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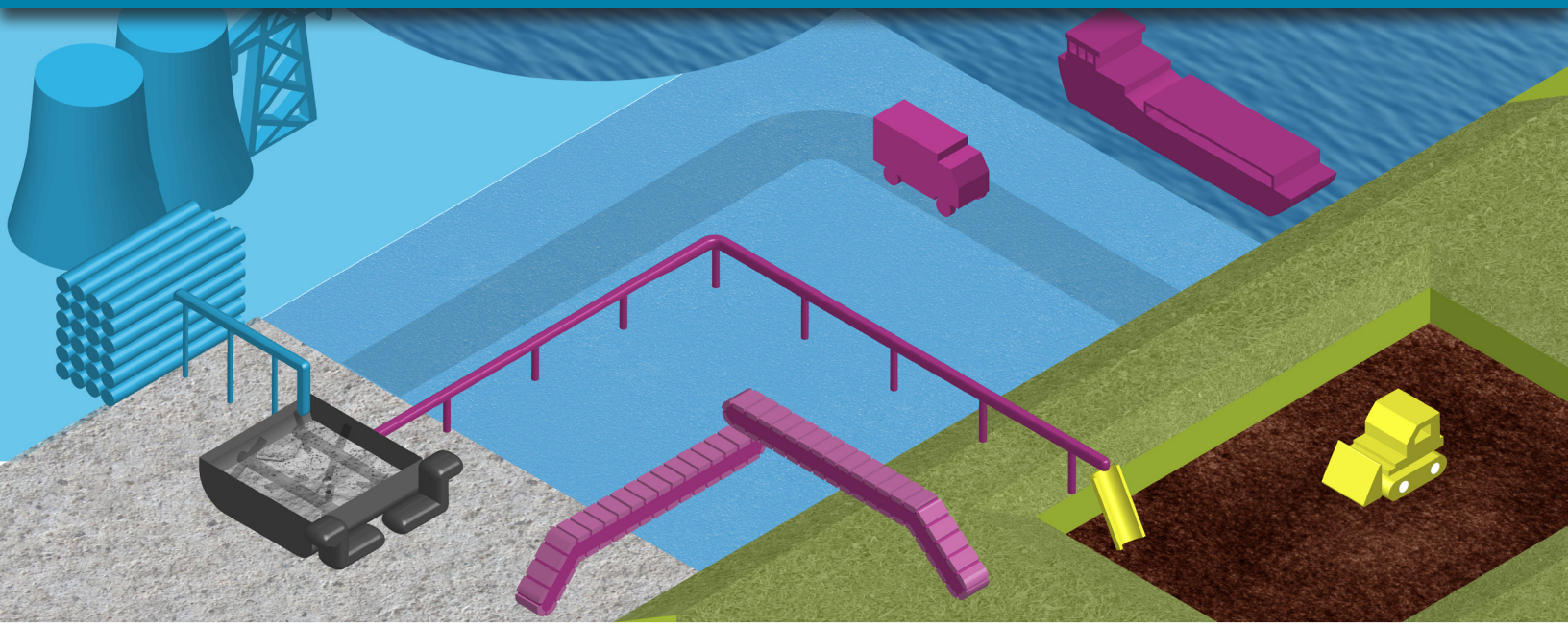
FROM POWER PLANT TO LANDFILL: ENCAPSULATION



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ELECTRIC POWER RESEARCH INSTITUTE

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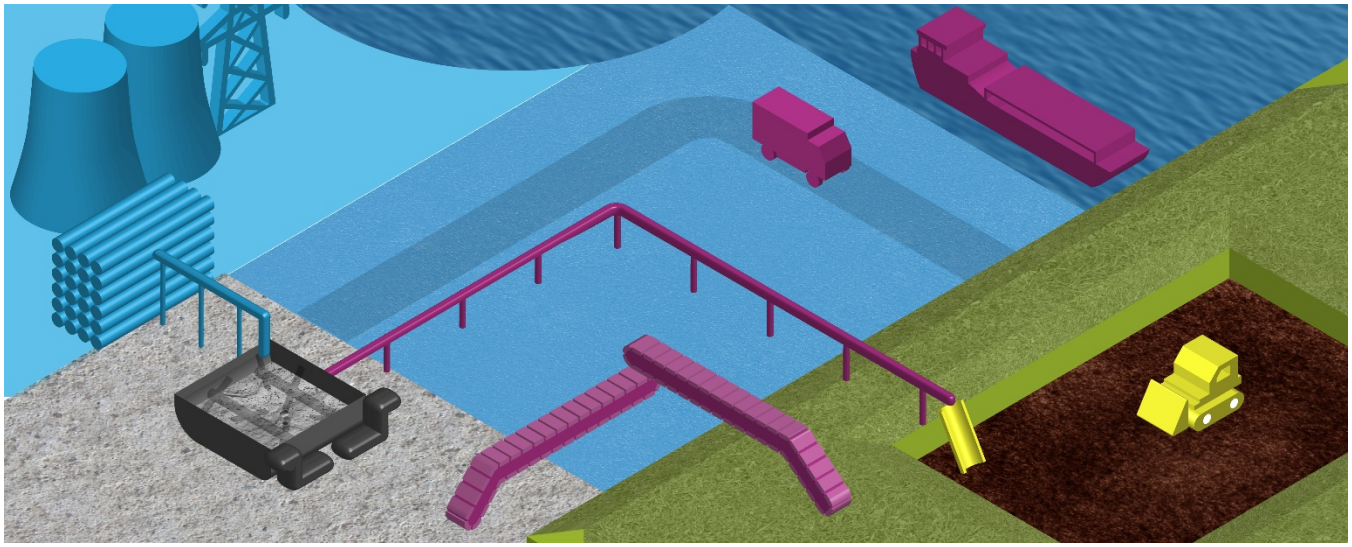


Innovative Technology Offers Elegant Solution for Disposing of Multiple Types of Waste

By Debbie Sniderman

A process known as encapsulation is a potential game-changer for waste management at coal-fired power plants. EPRI laboratory and field studies suggest that it could safely combine disposal of two waste streams now handled separately.

The first is coal combustion products, which include fine particles of fly ash typically stored in impoundments. Recent federal regulatory actions are driving operators to close these facilities and identify alternative disposal options such as landfills.

The second is wastewater streams, such as those produced by a plant's flue gas desulfurization systems that absorb sulfur dioxide emissions. Operators must treat such wastewater to comply with revised U.S. Environmental Protection Agency rules that include limits on dissolved solids and trace elements such as arsenic and mercury.

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

With encapsulation, brines are mixed with fly ash along with binders such as lime, producing a material that is transported to a landfill. This product can range from a low-moisture material with a soil-like consistency to a high-moisture, flowable paste. (Watch a video of the paste.) As the product solidifies in the landfill, its constituents stabilize chemically and physically. The solid should be resistant to rainwater infiltration, minimizing the leaching of constituents into the environment.

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

EPRI is among the first organizations to conduct in-depth research of encapsulating power plant wastes, building on recent studies by Sasol and Southern Company. EPRI researchers are investigating the chemistry and mineralogy of the initial ingredients, the reactions, and the final products, along with the entire chain of activities: mixing materials, transporting and landfilling the product, and monitoring its long-term stability.

Decades of applying encapsulation to manage contaminated soils and mining waste provide a technical basis for its application to power plant waste management.

The Logistics of Encapsulation

Encapsulation of power plant waste streams involves five main steps (see graphic below):

1. Treat wastewater to produce a brine.
2. Mix the brine with fly ash and other ingredients.
3. Transport the resulting product to a landfill.
4. Place the product in a landfill.
5. Manage the landfill.

The equipment needed for encapsulation may already be available. At the power plant, it would be necessary to deploy systems to move wastewater or brine, fly ash, and other ingredients to a mixer. Standard ash handling equipment such as pugmills could be used to combine the ingredients.

Siting the processing equipment will depend on the location of a power plant's ash handling and moisture conditioning system. Some operators may transport the ingredients for mixing at the landfill, while others may perform initial mixing at the power plant and final mixing during transport to the landfill. Some may manage the entire process—mixing, transport, and disposal in landfills—at the power plant.

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

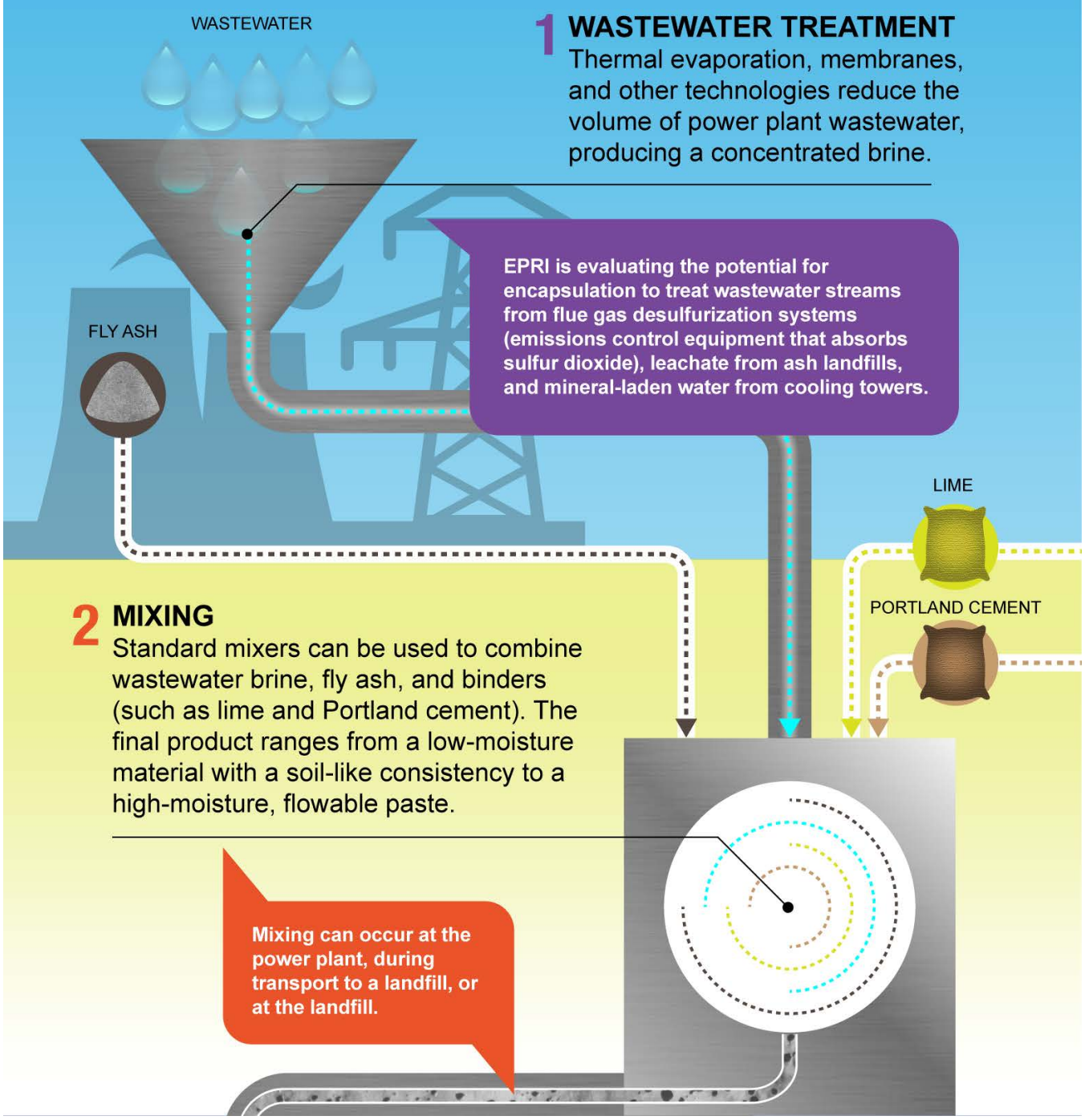
"There will be tons of material to move," said EPRI Senior Technical Leader Jeffery Preece. "In transporting it to a landfill, whether by land, in a paste pipeline, or on a barge, we have to understand how the material solidifies to avoid problems during transportation."

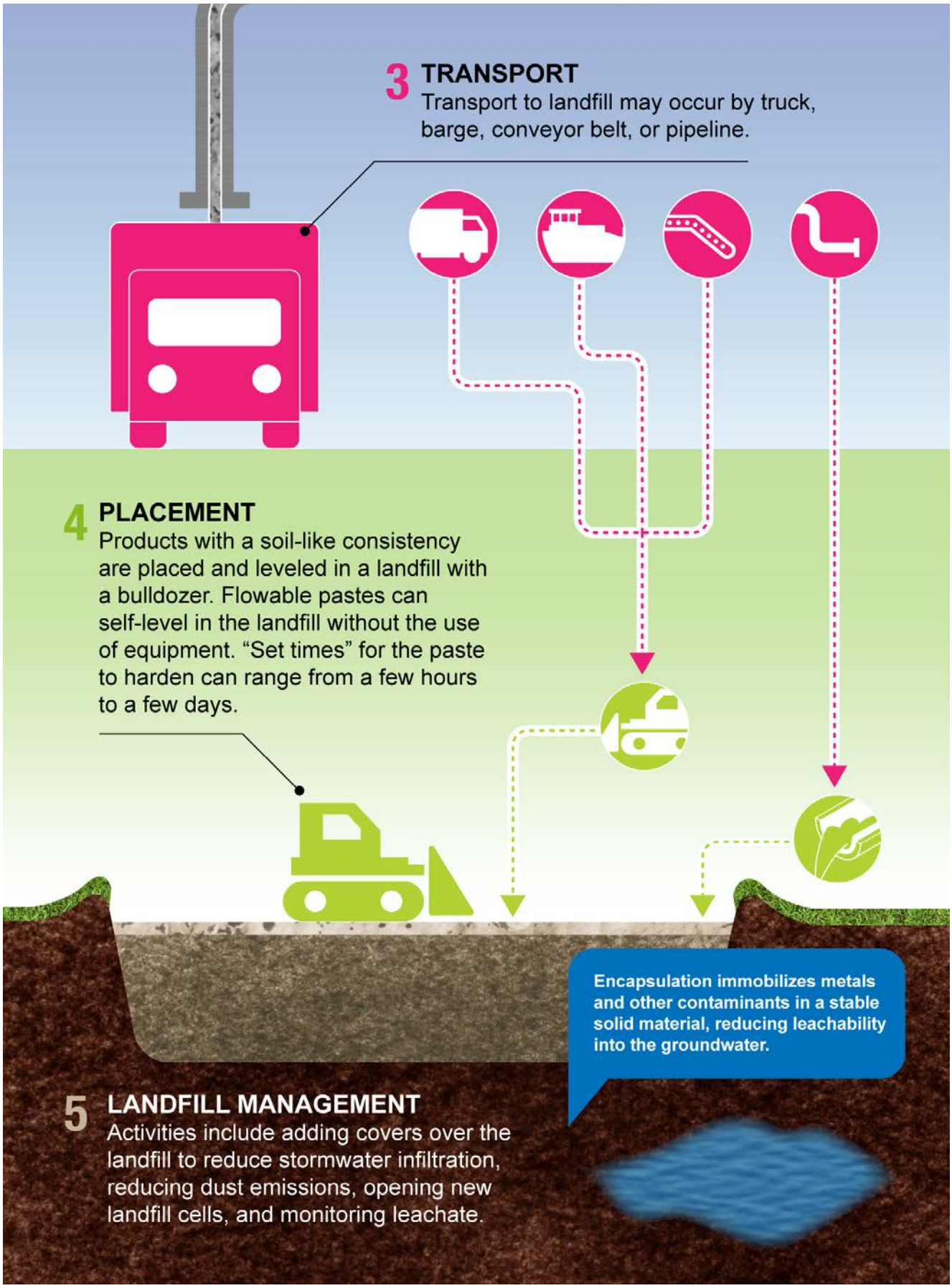
Because coal power plants usually have much more wastewater to dispose of than ash, it would be beneficial to maximize wastewater elimination. EPRI's research has focused on evaluating the high-moisture paste rather than the drier material because the former could potentially double the amount of wastewater a plant could eliminate.

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

Encapsulation: From Power Plant to Landfill

EPRI is examining encapsulation to treat power plant waste. This process binds waste materials into a stable form to minimize their release into the environment. This graphic shows how the process is envisioned to work at commercial scale.




3 TRANSPORT
Transport to landfill may occur by truck, barge, conveyor belt, or pipeline.
4 PLACEMENT
Products with a soil-like consistency are placed and leveled in a landfill with a bulldozer. Flowable pastes can self-level in the landfill without the use of equipment. "Set times" for the paste to harden can range from a few hours to a few days.
Encapsulation immobilizes metals and other contaminants in a stable solid material, reducing leachability into the groundwater.
5 LANDFILL MANAGEMENT
Activities include adding covers over the landfill to reduce stormwater infiltration, reducing dust emissions, opening new landfill cells, and monitoring leachate.

Diving into the Encapsulation Details

EPRI has completed a year of laboratory and field studies to help characterize and refine the encapsulation process.

In the laboratory, researchers investigated the chemistry of brine from treated flue gas desulfurization wastewater, which varies by coal type. For example, coal from the eastern United States produces wastewater with high salt content and reactive fly ash, while Powder River Basin coals yield wastewater with relatively less concentrated salts and more reactive ash. EPRI evaluated different mix recipes, the reactions among ingredients, and the final products' chemical and physical properties.

"We're compiling a first-of-its-kind database with information about the various materials that form from these chemical reactions," said Preece.

Field studies in 2016 looked at four different wastewater chemistries at two coal plants, including flue gas desulfurization wastewater, blowdown, and leachate from an on-site ash landfill.

At the Water Research Center at Southern Company's Plant Bowen, a pilot encapsulation system mixed wastewater with fly ash, lime, and other binding materials to produce a chemically and physically stable paste. EPRI and Southern Company compiled data on the mixing process, the chemical reactions, and the differences among brine chemistries. They examined various aspects of landfill management, such as placing the paste, adding covers for stormwater runoff, reducing dust emissions, and determining when to open new landfill cells.

"We developed recipes and figured out how to move the product to a disposal facility," said Southern Company Senior Engineer Benjamin Gallagher. "We found that mixtures could be pumped and placed effectively, demonstrating that the technology is ready for full-scale testing. By testing chemically and physically diverse materials, we covered the gamut of conditions across our fleet and found that we can encapsulate wastewater from any of our plants."

Encapsulation may not be cost-effective at plants where wastewater volume is very large relative to the volume of ash, because wastewater volume reduction systems can be capital- and energy-intensive.

"Encapsulation is the leading option for several of our power plants because it saves capital investment costs compared to wastewater treatment systems—and the final product has favorable environmental properties," said Gallagher. "There's no wastewater to discharge, which helps us streamline compliance with wastewater permits."

Expanding the Field Tests, Fine-Tuning the Processes

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

A mobile mixer used for creating paste on-site for field-scale testing.

“At a range of sites, we’re going to field-test a pilot encapsulation system with an off-the-shelf grout mixer, along with different evaporative technologies for making wastewater brines,” said Ellison. “We plan to establish test landfill cells, fill them with encapsulated material, and monitor runoff and leaching for one to two years.”

EPRI will continue to optimize brine chemistries and encapsulation recipes that yield impermeable products, and will evaluate the various costs—capital investment, equipment operations and maintenance, and materials transportation. EPRI will investigate applying encapsulation to difficult-to-treat wastewater streams such as those from carbon capture and storage, which can be three times saltier than ocean water.

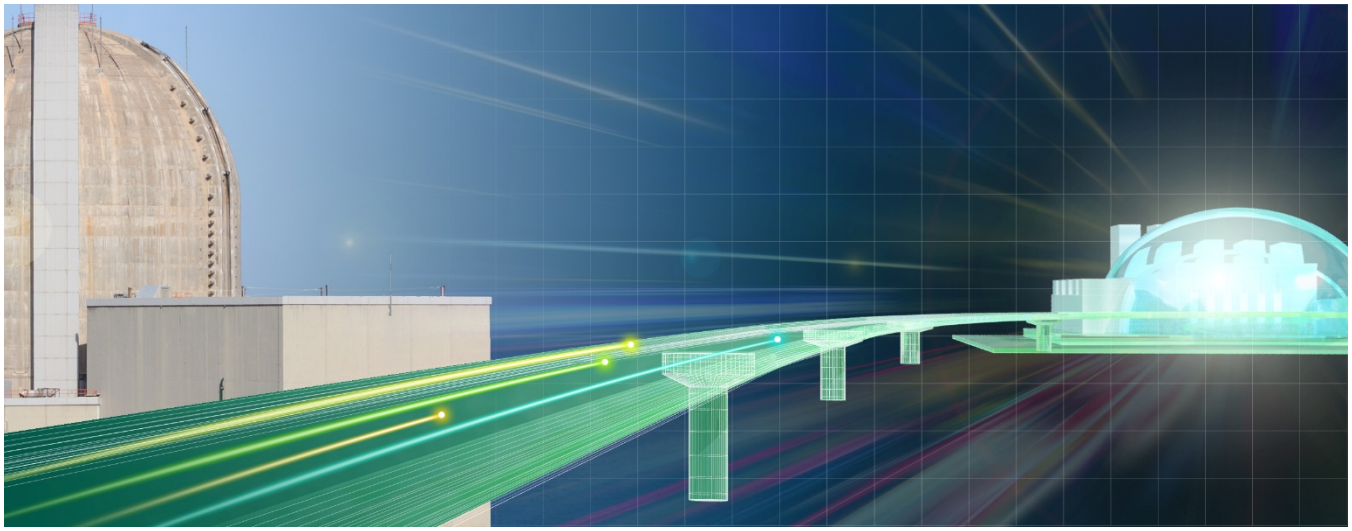
“Could encapsulation be used at any power plant and for other types of wastewater? As we get more answers about the chemical reactions and the properties of the products, we’ll be able to answer that more clearly,” said Preece.

“Developing a cost-effective, reliable technology that effectively eliminates the discharge of wastewater at power plants would be a great win for the energy industry,” said Southern Company’s Generating Fleet R&D Manager Jeff Wilson. “The results of encapsulation testing at the Water Research Center show that this technology has a promising future.”

Key EPRI Technical Experts

Kirk Ellison, Jeffery Preece

Nuclear Plant Life Extension: A Strategic Bridge



By Brent Barker

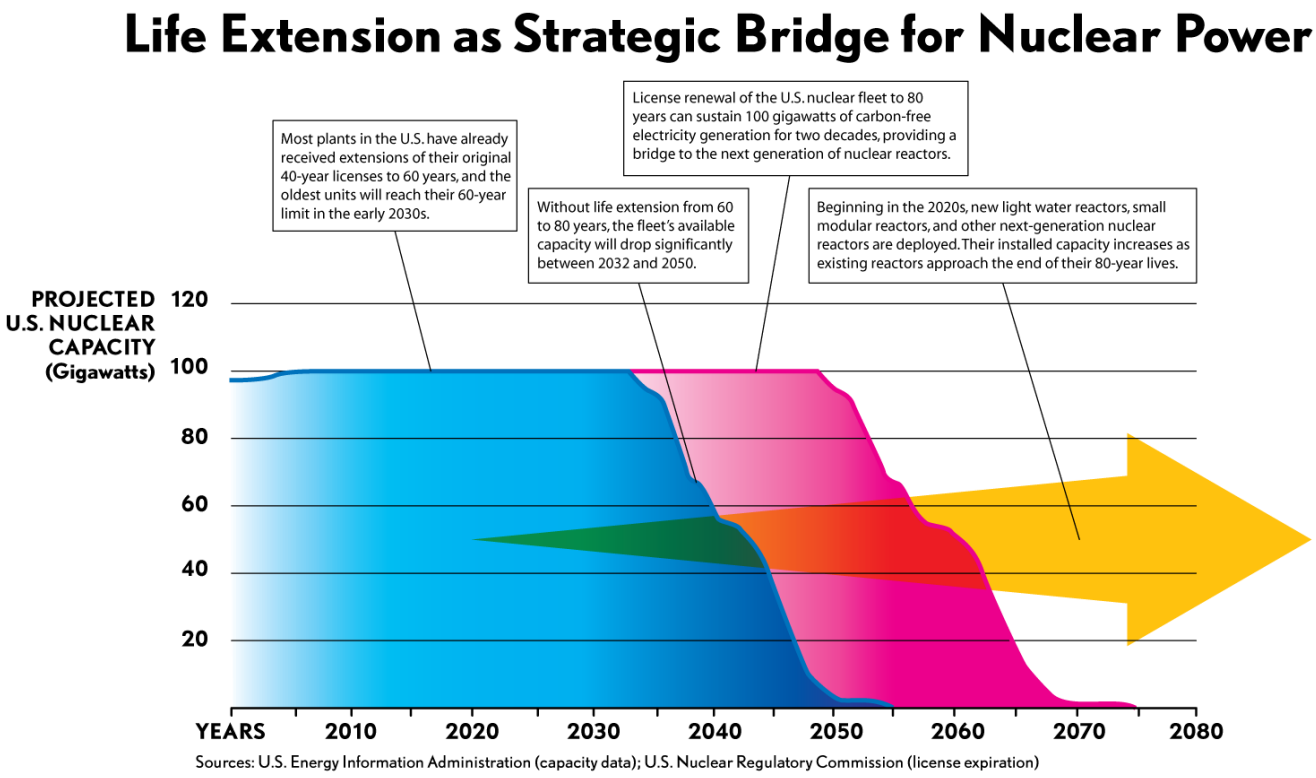
The nuclear fleet in the United States has reached a milestone. The U.S. Nuclear Regulatory Commission (NRC), which originally licensed plants to operate for 40 years, has now approved 20-year license extensions for more than 75% of the fleet, enabling operation to 60 years. The fleet is now moving forward with plans for a second round of license renewals (which the NRC calls “subsequent license renewals”) to allow operation out to 80 years.

Two utilities have announced their intent to submit applications for this second round. In 2018 Exelon expects to submit an application for its 2,800-megawatt Peach Bottom Atomic Power Station (two boiling water reactor units), and Dominion Energy expects to submit for its 1,600-megawatt Surry Power Station (two pressurized water reactor units) in 2019.

License renewal involves a systematic review of the plant, identification of degradation mechanisms, and the development of aging management programs. It proceeds through coordinated efforts on two distinct fronts—regulatory and technical. Participants in regulatory activities include electric utilities, the NRC, and the Nuclear Energy Institute. Technical work is being conducted by EPRI, U.S. Department of Energy (DOE), the national energy research laboratories, several universities, and the International Atomic Energy Agency.

Absent the second extensions, U.S. nuclear units will retire as they reach the end of their 60-year lives, and U.S. nuclear generation would begin a steep downward slope in the early 2030s. By 2035, approximately 30,000 of today’s 100,000 megawatts of nuclear capacity would be offline. By 2050, the current light water reactor fleet would be nearly gone (see graphic below).

The second round of license renewals represents a bridging strategy. It can potentially sustain a large source of carbon-free generation for an additional 20 years until deployment of the next generation of nuclear power units, including new light water reactors, small modular reactors, and other advanced reactor designs.

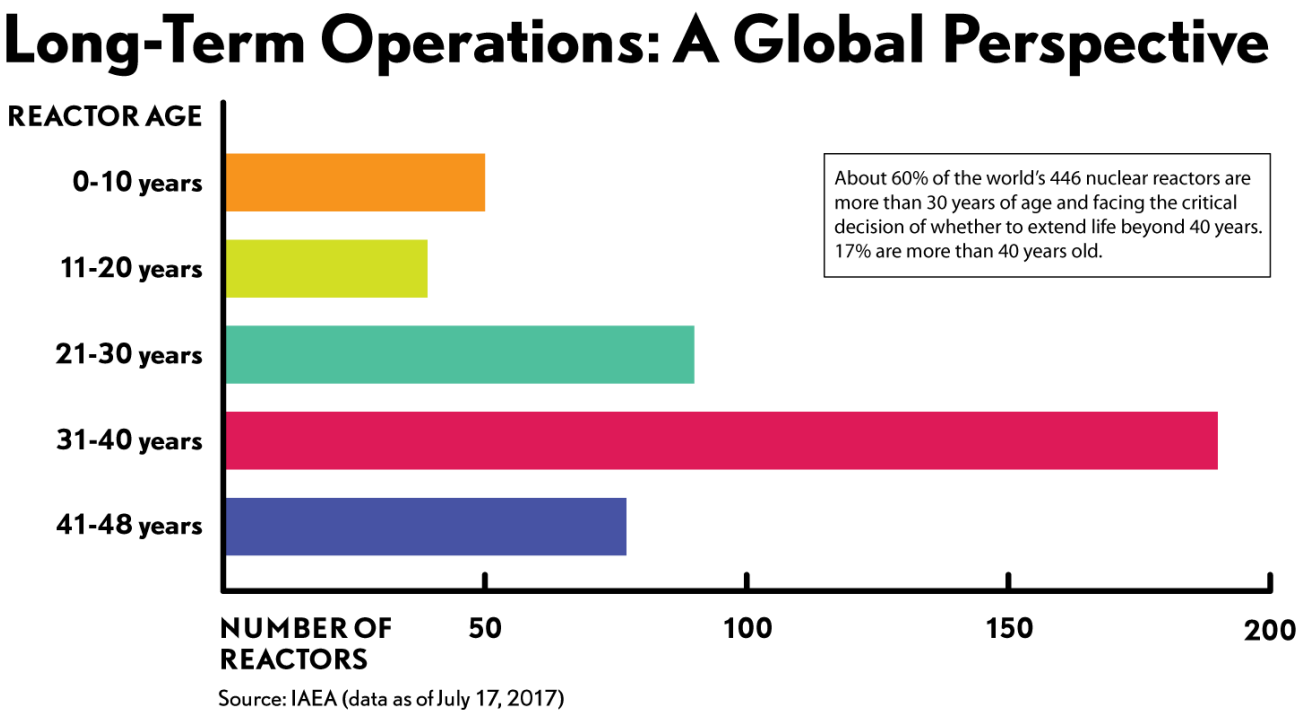


A Solid Foundation for the Second Round of Renewals

In 2014, the NRC concluded that the second round of license renewals can use the existing regulatory framework without rule changes, directing its staff to update license renewal guidance.

“This is a very positive result for the industry for a predictable review and approval process,” said Mark Sartain, Dominion Energy’s vice president of nuclear engineering.

In 2015, the NRC staff issued a draft report that provides aging management guidance for plants seeking to operate from 60 to 80 years. Referencing more than 125 EPRI studies, the document establishes the technical basis for the second round of license renewals. (An earlier NRC document called the Generic Lessons Learned Report identifies and reviews nuclear plant aging management programs acceptable for first license renewals from 40 to 60 years.)



No Technical Showstoppers

Established in 2008, EPRI's Long-Term Operations Program provides research and technical basis that can inform utilities' license renewal efforts and aging management programs. It draws on a broad body of technical expertise and decades of research in materials, engineering, and plant operations.

"We've been actively working with Dominion Energy and Exelon so that our technical results can inform their decisions and preparations for anticipated license renewals," said EPRI Senior Program Manager Sherry Bernhoft. "Long-term operations focuses on the components that are most critical to safety and hardest to replace: the reactor pressure vessel, reactor internals, large concrete civil structures, and the cable-supported nervous system of the plant. Replacing any of these components would most likely be cost-prohibitive and lead to plant closure."

Life extension to 80 years is technically feasible. "From all the research undertaken so far, we have not found a technical showstopper that would prevent a plant from operating safely for 80 years," said Bernhoft. "The caveat is that plant owners and operators will need to update and implement aging management programs for the critical components."

Effective aging management requires an understanding of the aging mechanisms and when and how to inspect, along with thorough evaluation of inspection results and good repair/replacement decisions.

"Just like with your own health, you inspect important areas more and take commensurate preventative measures as plants get older," said Bernhoft.

EPRI's long-term operations research focuses on:

- Neutron embrittlement of reactor pressure vessels
- Irradiation impacts on reactor vessels' internal components or "internals"
- Concrete degradation as a result of alkali-silica reactions and radiation
- Degradation of electrical cables and cable monitoring tools

Aging of Metals

Of greatest concern in a reactor pressure vessel is the possible reduction of its fracture toughness as a result of high fluence and high temperatures. For monitoring, irradiation surveillance capsules are placed inside, then periodically removed and tested. Extensive knowledge of embrittlement trends can be used to predict material properties out to 80 years of operation.

"We continue to monitor reactor pressure vessels, but there is nothing to indicate that the plants are not safe to continue operations," said EPRI Senior Technical Executive Robin Dyle. Advanced welding techniques such as laser welding and friction stir welding are being developed to repair highly irradiated materials.

Reactor internals operate in a harsh environment with respect to neutron bombardment, water chemistry, and temperatures. "Boiling water reactor operators have been evaluating the impacts longer than the operators of pressurized water reactors," said Dyle. "Boiling water reactors had degradation of reactor internals earlier in life, and the operators have a well-documented inspection program based on more than 20 years of experience to confirm that components are safe."

EPRI determined that pressurized water reactors have strong aging management programs as well, but some components have failed. Researchers had anticipated—and confirmed with inspection—that baffle-former bolts could fail due to stress corrosion cracking. The NRC concluded that there is no safety problem, but utilities and EPRI responded by changing inspection protocols to combine visual and ultrasonic techniques during scheduled outages.

Aging of Concrete and Civil Structures

Concrete degradation can occur as a result of irradiation and chemical reactions.

"Silica in the concrete aggregates can be highly reactive with the alkali in the cement, especially at high temperatures and humidity," said EPRI Technical Leader Sam Johnson. "Alkali-silica reactions form a gel around the aggregate that can stress the concrete and cause cracks, typically in radiating patterns that resemble spider webs. Because of reinforcement, this doesn't necessarily mean the concrete has lost any of its strength."

If cracks are large enough, water and chlorides can seep in and cause reinforcement corrosion. Such cracks can be sealed.

Aging management includes monitoring concrete structures around the plant for structural integrity and movement. "Concrete expansion as a result of alkali-silica reactions may cause misalignment of equipment, and we need to make sure alignment is within an acceptable range," said Johnson.

Inside containment, a key concern is irradiation of the bioshield, a large concrete structure that surrounds the reactor to reduce the effects of neutrons and protect workers. EPRI and others have conducted substantial research on how radiation impacts the concrete. A modeling study of a pressurized water reactor's bioshield showed that significant structural margin remained after an equivalent of 80 years of irradiation. The upshot: Irradiation effects are unlikely to be a technical challenge for the second round of license renewals.

Aging of Cables

Heat, radiation, and water can accelerate aging of cable insulation. Degradation is typically localized because cables often run through many different environments from beginning to end.

“Some run between buildings—for example, from office and equipment rooms into the turbine building and heater bay,” said EPRI Principal Technical Leader Drew Mantey. “Others run underground, through conduits embedded in concrete susceptible to moisture or through penetrations into containment. Some even run side-by-side with steam lines. Exposure and degradation vary segment by segment.”

In 2009 EPRI, in collaborative efforts with its members, developed aging management guidelines for the three categories of cables, drawing on industry experience and decades of research:

- Low-voltage cables for instrumentation and controls
- Low-voltage cables for motors and equipment
- Medium-voltage power cables, particularly those in wet environments

“The NRC has issued industry guidelines for aging management of cables for the first license renewals from 40 to 60 years,” said Mantey. “To prepare for life extension to 80 years, we brought together experts from the NRC, EPRI, DOE, and the national research laboratories to identify knowledge gaps.”

Led by Mantey, the group assigned areas of responsibility among the participants, with EPRI focusing on medium-voltage cables vulnerable to moisture, including those that run through conduits embedded in concrete.

“To inform cable research, EPRI is measuring radiation and temperature at an operating plant. Do we have to consider both temperature and radiation for predicting degradation, or is one predominant? We should have an answer soon,” said Mantey.

A search for better monitoring technologies is underway. “For medium-voltage cables, we have a good tool known as the very low frequency tan delta test that tells us we may have a problem somewhere along the cable, but not specifically where. And we have tools that tell us we have an anomaly at a particular place on the cable, but not whether it is a problem. We’re developing a new tool that indicates where degradation is a problem along the full length of a cable,” said Mantey.

Surry, Peach Bottom, and Beyond

Surry’s license renewal application remains on schedule for submission in the first quarter of 2019, according to Dominion Energy’s Mark Sartain. “We don’t feel there are any technical issues that cannot be managed through aging management,” he said. “To support our aging management, Dominion Energy has used EPRI research such as inspection guidelines for steam generators, reactor vessel internals, and water chemistry.”

According to Michael Gallagher, Exelon’s vice president of license renewal and decommissioning, it will take the NRC 18 months to review Exelon’s license renewal application for the Peach Bottom plant, which includes on-site audits and inspections, public meetings, and an environmental impact report.

“Exelon will devote approximately 100,000 man-hours to prepare and shepherd through the second license renewal,” said Gallagher.

Together, Surry and Peach Bottom can usher in the second wave of life extension for the entire industry.

“Research on long-term operations by EPRI and its collaborators—coupled with the industry’s success in meeting the requirements of the first round of license extensions—provides a strong technical foundation for the second round,” said Bernhoft. “Experience from Surry and Peach Bottom will help lead the way toward safe license renewal out to 80 years for dozens of other U.S. utilities. Success in the U.S. will help inform international license renewal guidelines and safe operations in countries where nuclear plants are 5–10 years younger.”

Key EPRI Technical Experts

Sherry Bernhoft, Robin Dyle, Sam Johnson, Drew Mantey

First Person—Advancing Safety in a Growing, Interconnected Fleet

The Story in Brief

Peter Prozesky is the CEO of the World Association of Nuclear Operators (WANO), which works to maximize safety and reliability in the global nuclear fleet. Prozesky speaks with *EPRI Journal* about the importance of reporting and sharing experiences globally, peer reviews, building expertise in countries that are new to nuclear power, and adapting to new technologies.

EJ: What are your top three insights during your first year as WANO's CEO?

Peter Prozesky

Prozesky: The first insight: It's important for the global nuclear community to support knowledge transfer from experienced to new personnel in countries with new nuclear programs and at companies with rapidly expanding fleets. Organizations such as the International Atomic Energy Agency (IAEA) and WANO need to engage with operators at the earliest stage—even before new plants are built. For IAEA, that can mean helping a country develop the necessary regulatory infrastructure. WANO needs to engage at various points as companies transition from construction and commissioning to safe, reliable operations.

A second insight relates to industry initiatives that began after Fukushima. While many have been completed or are well developed, some remain fragile. In a few countries, significant energy market pressures are weakening resolve to follow through with these interventions. WANO seeks to prioritize its resources to assist plants furthest away from excellence.

Third, plant operators and suppliers must responsibly introduce new digital control technologies by reporting, sharing, and discussing experiences during commissioning and operations.

EJ: What are your major objectives at WANO?

Prozesky: WANO's members are plant owners and operators, and its main products and services are peer reviews, support missions, training and development, and performance analysis. After Fukushima, some industry stakeholders observed that programs were not being delivered consistently across all regions. In response, we've introduced an oversight role in our London office to drive standards and consistency globally. This process is well underway and is a primary objective during my tenure. Given the market pressures on our members, WANO must deliver these products and services efficiently.

Post-Fukushima, WANO has expanded its peer review program and now conducts reviews at plants every four years. Corporate peer reviews will happen every six years. We began providing the CEO of each WANO member with a confidential, numerical performance assessment following a peer review at one of its plants. This is intended to strengthen accountability among members, and I would like to see nuclear CEOs discussing these ratings with each other to drive a strong learning and improvement culture.

EJ: In the global nuclear fleet, an incident at one facility impacts facilities across the world. How does this interconnectedness inform WANO's work?

Prozesky: WANO was founded on the idea that prompt reporting of serious events can prevent repeat occurrences, and our first program in 1989 was sharing of event information. All WANO members are required to report plant events following well-defined criteria. Our database of reported events is robust, but we still occasionally see 'silent' units that do not report any events in a year. We routinely assess the reporting culture and pursue improvements with these units.

When plant operators receive information on major events, they are responsible for applying lessons at their facilities. For example, WANO issues 'Significant Operating Event Reports,' which identify contributors to major events and recommend preventive measures. Implementation of these recommendations is mandatory and is evaluated during peer reviews at operational plants as well as at new units prior to fuel loading.

WANO is encouraging its members to work with vendors and construction companies to be more transparent about reporting events that occur during construction and commissioning. These can range from industrial safety events to technical challenges with components.

EJ: Global nuclear generation is expected to nearly double by 2040, with most of this growth occurring in developing countries. What is WANO's strategy to support these countries' efforts to build operational expertise, human resources, and a safety culture?

Prozesky: If announced expansion plans come to fruition, we will see a shift in the center of gravity of nuclear operations. The number of nuclear power countries has been relatively stable at about 30 for decades. This may grow by as much as 50% in the next two decades. The challenge is that many new entrant countries lack the infrastructure needed for a nuclear program.

WANO and IAEA are working together on this. Typically, IAEA is the first to get involved, helping a new entrant to assess and develop infrastructure. WANO usually gets involved when an operator is about to sign a contract for construction of a nuclear plant. WANO's New Unit Assistance program has 17 customizable training modules covering topics such as safety culture and establishing corrective action programs.

We also conduct peer reviews at new units prior to the first fuel loading to assess safety decision-making and operational readiness. Our teams observe the new operations personnel in challenging simulated scenarios such as accident management. If shortcomings are identified, WANO will require remediation prior to the first fuel loading or reactor startup.

To meet the growing need for services, WANO has increased staff at all of its offices and is redistributing resources to provide stronger support for new entrant countries and new units.

"The number of nuclear power countries has been relatively stable at about 30 for decades. This may grow by as much as 50% in the next two decades. The challenge is that many new entrant countries lack the infrastructure needed for a nuclear program."

EJ: How is WANO working with the nuclear supply chain?

Prozesky: We do not have any vendors or suppliers in our membership. Our influence is only indirect, through the organizations that purchase and operate the plants. We engage owners and operators early in plant contracting and construction, assisting them as they work with vendors. With emerging business models such as 'Build-Own-Operate,' WANO may need to engage more directly with companies in the supply chain. This is being assessed.

EJ: What do you see as the biggest challenges in advancing safety and reliability in the growing global nuclear fleet?

Prozesky: As mentioned previously, market pressures for nuclear plant owners and operators are a challenge. An imbalanced focus on cost reduction risks undermining equipment health and organizational resilience. When it is no longer possible to maintain safety and cost-effectiveness, retiring the plant is the only responsible decision.

The rapid expansion of nuclear fleets in certain parts of the world is straining their ability to build the required skills and experience in the workforce. In some cases, capacity building efforts have started too late.

Complacency continues to be a challenge. While the nuclear industry has made significant improvements over the past four decades, these have sometimes been in reaction to a large 'wake-up call' event. As the memory of Fukushima fades, the question remains—how can we maintain our culture of continuous improvement and prevent consequential events?

"As the memory of Fukushima fades, the question remains—how can we maintain our culture of continuous improvement and prevent consequential events?"

EJ: Small modular reactors are under construction or planned in countries such as China, Russia, and the United States. What are WANO's plans for engaging small modular reactor operators and sharing their experience globally?

Prozesky: WANO's products and services draw on the skills and experience of personnel who come from our members, but none of our current members operate small modular reactors. As the first small modular reactor in China approaches its pre-startup peer review, we have begun to build relevant skills in our staff. We are establishing industry working groups focused on specialized topics such as new entrants, and I envision that one of these groups will examine how WANO's products and services need to be adapted for small modular reactors.

EJ: How does WANO plan to incorporate Generation IV reactors and other new reactor technologies into its programs?

Prozesky: As reactor technology changes, we will need to adjust our programs so that they continue to advance safety. It is a bit early for WANO to be working on these changes right now, but we will do so as we understand new reactor types in greater detail. We have begun to conduct what we call 'design-informed peer reviews,' which seek to identify areas for improvement in the context of a plant's design. Such an approach will help us to accommodate significant design changes such as those in Generation IV reactors.

EJ: New digital technologies such as wireless workers and monitoring are being deployed in nuclear plants. What are your views on these changes, and how can R&D help?

Prozesky: I am an advocate for these 'intelligent' technologies. The new generation of workers has grown up in a connected world and is familiar with digital technologies. Tools such as handheld devices for delivery of field instructions, plant component identification, and work management offer huge potential to improve human performance.

Research is needed to investigate concerns about radio frequency interference in older plants. We also need to carefully consider cyber security when digital control systems are being designed.

But we must never lose sight of the fact that success in our industry is the result of many things in addition to a robust plant design—such as good leadership, a skilled and engaged workforce, a healthy safety culture, a commitment to continuous improvement, and an effective regulator.

For more about WANO and how it achieves its mission, go to www.wano.info.

‘Clean Energy’—It’s *Action*, Not a Category

Mike Howard, President and Chief Executive Officer, EPRI

Many people apply the term “clean energy” narrowly—to describe renewable sources such as solar, wind, hydro, and geothermal. For EPRI, we think of “clean energy” as action and progress across the full portfolio of energy production, delivery, and use.

This broad application of the term is necessary because it directs our thinking and our research portfolio to account for and to address all environmental aspects of energy. Simply stated, at EPRI we view the word “clean” as a verb rather than an adjective, describing actions to make energy cleaner—regardless of its source or the stage of production, delivery, and use.

Consider this article in the September/October *EPRI Journal*, which reports on a process that encapsulates coal combustion products, including fly ash. While the typical application of “clean energy” to coal might be disputed by some, EPRI research on encapsulation demonstrates how innovation can “clean” energy.

Regulatory actions are driving coal-fired generation plant operators to close impoundments typically called *ash ponds*. In contrast to the traditional water/ash mixture pumped into ponds, or the landfilling of ash, the encapsulation process results in a by-product that solidifies in a landfill, where its constituents stabilize chemically and physically—thereby minimizing the leaching of constituents into the environment.

Also significant is that the process may prove helpful in managing wastewater streams from plants’ flue gas desulfurization systems. The brine that is produced in treating these wastewaters can be used in encapsulation. For scientists and engineers, such win-win technologies are particularly gratifying. For the process overall, EPRI is investigating the chemistry and mineralogy of the initial ingredients, the reactions, and the final products, along with transporting and landfilling the product and monitoring its long-term stability.

EPRI Journal also reports on a positive development in dealing with gypsum, which is another by-product of coal plants’ desulfurization technology. On eight Ohio farms, we have been measuring the effectiveness of applying

gypsum to reduce phosphorus runoff from fertilizer use. This can make an important contribution to the health of surface waters and aquatic organisms. Our monitoring over a three-year period measured runoff reductions of 20–95% relative to control fields.

These examples reveal the value of bringing the problem-solving approach to every aspect of energy. A technology to help clean up emissions can be used to improve solid waste management and water quality.

This reminds me of the basic recipe for soap-making that goes back thousands of years. Some alert, innovative ancestor figured out that boiling wood ash in water produced a liquid that could be mixed with animal fat to produce soap. We have no way of knowing how the first soap-maker figured that out, but along with EPRI's work that I've highlighted above, these stories point to the importance of being alert and innovative to clean up after ourselves.

Making energy cleaner also requires quantifiable, methodical evaluation and analysis. Utilities closing their coal ash ponds need a consistent, measurable approach to understanding the environmental aspects of their decisions.

EPRI has developed a framework for analyzing and assessing options, reported in this article. Because such frameworks are technical and specialized, it can be a challenge to describe them to the public or to key stakeholders. But they can provide a technically valid basis for regulatory compliance and can help assure the broader public that environmental issues are addressed effectively. With EPRI's framework, utilities can quantitatively assess:

- Impacts to groundwater and surface water
- Impacts to air quality
- Probability of accidents
- Energy consumption, water use, and other impacts on natural resources

These are just a few aspects of our progress in clean energy. Like the long-ago discovery that we can make soap out of wood ash and animal fat, or today's application of gypsum to farm fields, we can harness human ingenuity to help clean up. We can put the scientific method and engineering discipline to work in ever more rigorous ways so that clean energy is more than a category—it is a work in (human) progress.

Mike Howard

President and Chief Executive Officer, EPRI

In the Field

Coal Ash Impoundments—Cap or Move?

EPRI Tool Helps Evaluate Best Course of Action

By Scott Sowers

A new EPRI tool can provide utilities with a comprehensive understanding of the impacts of closing coal ash surface impoundments, guiding more effective decision making.

With recent federal regulatory actions and the retirement of power plants, coal ash impoundments are closing at an unprecedented rate. Utilities have two options:

- Cap the impoundment.
- Excavate, transport, and dispose of the ash in a lined landfill; then refill the former impoundment.

Closing in place can reduce—but does not always eliminate—leaching of toxic contaminants from the impoundment to groundwater. Removing ash can eliminate future leaching, but it involves significantly more construction, with greater impacts to air quality and community safety. Removing ash often takes longer and can result in significant leaching during excavation. Balancing the relative advantages and disadvantages of the two options is complex, requiring input from various experts.

EPRI's Relative Impact Framework tool provides a way to organize and effectively analyze the expert input.

"EPRI developed this tool because our utility members were asking for a method to scientifically evaluate different alternatives for closing their coal ash facilities," said EPRI Principal Technical Leader Bruce Hensel.

The framework guides the user through a series of steps to quantitatively assess:

- Impacts to groundwater and surface water
- Impacts to air quality
- Probability of accidents
- Energy consumption, water use, and other impacts on natural resources

After EPRI tested the tool on a hypothetical site, it worked with Tennessee Valley Authority (TVA) to demonstrate its use with 10 TVA impoundments.

"We saw using EPRI's tool as an opportunity to inform our decision with respect to each impoundment," said TVA Senior Program Manager Anne Aiken.

TVA included the analyses in an Environmental Impact Statement, but the schedule did not provide time sufficient to collect all the data necessary for a full quantitative assessment. As an alternative, EPRI and TVA developed a method to qualitatively analyze the relative impacts of options for the TVA impoundments. After EPRI used the tool to quantitatively assess the hypothetical impoundment, the characteristics of the TVA impoundments were compared with those of the hypothetical site. Once the differences between the TVA sites and the hypothetical site were established, the results from the assessment of the hypothetical site were adjusted to account for the conditions at the TVA sites. The tool helped TVA with elements of its Environmental Impact Statement and provided additional credibility.

For closing in place, the analyses found that removing the water and capping the impoundments would reduce groundwater contamination and structural stability risks. Compared with ash removal, closing in place presented significantly lower risks related to workforce health, safety, and transportation (such as crashes, derailments, and road damage).

TVA elected to close all 10 impoundments in place and identified measures to minimize potential adverse impacts, including dust control systems, erosion and sediment control to protect surface waters from construction impacts, and revegetation with native species.

“The framework supports simple to complex modeling approaches to determine the impacts to groundwater, surface water, and air,” said Aiken. “Closure timelines can play an important role in the impacts.”

“The tool provides a way to organize and present information on multiple environmental media in a way that makes sense to people,” said Hensel. “It serves as a guide for making logical yet difficult decisions. This in-depth investigation can be expensive, but is a small fraction compared to the overall cost of either closure alternative.”

For its work applying the tool, TVA won a 2016 EPRI Technology Transfer Award.

Key EPRI Technical Experts

Bruce Hensel

In Development

Sustainability: "An In-Depth Look at Value Creation"

Business and Economic Issues Become More Important for Sustainability at Utilities

By Chris Warren

When Morgan Scott was tasked with refining and updating Con Edison's sustainability strategy in 2013, she gathered ideas from an EPRI report detailing 15 sustainability issues most relevant to the North American electric power industry. "That report helped us focus our sustainability efforts," said Scott.

Four years later, Scott is an EPRI Senior Technical Leader working with hundreds of stakeholders to update that EPRI study, accounting for changes in the sustainability concept and the industry. After reviewing utility sustainability reports and publications by academics, non-governmental organizations, regulators, financial institutions, and consultants, Scott and her team identified 28 priority sustainability issues with economic, environmental, and social aspects.

Next, they interviewed experts at more than 35 organizations, including Harvard University, Stanford University, Wells Fargo, JP Morgan, Rocky Mountain Institute, Edison Electric Institute, and National Association of Regulatory Utility Commissioners. EPRI also surveyed staff at the 40-plus utilities that participate and share best practices in EPRI's Energy Sustainability research steering committee.

Based on the findings, EPRI expanded the list from 15 to 20 issues, adding cyber and physical security, public policy relations, and others (see box at end of article). While environmental issues (such as greenhouse gas emissions and water) remained on the list, economic and business issues gained a stronger presence. These include supply chain, assets and operations, and customer relations.

"The industry's understanding of the business implications of sustainability is changing," said Scott. "Executive leadership is paying more attention to new technologies and the risks and opportunities they present to the long-term economic viability of utilities—and how all this relates to sustainability. This research demonstrates how the sustainability conversation has matured from setting up recycling programs and green teams to an in-depth look at value creation."

EPRI circled back to the utilities and other stakeholders with specific questions about the 20 issues on the final list.

"It's likely that each issue will not be equally relevant to all stakeholders, so we asked them whether each one was a high, medium, or low priority or not a priority at all," said Scott. "We also asked them to forecast how priorities might change."

The priorities most frequently cited are energy reliability and resiliency, safety and health, and cyber and physical security. Respondents viewed business model and cyber and physical security as increasing in importance the most over the next three to five years.

A report on the new list of key sustainability issues is expected this fall. Scott expects that utilities will use it to help update their sustainability strategies and initiatives. It will also help guide future EPRI research and updates to EPRI's online sustainability benchmarking tool, which enables utilities to compare their performance with peers.

Electricity Sector Sustainability: Changes Since 2013	
Compared to EPRI's 2013 list of sustainability issues most relevant to the electric power industry, the 2017 list incorporates more economic and business issues.	
2013	**2017**
Reductions of other air emissions	Air emissions
	Assets and operations*
Economic viability of electric utilities	Business model
	Climate change*
Community support and economic development	Community vitality
	Customer relations*
	Cyber and physical security*
Energy affordability	Energy affordability
Energy reliability	Energy reliability and resiliency
Greenhouse gas emissions	Greenhouse gas emissions
Habitat protection and biodiversity	Habitat and biodiversity
Job satisfaction	Job satisfaction
	Labor relations*
	Public policy relations*
Employee safety and health; public safety and health	Safety and health
Skilled workforce availability	Skilled workforce availability
	Supply chain*
Waste management	Waste
Water availability; Water quality	Water
Engagement and collaboration	Workforce diversity, inclusion, and equal opportunity*
*New issues identified in the 2017 assessment.	

Key EPRI Technical Experts

Morgan Scott

Innovation

More Clarity on the Social Cost of Carbon

Panel Calls for More Rigorous, Transparent, Defensible Approach to Estimate Benefits of Reducing Emissions

By Scott Sowers

Drawing on EPRI research, a new study from the National Academy of Sciences (NAS) recommends that government agencies and other stakeholders take a completely different approach for calculating the social cost of carbon (SCC)—a metric used in dozens of federal regulations to estimate the benefits of reducing CO_2 emissions.

EPRI Senior Research Economist Steven Rose and EPRI colleagues laid the groundwork for the NAS study in an EPRI report on the design and inner workings of SCC models. Rose is a member of the scientific committee that produced the NAS study.

"EPRI's research was a key resource for the committee for understanding the state of the science and modeling that underlies social cost of carbon estimates," said Rose.

The current federal approach for estimating the SCC involves combining 150,000 values from three separate models, known as FUND, PAGE, and DICE. The models' different structures and calculation idiosyncrasies affect results in ways that are not apparent or well understood.

The models' key assumptions relate to future economic and demographic conditions, climate system behavior, potential societal risks if the world warms, and discount rates. EPRI's study, along with a recent scientific journal article expanding on that work, reveal internal variations in structure and intermediate results that contribute to significant differences in the SCC estimates from the three models. With these insights, EPRI identified opportunities for improvement.

Instead of the current approach and models, the NAS study recommends developing the steps associated with SCC calculations as separate, but integrated, modules—each drawing from the most up-to-date scientific research:

- A socioeconomic module that projects greenhouse gas emissions based on population and economic output estimates
- A climate module that calculates future temperature and sea level changes based on projected emissions
- A damages module that estimates the potential impact of temperature and sea level changes in dollars
- A discounting module that adjusts the projected dollars based on an appropriate discount rate

"Developing the modules separately and using the scientific expertise from relevant disciplines can result in a more rigorous, transparent, and defensible estimate of the social cost of carbon and clarify the associated uncertainty," said Rose.

The NAS study recommends using this approach to develop new estimates in the next 2–3 years. Rose and his NAS panel colleagues presented the results to U.S. executive branch offices (including the Office of Management and Budget and Council of Economic Advisors), federal agencies (including the U.S. Department of Energy and U.S. Environmental Protection Agency), and committees in the U.S. Senate and House of Representatives.

"For policy and regulatory discussions, it's important to quantify the potential benefits of reducing greenhouse gas emissions in dollar terms," said Rose.

Federal agencies are required to use the SCC to estimate CO_2 reduction benefits of regulations, such as fuel economy standards for vehicles, emissions standards for power plants, and appliance energy efficiency standards. In addition, several state public utility commissions are using or considering using the federal SCC estimates in zero-carbon technology subsidies and to incorporate in resource planning the impacts of utility emissions on public health and the environment. Canada is using the U.S.-developed SCC estimates to value emissions changes in regulatory matters.

"U.S. climate policy is uncertain right now, but the social cost of carbon is unlikely to go away," said Rose. "Decision makers across the country and the world are asking about the potential consequences of CO_2 and other greenhouse gases and the benefits of avoiding emissions."

EPRI's research on the social cost of carbon and other greenhouse gases continues. Areas of focus include enhancing public understanding; identifying, communicating, and evaluating technical issues; assessing prospects for better SCC estimation; and informing SCC use in estimating the potential benefits of emissions reductions.

Key EPRI Technical Experts

Steven Rose

Shaping the Future

Avoiding Costly Damage from 'Foreign Objects'

EPRI Model to Help Nuclear Plant Operators Determine Best Course of Action

By Sarah Stankorb

On first glance, it may not seem like a big deal: A bolt, gasket, or other small part gets stuck in a steam generator tube bundle in a nuclear power plant.

But decades of operating experience have shown that such foreign objects can lead to costly damage. When subjected to a rapid water flow, an object's repeated motion can wear a tube's surface, causing a leak. Because steam generator tubes serve as a pressure boundary between the plant's primary (radioactive) and secondary (nonradioactive) water systems, a leak would result in radioactive contamination of secondary water. At a prescribed rate of leaking, operators must shut down the plant to fix it, possibly costing $500,000 to $1 million for maintenance and lost production revenue. Each year, the U.S. nuclear fleet plugs 50 tubes on average to address such damage, with eight tube leaks documented since 2000.

EPRI is developing a model to help operators predict tube wear rates related to foreign objects and determine if immediate removal is needed or if it's reasonable to defer the task to a refueling outage. The model's predictions are based on the object's location and size, the tube's position in the steam generator tube bundle, the rate of water or steam flow between tubes, and other factors.

"Validation of the model must demonstrate conservative tube wear predictions so that tube structural integrity is always maintained," said EPRI Technical Executive Jim Benson.

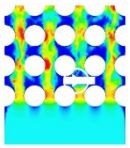
Foreign objects can enter the steam generator tube bundle during maintenance or as a result of degradation of component materials. During scheduled outages, inspectors look for foreign objects, either by guiding cameras between tubes or by passing eddy current probes inside tubes. Foreign objects vary in shape and size and often require tools and removal methods tailored to the situation.

In developing the model, EPRI and Polytechnique Montreal used a 3-D printer to recreate more than a hundred foreign objects based on objects found in nuclear plants. Researchers printed versions of these objects with various dimensions and, in the laboratory, placed them in an experimental tube array and subjected them to water flowing at various rates. From this, they determined the force that the objects imparted on the tubes.

"We used the results to obtain the parameters for calculating wear rates," said Benson. "This formed the basis of our model."

EPRI has asked nuclear operators in the United States for size, shape, location, and other data on foreign objects identified at their plants. EPRI will use these data to validate the model, using at least 20 objects to compare the predicted wear rates and those observed at the plants based on eddy current inspection.

If the model is proved accurate, EPRI plans to develop software that operators can use to predict wear rates as well as potential impacts related to foreign objects.



This video shows the changes in water velocity and direction as it flows past a foreign object in a steam generator tube bundle. Red and yellow indicate higher velocities, and green and blue represent lower velocities.

Key EPRI Technical Experts

Jim Benson

Shaping the Future

From Interdependent to Integrated

Building a Robust Grid an Essential Step in Integrating Electricity, Gas, and Water

By Chris Warren

The systems and infrastructure that supply society with electricity, gas, and water are more interdependent than ever before. A few examples: Water is needed to cool power plants and produce natural gas, and the natural gas supply system needs electricity to run compressor stations and manage transport. The number and complexity of connections across the energy system are growing as consumers opt for electric vehicles—and as digital technology and telecommunications become integrated into every aspect of energy.

But this interdependence does not yet translate into integration. Fragmentation leads to inefficiencies, higher costs, and increased vulnerability to cyber attacks and natural disasters.

It doesn't have to be this way. EPRI's Integrated Energy Network provides a blueprint for harnessing emerging technologies and markets to advance integration, increase customer choice, and improve affordability, reliability, and efficiency.

The electric power industry is already testing and deploying at scale the technologies and standards needed for greater coordination among the water, natural gas, and electricity systems. EPRI's Integrated Grid pilots and other efforts to incorporate distributed energy resources such as solar and wind into the grid are helping to preserve the benefits of central station generation, facilitate two-way power flows, and enable a cleaner grid.

The Integrated Grid initiative is pioneering the metering, telecommunications, data standards, security, and analytical tools required for integrating key elements of the energy and natural resource systems. Successful implementation of the Integrated Grid will help limit unnecessary and expensive duplication of efforts. For example, if a utility builds a telecommunications system to enable advanced metering in homes, there's no reason the water and gas companies need to reinvent the wheel.

Natural gas planning, dispatch, and markets offer further integration opportunities. As natural gas is used increasingly for both electricity generation and heating, improved integration can provide utilities and customers with more choices and flexibility when demand is high. As electric vehicles proliferate, timing charging with periods of abundant solar generation can provide tremendous value to drivers and utilities.

Other opportunities include improving coordination of water and electricity systems to bolster water conservation and using water and thermal energy storage to provide flexibility for the electric system.

Key actions for integrating energy resources include:

- Developing interconnection rules, communication technologies, and standards for data transfer and privacy
- Testing and deploying sensors, smart inverters, and distribution management systems
- Devising strategies to better integrate distributed energy resources into grid planning and operations
- Informing policy and regulations to speed cost-effective integration of distributed energy resources
- Enhancing the transmission system to enable integration of more variable generation
- Identifying ways to integrate systems that deliver electricity, natural gas, and water as they become more automated

- Analyzing the potential for integrating gas and electric markets, including consideration of operations, planning, and environmental challenges and opportunities
- Investigating how “big data” can be tapped to meet real-time grid needs

The Three Pillars of the Integrated Energy Network

The Integrated Energy Network provides EPRI’s perspective on the future of energy. Research needs are identified for each of three supporting pillars:

- **Using affordable, cleaner energy through efficiency and electrification**: focuses on the opportunities and challenges—both technical and institutional—involved with scaling the use of cleaner energy sources.
- **Producing cleaner energy**: details the potential of cleaner electric generation technologies—renewable energy, nuclear power, and fossil-fueled generation with carbon capture—along with promising non-electric technologies.
- **Integrating energy resources**: examines how new technologies and markets must be tapped to better integrate the electricity, gas, water, and transportation systems.

EPRI invites you to share your ideas and approaches for addressing each of the three pillars.

Technology At Work

Zero Net Energy for the Masses

Lessons from California Community to Inform Large-Scale Deployment of Super-Efficient Homes

By Sarah Stankorb

While strolling among the handsome stucco houses and landscaped playgrounds of the Sierra Crest development in Fontana, California, most pedestrians will not notice that an innovative experiment is happening here.

Twenty zero net energy homes have revealed important insights on the cost-effectiveness and grid impacts of such residences, paving the way for similar communities elsewhere. EPRI led the initiative to integrate energy efficiency and solar generation into the new homes, resulting in the first zero net energy neighborhood by a production builder. The team, which included Southern California Edison and developer Meritage Homes, designed and constructed the houses to California's Title 24 Zero Net Energy standards and then monitored the houses for a year.

Funded by the California Public Utilities Commission through the California Solar Initiative, the project is intended to explore the grid impact and economics of zero net energy communities and provide guidance for scaling them. As part of California's goal to reduce carbon emissions by 80% between 1990 and 2050, the state aims to achieve zero net energy in all new residential buildings by 2020.

The Challenge of Zero Net Energy

Zero net energy homes have rooftop solar arrays and include more energy efficiency and electric end uses than traditional homes. Such communities pose a challenge: During the afternoon, solar panels may generate excess electricity that can flow back to the grid. During evening hours, the houses may dramatically ramp up demand for electricity. The resulting two-way power flows can strain the distribution grid, and utilities want to understand how this will affect grid operations and planning.

"Before this study, data on zero net energy homes was limited," said EPRI Technical Executive Ram Narayanamurthy. "We combined solar with energy efficiency on a neighborhood scale, and looked at how *real* people interact with *real* homes and how that impacts the grid."

Efficiency features included LED lighting, smart thermostats, energy management systems, efficient air conditioners and appliances, electric heat pumps, and heat pump water heaters. Spray foam insulation, which is far more effective at limiting air gaps than traditional insulation, was applied to the underside of roofs.

Because the homes were so well-insulated, builders could use smaller heating and cooling systems. "That allows you to electrify heating," said Narayanamurthy.

Meritage targeted buyers who weren't home-shopping based on energy efficiency. "The objective was to sell these homes just as a builder would sell any other home," said Narayanamurthy.

Lower Utility Bills, Lower-Than-Expected Peak Load

While average residential utility bills in the region are about $115 per month, the Fontana residents' monthly bills average about $20 for electricity and $20 for natural gas. A major component of both is customer connection charges. Additional mortgage costs for the solar and energy efficiency measures were more than offset by utility bill savings.

As a result of the energy efficiency measures, evening peak load in the homes was lower than what is predicted by existing models for high-solar-penetration neighborhoods. The models indicated that electrification of water and space heating systems could test transformer capacity limits, but these limits were not exceeded over the year in actual operation. The timing of high energy use varied from home to home depending on when people woke up, returned from work, used hot water, did laundry, and ran the dishwasher. This reduced the magnitude of aggregate peaks and valleys in energy use.

Energy storage batteries, added to 9 of the 20 homes, demonstrated limited future potential. The still-maturing technology marginally reduced peak load at the transformer but was not cost-effective for grid balancing. To enhance cost-effectiveness and controllability by grid operators, EPRI recommends further research on deploying storage on the utility side of the meter in community solar systems or on transformers, feeders, and substations. Also, further development of various aspects of residential storage—such as controls, communication approaches, rate structures, and ownership models—can improve storage economics and support grid flexibility.

The project revealed that the most reliable path today for integrating zero net energy communities in distribution planning is to increase transformer and utility wire sizing, rather than to rely on customer-sited battery storage. Researchers also observed that better insulation and air sealing drives greater efficiency, reducing the size of the solar array needed for zero net energy. This benefits the grid by reducing surplus solar generation during midday hours and reducing steep increases in energy demand after the sun goes down.

"We're working with EPRI to augment batteries with advanced construction techniques to manage excess generation and demand peaks," said C.R. Herro, vice president, energy efficiency and sustainability at Meritage Homes. Meritage is also looking at using appliances during off-peak demand times and shifting heating and cooling loads.

The Fontana project demonstrated the technical and economic feasibility of zero net energy homes, and the state of California is now considering incorporating EPRI's findings into its building codes and distribution planning proceedings. EPRI is initiating similar zero net energy projects with Duke Energy and Southern Company in the Southeast, as well as larger, community-scale projects with utilities and builders in California.

Key EPRI Technical Experts

Ram Narayanamurthy

In the Field

Clouds, Snow, and Solar in the Midwest

EPRI, Alliant Energy Compile Results from First Year of Madison Solar Demonstration Project

By Debbie Sniderman

A solar demonstration project at Alliant Energy's headquarters in Madison, Wisconsin is revealing how clouds, snow, and weather affect solar photovoltaic performance in the Midwest, informing the utility's ongoing work to incorporate solar in the electric system.

The fixed- and dual-axis tracking systems at the Madison demonstration site.

Since April 2016, more than 40 solar arrays with a combined capacity of 291 kilowatts have been generating power from which EPRI has helped gather data and analyze results.

"This project provides Alliant Energy, its customers, and the power industry with an opportunity to learn about the many ways solar can be used in the Midwest," said Dave Sinner, product manager for customer-centric generation at Alliant Energy. "We're sharing the data with our customers so that they can make a more informed decision about adding solar generation. We're also sharing with other utilities, academics, and the solar industry and comparing our results against similar research in other parts of the country."

Confirming what is well known in the solar industry, the first year's data show that solar power generation in the Midwest is highly dependent on the weather and the season. Summer generation was the highest and the most intermittent as a result of frequent fast-moving clouds.

Winter generation was just a fraction of summer generation as a result of shorter days, many overcast days, and partial shading from snow. It was less variable, which points to the importance of considering winter performance in solar plant design and energy resource planning.

Consider snow effects, which can be minimized by focusing on panel tilt angle, orientation, and location. Steve Greidanus, an electrical engineer in Alliant Energy's Generation Engineering Group, said that accumulated snow reduced generation by 30–80% on some arrays. For steeply tilted ground-mounted systems, snow was gone the day after a storm. Roof-mounted arrays with lower angles remained under drifts for several days.

This video shows how snow and ice impact the power generation from a southeast-facing solar array with a 35-degree tilt. On the chart at left, *irradiance* refers to the sunlight the array receives, and *power* is what the array produces. The closing gap between the two lines indicates that as the snow and ice melt, the array generates more power relative to available sunlight.

For Madison, the optimal array orientation to capture more winter sunlight and maximize annual generation is south-facing at a 35-degree angle. Lower angles maximized summer production. Southeast- and southwest-facing arrays generated less power overall but produced higher output earlier or later in the day.

“In Wisconsin, demand spikes between 3 and 5 p.m., so many customers without south-facing roofs would be best suited with a west-facing array to offset more load,” said Sinner.

Initial data for a dual-axis tracking ground-mounted array indicate that it can produce up to 44% more energy than fixed-tilt systems. Researchers expect to test two recently installed single-axis tracking arrays in the coming year.

“Tracking increases capital costs but also increases production, which can reduce the levelized cost of electricity. This benefit is most pronounced at sites with high-quality solar resources,” said EPRI Senior Technical Leader Cara Libby. “Prior EPRI research has shown that the performance gains from trackers outweigh the higher upfront costs in some locations such as the desert southwest, but not in all locations.”

As costs for trackers come down, their economics will improve in more locations, leading to more deployment. Today, 70% of ground-mount solar arrays are installed with trackers.

“Although tracking generates more energy throughout the year compared with fixed-tilt systems, the steeper ramp-up of morning power and ramp-down of evening power can present grid-integration challenges,” said Libby. “This project is exploring opportunities to support efficient integration of solar using short-term forecasting and battery storage systems.”

Following two years of data collection, Alliant Energy plans to analyze long-term generation trends. Alliant Energy can use the results of the demonstration, coupled with weather station and sky imaging data, to predict generation potential in the Midwest and determine how best to deploy solar in its service territory.

Solar parking canopies at the Madison demonstration site. Drainage is in the middle of the structures so that snow and ice do not fall on vehicles or people.

Alliant and EPRI provide a publicly accessible online dashboard of the demonstration’s real-time and historical data.

Additional Results of Madison Demonstration Project

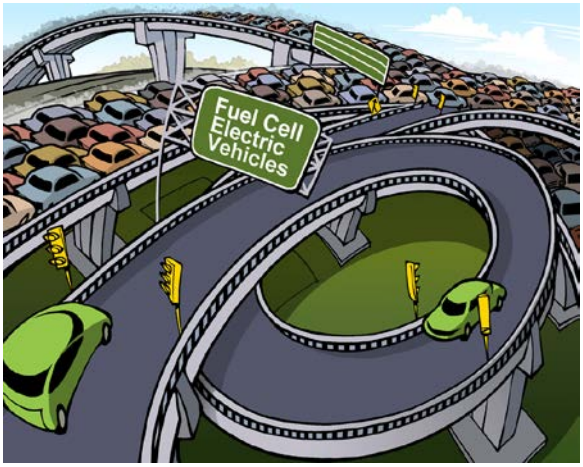
- 30% of sunlight in Madison comes in the form of diffuse light, including light that is scattered due to atmospheric particles and reflected from the ground, clouds, and other nearby objects. This percentage is typical for an area with frequent partly cloudy days.
- Solar carports with downspouts and gutters in the center (see photo above) provide safety for people and cars underneath, but they are not ideal configurations for shedding snow.
- There was a wide range of performance among the various panel technologies (polycrystalline silicon, cadmium telluride, monocrystalline silicon, copper indium gallium selenide, and hybrids), depending on weather, temperature, and other seasonal effects.

Key EPRI Technical Experts

Cara Libby

R&D Quick Hits

Fuel Cell Electric Vehicles Face a Long 'On-Ramp'



Despite great technological advances over the past two decades, an EPRI study concludes that fuel cell electric vehicles still lack the low cost and long life needed for commercial viability, with no real prospects for market share before the mid-2020s.

Since the early 1990s, several major automobile manufacturers have invested billions of dollars to develop proton exchange membrane fuel cells for electric vehicles. Government R&D programs in the United States, Japan, and Europe have led to prototypes and early-production vehicles with good drivability.

Drawing on nonproprietary information from technical literature, conferences, developers, and fabricators, researchers compared the cost and endurance of current fuel cell technology with the U.S. Department of Energy's generally accepted targets for market success. Key insights:

- Cost estimates for state-of-the-art systems exceed the target of $30–40 per kilowatt by 50–80%.
- Some fuel cell stacks are approaching the target of 5,000 hours of life (equivalent to 150,000 miles), but they use high-cost, platinum-based electrodes.

Reducing platinum content can lower manufacturing costs, but this may also accelerate degradation of stacks and electrodes, making R&D necessary to address the degradation mechanisms.

Annual manufacturing capacity is about 6,000 vehicles, or 1–2% of the capacity needed for low-cost, mass production. Uncertainty regarding widespread availability of competitively priced hydrogen fuel is likely to delay the expansion of automotive production capacity by several years.

R&D Quick Hits

Gypsum from Power Plants: An Antidote to Algal Blooms

As a plentiful power plant by-product, flue gas desulfurization gypsum offers great potential to improve water quality and protect aquatic ecosystems by reducing phosphorus runoff from fertilized fields, an EPRI study reveals.

Such runoff can degrade surface water quality and cause algal blooms. These have led to the temporary loss of drinking water in Toledo, Ohio and the creation of ecological "dead zones" in the Gulf of Mexico and Lake Michigan.

Laboratory research had indicated that applying flue gas desulfurization gypsum to agricultural fields can reduce phosphorus runoff. Since 2006, the electric power sector has tripled its production of gypsum as it removes more sulfur dioxide from flue gas to meet new emissions requirements. Half of this gypsum is disposed in landfills.

EPRI worked to measure the effectiveness of this gypsum at working farms, applying it on eight Ohio farms and monitoring phosphorus concentrations in edge-of-field drainage over three years. Concentrations in most fields were reduced by 20–95% relative to control fields. The magnitude of the reductions diminished somewhat after three years, indicating that reapplication may be necessary. There was no significant effect on crop yields.

For a decade, EPRI and The Ohio State University have studied gypsum application at a network of farm sites in seven states, finding no adverse environmental impacts to soil, water, and plant quality. Informed by this work, the Natural Resources Conservation Services (part of the U.S. Department of Agriculture) in 2015 established a national standard that enables state programs to reimburse farmers for gypsum application. To help states facilitate gypsum use in water quality trading initiatives, EPRI plans to compile more detailed field data on phosphorus reductions.

R&D Quick Hits

One Valve Repair = $700,000 in Savings

Fixing one leaky valve at a combined-cycle power plant could save hundreds of thousands of dollars in annual fuel costs, an EPRI study finds.

As U.S. combined-cycle plants operate at higher output, spending increases for fuel and emission controls. Plants that reduce heat rate can save significant dollars. Among the dozens of potential modifications and actions EPRI is evaluating to improve heat rate, one focuses on leakage in the steam cycle's fluid paths. Often undetected, steam or water losses result in less fluid available for generation and may increase fuel consumption.

In field tests, EPRI identified and quantified the cost implications of steam cycle leaks at two combined-cycle plants. At one plant, six leaking valves increased heat rate by 0.8%; repairs could save more than $1 million in annual fuel costs. (Restoring one leaking valve costs $8,000–$20,000.) Repairing just the largest leak offered savings of more than $700,000. At the second plant, EPRI identified nine leaks and found that repairing the largest one could save about $250,000 per year. Both plants are well-maintained, suggesting that even more leaks could exist at facilities with limited resources.

The report provides methods to identify leaks and determine leakage rates.

R&D Quick Hits

A Wind Turbine Inspired by the Palm Tree

Folding Rotor Concept Could Enable Offshore Turbines with Six Times More Power

Imagine a wind turbine with blades longer than two football fields that curve and fold in the wind like a palm tree's fronds. According to a technical brief by EPRI's innovation scouts, the application of this concept—known as the *segmented ultralight morphing rotor*—has the potential to increase a turbine's power output by six times and cut in half its levelized cost of electricity.

The size of conventional upwind turbines is constrained by blade mass. Blades must be stiff so that they don't bend back and strike the turbine. These stiff, heavy, long, and massive blades place stress on the turbine and require expensive towers. Their manufacturing and transportation costs also add up. The largest commercially viable machines are rated at 8 megawatts and have 260-foot blades.

With funding from the U.S. Department of Energy, a team led by the University of Virginia is designing a downwind turbine with an ultralight, segmented rotor that flexes and "morphs" in the wind. Blades are open at low wind speeds to catch as much wind as possible. As wind speeds increase, the blades curve inward to align the load and optimize energy production. In extreme winds, the blades fold together, avoiding rotor damage and reducing stress on the tower. The design could potentially enable 50-megawatt turbines with 650-foot blade lengths; less massive towers and foundations; and lower manufacturing, transportation, and assembly costs. It could also facilitate offshore development despite hurricanes and other severe weather with wind speeds greater than 200 miles per hour.

The concept has been simulated, and in 2019 the University of Virginia team plans to test a prototype one-tenth of the size anticipated for a 50-megawatt turbine. Given the significant R&D needed to optimize the blade, rotor, generator, tower, and other components, commercial deployment of 15- to 25-megawatt turbines may be about a decade away.

R&D Quick Hits

Solar Plant Owners: Design for Lower Lifetime Electricity Costs

An EPRI study points to the design of solar power plants as a critical driver of long-term performance and electricity costs.

Because companies that build solar photovoltaic plants often do not own them long-term, they often choose designs that reduce upfront capital costs and meet near-term performance guarantees. However, over the life of the plant this may lead to lower-than-expected generation and higher-than-expected operations and maintenance costs. As utilities increasingly own and manage solar assets, design decisions should consider long-term performance and costs.

EPRI interviewed experts in the solar and electric power industries to compile insights on how various design innovations can improve lifetime plant quality and durability. These included row spacing, racking, cable management, ground and vegetation management, and data monitoring. For example, while grading and graveling an entire plant site is the most expensive ground management option, it can reduce soil erosion and vegetation management costs—and potentially yield a lower levelized cost of electricity.

Robust standards and best practices can help drive effective plant design and reduce performance uncertainty, but the solar industry's growth has outpaced standards development. As an example, there are no widely accepted practices for plant commissioning or acceptance tests.

The industry is overhauling and implementing standards, and EPRI is working with standards organizations to translate updates into best practices. EPRI's aim is to inform design decisions based on accurate, objective knowledge of their implications for long-term operational performance and costs.

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3002009256

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