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Preparing for a Grid-Forward Future

ALSO IN THIS ISSUE:

Safeguarding Thermal Power Plants in Extreme Cold

A New Approach to Utility Cybersecurity

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Hot Zone Challenge

Bridging the Welding Gap

Table of Contents

Preparing for a Grid-Forward Future....1

Safeguarding Thermal Power Plants in Extreme Cold....5

A New Approach to Utility Cybersecurity....8

A Platform to Connect EV Customers to Utilities.... 12

Hot Zone Challenge 16

Bridging the Welding Gap.... 20

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Preparing for a Grid-Forward Future

By Chuck Ross

2024 was a transformational year for EPRI and those in the energy sector. Together, we worked to prepare for a more connected, data-responsive, and grid-forward power future as demand forecasts raised prospects for rapid growth. These growing power needs dominated energy-related headlines in the last 12 months. Among drivers were AI-related data centers, transport electrification, industrial onshoring, and digitalization, which are turning demand forecasts sharply up for at least the next decade.

Our researchers and collaborators are working closely together to address these and other electric industry challenges and opportunities, including:

- Preparation and recovery related to increasingly extreme climate events
- A burgeoning nuclear power renaissance
- Grid-planning to meet electric vehicle charging needs

EPRI has been at the forefront of these and other issues critical to supporting and growing our electricity infrastructure. We are proud to share the following highlights of our 2024 efforts and progress, and we are grateful for our members and other collaborators' continued commitment to science-backed solutions as we move into our shared future.

PREPARING FOR AI'S FUTURE

EPRI has been leading the work in addressing the surging power needs of data centers. In May 2024, we released a frequently cited analysis, projecting that data centers could consume up to 9% of U.S. electricity generation by 2030.

EPRI President and CEO Arshad Mansoor shared these findings with the U.S. Department of Energy's (DOE) Secretary Advisory Board, which led to an AI and data center report from the group in July.

Then, in September, Mansoor joined fellow leaders from the technology, hyperscaler, and utility sectors at an invitation-only White House meeting with cabinet secretaries, informing them about the increasing power needs from data centers and what may be needed to ensure a reliable and affordable energy future.

Building on EPRI's work in this space, in October, the institute launched the DCFlex initiative to explore how data centers can support the electric grid, enable better asset utilization, and assist with energy transformation. With a variety of utilities, hyperscalers, and data center operators as members, the effort will coordinate real-world demonstrations of flexibility in a variety of existing and planned data centers and electricity markets. The aim is to create reference architectures and provide shared learnings to enable the broader adoption of flexible operations that benefit all electricity consumers.

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NUCLEAR'S EXPANSION

Nuclear generation is an energy source that has zero emissions and provides electricity around the clock, playing a key role as part of an affordable, reliable energy future.

EPRI provides guidance, R&D, and practical tools to help the sector increase capacity, deploy next-generation technologies, and develop the workforce of the future. Through expanding collaborations and innovation, we are making notable progress.

EPRI's programs are supporting ambitious U.S. targets for increased nuclear capacity. In November, the DOE announced plans to deploy 200 gigawatts (GW) of net new nuclear capacity by 2050, which would almost triple current figures. This goal would likely be met by combining improvements at existing plants and introducing new technology, such as small modular reactors. EPRI's nuclear research and subject matter experts are actively supporting these efforts.

- **Maximizing current potential.** A report issued by EPRI in the fall reported that increasing U.S. nuclear capacity from the existing fleet of reactors—through restarts, uprates/expansions, and extending operating life—could create 9 gigawatts (GW) of generation, the equivalent of nine additional large-scale U.S. nuclear units. Restarting plants that have already been decommissioned is another strategy being considered or pursued at three shuttered plants, with the possibility of an additional 2.4 GW of capacity if all three are brought back online. Extending the licensed life of today's operating plants is another option for making the most of current assets. EPRI has contributed to research that found reactor life could extend to 80 years, which, if applied to today's fleet, could mean an added 97 GW of carbon-free electricity by 2050.
- **Bringing New Technology Online.** New nuclear designs, including several approaches to small, modular reactors, offer the promise of faster construction and safer operation. Some designs are even being tailored for individual industrial sites. EPRI provides customized, expert guidance for each project stage, from identifying technology requirements to commissioning and operations. Additionally, EPRI is monitoring advances in fusion technology. New breakthroughs in materials science, manufacturing, computational power, and artificial intelligence are speeding fusion's shift from fundamental research to applied engineering.
- **Developing the Nuclear Workforce.** The nuclear industry now faces a workforce gap, with seasoned professionals retiring, particularly in nondestructive examination (NDE), and fewer new technologists entering the field. EPRI's recent NDE workforce study proposes actionable steps to stem this decline. EPRI is using this study's findings to develop a strategic roadmap for revitalizing this workforce, with final guidance expected this year.

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Non-Nuclear Generation

EPRI's Generation sector R&D is focused on a comprehensive range of non-nuclear energy-supply resources. These efforts include research on existing assets such as gas, coal, solar, wind, hydropower, and geothermal, along with advances in carbon capture and storage (CCS), energy storage, hydrogen, and other low-carbon energy carriers.

- **Existing fleet expertise.** With decades of experience across all non-nuclear power generation types, including gas, coal, solar, wind, hydropower, and geothermal, EPRI offers unparalleled expertise to optimize plant operations. Our research helps plants respond to increasing flexibility demands, resolve complex materials challenges, and minimize environmental impacts across the asset lifecycle. EPRI's Generation sector R&D supports advances in gas plant flexibility, materials science to enhance fitness for service, and affordable, effective O&M solutions, including self-maintenance strategies.
- **Emerging resource advances.** Our bulk energy storage research is evaluating more than 100 promising new technologies. On the CCS front, we conduct essential R&D into the energy economy needed to support future plants from capture to CO_2 transport to underground storage, collaborating with industry stakeholders to accelerate solutions. Through the Low-Carbon Resources Initiative, EPRI demonstrates hydrogen blending and innovative approaches to achieve net-zero goals.
- **Reducing transition risks.** While the decarbonization end goal may dominate headlines, energy companies recognize the importance of preserving affordability and reliability at every step. Through the Generation Transitions project, EPRI convenes global energy leaders to address the practical realities of the energy supply transition, anticipate challenges, and maximize the contributions of both current and future resources.

ENERGY DELIVERY AND CUSTOMER SOLUTIONS

EPRI's Energy Delivery and Customer Solutions sector works with members to integrate renewable sources, energy storage, grid-edge technologies, electric vehicles, and distributed energy solutions into the evolving electric landscape. We help clarify and guide power system complexities, from strategic planning and operations to end-use electrification and customer dynamics. Following are several of the initiatives that topped our 2024 to-do list:

- **eRoadMAP™ for EV planning.** The transition to electric transportation presents both opportunities and challenges for the utility industry. For example, unlike traditional load planning for buildings, electric vehicle (EVs) installations can be added quickly, often leaving utilities with limited lead time for distribution upgrades. The eRoadMAP™ tool, part of EPRI's EVs2Scale2030™, offers utilities an unprecedented data set for tracking local EV adoption trends. Incorporating this data into utility planning enables utilities to prepare for rising EV demand and better serve customers. eRoadMAP™ also integrates key data layers, such as hosting capacity maps, to help drive data-informed decisions. To support ongoing utility planning, EPRI gathers, updates, and shares data, including data methodology and assumptions, via a public website accessible to utilities and the general public.

- **ISO-NE extreme weather risk assessment.** EPRI and ISO New England (ISO NE) created a methodology to assess risks posed by future extreme weather conditions to the region's bulk power system. The study focuses on the New England power system for the years 2027 and 2032, accounting for shifts in demand, generation sources, and climate patterns. The results of this work establish a foundation for an ongoing, forward-looking risk assessment framework for ISO NE and others. This systematic approach offers a replicable model for identifying future conditions and mitigating future operational challenges.
- **Mercury consortium.** The consortium, conceived by Kraken and managed by EPRI, will develop guidelines and best practices that make it easier for millions of customers to adopt energy technologies like EV chargers, heat pumps, solar panels, smart thermostats, and residential batteries. Consumer devices that have the capability to operate with utilities' requirements, integrate into energy systems, and participate in demand-response programs and markets could help the energy system be more responsive and flexible. The consortium was launched in December and already has 40+ members.

TECHNOLOGY INNOVATION

As EPRI's innovation engine, the Technology Innovation (TI) sector leverages fundamental science, exploratory research, and collaboration to help electric utilities move toward a decarbonized, sustainable energy future. These efforts also include new ways of looking at utility business models and fostering collaborative technology development.

- **Emerging technologies.** EPRI's Technology Radar interactive tool helps energy professionals explore and follow transformative new technologies. The online resource tracks nearly 50 emerging technologies. In October, TI launched its inaugural TechRadar Pulse Report, which analyzes emerging technologies, market disruption potential, technology readiness levels, and commercialization timelines. Space-based solar power is one of these emerging technologies, and TI's August white paper, Power Beaming Aspects of Space-Based Solar Power, examines its opportunities and remaining challenges.
- **Beyond technologies.** The power industry's traditional cost-of-service regulation is in the early stages of a profound transformation. EPRI is now collaborating with industry stakeholders to explore future scenarios and business models. EPRI also convened a utility business model interest group to share perspectives. This kind of outreach also informed 2024's 24/7 Carbon Free Energy (CFE) Buyers Forum project, which brought together sellers of 24/7 CFE, the U.S. federal government, and data center owners interested in purchasing 24/7 CFE. Participants addressed technical and contractual challenges for developing 24/7 CFE commercial power supply agreements and regulated utility tariffs.
- **Encouraging innovation.** In 2024, EPRI continued its Global Innovation Effectiveness Project, which leverages the world's largest benchmark of utility innovation capabilities to help participating companies measure their own performance and improvements. Additionally, EPRI's Incubatenergy Labs held its seventh startup accelerator program, connecting established energy providers with promising early-stage startups.

LOOKING FORWARD

EPRI will continue its work in these and other research areas this year. You can look forward to learning more about them on the EPRI Journal pages as we drive innovation as part of an affordable, reliable energy future.

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Safeguarding Thermal Power Plants in Extreme Cold

A methodology for determining minimum operating temperatures

By Chris Warren

2021's Winter Storm Uri illustrated the critical importance of maintaining thermal power plant reliability when temperatures plummet. The storm brought record cold and snowfall to areas of the U.S. where frigid temperatures and frozen precipitation are exceedingly rare. In Texas, the storm caused outages that resulted in millions of people losing electricity and dozens of deaths due to hypothermia, accidents, carbon monoxide poisoning, and other medical emergencies.

Understanding minimum operating temperatures during cold weather is a key ingredient in thermal power plant reliability. At the most basic level, minimum operating temperatures are the lowest temperatures at which thermal plants can safely start up and reliably function. Turbines, boilers, pipes, tubing, and other equipment can freeze and become less efficient or even stop working when temperatures fall below that minimum temperature.

This is why it's so important to be able to accurately determine a thermal plant's minimum operating temperature, both for the sake of the plant itself and for the customers it serves. "At the fundamental level, it's about safety for society," said Mike Caravaggio, EPRI's vice president of fleet reliability, who leads research on the long-term reliability of existing non-nuclear power plants. "It's about the ability of the bulk energy supply to reliably serve load on the coldest day when you need more electricity than ever, and everything is more stressed in the extreme cold."

It's not just about maintaining reliability in a single power plant. In worst-case scenarios, such as Winter Storm Uri, an individual generating unit that freezes up and ceases operations can trigger cascading failures due to frequency variations. "When it gets really bad, everybody survives together, or the system can collapse," Caravaggio said.

In 2019, before Winter Storm Uri, the North American Electric Reliability Corporation (NERC) began to increase cold weather emergency preparedness requirements under Standard EOP-011. NERC's Standard EOP-012 was developed in the aftermath of Uri to address reliability in extreme cold more explicitly. This included defining a generator's minimum operating temperatures, which can vary significantly depending on the equipment used and any winterization steps taken. For example, a plant with a powerhouse providing temperature control and protection to turbines, boilers, and other critical equipment can operate reliably in cold weather in a way that facilities lacking a powerhouse can't.

This means that complying with NERC's standards and consistently ensuring plant reliability in extreme cold will vary from facility to facility, depending on its geographic location, fuel and asset type, and winterization steps. Nuances include whether coal and natural gas plants are exposed to ambient temperatures. Many natural gas plants are exposed to the elements as are coal plants located in southern states, which can also experience frigid temperatures. Effective winterization can be helped significantly with the aid of a methodology to guide how to determine the minimum operating temperature at any plant. In the absence of a methodology, plant operators have relied on tribal knowledge—knowledge that, while often very effective, is disappearing as large numbers of utility employees reach retirement age.

"This knowledge is in people's heads," Caravaggio said. "Jim knows the minimum operating temperature and knows what to do when it starts to get cold to keep the plant running. But Jim is retiring, and that knowledge is going with him, so the question is how to institutionalize that expertise and keep it at the plant."

A FRAMEWORK TO BENEFIT THE INDUSTRY

Sunflower Electric Power Corporation in Kansas recognized the need for a structured approach to determining thermal plant minimum operating temperatures and approached EPRI to develop one. From the beginning of the engagement, Sunflower wanted the resulting framework to be shared publicly so the entire industry could benefit.

The result is a framework that utilities can follow to develop minimum operating temperatures, which is presented in the report, *Cold Weather Operation: Evaluating Minimum Temperatures for Thermal Generation.* Sunflower was awarded an EPRI Technology Transfer Award for the project.

To develop the methodology, EPRI conducted an industry survey and leveraged both existing EPRI research and NERC resources focused on cold weather operations. The creation of a high-level framework to guide the development of site-specific minimum operating temperatures had to consider numerous challenges. For example, most thermal plants in the U.S. have been in operation for decades. If minimum startup or operating temperatures were documented when the plants were initially designed, they may no longer be available or relevant due to changes, such as the addition of environmental control equipment.

Other wrinkles in developing a framework for determining the startup and operating temperatures of thermal plants are related to how individual plants are used. For instance, many power plants across the country are used briefly and infrequently—usually in the summer—to meet peak demand or to provide ancillary services to the bulk energy system. In 2021, for example, about 20,000 megawatts of steam turbine, combined cycle and combustion turbine-based capacity in the Electric Reliability Council of Texas (ERCOT) had a capacity factor under 10 percent.

Further complicating the determination of minimum operating temperatures is that conditions that often accompany cold weather, such as snowfall, high winds, and ice accumulation, can alter the temperatures at which units reliably startup and run. Also important to keep in mind is that thermal plants are made up of myriad interconnected components. "Every detail matters," Caravaggio said. "Water freezes. And what is a thermal plant? It's a plant that takes water and makes it into steam. So, it's miles of piping and tubing that can't freeze."

FRAMEWORK BASICS

Clearly, every operator must determine the most accurate way to calculate the minimum operating temperature at a thermal plant. However, EPRI's report outlines steps plant operators can follow to establish minimum operating temperatures. They include:

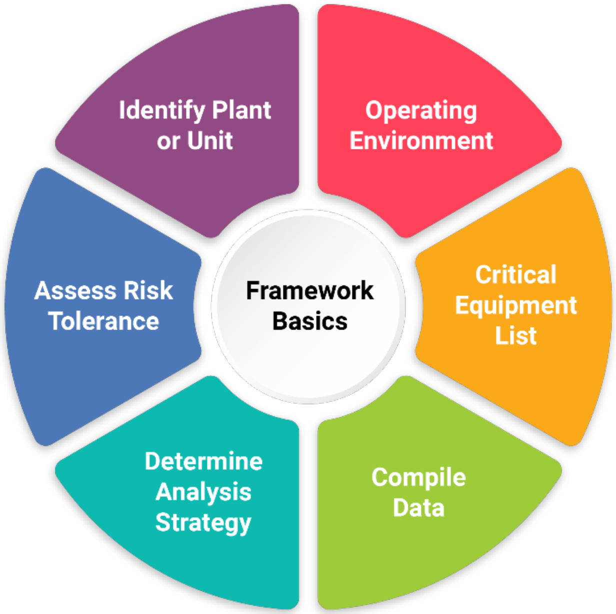
Identify the Specific Plant or Unit: This initial step is all about the prioritization of time and resources needed to confidently determine minimum plant temperatures. Criteria for prioritization include focusing on large capacity generators that contribute significantly to grid stability and how individual units performed during cold conditions in the past. Another factor to consider in determining where to focus resources is whether a thermal plant is slated to cease operations soon.

Identify the Operating Environment: Plant operators can also take steps to assess and prepare for extreme weather conditions under the NERC EOP-012-1 standard. The standard prioritizes pinpointing the lowest temperature plants have reliably operated in historically and determining if there is a gap between that performance and required minimum temperatures. Methods to identify any gaps include evaluating the possibility equipment will freeze, whether fuel supplies are reliable, and how wind, snow, and ice impact critical systems.

Utilize a Plant's Critical Equipment List: Certain equipment at a plant is essential for a unit to startup or to operate reliably. Identifying and documenting which equipment is critical should be followed by an assessment of its vulnerability to extreme cold. Equipment that can often be deemed critical includes transmitters, instrument air systems, and water pipes with fire suppression systems.

Compile Data for Critical Equipment at Greatest Risk: After identifying critical equipment, the next step is to gather as much information as possible about what makes it vulnerable to low temperatures. This can include collecting specified temperature limits for outdoor equipment and evaluating ancillary equipment like heat lamps and temporary enclosures that can be used to maintain minimum operating temperatures.

Determine the Best Analysis Strategy: Choosing the best analysis strategy depends on the available data, which can range from manufacturer specifications to operating histories or engineering analyses based on design sensitivity to cold. The strategy must adapt to the data quality and include caveats like startup time, safe human intervention, and material supply reliability. Operating history can be helpful, but it must account for variables like weather. When equipment has limited data or history, confidence in the analysis inevitably decreases.



Assess Risk Tolerance: Determining a plant's minimum startup or operating temperature means being clear-eyed about the data and analysis used to do it. For example, if critical components fail and risk plant outages or reduced capacity, lower analysis confidence could encourage the use of conservative safety margins. Startup temperatures that require interventions are riskier than those that don't. Ultimately, plants that have low-risk tolerance should implement multiple protective measures.

Sunflower Electric Power Corporation has acted since the development of the framework. "They created procedures and hired an EPC (engineering, procurement, and construction) company to help them winterize their systems," Caravaggio said.

Not only is the framework public and available for other utilities to use, but the research that went into its development also informed EPRI's Climate READi initiative by providing guidance for reliable operations in extreme cold and how to comply with NERC's extreme cold weather standard. "The cold weather aspect of the project benefitted significantly from all the work we did with Sunflower," Caravaggio said.

EPRI TECHNICAL EXPERT

Michael Caravaggio

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A New Approach to Utility Cybersecurity

EPRI teams up with Nvidia, Sygnia, member utilities, and other partners on the Hardware Accelerated Security at the Edge (HASE) project

By Chris Warren

Many data points illustrate the transformation of the electric power system over the past decade-plus. One of the most obvious is the dramatic increase in power generated by renewables like wind and solar. For example, the U.S. was expected to install over 40 gigawatts of new solar photovoltaics (PV) capacity in 2024, according to the Solar Energy Industries Association (SEIA) and the consultancy Wood Mackenzie. In 2015, by comparison, America installed less than six gigawatts of PV.

The shift in generation type has been accompanied by a huge proliferation in the number of generation facilities. In the U.S., for example, there was a net increase of 5,541 power generation facilities in the decade between 2012 and 2022. The are many implications to this changed generation landscape, including the daunting challenge of ensuring both new and existing facilities maintain robust cybersecurity.

Indeed, most new renewable generation facilities don't have staff on-site continuously. Instead, they rely on remote monitoring and control capabilities. These include servers to aggregate data and provide remote monitoring; protective relays to secure electrical equipment; programmable logic controllers, or PLCs, to handle automation and control tasks; and firewalls for cybersecurity. Distributed generation facilities—along with large fossil fuel power plants—also utilize network interface cards (NICs) for networking communications, executing control commands, and interfacing with SCADA systems.

Unfortunately, there are limitations in the cyber protections this traditional ecosystem can provide to the quickly growing number of distributed generation assets, limitations that also apply to conventional power plants. One is simply that new-generation facilities that depend on connectivity to be remotely monitored and controlled have a dramatically expanded attack surface that increasingly sophisticated cyber criminals can exploit. An even more fundamental vulnerability is that generation facilities rely on existing control systems: they lack robust detection capabilities.

"You can't respond to a cyberattack if you don't know it's happening. As defenders, we are oblivious without strong cyber detection," said Jeremy Lawrence, principal technical leader in EPRI's cybersecurity program. "The only way we know an attack is happening is if something turns off. The problem we need to solve is that the control systems that run power plants and critical infrastructure aren't compatible with many of the detection tools we use in other IT (information technology) infrastructure."

LEVERAGING THE SECURITY POWER OF HARDWARE AND AI

EPRI and a group of partners, including Nvidia, Clemson University, Waterfall Security Solutions, Con Edison, Ameren, Southern Company, Emerson, and others, recently launched a three-year research project aimed at vastly improving the detection and response to cyberattacks targeting generation facilities. With funding provided by the U.S. Department of Energy's (DOE) Office of Cybersecurity, Energy Security, and Emergency Response, EPRI and its collaborators kicked off the Hardware Accelerated Cyber Security at the Edge (HASE) project in the fall of 2024.

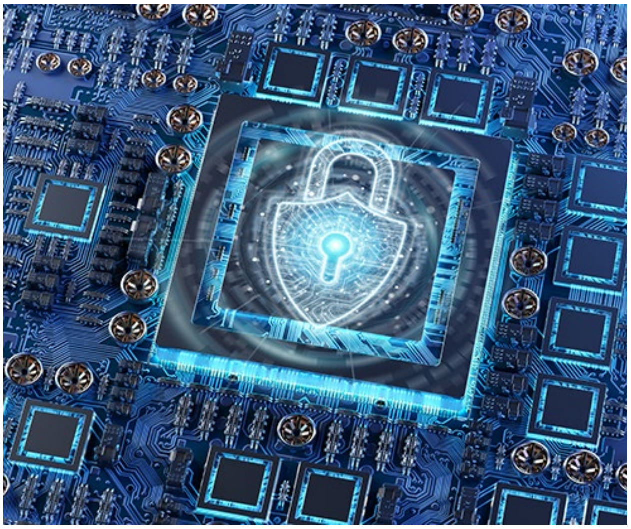
At the most basic level, the HASE initiative seeks to do a few things. The project will integrate data processing units (DPUs) and graphics processing units (GPUs) into control systems. These DPUs replace the NIC and add many detection capabilities built directly into the DPU. By integrating DPUs and GPUs, cybersecurity can benefit from greatly expanded OT network visibility, detection, and event response capabilities, including leveraging the power of artificial intelligence (AI).

Lawrence uses the analogy of a home equipped with both a personal computer and smart devices to illustrate the benefits of integrating hardware like DPUs and GPUs into a generation asset's control system. "Let's say you have a smart microwave and a laptop. You can install an antivirus program and several other tools on your computer to protect it. But you can't install those on your microwave," Lawrence said. "It's exactly the same thing for all the tailor-made devices in a control system and a power plant. But you can install hardware, and that's what we are doing. We are using pieces of hardware to replace that software that would be installed to provide detection and response."

Integrating DPUs and GPUs into control systems bolsters cybersecurity in many ways, including harnessing the unique power of AI. For example, AI can analyze the enormous volume of raw data across a network and perform signature analysis to detect malware. AI can also incorporate heuristics and behavior to identify potential attacks.

This added intelligence can be especially helpful in understanding false positive alerts, which are a major challenge in cybersecurity. "Where the AI comes in is by analyzing all these different alerts, the raw traffic, and making the defenders' job easier by filtering through things like false positives, but then also identifying attacks that maybe otherwise wouldn't be seen," Lawrence said.

The benefits DPUs and GPUs can deliver in terms of fast processing power that AI demands can't be matched by a NIC. "Traditionally, those perform basic functions, like communication, and that's about it," Lawrence said. "But AI requires lots of processing power, and DPUs and GPUs working together provide it. The DPUs can analyze data locally in real-time as it comes in, and then we have a separate communication back to the centralized GPU platform." Think of it this way: the DPUs provide a frontline, initial layer of analytics, detection, and response, while the GPUs aggregate data to diagnose and respond to attacks even more powerfully.



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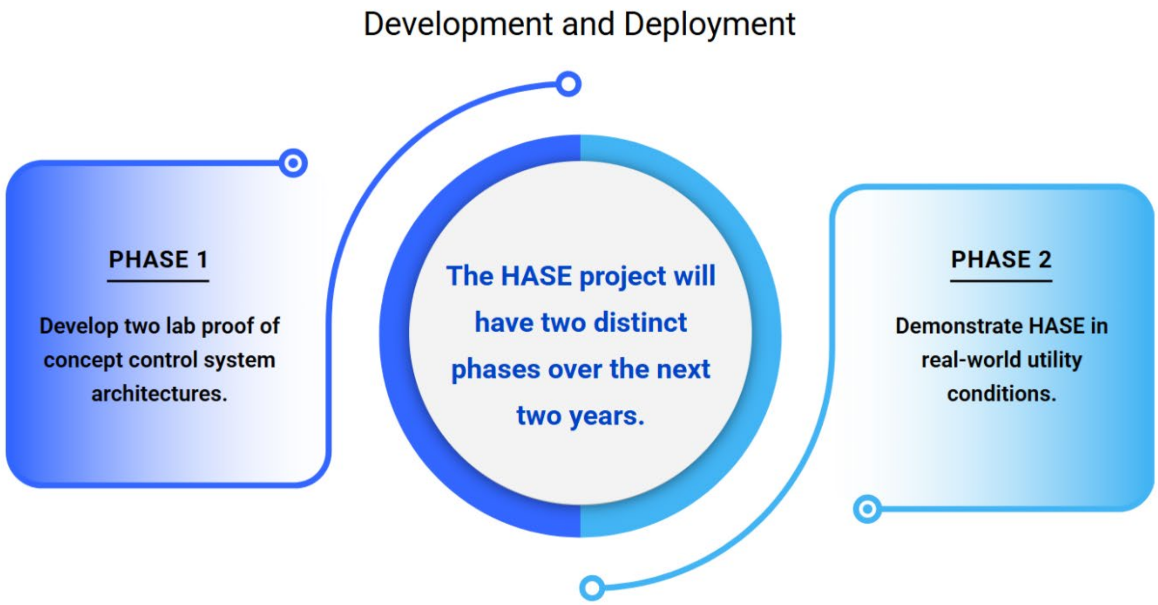

Design

The initial phase of the project will be devoted to developing two lab proof of concept control system architectures following design engineering, stakeholder working groups, and software development. This first phase will take place in EPRI's Charlotte laboratory and Clemson University's lab.

Once the proof-of-concept designs are completed, they will be thoroughly tested in the lab. This will include assessing the basic functionality of the HASE, such as its effectiveness in detecting attacks. Then, the HASE platform will be subjected to a wide variety of simulated cyberattacks based on prevalent attack techniques highlighted by cyber threat intelligence (CTI) and attack frameworks developed by the not-for-profit organization MITRE. "We are going to see if HASE can protect and defend against attacks better than a software-based defense," Lawrence said. "We want to see where there are weaknesses, and then we will tune HASE to solve those weaknesses."

The design and lab testing phase will also include an assessment of HASE based on EPRI's Cybersecurity Technical Assessment Methodology (TAM). TAM is a risk-informed methodology that provides step-by-step guidance that helps power plant operators assess their cyber defenses by prioritizing the protection of devices that are most essential to plant operations. Initial design work will also be informed by Cyber Informed Engineering (CIE) principles developed by the U.S. Department of Energy (DOE) and the Department of Homeland Security (DHS).

Utility Demonstration

The second phase of the project will be to demonstrate HASE in real-world utility conditions. Before that step, HASE must meet certain effectiveness, coverage, and compatibility metrics. "We want to make sure HASE is as good or better than existing solutions before we move forward to a utility demonstration," Lawrence said. "We don't want to introduce something that is less effective or isn't compatible with what a utility is already doing."

Once the lab work and utility demonstration are complete, an important deliverable of the HASE project is a commercialization plan. HASE is not meant to be a research and development (R&D) project yielding abstract lessons that can't be applied. Developing a commercial strategy as part of the project is designed to speed the uptake of a more robust cybersecurity solution.

STRONG DEMAND FOR ENHANCED SECURITY TOOLS

There is demand among utilities for more sophisticated cybersecurity tools that meet the needs of a changing power system. One indication of the demand is the participation of utilities like Con Edison, Ameren, and Southern Company in the HASE project.

For Charles Boohaker, principal engineer, research, environment, and sustainability for Southern Company Services, Inc., the potential for greater OT visibility was a big draw to partner in HASE. “As an operator of a large generating fleet, Southern Company is always looking for ways to improve the visibility and security of the OT network,” Boohaker said. “That's why I am excited about the proposed R&D project that aims to develop hardware-based offloading solutions that can integrate with the existing fleet and generate more actionable alerts.”

Joseph Bradley, Sr., manager of cybersecurity at Ameren Digital, was eager to join the HASE project because it promises compatibility and flexibility to defend OT assets. “As a company that operates a wide range of critical infrastructure facilities, we need security detection solutions that are compatible with a wide range of OT equipment. The proposed Hardware Based project (HASE) is an agentless solution that provides the same visibility and control as an agent but with minimal overhead and impact on the device,” Bradley said. “These approaches increase interoperability across a wide array of OT devices, from legacy PLCs to modern IoT sensors. Having the ability to improve the cybersecurity capabilities of critical infrastructure environments without needing to rip and replace significant components will significantly improve our ability to adapt effectively.”

Even as the HASE project moves forward, Lawrence can already anticipate future research and partnerships that can fully leverage the security benefits of hardware at the edge. For instance, control system vendors could integrate the hardware directly into their new products or retrofit existing control systems to include them. Future research could aid that effort by reducing the form factor of the hardware.

Regardless of the exact form or forms it takes, the use of hardware to better protect OT assets is a distinctive shift in how utilities can ensure cybersecurity. “It’s a different approach. The same old, same old is installing software. We want to make this as secure as possible right out of the box,” Lawrence said. “It’s a bit of a paradigm shift, and that’s why I’m excited about it.”

EPRI TECHNICAL EXPERT

Jeremy Lawrence

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A Platform to Connect EV Customers to Utilities

EPRI introduces GridFAST, a tool that streamlines and encourages early communication between customers with EV projects and utilities

By Chris Warren

The evolution of job searches over the past decade-plus has many lessons for navigating quickly changing customer expectations, including even those in the electric vehicle (EV) market.

In the past, job seekers scoured newspaper listings to find positions that were a good match for their skills and experience. Applicants responded to promising job openings by submitting a cover letter and resume directly to the employer. The newspaper's role as a platform connecting employers and potential employees ended after that initial introduction. "You could find jobs in newspaper classified ads, but then you had to apply somewhere else," said Watson Collins, an EPRI senior technical executive whose work focuses on electric transportation.

Today's job search and application process is dramatically streamlined and standardized. Sites like Indeed and LinkedIn not only bring job searchers and employers together, but they also make it simple and fast to apply and begin communicating with a company. There is no reason to leave the platform.

This modernization and digitization of the job search has more to do with scaling EVs than may seem immediately apparent. One of the reasons EV projects—be it for fleet electrification or to add charging infrastructure to travel centers and other locations—can take longer than utilities or developers would like is because there has not been a single platform to initiate and support the ongoing communication and collaboration needed to accelerate EV infrastructure energization.

The lack of a platform allowing those who want to build and interconnect EV chargers to find and begin working with utilities has translated into delays, unnecessary expense, frustration, and damage to the reputation of utilities. It doesn't have to be this way. Utilities can work collaboratively with their customers to seamlessly serve the expected scale of EVs, which may account for half of all new vehicle sales by 2030.

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GRIDFAST: EFFICIENT COMMUNICATION TO SPEED EV CHARGING PROJECTS

EPRI introduced GridFAST, an information exchange platform where customers with EV projects find and work with utilities to speed infrastructure energization. A group of EVs2Scale utility members are currently piloting and testing GridFAST, and the platform will be rolled out more comprehensively throughout 2025.

The development of GridFAST recognizes that utilities and those with EV infrastructure energization projects are still learning how to work together best.

“This is a novel process,” said Collins. “Utilities are becoming a fuel provider for fleets and EVs. Tools are needed to help navigate important project decisions early for successful EV service connections.”

Consider this scenario: a corporate decarbonization commitment requires the electrification of a commercial fleet. The fleet operator will already be an expert at ensuring its gas- and diesel-powered cars, trucks, and vans are fueled up to complete their routes reliably and contain operating costs.

The transition to a new fleet of EVs raises a range of questions and potential risks for the operator. Some fear that their lack of experience with EVs could result in a significant increase in fuel costs or instances when a fleet can’t complete its scheduled routes because vehicles aren’t sufficiently charged.

The timeline and expense of building and energizing chargers may also be unknown to utility customers. For example, does the current (or proposed) location where EVs will be charged have sufficient grid capacity to accommodate the load, or will upgrades be necessary? How long will necessary upgrades take to plan and complete, and how will the expense impact a company’s business case for electrification?

WHY CONNECTING UTILITIES AND CUSTOMERS EARLY IS IMPORTANT

The list of questions utility customers with infrastructure energization projects need to answer is long. It includes complex topics like how demand charges could impact operations budgets and whether managed charging and favorable rates can contain those costs. Education about the charging speed and power needs of Level 2 and DC fast chargers is also foundational to guide customer selection of technologies.

Answering these and other questions early in a project’s life cycle creates mutually beneficial ripple effects that foster efficient and rapid progress. For example, early collaboration lets utilities provide customers with detailed information about grid capacity at a project’s proposed location. If grid capacity is insufficient to meet the future charging load, utilities can inform customers about the costs and timeline of upgrades and suggest phase-in power solutions or alternate locations.

Utilities are also major beneficiaries of early engagement with customers. For example, utility infrastructure planning improves when it is informed early by accurate and up-to-date customer charging plans. Early collaboration also gives utilities the opportunity to better serve their customers, an increasingly important priority for utility leaders. For instance, utility expertise can help customers avoid expensive grid upgrades and project delays with the addition of energy storage, solar, managed charging, flexible interconnection, and other measures.

HOW GRIDFAST WORKS

The typical EV infrastructure energization project has many steps, from idea to interconnection. Here's how GridFAST drives early, consistent, and standardized communication at each project stage:

Project input: Every infrastructure energization project is unique. GridFAST prompts utility customers to provide basic information about project location, power needs, and timeline to be operational. Gathering as much of this information as possible—not all projects will know all these details—is the first step to initiating communication with a utility.

Utility match: One of the challenges customers with EV projects face is connecting with the right utility to begin answering questions about siting and grid capacity. GridFAST vets the information project developers provide and then matches it to the appropriate utility. Once that initial connection is made, the utility can begin providing tailored advice to help move the project forward.

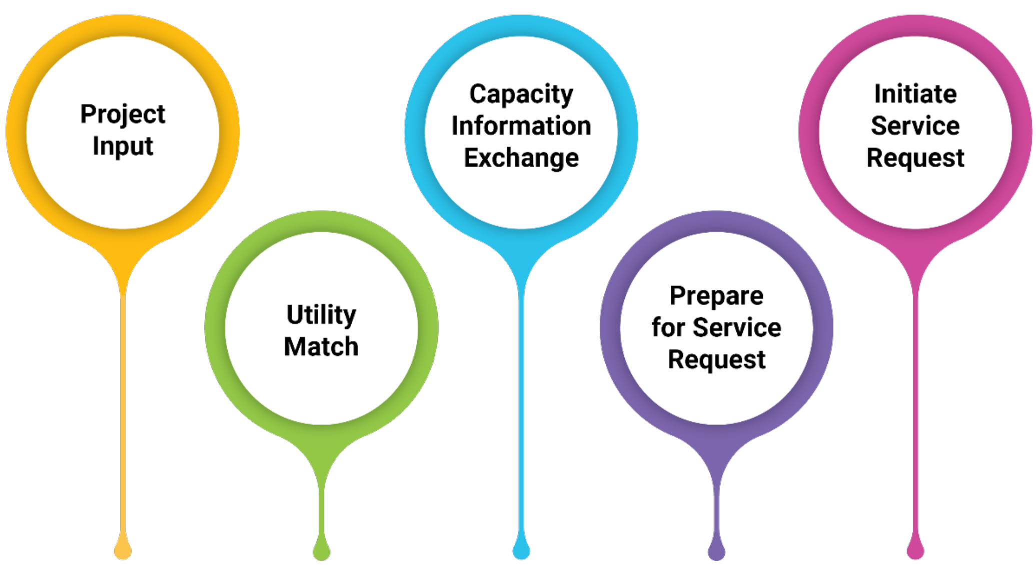
Capacity information exchange: GridFAST provides a secure platform for customers to exchange information necessary to size and improve projects.

Preparation for service request: GridFAST is also where customers can securely and collaboratively finalize project information with the utility in preparation for a service request submission.

Initiate service request: Once all the project details are finalized, utility customers can submit a service request to the utility. The utility will then work with the customer to energize the project.

IMPROVED STAFF PRODUCTIVITY HELPS SCALE EVS

Utilities already have systems and processes for EV customers to access the grid. GridFAST complements existing utility systems and provides a common portal that makes it easy for customers with national and regional EV infrastructure to reach the roughly 3,200 utilities in the U.S. "We've heard from customers that they have trouble finding the right utility contact. Utilities then have different ways of listing and even talking about their programs and other relevant information. There is no standardized format." said Jen Robinson, an EPRI technical executive and project manager of GridFAST. "GridFAST helps both customers and utilities to share information and streamline EV project sticky points."



Utility staff charged with processing project information also benefit because the information they receive from GridFAST is already vetted and in a standard format. This makes the utility more efficient and better equipped to handle a large volume of projects.

"It's important to note that GridFAST doesn't take the place of utility planning or customer interaction. It is designed to reduce much of the early back-and-forth between customers and utilities that leads to significant non-value effort and time spent on both sides," said Britta Gross, director of transportation at EPRI. "Both customers and utilities have identified this as a major pain point in the interconnection process, and GridFAST aims to address this issue head-on."

The rapid growth of EVs can obscure the fact that their mainstream availability and affordability are still a relatively recent phenomenon. That is why it should come as no surprise that utilities and their customers with EV projects are continuously developing more efficient and transparent ways to

communicate and collaborate. By leveraging the unique capabilities of a platform, GridFAST is an important step forward.

GRIDFAST TIMELINE FOR CUSTOMERS AND UTILITIES

GridFAST is available to all customers and utilities as of March 2025. GridFAST accounts are free for customers of U.S. utilities with EV charging infrastructure projects, including fleet operators and the developers of public charging, workplace charging, and multi-family charging sites.

To learn more about GridFAST, visit gridfast.com. For inquiries, please contact Jen Robinson at jrobinson@epri.com.

EPRI TECHNICAL EXPERTS

Mariela Arceo, Watson Collins, Erin Costigliolo, Britta Gross, and Jen Robinson

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Hot Zone Challenge

Researching the impact of hydrogen and ammonia on gas turbine component durability

By Chris Warren

The use of low-carbon fuels in power-generation gas turbines has attracted significant research and investment in recent years. There are several reasons hydrogen and ammonia have garnered so much interest as low-carbon fuels to blend with natural gas or eventually burn on their own to generate power.

A big driver, of course, is the potential to reduce power sector greenhouse gas emissions (GHG). For example, hydrogen produced using an electrolysis process powered by nuclear or renewable energy results in an ultra-low carbon fuel that can be burned in natural gas turbines, thereby dramatically lowering emissions. Additionally, as more intermittent renewable generation is added to the grid, increasing amounts of clean, firm, dispatchable electricity will be needed to maintain grid reliability when the sun isn't shining and the wind isn't blowing.

The U.S. Department of Energy (DOE) provided billions in funding to support the creation of a network of hydrogen hubs across the country to accelerate the production, storage, delivery, and end-use of hydrogen, including in power generation. Two California cities, Industry and Lancaster, announced the creation of the nation's first public hydrogen utility in early 2025.

© Adobe/Aerial view of hydrogen storage hub under construction

INITIAL RESEARCH DOESN'T FOCUS ON MATERIALS

Given its potential to drive decarbonization, numerous laboratory and field tests have been launched to probe the turbine performance and emissions reduction of hydrogen blended with natural gas. For example, EPRI's Low-Carbon Resources Initiative (LCRI) partnered with utilities like Georgia Power, Constellation, and the New York Power Authority (NYPA) to evaluate co-firing gas turbines with fuels made up of 20 percent, 38 percent, and 44 percent hydrogen, respectively.

If low-carbon fuels are to be used more in gas turbines, however, a lot more needs to be understood about how they may potentially impact the components inside the turbine, especially in the so-called hot zone, where the combustion takes place. Because the components are exposed to such high temperatures, they tend to be the most expensive in the turbine. Hot-section components include the combustion liner, transition piece, and the vanes and buckets.

"As we think about hydrogen and other alternative fuels for low-carbon purposes, we mostly talk about burning it and whether the combustor can handle it and what the emissions are," said Bobby Noble, an EPRI senior program manager whose work focuses on gas turbine research and development. "But there has been very little work on the implications for the rest of the hot section."

AN IMPORTANT FIRST STEP TO UNDERSTAND MATERIALS IMPACT

That is beginning to change. Last year, EPRI released "Preparing Gas Turbine Engine Materials for Low Carbon Fuels," a review of research that had already been conducted and a suggested roadmap for future research to close knowledge gaps. Later this year, LCRI is also expected to publish the findings of tests of components with different coatings that have operated inside gas turbines for multiple years. The turbines used for the tests don't burn hydrogen but instead have water injections for nitrous oxide (NOx) control that mimic fuel containing hydrogen.

The report released last year identified the elevated water content in the exhaust of gas turbines burning hydrogen or ammonia as a potential cause of accelerated material degradation. For example, when hydrogen burns, it reacts with oxygen, and water is the primary byproduct. Similarly, ammonia also produces water when it burns in a gas turbine. By contrast, when natural gas, which is primarily methane, burns in a gas turbine, it reacts with oxygen to produce both carbon dioxide and water. The water content present in the natural gas exhaust depends on the fuel's composition and other factors.

THE IMPACT OF WATER CONTENT

How does water content in a turbine's combustion fuel exhaust impact the health and durability of components? A simple way to understand it is to imagine your own physical reaction to humidity, which measures the water content in the air. "70 degrees Fahrenheit with five percent humidity may be cold to some people. But 70 degrees Fahrenheit with 95 percent humidity is going to be miserable and sticky," Noble said. "Similarly, having more water in the combustion exhaust in a turbine affects the heat transfer to the components. So even though the temperature of the fuel may be the same, the heat transfer can make the components hotter."

The question is how much hotter components burning fuel mixtures with high water content can get and what extended exposure to elevated heat means for their expected useful lifetime. A greater

© Adobe/Gas turbine power plant stack

understanding of the effectiveness of coatings and the turbine's cooling system is also an important consideration when contemplating alternative fuels. "These components are designed to handle natural gas exhaust products," Noble said. "The cooling schemes and everything else are highly tailored to keep the components to the right temperature under typical conditions for that fuel. Now that we are considering different fuels with higher water content, that design may or may not be sufficient."

Other key findings of the report, which was spearheaded by Jacqueline O'Connor, professor of mechanical engineering at Penn State University, included:

- Past studies to understand the impact of higher water content exhaust on hot zone components were not done at relevant operating conditions and environmental conditions, making it difficult to estimate the impact of low-carbon fuels.
- Studies of material compatibility for high hydrogen fuels have mainly focused on fuel handling systems like piping and compression. While important, this is one piece of advancing long-duration operation of hydrogen in power generation gas turbines.
- Many additional research questions need to be investigated and answered.

THE ROAD AHEAD

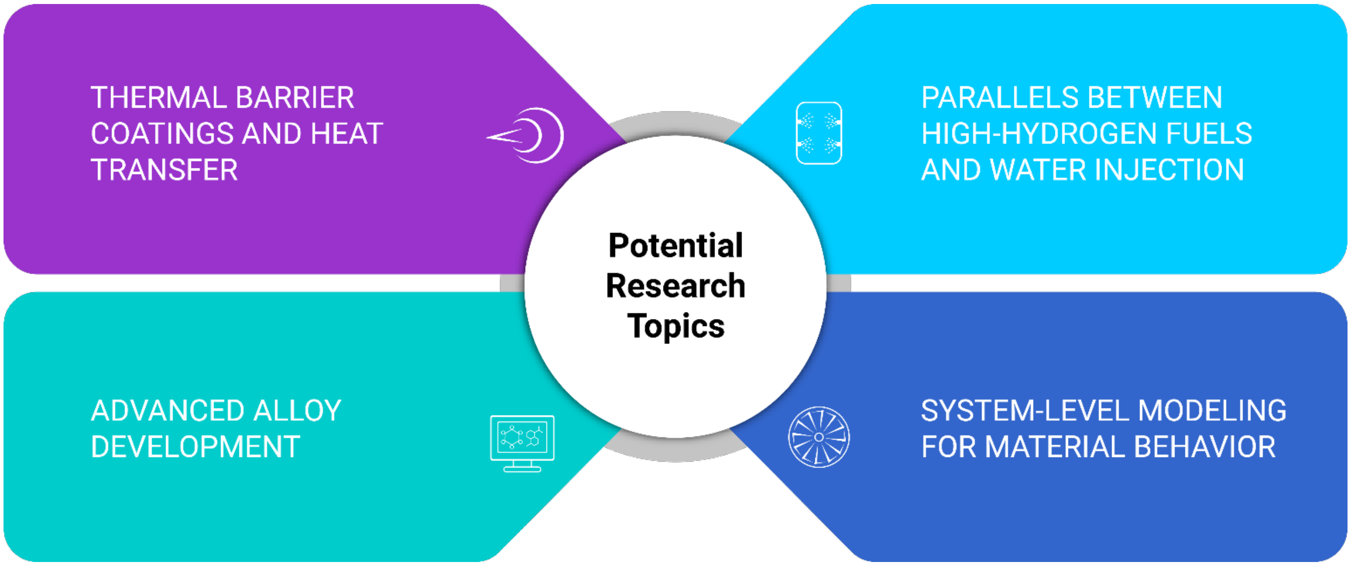
There is a benchmark for how long components should last. There are always nuances in terms of which specific components and protective coatings are used and the type of turbine and fuel mix. However, in a general sense, components in the hot zone of a turbine running about 7,000 hours per year should last between four and six years.

Some refineries and chemical plants have gas turbines that have burned hydrogen for years. However, the components in the turbines are older technology, and there have not been any systematic studies comparing the impact of burning hydrogen and natural gas on their useful lifetimes. Modeling is currently the only way to gauge how new fuels may impact components.

That is now changing. Recently, EPRI and Penn State teamed up to begin laboratory testing of hot-zone components. The testing is being informed by input from LCRI and EPRI's advanced gas turbine (Program 217) and materials program (Program 229). The testing will expose components to differing levels of heat and humidity for various periods of time. The components will also be subjected to destructive testing. "We want to build a materials database based on various scenarios," Noble said.

In his discussions with utilities, Noble has found that there is a lot of interest in the test results. But it's also clear that a lot more research will be necessary to fully understand how low-carbon fuels with high water content will affect the lifespan of hot-section components.

© *Adobe/*Gas turbine engine



A wide range of potential research topics were laid out in the EPRI report released last year.

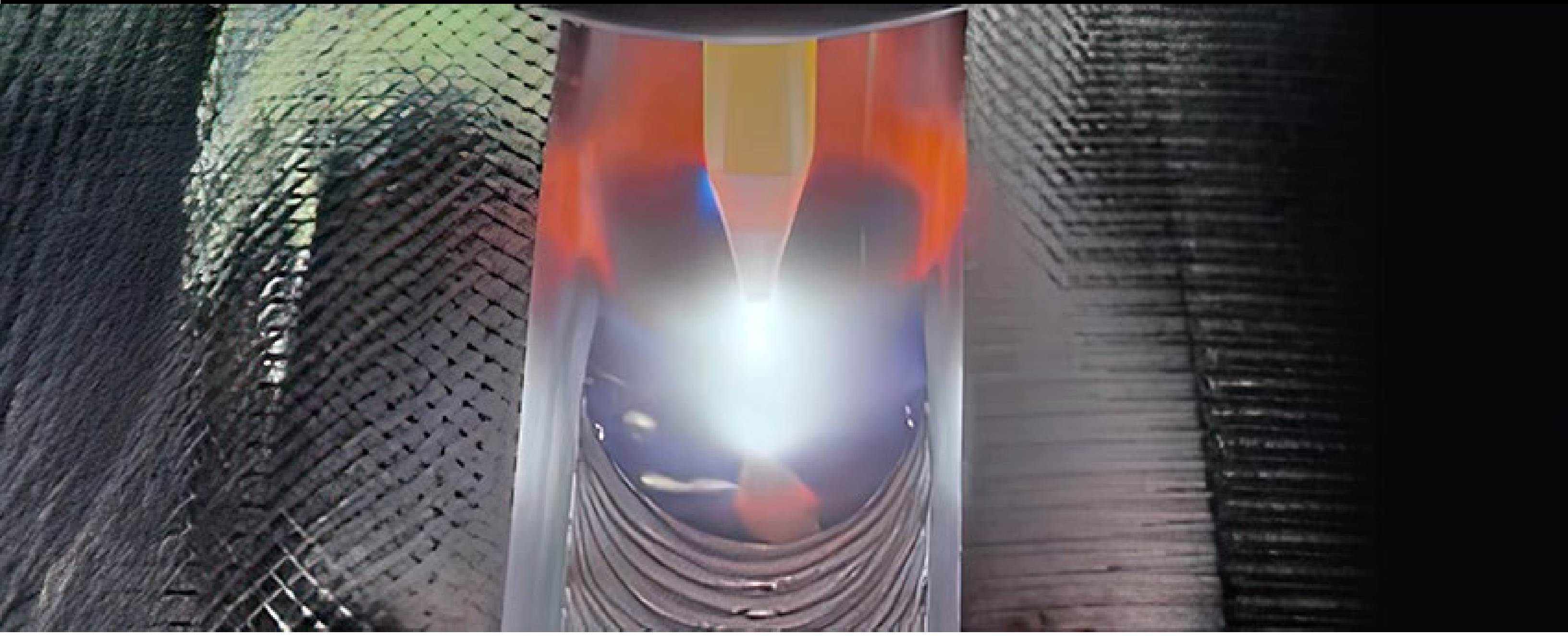
A few of the possible areas of research focus on:

- **Thermal barrier coatings and heat transfer:** Thermal barrier coatings (TBCs) are a special protective layer applied to gas turbine parts to provide protection from the extreme heat that can cause damage and reduce component lifetimes. More research is needed to understand the effectiveness of TBCs better as they age and are exposed to high water vapor environments.
- **Parallels between high-hydrogen fuels and water injection:** Gas turbine temperatures are often managed with water injections. Researchers could analyze the similarities between water injection effects and the combustion of hydrogen. Maintenance lessons and strategies could be drawn from water-injected turbines and applied to those burning hydrogen.
- **System-level modeling for material behavior:** As the use of fuels with low carbon but high water content increases, models that can help predict how fuel blends impact component lifetimes, maintenance schedules, and performance become more important.
- **Advanced alloy development:** Research is needed to develop new alloys that can be incorporated into gas turbines burning hydrogen and other low-carbon fuels. Oxide-dispersion strengthened (ODS), and refractory alloys need to be tested in real-world turbine conditions to gauge their durability and compatibility inside gas turbines.

As the electric power industry considers greater use of low-carbon fuels, gas turbines must also evolve to handle the unique challenges of hydrogen, ammonia, and other alternatives. Continuing research into materials, coatings, and system performance is crucial to ensure turbines remain reliable as alternative fuels scale and become more viable options.

EPRI TECHNICAL EXPERT

Bobby Noble



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Bridging the Welding Gap

EPRI explores how AI can address the nuclear power industry's welder shortage

By Chris Warren

Nuclear power is grabbing headlines. For example, early in 2025, French President Emanuel Macron and India's Prime Minister Narendra Modi announced plans to jointly develop small modular reactors (SMR). In 2024, Constellation Energy and Microsoft declared their intention to restart a closed reactor at Three Mile Island to generate carbon-free energy for data centers the tech giant needs to power artificial intelligence (AI). "Nuclear energy is making a strong comeback, with rising investment, new technology advances and supportive policies in over 40 countries," said the International Energy Agency (IEA) in a new report, *The Path to a New Era for Nuclear Energy*.

While the IEA forecasts global nuclear capacity growth will reach between 650 gigawatts to over 1000 gigawatts by 2050, there remain significant policy and financial challenges. One little-mentioned challenge—a hurdle both for new construction and maintenance on existing nuclear power plants—is a shortage of skilled welders to build, replace, reinforce, or repair piping systems, reactor vessels, valves, and other critical infrastructure. In the U.S., for example, the American Welding Society estimates there will be a shortage of 400,000 welders across the economy.

"Experienced welders are retiring, and industries are struggling to replace those roles with the same quality of welders," said Jon Tatman, an EPRI principal team lead whose research focuses on developing welding solutions for the electric power industry. "We don't expect that trend to stop anytime soon." The labor shortage doesn't just impact welders. There also aren't enough inspectors to ensure that welds are correctly done, a cause of potential project delays even when welders are available and work quickly and efficiently.

While efforts to encourage and train more young people to pursue welding careers are important and necessary, improved recruitment and retention won't be enough to tackle the labor supply and demand gap. Advances in artificial intelligence (AI) and sensor technology have the potential to both address the welder shortage and significantly improve the precision, quality, and safety of welds. EPRI has been collaborating with the Fraunhofer

Institute and the welding equipment supplier Liburdi Dimetrics to develop and commercialize AI-driven adaptive welding capabilities.

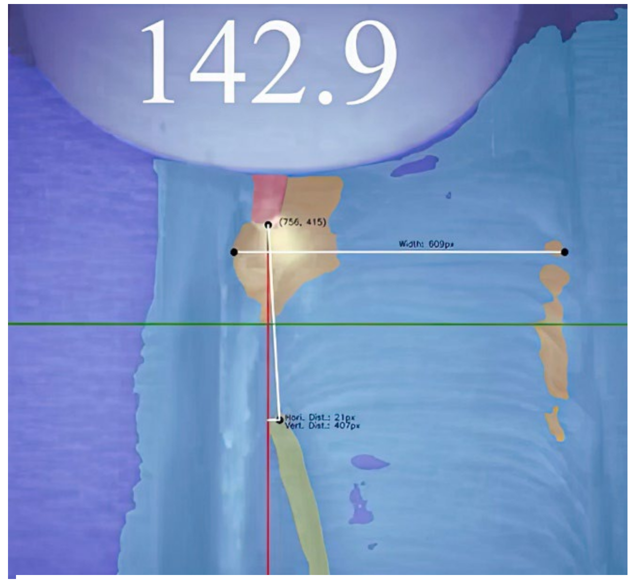
HOW SENSORS, CAMERAS, AND AI CAN MIMIC A SKILLED WELDER

The current approach to mechanized welding at nuclear projects combines both automation and the guidance of a skilled welder. At a very basic level, a welder will observe the speed, position, voltage, and other aspects of the wire making the weld to ensure its quality. "You have an operator watching the weld and adjusting it to ensure nothing goes off course. They're watching it remotely, so even though it's mostly automated, you still require an operator to sit there and watch," said Nick Mohr, an EPRI program manager and welding engineer.

EPRI and its partners have explored how a combination of cameras, sensors, and algorithms can potentially eliminate the need for a skilled welder to continuously observe a weld and sometimes adjust it to ensure its quality. The welding system uses two algorithms, both developed by Germany's Fraunhofer Institute. The first analyzes images of a weld in real-time and adjusts the wire to ensure a precise and safe weld. The algorithm examines a host of features, like the weld pool (the melted metal), the wire, and the groove, to determine whether any adjustments are needed.

"The camera continuously monitors the weld in real-time and collects data, which the algorithm processes in real-time," Tatman said. "It identifies different key areas of the weld, like the weld pool, the welding wire, and the groove geometry. By analyzing different aspects of the weld, the algorithm effectively acts like a skilled welder, making decisions and adjustments necessary to maintain optimal welding conditions."

The algorithm's ability to adjust depends on its training. EPRI and Liburdi Dimetrics worked with AI experts at Fraunhofer to provide images and data to instruct the algorithm about what good and bad welds look like. "You really need welding expertise upfront to guide the AI development," Tatman said. "Without that baseline of knowledge built into the algorithm, it won't be able to make the right



© EPRI Real Time Control of Wire Position

adjustments. The cameras and the sensors are like the welder's eyes and ears, and the algorithm is like the brain. All of that must be working well to automate these welds."

One algorithm continuously monitors and adjusts weld settings in real time, fine-tuning the welding wire's entry position into the weld pool to maintain optimal conditions. Meanwhile, a second, future-focused algorithm predicts the optimal weld parameters for adding new layers of metal. This predictive capability ensures process consistency and preemptively prevents potential defect formation.

Adaptive welding also has the potential to eliminate the need for post-weld inspections. If algorithms become sufficiently precise, real-time monitoring and inspections could follow along with the automated welds and immediately raise potential issues to address and correct. "If you can inspect as you're welding, you could save a lot of time on the backend in terms of your post-inspection," Mohr said. "We haven't done that yet, but that is a potential future research effort."

EXPLORING ADAPTIVE WELDING APPLICATIONS

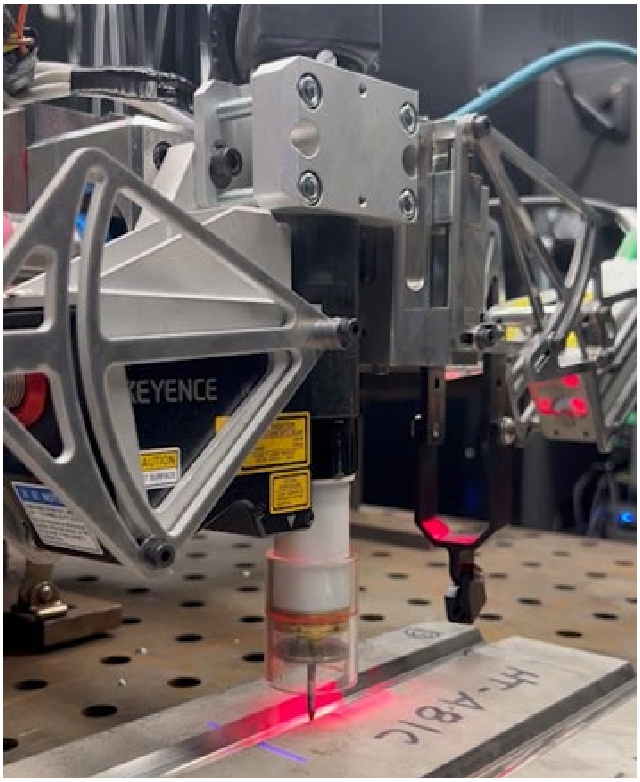
While future research to improve adaptive welding is necessary, it is not purely a laboratory technology. Liburdi Dimetrics, a welding vendor, has already licensed the technology from EPRI and begun to incorporate the algorithms into their welding systems. Liburdi Dimetrics has also identified about 10 applications where adaptive welding can be used.

EPRI and Liburdi Dimetrics have already worked with the Fluor and the Central Plateau Cleanup Company to leverage and directly apply this developed adaptive welding technology. The application involves a dry storage canister seal welding application to contain highly radioactive nuclear waste, a scenario where it's important to keep welding personnel away from dangerous radiation levels. "You can't have an operator nearby to monitor what's happening," Tatman said. "The driver of fully automating the process is safety concerns." A similar system could be used for commercial nuclear spent fuel canister welding, and another possible future application is for the welding needed at a plant's spent fuel pool liner.

The specific applications identified can also guide future algorithm development. For instance, algorithms could be trained to automatically shut down a weld if it recognizes a condition that indicates a safety concern or a faulty weld.

Regardless of the potential applications identified for adaptive welding, its implementation into real-world scenarios will inevitably require building trust among operators. "For the first few times in the field, there are going to be people watching. Mechanized welding always has an emergency stop," Mohr said. "You're going to have an expert welder there looking at it and using adaptive welding won't save time and money at first. But as trust in the model builds, I think you're going to get to the point where the welder sets this up, gets it started, and walks away."

As much as adaptive welding has the potential to improve safety, precision, and efficiency, one thing it won't do is fully replace the need for actual human welders. Indeed, even the use of adaptive welding requires a skilled welder to set up and operate the system. In the case of a circular storage container, where the same weld is necessary repeatedly, a welder will still be needed to initiate the automated welds.



© EPRI Adaptive Weld System

"There is always going to be a need for manual welders," Mohr said. "In many cases, it's just going to be quicker to send a welder to do a job rather than getting all the equipment needed for adaptive welding into the field and setup. What adaptive welding provides is another tool to improve welding consistency and address the labor shortage."

EPRI TECHNICAL EXPERTS

Jon Tatman, Nick Mohr

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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