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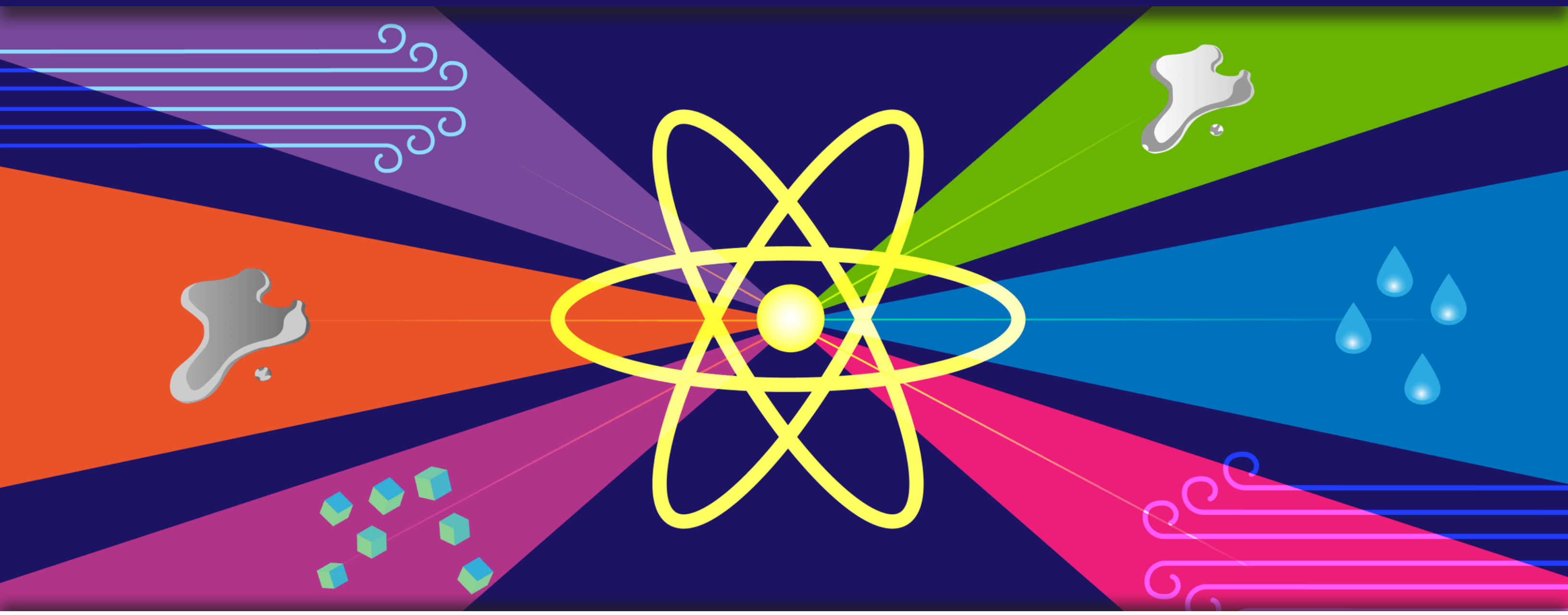
# TIME FOR A NUCLEAR COMEBACK?



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ELECTRIC POWER RESEARCH INSTITUTE

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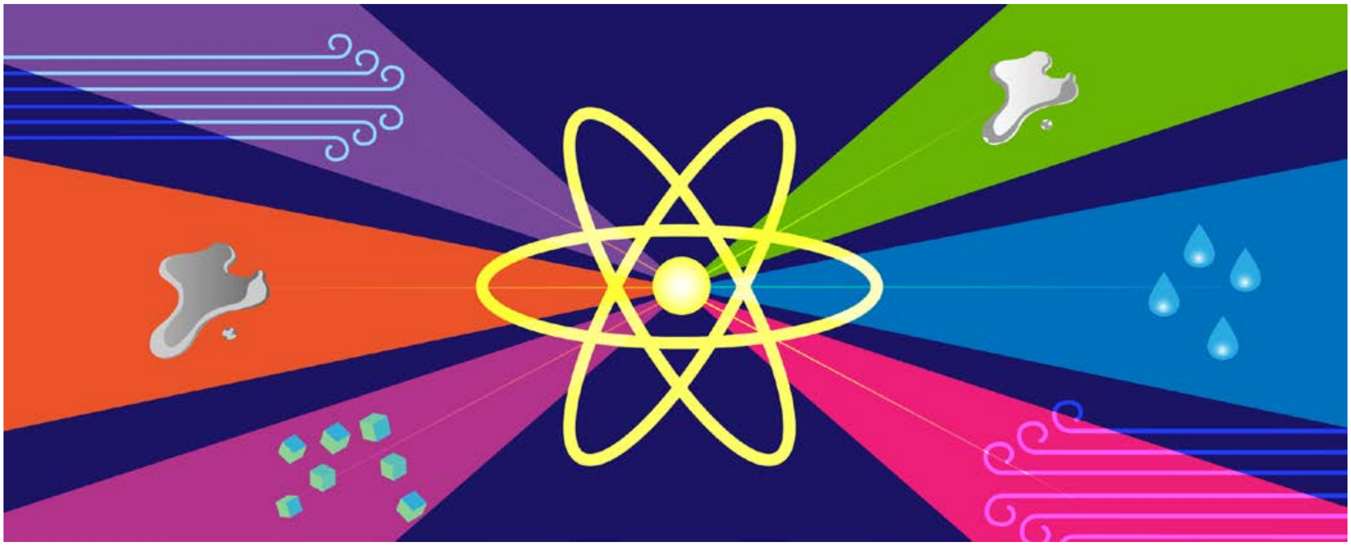
# Time for a Nuclear Comeback?



## *Advanced Reactor Technologies Offer Diverse Options for the Electric Power Industry*

***By Scott Sowers***

It's an uncertain juncture for nuclear power generation. On one hand, the World Nuclear Association reports that China is ramping up investment in nuclear, with 20 plants under construction and plans for up to 150 gigawatts of nuclear capacity by 2030. Globally, 58 nuclear reactors are under construction in countries such as France, Finland, South Korea, United Arab Emirates, India, and Russia.

Outside of Asia, deployment of new nuclear generation has slowed or stalled. In the United States, most nuclear projects proposed to the U.S. Nuclear Regulatory Commission have been shelved or canceled. After costly delays in constructing its AP1000 plants, Westinghouse filed for bankruptcy in March 2017. In July, South Carolina Electric & Gas halted construction of two reactors at the V.C. Summer Nuclear Station, citing cost overruns. In Georgia, the unfinished Vogtle Units 3 and 4 project faces similar financial challenges, though owner Southern Company signaled its intent to move the project forward, pending approval from the Georgia Public Service Commission.

Falling costs of other generation sources globally—and particularly low natural gas prices in the United States—emerged as a primary challenge to nuclear power's economic viability. For new nuclear plants, high construction costs and delays are reducing cost-competitiveness.

At the same time, the impetus to address climate change makes zero-carbon nuclear power more attractive. In providing reliable 24/7 baseload power, it potentially remains a key in balancing grids with intermittent renewable energy sources and dynamic loads. With high energy density, nuclear plants need refueling only every two years, providing security against fuel supply disruptions as a result of extreme weather.

These competing factors raise questions regarding nuclear power's role in meeting the world's energy needs in the coming decades.

To a great extent, the answer depends on the progress toward commercializing the new safer, more cost-effective nuclear reactors under development. EPRI's Advanced Nuclear Technology Program conducts collaborative R&D to support and accelerate the near-term deployment of these advanced large light water reactors, small modular light water reactors, and advanced non–light water reactor reactors, often referred to as Generation IV.

## Generation IV Reactors
At a Glance

### COOLANTS
In the core of a nuclear reactor, the fission of nuclear fuel releases heat. Coolants remove the heat, transferring it for various uses (such as electricity generation and process heat) and dissipating it into the environment. This also protects reactor components. Unlike today's operating reactors, most Generation IV technologies use coolants other than water, enabling operations at higher temperatures and lower pressures.

### TEMPERATURE
Higher temperatures in Generation IV reactors can enable higher electricity generation efficiencies, use of more water-efficient cooling systems, and access to new markets for process heat.

### PRESSURE
Lower pressures in Generation IV reactors translate into lower accident risks and simpler, less costly systems, structures, and components.

### NEUTRON SPEED: FAST VS. THERMAL
The speed of neutrons in a reactor determines much about how it uses fuel. Most reactors in operation today are thermal reactors, which use slow-moving neutrons to sustain fission reactions in the fuel. Materials known as moderators reduce neutron speed. Most Generation IV technologies are fast reactors, which use more energetic, fast-moving neutrons to sustain fission reactions.

### BREEDERS AND BURNERS
Compared to their slow counterparts, fast neutrons can induce fission in more types of atoms and are more effective in converting non-fuel isotopes into usable fuel. As a result, fast reactors can be configured as "breeders" to produce more nuclear fuel than is consumed by fission, or as "burners" to consume the long-lived actinide elements present in used fuel. These capabilities can reduce fuel requirements and radioactive waste.

## Generation III and III+

Most projects under construction today are advanced light water reactors, also known as Generation III and III+ reactors—a technology pioneered in the United States that remains the workhorse of nuclear power generation. Water serves as the coolant and moderator, helping to slow down neutrons to enable sustained nuclear reactions. Compared with the Generation II reactors built between the 1960s and the 1990s, advanced light water reactors offer greater fuel efficiency and longer plant life. They also include enhanced and passive safety features.

## Simpler, Cheaper Reactors

Small modular reactors (SMR) are generally rated at 300 megawatts or less and designed so that major components are built in a factory and then shipped by truck or rail to a plant site for assembly. In contrast, most major components for a typical 1,000-megawatt light water reactor are built on-site.

"Nuclear power's future depends on the cost of electricity generation, and a large percentage of that is cost of construction, followed by the cost of operation. Small modular reactors are designed to be simpler and cheaper to build and operate, and that can help bring down costs," said EPRI Program Manager Ron King.

Relative to large light water reactors, SMRs can potentially lower construction costs, streamline licensing, and require a smaller footprint. Most SMR designs include passive safety features and a reduced fuel load. Some include below-ground construction. Should an accident occur, there would be a smaller impact on the surrounding area.

SMRs offer a new take on proven light water reactor technology. While nuclear utilities have not yet built SMRs, small reactors have been used for naval propulsion and other military applications since the 1950s. Regulatory approval of SMR designs will take time, but the process is moving forward. In March 2017, the U.S Nuclear Regulatory Commission accepted for review NuScale Power's SMR Design Certification Application.

In a two-year project with the U.S. Department of Energy (DOE), EPRI is evaluating integrated pressurized water reactors—an SMR design in which the reactor, steam generator, and pressurizer are housed in a smaller containment shell. These reactors have the potential to reduce the deposition of radioactive particles on adjacent land during an accident. This can enable smaller emergency planning zones, reducing regulatory burdens, compliance costs, and a plant's footprint.

## Molten Salt Reactors

Generation IV reactor technologies offer significant potential improvements in economics and safety relative to existing light water reactors. Most use coolants and moderators other than water, enabling operations at higher temperatures and lower pressures.

Higher temperatures can enable higher energy conversion efficiencies, use of water-efficient dry-cooling and hybrid cooling technologies, and access to new markets for high-quality process heat. Lower pressures translate into lower accident risks and thinner walled—and therefore less costly—components.

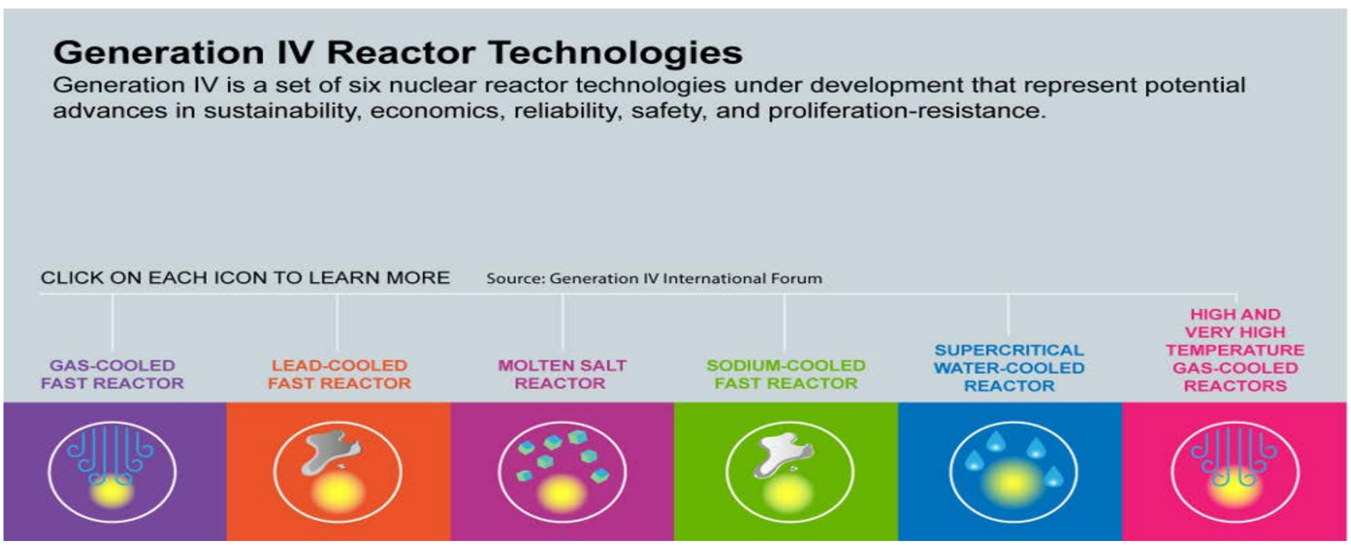
The Generation IV technology known as a molten salt reactor runs on fuel that is dissolved into the coolant, facilitating heat removal from the reactor core and providing other potentially game-changing safety and operational benefits. Molten salt reactors can be designed as "burner" reactors that consume stockpiles of used fuel and plutonium, or as "breeder" reactors that generate more nuclear fuel than they consume. Because fuel circulates through the coolant system, many have historically believed that the technology poses a greater risk of diversion of nuclear materials for harmful purposes. Developers face the need to address these concerns.

In collaboration with Southern Company, EPRI in 2015 completed a technology assessment of a liquid-fueled molten salt reactor, which demonstrated the value of examining safety early and often in plant design.

Building on this collaboration and experience, EPRI is participating in a Southern Company–led project to examine a molten salt reactor design known as the chloride fast reactor. TerraPower, a company backed by private investors such as Bill Gates, is developing the technology. DOE is providing $40 million for the project, with a minimum $10 million cost share from industry stakeholders. An EPRI-led team is providing independent technical peer review of the reactor design and testing program. A key task for this large undertaking is to build an "integral effects test machine" for evaluating heat transfer, fuel/coolant chemistry, materials corrosion, and other aspects.

"If successful, at the end of this five-year project the developer and utility will be well-positioned to proceed with licensing and construction of a test reactor to demonstrate that the technology works as intended," said EPRI Technical Executive Andrew Sowder.

While the technology has never been commercialized, Oak Ridge National Laboratory successfully demonstrated a prototype in the 1960s, and the project team is building on the lab's expertise. During the Cold War, it was considered for powering long-range strategic bombers.




Learn more about Generation IV reactor technologies.

## Other Generation IV Technologies

Researchers globally are working to improve sodium-cooled fast reactors, which operate commercially in many countries, notably France and Russia. Advantages include sodium's high thermal conductivity, which provides substantial protection from overheating and enables operation at atmospheric pressures and moderately higher temperatures (about 550°C). Liquid sodium is compatible with proven reactor materials such as stainless steel. As with other fast reactors, the technology can operate as either burners or breeders. A drawback is that sodium is highly reactive with air and water and requires special handling to prevent fires.

A related technology, lead-cooled fast reactors, offers benefits similar to those of sodium-cooled fast reactors. Unlike sodium, lead doesn't react with air or water but does present significant challenges with materials corrosion.

High-temperature gas-cooled reactors use helium as the heat transfer fluid. Helium is inert, but its low heat capacity requires that it be pressurized for effective heat transfer. In modern designs, microspheres of fuel are dispersed in a large graphite matrix designed and demonstrated to handle the highest temperatures that occur during a severe accident. Like water, graphite is effective at slowing neutrons, making this a thermal reactor technology. The fuel's lower energy density requires a larger reactor core and plant per unit energy, limiting scalability. High helium pressures and flow rates lead to larger components, increasing material and manufacturing costs.

These are among the most mature advanced reactor designs. In the United States, two high-temperature gas-cooled reactors—Peach Bottom 1 and Fort Saint Vrain—operated between the 1960s and 1980s. Ten larger commercial high-temperature gas-cooled reactor units were canceled in the late 1970s (along with many more light water reactors) primarily because of a sluggish economy and reduced growth in electrical demand. China is expected to start up a commercial prototype in 2018.

Developers of "very-high-temperature gas-cooled reactors" are targeting even higher temperatures (above 850°C) to further enhance economics. Some are pursuing a fast reactor version with new fuel designs that enable operation at very high temperatures.

## Options for the Future Power System

Outside of Asia, social, economic, and political headwinds have slowed deployment of nuclear generation capacity. In the United States, factors include low natural gas prices, unfavorable market conditions, a complex licensing process, high construction costs, and long, uncertain lead times. In France, with its traditionally pro-nuclear policy, the nuclear contribution to the electricity mix could drop from 75% to 50% if recent policy shifts hold. Germany reinstated a nuclear phase-out in 2011 and is targeting shutdown of all nuclear plants by 2022.

"Most markets aren't valuing the zero-carbon emissions of nuclear power and the important benefits it provides to the grid," said Sowder.

Nevertheless, Sowder sees an opportunity for a new generation of reactor technologies to overcome these hurdles.

"The real promise of the advanced reactor technologies is that they provide new options to maintain safe, reliable power generation in a rapidly transforming power sector," he said. "They may offer the best hope for nuclear to sustain its substantial role through the 21st century."

With uncertainty regarding climate policy, natural gas prices, deployment of intermittent renewable generation, and electricity market structure, the optimal generation mix decades from now is unknown. For utilities, a new generation of nuclear technology broadens their options in navigating these potentially disruptive variables.

### EPRI's Utility Requirements Document

Since 1990, EPRI has regularly updated its Utility Requirements Document, which provides more than 40,000 technical and design requirements for advanced light water reactors and small modular reactors. For plant designers, the document provides a roadmap for successful deployment of next-generation reactors. In 2014, EPRI published the document's 13th revision.

"The Utility Requirements Document represents an important tool for communicating with the public, regulators, and other stakeholders and for aligning nuclear plant designs with utility needs," said EPRI Technical Executive Andrew Sowder. "The intended result is a new generation of safer, simpler, more competitive, and licensable plants."

Now, EPRI is developing a new set of requirements for Generation IV reactors to help align the many proposed designs with the needs of utilities and other potential customers.

For example, Generation IV reactors' higher operating temperatures can enable more efficient generation while opening to utilities and other owner-operators access to new power markets such as the sale of steam to industrial facilities. The lower operating pressures of many Generation IV designs could result in less costly reactor components and lower construction costs, improving cost-competitiveness with other generation. The ability to "breed" fuel could provide greater energy security. SMR designs could streamline licensing and enable faster deployment.

"One can imagine unique uses of a scalable nuclear energy source that only requires refueling every two, ten, or thirty years," said Sowder. "For reliability and resiliency, there is no match for a nuclear plant that can operate without the need for functioning pipelines or regular rail and truck transportation of coal or liquid fuels."

"We don't know exactly what options or generation attributes will be needed in thirty years," said Sowder. "Diverse options give the industry the power to adapt to changes."

### The Promise of Fusion

All nuclear power generation today harnesses fission, or the breaking apart of heavy atoms, usually uranium, to produce heat energy. Nuclear fusion—merging hydrogen atoms to form helium—also produces large amounts of energy, but its application for electricity generation is still theoretical. Nevertheless, because hydrogen is abundant and helium is inert, fusion offers the potential of virtually limitless supplies of safe, non-emitting energy without long-lived radioactive waste.

The sun provides the working model for fusion, combining hydrogen isotopes under extreme pressure and temperature to produce helium, neutrons, and a huge output of energy. For fusion developers, the challenge is to mimic sun-like conditions on earth, control the reactions, and engineer a reactor that harnesses the residual heat to produce electricity.

"You have to find a way to package the fusion process in a machine that produces power," said EPRI Technical Executive Andrew Sowder. "You have to make something that can operate reliably on a commercial scale, which is very different from operating in a laboratory."

Many organizations are working to develop devices that create heat and pressure sufficient to fuse atoms. Some use magnets to confine hydrogen and create plasma. Others use lasers to heat and compress hydrogen.

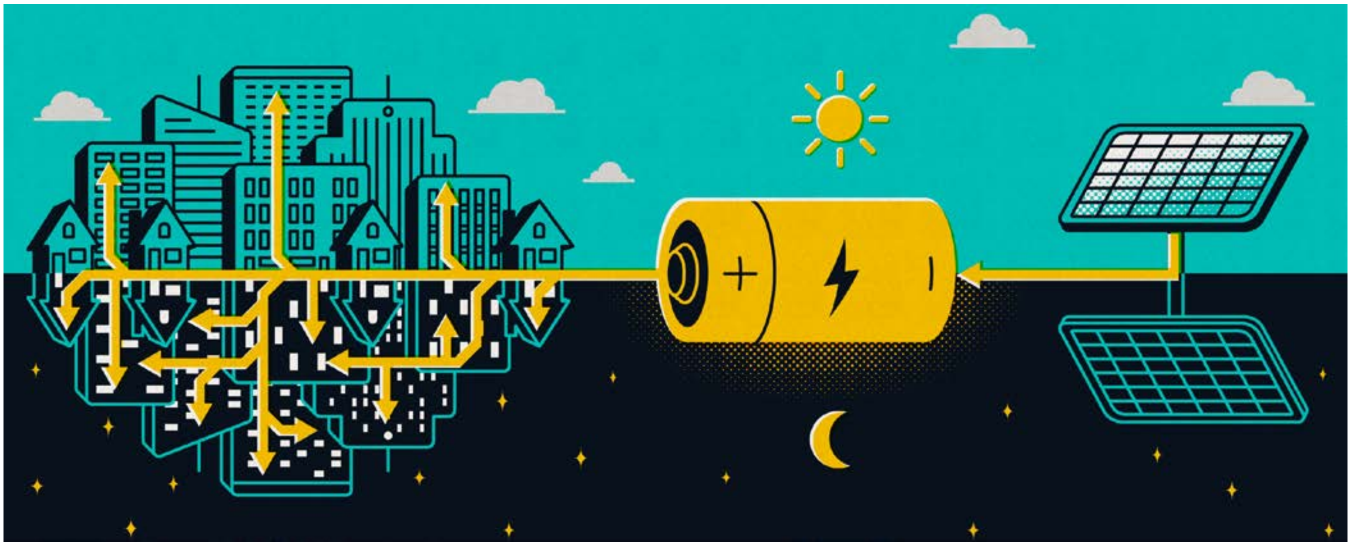
Most fusion research projects are large. Sprawling across 42 acres in southern France, the International Thermonuclear Experimental Reactor cost $14 billion to build, involves 35 countries, and is expected to come online in 2025.

A handful of fusion startup companies are working at a much smaller scale. EPRI is working with California-based TAE Technologies, which is using a "beam-driven field reversed configuration" to produce plasma from superheated hydrogen and boron. The plasma is held in place and spun like a top by magnetic fields and neutral hydrogen beams. In July 2017, the company started up "Norman," a 100-by-45-foot fusion reactor that can generate temperatures between 50 and 70 million °C—about the same as the sun's core. Since 2011, EPRI has tracked technology development as a member of TAE Technologies' Science Council.

### Key EPRI Technical Experts

Andrew Sowder, Ron King

# Storing in Bulk



## *The Need for Large-Scale Energy Storage Grows, but the Business Case Remains Uncertain*

***By Brent Barker***

Energy storage on the electricity grid has been around since the 1880s when Thomas Edison used lead-acid batteries to store power for the nighttime illumination peak. At the time, Edison's direct current grid extended no more than a few city blocks in lower Manhattan, and nearly all the electric demand was for lighting.

The first bulk energy storage system in the United States was a pumped hydroelectric storage facility, commissioned in 1929 in Connecticut. Pumped hydro consumes electricity to move water from a lower reservoir into an upper reservoir. Then, when power is required, water released by the upper reservoir flows down through a hydroelectric turbine to generate electricity. The technology offers large capacity discharge, fast response, and economies of scale. Over the next 50 years, more than 20 gigawatts of pumped hydroelectric storage were installed in the United States, and more than 127 gigawatts worldwide. Today it accounts for about 98% of bulk electricity storage globally.

The Bath County Pumped Storage Station in Virginia's Allegheny Mountains has a capacity of more than 3,000 megawatts. Photo courtesy of Jeffrey G. Ocampo, Dominion Energy.

In the 1980s and 1990s, however, deployment in the U.S. slowed to a halt as a result of restrictions on land and water use. "Utilities that have it, love it, because it provides flexible power to help balance their grids," said Brittany Westlake, a scientist in EPRI's Energy Storage and Distributed Generation Program. "But the best sites in the U.S. are already taken, and costs for construction and permitting for new sites can be prohibitive." The most recently built facility in the U.S. went into service in Georgia in 1995.

For more than two decades, the scientific and engineering communities have been on a wide-ranging, determined search for viable alternatives to pumped hydro. The search has intensified as intermittent renewable generation has grown and the grid has become more complex, calling for the operational flexibility and support that bulk energy storage can provide.

## The Strategic Role of Bulk Energy Storage

Bulk storage offers grid operators two essential attributes: hundreds of megawatts of power capacity and an ability to deliver electricity continuously for many hours.

“Today, the biggest drivers for bulk storage are the need to integrate intermittent, utility-scale renewables and the potential to defer investment in transmission and distribution infrastructure,” said Matt Pellow, a scientist in EPRI’s Energy Storage and Distributed Generation Program. “Utilities are saying, ‘My wind resources are blowing at night, which is not when I need them. How do I maximize my returns on those assets?’ This thinking leads inevitably to storage.”

Recognizing the forecasts for significant wind and solar investment, regulators and grid operators are eager to couple renewables with bulk storage to maximize value and support grid integrity. In 2013, the California Independent System Operator estimated that it needed as much as 6,000 megawatts of electric capacity to cover the loss of solar to meet the evening peak. It predicted that the gap would grow to more than 13,000 megawatts by 2020. The same study projected over-generation in the middle of the day, pointing to a possible opportunity for energy storage to shift midday generation to the evening peak. Although natural-gas-powered generation is capable of providing this capacity, that approach runs counter to the state’s renewable energy targets.

As utilities review supply and demand forecasts throughout their service territories, they recognize the implications of bulk storage for cost-effective, reliable power delivery. “If they forecast a need for additional transmission capacity, they are faced with an expense that has to be passed along to ratepayers,” said Pellow. “This is a potential opportunity for storage to reduce the cost of meeting that need, but only if it costs less than building transmission lines. In industry meetings, the issue of deploying storage for grid upgrade deferral is moving from an interesting discussion topic to serious consideration. The cost of storage, though declining, is still significant, so careful analysis is required to establish the business case.”

Installing bulk storage downstream from a nearly overloaded transmission node could defer costly infrastructure investment for years. Since the highest loads on a node typically occur only a few days or a few hours per year, even a small amount of storage could provide enough capacity to delay—or conceivably eliminate—large and costly upgrades.

Transmission congestion can hinder delivery of least-cost energy from remote generation. Adding storage at strategic locations can potentially facilitate cost-effective power delivery to rapidly growing markets.

Increasingly, bulk storage systems will be called upon to provide direct and ancillary electricity services, such as:

- **Load leveling**: Smoothing load by absorbing energy from or injecting energy into the grid.
- **Ramping support**: Providing supplemental power during startup and shutdown of baseload generation or when solar or wind generation output fluctuates.
- **Energy arbitrage**: Shifting energy production from low-value to high-value periods.
- **Firm capacity**: Guaranteeing availability of backup energy to compensate for dips in renewable energy production.
- **Spinning reserves**: Grid-connected reserve power ready for instantaneous delivery.
- **Non-spinning reserves**: Reserves not connected to the grid but able to deliver power within minutes.

- **Black start**: Bringing a generation plant from shutdown to a specified power level within a specified time, without support from transmission lines.
- **Frequency regulation**: Providing short-term power adjustments to help maintain system frequency within required levels.
- **Voltage support**: Producing or absorbing reactive power to maintain a specific grid voltage.

A single storage system may be able to provide multiple services simultaneously.

"In industry meetings, the issue of deploying storage for grid upgrade deferral is moving from an interesting discussion topic to serious consideration. The cost of storage, though declining, is still significant, so careful analysis is required to establish the business case."

## Bulk Storage Concepts and Requirements

For electricity to be stored, it must be converted to a different form of energy. When electricity is needed, the process is reversed. For example, batteries store electricity by using it to drive a chemical reaction, which is later reversed to provide electricity. With pumped hydro storage, electricity is used to pump water uphill to an upper reservoir, converting it to potential energy. To reverse the process, water is allowed to flow to the lower reservoir through a turbine, which converts the potential energy back to electrical energy. Compressed air energy storage systems use electricity to compress air and store it in a reservoir, either an underground cavern or aboveground pipes and vessels. When electricity is needed, the compressed air is heated, expanded, and directed through a conventional turbine-generator to produce electricity.

Technology developers, utilities, and other stakeholders are actively investigating diverse forms of storage for inexpensive, efficient options. Technologies being considered include flow batteries, which are commercialized in limited applications, as well as adiabatic compressed air energy storage and liquid air storage, which are in early commercialization. Molten salt thermal storage and advanced rail energy storage are also under development, but the economics for these technologies are less certain.

"The technology portfolio, and timeline to commercialization, will depend on who can lower their costs, by how much, and when," said Pellow.

Today, there are only two technologies—pumped hydro and compressed air energy storage—with decades of operational experience providing energy storage that:

- Delivers energy for 6 or more hours at maximum-rated output.
- Charges and discharges at power ratings ranging from 10 to hundreds of megawatts.

Geology and geography have held back the expansion of traditional compressed air energy storage, which is deployed globally at just two facilities—one in Germany (installed in 1978) and one in Alabama (installed in 1991). Historically, large underground salt caverns have been required to store the compressed air, restricting application in the U.S. to the Gulf Coast region. More recently, porous rock and abandoned underground natural gas reservoirs are being investigated as possible sites, but these are often located far from load centers and are therefore less cost-effective.

While pumped hydro and compressed air energy storage provide large-scale, long-duration storage, batteries and flywheels—storage technologies more commonly deployed in recent decades—are particularly good at providing power on very short notice for shorter durations. However, large-scale, long-duration energy shifting is increasingly necessary on a high-renewables grid.

## Emerging Technologies

Some innovation in bulk storage focuses on a rethinking of compressed air energy storage. Traditional compressed air storage requires heating of the released air, usually by natural gas, before it is run through a turbine-generator. Alternatively, with adiabatic compressed air energy storage, thermal energy produced during compression is stored in a material such as a molten salt and then used during expansion. The adiabatic version of compressed air storage is fuel-free, reducing costs and eliminating combustion-related emissions.

In an adiabatic compressed air energy storage system developed by Toronto-based Hydrostor, air is compressed and stored in a constructed cavern at the bottom of a 1,200-foot-deep well. Water drawn from a nearby lake or pond fills the well, and its weight keeps the air pressurized in the underground cavern. The heat released from compressing the air is stored. When power is required, a valve is opened, and the compressed air exits the chamber, expands, and drives a turbine-generator. Hydrostor believes that this configuration will allow compressed air storage to be built in diverse locations.

Another technology innovation is liquid air energy storage, which uses electricity to compress air, cool it to liquid phase (-194°C), and store it in a tank. When the liquid air is heated back to a gas and allowed to expand, it turns a turbine-generator and produces electricity. The volume of stored air per megawatt-hour of electricity is substantially smaller relative to traditional compressed air storage. United Kingdom–based Highview Power Storage is developing this technology.

A 5-megawatt liquid air energy storage demonstration facility built by Highview Power Storage. Photo courtesy of Highview Power Storage.

Many compressed air storage developers are considering decommissioned power plants as possible locations. "Ideal sites may have a connection with a transmission line and a water source previously used for plant cooling," said Westlake. "Using existing infrastructure makes a lot of sense. For example, there's a large coal plant shutting down in Utah that looks like a contender because it is near underground salt caverns for air storage and has a direct transmission connection to Los Angeles."

Batteries are also being explored for bulk storage applications. Flow batteries use two liquid electrolytes that are stored separately and flow together in a reaction cell to produce electricity. Like pumped hydro and compressed air storage, they allow power and energy to be scaled separately. Enlarging the storage tanks prolongs the duration of energy output (megawatt-hours), while enlarging the reaction cells increases the power (megawatts).

"One of the strengths of flow batteries is they enable independent adjustments to energy and power, so that you can tailor the system to fit your needs," said Westlake. Power ratings range from 100 kilowatts to 10 megawatts, with durations of 2 to 8 hours.

More than 20 flow battery companies are developing technologies, some with the assistance of the Pacific Northwest Laboratories, a pioneer in flow battery chemistry. So far, most installed flow batteries have less than 1 megawatt of capacity—far smaller than typical bulk storage facilities. However, deployments have been growing in size. In 2017, two 2-megawatt systems were commissioned in the United States, and two more have been announced for future construction.

Longer term, more speculative technologies include thermal storage, advanced rail, and hydrogen.

"Google X is exploring a large-scale thermal storage concept, one component of which stores heat in molten salt—an approach that is used widely in concentrated solar power plants," said Pellow. "EPRI's Innovation Scouts are conducting preliminary due diligence on the concept."

Advanced rail energy storage moves rocks in specialized rail cars to a higher elevation, using gravity to store potential energy. ARES North America is developing this technology.

Hydrogen is another major area of intensive investigation. One pathway for producing hydrogen gas is electrolysis (splitting water with electricity). Although electrolyzer costs remain high, researchers are working toward lower cost hydrogen generation, and EPRI is tracking the emerging technologies.

"The U.S. National Labs are now actively assessing hydrogen for storage to balance the grid," said Pellow. "There is already traction in Europe, especially Germany, to use off-peak electric power to generate hydrogen gas to complement renewables."

Energy arbitrage is not an economically viable application of hydrogen storage under current market conditions, as EPRI research has shown. Rather, a major focus of current research is hydrogen's potential to integrate different energy sectors, such as renewable generation, transportation, and industrial.

The need for bulk storage has never been greater. The support, flexibility, and responsiveness that storage can potentially provide are crucial to maintain forward momentum in renewables. Strategically placed storage can defer or minimize transmission investment.

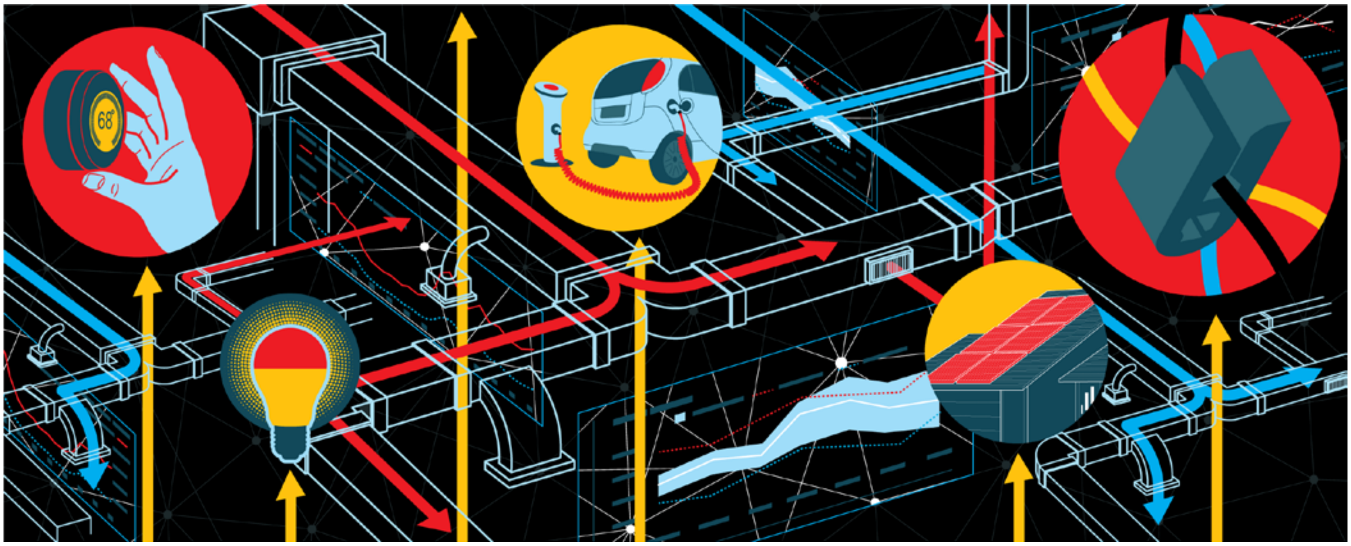
That said, high costs for most technologies—and limits on the returns that they can yield—challenge the business case for storage deployment. In a 2016 modeling study on the California and Texas markets, EPRI found that storage can be valuable in systems with high renewable energy levels, but revenues diminish as storage deployment increases.

"Bulk storage technologies have the potential to bring together all the disparate pieces of the future grid, including decentralized, variable renewable energy. They can also support flexible operation of fossil and nuclear power plants," said Westlake. "They are moving from being just another valuable asset on the grid to becoming a strategic imperative."

## Key EPRI Technical Experts

Matt Pellow, Brittany Westlake

# *First Person*—Buildings with Brains, Billions in Savings



## The Story in Brief

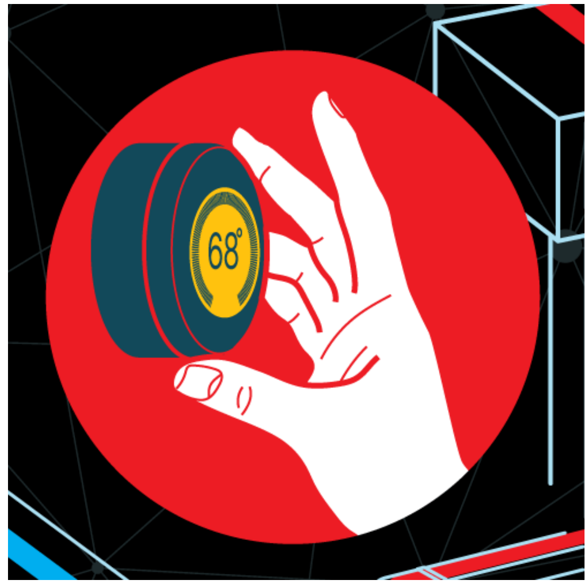
Building energy management company Verdigris has been supported by members of the EPRI-led Incubatenergy Network, which connects clean energy entrepreneurs worldwide with incubators, accelerators, investors, and electric utilities in search of novel technologies for the future grid. *EPRI Journal* spoke with Verdigris CEO Mark Chung about how building energy management systems work, the state of the technology, and the huge potential implications for electricity consumption, greenhouse gas emissions, and grid integration.

## EJ: What is a building energy management system?

**Chung:** A building energy management system helps to optimize energy use in a building. By optimize, I mean identify specifically where energy is being consumed, make adjustments, and achieve an efficiency target. Based on our experience working with clients, a conservative estimate is that commercial and industrial buildings waste 30% of their energy. For instance, even when a building is unoccupied, it may be actively cooling or have lights on. You can improve efficiency by tightening a building's cooling schedule or adjusting when lights are on and off.

Mark Chung

A building energy management system consists of two basic components. One is hardware, which includes sensors that measure electricity and produce data. The second component is software that collects the data and produces a visual display of the information to help the building manager better understand and optimize how and where energy is being used.




### EJ: Is the system automatically making changes in energy consumption, or is it giving information to the building manager who uses it to make changes?

**Chung:** It's a combination of both. The level of automation varies across different energy management technologies, buildings, and customer needs. Automation is possible when the energy management systems are integrated with building controls, which can manage the operation of HVAC systems, refrigeration, lighting, and other equipment.

### EJ: There are many companies offering building energy management systems. Is there a unifying principle among all these technologies? In what ways do they differ?

**Chung**: The unifying principle for all these systems is a feedback loop in which data is used to understand performance and then make adjustments. It's like adjusting the speed of your car based on the speedometer reading. The main differences among these technologies lie in the data collected and the proprietary methods to analyze the data.

Most systems have a combination of hardware and software, but there's more industry focus on software-based solutions, as companies view software as the way to provide the most value.

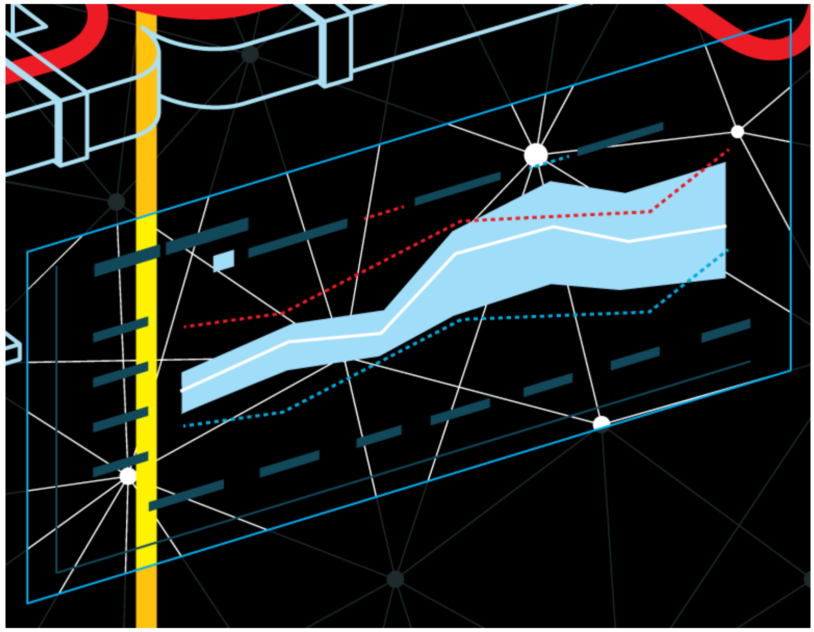
### EJ: How does Verdigris' building energy management technology work?

**Chung**: Our hardware comprises digital sensors and a data transmitter on a 4G wireless network. The sensors clamp onto electrical circuits at various building locations, and the data transmitter organizes and sends the sensor data to the cloud. No other hardware and no rewiring of circuits in the electrical panel are required.

Our software uses artificial intelligence to sort through, characterize, and manipulate the sensor data. The data reveals electrical waveforms, and our machine learning algorithms are able to recognize patterns and infer loads for each monitored circuit.

> "In five years, a smart building will be much more human-like. It will be self-aware in that it will know when people are in it, what to set its temperature at, when to reduce consumption from the grid based on price signals, and when to take energy from solar panels rather than from a battery. It will be able to share intelligence with nearby buildings so that they can work in concert to manage energy resources."

Large companies that do their own analysis can import Verdigris sensor data into their tool of choice. For customers with less sophisticated analytics capabilities, the Verdigris system can analyze the data and generate reports that can be used to benchmark performance, measure and verify energy savings, identify inefficiencies, and recommend actions. These reports are tailored to customer needs by industry and application. Some



reports are itemized bills that rank the most expensive equipment—what's consuming the most electricity and when that consumption is happening—while other reports identify machine failures or when equipment is acting irregularly. For example, you could have a motor or a pump that's rapidly turning on and off. This cycling, which can cause premature wear, usually isn't revealed through aggregate energy figures but will appear in a time-series graph.

We have another product that's not widely available yet that feeds insights back into the energy management system, which in turn automatically controls the operation of equipment, whether it be chiller cycle times or settings for exhaust fans and lighting. This system can be used to shave peak demand loads.

### EJ: Could you share a recent anecdote about how your company's technology resulted in huge energy savings for a customer?

Chung: The global manufacturing company Jabil has deployed Verdigris systems in 9 sites with approximately 8 million square feet. The systems have helped Jabil to determine causes of peak demand events and machinery load surges, enabling improvements in scheduling and operations. They helped to identify inefficiencies such as equipment cycling and inappropriate heating, cooling, and lighting changes. By providing a deeper understanding of load distribution, they also helped to size new equipment accurately.

### EJ: To what extent are building energy management systems already deployed in commercial and industrial buildings?

**Chung**: We're very early in the adoption of building energy management. Only about 20 to 25 percent of buildings are actively managing their energy use in some way. This figure includes customers that are simply evaluating their utility bills and making changes based on that. According to a 2012 survey by the U.S. Energy Information Administration, approximately 10% of commercial buildings use building automation or control systems. Typically, these are buildings larger than 100,000 square feet.

> "Improving the energy efficiency of commercial and industrial buildings by 10 percent could save $40 billion annually and result in a reduction in greenhouse gas emissions roughly equivalent to eliminating 1 out of every 5 registered highway vehicles."

### EJ: What are the implications for broad deployment of building energy management systems with respect to electricity consumption?

**Chung**: The implications are enormous. Energy use in commercial and industrial buildings in the United States costs an estimated $400 billion annually, and approximately 30% of energy in buildings is used inefficiently or unnecessarily. Improving the energy efficiency of commercial and industrial buildings by 10 percent could save $40 billion annually and result in a reduction in greenhouse gas emissions roughly equivalent to eliminating 1 out of every 5 registered highway vehicles. [Source: ENERGY STAR]

### EJ: How can communication between buildings and grid operators be enhanced?

**Chung**: Communication between existing building energy management systems and utilities is virtually nonexistent today. There are steps that both utilities and energy management companies can take to address this. Utilities should avoid investing in proprietary advanced metering infrastructure, which results in devices that are not interoperable. Companies like Cisco and Juniper have already built widespread, secure communications networks. The Green Button initiative to make utility data more interchangeable is a step in the right direction but is too slow. The larger energy management companies could set up consortia for open industry standards, which can help accelerate adoption of these technologies among building managers and grid operators.

### EPRI Research on Efficient End-User Technologies

EPRI's End-Use Energy Efficiency and Demand Response program tests and demonstrates emerging energy-efficient, demand-responsive customer technologies—including building energy management systems—to accelerate adoption into utility programs for the benefit of the public. Researchers are characterizing their grid impacts and providing information to advance the progress of codes and standards. To advance grid connectivity, EPRI is demonstrating a new interface that enables customer appliances to connect to any communication network and receive and execute commands using a common language.

### EJ: What building energy management innovations do you see emerging in the next five years? What will a smart building be like?

**Chung**: In recent years, the biggest energy management innovations have been in data analytics. I think the next phase of innovation is going to be in artificial intelligence. Machine learning and control loops are going to drive significant reduction in building energy consumption. In five years, a smart building will be much more human-like. It will be self-aware in that it will know when people are in it, what to set its temperature at, when to reduce consumption from the grid based on price signals, and when to take energy from solar panels rather than from a battery. It will be able to share intelligence with nearby buildings so that they can work in concert to manage energy resources. A building will be able to compare its performance with that of other buildings and determine what it can do better. A city of 'intelligent buildings' could share best practices and learn from each other to help optimize the grid.

### EJ: As buildings get more effective at sensing and controlling energy use, what potential benefits could they provide to grid operations?

**Chung**: Utilities typically provide a lot more grid capacity than is used because of demand and the lack of grid-scale energy storage. Smart buildings can serve as controllable grid resources that could dramatically reduce peak loads and the amount of grid infrastructure needed.

"Based on our experience working with clients, a conservative estimate is that commercial and industrial buildings waste 30% of their energy."

### EJ: What is the potential for integrating building energy management systems with battery storage?

**Chung**: The biggest driver of integrating energy management systems with battery storage is the need for demand management and resource planning. Verdigris' system generates 15-minute, 2-hour, and 4-hour demand forecasts. If a building stores enough energy in batteries to handle peak demand, the energy management system can shape the building's load profile to save energy costs and help pay for the integrated battery/Verdigris system.

### EJ: How about building integration with electric vehicle charging?

**Chung**: Fortunately, most electric vehicle infrastructure is enabled with Internet Protocol communications, so there's potential for interoperability with building energy management systems. That integration hasn't happened yet, but is likely to be adopted soon. Energy management systems can take advantage of the variable charging load to do more intelligent things. For example, a bank of electric vehicles can serve as battery storage for the building, with the energy management system optimizing when vehicles charge and discharge. You could potentially charge a car for free and borrow that charge back at the right times.

### EJ: How do electric utilities need to consider potentially significant changes in building energy consumption as they update their grid models and conduct long-term grid planning?

**Chung**: I don't think this is going to happen at utilities in a bubble. If building energy data were made accessible in an open, modern framework while protecting the privacy of individual businesses, the energy management community can work on the problem with utilities.

### EJ: What R&D in the electric power sector is needed to more fully integrate buildings into grid operations?

**Chung**: We need more research on controlling building equipment. Besides HVAC equipment, how can we control other equipment like refrigerators and motors and create more interoperability among them? All the energy-consuming devices in a building need to speak a common language.

### By the Numbers: The Potential of Building Energy Management in the United States

- Number of commercial and industrial buildings: nearly 6 million
- Annual energy costs for commercial and industrial buildings: $400 billion
- Energy wasted in commercial and industrial buildings: 30%
- Savings as a result of improving building energy efficiency by 10%: $40 billion
- Percentage of greenhouse gas emissions generated by commercial and industrial buildings: 45%
- Greenhouse gas emissions reductions from improving building energy efficiency by 10%: roughly equivalent to eliminating 20% of registered highway vehicles
- Energy savings identified by Verdigris customers: up to 50%

Sources: U.S. Environmental Protection Agency, U.S. Energy Information Administration, Verdigris

# *Viewpoint*—The Grid Under Attack—How Should We Prepare?

Mike Howard, President and Chief Executive Officer, EPRI

What would happen to the grid if an adversary detonated a nuclear weapon high above us?

This once-obscure question has emerged as a primary consideration of national security and grid reliability and resilience.

In reporting our research on high-altitude electromagnetic pulse (HEMP) events, EPRI carefully considers how we characterize the risks, potential consequences, and the ongoing work that is necessary to address all aspects of the issue.

Triggered by the high-altitude detonation of a nuclear weapon, a HEMP is a sudden burst of electromagnetic radiation that can damage electronic components and low- and medium-voltage electric infrastructure. One part of the HEMP known as E3 can drive low-frequency, geomagnetically induced currents in transmission lines and bulk power transformers. These can cause voltage collapse and "hotspots" in transformers.

EPRI research examining the potential risk to the U.S. electric grid suggests that service interruption resulting from E3 would be limited to a region and not trigger a nationwide grid failure.

Equally important, the research identifies steps that could potentially limit impacts, including technologies to reduce or block the flow of geomagnetically induced currents, and controls to disconnect power system loads automatically.

Ongoing research will assess potential impacts of HEMP on critical electronic systems and develop cost-effective options for mitigating potential damage or disruption.

It's natural that the public express its unease when considering an attack on our power system. While we rarely need to confront such threats directly, we recognize that electricity is essential to our lives and must pursue research to mitigate the risks.

For EPRI, "vigilance" and "research" go hand-in-glove. We see that the power system is, in fact, under attack everywhere and always. These are not attacks in a military sense and do not create in us a siege mentality.

For example, our materials scientists work every day to blunt, reverse, or manage the attack of time on power system components. Corrosion takes its toll in power plants, and weathering damages power delivery hardware. The relentless effects of high-temperature, high-pressure steam and friction represent a predictable, long-term attack on materials and components in steam turbine power plants.

The weather mounts assaults with lightning, cyclones, floods, and temperature extremes. Basically, we never cease working to help utilities prepare for, prevent, mitigate, and recover from the damage that results.

In dealing with such overarching and sustained challenges, we find that two keys to success are effective collaboration and meticulous science. EPRI itself was created in the wake of a widespread U.S. power outage based on the need for collective, scientific action.

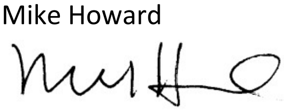
When nuclear plant operators faced public concerns in the wake of Three Mile Island, they realized that they would be much stronger by working collectively to address wide-ranging technical and operational needs. The Institute of Nuclear Power Operations and the World Association of Nuclear Operators are prominent among the organizations that work with EPRI to address these challenges.

Today, along with the more traditional or long-term issues we are addressing, I see cyber security and HEMP attacks as characteristic of our times. The cyber world has overtaken business, technology, and society in unprecedented ways, bringing with it a variety of risks and threats. In a world in which political antagonisms involve nuclear weapons and missiles, the power system will continue to be an obvious target.

What this means is that we can expect our work to succeed if we build on the time-tested lessons we have already learned. Band together. Discuss the threats and risks comprehensively and openly. Define them carefully and accurately. Address them with solid science and proven, strong technologies. Test and prove these technologies comprehensively, then deploy them systematically.

EPRI is continuing its work to characterize and understand the risks of HEMP events. We see a broadening collaboration across the electricity sector, in government and industry, to build on the work done to date. We will need this broader collaboration to strengthen the power system, enhance its resilience, and raise our preparedness for these events.

Mike Howard



President and Chief Executive Officer, EPRI

In the Field

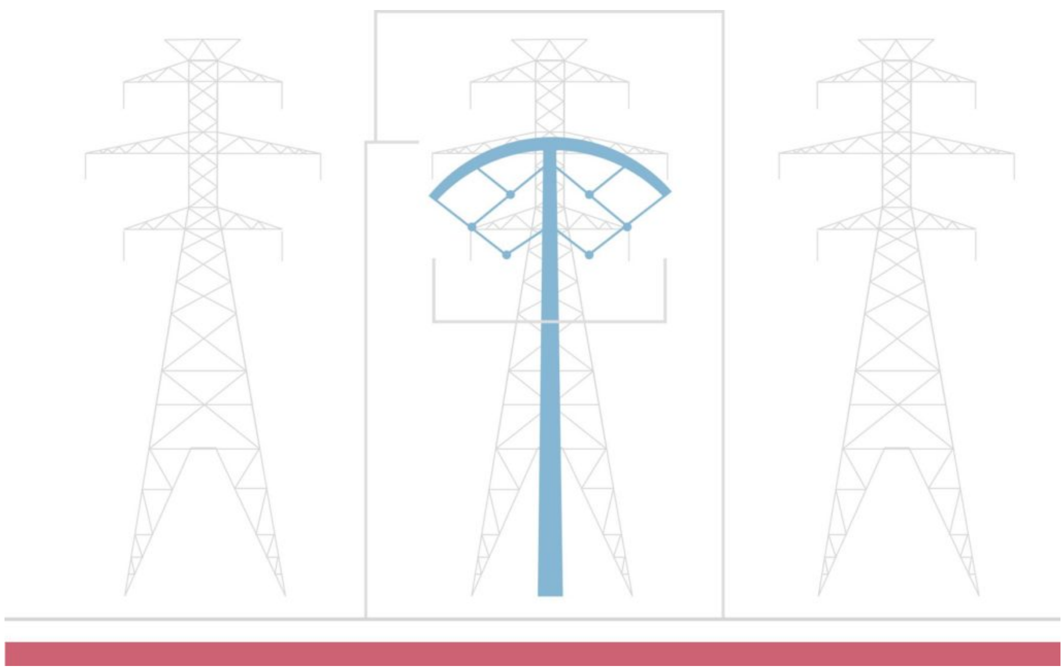
# A Smaller, More Efficient Transmission Line

## *EPRI Tests Help Prepare AEP's New Power Line Technology for Commercial Deployment*

***By Debbie Sniderman***

With testing support from EPRI, American Electric Power (AEP) has developed a transmission line technology known as Breakthrough Overhead Line Design (BOLD®). Relative to conventional 345-kilovolt power lines, BOLD provides up to 60% greater power-carrying capacity, lowers line losses by as much as 33%, and reduces structure height by up to 30%. In 2016, AEP completed the first line in Indiana using the technology.

BOLD lines are more compact than conventional lines. The configuration eliminates the large metal pieces typically positioned between the line's three phases so that the phases can be closer together, increasing power-carrying capacity, mitigating the intensity of electric and magnetic fields, and reducing construction costs. BOLD lines can transfer more power over long distances without relying on series capacitors and other expensive equipment to increase line voltage.



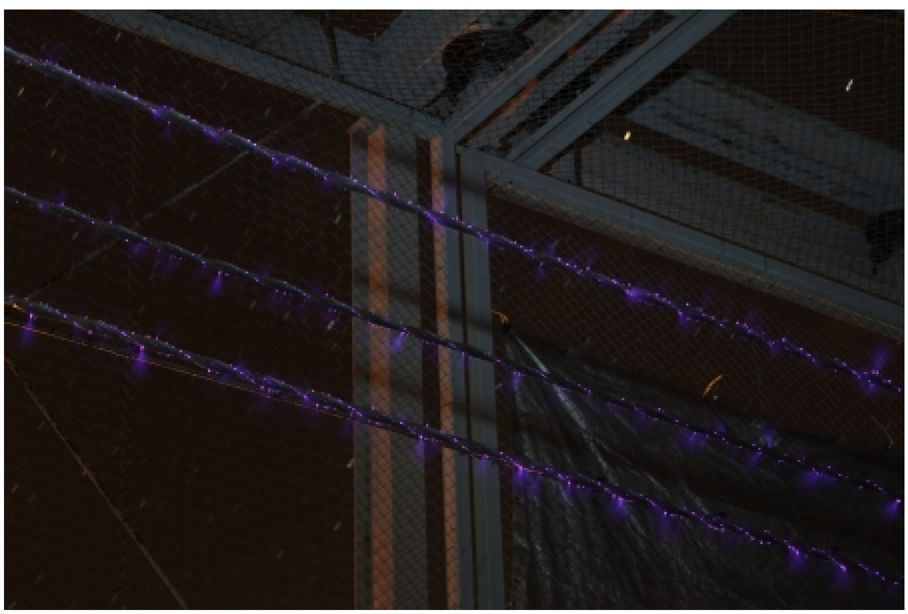
A 345-kilovolt BOLD transmission tower has a height of 100 feet, while a conventional 345-kilovolt tower has a height of 145 feet. Image courtesy of AEP.

According to Andrew Phillips, EPRI's director of transmission, distribution, and substations, public acceptance helps drive the need for BOLD's smaller structure. "People want power lines to be invisible," he said. "This compact, aesthetically pleasing design may look much better than larger structures and may also require a smaller right-of-way. Public acceptance can lower costs by speeding approval of construction."

Utilities develop transmission line designs to balance various considerations, such as narrow rights-of-way, public acceptance, ease of maintenance for energized lines, construction costs, and electric and magnetic fields on the ground.

At EPRI's High-Voltage Test Laboratory in Lenox, Massachusetts, researchers conducted tests to help AEP optimize BOLD's design and confirm acceptable performance. "A compact configuration could potentially lead to technical problems such as flashovers during lightning and excessive noise," said Phillips. "Our tests looked at these issues."

AEP's first 345-kilovolt BOLD line in Indiana. Conductors are suspended from a crescent-shaped crossarm on a 100-foot tubular steel pole.



EPRI's test chamber for corona activity along power lines. Blue flashes indicate where air is ionized. Photo taken as part of AEP testing performed at EPRI's Lenox, Massachusetts laboratory.

Lightning tests on a BOLD line. Photo taken as part of AEP testing performed at EPRI's Lenox, Massachusetts laboratory.

In traditional power lines, flashovers usually occur from the energized conductor to metal sections of the structure between conductors. BOLD has insulators instead of metal sections between conductors, so flashovers could occur from one energized conductor to another. The tests showed that BOLD can withstand an acceptable level of surges and lightning, while minimizing flashovers.

Another test looked at noise that results from coronas—electrical discharges that can occur when the line's electric field ionizes the surrounding air. EPRI and AEP determined that BOLD's line noise was within acceptable limits. The team optimized the configuration to limit coronas to help prevent degradation of the polymer insulators.

"EPRI's Lenox lab is the only one that can do this type of testing," said Phillips. "Because the line is not a traditional design, we can't use standard tests. Our experts spent several years designing tests and equipment appropriate for the BOLD design to verify its performance and offer suggestions for refining the design."

Researchers used an EPRI-designed suite of radio frequency sensors to monitor various aspects of the first generation of in-service BOLD lines, including electrical performance, structure loading, and motion. AEP and EPRI deployed the sensors on the new Indiana line in late 2016 and plan to monitor performance for two years. For 2018, EPRI has slated additional tests at two BOLD lines at lower voltages (230 and 161 kilovolts).

**Key EPRI Technical Experts**

Andrew Phillips, Ray Ferraro

**Further Resources:**

BOLD website

Innovation

# Power to the Pollinators

## *New EPRI Initiative to Foster Utility Collaboration on Pollinator Conservation*

***By Chris Warren***

When it comes to conservation of pollinators, Wisconsin-based Dairyland Power Cooperative was ahead of its time.

In 1994, Dairyland was required to cover a coal ash landfill near one of its power plants. Instead of laying road mix over the landfill, Dairyland invested extra time, labor, and money to seed and cultivate the 40-acre plot with dozens of varieties of native prairie grasses. One of the objectives was to provide habitat for pollinators.

"At that time, such efforts were uncommon at landfills," said Brad Foss, Dairyland's senior environmental biologist. "We were fortunate to have the support of senior management, who understood the ecological benefits."

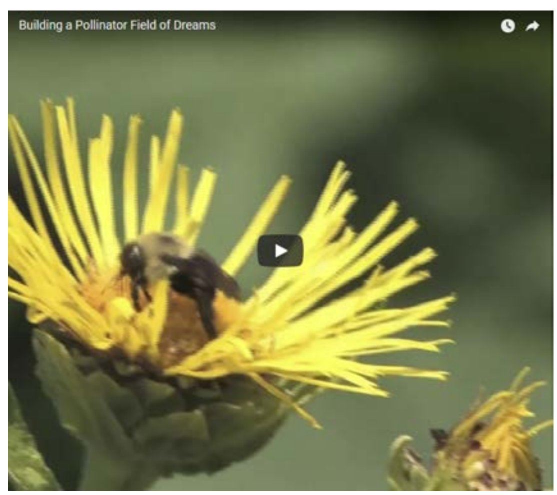
After about five years, populations of bumble bees, monarchs, and other butterflies were thriving on the plot.

Dairyland Power Cooperative recently planted this pollinator plot at its Downsville Solar Project. Photo courtesy of Dairyland Power Cooperative.

More than three decades later, Dairyland was the first electric utility to join EPRI's new Power-in-Pollinators Initiative, which seeks to foster collaboration among utilities to increase the effectiveness of their pollinator conservation activities.

"We launched the forum for many reasons," said EPRI Senior Program Manager Jessica Fox. "There's a growing societal need to protect pollinator populations, potential new state and federal regulatory actions, and an extraordinary opportunity for the power industry to make a difference—by improving land management practices in transmission and distribution corridors and other landholdings."

Healthy pollinator populations are necessary in supplying about one-third of the food needed by the human population. From strawberries to chocolate to coffee, we depend on bats, birds, bees, butterflies, and other insects, familiar and unfamiliar. Many pollinator populations are at risk as a result of habitat loss, invasive species, pesticides, and climate change.




View the video: https://youtu.be/_cbHp8xwHGg

"The global human health and financial implications of pollinator extinction are huge," said Fox. "We see opportunities to work together on industry-wide goals to support pollinators."

Species such as the Rusty Patch Bumble Bee are among the approximately 45 pollinators listed as endangered under the U.S. Endangered Species Act. Dozens of others may soon be afforded similar safeguards.

Utilities are uniquely positioned to boost the health of pollinators. Many own huge tracts of largely undeveloped land, including transmission line rights-of-way. Some are managing land as conservation areas to attract pollinators.

Many are planning and implementing pollinator protection projects as part of their corporate social responsibility efforts.

"The Power-in-Pollinators Initiative is creating a forum to share ideas and research findings, and to lead innovative, collaborative conservation," said Fox.

EPRI gives participants access to its tool that uses geographic information systems to identify pollinator-rich, company-owned land well-suited for conservation. It's also creating opportunities for collaboration with other utilities. EPRI is actively working with participants to improve the tool.

"The ecological benefits of one company's conservation efforts may be limited if the species migrate into other regions," said Fox. "We see opportunities for companies to work collectively to protect habitat corridors."

EPRI will develop metrics for the effectiveness of pollinator conservation efforts. These in turn can be used to identify projects with significant potential benefits and track progress relative to their goals.

The initiative will convene webcasts and an annual conference. These will advance technical research and establish relationships to cultivate collaborative conservation efforts. Participants will contribute to a pollinator database of leading and broadly relevant research.

They will be looking for lessons learned. For example, Dairyland's two-plus decades of pollinator protection reveals the importance of a plan, coupled with patience (it takes between three and five years to establish a vibrant pollinator habitat).

"The last thing you want to do is plant a bunch of seeds and walk away," said Dairyland's Foss. "You have to have a long-term management plan and stick to it."

Dairyland, which has recently established pollinator plots at 15 solar power plants, joined the EPRI initiative to learn how to become even more effective and find partners for its conservation efforts.

### Key EPRI Technical Experts

Jessica Fox

### Further Resources:

- Minimizing Impacts of Land Use Change on Ecosystem Services Using Multi-Criteria Heuristic Analysis(Journal of Environmental Management)
- Assessing Ecosystem Services Using the InVEST Model: Case Study of the American Electric Power ReCreation Lands, Ohio
- Ecological and Wildlife Risk Assessment of Chemicals Encountered in Vegetation Management on Electric Utility Rights-of-Way

- Wildlife and Integrated Vegetation Management on Electric Transmission Line Rights-of-Way
- Study Evaluates Effects of Vegetation Management and EMF on Native Bee Populations
- Use of Transmission Line Easements for the Benefit of Native Bees (2011 report)
- Use of Transmission Line Easements for the Benefit of Native Bees (2013 report)
- Honeybees and Power Line EMF Environments

Shaping the Future

# The Future of Energy Will Be Augmented

## *EPRI Looks at Augmented Reality for Storm Response and Nuclear Plants*

***By Chris Warren***

For the U.S. electric power industry, its mutual assistance network is essential in responding to destructive hurricanes, tornadoes, and winter storms. For decades, this nationwide, voluntary partnership among electric companies has expedited outage restoration through the network's access to workers and equipment. The track record is strong but includes this fundamental challenge: Visiting line workers may be unfamiliar with the area, and this can hamper and delay work.

"You have a lot of people who come to a service territory to do storm restoration, and usually it is the first time they've ever been there," said Aleksandar Vukojevic, manager of Duke Energy's Emerging Technologies Office.

Since 2014, Duke Energy and EPRI have been testing a tool that could help employees and visiting recovery crews quickly grasp the lay of an unfamiliar land: augmented reality–enabled smart glasses. Their collaborative research with telecommunications company Verizon equipped a team of line workers with glasses during a simulated storm response. Made by RealWear, the glasses use geographic information systems (GIS) to provide workers with information critical for repairing damaged utility infrastructure.

"When you come to a particular area, these glasses tell you where all the components should be located, whether it be a downed utility pole or the equipment attached to that pole," said Vukojevic.

"The GIS has detailed information on each component," said EPRI Technical Executive John Simmins. "It knows a pole's height and what it's made of—metal or composite material."

The glasses can automatically send an order to a utility warehouse for the equipment needed for repairs. "While wearing the glasses, a user can indicate that a pole or other part is missing," said Simmins. "The information is sent to the warehouse, where parts are packaged and sent out on the next truck. This takes hours out of the process and reduces errors."

A Duke Energy line worker wearing augmented reality–enabled smart glasses as part of a simulated storm damage assessment with EPRI. Photo courtesy of Duke Energy.

Results from the simulated storm response were encouraging to the R&D team. The line workers found the smart glasses easy to use, adjusting to them in just minutes. Workers using the glasses completed tasks more quickly, with fewer errors relative to workers using pen and paper to document storm damage.

## The Promise of Augmented Reality for Nuclear Plant Construction

In July 2017, EPRI released a study evaluating augmented reality's potential to improve the productivity, efficiency, reliability, safety, and security of nuclear power plant construction and operation.

"As the nuclear industry in the United States grapples with economic headwinds driven by low natural gas and renewable energy costs, a key strategy for successful plant construction involves using technology to reduce construction timelines, improve quality and repeatability, and increase worker safety," said EPRI Senior Technical Leader Eric Harvey.

EPRI researchers reviewed more than 2,000 studies on augmented reality, interviewed 10 experts, and surveyed 32 nuclear utilities. A key takeaway: The nuclear utilities expressed significant interest in augmented reality, with nearly 80% indicating that augmented reality–enabled applications should be an integral part of the tool kit of operations and maintenance workers. However, more focused studies on the application of augmented reality are needed. Many expressed concerns about an uncertain business case. Researchers found that the building and construction industries in general have already taken the initiative to adopt the technology.

The study points to specific ways that augmented reality could reduce construction time and worker mistakes as well as improve safety. Among the potential applications:

- Connect field technicians with subject matter experts via wireless communication for real-time instruction on complicated tasks.
- Project a 3-D model of a nuclear plant onto a table or physical model to facilitate discussions about construction or to deliver training to construction workers.
- Use electronic boundaries to alert plant workers to radiation hazard zones.

Much work remains before augmented reality can be adopted broadly in nuclear plants. Owners, operators, and construction teams will need to conduct demonstration projects, assess costs and benefits, make a solid financial case, address privacy and cyber security, and potentially overhaul traditional construction and maintenance workflows.

Regardless of the challenges, EPRI's Simmins is confident that augmented reality will become a versatile tool across the utility industry. "Think about the maps on your cell phone that give you street-by-street instructions. They enable an ease of navigation that is not possible with paper maps," he said. "Augmented reality will be the same way. Years from now, people will say, 'How in the world did we do this before augmented reality?'"

### Key EPRI Technical Experts

John Simmins, Eric Harvey

### Further Resources:

- Advanced Nuclear Technology: Augmented Reality Technologies for New Nuclear Plant Applications

R&D Quick Hits

# A Break in the Clouds for Concentrating Photovoltaics?

Despite the dominance of traditional flat-plate photovoltaics (PV) in the solar industry, concentrating PV (CPV) technologies may still gain market share, according to an EPRI report.

Between 2009 and the first quarter of 2017, prices of flat-plate PV modules have fallen from $2 per watt to $0.35 per watt, challenging CPV business plans. Globally, the deployment of CPV is negligible relative to flat-plate PV—about 350 megawatts versus 400 gigawatts.

***Photo courtesy of National Renewable Energy Laboratory***

Four pathways could allow CPV to succeed:

- **PV supply constraints**. CPV could become cost-competitive if global demand for PV modules exceeds supply. However, there is little evidence for this in the next few years.
- **Develop innovative, much lower-cost CPV technologies**. A 40% system conversion efficiency along with system costs approaching $0.80 per watt would make CPV technologies cost-competitive in the next 5 to 10 years. While these targets require significant advances, they are achievable.
- **Strong commercialization partnerships**. Compared with PV, CPV offers greater opportunities to fabricate components locally, requiring less high-tech manufacturing infrastructure. CPV companies can reduce costs by working with local governments to establish manufacturing in exchange for low-interest loans and other incentives.
- **Develop dual-purpose technologies with complementary advantages**. Examples include deploying CPV in vertical configurations to accommodate other land uses, capturing waste heat, and integrating CPV into buildings to provide insulation and lighting.

This market assessment is part of a recently completed eight-year EPRI field study on CPV at the Solar Technology Acceleration Center (SolarTAC) near Denver, Colorado. It examined the performance of commercial-scale CPV systems under various environmental and seasonal conditions.

R&D Quick Hits

# EPRI Evaluates the Scientific Literature on HVDC Health and Environmental Effects

integration makes it important to fully investigate the technology's impact on human health and the environment. Unlike prevalent high-voltage alternating current (HVAC) transmission, HVDC lines produce static (zero frequency) electric and magnetic fields, along with air ions. The line's magnetic field can affect the magnitude and direction of the earth's magnetic field close to the transmission line.

***Photo of Bipole III transmission line construction courtesy of Manitoba Hydro***

EPRI's review of the scientific literature found that:

- Research to date has found no significant adverse health impacts of HVDC.
- Research would be useful to further examine effects of the altered geomagnetic field surrounding HVDC lines on migratory species and soil-dwelling animals.
- Impacts of air ions on humans and animals depend on topography and wind speed and direction, pointing to the value of studying HVDC lines in regions with diverse climates and atmospheric constituents.
- Because HVDC is preferred over HVAC for long-distance underwater transmission, research on marine ecosystem impacts could be useful.

As a next step, EPRI is pursuing opportunities to research environmental aspects of HVDC submarine cables, including effects on migratory species.

R&D Quick Hits

# How Efficient Are Your LEDs? Check the Color

The energy savings of light-emitting diodes (LEDs) depend strongly on the color of light they produce, an EPRI study finds.

In recent years, utility energy efficiency programs have achieved energy savings by encouraging customers to switch to LEDs from fluorescent, halogen, and other available technologies. With the introduction of color-tunable LEDs, utilities find it more difficult to predict savings, because their power consumption varies by color. Their applications can include replicating the sun's daily color shifts and providing light at wavelengths specific for indoor agriculture.

To specify how color-tunable LEDs may affect customer load, EPRI lab-tested 36 products in three categories: dim-to-warm, tunable white, and full color. For full color and tunable white products, the "luminous efficacy" ranged widely across different colors. Full color products were less efficacious at blue, purple, and red, and more efficacious at green and yellow. Dim-to-warm products generally declined in efficacy as they were dimmed.

"This research shows that color-tunable products have wide performance ranges," said EPRI Senior Technical Leader Frank Sharp. "As more of these products are deployed, utility planners need to understand their variable efficacy profiles to make effective use of them in efficiency programs."

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