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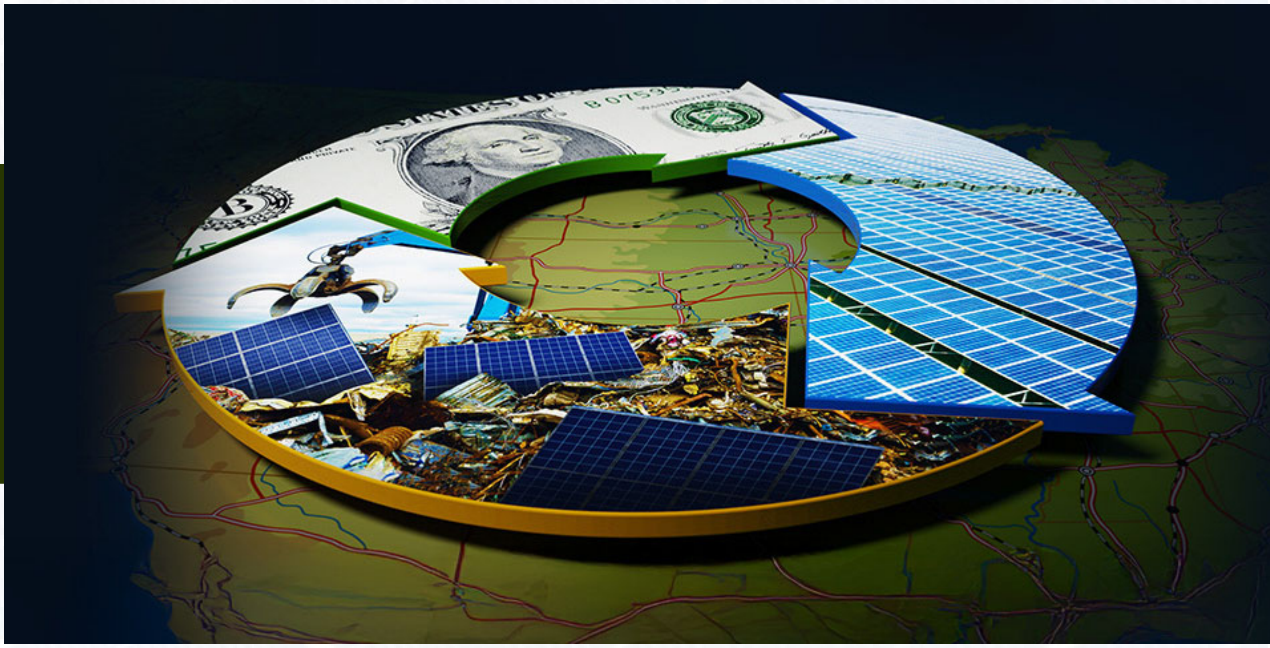
Building a Circular Economy for the Coming Wave of Solar Modules



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EPRI JOURNAL

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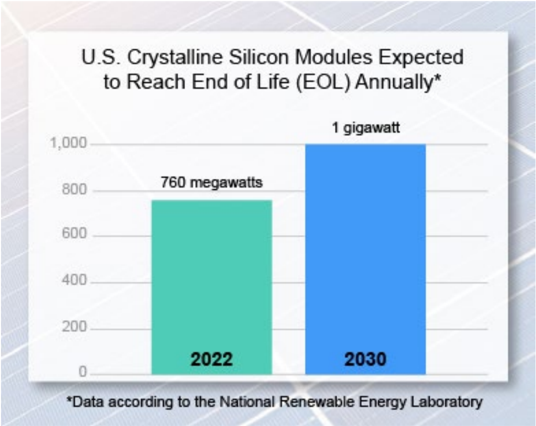
Building a Circular Economy for the Coming Wave of Solar Modules

By Chris Warren

This past February the U.S. Energy Information Administration (EIA) released its 2025 forecast of generation capacity it expected to see added to the U.S. power system in 2025. Overall, the EIA projected 63 gigawatts of new generation, an increase of 30 percent over 2024 and the most capacity installed in a year since 2002, when a weak economy, energy efficiency initiatives, and other factors dampened demand for electricity.

At 32.5 gigawatts, most of the new generation capacity forecast in 2025 is expected to be solar, totaling more than wind, natural gas, and battery storage combined. This is not a new story. The 30 gigawatts of solar added in 2024 represented over 60 percent of new capacity additions. Given the growing demand for electricity in the U.S. and around the world, the International Energy Agency (IEA) expects an additional 4,000 gigawatts of new solar to be installed globally between 2024 and 2030.

Regardless of the accuracy of these and other forecasts, the expanding market demand for solar underscores the need to plan for how to responsibly handle the increasing volumes of modules that reach the end of their expected operating life of 25 to 30 years (or need to be replaced due to damage, malfunction, or repowering). According to the National Renewable Energy Laboratory (NREL), about 760 megawatts of crystalline silicon modules in the U.S. were expected to reach their end of life (EOL) in 2022. By 2030, the number of modules forecast to reach EOL each year spikes to over one gigawatt, which is about five million 245-watt modules.



WHY UTILITIES CARE ABOUT WHAT HAPPENS TO PV MODULES

The large numbers of modules reaching EOL in coming years raise many questions for project owners, module manufacturers, regulators, policymakers, and utilities. For example, crystalline silicon modules and cadmium telluride (CdTe) thin-film modules usually contain trace amounts of the heavy metals lead (Pb) and cadmium (Cd), respectively. EPRI research shows that a small fraction of modules may qualify as hazardous waste under the U.S. Environmental Protection Agency's (EPA) Resource Conservation and Recovery Act (RCRA). A test to determine if a module is hazardous is typically required at EOL, and those that are deemed hazardous must be managed according to guidelines designed to protect human health and ecosystems.

Even when utilities don't own solar power plants, they may need to address liability concerns related to proper EOL module disposal or recycling. In the past, for instance, utilities have had to remediate many legacy environmental damages, and there is growing awareness about the potential for environmental issues related to the energy transition. Cara Libby, an EPRI Technical Executive whose research focuses on solar EOL management issues, also notes that utilities are owning and operating more solar assets, which is raising awareness about EOL management issues. "Utilities are starting to own more solar assets and are sometimes acquiring them midlife. They understand the need to deepen their knowledge and be prepared to manage end-of-life issues."

There is a growing recognition that managing EOL modules goes beyond mitigating potential liability risks or even promoting recycling. Instead, it's an opportunity to secure economic, environmental, and energy security benefits through the development of a circular economy.

A circular economy is one in which material loss to landfill or energy recovery is minimized, and usable materials re-enter manufacturing streams instead of being discarded. A circular economy can expand the environmental benefits of solar, including slashing its greenhouse gas emissions by as much as 50 percent while also preserving limited supplies of critical minerals, lowering the impact of mining raw

materials, and reducing PV's levelized cost of electricity (LCOE). A circular economy for solar modules also has supply chain benefits because it reduces reliance on products imported from overseas.

IS AMERICA READY?

PV circularity has the potential to deliver myriad benefits, but it also depends on having a sufficiently large and financially sustainable domestic ecosystem for manufacturing, repairing and refurbishing, reusing, and recycling PV modules. Assessing the current capacity, capabilities, and challenges faced by the repair, reuse, and recycling portion of that ecosystem was the objective of a report, *Review of End-of-Life Solar Photovoltaic Services in the United States*, released last year.

The report is based on information and data from 12 U.S. EOL service providers, 11 of whom completed an online questionnaire and seven who also participated in a one-hour interview with EPRI. Topics covered in the questionnaire and interviews included business focus areas, facility capacity, years of experience, types of modules accepted, recycling processes and repair services, as well as environmental accreditations and certifications. The study also identified research and development (R&D) gaps to guide future studies.

One of the main takeaways from the study is that the EOL industry in the U.S. is maturing and expanding. For instance, the combined recycling capacity of seven crystalline silicon module recyclers is enough to support NREL's prediction of the volume of EOL modules of that type through 2030. EOL service providers also indicated plans to expand capacity. Because EPRI received responses from 12 of the 27 U.S. EOL service providers contacted, the actual capacity may be larger.

However, there is some nuance in understanding available capacity. "Some of the capacity reported by recyclers may include capacity that they currently use to manage e-waste or automotive windshields, for example," Libby said. "It may not be dedicated capacity for solar that's just sitting idle."

Based on annual throughput for the same recyclers and NREL's estimate for EOL modules in 2022, EPRI estimates that the current U.S. recycling rate for PV modules is at least 10 to 12 percent. If CdTe modules, which represented 21 percent of PV installed in the U.S. in 2022, were included in the calculation, the overall recycling rate would likely be higher. That's because the largest CdTe manufacturer, First Solar, offers EOL module takeback and recycling services.

Another sign of maturity is that EOL service providers are generally able to handle trace amounts of Pb and Cd found in modules and that they collectively follow a similar process to recycle modules. It's a process that starts with removing the frame, junction box, and cables. The glass is then separated from the encapsulant and semiconductor layers of the module, typically by mechanical crushing and shredding but sometimes through delamination. Subsequent material separation may involve additional mechanical, thermal, optical, or chemical steps.

IMPROVING THE ECONOMICS OF CIRCULARITY

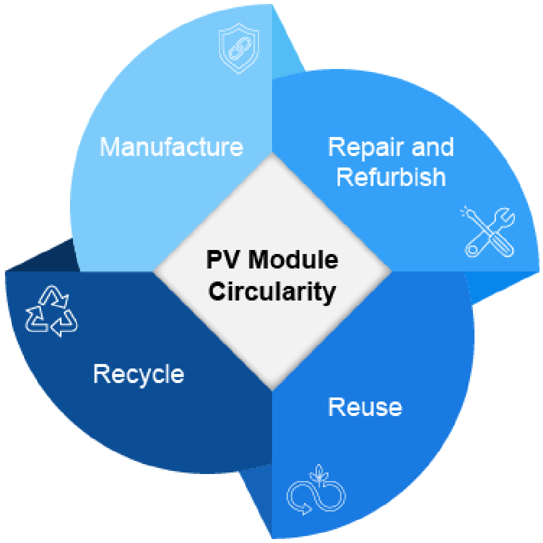
The reported growth in recycling capacity to handle the expected volume of modules reaching EOL matters. However, the EPRI report emphasizes that much more needs to be done to drive the widespread adoption of PV module recycling and other circularity measures. Making circularity financially attractive is crucial. As a start, the cost premium to recycle a module rather than landfill it must be overcome to encourage a greater recycling rate. According to the EOL service providers surveyed, in-house PV module recycling costs ranged from $14 to $30 per module in 2023, compared to between $1 and $5 to landfill the same module.

There are ways to drive recycling costs down, some of which are outside the control of EOL service providers. For instance, modules do not come in one standard size or configuration. So, while EOL service providers follow a standard process for disassembling modules, adjustments that slow the process down must be made to handle differing sizes. A similar uniformity in design could also help encourage module repair, which is environmentally superior to recycling.

But, encouraging design to facilitate repair and recycling is a challenge. "Manufacturers have spent years or even decades fine-tuning for efficiency and cost reduction, not for ease of repair or dismantling 30 years after a module is made," Libby said.

The promise of PV circularity—and circular economies generally—is that the modules or materials used in modules can be given second and third lives in new applications or products. This will only happen if market drivers, policy, or financial incentives are strong enough to encourage reuse and material recovery.

For many recyclers, a significant obstacle is extracting sufficiently pure materials to ensure their market value is financially attractive. Disassembled silicon-based solar modules produce glass, aluminum, polymers, silicon, and copper. "One way to advance circularity is to develop advanced recycling technologies that produce high-purity outputs. The revenue from selling those materials



into high-value markets can offset the costs of recycling, improving the overall economics," Libby said. "Right now, that is challenging because we are hearing from recyclers that the purity of recovered silicon is too low for high-value applications like silicon carbide, silicon nitride, or use again in solar products, which have very high purity requirements."

Policy changes and incentives encouraging recycling and circularity could help. Currently, about half of all states have decommissioning requirements; only a handful have PV recycling regulations. There are also few market signals to encourage PV module makers to use recycled materials and components or design modules that can be more easily recycled. Purchasers of modules could signal their support for recycling and circularity by requesting module makers provide products with certain sustainability attributes and encourage labeling to educate buyers about the use of recycled materials, reduced critical and hazardous material content, low carbon footprint, and other features.

THE NEED FOR COLLABORATIVE RESEARCH

There is growing interest among utilities, module manufacturers, project developers and owners, and EOL service providers in pushing PV circularity forward. First Solar, the world's largest producer of cadmium-telluride modules, is already recapturing the cadmium and tellurium from used modules to integrate into new products. Both First Solar and Qcells have registered products that meet Electronic Product Environmental Assessment Tool (EPEAT) ecolabel sustainability criteria. Partnerships are also forming between various project developers and recyclers.

Greater collaboration among stakeholders could accelerate the necessary shift towards PV circularity. EPRI is leading a series of ongoing research projects aimed at identifying knowledge gaps that limit PV circularity, developing solutions to make recycling and circularity more technically and financially viable, and enabling partnerships across the value chain.

These research projects, which benefit from the involvement of more utilities, manufacturers, developers, policymakers, and other stakeholders, are exploring a range of topics. For instance, EPRI is supporting the development of module repair and high-value recycling solutions, developing guidance on safe EOL management practices, estimating the costs of repowering and decommissioning, advancing technologies to accelerate module upcycling, and encouraging module manufacturers to make changes that bolster circularity.

Part of what is necessary is a shift away from the mindset that recycling is the only objective. Indeed, while recycling is a key component of circularity, there are financial and environmental benefits to having it as a last choice. "If you look at everything that circularity encompasses, there is a lot more than recycling," Libby said. "Recycling is what people think of when they hear circularity. But delaying recycling as long as possible by designing modules with long lifetimes and repairing and reusing modules will be a sign of real progress towards circularity."

EPRI TECHNICAL EXPERT

Cara Libby

EPRI JOURNAL

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Tackling Supply Chain Challenges with Advanced Manufacturing

By Chris Warren

A report released last year by the consultancy Wood Mackenzie underlined a very specific and tangible example of how a snarled supply chain can negatively impact the electric power industry. The report found that average lead times for transformers increased from 50 weeks in 2021 to 120 weeks last year. Large substation and generator step-up transformers have lead times ranging between 80 and 210 weeks.

The impact extends to the energy supply, where wait times are up from 1-4 years to now 5-7 years for gas-fired power generation turbines combined with some markets seeing cost increases up to 2.5X.

Supply chain risks, challenges, and consequences—particularly as a major contributor to inflation—have been the focus of intense analysis and debate since the COVID-19 pandemic. But what's important to keep in mind is that the supply chain for today's power generation equipment is well-established and includes plenty of eager buyers and suppliers.

That context is important when considering the supply chain challenges associated with a range of technologies like advanced nuclear reactors, bulk energy storage, concentrating solar power (CSP), and hydrogen production and turbines. This collection of advanced energy systems is increasingly important as the demand for electricity grows due to load growth from data centers, manufacturing, transportation, and other sectors.

©Adobe Stock: Gas turbine power plant

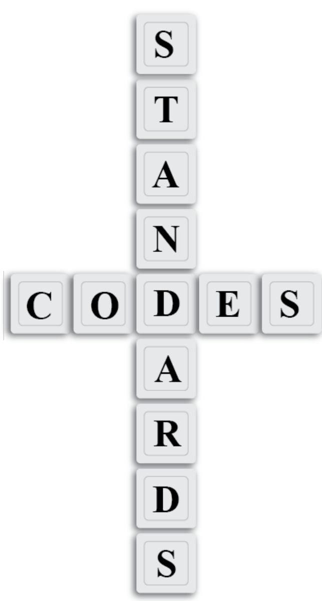
Yet, for a variety of reasons, the ability to leverage these advanced energy systems is inhibited by the lack of a reliable supply chain able to produce and deliver essential equipment and components in sufficiently large quantities and in a timely manner. If anything, supply chain risks are only escalating. Tariffs, ongoing shipping bottlenecks, international conflict, global competition from other industries, and the prospect of future pandemics all underscore the risks of relying solely on sprawling transnational supply chains.

The inescapable truth is that North America and other developed nations lack the resilient local supply chains needed to mitigate these risks. One big reason is the absence of foundational manufacturing capacity to meet the demand of a rapidly growing industry. “There are a limited number of casting and forging factories,” said John Shingledecker, an EPRI principal technical executive. “We haven’t been building a lot of stuff in the Western world, so you’re constrained, or you are beholden to shipping it from overseas, which has its own risks.”

THE NEED FOR INNOVATIVE SOLUTIONS

Traditional solutions to supply chain challenges are often expensive and slow. For example, dramatically expanding forging and casting capacity in the U.S. would require billions in investment. Manufacturers are understandably leery about making large investments without plentiful orders from customers, and financial support from the government to kickstart capacity expansion is always a question mark. “It takes hundreds of millions of dollars to build a new manufacturing facility,” Shingledecker said. “Even if you want to build the biggest forges in the world, nobody is going to do that without a big market signal and usually a lot of checks.”

Building a reliable supply chain for advanced energy systems demands thinking differently. Advanced manufacturing, an umbrella term that encompasses methods such as additive manufacturing, powder-metallurgy hot isostatic pressing, and advanced welding and cladding processes, has the potential to complement existing manufacturing capacity to supply advanced energy system projects. “It’s really something that the United States is a leader in,” Shingledecker said, noting its use in the aerospace and defense industries. “There’s an opportunity for the energy industry not to replace castings and forgings but to broaden the ability to make more things quicker.”



A COLLABORATIVE FORUM

Leveraging the potential of advanced manufacturing in the energy industry won’t be achieved by any single company. To kickstart the innovative thinking needed to address energy industry supply chain constraints, EPRI launched the Advanced Manufacturing Methods and Materials (AM3) initiative in 2022. A five-year effort, AM3 seeks to pursue the potential of several advanced manufacturing methods to support traditional manufacturing’s capacity to meet the demand from SMRs, bulk energy storage, and other advanced energy systems.

Since its launch, AM3 has hosted three supply chain workshops that have attracted over 120 organizations—including everyone from manufacturers to developers, utilities, and companies already pursuing advanced manufacturing—and initiated many new research and development (R&D) projects to build foundational data and skills advanced manufacturing requires and to accelerate its adoption. Research initiatives and the ecosystem of potential partners are necessarily wide-ranging because so many things need to be accomplished to begin leveraging advanced manufacturing’s capacity to deliver the materials and products advanced energy systems require.

For example, the codes and standards that have been used to guide the mass production of the materials and components of much of the power system were formulated decades ago. Evolving codes and standards to cover advanced manufacturing requires an enormous amount of collaborative data collection and testing, and it’s a necessary first step.

"The data required to change the code is often more than was originally required to implement the technology in the first place," Shingledecker said. "But the codes and standards are critical because they are the vehicle by which you can get industry acceptance and adoption. You have to get that done, or it's pretty much a non-starter. Suppliers need codes and standards approvals to understand what will be accepted and to drive consistency and scale across the industry."

EPRI is leading efforts to address challenges around the acceptance of codes and standards. For instance, EPRI launched the Advanced Reactor Materials Initiative (ARMI) to develop and deploy new and existing materials for advanced non-light water reactors, and the Advanced Reactor Roadmap outlines 46 actions that are necessary to support the deployment of a future nuclear fleet.

Whether it's innovative new reactors or other advanced energy systems, part of building a robust supply chain is qualifying materials. For instance, only six materials are qualified in ASME Section III Division 5 for high-temperature advanced reactors. Recent qualification efforts have shown that it can take up to a decade of testing and as much as $20 million to qualify a material, especially for nuclear applications and any material that will be exposed to high temperatures.

Global test campaigns are underway for some candidate materials. However, for progress to accelerate as quickly as needed, tests need to be better coordinated to produce the enormous amount of data needed to support ASME code qualification. A coordinated test program with a framework for sharing resources and accessible data will speed ASME codes and standards qualification of new materials without the need to rely on government funding, which has historically been the approach.

INCORPORATING ADVANCED MANUFACTURING INTO DEMONSTRATION PROJECTS

Another strategy to pursue is to pair technology pilots with advanced manufacturing. Currently, pilot projects must rely on existing supply chains and materials because they must be built relatively quickly. This limits the materials and processes that can be used. "Everything they use has to be off the shelf because they're under the gun on timeframe," Shingledecker said. "They will use a stainless steel 316 vessel or some other traditional component that will last the lifetime of the demonstration. But they would rather use a new alloy. They also will use a casting or forging that is fine for a one-off project but will run into supply chain problems if you want to make four or five."

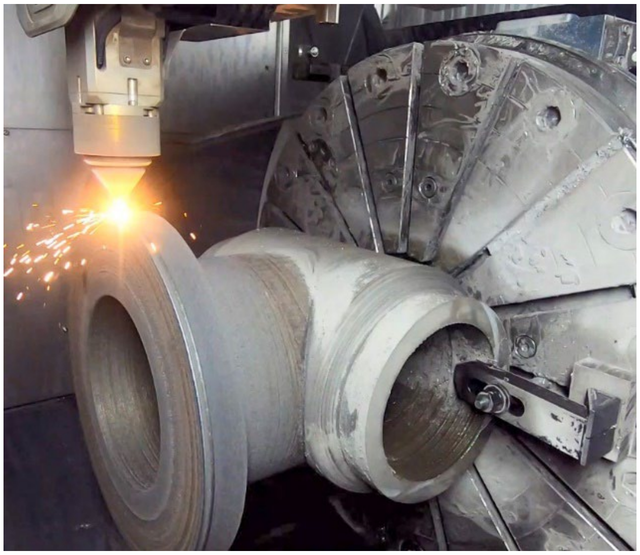
An alternative approach could allow for parallel processes where components are built using both traditional forging and casting and advanced manufacturing. The lessons and data could then be used to help modernize codes and standards, which helps build a more robust supply chain.

Part of building a more reliable supply chain for advanced energy systems involves expanding the overall ecosystem of suppliers. In the UK, the Fit for Nuclear (F4N) initiative was developed by the Nuclear Advanced Manufacturing Research Centre (NAMRC) to help companies that have not supplied the industry determine their readiness to meet the high safety, operational, and quality standards. Action plans, gap analysis, and other resources are provided to help companies meet the rigorous qualifications. After the first AM3 workshop, EPRI launched a pilot F4N in the U.S. to guide companies on initial steps and highlight the need to modernize nuclear quality assurance by focusing on product quality and leveraging risk-informed programs.

TVA EMBRACES ADDITIVE MANUFACTURING

There is nothing abstract about Curt Jawdy's experience with supply chain bottlenecks. Jawdy is senior manager of operational research and support at Tennessee Valley Authority (TVA), and his colleagues' angst about how long it took to get components compelled him to act. "COVID really bit into the supply chain. Things that used to take three months to get now take two years," Jawdy said. "I just got tired of listening to people stress about the supply chain, and I'm just trying to push us along the line of greater speed."

Jawdy toured the Oak Ridge National Laboratory to see the lab's additive manufacturing research, and about a year-and-a-half ago, TV bought its first metal printer. The printer is beginning to augment TVA's traditional machining capability, which includes one of the largest metal lathes in the nation. "We can do



©EPRI: 3D Additive DED Printer

some very high-quality and very large machining, but where we see problems is in casting parts," Jawdy said. "Many manufacturers have offshored casting, and that is becoming a big problem."

Jawdy hopes that additive manufacturing can help address that challenge. TVA is still qualifying and learning more about the printer it purchased but is preparing to print some small production parts. At least initially, printing will refurbish and improve valves that the utility would previously have replaced with new valves. "You mill off the worn area, print new material, and then mill it back down," Jawdy said. "It's all about saving time and money because we can do these operations cost-effectively."

TVA's experience with its first printer has been sufficiently successful and yielded enough lessons that the utility already ordered and expects to take delivery of a much larger printer, the AML3D Arcemy X, this summer. The Arcemy X has industrial-grade welding capabilities and can print a 20,000-pound part. One of the learnings TVA will apply to its new printer is to start as early as possible on qualifying materials. "For us to meet codes, we have to do test prints and qualify those test prints with TVA welding specialists and metallurgists witnessing them," Jawdy said. With the AML3D printer, TVA is qualifying four materials and will be sending personnel to witness test prints at AML3D's facility in Ohio.

Once qualified and delivered, TVA plans to print a bearing housing replacement for a pump at one of its nuclear facilities. EPRI is working with TVA staff to create this part as a pathbreaker to lay down procedures, making future part printing much quicker. TVA is also hoping to use its new printer to produce a pintle, the large hinge used for doors holding back water in hydropower facilities.

Jawdy hopes other utilities will join TVA's and EPRI's efforts to pursue the potential of advanced manufacturing. "There are a lot of opportunities for collaboration," he said. "No single organization can do everything, and as an industry, we need to push for speed."

EPRI TECHNICAL EXPERT

John Shingledecker

EPRI JOURNAL

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The Electric Power Pollinator Award: Five Years of Lessons from Award-Winning Projects

By Chris Warren

Jessica Fox noticed who *wasn't* represented when she attended the 2019 North American Pollinator Protection Campaign (NAPPC) conference in Washington, DC. NAPPC's mission is to promote the health of pollinators—like bees, birds, butterflies, bats, and insects—which are now known to be directly linked to essential nutrients needed by humans through the fruits and vegetables they pollinate.

The conference featured an awards ceremony recognizing people and organizations that had taken meaningful and lasting action to conserve pollinator habitat—winners included ranchers and farmers, roadside management organizations, and policy and educational advocates. Fox didn't see any electric utilities. And she knew from her nearly two decades of work across EPRI's environmental research that electric power companies were supporting pollinators.

"In 2019, we were just over a year into building our Power-in-Pollinator Initiative. I could see what the companies were doing, and some were doing a lot or ramping up programs," said Fox, an EPRI principal technical executive. "But there was no recognition of those efforts, and frankly, the companies were not telling their conservation stories." The electric power industry was not engaged in NAPPC or National Pollinator Week.

Photo courtesy Jessica Fox, EPRI

Fox approached the NAPPC board of directors and proposed the Pollinator Electric Power Award, which was later launched by NAPPC and EPRI in 2020. "If we were going to do the award, it had to be based on science and rigor," Fox said. "We spent a lot of time developing the scoring rubric to make sure it was unbiased, comprehensive, and scientifically based. NAPPC also forms an anonymous expert review committee every year, which has helped improve the process. It has only gotten more rigorous and competitive in the five years since it started." Since 2020, nearly 30 outstanding projects have been nominated, and five winners have been selected.

MORE THAN AN AWARD

While the award is an opportunity to celebrate energy projects that have started and maintained effective programs to support pollinators, the goal has always been much bigger. The award is a tool to build internal and external support for pollinator conservation. The application process is an opportunity to evaluate the performance of pollinator initiatives and make changes to both improve the chance of a future winning project and, more importantly, increase the beneficial impact on pollinators.

In other words, the existence of the award has ripple effects that extend well beyond the winning projects. "You see the winners, but what you don't see are all the applications and other people who are inspired to apply! The winning projects are examples that others can point to and say, 'Look at what these other companies are doing,' Fox said. "We now have this award category backed by consistent criteria, and all these stories and photos create inspiration and show how this connects to corporate strategy and risk management."

Five years of awards has also created a coterie of past winners who have experiences and lessons to share about what goes into developing an effective pollinator project. A sampling of winning projects is shown on the following page.

American Electric Power (AEP)

Photos courtesy AEP

American Electric Power (AEP) won the inaugural Pollinator Electric Power Award in 2020 for its work studying the substitution of native vegetation for traditional grasses to establish prairie habitat on typical transmission line corridors. The project included the development of native seed mixes meant to attract pollinators and reduce vegetation management costs.

Bonneville Power Administration (BPA)

Photos courtesy BPA

Bonneville Power Administration (BPA) earned the 2023 award for its collaborative project in Portland, Oregon's 5,200-acre Forest Park, the largest urban park in America. The project established 67 acres of pollinator habitat along BPA's transmission system corridor through the park. The project involved planting 250 pounds of native wildflower and grass seed mixes in 2018 and adding about 6,000 native shrubs like the Red-flowering currant and Willow in early 2019.

Tennessee Valley Authority (TVA)

Photo courtesy TVA

Tennessee Valley Authority (TVA) is the most recent award winner in 2024 for its work introducing pollinator habitat to land around the Douglas Dam Reservation along the French Broad River. The project was launched in 2016 and driven by a desire to improve views of the dam and river, which were obstructed by overgrown vegetation. Following a phased approach, the project has since added native vegetation such as Purple Coneflowers, Butterfly milkweed, and switchgrass to about 69 acres at the site.

Photo courtesy BPA

MANY LESSONS LEARNED

These projects provide myriad lessons about conceiving, launching, implementing, and maintaining pollinator-benefiting habitat. *EPRI Journal* spoke with several award winners, who shared their takeaways about everything from building project support to working with partners to embracing ambitious goals. Following is some of their advice.

Forge strong relationships and trust. Long before Himalayan blackberry and Scotch broom were removed to make way for native wildflowers and grasses in Portland's Forest Park, BPA had to do a different kind of cultivation to lay the groundwork for a successful project. BPA's past management of transmission rights of way through the park created mistrust with the city before the project began. "There was a lack of communication, hurt feelings, and anger among folks from the city managing Forest Park and previous BPA natural resource specialists," said Nancy Wittpenn, an environmental protection specialist at BPA.

The job of repairing those relationships fell to Chris Morse, a supervisory natural resource specialist at BPA. That outreach was especially important to the success of the Forest Park project because three different institutions—BPA, the city of Portland, and Metro, a regional governmental agency—each had distinct roles in preparing, planting, and sustaining the pollinator habitat.

Robust, consistent, and trust-filled communication about project responsibilities and goals was a necessity. Metro provided funding and expert input from botanists. BPA handled prep work before the plantings by incorporating it into regular vegetation maintenance, and the city helped develop and implement a long-term vegetation management plan and spearheaded pollinator education with trailside signage. "One of the biggest successes of the project was collaboration," Wittpenn said.

A key driver of strong communication and collaboration is positioning pollinator habitat to complement other utility goals. TVA had that in mind when the utility began developing an enterprise-wide biodiversity policy in 2021. "The idea was to garner internal support and recognition and acknowledgment of the value of biodiversity beyond compliance and listed species regulatory drivers," said Holly Hoyle, manager in biological compliance at TVA. "There are opportunities where biodiversity and pollinator protection are complementary to operational and institutional goals."

For example, environmental stewardship is one of the three key pillars outlined in the Tennessee Valley Authority Act of 1933 that established the utility (energy production and economic development are the others). Ensuring public access to the nearly 300,000 acres of land and 11,000 miles of shoreline, TVA manages is one way to pursue the mission. At the Douglas Dam, removing vegetation that obstructed the public's view and replacing it with pollinator habitat helps improve the public's enjoyment of the land while enhancing natural resource conservation. "Local, site-specific actions to establish pollinator habitat add up to significant change," said Heather Hart, senior specialist in natural resource management at TVA.

Photo courtesy TVA

"We tried to pick an area that is highly visible to the public. And the dam observation area at Douglas was a great place to do that because people go up to the top of that ridge anyway just to look at the lake and the dam," Hoyle said. "Then right below it, you've got this huge expanse of areas where we've enhanced the habitat with the native and warm season grasses and the pollinator-friendly flowers."

Be prepared to make a business case. Fostering strong internal relationships and trust is every bit as important as tending to external partners. Tim Lohner learned throughout his career in natural resources at AEP to keep an eye on the bottom line.

Lohner understood that getting the attention and support of people responsible for transmission system vegetation management budgets meant focusing on the financial benefits of pollinator-friendly habitat. "We made the business case," Lohner said. "Native vegetation is more drought tolerant; it's more flood tolerant; there's less erosion. And if you do it right, there will be fewer trees to manage." A compelling business case often requires education, including how the pollinator habitat is complementary to cost-saving and risk management.

Good preparation has long-term benefits. A common challenge all winning projects faced was vegetation removal before pollinator-friendly seeds could be planted. For TVA, that began with a well-developed integrated vegetation management plan. "Preparation is a big thing. You need to make sure you get as much of those unwanted plants or undesired vegetation under good control before you start moving forward with planting," Hart said. "One of the biggest lessons learned is that if you don't have the site preparation down pat, you're going to be fighting weeds and other undesirable vegetation that make it harder for the pollinator plants to get established."

Tim Lohner, AEP

Rigorous prep work adds initial costs to adding pollinator habitat. But it also lays a foundation for longer-term maintenance savings. "You don't have to mow as often, and you aren't going to have to use herbicide as much," said Suzanne Fisher, senior program manager in environment and sustainability at TVA.

Take full advantage of the excitement for the project. Pollinator projects are unique. They are visually beautiful. The stories behind their inception, development, and, most importantly, beneficial impacts are compelling. All these ingredients build enthusiasm for pollinator projects both within the utility and among customers. Take advantage of that enthusiasm to build support and momentum for pollinator-supporting initiatives.

Tim Lohner remembers the enthusiasm of corporate communications partners who were eager to tell the story and employees who were already doing their small part to support pollinators. "I think companies will find there are lots of people who raise honeybees, want to protect the monarch, or plant natives on their own," Lohner said. "One of our transmission vice presidents raised honeybees."

One reason TVA applied for the Pollinator Electric Power Award was because it provided opportunities—through webcasts, internal communications, and informal conversations—to talk about the value of pollinator protection. "It provides us an opportunity to speak to people internally and externally," Holly said. "We wanted to apply for the award to create materials and some recognition to be able to go out and talk about it. I think this will be helpful with us moving forward and engaging with our internal business units and project managers on the operational front."

The internal and external recognition award-winning projects receive can be used to increase pollinator protection ambition. At BPA, Wittpenn says the Forest Park project established a model to follow for future projects. "Now we work with Metro on replicating the project in other areas on rights of way," Wittpenn said. For example, BPA is working with Metro to create a pollinator-friendly habitat on a transmission right of way along the Willamette River.

If anything, Morse wonders if they should have been more ambitious with the Forest Park project. There was natural trepidation going into the project, Morse recalls. "If I knew how successful it was going to be, it makes me wonder if we should have gone bigger and done more," Morse said. "But the fact that we created this model and these relationships will help accomplish more in the future."

New energy projects can equal more pollinator protection. Fuel source transitions and load growth have focused energy companies on the need to build new transmission lines and energy generation sites. This is an opportunity to catalyze more pollinator habitat creation, argues AEP's Lohner.

In fact, pointing to past successes protecting pollinators can help get projects permitted. "As we build new infrastructure in different communities, municipalities are going to want us, as an industry, to do things for wildlife," Lohner said. "And if you have an example where you've done it before, you can use that to say, we can do this for you, too."

The Pollinator Electric Power Award is beneficial to projects that don't win and to projects that may apply in the future. Projects can measure themselves against the award's rigorous evaluation criteria—a process that illuminates strengths and areas of improvement. "People who haven't even applied yet can look at the scoring rubric and use it to inform how they set up their projects now to apply for the award years from now. The existence of this award is inspiring companies and people to think bigger about their land management programs," Fox said.

EPRI TECHNICAL EXPERT

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EPRI JOURNAL

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Location, Location, Location

How EPRI guides for siting power plants and for selecting the optimal technology help nuclear power reach its potential

By Chris Warren

It's challenging to get dozens of nations to agree on much of anything today. Yet at the 2023 Conference of the Parties (COP) gathering in the United Arab Emirates, 25 countries committed to work together to triple nuclear power capacity by 2050. At the 2024 COP in Azerbaijan, another six nations joined the United States, Canada, France, Japan, and the United Kingdom in their declaration to ramp up global nuclear capacity.

In the United States, support for nuclear power is a rare point of bipartisan agreement. The Biden administration's Bipartisan Infrastructure Law and Inflation Reduction Act provided billions of dollars to extend the life of existing nuclear power plants and to accelerate advanced reactors and other advanced nuclear technologies. The Trump administration recently released four executive orders designed to speed the deployment of advanced nuclear technologies.

The motivations to scale nuclear power are varied. For example, some advocates for nuclear energy point to its ability to deliver around-the-clock, carbon-free electricity that can complement variable renewable sources. Others focus more on its role in reliably delivering electricity as demand soars, especially from the data centers needed to power artificial intelligence (AI) applications. Indeed, analysis by the U.S. Department of Energy's (DOE) Lawrence Berkeley National Laboratory (LBNL) concluded that data center load growth tripled between 2014 and 2024 and was expected to double or triple again by 2028. An EPRI report released last year found that data centers could consume between 4.6 percent and 9.1 percent of annual electricity generation by 2030.

There are many reasons to believe that a nuclear resurgence is happening and accelerating, both to meet demand and to replace capacity from retiring coal and gas plants. However, for nuclear power to triple in capacity and be positioned to meet growing energy demand, there is a basic challenge: Every new plant needs a site, and choosing that site is one of the most consequential decisions in the life of any project. It's also a decision that is far from straightforward. Indeed, in today's environment, siting decisions are exceptionally complex because many reactor technologies are new, regulatory frameworks are evolving, and stakeholder expectations are higher than ever.

"We're at a critical moment. There's real momentum behind nuclear again. But to meet these ambitious targets, we need smarter, faster ways to evaluate both where to build and what to build," said Chad Boyer, Senior Principal Technical Leader, EPRI's Advanced Nuclear Technology (ANT) Program

WHY A NEW GENERATION OF TECHNOLOGIES BRINGS SITING CHALLENGES AND OPPORTUNITIES

The past decade has seen the rise of advanced reactor designs. These technologies promise to be more scalable and more flexible than traditional gigawatt-scale reactors. The Nuclear Energy Agency (NEA) reports that 56 commercial Advanced reactor (ARs) designs are in various stages of development in 17 nations around the world. Advanced reactors are frequently also referred to as Small Modular Reactors (SMRs), especially outside of the United States.

While attracting significant investment, these first-of-a-kind projects face challenges: cost containment, regulatory approval, supply chain readiness, and crucially, siting. "Advanced reactors have changed the conversation," Boyer said. "They enable siting in places that wouldn't have been feasible for large reactors—closer to load, at brownfield industrial sites, or in water-constrained areas. But they also require a new way of thinking about how and where we build." ARs also bring the promise of standardized designs and factory fabrication, both of which can support faster deployment and potentially lower costs. However, these benefits can only be realized if the early steps—technology selection and siting—are done thoughtfully.

A Guide for Siting

Recognizing the complexity of modern nuclear siting—and the critical importance of getting it right—EPRI released the *Site Selection and Evaluation Criteria for New Nuclear Energy Generation Facilities* in 2022, an update to EPRI's longstanding siting guide. The guide outlines a multi-step process designed to help utilities move from broad regional considerations to an approach appropriate for identifying specific sites.

The initial step involves defining a region of interest based on business objectives, grid needs, and the availability of infrastructure. This is followed by the identification of candidate areas, where basic exclusionary criteria such as flood risk, seismic hazards, and protected lands are applied. From there, utilities assess potential sites within those areas based on more nuanced criteria like constructability, stakeholder acceptance, and transmission access. Detailed screening and scoring help determine a proposed and an alternative site, providing a foundation for license applications and long-term development.

The 2022 update to the guide reflects a dramatically different landscape for nuclear. It integrates considerations for small and advanced reactors, including reduced emergency planning zones and compatibility with sites that lack abundant water. Social and economic concerns are also embedded in the methodology, recognizing the importance of trust and community support. New technologies offer promise, but they come with unknowns that the guide helps navigate.

"The process is scalable and adaptable," Boyer explained. "It doesn't prescribe a perfect site—it gives you the tools to make consistent, transparent, and justifiable decisions."

In addition to helping organizations select among potential sites, the guide also serves to coordinate internal teams and external stakeholders. It maps the flow of decision-making over time, guiding collaboration among engineering, environmental, public affairs, permitting, and real estate teams. This integrated approach is critical, particularly as timelines for nuclear development tighten and the need for predictability grows more acute.

The guide also seeks to proactively address future priorities. This includes providing recommendations for long-term data management and project documentation. Addressing data management and documentation early ensures that information gathered during siting activities remains accessible for future licensing work, thereby minimizing duplication and improving project continuity.

Scaling Siting for the Challenges Ahead

While advanced reactors expand the list of feasible sites, they don't necessarily reduce the number of variables involved. Advanced cooling technologies, for instance, allow nuclear plants to function with less water. However, those systems can also introduce additional costs and complexity. In regions like the U.S. Southwest, utilities must consider not just scarcity but legal water rights and inter-basin transfers.

Meanwhile, the process of interconnecting new generation to the grid has become increasingly difficult. Lengthy interconnection queues and regulatory bottlenecks make existing access to transmission lines an especially valuable site feature.

Advanced reactors also bring unique siting concerns. Some designs rely on new fuels or novel reactor geometries, which can trigger unfamiliar permitting hurdles. The EPRI guide takes these factors into account, helping provide a reality check of how new reactor designs fit real-world site conditions.

Additionally, siting must consider the social license to operate—an increasingly important factor for projects involving emerging technologies. Communities want assurance that their voices are heard and their concerns addressed. The EPRI guide incorporates community engagement strategies that align with best practices in public participation and trust-building. "The footprint is smaller, but that doesn't mean the process is simpler," Boyer said.

Choosing a Technology

To complement the Siting Guide, EPRI also published the *Owner-Operator Reactor Technology Assessment Guide*. The technology guide helps utilities avoid the high cost of misaligning their operational goals and their technology choices. The guide lays out a six-step approach to technology assessments. First, the utility must define its mission and business objectives, a step that is often glossed over. From there, a long list of reactor types is reviewed and winnowed based on technical and regulatory compatibility. Vendor-specific designs are then assessed against detailed criteria, including cost, constructability, licensing pathway, fuel cycle compatibility, and more.

"Too often, people chase the shiny object," Boyer said. "They hear about a new design and want to evaluate it. But we tell them: Start with your mission. Do you need firm power in a remote region? Flexible output to support renewables? That'll guide your decisions."

The technology guide also encourages utilities to create go/no-go screening thresholds that eliminate incompatible designs early in the process. Those remaining are ranked based on how well they align with the utility's stated objectives, allowing for a manageable shortlist.

The guide doesn't just deliver rankings; it establishes an institutional record that can support decision-making over time. With many nuclear projects taking years to develop, the rationale behind key decisions can easily be lost. EPRI's approach builds traceability into the process, ensuring continuity even if staff or leadership changes.

By following the guide's recommendations, utilities can also improve their ability to communicate with regulators and financial stakeholders. A well-documented decision process builds confidence in the choices being made and supports the case for investment.

REAL-WORLD USE AT SRP AND BRUCE POWER

Utilities across North America are using EPRI's siting and technology assessment guides. Salt River Project (SRP), the Arizona-based public power utility, is relying on both documents to evaluate the potential for deploying advanced nuclear technology in its resource portfolio. According to Barbara Cenalmor Bruquetas, senior resource development project manager at SRP, the guides provided a disciplined approach to exploring options without locking the utility into any single technology or site.

SRP began its evaluation with a focus on a brownfield location. The site under consideration is home to a coal plant and still holds valuable water rights and grid interconnection capacity. Cenalmor Bruquetas explained that the Siting Guide helped SRP evaluate not only the technical feasibility of the site—including cooling requirements and seismic resilience—but also the softer dimensions like environmental justice and public perception.

In parallel, the utility drew on the Technology Assessment Guide to navigate a growing universe of AR designs. SRP had clear priorities: minimal water consumption, scalability, operational flexibility, and alignment with desert conditions. The guide offered a structure for aligning those goals with existing and emerging vendor offerings. While SRP has not finalized its technology selection, the process has significantly narrowed the field and clarified what questions to ask. Cenalmor Bruquetas emphasized that the technology guide helped SRP consider future readiness, including how different designs might scale over time and how they might be affected by fuel availability and evolving regulations.

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"We're not selecting a vendor yet," Cenalmor Bruquetas said. "But the guide is helping us narrow the field and understand what technologies might realistically serve our long-term resource mix."

At Bruce Power in Ontario, where the existing nuclear infrastructure already supports large-scale operations, the emphasis has been more squarely on technology selection. Andrew Brooks, an Engineering Manager at Bruce Power, said the utility is considering the addition of up to 4,800 MWe of new nuclear on its existing site and how these reactors might complement the older units over time. The Technology Assessment Guide helped the company systematically screen options based on maturity, licensing readiness, and alignment with operational needs.

Brooks noted that early conversations around advanced nuclear often focus on potential rather than practicality. The guide's insistence on defining clear goals at the outset was critical for Bruce Power's process. Instead of investing time in a broad survey of unvetted designs, the utility created a focused shortlist of technologies that met specific performance, safety, and regulatory benchmarks. From there, the team engaged in deeper conversations with vendors to understand timelines, fuel strategies, and integration requirements. The guide also gave them tools to ask better questions about supply chain maturity, the ability to support a multi-decade lifecycle, and the all-important discussions about cost, schedule, and risk.

"It gave structure to a messy process," Brooks said. "And it helped us communicate internally with planning, operations, and leadership."

In both cases, the utilities used the guides not only to improve internal coordination but also to prepare more thoroughly for eventual public and regulatory scrutiny. In an era where stakeholders demand transparency and justification, these frameworks help utilities demonstrate due diligence.

CAN BETTER DECISIONS DRIVE FASTER PROGRESS?

While siting and technology selection don't guarantee project success, they lay the foundation for it. EPRI's tools are helping utilities make defensible decisions that avoid costly missteps. Utilities are no longer approaching these projects as one-off pilot efforts, but rather as critical components of long-term resource strategies.

"We've seen projects stall because the technology didn't meet the owner's needs," Boyer said. "These tools are about avoiding those false starts."

For Cenalmor Bruquetas, the process is key for creating a roadmap for SRP's future options.

"Even if we don't build tomorrow, we're preparing now," she said. "And these guides have been invaluable in shaping our strategy."

The same is true at Bruce Power. "We're better prepared to have meaningful conversations with technology providers, with regulators, and with our communities," Brooks said. "That preparation will help us accelerate once we're ready to build."

EPRI TECHNICAL EXPERTS

Chad Boyer

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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