ELECTRIC POWER
RESEARCH INSTITUTE

STATE OF THE TECHNOLOGY | 2017

THE FUTURE

EFFICIENT ELECTRIFICATION

EMPOWER INTEGRATION

OF ELECTRICITY

ADVANCE INFRASTRUCTURE/ TECHNOLOGY

BROADEN COLLABORATION

EPRI'S RESEARCH AREAS

Power Delivery & Utilization

Transmission, Distribution, and Substations

Power Delivery & Utilization

Distributed Energy Resources and the Customer

Nuclear

Generation

Energy and Environment

EIGHT INSIGHTS FROM THE

THE INTEGRATED ENERGY NETWORK

In reviewing EPRI's 2017 State of the Technology report, consider eight insights that emerged as we developed ***The Integrated Energy Network***—a future in which customers have flexibility to use, produce, and manage energy as they choose, while improving access to reliable, safe, affordable, and cleaner energy.

Michael W. Howard

President and CEO,
Electric Power Research Institute

INTEGRATED ENERGY NETWORK

EFFICIENT ELECTRIFICATION

- Efficient electrification will be instrumental in environmental improvement, and we see its potential to lower customers' costs, increase productivity, improve product quality, and provide a cleaner, safer work environment. As we rely more on cleaner electricity, we can use energy more efficiently and use natural resources more sustainably. Natural gas, hydrogen, and other cleaner energy sources will be instrumental in reducing emissions.

EMPOWER INTEGRATION

- Electric, gas, transport, and water systems are increasingly interdependent, but their planning and operations are largely separate. By integrating them, we can improve reliability, gain efficiency, and increase value to customers.
- As we integrate energy systems, we'll rely on advances in wireless connected technologies, sensors, and information and communications technologies, along with advanced data analysis and modeling. Investment in these technologies can drive the rapid advances essential for the efficient operation of energy systems' plants, wires, and pipelines—and for enhanced customer engagement.
- The Integrated Grid is essential to the *Integrated Energy Network*. Effectively integrating central and distributed energy resources can enable customers to use, produce, and store electricity as they desire.

ADVANCE INFRASTRUCTURE/TECHNOLOGY

- The emergence of low-cost shale gas and the rapid deployment of large-scale solar and wind energy are changing the power generation fleet in fundamental ways, imposing new demands and stresses on grid infrastructure. Investment is essential in transmission and distribution systems for grid reliability, security, resiliency, and to expand regional and long-distance transmission.
- Technological advances are essential for next-generation nuclear plants; thermal fossil plants with carbon capture, utilization, and storage; and renewable technologies. We must operate central generation more flexibly to support a much more dynamic and efficient power system.

BROADEN COLLABORATION

- We can reevaluate energy and environmental policies and regulations to understand how sector-focused policies create disincentives or can work to reinforce desired outcomes. This will be important for efficient, effective compliance throughout the energy sector. We look for people, technology, and trends from outside the traditional energy industry to change market designs and business models.
- Global collaboration in science and technology innovation, demonstrations, and thought leadership are key to navigating the rapidly changing, increasingly complex, multi-dimensional global energy sector. EPRI offers the *Integrated Energy Network* as a framework for discussion and research today and as a foundation for planning and action in the very near term.

Efficient Electrification

The Next-Generation Heat Pump: Poised to Take Off?

For several years, EPRI has been developing a next-generation heat pump that today is poised to transform space conditioning in American residences and businesses. Rather than burn fossil fuels, heat pumps use electricity to move heat from one area to another to heat in the winter and cool in the summer. They use a fraction of the energy consumed by fossil systems. Manufacturers have recently commercialized systems with EPRI's "next-gen" performance specifications, which include better efficiency, higher heat delivery rate in cold climates, variable operation for demand response, and grid connectivity.

These figures point to the game-changing potential:

62 million | U.S. residences are heated by natural gas and other fossil-fuel burning systems, according to the U.S. Energy Information Administration. With heat pumps used in just 12 million American residences, this represents a significant untapped market with the potential to save consumers billions of dollars in energy costs.

48% | of U.S. residential energy is consumed for space conditioning, according to the U.S. Department of Energy. Mass adoption of the next-gen heat pump offers enormous potential energy savings for utilities and their customers.

75% | of heating hours in New York City could potentially be served by the next-gen heat pump. The remaining heating hours (below 30°F) may be satisfied with a combined heat pump and backup furnace.

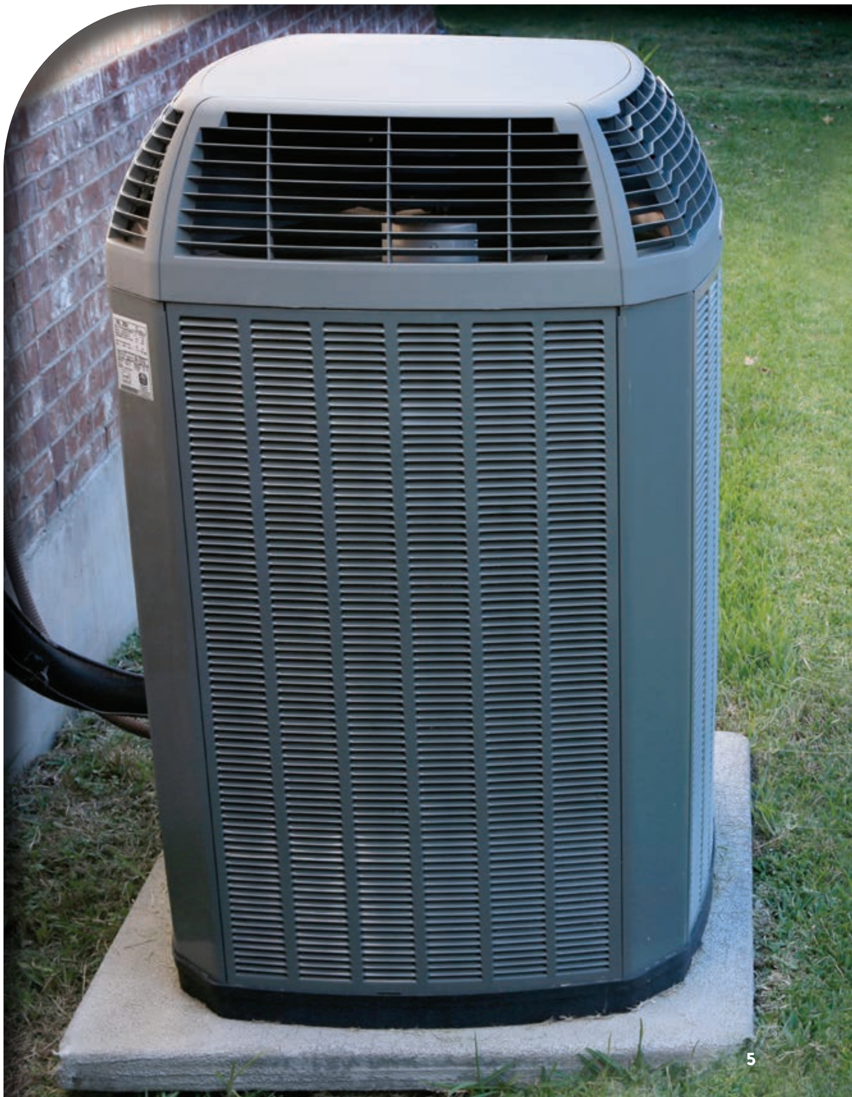
50% | boost in heating capacity can be provided by the next-gen heat pump relative to traditional heat pumps. The key is the next-gen version's variable-speed compressor, which runs at any speed within a wide range, depending on the load. Traditional heat pumps use single-speed compressors that continually cycle on and off.

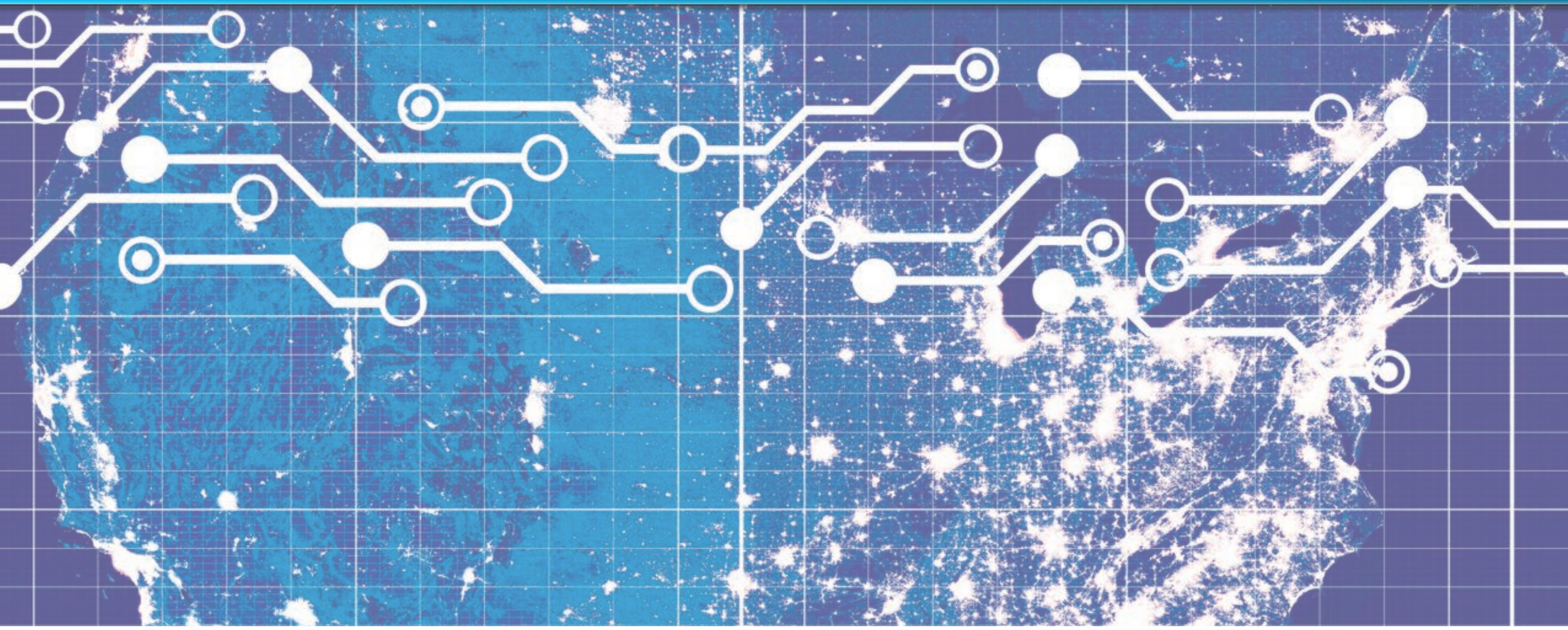
90% | of the U.S. population can potentially use the next-gen heat pump for comfortable heating and cooling. Their variable-speed compressor's additional heating capacity significantly increases applicability in colder climates where heat pumps have historically had limited performance.

10–30% | defines the range efficiency advantage of the next-gen heat pump relative to single-speed counterparts during demand response events, as measured in EPRI laboratory tests. They throttle back power draw while single-speed devices turn on and off.

0 | as in "zero" is the amount of backup electric heat installed with next-gen heat pumps during recent EPRI field tests in Ocala, Florida. Single-speed heat pumps typically engage backup electric heat on cold days, potentially increasing a utility's peak load. EPRI determined that next-gen heat pumps can provide adequate heat without engaging backup systems, eliminating this peak and pointing to potential savings for utilities in avoided infrastructure investment.

4,400 | pounds of CO_2 emissions from a next-gen heat pump operating at a typical Georgia residence compared with a typical residential gas furnace in Georgia producing 5,500 pounds annual CO_2 emissions.





US-REGEN Model Looking More Closely at States, Broadens to Focus on Electrification

When EPRI launched the U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model in 2012, research prioritized analyzing the impact of environmental regulations and climate policies on the U.S. electric power sector, with significant focus on the Obama administration's Clean Power Plan (CPP).

Even before the stayed implementation of the CPP, EPRI's US-REGEN model has been changing and adding features that enable EPRI member companies, policymakers, stakeholders, and the public to understand and prepare for possible changes in technology and the overall energy mix. Among the most significant recent modifications is that in addition to regional information, it can now provide more focused data on the 48 states in the continental United States.

"The electricity markets are regulated at the state level through state public service commissions, and different states have different characteristics in terms of their demand for electricity, depending on whether they have a lot of industry or consumers," said Francisco de la Chesnaye, senior program manager of the Energy and Environmental Analysis group that developed and maintains US-REGEN. "By developing the model at a state-level resolution, we are able to provide more detail and value-added research to different audiences."

This information is needed to respond to short-term policy and regulatory changes at the state level, but the model's ongoing development supports analysis of longer term technological changes and their potential impacts. With EPRI's nuclear research, for example, US-REGEN has been used to provide insights into the potential role for advanced nuclear power, including establishing a cost-competitive benchmark for its viability.

Such collaboration also extends to EPRI's fossil and renewables generation research, including modeling that examines the role of flexible operations as more renewable energy is integrated into the power system. "This allows us to better assess the impacts of increasing penetration of renewable energy and how that intermittent power impacts traditional baseload fossil and nuclear units, which find themselves having to cycle or ramp much more than they have in the past," said de la Chesnaye. US-REGEN has been used to evaluate the value of energy storage technologies and their ability to better manage intermittent renewable energy generation.

US-REGEN's ongoing enhancements now benefit EPRI's cross-sector research priorities and include a module for examining the potential for electrification and end-use electrification technologies (see story on page 7). This is a collaborative effort with EPRI's energy utilization group. It will be instrumental in EPRI's national electrification assessment, slated for completion at the end of 2017.

EPRI's energy utilization group helped develop a menu of technologies that could be electrified, information that informed the development of an end-use energy module in US-REGEN. "This is a module we didn't have before," said de la Chesnaye. "Our colleagues in energy utilization are providing us the cost and performance for all these technologies to put in the model to run scenarios to see how these technologies can be deployed and come into play with increased electrification throughout the U.S. economy."

Ahead: A Pivot to an Electrified Future?

There are plenty of reasons to believe that electricity will serve a broader role in meeting society's energy needs. As the supply mix continues to reduce its carbon footprint and as electric vehicles become more affordable and sophisticated, economic and environmental benefits of increased electrification become more apparent. This prompts policymakers, consumers, and electric power companies to investigate what a pivot to an electrified future would look like and require.

EPRI launched a national electrification assessment to evaluate the feasibility of transforming the U.S. energy sector between 2020 and 2050, and what will drive it. The basis is a scenario in which electricity's share of final energy use increases from 20% today to 30%, 40%, or more in the future. Consumer adoption of economically viable electrification technologies as an alternative to fossil fuel will substantially increase electricity's share of final energy while also providing significant benefits for society, customers, and utilities. The assessment is led by EPRI's Energy Utilization and Energy and Environmental Analysis research groups. Francisco de la Chesnaye is one of the lead researchers on the national assessment.

Question: What tools will you use in this assessment?

de la Chesnaye: We have developed a new energy end-use module for the U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model to better assess the potential for electrification. This new capability equips us to represent electronic technologies across the industrial, commercial, residential, and transportation sectors in much more detail. We are engaged with the energy utilization group at EPRI to better represent those technologies in the model and improve our electrification analysis.

Question: How significant is electricity's share in different sectors of the U.S. economy today?

de la Chesnaye: We have compiled the share of electricity from 1950 to the present in four end-use areas: commercial, industrial, residential, and transportation. In the residential sector, for instance, consumers can use natural gas, electricity, and oil. In the residential sector nationwide, about 43% of final energy consumption is electricity. But by comparison, electricity's share for transportation is very low. The objective of the national assessment is to examine what the U.S. energy system would look like if the share of electricity in the energy mix increases appreciably by 2050. This project started in April and will go forward for the rest of 2017. We will have data completed by the end of year, and the report will follow in the beginning of 2018.

Question: What is the basic methodology for the assessment?

de la Chesnaye: This ties back to US-REGEN. We are taking in different technology costs and performance inputs on electric technologies across the four economic sectors. Then, under various scenarios, we are looking at what the power generation would look like—how much will be from fossil fuels, renewables, and nuclear. These are not predictions but insights from "what if" scenarios. For example, if electrification is going to increase in a sector, something must drive that. We have seen tremendous declines in the cost of solar and wind power and battery storage. For modeling purposes, we can make assumptions whereby costs of electric technologies across all sectors decreases and performance increases. Take electric vehicles and heat pumps for instance. What results from dramatic improvement in those technologies? How could that incentivize electrification? What are the R&D implications?

Question: How will the results of the assessment be used?

de la Chesnaye: We think the results will be used to inform energy customers about the potential benefits of electrification—for example, if results point to increased efficiency and productivity in commercial manufacturing. What associations can we see between consumer benefits with electric heating and cooling technologies and any environmental benefits such as reduced emissions? We can examine both productivity and environmental improvements. If the analysis can assign more precise value and benefits through electrification, then the electricity sector and its stakeholders can consider a range of options and decisions with respect to increasing electricity's share of energy end use.

Distributed Resources Drive a Bigger Perspective of Environmental Impacts

Sometimes, the best way to gain a big-picture understanding of an issue is to use the bird's eye perspective. In the case of the environmental issues related to distributed energy resources (DER), there's nothing metaphorical about that approach.

Consider solar photovoltaic (PV) panels. The general perception is that such technologies have no environmental impacts, but the truth is both more complicated and increasingly important as deployment soars worldwide. A prime example is the "lake effect" related to solar installations and their potentially adverse impact on birds. "When they see a small solar plant, many birds perceive it as a lake because the color and reflection of the panels are like water," said Naresh Kumar, an EPRI senior program manager. "They want to come and take a dip or a drink, but instead are wounded or killed by the hot surface or the force of impact."

Gauging the impact of the lake effect on wildlife is just one of the research projects EPRI is considering to understand DER's environmental issues. These projects could include everything from solar PV to batteries to small natural gas turbines and diesel-powered reciprocating internal combustion engines. The need to do this lies in better risk management. "We are trying to get ahead of any issues and understand them sooner rather than later so we are prepared to adjust," said Kumar.

As DER are deployed more widely, the need becomes more pressing for research. Beyond impacts on wildlife, EPRI also delved into the responsible disposal of solar panels that have been taken out of service. Though solar and other technologies do not emit greenhouse gases or other pollutants, their materials may be toxic, requiring careful disposal or recycling to prevent harmful chemicals from leeching into groundwater. EPRI is testing both the toxicity of materials used to make panels and evaluating recycling options for discarded panels.

Also under evaluation are possible life cycle environmental impacts related to lithium ion battery storage. According to the U.S. Department of Energy's Global Energy Storage Database, 168 megawatts of lithium ion batteries operated in the United States in 2015. By the end of 2017, capacity is expected to nearly triple to 476 megawatts, with 330 megawatts under construction. The research focuses on understanding the impacts that this rapid deployment could have and is examining the materials, and the manufacturing process itself, to determine whether the batteries should be disposed of or recycled at the end of their useful life.

While many people associate distributed generation with renewables, an estimated 37 gigawatts of fossil DER currently operates in the United States. EPRI previously researched the local and regional air quality impacts of fossil DER along with an analysis of scenarios, including more widespread deployment. Regulatory scrutiny is driving the need for additional EPRI research with respect to the emissions associated with diesel generators, natural gas turbines, and other fossil DER in places such as New York state. "We are starting a program to characterize emissions from these units better and look at not just the environmental quality issues," said Kumar. "We are also looking at health and safety issues associated with these units."

An Elegant Solution for Power Plant Waste and Water Management

Coal-fired power plants may have a new option to simplify work in managing multiple waste streams and storing it safely. That option is *encapsulation*, a process that could safely combine disposal of multiple streams now handled separately.

One such stream is coal combustion products, which include fine particles of fly ash stored in impoundments. Another is wastewater streams, such as those produced by a plant's flue gas desulfurization systems that absorb sulfur dioxide emissions. Operators must treat these before disposal, complying with revised rules from the U.S. Environmental Protection Agency.

Biological technologies capture and treat selenium and convert nitrates to nitrogen. Concentrating membranes and thermal evaporation can reduce wastewater volume but produce a concentrated brine by-product for which there are few effective disposal solutions.

With encapsulation, brines are mixed with fly ash along with binders such as lime, producing a material that is transported to a landfill. This product can range from a low-moisture material with a soil-like consistency to a high-moisture paste. Similar in consistency to fresh concrete, the paste is a homogenous, thick fluid with just enough added water to be pumpable. As the product solidifies in the landfill, its constituents stabilize chemically and physically. The solid should be resistant to rainwater infiltration, minimizing the leaching of constituents into the environment.

By integrating wastewater brine and fly ash in a single waste stream, encapsulation could replace traditional ash transportation and landfilling. Disposal of pastes and other encapsulation products produces less dust than traditional ash disposal, reducing concerns about particulates in the air.

"The chemical reactions in encapsulation are similar to those in concrete production," said EPRI Technical Leader Kirk Ellison. "Water and salts in the brine react chemically with fly ash, binding them as hydrate minerals."

The product's water content, determined by the mixing recipe, is an important factor during transport to and placement in the landfill. Low-moisture products could be transported by a conveyor belt or truck and placed and graded with earthwork equipment. High-moisture pastes could be pumped via pipeline into the landfill similar to a concrete pour. Pastes can self-level without the use of landfill equipment. "Set times" for the paste to harden depend on the specific ash/brine mix and can range from a few hours to a few days.

EPRI is studying the entire chain of encapsulation activities: mixing materials, transporting and landfilling the product, and monitoring its long-term stability. In the laboratory, researchers have examined the chemistry of wastewater brines, different mix recipes, the reactions among ingredients, and the final products' chemical and physical properties. Researchers are investigating many types of wastewater, including flue gas desulfurization wastewater from various sites and leachate from an onsite ash landfill.

At the Water Research Center at Southern Company's Plant Bowen, a pilot encapsulation system mixed wastewater with fly ash, lime, and other binding materials to produce a chemically and physically stable paste. The team pumped and placed the paste effectively, demonstrating that the technology is ready for full-scale testing.

While encapsulation shows promise as a reliable waste management technology, the biggest question is determining where it is technically feasible and cost-effective. In 2017 and 2018, laboratory and field testing will expand to include six flue gas desulfurization wastewater chemistries that cover most coal types in the United States.

Pollinators and Power Companies—Gathering Knowledge, Launching Research, Orchestrating Action

Besides residing squarely in the category of life's great pleasures, chocolate, coffee, and strawberries share something else in common: their existence depends on healthy populations of pollinators. In fact, of every three bites of food we eat, one is dependent on pollinators, primarily bees (by far the most important group) but also bats, birds, butterflies, and other insects.

Unfortunately, they face habitat loss, pesticides, invasive species, and climate change, which puts many species at risk of extinction. Though clearly a concern for society as a whole, what makes this an issue of consequence to the electric power industry? There are regulatory considerations: pollinators such as the Rusty Patch Bumble Bee are classified as endangered under the federal Endangered Species Act, affording it certain protections under the law. A 2014 presidential memorandum also established a federal strategy to promote the health of honey bees and other pollinators, an initiative that includes the formation of a task force and research funding.

But there is also a more fundamental motivation. "Obviously, bees are not involved in running a power plant. While there are some pollinator species under federal protection, a core reason power companies care is corporate citizenship. They recognize the broader public value of pollinators," said Jessica Fox, an EPRI senior program manager, who is leading EPRI's Power-in-Pollinators Forum. Beyond corporate citizenship or sustainability goals, power companies own extensive landholdings that can be managed in ways that improve pollinator habitat. "It's not just that they care. Their opportunity is massive."

EPRI's pollinator research is part of broader industry interest in conservation to improve the health of bees and other pollinators on land they manage. For instance, some power companies have planted corporate gardens and other vegetation meant to provide healthy habitats for pollinators. EPRI's pollinator research (part of its endangered and protected species and T&D environmental issues programs), and the recently launched forum, are offered to promote industry collaboration and to apply robust science and metrics to ensure that their efforts are having a genuine impact on the species they are designed to help. "Many are doing pollinator work on their own," said Fox. "Why not collaborate so we can share ideas, best practices, and research?"

EPRI conducted a member survey, which found that 76% of companies are doing at least one pollinator activity, including surveys of pollinator species and the use of seed mixes and herbicides believed to benefit pollinators. The majority of those surveyed are not engaged in research. EPRI is also conducting literature reviews about herbicides and pollinators as well as protecting and promoting pollinators on electric power company land.

The pollinator research under EPRI's T&D environmental issues program will develop study protocols and then conduct multiyear field research projects aimed at answering two basic questions: what is the baseline diversity of pollinators on transmission line corridors, and what can be done to manage pollinator habitat in a cost-effective manner? According to EPRI's state-of-the-science review, little is known about pollinators on transmission rights of way. "EPRI's multiyear research program has the potential to add significant knowledge to the science of pollinators," said John Goodrich-Mahoney, an EPRI principal technical leader.

The Power-in-Pollinators Forum will host an annual technical workshop, develop a database of power company pollinator efforts, and create the only power-company-specific forum for sharing research and best practices. These efforts will help companies establish a business case for pollinator protection, while providing the scientific grounding to make the work more effective. In some cases, the best thing to do for pollinators is nothing. "Pollinators often prefer that you don't micromanage their habitat," said Fox. "In some cases, the best thing to do is leave the land alone. There may be opportunities to support pollinators without having to spend tons more money."

Wind Turbine Performance: Adding "How Well" to "How Much"

Your car seems to be running fine, but lately you've noticed some things—occasional odd sounds, decreasing gas mileage, a small puddle underneath. Experienced car owners know these signs point to the need for closer inspection or repair.

But what if the machine is a wind turbine? Today, the industry's understanding of their long-term performance relies to a great extent on availability—the answer to the question, "How often are my wind turbines running?" They typically don't have an answer to an equally important question—"How well are my wind turbines running?"

In a new project, EPRI is exploring wind turbine operating history behind these two questions and launching research to evaluate tools for tracking performance.

"The gap here may be rooted in the divide between 'sales' and 'service,'" explained Brandon Fitchett, a senior manager in EPRI's large-scale renewable generation research group. "OEM warranties for power performance are typically valid for one year, but long-term service agreements may be signed for much longer and with a different company. Those longer term agreements can no longer warrant performance, so are typically based on contractual availability measured with a binary, time-based metric."

Fitchett added, "Either the machine is running or it's not. Because performance warranties expire relatively early in the unit's life, we're evaluating the newest techniques for owners to track their assets long-term, relying on more than just availability."

There are ways to measure the power performance of wind turbines. The most widely recognized method, however, is neither cost-effective nor practical to use on each turbine. This method follows an IEC (61400-12) standard and requires hub-height wind measurements from calibrated instruments, usually from a meteorological tower constructed in front of a subject wind turbine. It is used only on select turbines that are free from wakes or other environmental factors, and results typically are warranted only in the first year of operation. Such stipulations are there to protect the manufacturer from factors external to the turbine, yet still prove that the turbine model is capable of making the promised "power curve," or power output at different wind speeds.

"Standardized tests for measuring a power curve are best applied in a controlled environment with costly instrumentation," Fitchett explained. "This controlled environment may not be representative of all turbines on a wind farm, though, and the test is too expensive for use on all machines. So, it's really not a tool for long-term asset management."

EPRI is examining alternative methods for analyzing wind turbine performance over time and comparing them with standard methods. Some state-of-the art analytical methods use supervisory control and data acquisition (SCADA) information, such as comparing relative energy output among nearby units. These methods may lead to improved monitoring options.

"Our members are looking to use standard SCADA data already flowing to them to monitor and flag individual turbines or whole power plants for underperformance," Fitchett said.

EPRI also is examining standard contractual approaches, obligations, and warranties for wind turbines and wind farm performance. Researchers are assessing the gaps between standard methods and the goals of asset owners and asset operators (with each needing its own performance metrics) and identifying new tracking methods, the causes of any under performance, and actions that can be taken to improve performance.

"We can then apply these methods to our members' operational data and suggest fixes for any real-world causes," Fitchett said. "Next steps will track the operational data over time and measure performance improvements from the actions taken. Some of those actions will be for maintenance crews, but some could be quite innovative."

Empower Integration

sensors network energy systems pipelines wireless data analysis wires communications investment gain efficiency connected interdependent integrating storage improve reliability planning gas water modeling transport electric technologies operations information

Examining the Energy-Water Nexus Improves Conservation and Efficiency

At this year's winter meetings of the National Association of Regulatory Utility Commissioners (NARUC) in Washington, DC, EPRI unveiled its concept of the Integrated Energy Network (IEN). Years in the making and the result of research and input from EPRI members and external stakeholders, it describes a future in which the systems managing energy and natural resources are tightly integrated—and extends an invitation to contribute ideas to help shape and achieve that future.

Central to IEN and its role in EPRI's future research is greater integration between the water and electricity industries. In many ways, this is nothing new. The water-energy nexus is fundamental to important EPRI research such as advanced power plant cooling systems to reduce water use or draw upon non-potable water sources. EPRI foresees even more emphasis on developing technologies and approaches to integrate and optimize water and energy systems to improve efficiency, flexibility, and conservation.

One example is research involving studies that examine the embedded energy in water stored at wastewater treatment sites in California and how much energy is saved through conservation. "At least in California, water conservation has the potential to save more energy than energy efficiency programs," said Kent Zammit, senior technical executive for EPRI's environmental sciences research programs. "We would like to perform similar studies at other sites across the United States to see if that correlation holds. Of course, not only do you save energy when you conserve water, you also reduce greenhouse gas emissions and emissions of criteria pollutants associated with that energy."

Because improved integration of water and energy systems has such wide-ranging potential benefits, a multi-discipline team conducts much of EPRI's water-energy nexus research. Researchers from EPRI's generation technology teams are pointing to research to explore and develop alternatives for power plant cooling.

EPRI helped to establish the Water Research Center at Georgia Power's Plant Bowen, which tests emerging water treatment and reuse technologies. EPRI also is pursuing an advanced cooling test center to move some of the new cooling technologies toward commercialization.

EPRI's Integrated Grid initiative is also essential in the IEN. Distributed energy resources (DER) such as wind and solar must be integrated with the grid to enhance flexibility and improve operation, including its existing power plants. Researchers point to the importance of researching water needs and impacts of different distributed generation technologies.

EPRI is now incorporating water use data into its U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model, which weighs how policy and market conditions impact the future electricity mix. "We can now assess what changes in the generation fleet mean for water use in power generation," said Zammit. "In general, the United States is moving to a less water-intensive generation fleet due to renewables such as wind and solar PV, which don't require water beyond a small amount used in manufacturing. New steam plant builds are generally natural gas combined cycle units, which also have a much lower water intensity."

EPRI also continues its work to improve sensor technologies, which are critical for effective integration. "We have a better handle on where water is being used and where electricity is used. With smart meters on both systems, we can get parallel data to do analysis on important questions," said Nalini Rao an EPRI technical leader in the water and ecosystems research group. "We can then use that analysis to help implement conservation and other strategies that improve both systems."

Understanding the Environmental Issues of the Natural Gas Revolution

The word *revolution* has been bandied about to describe everything from new hair care products to office chair designs, and its once powerful meaning has been diluted. But a revolution in the true sense of the word has taken place in the electric power sector over the past five-plus years as fracking technology unleashed both a boom in U.S. production of natural gas and plummeting prices.

Two statistics highlight the transformative effects: The U.S. Energy Information Administration reports that coal was the fuel source for 50% of America's electricity generation in 2004, dropping to about 40% in 2014. Today, coal's share has dwindled to around 30%, replaced largely by natural gas. While cheap natural gas can save customers billions of dollars, its rapid emergence has raised questions about the potential environmental impacts of natural gas production and combustion.

These questions arise in the wake of this rapid revolution coupled with the fact that much traditional fossil fuel research has focused more on coal. "The environmental issues related to natural gas have always existed, but I think in the past five years or so they have become more prominent because of how the generation mix has been changing," said Naresh Kumar, an EPRI senior program manager. "We are focusing our research efforts on the environmental impacts of the entire natural gas life cycle to gain a comprehensive understanding of the issue."

To better focus its research, EPRI reviewed what is scientifically known and unknown about topics such as greenhouse gas emissions from burning natural gas, impacts on air and water quality, and seismic activity possibly related to fracking. From that review, new research initiatives have arisen to build on past EPRI efforts to measure air quality in the Marcellus Basin, a center of natural gas production, and the possible impacts of environmental regulations on future prices.

An often-mentioned environmental benefit to natural-gas-fired power generation is an approximately 50% reduction in greenhouse gas emissions relative to coal-fired generation. But results from a handful of studies indicate that greenhouse gas emissions from the natural gas life cycle may be higher than coal, due largely to the release of methane during natural gas production and distribution.

Two EPRI projects are examining that question. One is in collaboration with the California Energy Commission. "We are going to deploy the latest technologies to measure methane leaks in the distribution system and as natural gas is delivered to power plants or into homes or fueling stations that deliver CNG (compressed natural gas)," said Kumar. "We will deploy instrumentation in those places and in airplanes to measure any leakage around power plants."

Separate EPRI research will examine life cycle greenhouse gas emissions of different generation technologies, including coal, natural gas, wind, and solar. "That kind of work has been done in the past, but there are many data gaps. We want to improve on the studies and provide an independent check," said Kumar. Another project is being considered to examine the water requirements for a range of generation technologies, including natural gas.

Nuclear Plants Look Beyond Wi-Fi for Online Monitoring

Nuclear power plants have opportunities to improve their operational efficiency using advanced technologies to automate monitoring, inspections, and other tasks. A distributed antenna system provides the backbone for a new wireless communications capability.

Distributed Antenna Systems (DAS)

EPRI Senior Technical Leader Nick Camilli is investigating the use of cellular long-term evolution (LTE) networks and distributed antenna systems to amplify and distribute radio frequencies. Such systems can be a cost-effective wireless solution as demonstrated by their successful application in large hotels, subways, and tunnels.

"Distributed antenna technology brings a flexible wireless platform to support voice communications, equipment monitoring, and other new technologies that the industry is adopting," said Camilli. "It can enable a faster, more efficient work execution process and increase the mobility of maintenance workers using handheld tablets and other digital devices."

Distributed antenna systems use a combination of antennas and radiating cables. Radiating cable is a slotted coaxial cable that can extend up to several hundred feet and operate as a single antenna. It can be snaked around equipment and into voids and "shadow areas," making it well suited for inside the power block.

Relative to conventional Wi-Fi, distributed antenna systems can operate at lower frequencies, which propagate more widely and penetrate more extensively. This is key in nuclear power plants with walls 2–3 feet thick and filled with rebar. "We're looking at frequencies in the 700–800 megahertz range—well below the 2,400 megahertz of conventional Wi-Fi," said Camilli. "Our testing has proven that these systems can produce coverage 2–3 times stronger than Wi-Fi."

Camilli and his team examined the feasibility of a distributed antenna system at two nuclear plants that are being decommissioned. "Both pilot demonstrations have proven that distributed antenna systems have the flexibility and reliability to address the needs of nuclear facilities."

Monitoring and Automation

Using DAS, many manual and periodic inspections could be done continuously with wireless sensors feeding data to an automated monitoring system. The software is programmed to detect abnormalities and performance deviations, then signal the need for intervention and maintenance.

"You could still get the high reliability that nuclear plant operators have come to expect, but do so with less labor in the field," said EPRI Senior Program Manager Rob Austin.

In 2016, Austin and utility technical advisors developed a five-part plan to help accelerate the adoption of automated, wireless performance monitoring:

- Develop a strong, quantifiable business case.
- Create a step-by-step implementation guide for utilities.
- Assess commercially available wireless sensors and provide guidance on the most effective locations.
- Assess commercially available statistical analysis tools for integrating equipment performance data from wireless sensors.
- Maintain cyber security.

At Catawba Nuclear Station, Duke Energy is installing this wireless sensor technology and consolidating the data in Charlotte, North Carolina. The utility will use the technology to closely monitor equipment, performance, and health.

"As we gain confidence with non-safety-related components, we will be able to extend automated monitoring to more critical components," said Austin.

A Break with the Past: Dynamic New Role for the Familiar Circuit Breaker

Over the course of his four decades in the electric power industry, EPRI Senior Technical Executive Tom Reddoch has observed his fair share of innovation. But there's something special about the new energy management circuit breaker (EMCB) developed by the power management company Eaton Corporation. "I've been in this business a long time, and I will say that the attribute set in the device is something we have been trying to achieve across my professional career of 40 years. It's in this gadget."

What makes the EMCB so remarkable is that it combines accurate, detailed monitoring of customer electricity use with secure Wi-Fi communications. This has the potential to improve how either or both utilities and homeowners manage consumer electricity use while bolstering how utilities manage the grid—by supporting demand response, distributed energy resources, energy management, and other products and services.

Because it is in the circuit breaker panel, the EMCB can provide detail about electricity use in residences and businesses beyond aggregate consumption captured by today's meters. "In addition to monitoring, you have the ability to simply open and close that circuit breaker with your phone," said Reddoch. "It also measures voltage, current drawn, the watts drawn, and VARs produced or absorbed, as well as local system frequency."

The implications of this precise monitoring and control are vast. For utility customers, it offers the ability to manage electricity use more precisely. Likewise, for utilities, it offers the ability to measure electric services that better reflect the value provided to customers. "We have typically monitored simple energy watt-hour information for residential customers to generate an electric bill," said Reddoch. "Going forward, simple energy measurement is becoming less and less relevant as an indicator of the actual electric service purchased. We are moving toward electric demand or capacity measurement with certain fixed charges and a small energy charge. The future demands a better way to track what the consumer is doing."

To ensure that the EMCB can reliably provide such information to consumers and utilities, EPRI and 13 member utilities are field-testing up to 500 devices in residences around the United States. The utilities extend from Seattle City Light in the West to Nebraska Public Power District in the Midwest to Commonwealth Edison in the Eastern United States and include investor-owned utilities, cooperatives, and municipal utilities. The expansive reach of the testing, which will last until mid-2018, will probe how the EMCB functions in widely diverse conditions and applications called *use cases*.

Which is exactly the point. "We want to take the attribute list and assess its robustness," said Reddoch. "Most of the time the circuit panel boxes are on the inside of a house, but we want to know what happens when you have them outside on a west-facing wall in Arizona in the middle of August when it's 118 degrees. We want to know if the electronics in that breaker are going to roast."

In Seattle, EPRI is also involved in evaluating whether the EMCB can be an effective tool for the city in charging its planned fleet of municipally owned electric vehicles. Working with the city and the municipal utility, Seattle City Light, EPRI is helping determine the best way to charge what could eventually be as many as 4,000 electric vehicles so that they are ready to go at 8:00 a.m. every workday. "There are about four or five decent options out there, and the EMCB is one. We are looking at all the options and comparing the trade-offs in terms of performance and how easy it is to get the vehicles ready as well as the economics," said Reddoch. "We hope that this will be a model project for municipalities because they frequently follow each other when looking to see what works and what doesn't."

Sensors Inform Capital Expenditures, System Operations, System Design, and More

At least in theory, the best approach to replacing important transmission and distribution system equipment is to follow a simple schedule: if a transformer has a life expectancy of 45 years, grid operators simply need to install it and let it operate for nearly a half-century before swapping it out.

But that is not the best approach in the real world, particularly when utilities are keen to get the maximum amount of reliable use from their assets. "Today, we run assets to failure or take things out of service that have more life because we don't know their actual condition," said Andrew Phillips, director, Transmission and Substations at EPRI. "Because equipment is not all operated the same way or in the same environment, you can optimize your investment costs if you know a little bit more about its actual condition."

The idea that better information leads to improved asset management and utilization is at the core of EPRI's research and development of advanced sensors for transmission, substations, and distribution. EPRI's research, which includes both laboratory testing and 38 field tests at utilities around the globe, established the goal of commercializing and bringing to market sensors capable of such things as alerting maintenance personnel when there is a downed conductor or determining if someone has approached or is tampering with a transmission structure. In total, EPRI has either already commercialized or is currently developing 13 different types of sensors.

One important aspect of EPRI's sensor research is to develop tests that utilities can include in their specifications to ensure that they procure highly reliable measuring devices. "Today there are no test specs. You just buy it off the shelf and believe the vendor," said Phillips. "Our focus is understanding performance and degradation and failure modes, and developing testing procedures that will evaluate sensors so one can say with confidence that they will operate flawlessly."

The reliability and capital investment implications of having a suite of advanced sensors are significant. For example, with a clear picture of how well transmission, substation, and distribution equipment is functioning, grid operators could more effectively identify potential risks. "If you could identify something that is going to fail, it could protect the public and workers in a dangerous situation and also improve reliability," said Phillips. Another benefit of accurate sensing data: the ability to dynamically rate assets, which leads to improved utilization. "Currently, we rate assets on how much current they can take based on the worst conditions ever—the hottest weather with the most amount of sun and no wind," said Phillips. "But if we knew the temperature of the actual device, we could rate it."

Improved data from sensors also could lead to more optimal system designs. For understandable reliability reasons, transmission line and other grid systems are possibly over-designed. "We use all these theoretical equations to calculate how much wind it can take and whether conductors will gallop, but we don't really know because we can't measure what's actually happening," said Phillips. "By knowing how assets perform in the field, we may be able to take some fat out of the design. We might not have to assume as many safety factors to account for our lack of understanding in our calculations because we have improved knowledge of how assets behave under normal and extreme operating conditions. In fact, we may be able to operate systems a little harder because we know how they perform in the field."

The Future Utility May Well Be Built on This Customer Model

It's no secret that the power system is in the midst of a fundamental transformation as distributed energy resources (DER) such as rooftop solar and energy storage are added to the distribution grid. EPRI's Integrated Grid Initiative, launched in 2014, has made significant progress facilitating the extensive addition of DER in ways that make effective, reliable, and efficient use of the existing, central station-oriented power system to enhance reliability and efficiency.

But as the power system is reshaped by adding new technologies, the traditional relationship between utilities and customers is also changing. Rather than exclusively providing electricity to businesses and homes and sending a bill each month based on kilowatt-hours used, utilities are increasingly forging two-way relationships with their customers.

This is both a necessity and a big opportunity. Many customers using smart thermostats and driving electric cars will want to communicate with utilities about the most economical times to charge their vehicles or adjust their thermostats. For their part, as utilities consider investing (or deferring such) to upgrade feeders and other infrastructure, they will seek more accurate information about where distributed generation is likely to be added to the grid and how customers use electricity.

"If we need capacity, can we get it from customers? Where do we need to build extra capacity?" said Mark McGranaghan, vice president, Integrated Grid. "To benefit customers, utilities, and the overall power system, we are going to need to increasingly include the customer in the evaluation of all our options for planning and operations."

Utilities then can see mutual benefits as they know more about their customers—everything from the likelihood that they will adopt electric vehicles, rooftop solar, and other technologies, to how those who do adopt them will use these resources. To help answer these and other questions, EPRI is developing a Customer Model of the Future. Though still in development, the model will provide a framework and best practices for utilities eager to translate knowledge of their customers into more efficient operations and planning.

"We want it to be an Amazon-type information model to help understand what's going on with each customer," said McGranaghan.

"Right now, we have load shape libraries, and we still want that, but we also want to know the individual characteristics of technology adoption and use for every customer, so that programs and services can be designed to maximize their value for the customer and the system. It's working with data from the bottom up to create a better understanding of the aggregated characteristics."

By necessity, McGranaghan says the Customer Model of the Future should be approached collaboratively and industrywide. The first step, already underway, is to forge a consensus about the vision and framework of the model, including which applications and technologies need to be included. "That is our initial effort, developing the framework based on applications that will use the model," said McGranaghan. Future steps may include marrying existing common models used for transmission and bulk system planning with detailed customer information based on everything from surveys and product purchase preferences to data from advanced metering infrastructure and sensors. Ultimately the model can be used to improve utility planning and operations and provide additional value to customers.

"These detailed models will help us identify opportunities for improvement and make recommendations to customers about things like upgrading their refrigerator and other demand management steps that make sense based on economic incentives," said McGranaghan. "This is a way to provide more efficiency to customers and make them more of a central player in how utilities function."

An Integrated Grid: A New Model for Modeling?

In the discussions and debates on how the grid must change to integrate distributed energy resources (DER) efficiently and effectively, one unchanging reality is sometimes overlooked—physics. "At the end of the day, the power system has to maintain the active and reactive supply-demand balance at every second," said Jens Boemer, PhD, a senior technical leader in EPRI's Grid Operations and Planning Group. "The physics of the system don't change, but the means to achieve equilibrium in the system change dramatically."

As rooftop photovoltaics (PV), energy storage, and other resources connect to the distribution grid increasingly and rapidly in places such as California, Hawaii, and Germany (and at a slower pace elsewhere), grid operators and planners (and physics) require improved modeling tools and practices. Even before EPRI launched its Integrated Grid Initiative in 2014, EPRI researchers began examining modeling methodologies and tools that, among other things, address the interface of the transmission and distribution (T&D) grids.

Over the past three years, EPRI's Grid Operations and Planning Group has been developing a "dynamic equivalent model" of distributed renewables for use in bulk system planning studies. "Bulk system planning means that you try to model the system as best as you can in order to derive various aspects of reliability across the system," said Boemer, whose career began in Germany, a pioneer in integrating DER. To help maintain reliability, EPRI's researchers developed models and techniques that could accurately represent small distributed generators, such as rooftop PV systems. EPRI's efforts were valuable enough to be incorporated into guidelines published by the North American Electric Reliability Corporation (NERC).

Because grid planning is based to a significant extent on modeling, EPRI is also exploring needs and opportunities with respect to hybrid modeling approaches. "This includes the use of high-performance computing to represent what is going on at the distribution level in greater detail and connect that to our relatively simplified transmission planning model," said Boemer. "We are exploring hybrid modeling that allows you to represent a distribution system or feeder in great detail and still use that output in overall bulk power system modeling."

All of these efforts to improve modeling have the same goal—to enable planning that better leads to a reliable and cost-effective electricity supply. But Boemer is quick to point out that the goal of developing new modeling techniques and tools is not to replace existing planning processes. In fact, the hybrid modeling EPRI is working on may simply validate or improve existing models. "As much as we can stick to the same tools and software as possible, that will make it easier for our members and other utilities to utilize these improvements," he said. To keep new modeling approaches as simple as possible, EPRI is identifying the minimum data exchange across the T&D interface necessary to maintain system reliability.

In his decade and a half of work in Germany and the United States, Boemer has learned that the biggest challenges to improving T&D system modeling and operations aren't technical, but relate to organization and people. Traditional T&D planning is largely compartmentalized. What is now required are better processes to share T&D system data needs.

"We first have to set up processes to transfer data across the interface, whether it's in real time in operations or on an annual planning cycle. You have to move information from one group to the next and back in order to come to meaningful assumptions. That requires new processes that will go far beyond the existing ones," he said. "As engineers, we get easily hooked on modeling and tools, but we need to look at the people component."

Advance Infrastructure/ Technology

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storage
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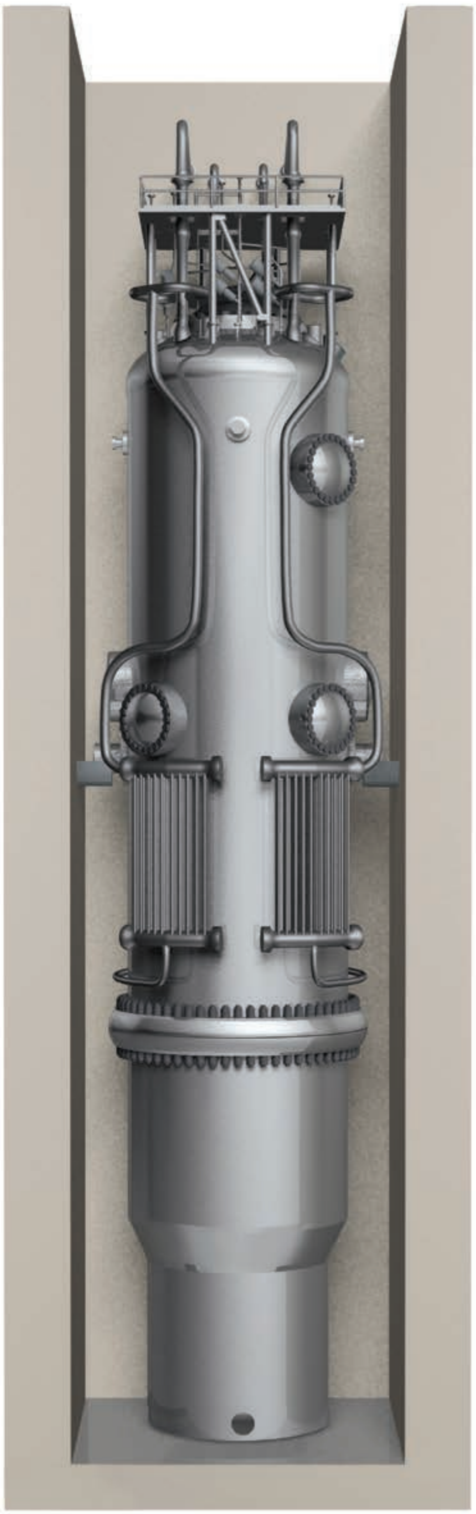
energy
carbon capture
security
thermal fossil
shale gas
grid
flexible
changing
low-cost
utilization
efficient
large-scale
transmission
solar
infrastructure
regional
investment
renewable
dynamic
distribution
technology

Advanced Manufacturing to Reduce Costs of SMR Production



Imagine being able to build a nuclear plant's reactor pressure vessel (RPV) in one year instead of four using metal powders instead of massive forgings and a fabrication process in which welds essentially disappear.

This is the central goal of a new four-year collaborative program spearheaded by EPRI, the United Kingdom–based Nuclear Advanced Manufacturing Research Centre (Nuclear AMRC), and the U.S. Department of Energy (DOE). Its success could broaden the manufacturing base of reactor pressure vessels beyond Asia. The team's immediate focus is on producing small modular reactor (SMR) component assemblies at two-thirds scale, using Oregon-based NuScale Power's 50-megawatt unit design.

Key Enabling Technologies

EPRI estimates that several new technologies, when used together on an SMR vessel, could reduce welding time by 70%, overall production time by 60%, and manufacturing costs by 40%.

- Powder metallurgy combined with hot isostatic pressing: In this process, metal alloys are atomized into powder form, inserted into a metal mold (or "can"), and subjected to high temperature and pressure, consolidating the powder into a solid metal component. Minimal machining is needed to achieve the final geometry, and the homogeneous microstructure affords easier inspection and good properties.
- Electron beam welding: This focuses a high-intensity energy beam to fuse two pieces of metal. Subsequent solution annealing, quenching, and tempering complete the process. Unlike traditional welding, no filler material is used. "We've demonstrated that we can remove all evidence of the weld through solution annealing," said EPRI Technical Executive David Gandy. "This could eliminate the need for in-service inspection."
- Diode laser cladding: By combining a metal wire or powder with a laser beam at the surface to apply extremely thin layers, this technology potentially reduces the amount of cladding material needed by 75%.

The SMR Reactor Vessel Demonstration Project

In 2009, DOE began looking for industrial participants to test advanced manufacturing techniques for SMRs. EPRI explored the project vision with Nuclear AMRC, drawing on its capabilities in advanced nuclear manufacturing. With DOE's support and sponsorship, a collaborative project on SMR manufacturing and fabrication emerged, building momentum in 2016.

"We have gathered an ideal combination of expertise on our team," said EPRI Technical Leader Craig Stover, who manages the collaborative with Gandy. Participants include:

- Nuclear AMRC, a co-investigator in the project with EPRI, to lead fabrication of critical SMR assemblies
- NuScale to provide the SMR design
- Pennsylvania-based Carpenter Powder Products to supply the powders
- UK-based Sheffield Forgemasters to produce several forgings for the SMR
- Los Angeles–based Synertech PM to lead the hot isostatic pressing

The project, which began in late 2016, has two phases. The first will focus on the RPV's lower assembly; the second on the more complex RPV top-head assembly. The team will produce two halves of the assembly and join them using electron beam welding followed by cladding and solution annealing.

These same advanced manufacturing/fabrication technologies can be applied to advanced nuclear and fossil units.

Growing Knowledge Base on Cycling Goes Online

As flexible operations become more prevalent in power generation, companies increasingly are challenged to provide reliable power while complying with environmental regulations and “filling the gaps” around variable renewable generation. The issue is made more complex by the spectrum of generation assets ranging from coal- and natural-gas-fired to nuclear plants.

EPRI has documented effects of cycling in generation plants for years. In addition, the combined effects of variable solar and wind generation and low natural gas prices point to much more cycling, ranging from ramping power generation up and down to shutting down and restarting assets. Cycling makes plant operations more complex, affects plant design margins, and requires plant workers to bring to their jobs new expertise and to develop skills related to operating innovative technologies using data analytics and central monitoring.

To compile and correlate knowledge from the field, EPRI’s researchers are delving deeply and comprehensively into issues associated with specific generation types, including subcritical natural gas boilers, supercritical natural gas boilers, gas turbine combined-cycle units, subcritical and supercritical coal-fired plants, and hydropower (Francis-type turbines).

“We started this by saying, let’s get boots on the ground,” said EPRI’s Mike Caravaggio, who is leading the Changing Mission Profiles project. “During these visits, we’re meeting subject-matter experts from across the spectrum, from all aspects of the operation, and listening to their issues.”

The nearly three years of site visits have led to the development of case studies connecting real-time experience with existing EPRI research. The knowledge being developed and digitized usually starts with key questions from the EPRI team including, “What is your plant currently doing, what are your constraints, and why is that a constraint?”

Key insights have already emerged. For example, newer plants that run more efficiently tend to be less flexible, a trade-off for greater efficiency.

“With thermal plants, a common strategy is reducing minimum load so you can stay online without having to turn things off and then turn them back on, which can cause a lot of damage,” said Caravaggio. The group is also looking at ramp rates, how layup practices affect costs, and component issues including corrosion concerns and mechanical and thermal stress.

Environmental controls add another layer of complexity to the challenge of flexible operations. “The environmental control equipment is designed to work at certain temperatures, so if you have all that on the back end, you can’t turn it down as low as you used to, and it’s different for every plant,” Caravaggio explained.

As the effects of cycling become more challenging, EPRI’s Mission Profile Working Group is preparing to launch FlexOps.EPRI.com, an informative web portal. Members will be able to use the site to access information about what other plants are doing to minimize the costs and damage associated with flexible operations. The portal also will provide access to previous and ongoing EPRI research. “The web platform (FlexOps.EPRI.com) should be a powerful tool for institutionalizing what we’ve learned over the last three years,” Caravaggio added.

Listening to the "Beating Heart" of a Power Plant

To get the full picture of a patient's health, doctors often rely on technology and diagnostic tests. The electrocardiogram is a familiar example used to monitor and record the heart's electrical activity. EPRI is looking to do much the same in power plants, focusing on a variety of equipment. Because different equipment speaks the equivalent of different languages, EPRI is harnessing data analytics to provide the translation needed to improve equipment reliability and operation.

In 2016, EPRI launched its Insight through the Integration of Information for Intelligent Generation (I4GEN) project to focus on a holistic approach for creating a digitally connected and dynamically optimized power plant. The complex and ambitious project seeks to provide the workforce with a digital platform that produces real-time information for estimating equipment condition, enhancing maintenance, optimizing processes, and augmenting decision-making abilities.

The project is focusing on data analytics where its major influence is in transforming large data sets into useful information. As flexible operations place increasing demands on plant assets, companies are beginning to explore using data analytics to augment monitoring and diagnostics during transient conditions and identify operation states not previously recognized by subject matter experts.

In developing the best tools and methodologies for implementing data analytics, a primary focus is on the "heart" of the power plant—the turbine. "I4GEN is evaluating multiple tools and techniques for their ability to provide a mechanism that uses data-driven solutions for early detection, diagnosis, and prognosis of anomalies in major components, especially focused on initial turbine problems," said Steve Seachman, senior technical leader for EPRI. "Some of the techniques include adaptive first-principle models, machine learning, deep learning, and neural networks."

Among its challenges, the group is working to get an entire industry on the same digital page. EPRI Principal Project Manager Susan Maley said, "We're figuring out the digital platform that allows you to collect, transfer, transport, integrate, and compute information. Everybody has a different set of systems, and not all of the software talks the same language; for example, components are not identified the same way across systems."

Beyond data analytics, the project is developing case studies that will assemble a diverse range of generating asset types along with multiple project participants and technologies. The lessons learned and findings from each case study will be shared with the working group. I4GEN is also exploring new generation sensors, advanced asset management techniques, data integration, digital worker technologies, and optimized operation and performance through advanced controls.

The program recently announced members of its I4GEN Working Group that include Duke Energy, Southern Company, TVA, Louisville Gas & Electric and Kentucky Utilities, We Energies, the New York Power Authority, Korea Electric Power Corporation (KEPCO), and technology developers. The working group will provide insights on products and technologies and how products and services may be integrated, reducing the time required to seek individual, unique approaches that could reduce effectiveness.

Power Companies Taking More Ownership of Renewables

Fast-moving clouds over a solar farm and changes in wind direction are good metaphors for what's happening in the renewables landscape. "Moving away from third-party ownership to direct ownership allows our members to control their own destinies," said Tom Alley, vice president of EPRI's Generation Sector, which focuses on fossil and large-scale renewable power R&D.

Traditional electricity generating companies are increasingly owning and operating wind and solar generation assets, motivated by improving economics, technology advancements, favorable government policies, and public opinion. Higher penetrations of variable renewables also drive new research for existing hydropower facilities, which are subject to impacts on component reliability from increased duty cycles.

EPRI's Renewables program is providing a knowledge base that utilities can use to improve the performance and reliability of their wind and solar assets. "The exponential growth of renewables is increasing the need for seamless integration on the grid," said Alley. "Our members need to be able to analyze the predicted versus actual performance of their assets and adapt their operation and maintenance strategies to maximize the value that they can derive from their investments," he added.

Broadly speaking, research needs are expanding for a market segment experiencing record growth. Solar photovoltaic capacity has grown from 1 GW in 2000 to more than 300 GW as of April 2017. More than 90% of the current solar capacity was installed in the past five years, and installed global wind capacity is now greater than 480 GW. The U.S. Department of Energy (DOE) Hydropower Vision finds that U.S. hydropower capacity could grow from 101 GW in 2015 to nearly 150 GW by 2050.

Research is focusing on assets' life cycles and going beyond data provided by original equipment manufacturers. EPRI is working with the Solar Technology Acceleration Center (SolarTAC) near Denver to evaluate performance and reliability characteristics of solar, advanced inverters, batteries, and other components using an outdoor "plug-and-play" test bed.

"The work at SolarTAC has helped us build expertise in energy performance, degradation, and seasonal impacts such as snow effects," said Alley. SolarTAC also provides research on data collection and analysis techniques and instrumentation and control, which is helping members design, build, and operate their own solar farms.

EPRI is looking at solar inverter reliability and advanced controls for wind assets. "Today, wind turbine controls are designed at the turbine level. Through advanced control strategies at the central farm level, the plant power production can be increased, fatigue on individual turbines can be reduced, and optimization strategies can be deployed to maximize the plant's performance," said Alley.

With respect to hydropower resources, existing facilities are wrestling with issues caused by cycling (ramping generation up and down). Research targeted at improving reliability through condition-based maintenance offers possible answers. "The research that EPRI is doing will help our members maximize the return from their renewable investments by enabling safe, economic, reliable, and flexible operations," said Alley.

Forging New Ways to Weld

EPRI research recently resulted in changes to the codes governing how certain power plant welds are finished. Several utilities now use the innovative welding technology developed by EPRI to repair piping and tubing made with Grade 91 steel, a workhorse alloy long used in fossil-fired power plants.

American Electric Power, Prairie State Generating Company, Florida Power & Light, and Xcel Energy have all saved costs and time using methods that reduce or eliminate the need for post-weld heat treatment (PWHT).

Historically, industry standards have dictated that a matching filler metal be used in welds on Grade 91 combined with PWHT regardless of thickness, component type, or condition of the material being repaired—a broad standard that is at times problematic.

“If you make a mistake during the PWHT by going too hot, which is easy to do, you can do irreparable damage to the material,” explained John Shingledecker, EPRI senior program manager. “A large percent of problems in the industry installations of Grade 91 over the past 20 years are tied to mistakes made in the field using PWHT.”

To overcome issues associated with PWHT, EPRI experimented with a range of filler materials, different types of weld joints, and how the welding process is controlled. Two years of research produced positive results. That was followed by four years of R&D to confirm the findings and inform members and stakeholders that the revolutionary approach is sound.

The next task was getting the new methods approved and included in the industry standards. “We had to demonstrate that we developed the new method in a safe and effective manner because PWHT is the standard practice for the industry,” Shingledecker said.

EPRI researchers presented their findings for inclusion in the National Board Inspection Code, the industry standards published by the National Board of Boiler and Pressure Vessel Inspectors.

The process took years, but once it was approved, the four early-adopting utilities put the new methods to the test in the field.

American Electric Power used the new technique, known as *Welding Method 6*, in 14 reheater tubing repairs. Prairie State Generating Company repaired extensive fly ash erosion. Florida Power & Light made more than 70 weld repairs to a variety of components. Xcel Energy was able to forego PWHT on a weld that has been subjected to more than 3000 hours of operation at temperatures greater than 1000° F.

Limiting the number of heat treatments in a plant can be a financial game-changer with cumulative savings from $5,000 to $100,000 per repair. Savings in the hundreds of thousands could be realized by improving the accommodation of component replacements. Millions of dollars could be saved by rapidly resolving outages by eliminating component damage resulting from heat treatment gone wrong.

The new methods are approved, field tested, and getting good reviews. Keith Rapkin, staff engineer at Florida Power & Light Company, said, “The use of EPRI’s alternative Grade 91 weld repair methods without PWHT increases our flexibility during unplanned outages, reducing repair time and O&M costs. Utilizing EPRI’s recommendations provides absolute certainty that we are doing the right thing from a technical standpoint.”

EPRI continues to investigate innovative repair options, expanding the use of these methods to new components, damage mechanisms, and materials.

Broaden Collaboration

Exploring Integrated Nuclear-Renewable Hybrid Energy Systems

EPRI is working with Idaho National Laboratory (INL) to evaluate the technical and economic feasibility of an integrated nuclear renewable hybrid energy system. The objective is to develop and demonstrate ways of using excess energy (electrical or thermal) during periods of low demand in an industrial process that yields a valuable product and minimizes plant cycling. A pilot program is slated to follow the study. The work strategically aligns with EPRI's efforts on the Integrated Energy Network.

EPRI's research associated with flexible nuclear power plant operations led to the project with INL, which, along with the National Renewable Energy Laboratory, received U.S. Department of Energy funding to develop tools for evaluating integrated hybrid energy systems. The collaboration with the labs has led to the formation of a utility advisory committee.

Some options being considered include processes for saltwater desalinization, compressed air storage, and hydrogen production. Sherry Bernhoft, senior program manager for EPRI, says, "The two that get the most conversation are desalinization and hydrogen production. Water is a very valuable commodity, and if we're taking a low-carbon asset such as a nuclear power plant and converting it to another low-carbon energy medium such as hydrogen, that's a benefit to society."

Several challenges need to be overcome, including quantifying the value of the grid services needed to produce the product and putting a value on the final product. There are also financial issues, regulatory hurdles, and public perception complications. Technical challenges may be the simplest part of the equation.

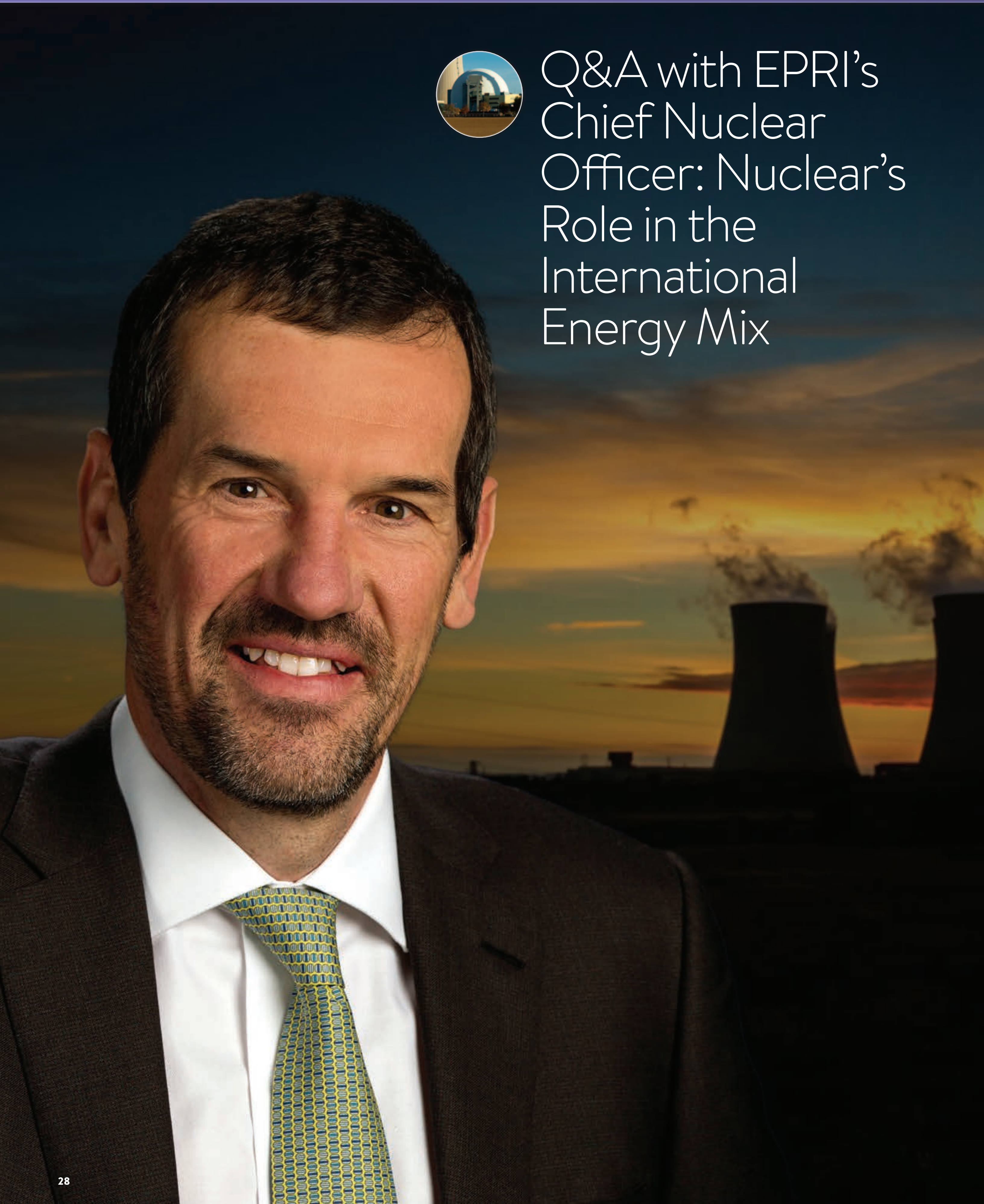
Bernhoft says, "You need a process that has embedded technology. Desalinization by reverse osmosis is a pretty well-known process so there's not a lot of risk there. There are also known technologies for producing hydrogen for use in fuel cells."

The research was kicked off with the idea of adding new technology and processes to nuclear plants that are still in the design phase. EPRI believes that the right process could also be retrofitted onto existing plants. "We have plants today that are struggling because of the increased grid variability," said Bernhoft. "Maybe there's a technical barrier with today's existing plants, but let's make sure that the lessons we learn along the way get passed on."

The lessons also have international implications with new plant construction underway in China and the United Arab Emirates. In addition to the goals of completing the feasibility study, and the eventual pilot program, EPRI is considering an international workshop to share learning and insights.

With distributed energy resources continuing to penetrate markets, creative options for cycling nuclear plants offer various benefits. Bernhoft says, "Exploring these options is a good strategic position for the utilities. They can minimize how much they should operate flexibly or cycle a plant. There is an impact from cycling and a cost. If you can produce another product that has a benefit, those impacts can be reduced."

Q&A with EPRI's Chief Nuclear Officer: Nuclear's Role in the International Energy Mix



More than ever, EPRI's role in supporting U.S. nuclear power plants' safe, reliable, and efficient operations is important as market and economic challenges affect its competitiveness. In contrast, the nuclear power market globally is thriving as new plants are planned and built throughout Asia, the Middle East, and Africa.

Neil Wilmshurst, EPRI's vice president and chief nuclear officer, discusses how EPRI's R&D will provide critical support to a clean energy future, with nuclear power serving alongside renewable energy's steady expansion.

Q: Currently a great deal of discussion focuses on the effects of renewables on baseload power generation. Does nuclear have a role to play in this conversation?

A: Absolutely. What is becoming an integrated energy network combined with greater electrification makes nuclear one of the prime candidates for the increased baseload generation that's needed to keep the grid stable. In recent years, renewables have been viewed, by some people, as an opponent of nuclear because of the perceived subsidies and special treatment. But this perception is changing. It's difficult to see a future with just renewables because of the intermittency of wind and sun and simply, the number of windmills or solar panels that you would need, let alone the transmission capacity required to move all this power around. But imagine a world that recognizes that renewables and nuclear have a synergistic relationship, and you could be looking at nuclear baseload and dispatchable renewables with the same carbon footprint effect.

Q: Is it possible that in the future renewables and nuclear will work side-by-side, depending on factors such as available space?

A: Yes, if you look at power density by considering a square mile that has a nuclear plant on it and has 1000 megawatts (MW) coming out, hour by hour, day by day, 365 days a year. Then consider how many square miles you would need to cover in solar panels or wind turbines to get the same thing. The capacity factor of a nuclear plant is about 90%; solar and wind is somewhere in the region of 50%. You may need to build a 2000-MW renewable facility to get the same output as a 1000-MW nuclear plant.

Q: Are there long-term business or geopolitical questions that could tilt the balance toward a desire for more nuclear power generation?

A: Yes. This is a consideration that people often don't think about, but it is drawing some interest in Washington. Think about the U.S. position in nuclear; the light water reactor technology is fundamentally a U.S. technology developed in the 1950s. This technology is the basis for virtually all the nuclear programs around the world. The United States has been a global leader in the active transfer of nuclear technology. If you export a solar panel, you have a transactional relationship. The client buys it, installs it, and when they need a new one they go buy one. If you transfer nuclear reactor technology to a country, you have a potentially 100-year relationship in the design, 60 to 80 years of operation, the decommissioning of the plant, and the supply chain of the fuel cycle—so there is a geopolitical national security aspect to nuclear that many in the United States have overlooked.

Q: Are there technical concerns about how far renewables can go toward supplying all the power that's needed on a daily basis, even if they were fully embraced and deployed?

A: The benefit of a large baseload generation plant such as a fossil plant or a nuclear plant is that they have this huge spinning mass of turbines and generators, and that gives the grid inertia—the ability to handle short-duration fluctuations in demand while maintaining the quality of the power on the grid. It is the quality of the power that is crucial to consider in that modern electronics rely on high-quality, stable power to function. Consider what happens when you start your air conditioning or even when you start your vacuum cleaner. You may see the lights in the house dip. If you had a home solely powered by renewables and without a grid connection, you might not be able to start your air conditioning without some kind of help because of the immediate need of power to start it. You could probably run it, but maybe you couldn't start it. And that is why this large baseload generation is needed—to absorb these fluctuations on the grid. So, the inertia offered by nuclear or large-scale fossil is an important attribute.

Q: Does the United States have a sound enough infrastructure to support a greater interest in emerging nuclear technology?

A: Yes, but not as much as we may need. If you believe there is a long-term need for nuclear power into the future, the only way you can build a credible nuclear program with new reactor technology is to have a sound foundation in an existing program with the existing technology, R&D efforts, the right people, university courses, students, and everything else. We have that, but it's not as robust as it could be.

Q: What is a prime "everyday" consideration with respect to the viability of nuclear?

A: The weather. Remember the polar vortex a few winters ago? The coal piles froze on many fossil plants so they couldn't move the coal. The natural gas contracts were for industrial and residential, so some of the combined-cycle plants didn't have gas. In the U.S. Northeast, the nuclear plants kept the lights on. Because nuclear plants have all their fuel in their reactors for 18 months or two years of operation, they have what many other generation sources don't have—security of supply.

Land of the Rising Sun: Research Learns from Japan's PV Development

Thanks to dramatic declines in the cost of solar photovoltaics (PV) and a generous feed-in tariff meant to encourage its deployment, Japan has deployed extensive distributed energy resources (DER) that are now delivering power to the grid. As of December 2016, Japan had more than 42 gigawatts of renewables installed on its grid, representing a significant achievement and a big challenge.

"They have so much renewable energy coming on the grid right now that they are at risk of having grid stability issues," said Matt Wakefield, EPRI's director of Information, Communication, and Cyber Security (ICCS).

To address those concerns, Japan's utilities, universities, the New Energy and Industrial Technology Development Organization (NEDO), and other stakeholders are working collectively on a three-year, national project to establish the technology to remotely monitor and modulate the output of distributed PV systems. The project team is working to ensure that customers and electric utilities benefit from this large influx of renewables. As part of this effort, EPRI is working with the TEPCO Research Institute to help develop software and with plans to test the communications and power capabilities of the smart inverters being deployed.

EPRI's Integrated Grid Initiative and work in Japan have delivered lessons and insights that can guide other countries integrating DER extensively:

- Though there is plenty of global experience controlling large, transmission-connected wind and solar plants, DER traditionally have not been controlled or curtailed. Through the work in Japan, the need for additional DER control and curtailment capabilities has become more apparent. "The main lesson: think about more than just the power system architecture," said Wakefield. "The right information technology and cyber security architectures provide the foundation for flexibility, scalability, and security in an electric system—paving the way for success."
- Relative to manual curtailment, automatic curtailment significantly improves system operations—but we need more practice applying it to PV. More a driver of the Japanese program than a lesson, the emerging insight is that automatic or scheduled curtailment is important to integrate significant growth in variable generation.
- Though many smart inverter functions are considered common, 16 functions comprise most of the current guidance from grid codes and standards. The industry has defined nearly 30 inverter functions, but not all of these are in standards, and it's not yet practical to derive value from all of them. For Japan, the starting point is to use the inverter functions identified as most valuable and commonly used globally. "Implementing these 16 functions can set the foundation to do other functions," said Wakefield. "From an architecture standpoint, if you do curtailment you do it in a way that allows you to add other functions later."
- Inverter manufacturers are slow to implement communications technologies. Worldwide, the consumer is driving solar deployment, and thereby largely driving the products inverter manufacturers make. "Historically, the vendors look to produce products that meet consumers' needs, not necessarily utility needs," said Wakefield. "As a result, a consistent utility-to-DER interface has not been implemented widely." However, with greater PV penetration in Japan, that's beginning to change. "For example, in the TEPCO/NEDO project," said Wakefield, "inverter vendors are working closely with utilities to design features that meet their requirements because ultimately it will impact the customer if there are power quality or power service issues as the result of more extensive penetration."

New Tools and Value-Based Maintenance Support Industry Cost Efficiency

In 2015, U.S. plant operators developed the strategic initiative Delivering the Nuclear Promise® (DNP) to transform the nuclear power industry. The Nuclear Energy Institute says the plan is to strengthen the industry's commitment to excellence in safety and reliability, ensure future viability through efficiency improvements, and drive regulatory and market changes to fully recognize the value of nuclear energy facilities. A primary goal is to reduce operating and maintenance costs by 30% by 2018. That's where EPRI's research comes in.

EPRI is supporting one element of DNP by developing tools to enable a "value-based maintenance" methodology. EPRI Senior Technical Leader Jeff Greene says, "Value-based maintenance is all about establishing the right equipment reliability at the right cost, specifically when it comes to maintaining non-critical equipment."

Three web-based EPRI tools are used to enable this: the established Preventive Maintenance Basis Database (PMBD), the recently released Work Order Data Visualization tool, and the Cost Analysis tool, which is in development. Together they enable nuclear power facilities' maintenance organizations to make informed decisions by assessing the total cost of maintaining a specific component, cost impacts of changes to a maintenance strategy, and the component's anticipated reliability.

The Work Order Data Visualization tool was designed to help utilities implement the plan and was released in the spring of 2017. With the tool, members can view equipment work order data to identify components that may be ideal for examining maintenance strategies with respect to reliability and cost. The tool also can provide an industry dashboard, aggregating work order data associated with other participating utilities that can be used for benchmarking.

A Cost Analysis tool for developing custom maintenance strategies from a reliability and cost perspective is slated for launch in 2017. Members will pull information from within EPRI's PMBD, which houses industry maintenance templates for standard power plant equipment, then add cost insights from the Work Order Data Visualization tool.

EPRI has produced a series of webcasts to train members how to use the web-based tools and has planned an instructional video.

EPRI developed the tools for use with value-based maintenance and will document lessons learned from shifting to this methodology. While the DNP strategy started in the United States, nuclear plant operators worldwide are gaining insights from the concepts that accompany this strategy along with the EPRI tools and research that support its implementation.

EPRI and NEA Expand Collaboration to Advance Global Nuclear Research

On June 13, 2017, William Magwood IV, director general of the OECD Nuclear Energy Agency (NEA), and Neil Wilmshurst, vice president and chief nuclear officer at EPRI, signed a memorandum of understanding (MOU) establishing formal cooperation between EPRI and NEA in nuclear power safety, advanced nuclear fuel designs, operational experience, and economic analysis.

It became clear to both EPRI and NEA that the time had come for regulators and industry to consult with one another prior to undertaking major research and development requiring significant time and resources. Innovation will be significantly enhanced through this cooperation, leading to improved connections between research, industry, and regulation. Collaboration will enhance the scope and relevance of research and lead to the development of innovative ideas and new technologies that will benefit EPRI's global membership and NEA's member countries.

Wilmshurst said, "This is a groundbreaking culmination of many years of effort. We signed a similar MOU with the International Atomic Energy Agency as well, so this is really cementing our place in global R&D."

Jean-Pierre Sursock, an EPRI senior technical executive, said "In the past few years, particularly after the Fukushima accident, it has become increasingly clear that the industry and the regulators need to work together on selected projects to better understand the nature and risk of certain accident sequences to extract lessons learned and to develop analytical tools, procedures, and even conceptual fuel designs that would help prevent such accidents in the future."

Wilmshurst added, "By bringing EPRI's considerable pool of knowledge, expertise, and information to work at the strategic level with the NEA, we can join forces to ensure the safe operation of carbon-free nuclear generation."

EPRI expects the agreement to provide it with a better understanding of global priorities—particularly as viewed by the regulatory bodies—while optimizing the use of R&D's scarce resources for maximal impact on reactors' safety and performance.

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