EPRI JOURNAL

FALL 2024

Solar Module Recycling Progress Follows the Global Growth of PV

ALSO IN THIS ISSUE:

Table of Contents

EPRI JOURNAL

Solar Module Recycling Progress Follows the Global Growth of PV

By Chris Warren

Even for an industry accustomed to regularly smashing records, 2023's global solar photovoltaic (PV) installations were eye-popping. According to a new report by SolarPower Europe, the world installed nearly 90 percent more solar PV in 2023 compared to the previous year.

The report also found that the pace of new solar additions means that there will be two terawatts of cumulative global solar PV capacity by the end of 2024 – a rapid doubling of the one-terawatt mark reached in 2022. By 2028, the world could add an additional terawatt of solar PV every year.

This trend is good news for the world's efforts to decarbonize and limit the negative impacts of climate change. But it also underscores the critical importance of establishing and scaling up capacity to collect, repair, refurbish, and recycle used, defective, and damaged solar modules. Indeed, according to the International Renewable Energy Agency (IRENA), annual recycling streams by 2030 will total about 4 percent of the billions of modules installed around the world each year. To get a sense of the scale of recycling that will eventually be necessary, consider that one terawatt of 500-watt modules would equal two billion modules, which means that approximately 80 million modules may need to be recycled annually.

Recycling Advances Follow Accelerating Solar Installations

There is a widespread understanding of the need for proper end-of-life management of large volumes of solar modules. In 2016 and 2017, the International Energy Agency's (IEA) Photovoltaic Power Systems (PVPS) program conducted a study funded by the National Renewable Energy Laboratory (NREL) and EPRI that reviewed PV recycling technologies in Europe. The review found a small number of recycling technologies, including four commercial glass and metal recyclers that processed solar modules on an infrequent basis, as well as one PV-specific pilot processing facility.

But as anyone who follows solar will know, advances in virtually every aspect of the industry are remarkably speedy, making that snapshot of PV recycling capacity and sophistication out of date today. The recently released IEA PVPS Task 12 report, *Advances in Module Recycling – Literature Review and Update to Empirical Life Cycle Inventory Data and Patent Review,* provides an updated and comprehensive view of the state and future trajectory of PV module recycling.

One of the traditional barriers to greater PV module recycling capacity and innovation was the simple fact that not enough modules had reached the end of their useful life. While that remains an issue today, it won't last much longer. This is spurring recyclers to expand existing recycling technologies or pilot new ones.

"There has been a chicken and egg situation where recyclers didn't necessarily want to invest in a full-scale PV module recycling line because they're only getting a couple thousand modules a year," said Cara Libby, an EPRI technical executive and co-author of the recent IEA report. "They're still trying to figure out which are the optimal processes from a performance, economic, and environmental standpoint, which is why there are still several approaches in pilot scale."

That lack of scale has also made recycling financially unattractive to those considering end-of-life options for large volumes of solar modules. "One of the challenges is that recycling is expensive today, so many end users are choosing to landfill modules," said Libby. "In the U.S., there are no federal regulations encouraging people to recycle, so a lot of modules are just going to municipal waste landfills or, in some cases, even hazardous waste landfills because they may still be cheaper than recycling."

One of the ways to make recycling more financially attractive is to improve the recovery of high-value materials like silver and silicon, which can contribute to a circular economic model in which materials are repurposed and reused repeatedly. However, seizing the full economic value of recycling requires innovation in the processes and technologies deployed, especially in extracting module materials in as pure a form as possible.

"We know roughly how much of each material is in a module, and we know the market value," said Libby. "But that depends on how pure the recycled material is. We don't just care how much material we can recover, but how clean or pure it is because that influences which market applications it can be used for."

Policymakers and regulators are also keen to improve the quality and scale of PV recycling. In the U.S., the 2021 Bipartisan Infrastructure Law (BIL) set aside $1.5 billion to advance recycling RD&D along with clean hydrogen manufacturing. In 2023, the U.S. Department of Energy's Solar Energy Technologies Office (DOE SETO) awarded 10 million and announced another $20 million in BIL funding to drive PV technology reuse and recycling. DOE SETO's action plan aims to make PV recycling cost-competitive with landfill disposal. The European Union's Waste from Electrical and Electronic Equipment (WEEE) Directive has resulted in rules for collecting and treating end-of-life solar modules.

A Comprehensive Examination of PV Recycling

The fundamental goal of the IEA research was to pinpoint technology advances that make PV module recycling more affordable, technically feasible, and environmentally responsible. To gain an understanding of both the overall state of solar module recycling as well as specific technology improvements, researchers followed a multi-prong approach. As a start, the research team identified 177 recyclers and manufacturers of recycling technology through a combination of online searches, press releases, past studies, and industry connections.

From that initial list of 177, the researchers identified 24 recyclers who were utilizing advanced recycling technology at either a commercial or pilot scale and invited them to complete a questionnaire. Soliciting feedback from recyclers was designed to deepen the researchers' understanding of the state of technology. Six of the 24 recyclers invited to complete the questionnaire responded with life cycle inventory (LCI) data. Past data collection and recycler responses also allowed the researchers to develop a seventh LCI case. This data collection allowed for a comparative analysis of the rates of material recovery and energy consumption involved with recycling methods and technologies.

In addition, researchers reviewed technical research and patents from universities, research institutions, national research laboratories, and private companies focused on solar module recycling. This surfaced 569 publications about PV recycling and 456 patents related to recycling PV components, processing methods, and recovered materials. Researchers also interviewed recyclers and subject matter experts to better understand their technologies and processes and identify data gaps that need to be addressed.

Steady Advances in Recycling

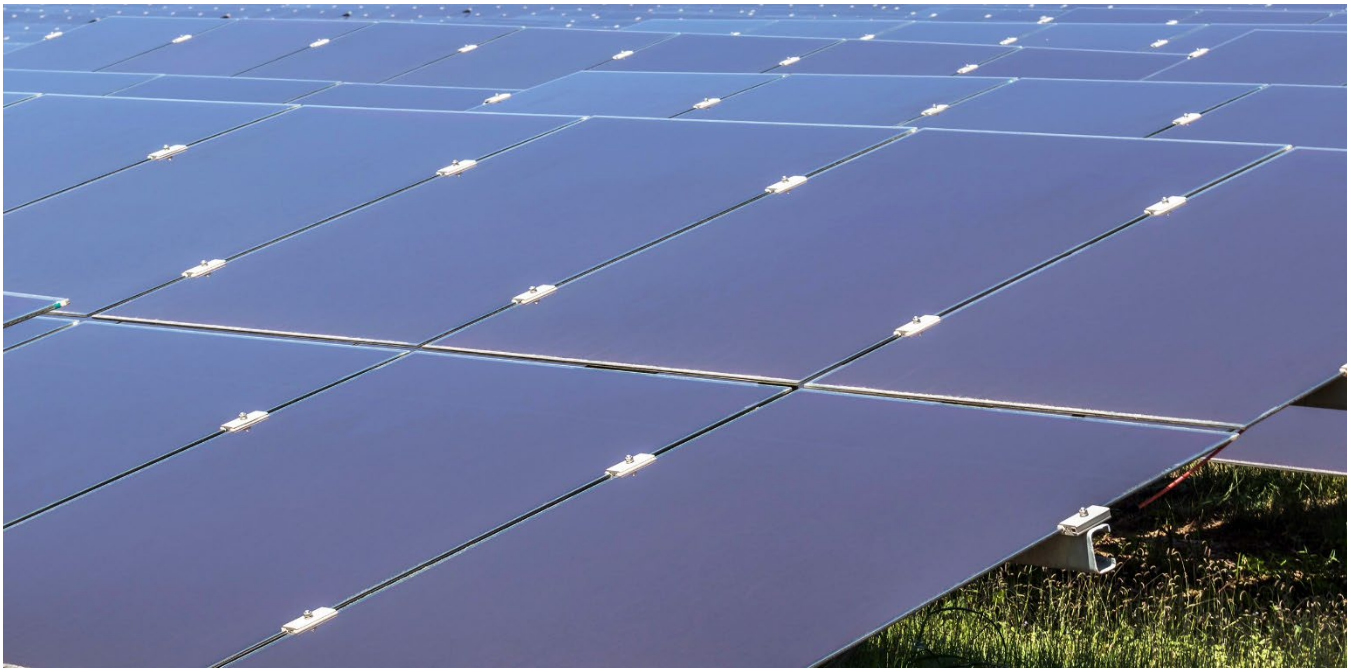
One indication of the maturation of PV recycling is how many recyclers surveyed in the report focus on treating end-of-life modules. In the 2015-2016 IEA PVPS Task 12 report, only one of the five processes featured was explicitly customized for PV recycling. In this year's report, however, all seven facilities examined are dedicated to processing solar modules.

Other key findings from the survey, LCI analysis, and review of research include:

Mechanical recycling remains dominant. There are three basic approaches to recycling PV modules: mechanical, chemical, and thermal. Currently, mechanical recycling processes are the benchmark approach. In mechanical recycling, modules are shredded, crushed, and milled to extract individual materials like silicon, glass, and silver, which can be processed and refined for reuse.

There are both advantages and disadvantages to this prevailing recycling technique. Its cost and ability to scale make it attractive for large volumes of solar modules. The benefits and the limitations of mechanical recycling were apparent in the study's examination of LCI data from Germany-based Reiling Glas Recycling GmbH. Reiling's new facility, with an annual capacity of 50,000 tons, is an example of a mature mechanical recycling approach optimized for cost and low energy consumption. However, Reiling's well-established recycling process does not allow for the recovery of valuable silicon and silver.

New technologies hold the promise of improved recycling quality. Though mechanical recycling remains the benchmark approach, several innovative technologies are in the pilot stage and show the potential to lower the energy needed to recycle and bolster the total amount and purity of materials recovered, including silver and silicon. Some recyclers, for example, are now testing chemical processes to remove materials from solar modules, including using solvents like water vapor and limonene that dissolve module components and allow for the extraction of silicon, silver, and other metals. Other recycling techniques rely on thermal measures, such as pyrolysis, incineration, or polymer melting.



Researchers examined companies pursuing innovative recycling techniques, including the German company Flaxres GmbH. Founded in 2017, Flaxres combines mechanical and thermal techniques, including applying high-intensity light pulses to heat silicon and enable delamination. Flaxres's pilot recycling line is also mobile, meaning that it can be transported to project sites where large volumes of solar modules need to be recycled.

First Solar has a mature recycling process for thin-film modules. U.S.-based thin-film module manufacturer First Solar has a well-established approach to recycling its modules. One of the largest module manufacturers in the world, First Solar has recycling plants located alongside its manufacturing facilities in the U.S., Malaysia, Vietnam, and Germany. Taken together, the facilities can treat 50,000 tons annually and recover more than 90 percent of all the materials in the recycled modules.

Steep increase in patent and research activity. Another indication of interest in solar module recycling is the growing volume of patent applications and scientific research. The study identified 456 patents related to recycling PV components and 569 scientific papers and publications. Almost 80 percent of the patents are associated with recycling processes for silicon modules, cell metals, polymers, glass, and devices.

Not surprisingly, most patent filings have occurred in countries with large manufacturing capacity and big installation markets, such as China, the U.S., South Korea, Japan, and Europe. For the most part, universities, module makers, and research organizations are behind the patent filings, although some recyclers and waste treatment companies have also applied for patent protection.

Universities and research institutions are also the leading publishers of academic papers focused on PV recycling, albeit often in conjunction with module manufacturers, equipment suppliers, and recyclers. There is wide geographic diversity among the authors publishing papers and articles. While U.S. authors have the most publications, followed by Italy and China, researchers from developing countries and emerging PV markets like Ghana, South Africa, and Mexico have also produced scientific papers.

A Closer Look at PV Recycling in the U.S.

While the IEA PVPS study focused mainly on Europe-based recyclers, another recent EPRI study examined the state of PV recycling in America. Released in June, *Review of End-of-Life Solar Photovoltaic Services in the United States* is the result of information provided by 12 end-of-life PV service providers. 11 of the 12 companies completed an online questionnaire, and seven of the firms also participated in a one-hour interview. EPRI partnered with the Colorado School of Mines to conduct the research and publish the study.

A future *EPRI Journal* story will delve more deeply into the report's findings. Some initial takeaways include:

- There is sufficient recycling capacity to process the expected volume of crystalline silicon (c-Si) modules reaching end-of-life through 2030. Currently, the throughput for the seven c-Si recyclers that provided data is between 6,500 and 7,400 tons per year, which is equivalent to around 10 to 12 percent of all U.S. c-Si modules reaching end-of-life. Additionally, recyclers providing these services plan to expand capacity to meet higher demand and implement new processes to reduce costs and improve output quality.
- The largest challenge faced by recyclers is recovering high-value components like glass and silicon with sufficient purity to be reused.
- Another substantial barrier to more widescale PV recycling is the low cost of landfilling end-of-life modules.
- Nine recyclers that participated in the study provide in-house PV recycling, while the other three work with third parties. Recycling prices of the companies providing in-house recycling range from $14 to $30 per module compared to between $14 and $35 per module for third-party recyclers.

The report also identified research gaps that need to be filled to affordably and sustainably scale PV recycling in the U.S. They include:

- Demonstrating innovative new technologies that improve the yield and purity of components recycled from modules
- Gain a greater understanding of the environmental performance of advanced recycling techniques
- Informing the regulatory guidance for federal, state, and local governments for the reuse, repair, decommissioning, handling, transport, and storage of used solar modules

Like the IEA PVPS study, the findings of this survey of the U.S. recycling landscape were encouraging. "There has been a lot of progress in PV module recycling over the past few years," said Libby. "Pilot demonstrations are resulting in high-yield recycling and improvements in extracting pure, high-value materials. If these technologies can scale, the value proposition for recycling will improve."

EPRI Technical Expert

Cara Libby

EPRI JOURNAL

Coming Together to Protect Water Supplies in an Energy Transformation

By Chuck Ross

Decarbonizing electricity generation has become a critical element in plans to limit the impact of climate change. Renewable-generating resources are quickly becoming important contributors to this effort. However, maintaining a diverse generation mix is important—and technologies like carbon capture and hydrogen can enable traditional natural gas and coal plants to continue to operate with minimal carbon footprint. Nuclear owners are seeing their plants' lives extended—and new plants proposed—for the same reason.

However, these thermal strategies all place heavy burdens on a valuable and often threatened resource: water. Whether it's for cooling operations, carbon capture, or as a hydrogen feedstock, water is key for their successful operation.

Scientists refer to this interaction between water and electricity as the Water-Energy Nexus, and complicating this nexus are the growing demands for electricity production and increased pressure on freshwater use. It's at the center of EPRI's third annual Water-Energy Transformation (WET) Forum, to be held October 22-23, 2024 in Atlanta. This year's WET forum is especially timely as electricity companies, manufacturers, and other industrial-scale operations work to meet decarbonization goals, ideally without negatively impacting freshwater supply in the process. Water conservation is critical as demand for it is growing for a range of other uses, including industrial applications, agriculture, data center cooling, and manufacturing. Because of the wide-ranging impacts of the water-energy nexus, we're hoping for broad participation across affected industries, including **utilities**, **data center operators**, **food and beverage producers**, **pharmaceutical companies, municipalities,** and others exploring their carbon-reduction options.

Climate Change Drives Urgency

Water has always been a part of electricity production, but the conversation has become more urgent lately, as climate change is driving water shortages in some regions while electricity demand continues to climb. Though all but 3% of U.S. power-related water withdrawals are returned to their sources, the industry was responsible for 41% of all

U.S. water withdrawals in 2015, according to the U.S. Geological Survey.

Even returned water (discharged to the environment) can pose challenges if it's not treated to applicable water quality standards after use. "Generating power comes with a certain water footprint," said Kirk Ellison, EPRI program/area manager, Water and Land Management. "Any water that you're taking out of a river or the groundwater and using for power generation, whether most of that water is being returned or some is being consumed, creates a potential impact to the water-energy nexus and other potential uses such as drinking water and & agriculture as well as emerging users such as low carbon fuels, carbon capture, and data centers."

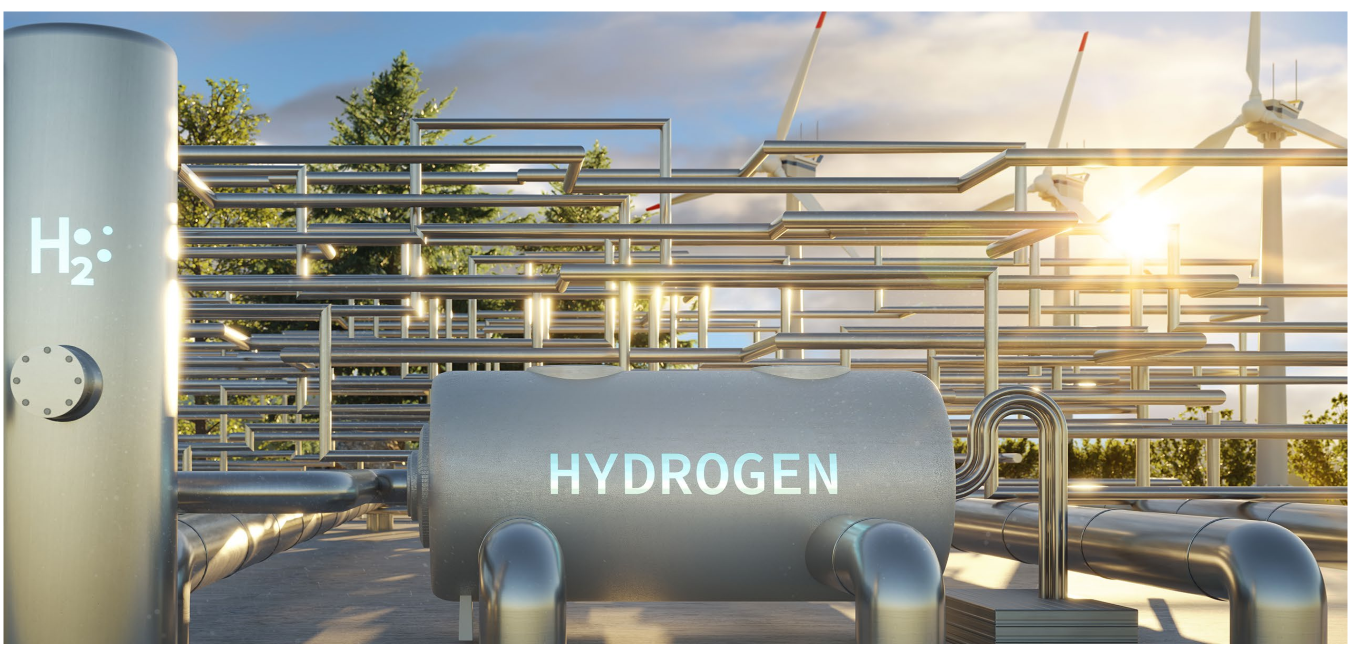
Ellison noted that the dependence of electricity generation on water often gets overlooked in today's conversations regarding rapidly growing demand. For example, he cited Google's July 2024 report that its carbon emissions have risen 48% since 2019 due mainly to rapid AI-related data center expansion.

"Every time I hear a story like that, I know there's a side story that is often overlooked," he said. "If power use goes up, water use goes up, but that's not often talked about."

Defining the Problem for Emerging Tech—Hydrogen Production

The emerging potential of hydrogen as a low-carbon fuel as a possible fossil fuel alternative is a good example of the overlap between energy production and water use. Hydrogen is both energy-dense and carbon-free, making it an attractive baseload option for electricity generators and a fuel replacement for heavy industry and transportation. Electrolysis, a process used to make hydrogen fuel, uses electricity to split water into hydrogen and oxygen. This could be a climate-friendly approach to its production if the electricity is sourced from renewable or nuclear generators.

However, electrolyzers—the equipment used in this process—have high cooling needs, with larger installations incorporating utility-scale cooling towers requiring water resources exceeding those needed to directly produce the hydrogen. In fact, these cooling demands could reach two-thirds of a facility's overall water consumption. Cooling water not lost through evaporation can be reintroduced to freshwater supplies but will typically need treatment to handle concentrated saline and other contaminants first. It also might be too warm to directly replenish supplies at its source because of concerns regarding fish and plant life, and it might also add to trends of increasing temperature and salinity in local water bodies.



Carbon Capture and Sequestration

Capturing CO_2 from fossil fuel-based power plants and sequestering it in the ground could allow electricity companies (as well as other industries such as cement manufacturing) to continue to use existing generation technologies while significantly reducing greenhouse gas emissions. Here, too, though, the most commercially available carbon capture process—post-combustion capture—is highly water-intensive. Cooling loads exist at four steps in the process for the amine-based, post-combustion capture system, which is the most commercially available process today.

CO2 sequestration, which is not yet utilized at a large scale, also could have significant water consequences—for example, through the potential need to extract water from highly saline underground aquifers to provide room for the stored CO_2. That water would require treatment before it could be returned to other aquifers or otherwise reused.

Exploring Options

As the electric power industry moves forward with decarbonization efforts—especially with promising new technologies—it's important that electric power utilities don't overlook possible unintended consequences. Also, broader connections across industries will help ensure best practices are adopted for addressing water resource concerns. EPRI's Technology Review, "Water Considerations for the Energy Transformation," provides an overview of the complexities this transition is raising and serves as a key reference for electric power utilities.

The third annual Water-Energy Transformation Forum is one of the ways EPRI is helping to facilitate discussions to enable utilities to lead the energy transition while maintaining environmental stewardship. "The point of the forum is to raise awareness—and this year's forum is more externally facing," said Ellison, one of the event's organizers. "It's really EPRI trying to lead the conversation in this space, to say the electric power utilities need to be thinking about some of the water and environmental parts of these decarbonization pathways, as well. Research can help address some of these gaps."

Like last year's forum, this year's gathering in Atlanta will be held in collaboration with a local utility—in this case, Georgia Power—located in a region that has faced its own water issues amid growing energy demand and a changing climate. Organizers hope to attract representatives from local industrial companies to speak to the many demands being placed on limited water supplies.

"It's trying to drive the issue through a broader venue and context," Ellison said, noting the importance of looking beyond needs related to electricity generation. "The power industry is not the only industry talking about needing more water. The landscape of the water-energy nexus is changing. At the end of the day, this positions EPRI to have a seat at the table, drive collaboration, and lead research on these issues going forward."

EPRI Technical Expert

Kirk Ellison

Take Home Tools

This year's Global Forum for Nuclear Innovation (GFNI) equipped attendees with tools to turn ambition into action in their daily work.

Interview By Chris Warren

As a senior regulatory policy officer at the Canadian Nuclear Safety Commission (CNSC), Kevin Lee's job responsibilities are understandably wide ranging. But there's a common thread that flows through virtually all of Lee's duties: the need to drive innovation.

Indeed, Lee created and now leads the Disruptive, Emerging, and Innovative Technology (DIET) team at CNSC. DIET is charged with prepping his agency to evaluate and regulate nuclear activities that incorporate new technologies, like artificial intelligence (AI), robotics, and additive manufacturing. Lee previously worked on CNSC efforts to evolve and modernize the commission's regulatory framework to be ready for small modular reactors (SMRs) and advanced reactor technology.

Not surprisingly, Lee's work requires attending events focused on everything from new reactor technologies and regulations to emerging technologies. While the events are valuable opportunities to collaborate with colleagues and hear about their experiences, Lee doesn't view them as forums to learn new things. "You usually already know what people are going to talk about and you have some familiarity with the subject matter," Lee said.

A Different Type of Event

But that was not the case for Lee at the most recent Global Forum for Nuclear Innovation (GFNI), which was held this past June in Miami. The event in Florida was the third GFNI, an event dedicated to building innovative cultures and behaviors throughout the global industry to ensure nuclear can reach its full potential as a source of carbon-free energy. The GFNI in Miami built upon the successes of the first two events. The inaugural gathering in South Korea in 2019 identified four technological innovations that could drive meaningful progress in the industry. The 2022 event in London centered on the necessity of creating innovative cultures and pinpointed four behaviors that can bolster innovation in organizations.

The gathering in Miami was the first GFNI Lee attended. While he wasn't exposed to any unfamiliar information, Lee found the three-day experience challenging and expansive in ways he did not expect. "What I really found interesting, and it's probably something I'm going to use as an approach at CNSC, was when they had us play games," said Lee, who noted that he was initially skeptical about the value of playing games like Connect-4, Jenga, and Kerplunk. "At first, I was thinking, okay, I'm a little old for this, but I'll play along."

However, the rationale behind playing games and many other activities at GFNI was not team building or camaraderie. Instead, it was to convey and utilize the attributes and behaviors needed to translate ambitions around innovation into tangible action. For Lee, the game playing and collaboration in small groups was dynamic and instructive.

"We started realizing that we were utilizing parts of our brain that we don't usually use at work," Lee said. "I was really impressed with some of the ideas that came up in that session. From a hands-on practical level, it showed how you can get a group of people together who have never met who have a common interest in innovation within nuclear and have them work together for a very short period and come up with some innovative, cool, neat ways of thinking." For example, one idea that bubbled up was about an international, web-based network that connected people with specific skills to jobs.

Lee can envision using some of what he learned at GFNI for his work at the CNSC. For instance, teaching innovative attributes through game playing is a tool that could help Lee and his staff develop digital solutions that make it simpler and easier to produce commission member documents or even to schedule staff travel. "I may use the games to walk people through how to think differently about how we can make things better, faster, and a lot more efficient using digital solutions," Lee said.

A Framework for Innovation

The fact that Lee came away from GFNI with tangible ideas about developing and implementing innovative ideas in his organization is exactly what the event organizers hoped would happen. An *EPRI Journal* article earlier this year chronicled a year-long effort in advance of the GFNI in Miami to develop a practical framework professionals in the nuclear industry can use to translate ambitions to innovate – and to be clear, the industry is full of people with big, bold ideas – into action. The framework was intentionally designed to be useful for people in any size or type of organization located anywhere in the world.

The introduction of the framework to translate ambition into action was the centerpiece of this year's GFNI, which brought together over 150 people from 20 nations, including representatives from utilities, technology companies, regulators, academia, and entrepreneurs. The earlier *EPRI Journal* story provides details about the framework, which has three basic steps:

Define the ambition Innovation can take many forms, which can make defining its purpose elusive. But clearly defining the ambition and outcomes sought is an important step in driving innovation.

Identify the actions Getting from point A to point B requires action. Similarly, achieving a defined ambition and outcomes will only happen by completing a set of actions. Actions are taken at the individual, team, and organizational level and drive progress towards milestones and, ultimately, the defined ambition.

Balancing the barriers and enablers Any project inevitably must balance challenges and obstacles with the support and positive attributes driving its progress. In some cases, barriers and enablers are the same, but whether they are positive or negative forces comes down to their execution. Identifying barriers and enablers is an important step in guiding which actions will help achieve the ambition.

Making the Framework Actionable

Just as the mission of this year's GFNI was to turn ambition into action, the event itself included activities to help attendees translate the framework for innovation into effective attitudes and behaviors. For example, building on its successful use at the London gathering, the GFNI in Miami featured a Bitesize Behaviors workshop.

Specifically, the workshop was designed to underscore the importance of four behaviors essential to innovation. They are:

A Challenger Mindset: Innovation demands doing things differently. For many people, questioning the status quo can be uncomfortable. A challenger mindset means having the confidence to challenge how things are normally done, embracing the instructive power of failure, the willingness to be open-minded, and encouraging shifts in culture needed to drive innovation.

Diversity in Thought: Group think is the enemy of innovation. Generating the types of new ideas that foster innovation means questioning the thought patterns that settle in through our education and work lives. One key to redirecting common pathways of thought is to embrace 'what if' thinking, which encourages new ideas and approaches to problems.

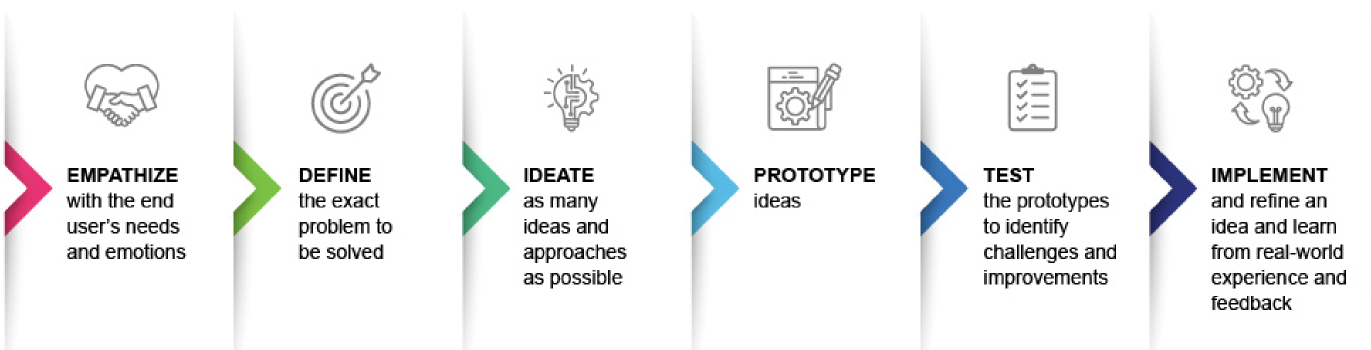
Courage: The discomfort that naturally spikes when questioning accepted ideas and processes provides a strong incentive to never suggest or try anything new. Breaking out of that rut requires courage to challenge the status quo and take calculated risks.

Role Model and Diversity: Diverse teams with different experiences and viewpoints are more innovative than groups of like-minded people, which is why it's so important to build teams with varied backgrounds and to recognize and role model that there is no one formula or source of innovation.

Practicing New Skills

It's one thing to learn new concepts and modes of thinking that can help drive innovation. Utilizing them takes practice, which was the rationale behind GFNI's hackathon activity. Before dividing into teams for the hackathon, attendees received training in design thinking. Design thinking is geared towards developing innovative solutions for unconventional uses and challenges, such as designing a car ideally suited for a dog rather than a human. Ideally suited for complex or ill-defined challenges—which are common in the nuclear industry—design thinking rewards collaboration, creativity, and focus on the end user's experience and goals.

The design thinking methodology GFNI participants trained on included six steps.



Seven teams took their training and applied it to develop new ideas to address industry challenges. The hackathon teams then presented their ideas to judges. Florencia Renteria served as a facilitator guiding one of the hackathon teams. Renteria is a scientific and strategic advisor for the Women in Nuclear Young Generation group and has extensive experience with the International Atomic Energy Agency (IAEA) and other organizations.

Innovation has been central to Renteria's PhD research and her professional career. "You have a lot of tools like artificial intelligence, virtual reality, and quantum computing," Renteria said. "How are we going to integrate those tools into a framework or infrastructure development for the coming years because the technology is accelerating? We have a lot of innovations going, and some need to be organized systematically to recognize how to implement them."

In the hackathon, teams were charged with using the innovation methodology they learned at GFNI. While the original task was to focus on applying the methodology to one scenario, Renteria's team insisted on combining three scenarios together. "They didn't want to limit themselves to one challenge, and the team preferred to integrate more items into the concept," Renteria said.

The mere fact that Renteria's group wanted to expand the ambition of their work is a good indication that the main message of GFNI was having an impact on attendees. But Renteria also says that her group found real value in identifying enablers and barriers as a tool to accelerate innovation. "Sometimes, we think that we have to build something from scratch to be innovative. But it's very useful to have a framework that guides you to identify enablers and barriers and organize information systematically," Renteria said. "It's more like a puzzle we are building based on a certain frame, and I think it helps accelerate innovation."

For Renteria, the value of the framework introduced at GFNI will multiply as instruction about its application spreads. This is particularly important for early career professionals in the nuclear industry. "The earlier we start implementing and exposing the framework to the younger generation, the better we can accelerate capacity building," Renteria said. One way to do that, suggests Renteria, is by holding mini hackathons online and incorporating them into other industry events.

Innovation Can Apply Everywhere

At first blush, it may not seem as though Chris Saville's job at Duke Energy has much need for innovation. Saville, a lead engineer at Duke, is part of a team that is working on securing license renewals for its fleet of eleven commercial reactors to operate for 20 more years.

But Saville understands that new approaches—another way to say innovation—to relicensing can make the process more efficient. "An example of that would be putting all our application's technical information into computer software which then prints it out and organizes it and formats it," Saville said. "We are working on our second application now, but for our first project we did all of that manually by hand using Word and Adobe and it was very time consuming and painful. We're still perfecting this tool, but we are going to use it for the rest of our fleet."

Another example of innovation is how Duke is also using AI to go through 10 years of plant operating data to look for any signs of aging impacts. This is a task that Saville describes as being akin to looking for a needle in a haystack, and the application of AI can accelerate and improve the work. Given these initiatives, it's no surprise that the GFNI theme of turning ambition into action resonated with Saville. "The theme of turning ambition into action is important to talk about because a lot of times in nuclear we say, well, we can't fail, and we're going to be ultra conservative," Saville said. "That has its place with safety. But there are areas, especially in project work, where you can find areas to improve and try new things, even if you fail."

Already focused on how innovation can improve his day-to-day work, Saville brought home additional ideas from GFNI that he hopes will help. One came from his participation in the Hackathon, specifically the direction to not self-censor when first brainstorming ideas for solving a challenge. "Just throw everything at the wall and see what sticks. If you have an idea for a solution, maybe it's not a good solution or maybe it's a partial solution," Saville said. “I think that approach allows us to think more outside the box freely. You don't have to present a solution that fixes everything upfront. This gets the conversation going.”

Saville also appreciated the GFNI workshop about storytelling. Which may seem odd, since the relicensing applications he works on are thousands of pages full of technical information. But Saville sees the value of storytelling in communicating what all that technical information actually means. “We want to take the conclusions from our work and tell the story about the condition of the plant, what we're going to do to keep the plant in good condition, and why it's safe to operate for 20 more years when it was originally designed for 40,” Saville said. “The way we tell that story is important to our audience, which is the NRC (Nuclear Regulatory Commission) and the public.”

EPRI Technical Expert

Heather Feldman

How EPRI Laboratories Deliver Confidence to a Rapidly Changing Industry

By Chris Warren

In the spring of 2024, the U.S. Department of Energy (DOE) released a report detailing the potential benefits that several grid-enhancing technologies (GETs) could provide to improve the capacity of the transmission system. The critical need to bolster bulk grid capacity has been a topic of intense interest recently, thanks to the growing demand for electricity, the push to decarbonize, and the high cost and slow pace of permitting, financing, and building new transmission lines.

Put simply, GETs have attracted a lot of interest because they can be cost-effectively and rapidly deployed while new grid infrastructure is being built. However, as is the case with any new technology, there are questions about the performance and reliability of GETs, which include dynamic line ratings (DLR), advanced conductors, advanced power flow controllers, and transmission topology optimization. In some cases, GETs haven't been deployed widely or for a sufficiently long time for utilities and grid operators to be fully confident that they can extract all the potential value from the technologies.

Fortunately, there are ways to build the confidence that utilities, regulators, and others need that relatively new technologies can perform as hoped before widescale deployment. For instance, EPRI Laboratories in Charlotte, North Carolina, Knoxville, Tennessee, and Lenox, Massachusetts, offer the testing capabilities and deep industry expertise needed to help the industry use, understand, and get comfortable with beneficial technologies before they are installed in the real world.

That's exactly what happened with GETs. "When GETs really emerged as a priority about a year ago, people came to EPRI because we've been testing advanced conductors for more than a decade," said Drew McGuire, director of transmission and substations R&D at EPRI. "So, when the industry needed to understand advanced conductors, we could raise our hand and say we've already done it. Here are the test results. We aren't just responding quickly; we are ahead."

And when it comes to GETs specifically, EPRI's laboratories—including new, purpose-built test sites in Lenox, Massachusetts—are making investments in personnel and equipment to better understand the performance of advanced power flow controllers and the potential benefits of DLR.

Keeping Up with the Rapid Pace of Change

The emergence of interest in GETs is not an anomaly. These days, any discussion about the utility industry inevitably includes descriptors like transformation, transition, and rapid change. These assessments are not wrong. The ongoing shift of the power system to become more decentralized, digitized, and decarbonized involves an unprecedented level and pace of change. However, as the demand for electricity from transportation, heating, cooling, and industry increases, the goal of the industry to deliver reliable and safe energy remains the same.

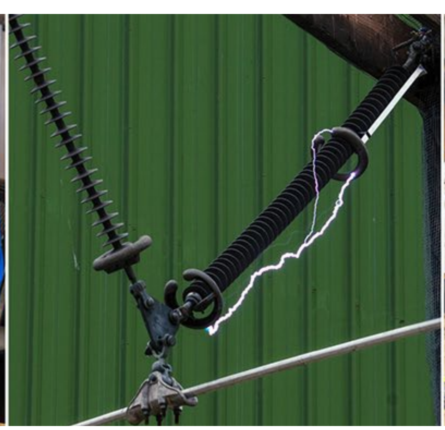
Utilities and grid operators must manage immense and rapid change in generation and grid systems that, in many cases, are a century old. They must also reliably deliver electricity, increasingly from renewable and low-carbon sources. One of the most obvious manifestations of the change utilities must successfully navigate is the assessment and integration of new technologies. Deploying new technologies—or improved iterations of existing technologies and materials—inevitably requires robust testing to ensure they don't introduce new risks that reduce grid reliability or raise safety concerns. EPRI laboratories can accelerate testing to close knowledge gaps and increase confidence in new technologies.

"The pace of change is accelerating. This means that new needs and new technologies are coming into the market all the time. Grid owners are in a position where they're operating real transmission lines and real distribution lines that are serving load," McGuire said. "But they simply don't have the performance data or the experience to know if it's the right time to deploy new technology or if it's deployable at all. The labs can derisk technology so that the end users can apply it confidently and intelligently, adding value. That's a key part of what the labs do."

Building on a Foundation of Equipment and Expertise

The capacity to respond quickly or even anticipate industry needs is not something that emerged overnight. Years of continuous and meaningful investments in the labs have provided a foundation of capabilities enabling EPRI to address the industry's wide range of opportunities and challenges.

"We strategically invest in state-of-the-art capabilities that provide a strong foundation that can be reused for multiple projects and also enables EPRI to be flexible and dynamic to respond to new testing needs, whether it's asset management, cyber security, or DER (distributed energy resources)," said Matt Wakefield, director of information, communication, and cyber security (ICCS) at EPRI. "In Knoxville, we have the electrical infrastructure for performing a whole host of designs and tests on various types of power quality equipment to replicate any type of power quality scenario. And in my area, we have virtually every piece of equipment installed in North American substations, so we can replicate any utility substation environment and evaluate its safety and security against cyberattacks."


Here's a helpful way to bucket the high-level capabilities of EPRI's laboratories:

Generation and Low-Carbon Resources: The generation mix in the U.S. and worldwide is changing rapidly. However, there are fundamental attributes that both new and traditional generation assets require to efficiently, safely, and reliably deliver electricity. With over 20 unique capabilities, EPRI's Generation and Low-Carbon Resources Laboratories conduct tests spanning materials science, materials testing and characterization, chemistry and corrosion, welding, non-destructive evaluation, and digitalization.

Energy Delivery and Customer Solutions: With outdoor test lines and substations exposed to changing weather conditions and indoor lab facilities in Knoxville and Charlotte, EPRI has a broad set of capabilities to evaluate new and existing technologies and how they integrate and perform with one another. Among the transmission and distribution testing capabilities are the ability to evaluate advanced transmission conductors, drones and robotics, distribution structures, and underground transmission cables. EPRI's labs and test fields also provide testing capabilities to assess the wide range of customer-sited technologies being connected to the grid, including energy storage, electric vehicles (EVs), and EV chargers.

Nuclear: EPRI's laboratories are ideally positioned to support and advance the global resurgent interest and commitment to nuclear energy. EPRI's labs have state-of-the-art facilities for evaluating components and materials and are staffed by experts in welding repair and research along with non-destructive evaluation (NDE) techniques, including eddy current, phased array, and ultrasonic testing. EPRI's buildout of ultrasonic testing capabilities is an example of how the laboratories are responsive to member needs and how new testing competencies build upon an existing foundation.

The labs can help lead and advance both the industry and benefits to the public through engagement with codes, standards, and other regulatory bodies. "We have a lab for ultrasonic testing that was developed because utilities agreed they needed a single place to do testing for qualifications for technicians to meet regulatory standards," said Michael Ruszkowski, director of plant support at EPRI. "Over the course of three decades, we've accumulated 700 different samples of different metals, different welds, and different weld overlays of dissimilar metals. People can come and get qualified at our site and because we have such a large sample, it allows us to have all different aspects of degradations that you would find in the field at a nuclear power plant."

The ongoing and wide-ranging investments in cutting-edge equipment and facilities at EPRI's laboratory facilities are an important differentiator, particularly compared to other more specialized labs. Equally important is that EPRI has also continued to make investments in expanding lab staff. This is particularly critical today because of the wave of retirements that are impacting the industry. "Good people are equally or more important than good equipment," said John Shingledecker, a principal technical executive at EPRI. "We're increasingly being asked to respond rapidly to industry challenges, whether it's failure investigations or root cause analysis, because there is a knowledge gap in the industry, and our expert teams are filling that gap with unbiased assessment grounded in deep technical knowledge."

A Collaborative Approach to Research

With so many new technologies and so much change impacting the utility industry, how do the labs prioritize their work? EPRI's internal expertise and forward-looking research provide invaluable insights about emerging challenges, opportunities, and technologies. However, the labs' work and the investments in equipment and people necessary to do rigorous testing are also guided by specific needs and gaps pinpointed by member utilities. "They will come to us and say, here's a problem I'm having, or here's a question that I need an answer to," said McGuire. "Or this piece of equipment just failed in a substation; what can we learn?"

Inevitably, this results in the labs focusing on both emerging and existing technologies as well as the compatibility of new and old. Cybersecurity is a good example of how the two come together in the work of the labs. "On the innovation side, there are areas like evaluating artificial intelligence capabilities to detect attacks," said Wakefield. "Then, on the other side of that are assets like digital relays that have been installed for years. How well are they protected against attacks, and what mitigations are needed because they don't necessarily have the latest and most advanced defensive capabilities?"

While most of the work done at the labs is targeted at broad industry challenges and opportunities, individual member utilities can fund specific and targeted tests. But even if the labs pursue bespoke projects, the findings are still used to inform the entire industry. "We will do one-off projects," said Shingledecker. "The learnings come back to EPRI and the industry. We can help with a specific issue, but then we can proliferate that knowledge, and the learnings will help drive future research."

A Wide Breadth of Expertise

One of the hallmarks of the emerging power system is the erosion of traditional silos. As just one example, consider the growing importance of transmission and distribution system planners working together to ensure grid reliability and the smooth integration of distributed energy resources (DERs).

Managing the challenges and opportunities that arise with greater interdependence necessitates a holistic approach to research and testing. EPRI's laboratory capabilities reflect its broad research expertise. This is unique. "From nuclear to generation, transmission, customer solutions, telecommunications, and cybersecurity, we've got the whole ecosystem covered among our labs," said Wakefield. "There are other labs that have bigger capabilities, but they don't have the same breadth."

That breadth allows EPRI to leverage its labs to pursue combined, multi-stakeholder research projects that reflect utilities' real-world challenges. For example, EPRI programs focused on distribution operations, DER integration, data connectivity, and cybersecurity have intersecting research and testing imperatives that are best pursued together. "We’ve established an ecosystem here from operations to asset management to telecommunications to data integration and cybersecurity that allows us to do combined research and training that leverages the same resources,” said Wakefield.

Arguably, though, the laboratories’ biggest differentiator flows from the simple fact that its work reflects EPRI’s core mission to serve society. “Other labs serve important functions to develop new products, educate students, and generate fundamental learnings,” said McGuire. “EPRI laboratories exist to achieve our public mission in an independent, unbiased way. That’s our motivation.”

EPRI Technical Expert

Drew McGuire, Michael Ruszkowski,
John Shingledecker, Matt Wakefield

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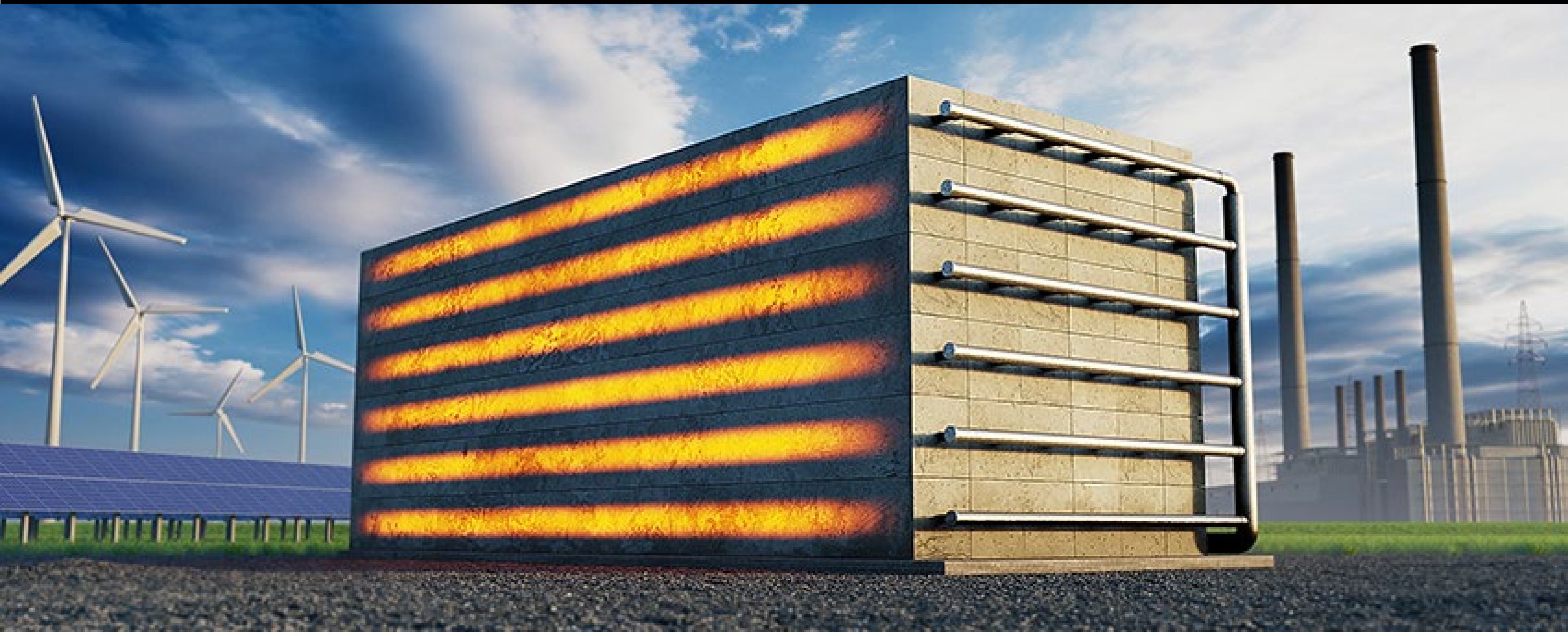


Lessons From a Concrete Thermal Energy Storage (CTES) Demonstration Project

By Chris Warren

There is little debate about the urgent and growing need for large amounts of affordable energy storage. The many reasons energy storage is an essential pillar of a resilient, reliable, and decarbonized grid are well-known, particularly its role in supporting the installation of large amounts of intermittent renewable generation.

For example, the International Energy Agency (IEA) recently reported that global renewable electricity capacity additions surpassed 500 gigawatts in 2023 and would exceed 40 gigawatts in the U.S. alone in 2024. As renewable penetration increases, so does the need for storage. Indeed, the IEA projects that about 1,500 gigawatts of energy storage will need to be installed by 2030 under its net-zero emissions by 2050 scenario.

Though pumped hydro has long been the dominant energy storage technology, the need for low-cost, reliable, and flexible storage technologies has spawned significant investment and research and development (R&D). While much of the energy storage focus is on various battery technologies, it is increasingly clear that a diverse mix of short-and long-duration storage solutions will be needed to cost-effectively handle the growing number of storage use cases.

Growing Attention to Thermal Energy Storage

Over the past few years, thermal energy storage systems have attracted a lot of interest and been the focus of significant R&D. Earlier this year, the readers of *MIT Technology Review* chose thermal energy storage as one of the ten breakthrough technologies of 2024. That interest is expected to translate into meaningful deployments. The International Renewable Energy Agency (IRENA) forecast indicates that thermal energy storage technologies could triple in size by 2030, reaching 800 gigawatt-hours of installed capacity.

At the most basic level, thermal energy storage systems capture and store heat in materials like bricks, molten salt, and concrete for discharge later. An earlier *EPRI Journal* story detailed how concrete thermal energy storage technology works and its potential benefits, including providing a far cheaper and much longer-duration storage option than lithium-ion batteries. The story also chronicled laboratory research EPRI conducted with concrete thermal energy storage system developer Storworks Power that successfully validated the technology's design and performance.

However, anybody involved with R&D knows that strong laboratory performance does not guarantee that a technology will work as expected in the real world. "There's always a vision of what works from a modeling and lab point of view," said Scott Hume, an EPRI technical executive whose research focuses on energy storage. "But ultimately, it's only when you truly build and operate it that you start to see real challenges, or if the technology works as you hoped."

The aim of a recently completed pilot project conducted by EPRI, Storworks, and Southern Company was to gain a realistic understanding of how concrete thermal energy storage functions in an operational utility setting. A 10-megawatt-hour concrete thermal energy storage system (CTES) was designed and constructed at Alabama Power's Plant Gaston, a five-unit, 1880-megawatt natural gas and coal power plant in Wilsonville, Alabama. The CTES included 42 of Storworks' concrete "Bolderbloc" units, each embedded with numerous stainless-steel tubes. The pilot project finished construction in the summer of 2023 and began commissioning and testing in the fall of the same year.

For Storworks Power, the project was an opportunity to test its CTES at a scale that is impossible to reach in the lab. "Storworks has done many lab-scale tests on different full-size CTES modules," said Jennifer Tuey, the company's director of R&D. "The Plant Gaston pilot project gave Storworks the opportunity to build a system more than 10 times larger and integrate with a live boiler at an operating facility." Tuey says Storworks was eager to learn how its CTES operated as it was charged with superheated boiler steam and discharged to make superheat steam.

For Southern Company, one of the aims of the demonstration of the CTES at Plant Gaston's Unit 5 was to understand better how this technology could support plant flexibility. "Our primary goals were to prepare for successful large-scale deployment via hands-on testing and evaluation, reduce cost and technology risk, and identify gaps and learn," said Josh Barron, a senior research engineer at Southern Company, the parent company of Alabama Power. "The primary metrics we were interested in were roundtrip efficiency, thermal losses, and reliability."

Enhancing Flexible Operations at Fossil Plants

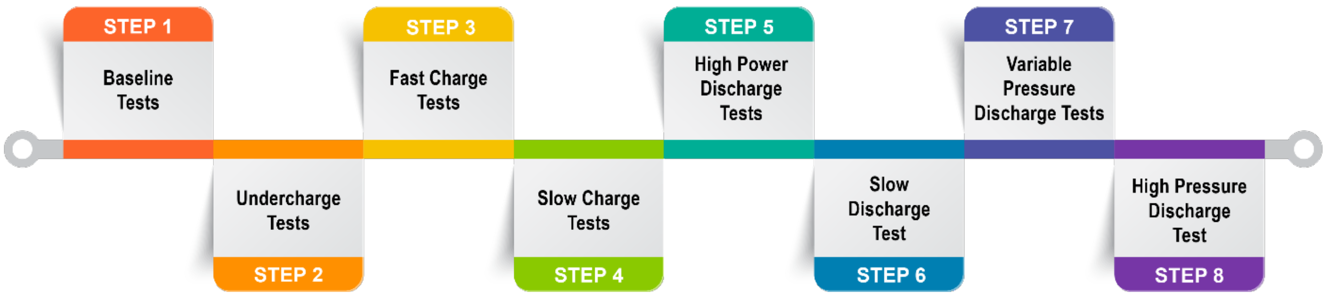
In recent years, coal plants and other fossil fuel assets across the U.S. have had to operate in ways they weren't initially designed for. As more wind and solar have been added to the grid, some coal plants have evolved from continuous baseload operation to more flexible load-following output. To operate with greater flexibility usually means a power plant must ramp up and down quickly to respond to changes in net demand.

EPRI has conducted extensive research about the potential strains that can result from flexibly operating a fossil fuel power plant originally designed for baseload generation. The CTES demonstration at Plant Gaston probed how thermal storage could help by accepting steam from the plant's boiler when net demand was falling or quickly responding to increased net demand by generating steam. Discharging steam in response to increasing demand is especially helpful in regions with large amounts of solar, where total generation declines significantly as the sun sets. Among other performance metrics, the researchers at Southern Company monitored whether the temperature, flow rate, and duration of the CTES discharge could accurately mimic the typical supply to the turbine.

A Rigorous Testing Plan

The testing protocol for the CTES was designed to reflect myriad conditions. The CTES was charged at different rates to validate its capacity to store thermal energy and discharge it at differing rates. For example, while the need to respond to a setting sun and dropping solar generation by rapidly producing steam for the coal unit's turbine is one important scenario, it's not the only one. Also important is the ability to discharge steam to supply the turbine at a more modest pace but over a longer period.

Eight-Part Testing Plan



The research and construction teams also had to navigate challenges well beyond the normal hurdles of a pilot project. Indeed, the project began during the COVID-19 pandemic, when access to the plant was limited to essential personnel. The project also faced supply chain constraints, resulting in cost increases due to the disruption caused by the pandemic. "The pandemic created significant challenges for the overall timeline of the project. The Southern Company and Alabama Power staff did an excellent job managing the construction team to get this project built," Hume said. "Some of the special hardware, such as small valves needed for high pressure and temperature, arrived over a year after they were ordered. But Southern Company did a great job scheduling workers around when parts arrived."

When construction of the CTES was finished, an eight-part testing plan began. The testing plan included:

- **Baseline tests** involved charging the CTES at full supply pressure for four to six hours and then discharging at the same nominal flow rate for four hours.
- **Undercharge test** in which the CTES was charged at the same rate as the baseline test but where the charging was stopped after two to three hours and then switched to discharge.
- **Fast charge test** involved delivering the maximum feed pressure at a higher than nominal flow rate to the CTES.
- **Slow charge test** charged the CTES at a deliberately slow flow rate.
- **High power discharge test** was designed to probe the system's capacity to deliver the maximum quantity of steam. However, limitations with the condensate pump prevented the test from being completed.
- **Slow discharge test** evaluated the CTES' ability to deliver steam over a prolonged period at partial load conditions.
- **Variable-pressure discharge test** investigated the possibility of changing the pressure of the steam released by the CTES to optimize the system's capacity.
- **High-pressure discharge test** probed whether the CTES could produce higher-pressure steam that could be used for higher work potential.

Lessons Learned

The CTES at Plant Gaston completed 86 full charging and discharging cycles under a wide range of conditions. One important takeaway from the testing is that the CTES consistently and successfully demonstrated its ability to enhance the unit's flexible operations without any adverse impacts on the plant and its components.

Enhanced flexibility was made possible by the reliable responsiveness of the CTES. "Storworks operated the CTES system 24/7 for three weeks, and the system responded immediately with changing pressures, temperatures, and flow rates at all states of charge and discharge," Tuey said. "We were pleased that the system operated as expected and thermal performance matched our modeling. Another key takeaway is that at the end of a discharge, the discharge pressure can be lowered to access a 'reserve' of thermal energy that is available to extend the value of the system even if operating below rated conditions."

Photo courtesy: Southern Company

Other specific lessons learned from the project include:

- The initial concrete drying and commissioning procedures were refined for future deployments to improve their efficiency.
- The flexibility of the constructed CTES exceeded expectations, and the CTES was able to respond consistently to changing conditions.
- Design improvements were identified to enhance system efficiency in future deployments. “For future iterations, more insulation is needed on the hot end of the blocks to reduce thermal losses,” Barron said. Barron also noted that consistent heat transfer between each row of blocks could be improved by installing control valves at each manifold.
- Full cycle thermal roundtrip efficiencies exceeded 88 percent, and Storworks believes efficiency can be significantly improved. “With improvements identified in the final project report, Storworks believes thermal roundtrip efficiencies will be more than 98 percent,” Tuey said.
- The experience of integrating CTES into an operating power plant provided Storworks with insights that can lower the costs of future projects. “Storworks has a better understanding of the processes for plant integration and costs of construction and operation of their system onsite,” Tuey said. “Storworks is very cost-conscious. Thus, we have refined these details and added reduction opportunities in our cost models.”

Looking Ahead

After any successful demonstration project, the question is always the same: What comes next? While there are no immediate plans to deploy CTES at scale in Southern Company’s system, Barron says there may be potential applications in the future.

“It will be an option to consider as renewable energy and the need for long-duration storage grow within our service territory,” Barron said. “One potential near-term application of CTES would be to deploy it at industrial customer sites to decarbonize high-temperature industrial heat. That was not an application we had initially considered when we started this demonstration project, but interest in this type of technology is growing among industrial customers.”

It's not just utility industrial customers who are interested in CTES and other thermal storage technologies. One big reason industrial customers are exploring thermal storage is that they see it as a tool to help drive their decarbonization efforts. The size of the storage system needed at industrial sites also makes them more viable projects. “Industrial market deployments are smaller, so it’s easier to make a project happen because it’s a smaller use case,” Hume said. “A utility-scale storage system is on a gigawatt-hour scale whereas something on a petrochemical plant or a factory could be on the tens of megawatt-hour scale.”

Demonstration projects like the one at Plant Gaston are important for advancing technology and understanding gaps that need additional research and development. In fact, Southern Company’s Barron says more storage technology demonstrations are needed. “First-of-a-kind technology deployments are always difficult, but many more projects like this are needed to meet clean energy goals,” he said.

But it’s also important to remember that no single technology will be enough to meet the large and growing need for energy storage. And choosing the right storage technology will be determined in large part by its application, where it’s located, market conditions, and regulatory approval.

“Each technology has pros and cons in terms of performance and cost,” Hume said. “It’s relevant to your location, too. Are you in a location with a lot of nuclear power? Is it a highly renewable environment? If it’s a solar-dominated market, the storage durations and roundtrip efficiencies will be different than if it’s wind-dominated. CTES and thermal storage will be part of the answer. The industry, customers, and other stakeholders need to figure out when and where it should be deployed.”

EPRI Technical Expert

Scott Hume

EPRI JOURNAL

EPRI's GET SET Initiative Gets Going

As the need for transmission capacity grows, EPRI launches a new effort to evaluate the performance of grid-enhancing technologies.

By Chris Warren

America needs a lot more transmission grid capacity. That was the basic finding in the U.S. Department of Energy's (DOE) National Transmission Needs Study released last year. There are many reasons why an expansion of transmission grid capacity is a priority, including the system's role in providing reliable and resilient electricity as demand grows and extreme weather increases in frequency and severity.

Abundant transmission system capacity is also integral to the clean energy transition. For example, the DOE study found that the U.S. must double its current regional transmission capacity and increase interregional transmission capacity over five-fold to reach the federal government's goal of a carbon-free power system by 2035. Princeton University estimates that 75,000 miles of new high-voltage transmission lines—enough to stretch around the world three times—need to be built to reach that 2035 goal.

While there is widespread agreement and increasing levels of incentives and investments to support critical new transmission system infrastructure, the reality is that these projects take many years to get approved, permitted, designed, and built. As the essential work of developing, financing, and building new projects moves forward, however, the need for more transmission grid capacity grows by the day.

The pressing imperative to expand transmission grid capacity quickly has focused attention on grid-enhancing technologies (GETs). GETs are hardware and software that can improve the efficiency, reliability, capacity, and safety of existing transmission lines. GETs are seen as a potentially powerful tool to reduce congestion and speed the integration of renewable generation.

In its Transmission Needs Study, the DOE highlights GETs and describes them as, "solutions capable of managing transmission congestion and increasing line utilization rates by expanding existing transmission system capacity and improving operational efficiencies." The DOE's Grid Resilience and Innovation Partnerships (GRIP) Program is making significant investments in technologies, including GETs, that can bolster the flexibility and reliability of the existing grid.

A Known Unknown

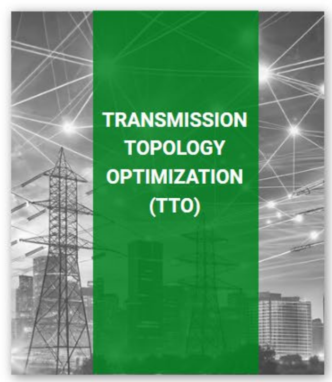
While the potential role of GETs in supporting the transition to a decarbonized and reliable electric power system is widely accepted, the utilities and grid operators that would deploy them have limited experience installing and operating them. This raises a challenge for utilities that want to quickly leverage the benefits of GETs but don't have the time or resources to vet them alone. Closing the gap between the potential GETs have to augment transmission grid capacity and providing confidence that they will operate as expected is the main mission of EPRI's Grid Enhancing Technologies for a Smart Energy Transition (GET SET) initiative.

Launched in July of 2024, GET SET builds on years of research EPRI has devoted to GETs to help utilities understand and be comfortable that the hardware and software will perform reliably. "EPRI has been doing research about grid enhancing technologies for over a decade. The reason that we wanted to have an initiative now is because the technology has advanced to a level where that transition from pilot to deployment stage is happening now," said Anna Lafoyiannis, an EPRI deputy program manager whose work focuses on operations and planning research.

GET SET is driven both by a sense of urgency and practicality. "The idea is that we can put in substantial and focused work that looks at all the technologies in a collaborative way," Lafoyiannis said. "And that will allow utilities to use the findings immediately."

A Focus on Four GETs

The GET SET initiative will focus on four potentially high impact GETs:



Dynamic Line Ratings (DLR): A transmission line's capacity is not constant. When air temperatures are cool, for instance, a transmission line has greater carrying capacity than when higher temperatures risk overheating lines. Wind speed, solar radiation, and the condition of a line also affect its capacity. These conditions not only change frequently, but they are also location-specific. DLR utilizes both real-time monitoring and prediction of local weather conditions to continuously optimize its capacity. DLR's localized, real-time approach is fundamentally different from assessing transmission line capacity compared to more traditional approaches, like static ratings. Static ratings assume worst-case environmental conditions to ensure lines operate safely under any scenario, even if it means significantly reducing capacity much of the time. Ambient Adjusted Ratings (AAR) utilize the prediction of ambient temperature to determine ratings. DLR utilizes both predictions and measurements of wind, solar and radiation, and ambient temperature.

Advanced Conductors: Traditional conductors are made using aluminum that is wrapped around a strong steel core that can be operated at relatively low temperatures of under 100ºC. In recent years, however, conductor manufacturers have begun making conductors using both aluminum and steel, as well as using newer materials such as carbon or ceramic composites that can operate at higher temperatures. The DOE's Advanced Materials and Manufacturing Technologies Office (AMMTO) even launched a contest called the Conductivity-enhanced Materials for Affordable, Breakthrough Leapfrog Electric and Thermal Applications (CABLE) Conductor Manufacturing Prize to spur innovation. Reconductoring existing transmission lines or building new transmission lines with advanced conductors can, in certain cases, have a big impact. For instance, when short-distance AC lines are thermally limited by a conductor, advanced conductors can increase current-carrying capacity by between 5 and 50 percent.

Advanced Power Flow Control (APFC): Transmission system capacity benefits when it has the equivalent of a sophisticated air traffic controller. Advanced power flow control technologies are power electronics-based solutions that provide intelligence to how power flows through a system, directing it away from already congested lines to ones with extra capacity without changing generator dispatch or network topology. APFC technologies have flexibility and responsiveness that traditional power flow control approaches like phase-shifting transformers and series reactors can't match. APFCs have also been singled out in FERC's Orders 2023 and 1920 for their value in helping America achieve its renewable energy objectives.

Transmission Topology Optimization (TTO): Software that monitors and analyzes the transmission system and suggests new configurations is another tool to improve its efficiency, reliability, and affordability. Transmission topology optimization does just that by optimizing the operation of substation circuit breakers to reduce congestion that would normally be addressed with the expensive re-dispatch of generation assets. TTO is a low-cost tool to maximize the efficiency of existing grid assets and to improve the overall operation of markets. TTO can also be complemented with other GETs.

Gaining Confidence with GETs

Though these four GETs have meaningful potential to improve transmission grid capacity, utilities need confidence about their performance, benefits, and impacts as they are deploying them. The GET SET initiative has already produced high-level executive summaries about each of the GETs (which are linked above in the technology descriptions) to raise awareness and understanding; more detailed white papers, case studies, and regular workshops and user groups will also share lessons learned and experiences.

GET SET will also include lab testing and the collation of results from field implementations that will inform the development of everything from frameworks for effective GETs deployments to a quantification of the value they can deliver in local operating conditions.

"We want to take the participants in GET SET on a journey. We are going to begin with several deliverables related to understanding the reliability and uncertainty of these technologies by doing laboratory testing and then sharing overall results so people know what they can expect from a specific class of technology," said Alberto Del Rosso, an EPRI senior manager who oversees grid modernization research and development (R&D) projects. "Then we will be providing a framework and guidance about planning and the best way to operate them from a system perspective."

There have been numerous studies assessing how GETs can improve transmission grid capacity. But what past analysis has lacked is a local focus that makes findings immediately relevant and practical for utilities. "Saying GETs provide benefits across North America doesn't provide meaning for someone that needs to do the work," Lafoyiannis said. "Being able to quantify benefits and impacts at a more regional level, or even at a utility level, is helpful because electric conditions and environmental conditions can vary. And an assessment should also include practical considerations, like deployment timelines, permitting considerations, and supply chain, to fully prepare for the future."

The Role of EPRI Laboratories

Besides EPRI's long history researching GETs, new investments in the capabilities of EPRI Laboratories in Lenox, Massachusetts, Charlotte, North Carolina, and Knoxville, Tennessee, will help utilities get comfortable with the technologies before they're deployed. "When GETs really emerged as a priority about a year ago, industry stakeholders came to EPRI because we've been doing testing on advanced conductors for more than a decade," said Drew McGuire, director of transmission and substations R&D at EPRI. "So, when the industry needed to understand advanced conductors, we could raise our hand and say we've already done it. Here are the test results. We aren't just responding quickly; we are ahead."

For example, in Lenox, Massachusetts, EPRI has commissioned a DLR test facility that includes a new outdoor 625-foot three-phase test span where the current flowing through individual conductors can be controlled, and a wide range of loading conditions can be simulated and monitored. This new test span adds to EPRI's DLR research capabilities, which presently includes thirteen one-to-two-year-long field demonstrations building on dozens that have been ongoing since the 1990s.

Another example: EPRI's Charlotte lab includes a conductor test rig, where conductor-connector systems undergo intense thermal and mechanical stresses, including mechanical loads of 30,000 pounds and temperatures up to 250° Celsius. The GET SET project will also include real-world, fully monitored deployments of technologies with member utilities, including carbon core conductors in the Northwestern U.S. to better understand how resilient they are to icing.

With all the testing, the goal is to first assess categories of GETs rather than the features and performance of individual technologies. "While we will bring out technology providers and do individual tests for them, what we hear from decision makers is before they're even selecting individual technologies, they want to know as a class how DLR, advanced power flow controllers, or advanced conductors perform," Del Rosso said. "They want to know what to expect so they can use the information to evaluate it against other technologies and solutions."

While GET SET will last for three years, the project will regularly share results from its testing and research. Even before the initiative officially launched, Lafoyiannis was reminded of the thirst for knowledge about GETs when EPRI gathered over 200 participants for a workshop about the state of the science of the four technologies. "We had participants from over 75 utilities. We had technology providers, NERC, and other companies and developers in the room," Lafoyiannis said. "There’s broad interest.” And the audience was all saying there’s a strong need for new capacity, and they need to connect new loads and generators on short notice. That’s where we can help.”

EPRI Technical Expert

Anna Lafoyiannis

About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe.

Together, we are shaping the future of energy.

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