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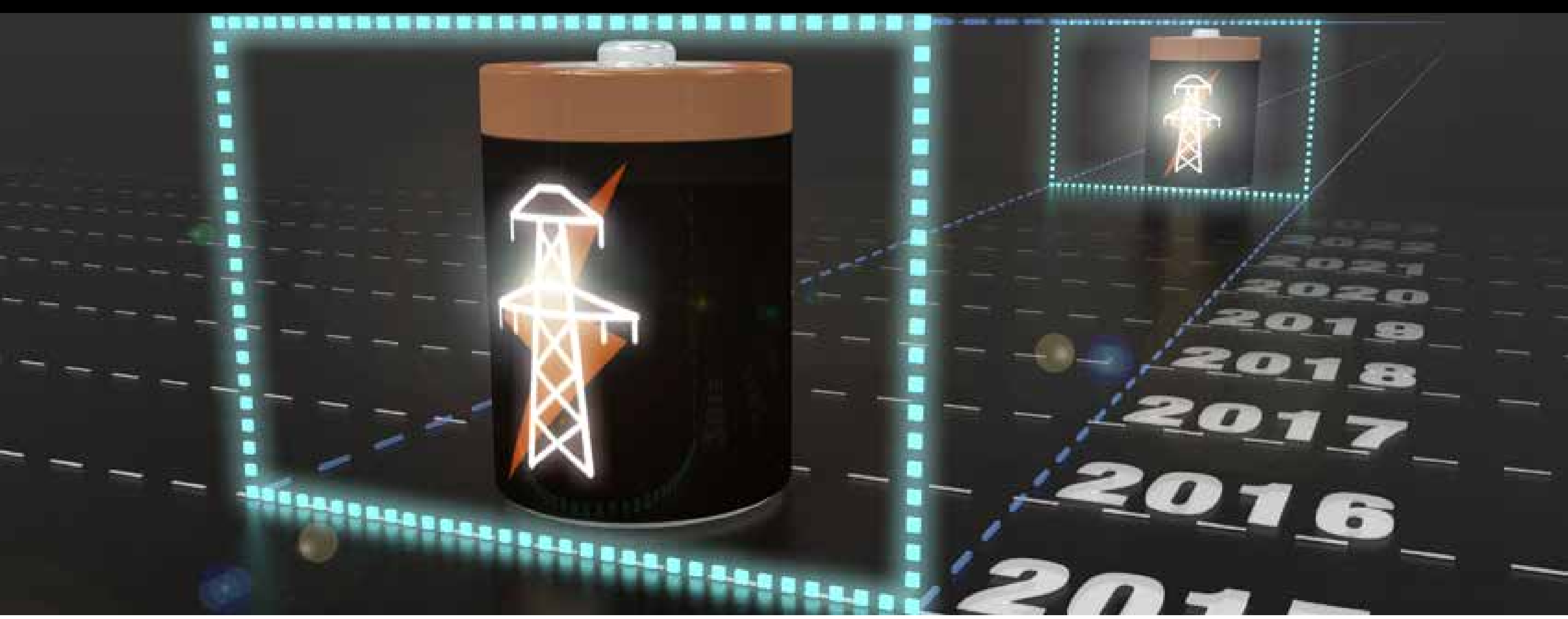
A REALITY CHECK ON ENERGY STORAGE



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Viewpoint—Threat or Opportunity? Managing Risk Through R&D

Mike Howard, President and Chief Executive Officer, EPRI

The June 2012 edition of *Harvard Business Review* featured an article by Robert Kaplan and Annette Mikes titled, "Managing Risk—A New Framework." In that article, they wrote, "Managing risk is very different from managing strategy. Risk management focuses on the negative—threats and failures rather than opportunities and successes. It runs exactly counter to the 'can do' culture most leadership teams try to foster when implementing strategy. And many leaders have a tendency to discount the future; they're reluctant to spend time and money now to avoid an uncertain future problem that might occur down the road, on someone else's watch."

From my perspective, research and development (R&D) uniquely bridges "threats and failures" and "opportunities and successes." I believe strongly in the proposition that R&D represents some of the best can-do thinking in business today, even as we acknowledge that the results and successes of our work can never be a foregone conclusion.

To Kaplan and Mikes' point that leaders can discount the future and avoid uncertain problems, I am pleased to respond that at EPRI we work closely with leaders who demonstrate both a keen interest in the future and a commitment to addressing problems, even with all the uncertainties in both.

EPRI Journal is beginning a series of articles that look at how R&D is integral to managing risk in the electric power industry. The stories will report on specific cases of risk management and illustrate common themes: the certainty of uncertainty; the fraternal (in contrast to identical) twins of threat and opportunity; the potential failure of everything from a working hypothesis to a proposed technological solution.

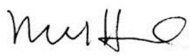
At EPRI, we always view R&D as an opportunity. It is the thread through all our work—the opportunity to learn, explore, experiment, collaborate, and ultimately succeed—to answer fundamental questions and solve important problems.

Read the story that describes how Great River Energy started with a used culvert and propane heaters to develop an innovative technology to reduce emissions from lignite-fueled power generation. This turned out to be a more cost-effective approach than installing expensive new scrubbers at the company's Coal Creek Station—and one that exceeded expectations for emissions reductions. The patented technology is now commercially viable and poised for adoption anywhere in the world where lignite is abundant and available to fuel the grid. EPRI is proud of Great River Energy's initiative and innovation, and we are grateful for the opportunity to work closely with them and contribute to their success. In this story we see the elements of successful risk management—identifying the risks to the company's generation portfolio, costs, customers, and to society as a whole, and then addressing them head on. It's a long but satisfying journey from hypothesis to solution, and our traveling companions always include success and failure.

In the second article of the series, *EPRI Journal* reports on how We Energies turned a by-product from power generation into a promising environmental solution and source of revenue. For years, the risks associated with fly ash have received broad attention from the public, regulators, and scientists. In the case of We Energies, EPRI contributed to a solution that may pave the road to effective risk management with a new kind of asphalt—one that includes fly ash.

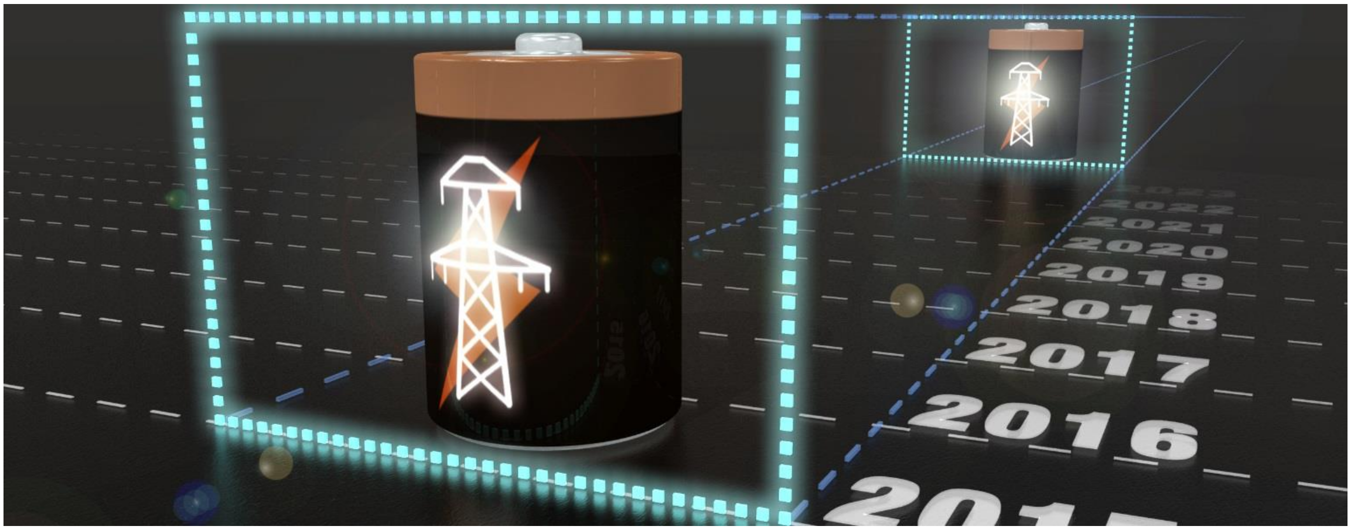
Discussions of R&D occasionally focus on whether it is an expenditure or an investment. That is not unlike looking at a risk to determine if it represents threat or opportunity. For us at EPRI, we join with others in drawing our motivation from the risks, while seeking the opportunities embedded in them.

Mike Howard



President and Chief Executive Officer, EPRI

Feature—A Reality Check on Energy Storage



Widespread Grid Storage Is Coming, But Not as Fast as Many Think

By Garrett Hering

The eager anticipation at a recent solar energy trade fair in San Francisco felt familiar, reflecting an emerging technology seemingly on the verge of a major commercial breakthrough. But instead of solar photovoltaics (PV), it was electrical energy storage that stole the show at this year's Intersolar North America.

Haresh Kamath, EPRI's program manager for energy storage

The battery buzz was palpable in standing-room-only presentations featuring bullish views on market prospects, game-changing chemistries, and electricity sector disruption. Sprawled across a bustling exhibition hall, vendors showcased new products, partnerships, and investments. Ambitious technologists tantalized participants with bold predictions, often blurring the lines between hype and hope, vision and spin.

"There's going to be much faster growth of grid energy storage than most people expect," Tesla Motors Chief Technology Officer and co-founder JB Straubel told a packed auditorium in his keynote address. "Batteries are going to win the day."

Relying on the same lithium ion technology at the heart of its electric vehicles, the California electric carmaker is ramping up its new battery venture for residences and businesses. "We don't just want to make cars electric," said Straubel. "We need to link electric cars back to where energy comes from."

Straubel predicted that as most ground vehicles move "toward battery electric," the collective fleet of electric vehicles "will integrate with growing renewables on the grid to allow 100-percent non-carbon energy for electricity and transportation." Straubel said he is certain that an "amazing tipping point" will occur when battery-backed PV systems become "cheaper than fossil energy," though he did not pin a date on this prediction.

Hype Meets Reality

Not everyone agrees that such a tipping point is imminent.

“Batteries have a lot of potential, but are not yet ready in the way many people think they are,” said Haresh Kamath, EPRI’s program manager for energy storage. “We believe energy storage will bring vast, sweeping change, but the timeframe will be longer than the next two to three years. We will see a more subtle transition, leading to a substantially different grid in 10 to 15 years.”

Some technology developers share this measured view. “We are seeing a shift similar to what we saw in solar PV several years ago,” said Kevin Fok, senior project manager at LG Chem Power, a subsidiary of South Korean lithium ion battery manufacturer LG Chem. “In terms of product maturity, services, bankability, and an increase in commercial contracts, batteries definitely have crossed a threshold in the past year or two. But we still need some combination of cost reduction, manufacturing expansion, higher power density, and enhanced product durability and safety.”

Market data reflect the nascent stage of electrical energy storage. According to the U.S. Department of Energy’s Global Energy Storage Database, only 188 grid-tied electrochemical and electromechanical storage projects were operating nationwide as of September, totaling 462 megawatts. That is equal to less than 0.04% of the country’s total installed generating capacity. By comparison, pumped hydroelectric storage, by far the most established form of electricity storage, accounts for more than 20,000 megawatts.

According to Kamath, much work remains in various technical areas before substantial market growth for non-hydropower-based storage can occur. “The real issues in the near term are establishing product reliability and determining which services energy storage can provide,” he said. “There are still many gaps in these and other areas right now. Until these gaps are addressed, storage is still something of a niche product.”

Battery Believers

To be sure, electrochemical storage is growing quickly in a few regions. The German market for small-scale battery storage systems jumped after the Federal Ministry of Economic Affairs and development bank KfW started offering incentives in 2013. In August, German solar association BSW estimated that the country has nearly 25,000 battery-coupled, on-grid PV systems.

Numerous analysts expect the United States to emerge as one of the strongest markets, beginning this year. GTM Research forecasts 220 megawatts of battery storage additions in 2015, with utility, residential, and commercial and industrial capacity more than doubling compared to 2014. By 2019, the annual market could grow to 858 megawatts, according to GTM, fueled by high electric rates and regulations in California, New York, Hawaii, and other states.

EPRI’s Kamath also expects robust growth for energy storage, but with a caveat. “Projecting exponential growth rates doesn’t mean much when the market is so small right now,” he said. “A significant percentage of the systems that are bought today are experimental systems purchased by early adopters, and market projections on the basis of those purchases must be taken with a grain of salt. There’s still a lot of uncertainty about just how storage systems will be used in the future, and that affects our certainty about how big the market will be.”

For companies making big investments, the future is now. Along with Japanese consumer electronics giant and battery supplier Panasonic, Tesla is investing $5 billion in the “Gigafactory” under construction near Reno, Nevada, with planned production capacity exceeding all current lithium ion battery factories combined. The facility’s scale and integrated production of materials, cells, and battery packs are designed to do for lithium ion batteries what large-scale PV factories have done for solar: cut manufacturing costs and lower consumer prices.

"Almost no one would have predicted that photovoltaic prices would fall as far as they have, and storage is right at the cliff heading down that price curve," said Straubel. Currently, Tesla prices its residential product at $350 per kilowatt-hour (inverter and installation not included), which Straubel called "by far one of the most competitive prices out there." A larger product for industrial use is advertised at $250 per kilowatt-hour.

While Tesla's battery prices are indeed competitive, EPRI's Kamath cautioned that comparisons of energy storage prices and costs often exclude important details. "These figures can be easily misunderstood," he said. "There is a wide range of utility and customer applications, each with specific installation and operations costs and prices, and often some or all of these are not included. Metrics such as dollars per kilowatt-hour can be useful general benchmarks, but you really have to look at the cost of an entire storage system designed for a particular application."

EPRI's Energy Storage Initiatives

EPRI is working on various fronts to inform fact-based analysis of storage markets and technology. It has created the Energy Storage Cost Benchmarking Database to track the costs and benefits of selected storage systems providing services such as frequency regulation, renewable energy integration, voltage support, and demand-charge management. The database, which EPRI is updating in 2015, draws on vendor surveys and considers a range of technologies, from electrochemical and electromechanical to pumped hydro storage and compressed air.

For instance, preliminary estimates for the capital cost of lithium ion batteries in distribution applications range from about $350 to $500 per kilowatt-hour for the battery alone, while fully installed lithium ion systems (including power conversion electronics) may cost $1,000 to $1,200 per kilowatt-hour of storage.

EPRI's regularly updated Energy Storage Valuation Tool helps regulators and utilities to understand when and where grid-connected storage systems make economic sense. In 2013, California regulators used the tool to help set the state's energy storage targets. Since then, EPRI has worked with more than a dozen utilities using the tool to assess the value of storage in their service territories.

The EPRI-led Energy Storage Integration Council (ESIC) provides a technical forum for utilities, energy storage vendors, government organizations, and other stakeholders to advance safe, reliable, and cost-effective energy storage. Activities include:

- Identifying technical grid challenges that energy storage could solve and communicating requirements to vendors
- Defining common performance metrics and verification methods for products
- Performing cost-benefit analyses
- Providing guidelines for the safe operation of products and projects
- Documenting and disseminating best practices for installation, integration, and operation

"We are trying to understand how storage fits into our portfolio, what the multiple value streams are, and how to price those values," said Thomas Golden, Technology Development Manager for Duke Energy, who chairs an ESIC working group on grid integration.

In addition to its participation in ESIC, Duke Energy, the largest U.S. utility, is exploring energy storage through numerous projects across the country, including a 2-megawatt project at a retired coal plant in Ohio and a 36-megawatt project at a Texas wind farm.

Golden isn't bothered by the exuberance about batteries. "Young, immature industries need a certain amount of hype," he said. "There is this big swell of excitement when a new technology takes off, followed by a shakeout separating winners from losers, and then it matures. It's part of how the market gets built. We are excited about storage and its potential to make the grid more flexible and reliable."

For EPRI's Kamath, energy storage today is reminiscent of computers 30 years ago. "In the early 1980s, people knew personal computers would be a big deal, but they had no idea how they would use them," he said. "Now most personal computers are handheld devices used for things people never imagined they would do but are nonetheless considered essential. In the same way, we are still figuring out what storage will become."

Energy Storage: Past, Present, and Future

Although energy storage is considered one of the most exciting new technologies in electric power today, it is nothing new. Alessandro Volta invented the voltaic cell, the basis for the modern electric battery, at the dawn of the 19th century. Lead-acid batteries, the first rechargeable batteries, made their commercial debut in telegraph systems of the 1830s and were used in New York's direct-current grid of the 1880s before entering global automobile markets in the 20th century.

Connecticut Light & Power completed the first large-scale energy storage system in 1929, a 31-megawatt pumped hydroelectric storage installation. Today, pumped storage makes up the majority of energy storage capacity, with approximately 130 gigawatts in operation worldwide—including more than 20 gigawatts in the United States. Pumped storage can provide bulk energy services, with storage discharge times in the tens of hours and generating capacities larger than 1 gigawatt at individual facilities. Another form of bulk energy storage is compressed air.

In contrast with compressed air and pumped storage, various electrochemical batteries have emerged that provide shorter periods of storage, with discharge times ranging from approximately one to six hours. In addition to lead-acid, commercial energy storage chemistries include sodium-sulfur, sodium-nickel-chloride, nickel-metal-hydride, vanadium redox flow batteries, and lithium ion.

Each has advantages and disadvantages when it comes to costs and performance factors, such as cycle life, service life, charge rate, discharge duration, round-trip efficiency, and operations in different temperatures.

Among electrochemical technologies, lithium ion batteries dominate the market for grid-scale battery storage in the United States—partially because of their ability to ramp quickly in applications, such as frequency regulation, requiring less than four hours of storage. Other technologies, notably sodium-sulfur and certain types of flow batteries, have an advantage for grid services requiring longer discharge.

"We don't believe that a single battery will ever address all the energy storage applications or that battery innovations will end any time soon," said John Jung, CEO of Greensmith, one of the largest integrators of grid-scale storage in the United States. "That is why our technology and business model have been and always will be battery-agnostic."

No one has invented a super-battery yet, but many are trying. The mission of the U.S. Department of Energy–funded Joint Center for Energy Storage Research—led by Argonne National Laboratory and including EPRI as an affiliate member—is to "develop new technologies that move beyond today's best lithium ion systems to provide five times the energy storage at one-fifth the cost within five years." Tesla's mission is similar, focusing on commercially available lithium ion batteries from Panasonic. While it remains to be seen which group gets there first, it's a competition worth watching.

Key EPRI Technical Experts

Haresh Kamath

Feature—Building a Research Bridge to China

By Brent Barker

The Story in Brief

Nuclear power in China is on a steep growth trajectory. EPRI and the Chinese nuclear utilities have embarked on a major collaboration, bringing together EPRI's extensive research and technology and China's impressive advanced nuclear research facilities. The engagement has the potential to substantially bolster the safety and efficiency of nuclear power worldwide.

On a tour arranged by China General Nuclear Power Corporation (CGN), EPRI Fellow Rosa Yang was impressed as she entered the research laboratory in Shenzhen. "On the way to the lab, I was thinking that this is probably a facility I've seen before," said Yang. "But walking in was a revelation. The facility was marvelous, with some of the most advanced technology in the world for thermal-hydraulic and safety-related testing of nuclear fuels and components, including simulating severe accident conditions."

Yang, along with Neil Wilmshurst, EPRI's Nuclear vice president, and Shanshan Liu, EPRI's country manager for China, were escorted in March through the 13,000-square-meter, five-story Comprehensive Thermal Hydraulics and Safety Testing Facility. Its 17 experimental engineering stations are for testing existing plant performance and designs of new nuclear reactors, and for simulating both normal and off-normal operations. "The interesting thing about this facility is not only the large scale, but the fact that this is just Phase 1 for this lab," said Yang. "There are open fields next door where they intend to expand. Phase 2 is still undetermined."

EPRI's nuclear staff view this lab as a precursor of something larger in EPRI's future with China. Advanced laboratories such as the one in Shenzhen have largely closed in the United States, even as the expertise and knowledge remain with EPRI and its members around the world. During the past several years, EPRI and the Chinese nuclear utilities have come to appreciate the potential for collaboration and have embarked on a carefully managed engagement. This collaboration has the potential to substantially bolster the safety and efficiency of nuclear power worldwide.

"The nuclear utility CGN is already halfway to full participation in EPRI's Nuclear sector programs," said Wilmshurst. "We are continuing the relationship and want to get a better grasp of their research capabilities.

What we saw at Shenzhen is very promising—the kind of facility where we could place some of our future research."

Nuclear Trends in China

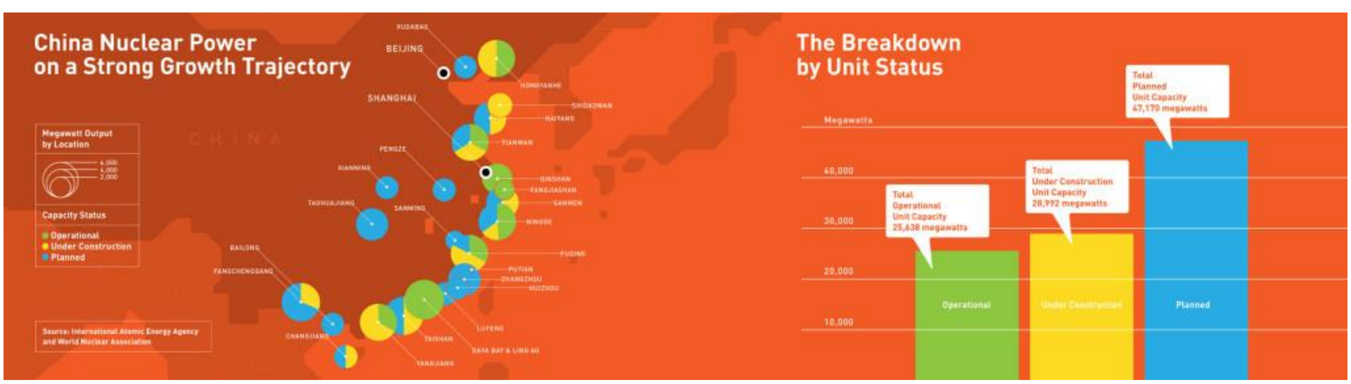
China is one of the few places in the world where nuclear power is on a strong growth trajectory, with 27 operating reactors, 26 under construction, and 6–7 units projected to come online every year through 2040. CGN projects that Chinese nuclear capacity will grow from roughly 23 gigawatts today to 58 gigawatts by 2020 to 200 gigawatts by 2040. According to the U.S. Energy Information Administration, the nuclear portion of the generation mix in China is expected to grow from only 5% today to roughly 11% by 2040 (see chart). With a rapidly growing Chinese economy and power generation straining to keep up with surging demand, coal is believed to continue as the dominant resource.

Today, 87% of China's electricity is consumed in the commercial and industrial sectors. Pent-up demand for power in the residential sector—currently just 13% of the country's consumption—may foreshadow more rapid growth in generation in coming decades.

The recent climate agreement between China and the United States focused on capping carbon dioxide emissions. China's commitment to cap carbon dioxide emissions by 2030—at a level not yet specified—will require building a staggering 800–1000 gigawatts of non-fossil generation in the next 15 years. 1000 gigawatts is equivalent to 80% of China's installed generation capacity at the end of 2013. Based on CGN's capacity projections, nuclear will account for 20–25% of this new generation by 2040.

Much of the nuclear technology in China is a mix of Chinese designs and Western designs modified by Chinese engineers. According to TG Lian, EPRI program manager for corrosion research and previous China country manager, China National Nuclear Corporation (CNNC), the country's other major nuclear utility, built and operated the first Chinese-design reactor in the early 1990s. A year or two later, CGN built the first foreign-design nuclear plant near Daya Bay, which supplies most of Hong Kong's electricity. CGN worked with the French firm AREVA to install its technology and adapt it to China's needs.

The Chinese are moving fast to install reactors with passive safety features, including the Westinghouse AP1000, the European Pressurized Water Reactor (EPR), and the Chinese Hualong-1 Generation III design. The EPR is a French/German design, and the Hualong-1 was developed from the French Generation II design.



Data as of October 15, 2015

Roadmap for Engagement

EPRI engagement with China began in the early 2000s with a few in-country meetings with key nuclear industry personnel. In 2006, a plant management subsidiary of CGN at the Daya Bay plant joined EPRI's Nuclear Maintenance Applications Center (NMAC) program. This afforded the first formal, ongoing relationships between EPRI and CGN, the smaller and more internationally focused of the two nuclear utilities.

With its reports and databases, followed by workshops and informal consultation, NMAC quickly proved its value, and by extension, EPRI's potential value. The relationship with NMAC continues.

"From 2006 to 2011, engagement stayed at the level of intermittent touch points," said Wilmshurst. "After the Fukushima accident, Mike Howard, EPRI's CEO, made it an increased focus to collaborate on R&D projects with China's nuclear generation companies to help ensure the safe and reliable operation of nuclear plants. At the World Association of Nuclear Operators (WANO) biennial meeting in September 2011, we met a number of key people from the Chinese nuclear utilities, and in 2012, we visited the companies to build these relationships."

Priorities in Technology Transfer

EPRI's Chemistry and Fuel Reliability staff met with CGN counterparts at Daya Bay in 2014 to explore topics of priority for technology transfer. CGN has a particular interest in the chemistry involved in applying zinc to reduce radiation fields, and EPRI staff were able to draw upon their numerous engineering and laboratory assessments as well as fuel examinations at plants injecting zinc to ensure that zinc chemistry does not negatively impact the fuel. Other areas of interest included EPRI's water chemistry guidelines and the use of dispersants to reduce steam generator fouling.

At a subsequent international meeting focused on Fukushima, sponsored by the Institute of Nuclear Power Operations (INPO), Wilmshurst and Yang met with Zhu Minhong, the Deputy General Manager of one of CGN's operating subsidiaries, who reviewed the agenda and contact list for an upcoming meeting with CGN in China. He suggested higher level contacts, and that evening, Zhu and Wilmshurst used a whiteboard to devise a Four-Step Roadmap to guide future engagement.

"The first step was to elevate the NMAC relationship at CGN from the plant operations level to the corporate level," said Lian. "Step two was for CGN to identify and better understand the specific EPRI programs and to select the right programs to join. Step three was assessing the value of the EPRI engagement, quantitatively and qualitatively, including sending resident researchers. Step four would be full membership in EPRI's nuclear programs."

"What the Roadmap set in motion was a very deliberate and purposeful path of growth for CGN's engagement—one that can be controlled on both ends," said Wilmshurst. "It is controlled on their end by the speed with which they can digest what they are getting from us. From our end, the careful pacing helps us to understand their organization and culture and the capabilities they bring to our research program."

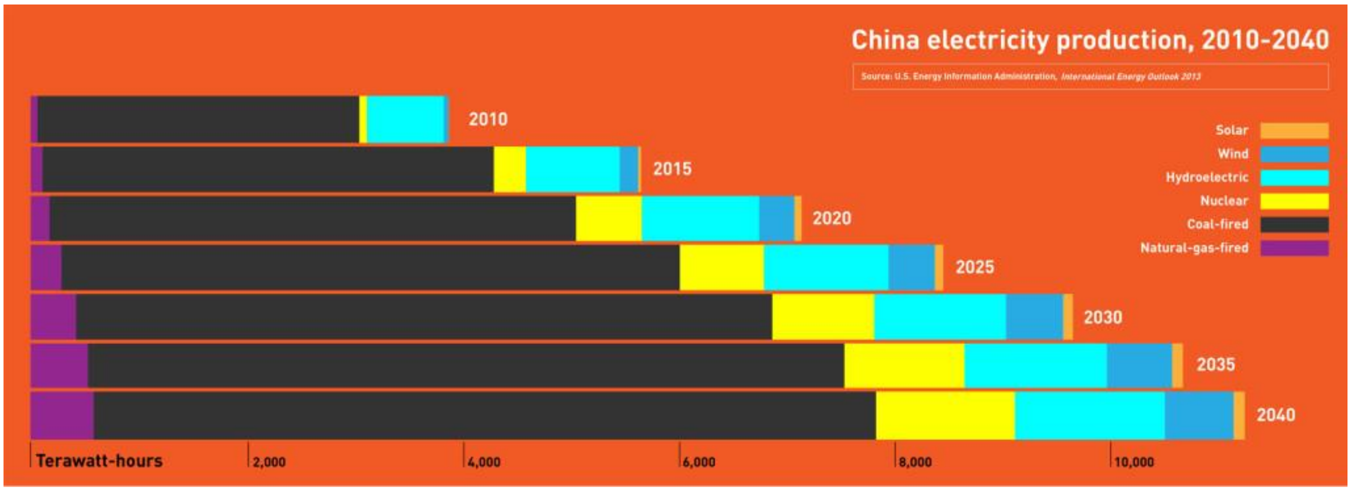
The Breakout Year

In 2013, CGN identified the five nuclear programs of greatest interest, and a visit to China was arranged to showcase the programs. "I took a team of seven to China to conduct parallel, in-depth, two-and-a-half-day workshops," said Yang. "We led off with a general meeting, then broke into five groups to discuss the specifics of each EPRI program with our technical counterparts from CGN. After the breakouts, we returned to the general meeting where their experts reported to their senior management what they had learned about the value of EPRI programs to their fleet."

A fortuitous extension of this China trip was added at the last minute. "We thought that as long as we had the team together in China, we might as well build ties with the other nuclear utility, CNNC," said Yang. "We traveled to CNNC and gave them a shorter version of what we had presented to CGN."

The result: deeper involvement in EPRI research. CNNC joined two programs, NMAC and Nondestructive Evaluation (NDE) for 2013 through 2015. In 2013, CGN joined four of the five programs presented—Water Chemistry, Instrumentation and Control (I&C), Fuel Reliability, and Steam Turbines.

"CGN has assigned a technical lead for each program," said Shanshan Liu, EPRI's China country manager, responsible for EPRI's growing relationship with the two Chinese utilities. "They also have appointed a manager of EPRI Technology Transfer to coordinate all the visits and requests." Liu added that CNNC has established a special EPRI Collaboration Committee to ensure that the engagement is strong. "They are gaining confidence as evidenced by their decision to join two additional programs in 2015: Water Chemistry and I&C."



Reciprocity of Interests and Resources

Strong reciprocal interests, resources, and capabilities drive EPRI's growing engagement with the Chinese nuclear industry. "The Chinese utilities are finding value in EPRI research and technology through their participation," said Yang. "They are building nuclear plants at a fast pace and see that our technology can improve the operational performance of their plants. EPRI can also provide a basis for them to use in training their less experienced engineers." The growth of the country's nuclear industry brings the potential for worker shortages and competition for skilled staff. "They are striving to maintain a corps of experienced engineers at their plants," said Liu. "EPRI's reports and technology transfer provide value through support and guidance for training. If they are working on a problem for which we have a solution, they can take the results and apply them, saving considerable manpower and time."

On the other side, EPRI and its members are seeking access to advanced research facilities and testing grounds that can provide a deeper understanding of the performance of advanced nuclear plant designs. The Chinese are investing substantially in such facilities and seek the experience, knowledge, and data accumulated over decades by U.S. and European nuclear organizations. "It's an ideal match," said Yang. "China wants access to EPRI's global network, and EPRI and its global members want access to China's research capabilities and experience."

Both EPRI and the utilities have conducted each step of the engagement under the auspices of the U.S. and Chinese export authorities.

A Human and Institutional Success Story

Continued growth of the EPRI-China collaboration is expected. The Four-Step Roadmap provides the structure, and the engagement's cautious progression has instilled confidence. The commitment of the Chinese is evident in a recent statement by Chen Hua, president of a CNNC subsidiary called CNNP: "CNNP's participation in EPRI will enhance our mutual understanding, and I'm convinced that CNNP will expand its engagement with EPRI soon to become a full member in all of its nuclear research programs."

"Asia is in many ways at the center of the nuclear industry today, and we want to be part of it," said Wilmshurst. "We already have substantial engagements in Japan, Korea, and Taiwan, and now we have our growing engagement in China. The benefits to our members in the United States and Europe will be substantial."

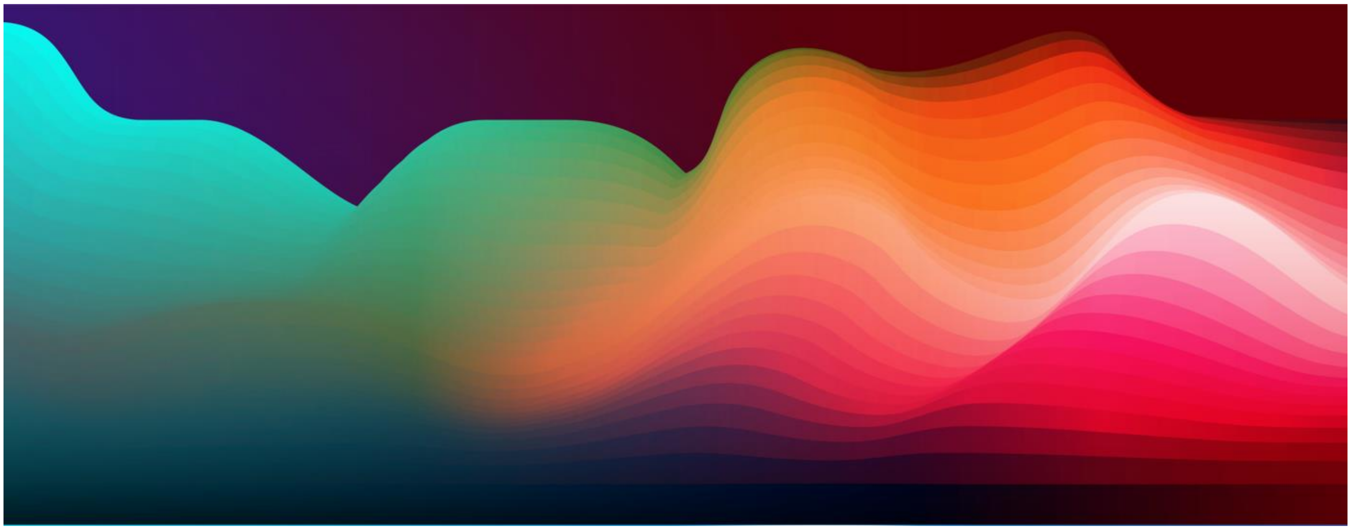
These benefits will continue to grow as EPRI expands its engagement with China's extensive nuclear research. Yang believes that there could be more resources throughout China equal to the Shenzhen lab she saw earlier this year. Last year, Liu visited another lab—a materials testing facility in Shanghai. Neil Wilmshurst has asked Yang to organize a visit later in 2015 for EPRI technical staff to visit some of these laboratories where future EPRI research may be conducted.

"This has been an amazing success story in two ways," said Wilmshurst. "First, the human and institutional story: we have grown personal relationships into a much bigger engagement of major institutions serving the interests of everyone. Second, we have succeeded in strengthening collaborative research that will advance safe and operationally efficient nuclear power throughout the world."

Key EPRI Technical Experts

Rosa Yang, TG Lian, Shanshan Liu

Feature—A Strong Current of R&D



EPRI Pursues Broad Portfolio of Efficient Plant Cooling Technologies

By Garrett Hering

In 2015's record heat, drought across the Western United States ranged from severe to exceptional, creating hardship and danger from California to the typically wet Northwest. This pattern may provide a glimpse of what's to come, according to researchers at Columbia and Cornell universities and the National Aeronautics and Space Administration (NASA). In a study published earlier this year, they predicted that a multi-decade "megadrought" stretching from the Pacific Ocean to the Central Plains could set in by mid-century, with unprecedented consequences for the regional water supply and national economy.

Drought, along with growing population and competition for resources, is driving the electric power industry's increased focus on freshwater sustainability. Water-use restrictions in many regions are increasing pressure on thermoelectric power plants to reduce their reliance on freshwater sources. Increasingly, investors and the public are calling on electric utilities to disclose their current and future water needs.

To help plant owners and operators meet these challenges, EPRI is accelerating its research and development of advanced, water-efficient, power plant cooling technologies and freshwater alternatives in collaboration with U.S. government agencies, national laboratories, universities, electric utilities, and entrepreneurs.

Most thermoelectric power plants withdraw large volumes of water from lakes, rivers, and oceans to cool and condense steam used in generating electricity. Next-generation cooling technologies could help to conserve billions of gallons of water used by coal, natural gas, nuclear, biomass, geothermal, and solar thermal generators.

According to the U.S. Geological Survey (USGS), power plants and irrigation each accounted for about 38% of the country's total freshwater withdrawals in 2010. The USGS reports that from 2005 to 2010, power plant cooling withdrawals decreased by 16%, due in part to a decrease in coal-fired generation, increases in natural gas and renewable generation, increased power plant efficiency, and improved cooling technologies. USGS will begin updating its estimates next year.

But water *withdrawals* do not tell the whole story. Because most cooling water is returned to its original source, power plants make up only 4% of freshwater consumption, according to EPRI's analysis of U.S. Department of Energy (DOE), USGS, agricultural, and weather data. The largest consumer of freshwater in the United States is the food and agriculture sector, with a 67% share, followed by the domestic (household uses) and municipal sectors at 25%.

Broad R&D Portfolio

EPRI's power plant cooling R&D portfolio includes nearly two dozen technologies at various stages of maturity. EPRI also is exploring options to reduce reliance on freshwater supplies by using degraded and recycled water sources (see sidebar).

"Our research on new water-cooling technologies focuses on characterizing water resources and potential breakthrough technologies, and piloting and demonstrating technologies on the pathway to commercialization," said Robert Goldstein, EPRI senior technical executive for water and ecosystems.

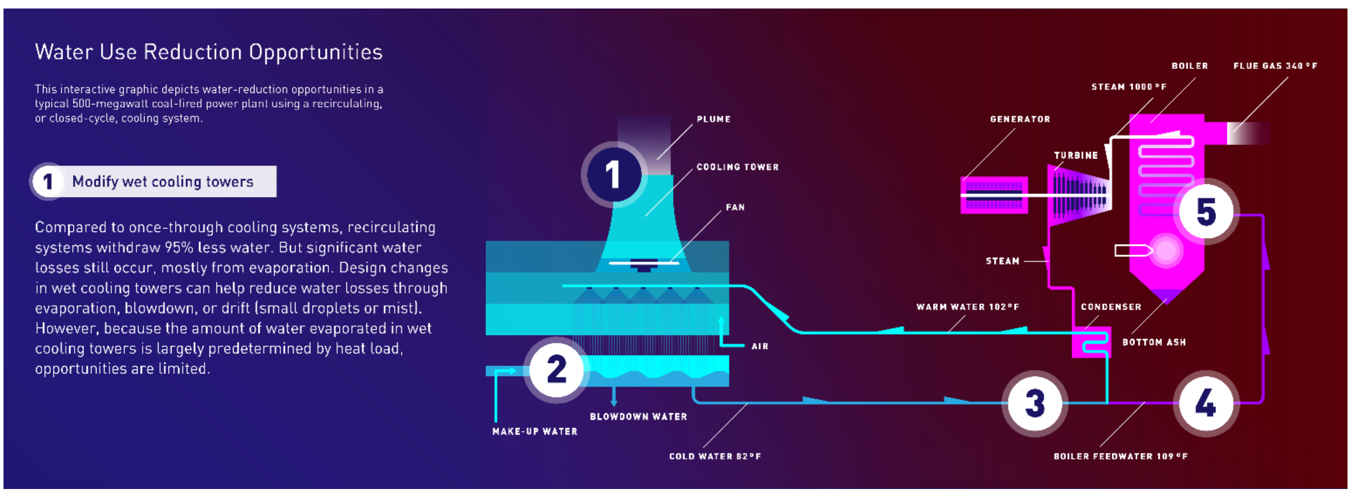
Kent Zammit, EPRI manager of land and water sciences, added, "We cover a broad fleet of technologies with potential to significantly reduce plant water consumption and are developing ways to tap alternative sources for water, such as treated wastewater."

Cooling technologies in EPRI's research portfolio fit into three categories:

- Technologies to reduce evaporative water losses in recirculating wet-cooling systems (closed-cycle cooling)
- Technologies to improve efficiency and reduce the cost of dry-cooling systems
- Hybrid systems that combine the cost and performance of wet cooling with the water efficiency of dry cooling (see graphic)

Many technologies are being evaluated at the Water Research Center, a field laboratory at Plant Bowen in Georgia established by EPRI, Georgia Power, and Southern Research Institute.

The following five-part graphic depicts water-reduction opportunities in a typical 500-megawatt coal-fired power plant using a recirculating, or closed-cycle, cooling system.

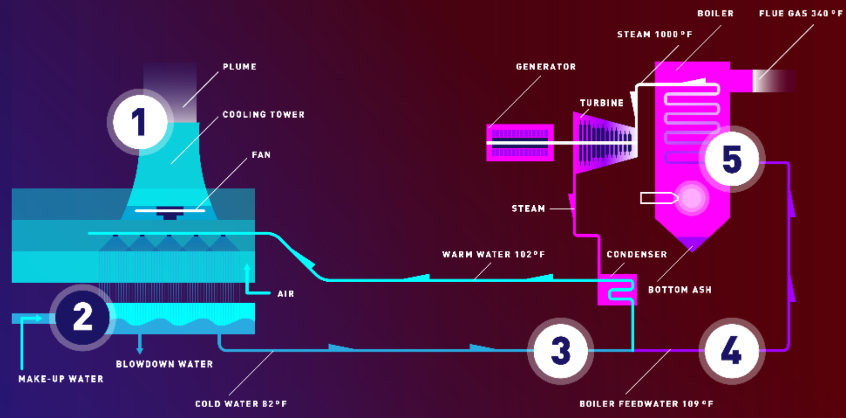


Water Use Reduction Opportunities

This interactive graphic depicts water-reduction opportunities in a typical 500-megawatt coal-fired power plant using a recirculating, or closed-cycle, cooling system.

2 Conserve and use freshwater alternatives

Reclaimed wastewater is a possible alternative to freshwater sources for power plant make-up water—water needed to replenish a plant's cooling system due to evaporation, blowdown or other losses. EPRI research seeks to enable alternative, non-potable sources of makeup water. These include treated municipal wastewater, agricultural and stormwater runoff, saline groundwater, and produced water from mining or drilling. Careful management of blowdown water—water that is removed from the cooling system to reduce dissolved and suspended solids—can help conserve water.

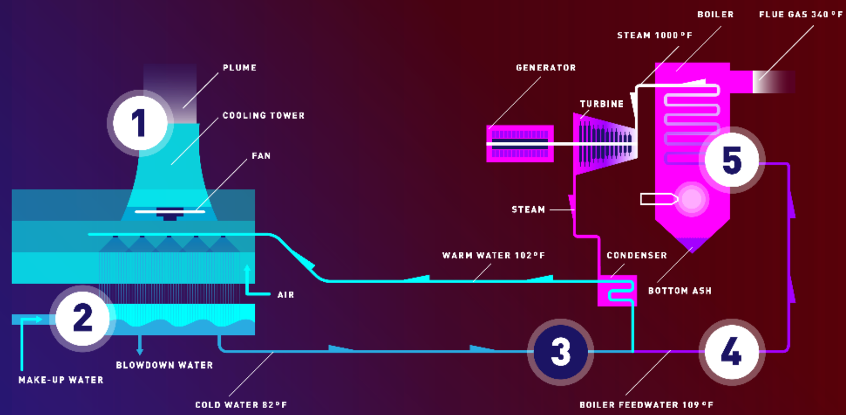


Water Use Reduction Opportunities

This interactive graphic depicts water-reduction opportunities in a typical 500-megawatt coal-fired power plant using a recirculating, or closed-cycle, cooling system.

3 Hybrid Cooling

By combining dry and wet-cooling components, hybrid systems have the potential to reduce evaporation by more than 50% compared to closed-cycle wet-cooling systems. Conventional hybrid systems, however, share the same cost disadvantage as dry cooling systems. As an alternative approach, EPRI is exploring an early-stage, innovative hybrid dry/wet dephlegmator with the University of Stellenbosch in South Africa. Together with Johnson Controls and Georgia Power, EPRI has also supported a near-commercial demonstration of the Thermosyphon Cooler Hybrid Cooling System.

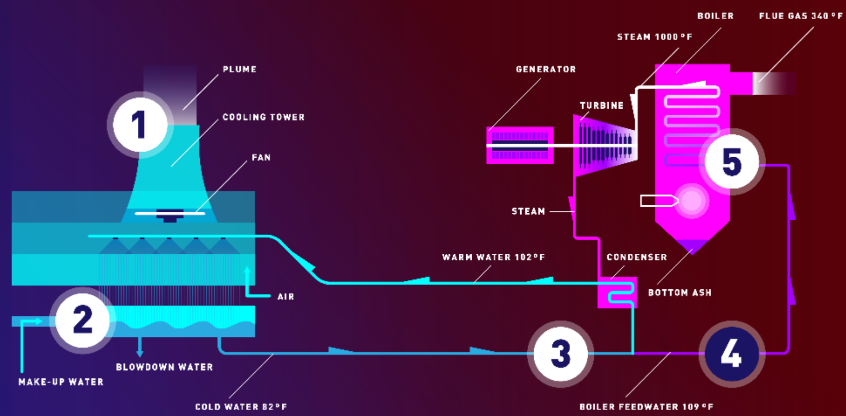


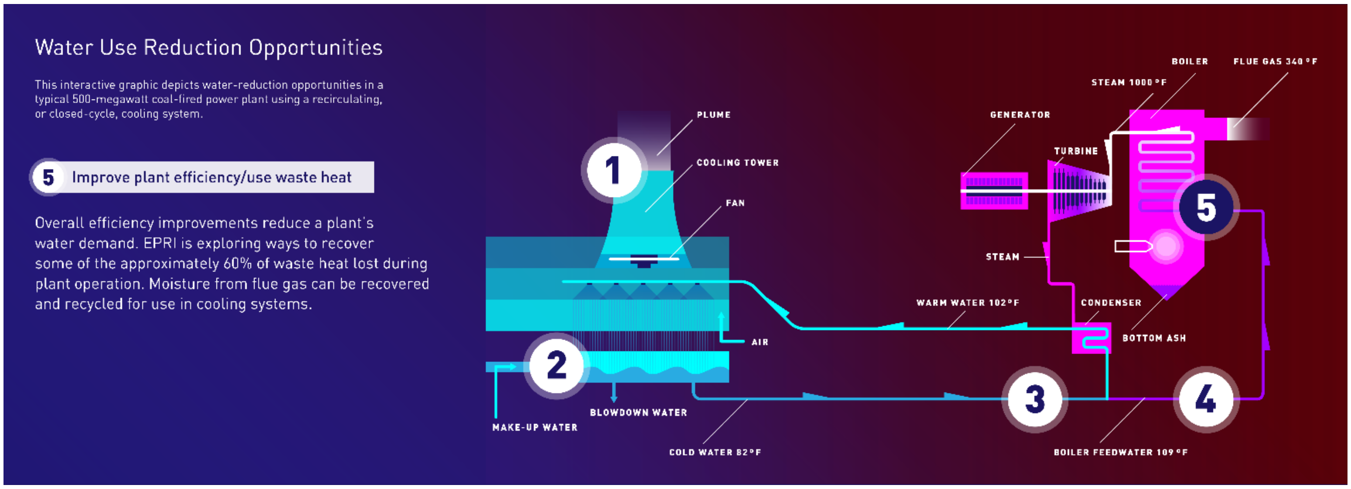
Water Use Reduction Opportunities

This interactive graphic depicts water-reduction opportunities in a typical 500-megawatt coal-fired power plant using a recirculating, or closed-cycle, cooling system.

4 Dry-Cooling

Dry-cooling systems offer dramatic water savings by completely eliminating freshwater inputs through reliance on air-cooled condensers or heat exchangers to condense steam. However, conventional dry-cooling systems can reduce power production by up to 10% due to higher steam condensation temperatures on hot days and can increase capital costs up to five times compared to wet-cooling systems. To address these challenges, EPRI research targets both improvements to conventional dry-cooling technologies and innovative new approaches. This includes two early-stage projects funded by DOE ARPA-E and 10 projects in a joint program with the National Science Foundation.





Dry-Cooling Collaborations

In 2015, DOE awarded an EPRI-led team $3 million through its Advanced Research Projects Agency-Energy (ARPA-E) to develop an economically viable indirect dry-cooling system that uses a special mesh heat exchanger with encapsulated phase-change materials. It has the potential to reduce both steam condensation temperatures and power consumption. Encapsulating the intermediate coolant also limits potential environmental problems.

EPRI and its research collaborators—including Drexel University, the University of Memphis, Evapco, WorleyParsons, and Maulbetsch Consulting—will develop, manufacture, and demonstrate a prototype by 2018.

The effort is one of five $3 million project awards from DOE's ARPA-E Advanced Research in Dry Cooling (ARID) program. In total, DOE is funding 14 projects with a combined $30 million through ARID. This program supports technology development, from early-stage high-risk concepts to prototypes that can be scaled up for use in thermoelectric power plants, either as retrofits or new plant installations. With the program ending in 2018, commercialization could begin as early as 2020.

Freshwater Alternatives

In addition to dry-cooling technologies that eliminate freshwater withdrawals, EPRI is exploring the use of degraded and recycled water sources for plants with recirculating wet-cooling and hybrid cooling. Examples include municipal wastewater, agricultural and stormwater runoff, saline groundwater, produced water from mining or drilling, and recovered moisture from power plant flue gas and cooling towers. EPRI also supports innovation in filtration, distillation, desalination, and other approaches to harness alternative sources.

EPRI is participating in a second $3 million ARPA-E project led by the University of Maryland to develop a plant cooling system based on microemulsion liquid absorbents. These materials improve cooling system performance by collecting water vapor and releasing it as a liquid. The system is driven by waste heat from plant flue gas.

The DOE awards accelerate or expand research already supported by EPRI and the National Science Foundation (NSF), which last year launched a joint three-year, $6 million initiative called NSF-EPRI Power Plant Dry Cooling Science and Technology Innovation Program.

In 2014, the NSF-EPRI program selected 10 projects for funding. Of these, four target the enhancement of conventional air-cooled condensers, while six focus on developing alternative dry-cooling technologies. The latter group includes the University of Maryland–led project using microemulsion liquid absorbents—which DOE also is funding through ARPA-E—and a project with Drexel University using non-encapsulated phase-changing materials as an intermediate coolant. Compared with the encapsulated approach funded by ARPA-E, this alternative design offers potential cost advantages because it does not require a special mesh heat exchanger.

In another NSF-EPRI project, the Georgia Institute of Technology and Johns Hopkins University seek to significantly improve heat transfer and power-plant efficiency by enhancing the design of fins for the steam-condensing tubes in air-cooled condenser modules. The design's low-cost thin reeds induce turbulence in air flowing across the fins for more efficient heat transfer and improved dry cooling. Southern Company and technology vendor SPX Cooling Technologies are supporting laboratory-scale versions, marking a path to potential commercialization.

Also funded by EPRI and NSF is a University of Illinois concept to enhance air-cooled condensers by adding aerodynamic *vortex-generator arrays*—devices that increase turbulence and improve heat transfer—between condenser fins.

Hybrid Systems

Separate from the ARPA-E projects and NSF-EPRI program, EPRI is funding laboratory research at the University of Stellenbosch in South Africa on the design of a hybrid dry/wet dephlegmator. A standard component of air-cooled condensers, traditional dephlegmators help condense steam and remove noncondensable gases. The University of Stellenbosch–designed hybrid system adds a new component and a second stage that enables the system to operate in dry mode when ambient temperatures are cool and in hybrid mode on hot days. This results in increased power generation, compared with conventional air-cooled condensers, and requires much less freshwater than wet-cooling systems.

According to Jeff Stallings, senior project manager at EPRI, the University of Stellenbosch is exploring two designs—a new air-cooled condenser with the hybrid dephlegmator and a retrofit version. EPRI is working with the researchers on design improvements.

The technology in EPRI's plant-cooling R&D portfolio that is closest to commercialization, according to Zammit, is the Thermosyphon Cooler Hybrid System. Developed by Johnson Controls and demonstrated at the Water Research Center at the coal-fired Plant Bowen from August 2012 to October 2013, this hybrid system combines air cooling with an experimental cooling tower. Pending funding, a 15-megawatt thermosyphon module will begin commercial deployment later this year.

The pilot demonstration showed potential water savings from 34% to 78% on average per month. Modeling its use in the desert Southwest and other U.S. locations indicated dramatic, cost-effective water use reductions. The technology can be retrofitted in existing plants.

"EPRI is researching many different technologies that should lead to commercial alternatives to existing water conserving technologies," said Zammit. "These technologies for new and existing plants will become more attractive, especially as water prices increase or availability decreases."

Key EPRI Technical Experts

Richard Breckenridge, Sean Bushart, Robert Goldstein, Jessica Shi, Jeff Stallings, Kent Zammit

First Person—Grid Operator: Riding Midwest Winds

The Story in Brief

Kristian Ruud is Senior Manager, Engineering Support at MISO, the grid operator that serves the Midwest United States and the Canadian province of Manitoba. In this interview with EPRI Journal, Ruud discusses MISO's experiences with an innovative new program to manage and integrate rapidly growing intermittent wind resources.

EJ: Describe the operational challenges that led MISO to rethink how it manages intermittent wind resources.

Ruud: Between 2005 and 2010, we had an explosion in wind deployment that was outpacing transmission development. We ended up with a lot of generation in areas that didn't traditionally have much generation or load, and the transmission system in those areas wasn't robust enough to support that generation. This led to a great deal of local transmission congestion, and we didn't have traditional generation resources that could be effectively re-dispatched to alleviate those constraints.

A good example was in southwestern Minnesota, one of the first regions in the MISO's service territory to see significant wind development. This rural area was traditionally served by remote generation facilities. As the wind capacity in the area increased and exceeded the local load, it led to eastward energy transfers on the transmission system along the Minnesota/Iowa border. The existing transmission infrastructure, mostly consisting of a single 161-kilovolt line, was quickly overwhelmed by these transfers, and there was not enough traditional generation to "push back" on the transfers.

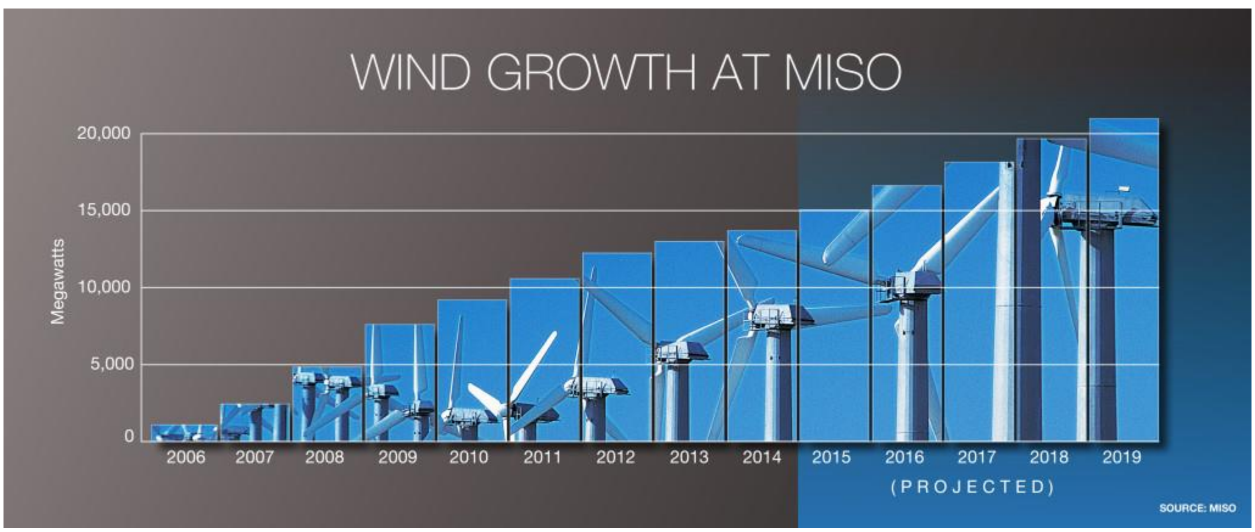
EPRI R&D on Bulk-Level Renewables Integration

EPRI's Grid Operations and Planning group conducts research to help grid operators more effectively integrate significant levels of wind and solar power into the bulk electricity system. Areas of focus include using improved wind and solar forecasting for operations, developing useful renewables forecasting performance metrics, determining optimal operating reserve levels, and evaluating the design of wholesale electricity markets in changing systems. Learn more about EPRI's research portfolio in Grid Operations, Grid Planning and Bulk Power System Integration of Variable Generation.

In this and other instances of congestion, our only option was to pick up the phone and call the wind operators to tell them to curtail production. This "manual" curtailment process, without a robust operator tool supporting it, has a number of drawbacks. It doesn't send the appropriate price signals to the market to indicate that transmission congestion is present and to help reduce it. Our operators were spending nearly all day every day tracking transmission congestion, figuring out who needs to be curtailed and by how much, making the phone calls to implement the curtailments, tracking the results, and ultimately reversing the process to release the curtailments. All this took their attention away from other important activities.

These were the main drivers to create our Dispatchable Intermittent Resources program in 2011. This program effectively eliminates manual wind curtailment. Our intent was to find the most cost-effective dispatch of all dispatchable generating resources on the grid while respecting transmission limitations. The program aims to treat wind resources like any other generating resource in MISO's real-time market.

One major obstacle was that other resources in our market have to give us data on their minimum and maximum production on an hourly basis at least 30 minutes before the start of any given hour. It isn't practical to use that construct for wind because it varies significantly over that 90-minute period. So we created a mechanism by which wind power operators provide generation forecasts for each 5-minute interval, and these forecasts are treated as the maximum production for each interval. They can update these forecasts as often as they want, but they have to give us a forecast at least 10 to 15 minutes prior to the interval in question.



MISO is experiencing a rapid expansion in installed wind power capacity.

Besides that 5-minute forecast, the Dispatchable Intermittent Resources provide the same parameters with their electricity offers as any other generation resources, such as ramp rates and price curves. The price curves given by wind generators indicate the prices below which they would be willing to curtail production. These numbers can be close to zero or even negative.

"Our operators were spending nearly all day every day tracking transmission congestion, figuring out who needs to be curtailed and by how much, making the phone calls to implement the curtailments, tracking the results, and ultimately reversing the process to release the curtailments."

Our computer systems collect and automatically process all this information to determine market dispatches in megawatts for every 5-minute interval. MISO then sends dispatch signals to wind resources through a communications protocol just like it does for any other resource. Curtailments are built into this automated process by issuing dispatches below the current generation capability of a wind operator.

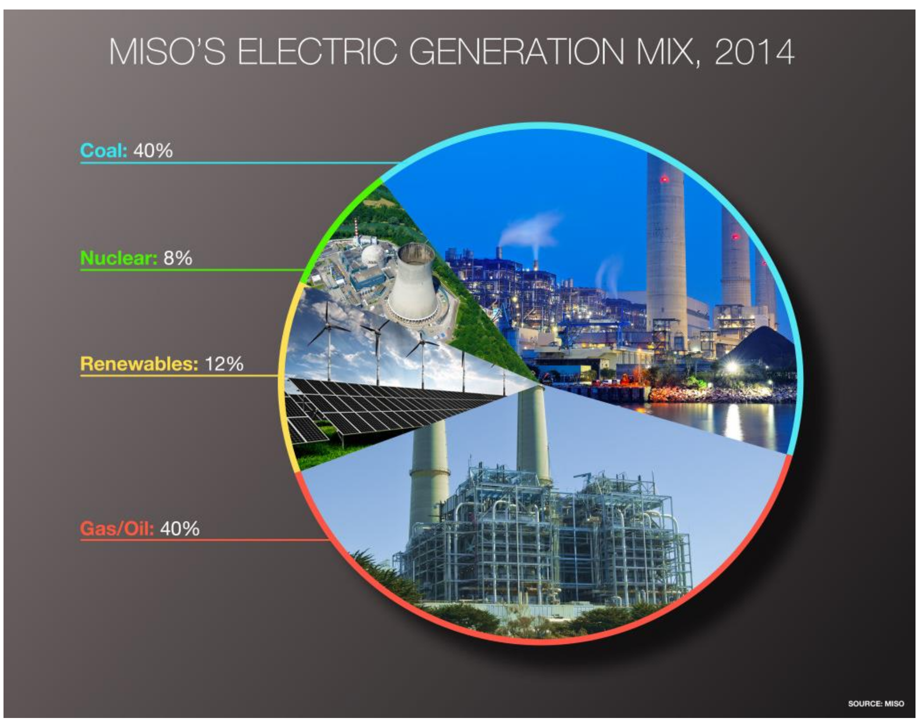
EJ: How are the wind production forecasts done, and what are their limitations?

Ruud: Before the Dispatchable Intermittent Resources program, we used hourly wind generation forecasts that went out over the next seven days. Now, for Dispatchable Intermittent Resources, we collect wind generation forecasts for each 5-minute interval over the next hour. Some wind power operators submit their own forecasts to us. Others decided to use MISO's 5-minute forecast. These forecasts feed into our automated dispatch.

"Our intent was to find the most cost-effective dispatch of all dispatchable generating resources on the grid while respecting transmission limitations."

Sub-hourly wind forecasts are based on persistence logic—in other words, forecast output in the next 10 to 15 minutes is whatever the current output is. Keep in mind that 10 to 15 minutes is not much more than the 5-minute intervals for our dispatches. With this forecasting approach, we're not very good at predicting output during up or down ramping, and that erodes the effectiveness of the Dispatchable Intermittent Resources program. For now, we're able to manage around forecasting challenges either by manually intervening or accepting short-term inefficiencies. We're engaged with industry groups focused on forecasting and are also vocal about our concerns with the sub-hourly forecast capability. Besides this challenge, the program has been successful overall.

Wind power forecasting is a relatively new science. Most of the wind forecasting prior to the wind generation boom was for aviation and weather, which forecasts five, ten, fifteen thousand feet in the air, not a few hundred feet.

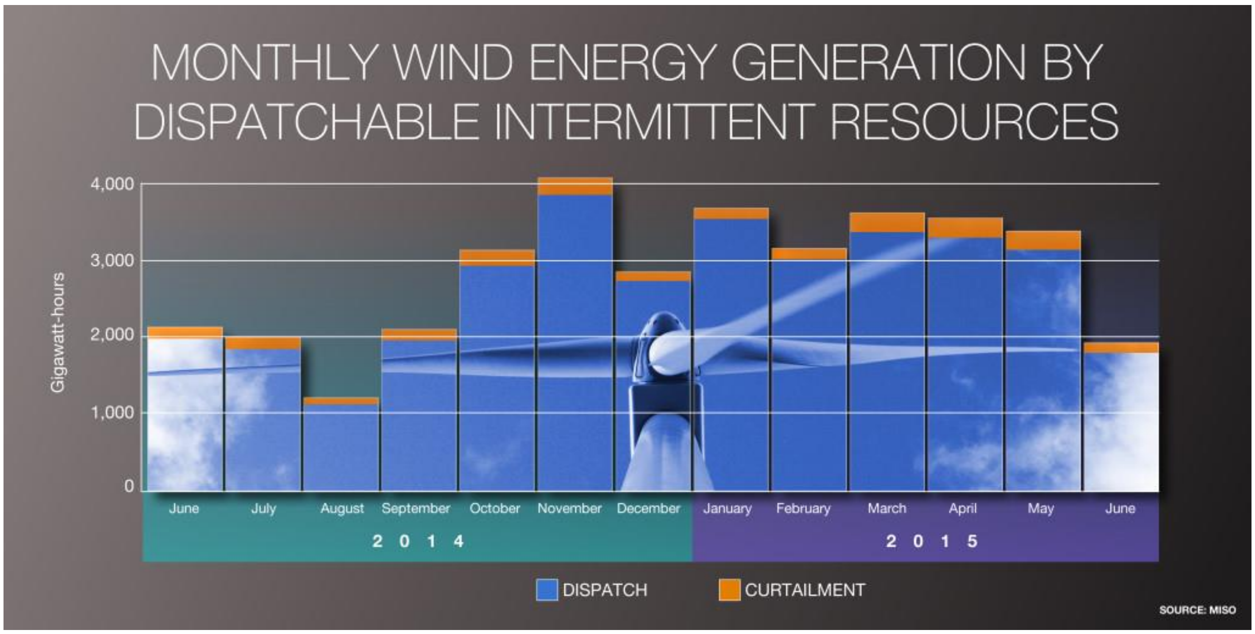


In 2014, MISO's electric generation portfolio totaled about 178 gigawatts, with wind accounting for approximately 14 gigawatts.

EJ: What has been the typical forecast error with your program?

Ruud: We have error metrics, but they don't tell the full story. Wind output is fairly steady for long periods, and the ramping periods—where the largest error occurs—are relatively short-lived. This nuance is not easily captured in a metric. Consider this example: we have a 100-megawatt wind farm that went from zero megawatts to full output and then back to zero in 3 hours. During this time, the forecast was off by 3 to 40 megawatts. The rest of the time, the forecast error was considerably lower.

We're aided by our large geographic area and large number of wind farms. If one farm is ramping up in southwestern Minnesota, another one in northeast Iowa may be moving down. The geographic diversity tends to cancel out some small ramping periods. Because about 90 percent of our wind resources are in Minnesota, Iowa, and the Dakotas, we do get large output increases when a weather front moves through that region, but that ramp happens over hours, not 10 or 15 minutes.



This graph shows wind dispatches and curtailments over a year in MISO's Dispatchable Intermittent Resources program. It reveals how wind generation varies significantly from month to month.

EJ: What are the program's key successes?

Ruud: One main success is transparency in the market. When we manually curtailed wind operators in the past, they would wonder, 'Why am I being curtailed? What is the constraint? How can I help fix the problem?' Standards of conduct limit what we can tell them in that context. Also, with the old system, prices did not reflect transmission congestion and the need to curtail, because we were simply masking the problem through manual action. Now curtailments are part of our automated market dispatch, and we're posting information on transmission constraints in real time on our website, so everyone can track their impact on the grid. With our dispatches, we use algorithms to calculate prices that more accurately reflect transmission and generation constraints. Additionally, wind generators in our market can now submit offers and set prices that factor in system conditions.

The program makes the market more efficient. Previously, when our operators issued curtailment orders, they were not reviewing and adjusting the curtailment every 5 minutes as needed. When it came to easing curtailments, they had to err on the conservative side to make sure that they didn't damage the transmission system. Today, because our market operates every 5 minutes, it can continually optimize the curtailment in the dispatches. That means we're able to let more megawatts on the system.

EJ: How are operating reserve requirements impacted by wind variability and uncertainty?

Ruud: Because of MISO's large size, both geographically and in terms of load, we haven't seen a need to increase our reserves due to growing wind resources. As I mentioned previously, while wind may be increasing over here, it's decreasing over there, and that smooths out the overall system production. Ramping up or down takes place over hours rather than minutes. With our 5-minute dispatch, this ramping pattern has little impact on reserve needs at the current wind penetration.

EJ: Many states in MISO's service territory have ambitious renewable energy mandates that will drive substantial wind capacity increases over the next 10 to 15 years. What additional operational challenges do you expect from this?

Ruud: Several years ago, we did a study concluding that we don't need any additional operating reserves for wind capacity up to about 20,000 megawatts. We're currently at about 14,000 megawatts. So while this is not a pressing concern now, we have taken some steps to prepare for continued growth.

"As grid operators, we have a responsibility to manage the grid efficiently and reliably, and that may require changing our business practices as the system changes. We must remain flexible."

We're developing a ramp capability model to help during times when a significant generation ramp is needed, such as during the morning load increase. This model helps to quantify the resources needed to provide that ramp and ensure that there are enough resources that can move fast enough during a specific time. This is different from having enough resources to meet the peak load. For example, if wind is dying off during the morning load increase, we need to be able to move fast enough to keep up with that load even if it's not going to be a peak load day.

We're also implementing a new pricing approach, called extended locational marginal pricing, which enables fast-start energy resources that are offline or scheduled at their operating limits to set prices. It also enables emergency demand resources to set prices. These are the resources that can help smooth generation profiles in a market with more intermittent generation.

EJ: What can other grid operators learn from MISO's experience?

Ruud: As grid operators, we have a responsibility to manage the grid efficiently and reliably, and that may require changing our business practices as the system changes. We must remain flexible.

"The biggest need is enhancing the sub-hourly wind and solar forecasts."

The biggest thing we've learned from engaging with the industry is that no two grid operators are the same. Our major operational challenge with wind penetration was transmission congestion. Many smaller operators have a much bigger challenge with balancing wind generation and load. We're each going to have unique issues, but that doesn't mean that we can't learn from each other. We're not going to have the solar penetration that California is expecting, but we're still monitoring that market and how the grid operator is responding to challenges. Talking with our neighbors and sharing operator experiences will help us deal with the challenges ahead.

EJ: What R&D is needed to help grid operators integrate wind and other renewable and emerging technologies?

Ruud: The biggest need is enhancing the sub-hourly wind and solar forecasts. The less uncertainty grid operators have to deal with, the better they can operate the system. Solar poses a different set of forecasting and operational challenges, particularly because operators need to manage small distributed rooftop solar along with much larger utility-scale solar installations. Today's grid monitoring tends to make solar generation look like a reduction in load. Operators need better tools to differentiate between load reduction and generation.

Technology At Work

Turning Eureka into Results

How EPRI Helped Great River Energy to Reduce Emissions and Expenses at Its Coal Creek Station

By Chris Warren

In 1997, David Saggau received an odd request from engineers at Great River Energy's Coal Creek Station in North Dakota. They were seeking his approval to try a novel approach to reduce the 1,150-megawatt plant's emissions. To comply with tighter federal emissions regulations, Great River Energy faced a potential tab of $300 million to outfit the plant with additional air pollution control devices known as scrubbers. The engineers hypothesized that drying the lignite that powers the plant would reduce the volume of flue gas going through the existing scrubbers—decreasing plant emissions more cost-effectively than installing new scrubbers.

"For their initial drying experiments, they wanted to pile lignite on top of a culvert that had been recently pulled out of the ground," recalled Saggau, now Great River Energy's CEO. "Then they wanted to put propane heaters in the culvert and moisture sensors in the lignite pile."

Saggau approved their innovative approach, and the experiments moved forward. Their hypothesis was right, though it took years of research for Great River Energy to develop and install its patented DryFining™* technology at Coal Creek in 2009. With DryFining, lignite coal is dried by power plant waste heat and moved by enclosed conveyor belts. It's a *fluidized bed* drying process: the solid lignite particles are percolated through a dryer using heated air to vaporize some of the fuel moisture. This produces a higher quality fuel with increased energy density and fewer contaminants.

This article is part of an *EPRI Journal* series exploring how collaborative R&D helps electric utilities manage various types of risk.

Read another article in this series about how We Energies reduced risk by transforming fly ash into asphalt.

The benefits have exceeded expectations. It turns out that DryFining not only reduces moisture, but also removes heavier particles such as pyrites that contain higher concentrations of mercury and sulfur. The result: up to a 40% reduction in Coal Creek's mercury and sulfur dioxide emissions and a 20% drop in nitrogen oxide emissions. Because reducing lignite's moisture content increases the plant's efficiency, Coal Creek uses less lignite to produce the same amount of power. That has cut carbon dioxide emissions by 4% and annual expenses by more than $20 million, providing benefits to Great River Energy's consumers and society.

A Collaborative Effort

The path from propane heaters and a used culvert to a sophisticated and proven technology was neither easy nor one that Great River Energy could travel alone. "I don't think the project would have been what it is today without the help of EPRI, especially in the early technical stages," said Saggau.

Although the Coal Creek engineers had the original idea for DryFining, the plant's operators received monthly guidance from two EPRI engineers as the technology moved from concept to prototype. "We tapped EPRI's

**DryFining is a trademark of Great River Energy.*

expertise and experience in the fluidized-bed technology that was incorporated into DryFining," said Saggau. "We leaned heavily on their advice." He added that EPRI's input was instrumental in the company's successful grant application to the U.S. Department of Energy's Clean Coal Power Initiative, helping the utility advance from prototype to commercialization and installation. "They kept us on task and helped us make the case for the potential global market impact of DryFining" he said.

Concept: In 1997, Great River Energy used propane heaters and an old culvert to experiment with the lignite-drying process.

In 2003, six years before Great River Energy commercialized DryFining, this small-scale facility was built adjacent to Coal Creek Station.

Coal Creek Station's power plant (the brown building on the left) houses the commercial-scale DryFining facility.

A Bright Future

Although coal processed with DryFining is used today only at Coal Creek and a smaller Great River Energy combined heat and power plant, Saggau is optimistic about its commercial potential globally. In countries such as China, high-moisture lignite is widely used. Recently, Great River Energy completed a licensing deal with Tangshan Shenzhou Manufacturing Company, an equipment manufacturer that serves Chinese utilities. “We are working with them to build a mobile demonstration unit similar to our initial pilot-scale plant so they can show their customers how it works,” said Saggau.

The U.S. Environmental Protection Agency recently finalized rules limiting greenhouse gas and mercury emissions from power plants, which could spur more utilities to consider the technology. “In the six years since DryFining became operational at Coal Creek, we have not had regulatory certainty, so it has been difficult to make the case for investing in the technology,” said Saggau. “Now there is more certainty, and DryFining can help with cost-effective compliance.”

In The Field

Turning Expenses into Revenue

We Energies Reduces Disposal Risk with ASHphalt

By Chris Warren

When Bruce Ramme joined We Energies in 1980, he didn't expect his University of Wisconsin–Milwaukee master's thesis on fly ash use in concrete to be of much use in his transmission and substation engineering job. Yet Ramme encountered a compelling reason to continue thinking about *fly ash*, a mineral by-product produced when coal is burned at a power plant. "When I came here, I found that only five percent of our fly ash was being used," said Ramme, now vice president of We Energies Environment Group.

Now, 35 years later, We Energies uses nearly 100% of its fly ash and other coal combustion products (see chart), including gypsum and bottom ash. According to the American Coal Ash Association, the U.S. electric power industry's average use rate is approximately 45%. Recycling coal plant gypsum materials for wallboard and agricultural products generates revenue for We Energies and minimizes risks and expenses associated with landfill disposal. "Strict Wisconsin regulations make landfilling very expensive and helped motivate us to find better uses for these materials," said Ramme.

This article is part of an *EPRI Journal* series exploring how collaborative R&D helps electric utilities manage various types of risk.

Read another article in this series about how EPRI helped Great River Energy to reduce emissions and expenses at its Coal Creek Station.

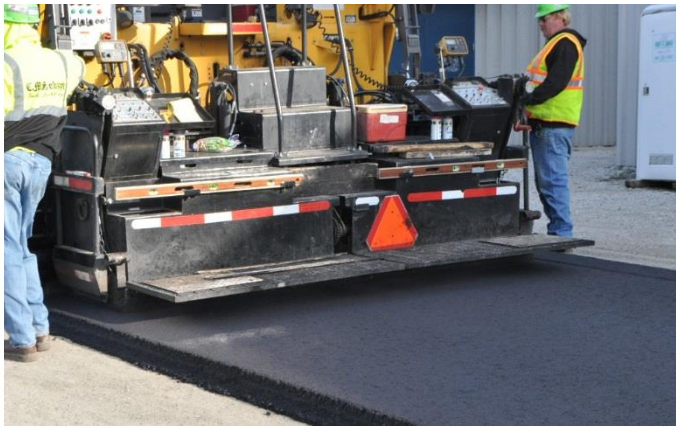
Turning Fly Ash into ASHphalt

For years Ramme pondered the use of fly ash in asphalt for road pavement but was stymied by the response from manufacturers. "They always told me, 'We have our own filler,'" he said.

Dissatisfied with their answer, Ramme returned to his alma mater, the University of Wisconsin–Milwaukee, to learn more. A professor directed him to a paper by a Turkish researcher concluding that fly ash has a positive impact on asphalt. "The study found that fly ash reduces the need for bitumen oils that help asphalt ingredients stick together," said Ramme. "It also is much more cost-effective than bitumen oils and results in less cracking."

To test these findings, We Energies funded a 2005 study at the University of Wisconsin–Milwaukee. The utility created a technical advisory panel with representatives from a county highway department, the Wisconsin Department of Transportation, civil engineers, and university researchers. Ken Ladwig, an EPRI expert on coal combustion products, was brought in to help guide research design and to review the results. "The study demonstrated fly ash's potential benefits for asphalt durability and longer life—all at a lower cost," said Ramme.

We Energies continued to work with academics and EPRI to develop and test a product called *ASHphalt*—a form of asphalt that uses fly ash to bind its ingredients. In 2012, We Energies and the University of Wisconsin–Milwaukee investigated ASHphalt's performance in a road pavement project at the utility's Oak Creek coal plant. The demonstration project confirmed what the utility had discovered in its earlier study with the university: A road paved with ASHphalt can be cheaper and more durable than one paved with traditional asphalt.



Ease of use: The introduction of fly ash to asphalt didn't require any new equipment or change in process for the crews that paved the road at the Oak Creek coal plant.

According to Ramme, EPRI's involvement in each R&D step was essential. "We don't have dedicated researchers in our company," he said. "The EPRI experts helped us more fully tap our in-house talent to develop and implement rigorous, defendable research needed for wider application and success." Ramme also credited an EPRI research project, supported by We Energies and other utilities, that facilitated laboratory tests and demonstration projects on the durability of fly ash–based binders.

The Road Ahead: Paved with ASHphalt

In addition to producing better performing asphalt at a lower cost, other benefits of using coal ash for asphalt include reducing the amount of ash sent to landfills and creating a more environmentally sustainable approach for repairing and rebuilding roadway infrastructure.

EPRI is involved with We Energies' continuing ASHphalt testing at other facilities. As with its other beneficial uses of coal combustion products, We Energies recognizes that commercializing and developing a market for ASHphalt can give the utility and its customers an economic boost. "If you can take materials with a disposal cost and turn them into products with revenue, that's a big benefit for customers and the general public," said Ramme. "There's huge savings in not throwing things away and making use of these valuable mineral resources."

Proof of concept: After lab results pointed to the effectiveness of using fly ash as an ingredient in asphalt, We Energies field-tested ASHphalt by using it to pave a road at its Oak Creek coal plant.

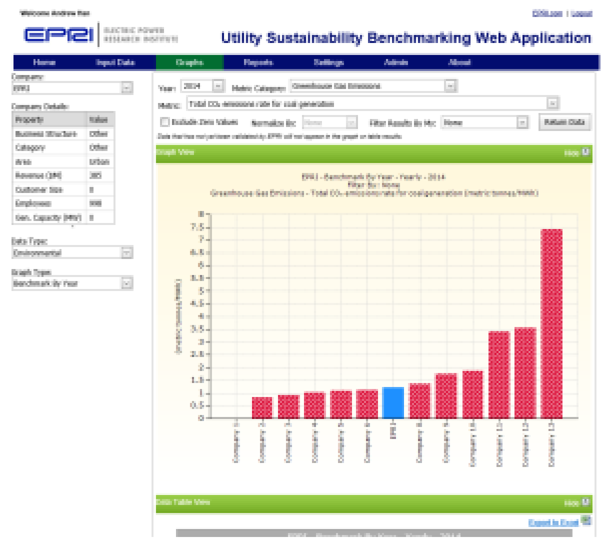
Innovation

Making Sustainability Sustainable

New EPRI Database to Help Streamline Benchmarking

By Chris Warren

Sustainability is how a company balances environmental, social, and economic issues and decisions to ensure the long-term viability of the company itself, the community, and the environment. However, different stakeholders focus on and measure sustainability in a staggering variety of ways. Reporting organizations, such as the Dow Jones Sustainability Index, CDP (formerly the Carbon Disclosure Project), and the Global Reporting Initiative, use nearly 450 different criteria to measure and rank electric utilities' sustainability. These criteria range from employee safety to the number of senior managers hired from the local community, and are distinct from performance measures that power companies must report to regulatory agencies. Reporting on a multitude of sustainability measurements—many of which may be less relevant to operations—can require resources better devoted to sustainability initiatives.



EPRI's online benchmarking database enables companies to compare their sustainability performance with peers.

To make sustainability reporting more efficient, rigorous, and relevant, EPRI is developing an online database that equips electric utilities to benchmark sustainability performance using a carefully chosen set of 15 issues. "A lot of other organizations use long lists of metrics to benchmark electric utility performance and then publish company rankings based on the results," said EPRI Technical Executive Jessica Fox. "No one knows this industry better than the power companies themselves, so the idea was to convene them to decide on the most relevant issues and metrics." Fox and EPRI Technical Leader Morgan Scott manage EPRI's Energy Sustainability Interest Group, which convenes 45 electric utilities to share sustainability best practices and advance technical work.

The streamlining of issues and metrics reflects the power industry's desire to bring greater focus to measuring sustainability. Working toward alignment on the most important criteria and appropriate metrics will reduce reporting costs and improve information quality.

Defining Issues and Metrics

The online database, which is available this fall, builds on work by EPRI and the Tennessee Valley Authority (TVA). In 2015, EPRI assumed the environmental benchmarking effort that TVA maintained since 2010. EPRI brings to the task its recently completed research identifying the 15 most relevant sustainability issues in the North American electric power industry and expanding benchmarking beyond environmental measures to include social and economic performance (see sidebar). EPRI's research team interviewed utility managers and other industry stakeholders, and compiled surveys filled out by 134 electric power company managers and stakeholders at government, private sector, nonprofit, environmental, and academic institutions.

In 2014, the Energy Sustainability Interest Group began work to identify two to five metrics for each of the 15 sustainability issues. This effort required consensus among companies of varying sizes and business models. An example: for greenhouse gas emissions, interest group members narrowed down 78 metrics to 7 that include emissions from owned generation, purchased power, and customers. The interest group has defined metrics for 11 of the 15 issues, with the remainder to be finalized in 2016.

A Versatile Tool

Companies that fund the project will have 24/7 access to the online benchmarking database, which they will use to store data, track performance, and compare with other participating companies. “Benchmarking used to be on hard copies, and you’d have to print out a lot of graphs,” said Fox. “With the online database, users will be able to apply filters, such as generation capacity, revenue, and organizational structure, so they can make the most relevant comparisons.” The database will also be used to produce metric summaries and reports on five-year trends.

“Some electric utilities may want to use the performance information from the tool to help guide internal planning and goal setting,” said Fox. “Others may use it to communicate with investors, regulators, and customers about their progress in sustainability. No matter how it’s used, it helps to have quick and easy access to this information.”

15 Sustainability Issues Identified by EPRI

- Greenhouse gas emissions
- Reductions of other air emissions
- Water quality
- Water availability
- Habitat protection and biodiversity
- Waste management

- Public safety and health
- Employee safety and health
- Job satisfaction
- Community support and economic development
- Engagement and collaboration

- Energy reliability
- Energy affordability
- Skilled workforce availability
- Economic viability of electric utilities

Sustainability: Not Just About the Environment

Environmental stewardship, such as protecting habitats and ensuring good air and water quality, is only part of what it means to be a sustainable electric utility. There are also important social and economic components, including community responsibility, employee safety, and having a sizable pool of skilled workers to prepare for the industry’s retirement wave. These factors, along with capital and assets, relate to another important sustainability issue: economic viability.

Key EPRI Technical Experts

Jessica Fox, Morgan Scott

In The Field

Unmanned Aircraft Systems Pass Field Tests with Flying Colors

By Robert Ito

"Drones" have a mixed reputation these days. The public is working to sort out drones that bomb terrorists, those that can deliver retail purchases, those that threaten airline safety, those that spy, and those that provide a whole new kind of wedding photo. Recent field research on electric power industry applications of drones may add to the growing list of drone jobs that the public can embrace enthusiastically.

An unmanned aircraft system under evaluation in Toronto

The U.S. Federal Aviation Administration prefers a more technical moniker: unmanned aircraft systems, or UAS. Last summer, EPRI researchers and UAS vendors gathered in Toronto to evaluate their potential to improve the speed, safety, and accuracy of one of the utility industry's most dangerous tasks: inspecting transmission towers.

Passing a Towering Test in Toronto

At a Hydro One Networks facility, vendors piloted six drones around five de-energized transmission towers intentionally modified with defects, such as missing bolts, loose cotter pins, and chipped insulators. The payloads were high-resolution cameras and high-definition video to capture and transmit images to operators on the ground. Weighing between 10 and 60 pounds and measuring between 24 and 60 inches in diameter, the drones were able to maneuver closely and precisely around the transmission equipment.

Each test team included a pilot and a transmission line inspector to observe the device's line of sight on a laptop monitor wirelessly linked to the onboard camera. The inspector directed the pilot—go left, hover, go right—as the drone-mounted gear inspected the 100-foot towers, capturing defects on still images and video. The outcome is promising: Using the quadcopters, hexacopters, and octocopters, the teams successfully navigated and inspected the towers, locating and recording images of all the flaws.

"The evaluations showed how we can use these systems to reduce the cost and risks of transmission line inspections while increasing their accuracy," said EPRI Senior Program Manager Fabio Bologna, who supervised the tests.

The tests also led to insights for using other sensors such as infrared and ultraviolet cameras. Researchers determined that cameras with a minimum of 16 megapixels are needed for useable images. Some drones can carry only one camera, but certain inspections may require two or three cameras. While the aircraft are relatively light, the ground control stations often are not. "The stations ranged tremendously, from very small to so heavy that you needed two people to lug it around," said Bologna.

Traditionally, teams of utility line inspectors climb tall towers or get hoisted on bucket trucks, which is time-consuming and potentially dangerous. The U.S. Bureau of Labor Statistics ranks power line installers and repairers as the ninth riskiest job in the country. "If you climb a structure and do a very detailed inspection, you won't get very many done in a day," said Bologna.

Other common methods include inspecting towers with binoculars from the ground 100 feet or more below or from inside a helicopter, which must maneuver at least 50 feet from electrified 345-kilovolt towers. Drones can fly much closer to the towers, providing a clearer picture of damage.

“An inspector in a helicopter may not be able to see everything at all the angles, like underneath and behind components,” said Bologna.

EPRI initially tested unmanned aerial systems for transmission line inspection in the late 1990s, but their imaging capabilities and cost made them unfeasible. Today’s systems cost less and are much lighter and more maneuverable. Some models can use autopilot capabilities to fly predetermined inspection paths around structures.

High-Voltage Testing

Beginning this year, researchers will evaluate drones as they inspect energized power lines in New York State. The tests will look at the effects of arcing, sparking, and electric and magnetic fields on the aircraft’s operation and help determine safe flying distances from energized lines. Researchers will also evaluate the effectiveness of infrared and ultraviolet cameras and other sensors, including how close and how stable they must be to provide a clear picture.

In the near future, Bologna expects that work now done by tower-climbing linemen will be done more safely and more precisely with drone-mounted equipment. “This is going to change a lot of things for the power industry,” he said. It may also help the public see drones as “the guys in the white hats.”

Key EPRI Technical Experts

Fabio Bologna

In Development

Beyond Filing Cabinets and Three-Ring Binders

A Strategy to Eliminate Paper in the Nuclear Industry

By Chris Warren

One of the most common materials traditionally required to build nuclear power plants in the United States is also one of the least expected: paper. Most operating plants in the United States were designed in the pre-personal computer era of the 1970s, when reams of paper were used for the blueprints and equipment manuals. When the builder turned a plant over to its new owners and operators, it came with a massive collection of documents and microfilm reels.

In the 2010s, it's difficult to imagine searching voluminous paper and microfilm repositories to find information necessary for plant operations. Indeed, the nuclear industry has made significant progress transitioning to electronic documents. But much work remains. As part of a multiyear effort to help the nuclear industry move away from its legacy reliance on paper documents, EPRI determined that plant personnel could spend 30–40% of their time searching for and validating information in various documents to ensure the accuracy of data for operations and engineering assessments.

Saving Time and Money for Nuclear Plants

In a 2014 study, EPRI probed the economic benefits of moving from paper documents to a *data-centric configuration management information system*. Widely used to manage complex projects, such as building and operating weapons systems and oil drilling platforms, *configuration management* is a systems engineering process that can enable quick retrieval of important information related to licensing, design, and operations. For example, 3-D digital models could replace nuclear plant blueprints, making it unnecessary to search through boxes of documents.

According to the EPRI study, fully adopting data-centric configuration management could reap savings of $8 billion at the 100 existing U.S. nuclear plants over the next 20 years. For the four U.S. plants under construction, the figure is estimated to be $1 billion over their projected 80-year life.

"We arrived at these figures by accounting for every person impacted by configuration management in nuclear plants," said EPRI Technical Executive Ken Barry. "We determined how many more hours they could devote to their jobs if they had electronic access to information and didn't need to look in the binders in the library to find it."

Consider the replacement or repair of a safety pump if its design were stored in a 3-D model. Instead of searching the library to find the pump's specifications, a plant operator could go to the model to retrieve information such as the pump's capacity and power. "The dream scenario: I have a 3-D model of the plant, I know where the pump is located, and I find it on the model and click," said Barry. "All the information needed for the replacement pops up on my screen."

Making Steady Progress

The scenario that Barry describes is already a reality in other industries. Some container ships and submarines are built, operated, and maintained using 3-D models.

Nuclear plants are more complicated to build and operate, but implementing configuration management systems can quickly yield savings and increase efficiency and safety. Many nuclear plant operators have digitized paper documents, synchronizing information once held in separate databases and ensuring that data needed often for operations can be accessed easily and electronically. "Today, most plants use electronic documents," said Barry. "It's a step in the right direction, but much more is possible."

Besides making the business case for configuration management, EPRI is working with the Nuclear Information and Records Management Association (NIRMA) and other industry stakeholders to develop guidelines for improving these systems. Guideline revisions are expected by 2017.

Key EPRI Technical Experts

Ken Barry

Technology At Work

EPRI Helps APS Thread a Vital Inspection Needle

By Chris Warren

It makes sinking a half-court shot in basketball look easy. To ensure that pressurized water reactors in certain nuclear power plants are functioning properly, it's necessary to insert an ultrasonic inspection device through three-quarter-inch nozzles on the reactor vessel's bottom head (known as *bottom-mounted instrumentation nozzles*).

Palo Verde Unit 3's reactor vessel has 61 bottom-mounted instrumentation nozzles.

There's little room for error. The technician must remotely guide a robotic arm from the top of the reactor to the bottom of a 110-foot-deep cooling water pool surrounding the reactor. Video transmitted from the delivery tool inside the reactor helps guide the technician through the task. "It takes the skilled hand of an operator to get the probes where they need to go," said EPRI Principal Project Manager Robert Grizzi. "It's like threading a very tiny needle." Nuclear plant operators conduct this comprehensive nozzle inspection when initial visual exams reveal potential areas of concern.

A Mock-up to Test the Inspector

This job cannot be done by just anyone. It is standard practice for nuclear utilities to hire specialized vendors to complete the inspection procedures, which are governed by federal regulations and American Society of Mechanical Engineers (ASME) codes and standards.

In 2013, Arizona Public Service (APS) asked EPRI to help ensure that the vendor it selected for comprehensive nozzle inspections at its Palo Verde Unit 3 nuclear plant could do the work properly. "The vendor needed to demonstrate that its inspection technique works and follows standards and federal requirements," said Grizzi.

To assess the vendor's effectiveness, EPRI built a full-scale replica of a bottom-mounted instrumentation nozzle at Palo Verde Unit 3, incorporating cracks and other defects in it. The vendor successfully inspected the mock-up in accordance with standards and regulations, locating all the cracks.

By qualifying the vendor, the demonstration enabled APS to decide to move forward with its inspection. It also helped the utility prepare for future inspections, avoiding extended outages.

"If APS didn't have the vendor, equipment, and processes ready for the comprehensive inspection, it could have taken five to six months to find and qualify the vendor," said Grizzi. "The plant can't go online until all that is in place."

Ready for Application to Other Plants

Given Palo Verde's unique reactor designs, the results of the EPRI-APS collaboration are not directly transferable to other nuclear plant operators. Nevertheless, the mock-up methods and experience equip EPRI to construct and test customized mock-ups for other plants. "There will eventually be follow-up work," said Grizzi. "When we have the opportunity to apply the same methods, it can enable as positive an impact for other utilities as it did for APS."

Key EPRI Technical Experts

Robert Grizzi, Leif Esp

Shaping the Future

Preparing Engineers for the Grid of the Future

By Garrett Hering

About 2,500 years ago, Greek philosopher Heraclitus memorably declared that the only thing constant in life is change. This applies as much to the 21st century electric power industry as it did to ancient Greece.

In the next five years, industry sources estimate that 40–50% of the U.S. utility sector's electrical workers will retire. The new generation of workers faces one of the most fundamental changes in the history of electric power: the widespread adoption and integration of distributed energy resources.

Students in GridEd's Electric Power Distribution Systems course in 2014 at Con Edison in New York

EPRI has created an educational initiative to train the next generation of power engineers for this industry transformation. Launched in 2013, GridEd—The Center for Grid Engineering and Education is a five-year, $6.4 million collaboration co-funded by the U.S. Department of Energy (DOE), 14 utilities, 1 independent grid operator, 4 partner universities, and 17 affiliate universities. GridEd's geographic focus is the Eastern United States, though it's expanding into the West. The initiative is part of the DOE's broader Grid Engineering for Accelerated Renewable Energy Deployment (GEARED) project.

"GridEd is addressing two high-level needs: preparing existing and future power engineers for changes in grid operations and replacing a large part of the workforce that is retiring," said Steven Coley, EPRI's GridEd project coordinator. "We are sharing the extensive work of EPRI and our partner utilities on integrating distributed energy resources into the grid, and we're fostering ties with the next generation."

Curriculum Focused on Changing Grid

With its growing selection of courses, tutorials, and events for practicing engineers and undergraduate and graduate-level scholars, GridEd is gaining momentum as a platform for power-engineering education and utility workforce development. GridEd is also developing teaching materials for primary and secondary schools, and K–12 outreach is underway.

Based on a survey of utility sponsors to identify gaps, GridEd in 2014 offered a tutorial series for industry professionals. The four 2-day courses, held at different locations in the Eastern United States, focused on electric utility industry business case analysis, power distribution systems, distribution system modeling, and distributed storage and generation technologies and applications.

The 59 participants earned a combined 848 hours of professional development. Based on their feedback, GridEd is expanding its short courses for industry professionals to include computer-based distance-learning opportunities.

The first tutorial of 2015—a one-day course at Salt River Project in Tempe, Arizona—provided a summary of the four-course series and emphasized distributed photovoltaic solar. Additional short course offerings in 2015 focus on distributed generation, distribution systems, and smart inverters and their ability to address voltage problems resulting from distributed solar.

Engaging Students

GridEd's four partner universities—Georgia Institute of Technology, University of North Carolina at Charlotte, Clarkson University, and University of Puerto Rico at Mayaguez—are leading an effort to assess and develop power engineering curricula for university undergraduate and graduate students. The course content will be presented at GridEd's 4 partner and 17 affiliate universities later in 2015.

University students can further engage in power engineering career development through GEARED student conferences and the GridEd Student Innovation Board, which consists of two students from each partner and affiliate university. The board advises GridEd, serves as a liaison between the initiative and students, and advocates for participation in GridEd activities, such as design competitions and research projects.

For primary and secondary schools, the universities are also helping GridEd develop introductory courses on electricity basics, fossil fuels, and renewable energy technologies. Feedback from high school teachers will help shape more advanced coursework for secondary school students. Georgia Institute of Technology and the GridEd co-funders are leading a summer program at four high schools in the Atlanta area, featuring classroom and laboratory work on solar and battery-powered systems.

"We are constantly developing GridEd and expanding the initiative based on feedback from students, universities, and industry professionals," said Coley.

Key EPRI Technical Experts

Steven Coley

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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.

3002007151

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