

## FLIPPING THE SWITCH



### ALSO IN THIS ISSUE

Water Chemistry in Nuclear Power: Smarter, Automated, Precise  
Learning by Doing

Protecting Groundwater at Coal Combustion Product Facilities

Electric University

A Blueprint to Electrify the Golden State

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## Flipping the Switch



### *New EPRI Initiative Aims to Unleash Electrification's Enormous Potential Benefits for Society*

**By Chris Warren**

As the United States prepared to enter World War I in 1917, most American households, including the wealthy ones, lacked running water and a telephone. What happened in the ensuing 100 years to transform elusive luxuries into basic necessities? A big part of the answer: widespread availability of electricity and steadily advancing end-use technologies to harness its power.

“As we improved the quality of life in the American home through technology, we have increased electricity use,” said Mark Duvall, director of energy utilization at EPRI. “In the kitchen, refrigerators replaced iceboxes and electric stoves replaced wood-fired stoves. We added appliances, TVs, and other connected loads that made the house a cleaner, more comfortable place to live.”

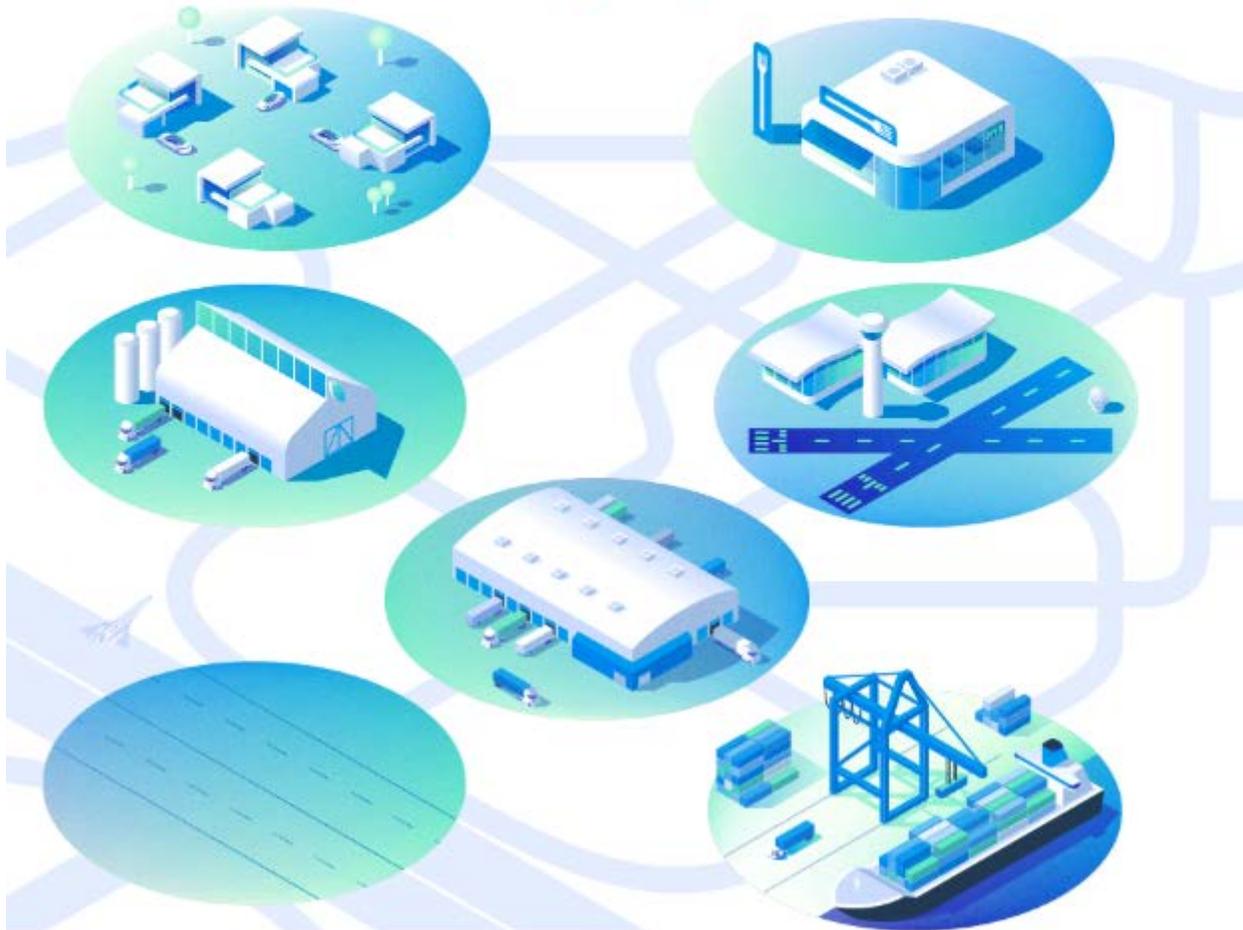
Today, new momentum is building for electrification to extend its reach and its benefits. In the residential, commercial, industrial, and transportation sectors, customers are switching technologies such as automobiles, forklifts, and furnaces from direct combustion of fossil fuels to electricity. The switch to electric vehicles (EV) illustrates benefits that are common across the board.

“If I buy a vehicle with an internal combustion engine today and drive it for 11 years, society will never realize any air quality or carbon improvements during that period,” said Rob Chapman, vice president of EPRI’s Energy and Environment Sector. “Compare that with a vehicle powered by the electric grid. Since 2000, the electric power sector has reduced emissions of criteria air pollutants by 80% and carbon dioxide by 20%. If we continue to ‘green’ the electric supply and make the grid more dynamic and flexible, EVs get cleaner the longer you have them.”

# An Electrified World

The core idea behind EPRI's Efficient Electrification Initiative is that more widespread adoption of electric technologies can deliver significant environmental, economic, and productivity benefits to individuals and society. What could increased electrification look like in America's homes, businesses, farms, airports, and ports?

**Click on the images of an electrified city of the (not so distant) future to learn more.**



Click [here](#) to enter this interactive graphic about electrification.

Even as society's energy appetite grows, electrification points to new, diverse uses and benefits. EPRI estimates that Southern Company avoided approximately 5,000 tons of nitrogen oxide, sulfur oxide, and carbon dioxide emissions by choosing electric equipment instead of diesel to dredge at the Port of Mobile, Alabama.

Often, the most significant challenge to lower bills and a cleaner environment is that utility customers don't know what's possible with electrification. With support from EPRI, utilities have added a new component to their customer engagement strategies—identifying electric technologies that could save money for commercial and residential customers and educating them about these and other benefits.

## The Efficient Electrification Initiative

According to the U.S. Energy Information Administration, today about one-fifth of America's final energy consumption is electricity, with the rest coming from direct combustion of fossil fuels such as coal, natural gas, and petroleum. The U.S. Department of Energy has chronicled how the burning of fossil fuels has provided more than 80% of the nation's energy for the past 100 years, enabling the first wave of electrification that provided running water, lit up homes, and switched on radios and TVs.

EPRI's wide-ranging Efficient Electrification Initiative aims to describe and enable the economic, environmental, productivity, and other improvements that individuals and society can realize through electrification using advanced power systems and end-use technologies. Launched in 2017, the initiative takes an in-depth, fact-based look at the benefits and costs of far greater electrification, analyzing scenarios in which up to 50% of energy end use comes from electricity by 2050. Participants include utilities, policymakers, regulators, manufacturers, consumers, and other energy sectors.

EPRI spearheaded the initiative as an extension of its [Integrated Energy Network](#), which describes a future with an integrated "system of systems" for electricity, water, natural gas, and transportation, along with a pathway to get there. The Integrated Energy Network encourages collaborative, innovative thinking to tackle the challenge of delivering cleaner, affordable, reliable energy to a global population expected to reach 10 billion by the end of the century. Efficient electrification will be instrumental in achieving this.

### Drivers: Cleaner Grid, Advancing Technology, Customers

As innovative electric technologies are adopted along with significantly improved traditional technologies, the time is right for a closer examination of widespread electrification. Again, EVs are instructive. To become mainstream, electric cars, trucks, and buses need affordable batteries that enable significant driving range—and an enormous scope of research focuses on this. EPRI projects that EVs will reach price parity with internal combustion vehicles within the next five years.

As the penetration of natural gas and renewable energy technologies grows, the electric supply's carbon footprint declines. Also, the grid is becoming more efficient through the interconnection of advanced sensors, automation, and communication devices.

"There will be as much technological change in the next seven years as what occurred over the past 30 years," said Chapman. "These advances will occur in electric supply, grid, and end-use technologies. A more dynamic, flexible grid will help tap the potential of these technologies."

Electrification also is growing as a result of policy and corporate trends. Currently, U.S. cities and states have maintained or deepened their commitments to reduce greenhouse gas emissions and deploy renewable energy. California's 2030 targets include 50% of electricity from renewable sources and a 40% reduction in greenhouse gas emissions. To help achieve carbon reductions and improve air quality, the state is looking at cross-sector solutions that include transportation electrification. Large companies such as Google, [IKEA](#), and Walmart have committed to procure a large portion (in some cases, 100%) of their energy from renewables.

Customer attitudes and priorities also propel EPRI's initiative, even as they choose from expanding options in rooftop solar, EVs, smart thermostats, and numerous other end-use technologies.

"Residential customers want options, flexibility, and the ability to manage and control energy expenses," said Chapman. "Commercial and industrial customers want these as well, and they recognize that energy flexibility can translate into greater affordability, productivity, and safety."

## A Focus on Analytics, Technology, and R&D Collaboration

Analytics encompasses modeling, simulation, and other data analyses to quantify the implications of widespread electrification.

“If you’re talking about how electrification benefits the consumer and society and leads to a cleaner environment and more affordable energy, you can’t say that without the analytics to support it,” said Chapman. “Our analytics team is looking at macroeconomic trends and scenarios for future carbon emissions to understand the impacts that increased electrification can have on air, water, and energy efficiency.”

In April 2018, EPRI released its [National Electrification Assessment](#) examining societal, customer, and utility impacts of 50% electrification by 2050. The analysis is based on EPRI’s recently updated U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model.

“Over the past two years, we developed a very detailed model that equips us to track the consumption of energy by fuel and technology across the transportation, residential, commercial, and industrial sectors,” said Francisco de la Chesnaye, an EPRI senior program manager who is leading the analytical work. “The study’s key finding: Across a range of assumptions, economy-wide electrification leads to a significant reduction in energy consumption, spurs steady electric load growth, increases grid efficiency and flexibility, and reduces greenhouse gas emissions—even when there is no assumed climate policy.”

In 2018, EPRI will begin similar assessments of the impacts of expanded electrification for states and utility service areas (see box at end of article).

More widespread electrification depends on technological innovation. EPRI researchers collaborate with companies, national laboratories, and utilities to establish a pipeline of early-stage efficient electrification technologies. As these technologies prove their potential in the laboratory, they are put in the field as part of utility demonstration projects.

“We are focused on the devices that utility customers own, such as EVs, energy-efficient appliances, zero net energy houses, and energy storage,” said Duvall. “We’re accelerating our R&D in these areas and examining technologies that aren’t being addressed currently.”

New EV research includes an examination of consumer expectations regarding the availability of public fast-charging infrastructure. The results will help guide utilities, automakers, regulators, and policymakers as they make investment decisions about the type and number of charging stations necessary to make consumers comfortable purchasing EVs.

Electrified indoor agriculture has the potential to move food production closer to consumers and cut water use by 95%.

“Most areas of the country don’t grow their food year-round. Indoor agriculture could eliminate the land and climate barriers—making it possible to grow tomatoes during a Wisconsin winter,” said Duvall. “Think of the enormous reduction in transportation costs and emissions if 50% of the produce for New York was grown within 10 miles of the city. EPRI is monitoring demonstrations to validate environmental and productivity claims and better understand electricity demand.”

EPRI is working with member utilities to identify how they can help residential and commercial customers reap the benefits of electrification. Often, it’s a matter of pinpointing how a customer can benefit by adopting a specific technology. In many cases, customers simply don’t know how and where electrification can save them money or reduce pollution.

“The Efficient Electrification Initiative can provide opportunities to educate customers more broadly to understand the costs, benefits, and obstacles to adoption,” said Duvall.

In 2018, EPRI will develop an electrification R&D roadmap and begin an electrification cost-benefit assessment.

In August 2018, EPRI will host an [Electrification 2018 International Conference & Exposition](#) in Long Beach, California—a forum for utilities, government agencies, nonprofits, and other energy companies to share experiences and insights and learn about EPRI research findings. This will become an annual gathering to sustain momentum and chart a path forward. Stakeholders can identify avenues for collaboration, technologies requiring additional research, and policies that need to be formulated or reconsidered.

“Let’s bring all the stakeholders together and make the research transparent,” said Chapman. “We provide our unbiased research and facilitate the conversation. This is a key part of the initiative because so many people are interested in the benefits of electrification relative to other forms of energy.”

### Dialing into State-Level Electrification

EPRI’s recent [National Electrification Assessment](#) found that economy-wide electrification leads to a large reduction in energy consumption and greenhouse gas emissions as well as significant improvements in grid efficiency and flexibility.

For a more detailed look at the opportunities and challenges, EPRI is using the U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model for state- and utility-level electrification assessments. “The results of the national assessment serve as a starting point for our work at the state and utility level,” said EPRI Senior Program Manager Francisco de la Chesnaye.

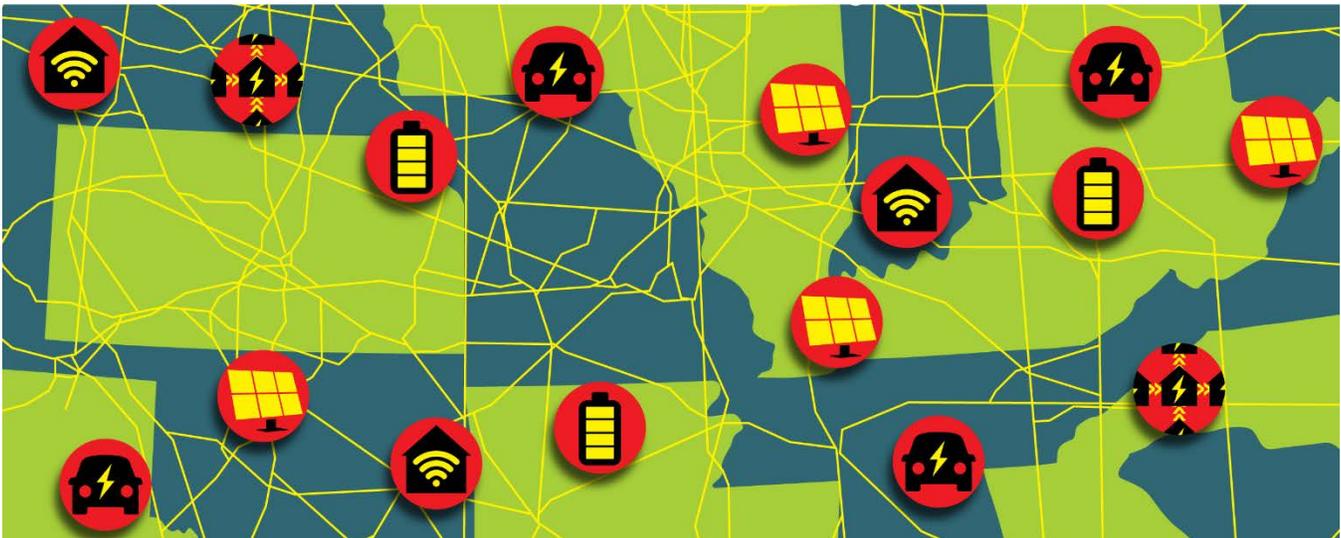
The results will vary by state and utility service area. “Just as the electricity generation mix varies by state based on fuel prices and energy and environmental policies, energy consumption also varies,” said de la Chesnaye. “Over the next 5, 10, or 15 years, these assessments can provide electric utilities, policymakers, and regulators with actionable insights on critical issues such as capacity expansion.”

For example, de la Chesnaye points to the increase of electric vehicles that may result from a combination of state policies, consumer choice, and technology advances. When more electric vehicles are charged at night, state-level assessments can illustrate the potential impact across an energy system. “We can assess where that energy comes from,” he said. “How much will be from wind generation? Will baseload power plants have to cycle more, ramp up and down, or shut down? What are the implications for transmission?”

### Key EPRI Technical Experts

Mark Duvall, Francisco de la Chesnaye

## Learning by Doing



### *Two-Plus Years of Integrated Grid Pilots Have Yielded Important Lessons*

**By Chris Warren**

When EPRI launched the [Integrated Grid](#) initiative in 2014, it highlighted the need for a grid that integrates all resources, from large power plants to the smallest of distributed energy resources (DER). To help the industry move toward a well-functioning integrated grid, EPRI researchers have emphasized the importance of hands-on experience with solar photovoltaics (PV), energy storage, microgrids, and other technologies.

“Demonstration projects with utilities are key opportunities to address gaps between theory and implementation in advancing these technologies,” said EPRI Senior Project Engineer Steven Coley. This understanding prompted EPRI and its members to initiate more than two dozen [Integrated Grid pilot projects](#) in the U.S. and internationally.

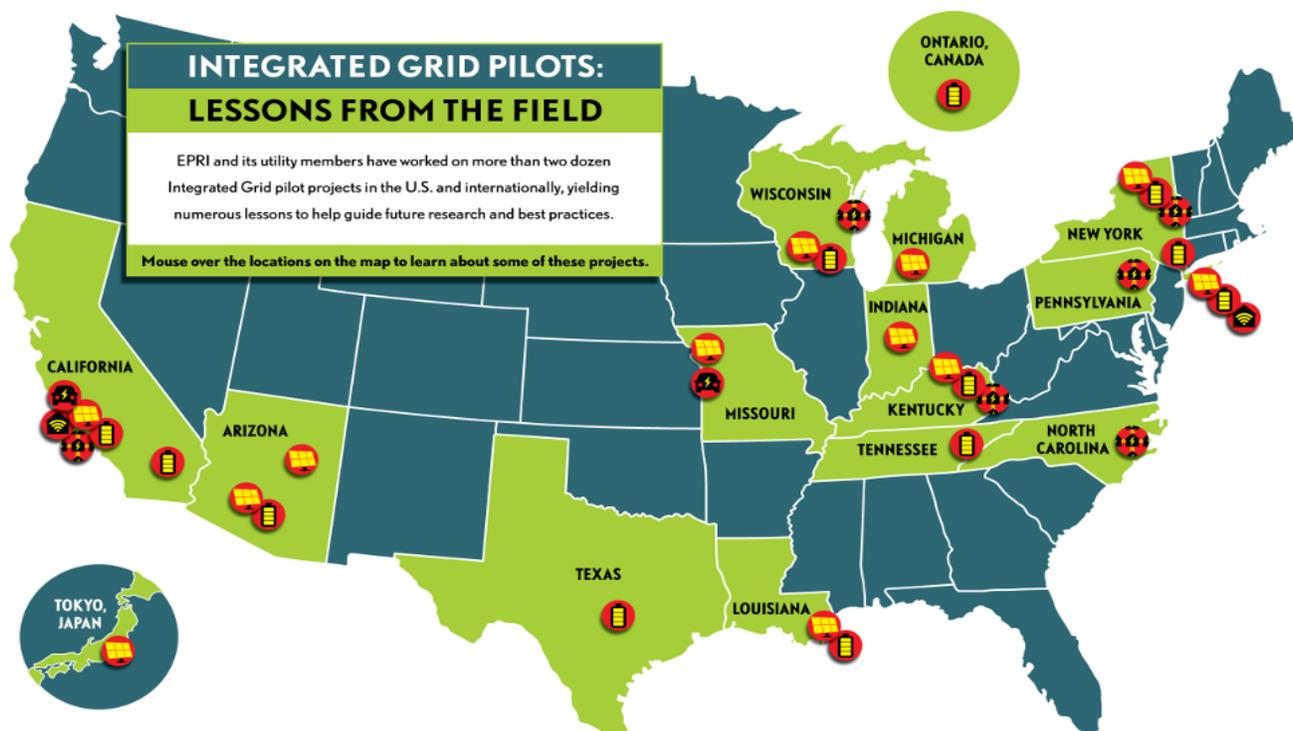
More than two years of field work have yielded numerous lessons that will help guide future research and best practices for integrating DER. Here, we describe several insights, grouped according to the four-part action plan in EPRI’s Integrated Grid [concept paper](#).

#### **Interconnection Rules and Communications Technologies and Standards**

In an integrated grid, large numbers of solar panels, smart inverters, energy storage, and other technologies need to mesh seamlessly with utility operations. “Common languages and open protocols reduce the complexity of coordinating distributed resources,” said Coley. “But we are finding that there is limited deployment experience, and customized control configurations are used, so there is still a lot of room for improving and streamlining the process.”

Louisville Gas and Electric experienced a problem with its deployment of energy storage because its vendor’s technology did not originally communicate properly with grid operations, and a unique system-control topology had to be developed and implemented. This type of case-specific fix underscores the need for more coordination between utilities and DER vendors.

“Too often, customized solutions are needed to achieve suitable control of DER—an approach that is not streamlined enough for broad deployment,” said Coley.



Click [here](#) to enter this interactive graphic.

EPRI has been heavily involved in the efforts of the IEEE Standards Association—in collaboration with DER vendors and developers, distribution and transmission utilities, researchers, and other public stakeholders—to develop and revise the IEEE 1547 standard, which governs the interconnection of DER. The revised standard is expected to take effect in 2018 and requires that DER have at least one means of open communication.

“Most of our pilot projects have demonstrated the necessity of updated interconnection standards,” said Dr. Ben York, technical leader in EPRI’s Distributed Energy Resources program. “The standard’s development is being informed by our experience with the pilots.”

Over the past four years, EPRI’s technical expertise and thought leadership have contributed to a successful, timely revision of the standard.

“An example of this is EPRI’s 2015 white paper on low-voltage ride-through, which helped stakeholders on the standard’s working group better understand this highly technical topic and reach consensus on new requirements for this function,” said Dr. Jens Boemer, a senior technical leader in EPRI’s Grid Operations & Planning program. Adequate ride-through requirements for DER help to maintain power system reliability and keep the lights on, even with extremely high levels of DER connected to the system.

Because the previous version of IEEE 1547 lacked a common approach to communications and grid support, it is a challenge for utilities to communicate with DER installed on the distribution grid, leading to reduced awareness of grid conditions and potential system reliability risks.

“Every time you connect a new inverter to the system, you have to learn a new language. It’s like having to learn French or Spanish every time you want to talk to a different inverter,” York said. “If you have 10 different

inverter manufacturers, you have to learn 10 different languages. What ends up happening is that utilities don't communicate with any of them."

Through activities such as presentations at IEEE conferences and public utility commission hearings, EPRI plans to educate the industry and all interested stakeholders about the revisions to the IEEE 1547 standard as they are rolled out.

"Our education is vital so that the standards are interpreted and implemented appropriately," said Coley.

### **Assessment and Deployment of Advanced Distribution and Reliability Technologies**

The pilots are examining how several technologies perform in actual operating conditions on distribution circuits. Confirming prior EPRI modeling work, the Arizona Public Service pilot demonstrated that smart inverters—by providing voltage support—can help address technical challenges that limit the safe interconnection of solar power. The project also showed that allowing smart inverters to adapt certain functions autonomously produced the most benefit to the grid. The inverters provided voltage support without noticeable impact on solar energy production.

"Even during hot Arizona summers, the temperature varies widely throughout the day. As air conditioning ramps up, voltage support from inverters needs to adapt," said York. "The Arizona Public Service project showed us that sizing your inverter even slightly larger than the amount of solar power that comes through it can create big opportunities for grid support."

### **Strategies for Integrating DER with Grid Planning and Operations**

Pilots with Southern California Edison (SCE) and Hydro One are exploring how the sizing, location, and control functions of distributed energy storage systems impact grid planning and operations.

"EPRI is working with these utilities to develop a framework that can help them extract the most benefit from these resources," said Coley. "We're evaluating various scenarios, including one in which the utility controls where the storage is located and how it operates and another in which utility customers have all the control."

Both projects have shown that there are no simple answers about optimal location and operations of storage. Utilities must evaluate the trade-offs for each case. For example, locating storage near the end of a feeder near load might significantly reduce capacity constraints, benefiting distribution grid operations.

"However, if you want to maximize the value of the storage at the bulk transmission level, you may want to locate it closer to the substation, where its output is not as constrained by the distribution feeder. This could yield greater returns from interacting with the wholesale markets," said Coley. "Utilities need to determine where the value is higher and assess capacity constraints in the distribution system. It can be difficult to balance these considerations."

In Michigan and Indiana, American Electric Power connected four PV plants to its distribution grid and estimated that in one month of operation, snow on the panels reduced power generation from one of the four plants by 20%. This finding has implications for how utilities interpret results from solar plant performance models and how they account for snowfall—a known source of error.

"The performance models estimated energy output to be plus or minus 5% of actual production. But in the snowy winter months, energy generation can vary a lot more," said Coley. "Utilities need to consider the reality that snow can drastically affect performance and adjust their planning accordingly."

## Enabling Policy and Regulation

While EPRI does not advocate for specific policies and regulatory frameworks, the pilot projects are designed to provide policymakers with research and data to inform good decisions.

“For each demonstration project, we are documenting costs, benefits, grid constraints, and other relevant information for policymakers,” said Coley. “We’re also demonstrating how the application of EPRI’s Integrated Grid benefit-cost framework can inform policymakers and regulators.”

The utilities WEC Energy Group and PECO are using the benefit-cost framework to evaluate proposed microgrids. In these microgrids, DER would serve local loads and provide electricity to communities when weather or other emergencies disrupt transmission and distribution systems.

“Through these feasibility studies, we learned that a clear understanding of the objectives for the specific microgrid application is important in finding the most value,” said Coley. “Each microgrid is different, and there are many case-specific factors that drive what is and isn’t valuable.”

The PECO study evaluated a utility-integrated, community microgrid that would deliver electricity to medical centers, shelters, a fire station, and other essential service providers during a utility outage. The study led to important insights on microgrid sizing and design, required distribution system reconfigurations, customer energy use, costs, and benefits. PECO withdrew its regulatory filing on the project as a result of a lack of statutory clarity regarding ownership of some microgrid assets. Now, the utility is engaging with legislators and regulators to help establish a statutory and regulatory framework to guide microgrid development in the state. All these experiences and lessons are informing PECO as it embarks on a new microgrid project, with EPRI serving as a technical advisor.

With funding support from New Energy and Industrial Technology Development Organization, Tokyo Electric Power Company Holdings, Inc. (TEPCO) is conducting research to help integrate large amounts of PV in Japan. EPRI is providing technical support to TEPCO. “The initial focus was how the grid responds to excess solar and how to manage that,” said York. “It has since morphed into understanding all the potential benefits of inverter technology in managing solar energy.”

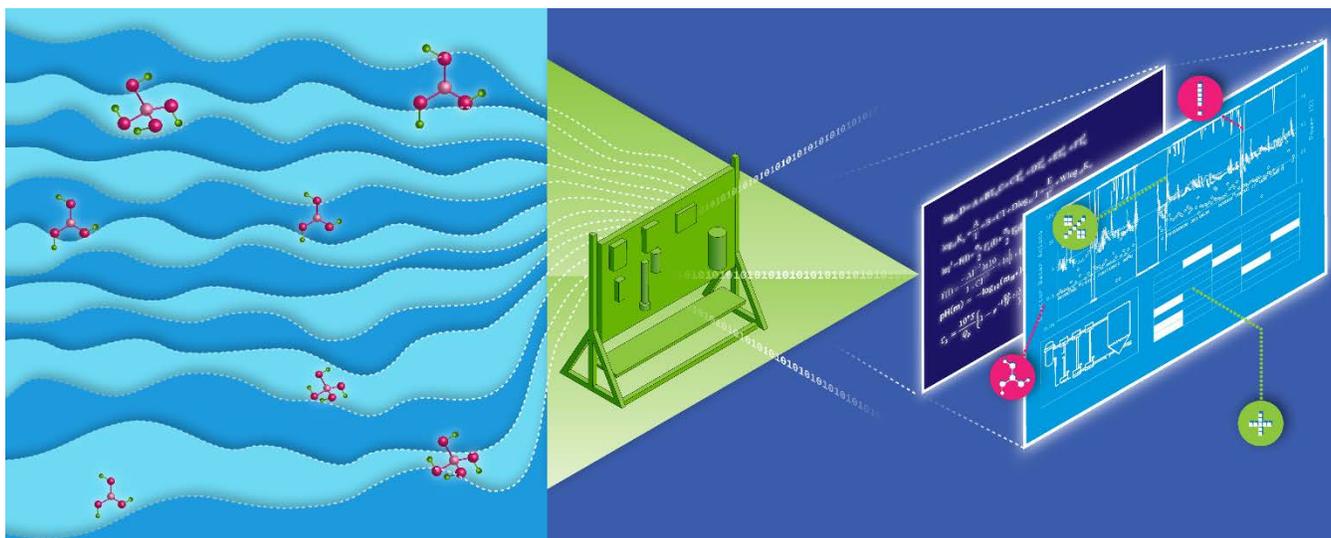
One lesson is that the challenges and benefits of integrating solar into the distribution and bulk power grids depend on how much is interconnected. In some cases, modest amounts of solar can improve grid management while larger amounts may pose grid management challenges.

“We are learning about a lot of the technical issues that come from high levels of solar,” said York. “International experience helps everyone understand the role technology and policy can play in making DER integration as smooth as possible.”

## Key EPRI Technical Experts

Steven Coley, Ben York

## Water Chemistry in Nuclear Power: Smarter, Automated, Precise



### *Field Demonstration Pursues Better Information with Fewer Resources*

**By Brent Barker**

Forty years ago, when many of the nuclear power plants in the United States began operating, plant water chemistry was monitored by technicians who drew water samples manually, then walked them back to the laboratory for analysis, trending, and recording. This occurred at regular intervals, ranging from every 4–6 hours to once a day to once a week, depending on the parameter or chemical being measured.

For the most part, it's still done that way, relying on significant resources while providing infrequent data that requires assumptions and informed guesses about conditions between measurements. Conservatism is built into operational guidelines to help compensate for an incomplete picture of water chemistry.

All that could change with EPRI's Smart Chemistry initiative, which has slated a major demonstration in 2018. "If we can send a rover to Mars to pick up samples, do chemical analysis, and beam the results back to Earth, we should be able to automate nuclear water chemistry," said EPRI Senior Program Manager Lisa Edwards. "We are on the verge of a new era in water chemistry. Through automation and smart analytics, we can provide better information with fewer resources and rethink our operational guidelines."

#### **Chemicals That Matter**

In nuclear plants, water chemistry programs measure dozens of parameters and chemical constituents that interact with each other and with plant materials. For example, plant chemists are concerned about the levels of anions (such as chloride and sulfate) that can lead to cracking of major components. Radioisotopes are tracked because they can indicate problems such as a leak in the fuel cladding. Corrosion products can impact heat transfer efficiency and, when activated, can expose workers to radiation. Additives are also monitored and controlled. These include boron (which impacts the core's reactivity), zinc (which can reduce corrosion products and radiation fields), and amines and alkalis (which help manage pH).

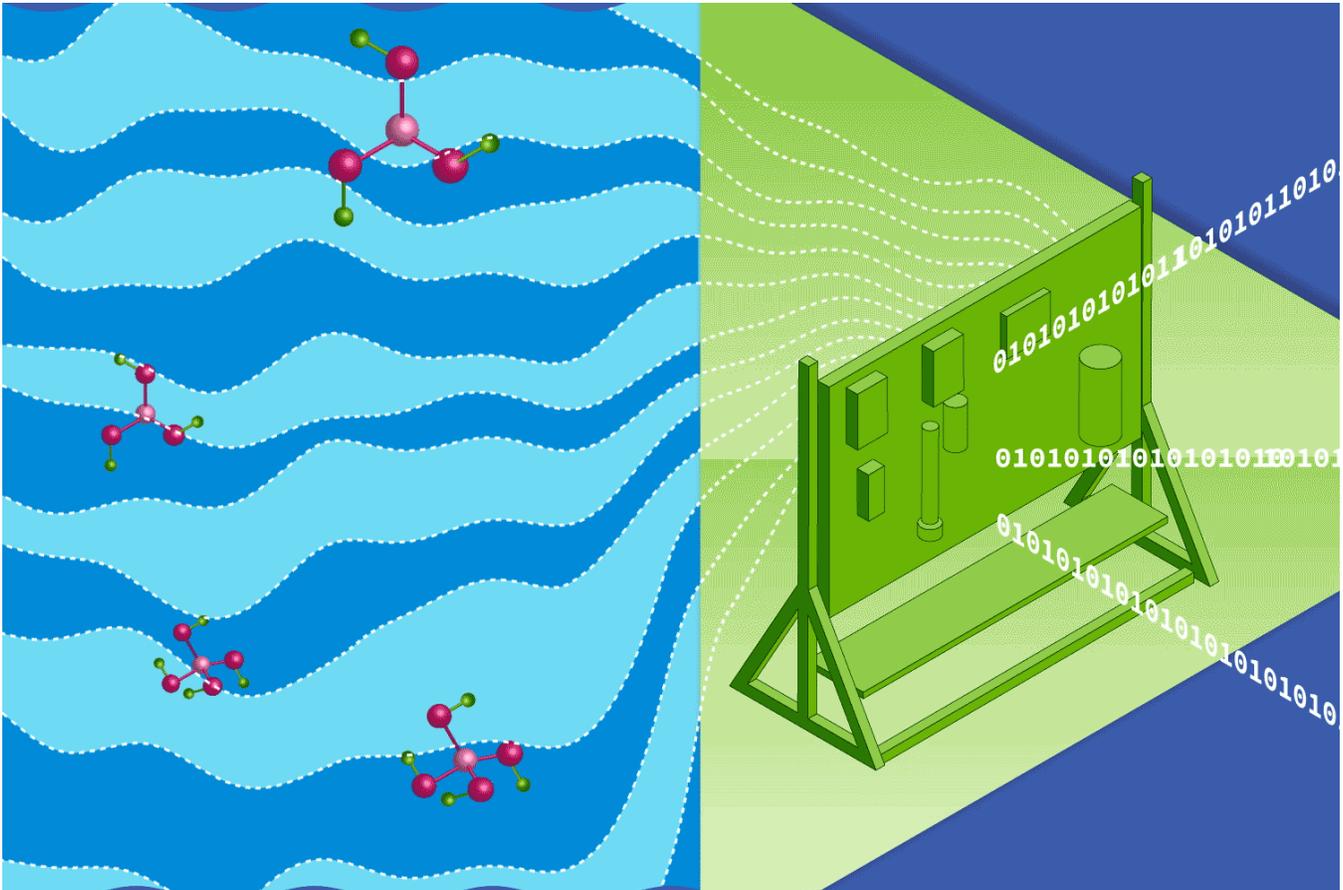
Smart Chemistry addresses the three main objectives of water chemistry control in nuclear power plants:

- Materials integrity—prevent degradation of the metals in the reactor pressure vessel, piping, steam generator, and other key components.
- Fuel reliability—optimize fuel performance and protect the fuel cladding.
- Worker safety—reduce radiation fields outside the reactor core.

While the important constituents are currently monitored (see sidebar), the frequency of sampling remains an obstacle to more detailed knowledge of water chemistry. Consider two manual measurements of chemical X taken one week apart that are quite different—the first low, the second high. Which is more indicative of the plant’s chemistry? Is the first an outlier? Is the second a brief spike?

“With nothing else to go on, we have to make the most conservative assumption that the level of chemical X was high the entire week,” said Joel McElrath, project manager of the Smart Chemistry Initiative. “If we increased the frequency to hourly or daily, we’d have a much better picture of how things are changing, and the accuracy of assumptions would improve. However, more frequent manual sampling requires more labor and becomes cost-prohibitive.”

That’s where smart chemistry comes in. Its automated sampling provides better information without expending additional resources.



“With more frequent data, you have a better picture of reality,” said Dan Wells, who manages EPRI’s Chemistry Program. “You can better understand your margin for harming plant materials, impacting fuel operations, and increasing radiation fields.”

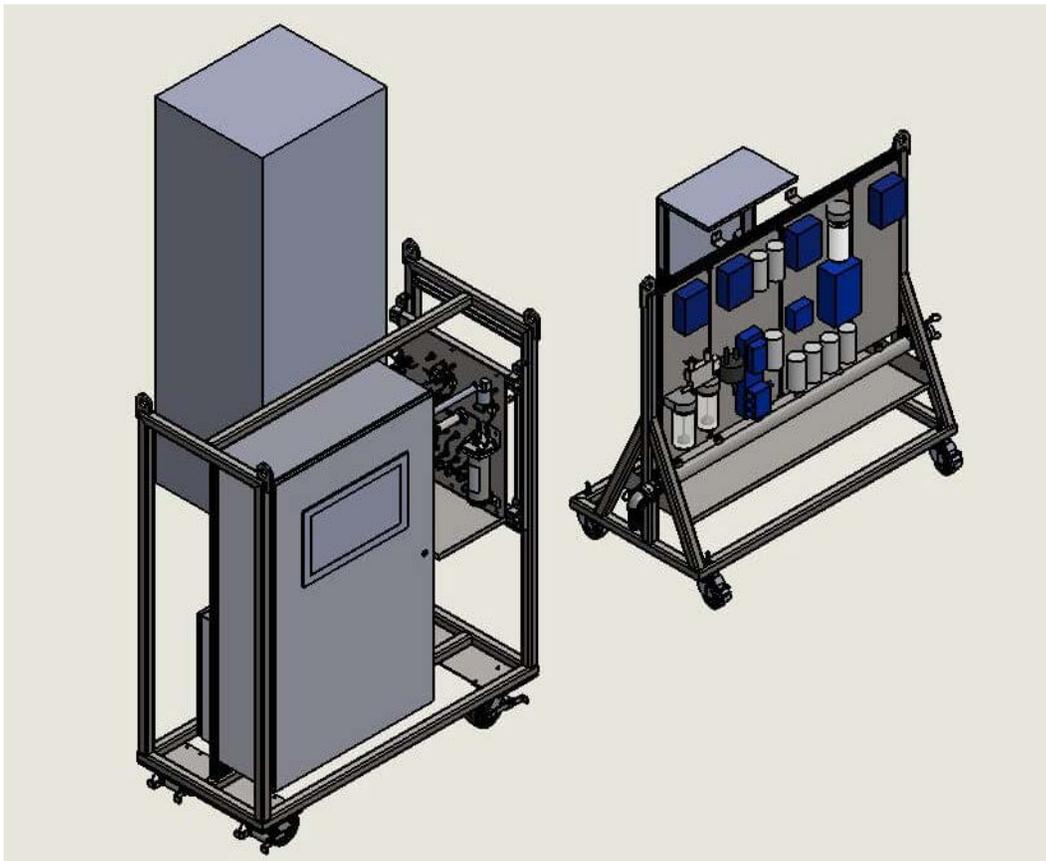
“In many cases, the real concern is about the condition of plant materials, which are not affected by just one event,” said Edwards. “They are affected by prolonged exposure to contaminants. But because we still take samples periodically, we have to assume the worst about what happened between the samples. The path forward is automation, which provides more frequent sampling and minimizes the need to make those assumptions.”

### 2018 Demonstration of Smart Chemistry Automation

After years of planning by EPRI and its utility members, a comprehensive demonstration of water chemistry automation is now underway. Researchers have built three skids, each about 4.5 feet long and 1.5 feet wide and capable of housing up to eight instruments for automated inline measurement of various chemicals and parameters.

Each skid operates independently. One measures water streams from the reactor coolant system, one is for the steam generator blowdown system, and one is for the main feedwater system. On each skid, the water stream flows through a line with branches to each of the instruments.

Additional equipment on the skid will capture and analyze the readings. For future applications, the skids will be connected through wires and wireless technology with the plant’s data acquisition system.



Each skid in EPRI’s demonstration consists of separate modules for various instruments, conditioning of water samples, and data acquisition. This is a design drawing of one of the skids.

In 2018, the three skids will be tested in up to four power plants, beginning with the Salem Nuclear Power Plant in New Jersey. After completing a two- to three-month demonstration at Salem, EPRI plans to move the skids to other plants in pairs or individually.

“The purpose of the demonstration is to prove to the industry, including new nuclear power plant designers, that the current state of technology is sufficient to generate the water chemistry data and analysis that plants need for reliable operation,” said McElrath. “It will allow us to see these instruments perform in operational power plants, identify the instruments’ shortcomings, and then develop any needed improvements.”

Paul Frattini, EPRI senior technical executive, led the effort to identify and purchase the demonstration’s inline instruments. “We pulled together industry experts and walked through every instrument and measurement required for water chemistry control,” he said. “We made sure that we could buy the instrument and that it could make the required measurement inline. If such an instrument was not commercially available, we explored or developed alternatives.”

A key objective is to examine the cost of maintaining the instruments. “Twenty years ago, some nuclear utilities bought ion chromatography instruments for water chemistry analysis and deployed them for field trials. They required a lot of staff time for maintenance and were not cost-effective,” said Wells. “In our demonstration, we’ll collect information on the maintenance costs of these instruments. If some require too much care, we’ll innovate to drive the maintenance cost down.”



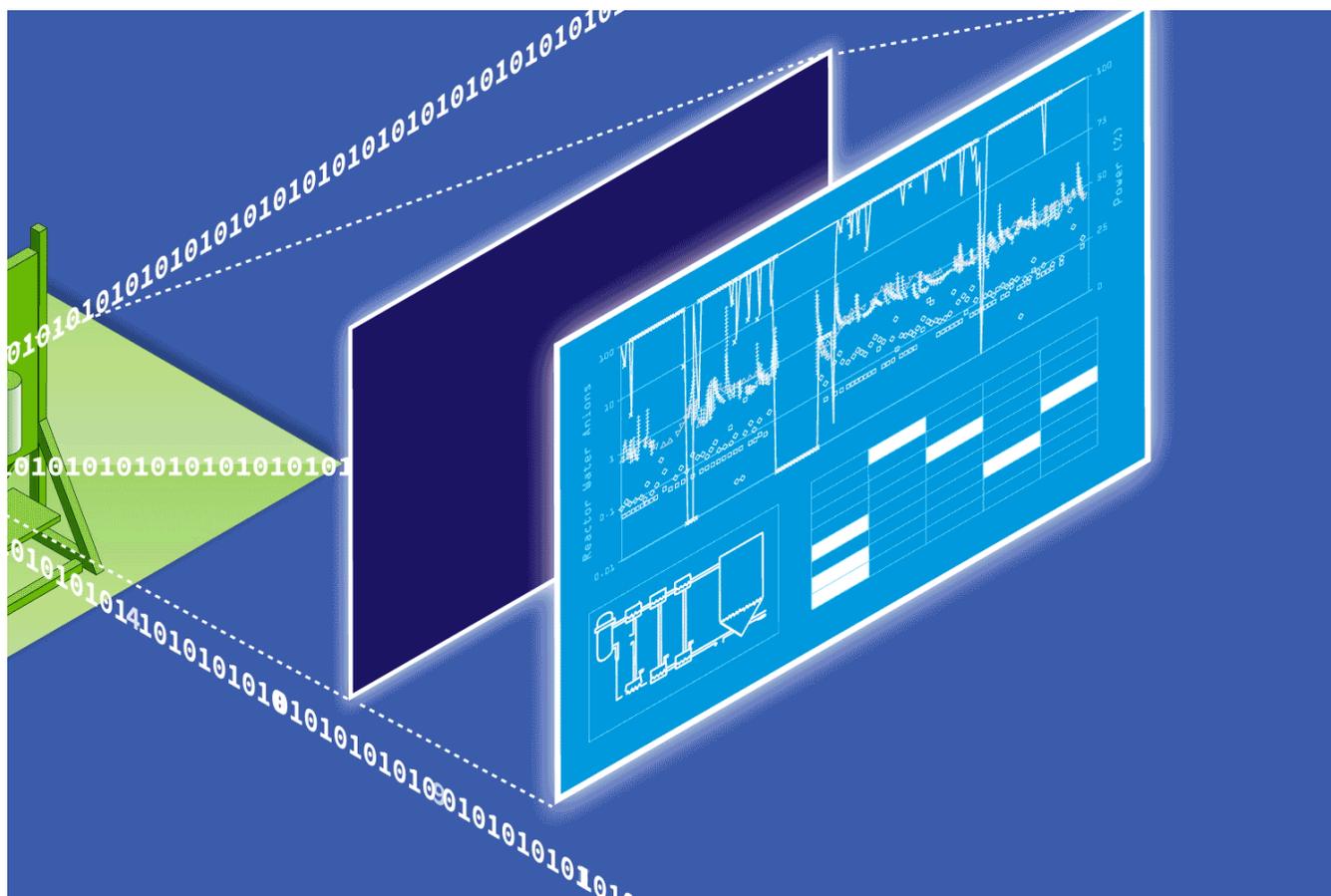
A cart of instruments for EPRI’s Smart Chemistry demonstration.

## Analytics and Guidelines

For automated water chemistry data collection to be useful, the data must be processed and analyzed.

“Automation is just the first part of it,” said Edwards. “As instruments and sensors collect a flood of data, you need smart analytics to interpret the information. This enables plants to identify incipient events earlier and take action faster.”

Smart analytics also can bring a more integrated perspective to water chemistry. “We will be able to look at multiple parameters at the same time,” said Wells. “Rather than focusing on whether the levels of individual chemicals reach thresholds, we may be able to rely on a combination of factors—the cumulative exposure to multiple chemicals over a longer period. In addition, we may find that we don’t need to monitor all the things we used to.”



## An Opportunity to Reimagine Chemistry Guidelines

Today, most of the nuclear industry uses EPRI’s water chemistry guidelines, which are based largely on thresholds. “Our operating experience and engineering analysis tell us that exposure to certain contaminant levels over a certain period can lead to degradation of plant materials,” said Edwards. “Currently, the EPRI chemistry guidelines contain limits based on concentration thresholds, also known as action levels. So, for a plant sample in which a contaminant exceeds a certain concentration, a specific action is taken. ‘Action level one’ may be to clean up the contaminant. Higher levels may involve reducing the plant’s power.”

“With better information and analytics, we may be able to reimagine the water chemistry guidelines,” said Edwards. “In some cases, it may be more suitable for the limits or action levels to be based on an ‘integrated exposure’ to many chemicals over a longer time, rather than on a single sample or limited set of samples. Advanced analytics could be used to calculate such an exposure. For example, a plant that operates for an entire fuel cycle with very low contaminant levels may be well-protected even if a short-term elevation occurs.”

“With automation technology combined with data analytics, we can discern combinations of impurities developing across the plant and indicating a risk to materials, fuel, or radiation management,” said Frattini. “Based on such patterns, the guidelines could signal a set of actions to correct the situation.”

### **The Path Forward to Smart Chemistry**

Next steps for the Smart Chemistry Initiative include incorporating lessons from the demonstration, closing technology gaps, working with vendors to fine-tune the instruments, developing a cost-benefit analysis, optimizing maintenance, enhancing analytics, and revising water chemistry guidelines.

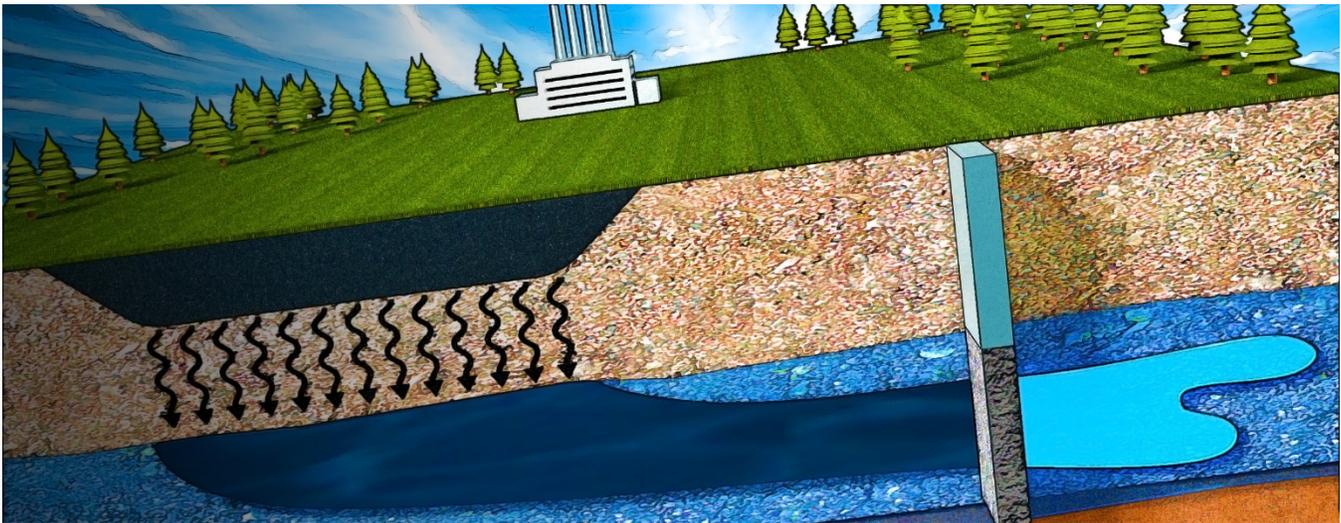
A full-scale demonstration and rollout of automated water chemistry are targeted for 2021. “We’re going to do a final demonstration in 2021, applying everything we have learned since this year’s demonstration—optimized instrumentation, improved analytics, and more effective operational guidelines,” said McElrath.

“The purpose of this three-year project is to apply better information to water chemistry control with fewer resources,” said Edwards. “We’re approaching this comprehensively, with a methodical plan and a solid vision. The project pursues the nuclear industry’s important objective of reducing cost, and it puts us on a path to have better water chemistry information on which to base operational decisions.”

### **Key EPRI Technical Experts**

Lisa Edwards, Dan Wells, Joel McElrath, Paul Frattini

## Protecting Groundwater at Coal Combustion Product Facilities



### *EPRI Examines Alternative Technologies for Groundwater Remediation*

**By Tom Shiel**

Each year, coal-fired power plants in the United States produce more than 100 million tons of coal combustion products (CCPs). These include fly ash (fine particles), bottom ash and boiler slag (coarse particles that form in the bottom of a coal furnace), and flue gas desulfurization solids.

About half of these materials are reused for products such as wallboard and concrete and in applications such as road base, saving on the use of other materials, reducing greenhouse gas emissions produced by other processes, and often providing superior performance. The remainder is managed in landfills and impoundments. CCPs can contain soluble salts such as calcium and sulfur along with trace elements such as arsenic, boron, molybdenum, and selenium. If water enters a landfill or impoundment and is not captured by a liner or leachate collection system, these elements can be released to groundwater.



A coal combustion product impoundment.

In 2015, the U.S. Environmental Protection Agency (EPA) published a [final rule](#) regulating the management, disposal, and beneficial use of CCPs. As part of provisions to address risks associated with releases to groundwater, the rule provides criteria for determining whether a release has occurred as well as timelines for corrective actions. (Other provisions deal with the design, operation, and closure of CCP landfills and impoundments.)

In anticipation of the groundwater requirements, EPRI has been researching remediation technologies that can help utilities implement corrective actions at CCP landfills and impoundments.

### Enforcement Through Citizen Suits and State Programs

The 2015 federal rule gave utilities until October 2017 to collect groundwater monitoring data at their landfills and impoundments. Now they are using the data to develop strategies for complying with groundwater standards.

Under the 2015 rule, citizens can enforce compliance by filing lawsuits under the federal Resource Conservation and Recovery Act. Subsequent federal legislation clarified that states can develop permit programs to implement the federal rule. In addition, many states have their own requirements that predate the federal rule and continue in effect. The federal rule requires that utilities annually publish their groundwater data and other information on a public website.

### Testing Alternative Remediation Technologies

Most groundwater remediation researchers and developers have devoted less attention to the inorganic constituents that CCPs can release to groundwater, focusing instead on organic compounds from fuels and solvents. Among those that do address inorganics broadly, EPRI research is unique in that it addresses inorganic constituents found at CCP facilities.

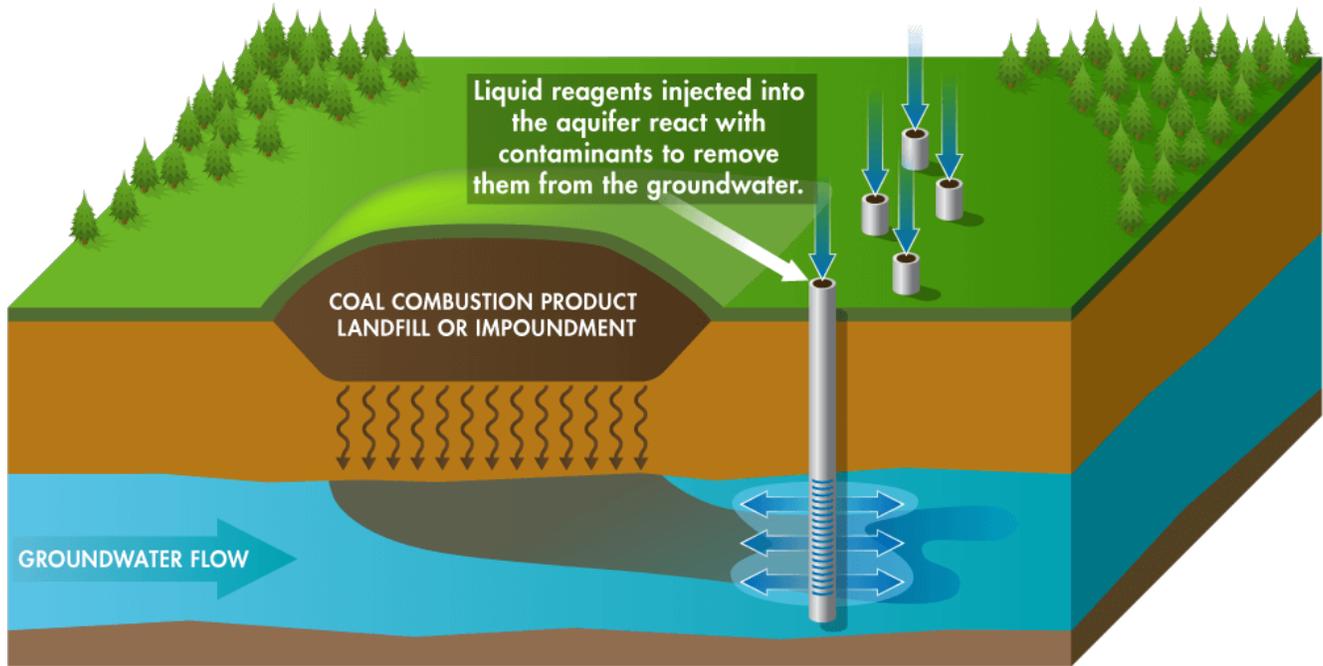
For CCP landfills and impoundments, several options are available and effective for groundwater remediation:

- Excavating CCPs (which are then either reused in various beneficial applications or placed in a lined facility)
- Capping the facility to limit infiltration of precipitation
- Constructing a barrier around the facility to contain groundwater and prevent its migration to other areas
- Pumping groundwater out of aquifers to remove contaminants and prevent migration off-site
- Monitoring natural attenuation of contaminant concentrations in groundwater

For many CCP landfills and impoundments, these strategies are the only feasible options. However, they can be expensive, take years to complete, and in some cases are not ideal from environmental and public-interest perspectives. EPRI is assessing the effectiveness of two alternative remediation technologies—*in situ* injection and permeable reactive barriers—with potential for faster results at lower cost.

With *in situ* injection, liquid reagents are injected into an aquifer to treat the groundwater in place. While commonly used to remediate groundwater contaminants such as arsenic, the applicability to CCP impoundments and landfills is a research gap when given the need to remove multiple contaminants.

# How In Situ Injection Works



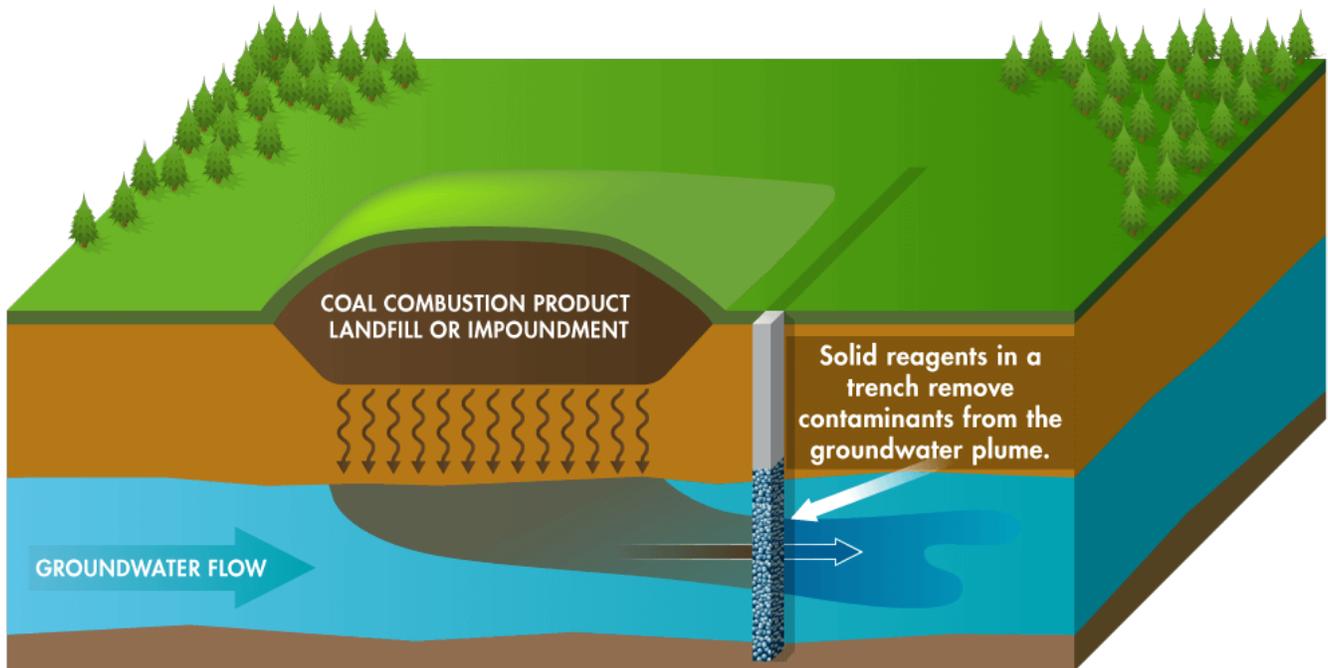
EPRI lab-tested several reagents' injectability and evaluated their capacity to reduce concentrations of various contaminants. The reagents proved effective on some elements (such as arsenic and molybdenum) while concentrations of other elements (such as boron) were unaffected.

"Next, we are planning field tests to inject a reagent in groundwater and see how it performs," EPRI Technical Leader Bruce Hensel said. "In the laboratory, it's difficult to completely reproduce conditions in an aquifer. Reagents may be more effective or less effective in the field."

According to EPRI Technical Executive Ken Ladwig, research is needed on obtaining good mixing of the reagent with the affected groundwater. In a prior field test, difficulties with injection limited the reagent's area of influence.

For permeable reactive barriers, the approach differs. A trench is dug into a contaminated aquifer, and a mixture of solid reagents is placed into the trench. Groundwater flows through the trench, and the reagents react with contaminants—removing them from the groundwater plume.

# How a Permeable Reactive Barrier Works



This is a mature technology but has rarely been applied to groundwater plumes from CCP impoundments and landfills. EPRI is examining its effectiveness in removing the contaminants commonly found at CCP sites. In the laboratory, researchers tested various compounds on soil and groundwater samples from a CCP landfill known to have elevated arsenic and boron levels. Several compounds successfully treated arsenic, though only one was effective at removing boron.

“Permeable reactive barriers show promise for application at CCP facilities. We have a pretty good idea of how to select reagents and design barriers for various constituents found in the leachate,” said Ladwig. “Now we need to test how they work with complex mixtures and groundwater flow conditions that may occur in the field.”



An EPRI test site for *in-situ* injection near a coal ash pond.

### Developing Site-Specific Groundwater Solutions

Because no two CCP facilities are the same, remediation strategies will be site-specific—dictated by differing geology, geochemistry, contaminants, facility configurations, and state rules.

“Some states have not required groundwater monitoring around CCP facilities; others have required it,” Hensel said. “So, some impoundment and landfill owners have historical monitoring data while others don’t.”

When states adopt the federal rule, they may allow risk-based remediation, which involves site-specific assessments and remediation to acceptable risk levels. This would have significant effects on the types and duration of remediation programs.

“We are going to sustain active research on risk-based remediation because we expect it to be an important component of corrective action in the future,” Hensel said.

By helping utilities better understand the state of remediation technology and the available and emerging options, EPRI is helping inform their compliance planning.

“Remediation can cost tens of millions of dollars per site and take decades to complete,” said Hensel. “Great care must be taken to select the most effective, economic technologies. Utilities can use EPRI research to start off in the right direction by identifying promising options most suitable for their sites. This will guide their future work with consultants as they develop detailed remediation strategies.”

### Cap or Move a Coal Ash Facility?

EPRI developed the [Relative Risk Framework](#) tool to assist utilities in determining whether to cap a coal combustion product facility or excavate and move it. “If you cap it and leave it in place, the risk involves groundwater and surface water,” said EPRI Technical Leader Bruce Hensel. “If you dig it up, you’re adding new risk pathways such as air quality and worker safety.”

The tool informs utilities on the various impacts of each option, including groundwater, surface water, air quality, accidents, energy consumption, and water use.

“We want to provide utilities with the information they need to make fact-based, scientific decisions no matter which way they decide to go,” Hensel said.

### Key EPRI Technical Experts

Bruce Hensel, Ken Ladwig

## Viewpoint—Electrification: The Conversation Is Changing



In launching our [Efficient Electrification Initiative](#), EPRI defined a contrast between the original meaning of electrification and the meaning that best fits developed economies in the 21st century.

“Electrification” initially pointed to the extension of electrical service to people who lacked it. In the United States, the federal government established the Rural Electrification Administration to bring electricity to rural residents and farms through the creation of rural electricity cooperative companies and the construction of power generation and distribution systems.

In the 1930s, only 10% of rural dwellers had electric service, and 9 of 10 farms likewise were power-less. By 1945, that had been reversed with an estimated 9 out of 10 farms electrified.

In moving electrification beyond the basic (and binary) question of haves and have-nots, [Efficient Electrification](#) looks to an [Integrated Energy Network](#) to help achieve the most efficient use of energy, the cleanest production, delivery and use of that energy, and measureable benefits to consumers, workers, drivers, and others.

Today, where the modern grid is poised for fundamental change, the original binary question gives way to a matrix of questions and overlapping or intersecting answers. [When EPRI rolled out its U.S. National Electrification Assessment on April 3 at the National Press Club](#) in Washington, D.C., this was made apparent in key findings such as these:

Electricity’s share of final energy consumption can be expected to grow from 21% today to 32–47% in 2050. Transportation accounts for a large share of this growth, both for personal vehicles and for commercial truck fleets and other heavier duty applications. Beyond that, we’re looking at advanced heat pumps, industrial process equipment, and other technologies. The analysis directs our thinking to regulatory and economic barriers and points to opportunities for financing. (Think of how rural electrification financing made possible electric milking machines, dramatically increasing the production of dairy farms. For the 21st century, we are looking closely at indoor agriculture, in which electrified crop production can sharply reduce consumption of water and other resources.)



Mike Howard, President and Chief Executive Officer, EPRI

EPRI's analysis points to one fact that may surprise some readers. Even as the use of electricity increases, the overall final use of energy decreases. That's fundamental to EPRI's pairing of "Efficient" with "Electrification."

This is why the conversation is changing. The energy system overall becomes more efficient through efficient electrotechnologies. (Read an [interview with Joe Stagner](#) about how electrifying helped Stanford University improve its overall energy efficiency by 50%.) It becomes cleaner at the point of use as the entire system becomes cleaner and as we use less energy to do the same work. ([Edison CEO Pedro Pizarro spoke with EPRI Journal](#) about his company's plan to reduce greenhouse gas emissions and air pollution in California through electrification.) The entire system becomes more dynamic, too. As more uses rely on electricity, grid operators have more resources to manage and draw upon as they balance supply- and demand-side resources, taking advantage of a more interconnected system.

At the National Press Club event in April, we were joined on the podium by three members of the EPRI Board of Directors in a panel discussion about the National Electrification Assessment and Efficient Electrification. While I encourage you to watch [the discussion](#), I offer these quotes from the panel to show how the conversation is changing.

Jeff Lyash, Chairman, President, and CEO of Ontario Power Generation, offered these points: "[In Ontario] we've essentially already decarbonized the electricity sector.... We're at 40 grams of carbon per kilowatt-hour.... And so what we're turning our attention to is exactly this: how do we take this clean electricity and drive decarbonization in mobility, in space heating, and in industrial processes?"

Sheryl Carter, Director, Power Sector, Natural Resources Defense Council (NRDC), said this: "...electrification has become a really important part not only of NRDC's advocacy but other environmental groups as well because of the environmental and public health benefits that [it] can bring. The ways that we're addressing this issue include working to make sure that we are making these efficient choices across the energy system, across the economywide energy system—instead of just looking at one sector versus another, like electricity, natural gas, petroleum. That's really important."

Pat Vincent-Collawn, Chief Executive Officer and President, PNM Resources, Inc: "We [the utilities] are the ones in the middle that can help look at it from a systems perspective, because if we don't... we'll have unintended consequences.... Think about cyber security, for example. We're going to have all sorts of things plugging into the grid and the network. We need somebody that makes sure people are up to cyber security standards as more and more stuff gets plugged into our grid. I think we also need to make sure that we involve our friends in the water and natural gas industries to think, again, about the systems approach."

It becomes apparent that the [Integrated Grid](#)'s dynamic mix of traditional, renewable, and distributed resources, is integral to the Integrated Energy Network, which comprehensively considers electricity, natural gas and other resources. In that framework, electrification can provide improved efficiency across the board. EPRI is conducting analyses at the state level to bring more details and insights to the discussion. But one point is clear: The conversation is broadening to include more technology, more systems, and more participants.

Based on everything we're hearing at EPRI, I see also a common theme of optimism that we can realize significant gains in overall efficiency, sustainability, service, and customer satisfaction. Clearly the conversation is focused on progress across the board.

Mike Howard



President and Chief Executive Officer, EPRI

## First Person—A Blueprint to Electrify the Golden State



### The Story in Brief

When it comes to electrification, utilities need to “think ahead, think hard, and think fast because customers are demanding it,” says Pedro Pizarro, president and CEO of Edison International, the parent company of utility Southern California Edison. Pizarro speaks with *EPRI Journal* about his company’s [Clean Power and Electrification Pathway](#), an integrated approach to reduce greenhouse gas emissions and air pollution through action in California’s electricity, transportation, and building sectors.

### EJ: What is the Clean Power and Electrification Pathway, and why are you embarking on it?

**Pizarro:** California has set aggressive climate targets—a 40% reduction in greenhouse gas emissions from 1990 levels by 2030 and an 80% reduction by 2050. The state’s air quality goals include a 90% reduction in nitrogen oxide emissions from 2010 levels by 2032. It’s not that long until 2030. We believe California will have to move aggressively to get there. The Clean Power and Electrification Pathway is our view on how all sectors of the California economy—not just utilities—can achieve these targets in the most efficient, affordable manner. The pathway has become even more relevant: Last year we saw the impact of climate change in the severe wildfires across the state, which produced almost as many tons of greenhouse gas emissions as the entire power sector did that year.

To develop this blueprint, we looked at the costs of hundreds of greenhouse gas abatement measures available across the economy and assembled the information into three alternate pathways to achieve the state’s targets. One uses efficient electrification and clean energy sources, another uses more hydrogen, the third uses more renewable natural gas. We looked at the cost of each scenario



Pedro Pizarro. Photo courtesy of Edison International.

for consumers across the economy and determined that the clean power and electrification pathway was the lowest.

### **EJ: The pathway calls for 30 gigawatts of additional wind, solar, and hydro capacity in California by 2030. What is needed to get there?**

**Pizarro:** The pathway starts with clean power. We believe California’s electric power resource mix needs to be 80% carbon-free by 2030, and that requires 30 gigawatts of wind and solar capacity. We need clean power investments across the state—both large-scale, central-station resources and distributed resources.

California utilities need to ensure that their distribution grids are more modern and able to handle thousands of interconnected resources. Southern California Edison’s 2018 rate case, which is under review by the California Public Utilities Commission, requests \$1.8 billion in capital over three years to modernize the grid. Utilities also need to expand their capabilities as distribution system operators to plan and manage the modernized plug-and-play grid. We need to design the right rates and programs to help customers transition to more distributed energy resources.

**“Because the technologies are maturing so quickly—whether it’s transportation, indoor agriculture, space and water heating, or commercial processes—we saw a real opportunity across the country for utilities and, more importantly, for customers in terms of reduced costs and environmental footprint.”**

On the bulk power side, 28% of Southern California Edison’s resources are renewable under the state’s renewable portfolio standard. We are in good shape to meet our 33% renewables by 2020 milestone and our 50% by 2030 milestone. We think that the state may have to go beyond that 50% to achieve the pathway’s target of 80% carbon-free power. We need a strong transmission system and more regional coordination among grid operators, such as the California Independent System Operator’s Energy Imbalance Market.

### **EJ: Do you anticipate any challenges with deploying the transmission infrastructure needed for large-scale solar and wind projects?**

**Pizarro:** The California Independent System Operator recently updated its transmission plan, and they’re expecting lower transmission needs than they did a couple years ago as the state increasingly turns to distributed resources and energy efficiency. The greater challenges are with modernizing the distribution system—adding more remote sensors and automated controls to enable faster system response and resiliency, and doing all that in a cyber-secure way. About 5% of our 4 million residential customers have rooftop solar, and each month we’re interconnecting another 4,000 to 5,000 customer-sited solar systems. A distribution grid with that diversity and scale of connected resources demands fast modernization.



## EJ: The pathway calls for 10 gigawatts of storage. What will be the role of energy storage in California's grid in 2030? How will Southern California Edison address the high costs and uncertain business case of storage?

**Pizarro:** When you have a system with 80% carbon-free power, a lot of which is coming from renewable resources, storage has to play a key role in balancing out the intermittency. Today, natural-gas-fired plants are used to meet the ramps in demand when the sun sets or the wind stops blowing. Tomorrow this role will be taken by storage, particularly as there is less room for burning natural gas in a state with aggressive greenhouse gas reduction targets.

Regarding the high costs of storage, we've lived through this experience with renewables. In the early 2000s, California took an aggressive but measured approach when it aimed for 10% renewables. Some of those early renewable contracts cost us 12, 13, or 14 cents per kilowatt-hour. Today you see public announcements of solar contracts around the 3 cents per kilowatt-hour level. We've seen a dramatic cost reduction as the technology matured, in part because early targets created demand and stimulated production and scale to bring costs down. Now, the scale is driven more by economics and less by mandate.

Bloomberg New Energy Finance predicted that utility-scale battery costs will decrease from \$700 per kilowatt-hour in 2016 to less than \$300 per kilowatt-hour by 2030. There's a balancing act in terms of what commitments we make today versus a year from now, three years from now, and five years from now. We need to move quickly enough now to start realizing the benefits of batteries while recognizing that the technology will improve and that contracts we sign five years from now will be more cost-effective.

We're already seeing some cost-effective applications today. [Edison Energy](#), Edison International's nonutility company that develops energy solutions for large industrial and commercial customers nationwide, has customers that are deploying storage at today's prices to shave peaks. Southern California Edison has married two natural-gas-fired peakers with 10 megawatts of battery storage. The batteries lowered the overall cost by reducing the number of plant starts needed for load following. These and other cost-effective applications stimulate the battery market, helping to bring down costs further.



In 2017, Southern California Edison deployed this hybrid natural gas turbine/battery energy storage system. The 10-megawatt battery system enables the gas plant to respond more quickly to changing grid needs. Photo courtesy of Edison International.

In total, we've procured 450 megawatts of storage. We're deploying storage at the bulk power level, at substations, and at the distribution level on the grid side. We're also contracting with companies that aggregate storage resources behind the meter at hundreds of customer premises, so that we can dispatch them as a single package.

### **EJ: Today, about 300,000 cars and light-duty trucks in California are electric or plug-in hybrids, and the pathway calls for 7 million light-duty electric vehicles by 2030. What is needed to get there?**

**Pizarro:** Our market estimate of 7 million vehicles is what's needed to achieve the state's greenhouse gas and air pollution reduction targets most cost-effectively. To get there, it starts with the automakers bringing the models to market, marketing them well, and educating consumers about the growing number of affordable options and the experience of owning and charging a vehicle.

Utilities have a role to play in this education and need to help demystify electric vehicles. With Plug In America, we host 'ride and drive' events in our communities, where consumers have the chance to get behind the wheel of an electric vehicle to experience it firsthand. We provide information about incentives and the financial advantages of electric vehicles. At each event there are 50 to 100 test drives.

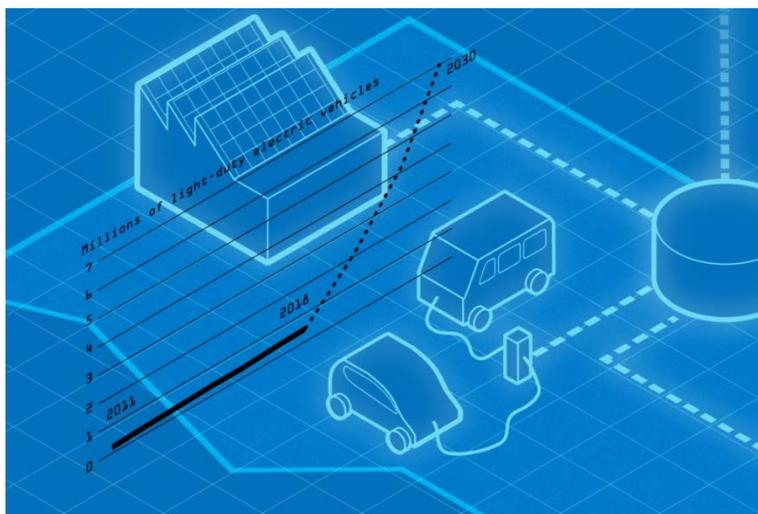
Deployment of chargers and vehicles needs to grow in lockstep. Southern California Edison has a number of initiatives to stimulate the market. Through a \$22 million program, we have installed around 1,000 chargers and provide incentives for charging in multiple locations—typically work places, shopping areas, and schools. Later this year, we plan to propose an expansion of that program to significantly increase the number of chargers. We have proposed another \$500 million program to deploy chargers for heavy-duty vehicles.

**“We believe California's electric power resource mix needs to be 80% carbon-free by 2030, and that requires 30 gigawatts of wind and solar capacity.”**

In areas where we expect earlier deployment of electric vehicles, we are getting the grid ready ahead of the need. In some cases, this means increasing the capacity of circuits. We recognize that charging needs may change quickly with the rise of vehicle sharing and advances in autonomous vehicles. So, for example, we may need to develop more garages that enable charging of 50 or 100 autonomous vehicles.

### **EJ: How will California building codes need to be updated to enable your electrification goals?**

**Pizarro:** The challenge here is translating California's broader policies into building codes. The state's greenhouse gas emissions policies have changed the energy landscape, but some building codes still favor natural gas heaters over electric heaters, based on the conventional wisdom 10 or 15 years ago that natural gas heating is more efficient. Electric heat pump technology has advanced quickly and is more efficient today. The building code process in California runs on a three-year cycle under Title 24. Efforts are beginning now to develop the 2022 codes, and we expect the state to incorporate zero net energy into that cycle.



Another aspect is getting builders and equipment manufacturers to meet consumer demand and deliver products to market. For example, as the codes change, homes may need heat pump water heaters and connections for behind-the-meter battery storage.

### **EJ: How will California utilities and regulators need to coordinate to meet these electrification goals?**

**Pizarro:** The pathway integrates many pieces—clean power, energy efficiency, storage, transportation, and space and water heating. This requires a lot of coordination among utilities, regulators, manufacturers, other market players, and consumers. A big part of this alignment can happen with the integrated resource plans that privately owned utilities submit to the California Public Utilities Commission. For example, we need to make sure that there's consistency among utilities so that vendors don't have to make different water heaters for the Southern California Edison market versus the Pacific Gas and Electric market. We also need to make sure that the resource planning by the municipal and publicly owned utilities is consistent with this pathway for California.

Policymakers have an important role to play in helping to stimulate the marketplace for new electric technologies, while utilities need to make sure that the grid can accommodate them. Rate structures must meet customers' needs and be fair across all customer classes. For electric transportation, charging rates should align with customer driving patterns while decreasing overall system costs.

### **EJ: What technologies could be game changers for electrification?**

**Pizarro:** Electric light-duty vehicle and electric bus technologies are moving quickly. Battery storage will continue to decline in cost. Although most batteries today are lithium ion, there's a lot of research emphasis on different chemistries that could be more suitable for various grid applications.

Another big area is data analytics and machine learning. Recently we've made some great advances in using our five million smart meters to collect real-time and near real-time information on the state of the system. We can leverage data from smart meters, social media, and other data feeds to speed up the process of detecting outages, pinpointing their locations, and communicating this information to field workers and customers.

### **EJ: Why did you decide to become such an active participant in EPRI's Efficient Electrification initiative?**

**Pizarro:** It has become clear to us that efficient electrification is an opportunity not just for states like California with ambitious policy targets. Because the technologies are maturing so quickly—whether it's transportation, indoor agriculture, space and water heating, or commercial processes—we saw a real opportunity across the country for utilities and, more importantly, for customers in terms of reduced costs and environmental footprint. By supporting EPRI's initiative, we can help policymakers, customers, and utilities across the country understand the scale of the opportunity.



Southern California Edison installed this electric vehicle charger as part of its Charge Ready Program. Photo courtesy of Edison International.

An important part of that is communicating the state of the R&D, and [EPRI's electrification conference](#) in August is the first global meeting place for manufacturers, utilities, and customers to gather and learn about this.

**EJ: What advice can you offer to other utilities that are setting out on a similar electrification path?**

**Pizarro:** The headline would be, 'Think ahead, think hard, and think fast because customers are demanding it.' Even though other states may not have climate policies as aggressive as California's, consumers are interested in electric technologies. Drivers increasingly want electric vehicles. Through Edison Energy, we see large companies that want to use electric technologies because of the economic and sustainability benefits. These technologies demand that utilities step up to the plate and ensure that their grids are modern and resilient.

## First Person—Electric University



### *Stanford Electrifies Its Campus, Cuts Greenhouse Gas Emissions by 65%*

#### The Story in Brief

“Buildings are a big chunk of the challenge to develop sustainable, affordable energy for the world,” says Joe Stagner, executive director for sustainability and energy management at Stanford University. Stagner speaks with *EPRI Journal* about how Stanford’s new energy system works, the environmental and financial benefits, and its applicability in other settings, including his own house.

#### **EJ: Describe Stanford’s energy supply system.**

**Stagner:** Stanford previously powered its campus with a natural-gas-fired cogeneration plant. It heated buildings through a network of underground steam pipes and cooled buildings with cold water pipes. In 2015, we decommissioned the plant and converted the campus to a mostly electric energy supply system. An innovative aspect of the system is heat recovery to meet overlapping heating and cooling needs. Cooling the campus involves collecting waste heat from buildings and transporting it via underground chilled water pipes to a central energy facility. There, devices known as heat recovery chillers (also called heat pumps) transfer the waste heat to a new network of underground hot water pipes to heat buildings.

The central facility houses several large hot and cold water tanks that serve as thermal storage, enabling the system to time-shift cooling and heating. For example, if it’s hot in the daytime, you could save the extra heat and use it at night when it’s cold. When waste heat recovery from cooling processes is not sufficient to meet campus heating needs in winter, late fall, and early spring, the same heat recovery chillers can fill those gaps by extracting heat



Joe Stagner. Photo courtesy of Linda Cicero.

from the ground or Stanford's lake water irrigation system. Control software operates all these components efficiently. For backup heating and cooling and to meet thermal loads not covered by the heat recovery process, we have conventional electric-powered chillers and natural-gas-fueled hot water generators.

Another important aspect of our energy system is clean electricity. Stanford signed 25-year power purchase agreements for new on- and off-campus solar projects to supply 53% of our electricity. The remainder comes from the California grid.



Stanford's central energy facility. Photo courtesy of Matt Anderson.



Heat recovery chillers in Stanford's central energy facility. Photo courtesy of Robert Canfield.



Aerial view of Stanford's central energy facility. The large cylinders are thermal storage tanks. Photo courtesy of Steve Proehl.



An operator uses the control software for Stanford's energy system. Photo courtesy of Linda Cicero.

## EJ: Why did Stanford electrify?

**Stagner:** According to the International Energy Agency, heating, cooling, and power in buildings consume about 40% of the developed world's energy. So, buildings are a big chunk of the challenge to develop sustainable, affordable energy for the world. That's the context for our energy system.

Many scientists believe that over the next few decades the only practical path to more sustainable energy is electrification across all sectors and supplying the electricity with a clean, economic, reliable, resilient, and open-access grid. That's not just the finding of Stanford and why we built our system. It's been verified by the International Energy Agency, United Nations Environment Program, and the national laboratories. [Southern California Edison](#) has arrived at a similar conclusion as well. In buildings—whether it's the Stanford campus or a

house—this means electrifying the power, heating, and cooling, each of which represents about a third of building energy use. The power component is already electric, and cooling is primarily electric.

**“The new system’s heat recovery increased overall energy efficiency by 50%, which translates into a 50% reduction in campus greenhouse gas emissions. When factoring in the solar power purchase agreements that help power the system, our greenhouse gas reduction grows to 65%.”**

The challenge is the heating and hot water components. Electric resistance heating is very inefficient, which is why many have moved to natural gas for heat. The key for heating and hot water in buildings is electric heat recovery chillers. They are five to six times more efficient than electric resistance heating and twice as efficient as using natural gas.

With heat recovery chillers as part of the building energy system, you can recover and reuse your waste heat from cooling and extract heat out of the ground or a water body. During summer in all climates across America, there’s a surplus of environmental heat, so there’s no reason to burn fossil fuel to generate more heat. You can use heat recovery chillers to provide 100% of heat and hot water needs. That may be only 4 or 5 months in Boston or 10 months in Phoenix.

#### **By the Numbers: The Stanford Energy System Innovations Project**

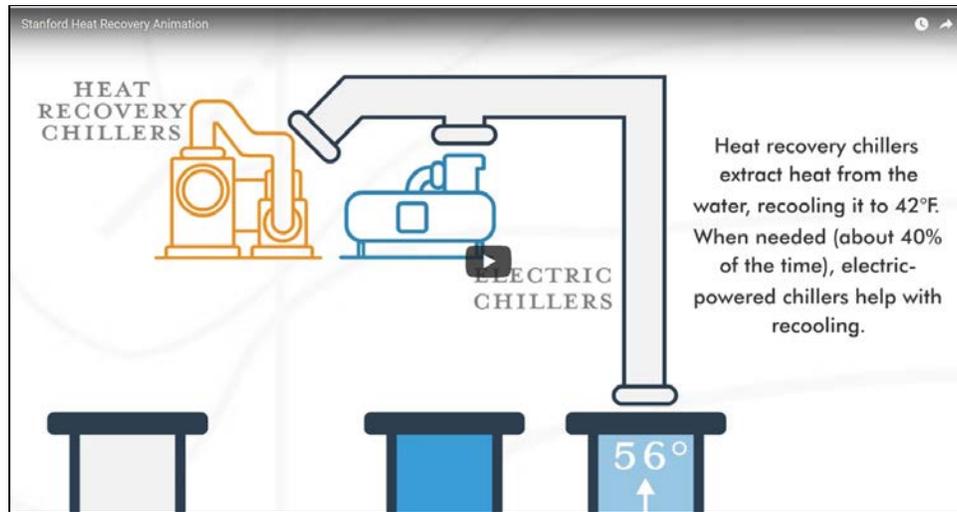
- Miles of underground steam pipes converted to hot water pipes: **22**
- Number of buildings upgraded to hot water pipes: **155**
- Percentage of time during which campus heating and cooling demands overlap: **70%**
- Percentage of waste heat recovered from cooling: **53%** (Stanford’s previous natural-gas cogeneration system lost 100% of its waste heat)
- Percentage of campus heat load met by recovery of waste heat: **88%**
- Percentage of Stanford’s electricity supplied by on- and off-campus solar projects: **53%**
- Increase in overall energy efficiency relative to Stanford’s previous cogeneration system: **50%**
- Reduction in greenhouse gas emissions relative to the previous cogeneration system: **65%**
- Reduction in water use relative to the previous cogeneration system: **18%**
- Increase in system efficiency as a result of the automated control software: **15%**
- Capital cost: **\$485 million**
- Projected savings relative to the costs of the previous cogeneration system: **\$420 million over 35 years**

Source: Stanford University

In winter, particularly in northern areas like Boston, you hear people say, ‘It’s too cold for waste heat recovery.’ What they don’t understand is that even in cold regions there’s a small amount of waste heat available from cooling and humidity control in complex buildings. Our data shows that more than 50% of annual heating and hot water needs at two large universities in Illinois and Massachusetts can be met by deploying heat recovery chillers and recovering waste heat from existing cooling processes. Those same heat recovery chillers can also extract the other 50% of needed heat from the ground, lake, or ocean. We can therefore fully electrify heating and hot water supply for buildings.

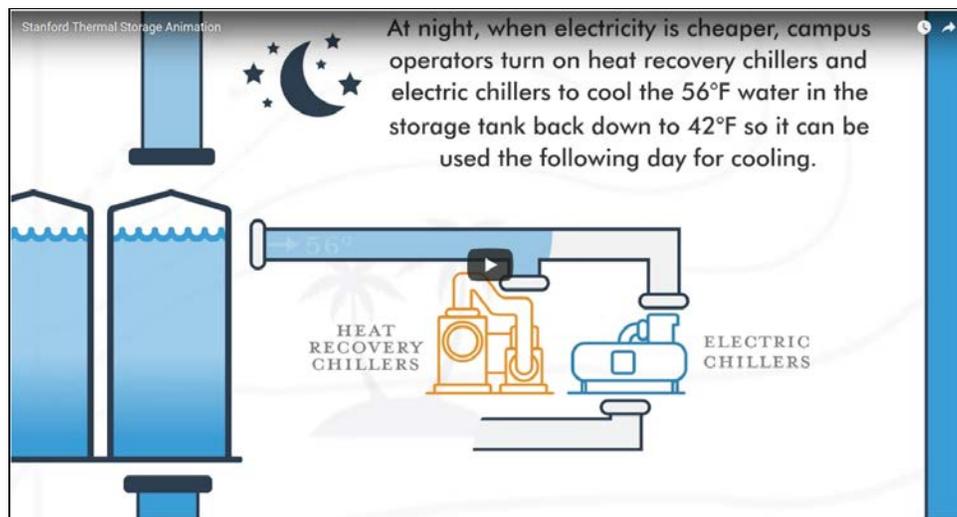
## EJ: How do the heat recovery and thermal storage work?

**Stagner:** We have a chilled water loop that cycles around campus continuously. The central energy facility delivers 42°F water to campus buildings through cold water pipes. At each building, heat exchangers use this cold water to provide cooling, and 56°F water is returned to the central facility. There, a heat recovery chiller cools it back down to 42°F and transfers the heat to a separate hot water circulating system. This continuously cycling loop delivers 160°F water to buildings to provide heat for space heating and hot water and returns 130°F water to the central energy facility where the heat recovery chiller reheats it to 160°F (see animation below).



[Watch](#) an animation about how Stanford's heat recovery system works.

The thermal energy storage system consists of 70-foot-tall tanks of hot and cold water. The cold water tank has a pipe coming out the bottom to supply 42°F water to campus for cooling, simultaneously replacing it with 56°F water from campus through a pipe at the top. The hot water tank has a pipe coming out the top to deliver 160°F water to campus for heating and receives 130°F water back at the bottom. The large temperature difference between the top and bottom of the tanks creates a 'thermocline' that separates the warmer and colder water. Temperature probes placed every 1 foot from top to bottom indicate how much cold and hot water is available for campus heating and cooling (see animation below).



[Watch](#) an animation about how Stanford's thermal storage system works.

Cold water storage saves money in three ways: It allows you to shift cooling to off-peak hours when electricity is cheaper; it's less capital-intensive than deploying extra heat recovery chillers or regular electric chillers to meet peak loads; and its operations and maintenance costs are lower than heat pumps and chillers. Imagine that the daytime cooling load for a campus is 30,000 units, and the night cooling load is 10,000 units. Without cold water storage, you need to deploy and turn on 30,000 units of heat recovery chillers or regular electric chillers in the daytime and run 10,000 units at night. With cold water storage, you can install and run 20,000 units of heat recovery chillers or chillers 24 hours a day and store the 10,000 units of cooling not needed at night. In the day, when you need 30,000 units of chilling, you can borrow 10,000 units from storage to complement the 20,000 units of heat recovery chillers or chillers. A hot water storage system offers those same cost benefits for heating.

### EJ: How does the control software work?

**Stagner:** Stanford developed a software program called the Central Energy Plant Optimization Model to prove the heat recovery concept and help with system design. Stanford commissioned Johnson Controls to develop an industrial version of this software that can be used for real-time operations and planning. The operational function is like an airplane autopilot, constantly seeking the best path forward, given constantly changing weather, heating and cooling loads, grid electricity prices, thermal energy storage balances, and many other factors. Every 15 minutes, it interrogates the thermal storage tanks to see how much usable hot and cold water they contain; determines which heat recovery chillers, chillers, and hot water generators are available and which are down for maintenance; and fetches the campus-area weather forecast from the National Weather Service. Based on all this information, it reforecasts the heating, cooling, and power loads and optimizes the use of heat recovery and thermal storage to meet loads and reduce electrical peaks. We've found that the software makes the entire system 15% more efficient than it would be if operated by humans.

We can use the software's planning function to simulate operations in future years with differing loads. For example, if loads grow as a result of campus expansion, the software may tell us that we need to change or add more equipment.

**“Even though Stanford has a district energy system with complex buildings, the insights are applicable in many types of buildings all the way down to the residential level.”**

### EJ: What have been the environmental benefits?

**Stagner:** With our previous natural-gas cogeneration system, 100% of the waste heat from cooling the campus was thrown away in evaporative cooling towers. The new system's heat recovery increased overall energy efficiency by 50%, which translates into a 50% reduction in campus greenhouse gas emissions. When factoring in the solar power purchase agreements that help power the system, our greenhouse gas reduction grows to 65%.

If we power campus with 100% clean electricity, we could achieve an 85% greenhouse gas reduction. The remaining 15% is a result of scattered natural gas and liquid fuel use in vehicles, emergency generators, and other campus equipment not served by our new energy system yet. While we want to be powered by 100% renewables eventually, for now we want to see how electricity markets and technologies evolve. For example, we may determine that we need more load-following generation or baseload renewables such as geothermal energy.

The new system also uses 18% less water than the cogeneration system, which consumed significant water as it rejected waste heat via evaporative cooling.

“Utilities and regulators need to set in motion a long-term plan to electrify everything by enabling widespread use of local and grid-scale renewable energy and by providing grid infrastructure including robust transmission systems, thermal and electricity storage, grid-scale system management software, and regulatory rules and electricity tariffs to incentivize electrification.”

### EJ: How about the financial benefits?

**Stagner:** The new system had a capital cost of \$485 million. At the outset of the project, we calculated that it would save us about \$420 million over 35 years, relative to the costs of our previous system.

The control software and thermal energy storage helped us to reduce our peak load and increase our load factor on the grid. This is contrary to conventional expectations when electrifying a load previously served by natural-gas-fired cogeneration. For example, when the cogeneration plant was offline for maintenance, we'd pull a peak of 46 megawatts from the grid to run our campus. Now that we're electric, our peak is down to 38 megawatts.

A recent audit found that we're 10% under the original cost estimates for the system. This is mainly a result of two factors: our low-cost solar power purchase agreements and our ability to purchase California grid electricity through [direct access](#).

### EJ: To what extent can Stanford's approach be applied in residential and commercial buildings?

**Stagner:** Even though Stanford has a district energy system with complex buildings, the insights are applicable in many types of buildings all the way down to the residential level. Heat recovery and heat recovery chillers can be used at many scales. I am considering doing what we did at Stanford at the next house I design when I retire and move. I said, 'If I'm going to design a house, would it be practical to have both hot and cold thermal storage and model the system with predictive software?' Instead of burning natural gas, I could use the waste heat from the air conditioning to produce the hot water that my kid's using in the shower or my wife's using in the washer. It turns out the answer is, 'Yes, this can be done.'

Many houses have hot water tanks, which can serve as hot thermal storage. Cold water storage tanks may or may not be needed depending on the house's load profile. Heat recovery chillers like the ones we installed at Stanford are commercially available for houses. They're called 'triple-function geothermal heat pumps' and 'reverse cycle chillers,' depending on whether they extract heat from the ground or air. They can recover waste heat from your air conditioning in summer to make 140°F hot water for your house. They also can extract heat from the air or ground whenever you are not running the air conditioning. Control software similar to Stanford's can be used to optimize heat storage and use.

“With heat recovery chillers as part of the building energy system, you can recover and reuse your waste heat from cooling and extract heat out of the ground or a water body. During summer in all climates across America, there's a surplus of environmental heat, so there's no reason to burn fossil fuel to generate more heat.”

However, research is needed to apply this solution and develop software at different scales. Residential and commercial demonstrations would be great, and several building projects in North America are considering this approach. EPRI could model what an electrified America would look like and cost over the next 50 or 100 years. We also need more education to inform the public of these new opportunities, as well as development and dissemination of heat pump and other technologies. Research on new cooling fluids or compression methods to

increase the efficiency of heat pumps and heat recovery chillers could lower the costs of electrification even further.

### **EJ: Stanford's campus is similar to a small city. What lessons can cities draw?**

**Stagner:** While you can apply this approach in individual homes and commercial buildings, it's enhanced if you apply it in district energy systems. Any time you collect a series of buildings together you get more efficiencies. You get better thermal balance and more ways to recover waste heat from buildings for use in other buildings. In Europe, there are many good examples of cities that use district heating. Hot and cold water for district heating and cooling can be part of the basic city infrastructure just like natural gas, water, sewer, storm drainage, and communications.

### **EJ: What can utilities and regulators do to facilitate electrification?**

**Stagner:** To make electrification work, you need clean power. Once you have that, natural gas is no longer a greenhouse gas reduction strategy. Is a clean grid economically competitive with natural gas distributed to buildings? It probably will be long term. We modeled a new cogeneration plant powered by cheap natural gas for the next 30 years and compared it to an all-electric scenario with electricity at more than 10 cents per kilowatt-hour, and electric won out. With our power purchase agreements, we locked in solar power for 5 cents per kilowatt-hour for 25 years, helping our system outcompete cogeneration by an even wider margin.

Utilities and regulators need to set in motion a long-term plan to electrify everything by enabling widespread use of local and grid-scale renewable energy and by providing grid infrastructure including robust transmission systems, thermal and electricity storage, grid-scale system management software, and regulatory rules and electricity tariffs to incentivize electrification.

In Development

## Solar Storm Preparedness

### *EPRI Collaborative Research Aims to Protect Society from a Worst-Case Scenario Solar Storm*

**By Chris Warren**

On March 13, 1989, a geomagnetic disturbance triggered a 9-hour blackout in and around Montreal, shutting down schools, businesses, and the city's airport and underground transit system. While memories of that day have likely faded for most Quebecois, the event has had an enduring impact on the electric power industry.

It set in motion a series of efforts by regulators, policymakers, and electric utilities to protect the bulk power system against geomagnetic disturbances, also known as solar storms. Most recently, in 2016, the Federal Energy Regulatory Commission (FERC) approved the North American Electric Reliability Corporation's (NERC) reliability [standard](#) for geomagnetic disturbances. As part of its approval, FERC required owners and operators of bulk power systems to develop action plans and mitigation measures to address the threat of geomagnetic disturbances.

The FERC order also mandates that system owners and operators assess potential impacts of a 100-year solar storm. It requires NERC to modify the new standard and develop tools to better protect against these impacts. At NERC's request, EPRI spearheaded a three-year, multi-million-dollar research initiative to advance understanding of worst-case scenario solar storms, with participation from national research laboratories, the National Aeronautics and Space Administration (NASA), and electric utilities.

"With a better understanding of what a 100-year solar storm looks like, we can build tools that help planners identify system weaknesses," said EPRI Senior Technical Executive Bob Arritt, who leads the work.

FERC mandated research to improve the science behind NERC's projection of a 100-year solar storm's severity, which is based on an average of worldwide geoelectric field amplitude measurements made between 1993 and 2013. While NERC reasoned that this "spatial averaging" approach would best reflect the effects of a severe solar storm over a wide area, FERC expressed concern that such estimates "could be weighted by local effects and suggest unduly pessimistic conditions..."

EPRI and its collaborators are examining spatial averaging and its implications for how grid operators prepare for a severe geomagnetic disturbance. "We need to advance the science behind our definition of a 100-year storm," said Arritt. "For example, we know that the geoelectric field is not uniform across a large area, and it is made up of small peaking areas. Better defining the



A bulk power transformer.

characteristics of an extremely rare, severe solar storm will help us understand its impact on the bulk power system.”

A primary concern outlined in the FERC order is the overheating of transformers, which could potentially lead to failures. Transformers are extremely expensive and take a long time to build, transport, and install. If widespread failures were to occur, they could result in long-term blackouts. To fulfill the requirements of FERC’s order, EPRI’s research initiative must analyze the current approach used to estimate transformer heating limits. If deemed inadequate, researchers are tasked with developing alternative methods.

“We will use data from lab testing and transformer monitoring in the field to improve the transformer response models used to estimate how equipment reacts to a solar storm,” said Arritt.

Researchers also will focus on harmonics generated by solar storms, developing tools to analyze impacts on transformers. “It’s important that bulk system operators understand harmonics, which can cause additional heating and equipment to trip off when it is needed most,” said Arritt.

Arritt believes the next two years of research will provide a more scientifically rigorous foundation for NERC’s reliability standard. Equally important, he emphasizes that EPRI’s research will result in better tools that grid operators can use to prepare for the worst possible impacts of a solar storm.

“This research is where science meets practice,” he said. “The results will inform solar storm vulnerability assessments and potential mitigation actions. It’s where the rubber meets the road.”

### **Key EPRI Technical Experts**

Bob Arritt

Shaping the Future

## EPRI Takes the Lead at Incubatenergy

*By Scott Sowers*

This June, EPRI takes the reins of [Incubatenergy](#), a network of technology incubators and accelerators that supports more than 500 startup companies. Incubatenergy was launched in 2014 through a partnership among EPRI, the U.S. Department of Energy (DOE), and the National Renewable Energy Laboratory (NREL). When DOE funding ends this year, EPRI will continue to support the network.

Incubators in the network include more than a dozen organizations such as [Greentown Labs](#) in Boston and the [Los Angeles Cleantech Incubator](#). The startups have received about \$1.5 billion in funding from various sources, generate \$440 million in revenue, and employ more than 3,300 people. They have access to hundreds of technology experts and business development mentors across the incubators, NREL, and EPRI's utility members.

"We have seen great value in connecting our utility members with the innovative entrepreneurs supported by members of the network," said EPRI Project Manager Beth Hartman. "EPRI is continuing to support the network as integral to our innovation scouting."

Incubators and accelerators play a critical role in supporting new energy technologies along the challenging journey from concept to commercialization. While incubators typically work with entrepreneurs for longer, more flexible periods, accelerators offer shorter, more standardized programs. Incubators and accelerators often aggregate themselves into networks for sharing best practices and new methods. EPRI is linking with other incubators and accelerators.

### Going Global

Incubatenergy has expanded its reach internationally through a partnership launched in 2016 with [InnoEnergy](#), a Netherlands-based accelerator for sustainable energy startups in Europe. The two organizations share company referrals between Europe and North America to facilitate and expand global coordination among technology developers, incubators, and accelerators—and to help startups break into new markets. For example, as a result of the Incubatenergy/InnoEnergy partnership, San Francisco-based accelerator [Powerhouse](#) is hosting Barcelona-based energy forecasting firm [Nnergix](#).

In 2017, Incubatenergy—in collaboration with the California Clean Energy Fund, the World Bank, the World Wildlife Foundation, and the Asia Development Bank—organized the Accelerate Energy Summit in Shanghai. The summit convened 66 organizations from 21 countries to consider strategies for supporting entrepreneurs.

"At the Shanghai summit, Incubatenergy continued to develop important connections with groups that can help expand our international reach," said Hartman. "We plan to host similar gatherings to expand connections among energy incubators and accelerators around the world." For example, the upcoming [Electrification 2018 conference](#) hosted by EPRI will include stakeholders such as global energy entrepreneurs as well as incubators, accelerators, utilities, investors, government staff, and corporate partners.

### The State of Innovation in Electric Power

According to Hartman, particularly active areas of technology innovation in the electric power sector include electric vehicle charging systems, data analytics and artificial intelligence applications, and indoor agriculture that uses electricity to run fans, lights, and other equipment. "Several new startups are using shipping container-sized structures to grow everything from tomatoes and lettuce to flowers," she said.

Another hotbed of innovation is end-use technologies. For example, Pick My Solar, supported by Los Angeles Cleantech Incubator, helps residential customers find the best bids for rooftop solar projects. More companies offer home energy storage that can be paired with solar panels and serve as backup power or a grid resource.



Indoor agriculture is an active area of technology innovation in the electric power sector.

“There are more and more ‘prosumers’—people who both produce and consume energy,” said Hartman. “As utilities adapt their business model for the future, they are thinking of innovative ways to work with prosumers.”

Hartman points to technology innovation in small modular nuclear reactors as an important trend. “Nuclear is an established carbon-free energy technology, and there are several interesting startups working in that space such as Transatomic and TerraPower,” said Hartman.

Hartman also sees utilities expanding collaboration with incubators and accelerators. “Increasingly, utilities are realizing the importance of partnering with innovation groups as disruption in the industry is happening faster and more frequently,” she said. For example, Ameren recently launched its own [accelerator](#), and a consortium of international utilities supported the [Free Electrons](#) program last year. Other utilities are working more closely with incubators in their areas, such as Duke Energy with [Joules Accelerator](#) in Charlotte, North Carolina, and National Grid with the [ACRE incubator](#) in New York.

## Key EPRI Technical Experts

Beth Hartman

Technology At Work

## Helping Grid Components “Fail Gracefully”

### *EPRI Investigates More Resilient Designs, Controlled Failure Points, Inspection, and Maintenance*

**By Tom Shiel**

What do automobile designs and electric grid designs have in common?

Both incorporate features that minimize damage during major accidents. When a car crashes, “crumple zones” in the vehicle’s outer parts absorb the energy of the impact, reducing damage to the passenger cabin and preventing or reducing injury. Similarly, when a tree falls on a distribution power line during a major storm, certain design features can minimize damage to poles and overhead structures.

For several years, EPRI research has worked to better understand how overhead line components and structures fail. In 2018, it is now identifying resilient overhead structure designs and providing utilities with a tool for prioritizing resiliency investment.

“Broken poles need to be replaced and require expensive repairs,” said EPRI Technical Executive John Tripolitis. “The key is to minimize the number of poles that break, whether it be from a falling tree, ice accumulation, or high winds. We want to design these components so that they fail gracefully, or in a known manner. If we can preserve the poles and contain damage to the pole-top components, this can result in easier and quicker repairs.”

Prior EPRI stress tests on poles have shown that a pole’s strength is correlated with its top circumference. In 2018, EPRI is testing distribution poles and pole-top components to determine the structures most resistant to pole breaks.

EPRI is exploring how designing controlled failure points into the system can reduce damage. For example, when struck by trees, conductors can slip through conductor ties, minimizing the forces on poles and pole-top components and reducing repair costs.

An additional challenge is that structures must meet National Electric Safety Code. “We’re not weakening the structure,” said EPRI Engineer/Scientist Joe Potvin. “We’re designing it so that it breaks in a specific way when a significant force is applied.”

“Our research is showing quite a bit of promise,” Tripolitis said. “Several companies have sent us pole-top designs so we can test them.”

EPRI also is looking at inspection and maintenance practices. “In field studies where we dropped trees on lines, we learned that the forces on the system tend to seek out weak spots—places with deteriorated components such as rotted crossarms,” said Tripolitis. “Weak spots can cause unpredictable failures.” In 2018, EPRI plans to identify inspection and maintenance approaches that can pinpoint and strengthen weak spots.

### **Getting the Most ‘Bang for the Buck’ out of Resiliency Efforts**

Hardening poles and overhead structures is one of numerous strategies for making the grid more resilient. Other strategies include vegetation management, burying lines, and enhanced technologies such as advanced meters, stronger poles and components, and automated switches.

For utility planners, a primary challenge is to determine the best strategies for a particular distribution system.

“When I’m looking at a set of circuits that I want to harden, I could choose among various options—move the circuits underground, upgrade the poles, use larger wire, apply automation technologies, and others,” Tripolitis said. “So how do I choose?”

To inform such decisions, EPRI is developing a tool for estimating the reduction in outage risk per dollar spent for a given resiliency strategy. It evaluates circuits’ risk factors with respect to the likelihood of outages. For example, dense tree stands can increase risk.

“If tree density data is not available, a utility could assess risk using historical data on outages caused by trees and other vegetation,” said Tripolitis.

Circuit age is another risk factor, with older circuits posing a greater risk. Most utilities have good information on the age of wood poles but not small pole-top components.

“You can use the age of the poles on a circuit as a proxy for circuit age,” Tripolitis explained.

Users input the set of circuits to be evaluated, the resiliency strategies to be compared, their costs, the circuit risk factors, and the anticipated change to the risk factors associated with each strategy.

“The tool produces a ranking of resiliency strategies based on their expected ability to reduce circuit risk—their relative ‘bang for the buck,’” said Tripolitis.

### **Key EPRI Technical Experts**

John Tripolitis

In the Field

## Data-Driven Insights for Electricity Customers

### *How the Energy Management Circuit Breaker Can Benefit Utilities and Customers*

**By Chris Warren**

In the near future, it may be common for utilities to send texts to homeowners or businesses alerting them that their compressor isn't functioning properly or that the filter on their air conditioning unit needs to be replaced. Avoiding a compressor failure and keeping an AC unit at peak efficiency can save utility customers a lot of money and prevent headaches.

Such preventive maintenance is possible only when utilities and customers have accurate, real-time views of how specific devices are consuming electricity, made possible through 'signature analysis.' "When a unit runs properly, it exhibits certain operating characteristics," said Tom Reddoch, an EPRI senior technical executive. "When you start seeing deviations from the normal characteristics, you can quickly realize that something is not right."

Historically, such detailed measurements have been unavailable: electric meters measure aggregate watt-hours for billing. But that may soon change with a device called the energy management circuit breaker (EMCB). Developed by Eaton Corporation, the EMCB is installed in a residential or commercial circuit breaker where it can continuously monitor voltage, current, and real and reactive power consumed by the appliances and devices for that circuit. This monitoring also can be used in real time to help with voltage control, power management during system restoration or peak load, and other aspects of distribution system management.

When the EMCB is combined with secure WiFi communication for data transmission, both utilities and their customers can monitor and control electricity use. For instance, smartphones can be used to open and close a circuit breaker to save energy or to address concern about an end-use device failing. The EMCB can also enable more cost-effective electric vehicle charging.

"Today, if you want to charge an electric vehicle at 240 volts, the National Electric Code requires you to spend at least \$500 on special equipment that can include a three-prong wall outlet connector, a power supply cable, and a vehicle connector cable," said Reddoch. "The EMCB eliminates the need for both this equipment and the charger itself. All you need is a charging cable to connect the power source to the vehicle and the EMCB."



EPRI and member utilities are field-testing the performance of the energy management circuit breaker in more than 20 applications, including electric vehicle charging.

For utilities, more precise measurement of devices and electric services can enhance demand response, inform more equitable rate design, and help integrate distributed energy resources.

The EMCB has shown promise in EPRI laboratory tests and in preliminary field deployments. Now, EPRI is working with 12 member utilities to test its performance in diverse applications at residences, businesses, and government sites across the United States. So far, 280 devices have been installed at 80 sites.

The utilities have opted to use the EMCBs to monitor more than 20 end-use loads, including HVAC equipment, hot water heaters, EV charging stations, photovoltaic systems, pool pumps, street lights, batteries, and even an aquarium.

“We want to see if the device performs per its specifications, what its weak spots are, whether it fails in conditions of extreme heat and cold,” said Reddoch. The project will also provide feedback to improve user interfaces and identify new applications.

The initial field results are encouraging. The EMCB hardware and WiFi communication have worked exactly as expected. The testing has also revealed the need for improvements in certain software systems—one (developed by Eaton) that sends commands to and retrieves data from the devices, and another (developed by EPRI) that presents the data in a usable format.

“In the field, we have observed some flaws, but they are manageable and are being corrected,” said Reddoch.

EPRI continues to gather data and examine the power profiles of water heaters, HVAC systems, and other devices in homes and businesses outfitted with EMCBs. Those will be included in EPRI’s electric load shape library, which utilities can access to improve their operations and efficiency. “The profiles can help utilities more easily execute load control or manage end uses,” said Reddoch. “If you have three electric vehicles being charged on one transformer, you could manage them so that they won’t overwhelm the transformer.”

When the first round of field tests ends in August 2018, participants will have the option to continue for another two years. Another possibility is for EPRI to help utilities design programs that encourage customers to incorporate EMCBs into their homes or businesses. Utilities that did not participate in the first round of field tests can still join this second phase of activities.

“This device gives us a viewing port into the operation of the electric system. It makes it highly visible,” said Reddoch. “It allows for a wide range of actions that can provide benefits to both utilities and customers.”

### **Key EPRI Technical Experts**

Tom Reddoch

In the Field

## Miniature Monitoring

### *EPRI Investigates the Potential of Environmental Microsensors in Utility Applications*

**By Brent Barker**

Advances in electronics manufacturing are driving the proliferation of small, portable, inexpensive environmental sensors. These microsensors are far less expensive than the larger monitoring equipment used today by the electric power industry for compliance with environmental regulations. However, the number of parameters that they can measure is limited, and the measurement quality is not regulatory-grade. Nevertheless, as their performance improves and costs come down, the future role of environmental microsensors is likely to expand.

“Monitoring equipment is being miniaturized,” said EPRI Principal Technical Leader Stephanie Shaw. “Although microsensors don’t include the complex analyzers and extra calibrations needed for regulatory compliance, they have the potential to provide utilities with screening data in unmonitored areas and supplement existing monitoring programs. They can run on batteries or small solar panels and are light enough to be carried by technicians, whereas regulatory-grade instruments are very bulky and often must be stored in climate-controlled cabinets.”

To date, the quality of microsensor measurements has not been consistently high, though the U.S. Environmental Protection Agency (EPA), the California South Coast Air Quality Management District, and other industry stakeholders are working to improve measurement quality through thorough testing and comparison against reference instruments.

Microsensors may also put environmental monitoring in the hands of the public. Today it’s feasible as part of emerging “citizen science” for the public to use smartphone-powered sensors to measure air quality near industrial facilities. This has spurred some utilities to work with EPRI to test these devices.

EPRI’s SENTINEL project is investigating the potential of new microsensors, and electric utilities in the United States have hosted field studies of three applications: measuring airborne particulate matter near a coal-fired plant, measuring indicators of groundwater quality near a coal ash impoundment, and real-time monitoring of ground movement at a coal ash impoundment.

“We’re trying to answer two questions,” said EPRI Senior Technical Leader Bruce Hensel. “First, since there has been insufficient verification of the quality of these sensors, we want to find out what they can and cannot measure in the field and assess the accuracy of the data they capture. Second, if they work well, do they represent an opportunity for utilities to expand their environmental monitoring networks and save on monitoring costs?”



A microsensor for groundwater monitoring.

Environmental applications for microsensors potentially relevant to utilities include:

- Provide environmental data to help identify the best locations for regulatory-grade monitoring instruments
- Detect pollutants at power generation facilities
- Create early warning/detection systems
- Monitor worker exposure
- Educate local communities and other stakeholders about environmental conditions and other issues

### Particulate Matter at Coal Piles

The utility hosting the study of particulate matter measurements wanted to know if microsensors could detect a dust plume coming from the power plant's on-site coal stockpiles. Those in long-term storage, typically a year or more, are coated with a sealant, while those being moved and conveyed into the plant are subject to wind and other weather.

Downwind of the coal piles, EPRI and the utility tested microsensors that measure various sizes of airborne particulate matter (1, 2.5, and 10 microns). Their accuracy was gauged relative to measurements from equipment whose precision is accepted by the U.S. federal government.

The nine-month test yielded mixed results for the microsensors. Comparisons to the reference monitor showed numerous false positives when the temperature fell below 0°C. The sensors didn't perform well in winter cold or summer humidity but did pick up the dust plume under more moderate conditions.

"The sensors are not perfect, but they are useful for screening. They can fairly reliably detect the presence of windblown dust and, when placed in multiple locations, give utilities a tool to inform action," said Shaw.

### Measuring Ground Movement

Another utility's network of ground movement microsensors monitors the stability of berms (man-made embankments) at a coal ash impoundment. The utility has shared its real-time data with the SENTINEL team, which in turn will share with other industry stakeholders.

Sensors known as piezometers measure pore water pressure. In-place inclinometers measure the lateral displacement of a berm. Settlement plates characterize the interface between native soil and fill material, and other sensors measure soil settlement at various depths.

"The ground movement tests revealed that these are very sensitive instruments and provide a powerful data set capable of showing early stages of ground movement. This provides an early warning system for potential failure of berms, dikes, or impoundments at coal ash facilities, giving utilities time to take action to shore-up these structures before a catastrophic failure occurs," said Hensel.

### Measuring Groundwater Quality

EPRI is also testing microsensors in a groundwater monitoring project at a coal ash management facility. At present, there is no suite of microsensors that can replace a comprehensive groundwater monitoring program, which relies on laboratory measurement of pH, total dissolved solids, sulfate, chloride, calcium, and boron as well as various trace elements, such as molybdenum and arsenic. Microsensors are available only for measuring pH, chloride, and electrical conductance (which provides a close parallel to total dissolved solids).

“Whereas the ground movement sensors are reliable and provide very useful information, sensors for groundwater monitoring are not as advanced,” said Hensel. “For the most part, the groundwater sensors we need are not available. The ones that are available are not cost-effective yet; they are not always reliable and require routine maintenance.”

That said, new microsensors can supplement traditional groundwater monitoring in a few applications. “Strategically positioned sensors can provide additional data between manual sampling events, particularly in karst and other groundwater systems with rapid flow,” said Hensel.

### “Wide Open” Future

“We wanted to give these new microsensors a solid test in practical applications at utility facilities, comparing them with the more expensive, sophisticated monitoring systems used by utilities today,” said Shaw. “They are at an early stage of development, and we see promise if not perfection. Because of their portability and lower cost relative to other monitoring equipment, they are ready for some specific applications now—detecting a coal dust plume, characterizing water flow underground, providing early warning of dike instability. The future possibilities are wide open. EPRI will continue to track microsensor technologies with potential to provide more detailed environmental data and lower utilities’ monitoring costs.”

### Key EPRI Technical Experts

Stephanie Shaw, Bruce Hensel

Innovation

## Solar for the Long Haul

*As Solar Goes Mainstream, EPRI Expands Research Portfolio to Address Long-Term Issues*

**By Sarah Stankorb**

Solar photovoltaic (PV) energy is fast approaching a tipping point. Nationally, 29 states have renewable energy standards. Solar is a low-cost power source in a growing number of regions. These trends are driving utilities and corporate and retail customers to invest in, own, and operate solar plants.

To inform solar plant owners and operators in their efforts to reduce costs and enhance reliability, EPRI has broadened its solar generation research portfolio, including technology assessments, technical assistance for solar plants, demonstration projects, and best practices for a plant's life cycle.

### Short-Term Design, Long-Term Thinking

Companies seeking to purchase existing large-scale solar plants face a challenge. In the United States, independent power producers own about 90% of these facilities, and some were built as short-term investments—driven in part by federal tax credits requiring plants to be owned by a single entity for six years.

“Plants are expected to have lifetimes of more than 20 years. However, if the initial owners expect to sell the plants after 6 years, their design and procurement decisions might not consider the full lifetime of the plant,” said EPRI Senior Project Manager Michael Bolen. “EPRI recognizes the need to better understand the impacts of upfront decisions on long-term operations and maintenance.”

EPRI is developing best practices for PV plant specifications and commissioning, drawing on existing guidelines and input from subject matter experts and other stakeholders. For example, a recent EPRI [study](#) examined trade-offs associated with plant wiring. Power cable buried without conduit is cheaper but more prone to damage from animals, water infiltration, and other causes—and it costs more to diagnose problems, repair, and replace.



A large-scale solar power plant.

## Monitoring and Maintenance

Upfront equipment choices, such as the type and quantity of sensors and inverters, impact plant monitoring and diagnosis capabilities. Advanced pattern recognition and other real-time monitoring systems often trigger alarms without adequate information about the causes of an excursion. There can be many false alarms. For technicians requiring hours to reach plants, it is necessary to dispatch them with the right information and equipment. EPRI is investigating the potential of advanced data analytics for solar plants. According to Bolen, emerging technologies may offer enhanced diagnostics, such as the ability to identify fault signatures and account for a plant's power degradation over time.

For decades, EPRI has studied and fine-tuned maintenance practices for fossil plants and is now evaluating ways to apply tried-and-true practices at solar facilities. For example, the Equipment Reliability Framework directs fossil plant operators to identify critical equipment as the focus of preventive maintenance. Using this framework, EPRI identified the inverter as the most critical component in PV plants.

At an EPRI workshop later this year, participants will conduct a comprehensive analysis of potential component and system failures in PV plants along with causes and effects. EPRI will incorporate this information in its Preventive Maintenance Basis Database, a web-based tool that utilities and other solar plant owners can use to develop maintenance strategies for various components.

EPRI researchers are investigating other long-term considerations for large-scale solar plants, such as whether and when to replace old equipment with new technology, and decommissioning. Considering end-of-life issues during plant design is important for environmentally responsible electricity generation.

"To the greatest extent possible, PV modules and other solar equipment should be reused or recycled," said Bolen. "When designing new plants or purchasing existing ones, it is important to think long-term and comprehensively."

### Understanding DC Arc Flashes

At solar power plants, arc flashes in high-power direct current (DC) equipment can present safety concerns and damage equipment. There is a safety standard for assessing arc flash hazards in alternating current (AC) equipment (IEEE 1584), but not one for DC systems—which include PV plants. As more PV plants, utility-scale batteries, electric vehicle charging stations, and other DC systems come online, there is an increasing need for such a standard. In a three-year, \$1.1 million [cooperative agreement](#) with the U.S. Department of Energy, EPRI is researching arc flash mechanics in PV systems to quantify the hazards and develop safety recommendations for the electric power industry.

### Key EPRI Technical Experts

Michael Bolen

R&D Quick Hits

## EPRI Demonstrates Laser Sensors to Optimize Coal Plant Combustion

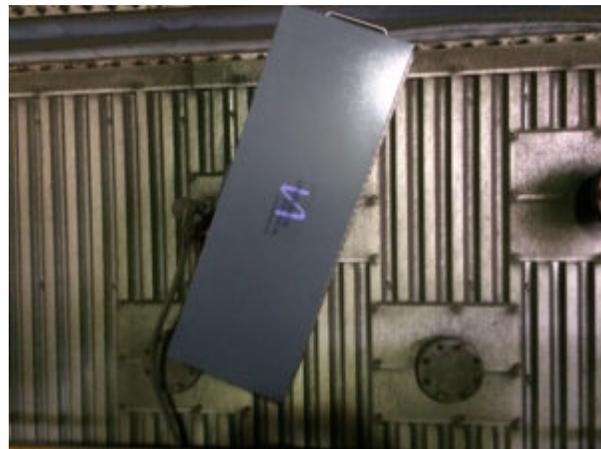
Precise measurements of combustion gases in power plants can potentially save operators hundreds of thousands of dollars each year, an EPRI [study](#) finds.

To tune boilers and optimize combustion in coal-fired power plants, plant operators periodically extract combustion gases to measure oxygen distribution, which can then be adjusted to be more uniform. Plant operators today need even more precise combustion control as they face greater competitive pressures, flexible operations, more stringent nitrogen oxide emission mandates, and the potential for carbon dioxide emission limits. This can be achieved through real-time monitoring of oxygen and carbon monoxide levels in numerous areas of the flue gas duct, which is typically 50–90 feet wide.

EPRI demonstrated a device that can be inserted to measure oxygen and carbon monoxide from a single point in the flue gas flow, using laser-based sensors. Over several months at an 805-megawatt coal-fired boiler, the device collected continuous measurements with high accuracy and limited maintenance needs.

While the prototype measured only at a single point, results suggest that a similar device designed for multiple-point monitoring can enable operators to fine-tune burners, reduce excess oxygen, and maintain acceptable carbon monoxide levels. This can help enhance plant efficiency and reduce CO<sub>2</sub> and other emissions. Researchers estimate that using this approach, operators could potentially reduce annual operating costs by hundreds of thousands of dollars, based on factors such as improved boiler efficiency and reduced nitrogen oxide levels.

The study's authors report that refinements are needed to define multi-point approaches with capital costs acceptable for commercial application. EPRI is conducting a cost-benefit analysis of potential approaches.



The measurement device used in the EPRI demonstration was mounted on a flue gas duct.

R&D Quick Hits

## From Refrigerators to Hot Dog Rollers: Making Convenience Stores More Efficient

Per square foot, convenience stores are among the biggest energy users in the commercial building sector because of considerable refrigeration, lighting, and space conditioning, coupled with long operating hours. According to the 2012 [Commercial Buildings Energy Consumption Survey](#), the 131,000 convenience stores in the United States consumed 27 billion kilowatt-hours—roughly comparable to annual electricity sales in [Connecticut](#).

While many utility efficiency programs already include offerings for convenience stores, an [EPRI assessment](#) of equipment in 24 Tennessee stores revealed further opportunities for energy savings:



- **Heating and cooling:** For space heating, replace electric resistance heat with more efficient heat pump technology. Improve heating and cooling through better ventilation systems, blowers, and variable-speed compressors. Install whole-building controls to coordinate multiple units.
- **Refrigeration:** Adjust units' temperature setpoints, use evaporative cooling, and improve defrost control.
- **Lighting:** Replace old 24/7 indoor lighting with a configuration that uses daylighting coupled with photosensors and dimmable LEDs. Stores already using LEDs in some applications can make additional gains through a full conversion to LEDs. In some stores, 24/7 outdoor lighting can be optimized.

EPRI's next step is detailed monitoring of two Texas convenience stores, determining load shapes for all equipment—even the hot dog rollers. From this, researchers can quantify savings achievable through central control systems and estimate loads that can be shifted or shed without disrupting store operation.

## R&amp;D Quick Hits

## Street Lights: Not Just for Lighting Anymore

In the city of the future, could street lights help meteorologists forecast the weather? Could they identify open parking spaces for drivers circling the neighborhood? Quite possibly, according to an EPRI [study](#) on “smart city” lighting.

A growing number of commercially available technologies can be mounted on or in street poles and street lights to provide new city services, data streams, and revenue. Potential applications and opportunities include:

- **Environmental sensors:** The data could potentially be sold to weather providers, emergency services, and other parties.
- **Communication networks:** Antennas and routers could expand cellular and WiFi networks.
- **Grid services:** These include electricity metering, fault detection, and distribution automation.
- **Cameras and microphones:** Audio and video data could be used for security, accident reporting, and parking optimization.
- **Charging:** Electricity is already delivered to street lights and could be routed to electric vehicle chargers or inductive chargers for drones (used for city and safety services).
- **LED billboards:** These could be used for advertising.

Other examples include traffic monitoring, gunshot detection, and air quality monitoring. Utilities could potentially invest in a single communication infrastructure that integrates street lights, smart meters, and many other smart city technologies. Questions about these technologies remain, and EPRI is examining their deployment, technical requirements, performance, payback, costs, and benefits.



R&D Quick Hits

## The Key to Success with Drones for Environmental Applications: Diligence

For utilities interested in operating drones along transmission and distribution rights-of-way, an EPRI [study](#) offers this insight: A full-fledged drone program can significantly bolster wildlife, vegetation management, resource mapping, and an ever-expanding list of other environmental programs, but success depends on careful planning and evaluation of costs, risks, and limitations.

Drones can be used for numerous environmental applications along rights-of-way. Examples include marking power lines to reduce bird collisions, surveying bird nests prior to line work, counting wildlife, tracking marked animals, and documenting vegetation health and intrusions into rights-of-way. Small, high-resolution cameras, infrared cameras, software for generating three-dimensional models, and numerous other sensors are expanding drones' capabilities.



Among best practices recommended by EPRI:

- **Hardware, software, and firmware:** These require careful selection and regular maintenance and updates.
- **Mission planning:** The flight operators, data analysis team, and end users of the data need to agree on mission parameters and deliverables. Preflight checklists can minimize forgotten tasks.
- **Data storage and management:** Selecting the right solution requires consideration of many factors such as the frequency and scope of missions, camera resolution, and types of sensor measurements.
- **Insurance:** Traditional insurance plans may not adequately cover drone missions, so utilities may need to evaluate alternatives.
- **Privacy:** Because drones operating in rights-of-way will inevitably collect images of the public and adjacent properties, utilities should adhere to the National Telecommunications and Information Administration's voluntary privacy guidelines.
- **Flight logs:** These can be used to document training, maintenance, firmware updates, flight locations and durations, mission goals, and unexpected incidents.
- **Electrical impacts:** The electrical environment around high-voltage lines can potentially impact drone operations. Utility staff need to understand and account for these impacts in planning missions.
- **Training:** Sufficient training in the use of drones should be provided to utility staff.

The results of the study can help utilities decide whether to start their own drone program or contract for these services—and formulate appropriate requirements if they choose the latter.

R&D Quick Hits

## Solar Module Recyclers: On a Mission to Recover More Materials with Less Energy

A [survey](#) of recycling companies points to a critical trade-off in recycling of solar photovoltaic (PV) modules. On one hand, greater recovery of valuable trace constituents such as silver can reduce lifetime environmental impacts of solar generation and make module recycling more economically viable. On the other hand, it also requires more process steps and energy consumption. To be successful, the nascent PV recycling industry will need to strike a happy medium. That said, as processes and technologies for PV module recycling advance, it may be possible to increase recovery of materials while reducing energy use.



While the massive growth in solar energy has clear environmental benefits, solar panels have a finite lifetime and could end up in the waste stream. Landfilling is not an option. Some panels contain heavy metals such as cadmium and lead that can potentially leach into the environment. Disposal of other panels could contribute to the depletion of rare elements such as gallium and indium. Recycling is not easy because panels are assembled from numerous different materials.

Most experience with PV recycling is in Europe where it is mandatory. In the United States, there are no federal regulations for PV recycling, though several states are considering or developing policies and initiatives. Because volumes of PV waste are still low, dedicated recycling facilities are not yet economically justified. Today, glass, metal, and e-waste facilities perform most PV recycling, running only periodically to process batches of modules.

The National Renewable Energy Laboratory, Wambach Consulting, and EPRI surveyed five European recycling companies about their commercial and pilot-scale PV recycling processes and examined their data on consumption of energy and recovery of materials. Four companies incorporated module recycling in their existing glass and metal lines with only minor modifications, using crushing, sieving, and other mechanical processes to separate materials. The fifth company is demonstrating a new, dedicated PV recycling system that uses mechanical, thermal, and chemical processes. Relative to the other facilities, it recovers a greater proportion of materials, particularly metals and silicon. It consumes less energy than the metal recycler and more than the glass recyclers.

As more companies develop dedicated PV recycling facilities, R&D can help them recover materials more efficiently, enhance worker safety, and reduce the toxicity of residual materials.

# EPRI JOURNAL

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