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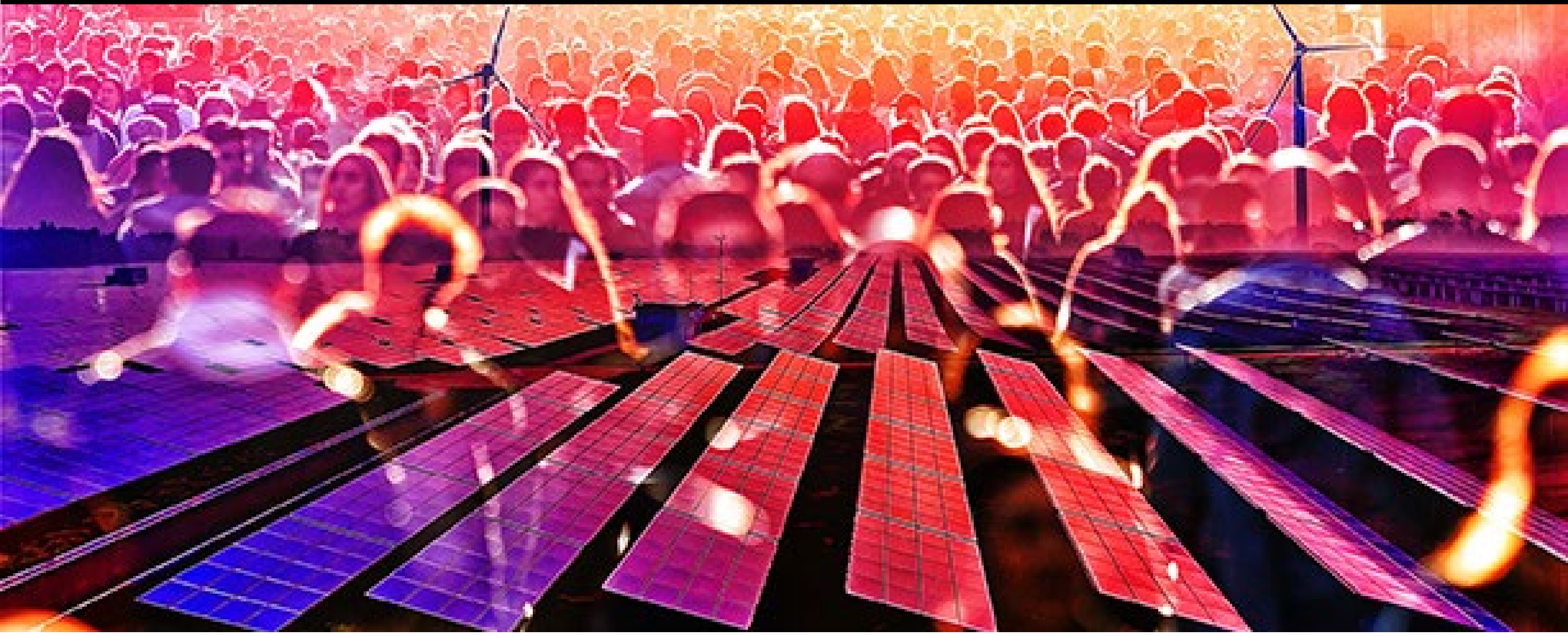


Using the Energy Transition to Accelerate Equity

EPRI's new Equitable Decarbonization Interest Group aims to explore ways the clean energy transition can advance a more just society

By Chris Warren

The fundamental mission of the ongoing energy transition is decarbonizing the global economy to avoid the worst impacts of climate change. However, the need for massive investment to re-imagine how societies and communities produce and use energy—whether in the construction of wind turbines and solar panels or the deployment of smart meters to elevate the intelligence and interactivity of the grid—is also an opportunity to create a more just and equitable society.

"This is not just about how we make the energy transition itself more equitable, although that's obviously a big part of it," said Morgan Scott, EPRI's sustainability and ecosystem stewardship research director, who spearheaded the creation of EPRI's Equitable Decarbonization Interest Group last year. "Let's think beyond the fair cost and benefit allocation of decarbonization investments. Are there also ways we can leverage this transition to create a more equitable society? Electric transportation can improve local air quality in heavily trafficked neighborhoods. Energy efficiency can lower energy burden for low-income households."

Put more simply, the transition to a more distributed, intelligent, and decarbonized power system can be a vehicle for delivering environmental, health, and economic benefits to communities that have historically borne mostly negative consequences as a result of energy development. Changing that paradigm requires not just placing historically disadvantaged communities at the center of decisions about policies and investments designed to drive decarbonization but also having those communities actively participate in the process.

"There are opportunities to explore and enhance equity in the communities we serve," said Kimberly Pickford, senior sustainability specialist at FirstEnergy and a member of the Equitable Decarbonization Interest Group. "For example, if there are plans for electric vehicle infrastructure in our areas, we would want to be sure equitable

accessibility is discussed. It's about engaging the stakeholders on the front end and considering their ideas in the decision process."

Intensifying Focus on Equity

Increased interest in equitable decarbonization among utilities, policymakers, regulators, private businesses, and communities has roots in longstanding social movements. The modern environmental justice movement began in the 1980s, when Warren County, North Carolina residents protested the dumping of toxic PCBs in their communities. In the decades since then, a wealth of research has shown how inequitable the environmental and health impacts of industrial developments have been for low-income communities and communities of color.

A study published in the journal *Science* examined 36 years of particulate matter emissions data and found that while pollution levels have dropped across the U.S., poor and minority communities have seen the fewest benefits. Particulate matter pollution is associated with adverse health effects like cancer, lung and heart disease, infant death, and reduced life expectancy. Research released last year by the U.S. Environmental Protection Agency (EPA) revealed that people of color are exposed to higher levels of pollution, regardless of their income or where in the country they live.

Pollution disparities aren't the only way inequality manifests itself in disadvantaged communities. Energy burden, which is the proportion of household income needed to pay for electricity, natural gas, fuel, and other forms of energy, is far higher in low-income homes than in wealthier households. According to the U.S. Department of Energy, low-income households spend 8.6% of their gross income on energy, compared to 3% for non-low-income households.

Renewed attention to historic inequalities surfaced by the COVID-19 pandemic have sharpened the focus on environmental justice and how the energy transition can be a tool for tackling it. Indeed, last year the incoming Biden administration issued executive orders directing the entire federal government to advance environmental justice, including establishing a goal that 40% of the benefits of federal investments reach marginalized communities.

There's also movement in the utility sector. Across the U.S., states including North Carolina, Rhode Island, and Wisconsin are developing equity plans and metrics. The California Public Utilities Commission released an Environmental and Social Justice Action Plan in 2019 and updated it last fall. Washington updated its State Energy Strategy in December 2020 and devoted a chapter to the development of an equitable clean energy economy. Illinois is also leading efforts to establish energy equity metrics, offering an example of how policy can incorporate equal economic participation into the energy transition. Individual companies like Pacific Gas & Electric, Duke Energy, American Electric Power, and Dominion, among others, have issued statements and launched programs designed to raise awareness and drive progress towards equity and justice.

But a desire for a more equitable society is not the only driver of environmental justice efforts. The reality is that the ultimate goal of decarbonization simply can't be met if its benefits and costs aren't shared equally. "We won't achieve economy-wide decarbonization unless we bring everyone along and don't leave anyone behind when it comes to the benefits of decarbonization," said Brenda Brickhouse, who leads the EPRI interest group and formerly worked as chief sustainability officer at the Tennessee Valley Authority (TVA). "Fair treatment and meaningful involvement of all people regardless of race, ethnicity, and income are critical to this transition."

ANSWERING QUESTIONS, SHARING KNOWLEDGE, AND SPURRING ACTION

Recognizing that there is a unique opportunity to advance fairness and equity through decarbonization is an essential start. But utilities face a steep learning curve around the tools, programs, and community conversations needed to advance and measure progress towards equitable decarbonization. EPRI's Equitable Decarbonization Interest Group was launched with the goal of bringing together utilities, policymakers, regulators, academics, communities, nongovernmental organizations, and others to learn from one another, share leading practices, and identify needed research that will support better decisions and programs that advance equity.

During its first year of operation, the Equitable Decarbonization Interest Group hosted a series of technical workshops and speakers to explore a wide range of topics, including the digital divide, metrics and tools, and modeling and policy. Presentations and recordings from technical workshops and the group's speaker series are available here.

"It's about informing members but also about elevating the conversation," Brickhouse said. "We are pulling together the insights with gaps and research ideas from the feedback that we got in those sessions and putting it into a research roadmap. There are many questions to answer, but we already know that delivering the benefits of decarbonization to disadvantaged communities requires public and private partnerships and an unprecedented level of advanced planning, outreach, and smart program design."

To understand just how complex a task it is to leverage decarbonization as a tool to promote equity, just take the simple example of terminology. “Climate justice,” “affordable decarbonization,” and just “transition” are all used to describe efforts to advance the creation of a low-carbon society in ways that benefit historically marginalized communities. While efforts that fall under the umbrella of each term have some overlap, they also are distinct in other ways.

Plenty of other questions merit research, including the best ways to engage with communities, how to integrate equity and affordability into modeling, how to pursue community development with plant decommissioning, and how to use rate design and utility programs to drive equitable decarbonization. Another important question is how to transition workers who may be impacted when fossil fuel plants and other industrial facilities close down.

Beyond hosting information-sharing workshops and a speaker series, EPRI will seek to identify pressing research questions that utilities, communities, and other stakeholders in equitable decarbonization need to answer. Two helpful frameworks will guide EPRI’s research initiatives and the development of new tools to support equitable decarbonization: distributive justice, which is the fair allocation of resources, and procedural justice, which seeks fairness in the process of allocating resources.

Effectively identifying community members, finding the best ways to engage with them, and committing to a long-term two-way relationship are all necessary as utilities consider equitable decarbonization. “When we talk about equity, we are really talking about meaningful participation. So the concept of procedural justice is how you are bringing in communities early and often in the planning and decision-making process,” said Scott. “There are a lot of questions about tools. What do you do to actually get meaningful participation when oftentimes people in these communities have two to three jobs, they’ve got eldercare, and they’re responsible for children? Probably last on their list of things to do is to come to a meeting about how to plan the power system. But we must have their perspective. So what can we do to better engage these communities and truly understand their needs?”

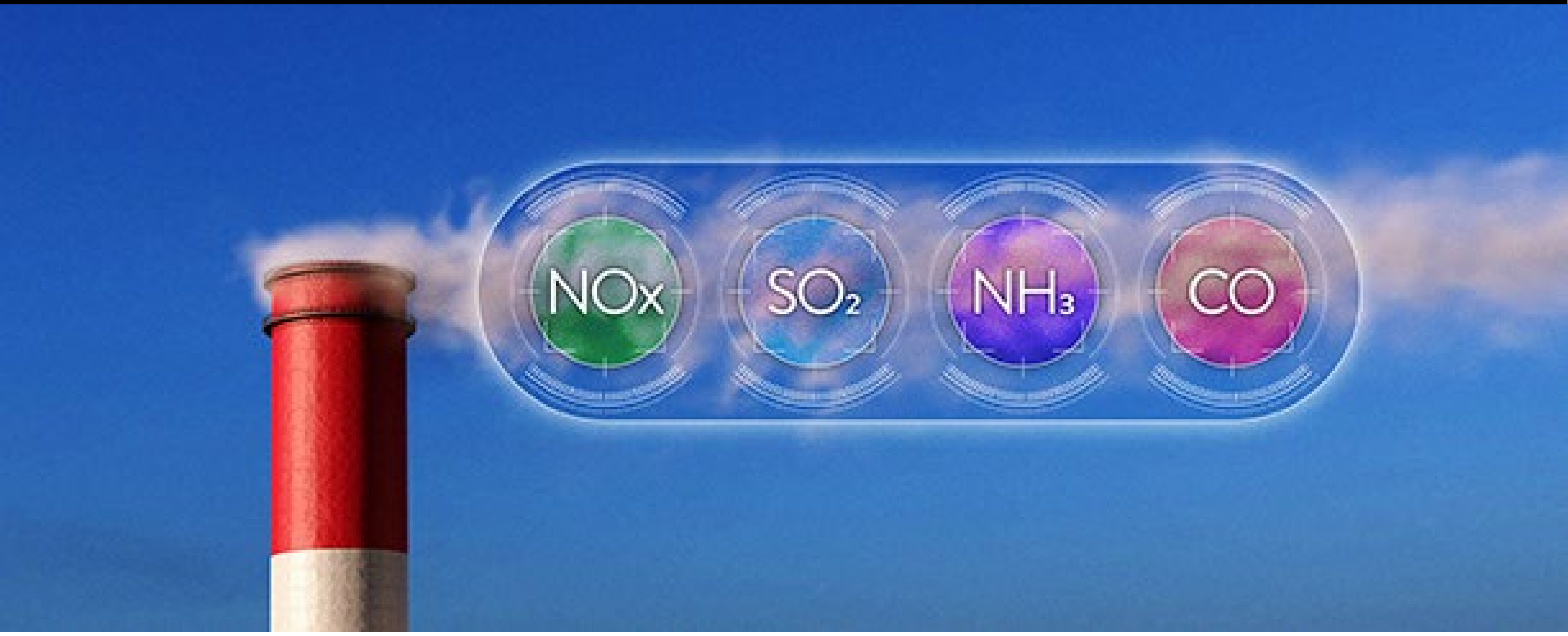
The fair allocation of resources also has plenty of nuances. For instance, some disadvantaged communities would not reap the sorts of benefits one might imagine from investments in solar unless investments in other infrastructure are made first. “Sometimes we can be well-meaning in our equity effort but miss the mark if we don’t include communities in the discussion early,” Scott said. “Why tell people about a solar system if they have a hole in their roof they need to fix? It’s important to be careful in designing programs to ensure they actually meet the need.”

For its part, FirstEnergy is developing its environmental justice program. Pickford says its efforts are grounded in a commitment to listening to communities and other stakeholders. “As our environmental justice program evolves, are we targeting the right people? Are we being inclusive?” Pickford said. “Ultimately, we will look for opportunities to incorporate their feedback into our process. Our goal is to have stakeholder engagement that proactively addresses environmental justice and equal access to opportunities that support decarbonization.”

One reason FirstEnergy joined the Equitable Decarbonization Interest Group was to avoid having to navigate this complex topic alone. “We want to do our part to have a low-carbon economy and consider equity wherever possible, but we can’t do that in a silo,” Pickford said. “We all need to share best practices and benefit from EPRI’s research. For these important issues, all of us are on the same team working towards the same goals.” Utilities across the world are working to ensure that all people and communities, regardless of race, national origin, or income, are afforded a voice in decision making.

EPRI TECHNICAL EXPERTS

Brenda Brickhouse, Morgan Scott



A Foundation for Future Emissions Monitoring Success

Three decades of emissions monitoring research help industry navigate new challenges

By Chris Warren

In 1990 the U.S. Congress amended the Clean Air Act to create the Environmental Protection Agency's (EPA's) Acid Rain Program. The program, which officially launched in 1995, was targeted at lowering the impacts of acid rain on human health as well as fish, wildlife, and entire ecosystems (a common consequence of acid rain was dying forests). To address those problems, the Acid Rain Program was designed to drastically reduce the power sector's emissions of sulfur dioxide (SO_2) and nitrogen oxides (NOx), which are the primary precursors of acid rain.

Fast-forward 30-plus years, and the effort to slash pollutants associated with acid rain is considered a big success. The cap-and-trade system that established market incentives and encouraged technology innovations has resulted in significant NOx and SO_2 emissions reductions.

For the past three decades, various other regulations have also required utilities to monitor and reduce emissions at natural gas- and coal-fired power plants. The most consequential EPA regulations include the Cross-State Air Pollution Rule and the Mercury and Air Toxics Standard (MATS). These regulations are designed to reduce smog, soot, and air toxics. They also establish monitoring and performance requirements related to everything from mercury to particulate matter, as well as hydrochloric acid in site-specific instances.

Two years after Congress established the Acid Rain Program, EPRI launched the Continuous Emissions Monitoring (CEM) Program, which became the Continuous Emissions Monitoring and Measurements Program last year. The ongoing EPRI initiative combines longstanding work by the generation sector with EPRI's environmental controls expertise.

HOW LARGER INDUSTRY TRENDS IMPACT EMISSIONS MONITORING

In recent years, the ability of utilities to accurately monitor and analyze emissions from their power plants has been shaped by larger industry trends. For example, power plant operators face the challenge of continuously changing and increasingly strict regulations. At the local level, limits on NOx, ammonia (NH_3), and carbon monoxide (CO) can require increasingly accurate gas turbine emissions measurements on the order of two parts per million.

Even as regulations tighten and the importance of accurate monitoring rises, many utilities are also navigating lower operations and maintenance (O&M) budgets and a wave of retirements by workers with expertise and experience. Indeed, a report issued by the U.S. Department of Energy (DOE) in 2017 forecast that a quarter of electric and gas utility workers in the country would retire by 2022.

The evolution of the power system is also changing the emphasis of CEM systems. According to the U.S. Energy Information Agency (EIA), nearly 30% of America's operating coal plants are set to be retired by 2035, a total of 59 gigawatts of capacity. Between 2011 and 2020, over 100 coal plants representing nearly 50 gigawatts of capacity either closed or converted to natural gas. "What keeps us busy is that regulations continue to change, and the industry portfolio also is changing due to low natural gas prices, increased pressure to scale renewables, and future planning based on accelerated decarbonization," said Cassie Shaban, an EPRI technical leader. "We continue to support coal plants with our research, but we have also added new gas-related topics to help members."

THREE DECADES OF RESEARCH INFORMING CEM IMPROVEMENTS

EPRI's ability to support a changing industry's capacity to cost-effectively comply with regulations while also providing objective research to inform regulatory changes is built on its long history of CEM achievements. In fact, many of the best practices and regulatory insights EPRI has collected over the past three decades can be found in the regularly updated Continuous Emissions Guidelines.

To better understand EPRI's ongoing role, it's helpful to know how CEM regulations work in the U.S. Unlike European regulators, which certify individual monitoring systems, the EPA gives plant operators some flexibility in the technologies they use to monitor emissions. "Instead of bringing a CEM system to a test facility, in the U.S., the EPA monitoring regulations have very prescribed initial certification, quality assurance, and quality control tests," Shaban said. In addition to federal regulations, some utilities are subject to state and local laws.

This means that EPRI works with a wide array of equipment manufacturers, utilities, and other stakeholders to improve the performance of CEM equipment so that it can consistently meet the EPA's quality assurance requirements. Common CEM systems include gaseous monitors, stack flow monitors, mercury CEM, and continuous particulate matter monitoring systems.

One area where EPRI has been especially active is developing, testing, and improving the calibration of particulate matter monitoring systems. Over the past decade, EPRI has worked with several equipment vendors to pilot an approach to calibrating these systems. These and other research efforts have also helped inform the EPA's approved calibration methodology.

For the operators of fossil fuel power plants, the calibration of particulate matter monitoring systems has been an expensive and time-consuming task. That's because the rules require them to change the concentration of particulate matter emissions to demonstrate that the monitor accurately tracks the change. "But to do that, you have to adjust the load of the plant or turn down whatever particulate matter capture device you have. But at the same time, you are not allowed to go over your emissions limit," Shaban said. It's a process that consumes a lot of time and typically involves bringing in contractors to help—an added expense for utilities. In response, EPRI developed an alternative calibration method that achieves compliance but does not require a plant to go offline.

EPRI has also helped drive technology improvements in mercury emissions monitoring. EPRI has worked with equipment manufacturers, utilities, and other stakeholders to test and demonstrate mercury sorbent trap monitoring systems and mercury continuous emission monitoring systems. Today, about two-thirds of emissions sources that are subject to MATS requirements for mercury use either continuous emissions monitoring or sorbent trap systems.

TECHNOLOGY DEVELOPMENT TO AID A CHANGING INDUSTRY

Recent EPRI research has been focused on ways to help utilities navigate smaller O&M budgets, a smaller number of experienced workers, and generation portfolios more heavily reliant on gas. Optical-based monitoring systems installed directly in a power plant's stack or ductwork—known as in situ installations—are one of the most promising new technologies.

In situ optical-based CEM systems have the potential to dramatically reduce CEM O&M costs by eliminating the need for a sample probe, heated umbilical sample line, and sample conditioning system, as well as reducing required service and consumables such as calibration gas. EPRI is currently demonstrating the application of optical-based CEM systems in both gas- and coal-fired plants for a range of species measurements.

While there are different optical-based measurement technologies, all rely on the basic fact that the amount of light a molecule absorbs is proportional to its concentration. Therefore absorption patterns can be used to identify a specific component. EPRI is currently pursuing demonstration projects to test different optical-based monitoring technologies.

In situ optical-based measurement systems could also be beneficial for selective catalytic reduction (SCR) process control of ammonia injection on gas-fired combustion turbine units that are operating flexibly in response to intermittent renewable generation. This is because in situ measurements provide a much faster response than extractive approaches. EPRI is looking to demonstrate the potential benefits of an in situ SCR process control approach in a supplemental project.

EPRI is also working to help lower O&M costs by helping utilities navigate end-of-life issues around their CEM systems, many of which have been in operation for decades. EPRI surveyed utilities last year to better understand how companies manage equipment life cycles, including whether they are opting to buy new equipment or maintain existing systems.

The survey found that 42% of utilities included CEM life cycle in their equipment replacement and maintenance strategy and that 58% have a lifespan plan for each CEM system. Other findings included the reasons utilities replaced criteria pollutant CEM systems: 33% did so because vendors no longer supported the system, 15% cited increasing maintenance demands, and 17% pointed to the difficulty in finding parts. EPRI is taking that feedback along with other research and insights to develop a best practice guide for managing aging equipment and spare parts.

To help utilities educate newer workers who are replacing experienced employees, EPRI has put a special emphasis on knowledge transfer. EPRI's CEM Interest Group conducts quarterly webcasts and hosts an annual conference where utilities can share their experiences and learn about new technologies. The 2022 CEM User Group Conference and Exhibit will be held in Indianapolis on May 11 and 12.

These knowledge-sharing events deliver real value to utilities grappling with similar issues. "The EPRI programs and Continuous Emissions Monitoring User Group [CEMUG] have always provided beneficial work to help solve emissions monitoring problems for us," said Wade Bice, the co-chair of EPRI's Continuous Emissions Measurement and Monitoring Program (Program 233) and a supervisor at Alabama Power Company. "They allow multiple utilities to gather together to discuss issues we face on a daily basis. And, where applicable, EPRI works as a central group to develop solutions that will benefit everyone involved. They help us stay current with cutting-edge technology and help determine whether or not a particular instrument or technology application is beneficial to the industry."

EPRI TECHNICAL EXPERTS

Cassie Shaban, Richard Himes

An Enduring Mission

As the Electric Power Research Institute (EPRI) marks its 50th anniversary, President and CEO Arshad Mansoor outlines a future vision that builds on past successes

By Chris Warren

The timing couldn't have been much worse. During rush hour on November 9, 1965, millions of New York commuters were on their way home from work and school when a massive power outage struck.

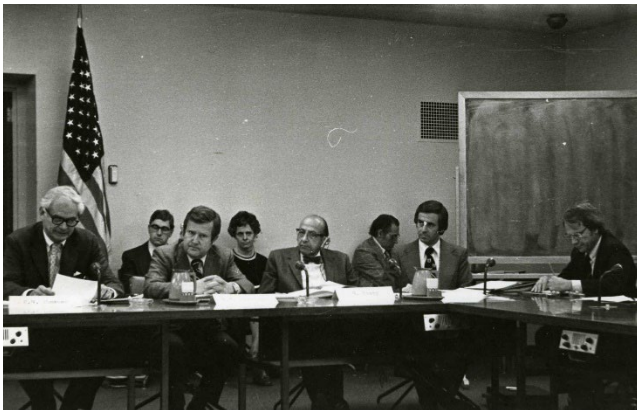
For a time, 850,000 New Yorkers were trapped in subway cars while countless others were stuck in buildings and elevators. "One moment, New York was glittering Gotham," a newsreel from the time proclaimed. "The next moment, only flickering candles, automobile headlights, and bobbing flashlights were probing a stygian darkness."

It wasn't only New Yorkers who found themselves suddenly flung into darkness. The transmission line near Ontario, Canada, that caused the cascading outage ultimately left 30 million people in eight Northeastern states and the provinces of Quebec and Ontario without power. Some people lacked power for as long as 13 hours.

OUT OF CRISIS, A SEARCH FOR ANSWERS

In many ways, the blackout was a revelation to the general public and policymakers about the fundamental importance of the electric power grid to the daily functioning of society. It was also a key step in the creation of EPRI 50 years ago.

In the years following what became known as the Great Northeast Blackout, more pointed questions about the resilience and importance of the grid were raised due to the 1967 war in the Middle East and the energy crisis that dominated the early 1970s. Eventually, it became clear that a collaborative, science-based research organization was needed to help inform utility decisions about technologies, planning, system maintenance, and the lengthy, evolving menu of topics energy companies must understand to serve society reliably.



EPRI IS BORN

The U.S. Congress acknowledged the need for research and development (R&D) to benefit both the electric power industry and the society it served when it proposed a new federal agency in 1971. In response, public and private utilities came together to recommend a private alternative, which ultimately resulted in the creation of EPRI in April of 1972.

Initially led by Chauncey Starr, a Manhattan Project veteran and the originator of the academic field of risk analysis (among many other accomplishments), EPRI began its research in earnest in 1973 when it took over R&D projects that had been managed by the Electric Research Council and the Edison Electric Institute.

Before EPRI was formed, Starr explained the role he envisioned for the new organization—a role that still sounds familiar today. "I had an almost idealistic objective," Starr recalled, when he was interviewed as part of a celebration on his 90th birthday. "Science and technology really ought to have a major social service. I am a committed believer that science and technology can make a tremendous difference in the quality of life of people."

Starr took on the leadership of EPRI under one condition: that EPRI's research would be independent and serve society at large. In that regard, little has changed during the past five decades.

A VISION OF EPRI'S FUTURE

EPRI President and CEO Arshad Mansoor reflected on what has changed (and what hasn't) about how the organization functions and how EPRI is uniquely positioned to lead the transition to a clean energy future.

Having worked at EPRI for nearly 16 years, Mansoor has experienced the many changes, challenges, and opportunities the energy industry is currently navigating. For example, in 2006, when Mansoor started working at EPRI, just over 9 gigawatts of solar photovoltaics (PV) were installed worldwide. In 2020, 133 gigawatts of solar were installed due to substantial cost reductions, increased manufacturing scale, and policy support. Data about wind generation, energy storage, electric vehicles, and other distributed energy resources (DER) tell a similar growth story.

Significant increases in zero-carbon variable generation resources—including DER—represent a paradigm shift from how utilities traditionally generate, transmit, and distribute electricity. At the same time, society is relying on electricity to play a crucial role in achieving global decarbonization goals announced by corporations and governments around the world.

The energy transition underway aligns with EPRI's core mission to be a research organization that collaborates with key stakeholders to conduct effective R&D programs for the benefit of society.

Recent examples include EPRI joining with the Gas Technology Institute in 2020 to launch the Low-Carbon Resources Initiative (LCRI) to advance low-carbon electricity generation technologies and chemical energy carriers, as well as EPRI's Integrated Grid initiative that explored pathways to maximize the benefits of both existing grid assets and newer DER—work that included research and modeling and dozens of pilot projects.

A NEED FOR INCREASED AGILITY AND COLLABORATION

While EPRI's research priorities evolve, the organization remains committed to approaching work the same way it has since its founding. "EPRI was created with a unique mission, the mission of using science, being the voice of science to ensure the safe, affordable, and reliable delivery of electricity to meet the needs of society," Mansoor said. "That vision has blossomed into an organization that works with 450 energy companies across 45 countries, that works with universities worldwide, national labs, and is making a difference in the way society uses, produces, and distributes energy."

But Mansoor also understands that EPRI needs to continue to evolve. "EPRI, just like any other organization, any other business, will need to be agile," he said. "In particular, that means being agile in understanding how markets, EPRI members, and societal expectations are evolving."

He noted that being attuned to and fully grasping all of those changes will impact the science-based research necessary to navigate a quickly evolving industry.

A big part of EPRI's future opportunities will involve working with a broader set of stakeholders. "The energy companies are not the only ones who are investing in clean energy today," Mansoor said. "Globally, governments are investing. States are investing. Countless entities now have clean energy as their key focus. We are now engaging with companies who will electrify their fleets like the U.S. Post Office and many other companies."

While each partnership and collaboration will be different, they will share the same fundamental goal. "We are partnering with energy companies so that industries and the transportation sector and others can have access to clean resources for their energy transition," Mansoor said. "Our future will be built on our foundation. Fifty years ago, what was true was that there needed to be a voice of science and technology that collaborates not just with energy companies but also with researchers worldwide. That is still true today. And that will remain true 50 years from now."

During the coming months, *EPRI Journal* will publish stories commemorating some of the major milestones and accomplishments EPRI has achieved in its half-century of existence.

EPRI JOURNAL

The Role of Thermal Storage in a Decarbonizing World

EPRI and the New York Power Authority explore low-cost, long-duration storage

By Chris Warren

The world is racing to achieve rapid decarbonization goals. Whether driven by entire countries like Denmark, Japan, and Canada or by cities or large corporations, the push to dramatically decrease or eliminate greenhouse gas emissions is accelerating.

A big part of the transition towards a net zero economy and society is an aggressive buildout of renewable energy generation, particularly wind and solar. For example, the International Energy Agency (IEA) recently reported that global additions of renewable power were expected to hit a record of almost 290 gigawatts in 2021. The IEA also forecast that stronger policy support and improving economics will increase renewable electricity capacity by more than 60% by 2026.

The challenge for countries, companies, utilities, and communities that increasingly rely on wind and solar electricity is keeping power flowing when the wind isn't blowing, and the sun isn't shining. "The need for decarbonized energy is becoming increasingly obvious. But renewable sources are intermittent," said Scott Hume, a principal technical leader at EPRI. "The way to have these resources become useful contributors to meet demand is to have substantial energy storage."

THE IMPORTANCE OF LONG-DURATION, LOW-COST STORAGE

The vast majority of energy storage today is supplied by pumped hydro. Increasingly, though, investments are pouring into battery energy storage, especially lithium-ion batteries. As a result, battery storage installations and future growth forecasts have spiked. For example, the U.S. Energy Information Administration (EIA) reported that systems providing 402 megawatts of small-scale battery storage and just over one gigawatt of large-scale battery storage were operational in the U.S. at the end of 2019.

The EIA forecasts that by 2023, an additional 10 gigawatts of large-scale batteries will be installed in the U.S., while global projections put the total market size for batteries by 2028 at nearly $27 billion. But while there are plenty of headlines about batteries and the important role they will play in the energy transition – both for storing electricity for use by the grid and for electric transportation – batteries alone aren't a sufficient solution for a decarbonized world.

Cost is one big reason a mixture of energy storage solutions is needed. Battery storage is growing at a robust rate because its costs have declined dramatically, with the National Renewable Energy Laboratory (NREL) showing a 13% drop in the price for utility-scale battery storage systems from 2020 to 2021. NREL also forecasts that battery prices will continue to decline, potentially dropping between 30% and 60% for a four-hour-duration battery system from 2020 to 2030.

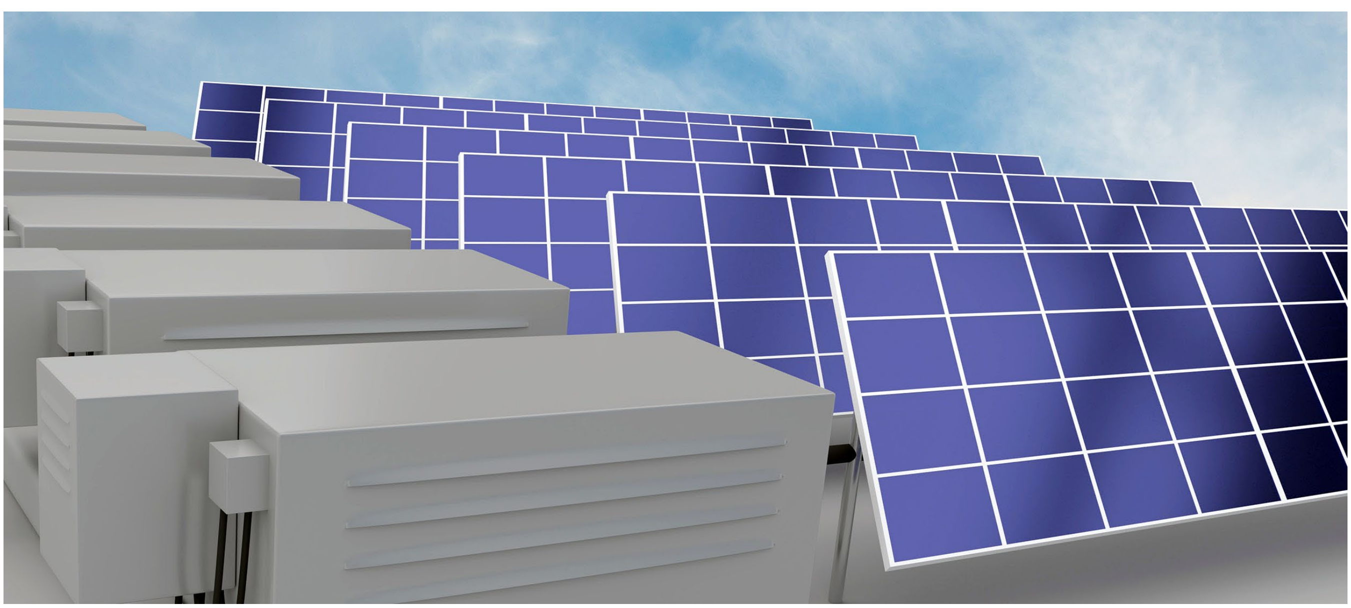
Despite that progress, future energy storage solutions will need to deliver energy for much longer durations and be far cheaper. This is why EPRI is collaborating with the U.S. Department of Energy (DOE) and utilities like New York Power Authority (NYPA), Southern Company, and Salt River Project to design, develop, and test thermal energy storage (TES) solutions.

"We are looking at energy storage solutions that have the potential to be substantially cheaper than electrochemical batteries and store large quantities of energy," said Horst Hack, an EPRI technical executive. "The grid of tomorrow is going to need storage that can provide energy for anywhere between eight and 40 hours, and it has to be very low cost. Which is why we are looking at storage technologies that use low-cost storage media, like sand, rocks, concrete, and other local materials that can be integrated with current fossil generation assets, as well as future renewable generation options."

EXPLORING THE POTENTIAL OF CRUSHED-ROCK THERMAL ENERGY STORAGE

A future *EPRI Journal* story will highlight research and demonstration initiatives focused on developing and testing TES systems using sand and concrete. In particular, EPRI is working with Southern Company and DOE to understand these storage technologies better.

Meanwhile, NYPA and EPRI are spearheading two projects focused on TES systems that utilize crushed rock as the storage medium. According to Alan Ettlinger, NYPA's director of research, technology development, and innovation, the utility is actively pursuing the projects to better understand TES because of New York State's Climate Leadership and Community Protection Act requirements. Signed into law in 2019, the act requires New York to reduce economy-wide greenhouse gas emissions 40% below 1990 levels by 2030 and 85% by 2050.



In support of those statewide objectives, NYPA developed a ten-year strategic plan called VISION2030, which, among other things, lays out a roadmap for decarbonizing the state's natural gas plants and partnering with customers to achieve clean energy objectives. Energy storage will have to play an increasingly important role in the state as intermittent wind and solar generation continue to grow.

Because of safety concerns and space constraints, NYPA understands that it can't rely on lithium-ion technology alone. "We are very interested in alternatives to lithium-ion technology because of the susceptibility of lithium-ion to thermal runaway and possible subsequent fire," Ettlinger said. "Getting to the scale of storage that you need is not going to happen by lining up 500,000 batteries. You need some kind of alternative technology, especially in New York City, where real estate is at such a high premium."

INTEGRATING STORAGE AT AN EXISTING NATURAL GAS POWER PLANT

Thanks to a grant provided by DOE, EPRI and NYPA are currently evaluating the feasibility of a pilot project that would integrate a TES system using crushed rock at NYPA's Zeltmann natural gas combined-cycle (NGCC) power plant in Astoria, New York. The Israeli-based company Brenmiller Energy initially developed the storage system named bGen. The design concept anticipates that the system that could ultimately be built as part of a pilot project would provide about four hours of storage or about 16 megawatt-hours.

The bGen TES system being evaluated for NYPA's natural gas plant has three components: a heat exchanger, crushed rocks to store heat, and a steam generator. One of its main benefits is very low cost – crushed rocks are inexpensive.

The storage system can be charged by heat (either flue gas or steam) produced at the combined-cycle plant, by electricity, or by a hybrid of the two. For example, high-temperature steam produced by the plant's turbine can be piped into the storage system, where its heat is stored in the crushed rocks. Alternatively, electricity can be used to power industrial heaters embedded in the crushed rocks to charge the system, either from renewable energy or from the power plant itself. This research has shown that a hybrid solution employing both steam and electrical charging provides the optimal integration with NGCC power plant applications. In either case, the Brenmiller TES system can then discharge the energy it has stored to power the plant's steam turbine to generate electricity.

The versatility in how the storage system is charged is important, particularly given how much variable renewable energy is being added to the grid in New York. "In many markets right now, there is a significant amount of variable renewable power generation, and there are times of the day when electricity prices are very low because of the mismatch between generation and electric demand," Hack said. "Electric prices are low or even negative in some areas, and if you can develop a system to capitalize on that, there are advantages, both financial and environmental." In the New York Independent System Operator market, the most financially advantageous time to produce electricity is in the evening hours.

Not only does this technology have the potential to increase revenues, but it also delivers much-needed flexibility to the grid – which will only become more important as the amount of intermittent renewable energy increases. There are also potential operational benefits for the existing natural gas power plants where TES is integrated. This is particularly true if the plants incorporate carbon capture and storage (CCS) technology. "If you have carbon capture on any fossil asset, coal or gas, you don't want to be ramping the gas plant up and down for demand purposes because the post-combustion carbon capture plant doesn't work efficiently if it's ramped up and down hourly," Hume said. "If we decarbonize with CCS, we will need storage to help levelize operation." Even where CCS is not present, ramping a coal or gas plant too often can damage or accelerate the degradation of the asset's equipment.

Other potential benefits of incorporating TES into a combined-cycle gas plant are faster starting time, a lower minimum load, and an increased maximum load. For example, at times when a gas plant is responding to peak demand, steam from the storage system can supplement steam produced by the plant's heat recovery steam generator. This can increase the thermal energy generated and up the plant's nominal capacity.

LESSONS LEARNED AT COMBINED HEAT AND POWER PROJECT

After the initial evaluation phase of the Zeltmann project is complete, a potential future step would be to actually integrate the system at the plant. This project would be five times larger than an existing 1.7-megawatt Brenmiller storage system located at a solar power plant in Israel.

Already, though, NYPA and Brenmiller Energy are in the process of commissioning a smaller Brenmiller TES system with a different use than that envisioned at Zeltmann. Instead of being integrated with an existing natural gas power plant, the storage system is being paired with a microturbine as part of a combined heat and power (CHP) system at the State University of New York (SUNY) at Purchase.

The project, which began in 2017 and was delayed along the way due to COVID-19, is being commissioned this month and was attractive to NYPA because of its hybrid features. “The CHP paired with the Brenmiller technology offers a level of efficiency improvement because of the stored energy,” said Steven Wilkie, a senior research and technology development engineer at NYPA. “You can store the heat and use it separately from the operation of the turbine or the limitations of recovered heat. Also, other technologies we were looking at, at the time, did not have the dual electric and thermal charging capability.”

Also attractive to NYPA was the modular configuration of the CHP and Brenmiller storage pairing. The microturbine being used is 200 kilowatts, and the storage capacity is 450 kilowatts/400 kilowatt-hours. “That could be scaled up with any size CHP,” Wilkie said.

Having reached the project’s commissioning phase, NYPA has learned several lessons that will help shape and improve its approach to future TES projects. One is simply that utility involvement is essential when it comes to integrating storage with existing or new assets. “With both batteries and energy storage, the main lesson we have learned is that there is a learning curve with technology providers in understanding the nuances of New York’s codes and installation issues,” Ettlinger said. “Almost without exception, we have had to provide assistance or oversight because we have experience with siting and integration and other issues.”

Other lessons learned are common to any advanced R&D project, including challenges with certification testing and the nationwide supply chain and personnel hurdles related to COVID-19. Nevertheless, NYPA believes the research is critical to advancing the storage technologies necessary to achieve the state’s decarbonizing objectives. “When the Climate Leadership and Community Protection Act came out, I was sitting next to our former CEO. And he said, ‘We don’t have the technology to reach those goals today,’” Ettlinger said.

Though the CEO's comment was specific to the situation in New York at the time, the reality is that the observation was true for the entire utility industry. As the world transitions to a larger proportion of variable generation, the need for advanced new storage technologies becomes more acute. That is why it's so important to continue pursuing thermal energy storage innovation and advances in New York and elsewhere. It's how technology can play a meaningful role in achieving ambitious decarbonization targets.

"I think thermal energy storage has a significant role to play in achieving those goals, and that requires advancements with the technology," Ettlinger said. "Every step forward is a step towards that end, and this is part of that effort."

EPRI TECHNICAL EXPERTS

Horst Hack, Scott Hume, Andrew Maxson

A Holistic View of Transmission System Resilience

The World Bank and EPRI partner with XM in Colombia to re-imagine resilience

By Chris Warren

Like many other power sector organizations around the globe, XM, the transmission system and market operator in Colombia, has been spending an increasing amount of time thinking about resilience.

It's hardly surprising that XM would view resilience as a pressing concern. Indeed, real-world events and trends have focused the attention of utilities, system operators like XM, policymakers, and regulators on the importance of resilience of the electricity system. In the U.S., for example, a recent EPRI analysis found that achieving net zero carbon emissions by 2050 could result in electricity's share of end-use energy consumption rising from 20% today to between 40 and 60%.

As electricity is more heavily relied on to power everything from transportation to buildings to heavy industry, extreme weather is also challenging those whose job it is to keep the grid up and running. According to the National Oceanic and Atmospheric Administration (NOAA), 2021 saw 20 weather and climate events that caused over $1 billion in damages, including the extreme cold in Texas that led to extended power outages, as well as one of the now-routine long, harsh wildfire seasons across the western U.S.

NO COMMON APPROACH TO RESILIENCE

But as much as circumstances compel electricity sector stakeholders to examine ways to improve resilience, no single approach will work for all geographies, markets, or power system configurations. Furthermore, decisions about the right policies and investments to improve resilience also have to take into consideration the risks represented by a range of threats, which include storms but also equipment failure, cyber attacks, and global pandemics.

"There are specific challenges to a power system in terms of the types of events that can occur, and that really depends on the utility," said Bob Entriken, a technical executive at EPRI. "The question is not just what kinds of events are important to consider for my location; it's also how much risk is acceptable. But if I ask that question, I assume I know the risk and can make a choice. But the answer is often that you don't actually know what the risk is."

In 2020 XM was in discussions with the World Bank about potential projects they could collaborate on to help improve the planning and operation of the system. The two organizations had already worked together on research about effectively integrating renewables, and XM was just beginning to grapple with resilience. "Resilience was a new topic for us in Colombia," said Carlos Mario Correa Posada, a specialist on planning operations at XM. "Back then, we had a view of resilience and thought it only applied to power system planning and operations regarding climate events."

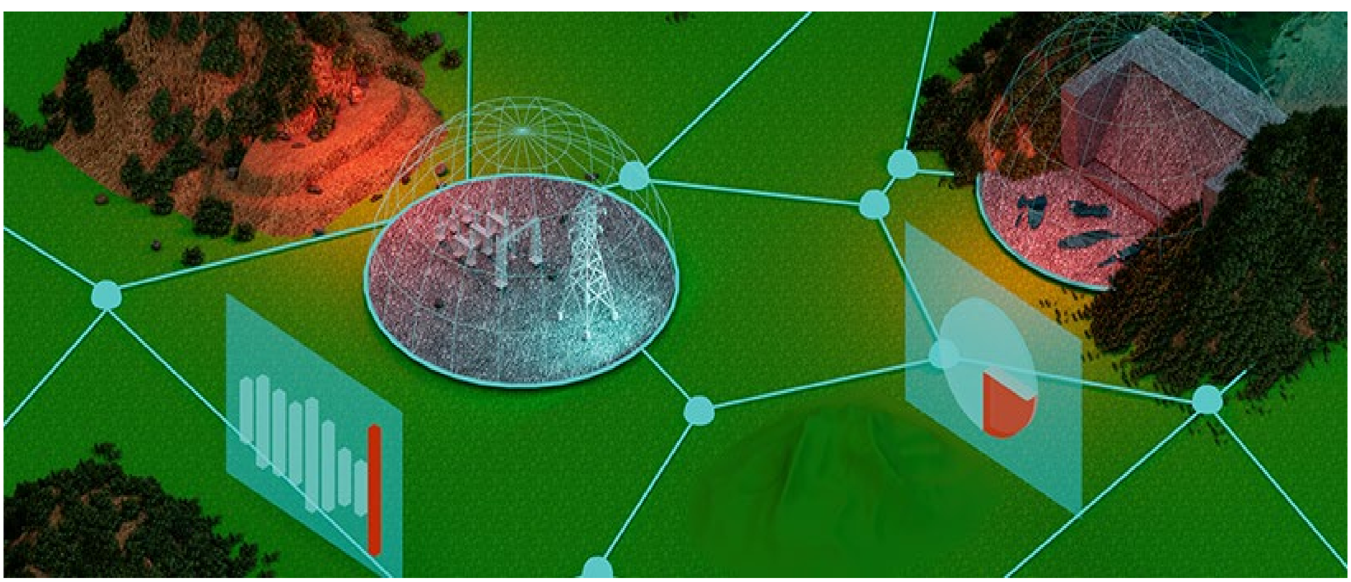
In fact, XM already performed grid simulations that could easily fall under the definition of resilience. For example, the system operator analyzed what would happen in the event of an extreme dry season—which could have a big impact because Colombia's grid relies on hydropower—or a terrorist attack leading to a dam closure. "There are some special events that we have studied before that can be categorized under resilience, but we were doing it more like special studies," Correa said. "We were not using a methodology, and we tried to adapt reliability tools and metrics to those particular studies. We wanted a state-of-the-art revision of our approach to resilience."

A MODEL FOR TRANSMISSION SYSTEM RESILIENCE

In response, EPRI, XM, and the World Bank teamed up to develop tools and approaches to both define and begin institutionalizing the system operator's approach to resilience. Because XM plays such a central role in the nation's power system, its efforts have a large influence on how utilities, government policymakers, regulators, and other energy sector stakeholders in Colombia approach resilience.

For XM, a key initial step was to determine the difference between reliability and resilience. Also important was to understand how to assess and monitor resilience, identify gaps in its understanding, and establish a resilience roadmap to guide its future activities.

At the start of the project, EPRI searched for any existing models or methodologies that would help guide a comprehensive approach to resilience. "It turns out that for their purposes, there was not much out there," Entriken said. But not long after the project began, EPRI worked with the North American Transmission Forum, the U.S. Department of Energy, and the Pacific Northwest National Laboratory to release the Transmission Resilience Maturity Model (TRMM), which exactly suited XM's needs.



helped XM to prioritize and coordinate the entire organization's resilience activities. "The idea of the maturity model is to start to be aware that resilience involves all these 20 things and then to begin working on it in the sense of finding the right people and starting to manage it," Entriken said. "And as you manage it, you get to the point where it's institutionalized instead of depending on a local expert who might leave his job or retire. It becomes documented and revised on a regular basis to become part of the organization and how it works."

To be more specific, the TRMM includes nine distinct domains, including everything from event response and recovery to resilience program management to supply chain and data exchange between organizations involved with resilience, such as first responders. Early in the project, EPRI and XM prioritized three of the TRMM domains according to XM's roles:

- **Situational awareness.** It is impossible to prepare for an event you haven't anticipated. Situational awareness is ultimately about being clear-eyed about vulnerabilities. "You need to be aware of the kinds of extreme events and phenomena that fit your geography," Entriken said. "You need to gauge how extreme they can be, and then you need to assess the impact they can have. XM pulled together an internal team to identify all the vulnerabilities in their system, not just extreme weather but cyber security and transmission and markets."
- **Risk identification, assessment, and management.** Situational awareness connects directly to risk management. With an ability to identify even high-impact, low-frequency events (such as a global pandemic), it's possible to estimate and quantify the possible effects on resilience and formulate steps to follow to address the risks.
- **Event response and recovery.** The utility industry has plenty of experience responding to power outages. But the nature of power system resilience today and into the future requires collaboration with a wide range of stakeholders outside the industry, including first responders and local business and government leaders. The TRMM provided XM with a way to identify resilience gaps and develop a roadmap for closing those gaps.

A CASE STUDY TO TEST THE MODEL

Understanding that there was a methodology to guide XM's resilience planning and preparation was an important conceptual step. But XM also wanted to test the methodology using a simulated event on the Colombian power grid model.

To do that, XM chose to simulate a landslide near a critical substation. The simulation allowed XM to analyze the likely effect of the landslide on equipment and the potential for it to result in cascading outages. The process of selecting the event to simulate was helpful in itself because it involved drawing in groups across XM to provide data and to collaborate about the possible impacts of the landslide on operations and markets.

"We established some templates in which people from different areas can answer some questions," said John Alexander Cardozo Duarte, an energy analyst at XM. "One challenge is how to go from the event to the power system impact and how to translate the same approach to an earthquake or a hurricane or some other event. But the case study was a way to test the methodology and be sure the tool was working properly."

One of the main benefits of the work required to complete the case study—and of the project overall—was to establish a common language and understanding of resilience. It also helped XM begin to establish metrics to track resilience efforts across the company. "The TRMM gives us a common perspective and a common metric to measure how the actions we take in our operations and in our daily work can help or hurt the resilience of the system," Correa said. "Now, it doesn't matter if you work in market operations or in the power system operations planning program, we can all measure our actions with specific questions. That is not something we even imagined before."

OUTREACH TO SHARE LESSONS ABOUT RESILIENCE

The message that resilience requires organizational collaboration has been shared throughout XM. After the project was completed, XM analysts and engineers were invited to participate in a workshop to learn more about the TRMM and to collaborate on developing a common resilience framework.

Correa and Entriken presented their findings to XM's CEO and board of directors, who have subsequently shared the results in their own discussions with external stakeholders.

Because resilience also requires collaboration with organizations outside of XM, the company has conducted outreach with industry and government officials. For example, Correa and Entriken delivered a presentation to Colombia's Ministry of Energy and regulatory board. "That was important because the ministry is working on a new power system resilience policy, and the regulator must start working on new regulations regarding resilience," Cardozo said. "The idea was to give them the holistic perspective when developing policy and regulations, and now they see us as a source of information and support as they work on policy and a regulatory framework."

Since the project was completed, XM has also launched a series of initiatives to continue making progress on resilience. One is the development of a roadmap to fill gaps identified during the project. In the realm of planning, for instance, XM is pursuing a more in-depth case study using the TRMM and the tools developed as part of the project. In operations, the company plans on holding restoration drills with transmission companies across the country and will work on improving its situational awareness. XM also plans to perform a TRMM evaluation of its markets to identify both gaps and a roadmap to address those gaps.

XM's approach to resilience will undoubtedly evolve. But for Correa, the two-year project with EPRI has provided an important framework and methodology that can be adapted and improved as vulnerabilities and solutions change. "With this project, we started at the beginning to identify what we had and what we didn't," Correa said. "The process we are now following in Colombia about resilience is the right one. It's a long road, but we are headed in the right direction."

THE INDUSTRY AT WORK

It's not just individual companies like XM focusing on this challenge. Last month, EPRI launched a three-year effort called Climate READi: Power (REsilience and ADaptation initiative), convening global thought leaders and industry stakeholders to develop a common framework to address this resilience challenge. The Climate READi framework embodies one of the most comprehensive, integrated approaches to physical climate risk assessment.

The Climate READi framework enables global energy companies, climate scientists, regulators, and other stakeholders to use these insights and assessments to address future power system challenges from extreme weather. At the same time, they continue the transition towards an affordable and reliable net-zero future.

EPRI TECHNICAL EXPERT

Robert Entriken

EPRI JOURNAL

Why Consistent Sampling Is Key to Solar Module Toxicity Testing

And why it matters to utilities and the solar industry's reputation

By Chris Warren

Although the forecasts vary, there is little doubt that solar will provide an increasingly large percentage of the electricity used around the world. According to the research and consultancy group Wood Mackenzie, solar accounted for 46% of all new U.S. electricity generating capacity added in 2021. In its Solar Futures Study issued last year, the U.S. Department of Energy laid out a roadmap for solar to produce at least 37% of America's electricity by 2035—up from around 3% today.

Regardless of the exact proportion of electricity provided by solar, it's clear that the volume of solar modules that will need to be recycled or disposed of in the future will increase dramatically. According to a report produced by the International Renewable Energy Agency and the International Energy Agency's Photovoltaic Power Systems Program, the cumulative volume of waste photovoltaic (PV) modules globally could reach 1.7 million metric tons by 2030 and over 60 million metric tons by 2050—an amount that would represent about 10% of current e-waste volumes.

Given the rapidly accelerating growth of solar installations, the fact that PV modules typically have a 20- to 30-year lifespan, and the accumulation by some owners of modules experiencing early failures, it's important for plant owners and utilities to rapidly develop science-based approaches to manage PV modules that have reached the end of their useful life. One important reason to do this is that failure to develop transparent and environmentally responsible methods for handling large volumes of PV modules threatens the reputation of clean energy.

"All technologies have benefits and challenges. The fact that there can be trace amounts of toxic elements in PV modules, even if small in mass, is something that needs to be dealt with," said Stephanie Shaw, a technical executive at EPRI whose research focuses on assessing and reducing the environmental and health impacts of energy generation and storage. "There is an inaccurate narrative that says that PV is not environmentally friendly because we are swapping the harm of fossil fuels for the harm of toxic or critical materials. But there are already options to recycle and reuse those materials before they need to be disposed. We need to improve those options, make them more cost-effective, and incorporate them into the normal environmental management processes for all types of solar PV projects."

A NEW STANDARD FOR SAMPLING PV MODULES

The recent release of an ASTM International standard practice represents an important step forward in providing a uniform and science-based approach to classifying solar modules for disposal. The practice is based on a standard operating procedure developed in EPRI projects, including *Assessing Variability in Toxicity Testing of Photovoltaic Modules*. More recently, EPRI and a number of utility and solar industry partners have collaborated on the supplemental project *Improving PV Sampling Methods for End-of-Life Leach Testing*. EPRI and the Photovoltaic Reliability Laboratory at Arizona State University (ASU) also presented *PV Module Toxicity Methods and Results: A Literature Review* at IEEE's 2022 Photovoltaic Specialists Conference (PVSC).

Co-led by Shaw and EPRI principal technical leader Cara Libby, this ongoing research began with the understanding that many PV modules contain hazardous materials, such as lead and cadmium. Both materials have the potential to leach into ground and surface water if they are not classified properly before being recycled or disposed of in a landfill.

Currently, PV modules in the United States have to pass the Toxicity Characteristic Leaching Procedure Test (TCLP) to be disposed of in a non-hazardous landfill. Modules that don't pass the TCLP are deemed hazardous waste and must be disposed of following far more stringent and expensive processes.

Photo courtesy Denver Waterjet

In the past, however, no uniform approach for extracting samples to be sent to TCLP labs existed. "EPA [Environmental Protection Agency] Method 1311 is the methodology used to determine how much material leaches out of an object ," Libby said. "Besides defining the maximum size and weight of the sample to be tested, it doesn't tell you how to obtain that sample. So you could take a drill or a saw or a hammer to cut pieces from the module laminate, include pieces of the aluminum frame or the electronics, or send the entire module to the TCLP lab and let them figure it out."

The result is that a sample from a crystalline silicon module could comprise only material with no lead, like pieces of aluminum frame and cell areas with little metallization. Using such a sample, a TCLP lab would deem the module non-hazardous. But another sample from the very same module – say, from the solar cell interconnect ribbon areas, where there typically are significant amounts of lead – could be designated as hazardous. "We said, 'There has to be a way to do this more consistently to avoid biasing the results,'" Libby said.

FINDING WAYS TO REDUCE VARIABILITY

Working with ASU and other partners, EPRI began developing a standard sampling protocol by first understanding why test results vary so much and then examining ways to improve their consistency. As a start, EPRI and its partners worked with ASU to send identical samples to a number of testing labs to see how much the results varied. Results were repeatable within the labs, but they were not replicable between different labs without clear and consistent instructions to not crush the samples further.

In the effort to reduce the variability in test results, researchers first used a diamond bit drill to extract samples from the module laminate. They learned that mechanical cutting methods could not achieve reasonable variability. "We saw huge variations, including the same module either passing or failing, depending on the sample extraction method," Libby said.

Instead of a drill, saw, or grinder, a water jet that shoots water at a very high force was used to cut samples from the modules. The improved precision of the water jet further reduced test variability because the pieces were less fragmented and cracked.

Perhaps the most important step in improving the consistency of test results was to preclude use of samples that are biased in terms of where they are collected within the module laminate. To do that, ASU came up with an approach that is now part of the ASTM standard. Samples include a total of about 100 grams of material from all four key sections of a module: the cell area, the cell ribbon area, the string ribbon area, and the non-cell and non-ribbon area.

The amount that comes from each area is proportional to that area's relative size and weight in the overall module. "ASU has a calculation so that proportional numbers of pieces from each of the key sections of the module represent the mass distribution in a real module," Shaw said. "Most of the sample is the cell."

DELIVERING CONSISTENCY AND CONFIDENCE

One potential benefit of the ASTM standard is its incorporation into procurement requirements when utilities source modules for solar installations. Facility owners already ask manufacturers for results of leach testing; now they can request use of the ASTM standard in collecting samples for the testing.

Consistent sampling can also lower risks and provide significant financial benefits at the end of a module's life. In the United States, responsibility for module end-of-life management typically rests with the PV plant owner. The plant can send a module to a water jet lab to extract samples, which are then sent to a TCLP lab.

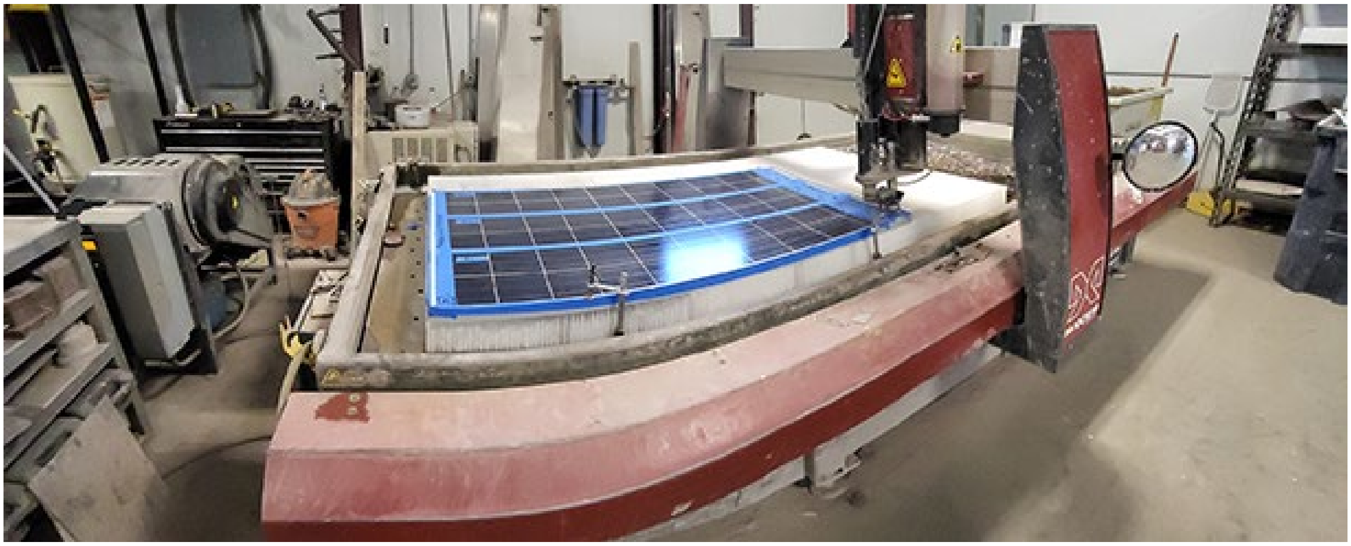


Photo courtesy Denver Waterjet

Given the costs of classifying a module as hazardous or non-hazardous, it's important to be certain that test results are precise. "If you put in the effort to get a sample, you want to make sure you can trust the results," Shaw said. "If you improperly classify a large volume of modules as non-hazardous based on inaccurate tests, you could face fines or have to retrieve modules from landfills. Or you could spend a lot of money treating them as hazardous when they actually aren't." Besides offering potential financial benefits and risk mitigation, the standard helps utilities achieve their environmental stewardship objectives.

For ConEd, a funder of the research that ultimately led to the standard practice, there are potential benefits for both its regulated and its non-regulated businesses. ConEd's Clean Energy Businesses owns and operates solar power plants across the country.

Most of ConEd's solar projects are early in their life cycle, and any modules that need to be taken out of operation are recycled. But John Oldi, manager of environmental programs for Clean Energy Businesses, says now is the time to establish processes and standards to consistently and transparently recycle or dispose of a large volume of solar modules at the end of their useful life. "From a regulatory and larger sustainability point of view, understanding the composition and risks associated with modules as a waste stream is important for me from an operational standpoint," Oldi said.

More specifically, Oldi said, ConEd could develop a protocol for sampling modules using the ASTM standard. Having a consistent approach to sampling modules for toxicity testing is also important to William Slade, project specialist for ConEd's Environment, Health and Safety division. "Waste management is the number one place of risk for the company's reputation and liabilities," Slade said. "Making sure we have the right answers about characterizing waste is important."

Another potential benefit of the research that led to the ASTM standard is to inform any potential state regulations about the disposal of modules. In a state like New York, this is particularly important. "New York is committed to a huge build-out of modules and farms, and research shows there is a big bump of waste as the modules reach the end of their lives," Slade said. "We hope we can provide good data to help if rules about disposal are developed so that regulations are workable and make sense for the industry."

EPRI's work in this area will continue. One area of focus is creation of a database of TCLP results from a variety of manufacturers and module types to help identify whether there are common characteristics that lead to a pass or fail determination.

Other questions require additional investigation and testing. For example, little is known about how weathering from environmental impacts like ultraviolet light exposure, temperature changes, and wind could change the leaching behavior of a module over time. "A plant owner might require a manufacturer to provide TCLP results at the beginning of a project," Libby said. "But 30 years later, when the modules are taken out of service, will the results still hold? We want to make sure cracks, backsheet tears, and corrosion from moisture ingress don't affect TCLP results. That is something we are hoping to test this year."

EPRI TECHNICAL EXPERTS

Cara Libby, Stephanie Shaw

Preparing the Power System for a Changing Climate

EPRI launches the Climate READi initiative

By Chris Warren

Chronicling extreme weather these days can be an exercise in the use of superlatives. The past seven years, for instance, have been the hottest in recorded history.

The extreme weather in 2021 included an extraordinary cold spell in Texas, known as Winter Storm Uri, which led to power outages that impacted 10 million people and contributed to over 200 deaths. Although not presently attributed to climate change, events like Winter Storm Uri demonstrate the need to consider and plan for the full range of climate conditions that could affect the electricity system in different locations.

Another example—more closely linked to climate change—was the heat dome that descended on the Pacific Northwest and broke records for all-time high temperatures in Seattle and Portland. The so-called whiplash effect of some weather extremes was also evident in 2021. In one instance, intense drought and wildfires spread across the western United States, even after California was hit by heavy rains and flooding in early 2021.

Overall, 2021 was a year of record-setting extreme weather events across the United States. According to the National Oceanic and Atmospheric Administration (NOAA), there were 20 individual weather and climate disasters whose overall losses exceeded $1 billion. In total, extreme weather across the country caused nearly 700 deaths and close to $150 billion in damages.

What were once accurately referred to as 1-in-50 or 1-in-100-year floods, droughts, or heatwaves may now occur more regularly or be more intense. Although many factors contribute to changing weather extremes, including natural climate variability, it is clear that the electric power system is increasingly exposed to multiple extreme weather and climate-related hazards that can produce severe consequences for customers if not adequately planned for.

This need is only exacerbated by society's growing dependence on electricity as a final energy source, driven in large part by decarbonization efforts. As a result, the industry needs to focus on proactively preparing the power system for the climate conditions of today and the future.

ACUTE AND CHRONIC CLIMATE-RELATED IMPACTS ON THE POWER SYSTEM

Increasingly frequent and severe extreme weather has been accompanied by more extensive power outages, underlining the need to examine power system preparedness in relation to current and future climate conditions. A recent Associated Press analysis of utility data submitted to the U.S. Department of Energy (DOE) found that the number of severe weather-related outages more than doubled from about 50 each year in the early 2000s to over 100 in each of the past five years. On average, U.S. customers experienced about eight hours of power outages in 2020.

The physical impacts of climate on the power system, and the potential changes associated with climate change, aren't limited to intense heatwaves, wildfires, and other extreme events—also known as acute climate impacts. More incremental, chronic climate impacts also pose challenges. For example, over the past few decades, unusually hot summer days have become more common across the contiguous 48 states, according to data from the U.S. Environmental Protection Agency (EPA).

Both acute and chronic climate impacts can have significant implications for the operation of a resilient and reliable electric power system. In fact, the challenges posed by a changing climate are increasingly apparent in all aspects of the power system, from generation to delivery to customer utilization, as well as power company operations, including planning, operations, and response to outages.

A COLLABORATIVE APPROACH TO POWER SYSTEM RESILIENCE AND ADAPTATION

In response to the need to prepare the power system against the effects of climate change, EPRI launched the Climate Resilience and Adaptation Initiative (Climate READi™) in April. The initiative is built on the understanding that the resilience of the electric power system requires unprecedented collaboration among utilities, regulators, policymakers, climate scientists, communities, and other stakeholders. It's also driven by the belief that adaptation and resilience investments must be responsive to unique local conditions and guided by technically rigorous and scientifically-informed insights that consider everything from worker health and safety to nature-based solutions.

"The motivation for this work is that we have observed changes in climate and understand that more change may be coming in the future," said Laura Fischer, a technical leader for climate resilience analysis at EPRI and technical lead for the Climate READi Workstream, Physical Climate Data, and Guidance. "The power system is affected by climate change and climate generally because it's a physical system exposed to weather-related hazards. The way the system is planned, designed, and operated has to be influenced by our understanding of current and changing weather and climate conditions."

Climate READi will leverage decades of research by EPRI, U.S. National Research Laboratories, the DOE, academic institutions, and others to create a comprehensive, industry-accepted framework to guide electricity system adaptation and resilience decisions and investments. Working collaboratively is a way to avoid duplicating research efforts and enhance transparency and confidence in the common framework.

The initiative currently has 17 members, including AES, Alliant Energy Corporation, Ameren Corporation, American Electric Power, Consolidated Edison Co. of New York, Exelon Corporation, National Grid PLC, New York Power Authority, Pacific Gas & Electric, Portland General Electric, PPL Corporation, Puget Sound Energy, Seattle City Light, Southern California Edison, Southern Company, Vistra, and WEC Energy Group.

The initiative will ultimately result in the creation of a series of Climate READi Power Guidebooks and other decision-support tools that will provide detailed guidance about how to implement different aspects of the framework.

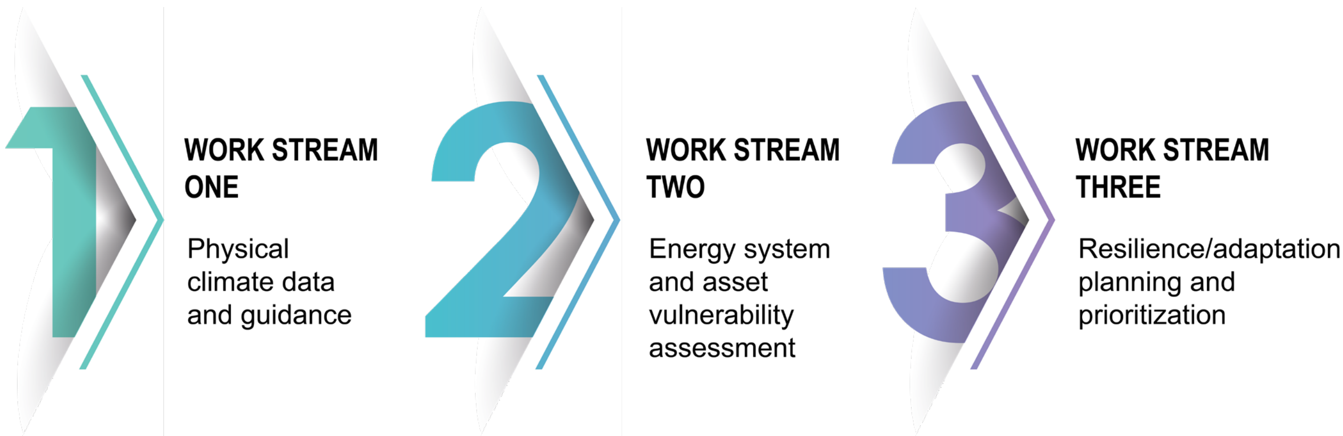
For example, the Climate READi framework will:

- Provide guidance on the specific climate and secondary physical data, datasets, variables, specifications, and interpretation needed to facilitate the assessment of a full range of power system-related applications. This includes characterizing how to treat the inherent uncertainty of climate and ecosystem modeling in power system applications.
- Deliver a consistent approach that power system stakeholders can use to apply climate-related information, including data about extreme weather and locationally specific climate data trends. This information can be used to analyze the potential vulnerability to chronic and acute climate impacts of individual assets and the system as a whole.
- Develop a common risk-based approach to prioritizing electricity system resilience and adaptation investments and decisions. It's impractical to expect that all new and existing electricity system assets can be made invulnerable to all climate impacts. The framework aims to build a cost-benefit analysis to evaluate and identify the adaptation investments that should be made to deliver an acceptable level of climate resiliency while also achieving other electricity system objectives, such as decarbonization, affordability, and equity.
- Provide stakeholders with confidence that the methods and approaches used in the framework are science-informed, technically rigorous, well-vetted, and consistently applied across the industry while still being flexible enough to account for regional differences in future climate trends and system configurations. At the same time, the framework seeks to understand the inherent uncertainty and limitations of methods and approaches so that the users of the guidebooks can be well informed when considering and prioritizing investments.

While Climate READi is focused on bolstering the resilience of the electricity system, the imperative of achieving that goal has much broader societal implications, as electricity is projected to meet greater energy demand in the future. Many states, for instance, have identified electrification as a key strategy for achieving emissions reduction goals.

According to the Clean Energy States Alliance, states from New York and Connecticut to New Mexico and California have set goals to achieve 100 percent carbon-free electricity by 2050 or sooner.

At the federal level, the Biden administration set a goal of decarbonizing the electric power sector by 2035 as part of a larger effort to reduce greenhouse gas emissions by 50 to 52% across the entire economy by 2030 and achieve net-zero emissions by 2050. As transportation, heating and cooling, industry and other sectors increasingly rely on electricity, society depends on the entire electricity system being prepared to withstand the impacts of a changing climate.



THREE CLIMATE READI WORK STREAMS

To develop a common and consistent framework to inform power system planning, operations, and investments, Climate READi includes three work streams. They are:

Physical climate data and guidance. Utilities have long made data-driven decisions to plan and operate their assets to maximize efficiency for their local conditions. Design choices for substations, power plants, and transmission and distribution lines have typically been based on a historical understanding of the local climate, including the occurrence of weather extremes. But as the understanding of trends in future climate variables and weather events improves, there is an opportunity for decisions to reflect that improvement. "We are focused on understanding the climate data requirements to make informed decisions about the physical risk to electricity systems or to make better investment decisions in the future," said Fischer.

Data on historical and current climate comes from both information collected at surface stations worldwide and reanalysis that combines observation data, including satellite measurements, with weather forecasting models to produce a more coherent picture of the past.

Forward-looking weather and climate data can be produced from near-term weather forecasting models or statistical extrapolations, as well as global climate models that simulate future decades to make projections about longer-term changes in variables such as temperature, precipitation, and wind speeds. Outputs from climate models can serve as inputs to secondary models to project future trends in other climate-related events like wildfire or drought.

Determining which data should be used in power system applications – and identifying data gaps—is not straightforward. This work stream seeks to identify relevant data that can be used to understand individual asset and power system vulnerabilities; it also will provide guidance about using the data in specific analysis contexts.

"It gets tricky because interpreting and consuming this vast world of climate data requires its own set of literacy skills," Fischer said. "One of the goals of this work is to provide guidance about how to apply the right climate data to specific circumstances. In the absence of uniform guidance that can be tailored to local conditions, companies are left to find their own way. That ends up being a heterogeneous approach where everyone has their own piecemeal solution."

Energy system and asset vulnerability assessment. The power system is made up of a vast collection of assets, from power plants and transmission lines to substations, feeders, and distribution lines. This work stream will apply the guidance on selecting and applying climate data produced in the first work stream to assets across the power system. The aim is to determine whether exposure to changes in chronic and acute climate hazards poses a substantial concern to their reliable operation.

"We are trying to build the tools and processes to assess the risks to assets based on their location and the climate data and modeling," said Brandon Delis, an EPRI director leading work stream two, along with colleague Jeffrey Thomas. This work stream will produce a probabilistic risk analysis methodology for analyzing asset vulnerability. This comprehensive approach for gauging risk includes an evaluation of what could go wrong, how likely it is that a specific problem could arise, and what the consequences would be.

Climate change can negatively impact power system assets in many potential ways. For example, a report by the DOE's Oak Ridge National Laboratory found that high ambient air temperatures can reduce the efficiency of thermal power plants and lower their overall generation capacity. Hydropower plants have reduced generation in the drought conditions that have settled over much of the western United States—in fact, every one-foot decline in Lake Mead results in a five- to six-megawatt loss of capacity at Hoover Dam.

The location and design criteria of individual plant assets also play an important role in their resilience to climate change. "In the power industry, climate models generally project a decrease in extreme cold events. But they don't project that they will disappear altogether," Delis said. "This is challenging for the power sector, particularly in places that historically don't experience much extreme cold. Even if these events happen less often, you still need to be prepared for them because their consequences can be catastrophic."

Delis says the first task of the work stream will be to collaboratively figure out what is already known about asset vulnerability and what still needs to be researched to close knowledge gaps.

Resilience/adaptation planning and prioritization. Improving the power system's resilience to weather extremes and more chronic impacts of climate change requires investment. But the reality is that budgets for those adaptation and mitigation investments are limited and must be targeted in ways that deliver the biggest and most equitable benefits to both the power system and society.

The aim of work stream three is to build on the climate data and asset vulnerability efforts to develop a framework to prioritize investments. "That framework will look at impacts across generation, transmission, distribution, and the customer to develop consistent ways to compare risk mitigation options and consider investments," said Anish Gaikwad, a program manager at EPRI who is heading up work stream three. "In addition to the power system, we will also look at societal impacts since you will have extreme climate events that will impact the health and safety of people, and we want to make sure the risk mitigation options are equitable."

Put another way, the framework to be developed will provide a cost-benefit analysis to guide investments to address the most concerning risks to both the power system and society. Many factors go into that prioritization. For example, imagine that climate modeling projects that the average number of extreme heat days in a certain location will increase. That increase could lead to a reduction in both generator output and transmission line capacity, reducing the amount of electricity that could be delivered to a community. At the same time, demand for air conditioning could spike.

Working through all those complex factors with a consistent framework is essential. It will help inform the work of the long-term system, resource, and transmission and distribution planners as well as utility decision makers and regulators.

The framework developed will also be useful in preparing for non-climate impacts. "The aim is to be able to also consider non-climate extreme events, like earthquakes, because at the end of the day, we want to be able to assess the range of impacts on the power system," Gaikwad said. "It also will consider other utility objectives around long-term reliability and decarbonization pathways. Climate change can't just be thought of in isolation from other utility objectives."

As Climate READi launched in April, many utilities have already signed up to participate, indicating the industry-wide recognition that action should be fast and collaborative. "It's incredible to see the momentum with which Climate READi is already moving. Proactively strengthening grid resilience against potential climate and weather impacts, now and in the future, will require unprecedented collaboration among the power sector and its stakeholders," said Arshad Mansoor, president and CEO of EPRI. "For years, utilities have done a great job of responding to extreme events—raising substations, installing concrete poles—but this framework will provide a consistent way to evaluate and prioritize proactive investments that can mitigate the risks of extreme weather and chronic climate change for the power system."

EPRI TECHNICAL EXPERTS

Morgan Scott, Laura Fischer, Brandon Delis, Anish Gaikwad

About EPRI

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

Together, we are shaping the future of energy.

3420 Hillview Avenue, Palo Alto, California 94304-1338 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com