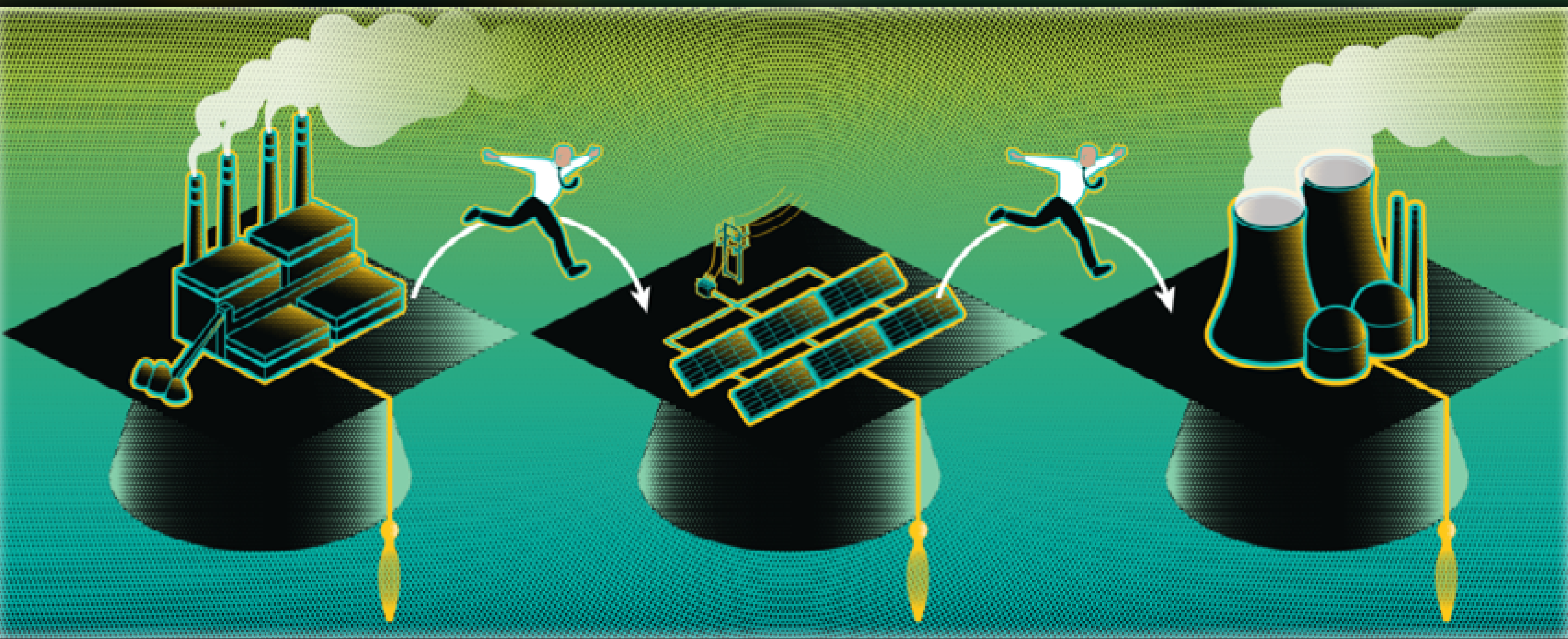
SEPTEMBER/OCTOBER 2018 NO.5

EPRI JOURNAL

EPRI U: Training for a "Fluid" Workforce



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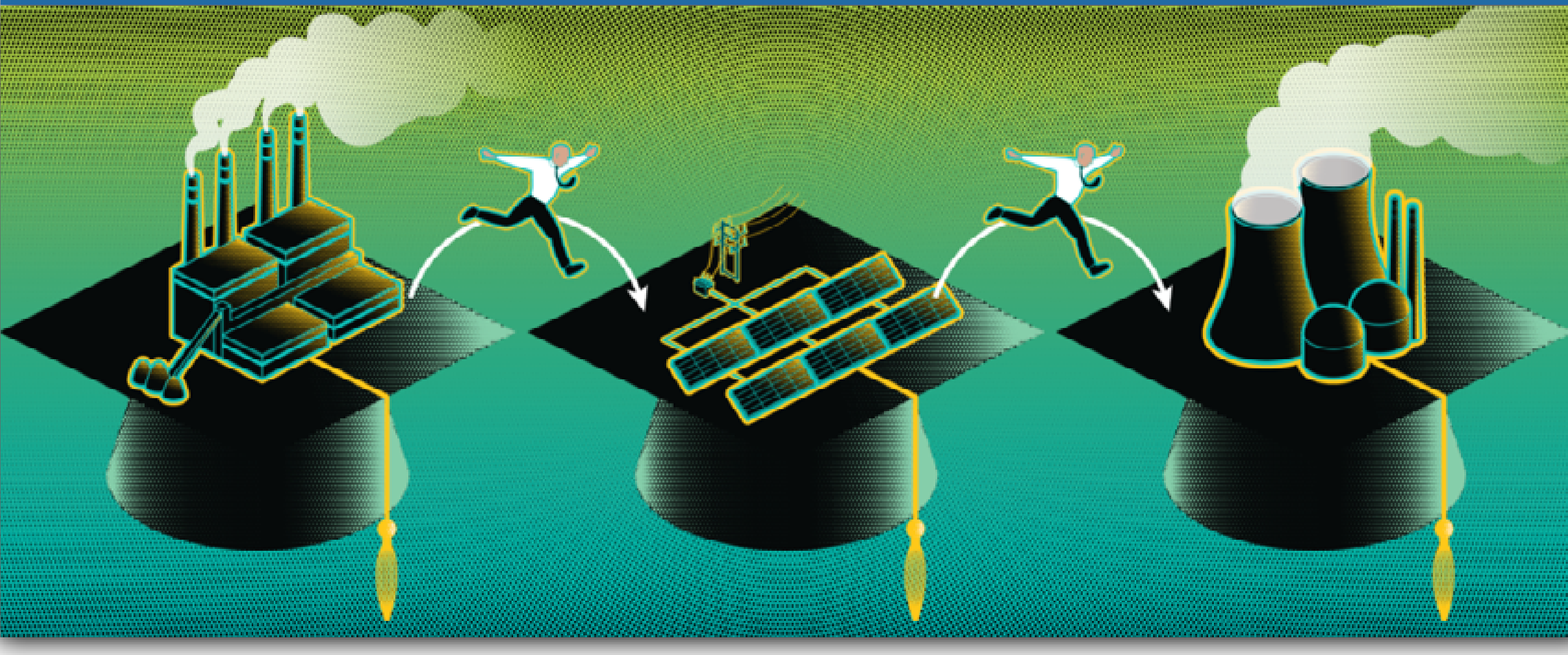


EPRI U: Training for a "Fluid" Workforce

By Sharryn Dotson

The electric power industry workforce is more "fluid" than it used to be. Historically, power industry workers were expected to master one area in their careers, whether it was coal-fired boiler maintenance or nuclear plant water chemistry. Today, utilities increasingly swap workers among generation facilities. A technician who spent years at a nuclear plant may transfer to a job monitoring a wind power plant. To thrive, workers must be nimble and learn multiple skills. Training is essential for ongoing success.

"It used to be that you chose a segment of the energy sector and became an expert in that for your entire career," said EPRI Training Manager Elizabeth McAndrew-Benavides. "With rapidly changing generation portfolios and power delivery systems, people are moving around rather than staying in one sector."

Clay Goodman, Arizona Public Service's (APS) training manager for fossil generation, said that utilities are encouraging workers to expand their knowledge and grow in their careers. "It's rare anymore for employees to stay in the same jobs for their entire careers. As employees mature, they move into leadership or transition to a different part of the company," Goodman said. "We want employees who are engaged and good problem solvers. Having access to information and training can support that."

For decades, EPRI has "transferred technology" and provided R&D results to the electric power industry through training, along with reports and other products. To address the industry's workforce needs, EPRI established *EPRI U* in 2017, providing improved systems for technology transfer through a range of convenient training opportunities.

Watch an overview of EPRI U with Training Manager Elizabeth McAndrew-Benavides.

"When EPRI completes research, the next question is always, 'What now?'" said McAndrew-Benavides, who manages EPRI U. "My team is focused on helping our researchers create new and innovative courses to support technology transfer."

EPRI U offers 380 online, classroom-based, and DVD courses encompassing power generation, power transmission and distribution, and nondestructive evaluation. It also incorporates EPRI's Standardized Task Evaluation Program, which helps utilities identify and qualify workers by developing evaluations for more than 100 maintenance tasks in the nuclear industry.

"People who register for EPRI U courses are often engineers who need training in specific areas such as turbines," said McAndrew-Benavides. "EPRI U courses also can address the needs of workers seeking promotions or professional development hours."

EPRI U Student Testimonial

"In each of the EPRI courses I attended, I left knowing how to do my task better. Whether through better understanding of the process or through learning the history of the industry that led us to how we operate today, I was able to bring something back to my job that would help me going forward. EPRI courses share a wealth of knowledge through experienced instructors and colleagues. I have built a strong network of resources through my EPRI attendance and plan to continue to use their classes to learn and move my career forward."

—Todd Cervini, an Exelon engineer who has worked at Calvert Cliffs Nuclear Power Plant in Maryland

EPRI U is built on the same principle as a college or university, in which professors teach students about their research and students provide feedback. "EPRI U brings the full-cycle university approach—problem, research, application, feedback, more research, application, and so on," said Goodman.

It is part of EPRI's broader effort to diversify its products and share industry knowledge effectively with digitally inclined professionals. EPRI is providing more videos, apps, and other interactive tools for knowledge transfer, which is essential for preserving knowledge from previous generations of workers. The Center for Energy Workforce Development reports that over the next five years, 11.5% of utility personnel are expected to retire, with an additional 16% leaving the industry.

Classroom, Online, and Customized Training Options

EPRI technical staff develop EPRI U courses based on the most up-to-date research. "Our trainings are tied to EPRI research," said McAndrew-Benavides. "Heat exchangers may not change, but heat exchanger research is always changing, and our courses reflect that."

Advisory groups inform the development of EPRI U courses. These comprise training experts from various power industry sectors, representatives from workforce development centers, vice presidents of operations at utilities, and human resources professionals.

In determining whether a course is better suited for the classroom or computer, EPRI considers the topics and the number of participants along with their professional experience.

EPRI staff and other industry experts teach classroom courses, which are usually held at EPRI's offices, offering networking opportunities. "You're getting trained by experts who know the latest and greatest," said McAndrew-Benavides. "You'll get the added benefit of meeting and having conversations with professionals you may not have access to anywhere else."

Classroom courses range from a couple of hours to six weeks; most are two to three days long. "The six-week course *Education of Risk Professionals* is split up into week-long sections," said McAndrew-Benavides. "After each week, students return to their jobs for a week and apply what they learned before coming back for the next section."

EPRI U has significantly expanded the roster of computer-based, online 'distance learning' courses, which are typically conducted through Webex. These courses expand EPRI U's reach to international students and other individuals who are unable to travel to classroom courses or who find online education more convenient.

EPRI U can customize courses for power companies and train a group of workers simultaneously. "A recent example is our *Aging Management* course, which focuses on the work needed for relicensing a nuclear plant," McAndrew-Benavides said. "We customized this course for staff at a domestic nuclear power plant to help them launch work for a license renewal."

Nondestructive evaluation courses combine classroom experience with hands-on examinations to qualify personnel for power plant inspection and maintenance tasks, such as ultrasonic and visual evaluation of components.

One-Stop Shop for Students

Before coming to EPRI in 2017, McAndrew-Benavides worked at the Nuclear Energy Institute, where she facilitated nuclear industry training programs and helped streamline training activities for nuclear engineers. This experience informed the design of EPRI U's web-based Learning Management System, which enables workers and managers to identify and register for courses and track completed courses, professional development hours, and certification requirements.

"Before we launched the digital portal for EPRI U, only supervisors knew what courses their employees needed to take for certifications or promotions," said McAndrew-Benavides. "Jane, the engineer, couldn't see the big picture of what she needed for the job she wanted."

The Learning Management System also gives students access to courses through tablets, computers, or smartphones. "EPRI U's digital resources make information sharing more robust and engaging, which can improve learning," Goodman said.

EPRI U: By the Numbers

Nuclear power courses (includes Standardized Task Evaluations): **202**
Power delivery and utilization courses: **28**
Generation courses: **44**
Nondestructive evaluation courses: **49**

What's Next for EPRI U?

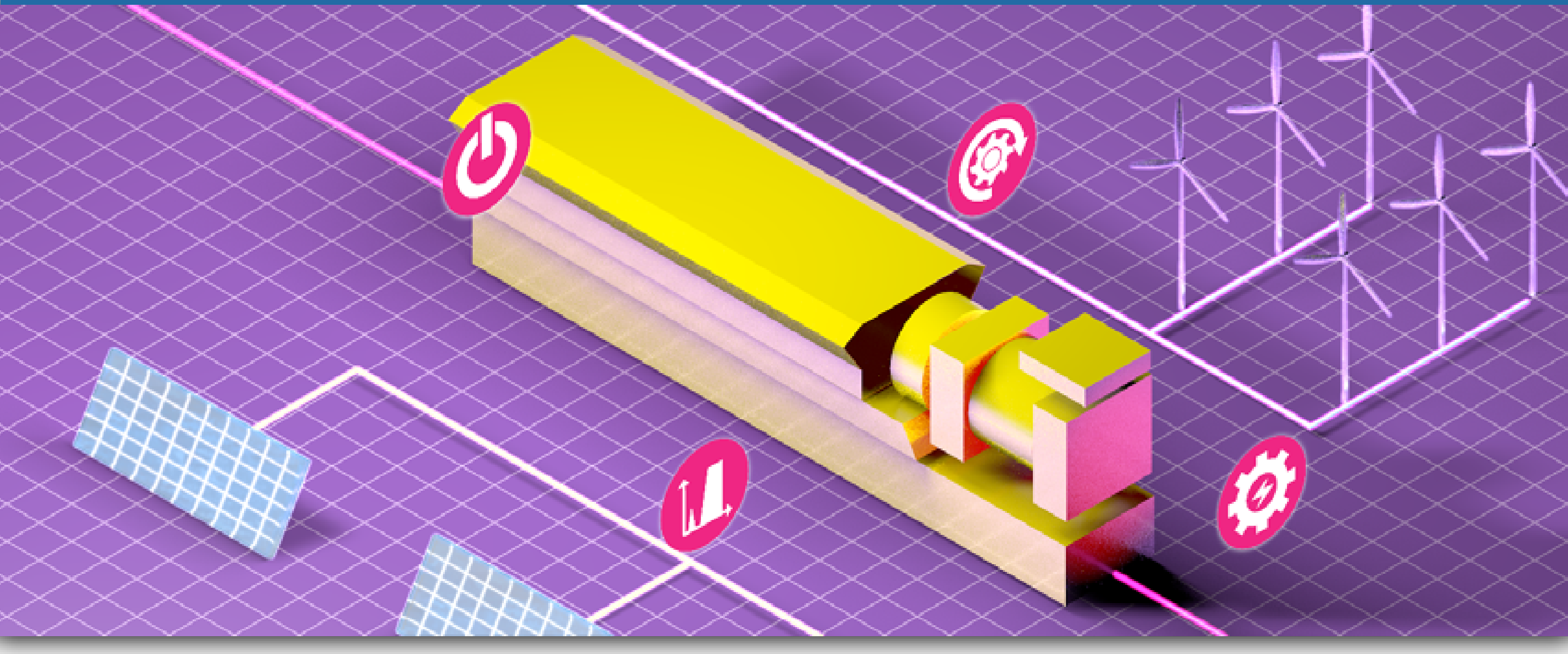
EPRI U's advisory groups are exploring how to expand and refine course offerings, according to McAndrew-Benavides. One group is considering courses for human resources professionals at utilities and power plants.

Student feedback on courses informs future offerings. "We're putting in place more feedback mechanisms so that the courses are helpful and effective," McAndrew-Benavides said. "Student surveys can provide valuable information for EPRI U's course developers and EPRI researchers."

"Through EPRI U, EPRI researchers can gauge the effectiveness of their courses in transferring technology and knowledge to the industry," said APS's Goodman.

Key EPRI Technical Experts

Elizabeth McAndrew-Benavides



Start Your Engines?

EPRI, 20 Power Companies Examine the Role of Reciprocating Internal Combustion Engines for the Grid

By Chris Warren

In recent years, the generation fleet of American Electric Power (AEP) has experienced a shift similar to those seen by other North American power companies. After being dominated for decades by large fossil and nuclear power generation units up to 1,300 megawatts, the fleet includes a growing number of renewable energy facilities and smaller units under 100 megawatts. With this transition, AEP is considering additional changes in its generation planning.

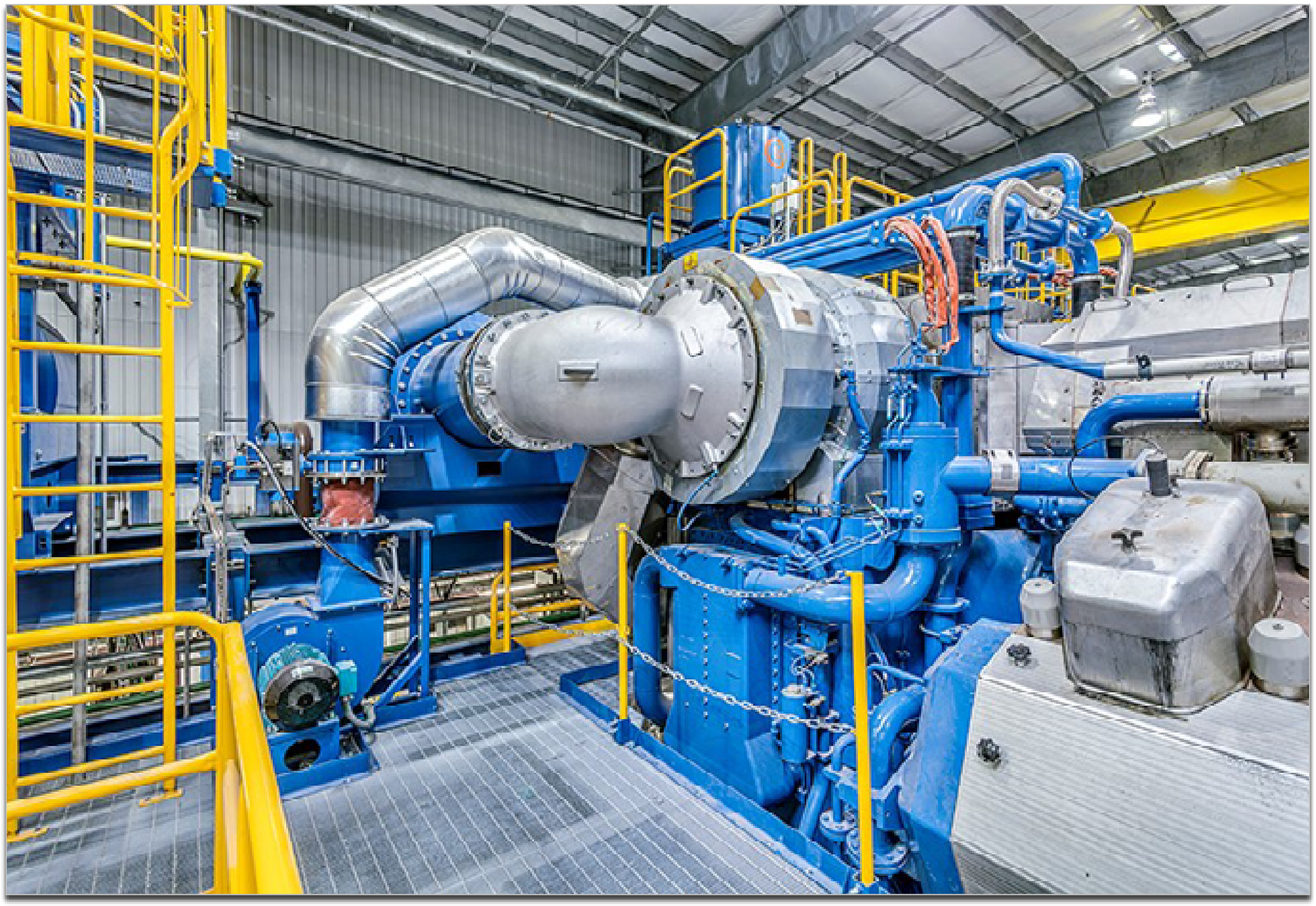
"We expect more renewables and smaller power plants rather than large natural-gas combined-cycle units," said Claudia Banner, AEP's principal engineer for new generation engineering. "This makes it more important to have generation that can start up and shut down quickly and provide backup for renewables."

These dynamics have prompted AEP to consider reciprocating internal combustion engines (RICE) for its generation portfolios. RICE technology is not new. Fundamentals of engines have been recognized for centuries, and the first internal combustion engines were developed in Europe in the nineteenth century. Their use in billions of automobiles has made them the most prevalent power generators on the planet. Power industry applications generally have been limited to smaller backup power and pumping stations.

Many power industry stakeholders see potential for larger RICE applications to help produce peaking power, support grid reliability, and provide other ancillary services largely related to balancing intermittent renewables. They point to the technology's operational flexibility, fast startup time, high efficiency at a wide range of loads, ability to use multiple fuels, low water use, and competitive costs. Another driver in North America is cheap natural gas to fuel engines.

Because coupling multiple, large RICE units (up to 18 megawatts each) for power generation is relatively new, power industry experience is limited. To explore the potential for RICE, EPRI in 2017 formed an interest group with participation from 20 power companies spanning North America, Australia, and Ireland. Group members are considering RICE for various purposes ranging from grid resiliency to baseload power (particularly for isolated or island-based sites).

South Texas Electric Cooperative's 225-megawatt Red Gate Plant with reciprocating engines. Photo courtesy of South Texas Electric Cooperative, Inc.



Top of a Wärtsilä engine at South Texas Electric Cooperative's Red Gate Plant.
Photo courtesy of Wärtsilä and South Texas Electric Cooperative, Inc.

"The power industry is less familiar with operating engines, especially in a power plant," said EPRI Program Manager Andrew Maxson, who leads the RICE Interest Group. "There can be misperceptions and a lack of understanding about what the technology can provide and how to best operate these engines. This is often based on experience with older reciprocating engines powered by diesel or oil, which are more costly and produce more emissions than the latest generation of reciprocating engines."

Duke Energy joined the interest group to better understand RICE operation and maintenance requirements. "We wanted to learn about the benefits and challenges and compare those to what we thought we knew about RICE and to the technologies we traditionally select for peaking applications," said Neil Kern, technology development manager at Duke Energy.

"We need to reduce maintenance costs with new sensors and effective maintenance strategies, better understand how to generate revenue for ancillary services, and obtain more accurate performance and cost numbers for portfolio planning."

Reciprocating Internal Combustion Engines (RICE): A Comparison with Gas Turbines

In the smaller-scale power generation market, engines and simple-cycle gas turbines can be competitors for peaking applications and ancillary services to counterbalance intermittent renewables. Determining the best option requires a comprehensive assessment of site-specific factors. Using data from site visits, engine vendors, and plant operators, EPRI's RICE Interest Group is examining differences between RICE and gas turbines.

RICE Opportunities

Engines can complete a warm startup in 5 minutes or less. Aero-derivative gas turbines can start in 5–10 minutes, but heavy-duty gas turbines take 10–20 minutes.

Engines can typically *turn down*[1] to 25% load while gas turbines can turn down to 30–50% load, depending on emissions requirements.

Engines' *ramp rates*[2] range from 50% to 130% of rated capacity per minute while ramp rates for simple-cycle gas turbines range from 15% to 25% of rated capacity per minute.

While the frequency of startups and shutdowns drives most maintenance needs for heavy-duty gas turbines and to a lesser extent for aero-derivative turbines, **maintenance needs for engines are driven largely by the number of operating hours**. This can reduce costs for power plants that run less often and have frequent starts and stops.

The full-load net efficiency for engines powered by natural gas is typically 3–6 percentage points higher than the full-load net efficiency for gas turbines.

At 50% load, engine efficiencies drop 2–3 percentage points while gas turbine efficiencies drop 6–9 percentage points.

Unlike gas turbines, **engine efficiency is not significantly impacted by higher ambient air temperatures or elevation.**

Engines can operate at lower natural gas supply pressure relative to gas turbines.

Engines use little water (as little as 1 gallon per week). Gas turbines with *dry, low–nitrogen oxide combustors*[3] firing natural gas also consume little water.

RICE Challenges

On a dollar-per-kilowatt basis, **engines typically have 20–30% higher capital costs than gas turbines**, though they can be less costly per kilowatt in high-elevation or high-temperature locations.

Maintenance costs for engines typically are higher than for gas turbines. While precise comparisons are application-specific, a rule of thumb is that engine maintenance costs are double those of gas turbines.

For an equivalent power capacity, **engine footprints typically are 2–10 times larger** than those for simple-cycle gas turbines.

While both engines and gas turbines can have noise concerns, **engine noise is generally at higher frequencies and therefore harder to mitigate.** In addition, equipment outside the engine hall such as radiators and ventilation fans can increase low-frequency noise.

Unlike gas turbines, **engine operations consume a significant amount of lubricating oil.**

Carbon monoxide, hydrocarbon, and nitrogen oxide emissions are higher for engines than for gas turbines but generally can be mitigated with *oxidation catalyst systems*[4] and *selective catalytic reduction reactors*[5] (similar to gas turbines).

1—Turn down means reduce from full to partial load.

2—Ramp rates of power plants are often expressed as a percentage of rated capacity per minute. For example, a plant with a rated capacity of 10 megawatts and a ramp rate of 130% per minute will be able to ramp up from 5 to 10 megawatts in about 23 seconds.

3—Dry, low–nitrogen oxide combustors use a lean combustion design in which the air and fuel are pre-mixed. Because the flame is cooler, it doesn't produce as much nitrogen oxide, and no water injection is needed to cool the flame.

4—Oxidation catalyst systems use a catalyst material (such as platinum or palladium) to eliminate 80–90% of carbon monoxide and hydrocarbon emissions from a power plant.

5—Selective catalytic reduction reactors use a catalyst material to eliminate more than 90% of the nitrogen oxide emissions from the flue gas stream.

Hands-On Learning and Knowledge Sharing

The RICE Interest Group facilitates discussion among EPRI-member companies, vendors, dispatchers, construction companies, engine experts, and other RICE stakeholders. Topics include operations and maintenance, emissions, permitting and regulations, opportunities to reduce costs, portfolio planning, and dispatch strategies and corresponding uses for RICE. Participants are exploring how RICE's costs, emissions, and other operating characteristics compare with technologies such as gas turbines and energy storage.

The group participates in quarterly webcasts and annual site visits with in-person meetings. During a visit to South Texas Electric Cooperative's Red Gate facility—which houses twelve 18-megawatt natural-gas-fired engines—representatives from the cooperative, engine manufacturer, environmental controls vendor, and the project's engineering, procurement, and construction company were available to answer questions. "Everyone presented, and there was honesty and frankness in the discussion," said Maxson. "The members got to hear the pros and cons about the technology directly from an operator."

The group learned that RICE advantages depend on the situation and conditions. Relative to gas turbines, RICE is less sensitive to ambient conditions, requires lower natural gas pressures, and has a higher efficiency throughout its operating range. "The performance of gas turbines diminishes as the air temperature increases and as air pressure decreases," said Maxson. "Because the heat rate and power output of engines are less impacted by ambient conditions, engines may be a good option in a hot or high-altitude location."

Another insight relates to maintenance. For heavy-duty gas turbines in peaking duty, maintenance costs typically are driven by the frequency of startups and shutdowns, although aero-derivative gas turbines are much less sensitive to startup frequency. For engines, the key driver is operating hours, with significant maintenance implications. "Engines may only operate around 1,000 hours per year. The number of operating hours over the engine's 30-year life may be small enough that expensive maintenance activities like the replacement of bearings and rings, and potentially larger components like turbochargers, may never need to be done," said Maxson. "You need to look carefully at the engine's operational plan to understand its overall life-cycle costs."

During the visit to the Red Gate facility, the group learned that the operators do much of the maintenance on their own. "It was important for our members to realize that the learning curve is reasonable, and you can potentially reduce your costs by doing maintenance in-house," said Maxson.

RICE technology has a potential role in balancing intermittent renewable generation but is not always preferable to gas turbines. Details of the application matter. For example, turbines may be a better choice on smaller sites because they require less space than engines. While natural-gas-fired engines have received environmental permits in states with rigorous regulations—such as California and New York—it can be more challenging to meet environmental mandates for engines powered by diesel and other fuels.

To inform utilities as they compare RICE with gas turbines and other technologies, the RICE Interest Group is compiling RICE's advantages and disadvantages (see box on previous page).

"To determine whether RICE is a good fit, each company needs to evaluate the generation options with respect to its own unique circumstances," said Maxson. "The RICE Interest Group provides up-to-date information that our members can use in their portfolio planning to make the best decisions possible."

Future Research at EPRI

For the remainder of 2018, the RICE Interest Group will continue webinars and other meetings and identify research opportunities. The next step is to determine what new EPRI research should be done as part of existing programs. "Several research needs have already emerged," said Maxson. "We need to reduce maintenance costs with new sensors and effective maintenance strategies, better understand how to generate revenue for ancillary services, and obtain more accurate performance and cost numbers for portfolio planning. Continuing a collaborative forum to share lessons learned is also important."

According to Kern, the RICE Interest Group provided Duke Energy with valuable information on the technology and its benefits and challenges, informing the utility as it considers technologies for peaking applications. "We have gained a lot of insight on the RICE market, the manufacturers' offerings, and the development paths for power generation applications," said Kern.

Lessons from the group are informing AEP's plans for balancing a grid with more renewables. Though it's clear that RICE technology will play a role in the generation portfolio, the extent of its contribution has yet to be determined. "AEP is modeling reciprocating engines in generation planning," said AEP's Banner. "We will continue to improve our understanding of capital, operations, and maintenance costs. We're also looking at how much additional design is needed for these facilities to reduce noise, achieve desired startup times and ramp rates, and comply with emissions mandates. Reciprocating engines will play a part in balancing the grid and renewables."

Key EPRI Technical Experts

Andrew Maxson, Dale Grace

Welcome to the New World of the Interactive Energy Customer

EPRI hosted a remarkable conversation last month at our annual Summer Seminar—one in which we considered the many different trends that are changing almost every aspect of energy customers' actions and opportunities.

Compared with today's choices, the old customer model seems quaint. Deliver the power. Read the meter. Mail the check.

The entire relationship could be summarized through two basic transactions: someone delivers; someone pays.

Today's world is one of interaction. With our Summer Seminar theme of The Interactive Energy Customer, we discussed how, in the next five years, 85% of customers will manage business relationships without direct personal interaction.

Scan service options and status updates on your smartphone. Select those that serve your needs. Arrange payment via an app.

But that's just scratching the surface.

Customers now look beyond the transaction to consider aspects of the provider's energy portfolio, such as sustainability, cost, and reliability. Those who "drive electric" must locate and secure access to electrons. Those who integrate residential energy management with security and other systems will weigh cyber security. As more customers own distributed generation and energy storage, they become integral to utility operations, integrated resource planning, and long-term financial planning. Customers' thinking will turn to both production and consumption, along with the dynamic markets and price structures that will drive both.

Mike Howard, President and Chief Executive Officer, EPRI

The customer's individual energy solutions now become seamless with grid support. Grid operators and customers become mutually dependent for much more than just delivery (by one party) and payment (by the other party). Their relationship could be linked to something as individual as rooftop solar panels or widened to a community's microgrid. Customers now become integral to providing the most reliable service at the lowest cost.

The humble and familiar water heater can be used to emphasize the contrast. Traditionally utilities deliver the electricity that heats the water and then collect the revenue. The utility can then add up the water heaters served and project growth in that number over time to plan additions to its generation portfolio and secure revenues to build and operate its growing system.

What we face today are customer choices for more efficient water heating (by installing heat pumps), on-site power production and storage, dynamic pricing to shift load/production, and computer interfaces to enable much more precise and sophisticated on-site energy management. The customer, the water heater, and the utility are interacting for a variety of reasons.

There is much more calculating to be done. Customers have a lot more shopping to do, and utilities face much more complex planning and operations—that must effectively account for complex technological and financial considerations.

All these interactions will feed on and produce unprecedented data streams that will drive actions in real time and for days, months, years, and decades ahead. Everyone will have skin in the game—up to and including information technology systems and equipment manufacturers. It will go far beyond, "Have your computer talk to my computer."

With data streaming from unprecedented numbers and varieties of grid components on both sides of the meter, EPRI foresees a necessary role for artificial intelligence and the extension of smart, secure technologies to every component of the grid—including those on the customer side of the meter.

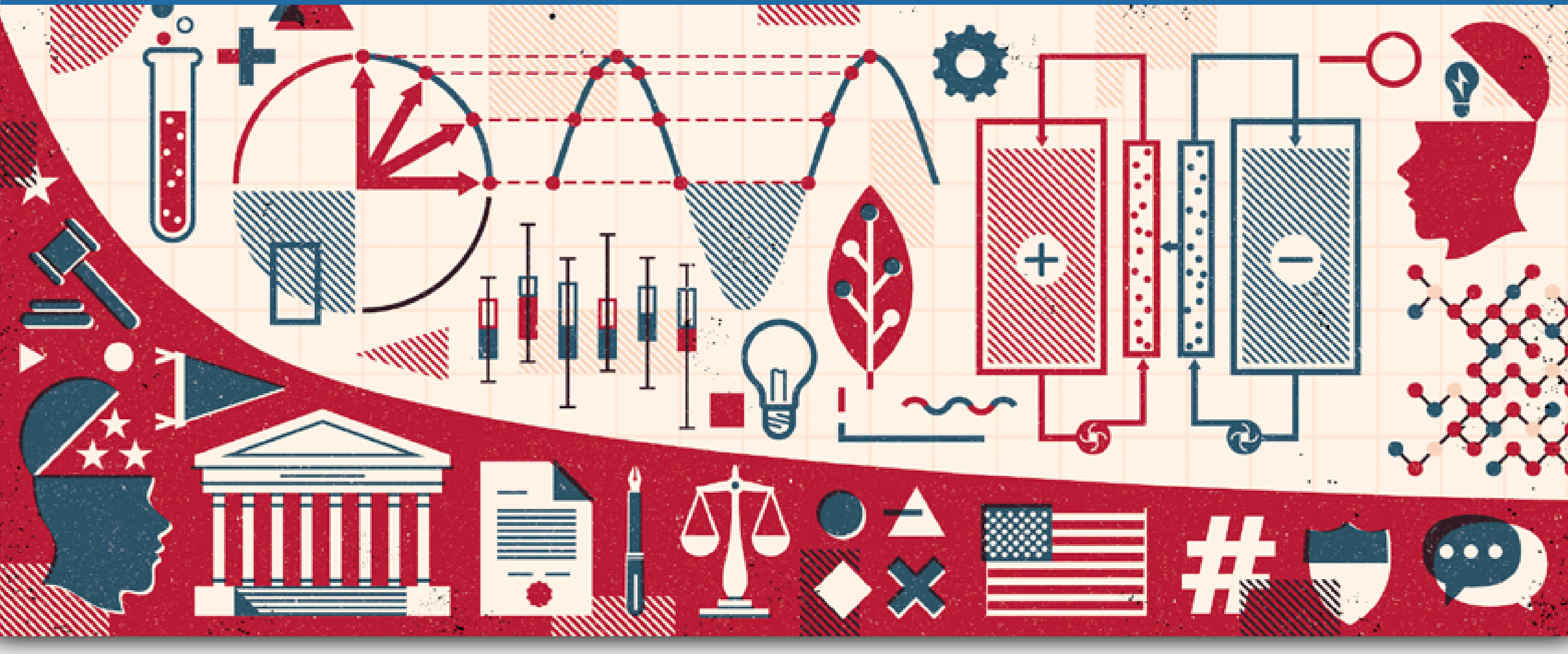
It is increasingly clear that all of this can enable unprecedented efficiency, reliability, and value to all parties involved, but the questions about how best to accomplish this will challenge everyone (on both sides of the meter) to protect privacy and keep components and systems secure.

For energy customers, EPRI often emphasizes six C's of value: choice, convenience, control, comfort, clean, and cost-effective. When we consider the accelerating changes in technology, the six C's remind us that we must continue to focus on three more C's: Keeping the customer at the center of the conversation.

President and Chief Executive Officer, EPRI

Watch a video about the interactive energy customer.

Watch a video about EPRI's shared integrated grid concept, which imagines a future when customers' energy assets become shared energy solutions that enhance grid reliability, resiliency, and value for all.



From Synchrophasors to Flow Batteries: A View Along the Learning Curve

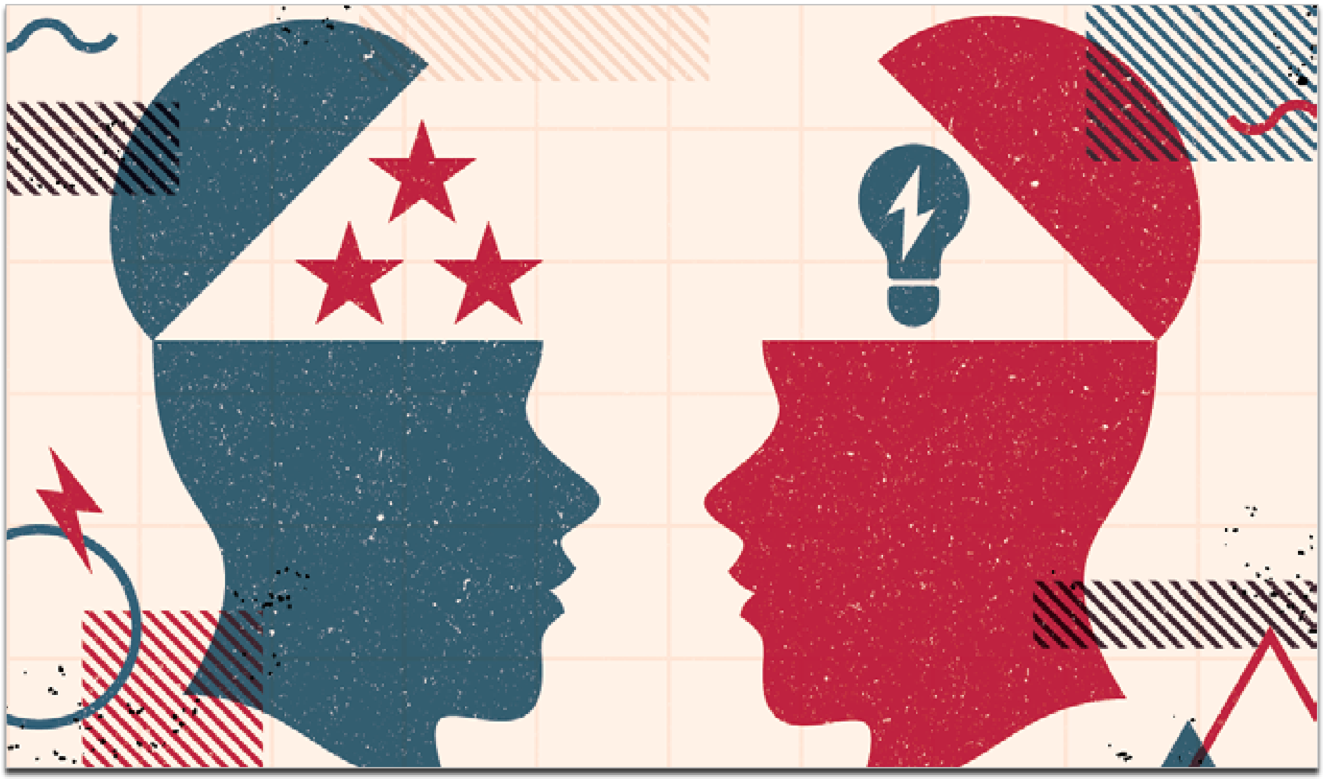
The Story In Brief

Ellen Williams is Distinguished University Professor in the Department of Physics at the University of Maryland and is a member of EPRI's Advisory Council. From 2014 to 2017, she served as director of the U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E). Williams speaks with *EPRI Journal* about technology innovation in the electric power industry—recent accomplishments, challenges ahead, and the role of entrepreneurs, power companies, and government.

Ellen Williams

EJ: What was your favorite part about being the director of ARPA-E?

Williams: People frequently say that being at ARPA-E is the best job in Washington, and I couldn't argue with that at all. It's exciting to be around so many high-powered, technical people with great ideas and great depths of understanding about the energy field. ARPA-E is also an agency that has a great sense of comradery, purpose, and urgency in empowering innovation to improve the energy system.



EJ: Looking at technology development in the electric power sector today, which potentially transformative technologies warrant greater emphasis and support?

Williams: Managing the grid for variable load presents many potentially transformative opportunities for enabling technologies—switching hardware, measurement software and hardware, demand response, energy storage, and distributed generation, to name a few. All these different components are coming together to augment the capabilities of our future grid.

In advancing technologies, we often discuss what's called the learning curve, which basically means that performance improves and costs go down as a technology is used more. As part of that learning curve, innovation, research and development, and fine-tuning of technologies play an important role. When you have a complex technological system like electric power, improvements in the many different components of the system contribute to improve the overall learning curve.

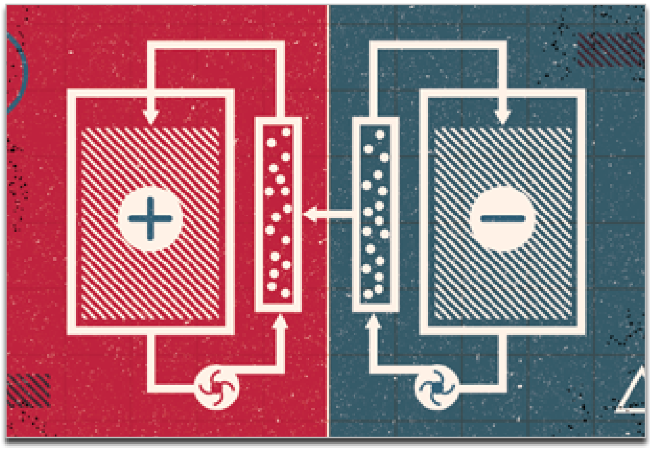
EJ: What recent technological innovations for electric power serve as models for future innovation?

Williams: The large-scale deployment of synchrophasors was a tremendous breakthrough, enabling precisely timed grid measurements of current, voltage, frequency, and phase. Now, universities, entrepreneurs, and big companies are responding to this opportunity by creating new approaches to managing the electric power grid. These include tools to analyze synchrophasor data in real-time, detect grid events, and monitor distribution feeders with high solar penetration. That's an important model for technology innovation. Once there is a new enabling capability, people will rally around in Edisonian fashion and drive innovation forward.

A second example is the development of low-cost flow batteries. These have been around for a long time as an expensive niche product. In the last 10 to 15 years, researchers have solved some fundamental technical challenges in making a flow battery work effectively—getting chemicals to interact effectively with the electrodes. Now we have many companies taking that enabling breakthrough and driving down the cost of flow batteries.

> "Because of variable demand, today's global electricity generation capacity is about two times the amount of electricity used. The future grid should improve that ratio."

"Power companies can stimulate innovation.... By clearly stating what is needed to improve their system without being prescriptive about the exact pathway to get there, utilities can create an incentive for innovators to come up with new ideas."



EJ: Over the next five years, do you expect flow batteries to be competitive with lithium ion batteries for grid applications?

Williams: There's a conundrum here. The existing lithium ion battery technology already has a large manufacturing scale and an existing infrastructure for service and components. A purchaser who's looking to put something in place right now may well choose a lithium ion battery system. Lithium ion can work for some applications on the electric power grid, but ultimately in terms of cost and performance, it won't get us where we need to be with respect to cycle life and cost for large-scale grid storage. There's no doubt in my mind that flow batteries can get us at least to the 4- to 5-hour storage time frame that we need to solve a lot of problems on the grid. But they still need demonstration and deployment time to get there. Technically, it easily could happen in 5 to 10 years, but there needs to be a first market for the product so that the learning curve can develop.

EJ: What challenges and gaps need to be addressed for momentum in innovation?

Williams: The hardest thing for a new technology is finding those first markets to generate early revenue. This is a big challenge in the power industry because electric power is an essential service. Power companies have to be very conservative about what they put in their system. They have to be sure that a new technology won't disrupt power delivery. As a result, getting a new technology into the system requires a lot of prior demonstration, so that when it goes online it's certain to be reliable and effective.

The other challenge is the regulatory complexity of the power system. Effective technical solutions can run into regulatory hurdles, and this is outside the comfort zone of most technology developers. More engagement among utilities, EPRI, other R&D organizations, policymakers, and politicians is needed so that the regulatory system can accommodate new technologies that improve grid reliability and responsiveness. There's nothing simple about this. It requires people who understand the interface of technology, policy, and regulation.

EJ: What can power companies do to facilitate innovation?

Williams: Organizations such as EPRI can provide the industry with information and support for using new technical opportunities. In addition, utilities can speed adoption of new technologies by using advanced grid modeling and simulation to characterize and demonstrate how they work. Today's advanced computation and analytics are now far more powerful than what was available even 10 years ago, so there is room for significant progress. Utilities also can identify ways to field-test grid technologies under conditions where they can control the risk and make sure their customers are well-supported.

"In preparing for a more electrified future, the electric power industry should not view the future grid as a bigger version of what it is now. We're going to need more electric power delivered at lower cost, environmental impact, and scale of generation capacity."

Power companies can stimulate innovation. Innovators will respond to a perceived challenge or opportunity. By clearly stating what is needed to improve their system without being prescriptive about the exact pathway to get there, utilities can create an incentive for innovators to come up with new ideas.

One approach could be for the electric power industry to hold prize competitions, such as XPRIZE. Given a well-defined question, it's a great way to pull innovators in and get them engaged with the problems that need to be addressed.

EJ: What are appropriate roles for government and policy?

Williams: There's an important role for government and policy at all stages of technical readiness, but especially in the very early stages and the transitional stage—when early-stage ideas are being advanced into a format that a private-sector investor would consider funding. That is a very difficult transition that government should continue to support. ARPA-E supports it and "angel investors" support it.

Often, early-stage technologies are more expensive or need time to move down the learning curve, so government can create a pull in the system—for example, a regulation that says we must have this level of energy efficiency or we must have this much energy storage. Effective government policy would enable the significant capital investments needed for modernizing the electric power system.

Government policy is also required in dealing with externalities such as climate change. In modernizing the electric power system, good policy can facilitate a power system that is as clean as possible now and capable of becoming as clean as we need it to be in the future.

EJ: How should the electric power industry prepare for a more electrified future?

Williams: In preparing for a more electrified future, the electric power industry should not view the future grid as a bigger version of what it is now. We're going to need more electric power delivered at lower cost, environmental impact, and scale of generation capacity.

The issue of capacity is quite interesting. Because of variable demand, today's global electricity generation capacity is about two times the amount of electricity used. The future grid should improve that ratio. The future grid may produce and deliver a lot more electricity, but it needn't scale up the amount of transmission and distribution by a proportional amount. Advances in technologies for grid management, energy storage, distributed generation, and demand response will help address this goal.

EJ: What's the system going to look like 15 years from now?

Williams: I can't predict the future, so I'll tell you what I'd *like* the electric power system to look like 15 years from now. There will be a lot more demand for electricity as we electrify a lot more things in our society, including vehicles and industrial processes. It will deliver more electricity, but by integrating many different types of power sources, it will have much lower carbon emissions. It will operate in a more distributed fashion and provide customers with much more choice in how they obtain and use electrical power.

Powering a Sprouting Industry

Indoor Agriculture May Offer an Efficient Solution for Future Global Food Needs

By Chris Warren

An indoor agriculture facility.

In the foreseeable future, farming may move indoors.

Agriculture's traditional reliance on more acreage for more products may not be adequate for much longer. By 2050, the United Nations estimates that the global population will reach 9.8 billion—up from 7.6 billion in 2017. Providing food for the additional 2.2 billion people could strain natural resources. According to the World Bank, agriculture uses 70% of freshwater resources in most of the regions of the world, and a University of Sheffield study reports that available land suitable for growing crops has decreased by 30% over the past 40 years. The drive to increase production per acre has made the use of fertilizers, pesticides, and herbicides in field agriculture a growing contributor to freshwater contamination.

The emerging indoor agriculture industry uses electric lighting to augment natural light or provide all light necessary for crop growth. Greenhouses, old warehouses, shipping containers, new construction, and other indoor facilities are typically equipped with lighting; heating, ventilation, and air conditioning (HVAC) equipment; electric pumps; and building controls. Through recycling they reduce water use and discharge. They eliminate fossil-fuel-powered farm equipment and reduce the risk of polluting rivers, streams, lakes, and oceans from fertilizer and pesticide runoff. Their controlled environments also can help prevent plant diseases. Most indoor facilities grow vegetables and fruits in coconut husks, cloth, or other growth media, reducing or eliminating the use of soil.

Field-grown lettuce can travel hundreds or even thousands of miles from farm to table. Indoor farms close to consumers in or near urban centers reduce fossil fuel emissions for transport, potentially increasing freshness and shelf life. "If lettuce is picked the day before you buy it, it can taste fresher, have a longer shelf life, and is less likely to be thrown out," said EPRI Senior Technical Leader Frank Sharp, who leads EPRI research on indoor agriculture and its implications for the electric power industry.

Some countries have already scaled up indoor agriculture. Although The Netherlands is only 41,543 square kilometers compared with the United States' 9,833,517 square kilometers, it is the world's second-largest food exporter, driven by its advanced greenhouse industry. After the Fukushima-Daiichi nuclear accident contaminated significant farmland, Japan aggressively repurposed factories and warehouses as indoor farms. EPRI estimates that in the United States today, there are fewer than 50 vertical farms greater than 10,000 square feet. This number is expected to increase significantly in the near future.

Cultivating U.S. Indoor Farming

Different plants grow best when exposed to specific light spectra, including non-visible spectra. Since 2012, EPRI has been examining aspects of horticultural lighting technologies, such as spectral output, potential effectiveness at enabling crop growth, and energy consumption.

"In recent years, we have measured visible and non-visible spectra of lights potentially used in indoor agriculture, including high-intensity discharge, induction, light-emitting plasma, LED, and fluorescent. We have gained insights on how certain light sources may impact plant production," said Sharp. "Plants need ultraviolet and infrared light, though the optimal lighting requirements vary from one plant species to another."

Indoor farms may have large electric loads such as lighting, pumps, heating, cooling, environmental sensors and controls, and (potentially in the future) crop-picking robots. EPRI is examining how utilities can engage effectively with these facilities, municipalities, and local organizations to support indoor farming operations.

"EPRI is working to inform utilities on how best to work with farms, communities, economic development agencies, and other stakeholders on issues such as siting, grid impacts, load profiles, and grid infrastructure," said Sharp. "Utilities need to understand the scale and power consumption of indoor agriculture. In some cases, there may be a need to build new substations or other grid infrastructure, or there may be an opportunity to convert an inactive industrial site to an indoor farm because it already has the necessary infrastructure."

A recent EPRI study on indoor agriculture examined crop yields, sustainability, energy and water consumption, the economics of various fruits and vegetables, and potential opportunities for load shifting. "For indoor farms today, it can make economic sense to grow leafy greens, strawberries, herbs, tomatoes, and other high-value crops that can be stacked or grown vertically and that have a short shelf life," said Sharp. "Though corn, wheat, and other row crops can be grown indoors, it is not economically viable to do so today because they have a low price per pound, have a long shelf life, and their production cannot be easily stacked."

According to Sharp, both indoor and outdoor agriculture are essential to future food production. "The model that appears to be developing is indoor cultivation of high-value, short-shelf-life crops and outdoor cultivation of low-price-per-pound, long-shelf-life crops," he said. "This is likely to continue for the foreseeable future."

New EPRI White Paper

Indoor Agriculture: A Utility, Water, Sustainability, Technology and Market Overview

Recently, EPRI launched a project to gather energy data on U.S. indoor agriculture facilities. Through site audits and smart meter monitoring, researchers plan to evaluate how energy loads, water use, and sustainability vary across different crops, facilities, and locations.

Another new EPRI project will evaluate how climate affects indoor farms' energy consumption, water use, sustainability, temperature and humidity, and other key operational parameters. "On most days, an Eastern Tennessee indoor farm will operate differently from one in the Southwest, as a result of different climates. However, in a given year, both climates bring to bear high- and low-temperature days and high- and low-humidity days," said Sharp. "By collecting data from farms throughout the United States, this study will help utilities understand how daily differences in outdoor temperature and humidity affect farm operations. This can help utilities to forecast load and assess the potential for load flexibility."

This research also will examine the facilities' incoming and outgoing water and carbon dioxide (CO_2) levels. "To drive higher yields, many farms maintain higher-than-normal CO_2 levels by burning propane or using bottled CO_2," said Sharp. "If the outside air is already high in CO_2, they may need to produce or purchase less CO_2 for the farm, which means lower costs."

Indoor farms offer significant potential to reduce agricultural water use, benefiting society and the environment. "Water is going to be a key driver in future discussions about energy and sustainability in many communities around the world," said Sharp. "Indoor agriculture offers a tool that can enable communities and society to use water more effectively and efficiently."

Short term, Sharp expects continued growth in the indoor agriculture industry. Long term, he sees potential for indoor agriculture to augment outdoor production of fresh produce and help feed growing populations.

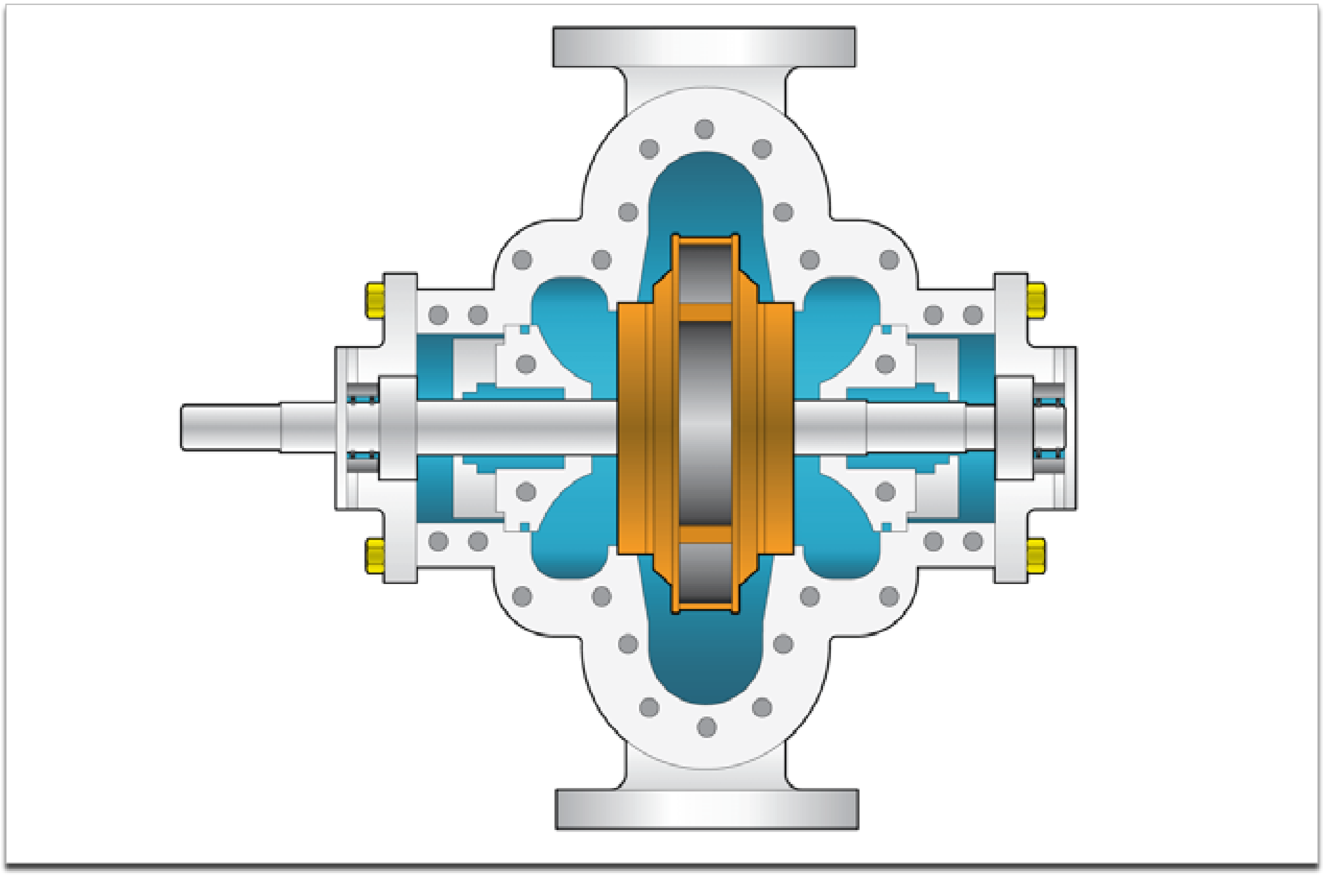
"Our role is to provide objective analysis," said Sharp. "We are informing utilities about various aspects and potential impacts of indoor agriculture, enabling them to partner effectively with this growing industry."

Key EPRI Technical Experts

Frank Sharp

EPRI Quick Guides Drive Smarter Maintenance in Nuclear Plants

By Brent Barker



One of EPRI's new Quick Guides focuses on the horizontal pump.

For decades, scheduled preventive maintenance—such as changing filters every 3 months or replacing pumps every 10 years—has been the mainstay of nuclear plant maintenance. Advances in specialized sensors and data analytics are driving a new form of monitoring and maintenance to the forefront.

"Continuous online monitoring can transform a utility's maintenance program from calendar-based to condition-based without increasing risk," said EPRI Principal Technical Leader Mike Taylor. "The condition-based approach takes the data from the instruments on your equipment and looks for anomalies and patterns. A hot spot on a motor rotor might suggest a bearing alignment problem. A reduction in a cooling system's performance might suggest fouling. A particular pattern in the data might indicate an impending failure. Inspection and maintenance are driven by insights, not the calendar."

Condition-based maintenance can help reduce labor costs, eliminate or extend the intervals of preventive maintenance, identify equipment problems early, and extend the life of plant assets.

Taylor is leading an effort to develop a series of "Quick Guides" that outline precise procedures for utilities to implement continuous online monitoring. Each guide is 6–10 pages and describes the suite of sensors and analytical methods that can reduce the number of manual, scheduled maintenance tasks for a component. A technical basis document accompanies each guide.

In March, EPRI published the first four Quick Guides—two on common pumps and two on common motors. Six more are to be published later in 2018. "We have another 31 planned," said Taylor. "For digital access, we expect to include the guides in our Preventive Maintenance Basis Database."

EPRI's Common Design Packages

Over the past few years, a nuclear industry collaboration called the Design Oversight Working Group has engineered guidelines to streamline the design of equipment installation. "All nuclear utilities across the U.S. are now using the same design process for installing new equipment," said EPRI Principal Technical Leader Mike Taylor.

EPRI has engineered design packages for the installation of distributed antenna systems and wireless vibration sensors, which can support communications and automated, real-time monitoring of equipment in nuclear plants.

"EPRI has done all the engineering work for these packages. The utility only needs to fill in plant-specific information to complete the engineering change package. Utilities can avoid performing the same evaluation for specific sensors and infrastructure, saving them time and money," said Taylor.

The development process has been exacting. "No fewer than 40 people have put their eyes on each document," said Taylor. "Reviewers included EPRI staff, utilities, and industry experts in vibration analysis, motors, and pumps."

The rollout has been highly anticipated. "Utilities had been asking for something like this for a long time," said Taylor. "As development progressed, the drafts were widely circulated so that many people in the industry were familiar with the approach. On the day of release, we had 50 downloads for each of the four guides. That represents about half the nuclear plants in the U.S. The guides are catching on swiftly."

One utility went further and asked EPRI to help develop 15 Quick Guides to address new pieces of equipment at a particular plant. "It will take us about 6 months to develop them, and we intend to share the generic information with other plants in the Quick Guide format," said Taylor.

Each Quick Guide evaluates every degradation mechanism specific to a component and, when possible, recommends a combination of sensors, monitoring, and analysis methods to address the mechanism. The guides do not eliminate all scheduled preventive maintenance tasks, but continuous online monitoring may extend inspection intervals.

"EPRI Quick Guides deliver concise knowledge of the required sensors to install on plant equipment for remote performance monitoring," said Howard Nudi, program manager for Duke Energy's Monitoring & Diagnostics Center. "This monitoring capability is the enabler for new condition-based maintenance strategies that can provide significant savings in the future."

At the heart of each Quick Guide is a preventive maintenance task assessment table, describing the methods applicable to each task and resulting in one of the following outcomes:

- Replace task completely with continuous online monitoring.
- Couple task with continuous online monitoring, and evaluate the potential to extend the interval between inspections.
- No change in task.

A limited number of preventive maintenance tasks are likely to remain in cases for which a human inspector is necessary to detect degradation, such as a cracked weld resulting from a manufacturing defect.

Key EPRI Technical Experts

Mike Taylor

New EPRI Tool Demystifies the Value of Energy Storage

By Cassandra Sweet

Southern California Edison's Mira Loma Battery Storage Project can store up to 80 megawatt-hours of electricity. Photo courtesy of Ernesto Sanchez/Southern California Edison.

Energy storage is emerging as the latest "killer app" for utilities, grid operators, and renewable energy generators. But identifying and valuing the technology's capabilities have proven challenging—until recently.

Enter EPRI's Storage Value Estimation Tool, or StorageVET®. This new web-based software models the value of services that storage projects can provide to the grid and utility customers. Services include infrastructure investment deferral, peak system load management, frequency regulation, energy price arbitrage, customer demand-charge management, backup power, and many others. The tool can be applied internationally.

EPRI released the first versions of StorageVET in 2013 and 2014 in its research programs, with access to funders and subsequent purchasers. With funding support from the California Energy Commission, EPRI in 2017 launched a publicly available version that can be used by regulators, storage developers, utilities, and other industry stakeholders.

StorageVET can be used to investigate storage projects for all applications (including solar-plus-storage) and sizes, from residential to bulk-scale. It can compare the costs and benefits of storage projects with those of conventional technologies, such as natural gas power plants and grid infrastructure upgrades. While conventional options often cost less than storage today, in certain situations storage may be economically attractive—particularly when factoring in the potential for multiple services. For example, a recent StorageVET analysis by EPRI found that a megawatt-scale battery storage system in a California urban area could be cost-effective for deferring a high-cost substation upgrade.

"An effective way to value energy storage opens new opportunities for utilities and their customers," said Ben Kaun, program manager in EPRI's Energy Storage and Distributed Generation program. "The conversation has been, 'What is the cost of energy storage versus the cost of a new transformer?' StorageVET is providing the power industry, regulators, and policy makers with deeper insights on the cost and benefits of storage."

Policy and Market Drivers

Recent policy changes have led to utilities' growing interest in the tool. In February, the Federal Energy Regulatory Commission's Order 841 directed the removal of barriers to participation by energy storage resources in bulk power markets. Historically, storage has been required to play by market rules designed for conventional generators.

Growing markets also are driving interest. U.S. developers installed 431 megawatt-hours of energy storage systems in 2017, up 27% from the previous year, according to a March report by the Energy Storage Association and GTM Research. (The same organizations reported a cumulative U.S storage deployment of about 1,000 megawatt-hours as of 2017.) Storage system prices fell 10%, to a median value of $1,538 per kilowatt. The U.S. Energy Information Administration reports average capital costs of $1,100 per kilowatt for an advanced combined-cycle natural-gas plant.

Many of the nation's large storage facilities are in California, where policies require utilities to use storage for smoothing the flow of electrons on the grid as more intermittent solar and wind power generation is deployed. By 2020, California's three investor-owned utilities are required to procure at least 1,325 megawatts of storage, plus 500 megawatts connected by customers. To help utilities and storage developers navigate the new obligations, the California Energy Commission, California Public Utilities Commission, and California Independent System Operator created an Energy Storage Roadmap for reducing costs and streamlining policies.

Energy Storage Integration Council

The EPRI-led Energy Storage Integration Council is an open, technical forum for utilities, energy storage suppliers, research organizations, and other stakeholders to advance safe, reliable, and cost-effective energy storage. The Council has published a series of guidelines on storage and has been instrumental in the development of StorageVET. The Council's next meeting is October 18, 2018 in Charlotte after the Energy Storage STUDIO conference.

Digging into the Details

EPRI is working with utilities in California and other states on StorageVET simulations. The aim is to provide insights on whether storage can compete with conventional technologies and to inform project specifications and evaluation of storage options. Utilities across North America, such as AVANGRID in the Northeast and Los Angeles Department of Water and Power, are participating in a collaborative EPRI project to evaluate various locations for storage deployment, quantify costs and benefits, and improve methods for incorporating storage into distribution planning.

To demonstrate StorageVET's capabilities, EPRI compared the economics of building a battery storage facility and a natural-gas-fired peaker plant in southern California. One finding: With relatively low upfront capital costs ($1,600 per kilowatt), storage could provide more value over several years than a peaker with capital costs of $1,300 per kilowatt. (Costs are higher in California for conventional natural gas plants relative to the U.S. average.) The value was derived from various grid services that storage can provide, such as frequency regulation and spinning reserves.

According to Kaun, the results of StorageVET analyses depend on numerous factors, including location and power prices. "As battery prices and installation costs continue to fall, storage projects are likely to become more competitive," he said. "Because the future value of energy storage is uncertain, it is important to evaluate a range of scenarios for robust outcomes."

For Southern California Edison (SCE), storage projects that address multiple grid needs—such as deferring the need to add costly distribution infrastructure and helping a natural gas plant operate more flexibly—tend to be more cost-effective and are more likely to be selected than projects not providing those benefits, a spokesman said. More than 2,000 megawatts of natural-gas-fired power plants are scheduled to be retired in a region of SCE's service area between Santa Barbara and Los Angeles Counties. In the past few years, SCE has procured most of the replacement capacity it needs with various resources, including storage.

With a $2 million grant from the California Energy Commission, EPRI plans to build a tool—similar to StorageVET—for evaluating the costs and benefits of all distributed energy resources. These resources include systems that integrate solar, storage, electric vehicle charging, demand response, and even microgrids.

Energy Storage Beyond California

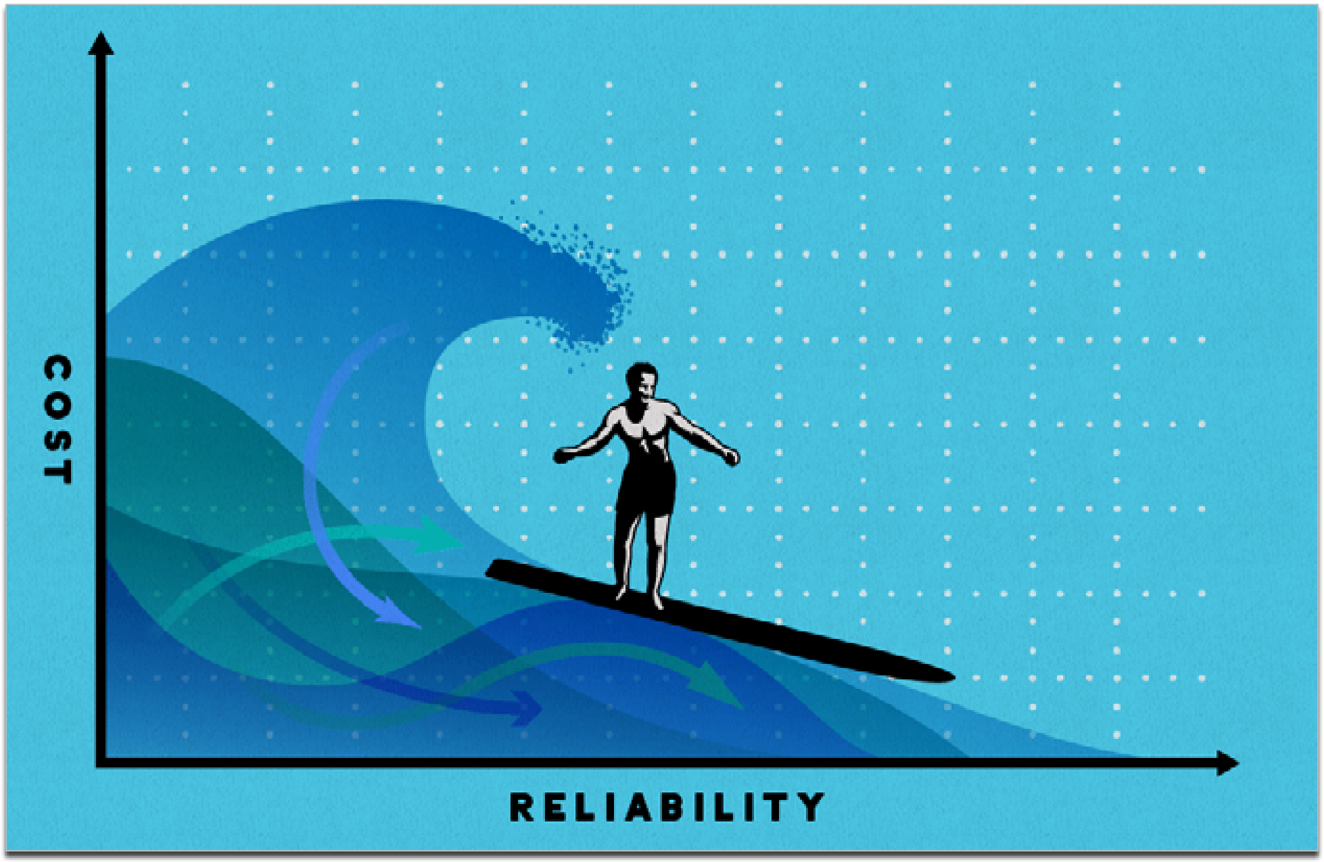
While California has been an early adopter of energy storage technology, other states and countries are pursuing significant deployments as well. For example, New York state recently issued a roadmap to achieve a target of 1500 megawatts of energy storage by 2025. The European Union's Bridge Horizon 2020 initiative is sharing lessons among storage demonstration projects. In 2017, Tesla completed a 100-megawatt storage system—one of the world's largest—in South Australia.

Key EPRI Technical Experts

Mike Taylor

A Win-Win for Grid Operators and Customers

EPRI Develops Better Methods for Calculating Reserves



Grid operational changes that improve reliability typically increase costs. An EPRI study of Hawaii's Oahu grid reveals that grid operators can have their cake and eat it too: More robust methods for quantifying the necessary capacity of operating reserves can increase reliability and reduce costs.

Increasingly, operators rely on reserves to accommodate intermittent renewable energy generation. The challenge is to determine the optimal reserve capacity needed based on anticipated conditions. Too much can be costly, and too little can make the system less reliable. Many of today's methods for calculating reserve capacity are "static" and do not adequately account for changing system conditions. Consider this simple example: At night when there is no solar generation, operators do not need reserve to account for a potential decrease in solar output.

EPRI identified potential enhancements in the methods used by Hawaiian Electric to determine reserve for Oahu. Researchers proposed new dynamic methods that can calculate real-time reserve needs based on historical system variability and uncertainty, then guide the on/off cycling of power plants throughout the day (rather than run them 24 hours a day). Simulations demonstrated that the methods can improve reliability by reducing the risk of being short on capacity during contingency events. Simulations also showed that the more efficient use of reserves could save Hawaiian Electric more than $21 million annually, given Oahu's high penetration of renewables. The utility is planning to test EPRI's methods in its grid operations.

EPRI has developed software (called *Dynamic Assessment and Determination of Operating Reserves, or DynADOR*) that grid operators can use to calculate reserves, incorporating the advanced methods demonstrated in the Hawaii study. Other utilities are evaluating the use of these methods for operations and for planning studies as they prepare for increasing penetration of renewables.

Key EPRI Technical Experts

Erik Ela

Electricity Demand from Bitcoin Miners: Gigawatts or Not?

There is significant uncertainty in quantifying energy use by bitcoin mining, according to an EPRI Quick Insights paper.

Bitcoin digital currency is released into circulation through "mining." As with other digital currencies, bitcoin is backed by blockchain technology, which uses cryptography to verify transactions and add them to the public record. To do this, a "miner" must solve a complex mathematical puzzle, which requires powerful computer hardware and significant electricity consumption. Successful miners receive a financial reward. As the value of bitcoin has skyrocketed since late 2017, so has the number of miners—and the difficulty of the puzzles.

Absent a central bitcoin authority, it's difficult to determine miners' aggregate electricity consumption. Digital currency researcher Marc Bevand estimates global demand at 1 to 3 gigawatts, less than 0.1% of global generating capacity. Predicting long-term demand growth is difficult given bitcoin's price volatility and continual changes in mining hardware.

According to the Cambridge Centre for Alternative Finance, most mining operations have been in China. However, recent reports indicate expanding operations in parts of North America that have low electricity prices. In considering the potential for stranded grid assets, utilities engaged in long-term planning have grappled with how to accommodate the industry.

"With so much uncertainty in the longevity of this market, utilities may best consider these customers cautiously," the report says. "Yet given the high load factor of these facilities, some utilities might consider them very attractive customers, if only for a limited time."

EPRI Testifies in Washington on Blockchain

On August 21, EPRI Technology Innovation Program Manager Tom Golden testified in front of the U.S. Senate Energy and Natural Resources Committee on the energy efficiency of blockchain and the cyber security implications of blockchain for energy industry applications. Golden pointed to EPRI's Utility Blockchain Interest Group, which provides blockchain information to nearly 40 energy companies. He also discussed EPRI's work to develop a blockchain-based energy market simulator.

Key EPRI Technical Experts

Micah Sweeney, Gerald Gray

How to Plan for the Integrated Grid

Significant changes in traditional electric company resource planning are needed to enable the industry's ongoing transformation, according to an EPRI white paper.

With growing renewable energy and distributed energy resources, multidirectional power flow, increasing customer choice and control, and other significant changes, electric companies' long-term resource planning tools, methods, and processes may no longer be adequate for sustaining and updating a modern power system.

According to the paper, planners face growing challenges related to grid modeling (such as understanding the reliability impacts of solar and wind), integrating forecasts (such as those for load, deployment of distributed resources, renewable energy production, natural gas prices, and customer behavior), and expanding stakeholder engagement. While the objective of today's planning is primarily meeting peak demand, future objectives must expand to include providing adequate energy and capacity at all hours, balancing various energy resources with continuously changing loads, and supporting the system's flexibility, resiliency, and sustainability. There will need to be more coordination among generation, transmission, and distribution system planners and among the electricity, water, natural gas, and transportation sectors.

Drawing from ongoing work in numerous EPRI programs, researchers are developing a framework to inform planning for a more integrated energy network. Research plans include technical workshops and case studies on how companies are addressing these planning challenges.

Key EPRI Technical Experts

Adam Diamant

A New Home on the Prairie for Birds, Bees, and Butterflies

Prairie species planted on a right-of-way in the service territory of American Electric Power.
Photo courtesy of Shana Byrd, The Dawes Arboretum.

In field tests in Ohio, EPRI, American Electric Power (AEP), and the Dawes Arboretum demonstrated the establishment of biodiverse prairie habitat along a transmission right-of-way.

To maintain reliability along power line corridors, utilities must plant and manage vegetation, control erosion, and trim or remove trees that encroach on grid equipment. Typically, corridors are dominated by non-native grasses and weedy species, which offer poor habitat for native wildlife and require regular tree removal, mowing, and herbicide treatments.

Native prairie grasses and flowers offer a much lower maintenance alternative for some regions with the potential to inhibit tree growth, control erosion, tolerate drought, and increase biodiversity. While native grass seeds generally cost more, they require no fertilizer, reducing overall costs. Establishing native prairie vegetation can yield savings over time by reducing the need for herbicides and mowing.

In the spring of 2017, AEP and EPRI planted native prairie species in six test plots along a transmission right-of-way through forest and farmland. Vegetation successfully established within four weeks. In the first year of monitoring, researchers observed no erosion and documented rich biodiversity: 21 bird species, 9 bee species, and 9 butterfly species. Over the next few years, they will monitor various aspects of the plots, including habitat quality, erosion control, species longevity, and tree growth. Reduced herbicide treatments could yield up to 50% savings in vegetation management costs over 20 years.

Key EPRI Technical Experts

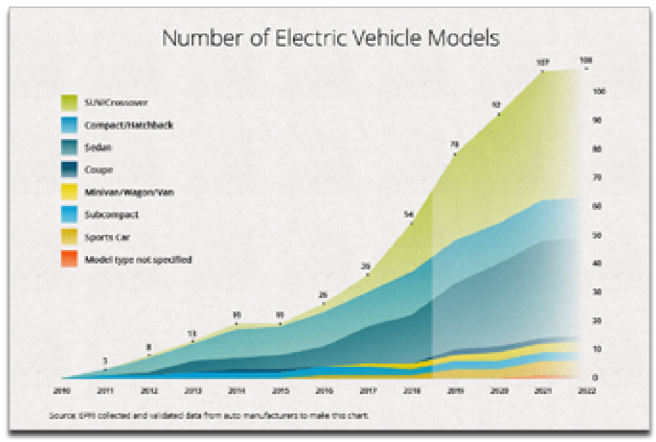
John Acklen

Electric Vehicle Market Revs Up

Across the board, market indicators for electric vehicles (EV) are up sharply, according to EPRI's quarterly market update. Key takeaways based on data from utilities, auto manufacturers, and research firm IHS:

- U.S. EV sales in the fourth quarter of 2017 totaled 55,400—up from 30,600 in the fourth quarter of 2014.
- 31 North American utilities are proposing EV charging projects worth $3.6 billion, including charging stations, supporting infrastructure, demonstrations, and customer education.
- 0 EV models are available, up from 18 models in 2014; 108 models are expected by 2022 (see chart at right).
- The average range of battery EVs available is 192 miles—up from 103 miles in 2014. By 2022, the average range is expected to be 249 miles.

"By 2022, more than 100 plug-in EV models are expected to be available in dealerships across the U.S.," said EPRI Program Manager Dan Bowermaster. "Mirroring customer demand, nearly one-third of them will be sport utility vehicles or crossovers. In addition, power levels of charging station infrastructure for light duty and larger EVs are increasing to more than 350 kilowatts. Electric transit and school buses are being demonstrated across North America, and utility customers big and small are doing pilot projects involving EVs, such as taxis, delivery vehicles, and garbage trucks."



International EV markets are growing rapidly as well. Britain, France, Norway, India, and many other countries have announced aggressive EV sales targets. China's EV market is booming. In July, Toyota announced that it will provide a fleet of 3,000 EVs for use at the 2020 Olympics in Tokyo. According to the International Energy Agency, global EV sales in 2017 surpassed 1 million, increasing the worldwide stock of EVs to more than 3 million.

Key EPRI Technical Experts

Dan Bowermaster

ELECTRIC POWER
RESEARCH INSTITUTE

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

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