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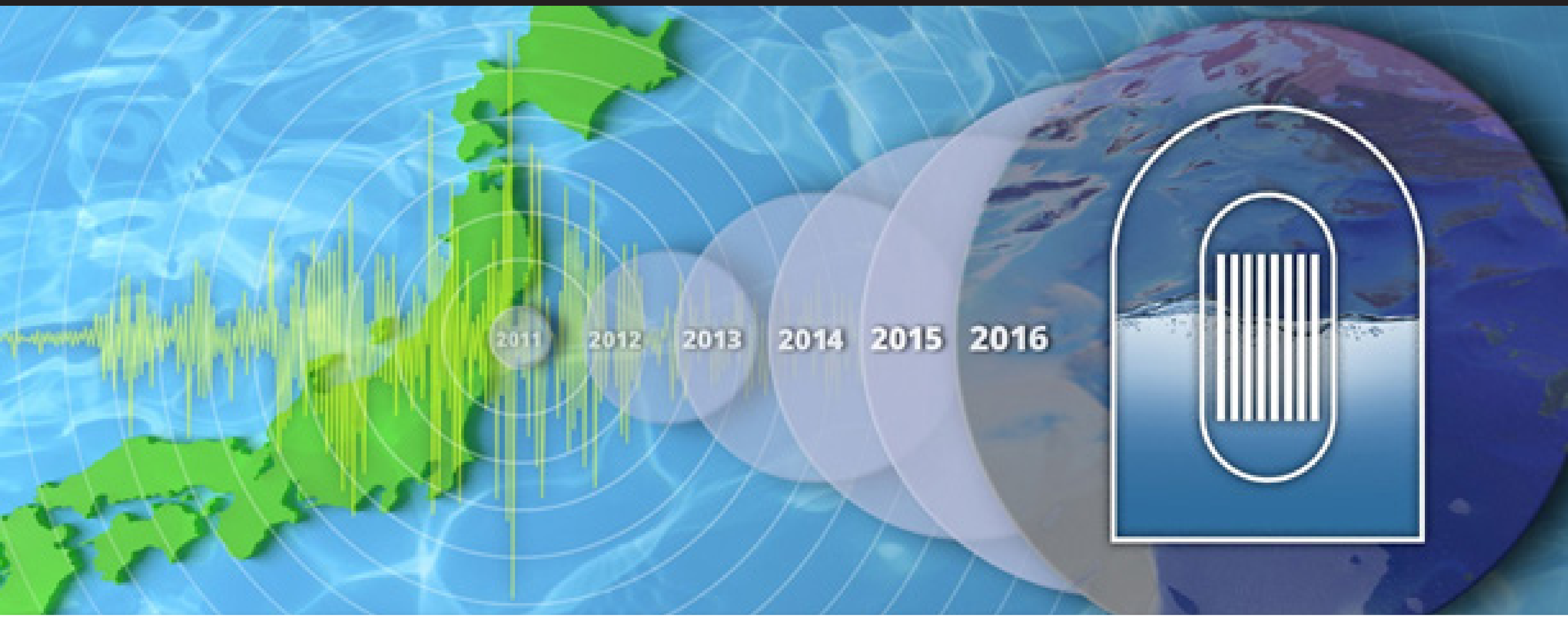
EPRI'S VALUE, POST-FUKUSHIMA



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Viewpoint—The Pump or the Plug?

Environmental Competitiveness and R&D

Today more drivers than ever are asking “the pump or the plug?” As drivers, they want acceleration, reliability, range, and convenient charging—on the consumer’s bedrock expectations for cost, convenience, comfort, choice, and control. Many also look upstream from the pump or the plug to ask how electricity competes with gasoline or diesel in terms of environmental costs and benefits.

For the future of electricity, an important aspect of its economic competitiveness will be its environmental advantages. It may seem a paradox to some, but this potential advantage is rooted in a long progression of environmental regulations.

More than a quarter-century ago, Harvard Business School Professor Michael Porter envisioned this kind of competition when he coined the famous Porter Hypothesis.

Simply stated, this hypothesis proposes that well-designed environmental regulation can enhance market competitiveness. He replaced the paradigm of cost versus benefit with his hypothesis that the benefits of regulation could offset, at least in part, the costs, even accounting for near-term cuts to jobs or profits.

Innovation and more efficient production drive this offset.

The May–June *EPRI Journal* may shed some light on these two aspects of environmental competitiveness. The Porter Hypothesis acknowledges that environmental regulations can add costs. For example, this can be expected to result from the U.S. Environmental Protection Agency’s regulations requiring power plant operators to reduce and, in some cases, eliminate pollutants from wastewater streams. EPRI research will help these companies understand these complex rules and make decisions on major technology investments.

With new biological and membrane water treatment technologies emerging, the benefits of the regulations may eventually accrue to farmers who are competing for scarce water resources or to cities banking long term on breakthroughs in desalination. Water is a finite and dwindling resource in many areas, and much is riding on its conservation. Incremental costs today in addressing power plant wastewater discharges may be more than offset by much wider benefits to society.

Managing risk is fundamental to considering environmental competitiveness. Society has subjected nuclear power to continuous cost-benefit scrutiny since its beginnings, with a keen interest in costs or potential costs associated with its risks. The earthquake and tsunami at Fukushima Daiichi provide a dramatic recent example. *EPRI Journal* reports on advances in seismic research and assessing plant components' vulnerability to earthquake damage, as well as methods to prevent radioactive releases in the wake of extreme conditions such as those at Fukushima.

In recent years as scrutiny increased exponentially on carbon emissions, we saw a new approach emerge with respect to nuclear power's costs and benefits. Competition, if you will, emerged between electricity from carbon-emitting sources and electricity from sources with low or zero emissions. Environmentalists reconsidered nuclear power and in some cases moved from adversary to advocate as they factored risks and benefits related to reducing carbon emissions.

Environmental competitiveness also hinges on economic efficiency. At the 21st session of the Conference of Parties to the United Nations Framework Convention on Climate Change ("COP21"), EPRI joined with Duke University's Nicholas Institute for Environmental Policy Solutions and the International Emissions Trading Association to examine the value and challenges of market mechanisms. Other EPRI sessions at COP21 examined the potential for international emissions trading partnerships and the science for estimating aggregate global damages to society from climate change. EPRI research is examining how emissions trading could benefit participating countries by reducing the societal cost of achieving emissions reduction goals.

An EPRI effort with 29 electric utilities is looking at how their customers can achieve cost savings and enhanced productivity by replacing fossil-fueled technologies with electricity. It's the "pump or plug" question for a greater spectrum of technologies and needs. Utility customers are looking for improved efficiency, costs, and air quality among other benefits, and are focusing on recovering their investment costs in three years or less. We have identified approximately 460,000 gigawatt-hours of electrification opportunities for the participating utilities.

Lighting offers a familiar example of how environmental competitiveness can play out. The U.S. Congress passed a law in 2007 phasing out the manufacture of incandescent bulbs. Many consumers balked at the cost, color quality, and inconvenience associated with alternatives. Today at EPRI, we see a pace of innovation in lighting similar to the computer industry at its prime. Consumers are driving renewed competition, even as the broader environmental and efficiency goals are realized.

In general, I like the term "environmental competitiveness." Typically, we hear the word "environmental" paired with "compliance," which describes a fundamental aspect of doing business. Environmental competitiveness describes a different perspective—one of success through innovation and competition—to serve customers and benefit society.

The competition between pump and plug provides a symbol of this. It centers on many factors. How will the environmental competitiveness be defined for internal combustion engines and electric motors? The market's demands will ultimately drive this, but I believe that the environmental aspects of energy production, delivery, and use will be right up there next to the driver, "riding shotgun."

Mike Howard

President and Chief Executive Officer, EPRI

Feature—EPRI's Value, Post-Fukushima

Industry Leaders Point to Research and Leadership in Four Areas

By Brent Barker

Five years ago, the Great East Japan earthquake, the second largest in recorded history, shook the islands of Japan for three minutes. The 9.0 magnitude offshore earthquake lifted the ocean and sent a tsunami racing across northeastern Honshu Island, devastating towns, killing thousands of people, and disabling and eventually destroying three operating nuclear reactors at the Fukushima Daiichi plant. Japan was thrust into a state of emergency, and EPRI and others rushed to provide critical technical assistance in managing an unfolding nuclear accident.

Fukushima raised concerns worldwide about nuclear power plants' ability to survive extreme external events that could severely damage reactor cores. To address those concerns, the U.S. nuclear industry mobilized quickly, and the Nuclear Energy Institute (NEI), Institute of Nuclear Power Operations (INPO), and EPRI spearheaded a collaboration called The Way Forward. At a time when ideas were flying in all directions, they provided focus and coordination in the United States. "We did a tremendous amount of work in a relatively short time," said Tim Rausch, chief nuclear officer of Talen Energy and chairman of EPRI's Nuclear Power Council. "The teamwork helped us to clearly articulate the problems and provide meaningful solutions, including a template for action."

The U.S. Nuclear Regulatory Commission (NRC) asked every nuclear plant to use the latest science to analyze the potential impacts of earthquakes. In response, NEI, INPO, and EPRI initiated a rigorous seismic hazard reevaluation to determine if changes were needed for earthquake protection.

"EPRI assumed a technical leadership role in this effort," said NEI Chief Operating Officer Maria Korsnick, who was chief nuclear officer of Constellation Energy at the time.

According to Dave Heacock, chief nuclear officer of Dominion Power, EPRI was instrumental in completing the multi-layered calculations required to accurately quantify earthquake effects.

In addition to seismic reevaluation, industry leaders point to three other areas of EPRI's technical leadership in the five years since Fukushima: response to the accident itself, updating the technical basis for severe accident management guidelines, and research on filtered venting to mitigate accidents.

Response to Fukushima

Immediately after Fukushima, EPRI helped Tokyo Electric Power Company with urgent needs, such as removal of cesium buildup in the cooling water of the damaged reactors. EPRI's Modular Accident Analysis Program (MAAP) was used from the outset to improve understanding of the sequence of events and observed phenomena, and to help efforts to locate the molten cores.

The Japanese government has begun funding enhancements to MAAP for use in decommissioning the plant. The code is now used by more than 70 organizations in 17 countries. As Japan's nuclear utilities conduct analyses to demonstrate that their plants can be restarted safely, they are using MAAP to evaluate plant responses to upset conditions and the progression of potential severe accidents.

"Fortunately for all of us, EPRI had built relationships of trust with the Japanese that preceded the accident, and this put EPRI in a special place," said Korsnick. "EPRI was granted unprecedented access to information, people, and conversations because they are so well trusted and have such high credibility. And their credibility helped frame the response of the U.S. nuclear industry."

EPRI applied knowledge gained through the Fukushima experience to other nuclear plants. In 2012, EPRI updated the technical basis for Severe Accident Management Guidelines developed by reactor vendors and plant operators. "This is used all over the world," said EPRI Fellow Rosa Yang. "It identifies measures that can be taken to minimize the severity of an accident at each stage, and can assist in providing the technical foundation for guidelines formulated for individual plants."

"The guidelines have positioned the industry to better prepare for and manage a severe accident," said Korsnick.

Seismic Research

EPRI worked with other experts to assist the industry through the NRC's seismic reevaluation. Fortunately, the scientific backbone had been under development long before Fukushima, according to Stuart Lewis, EPRI senior program manager.

"EPRI worked with the U.S. Department of Energy and the NRC to calculate the seismic hazard, capturing a lot of new geological data. In parallel, EPRI continued to develop and improve the methods for looking at the probability of failure as plants respond to earthquakes," said Lewis. "The result was the creation of a comprehensive seismic risk assessment model for nuclear plants at the time we needed it."

Researchers found that earthquakes east of the Rockies travel farther and vibrate at frequencies higher than those in the western United States. "The reason is that the rock in the East and Central regions of the country is older and more mature," said Heacock.

Most plants in these regions were designed based on west coast earthquake data because there was more of it. Newer data indicate that the seismic hazard to some plants in the Central and Eastern United States is greater than originally thought.

Five months after the Fukushima accident, a 5.8 magnitude earthquake in the Piedmont region of Virginia forced the shutdown of Dominion Power's North Anna nuclear plant just 10 miles from the epicenter. The earthquake—the second largest east of the Rockies since 1897—damaged the Washington Monument and was felt as far away as Florida and New York. The ground motion slightly exceeded North Anna's design standards, triggering NRC review.

"Once plants are shut down after an earthquake above a certain threshold, NRC approval is required to restart," said Dominion's Heacock. "We had to go through a formal public review to verify that the safety equipment wasn't damaged. EPRI helped with the analysis, which supported our case to the NRC."

The frequency of ground motion during an earthquake, measured in cycles per second or hertz (Hz), is critical in determining its impact on structures and equipment. The 1–10 Hz range is the riskiest for most structures, including nuclear power plants. 1–3 Hz affects plants' massive structural parts, such as containment, while 3–10 Hz affects piping systems, pumps, and other heavy equipment. Above 10 Hz, vibration primarily affects electronics, instrumentation, and relays.

NRC's reevaluation has relied heavily on seismic transport models, which calculate ground motion from the epicenter through bedrock to a location just below the structure under evaluation, and then up through the soil to the structure. Soils can amplify low-frequency vibrations and attenuate high-frequency vibrations. For structures, vibration amplitude increases with the building's height, which explains why the Washington Monument was damaged by the Virginia earthquake. For modeling earthquake impacts, each leg of the transport requires a separate calculation.

"EPRI played a huge role in determining the best way to calculate all those separate transport elements and how they work together," said Heacock.

The NRC also called for a separate analysis of impacts of high-frequency earthquakes. In the United States, EPRI took the lead to test equipment that might be affected by ground motion above 10 Hz. Researchers put switches, relays, and other potentially susceptible components through rigorous testing on shake tables, mostly in the 20–40 Hz range, though some tests went up to 64 Hz. The upshot: 75% of the components worked without problems. All the parts showing adverse impacts under high-frequency conditions also had impacts in previous low-frequency tests, indicating no unique high-frequency sensitivity.

Filtered Vent

Post-Fukushima, the NRC proposed a ruling that boiling water nuclear reactors with Mark I or II containments (similar to the damaged reactors in Japan) install large external filters on venting systems. Under normal operating conditions, operators wouldn't use the external filter. But under accident conditions, gases building up in the reactor would be vented to the filter to reduce pressure and temperature as well as scrub radioactive materials. Such systems had already been adopted in many parts of the world.

"The filter is similar to a big bubble bath," said Yang. "You bubble the gas through a large tank of water and chemicals that filter out most of the radioactive material without releasing it to the environment."

"The industry team, composed of EPRI, NEI, and INPO, opened up a wider discussion about the filters," said Korsnick. "What's the purpose? What are we really trying to do with the filter? We concluded that the purpose is to prevent releases of radioactive materials and prevent land contamination. EPRI proposed a better way to do that."

That better way consisted of flooding and injection of water into containment during an accident to lower the reactor's pressure and temperature, cool the damaged fuel, and trap radioactive particles. "Because these external filters are just tanks filled with water, the water in containment can be just as effective in cleanup," said Korsnick.

The NRC was skeptical, asking for proof of effectiveness under all possible accident scenarios—a tall order considering that there are thousands of pathways.

"We used the MAAP code to simulate accident scenarios," said Yang. "Most severe accident codes would take weeks to run a single case. But using MAAP on our supercomputer Phoebe, we could run thousands of cases overnight. In the end, we ran tens of thousands of scenarios to prove our concept."

"EPRI's work had the technical rigor that was needed to make a strong case to the regulator," said Joe Pollock, vice president of nuclear at NEI. "When presented with the MAAP runs, the NRC then ran its own independent calculations with different computer models to validate the results. EPRI's results held up, and the NRC accepted them."

Although safety and simplicity are unchanging objectives, eliminating the external filter will save an estimated $35–50 million for each of the 30 boiling water reactors in the United States. For the U.S. nuclear industry, savings could reach $1.5 billion.

"There is so much EPRI offers, in so many areas—avoided cost, cost savings, and improvements in safety, efficiency, and reliability," said Tim Rausch. "The value is a combination of savings across an entire industry and around the world, some tangible, some intangible."

Robust Design of Nuclear Plants

There is much empirical data on earthquakes' impacts on nuclear plant structures and components—what failed and what held up. One overarching observation is that nuclear plants are anything but fragile. They have been designed with exceedingly robust margins of safety and structural integrity and reinforced to ensure radiation protection. Inspections immediately after earthquakes have found little damage (see *EPRI Fukushima Daini Independent Review and Walkdown* for more details).

In Japan, earthquakes are part of life (19,000 earthquakes over 3.0 magnitude in 2011 alone), and its nuclear units have been tested repeatedly and held up well. While the tsunami triggered by the Great East Japan earthquake devastated the Fukushima Daiichi reactors, little damage resulted from the ground motion itself.

"The structures themselves are very robust, and the piping system, designed for high pressure and radiation protection, is not a problem," said Dave Heacock, chief nuclear officer of Dominion Power. "The problems are with tanks that can topple and electrical components. With high frequency vibration, relays start to chatter, and their settings change."

After Fukushima, concern arose regarding the susceptibility of spent fuel pools to earthquake damage. "An EPRI evaluation showed that spent fuel pools are also extraordinarily strong. Designed for radiation shielding as well as structural strength, they have two to three feet of reinforced concrete with a steel liner," said Heacock. "The pools have no holes except near the very top, so even if the piping system ruptured, the pool would not drain below a very high level. There would still be plenty of water over the fuel."

Key EPRI Technical Experts

Stuart Lewis, Rosa Yang

Feature—Wind, Sun, and Water

EPRI R&D Helps Utilities Better Understand the Promise and Challenges of Renewable Energy

By Chris Warren

Traditional wind turbine inspections can be risky and ineffective. Rappelling the turbine blades and working atop tall towers in windy conditions raise safety concerns and requires shutting down turbines. Standard visual inspection can identify degradation only on turbine blade surfaces.

John Lindberg, an EPRI program manager with decades of experience with maintenance and nondestructive evaluation of nuclear plant components, and EPRI's Renewable Generation R&D staff are collaborating to apply the benefits of nondestructive inspection to renewable generation technologies. Their initial focus is evaluation of wind turbines and blades.

"Most inspections are visual examinations done either by workers on the ground or rappelling from the top of the wind turbine and looking at the blades," said Lindberg. "You can't see if there are problems in the subsurface that could impact the structural integrity of the blades."

Lindberg worked with Digital Wind Systems during the development and testing of SABRE™*, Digital Wind Systems' tool that enables workers to more safely conduct inspections from the ground. SABRE™ has demonstrated an ability to identify potential problems before they become serious. "It can enable wind operators to address degradation long before blades fail," said Lindberg.

The SABRE™ system can be used to inspect the blades while the wind turbine is operating. EPRI estimates that SABRE™ could save operators hundreds of dollars per inspection in avoided lost power production, depending on turbine output, electricity prices, and downtime required for a visual inspection.

According to WindPower Monthly, nearly 4,000 blades fail each year. Replacing them can take units offline for days, weeks, or even months and cost tens to hundreds of thousands of dollars for repairs, replacement, and lost revenue. SABRE™ combines three technologies that can support more in-depth, ground-based inspections.

When placed close to a moving turbine, SABRE™'s thermography sensor detects temperature variations on the blades. "A flaw such as a crack creates a hot or cool spot that is one or two degrees different from the surrounding area," said Lindberg. At the same time, SABRE™'s microphones can pick up unusual noises. For example, a smoothly operating blade produces a muffled sound as it rotates while a blade with a small hole may whistle. SABRE™'s acoustic spectral analysis uses algorithms to help locate the abnormal noise. SABRE™'s camera can then help to pinpoint the location of flaws identified by thermography or acoustic spectral analysis. EPRI continues to examine SABRE™'s potential performance in certain weather conditions, such as rain, fog, and high humidity.

In demonstrations over the past two years, more than 1,800 blades have been inspected at wind farms in Pennsylvania, Texas, Michigan, Minnesota, and Wisconsin. Significant blade anomalies detected by SABRE™ prompted operators to take turbines out of service for repairs and replacements, supporting safe, reliable, cost-effective power generation.

Applying EPRI Experience from Other Sectors

The work on SABRE™ exemplifies how EPRI is applying lessons, experience, and expertise from fossil and nuclear generation to help advance R&D on renewables such as wind, solar, and hydropower.

"Solar and wind are becoming a much larger portion of the generation mix," said Tom Alley, EPRI's vice president of generation. "We have deep experience in operations, maintenance, and performance of coal, nuclear, and gas assets, and can provide value to our members by using this expertise in the renewable arena."

For example, one project in 2016 will examine corrosion of steel solar panel racks in utility-scale installations. Parts of the racks are sometimes underground, where soil pH and moisture can lead to corrosion, compromising structural integrity. EPRI plans to develop guidelines on the use of buried structural steel and then conduct laboratory and field tests to inform the selection of materials for solar projects.

"Until recently, EPRI's materials program focused on steam turbines and boilers," said Alley. "The solar racking work highlights how we are broadening the program's R&D to materials used across the range of power plant components."

Solar Performance, Short and Long Term

As power companies deploy more solar generation, they want to accurately predict their facilities' performance and reliability. "Utilities are keen to learn whether the capacity listed on a solar panel's nameplate is accurate and how production changes as the result of positioning, snowfall, and temperature," said Cara Libby, EPRI senior technical leader in renewable energy.

In 2012, EPRI installed eight 10-kilowatt solar photovoltaic (PV) systems using crystalline silicon and thin-film panel technologies on its test site at the Solar Technology Acceleration Center (SolarTAC) in Aurora, Colorado. Three years of continuous monitoring identified the manufacturer's nameplate rating as the greatest source of uncertainty in predicting performance. The data suggests that panels generated as much as 7% above and below the rating.

In seasonal tests, temperature exerted the biggest impact on performance, with higher efficiency in cold winter months. Initial results suggest that thin-film PV panels composed of cells in horizontal strings recover faster after snowfall than crystalline silicon panels with vertical strings. The rows of cells at the top of thin-film panels can produce current as the snow begins to melt.

These insights can help inform utilities' decisions on solar, enabling them to make better asset and operations choices that benefit the public through more cost-effective, reliable power generation. "By reducing performance uncertainty, this research has tremendous strategic value for utilities considering generating, purchasing, or integrating solar into their portfolios," said Nadav Enbar, a principal project manager at EPRI.

At Southern Research in Birmingham, Alabama, EPRI is studying how solar panels perform after 10, 15, and 20-plus years of operation. Because widespread solar deployment is relatively new, little is known about long-term panel degradation and its effect on performance.

In 2016, EPRI will begin accelerated aging tests in the laboratory. "In just a few months, these tests can simulate decades of temperature variations, high humidity, and other harsh outdoor conditions," said EPRI Project Engineer Chris Trueblood. To help validate the results, EPRI will compare panels subjected to accelerated aging with those subjected to several years of operation.

Collaborating with Utilities

Over the past decade, Minnesota-based Xcel Energy has seen customer demand for renewables shift from wind to solar. "Now we're seeing strong customer demand for solar in our territory, and it's becoming a much more cost-effective solution," said David Stevens, project manager for Xcel Energy's Emerging Technology team.

To bring more solar power online while ensuring grid reliability and safety, Xcel Energy seeks a deeper understanding of potential impacts on distribution grid voltage. "These distributed resources are tied to the grid at a much lower voltage than wind plants," said Stevens. "We want to make sure that a large increase in intermittent solar generation doesn't impact grid reliability, and we want to be clear on the benefits and limitations of energy storage."

Xcel Energy and EPRI are working at SolarTAC to evaluate the benefits of pairing solar with various battery technologies. For four years, they monitored an 850-kilowatt concentrating photovoltaic system connected to a 1.5-megawatt-hour lead-acid battery with capabilities such as smoothing of solar generation and time shifting. They also evaluated the performance of a 50-kilowatt-hour sodium nickel chloride battery coupled with kilowatt-scale solar arrays serving loads intended to approximate four residences.

The projects have yielded important lessons for Xcel Energy. "We know a lot more about how well the batteries respond to the intermittent generation of solar, how the battery chemistries perform over time, what energy storage management systems offer now, and where they need to be tomorrow," Stevens said. "The research at SolarTAC has prepared us to move forward with battery demonstration projects in real-world distribution systems."

EPRI, Southern Company, and its subsidiary Georgia Power are analyzing the performance of a 1-megawatt solar installation in Athens, Georgia. "A lot of utilities are interested in utility-scale solar," said Chris Trueblood. "The Athens facility will reveal how different panel orientations and other system configurations impact performance at this scale."

At the Athens installation, EPRI also is testing grid support functions of smart inverters. "The inverters can help adjust the voltage quality on distribution grid feeders," said Trueblood. "Understanding the real-world effects of these functions will help utilities integrate megawatt-scale solar generation into the distribution grid without impacting reliability."

Optimizing Hydropower

In 2016, EPRI is ramping up R&D on operations, maintenance, and performance of hydroelectric power plants, considering advice from members on priorities.

A recent EPRI study revealed the potential generation and financial benefits of more active management of hydro operations. The report notes that there is room for improvement in the number of plants that optimize operations by finding the "sweet spot" where a turbine's power generation is maximized while water flow is minimized. As grid operators impose changing demands on hydro plants, the challenge is to operate turbines more flexibly.

For instance, if there is excess power in the region, grid operators may ask plant operators to curtail generation by reducing water flow. EPRI's research shows that there can be a big financial upside to determining which units receive less water. For example, in a five-unit hydro facility, it may be more cost-effective to let three of the turbines operate at full capacity all the time and cycle the other two units up and down. Recent EPRI R&D shows that newer hydro turbines might offer improved generation performance but at the cost of more limited flexibility.

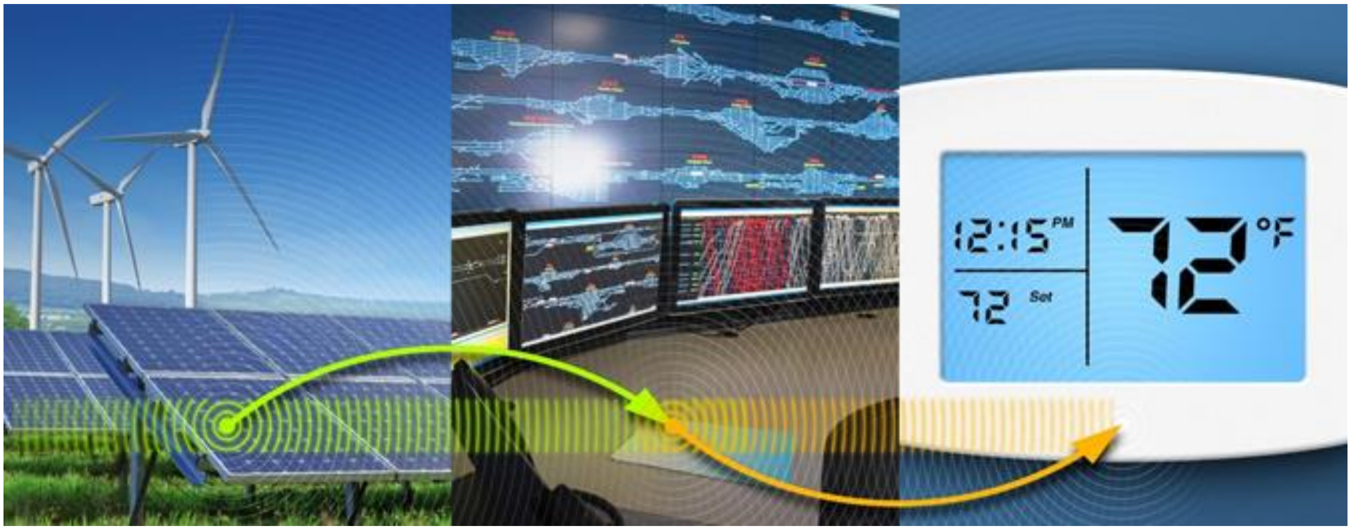
As utilities' needs change, so too will EPRI's renewable energy R&D. Tom Alley points out that just a few years ago, most utilities were not interested in owning large wind and solar assets. "We are seeing that change," he said. "For us to be relevant to our members, we have to be relevant in the renewable area. And we will through our public benefit research."

*SABRE™ is the trademark of Digital Wind Systems, Inc.

Key EPRI Technical Experts

Stan Rosinski, John Lindberg, Cara Libby, Nadav Enbar, Chris Trueblood

Feature—Opening the Door to Automated Demand Response



Field Demonstrations Show Effectiveness of Communications Language, Reveal New Applications

By Matthew Hirsch

Computer operating systems, web browsers, and even breweries have tapped the open-source process to enhance product design through collaboration. Now EPRI has completed an open-source collaboration to improve how grid operators manage energy demand and supply.

EPRI has created software based on the OpenADR 2.0 specification and made it openly available for modification and enhancement by software developers at utilities, equipment vendors, demand response aggregators, and other organizations. The software enables developers to set up secure networks so electrical appliances and energy management devices can automatically reduce consumption during peak demand. For example, grid operators can use the software to signal appliances to turn off, which in turn can signal operators that the actions were completed. Since EPRI released the software in February 2014, developers in dozens of countries have downloaded it more than 2,000 times. By enabling many independent programmers to test and debug the software, the open-source approach offers the potential for quicker innovation and a more reliable product.

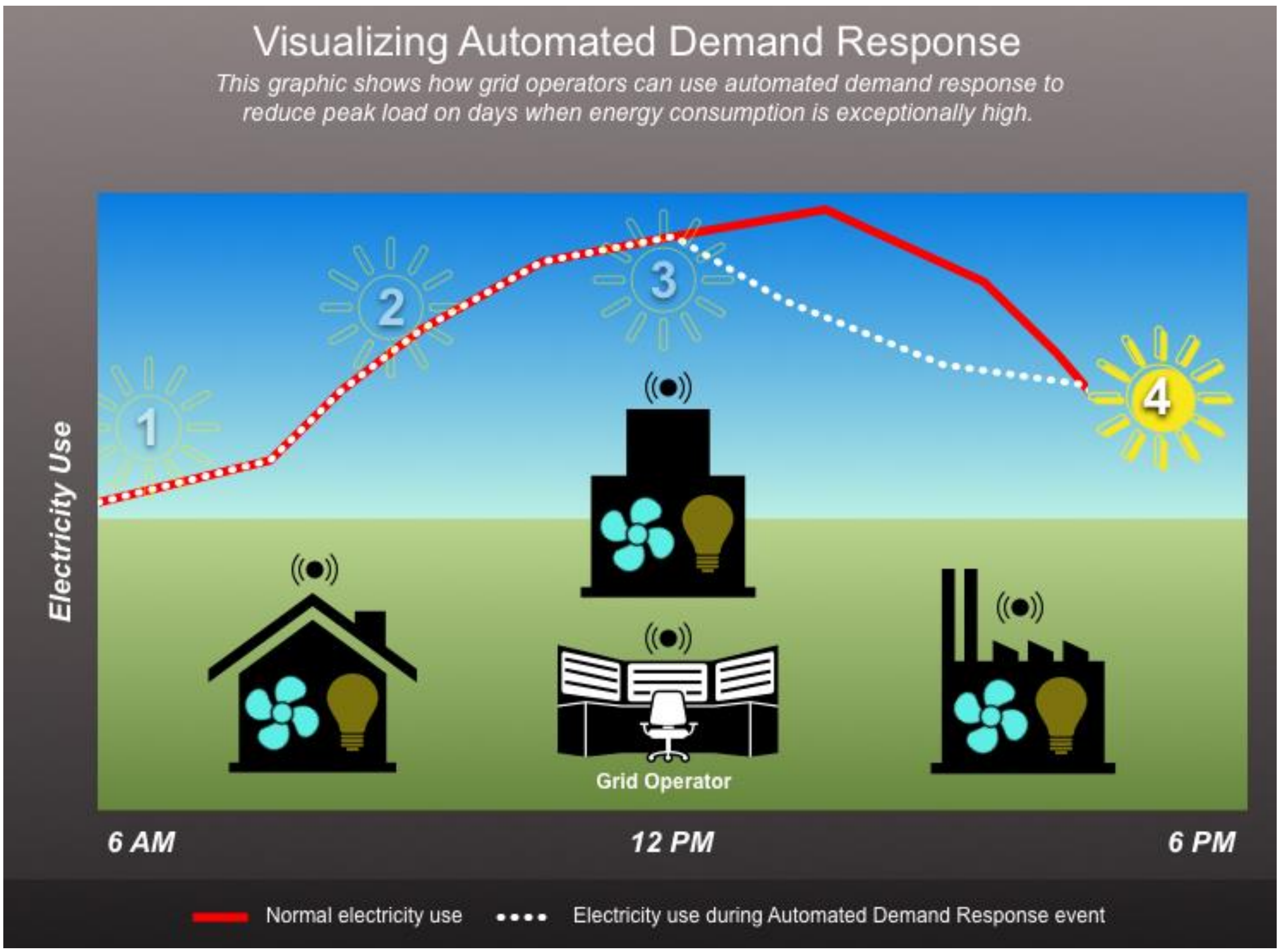
For the past four years, EPRI has led field demonstrations to advance adoption of the OpenADR specification, assess its effectiveness in automating demand response, and identify benefits for grid operators. Nine power companies and grid operators in the United States, France, Ireland, and Japan participated in the project, and four hosted field trials at their facilities.

A Young Language

OpenADR is still in early adoption. Lawrence Berkeley National Laboratory created it in response to California's rolling blackouts in 2000 and 2001, launching version 1.0. The nonproprietary language helped cultivate industry interest in demand response automation by enabling electricity providers to tell appliances when to reduce load. In 2010, the National Institute of Standards and Technology included OpenADR in a list of 16 recommended smart grid interoperability standards. The same year, a group of utilities and vendors started the nonprofit OpenADR Alliance to lower costs, ensure compliance with the specification, and improve reliability for OpenADR users.

OpenADR 1.0 was not suitable for widespread commercial deployment because it supported only one-way information flow. Appliances and devices could receive demand response signals but could not respond to grid operators. In 2013, the OpenADR Alliance completed version 2.0b with two-way communication and other features, such as frequency and voltage control. EPRI developed software in accordance with this version and released it for free to developers and programmers, facilitating software development for the commercial market. Utilities, transmission system operators, and third-party aggregators can use OpenADR server software to initiate requests for demand response, while electrical appliances and devices can use OpenADR client software and hardware to receive requests and respond.

This graphic shows how grid operators can use automated demand response to reduce peak load on days when energy consumption is exceptionally high.



1. In the morning, the grid operator observes a normal rise along the demand curve as people wake up and start operating home appliances while office buildings and industrial factories come to life.

2. Approaching midday, the grid operator forecasts that peak demand will be higher than normal as people run air conditioning to keep cool in the midst of a record heat wave. Instead of bringing additional generation online, the grid operator calls a four-hour demand response event starting at 12 p.m.

3. Using the OpenADR communication protocol, the grid operator transmits a signal instructing devices in hundreds of residential, commercial and industrial buildings to automatically turn down lighting, slow down cooling systems and take other measures to temporarily reduce consumption. Demand drops immediately and remains significantly below normal energy usage for the duration of the four-hour event.

4. By late afternoon, demand tapers off as office buildings and factories are shutting down, and people return home for the evening.

OpenADR Enables Reliable Load Reductions for California Grid Operator

One demonstration participant, California Independent System Operator (ISO), modified the building control system at its Folsom campus to accept OpenADR signals from Sacramento Municipal Utility District's (SMUD) PowerDirect Automated Demand Response program. During peak demand on designated summer afternoons, lighting is reduced and thermostats are adjusted by up to 4°F automatically in designated zones of the three-floor building.

In the summer of 2015, California ISO received 11 demand response event signals covering a total of 26 hours and exceeded its load reduction goal for all but four of those hours. "The OpenADR software enabled reliable, automated load reductions when SMUD requested them," said Jill Powers, California ISO Smart Grid Solutions Manager.

Because devices for controlling electricity consumption based on OpenADR version 2.0b were not widely available at the project's outset, California ISO used the older OpenADR version 2.0a, which provides one-way communication and includes fewer messages than 2.0b. The demonstration pointed to specific potential benefits of two-way communications. For example, because California ISO could not alert SMUD that its load reduction at certain times more than doubled expectations, the utility was missing important data about its demand response program.

For the most part, California ISO's automated load reductions did not bother building occupants. Powers said that the facilities team received only two complaints from small workspaces about higher-than-normal temperatures when load was reduced. No complaints were registered from the rest of the building with mostly large, open work areas.

Wind and Solar Applications

Through EPRI's demonstration, participants identified additional applications for OpenADR. Ireland's distribution grid operator ESB Networks used OpenADR 2.0b to design a two-way communication protocol with transmission operator EirGrid to help prevent distribution grid overloads that could result from excessive wind production. Because Ireland is small and relatively flat, EirGrid can forecast wind production reliably 5 to 15 minutes in advance. With OpenADR-enabled communications, EirGrid's proposed wind generation schedules are sent automatically to ESB Networks. ESB operators use this time to analyze grid-connected electric vehicle charging stations and thermal energy storage devices, feeder by feeder, to determine if there is sufficient load available to accept the power from EirGrid. Based on the analysis, ESB Networks also can use OpenADR to accept or reject EirGrid's dispatches.

Another participant, Électricité de France (EDF), is attempting to modify OpenADR 2.0b to deploy commercially available network devices that operate on power-line communications. EDF plans to connect an OpenADR-enabled server with a device that can control solar inverters, instructing them to supply local building loads, feed energy to the grid, or help stabilize the grid with voltage and frequency regulation when needed.

Long-Range Planning at Southern Company

In recent years, winter peak demand has grown across Southern Company's power system, due in part to increased adoption of electric heat pumps. In its Alabama, Florida, Georgia, and Mississippi service areas, the company traditionally meets this demand by deploying generation, without requesting large load reductions from business customers. Regulatory changes and increasing renewables are driving more demand response, according to Justin Hill, who manages Southern Company's demand response research portfolio. "In five to ten years, I see automated demand response having the potential to play a more central role in peak demand management," he said.

For the Southern Company system, participation in EPRI's OpenADR demonstration provided an opportunity to explore long-term demand response solutions. Southern Company's Alabama Power subsidiary has deployed an OpenADR 2.0b-enabled server that can send messages to identify target energy resources, request load adjustments, and schedule adjustments most convenient for the customer. Next will come software that enables customer lighting and temperature control devices to receive and respond to messages.

Hill said that the collaboration with EPRI has helped convince vendors to bring products to market. "There are a lot more devices certified by the OpenADR Alliance now than a year ago," he said.

The Future of OpenADR

EPRI's demonstrations are important in advancing OpenADR's ability to enable demand response on a large scale. While originally conceived for demand response, researchers now recognize that the language can support many transactions, such as the purchase and sale of electricity and grid-stabilizing ancillary services. One possible application: Grid operators can send OpenADR signals to all electricity generation and consumption devices, which respond automatically, based on financial incentives.

Because OpenADR can operate over many communication networks, it may be able to enable communications with distribution systems and distributed energy resources, and also perform demand response. Separate systems for these three applications would then no longer be necessary, saving utilities time and money. "The current OpenADR language already has about 90% of the functionality that you would need to do that," said Walt Johnson, a technical executive in EPRI's Information and Communication Technology program. "With these capabilities, you've got a key component of a self-healing smart grid. The only problem is that we would have to change the name of OpenADR to something that indicates that the language does more than just demand response."

Key EPRI Technical Experts

Walt Johnson

First Person—EPRI'S Cyber Security Guru Goes to Europe

The Story in Brief

EPRI's Annabelle Lee has gained international recognition for her wide-ranging experience in cyber security dating back to the early 1980s before the term had been coined. In this interview with EPRI Journal, she shares insights from her career, describes the cyber security threat in the electric sector, and discusses her role on a panel to inform regulations in Europe.

EJ: The European Commission selected you as the only American on its Energy Expert Cyber Security Platform–Expert Group, a 14-member panel providing cyber security guidance to the Commission. How did you become such an internationally recognized cyber security expert in the electric power sector?

Annabelle Lee

Lee: I began my career as a programmer in the mid-1970s working for a number of consulting firms on computer systems design, development, and analysis. I started in computer security in the 1980s at the MITRE Corporation, with a focus on law enforcement. I worked on-site at the FBI on computer systems design and cyber security for two of its very large systems, and I led a cyber security effort for the Drug Enforcement Administration. In 2004, I moved into power sector cyber security, first for the Department of Homeland Security, then the federal agency National Institute of Standards and Technology (NIST), and finally EPRI.

EJ: What got you into computer security?

Lee: In the early 1980s, I was doing computer system design and analysis at MITRE. A co-worker said that MITRE was starting a group on computer security and asked me if I was interested in joining. My response was 'I don't know anything about that,' and his response was 'Neither does anybody else.'

"As we modernize the grid with renewables and other new technologies, interconnectedness makes cyber security more challenging, and it's hard to predict consequences of cyber security events…."

EJ: What did you do at the Department of Homeland Security and NIST?

Lee: At the Department of Homeland Security for four years, I worked on security for control systems in the electric sector—the hardware, firmware, and software that operate and monitor the energy delivery systems.

I was at NIST when it was starting the Smart Grid Interoperability Panel, and set up a team to develop NIST's Guidelines for Smart Grid Cyber Security. This was the first cyber security guideline for control systems in the electric sector. Grid control systems are focused on availability—when they go down, people may lose electricity. This is different from the majority of information technology systems—think of banking and finance systems—that focus on confidentiality. The smart grid guidelines are used by organizations around the world to develop cyber security specifications. More than 100 technical experts authored the document.

EJ: What aspects of cyber security does EPRI focus on?

Lee: EPRI collaborates with utilities internationally to identify critical cyber security research in two main areas. I lead the first area—information assurance. This includes cyber security risk management, creating security metrics for the industry, designing security into products, and identifying and assessing technical solutions for compliance with the North American Electric Reliability Corporation's (NERC) Critical Infrastructure Protection Standards, with international standards, or with utility requirements.

The other research area focuses on testing of cyber security technologies in EPRI's Knoxville laboratory. One example is our research on Secure Substation Systems. EPRI worked with utilities to develop security requirements for five common uses of these systems. Five vendors made adjustments to their password management and other software products to comply with these requirements. EPRI's involvement helped enhance security and solutions available for the entire electric sector.

To make sure we don't duplicate research, we collaborate and coordinate with other industry stakeholders, and participate in conferences and workshops.

"Technologies and threats are constantly changing, and that makes cyber security a constant work area."

EJ: Drawing on your pioneering and extensive work in cyber security, what primary insights are you bringing to the discussion in Europe?

Lee: One is that technologies and threats are constantly changing, and that makes cyber security a constant work area. Five years ago no one would have considered that everyone would have one or more mobile phones. You can't just say, 'Okay, I've done a risk assessment, I've implemented my security controls, and I don't have to worry about it for the next year or two.'

In this environment, grid reliability is paramount. The grid must be resilient in the wake of a cyber security incident. Maintaining electricity availability today while simultaneously planning for future cyber security controls is extremely difficult. Utilities have to be conservative. You don't just deploy security technologies and then say 'Oops, guess what? I shouldn't have done that.' IT departments have accidentally shut down systems when they performed vulnerability scans. If you do that in the electric sector, people could lose their electricity. EPRI works with utilities to support reliability and resiliency in this constantly changing environment.

The second insight: We have to be right with our cyber security strategies and controls 100% of the time; the bad guys only have to be right one time. That makes this work very challenging.

I'll add a third: Cyber security is just one area utilities need to address. They have other important areas such as financial risk and safety risk. Utilities cannot spend all their resources on cyber security, so they have to prioritize systems and vulnerabilities. This is risk management.

EJ: Characterize the current cyber security threat in the electric power sector.

Lee: Before 9/11, I was managing NIST's cryptographic module validation program where I'd be lucky to have 20 or 30 people in the room for a speaking engagement. After 9/11, I spoke on September 30th and had 100 people in the room. The next day I had 300.

As we modernize the grid with renewables and other new technologies, interconnectedness makes cyber security more challenging, and it's hard to predict consequences of cyber security events—or any grid events, for that matter. Utilities are concerned about the potential for cascading failures, such as the one that occurred in the Northeast blackout in 2003. In 2011, more than two million people in the U.S. Southwest lost power after the loss of a single 500-kilovolt transmission line that led to cascading outages in Arizona, Southern California, and Baja California. Nobody could have anticipated that shutting down a 500-kilovolt line would have led to such a widespread blackout.

Some grid devices are 30 to 50 years old. Even though you cannot put cyber security controls on these old devices, you are not going to replace them unless they break because they can cost millions of dollars and require 18 months to two years to replace. So you are addressing an environment that has modern and old technologies and figuring out the best way to address threats and vulnerabilities.

Articles in the media about power sector security typically focus on data breaches. Utility control systems are not typically accessible via the Internet. NERC has specific requirements about how various grid devices can be accessed. So you can't just call up or connect to these devices and bring down the grid. Some people think that it's very easy to hack the grid, but it's not.

A couple years ago, a utility had its customer and billing information compromised, but that's the information technology side, not grid operations.

> "Maintaining electricity availability today while simultaneously planning for future cyber security controls is extremely difficult."

EJ: What's the status of cyber security in the European electric power sector?

Lee: Europe's power sector is different from the United States. In the United States, there are roughly 3,000 utilities—municipal utilities, co-operatives, investor-owned utilities, all different sizes, some vertically integrated, some not. In Europe, there are only a few major utilities in each country. These utilities make our large utilities look very small. They do not have mandatory cyber security standards as North American utilities have through NERC.

The European grid uses some different communication protocols than the U.S., but grid devices, vendors, and security requirements are the same internationally. So they're going to have the same cyber security challenges.

EJ: How might a utility's size affect its ability to secure the grid from cyber threats?

Lee: That is a huge issue. Let's say you decide to deploy an upgrade or a patch to a device in customer meters. You'll have to manage that with millions of meters, and those meters may be out of communication during the upgrade. The large scale of the European utilities will impact their decisions on cyber security solutions.

EJ: Describe the activities and plans of the European cyber security panel.

Lee: This group is providing guidance to the European Commission as the European Union looks at the potential of developing cyber security regulations for the energy sector in Europe. The Commission selected 14 individuals to provide input and recommendations and will take those to the European Union. All panel members are from Europe except me. We've had two meetings—one last December and one in March—and two more meetings are later this year.

I chair the working group called Practices and Gap Analysis. We've been requested not to publicly divulge information about our deliberations, even when we turn our reports over to the European Commission. They will determine what to make publicly available.

Cyber security in the energy sector is a small community. It's an impressive group of people, and the discussions are very technical. That makes it a lot of fun for me.

I'm also learning about the priorities and concerns of the other panel members and their organizations.

EJ: What lessons from your cyber security experience can you transfer to Europe?

Lee: When you work in cyber security, it's important to understand the requirements and needs of the specific application. I've written cyber security standards and guidelines for many different applications such as law enforcement, homeland security, and the federal government. Through these experiences, I've learned how to delve into an application and figure out its unique requirements. That's the fun part of this work.

In the Field

Delving into Solar in The Midwest

Alliant Energy, EPRI Study Panel Performance, Orientation, Trackers, and Energy Storage

By Chris Warren

"Location, location, location" isn't just a mantra for the real estate business. Geography has a huge impact on solar generation, which explains in part why California, Arizona, and other sunny states have significant solar photovoltaic (PV) capacity.

But as PV prices continue to decline, less sunny regions are taking a closer look at solar. Alliant Energy recently installed a 300-kilowatt solar facility at its Madison, Wisconsin headquarters to help the utility company and its customers better understand how solar performs in the U.S. Midwest. Wisconsin's solar capacity ranks 30th nationally, with 22 megawatts, according to the Solar Energy Industries Association.

"Solar is new in this area," said David de Leon, director of generation construction projects at Alliant Energy. "We want to be able to share information with our customers because their interest in solar is growing and they want choices."

Solar and Batteries

Alliant Energy's three-year Solar Demonstration Project will gather operational data for 10 crystalline silicon and thin-film solar panel technologies. EPRI provided guidance on installing and selecting technologies and is assisting with data collection.

Alliant Energy and EPRI also are evaluating panel orientation. Some panels are mounted on trackers, some are in a flat position, and others are oriented toward the west, northwest, and southwest.

The solar facility is connected to a battery system with 30 kilowatt-hours of usable energy storage capacity. "We want to learn how to use solar and batteries to reduce peak demand and shift energy use to off-peak periods when costs are lower," said de Leon. Alliant Energy will not feed any solar generation to the grid because its headquarters building can use all of it.

Knowledge for Alliant Energy, Its Customers, and the Industry

Alliant Energy's project is one of EPRI's Integrated Grid Pilot Projects, which are intended to increase understanding of the performance of distributed energy resources and their integration into the distribution grid.

EPRI's Integrated Grid Benefit-Cost Framework outlines four steps for a comprehensive assessment of the implications of adding distributed energy resources (see EPRI's Benefit Cost Framework below). Alliant Energy is focused on the first step: identifying core assumptions. This involves understanding technologies and the characteristics of a particular region.

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.

"We want to know how to tap the full potential of new technologies, whether they're smart inverters, batteries, or solar panels," said Kathy Trudell, an EPRI principal technical leader working on integrated grid pilot projects. "Until we have a thorough understanding of their capabilities, we won't know how to deploy and configure them in the most effective way."

Trudell says that the findings will inform EPRI's understanding of the performance and maintenance of solar coupled with batteries in Midwest weather conditions.

The project also provides a way for Alliant Energy to meet increasing customer interest in solar. It has placed interpretive signs for customers, employees, and the public along public paths near the solar facility, and it will post performance data on a new website. "We want to help our customers decide whether solar is a good choice for them," said de Leon.

Key EPRI Technical Experts

Kathy Trudell

Technology At Work

Raising the Bar on Air Quality Modeling

Research Collaboration Improves Accuracy, Efficiency, and Speed

By Matthew Hirsch

The electric power industry is emitting fewer air pollutants as new plants are constructed and current plants install emissions controls. Simulating how power plant emissions disperse in the atmosphere is needed to help understand their impacts on air quality—and the extent to which controls mitigate those impacts. Such modeling is not easy. Models must account for variable wind speeds and directions as well as reactions with atmospheric chemicals, requiring complex calculations to quantify the transport and transformation of emissions.

The U.S. Environmental Protection Agency (EPA) has several established tools for modeling primary pollutants and secondary pollutants. Nevertheless, Southern Company researcher Justin Walters says that there are opportunities to advance the science in air quality modeling.

Walters is participating in an EPRI research project to develop tools that could advance air pollutant modeling in the United States. As EPA reviews and updates its air modeling guidelines, it can consider these and other publicly available tools that have undergone rigorous evaluation.

Modeling Primary Pollutants in 10-Minute Increments

Since 2005, AERMOD has been EPA's preferred model for simulating dispersion of the primary pollutants sulfur dioxide (SO_2) and nitrogen dioxide (NO_2). AERMOD is versatile and works on a range of terrain, but it does not perform well in low-wind conditions and has difficulty simulating short-term periods, such as one-hour averages, which are relevant to air quality standards.

The EPRI tool Sub-Hourly AERMOD Run Procedure (SHARP) operates along with AERMOD, improving the accuracy of results by enabling simulations of primary pollutants under low-wind speeds in time increments as small as 10 minutes. The resulting simulations can be used to calculate one-hour average concentrations, consistent with the National Ambient Air Quality Standards.

Research from Duke Energy, a project collaborator, demonstrated the effectiveness of SHARP's continuous 10-minute simulations. The utility compared emissions data directly from the stacks of its 3,145-megawatt Gibson Station plant with AERMOD's hourly analysis and SHARP's 10-minute methodology. "We found AERMOD over-predicted hourly concentrations by 50% or more compared to measured values. SHARP results were generally within 10% of measured values," said Patrick Coughlin, a Duke Energy senior environmental specialist.

Faster Modeling of Secondary Pollutants

Secondary pollutants have been regulated since 1971, but regulatory air quality models to simulate those pollutants from single sources were not always available. In 2012, EPA granted a Sierra Club petition requesting that the agency establish regulatory air quality models for ozone and fine particulate matter, known as $PM_{2.5}$. Southern Company's Walters worked with EPRI to provide guidance toward the development of the Second-Order Closure Integrated Puff Model with Chemistry (SCICHEM) for consideration by EPA. SCICHEM uses data on primary pollutants to predict the formation and behavior of secondary pollutants. While simulations from

EPA-proposed models can take up to two weeks using supercomputing, SCICHEM requires just a few days on a single computer. The team analyzed ambient data to confirm that the model matches measured atmospheric conditions.

"SCICHEM provides a one-stop solution to modeling dispersion of secondary pollutants from any point source that emits pollution," said Eladio Knipping, a principal technical leader in EPRI's Environment Sector.

According to Walters, SCICHEM can provide "a technically sound model for assessing secondary pollutant formation in the atmosphere that is more cost-effective and efficient than other models being considered by EPA."

Informing Regulations

To inform EPA's review of its air quality modeling guidelines, EPRI submitted public comments based on these modeling efforts. The agency will review comments from diverse stakeholders regarding simulating low-wind conditions and secondary pollutants.

Using a preferred model can provide certainty to plant operators that EPA will accept the results. Alternatives may provide more accurate results, but they must demonstrate good performance and comply with other EPA and state requirements. "That's one of the reasons we've published these results in peer-reviewed literature," said Knipping. Plant operators can petition to use non-preferred models.

Great River Energy, another project collaborator, is now seeking state approval in North Dakota to use alternative methods for simulating SO_2 dispersion in low-wind conditions at one power station. The electric cooperative is using an EPRI peer-reviewed paper among other resources to support the request."

Key EPRI Technical Experts

Eladio Knipping, Naresh Kumar

In the Field

Integrating Rooftop Solar

APS, EPRI Pursue Answers in Project with 1,500 Residential Customers

By Chris Warren

With more than 40,000 residential solar systems installed in its service territory, utility Arizona Public Service (APS) reports that some solar arrays are causing problems with distribution system voltage, at times even tripping other customers' systems offline.

"We have a tremendous amount of rooftop solar on our system," said Scott Bordenkircher, director of technology innovation for APS. "We are still learning how to integrate these resources and mitigate these problems so our grid can better enable advanced technology such as rooftop solar."

Regulating voltage is just one of many technical challenges that APS faces as solar deployment grows. In 2015, EPRI and APS engineers framed 19 questions important to the effective integration of residential rooftop solar into the distribution grid.

Among them: To what extent can advanced inverters manage voltage fluctuations associated with intermittent solar generation? What are the best configurations and practices for advanced inverters during peak load and periods of low sunlight? How does distributed solar affect the duration of peak demand, and how can it reliably reduce the need for grid equipment upgrades?

Continuous Monitoring in Phoenix

Answers to these questions will become clearer soon, thanks to an APS-EPRI pilot project involving utility-owned solar systems on the roofs of 1,500 residential electricity customers in the Phoenix metropolitan area. The project is part of EPRI's Integrated Grid Pilots Initiative, which seeks to boost understanding of distributed energy resources and the most effective ways to integrate them into the power system. Each installation will include an advanced inverter and communications that enable the utility's grid operations center to change the unit's settings as needed.

APS and EPRI also installed sensors on underground feeders that will track for more than a year how inverter settings impact grid voltage, power flows, and power quality. "Every second, we are getting an update on the voltage, where the power is going, and whether it's good, clean power or is distorted in some way," said Ben York, EPRI senior project engineer.

To prepare for this analysis, EPRI completed extensive laboratory work to assess advanced inverters' data accuracy and responsiveness to external commands. "This informs our field work with APS," said York. "When we pull data from the inverters, we know how reliable it is. When we ask them to perform a certain function, we know how quickly and precisely they will complete it."

Advancing Industry Understanding

When data collection is completed in 2017, EPRI will issue a series of reports addressing the research questions and analyzing the requirements, benefits, and challenges of using advanced inverters for rooftop solar integration.

APS will use the insights and lessons to improve its grid planning and operations. The power industry will be provided data and findings generated by actual operating conditions and responses at customer sites and in distribution circuits. “Previous understanding of the grid benefits of advanced inverters has come from computer modeling,” said York. “That has given us a lot of good ideas about how advanced inverters can help utilities manage solar on the distribution grid. This project backs up those ideas with the hands-on experience needed to advance the industry.”

Key EPRI Technical Experts

Ben York

Innovation

Navigating New Wastewater Rules

EPRI Evaluates, Tests, and Publishes Guidance on Technologies for Compliance

By Garrett Hering

EPRI's effluent guidelines and water management technology programs are stepping up efforts to help the industry understand complex new federal wastewater rules and provide a technical and scientific basis for their decisions on major technology investments.

In September 2015, the U.S. Environmental Protection Agency (EPA) finalized more stringent restrictions on regulated pollutants discharged in the wastewater streams of steam electric power plants. The effluent limitation regulations apply to all existing and new steam power plants larger than 50 megawatts. Plant operators must implement new water treatment technologies to reduce and, in some cases, eliminate pollutants from wastewater streams. Compliance begins as early as 2018 and no later than 2023.

"Before the final rule, EPRI research focused on informing the rulemaking process with sound science and quality data," said Paul Chu, manager of EPRI's Effluent Guidelines program. "Our goal now is to get the guidance and technology in place."

Research Priorities

The rules introduce new limits for arsenic, mercury, selenium, and nitrogen discharges from flue gas desulfurization (FGD) systems. Also known as wet scrubbers, FGD systems absorb most of a plant's sulfur-dioxide emissions along with these trace elements, but also produce effluents that require treatment prior to discharge. EPRI has prioritized research on FGD wastewater treatment technologies because the rule could require upgrades in more than 100 plants. The rule also restricts the discharge of fly ash and bottom ash transport waters, requiring many facilities to upgrade their ash transport systems.

Through field demonstrations, EPRI is evaluating commercially available and new technologies for cost-effectiveness, reliability, impact on plant performance, and interaction with other plant systems (such as air pollution control technologies). These include FGD wastewater treatment with biological technologies—which the EPA describes as the "best available technology" for selenium and nitrogen—and physical/chemical technologies for arsenic, mercury, and solids removal.

EPRI is also investigating advanced membrane technologies and thermal evaporation treatment systems, for which the EPA established a voluntary incentive program, and is exploring solutions for treatment system by-products such as encapsulation by solids fixation and stabilization.

"We want to understand how these technologies and systems work in the context of the whole power plant and whether they can help utilities to meet the regulations safely, reliably, and cost-effectively," said Jeffery Preece, technical leader of EPRI's Water Management Technology program.

The Water Research Center—a field laboratory at Georgia Power's Plant Bowen set up in collaboration with EPRI, Southern Company, and Southern Research—hosts several technology demonstrations, including a pilot-scale wastewater evaporation system, membrane technologies, and by-product encapsulation.

EPRI is evaluating real-time monitors for trace metals and nitrates to enable continuous compliance and assist in process controls. Monitoring currently relies on “grab samples” shipped to a laboratory for analysis, which takes several weeks.

Bringing Value to Industry

Tennessee Valley Authority (TVA), which provides power to businesses and local utilities in seven southeastern U.S. states, is using EPRI research to help navigate compliance at 10 coal-fired power plants affected by the new rules. EPRI is evaluating wastewater treatment technologies at a TVA plant.

“EPRI research has provided great value to TVA,” said Lindy Johnson, the utility’s senior program manager for wastewater treatment. By participating in EPRI research and sharing information with other utilities, TVA is refining its approach.

“EPRI brings an independent voice,” said Johnson. “They have been useful in evaluating vendor claims and ensuring that the technologies we install are cost-effective and reliable.”

EPRI details its assessments of wastewater treatment approaches in technology transfer sessions at member utility sites. Each session can provide engineers with credits for continuing professional development. EPRI publishes case studies and guidance to help users operate complete systems, not just individual technologies. Because testing conditions are different from conditions in many power plant applications, EPRI recommends that each site complete its own studies to support decisions on implementing technologies. EPRI plans to complete guidelines for meeting FGD wastewater requirements and for physical/chemical treatment of FGD wastewater.

Key EPRI Technical Experts

Paul Chu, Richard Breckenridge, Jeffery Preece

Innovation

Policy Pathways, Post-Paris

EPRI Looks at Market Mechanisms, Emissions Trading Partnerships

By Garrett Hering

Representatives of 195 countries achieved an environmental policy milestone last December in Paris at the 21st session of the Conference of Parties to the United Nations Framework Convention on Climate Change, or COP21. The Paris Agreement seeks to decarbonize the world's energy systems and limit greenhouse gas emissions.

Now comes the hard part: doing that.

In conjunction with the Paris conference, EPRI hosted two events to examine policies to meet or go beyond COP21 emissions reduction pledges.

The first session, co-hosted with Duke University's Nicholas Institute for Environmental Policy Solutions and the International Emissions Trading Association (IETA), considered the value and challenges of bilateral and multilateral market mechanisms. (The United Nations Framework Convention on Climate Change designated this as an official side event.) The second EPRI session focused on country pledges and potential opportunities for international emissions trading partnerships. EPRI also hosted a third event exploring the state of science for estimating aggregate global damages to society from climate change.

Events Address Global Collaboration

"Global challenges demand global solutions," said IETA President Dirk Forrister, who moderated two of the events.

With standing room only, the session on market mechanisms featured panelists from the U.S. State Department, the European Parliament, and Norwegian energy company Statoil. Policy researchers, government representatives, energy market participants, and environmental advocates explored how signatory countries might collaborate in bilateral or multilateral emissions trading markets to achieve their pledges cost-effectively. Discussion included trading experiences in Europe, California, Quebec, and China, which plans to launch a market this year.

The session drew significant attention, said Forrister, because market mechanisms are anticipated to be an important part of the solution. The final Paris climate agreement includes a section that paves the way for widespread consideration of emissions trading among jurisdictions.

"It includes a solid package of market-based solutions that will allow for the creation of an international emissions trading system, informed by what has and hasn't worked," he said. "We have some examples that we can draw upon to combine the best elements that will achieve more bang for the buck."

Post-Paris Action

In 2015, EPRI launched research on the impacts of international climate policy on domestic emissions reductions. It focuses in part on the value of emissions trading partnerships in the context of the Paris agreement's national pledges. EPRI is examining carbon-market scenarios for meeting targets cost-effectively, using its MERGE model for estimating regional and global economic and energy system effects of greenhouse gas reductions.

Scenarios include bilateral markets, such as between the United States and China, and multilateral markets. Country-to-country partnerships are appealing because they are more manageable.

"The Paris agreement demonstrates credibility and commitment to international efforts that has not existed in the past, but uncertainty remains about how to achieve national targets," said Steve Rose, an EPRI senior research economist. "International cooperation is an important alternative to going it alone. Emissions trading is one of several potential forms of international cooperation and can benefit participating countries by reducing the societal cost of achieving emissions reduction goals."

Three insights from EPRI's research:

- Emissions trading partnerships can improve the economic welfare of citizens in participating countries regardless of whether the countries are buyers or sellers of emissions permits.
- A country can participate as a buyer in one partnership and as a seller in another.
- More participation increases the total value of collaboration but affects the distribution of benefits among partners. The specific outcome depends on whether net permit buyers or sellers join.

"There are economic benefits to linking emissions trading efforts, but different partners produce different outcomes," said Rose.

For example, one comparison of scenarios that Rose presented in Paris indicated that the United States could receive more economic benefit from bilateral emissions trading with China, while China could benefit more from a multilateral partnership that includes the European Union.

As signatory countries seek to ratify the Paris agreement, EPRI will continue to examine impacts of international climate policy options on various economic sectors, technology deployment, domestic emissions compliance costs, and potential long-term climate.

Key EPRI Technical Experts

Steven Rose

Shaping the Future

Seeing Deeply into a Nuclear Reactor

'VERA' Software Enables Simulation of Atomic-Level Physics

By Brent Barker

Like an engaging host, VERA invites researchers to take a walk through the core of a nuclear reactor—in full-scale virtual 3-D—to observe in luminous color the neutron population density in the fuel rods (see photo at right). At Oak Ridge National Laboratory, scientists are using the western world's most powerful supercomputer, named Titan, to operate VERA, short for Virtual Environment for Reactor Applications.

U.S. Energy Secretary Ernest Moniz views a 3-D simulation of a nuclear reactor core enabled by VERA.

The VERA software is made up of many interacting computer codes that will enable researchers to simulate the atomic-level physics of any reactor core element at any time, with unprecedented clarity.

"Steven Chu, as Secretary of Energy, recognized that computers could be harnessed to model at the atomic level what happens in the core of a nuclear reactor," said Neil Wilmshurst, vice president of EPRI's Nuclear sector.

Secretary Chu set up four Energy Innovation Hubs, beginning in 2010 with the Consortium for Advanced Simulation of Light Water Reactors (CASL). Using an organizational model pioneered by the Manhattan Project and Bell Labs, Chu established CASL's research focus and provided funds, as well as a mechanism to assemble a virtual team of scientists and engineers from national laboratories, industry, academia, and EPRI. CASL's primary goal: Advance the nuclear industry's modeling and simulation capabilities and use them to address design, operational, and safety challenges for light water nuclear reactors. VERA is instrumental in their work.

Oak Ridge National Laboratory was assigned to lead. Founding partners included Sandia National Laboratory, Los Alamos National Laboratory, Idaho National Laboratory, Massachusetts Institute of Technology, University of Michigan, North Carolina State University, Tennessee Valley Authority (TVA), Westinghouse Electric Company, and EPRI. "Besides our technical talent, one of the distinguishing features EPRI brings to the partnership is a strong, collaborative interface with the utility industry," said Heather Feldman, a program manager in EPRI's Nuclear sector.

One challenge with such an integration of science and engineering is to address both basic science and practical application. To ensure that CASL provides real-world benefits, an advisory council helps guide its work. Members include nuclear plant operators, fuel vendors, design engineering firms, and computer technology companies. "CASL made it clear from the outset that research had to be 'used and useful,'" said Feldman.

"I expect that we will look back and say, 'Wow, that technology really changed how we predict what is happening in a reactor.'"

Reactor Behavior, Coolant Flow, and Fuel Pellets

Some founding industry-related partners have established Test Stands, or platforms, for testing VERA's modeling and simulation capabilities. Each partner focuses on a specific technical challenge. Westinghouse is examining the core's reactivity and power distribution behavior of its advanced reactor, the AP1000®, and TVA is looking at coolant flow in the reactor vessel of its Watts Bar Unit 1 plant. EPRI's focus is a problem involving nuclear fuel rods called pellet-clad interaction.

Cylindrical fuel pellets, less than a quarter of an inch in diameter and roughly a half of an inch long, are stacked one on top of the other in the hollow fuel rods. "Under some circumstances, if operators power up the reactor too quickly, the pellet can expand and crack the cladding, releasing radioactive material from the fuel rod," said Feldman. "Or, if pellets aren't perfectly round due to manufacturing, the stress on the cladding will be concentrated in certain regions, which can also lead to distortion and cracking." EPRI is using VERA on its high-performance computer called Phoebe for modeling and simulating pellet-clad interaction. Effective solutions can lower costs, provide more operating flexibility, and lead to more complete fuel burnup.

"The computational methods and computer codes representing all the key physics to be included in VERA—neutronics, fuel performance, chemistry, and fluid flow/heat transfer—have undergone their initial development and have been integrated into the software," said CASL director Jess C. Gehin in Congressional testimony in 2015, adding that "early deployment of VERA has been performed through CASL Test Stands."

The U.S. Department of Energy (DOE) originally funded CASL from 2010 to 2015. In Phase 2, funded by DOE as a five-year extension, CASL will expand VERA applications to boiling water reactors and new reactor designs, including small modular reactors.

"VERA is a game-changing technology. In this development phase we're seeing its early benefits. For example, Westinghouse used its Test Stand to reinforce its confidence in predictions for how the fuel core of the AP1000 nuclear plant will behave during startup," said Feldman. "It will take 10 or so years to see the full effect of VERA on nuclear R&D. I expect that we will look back and say, 'Wow, that technology really changed how we predict what is happening in a reactor.'"

Key EPRI Technical Experts

Heather Feldman

Shaping the Future

Telecom Transformation

EPRI Initiative Points the Way to New Telecommunications Networks

By Matthew Hirsch

Technology disrupts. Digital publishing software made pen and paintbrush obsolete for many artists and designers. Publications abandoned the printing press for digital networks. As EPRI Technical Executive for Information and Communication Technology, Tim Godfrey says telecommunications services are poised to disrupt systems long used by electric utilities.

Even as utilities rely more than ever on data to integrate distributed energy resources, commercial telecom carriers are phasing out services such as time-division multiplexing (TDM) communication that utilities have used for decades. As telecom providers switch to newer technologies, it becomes more difficult and expensive for utilities to continue using older services, potentially raising costs for consumers.

"We can no longer do what we have always done," said Godfrey.

In 2015, EPRI launched its Telecommunications Initiative to address such critical telecom issues, including loss of service and development of new network infrastructure.

A Strategy for Modern Telecommunications

Utilities traditionally transmitted data on TDM networks that telecom carriers designed for sending and receiving voice calls. Carriers have changed many of their voice and Internet services to use packet-based communication networks and have announced plans to discontinue by 2020 frame relay service, a type of TDM network that many utilities use to monitor and control substations and other grid assets. Carriers also plan to retire copper loops, the physical infrastructure supporting some frame relay and other TDM circuits. As the old networks diminish and new ones gain subscribers, manufacturers have phased out TDM communications equipment, making its continued use more expensive.

"Over time, it will become impractical to do so," said Godfrey. "The writing is on the wall."

The Federal Energy Regulatory Commission (FERC) in 2013 approved new standards for protecting the bulk power system against cybersecurity threats, eliminating an exemption for TDM communications. This requires utilities still using TDM networks to develop action plans to safeguard their communications infrastructure. Such plans may not be worth the effort in light of TDM's tenuous future.

EPRI is nearing completion of a field project collaborating with utilities to demonstrate various communication networks that could be used for meter reading, distribution management, substation data acquisition and control, and other purposes. Building on this effort, EPRI's Telecommunications Initiative is investigating approaches for replacing carrier-provided TDM networks.

One option is for utilities to break away from the telecom carriers entirely and form private networks to acquire and share wireless spectrum. Such private networks would give utilities control over development and operation of this critical asset, but they would require a significant commitment of time and capital.

A second option is to move to telecom carriers' commercial cellular networks and develop ways to help establish reliability, security, and quality of service. In the future, utilities may also consider partnering with a national, high-speed wireless broadband network dedicated to public safety, known as the First Responder Network

Authority (FirstNet). In 2012, Congress allocated a slice of the telecommunications spectrum for FirstNet along with up to $7 billion in funding. But deployment has been slow, and with the sharing model currently planned by FirstNet, utility users could be completely cut off from network access during a natural disaster, terrorist attack, or other emergency.

“That’s a non-starter for some critical applications,” said Godfrey. “Utilities have to know what’s happening on the grid.”

The third option is the most capable, but also the most expensive: Deploy fiber-optic communications networks. According to Godfrey, fiber has the best reliability, has bandwidth that handles the greatest volume of data, and presents minimal technical challenges.

“It’s the Ferrari of telecom,” said Godfrey. “This initiative will look at the utility business case to invest in fiber and ways to use it to create new revenue streams, such as leasing out bandwidth and offering Internet, telephone, and television service to customers.”

A fourth option: Use Internet service providers’ broadband services—which already connect utility customers—to monitor and control rooftop solar, electric vehicles, and other distributed energy resources.

EPRI’s initiative is looking at telecom technologies for all grid applications, including distribution automation, sensors, and metering. Some options may be appropriate for non-critical field- and customer-sited applications, but not as a TDM replacement for critical energy management and SCADA circuits.

Networking Versatility

EPRI will test, demonstrate, and publish guidance on network strategies and replacement technologies. Godfrey expects that EPRI’s work will identify the value that can be extracted from packet-based networks relative to legacy technologies. Many legacy communications systems were designed to support a single function such as billing data collection, capacitor bank control, and substation SCADA. They are not expandable, scalable, or upgradable. Newer packet-based network devices perform multiple functions, have longer lives, and reduce operations and maintenance costs.

It is likely that no single option will offer utilities a comprehensive telecom solution. “The challenge is to select the right combination of technologies and services, whether it be fiber, commercial cellular, licensed spectrum, or unlicensed spectrum,” said Godfrey.

Key EPRI Technical Experts

Tim Godfrey

Technology At Work

‘Can We Talk?’

With New Interface, the Answer for Appliances, Utilities, and Demand Response Will Now Be ‘Yes’

By Garrett Hering

There’s much talk these days about “The Internet of Things”—the vast amalgamation of digital devices, machines, and other “things” that collect and exchange information to unlock new capabilities. For the power grid, such talk focuses on the potential for interconnection among emerging energy technologies to enhance reliability, safety, cost-effectiveness, and efficiency.

But without a common language, the technologies can’t talk to each other, and such opportunities and benefits can be lost in a dense digital Babel.

To help technologies talk and to advance grid connectivity, EPRI is co-developing and demonstrating a new interface, or port, based on a 2013 Consumer Technology Association standard known as CTA-2045 (formerly CEA-2045). The port enables customer appliances to connect to any communication network and receive and execute commands using a common language and mechanical interface. The port makes it possible for thermostats, water heaters, electric vehicle chargers, pool pumps, and other devices to participate collectively in automated demand response programs or other services.

“Coordinated control of intelligent customer devices can help to balance supply and demand by reducing their electricity use during peak periods. It can also lead to lower power prices,” said Chuck Thomas, EPRI technical leader. “We are helping them to speak the same language.”

Refining Prototypes with Manufacturers

In 2015, EPRI launched a three-year project with 23 electric utilities and 14 manufacturers to develop and demonstrate CTA-2045-compliant devices.

Using the standard and functional specifications, manufacturers are developing prototypes of domestic electric and heat pump water heaters, thermostats, variable-speed pool pumps, solar inverters, electric vehicle supply equipment, and packaged terminal air conditioners. They are using EPRI software to support product development and interoperability.

Manufacturers send prototypes to EPRI’s Knoxville facility, where Thomas and his team evaluate them with respect to CTA-2045 and functional specifications. Based on the results, manufacturers provide refined prototypes.

“We go through several prototyping cycles,” Thomas said.

EPRI and participating utilities are evaluating the prototypes’ effectiveness in laboratories and at customer sites. EPRI reports will provide results, recommended changes to the standard, specifications, and product development status.

Approaching Commercialization

One product that EPRI has helped advance to the brink of commercialization is a water heater from a manufacturer that is unnamed for competitive reasons.

“You can’t buy it in retail stores yet, but the company is shipping products to utilities that were manufactured on real production lines, not by hand,” said Thomas.

Development of CTA-compliant pool pumps is also proceeding at a fast pace.

“EPRI’s project is helping to address the chicken-and-egg dilemma with market adoption and product availability,” said Jeff Farlow, program manager of energy initiatives at Pentair Water Quality Systems. “The module allows us to proceed with product development without having to worry about which communication protocol wins the race to mass market adoption.”

Pentair is delivering variable-speed pool pumps for field demonstrations in 2016. While these units are hand-built, Pentair is prepared to transition to CTA-compliant production volumes in coming months if strong demand emerges.

Farlow points out that customers using CTA-compliant pool pumps in EPRI’s field demonstration seldom notice when the devices remotely respond to utility commands.

“It is invisible,” he said.

George Gurlaskie, Duke Energy technology evaluation manager, said that avoiding adverse impacts to customers is critical to increasing their participation in demand response programs. Duke Energy is one of the participants in EPRI’s field demonstrations.

“EPRI’s work with manufacturers to enable demand response, automation, and remote management of devices is giving us more flexibility to design programs that are attractive to our customers,” said Gurlaskie.

Key EPRI Technical Experts

Chuck Thomas

In Development

Customer Energy Savings and Societal Benefits Through Electrification

By Chris Warren

An EPRI effort with 29 electric utilities is pursuing cost savings and enhanced productivity for utility customers through electrification while also providing social benefits such as reduced carbon emissions and improved air quality.

For three years, EPRI and the utilities have identified fossil-fueled technologies that customers could profitably replace with electric alternatives. Prominent examples include forklifts, industrial processes, and airport ground support vehicles. The focus is on technologies that recover investment cost in three years or less.

Strategic, Collaborative Approach

EPRI Senior Program Manager Allen Dennis and his team have identified approximately 460,000 gigawatt-hours of electrification opportunities for the participating utilities over the 30-year lives of the installed equipment. 460,000 gigawatt-hours is about 12.5% of U.S. end-use electricity consumption in 2013 (based on data from the U.S. Energy Information Administration's *Annual Energy Outlook 2015*). Because promising technologies and target customer groups will vary by utility, EPRI staff provides customized assessments for each company. EPRI and the utilities meet regularly to develop electrification strategies.

"If you find something with a short payback that the customer can adopt, you improve his bottom line," said Dennis.

Using EPRI's electrification database, the utilities and their customers can compare costs of common fuel-powered technologies with electric alternatives. "This enables our customer payback analysis," said Dennis. "For example, if a new electric forklift costs $15,000 more than the fossil-fueled version, I have to generate $5,000 a year in savings for a three-year payback."

They also examine market potential for specific technologies. "If 95% of forklifts in a certain market are already converted to electric, then I'm just spinning my wheels," said Dennis.

From Idea to Implementation

The analysis yields a utility case study that details the three most beneficial electrification technologies and their target customers. In two instances, utilities asked EPRI to work with their customers to develop plans to electrify certain industrial equipment. EPRI also is helping utilities develop customer programs and incentives to encourage electrification.

"We support members in many aspects of electrification, from figuring out target technologies to developing programs to implementing technologies," said Dennis. "When we find a good opportunity for energy cost savings, our goal is converting the target technology to electric."

Carbon Reduction and Other Societal Benefits

While the program is aimed at helping utility customers, electrification is also a key element of EPRI's research on carbon reduction strategies. Decarbonizing electricity and then using it to enable greenhouse gas emissions reductions in other sectors is one of the most efficient pathways to a low-carbon economy.

Electrification serves the public interest in several other ways:

- Reduces exposure to exhaust
- Improves worker safety by eliminating open flames associated with fuel-based processes
- Provides enhanced fuel diversity and energy security
- Offers more controllability, precision, versatility, and efficiency compared to fossil-fueled alternatives in many situations

"If an electric technology is good for a customer, it's good for the utility and good for society," said Mark Duvall, director of electric transportation at EPRI.

Key EPRI Technical Experts

Allen Dennis, Sara Mullen-Trento, Baskar Vairamohan, Brandon Johnson

In Development

Innovation at the Speed of Light

EPRI Sheds Light on Opportunities and Pitfalls in Lighting

By Brent Barker

Lighting is one of the most fruitful areas of energy efficiency, a mainstay of utility rebate programs, and among the most innovative fields of electricity research and development. “Currently, some lighting products see as many as five product updates throughout a single year—an innovation rate similar to the computer industry at its prime,” said Frank Sharp, technology research manager of EPRI’s lighting program. “We see a growing array of lighting sources, products, systems, and networks.” The familiar 250-watt high-intensity discharge (HID) street light can now be easily replaced with a 100-watt light-emitting diode (LED) lamp, and for a few extra watts the LED becomes multifunctional—equipped with a camera, speakers, environmental sensors, cell phone booster, and more.

The pace of innovation has ended a long era of product dominance, exemplified by the 100-year run of incandescent bulbs. Predictions of LED dominance by 2025 may or may not pan out. “What’s to say that the next product in the pipeline won’t beat out LED,” said Sharp. “Lighting will continue to offer large energy savings, and by 2035 these savings will be much larger than today.” Indeed, EPRI research has shown that commercial indoor lighting can yield 180 terawatt-hours of savings through 2035. 180 terawatt-hours is about 5% of U.S. end-use electricity consumption in 2013 (based on data from the U.S. Energy Information Administration’s *Annual Energy Outlook 2015*).

EPRI’s AMMP robot evaluates lighting and other factors in indoor and outdoor spaces.

This two-meter integrating sphere in EPRI’s lighting lab is used to evaluate illuminance and other lighting characteristics.

Evaluation of power cycling and lifespan of various screw-in lamps in EPRI's lighting lab.

EPRI's lighting team is charged with understanding the spectrum of lighting technologies—halogen, compact fluorescent (CFL), HID, LED products, light-emitting plasma, and induction, to name a few. Utilities manage an array of lighting programs, ranging from rebates and customized incentives to accelerated replacement, consultation, design, and specialized rates. With so many new commercial products, it is inevitable that some will fail or fall short of manufacturers' claims. Utilities must be progressive and cautious, and EPRI helps them navigate the opportunities and pitfalls.

"Our lab looks at how technologies work in the real world and tests new lighting product claims through use and life cycle evaluations," said Sharp. "Utility company reputations are on the line as they make decisions about lighting products. Further, their ability to meet state-mandated energy efficiency goals is strongly affected by the success of these products."

"Utilities must be progressive and cautious, and EPRI helps them navigate the opportunities and pitfalls."

Key EPRI lighting research areas include:

- **Dimmer incompatibility**. Consumers expect all dimmable lighting products to operate similarly. In 2015, EPRI evaluated 20 different LED lamps when dimmed by 5 different controls. Lamp and dimmer performance varied significantly, depending on the pairing.
- **Networked lighting controls**. Networked controls offer additional energy savings, but performance varies widely by application. EPRI is examining these variations and educating utilities on how to fit controls in customer programs.
- **Linear LED products**. Linear fluorescent lighting is efficient, and it is the most widely installed technology in U.S. commercial and industrial buildings, but LEDs typically offer energy savings of 40% or more. EPRI is evaluating the advantages and disadvantages of four approaches for replacing linear fluorescent with LED.
- **Robotic measurement**. EPRI has developed the Autonomous Mobile Measurement Platform (AMMP) robot, which moves through indoor and outdoor spaces to evaluate lighting performance, thermal profile, electromagnetic interference, and other factors. Results are incorporated in high-resolution maps. EPRI is expanding the range of factors AMMP can evaluate.

- **Next-generation lighting technologies**. Among the new technologies that EPRI is scouting are laser-based lighting, organic LEDs, next-generation incandescent, graphene-based lighting, and ultra-efficient LEDs.
- **Life cycle testing**. At any one time, EPRI's lab is testing more than 60 new lighting products to determine their lifespan.

"There are many good lighting labs out there," said Sharp. "What makes EPRI's lab unique is its zeal for evaluating novel concepts, combined with an understanding of how products function in real-world power conditions."

Lighting for Indoor Agriculture

Indoor agriculture is becoming a major load in some areas. EPRI's agricultural lighting research primarily focuses on how and when to use various lighting and lighting control technologies to maximize crop yields, as well as the operation of indoor agricultural facilities. Modified greenhouses use electric lighting to augment natural light. Converted warehouses use electric lighting 12–16 hours per day, depending on the crop growth cycle. Where growing beds move on a conveyor system, lighting is commonly used 24/7. Agricultural lighting fixtures range from a few watts to a few thousand watts, with some designed to emit specific wavelengths depending on the crop. Spinach, for example, responds to different wavelengths than kale. EPRI recently published an industry outlook for lighting applications in indoor agriculture.

Key EPRI Technical Experts

Frank Sharp, Doug Lindsey

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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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 | PO Box 10412, Palo Alto, California 94303-0813 | USA
800.313.3774 | 650.855.2121 | askepri@epri.com | www.epri.com