning.

Lessons from the MAAP Fukushima analyses have been incorporated into EPRI's severe accident management guidelines, which help plant operators prepare for and navigate accidents. Since Fukushima, plant operators and regulators around the world have aggressively sought to better understand plant vulnerabilities. They have used MAAP to evaluate the effectiveness of new safety equipment and procedures and to conduct plant stress tests.

MAAP itself has been updated based on Fukushima lessons. For example, the latest version includes modeling options to better understand the use of vents to reduce reactor core pressure during an accident.

"All nuclear plants worldwide are safer today than before March 2011 because of all we have learned from Fukushima," said Yang.

Key EPRI Technical Experts

Richard Wachowiak, Rosa Yang, Kelli Voelsing

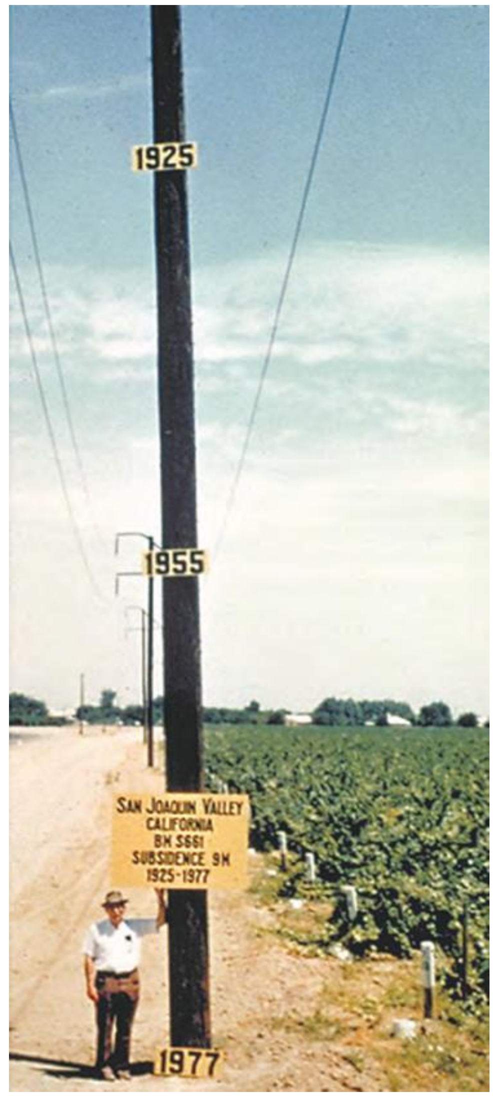
Shaping the Future

Delving into Groundwater

New EPRI Center to Spur Collaboration on Vital Groundwater Issues

By Chris Warren

The ground is sinking beneath our feet. That's not the beginning of a science fiction novel. In certain locations, it is a literal fact. Take a look at a photo (right) from California's San Joaquin Valley. It's startling to see that the ground level has dropped by as much as 35 feet since the 1920s. This phenomenon, known as *subsidence*, is due largely to groundwater being withdrawn faster than it can be replenished by rainfall.



Subsidence largely due to groundwater withdrawals in California's San Joaquin Valley

Groundwater—the water that fills underground spaces in soil, rock, and sand—is critically important to society, including the power industry. Currently, 82 billion gallons of groundwater are used each day in the United States. It supplies drinking water to more than half of the population. Based on data from the U.S. Geological Survey, the great majority of groundwater withdrawals are for agricultural irrigation.

While the power industry relies primarily on surface water to cool power plants and for other purposes, it still uses about two billion gallons of groundwater daily. Another important consideration for the industry is the link between groundwater and surface water. "Groundwater is a major contributor to surface water," said EPRI Technical Executive Ken Ladwig. "They are tied together."

Research Clearinghouse and Platform for Collaboration

EPRI recently launched its virtual Groundwater Center to serve as an information hub and a platform for electricity sector collaboration on this complex issue. The center reflects the industry's priorities of monitoring and managing this limited resource.

An important component of the center is a website to serve as a clearinghouse for groundwater-related EPRI research reports as well as studies, news, and best practices produced by diverse stakeholders with groundwater expertise. "We are going to have links, news items, and summaries of external research at the U.S. Geological Survey, U.S. Environmental Protection Agency, and several university consortiums devoted to groundwater," said Ladwig, who manages the center. "The purpose is to bring together both these external resources and EPRI resources to provide comprehensive, quick access to key information needed to anticipate risks and establish action plans."

The center is also expected to be a springboard for expanded research collaboration across EPRI. Potential research areas include groundwater–surface water interactions, applications of models and other advanced assessment tools, and tests on groundwater supply and remediation technologies. By raising awareness of groundwater research among different arms of EPRI and other organizations, the center can help avoid duplication of efforts for better management of funders' resources. "There are plenty of opportunities for synergy across different EPRI research programs and for facilitating interaction with other groups," said Ladwig.

Conferences and Workshops

The Groundwater Center will organize an annual conference for member companies, academics, government researchers, and other technical experts to share research and case study results. It will host workshops to provide utility field project managers and others with practical knowledge about site assessments, data interpretation, and analytical methods, helping them better manage groundwater. The first workshop, tentatively scheduled for fall 2015, will likely focus on groundwater modeling.

Better serving society's long-term interests is a unifying theme among the Groundwater Center's projects and topics. "While the center will help power companies directly address near-term needs related to groundwater, its activities are also driven by EPRI's public interest mission," said Ladwig. "Effectively managing groundwater today is critical to ensuring a healthy resource in the future."

Key EPRI Technical Experts

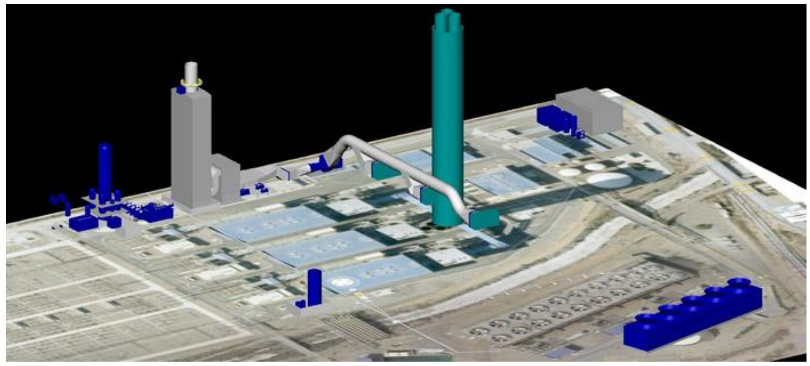
Ken Ladwig

Shaping the Future

EPRI Studies Carbon Capture at Combined-Cycle Plant in Spain

By Chris Warren

Although a natural-gas–combined-cycle plant emits about half the carbon dioxide of a conventional coal plant, a massive transition from coal- to gas-powered plants is not enough to adequately address the carbon reductions being contemplated domestically and internationally. "Just switching everything to natural gas won't get you the carbon reduction levels needed to meet the targets," said EPRI's Des Dillon.



One of several proposed layouts for full-scale carbon capture retrofit at the Cartagena natural-gas–combined-cycle plant

Which is why Dillon and Dale Grace, both EPRI senior technical leaders, spearheaded a study on the performance and cost impacts of retrofitting Spanish utility Gas Natural Fenosa's 1200-megawatt combined-cycle plant in Cartagena with carbon capture technology.

In most scenarios worldwide, carbon capture and storage (CCS) is uneconomical at natural gas and coal fired plants; installation of carbon capture equipment is unlikely near-term. A handful of small (10 to 25 megawatts) CCS demonstration projects worldwide has been followed by the 110-megawatt Boundary Dam coal plant in Canada, which opened last October as the first large-scale power generation facility built and operated with CCS. Its economics benefit from government support, Canada's carbon legislation, and the sale of captured CO_2 to nearby oil fields for enhanced oil recovery.

Site-Specific Guidance and Industry Cost Targets

The Cartagena analysis modeled a retrofit with commercially available technology based on the plant's current equipment and site, providing the utility with guidance on performance and cost. "This work helps the utility make a compelling argument to regulators and the public that doing carbon capture now is difficult because of the economics," said Dillon. "If the economics change, the utility is better positioned for a credible analysis of carbon capture retrofit."

The study reveals the importance of evaluating the technology in the context of a plant's specific layout, equipment, and market conditions. For example, natural gas is three to four times more expensive in Spain than in the United States. The Cartagena plant has a *low capacity factor*—meaning that it runs at low output levels—because of the country's struggling economy and the addition of significant renewable energy over the past decade.

While these factors make a retrofit uneconomical now for Cartagena, the EPRI study outlines circumstances when it would make financial sense. The best-case scenario: running the plant at a capacity factor above 70% and retrofitting all three generation units for economies of scale.

Other takeaways include how to minimize the retrofit's impact on plant efficiency and net power output, as well as impacts on site water use. The study provides cost and performance targets that carbon capture developers with new technology need to surpass.

But a bigger lesson may simply be the importance of being prepared for a future that includes more gas and significantly reduced carbon emissions. “These issues are not going away,” said Grace.

Key EPRI Technical Experts

Dale Grace, Des Dillon

EPRI JOURNAL

The **Electric Power Research Institute, Inc.** (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI members represent 90% of the electric utility revenue in the United States with international participation in 35 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

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