EPRI JOURNAL

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50TH Anniversary 1976-2026

ALSO IN THIS ISSUE:

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EPRI Journal: Celebrating Fifty Years of the Long View

Celebrating a half-century of EPRI Journal and looking forward to the next

By Chris Warren

EPRI had a very clear mission when it was founded in 1972. Launched in response to a 1965 blackout that left around 30 million people in eight Northeastern states and two Canadian provinces without power, the formation of EPRI was an acknowledgment both of the vital importance of electricity and the critical need for independent, science-based research and development (R&D) to support its safe and reliable generation and delivery.

Although the world and the electric power industry have changed dramatically since then, EPRI's mission persists to this day. So, too, has the understanding that achieving EPRI's mission is not only about conducting world-class R&D; it's also about communicating the findings of that research with the clarity necessary for utility engineers, decision makers, regulators, policymakers, and the public to understand and apply them.

A NEW PUBLICATION

That understanding was behind the February 1976 release of the first issue of *EPRI Journal*. EPRI's founder and first president, Chauncey Starr, introduced the first issue by laying out four core objectives for the *Journal*: to communicate EPRI research findings; provide useful information for utility engineers; present a monthly update on research activities; and share regular updates on EPRI's program plans, budgets, and relationships with government agencies.

Starr's introduction placed the *Journal* within EPRI's broader communications efforts, grounded from the start in the Institute's technical reports. But that first issue was more than a mere administrative announcement. It also offered a tangible preview of the editorial ambition and approach the *Journal* would embrace for the next fifty years. For example, from the very beginning, the *Journal* has taken a long-term view of the forces and technologies shaping the utility and larger energy industry as well as society.

IMAGINING THE FUTURE, STAYING GROUNDED IN THE PRESENT

Indeed, the publication's first feature article, "Solar Realities," envisioned a late-21st-century future "powered directly and totally by the energy of the sun." This was long before utility-scale solar projects became the mainstream generation assets they are today, a time when EPRI research focused on solar-assisted building heating and cooling as the most viable near-term option because producing electricity from sunlight was still impossibly expensive.

That first issue also had articles aimed at providing more immediately valuable insights to utility professionals and the industry. One piece examined the challenge posed by circuit breaker failures due to the growing prevalence of fault currents. At the same time, another explored a novel approach to identifying flaws in nuclear reactor vessels. The tone of the *Journal's* subsequent half-century has mirrored that inaugural issue, with coverage balanced between practical, relevant information of use in the moment and the identification of emerging technologies and trends likely to shape the industry decades in the future.

DECADES OF HISTORY

It is a dramatic understatement to say that the *Journal* has had plenty to cover over the decades of its existence. Indeed, the grid of the 1970s is almost unrecognizable from today's power system. In the early years of the *Journal*, coal was the primary generation source and would remain so for many decades, but was supplemented by oil-fired power plants, hydropower, and nuclear power, which began an era of rapid expansion.

The *Journal* covered the rapid ascent of nuclear power in real time. A story from 1978, "The Birth and Early History of Nuclear Power," described the many twists and turns of nuclear power, going from being dismissed as "moonshine" to supplying 12 percent of America's electricity. The focus on nuclear was unsurprising, as utilities and the nation sought to reduce the risks of continued dependence on imported oil by accelerating research and deployment of both nuclear and coal technologies. After the 1979 Three Mile Island accident, the *Journal* devoted an entire issue to nuclear safety, including in-depth articles about what had actually happened to cause the accident, the response by industry and government, the impact of the event, and what could be learned about the design and operation of plants to make them all safer.

While headline-grabbing events like Three Mile Island inevitably garnered extensive coverage, the *Journal* continued to write about more slow-moving forces reshaping the industry through the 1980s, 1990s, 2000s, and beyond. While research into established and emerging technologies was a constant, the *Journal* also strove to educate readers about important market conditions. In the 1990s, for instance, deregulation reshaped electricity markets, and a 1994 cover story guided navigating the tectonic change. "Increasingly, the key to success in this more competitive environment is anticipating and actively responding to the forces that are shaping the new markets for electric power," the story declared.

As the industry and the world around it continued to change quickly, the *Journal* strove to keep pace, albeit with the unique benefit of having identified and studied trends decades before they became pressing current topics. For example, the 2000s and 2010s saw the emergence of natural gas as a major power generation source, the rapid growth of renewable energy sources such as wind and solar, efforts and mandates to decarbonize, and the acceleration of electric vehicle (EV) purchases.

These and many other topics that appeared novel to other publications were covered in the *Journal* with a depth and legacy of knowledge made possible only because it reflected EPRI's unparalleled research agenda. Solar energy, after all, had been the topic of the *Journal's* inaugural feature article, and what seem today like prescient looks into a future characterized by EVs, geothermal, advanced nuclear reactors, and other technologies were regular mainstays of the publication.

LOOKING AHEAD

That same long-term, independent research perspective still defines the *Journal* today, and it may matter more now than ever. It helps make sense of a power system growing more distributed, digitized, and renewable. It also grounds coverage of the complex current moment, defined by load growth driven by data centers and electrification, and electricity's increasingly central role in economies and societies worldwide.

Much has changed since Starr introduced the *Journal* 50 years ago. But much of his original mission remains in the publication's vision moving forward. New technologies, policies, and market conditions will inevitably emerge. The *Journal* will continue to cover them, drawing on EPRI's research and long-term perspective. At the same time, the *Journal* will stay focused on the topics, challenges, and opportunities that matter most today, whether that's how flexible loads can help meet electricity demand or how to get the most out of the growing number of batteries deployed across the grid.

FROM PRINT TO DIGITAL

The *Journal* has also evolved with the technologies used to publish and distribute it, moving from print to dedicated digital platforms and, ultimately, to the open web. In 1976, print offered a fixed, one-way experience shaped by production schedules, physical layouts, and material costs. Later, mobile apps created more personalized, focused reading environments, while websites enabled quick story updates, multimedia integration, and global reach. Today's web-first model gives the *Journal* greater flexibility to deliver timely, accessible, and engaging coverage wherever readers are. A new platform and upgrade to https://eprijournal.com/ are planned in 2027.

The other important constant in the *Journal's* future is you, our readers. To both longtime and new readers, thank you. You should know that the original vision to provide information that helps you do your jobs and understand the industry better will remain a cornerstone. But we also welcome your input about what would make the *Journal* an even more valuable resource as we head into the next half-century. It has been a fascinating and unpredictable journey so far. We hope you'll stay with us for the next leg.

EPRI Journal has chronicled five decades of transformation in the power industry. Watch the anniversary video.

EPRI JOURNAL

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EPRI's Roadmap for a Rapidly Growing Battery Storage Industry

By Chris Warren

Installations of battery energy storage are rapidly accelerating across the globe. According to the International Energy Agency (IEA), 108 GW of new battery storage was deployed globally in 2025, an increase of 40% over 2024 and 11 times more than in 2021. A similar story is playing out in the US, where nearly 19 GW of new storage capacity was added last year.

The momentum driving the dramatic upswing in energy storage installations is not stalling. According to a forecast from Wood Mackenzie and the American Clean Power Association, annual installations in America will exceed 28 GW by 2031. Put simply, there is little doubt that energy storage will play an increasingly prominent role in grids across the world.

There are myriad reasons why this is happening. One is simply that energy storage is increasingly cost-competitive, with a nearly 90% reduction in the cost per kWh of lithium-ion batteries over the past 15 years, making it the most deployed new battery technology chemistry (pumped storage is the world's most used energy storage technology). While falling costs have made energy storage financially viable, its adoption is also spurred by the many benefits it can deliver—from supporting variable renewable generation to enhancing resilience, relieving grid congestion, and reducing capacity and energy costs across the power system.

A FAST-MOVING INDUSTRY WITH MANY QUESTIONS TO ANSWER

While demand is driving a proliferation of new projects, it's important to remember that battery energy storage remains a rapidly evolving industry. For example, lithium-ion batteries have been the dominant battery energy storage technology, and they continue to evolve with larger-format cells and improvements in balance-of-system and safety. But other technologies, such as flow, sodium-ion, and iron-based batteries, are also maturing quickly. Substantial and ongoing efforts have been made to modernize safety codes and standards, which inevitably lag behind design changes and emerging battery chemistries and their integrated solutions.

And communities and local officials responsible for project approvals may have limited access to the objective technical information needed to evaluate proposals.

According to one estimate, at least 150 local governments across 17 states have temporary moratoriums, bans, or restrictive ordinances that limit battery energy storage. Other growing pains stem from the fragmented way projects are planned, developed, built, operated, and maintained. The team that initially plans an energy storage project rarely procures the equipment, secures the necessary permits, or handles the operations and maintenance (O&M) after commissioning. Developers, utilities, regulators, and communities often have distinct and differing assumptions about how a project should move forward and the value it should create.

SCALING ENERGY STORAGE RESPONSIBLY

Demand for battery energy storage will continue to drive the development and construction of more projects. But the full benefits of the technology can be more readily achieved by sharing industry best practices and experiences, and by identifying and filling knowledge gaps. That was the rationale for the development of EPRI's Energy Storage Roadmap in 2020. "Initially, we wanted to help bring order out of the chaos of a new industry with different technologies and multiple development steps with different teams and stakeholders," said Eva Gardow, Technical Executive in EPRI's Energy Storage and Distributed Generation program. "Now we are focused on refining and optimizing the roadmap to better serve the industry, utilities, and communities at each stage of a project."

The roadmap was most recently updated in 2024 and reflects the objectives that utilities, developers, and regulators have identified as most important for projects to achieve for battery energy storage to be deployed responsibly at scale. The roadmap is organized around four future state pillars—safe, reliable, affordable, and clean—that match EPRI's mission as an organization. Underpinning all four pillars is a commitment to innovation to advance energy storage equitably, ensuring the technology's benefits are fully shared with the communities that host projects. For each pillar, the roadmap also identifies the vision of what success looks like and the gaps standing in the way of achieving it. Identifying the gaps builds consensus about the research initiatives needed to fill them.

EPRI is well-suited to lead this effort. EPRI has a public benefit mission, a commitment to independent research, and a longtime role as a convener of utilities, regulators, policymakers, technology providers, and other stakeholders in the battery energy storage ecosystem. This ideally positions EPRI to organize and support collective efforts to scale energy storage deployments by providing the research, insights, data analysis, and best practices that projects need to be safe, reliable, affordable, and clean. EPRI also draws on decades of research across topics ranging from performance and reliability to thermal runaway and fire risks, to technoeconomic modeling, to end-of-life management.

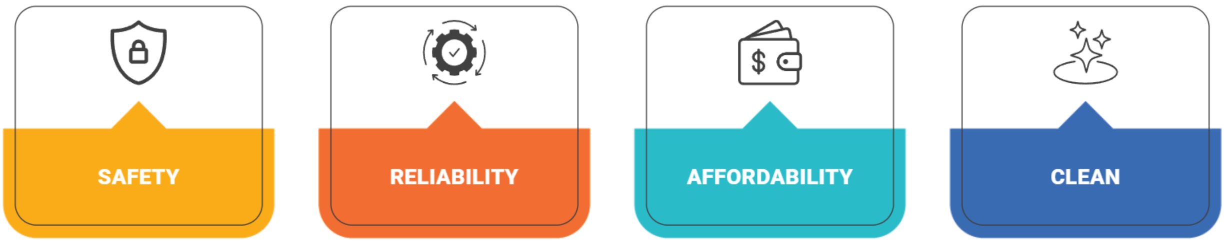
The roadmap is intentionally structured to be useful to companies and individuals responsible for planning, developing, building, operating, and decommissioning battery energy storage projects. "It's aimed at providing practical tools, resources, and guides that can be applied in day-to-day processes," Gardow said.

A ROADMAP BUILT AROUND HOW PROJECTS WORK

To provide practical guidance, the roadmap and the gaps it highlights are organized around the real-world project life cycle phases of planning, procurement, deployment and integration, operations and maintenance, and decommissioning. The logic is straightforward: different teams own different project phases, and a gap that matters to an O&M crew may be largely irrelevant to the group handling procurement. "By splitting it up by life cycle phase, it helps departments within organizations determine which gaps might be more applicable to them for what they're doing on a daily basis," said Taylor Kelly, an EPRI technical leader who led the creation of the most recent version of the roadmap.

The gaps identified in the roadmap are far from abstract research questions. They represent practical opportunities to mitigate risk, improve asset reliability, lower costs, and increase certainty across all stages of project development. A closer look at each roadmap pillar illustrates both the scope of challenges projects must surmount and the concrete steps underway to address them.

Roadmap Pillars



Safety

The safety pillar is where some of the most active work to apply knowledge and implement solutions is underway. Community pushback is one front, often driven by uncertainty about fire risk and environmental impacts rather than informed opposition. That uncertainty is understandable, given media coverage of high-profile incidents. But the [data](#) tells a more nuanced story. Despite a roughly 65-fold increase in global battery storage deployments between 2018 and 2023, the average number of failure incidents held steady at around 10 per year. The industry has incorporated lessons from failure incidents, and the trend in safety performance is moving in the right direction.

EPRI's nearly decade-old fire prevention and mitigation research project, which won a 2025 Chauncey Award, has produced guidance on thermal runaway characterization, failure incident response, and safe operations and maintenance practices. Current work includes an updated analysis of EPRI’s publicly accessible global failure incident database, which has become one of EPRI's most visited online resources and is regularly referenced by researchers, regulators, and first responders. Researchers are also investigating materials that could prevent failures from propagating and cascading into large-scale fires and conducting testing to documented and is important for guiding emergency responders' strategies.

Addressing community concerns requires more than data. A community perception survey currently underway aims to establish what the public actually understands about storage technology, with the goal of developing better educational tools for communities and local authorities.

Reliability

Because battery storage is a young grid technology, the operational history needed to understand long-term performance, degradation patterns, and meaningful end-of-life thresholds is limited. EPRI has responded to fill that gap with a benchmarking initiative called BEST Reliability, or Benchmarking Energy Storage Technology Reliability. BEST Reliability is a collaboration with energy storage owners and offtakers to collect operational data from deployed commercial systems and begin developing industry-wide performance baselines. "If we can get enough system data, we can help develop the foundation for what the expectation of performance should be," Kelly said. "Then, as we get more systems, we can start to benchmark performance over time."

Reliability gaps also affect asset management, operating costs, procurement, and risk allocation throughout the life cycle. Battery energy storage's modular nature introduces a large volume of components and associated data. Finding the balance between achieving greater visibility into the system's depth and efficiently and actively addressing maintenance tasks remains a challenge. Enhancing reliability will also de-risk and harden the asset owner in the face of vendor transitions and business changes. This helps ensure the ongoing operability of the system.

Affordability

Significant and ongoing cost reductions have dramatically improved the economics, making battery energy storage financially viable for applications ranging from firming variable renewables and reducing grid congestion to providing resilience and backup power. But affordability goes well beyond the purchase price of the technology itself. It also includes the full cost of an energy storage project across its life cycle, including installation and interconnection costs, battery degradation, O&M, and end-of-life requirements that are often ignored when a project is first planned. EPRI's Energy Storage Integration Council (ESIC) offers 17 products and tools to improve capital efficiency, reduce soft costs, and lower O&M expenses.

New technologies add both opportunity and complexity to the affordability picture. Lithium-ion batteries dominate today's market, but sodium-ion, zinc-based, and long-duration flow battery technologies are advancing quickly, and each has distinct cost profiles, performance characteristics, and lifecycle economics. Understanding those differences requires rigorous technoeconomic analysis that accounts for the full range of variables, from capital costs and degradation rates to the value different technologies can capture across multiple use cases.

Besides the ESIC, EPRI also developed the Distributed Energy Resource Value Estimation Tool, or DER-VET™. This free, publicly accessible platform allows utilities, developers, and other stakeholders to calculate and optimize the value of storage and other distributed energy resources based on site-specific conditions. DER-VET was built out of necessity. "Fifteen years ago, there was no tool that could calculate the energy going in and coming out," Gardow said. "That's why we started building this."

Clean

The clean pillar addresses the environmental and human health dimensions of storage deployments across the full technology life cycle, from the sustainability and social impact considerations of mining critical minerals used in battery manufacturing to the reuse, repurposing, recycling, and disposal of systems at end of life. Public and industry awareness of both the environmental benefits and challenges of battery storage is growing, and the scientific understanding of these topics is improving alongside it.

One of the most tangible environmental benefits of battery storage is its potential to reduce or replace the operation of fossil-fuel peaking generators, which tend to run during periods of high heat and pollution in densely populated areas. Plant-level data shows that replacing peaker plants with battery storage can yield very large reductions in local air emissions, including nitrogen oxides and particulate matter. One hybrid project in California's Central Valley saw reductions of up to 78% in particulate emissions and up to 60% in greenhouse gas emissions. Replacing peaker plants with batteries can produce disproportionately large health benefits for the communities closest to those facilities.

Battery storage also has the potential to deliver more direct community benefits. When deployed in underserved communities, it can lower energy bills, improve grid resilience, and support essential services ranging from food storage to medical equipment. EPRI's research on tangible benefits documents real-world examples of these outcomes, from households in Puerto Rico that saw electricity bills drop sharply after solar and storage installations to communities in New York and California that gained both jobs and improved grid reliability from storage deployments.

For emerging battery technologies beyond lithium-ion, important environmental gaps remain. New chemistries require fresh assessments of their life cycle impacts as designs evolve. For lithium-ion batteries, EPRI has already developed scorecards and modeling tools to characterize the environmental and health impacts of both normal and abnormal operations. These are being applied to inform storage design, codes and standards, permitting decisions, and responses to community questions.

At the end of life, few large-format battery modules in stationary or electric vehicle platforms have yet reached that point, which means recycling markets and their operating requirements are still developing. Contrary to what might be assumed, recycling capacity is not the binding constraint today. Rather, it is the volume of modules reaching end of life that remains low, and the regulatory and policy frameworks governing what happens at that stage are still taking shape in most jurisdictions. EPRI's role is to track and inform policy development with fact-based research, while also supporting work to improve the costs and efficiency of reuse, repurposing, and recycling as those markets mature.

EPRI is continuing to pursue applied research across all four pillars. Energy storage is no longer just a promising emerging technology. It has quickly become a mainstream, viable solution that addresses many of the power industry's most pressing challenges. But the rapid growth of battery energy storage doesn't mean it can't scale more efficiently, safely, and affordably in the future. "Independent research and collaboration can support the industry to achieve its potential to benefit the grid, customers, and society," Gardow said. "Our job is to help."

EPRI TECHNICAL EXPERTS

Eva Gardow and Taylor Kelly

EPRI JOURNAL

Photo Credit: Hamaoka / Chubu Electric Power Co.

The Long Wait

How EPRI helped Japan's nuclear industry navigate an extended shutdown, modernize for the future, and generate valuable lessons for the rest of the world

The second in a series of three articles about EPRI's long-term commitment to the Japanese nuclear industry post-Fukushima examines the days and weeks after the 2011 tsunami.

By Chris Warren

There are many ways to describe nuclear power plants. Collectively, they are the [second-largest provider] of carbon-free electricity globally and the [largest] in the United States, France, and Japan prior to March 11, 2011. Individually, they are marvels of engineering and physics, where vast structures of steel and reinforced concrete safely contain controlled atomic reactions that convert heat into electricity.

Nuclear plants are also designed for continuous operation, typically ceasing power production for only a month or two each year to refuel and perform maintenance. But the tsunami triggered by the March 11, 2011, earthquake was anything but typical. Flooding inundated the Fukushima Daiichi site, knocking out power and cooling to three reactors and ultimately causing them to melt down, even though all operating units had safely shut down after the earthquake. In response, Japan [shut down] its entire fleet of 54 reactors for inspections, safety tests, and a complete overhaul of the nation's regulatory framework.

The first reactors restarted in 2015, and more than a dozen are back in operation today, with many others working to secure the necessary approvals to begin generating electricity again. The long, unexpected shutdown of Japan's nuclear fleet highlighted a fundamental reality and a challenge. "If you think about it, a nuclear power plant is a giant metal structure to contain water," said Dan Wells, director of EPRI's Nuclear Sector Fuels and Chemistry research department. "They're not designed to sit there for 10 years and do nothing."

While the metallic components and other materials used in nuclear power plants are designed to be robust and withstand the harshest conditions, confidently approaching a pause in operations of unknown duration requires clarity about the possible impact on components and materials.

"Water chemistry is a key piece of managing the corrosion of materials during extended periods of inactivity," Wells said. "What does the science tell us about these materials that are going to sit there for an extended period? And what do we know from actual experience from plants around the world that did shut down for extended periods of time?"

KEEPING ASSETS ALIVE AND SAFE

These are exactly the kinds of questions EPRI helped answer for Japan's nuclear industry after the Fukushima accident, when the country's reactors went offline. "We gathered all the available operating experience and materials research and shared it with the Japanese to say, OK, here's what we have seen before and here's what our recommendation is for how to manage these assets while they're idle," Wells said.

Though the plants were no longer generating electricity, they weren't abandoned either. Fuel remained in spent fuel pools and required continuous cooling, and control rooms remained staffed.

This support built on EPRI's immediate response to the tsunami, chronicled in the first story in this series. This story, the second in a three-part series, explores EPRI's role in transitioning reactors from being active generators to an extended period of carefully managed shutdown, known as layup, and how EPRI supported plant modernization initiatives during that time. The final story in the series will explore how EPRI has helped with the restart and life extension of reactors.

Grappling with how to maintain material and component integrity during an extended layup was critical. But it was by no means the only issue Japanese nuclear power plant operators faced. For example, one non-technical challenge centered on the status of operating licenses during the layup. "Japanese regulations were such that time was being accrued towards the plants' operating licenses, even though they weren't operating," said Nathan Palm, a program manager who leads EPRI's Boiling Water Reactor Vessel and Internals Project.

In response, EPRI prepared a technical report explaining that under the expected conditions, aging degradation should not occur while the plants were shut down with effective layup controls and that there was a reasonable basis for extending the plants' licenses by the amount of time equal to the shutdown period. Japanese regulations were ultimately revised to allow operating licenses to be extended to account for the generation time lost during the shutdown. The learnings from this research and experience could be leveraged in other countries or instances where the restart of shutdown plants is being considered.

A RARE OPPORTUNITY

At the time, the answer to whether and how the reactors would be used in the future was unclear, due to both public concerns about safety and pure economics.

The economic pressures of competing with other electricity sources was not new. "Nuclear plants have high labor costs compared to renewables and gas-fired power plants, even though their fuel costs are a rounding error compared to a gas plant," said Rob Austin, who leads EPRI's Nuclear Plant Modernization and Artificial Intelligence (AI) initiatives and contributed to EPRI's post-Fukushima work. "Anything to reduce labor, while at the same time preserving safety and reliability, needed to be looked at."

That economic uncertainty shaped how utilities thought about the decade ahead. On the one hand, an extended layup period represented an unprecedented opportunity to modernize aging reactors. "They found themselves in a very unique situation where if they got to start their plants again, it would be in a decade. It's like a 10-year outage," said Randy Stark, director of materials R&D at EPRI. "It's a chance to do all the things they never could do before because they had at most a 30-day or 60-day outage."

On the other hand, investing significant amounts of money to modernize a plant that might never come back online didn't make much sense. On a more practical level, plant operators inevitably struggle to prioritize which modernization initiatives to pursue because there are so many potential improvements.

BUILDING A MODERNIZATION PROGRAM

EPRI worked with utilities across the Japanese fleet to identify and prioritize modernization opportunities during the shutdown period. At Chubu Electric's Hamaoka Nuclear Power Station on the Pacific Coast between Tokyo and Nagoya, for example, modernization projects that would drive efficiency were elevated. "They were spending a lot of money getting the plant ready to restart, including building a huge seawall to protect against tsunamis," Austin said. "And obviously, during that time, they were not making any money because they were not generating electricity. So, they want to be as efficient as possible when they do get to restart."

At Hamaoka, EPRI and Chubu chose to start with a single pilot project that plant staff could see working firsthand, with the intention of expanding the program from there. The modernization strategy was tailored specifically to Chubu's circumstances—including its financial constraints, regulatory environment, staffing, and business goals—rather than applied as a generic template. The process was designed to integrate with Chubu's existing procedures for project review, approval, and funding, so that modernization could continue as an ongoing program.

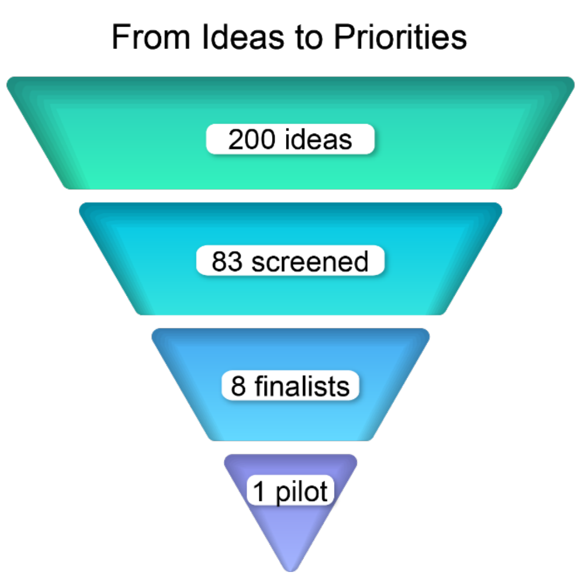
The modernization process EPRI brought to Hamaoka began with this basic question: of all the things that could be improved at this plant, which ones are actually worth doing, and in what order? To answer that, EPRI drew on its library of technology assessments and business case models and supplemented that foundation of knowledge with interviews of Hamaoka engineers and plant staff.

The result was an initial brainstorm of roughly 200 improvements, which is far too many projects to pursue. That list was then put through a structured screening process that applied even greater location-specific rigor to evaluating each idea. Each possible improvement was assessed against two questions: could it actually be applied at the plant, and did it address one of the operational priorities Chubu Electric had identified? Those priorities centered on reducing operations and maintenance costs, improving efficiency ahead of restart, and, where possible, transitioning from time-based to condition-based maintenance schedules informed by real-time equipment monitoring.

This reduced the list to 83 potential improvements. From there, EPRI worked with plant and utility staff to determine how applicable each improvement was to Hamaoka's specific situation, the plant's interest in pursuing it, and what the improvement would realistically deliver. Each idea was then scored across six factors: implementation cost, expected savings, projected payback, regulatory readiness, technological maturity, and the level of expertise required to execute it.

Chubu's constraints shaped which ideas rose to the top. Funding for improvements was limited by the costs of shutdown and restart preparation. Japanese regulations at the time did not permit online maintenance of safety-related components, which shaped which improvements were practical to pursue. And because Chubu did not reduce its staff during layup, the efficiency gains needed to be translated into redeploying workers to higher-priority tasks rather than reducing headcount. After evaluating all 83 candidate ideas against those realities, eight emerged as worthy of a thorough business case analysis, with the goal of identifying a pilot project to begin.

Selecting the final pilot project wasn't just about financial analysis. Chubu's senior leadership wanted a project that plant staff could see working with their own eyes, something tangible enough to build confidence in the modernization program before pursuing broader implementation.



That pointed toward online condition monitoring for the plant's medium-voltage motors, the workhorses that drive the pumps and systems moving water and coolant through the facility. Under the traditional approach, workers conduct periodic manual inspection rounds to check on equipment health. But problems can develop and worsen between those scheduled visits.

By installing sensors that continuously monitor motor performance, the plant could detect potential issues before they caused failures, avoiding the unplanned shutdowns and power reductions that an unexpected motor failure can trigger. The business case analysis projected a payback period of under four years, and the monitoring program could be started during the shutdown and expanded incrementally after restart, with each additional piece of monitored equipment delivering more value at relatively low additional cost.

PREPARING TO RESTART

As plant restarts began moving from hypothetical to possible, the nature of EPRI's support also shifted. Instead of focusing on protecting plant assets, the priority became bringing them back safely.

EPRI developed guidance on managing water chemistry during the transition from layup conditions to full operation. A particular concern during startup is the intrusion of chlorides and sulfates into plant systems. If not carefully controlled, these contaminants can compromise the integrity of components and piping. EPRI's guidance provided specific recommendations for flushing systems and managing chemistry during a startup sequence to prevent excursions that could damage fuel or create radiation exposure challenges for plant workers. The approach proved its worth. After more than 13 years of shutdown, Tohoku Electric Power Company's Onagawa Unit 2 and Chūgoku Electric Power Company's Shimane Unit 2 became the first Japanese boiling water reactors to return to service in 2024. Neither reported significant corrosion issues, validating the layup and chemistry management work that had been done.

EPRI experts also took on an independent review role, evaluating the startup plans Japanese utilities had developed to ensure they were consistent with EPRI guidance. That review surfaced a consequential

> *After a decade offline, Japan's hard won nuclear lessons are shaping the next generation of restarts.*

finding. Some plants had struggled to maintain optimum chemistry during the long shutdown period. For those plants, proceeding with a standard startup sequence was not sufficient. Recovery plans had to be developed first, drawing on additional EPRI guidance to address the specific conditions those plants were in and reduce the risk of chemistry problems or fuel integrity issues during restart.

LESSONS FOR THE WORLD

The work EPRI did with Japan's nuclear industry during the decade-plus shutdown addressed problems that were, at the time, largely unique to Japan. No other country had ever shut down an entire national nuclear fleet simultaneously and faced the challenge of managing, modernizing, and eventually restarting dozens of reactors after an extended pause. The body of knowledge that the work produced, however, now belongs to and benefits the whole industry. That knowledge was built over years of close collaboration between EPRI and Japanese utilities, a relationship that deepened after the Fukushima accident.

EPRI's 2025 plant restart guidelines draw directly on the Japanese experience and provide technical, regulatory, and administrative guidance for any utility considering a restart. The layup strategies Japan developed, the chemistry controls that proved effective, and the independent review process that caught gaps before they became problems are now codified in guidance available to plants around the world.

The relevance is not theoretical. Plants in the United States that spent years on a path toward decommissioning are now asking the same fundamental questions Japan spent a decade answering. "There are plants coming back online in the United States after years of thinking they were going to decommission," Stark said. "They are reaching out to the Japanese, saying, 'You were down for an extended period of time.' What did you do? What were the lessons learned?"

What Japan has had to learn from tragedy and disruption, the rest of the world is now seeking out by choice. More plants are working through the approval process to restart, and the conversation about extending operating licenses well beyond their original terms is ongoing. How EPRI is supporting that effort, and what it means for nuclear power's future in Japan and around the world, will be the subject of the final story in this series.

EPRI TECHNICAL EXPERT

Randy Stark, Robert Austin, Dan Wells, Nathan Palm

Image created with Microsoft CoPilot

Why Grid Models Need a Solid Data Foundation

By Chris Warren

The distribution grid isn't what it used to be. Traditionally, the lower-voltage grid carried electricity in one direction from large power plants to businesses and residents who needed it. Though distribution grids have always been inherently complex, the one-way flow of electrons from power plants and the transmission grid to customers made it relatively straightforward to plan, upgrade, and operate them.

The distribution grid that has emerged over the past decade is significantly more complex, characterized by a massive and growing influx of distributed energy resources (DERs), such as rooftop solar, battery storage, and electric vehicle (EV) chargers. Not only can these and other DERs consume electricity from the distribution grid, but they can also produce and export it in the other direction, creating two-way power flows that can both provide support during times of peak demand but also negatively impact grid voltage, frequency, and reliability.

While significantly more complex, the distribution grid is also arguably more important than ever before. With electricity demand rapidly increasing due to large loads such as data centers, domestic manufacturing, and the electrification of transportation, utilities and businesses are seeking capacity that can be accessed quickly and at scale. States like New Jersey, Virginia, and Illinois have enacted legislation and regulations to accelerate the adoption of virtual power plants (VPPs), which are collections of DERs and other resources managed by software to operate like a large power plant.

This evolution of the distribution grid has heightened the importance of grid models, which are mathematical representations of the physical power system that capture the electrical characteristics of power lines, transformers, switches, and other equipment that make up the distribution system. Utilities use these models to inform important decisions about future grid investments, to configure protection systems to guard against faults, and to manage daily grid operations.

While grid models have long been a standard tool for planning and operating the transmission system, they are a relative novelty for distribution grids.

"We have not needed them because we have not managed the distribution grid actively," said Sean Crimmins, a program manager in EPRI's Information and Communication Technology program, which provides frameworks and methodologies for effective grid model data management. "To make the most of the grid we've already built, you need a good model of the distribution grid, and historically we have not had one."

WHY DATA MANAGEMENT MATTERS

Getting the most out of the distribution grid today and in the future requires both robust models and a better approach to building and maintaining them. An EPRI supplemental project, Applied Grid Model Data Management (GMDM) for Distribution, aims to improve the management of grid model data. The project aims not to provide the grid models themselves, but to improve the availability and accuracy of the data that feeds the models, and to enable centralized management and sharing of the models for planning, operations, transmission, and neighboring utilities. Addressing the data that goes into grid models improves grid planning and operation by enhancing the simulations they run, making superior distribution grid management possible.

EPRI's Applied GMDM project builds on earlier research that brought utilities and vendors together to develop a common architecture for enterprise-wide grid model data management. The underlying mission of the Applied GMDM project is to help utilities apply that architecture, improve quality and consistency, reduce data-prep time, and unlock the full value of grid models.

It's a challenging task, and one that varies from utility to utility because each distribution grid is unique. But the most consequential transformation that needs to take place is streamlining, standardizing, and centralizing how grid data within a utility is collected, stored, and managed. In most cases, distribution grid data today is fragmented, stored in silos by the teams that use it, and transferred manually when other utility departments need to use it.

This balkanized approach to data management and sharing has many negative consequences. One is simply the time and effort staff must devote to assembling data. "When planning engineers work, they spend somewhere between 60 percent and 80 percent of their time gathering and preparing data. Then they get to do the engineering," Crimmins said. "If a utility is also using a model in operations, in an ADMS (Advanced Distribution Management System), engineers are spending far too much time creating another model, from different sources, and then comparing models to figure out why one model is different from another and why their results are so different."

Instead of fragmented, siloed systems, the long-term vision is to create a centralized grid model manager that automatically shares and updates data in near real-time. The model manager would gather data from utility planning, design, construction, materials, and asset management teams, then distribute validated models to those who need them. "The North Star is this central capability that's doing all the gathering and all the sharing with people that need data, sometimes at different granularity, often for different time frames," Crimmins said. For example, a planning engineer needs a model that reflects planned future projects and operations to understand the as-built and as-operated pictures of today's grid.

Establishing an authoritative, centralized model manager is a challenging, years-long effort. It's a journey that also depends on a utility's starting point and priorities. What systems are they using today? What are their goals? What are the drivers for new power flow analytics? EPRI can help at each stage of the journey by clarifying where a utility is, where it wants to go, and the necessary steps to get there.

FINDING THE GAPS, IDENTIFYING A PATHWAY FORWARD

The project begins with an in-person workshop that brings together utility teams from planning, operations, protection, and IT with EPRI power system engineers and data and enterprise architects. The initial goal is to better understand and document how grid model data moves through the utility. The exercise involves detective work to clarify which applications produce data, what protocols are in place, and where problems arise. Sometimes, the bottlenecks are straightforward, like manual data transfers, spreadsheet handoffs, and the need for multiple follow-up phone calls. Other times, the problems run deeper, rooted in workflows that were never clearly defined or communicated, or in teams that lack a clear picture of how their data connects to everyone else's.

These lessons are all documented and summarized to explain the current state of grid model data management, its level of maturity relative to industry benchmarks, and short-term steps that can be taken to improve it—such as eliminating the need to exchange spreadsheets or make numerous phone calls by automating data exchanges. That clarity about the current state of a utility's grid model data management practices serves as the foundation for the next step: collectively determining a long-term vision.

LESSONS FROM PUGET SOUND ENERGY (PSE)

EPRI has applied this methodology at several utilities, including Ameren, AEP, and Hydro-Québec. More recently, Puget Sound Energy (PSE), a utility serving about 1.2 million electric customers in Washington State, worked with EPRI to assess its grid model data management practices and chart a pathway forward aligned with the utility's priorities. Drivers of the initiative include PSE's implementation of an ADMS, a sophisticated platform for real-time grid monitoring and control that relies on accurate, continuously updated models to be effective.

PSE has also seen widespread adoption of electric vehicles (EVs), battery storage, and other DERs across its service territory. The utility wanted to explore opportunities to improve its approach to hosting capacity analysis, enabling it to connect resources to the grid faster and in locations that provide the greatest benefits. To achieve these and other objectives, PSE reimagined its approach to grid modeling, decentralizing it with tools managed by individual groups. "This has resulted in data inconsistencies, inefficiencies, and a complex web of point-to-point interfaces with data sources and consuming applications," said Rebeca Rogers, an engineer who works in PSE's Grid Modernization Strategy & Enablement group. "Many of these integrations are a mix of automated and manual processes."

Image created with Microsoft Copilot

On a practical level, the decentralization requires PSE staff in planning, operations, and engineering to build, maintain, and clean multiple versions of grid models.

An initial workshop led by EPRI included nearly 40 utility staff from planning, operations, IT, and GIS, reflecting the organizational importance of grid model data management. "PSE's collaboration with EPRI played a key role in shaping the strategic direction for our grid model management efforts," Rogers said. "EPRI helped define a clear vision for GMDM."

One outcome from that initial engagement: PSE built a business case for establishing and funding a dedicated data governance working group. Another was to translate findings about current data flows into a living document that will update as workflows and systems change. PSE is now developing requirements for a grid model manager, software that will centralize how the utility collects, validates, and distributes grid model data across departments. "We aim to improve data consistency and traceability across systems, strengthen data governance practices, and establish a scalable foundation that can support the integration of future modeling and analytics tools," Rogers said.

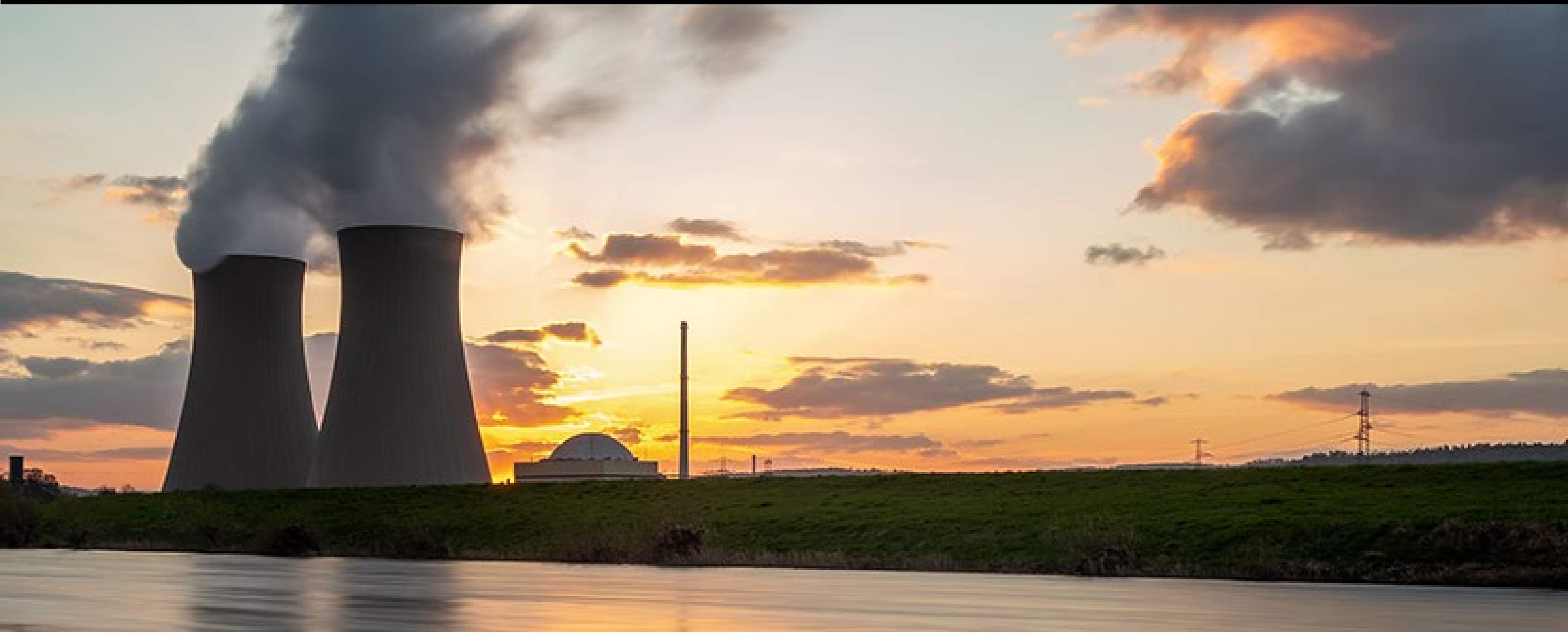
With EPRI's grid model manager functional requirements report and experience from the Applied GMDM, PSE has a clear picture of what that software needs to do and how it fits within its organization. This will make the procurement process considerably more precise. "They have a good idea of where that fits in their organization because of the work this project did," Crimmins said. "And we have generic requirements for what the software should be able to do to support model managers and consuming applications."

Though pioneering, the work at PSE reflects broader changes underway across distribution utilities as the grid grows more complex and faces greater demands. "Having an accurate picture of the grid you're operating and changing in the future is really critical," Crimmins said. "And having an efficient way of doing that accurately is really important."

EPRI TECHNICAL EXPERTS

Sean Crimmins

EPRI JOURNAL



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Restarting Nuclear Power Plants: Preserving and Restoring Value

Recent growth in electricity demand, expanding carbon-free energy goals, and renewed concerns about energy security are driving utilities to reconsider nuclear power plants that have been permanently shut down or are approaching retirement. EPRI examines the technical, regulatory, and business factors that influence whether these facilities can return to service and what steps can preserve that opportunity. The paper, *Restarting Nuclear Power Plants: Preserving and Restoring Value*, draws on EPRI's *Plant Restart Guideline: Preserving and Restoring Nuclear Power Facilities* and highlights lessons from industry experience in the United States and internationally.

A NEW PERSPECTIVE ON NUCLEAR PLANT SHUTDOWNS

Historically, a permanent shutdown was generally viewed as the first step toward license termination and decommissioning. Today, however, rising electricity demand—driven in part by data centers and electrification—combined with policy support for carbon-free generation, has changed that perspective. Plants that ceased operations for economic reasons rather than technical limitations may represent stranded but recoverable assets. Research emphasizes that restart viability is highly dependent on decisions made before and during shutdown, with early actions often determining whether a future restart remains practical.

A central theme is that restart decisions should be guided by a structured Business Case Analysis (BCA). Rather than a one-time assessment, the BCA is intended to be a living framework that evolves with changing market conditions, policy incentives, and plant conditions. Scenarios involving preservation during an extended shutdown were evaluated, as were restart efforts initiated after decommissioning work had begun. While restarting following decommissioning generally requires significantly greater capital investment, both approaches may be justified under favorable conditions.

PRESERVATION IS CRITICAL TO FUTURE RESTART OPTIONS

One of the most significant findings is the distinction between preservation-focused shutdown strategies and traditional decommissioning. Preservation measures, including controlled wet or dry layup, chemistry management, workforce retention, and records preservation, maintain a clearer path to restart but require ongoing investment and operational discipline. Traditional decommissioning, while often minimizing short-term costs, can reduce restart feasibility by allowing equipment degradation, dismantling systems, and the loss of institutional knowledge. Research suggests that hybrid approaches, which preserve high-value components while planning to replace lower-value systems, may offer an effective balance between flexibility and cost control.

The condition of key plant components often has a greater impact on restart viability than the overall condition of the facility. Steam generators, turbines, large power transformers, and reactor pressure boundary components are among the most critical assets influencing both cost and schedule risk. Effective preservation practices, particularly chemistry control for wetted systems, can significantly slow aging mechanisms and help maintain equipment integrity. Conversely, inadequate preservation can lead to costly discoveries late in the restart process. The report also highlights the importance of preserving plant records, which can provide valuable evidence of component condition and reduce the need for extensive inspections.

REGULATORY AND WORKFORCE CHALLENGES

Regulatory strategy is another major consideration. There is no statutory prohibition on restarting a permanently shutdown nuclear power plant in the United States. However, the complexity of the process increases considerably if decommissioning activities have progressed without regard for future restart possibilities. Recent Nuclear Regulatory Commission guidance provides a structured pathway for restoring licenses at plants that have entered decommissioning. Recent U.S. experience suggests that maintaining or restoring an existing licensing basis can reduce uncertainty compared with pursuing an entirely new plant licensing basis.

Beyond equipment and infrastructure, human capital is a critical factor in the success of restarts. Retaining or rehiring experienced operators, engineers, and technical personnel can significantly reduce project risk and duration. Operator licensing and training programs are frequently on the critical path for restart efforts, making workforce planning essential. Just as importantly, safety culture, configuration knowledge, and informal expertise can be difficult to reconstruct once lost.

LESSONS LEARNED AND STRATEGIC IMPLICATIONS

Industry case studies demonstrate that restarting a decommissioning plant is possible, though often complex and capital-intensive. Safe storage strategies can limit irreversible dismantling and preserve future options. Long-term wet layup combined with disciplined chemistry control has been shown to maintain the integrity of nuclear steam supply systems for more than a decade. At the same time, insufficient early attention to staffing, supply chain readiness, and documentation can create significant obstacles during restart planning and execution.

Utilities and policymakers are encouraged to view shutdown decisions not simply as end-of-life choices, but as decisions about preserving future options. EPRI’s research indicates that relatively modest investments made early in the shutdown process can protect strategic flexibility that may be worth billions of dollars under future market conditions. For utilities, this means incorporating restart considerations into decommissioning and asset management planning. For policymakers, regulatory clarity, targeted incentives, and early engagement may influence the long-term value of existing nuclear assets.

Findings reflect a changing industry perspective on retired nuclear facilities. Restart is no longer viewed as merely a theoretical possibility, and preservation efforts can have a decisive influence on future outcomes. Disciplined technical, regulatory, and organizational planning can help transform shutdown nuclear plants from potential liabilities into strategic assets capable of supporting future electricity needs.

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How a Common Language for Flexibility Can Speed Large Load Interconnection

By Chris Warren

In a relatively short time, large loads have become a focus for utilities, policymakers, regulators, and retail customers. For example, according to the Smart Electric Power Alliance, state regulators approved 29 large-load tariffs in 2025, compared to just 14 between 2018 and 2024. In the summer of 2026, the Federal Energy Regulatory Commission (FERC) is expected to take action on the U.S. Department of Energy's 2025 proposals to reform large load interconnection to the transmission grid.

The main reason large loads are grabbing so much attention these days is simple: there are a lot of them, and the speed and nature of their connection to the grid matter to utilities, retail customers, large customers that need electricity quickly, and the power system as a whole.

After years of flat electricity demand, large customers, such as data centers, are a significant driver of rapid load growth. Between 2025 and 2030, annual electricity demand is expected to grow at 2%-3.6% per year, compared with an average annual rate of 0.8% between 2019 and 2024. EPRI estimates that data center electricity use in the U.S. could account for between 9% and 17% of total electricity consumption by 2030, up from about 4% to 5% today.

THE INTERCONNECTION BOTTLENECK

Another reason large loads are attracting so much attention is that many face long wait times before they can interconnect to the power grid. According to the Lawrence Berkeley National Laboratory (LBNL), projects that began commercial operation in 2024 spent an average of 4.5 years in interconnection queues, up from just 22 months in 2008.

powerful tool to address the challenges of interconnecting large loads is a concept that sounds simple but is surprisingly complex in practice: flexibility. At a fundamental level, flexibility describes a load's ability to adjust its electricity consumption in response to grid conditions. On a hot summer day, for example, when demand for electricity from air conditioning is high, a large, flexible load can temporarily ramp down its consumption, providing relief to a strained grid.

The details and definitions of flexibility, however, quickly become complicated, with different meanings across regions, markets, and industries. A utility may define flexibility very differently from a regulator, grid operator, or large load operator. The lack of a shared language and a definition of flexibility is not an abstract semantic problem. It is a meaningful barrier to securing faster, large-load interconnection times and grid support. It's also a solution that is very much within reach with the right collaboration and cooperation.

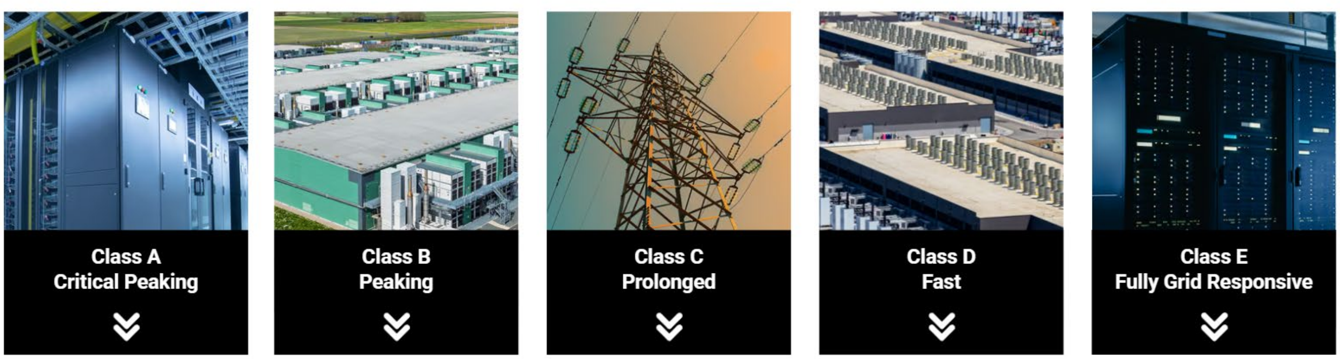
"The technical solutions for flexibility exist. This is not a technology problem," said Irene Danti Lopez, an EPRI senior team lead. "In our discussions, we found ourselves getting into a circular loop. The utility would come in and say it would value flexibility, noting that flexibility could unlock opportunities for faster interconnection. The utility would then ask the large load what flexibility it could provide, and the large load would respond that it was interested, but would first need to understand what the utility was looking for. As a result, the conversation would loop without converging on specifics."

A COMMON LANGUAGE FOR FLEXIBILITY

Establishing the shared language needed for flexibility is the aim of EPRI's Flex MOSAIC™ project. Officially launched at CERAWeek in March 2026, Flex MOSAIC™ is a framework for uniformly classifying large load flexibility. The voluntary framework was developed through EPRI's DCFlex initiative and resulted from collaboration among more than 70 utilities, system operators, regulators, hyperscalers, and technology providers.

Involving a broad set of collaborators in developing the framework was a necessary foundation for Flex MOSAIC™. "This is all about finding win-win solutions for utilities, grid operators, as well as data centers and other large loads so that we can accelerate speed to power, but also keep supporting power system reliability and operability," Lopez said. "We don't want one at the expense of the other, and we're really trying to provide solutions to deliver both."

Large Load Classifications



- **Class A (Critical Peaking):** A large load that can reduce its electricity consumption during rare and brief grid emergencies lasting five hours or less.
- **Class B (Peaking):** A large load that can do everything Class A can do, but is also able to ramp down consumption more routinely, not just during emergencies.
- **Class C (Prolonged):** Builds on Class A and B by sustaining flexibility over prolonged events, such as transmission-related outages.
- **Class D (Fast):** A large load that can also do everything Classes A and B can, but can also reduce consumption with short notification times when the grid needs near-instant support.
- **Class E (Fully Grid Responsive):** A fully flexible large load can respond to any grid condition, including all capabilities from Classes A through D.

The Flex MOSAIC™ framework defines flexibility based on a set of specific performance characteristics. These include how quickly a load can respond to a signal to ramp down consumption, how long that reduction can last, and how much power can be reduced or shifted. The performance characteristics are organized into five specific classes that utilities, large loads, and system operators can use and adapt to suit their local markets and conditions. The five classes are designed so that a utility or grid operator can look at a large load's classification and immediately understand what to expect from it, just as they would assess any other resource on the system.

A FRAMEWORK TO BENEFIT EVERYONE

The definitions outlined in Flex MOSAIC™ provide critical certainty for large loads seeking interconnection and utilities and grid operators charged with operating a reliable grid. To understand how this shared understanding of flexibility benefits utilities and grid operators, consider the typical process they follow upon receiving an interconnection request.

Their first step in evaluating the request is to run a series of studies to assess the impact of the new load on the grid. Among other things, those studies assess whether existing transmission lines and other infrastructure can accommodate the new load without exceeding thermal or voltage limits. Upstream, studies are also conducted to assess whether sufficient generation capacity exists to meet demand during periods of grid stress.

Traditional planning approaches develop plans based on worst-case scenarios, where a large load runs at full power regardless of grid conditions. It's an understandable approach for ensuring reliability. But it is also expensive and time-consuming because meeting peak demand often requires large grid investments that take years to complete.

A standardized flexibility classification is a necessary foundation. But it is only part of what utilities need to plan with confidence. Flex MOSAIC™ provides that necessary foundation by establishing clear, consistent definitions of what different classes of flexibility look like in practice. Equally important are the processes that verify that a large load can deliver what its classification promises, along with the controls grid operators need to activate flexibility when needed. Taken together, the framework and supporting processes allow utilities to treat a flexible, large load the same way they treat other system resources. For example, a utility reviewing an interconnection request from a Class C large load would have clarity about how to model it, what a realistic response could be, and how much weight to give to flexibility in its studies. This depends on a load's performance being measured and validated against the framework's definitions.

The benefits of a standardized framework for flexibility extend to the large loads seeking interconnection. Large loads that can demonstrate a credible flexibility classification give planners the predictability they need to accelerate interconnection. Rather than being treated as an inflexible contributor to rapidly increasing demand, large loads can also be assessed for what they offer to help the grid when support is needed. In some cases, a load's flexibility classification may allow it to interconnect sooner, at a location that would otherwise be unavailable, or under terms that reduce the infrastructure investment required to serve it.

Standardized definitions of flexibility also allow owners of large loads to invest in enhancements that increase their flexibility. This information is needed by large load developers as early as possible. For example, a large load's eligibility for a higher flexibility class may depend on its ability to modulate demand, as well as on whether it has on-site battery storage, backup generation, or other infrastructure built in during construction. Trying to add that capability later can be prohibitively expensive or, in some cases, impossible.

"If you need an energy storage unit on site to provide flexibility, a data center or factory builder needs to know that when they're building," Lopez said. "It will impact land requirements. It will impact permitting. If you try to add it later, it might be more expensive or simply not possible because you haven't bought enough land and there are neighbors."

PUTTING THEORY INTO PRACTICE

As Flex MOSAIC™ was being developed, EPRI and a group of partners conducted real-world tests to validate its core premise. In December 2025, EPRI, the utility National Grid, AI cloud provider Nebius, and the compute and energy management firm Emerald AI conducted a series of tests in the United Kingdom to evaluate whether a cluster of graphics processing units (GPUs) training AI within a data center could actually deliver the kind of flexibility the framework describes without compromising the computing work it was built to do.

To do that, the cluster was taken out of production and tested. The results: the cluster achieved 100% compliance with more than 200 requested power targets and ramp-rate constraints. Load reductions of up to 40% were delivered in under a minute, while service agreements for high-priority computing workloads were maintained even as power demand ramped down.

Several of the tests were designed to mimic unpredictable grid conditions, including unannounced, back-to-back grid events. This helped demonstrate that certain flexible, large loads can respond to repeated, operationally varied grid events, not just serve as a one-time demand-response asset. Besides demonstrating that a large load could provide flexibility to mitigate grid stress, the tests also showed that the cluster could respond to carbon-intensity signals, reducing emissions by more than 10% during the test period.

"What those results showed us is that high AI performance and grid responsiveness are not in conflict," Lopez said. "A data center and other large loads can be real grid resources, and that changes what's possible.

The tests provided a source of real-world operating evidence for the development of Flex MOSAIC™ and gave the framework's performance definitions a foundation in real operating experience. A second set of six additional demonstration projects in the United States and Europe was announced in February 2026. Late in 2026, EPRI plans to conduct flexibility testing at the Aurora Project, a U.S.-based facility targeting nearly 100 megawatts of flexible AI load. That test will assess whether the flexibility demonstrated can be replicated at scale.

> Load reductions of up to 40% were delivered in under a minute.
>
> Response to carbon-intensity signals reduced emissions by more than 10%.

By October 2026, EPRI expects to publish a final version of the framework, along with practical guidance and tools to help utilities and large loads implement it. "The goal from the beginning has been to give everyone involved a common ground to work from," Lopez said. "When utilities and large loads are speaking the same language, decisions get faster, interconnection gets easier, and the grid gets stronger. That's a win for everyone, including the customers who depend on it every day."

EPRI TECHNICAL EXPERT

Irene Danti-Lopez

EPRI JOURNAL

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Large Load Ride-Through for Data Centers

Bridging the Gap Between Grid Requirements and Facility Performance

EPRI examines a growing reliability challenge facing the power sector: ensuring that large, power-electronics-dominated loads such as data centers remain connected during grid disturbances. As data centers continue to scale, individual facilities can reach gigawatt-level demand, making their unexpected disconnection a potential threat to bulk power system stability. The paper does not propose new ride-through requirements. Instead, it identifies gaps in how existing requirements are interpreted, implemented, and verified, and outlines areas where additional industry coordination is needed.

WHY RIDE-THROUGH CAPABILITY MATTERS

Electrical disturbances, such as short circuits and system faults, are unavoidable in power systems. Historically, the temporary loss of individual loads during such events had limited system-wide consequences because loads were relatively small and geographically dispersed. Today, however, large data centers, cryptocurrency mining operations, and green hydrogen facilities can represent hundreds or even thousands of megawatts at a single point of interconnection. The sudden loss of these loads can cause voltage and frequency excursions, compromising grid reliability.

In response, utilities and system operators have begun establishing ride-through requirements that define how large loads should behave during voltage disturbances. These requirements are intended to keep facilities connected through specified voltage sags and support rapid recovery once normal conditions return. Utilities and transmission operators in North America and Europe—including ERCOT, SPP, AESO, RTE, Fingrid, EirGrid, and Energinet—have published or proposed ride-through curves that define the voltage levels and durations at which facilities are expected to remain connected.

GAPS BETWEEN GRID-LEVEL REQUIREMENTS AND FACILITY BEHAVIOR

The disconnect between requirements defined at the point of interconnection and the behavior of equipment inside a data center is a core theme of this research. Ride-through requirements are typically expressed in terms of voltage measurements at the facility's grid connection. Still, compliance ultimately depends on how internal systems—including uninterruptible power supplies (UPS), power distribution units, adjustable-speed drives, and protection schemes—respond to disturbances.

Several interpretation challenges are highlighted. Utilities may define the voltage used for compliance differently, such as using positive-sequence voltage or the most severe phase voltage. These distinctions can significantly affect compliance assessments during unbalanced faults. In addition, the voltage experienced by equipment within a facility may differ from the voltage measured at the point of interconnection due to transformer configurations, cable impedance, and internal distribution systems. As a result, equipment can experience more severe voltage conditions than those implied by system-level measurements.

There is also a distinction between utility ride-through requirements and equipment immunity standards such as CBEMA, ITIC, IEEE 1668, and SEMI F47. While immunity standards are intended to evaluate equipment survivability at low-voltage terminals, utility ride-through requirements are designed to maintain grid reliability. The lack of a consistent mapping between the two creates uncertainty in equipment specification, testing, and procurement.

COORDINATING DATA CENTER SYSTEMS FOR COMPLIANCE

Meeting ride-through requirements requires coordination across the entire electrical infrastructure of a data center. UPS systems and rack-level power supplies must be configured to continue supporting loads during allowable voltage sags, often through coordinated use of both grid power and battery systems. Automatic transfer switches and backup generation schemes must also be carefully configured to avoid unnecessary transfers to backup power during disturbances that remain within the ride-through envelope.

Cooling systems are a particularly important but often overlooked part of ride-through compliance. Modern hyperscale and AI-focused data centers rely on tightly controlled cooling architectures, and even brief interruptions can threaten thermal limits. While UPS systems may protect pumps and fans, chillers are often not protected. Voltage sag–induced chiller trips can therefore become a limiting factor in overall facility resilience. Mitigation approaches are discussed, including improved control power immunity, optimized voltage-sag settings for adjustable-speed drives, and rapid-recovery chiller features offered by several manufacturers.

IMPLEMENTATION, VERIFICATION, AND EMERGING CHALLENGES

One of the industry's largest unresolved challenges is demonstrating compliance. Although ride-through requirements are increasingly specified at the utility level, no widely accepted equipment-level testing or certification framework currently exists for large loads. Unlike distributed energy resources, which can demonstrate compliance through standards and certification programs such as IEEE 1547 and UL 1741, comparable frameworks for data center equipment are largely absent.

Manufacturers and developers face uncertainty when translating utility requirements into equipment specifications and procurement decisions. The authors note that requirements continue to evolve and differ across regions, creating additional complications for product design, firmware development, and long-term planning.

Another emerging issue involves facilities that combine large loads with on-site generation, sometimes referred to as "Energy Parks." Existing ride-through requirements for loads and generators have generally been developed independently. The resulting misalignment can create unintended imports from or exports to the grid during disturbances, introducing new reliability risks unless protection and control systems are carefully coordinated.

DCFLEX AND THE PATH FORWARD

Drawing on lessons learned, the research emphasizes the importance of clear definitions, broad stakeholder engagement, harmonized requirements, and verifiable compliance pathways.

To help address current gaps, EPRI's DCFlex collaborative is pursuing two complementary pathways. The first focuses on improving consistency and clarity in ride-through requirements by using common terminology, aligned definitions, and enhanced traceability between grid-level obligations and facility-level performance. The second focuses on developing practical testing, certification, and compliance methodologies, drawing on EPRI'experience in power quality testing, UPS evaluation, and certification programs.

The ultimate goal is to move the industry from fragmented, utility-specific expectations toward a more harmonized framework supported by a common testing language, clear pass/fail criteria, coordinated facility controls, and transparent methods for demonstrating compliance. By bridging the gap between grid reliability objectives and equipment-level performance, DCFlex aims to help data centers support grid stability while providing greater certainty for utilities, developers, and equipment manufacturers.

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Building the Future of Nuclear Inspections on a Powerful Legacy

By Chris Warren

Nuclear power is playing an increasingly critical role in meeting the world's quickly growing demand for electricity. According to the International Energy Agency (IEA), global nuclear power plant generation reached a record high in 2025, with output increasing by 1.2 percent from 2024, thanks to new units coming online worldwide and restarts at Japanese power plants. A new report from Bloomberg New Energy Finance (BNEF) found that 76 large reactors are under construction globally, and forecasts that nuclear energy capacity will increase 44 percent by 2036 compared to 2025 levels.

At the same time, interest and investment in new nuclear technologies, such as small modular reactors (SMRs), is accelerating. IEA has pointed to surging data center electricity demand as one driver behind faster SMR commercialization. For example, the pipeline of conditional offtake agreements between tech companies and SMR projects grew from 25 gigawatts at the end of 2024 to 45 gigawatts by April 2026, according to the agency's reporting.

This growth is unfolding on two fronts at once. Utilities are restarting plants that had stopped generating electricity years ago and extending the operating licenses of reactors approaching the end of their original terms. At the same time, developers are racing to bring entirely new reactor designs online. Both fronts depend on the same underlying requirement: proving that the components inside these reactors, old and new alike, can be reliably inspected for safety.

That is where EPRI's performance demonstration (PD) facility in Charlotte, North Carolina, comes in. For more than three decades, the lab has been where the nuclear industry proves its inspectors and inspection techniques actually work, not just on paper, but in practice. As the industry expands, that role is only becoming more central.

BUILT TO SOLVE A PROBLEM

Carl Latiolais has led much of that work. When he joined EPRI on Valentine's Day 1994, the use of non-destructive evaluation (NDE) inspection techniques in the nuclear industry faced a crisis. NDE describes several methods for inspecting components without damaging them. The primary method is ultrasonic testing (UT), which uses high-frequency sound waves to detect cracks and other defects in reactor pressure vessels, dissimilar metal welds, piping, and other critical components in both pressurized water reactors (PWRs) and boiling water reactors (BWRs).

But the inspections meant to keep those plants safe were themselves in trouble. "During the 1980s, there were a lot of material issues with detecting intergranular stress corrosion cracking in piping systems, mainly in boiling water reactors," said Latiolais, who received the EPRI 2025 Chauncey Awards' Lifetime Achievement Award for his NDE leadership and work as EPRI's PD Lead.

Stress corrosion cracking had a serious impact on the industry because it raised the possibility of reactor coolant leaks, which also elevated safety concerns if cracks grew undetected. The risk of cracking increased inspection and maintenance requirements, leading to higher outage costs and reduced plant availability. "It got to a level where the regulators were about to force shutdowns of these plants until they either repaired or replaced the components. They had lost a lot of trust in NDE."

AN INDUSTRY RESPONSE

A series of actions followed to rebuild trust in NDE, which ultimately included the creation of EPRI's PD testing facility in Charlotte. After it became clear that NDE was not adequately detecting and characterizing flaws that led to leaks, EPRI joined with the Nuclear Regulatory Commission (NRC) and the Boiling Water Reactor Owners Group (BWROG) to establish the Tri-Party Agreement, which established a UT testing and training program. Later, the NRC decided more was needed and that the qualification rules needed to be formalized so they would apply to the entire fleet, not just the BWRs. After the NRC proposed qualification requirements, the industry formed a committee to develop what eventually became the ASME Appendix VIII requirements, which required that inspectors, procedures, and equipment demonstrate they could reliably find and size flaws by testing against samples manufactured to replicate real, albeit defective, components. ASME published Appendix VIII in 1989, and utilities were given until 1997 to comply fully.

Photo courtesy: EPRI BWRVIP Lab

U.S. utilities needed one program to meet that requirement efficiently across the industry, and they selected EPRI to administer it. In 1991, member utilities funded EPRI's Performance Demonstration Initiative, and the work of developing a program capable of confidently qualifying NDE inspectors and processes began. Latiolais was hired in 1994 to run the piping portion, the largest piece of the effort, and the first qualifications began that same year, with reactor pressure vessel testing following in early 1995.

A new challenge emerged in the 2000s, with the discovery of pressurized water stress corrosion cracking (PWSCC) in the PWR fleet. The cracking was found in nickel-based alloys, known as Alloy 600, which was used extensively in the construction of both PWR and BWR units. Routine inspections early in the decade revealed failures in a reactor upper head penetration and a main loop dissimilar weld at two different operating plants in the PWR fleet. The widespread use of Alloy 600 called into question the continued operation of the PWR fleet.

In response, regulators ordered expedited inspections of components with the nickel-based alloys. But it soon became clear that research was needed to address significant limitations in the inspection technology. EPRI took the lead by supplementing the existing PD program infrastructure with new mock-ups suitable for qualifying both techniques for examining existing welds and for techniques used to mitigate and repair degradation, such as weld overlays. For much of the 2000s, EPRI's PD worked to develop and qualify a variety of examination techniques capable of reliably detecting and sizing flaws. The work provided regulators with reasonable assurance that NDE could be used as a tool to effectively manage the threat to the PWR fleet.

"BUILDING FLAWS"

Latiolais recalls the early years of necessary improvisation. Testing was initially scattered across borrowed lab space in a shared EPRI building, with staff monitoring each room individually to preserve the blind conditions the tests depend on. In 2011, the program moved into a dedicated facility, a former floppy disk manufacturing plant that was retrofitted to consolidate testing, sample storage, and staff offices into one secure, controlled space.

Building the samples that allow for rigorous blind tests was its own technical challenge. Each mockup needed flaws of precisely known size and location, engineered to produce realistic ultrasonic responses without the kind of defects that would make a test unreliable. The very nature of that work, creating component mockups that are intentionally defective, can seem counterintuitive. "We're building flaws," Latiolais said. "The quality assurance people come in and say, 'I can't get my head around this.' I said, well, look, but these samples are not going to get installed in the plant."

Today, that facility houses more than 700 component mockups and has conducted over 20,000 qualifications for more than 1,000 personnel and 100 procedures, making it, by EPRI's account, the largest and most influential program of its kind in the world.

"A lot of countries follow some or all aspects of the U.S. codes. They have their own regulators, but their regulations often mirror what the U.S. is doing," Latiolais said. "If the U.S. regulators require something, it's generally required in some form or fashion elsewhere."

A NEW KIND OF EXAMINATION FOR A NEW ERA

EPRI's PD program is evolving to continue supporting a growing and changing nuclear industry. One way is to help develop artificial intelligence (AI) to support NDE inspectors.

Nuclear inspection has always required a lot of inspectors. Inspections require the skills and experience to analyze ultrasonic data for anomalies that may indicate a flawed component. Training and sharp judgment are necessary, but not enough on their own. Inspectors also need to remain focused for extended periods as they review large volumes of mostly normal data.

Federal researchers have identified fatigue and distraction as recurring contributors to missed flaws in reactor inspections. Now, EPRI is working with vendors and utilities to bring AI into the examination process, not to replace the inspector's judgment, but to sustain the vigilance that judgment depends on.

The results from early deployments are encouraging. In one field trial reviewing reactor vessel head inspection data, EPRI found that AI-assisted screening could flag the small fraction of data that warranted a closer look. This reduced the volume of data an inspector needed to review from roughly 7 kilometers to about 140 meters, without sacrificing the quality of a fully manual review. The technology is now qualified for use at Sweden's Ringhals 3 and 4 reactors. It is also supporting inspection oversight at three U.S. plants, work that regulators, including the NRC, have observed directly in the field.

The challenge isn't just proving that AI-assisted inspection has value and works. It's proving, rigorously and repeatedly, that it does, and building a process to requalify it whenever the algorithm changes. That work is a priority for Latiolais and his team and requires close coordination with the regulators and the organizations responsible for developing codes.

Another priority is developing NDE inspections of advanced reactor designs, including SMRs. Developers of SMRs and other next-generation reactors are working with EPRI to determine how their components can be inspected and monitored. Traditional ultrasonic techniques may not apply directly, and EPRI is now helping to write entirely new sections of the ASME code to define what qualification will look like. Separately, the lab continues to push the underlying measurement technology, developing faster, higher-resolution ultrasonic techniques that promise to reshape inspection over the next decade.

After thirty years spent building an inspection qualification process that works so well the industry barely notices it, Latiolais is ready for others to write PD's next chapter, not that he plans on going anywhere soon. "Eventually, it will be handoff time," he said.

What he's handing off is not just a modernized, expansive facility unmatched around the world, but a team built to keep asking the same question he's asked since 1994: can an inspector, a technique, or now an algorithm, prove that it is consistently reliable and trustworthy? It's a question that will only grow in importance as nuclear power plays an increasingly important role in meeting the world's energy needs.

EPRI TECHNICAL EXPERTS

Carl Latiolais

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, and affordable access to electricity across the globe. Together...shaping the future of energy.

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