POWER

NEWS & TECHNOLOGY FOR THE GLOBAL ENERGY INDUSTRY SINCE 1882

www.powermag.com

Vol. 169 • No. 6 • June 2025 Special Report

ENERGY TRANSITION

SPECIAL REPORT

Page 4

Access Intelligence

POWER

Established 1882 • Vol. 169 • No. 6 June 2025 Special Report

www.powermag.com

ON THE COVER

Renewable energy continues to grow as an increasing share of new power generation, while traditional energy sources face numerous challenges. The power sector is clearly in a transition period where established industries and emerging technologies work toward a balanced and resilient energy future. *Source: POWER*

FIND THE LATEST POWER NEWS AT POWERMAG.COM

- Transitioning to a Cleaner Energy Future Without Sacrificing Reliability
- Industry Experts Say Storage, Renewables, Transmission Key Parts of 2025 Energy Outlook
- Microgrids with Hydrogen: Supporting Energy Systems for the 21st Century
- Trump Energy Policy Changes Signal Major Industry Shifts in 2025 and Beyond
- Making Clean Energy Credits Count: What the IRA Means for Your Bottom Line
- Going Nuclear: Why AI Will Lead the Next Energy Transition
- Factors Impacting the Transition to Carbon-Free Energy
- The Role of Carbon Capture in Power Generation: Economic, Environmental, and Technological Insights
- Geothermal Energy Growing as Renewable Energy Resource

POWER

NEWS & TECHNOLOGY FOR THE GLOBAL ENERGY INDUSTRY SINCE 1882

Visit POWER on the web: www.powermag.com
Subscribe online at: www.powermag.com/membership

POWER (ISSN 0032-5929) is published monthly, 9 times print and digital, 3 times digital only, by Access Intelligence, LLC, 9211 Corporate Blvd., 4th Floor, Rockville, MD 20850-3245. Periodicals Postage Paid at Rockville, MD 20850-4024 and at additional mailing offices.

Postmaster: Send address changes to POWER, 9211 Corporate Blvd., 4th Floor, Rockville, MD 20850. Phone: 800-777-5006, Fax: 301-309-3847, email: clientservices@accessintel.com.

Canadian Post 40612608. Return Undeliverable Canadian Addresses to: IMEX Global Solutions, P.O. BOX 25542, London, ON N6C 6B2.

Subscriptions: Available at no charge only for qualified executives and engineering and supervisory personnel in electric utilities, independent generating companies, consulting engineering firms, process industries, and other manufacturing industries. Subscription request must include subscriber name, title, and company name. For specific pricing based on location, please contact Client Services, clientservices@accessintel.com, Phone: 1-800-777-5006. For new or renewal orders,call 847-501-7541. Single copy price: $59. The publisher reserves the right to accept or reject any order. Allow four to twelve weeks for shipment of the first issue on subscriptions. Missing issues must be claimed within three months for the U.S. or within six months outside U.S.

For customer service and address changes, call 800-777-5006 or fax 301-309-3847 or e-mail clientservices@accessintel.com or write to POWER, 9211 Corporate Blvd., 4th Floor, Rockville, MD 20850. Please include account number, which appears above name on magazine mailing or send entire label.

Content Licensing: For all content licensing, permissions, reprints, or e-prints, please contact Wright's Media at accessintel@wrightsmedia.com or 877-652-5295.

General mailing address: POWER, 116225 Park Ten Place, Suite 523, Houston, TX 77084

CONNECT WITH *POWER*

If you like *POWER* magazine, follow us online for timely industry news and comments.

Become our fan at **facebook.com/POWERmagazine**

Follow us on X **@POWERmagazine**

Join the LinkedIn POWER magazine Group and the Women in Power Generation Group

IRA Incentives Fuel U.S. Solar Manufacturing Surge

Aaron Larson

The U.S. solar manufacturing landscape has undergone a remarkable transformation since the passage of the Inflation Reduction Act (IRA) in 2022. Through targeted domestic content incentives, the federal government has successfully ignited a manufacturing renaissance, boosting capacity nearly five-fold and creating thousands of jobs across the country.

Strategic Incentives

The centerpiece of this revival is the IRA's comprehensive package of tax incentives designed to rebuild America's solar supply chain. The domestic content bonus tax credit offers project developers an additional 10% on top of the base 30% investment tax credit (ITC) when they use U.S.-made components. This creates demand-side pull for domestically manufactured solar products. According to U.S. Treasury Department data, more than $196 billion in clean power investments have been announced since the IRA's passage, demonstrating the market's strong response to these incentives.

Complementing this approach, the section 45X advanced manufacturing production tax credit (PTC) directly supports manufacturers based on production volumes—providing 4 cents per watt for photovoltaic cells and $12 per square meter for photovoltaic wafers. This supply-side push has proven particularly effective for capital-intensive upstream components where global competition has historically been dominated by China.

Recent policy refinements further strengthen the incentive structure. In January 2025, updated Treasury guidance improved the domestic content bonus by providing default cost percentages and including alternative calculations for domestically produced wafers, addressing a critical supply chain gap.

Dramatic Manufacturing Expansion

The results have been striking. U.S. solar module manufacturing capacity has surged beyond 50 GW as of February 2025, positioning domestic factories to potentially meet nearly all U.S. demand at full capacity. Since the IRA's enactment, more than $92 billion in clean energy manufacturing investments have been announced, including 27 new solar manufacturing facilities. For example, First Solar, America's largest solar manufacturer, is expanding production to reach 10 GW of vertically integrated capacity by year end, while Qcells has established a manufacturing hub in Georgia and Silfab Solar recently raised $110 million through the sale of 45X credits to support its expansion into cell production in South Carolina.

Recent market data from Anza reveals important shifts in the solar supply landscape. In its "Second Quarter 2025 Domestic Content Insights" report, Anza said there are currently 17 suppliers offering U.S.-assembled modules, a number projected to increase further. More significantly, however, U.S.-made solar cell suppliers are expected to double from five in early 2025 to 10 by the first half of 2027, indicating a growing commitment to domestic production of this critical component.

Meanwhile, pricing dynamics reveal interesting trends. Solar modules with U.S.-made cells saw a 4.3% price increase from December to March, while modules combining imported cells with U.S. assembly have actually seen prices flatten or slightly decline by 0.4%. This suggests buyers are increasingly prioritizing higher domestic content to maximize tax incentives.

However, new tariffs announced by the Trump administration have created significant market uncertainty. These include a 25% tariff on steel and aluminum, a 10% tariff on all imports, and reciprocal tariffs for select countries (with China facing tariffs of 145%). While the tariff landscape is still fluid and subject to change, Anza said, "These measures have created pricing uncertainty for manufacturers, developers, and buyers alike, delaying procurement decisions and prompting some to re-evaluate sourcing strategies."

The Solar Energy Industries Association (SEIA) has advocated a strategic phased approach, prioritizing module assembly to build demand before expanding into upstream components like cells and wafers. This sequencing is proving effective—U.S. solar cell production has begun scaling with new factories like those mentioned previously, though capacity remains limited at under 10 GW.

Supply Chain Challenges

Despite remarkable progress, significant challenges remain, particularly in upstream production. The U.S. continues to lag in producing silicon ingots, wafers, and polysilicon, with most cell and wafer production still reliant on imported materials. Only 10 GW of wafer/ingot capacity is planned, compared to 62 GW of module capacity.

Cost competitiveness poses another challenge. U.S. manufacturers face higher labor and building costs compared to Asian competitors. While tax credits help offset these differences, achieving economies of scale remains difficult.

Perhaps most concerning, though, is the growing presence of Chinese firms in the U.S. market. Companies benefiting from Chinese subsidies and low-cost energy are establishing U.S. factories that primarily assemble imported components. By 2026, Chinese-backed firms could control nearly half of U.S. module production, potentially undermining the IRA's goal of reducing dependence on China.

Policy uncertainty also looms large. Anza reports some manufacturers "are accelerating U.S. production timelines to take advantage of domestic content incentives and avoid tariff exposure, while others have canceled previously announced plans due to financial or logistical constraints." The report also notes that domestic inventories are contracting and prices are rising as available stocks are deployed to backfill orders impacted by new tariff measures.

Despite these challenges, the progress is undeniable. In just three years, U.S. solar manufacturing has undergone a renaissance that seemed impossible before the IRA. As the industry continues to mature, balancing rapid growth with strategic development of a complete domestic supply chain—supported by stable policies and streamlined permitting—will be essential to the U.S. achieving true energy independence and security. ■

*—**Aaron Larson** is POWER's executive editor.*

The Great Shift: Navigating the Global Energy Transition

As the world grapples with the urgent need to combat climate change, the transition from fossil fuels to renewable energy sources is accelerating, driven by technological advancements and governmental directives. This global shift promises not only to reduce greenhouse gas emissions, but also to create a more sustainable and resilient energy future.

Aaron Larson

The world stands at a critical crossroad in its energy journey. For more than a century, fossil fuels—coal, oil, and natural gas—have powered unprecedented economic growth and technological advancement. Yet, this progress has come at an increasingly visible cost, which includes climate instability, environmental degradation, and growing concerns about energy security. Today, the world faces perhaps the most consequential shift in history—the global energy transition.

This transition involves not only a technical shift in how power is generated, but also a fundamental reimagining of humankind's relationship with energy. As coal plants have retired across developing economies, natural gas has emerged as a somewhat controversial bridge fuel—cleaner than its carbon-intensive predecessors, yet, still a fossil fuel with emissions to account for. Meanwhile, renewable technologies, specifically solar and wind power generation, continue to decrease in cost, challenging long-held assumptions about the economics of clean energy.

What makes this transition so complex is that it unfolds differently across regions, influenced by unique resource availabilities, existing infrastructure, policy priorities, and economic realities. For some nations, energy security drives the shift. For others, economic opportunity or environmental imperatives take precedence. The common thread, however, is clear—the global energy landscape is being reshaped, and the implications will touch every aspect of modern life.

The Legacy of Coal: Confronting a Carbon-Intensive Past

Coal's dominance in the global energy system spans generations, powering industrialization across continents and lifting millions of people out of poverty.

1. The Garzweiler open-cast mine is part of the large brown-coal (also referred to as lignite or soft coal) district in western North Rhine-Westphalia, Germany. The Garzweiler mine has been linked to extensive environmental and social harm, including greenhouse gas emissions, pollution, water management challenges, and the destruction of communities and ecosystems. Source: Envato Elements

Even today, coal generates approximately 35% of global electricity, with significant production in China, India, and parts of Southeast Asia. Yet, this once-revolutionary fuel now faces mounting challenges.

The environmental toll of coal extraction and combustion extends beyond carbon emissions. By some estimates, particulate pollution from coal plants contributes to as many as two million premature deaths annually, while mining operations can disrupt ecosystems (Figure 1) and contaminate water supplies. In economic terms, aging coal infrastructure increasingly struggles to compete with newer alternatives, even before accounting for externalities.

Perhaps most significantly, the financial landscape for coal is deteriorating rapidly. Major investment firms and development banks have enacted coal exclusion policies, while insurance companies retreat from underwriting new projects. This capital flight accelerates the closure of existing plants and complicates financing for proposed facilities, creating stranded asset risks across coal-dependent regions.

Nevertheless, the transition away from coal presents profound challenges, particularly in regions where it remains central to energy security and local economies. Communities built around coal mining and power generation face uncertain futures, highlighting the need for comprehensive transition planning that addresses both climate imperatives and social equity concerns.

Natural Gas: The Controversial Bridge

Natural gas occupies a unique position in the energy transition narrative. With roughly half the carbon dioxide emissions of coal when burned for electricity, expanded gas usage has delivered significant emissions reductions in several major economies. The U.S., for instance, achieved notable carbon reductions over the past decade largely through coal-to-gas switching in its power sector.

Beyond its comparative carbon advantage, natural gas offers valuable grid services in an evolving electricity system. Fast-ramping gas plants can complement variable renewable generation, providing flexibility and reliability as wind and solar deployments accelerate. This partnership between gas and renewables has become increasingly common in grid planning scenarios.

However, natural gas faces growing scrutiny on multiple fronts. Methane leakage across the supply chain—from production to distribution—significantly undermines its climate benefits, as methane exerts a warming impact many times more potent than carbon dioxide (CO_2) in the short term. Recent atmospheric analysis suggests these fugitive emissions may be even higher than previously reported.

Additionally, investing in new gas infrastructure creates potential lock-in effects (Figure 2). Pipelines, liquefied natural gas (LNG) terminals, and power plants

2. When companies or governments invest billions in new natural gas infrastructure to support gas-fired power generation, there are strong financial pressures to fully utilize these assets throughout their operational lives to recoup investments. Source: Envato Elements

typically operate for decades, raising questions about their compatibility with mid-century climate targets. For many climate advocates, gas doesn't represent a bridge, but rather, a dangerous detour, prolonging fossil fuel dependence when more sustainable alternatives exist.

The gas bridge debate ultimately hinges on time horizons and technology assessments. As a transition strategy for the next decade, particularly in heavily coal-dependent regions, gas conversions may deliver quick emissions reductions. Looking further ahead, however, even natural gas must eventually give way to lower-carbon solutions, if climate goals are to be achieved.

The Renewables Revolution: Economics Meets Technology

Perhaps no aspect of the energy transition has defied expectations more dramatically than the trajectory of renewable energy technologies. Solar photovoltaic (PV) systems have experienced price declines exceeding 90% over the past decade, while wind power costs have fallen by approximately 70%. These cost curves have fundamentally altered the competitive landscape, making renewables the cheapest form of new electricity generation in markets covering two-thirds of the world population.

Several factors have driven this remarkable transformation. The growth in manufacturing capability, particularly in solar supply chains, has unlocked significant economies of scale. Technological improvements continue to boost performance, with capacity factors for new wind and solar installations generally improving every year. Meanwhile, financing costs have declined as investors grow comfortable with renewable asset classes, further improving project economics.

The results speak for themselves—renewable capacity additions now

3. According to the International Renewable Energy Agency (IRENA), solar accounted for approximately 71% of the world's newly installed electric power capacity in 2024. This highlights solar power's dominant role in global power expansion. Source: Envato Elements

consistently outpace fossil fuel deployments globally (Figure 3). Even in previously resistant markets, utility-scale solar and wind facilities increasingly win on pure economic merit, without subsidies. Corporate procurement has emerged as a major additional driver, with companies from tech giants to industrial manufacturers seeking renewable power purchase agreements.

Yet, challenges remain. The variable nature of wind and solar generation creates integration challenges as penetration levels increase. Storage solutions—primarily batteries, but also pumped hydro, compressed air, and other emerging technologies—will play critical roles in managing this variability. Transmission expansion represents another essential enabler, connecting resource-rich areas to demand centers and smoothing intermittency across broader geographies.

Looking ahead, electrification of transportation, buildings, and portions of industry will expand the impact of renewables beyond the power sector. This sector coupling, particularly when paired with smart demand management, creates new opportunities for system optimization while accelerating decarbonization across the economy.

Nuclear Power: The Debated Zero-Carbon Baseload Resource

In discussions of low-carbon energy systems, nuclear power occupies a complex position. As the world's second-largest source of low-carbon electricity after hydropower, existing nuclear fleets provide approximately 10% of the global electricity supply with near-zero operational emissions. This clean baseload generation displaces significant fossil fuel consumption, particularly in countries like France, where nuclear provides more than 70% of electricity, and the U.S., where it remains the largest zero-carbon source.

Nuclear power technology offers several distinct advantages compared to other clean energy resources. Nuclear plants operate at capacity factors exceeding 90%, delivering reliable output regardless of weather conditions or time of day. This dispatchable, carbon-free electricity complements variable renewable generation, potentially reducing overall system costs by minimizing the need for storage and peaking capacity. Modern plant designs incorporate enhanced safety features, addressing concerns raised by past accidents at Three Mile Island, Chernobyl, and Fukushima.

Yet, nuclear power faces formidable challenges on multiple fronts. Economics remains perhaps the most significant barrier, with new large-scale reactors experiencing substantial cost overruns and construction delays across multiple markets. In the U.S. and Europe, recent projects have frequently exceeded budgets by billions of dollars while falling years behind schedule. These economics compare unfavorably with increasingly competitive renewable alternatives, particularly when financing costs reflect nuclear technology's perceived risks.

Public perception and regulatory complexity create additional hurdles. Concerns about waste management, proliferation risks, and safety continue to

4. *The International Atomic Energy Agency reports that China has 28 nuclear reactors under construction. Linglong One, the world's first commercial land-based small modular pressurized water reactor, is one of them. It has a power production capacity of 125 MW, and in addition to power generation, it can be used for regional heating, seawater desalination, and industrial steam supply. Courtesy: China National Nuclear Corp.*

influence public attitudes, despite nuclear power's strong operational safety record. Licensing and regulatory processes typically stretch over many years, increasing project uncertainty and costs while delaying carbon-reduction benefits.

Innovation may offer pathways forward for nuclear technology. Small modular reactors (SMRs) aim to address economic challenges through standardized designs, factory construction, and simplified safety systems. Advanced reactor concepts, including molten salt designs, liquid metal–cooled systems, and high-temperature gas reactors, promise improved fuel utilization, reduced waste, and enhanced safety characteristics. Several countries, including the U.S., UK, Canada, and China, are actively supporting these next-generation technologies through demonstration projects and regulatory frameworks.

The role nuclear power will ultimately play in the energy transition will likely vary significantly by region. Countries with existing nuclear expertise and infrastructure may maintain or even expand their nuclear portfolios (Figure 4), particularly as aging coal plants retire. Nations prioritizing energy independence may value nuclear power's dense energy production and minimal fuel requirements. Conversely, regions with abundant renewable resources and public opposition to nuclear energy may pursue non-nuclear decarbonization pathways, accepting the integration challenges those avenues entail.

What remains clear is that climate models achieving rapid decarbonization frequently include significant roles for existing and new nuclear capacity. Whether this potential materializes depends on the industry's ability to address its economic challenges, navigate complex regulatory environments, and earn public trust—all while competing with rapidly improving alternatives.

Beyond Electricity: Transforming Hard-to-Abate Sectors

While electricity decarbonization captures significant attention, the energy transition extends to sectors where direct electrification proves challenging. Industrial processes requiring high-temperature heat, heavy transportation, and certain chemical production pathways represent significant emissions sources that require specialized approaches.

Hydrogen emerges as a versatile potential solution across these applications. Produced through electrolysis powered by renewable electricity (green hydrogen) or natural gas with carbon capture (blue hydrogen), this energy carrier could replace fossil fuels in steel production, chemical manufacturing, heavy trucking, and maritime shipping. Early deployments focus on existing hydrogen markets, primarily ammonia production and petroleum refining, while building toward broader applications.

Sustainable biofuels represent another pathway, particularly in aviation where battery-electric solutions face fundamental energy density limitations. Advanced biofuels derived from agricultural residues, forestry waste, and specifically cultivated energy crops could significantly reduce emissions from existing aircraft fleets, though scale remains a challenge.

Carbon capture, utilization, and storage (CCUS) technologies (Figure 5) provide options for emissions-intensive processes where alternatives remain limited. In cement production, for example, process emissions independent of energy inputs account for roughly half of total emissions. Capturing these emissions for permanent storage or use in building materials closes an otherwise difficult decarbonization gap.

These complementary strategies underscore the multi-faceted nature of the energy transition challenge. No single technology or approach can address all sectors, necessitating a diverse portfolio of solutions adapted to specific applications and regional contexts.

The Policy Imperative: Creating Frameworks for Transformation

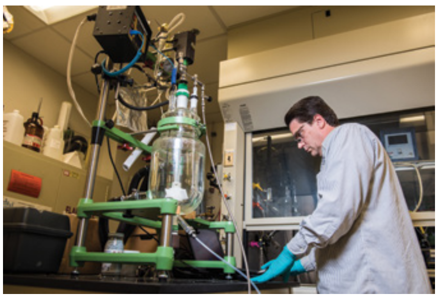
While economics increasingly favor clean energy alternatives, policy frameworks remain essential to managing this transition effectively. Carbon pricing represents perhaps the most economically efficient approach, internalizing climate externalities and creating market signals that drive decarbonization across sectors. Whether through cap-and-trade systems or direct carbon taxes, such mechanisms accelerate fossil fuel retirement while generating revenue that can support affected communities.

Renewable portfolio standards and clean energy targets provide important directional certainty for utilities and investors, establishing clear pathways for the evolution of the power generation mix. Performance standards for vehicles, appliances, and buildings similarly drive efficiency improvements and electrification, often delivering economic benefits alongside emissions reductions.

Research, development, and demonstration funding addresses critical innovation gaps, particularly for technologies not yet commercially mature. Public investment in hydrogen infrastructure, advanced nuclear designs, next-generation storage, and industrial decarbonization pathways helps overcome early deployment barriers and accelerates cost reduction trajectories.

Perhaps most importantly, however, just transition policies ensure the benefits and costs of this transformation are equitably distributed. Worker retraining programs, community economic development initiatives, and targeted infrastructure investments help fossil fuel–dependent regions navigate economic changes. Energy access and affordability protections prevent disproportionate impacts on vulnerable populations.

Meanwhile, international cooperation frameworks—from technology transfer mechanisms to climate finance—extend these principles globally. Developing economies face unique transition challenges, often balancing emissions reduc-



5. *The equipment pictured here was used at the Pacific Northwest Laboratory as part of a carbon capture program that was working to develop novel solvents for better capturing of CO_2 from a coal-fired power plant. Source: U.S. Department of Energy*

6. The energy transition requires not only investments in generation assets, but also massive upgrades to grid infrastructure to modernize existing networks and accommodate growing demand. Source: Envato Elements

7. Battery energy storage systems (BESS) are increasingly being paired with solar photovoltaic (PV) systems to capture excess daytime generation for use during evening hours when solar production stops but electricity demand often peaks. The AES Lawai Solar Project in Kauai, Hawaii, is one example. It has 28 MW of PV capacity and a 100-MWh BESS. Source: National Renewable Energy Laboratory

tion goals with legitimate development priorities and energy access needs. Recognizing these differences while providing support for leap-frog opportunities that bypass fossil-intensive development stages entirely, represents a critical dimension of effective global policy.

The Investment Challenge: Financing the Energy Transition

The scale of investment required for a comprehensive energy transition reaches into the trillions of dollars annually. Power generation alone requires massive capital reallocation, with renewable deployment needs far exceeding historical investment patterns. Transmission and distribution infrastructure demands similar attention (Figure 6), as grids evolve to accommodate distributed resources and bidirectional power flows.

Beyond electricity, transportation electrification necessitates extensive charging networks alongside vehicle manufacturing transitions. Building retrofits for efficiency and electrification represent another enormous capital requirement, spanning commercial, residential, and industrial structures. Industrial process transformations from hydrogen integration to carbon capture add further investment demands.

Financial innovation plays a crucial role in meeting these capital needs. Green bonds, sustainability-linked loans, and specialized climate finance vehicles connect environmental projects with interested investors. Concessional finance from development institutions helps reduce risk in emerging markets, while public-private partnerships address gaps traditional markets might overlook.

Divestment and investment exclusion strategies continue gaining momentum, redirecting capital from fossil assets toward transition solutions. Major institutional investors increasingly incorporate climate risk assessments into portfolio decisions, recognizing both physical climate impacts and transition risks associated with high-carbon holdings.

For energy companies themselves, capital allocation decisions today will determine competitive positioning for decades to come. Those pivoting toward transition-aligned business models—whether through renewables development, grid services, storage, or clean fuels—position themselves for long-term relevance as policy and economic pressures on fossil assets intensify.

Decisions, Decisions: Navigating the Inevitable Transformation

The energy transition represents not only a shift in technology, but also a fundamental reorganization of one of humanity's most essential systems. This transformation proceeds unevenly across regions and sectors, influenced by resource endowments, existing infrastructure, policy choices, and social priorities. Yet, despite this complexity, the direction of travel grows increasingly clear.

Economics increasingly favor clean energy pathways, with renewable costs continuing their downward trajectory while fossil fuel investments face growing risk premiums. Technology innovation accelerates across storage (Figure 7), hydrogen, grid management, and industrial applications, expanding the frontier of what's possible. While policy frameworks in states and countries around the world are always subject to change, most generally align with decarbonization imperatives, creating consistent signals for capital allocation.

This transition brings enormous opportunities alongside its challenges. Energy security improves through diversification away from concentrated fossil resources. Local air quality benefits deliver immediate health improvements for affected communities. New industries create employment opportunities that can offset losses in declining sectors, particularly when supported by proactive transition planning.

Like previous energy transitions—from wood to coal, from coal to oil—this shift will reshape economies, geopolitics, and daily life. Unlike those historical examples, however, this transition proceeds with greater urgency and intention, driven by climate imperatives alongside economic forces. The path forward involves continued technology innovation, policy development, financial mobilization, and above all, a commitment to ensuring this transformation delivers benefits across society.

As the world navigates this complex transformation, leaders face not only technical choices, but also fundamental questions about the future energy landscape. The decisions made in this critical decade will reverberate through generations, determining the systems that power human progress through the remainder of this century and beyond. ■

*—**Aaron Larson** is POWER's executive editor. This article was written in part with the help of artificial intelligence platforms including Claude, Copilot, Grok, and Perplexity.*


Ai

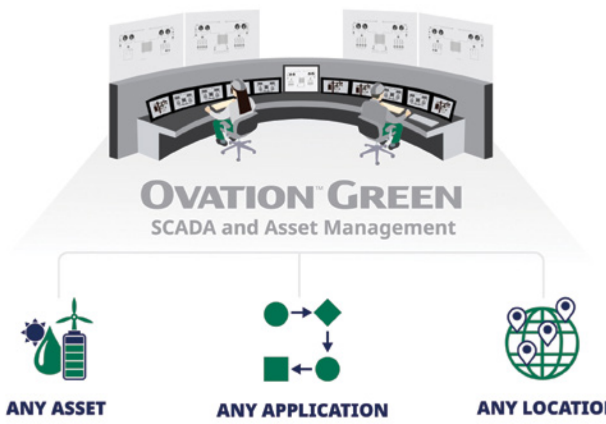
Partner Insights

Accessing Data-Driven Insights for Any Asset and Application, Anywhere

The world's renewable power capacity is projected to experience significant growth over the rest of this decade, with global additions between 2024 and 2030 expected to almost triple to approximately 5,500 gigawatts. But this expansion in renewable energy will generate more than sustainable megawatts; it will also produce significantly higher volumes of operational data (up to 50 percent more) compared to thermal sources. This is caused by the distributed, weather-dependent nature of renewables, which requires monitoring numerous individual units with complex variables. The influx of data translates into greater complexity, higher maintenance costs and lack of scalability due to the use of multiple, disparate systems. This is further complicated when integrating renewables with existing thermal assets.

Implementing low-risk advanced software solutions enables utilities to overcome these challenges by seamlessly integrating data collection, analysis and asset management to optimize performance and reliability. This can have far-reaching, positive impacts—not only enabling power producers to reduce costs while simultaneously improving multi-site operations—but also contributing to enhanced grid stability and resilience.

Emerson is at the forefront of innovation with a Boundless Automation vision of a simplified architecture that can drive operational excellence by removing data silos, liberating data and unleashing the power of software. This streamlined experience, delivered with one cohesive framework, unlocks access to contextualized data from anywhere in the world, at any time.



Scalable Ovation Green SCADA software enables efficient management of assets independent of equipment manufacturer, system type and vintage, and location.

Case in point is Emerson's Ovation Green SCADA, which is helping power producers more confidently navigate the energy transition. Ovation Green SCADA is revolutionizing renewable energy management by combining field-proven power plant controllers and purpose-built SCADA software to dynamically monitor, control and optimize asset performance and reliability. Ovation Green SCADA helps customers tackle today's challenges by:

- Unifying control and monitoring for solar, wind, hydro, and hybrid systems
- Providing real-time insights and customizable dashboards for informed decision-making
- Easily scaling from single sites to expansive renewable and fossil portfolios, and
- Staying relevant and secure due to end-to-end lifecycle product support and services.

With its open architecture and standard protocols, Ovation Green SCADA can integrate diverse devices and systems, transforming aggregated and contextualized asset data into actionable insights. This standardized approach enables quick deployment across multiple sites, reduces site visits and ensures consistent operations. With Ovation Green SCADA you get clear operational visibility through a single pane of glass with access to data-driven insights from any asset, any application, anywhere.

Learn more at https://www.emerson.com/ovation-green

EMERSON™

Utilities, Grid Operators Grapple with Adding Renewable Energy

Power generators and transmission system engineers have to rethink their planning strategies, and must continue to develop tools to allow more solar, wind, and other forms of renewable energy to populate the power grid.

Darrell Proctor

Integrating renewable energy resources such as solar and wind into the electric power grid involves addressing challenges, starting with the intermittent nature of renewables. *POWER* has often highlighted the issues, noting in part a lack of physical grid capacity to accommodate supply and demand in locations with the best resources. Another issue is that as the share of renewable energy increases, the lack of real-time network management at low voltages can bring network instability, which impacts reliability. Other problems include voltage instabilities, frequency inconsistency, and harmonic distortion of the power system.

This often requires projects to modernize the grid, along with the use of new technologies for both asset and grid management. Utilities and grid operators are utilizing energy storage, often at substations along the grid, to ensure reliable and efficient electricity delivery. The use of artificial intelligence (AI) also is supporting the addition of solar, wind, hydropower, and more to grids worldwide (Figure 1), as utilities and other power generators seek ways to utilize an ever-growing supply of data from renewable energy assets.

Brett Benson, director for Global Renewable Solutions at Emerson, noted, "Utilities and system operators face a number of challenges by integrating renewables into their systems. Not long ago, a utility would have had a few handfuls of large thermal generating assets strategically and geographically scattered across their system with very distinct operating profiles, heat rates, and diverse energy demands. These assets are very predictable and reliable for managing the supply of power to customers—residential, commercial, and industrial."

Benson added, "The addition of solar PV [photovoltaic] and wind assets has greatly changed this dynamic. The most obvious is the volatility of the intermittent generation of these renewable power-generating units. If it was just a few of these units, it would be fairly manageable with only fine adjustments necessary, but the growth in renewable generation has meant there may be dozens or even hundreds of solar and wind farms that may range from 2 MW to 1,000 MW. The utility or system operator has gone from managing a handful of large, reliable generation sources to adjusting generation for a multitude of various size and variable output assets."

1. The use of artificial intelligence is supporting the integration of renewable energy resources to the power grid. Smart grid technologies are optimizing energy distribution, managing grid operations, and improving grid resilience. Source: Oak Ridge National Laboratory

Smart grid technologies have been, and continue to be, developed to optimize energy distribution, manage grid operations, and improve grid resilience—all of which can enhance the integration of renewables. Investing in new transmission lines and upgrading existing ones can help deliver power from renewable energy sources to areas with high demand for electricity.

"Significant investment in grid modernization and advanced control systems is necessary to handle the variability and distributed nature of renewables. The deployment of energy storage solutions is also crucial to mitigate intermittency," said Hala Ballouz, Electric Power Engineers' co-founder and CEO. "Furthermore, a skilled workforce is needed to study, manage, and maintain these new technologies. Finally, bringing the industry together to create more comprehensive and consistent policies and regulations surrounding renewable integration is a must to ensure that we are creating an environment to maintain the reliability and resiliency of the grid."

"One of the most widely acknowledged challenges with renewable integration is the variability and unpredictability of generation. Wind and solar do not always align with demand—solar generation peaks mid-day, while peak demand often comes in the evening," said Bryan Schurko, Strategic Growth Leader of Power Delivery at Stantec. "This mismatch requires new tools and approaches to ensure reliability. Upgrades may also be required due to certain grid infrastructure limitations. Another issue is that renewable resources are often located in remote or rural areas where transmission infrastructure isn't

2. Utilities and grid operators face several challenges when it comes to integrating renewable energy on the power grid. That can include maintaining grid stability and reliability, in part due to aging infrastructure not adequate to handle the increased load from renewables. Source: Envato Elements

sufficient to move electricity to where it's needed. This congestion adds strain to already aging infrastructure.

"Beyond the physical grid, the administrative and the investment side of renewable integration poses barriers too," said Schurko. "Interconnection queues have become increasingly long and complex, especially in regions experiencing high volumes of new solar and wind projects. Even with reforms like cluster reviews underway in some jurisdictions, utilities and system operators still face resource constraints in processing and approving applications, which delays deployment and adds cost uncertainty for developers."

Brendan Andrews, vice president, Energy and Infrastructure at Bureau Veritas North America, told *POWER*: "To integrate renewable energy to the grid [Figure 2], utilities and grid operators face challenges including policy, maintaining grid stability and reliability, aging infrastructure not adequate to handle the increased load from renewables, long interconnection cues and slow planning processes, regulatory roadblocks, and managing and coordinating multiple stakeholders throughout any project. One of the reasons why the grid struggles to integrate modern renewable energy sources efficiently is that much of the infrastructure in the U.S. dates back to the 1950s, including transmission lines and substations. Upgrading and modernizing the grid is essential to handle the increased load from renewable sources."

Andrews added, "Renewable power generation is not the issue, transmission is. Enhanced transmission infrastructure, accompanied by grid enhancing technologies, will reduce congestion and improve reliability."

Obstacles to Deployment—The Interconnection Queue

Owners and operators of renewable energy projects know there are several obstacles to overcome even after a project is permitted and built. The biggest task is often getting through the generator interconnection queue (GIQ). Every independent system operator and regional transmission organization—the grid operators—in the U.S. has reported backlogs in its GIQ, and it can sometimes take years to process and complete an interconnection request. Lawmakers, along with energy companies and lobbyists for both thermal and renewable energy, have long decried the permitting process in the U.S.

"Grid interconnection is complex and time-consuming," said Ballouz. "Utility teams are continuously working toward an optimal solution for renewable integration, and with the changes in policy and regulation for how these studies are to be conducted and the number of solutions that may be available for any reliability concern are just going to continue to increase the complexity of this process."

Said Benson, "The other challenge is managing the interconnect of these resources. Where there is a substation, or at least a high-voltage line, you can arguably add generation there … whether that's a good spot in the grid for it or not is a different question and one that definitely complicates planning and management."

Benson told *POWER*, "No matter the interconnection, there is always permitting and work that needs to be done to prepare for new generating units, regardless of megawatt size. With these variable resources online, where you were once managing the handful of thermal generators, the utility and system operator must now monitor [and sometimes curtail] dozens or more intermittent assets and balance the system against that 'top of the stack' generation by ramping the thermal fleet. This is complicated as ramp rates and grid congestion are serious factors in the decisions on which unit to ramp. These decisions also increase fatigue on those units, many of which were designed as a fixed baseload, thus decreasing their availability and reliability while increasing maintenance costs."

Adding Energy Storage

Those who spoke with *POWER* generally agreed on the measures needed to support grid integration of renewables. "There's not one silver bullet but a combined strategy that adopts several methods to provide power grid stability," said Benson. "The most obvious is to add fast-acting energy storage systems to the grid to provide that instant support when a cloud moves over a solar farm or the wind dies down before traditional generation can ramp up. But going deeper, there needs to be an overall plan by the utility and system operator to govern and protect the grid.

"This incorporates enforcing compliance to regulations and use of transient models by non-traditional generators, adopting resiliency standards like IEEE-2800 and NERC CIP [North American Electric Reliability Corporation Critical Infrastructure Protection], locating and permitting power generating units at strategic locations, and very importantly, working with customers on load management programs, another way to respond quickly to intermittent generation," said Benson.

"Inconsistent and fluctuating renewable energy sources are among the major challenges facing integration," said Alex Ince-Cushman, co-founder and CEO of Branch Energy, a renewable energy and energy storage company. "Wind and solar energy vary in production, making energy storage an ideal solution to mitigate periods of inactivity. Utilities also face challenges integrating renewables in areas isolated from traditional power plants. DERs [distributed energy resources] are solving these challenges. They serve as backup sources during grid power outages and help reduce energy losses during long-distance transmission.

"Grid stability improves when we bring flexibility closer to the edge. Behind-the-

3. The Mantiqueira Transmission Line is among Cobra Brazil's transmission and distribution projects in Brazil. Cobra Brazil, also known as Cobra IS, recently received a contract to build seven high-voltage lines across 640 miles. Courtesy: Cobra IS

meter assets like batteries, paired with intelligent controls, allow for real-time demand shaping and localized support," said Ince-Cushman. "These resources operate in coordination, guided by clear price signals and responsive software. In turn, they reduce strain, smooth out variability, and help renewables integrate seamlessly without needing major infrastructure overhauls."

Kaio Kopko, engineering product manager with Operador Nacional do Sistema Elétrico (ONS), the Brazilian national system operator, noted that renewable resources—solar, wind, and hydropower—make up more than 80% of that country's energy output. Hydropower has long been Brazil's leading power generation resource, and wind and solar are continuing to grow.

"Wind and solar will [soon] be 45% of the grid," said Kopko, who spoke with *POWER* at the recent AVEVA World summit in San Francisco, California. "We have an entire area dedicated to [gathering] data, and evaluating data models, using the cloud [to store data]." Kopko said the use of AI is important as ONS looks at optimizing the grid.

"Our [data system] is basically ChatGPT for ONS," said Kopko. "AI will help us to find the best solutions. Being able to utilize automatic calculations is a huge improvement for us." Kopko said Brazil's renewable energy generation is "growing so fast, we're dealing with a lot of curtailments."

Kopko said adding more energy storage is one answer. Powin, a U.S.-based global energy storage integrator, and UCB, a leading provider of energy storage solutions in Brazil, earlier this year signed a memorandum of understanding to establish a partnership aimed at scaling the Brazilian energy storage market. The companies said the partnership is focused on addressing the growing demand for utility-scale energy storage in the country, driven by the continued expansion of renewable energy in Brazil. Kopko said adding storage also supports grid reliability. He said the work of ONS will be in the spotlight at this year's United Nations Climate Change Conference (COP30), scheduled for November in Belém, Brazil.

Brazil is building more transmission and distribution infrastructure (Figure 3) to support renewable energy. Engie Brazil recently awarded a $163.8 million design-build contract to Cobra Brazil for seven high-voltage electricity transmission lines (525 kV and 345 kV) across about 460 miles. Cobra Brazil, also known as Cobra IS, with this contract will now be in charge of building about 1,500 miles of high-voltage lines in several Brazilian states. The company has built more than 18,640 miles of high-voltage lines in Brazil over the past 20 years as part of public-private partnerships.

Caspar Herzberg, CEO of AVEVA, said his group's work with ONS and other grid operators "is bigger than [just] AI. If you invest in digitization, invest in data, you can do significantly better. The vast majority of our customers want to add more data points. Our task is to make all this data available, and make sure the flow of data is seamless. It's about helping customers make sense of anything they're dealing with."

Herzberg said integrating renewable energy into the power grid includes having the tools to understand what's happening with transmission and distribution at any given time. "Take wind farms ... we have to figure out every way to extract value out of their operations. We're working with utilities across the world to analyze their transmission lines."

Paying for Grid Upgrades

One often-asked question: Who should pay for grid upgrades to enable more and better integration of renewable energy resources (Figure 4)? Georg Rute, CEO at Gridraven, a company founded in Estonia that has based its U.S. operations in Austin, Texas, said investment for grid upgrades should be rethought when it comes to who pays for improvements.

"The fact that transmission owners in America do not pay for congestion is a major problem," said Rute. "It's the system operator, not the transmission owner, that pays for congestion by redispatching power plants. This additional fuel cost is borne by ratepayers and there is no penalty for the transmission owner that caused the problem. Nor is there any incentive for the transmission owner to fix it.

"Even worse, those incumbent utilities that own both transmission and thermal generators actually benefit from the high prices caused by congestion," said Rute, whose company is known for its AI-driven dynamic line rating technology that addresses grid bottlenecks. "The lack of grid capacity prevents cheaper solar and wind from flowing into their territory and eating into their profits. In Europe transmission system operators are not allowed to own generation. Fur-

4. Who takes payment responsibility for grid upgrades is among the most-debated questions when it comes to getting more renewable energy onto the power grid. Source: Envato Elements ther, congestion revenue in Europe is earmarked for investing into the grid. The difference in the amount of money paid by a consumer in a high-price zone and the money received by a generator in a low-price zone that supplied that power is placed in a special fund that can only be used for strengthening the grid to remove the congestion that caused the price difference in the first place."

"There continues to be much debate on this," said Benson. "One of the strongest arguments is that a utility that builds or purchases power from a renewable asset is saving money from the free fuel source and significantly less personnel, thus those savings should be utilized for the grid upgrades [and paid for by the ratepayers]. The retort is if the power generating unit was dispatchable there would be no argument, but since the utility needs to supplement that [roughly] 30% capacity factor with another dispatchable generation, [it is] resulting in a higher per-MW cost than thermal generation. Fortunately, this is changing as battery energy storage prices have greatly come down, as can be seen in the latest Lazard Levelized Cost of Energy (LCOE) report, making a hybrid solar PV and battery storage plant a viable option in the right locations."

"This varies by region, but cost-sharing is likely the only way to move forward with upgrades in a timely manner," said Andrews. "This means splitting cost among various stakeholders including utility companies, developers, ratepayers, and government funding."

Said Schurko: "In today's environment, it's clear that a shared approach to grid upgrade costs is necessary. Developers, utilities, governments, and ratepayers all benefit from a more flexible and modern grid, and each should play a role in financing these improvements. While utilities traditionally pass infrastructure costs to ratepayers, targeted government support and developer contributions—especially when upgrades enable specific projects—are also part of the solution.

"The bigger question is not just who pays, but how value is defined and allocated," said Schurko. "The traditional 'cost-causer pays' model was built for a centralized system and does not reflect the complexity of today's grid. Now that electricity flows in multiple directions and new players like aggregators and distributed energy resources' owners are involved, cost-sharing frameworks need to reflect the shared benefits of reliability, decarbonization, and long-term resilience."

Software and Other Technologies

Benson and others who spoke with *POWER* agreed that software solutions are among the best grid-enhancing technologies to support the grid integration of renewable energy. Other advanced technologies include better communication systems and advanced sensors, both along power lines and within solar and wind farms.

"Utilities once had only a handful of generating assets with predictable costs and output, and so was the daily load. Now, with the wide variability in daily generation and load, a utility must look to advanced software programs for managing the overall grid," said Benson. "Some of this software directs the real-time operation of the generating assets to support the grid while others predict the demand [and available power] for the minutes, hours, and even days ahead. These are the systems that need to anticipate excess generation and charge the batteries at the most optimal time for them to be available to serve as their peak need.

"Sensors play a part within advanced distribution management systems [ADMS] to ensure the right amount of voltage is served to the end of the distribution line and, where there can be dips, they are quickly detected and resourced through tap changers," said Benson. "In years past, the distribution system may have been sourced excess power to ensure adequate voltage thus more generator output, now this can be leaner to match demand saving on lost MWs. These sensors also provide the utility with pinpoint and instantaneous line break information for speedier outage recovery."

Andrews said, "Renewable energy resources depend on weather conditions, which introduces a variety of technical challenges to overcome to safely connect them to the grid while maintaining stability and reliability. Integrating technologies like Static Synchronous Compensator (STATCOM), inverter-based resources, advanced sensors and monitoring, energy storage, and advanced conductors can significantly enhance grid stability and efficiency.

"STATCOM can significantly enhance the power grid by providing voltage stability, improving power quality by mitigating voltage fluctuations, and offering fast response times to changes in power loads within milliseconds," said Andrews. "Advanced conductors can double the capacity of existing transmission lines allowing for more electricity, including renewable energy, to be transmitted without the need for new infrastructure. Reconductoring existing lines with advanced conductors is faster and cheaper than building new transmission line by leveraging existing poles and towers."

Energy storage also is taking on increased importance when it comes to supporting renewable energy, providing value along with more flexibility and balance for the grid.

"Energy storage, whether from battery, pumped storage, or mechanical storage, fills an important gap that could easily make managing grid frequency incredibly hard to do in areas away from large, rotating turbines," said Benson. "Their ability to store excess energy [aiding in their economy] and releasing it quickly to maintain frequency and inertia on the grid through grid-forming inverters is an essential service. The more solar and wind that connects to the grid, the more essential these resources are.

"Additionally, if you look at what was once called the 'duck curve' in California, [it] has greatly changed in the last 10 years where it's now a valley," said Benson. "The more you can reduce the amount of cycling of large thermal generation, the more the savings on capital expenditure, and operations and maintenance, can be had by the utility through increased reliance on energy storage during those non-solar hours."

"Grid-enhancing technologies are most impactful when they empower assets behind the meter. Smart inverters, building-level control systems, and real-time data platforms enable distributed systems to act as responsive grid resources," said Ince-Cushman. "AI plays

> ***"Grid-enhancing technologies are most impactful when they empower assets behind the meter."***
>
> —Alex Ince-Cushman, co-founder and CEO of Branch Energy.

a critical role in optimizing when to store, consume, or export power based on cost, load, and resilience needs. These tools let customers actively support the grid while cutting costs and improving reliability.

"DERs integrate renewables by bringing capacity closer to where it's needed—and faster than traditional infrastructure can," said Ince-Cushman. "Batteries, rooftop solar, and load controls reduce grid strain during peak hours and help manage volatility. These systems also enable buildings to participate in energy markets directly, stacking value across bill savings, demand response, and reliability."

Said Andrews: "Energy storage plays an integral role in grid stability and resilience. Energy storage systems can store excess energy generated during periods of high renewable generation, such as sunny or windy days, and release it during periods of intermittency/low generation or high demand. This helps balance supply and demand, ensuring a stable and reliable supply of power."

Arielle Kadoch, Canada Sector Leader for Power Delivery at Stantec, told *POWER*: "Energy storage will play a foundational role in supporting the future power grid, including those that integrate renewables. One of the most important functions of storage, particularly battery energy storage systems [BESS], is helping resolve the timing mismatch between generation and demand. Solar, for example, peaks during the day, but demand often peaks in the evening—storage allows that clean power to be shifted to when it's actually needed, storing excess renewable energy otherwise wasted and releasing it during high-demand periods."

Kadoch added, "Storage also provides critical grid services like frequency regulation, grid stability, and resilience by providing backup during outages, weather events, or disruptions—all of which become more valuable as inverter-based generation displaces traditional synchronous machines. Additionally, storage can relieve localized congestion on both the distribution and transmission system, deferring the need for costly infrastructure upgrades. As the technology continues to mature, and if combined with other smart technologies such as smart inverters, storage will be more powerful and remain an essential bridge between renewable energy and grid reliability.

"Energy storage is what makes renewable energy truly reliable. Without energy storage, we would be missing a critical piece of the puzzle in creating a more flexible and resilient clean energy future," said Kadoch.

5. Several companies are using scalable automation software and technologies to monitor performance of renewable energy equipment—including wind turbines—and gain visibility into how it is being integrated to the power grid. Courtesy: Emerson

DERs Support Renewable Integration

Several of those who spoke with *POWER* said the use of DERs also supports grid integration for renewables, though it also comes with questions.

"Traditional utility business models may face conflicts with the decentralized nature of renewable energy generation," said Ballouz. "While initiatives like FERC [Federal Energy Regulatory Commission] Order 2222 that aim to enable distributed energy resources to participate in electricity markets can help, state-level implementation often lags, limiting/delaying implementation opportunities."

Said Andrews, "DERs enable the development of microgrids, which can operate independently or in conjunction with the main grid. Microgrids enhance energy resilience by providing reliable power during outages and supporting the integration of local renewable energy sources. Rooftop solar is an example, it can be used to inject power back into the grid, also referred to as virtual power plants [VPP]. By leveraging the capabilities of rooftop solar and other DERs, we can significantly enhance the integration of renewable energy resources, making the grid more flexible, efficient, and resilient."

"Small-scale energy resources such as rooftop solar panels or diesel generators could help support the integration of renewables in a number of ways," said Benson. "For one, they can be looked at as additional fast-response generation should there be a need for a small amount of extra MWs on the grid. Clouds may be over a utility's solar farm, but if enough behind-the-meter generation is out there it can either be activated to serve its host's load, detaching that demand from the grid, or sending that excess power to the grid. Some of these DERs may be clustered, say at a university, as to island the campus in a microgrid, allowing the utility to shed them as a load in the moments when the generation is needed during peak conditions or lost generation."

Schurko said several technologies "are helping utilities modernize the grid to handle more renewable energy," and added that "there are a few top technologies or systems that make large cost-effective improvements. At the core is enhanced visibility—if grid operators can't see what's happening in real time, they can't manage it. That's where upgraded SCADA [supervisory control and data acquisition] and communication systems come in. These systems [Figure 5] collect and transmit operational data across the grid, allowing for faster fault detection, better load balancing, and more accurate forecasting.

"Platforms like advanced distribution management systems are critical for managing this data, providing operators with tools to monitor voltage, reroute power, and manage distributed generation," said Schurko. "Meanwhile, distributed energy resource management systems [DERMS] give utilities the ability to control and aggregate small-scale resources like batteries and rooftop solar systems. Together, these technologies help utilities operate the grid more efficiently while supporting two-way power flow and resource diversity."

Kadoch said DERs such as rooftop solar, batteries, smart appliances, and even electric vehicles (EVs) "are decentralized assets ... but they can have system-wide benefits when they are aggregated and coordinated properly. One of the most impactful ways DERs support renewable integration is by absorbing excess generation from utility-scale wind and solar farms. For instance, EVs or water heaters can be programmed to run during mid-day solar peaks, reducing curtailment and flattening the net load curve."

Kadoch added, "DERs also help relieve congestion on the transmission system by serving local load, especially in areas that would otherwise be grid-constrained. When combined with digital platforms like DERMS or virtual power plants, DERs can be dispatched to support the larger grid—providing voltage support, frequency regulation, and even emergency backup. While DERs and utility-scale renewables are often planned separately, when they're deployed as part of a coordinated strategy, they offer a powerful tool for decarbonization and system flexibility. Distributed energy resources are the key to unlocking the full potential of renewable energy by bringing flexibility, resilience, and innovation to the grid."

Uncertainty About Investment—and Incentives

Energy industry analysts, as noted earlier, agree that investment—whether public, private, or a combination of both—is needed to facilitate grid upgrades that could help with the integration of renewable resources. There also is agreement that incentives to make those investments are necessary, but uncertainty about incentives is growing not only in the U.S., but also worldwide as governments mull budgets, and private investors remain concerned about legal and regulatory issues.

Said Kadoch: "Utilities and system operators need certainty around the need for investment to incentivize continued upgrades to a grid that can effectively integrate renewables. Certainty can be provided by regulators, policymakers, and developers who facilitate new markets for services like demand response, energy storage, and smart grids, and as a result this would reduce outages, improve system flexibility, and enhance grid reliability and resilience.

"There could be an advantage to combine public with private funding to reduce the risk of major grid projects as they look to reach final investment decision," said Kadoch. "As an example, having government cover preliminary work, such as environmental work and permitting, while private partners fund construction and operations."

Benson noted making grid upgrades to help with the integration of renewables is just one reason to modernize infrastructure. "In many cases, grid upgrades will go hand-in-hand with overall grid reliability [storm mitigation, demand growth, etc.], primarily paid through rate recovery, sometimes with some government support," said Benson. "Other upgrades directly attributed to new renewables, say those required for a new data center, may be partly or fully paid for by the company or companies that are seeking the net-zero generation."

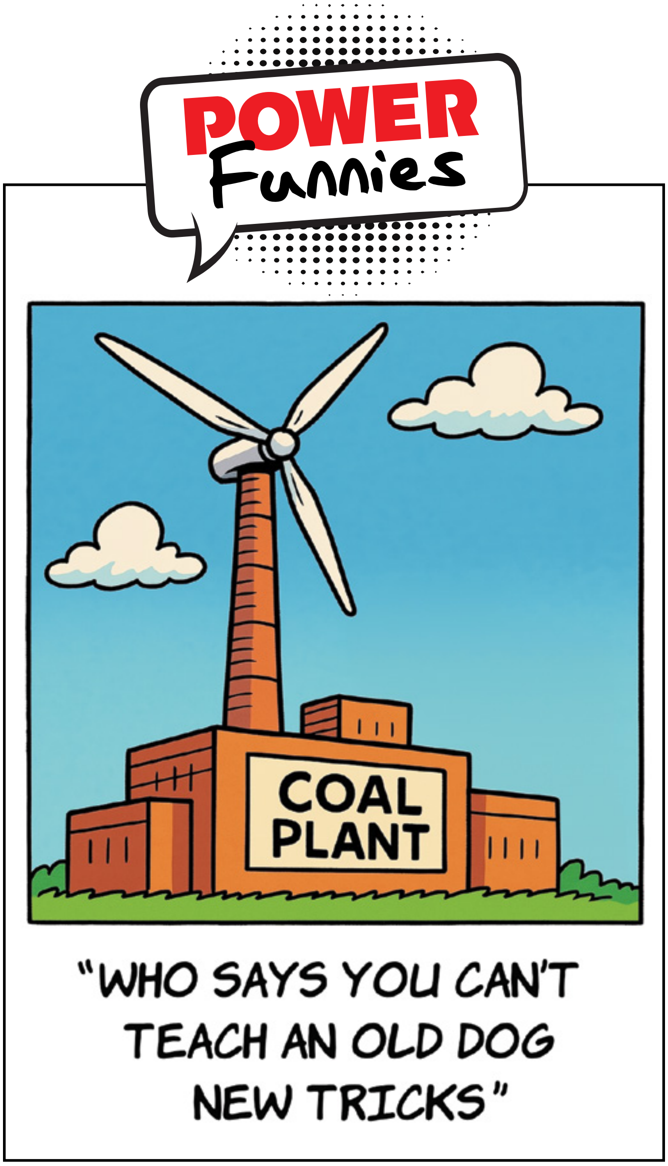
Government support—or lack thereof—also will impact how much renewable energy is added to any country's grid. Advocates for renewable energy are particularly concerned about the current political climate in the U.S., as federal funding is pulled from renewable energy projects. Some lawmakers, such as in Oklahoma, are pushing for measures to restrict renewables; many county governments across the U.S. already have signaled they will not approve clean energy projects in their areas.

Ballouz said, "Supportive policies and regulatory frameworks that incentivize renewable integration, streamline interconnection processes, and fairly compensate for grid services are essential for optimizing the contribution of renewables to a stable power grid. The government plays a significant role through federal and state-level funding and incentives."

Ballouz noted programs from the Department of Energy, funding from the Bipartisan Infrastructure Law, and tax credits from the Inflation Reduction Act (IRA) "all contribute to grid modernization and distributed energy projects, which include renewable integration. State-level programs, such as California's Microgrid Incentive Program (MIP) and New York's NY Prize, also provide funding."

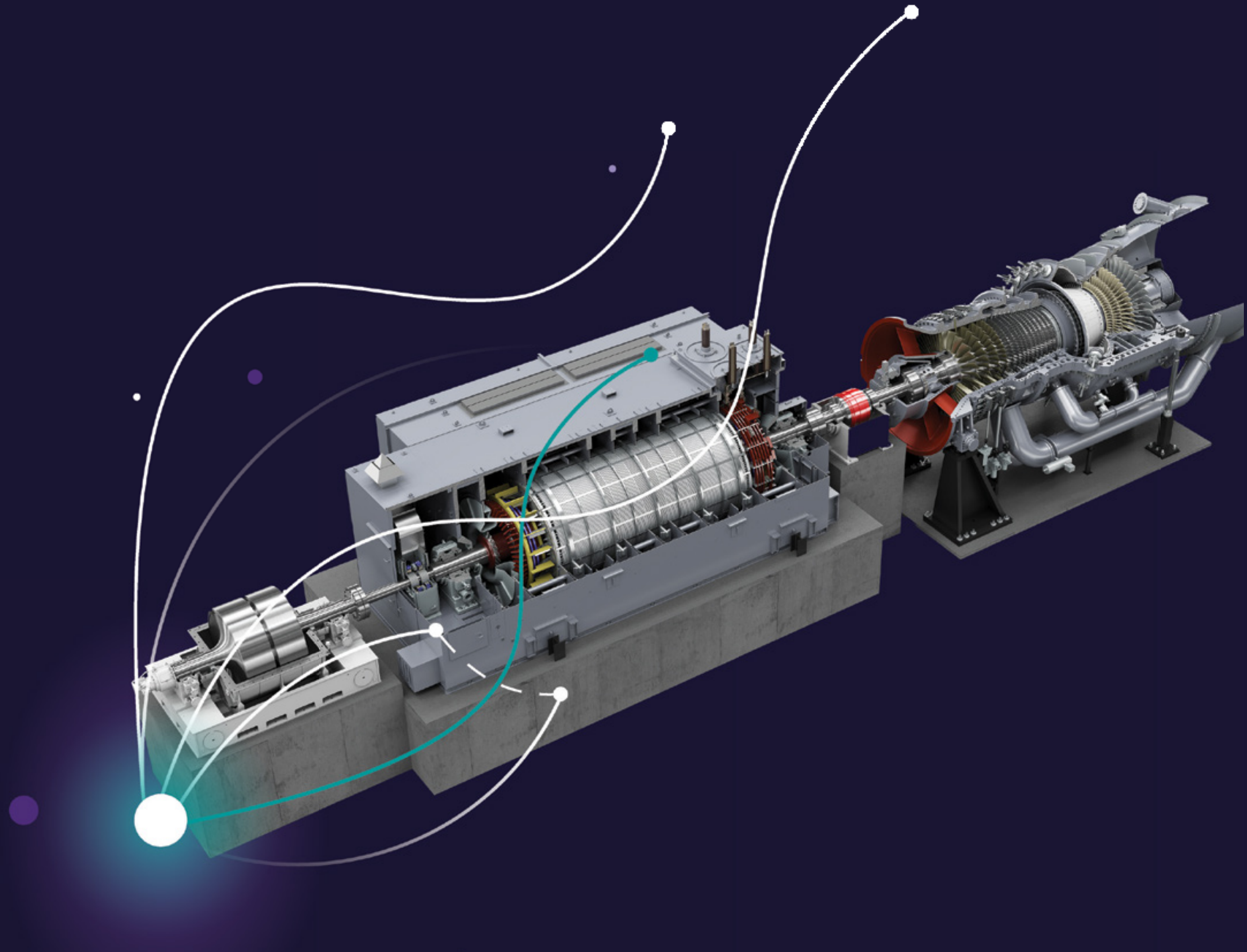
The future of that funding, though, is uncertain—particularly in the U.S. "The Trump administration's approach to energy policy has generally favored fossil fuels over renewable energy," said Andrews. "A repeal of the IRA would drive up electricity bills because less low-cost clean energy would be available and fewer electric vehicles on the road would increase spending on gasoline. While there have been some mentions of infrastructure priorities that include transmission and energy storage projects, the overall policy direction seems to be less supportive of renewable energy integration compared to previous administrations." ■

*—**Darrell Proctor** is a senior editor for POWER.*



SIEMENS energy

Alternate between grid stabilizer and power generation modes with Rotating Grid Stabilizer Hybrid Conversion



Visit our website to learn more: www.siemens-energy.com/rgs

siemens-energy.com

Partner Insights

Discover Siemens Energy Rotating Grid Stabilizer (RGS)

A tried-and-tested method for grid stabilization

In an era where renewable energy sources are becoming more prevalent in our power systems, ensuring the stability and reliability of electrical grids is more crucial than ever. Converting existing power generation equipment into a synchronous condenser stands out as an innovative solution designed to tackle these challenges, ensuring that our electrical grids can seamlessly manage fluctuations in power supply and demand.

Hybrid Rotating Grid Stabilizer: More than a synchronous condenser

With the Rotating Grid Stabilizer (RGS) conversion solutions, power plant operators can convert existing power plant assets to synchronous condensers to help maintain grid stability. A clutch can be added to existing turbines when repurposing generators that may otherwise become stranded assets or are experiencing lower utilization. This can provide necessary system inertia, short circuit power and reactive power to help maintain grid balance.

What sets the RGS apart is its unique hybrid capability, allowing it to switch between power generation and grid stabilization modes. This flexibility not only enables power plants to produce needed power but also allows them to generate additional revenue by providing essential grid services. By optimizing their operations, power plants can enhance their economic viability while simultaneously supporting the overall health of the electrical grid. In this way, the hybrid RGS plays a pivotal role in the transition to a sustainable energy future, combining the benefits of traditional rotating equipment with cutting-edge technology to meet the demands of modern energy systems.

Proven Success in Real-World Applications

Numerous case studies showcase the successful implementation of the Rotating Grid Stabilizer across various energy systems. A notable example is the Killingholme project in the UK, where Uniper repurposed two retired steam turbine generators into synchronous condensers equipped with flywheels. This innovative conversion was part of the Stability Pathfinder project initiated by National Grid ESO, aimed at enhancing grid stability. The collaboration between Uniper and Siemens Energy involved retrofitting existing equipment to provide essential grid services. This project not only highlights the effectiveness of RGS in supporting the integration of renewable energy sources while maintaining grid reliability, but also emphasizes the essential grid services that Killingholme can now provide.

Your Partner in a Sustainable Energy Future

As we navigate the complexities of the energy transition, maintaining grid stability is crucial. Siemens Energy Rotating Grid Stabilizer is not just a technological innovation; it is a vital component of the modern energy landscape. By providing inertia, short circuit power and reactive power without burning fossil fuels, the RGS is key to ensuring a reliable and sustainable energy future.

Siemens Energy Rotating Grid Stabilizer in action at Uniper's Killingholme power station, supporting grid stability and supporting renewable energy integration.

More Information:
https://www.siemens-energy.com/rgs

SIEMENS energy

How Decreasing Inertia Is Affecting Power Grids and What to Do About It

People in the power industry understand inertia and its importance to grid stability. As large thermal power plants and other inertia-providing units are replaced with renewable resources that provide no inertia, grid stability is at risk. Cost-effective solutions are available today, however, to maintain and even enhance grid operations.

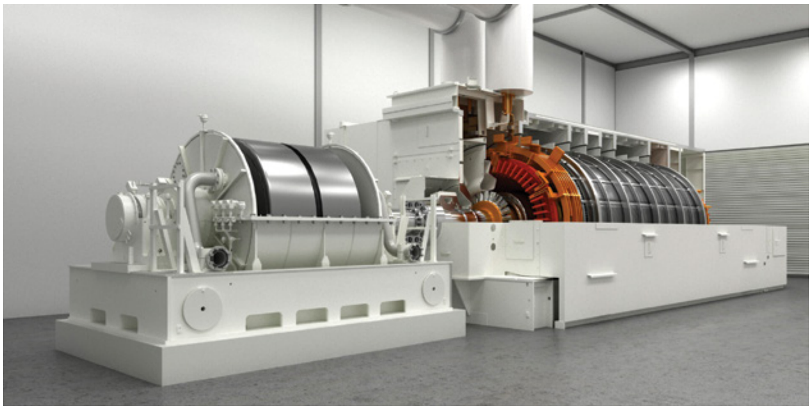
Aaron Larson

Concerning power grid operation, inertia refers to the energy stored in the rotating masses of synchronous generators, typically found in conventional power plants such as coal, gas, nuclear, and hydropower facilities. This stored kinetic energy provides an automatic and instantaneous response to fast frequency changes in the grid.

For example, when a sudden imbalance occurs between power generation and load demand, such as when a large generator trips offline or a factory suddenly engages massive equipment causing an increase in demand, the rotating masses of generators naturally resist changes in rotational speed. This is due to a release of energy as the rotating mass speed is reduced, or conversely, energy is absorbed by the rotating mass through a speed increase. This process slows down the rate of frequency change, providing crucial time for control systems to respond, which helps maintain grid stability during transient events.

Historically speaking, inertia has been essential for grid stability for several reasons. Because inertia limits the rate of change of frequency (ROCOF) during disturbances, it can prevent protective relays from tripping unnecessarily. Additionally, the valuable seconds of stability it provides allows primary frequency response mechanisms, such as governor controls, to adjust.

Meanwhile, the short circuit power of synchronous machines, such as a turbine generator in a thermal power plant, has also been essential for power system protection and stability. When a short circuit occurs, the generator's immediate high-current response activates protective relays and circuit breakers, allowing for quick isolation of the fault.



1. Adding a flywheel to a synchronous condenser significantly increases rotational inertia, which improves grid stability during disturbances by resisting sudden frequency changes. Courtesy: Siemens Energy

Synchronous generators are specifically designed with robust mechanical structures to withstand the electromagnetic forces generated during short circuits, along with thermal capability to handle the heat produced by fault currents. Their damper windings and field excitation systems help maintain stability during transient conditions, while the generator's physical inertia prevents rapid frequency collapse. This combination of features enables the power system to ride through faults without widespread instability or equipment damage, making short circuit power a fundamental design parameter for these machines.

The transition to renewable energy creates challenges for grid inertia. Wind turbines and solar panels are typically connected through power electronic converters, providing no natural inertial response. As conventional generators are retired, system inertia, short circuit response, and reactive power capabilities are all adversely affected, which makes power grids more vulnerable to frequency excursions and instability.

Synchronous Condensers: A Grid-Enhancing Solution

There are several ways to address declining inertia in power grid operations. One is with synchronous condensers. "Synchronous condensers are a sophisticated solution to the inertia problem in modern power grids," said Ruediger Jansen, head of Siemens Energy's Sales for Europe and Africa of FACTS (flexible alternating-current transmission systems) product lines. "They're essentially synchronous motor-generators that operate without being connected to a prime mover, such as a turbine, or a mechanical load."

As Jansen suggested, a synchronous condenser consists of a synchronous machine connected directly to the grid. It includes a large rotating mass, sometimes with additional flywheels (Figure 1), but it has no mechanical power generation. The inertial response is due to the conversion of stored kinetic energy in the rotating shaft, which injects or absorbs electrical power to or from the grid, effectively operating as a motor in the system.

2. After a 1.34-GW nuclear power plant in Gundremmingen, Germany, was removed from the power grid, measures were required to ensure grid stability with respect to inertia and reactive power compensation. A synchronous condenser was incorporated in Oberottmarshausen to stabilize the system. Courtesy: Siemens Energy

3. Addition of a flywheel enhances inertial response, providing better fault ride-through capability, superior frequency regulation, and increased short-circuit power contribution—benefits that are especially valuable in modern power systems with high renewable energy integration. Courtesy: Siemens Energy

When connected to the grid, the synchronous condenser spins at synchronous speed, matching grid frequency. Reactive power exchange can be controlled under steady state conditions. By over-exciting the machine, a synchronous condenser can provide reactive power, and by under-exciting, it can absorb reactive power. With this, the voltage level of the grid connection point can be controlled to a stable voltage level. Meanwhile, it provides inertia through its rotating mass and can absorb or deliver real power briefly during disturbances.

Synchronous condensers offer several advantages. They provide immediate inertial response during frequency disturbances, just like conventional generators. They can also supply or absorb reactive power, helping with voltage regulation (Figure 2). They contribute to system strength by increasing short-circuit current capability, improving the grid's ability to ride through faults. And, perhaps most importantly, they work seamlessly with existing grid infrastructure and protection systems.

Synchronous condensers can be deployed in several ways. One is as a new installation. Purpose-built units installed at strategic grid locations can be planned appropriately to provide a great grid stabilization option. New build is attractive for long-term investment and can be optimized to meet customer needs.

Converting a retired thermal generator into a synchronous condenser by removing the turbine is also an option. Conversion means repurposing already-existing assets, which makes good use of previous investments and generally allows grid connection on short notice.

"Siemens Energy offers rotating grid stabilizer [RGS] conversion solutions leveraging our engineering expertise and service capabilities," said Dr. Norbert Henkel, Siemens Energy's global head of sales for Steam Plant Modernization and Transformation. "The RGS conversion comprises complete solutions for converting existing power plant equipment into synchronous condensers, from engineering to installation and commissioning."

Repurposing an existing asset can be very cost-effective. "By utilizing power plants that may otherwise become stranded assets, RGS conversions provide necessary system inertia, short circuit power, and reactive power to the grid for that balance," Henkel explained. "It can be a great option in many cases."

The basic conversion provides a cost-optimized solution that converts existing turbogenerators into synchronous condensers quickly. As mentioned previously, generators can also be extended with additional rotating mass from a flywheel to provide maximum inertia. Flywheels (Figure 3) are operated in a partial vacuum and equipped with a cooling system to minimize friction losses and reduce cooling efforts. Siemens Energy says its extensive rotor dynamics knowledge, and decades of experience with countless other engineering aspects, allows the company to guide and confirm customer benefits with detailed technical support.

"We also offer a hybrid conversion package," said Henkel. "This option provides maximum flexibility. It basically couples a gas or steam turbine with an additional SSS [synchro-self-shifting] clutch between the generator and the turbine. The option also exists to add additional inertia with a flywheel coupled to the existing shaft line. Our engineers can help evaluate the best design for any given situation."

Successful Grid-Stabilizing Projects

Synchronous condensers have proven to be critical grid-strengthening assets across the global energy landscape, providing essential stability services as power systems transition toward renewable-dominated generation. As grids worldwide face the dual challenges of retiring conventional generation and accommodating intermittent resources, the examples that follow demonstrate how synchoronous condensers can be utilized to solve modern power system challenges without compromising reliability.

Moneypoint Power Station, Ireland. The Moneypoint Power Station has been a significant fixture in Ireland's energy landscape for decades. Located near Kilrush on the Shannon Estuary, it was developed as a major component of Ireland's strategy to diversify its energy resources following the oil crises of the 1970s. Construction of the station began in the late 1970s and was completed in 1987. The facility was designed with a deepwater port capable of receiving large coal shipments, making it strategically important to Ireland's energy security. With an output capacity of 915 MW, Moneypoint became Ireland's largest electricity generation station and its only coal-fired power plant.

The station has been operated by the Electricity Supply Board (ESB), Ireland's state-owned electricity company. For more than three decades, Moneypoint served as a cornerstone of Ireland's electricity system, typically generating about 25% of the country's electricity needs.

In recent years, as Ireland committed to decarbonization targets and renew-

4. The Moneypoint synchronous condenser, installed as part of ESB's Green Atlantic @ Moneypoint project, provides several key benefits to the Irish grid. Courtesy: Siemens Energy

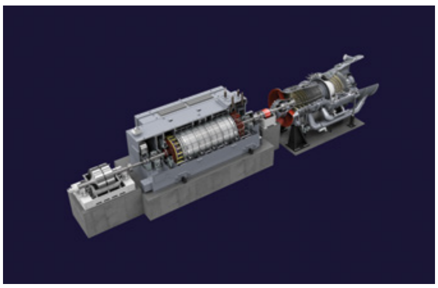
able energy goals, Moneypoint's role began to shift. Coal-fired generation has been gradually reduced, and the ESB announced plans to cease coal burning at the site by the end of 2025 as part of Ireland's climate action commitments. The "Green Atlantic @ Moneypoint" project represents the station's transformation from coal-powered generation to a renewable energy hub, with a synchronous condenser installation marking the beginning of this new chapter. This repurposing leverages the site's existing infrastructure, including its electrical connections to the grid and deepwater port facilities, to support Ireland's renewable energy future, while balancing the energy trilemma of security, affordability, and sustainability.

As renewable energy sources, most notably wind, increase in Ireland, grid stability becomes more challenging. The synchronous condenser at Moneypoint (Figure 4) helps alleviate some of those challenges. It includes the world's largest flywheel (130 tons) paired with a 66-ton rotor spinning at 3,000 rpm, providing 4,000 megawatt-seconds (MW-sec) of inertia.

The ESB said the synchronous condenser represented an investment of €50 million. It has enabled the site's transformation by stabilizing power grid frequency variations that could otherwise cause blackouts, essentially providing a low-carbon alternative to the grid-stabilizing functions of the old coal-fired plant. As part of the ESB's vision for the Moneypoint site, it expects to tie in a 1,400-MW offshore wind farm, delivered in two phases; a wind turbine construction and service hub; and the development of a green hydrogen production, storage, and generation facility. The Moneypoint installation is likely just the first of as many as six synchronous condensers needed for Ireland to reach its climate goals.

Townsville Power Station, Australia. RATCH-Australia Corp.'s Townsville Power Station (TPS) is a 242-MW combined cycle power plant that utilizes a single Siemens Energy SGT5-2000E gas turbine and an associated steam turbine (Figure 5). The plant is located about 20 kilometers north of Townsville, Queensland, Australia, and was commissioned in 1999. It supplies electricity to the National Electricity Market (NEM). The output from TPS's gas turbine is connected to the 132-kV Powerlink electrical network, and its steam turbine output is connected to the Ergon 66-kV network.

The station has undergone several upgrades and refurbishments over the years to improve efficiency and reduce emissions. Most recently, however, the owners decided to convert the gas turbine and generator at the site to a Hybrid Rotating Grid Stabilizer (RGS). This was spurred by concerns Powerlink had around grid stability as the share of renewables in Australia's energy mix has risen.



5. Adding a synchro-self-shifting (SSS) clutch to the shaft between the gas turbine and the synchronous generator at the Townsville Power Station was the least-cost option to procure system strength. The clutch allows a near-instantaneous switch from power generation to synchronous condenser mode. Courtesy: Siemens Energy

The Australian Energy Market Operator (AEMO) requires grid operators, including Powerlink, to provide a minimum fault level and procure system strength. After reviewing eight different possible solutions, Powerlink concluded the addition of a clutch to the shaft between the gas turbine and the synchronous generator at TPS was the least-cost option to address the shortfall. Thus, it entered into an agreement with TPS for the provision of system strength services.

To carry out the project, Siemens Energy will provide integrated service solutions to convert the gas turbine to a Hybrid RGS during a scheduled major outage this year. Replacing the intermediate shaft of the gas turbine with an SSS clutch will provide an instantaneous switch from power generation to synchronous condenser mode. When in synchronous condenser mode, the Hybrid RGS unit can provide rotating inertia and short-circuit power without the need to produce power. It has been calculated that this will provide a short-circuit contribution of approximately 350 MVA to 400 MVA. The electrical inertia while operating in the grid stabilization mode is calculated to be about 250 MW-sec and approximately 1,000 MW-sec while operating in power generation mode.

This is Siemens Energy's first project in Australia to convert an operating gas turbine unit to a Hybrid RGS. The project also marks the first Hybrid RGS conversion project on this size of gas turbine worldwide. The benefits to RATCH-Australia include a new revenue stream from providing grid services, and the capability to switch flexibly between power generation and grid stabilization modes. Moreover, the grid stabilization capability comes at up to 50% less cost than a new synchronous condenser, and it can be completed in 18 months rather than three years. The RGS can also be serviced in the same maintenance cycle as the gas turbine.

Intermountain Power Project, U.S. The Intermountain Power Project (IPP) is located in the Great Basin region of western Utah. It has generated an average of more than 13 TWh of energy each year from its two coal-fired units.

6. Uniper appointed Siemens Energy to install and commission two synchronous condenser units at its Killingholme power station in Lincolnshire, UK. This included the repurposing of two steam turbine generators and installing flywheels at the site. Courtesy: Siemens Energy

Operating continuously since 1986, the IPP is a story of unprecedented cooperation. The energy it produces is delivered over the project's alternating-current and high-voltage direct-current (HVDC) transmission systems to 35 participants that have operations across parts of six states, although most of the energy is supplied to customers in Utah and California. The participants include 29 cities and towns that operate their own electric utilities. Those municipalities range in population from 254 in rural Utah to 3.9 million in Southern California.

As these entities' current power purchase agreements near expiration, Intermountain Power Agency (IPA)—the owner of the plant—has expanded its role as a regional energy hub, including utilizing renewable energy resources to produce and store hydrogen that can be drawn upon to generate carbon-free electricity. As part of a project IPA calls "IPP Renewed," new natural gas–fueled electricity generating units have been installed capable of utilizing hydrogen for 840 MW of net generation output. The project utilizes much of IPP's existing infrastructure but also includes modernization of IPP's Southern Transmission System.

Simultaneously, underground storage caverns in a unique salt dome located deep beneath the power station are being developed to store hydrogen, which will be used to also fuel the power station. IPP will use this clean hydrogen—made from renewable energy–powered electrolysis—as dispatchable fuel. The new power station turbines will be designed to utilize 30% hydrogen fuel at startup, transitioning to 100% hydrogen by 2045.

The project will also highlight the crucial role of Siemens Energy's technology in integrating renewable energy resources and enhancing grid stability. Among the items supplied by the company are generator step-up transformers and synchronous condensers. The transformers are equipped with the Siemens Energy Sensformer solution, which uses proprietary models to assess data from physical and virtual sensors, allowing optimal efficiency for maintenance and operations. Three SGen-2000P series synchronous condensers, meanwhile, will greatly increase the amount of energy that can be delivered from IPP to project participants in Southern California. In fact, the HVDC line from Delta, Utah, to Adelanto, California, could not operate at 100% capacity without these condensers. Notably, this is the largest condenser project at one location in the U.S. and possibly the world.

Killingholme Power Station, UK. Commissioned in 1992, Killingholme has a rich history of innovation and is home to one of the biggest gas-fired power plants in the UK. As one of the leading power producers in the UK, Uniper has always delivered grid stabilizing services. When the country's grid system operator, National Grid ESO, launched the Stability Pathfinder project, Killingholme was identified as a prime site for Uniper to provide dedicated grid stability services. For this, Uniper sought to repurpose steam turbine generators decommissioned after the power station was converted from a combined-cycle plant to an open-cycle plant in 2017.

Converting an existing turbine generator and retrofitting a flywheel was a major undertaking for the station (Figure 6), so a team of engineers from Uniper and Siemens Energy collaborated on the project. Teamwork was essential in developing a bespoke solution for the Killingholme facility.

The team removed the steam turbine and reused the generator as a grid stabilizer. Then, they added a flywheel in place of the turbine to provide maximum inertia. This conversion provides much needed services to the area's power grid.

Siemens Energy was responsible for the supply, installation, and commissioning of major equipment including flywheels, auxiliary systems, electrical startup systems, excitation systems, and protection. The scope of supply also included the fully redundant Omnivise T3000 control system, including vibration monitoring for the synchronous condenser and the system's implementation into the existing control room. Siemens Energy also provided civil engineering, pipework, and electrical system integration.

The partnership between Uniper and Siemens Energy yielded numerous benefits. The group was able to make use of retired generators, while seamlessly providing essential grid stabilizing services to National Grid ESO. This proactive approach supports the UK grid's stability and enables the integration of renewable energy sources.

Effective Solutions for the Future

As power systems worldwide navigate the complex transition toward renewable energy dominance, synchronous condensers are a crucial bridge technology that marries traditional grid stability principles with modern decarbonization goals. The examples featured above demonstrate that these seemingly simple rotating machines offer sophisticated solutions to some of the most pressing challenges facing modern grids.

By providing essential system services—inertia, short-circuit strength, and reactive power support—synchronous condensers enable higher renewable penetration while enhancing reliability. Their ability to retrofit existing infrastructure at conventional power plants offers both economic and environmental advantages, transforming potential stranded assets into valuable grid resources.

As the world looks toward a future with ever-increasing levels of inverter-based resources, the humble synchronous condenser—a technology with century-old roots—may well prove to be one of the most important enablers of a clean energy future. For grid operators and policymakers alike, these installations represent not merely a technical solution but a strategic investment in creating resilient, stable, and ultimately sustainable power systems capable of supporting the renewable revolution. ■

*—**Aaron Larson** is POWER's executive editor.*

Decarbonization Whiplash Prompts a Power Sector Recalibration

What happens when a political U-turn suddenly upends years of decarbonization strategy? As the U.S. House of Representatives moves to dismantle key clean energy tax credits, *POWER* examines how utilities and developers are rethinking timelines, technologies, and financing, while racing to keep the energy transition on track.

Sonal Patel

On May 22, 2025, the U.S. House of Representatives narrowly—by a 215–214 vote—passed the "One Big Beautiful Bill Act." While the U.S. Senate is expected to take up the bill in early June—and Republicans aim to have it passed in both chambers by July 4—the bill's rapid (even if contentious) passage in the House has effectively driven a jolt through the power sector, adding a new element of uncertainty that threatens to upend strategic planning and investment, which has for years been tightly honed on decarbonization.

The bill's fate in the Senate is highly uncertain, owing to a slim majority and vocal opposition from some Republicans, which suggests a likelihood of significant amendments, especially to its most consequential energy tax credit provisions. Provisions of deep concern in the House bill include the following.

Accelerated Phase-Out of Tech-Neutral Tax Credits. The legislation begins phasing down the Section 45Y clean electricity production credit and the Section 48E investment tax credit in 2029, culminating in full elimination by the end of 2031—a year earlier than under the Inflation Reduction Act (IRA). In a major shift, projects must now be placed in service by these deadlines to qualify, replacing the former "commenced construction" standard. The change risks disqualifying projects already underway but delayed by permitting or interconnection bottlenecks.

Early Termination of the 45V Hydrogen and 45X Advanced Manufacturing Credits. The bill terminates the 45V clean hydrogen credit entirely as of Jan. 1, 2026—seven years earlier than scheduled—and shortens the 45X advanced manufacturing credit phase-out to zero by 2032, with an immediate cutoff for wind components by the end of 2027. The measure could significantly curtail investment in electrolyzers and domestic supply chains for solar and storage technologies.

Stringent Foreign Entity of Concern (FEOC) Rules. The legislation bars access to clean energy tax credits for any project that includes material assistance from, or financial ties to, designated foreign entities, particularly those based in China, Russia, North Korea, or Iran. These rules could apply retroactively in some cases and include indirect ownership, licensing agreements, and service provision thresholds.

Transferability Eliminated for Most Credits After 2027. Starting two years after enactment, developers will no longer be able to transfer tax credits for projects under Section 45Y (clean electricity production), Section 48E (clean electricity investment), Section 45Q (carbon oxide sequestration), Section 45Z (clean fuel production), and Section 45U (zero-emission nuclear power). The measure targets a key IRA reform that helped unlock tax equity for mid-market developers and public power entities, and is expected to tighten project financing and hinder smaller-scale clean energy deployment.

Nuclear Carve-Outs Preserve Eligibility and Transferability. In contrast to cuts elsewhere, the legislation preserves phased credit eligibility for existing and advanced nuclear projects under Section 45U through 2031, with reduced values beginning in 2029. However, like other clean energy credits, transferability for 45U is eliminated for projects that begin construction more than two years after enactment, potentially limiting its financing flexibility in later years.

Clean Vehicle and Energy Efficiency Credits Terminated. The bill terminates a slate of credits by the end of 2025, including the 30D clean vehicle credit, the 45W commercial electric vehicle (EV) credit, and credits supporting residential solar, heat pumps, and energy-efficient construction (25C, 25D, 45L). The changes are expected to affect consumer adoption, municipal fleet planning, and contractor hiring pipelines.

Industry Observers Respond

The immediate market reaction has been severe. "The Reconciliation Bill, as it currently stands, will have a tremendous and damaging impact on future renewable development—at a time that energy needs in the U.S. are projected to increase substantially," attorneys from law firm Vinson Elkins said in a brief. "The Reconciliation Bill's far-reaching consequences will affect manufacturers, developers, innovators, financiers, and customers, among many others. Potentially most damaging will be the loss of onshoring opportunities and the loss of jobs that have been created by the now substantial energy transition and renewable workforce."

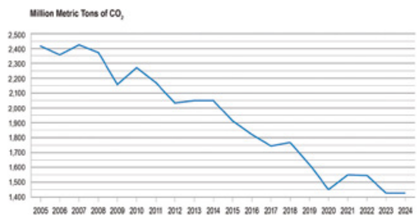
Clean energy groups and industry groups alike expressed similar consternation. "By a margin of one vote, the House voted to retreat in our competition with China for manufacturing jobs and to weaken our technology sector in the global race for digital dominance," said Jason Grumet, CEO of the American Clean Power Association. Ray Long, president of the American Council on Renewable Energy, warned that the bill would "undermine projects that are ready to come online, meet our nation's growing energy needs, and create jobs." And even groups like ClearPath Action, which support advanced nuclear and carbon capture, cautioned that the bill, as written, is "insufficient to support energy producers to meet growing demand."

A New Hurdle for Utilities

The measure throws a new wrench into the power sector, where utilities and power companies have spent the past decade advancing decarbonization strategies (Figure 1). Utility roadmaps cite a mix of drivers: regulatory compliance, financial incentives, risk mitigation, the improving economics of clean technologies, and the imperative to maintain a social license to operate. State mandates and federal policy have played a pivotal role, with public utility commissions and legislators pushing utilities to adopt carbon-reduction targets and cleaner generation portfolios.

Meanwhile, shareholder activism, and the rise of environmental, social, and governance (ESG) frameworks, have made carbon transparency and climate risk management central to utility strategy. Investors now routinely demand emissions disclosures and net-zero alignment, viewing strong ESG performance as a proxy for long-term business resilience and a prerequisite for capital access. Utilities have also responded to customer pressure for cleaner energy, noting that both residential and commercial buyers increasingly reward sustainability commitments and demand accelerated transitions. By early 2025, more than 80 U.S. utilities and their parent companies had announced long-term carbon reduction targets, ranging from achieving 100% renewable energy by 2030 to achieving net-zero greenhouse gas emissions by 2050.

Still, policy uncertainty and abrupt changes to federal incentives have become a significant obstacle for utilities seeking to implement long-term decarbonization strategies, as noted by the heads of several utilities during recent earnings calls. "We tend to look at this from the customer's perspective," said Duke Energy President and CEO Harry Sideris. "And really, our overarching objective is to maintain affordability for our customers. And that's what we've framed our advocacy around. The savings our customers receive from these energy credits fall right in line with what the president wants to do, which is delivering on his promise to reduce power bills across the country. As you know, each one of these dollars that we earn in energy tax credits goes back to our customers. The nuclear tax credits are most important to us. Our well-run, low-cost nuclear plants earn over $500 million of tax credits that go directly to reducing our customers' bills."



1. U.S. electric power sector carbon dioxide emissions have fallen nearly 41% since 2005, reaching their lowest levels in two decades as of 2024. According to preliminary estimates from the U.S. Energy Information Administration (EIA), this long-term decline reflects a shift toward carbon-free sources—which now supply 42% of U.S. electricity—and ongoing decarbonization across the power generation fleet. Courtesy: Edison Electric Institute

For now, however, company heads indicated they will push to stay the course on decarbonization. NextEra CEO John Ketchum framed the effort in terms of "energy realism" and "energy pragmatism." He noted, "Energy realism is about embracing all forms of energy solutions and understanding the demand for electricity in the United States is here now, and it's not slowing down. Frankly, it's unlike anything we've ever seen since the end of World War II."

While NextEra continues to push solar and battery storage as the "lowest cost form of power generation," Ketchum emphasized that these technologies are also uniquely ready to meet near-term needs. "We can build these projects and get new electrons on the grid in 12 to 18 months," he said, describing them as a "critical bridge" to emerging technologies. While the company sees long-term promise in natural gas and nuclear, Ketchum pointed to several constraints, including a shortage of gas turbines, construction timelines that have doubled, and rising costs due to labor shortages and tariffs. On nuclear, he cautioned, "SMR [small modular reactor] technology is still 10 years away at scale in the best of scenarios and at a much higher price point than gas-fired generation."

Rethinking the Resource Mix

Even as policy turbulence rattles long-range plans, utilities and developers are pushing ahead with energy technologies that can be scaled rapidly and decarbonize affordably. One reason is urgency: the power sector is bracing for an extraordinary period of load growth, fueled by electrification, artificial intelligence, industrial reshoring, and the data center boom. Another is inertia: Billions in planning and investment have already been committed to clean energy buildouts, and many developers remain bullish on their long-term viability. But as federal tax support enters a phase of deep uncertainty, the spotlight has gradually shifted to which decarbonized technologies are ready (or could become ready) to shoulder the load.

Solar and Battery Storage. Solar and battery storage remain the backbone of new U.S. power sector capacity in 2025, accounting for 81% of the 63 GW of utility-scale generation additions projected by the Energy Information Administration (EIA)—a nearly 30% increase over 2024—led by Texas and California. Battery storage is set for a record 18.2 GW, up 77% from last year. Residential solar costs appear to have stabilized at $3/W, and battery storage costs have decreased to $200–$400/kWh, driven by improvements in manufacturing scale and technology.

However, interconnection queues and permitting remain critical bottlenecks. Developers are reporting average wait times of four to five years as project withdrawals are rising, given climbing grid connection costs. Meanwhile, the policy environment remains volatile. The House-passed reconciliation bill would sunset key IRA tax credits for solar and storage after 2028, and eliminate credit transferability, thereby undermining project finance and threatening projects that rely on global supply chains, especially those with Chinese content. On the flip side, corporate demand remains robust: Amazon, Microsoft, and others are driving record procurement.

Nuclear. Riding on renewed momentum, the nuclear sector is being propelled by interest in advanced reactor projects and surging demand for 24/7 clean power from data centers and industrials. As noted above, the House's 2025 bill is set to accelerate phaseouts for 45U, 45Y, and 48E credits but generally preserves eligibility for advanced nuclear projects that begin construction before 2029. Still, project financing remains a challenge. The past year, however, has ushered in master limited partnerships for nuclear, which is effectively broadening private capital access.

Fuel supply is now the sector's biggest constraint. While the Department of Energy (DOE) has announced the distribution of high-assay, low-enriched uranium to five advanced reactor developers, domestic enrichment is lim-

2. Calpine's Sutter Decarbonization Project is a flagship carbon capture and sequestration (CCS) retrofit of the 550-MW Sutter Energy Center in Northern California. Selected for cost-shared support by the U.S. Department of Energy's Office of Clean Energy Demonstrations, the project will seek to capture and permanently store up to 1.75 million metric tons of CO_2 annually with a 95% capture efficiency. It is part of Calpine's broader CCS portfolio, which includes projects in Baytown, Texas, and at the Los Medanos Energy Center. Courtesy: Calpine

ited, and Russian supplies are set to end by 2028.

Carbon Capture, Utilization, and Storage (CCUS). CCUS has gained some traction over the past year, especially at natural gas plants. U.S. developers, such as Calpine (Figure 2) and ExxonMobil, are advancing Texas projects that aim to capture up to 2 million metric tons of carbon dioxide annually. For now, the uncertainty posed by the House reconciliation bill's proposed repeal of Section 45Q critically threatens project economics. Financing remains complex, and projects often rely on federal grants, power purchase agreements (PPAs), and storage partnerships, but project viability is often hindered by the need for coordinated investment across capture, transport, and storage. Permitting for Class VI injection wells and pipeline networks also continues to delay timelines, despite federal efforts to streamline approvals.

Hydrogen. Several utilities and original equipment manufacturers of gas turbines have piloting hydrogen-to-power and co-firing projects, showcasing a pathway to 100% hydrogen-capable turbines in demonstrations. Several utilities are also testing blending hydrogen with natural gas. However, the outlook for hydrogen in the power sector remains dismal.

The DOE's regional H2Hubs, which had spurred commercial partnerships, especially with data centers and industrials seeking long-term offtake, stand to suffer if Section 45V hydrogen credit provisions are terminated early. Infrastructure also remains a crucial bottleneck: storage and transport networks are lagging, though salt cavern storage and pipeline retrofits are in early stages.

Geothermal. The geothermal sector has marked several essential advances in conventional and enhanced geothermal systems (EGS), given strong DOE support. For now, the DOE's $4.5 billion roadmap for demonstration projects and new leadership prioritizing geothermal as a dispatchable, 24/7 clean power source remains intact.

Several projects are being spearheaded by utilities and tech companies, including Google and Meta, as well as oil and gas firms, which aim to leverage their drilling expertise. Startups like Fervo (Figure 3) and Sage Geosystems have notably raised record funding. The House bill, however, accelerates credit phase-outs, ends transferability, and introduces foreign content rules, which risk investment and slow pipelines. High upfront costs, lengthy permitting, and interconnection delays remain key hurdles for the sector.

Offshore Wind. While the global offshore wind market is projected to rise from $4.91 billion in 2024 to $6.6 billion in 2025, a federal executive order in January 2025 paused all new leasing in the U.S. and put pending projects under review, casting uncertainty over more than 60 GW of planned capacity. States are stepping up—eight coastal states have introduced more than two dozen bills to strengthen port infrastructure, supply chains, and workforce development, aiming to keep momentum despite federal headwinds.

Supply chain constraints in the sector have grown more acute over the past

3. Fervo Energy's enhanced geothermal project in Nevada—developed through a first-of-its-kind corporate agreement signed with Google in 2021—began delivering 24/7 carbon-free electricity to local grids in November 2023. The pilot uses horizontal drilling and fiberoptic sensing to unlock difficult-to-access heat, demonstrating how oil and gas techniques can help scale advanced geothermal deployment. Courtesy: Google

year. The National Renewable Energy Laboratory (NREL) estimates half of the U.S. offshore wind pipeline is at risk of delay beyond 2030, owing to limited port and vessel infrastructure. At least $22 billion will be needed for domestic manufacturing, ports, and installation capacity, it suggests. Meanwhile, domestically produced components are becoming more cost-competitive, but imports remain necessary.

Virtual Power Plants (VPPs). VPP capacity has reached 33 GW in North America, but it must increase to between 80 GW and 160 GW by 2030 to meet 10% to 20% of the peak load and offset the retirement of thermal plants, according to the DOE. So far, utilities including National Grid and Pacific Gas and Electric (PG&E) are launching VPP programs that aggregate rooftop solar, behind-the-meter batteries, smart thermostats, and EVs that can be deployed in under six months.

The Continued Evolution of Business Models

For now, U.S. clean energy business models are poised for significant transformation in response to mounting policy headwinds and shifting market structures. Historically, many developers, particularly small and mid-market players, relied on straightforward tax credit monetization through transferability, which allowed them to sell credits and avoid complex tax equity partnerships. However, the May 2025 House reconciliation bill, which proposes accelerating the phaseout of key tax credits and eliminating transferability for most non-nuclear projects within two years, could render traditional financing models unworkable, experts suggest.

"These provisions would deter the development of renewable projects in the U.S.," said Sylvia Leyva Martinez, principal analyst at Wood Mackenzie, in a May 2025 statement. The firm notes that the changes could disproportionately impact mid-market developers and public power entities that lack the tax liability to monetize credits directly and have depended on transferability to secure project financing. As a result, business models may shift toward more adaptive, risk-managed structures, emphasizing direct pay (for eligible public and nonprofit entities), strategic partnerships, and diversified revenue streams to navigate rising policy uncertainty and execution risk. ■

*—**Sonal Patel** is a POWER senior editor.*

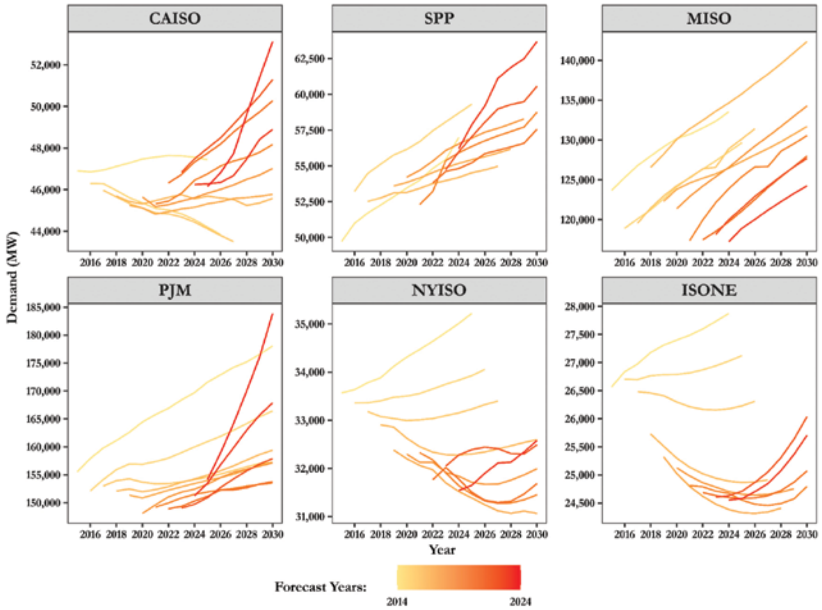
Out of Sync: The Infrastructure Misalignment Undermining the U.S. Grid

U.S. power infrastructure—the intricate physical fabric that laces together generation, transmission, and distribution—is under intensifying strain. Outdated and overextended, it must now absorb relentless growth from electrification and data centers or risk escalating reliability threats, surging costs, and a weakened global competitive edge. *POWER* examines the dysfunction and what it will actually take to future-proof the grid financially, physically, and institutionally.

Sonal Patel

In May, as the North American Electric Reliability Corporation (NERC) unveiled its latest summer reliability outlook, officials underscored a key point: The grid is stretched. "We've done a lot as a cross-sector industry—gas and electric—to make sure we're operating efficiently, reliably, cost-effectively, and affordably," John Moura, NERC's director of reliability assessment and performance analysis, told *POWER*. "Those paradigms have made the reserve margins get to a point where we have enough to serve demand and a little reserve to cover some contingencies. But as demand grows, we've got to build infrastructure. We really don't see a lot of ways around it."

The infrastructure "gap" has been a longstanding concern. Historically, grid buildout has been a reactive, incremental—even "lumpy"—process, advancing in fits and starts atop shaky scaffolding, vulnerable to shifting policy winds and uneven investment. For decades, the bulk power system was treated as a fixed structure, patched, retrofitted, and reinforced only as needed to support a largely stable load. Many utilities, driven by cost-recovery mechanisms that favored maintenance over modernization, found little incentive to extend transmission lines across jurisdictional divides in the absence of strong federal siting authority. And, given policy shifts with every changing administration and oversight still fragmented among state regulators, regional transmission operators, and federal agencies, the physical system is growing increasingly—and critically—misaligned (see sidebar "Engineering Organization Gives U.S. Energy Infrastructure a D+").



1. Forecasted peak summer demand is rising sharply across U.S. regional transmission organizations (RTOs) and independent system operators (ISOs), with updated 2024 projections outpacing pre-2020 expectations. PJM Interconnection, the Midcontinent Independent System Operator (MISO), and the Southwest Power Pool (SPP) show particularly steep upward revisions, highlighting mounting pressure on grid planning and capacity buildout timelines. Source: Federal Energy Regulatory Commission, State of the Markets Report 2024

Adding new pressure to the aging foundation is a fast-approaching new class of high-density load from data centers, artificial intelligence (AI) clusters, electrified industry and manufacturing, and synthetic fuel production. Utilities and grid planners are scrambling to adapt. American Electric Power (AEP) in May, for example, reported more than 180 GW of load in its queue, five times its system peak, and is already investing in 20 GW of new capacity to serve rising demand.

Regional transmission organizations (RTOs) and independent system operators (ISOs) have also sharply revised their forecasts (Figure 1). PJM Interconnection now projects a 47% rise in summer peak load by 2039; the Midcontinent Independent System Operator (MISO) expects electric load to surge 60% over the next two decades; and the Electric Reliability Council of Texas (ERCOT) forecasts its summer peak demand will climb 69%—from 85.8 GW in 2025 to 144.5 GW by 2031. ERCOT also projects total energy consumption to more than double over the same period, driven by

Engineering Organization Gives U.S. Energy Infrastructure a D+

In its latest *Report Card for America's Infrastructure*, released in March 2025, the American Society of Civil Engineers (ASCE)—the nation's oldest engineering organization, founded in 1852—gave U.S. energy infrastructure a dismal D+, citing infrastructure aging, investment shortfalls, and a widening mismatch between grid capability and modern demands. The mark represents a downgrade from the C– rating the sector received in 2021, its last quadrennial report, which reflected early momentum around grid modernization. Still, the current D+ rating generally echoes previous grades over the past decade.

According to the 2025 report, the U.S. energy system comprises more than 600,000 miles of transmission lines, 5.5 million miles of distribution lines, 180 million poles, and 79,000 substations, as well as 60 million distribution transformers, and extensive natural gas and petroleum pipelines. All of these serve a fleet of 12,500 utility-scale power plants. But that infrastructure is aging: 70% of transmission lines and transformers are more than 25 years old, 60% of circuit breakers exceed 30 years, and half of the nation's gas pipelines date back to the 1950s and 1960s.

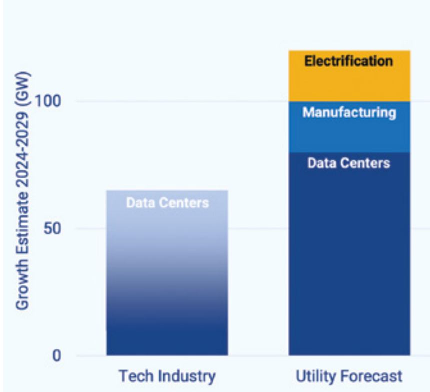
Worn and weathered—and in many cases operating well past their intended lifespans—components of the energy infrastructure are slipping into obsolescence, increasingly unable to accommodate the modern power system's demands: two-way power flows, fast-ramping inverter-based resources, and a gauntlet of extreme weather, cybersecurity threats, and precision-driven load events. Despite recent federal investment, ASCE warns that spending has not kept pace with need, and that inflation and supply constraints have eroded the purchasing power of public dollars. Distribution transformer lead times, for example, now average 120 weeks, up from 50 just three years ago, and prices have surged 60% to 80%.

The implications are increasingly visible, ASCE notes. While weather-related events have accounted for 80% of major grid outages since 2000, much of the system still lacks basic hardening. Aging transformers, deteriorating substations, and overloaded distribution lines have become liabilities as utilities battle against outages, wildfires, and storm-related damage. On the gas pipeline side, between 2013 and 2022, the U.S. reported more than 1,100 significant incidents, resulting in more than $4 billion in damage, 470 injuries, and 90 deaths. Without sustained investment and coordination, ASCE warns, the energy system risks becoming a structural bottleneck to economic growth, public safety, and national resilience.

To reverse the decline, ASCE calls for a comprehensive modernization strategy that focuses on expanding capacity, deploying advanced technologies, and accelerating project timelines. Its top recommendations include increasing sustained investment; streamlining permitting and siting processes for both transmission lines and natural gas pipelines; creating cost-recovery mechanisms that support innovation and a more flexible grid; and improving coordination among federal agencies, state regulators, and utility operators. ASCE also highlights an urgent need to strengthen the energy workforce, warning that deployment timelines will falter without enough skilled labor to implement system upgrades at scale.

large flexible loads like data centers, hydrogen production, cryptomining, and industrial electrification, alongside a rapid expansion in electric vehicle charging, which alone is expected to increase more than fivefold by 2031. RTO and ISO leaders all report efforts to accelerate unprecedented transmission buildouts, upgrade market structures, and launch interconnection and planning reforms to better align infrastructure with explosive demand growth.

Demand forecasts, however, remain a wildcard (Figure 2). At the Enverus Evolve conference in Houston this May, experts warned that the scope and scale of digital infrastructure, particularly AI-enabled data centers, are already outpacing traditional planning models. "We're in a very different, complicated growth phase that's hard to sort out," said Mark Mills, executive director of the National Center for Energy Analytics. He pointed to the sheer energy intensity of AI inference. If compared in terms of British thermal unit equivalence, "an Nvidia cluster, 1-GW-scale data center, every day, uses as much LNG [liquefied natural gas] as every single launch on a SpaceX Starship. It's going to be more than one



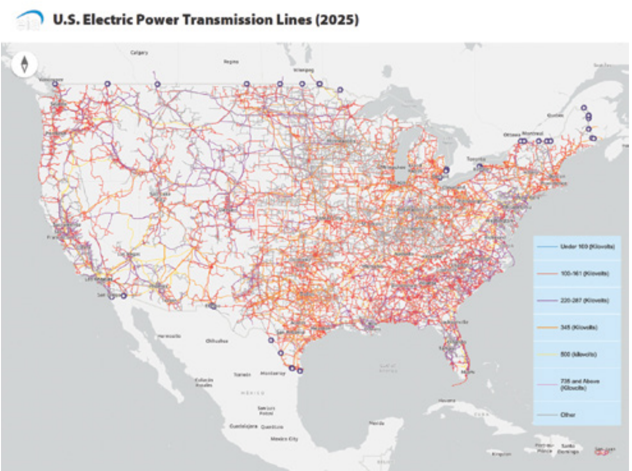
2. "In the aggregate, the power industry does not have access to the data it needs to accurately forecast data center load," noted Grid Strategies, a power sector consulting firm, in an April 2025 analysis. While industry specialists estimate five-year demand growth from 10 GW to 65 GW, Grid Strategies' rough estimate of aggregate utility data center load forecasts is about 80 GW—nearly 10% of the projected 2029 U.S. load. The firm cautioned that this figure relies on "informed speculation" for regions with inconsistent or unpublished breakout data. Courtesy: GridStrategies

cluster, and it's going to be running more than one day," he said. Mills also noted that deep-pocketed tech companies may follow behind-the-meter models, predicting the model could become dominant over the next five to six years, given that the value of getting a data center operational quickly now outweighs the traditional cost considerations.

Echoing the scale of uncertainty, Ryan Luther, director of energy transition research at Enverus, described the sector's expansion as "a capital treadmill." He noted: "If you're going to build a new gigawatt data center, that's about $37 billion of [capital expenditure] upfront, and the chips are $27 billion of that. The chips last five years, and then they need to be replaced." While utilities may not have that type of leverage, tech companies have large cash reserves, Mills noted, and may be uniquely positioned to sustain the investment cycle.

Transmission Expansion Bottlenecks and Reform Attempts

Over 2024, the federal government supercharged the effort to modernize the grid and build out new infrastructure, aided by billions of dollars in funding from the Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act (IRA). Through programs like the Grid Resilience and Innovation Partnerships (GRIP) and the Transmission Facilitation Program, the Department of Energy (DOE) began directing capi-



3. The U.S. power grid spans more than 600,000 miles of transmission lines, most of which operate at voltages under 287 kV, which is considered insufficient for efficient long-distance transfers or large-scale clean energy integration. High-voltage infrastructure of 500 kV and higher remains sparse, which limits interregional coordination and resilience. Source: U.S. Energy Information Administration, U.S. Energy Atlas (May 2025)

tal toward shovel-ready transmission lines and grid-enhancing technologies, and initiated the first National Interest Electric Transmission Corridor (NIETC) designations in over a decade—a measure that could unlock backstop siting authority and catalyze interregional projects long stalled by permitting delays. DOE also finalized its Coordinated Interagency Transmission Authorizations and Permits (CITAP) program in April 2024, establishing itself as the lead agency for environmental reviews and setting a binding two-year timeline for major onshore transmission projects.

Despite record federal investment, however, progress has remained incremental. As the Federal Energy Regulatory Commission (FERC) reported in March, the power system added just 5,578 circuit miles of transmission in 2024, primarily consisting of 138-kV upgrades aimed at addressing local reliability needs. Only 22% of those projects reached 230 kV or higher—the threshold typically required for regional power transfers or large-scale clean energy integration. For context, the DOE's 2023 *National Transmission Needs Study* projects the U.S. will need 54,500 GW-miles of new transmission by 2035—a 64% expansion—under moderate load and high clean energy growth scenarios (Figure 3).

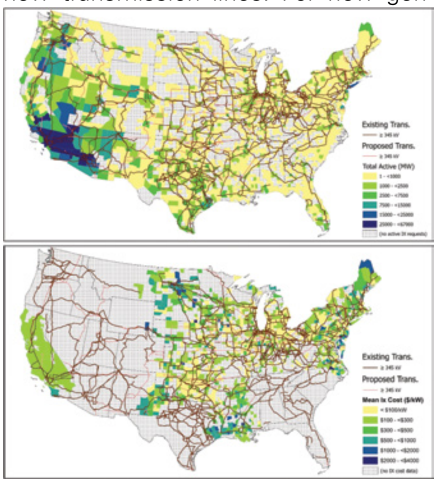
According to a May 2025 working paper from think tank Resources for the Future (RFF), transmission delays remain mired by long-standing barriers. "Linear infrastructures such as transmission lines face siting and permitting challenges in multiple jurisdictions, adding to the timelines for moving from identification of a recognized need for a transmission expansion to having one that is operational," it noted. Over the past few years, "the average development timeline has grown to 10 years for new transmission lines. For new generation capacity, it now takes five years from interconnection request to commercial operation, up from two years in 2008," RFF noted (Figure 4).

The delays directly exacerbate grid stress and congestion, and that has had real implications for overall grid reliability and costs, the think tank warned. Under RFF's central assumptions, transmission delays alone raise total congestion by 14%, with measurable ripple effects: electricity and gas costs rise by $22 billion, or 3% of economy-wide retail energy spending—"more than four times the capital cost savings" from deferring projects. In regions such as PJM, delays have already manifested in record capacity market spikes, underscoring what RFF calls "a key indicator of system reliability."

To address persistent planning and cost-sharing hurdles, FERC in May 2024 issued Order No. 1920—its most consequential transmission rule in more than a decade. The rule requires long-term (20-year) regional transmission planning horizons, updated every five years, and gives states a formal role in scenario development, project selection, and cost allocation. Transmission providers must propose at least one ex ante cost allocation method per selected project, but a dedicated six-month window gives states time to negotiate alternatives. Follow-on orders in November 2024 and April 2025 further strengthened state engagement and clarified compliance milestones. While filings are underway, and FERC officials say the rule is structured to break longstanding logjams, implementation will take time—and friction remains around balancing regional priorities with multistate coordination.

At the state level, several legislatures—including Oregon, Washington, and Montana—moved in 2025 to create dedicated transmission authorities to streamline permitting and financing, following earlier models in Colorado and New Mexico. Regional task forces in Nevada, the Carolinas, and parts of the Midwest are working to harmonize siting rules and planning assumptions.

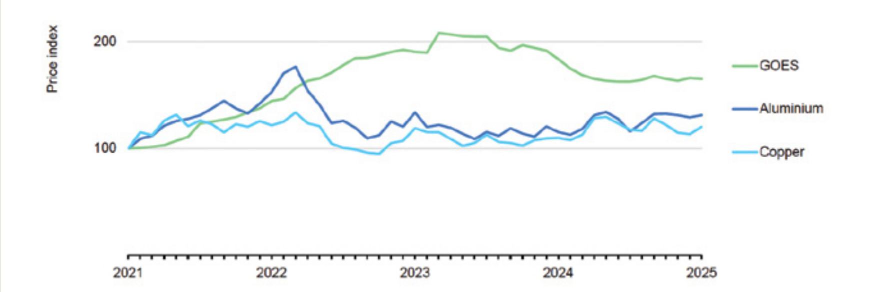
On the project front, large-scale transmission investments also appear to be advancing, despite supply chain constraints (see sidebar "Transmission Supply Chains Are Stretched to the Limit"). Construction is underway on the 732-mile, 3,000-MW TransWest Express high-voltage direct current (HVDC) line, the first major interregional project in the West in decades, which will deliver



4. This graphic, created by researchers at Lawrence Berkeley National Laboratory, illustrates the geographic variation in active interconnection queue capacity (top) and historical interconnection costs (bottom), revealing how transmission access influences where projects are proposed and what it costs to connect. As of late 2024, more than 2,600 GW of capacity is awaiting interconnection approval, double the nation's installed generation. Average wait times have increased by 70% over the past decade, with 80% of projects ultimately being withdrawn. Wide cost variability further underscores the system's uncertainty, particularly for projects requiring significant transmission upgrades. Source: Grid connection barriers to renewable energy deployment in the United States, Gorman, Will et al., Joule, Volume 9, Issue 2, 101791

Transmission Supply Chains Are Stretched to the Limit

According to the International Energy Agency's (IEA's) March-released *Building the Future Transmission Grid* report, investment in global transmission infrastructure surged 10% in 2023, growing to $140 billlion. Yet, it will need to "more than double" by the 2030s in scenarios that meet national and global climate goals. The report notes that while many advanced economies have introduced policies to accelerate transmission investment, the market is also serving a surge of energy demand from data centers for electrical components. That is setting up a cut-throat competition for cables, materials, and critical electrical components—and, in effect, putting extraordinary pressure on supply chains.



5. Global prices for grain-oriented electrical steel (GOES), copper, and aluminum—key materials for transformers, conductors, and cables—have risen significantly since 2021. GOES prices doubled between 2021 and mid-2023, driven by surging transformer demand and competition from electric vehicle manufacturing. Copper and aluminum saw spikes tied to pandemic-era disruptions and energy costs. Materials now account for more than 50% of transformer costs and up to 80% of cable weight—making supply and pricing critical constraints for grid expansion. Source: International Energy Agency, Building the Future Transmission Grid, 2024. Price index data from Bloomberg, T&D (Transmission & Distribution) Europe, and the Federal Reserve Economic Data (FRED)

"Manufacturers are experiencing skyrocketing demand, leading to higher prices, longer procurement lead times, and record-breaking order backlogs," the report says. Transformer and high-voltage direct current (HVDC) cable manufacturing—already concentrated among a handful of suppliers—is struggling to keep up. Manufacturers report procurement timelines of two to three years for alternating current (AC) cables, and up to five years for large HVDC submarine cables. Transformer delivery timelines have nearly doubled since 2021, now reaching four years in some cases. Power transformer prices, the IEA notes, have climbed as high as 2.6 times their pre-pandemic levels in real terms.

A core challenge is that high-voltage transformers are customized for each project, requiring large drying ovens, advanced insulation processing, and grid-specific load and site design. Cable manufacturing is equally constrained, given that only 10 companies account for half the global market. Installation capacity is even tighter: only about 60 vessels worldwide can lay submarine cable, and many are already booked through 2030. Supply chain constraints have been exacerbated by disruptions in global logistics, while tight markets for raw materials, and skills shortages for manufacturing and installation, have added complexity to the landscape.

Meanwhile, prices have surged across nearly every transmission component category. IEA data show cable prices have nearly doubled over the past five years, even accounting for a brief plateau in 2022. Transformer prices have risen more steeply—up to 160% in real terms—driven by material shortages, energy costs, and extreme backlog competition. Grain-oriented electrical steel (GOES), which accounts for more than 20% of a transformer's cost, has doubled in price since 2021. Copper, which makes up roughly 60% of underground cable weight, and aluminum, used for overhead lines, have also spiked (Figure 5). High-power semiconductors used in HVDC converter valves and circuit breakers also remain in short supply.

As a bright spot, the report suggests manufacturers are responding. Hitachi Energy recently announced investments of $1.5 billion to expand transformer capacity across six countries, including the U.S. Siemens Energy last year set out to build its first U.S. transformer plant—a $150 million investment. Cable makers Prysmian, Nexans, NKT, and LS Cable have all announced major expansions, citing long-term contracts as key enablers. Still, most new capacity isn't slated to come online until 2026 or later.

Delays are already affecting projects. Belgium's Princess Elisabeth Island transmission hub, for example, has tripled in cost, from $2.3 billion to $7.3 billion, while Poland's Harmony Link has slipped from 2025 to 2028 due to equipment constraints.

The IEA warns that the global scramble for transmission hardware has fundamentally altered the nature of procurement. "Buyers, who once had the option to choose between multiple suppliers based on price and quality, are now competing for limited production slots. In many cases, there is only one supplier available, and companies often need to negotiate years in advance to secure their needs," the report notes. Framework agreements—once limited to smaller equipment—are now standard for major components, often running up to five years and combining fixed and variable pricing indexed to inflation and raw material costs. In Europe, for example, transmission operators like TenneT and RTE have secured multi-billion-dollar cable contracts stretching through 2028. In the U.S., developers are increasingly forced to lock in transformer and cable capacity before final project approvals.

To mitigate risks, the IEA outlined a coordinated response. It suggested grid planners and policymakers enhance visibility into long-term demand through transparent project pipelines and credible investment plans, while strengthening dialogue among governments, grid operators, regulators, developers, and manufacturers to improve demand forecasting. Regulatory frameworks should encourage proactive grid investment and streamline permitting without compromising environmental safeguards. At the procurement level, utilities and developers are urged to adopt long-term, standardized contracts that offer price and volume certainty. Maximizing the efficiency of existing assets through digital technologies—such as dynamic line ratings and power flow controls—can help ease immediate pressure. At the same time, the agency calls for deliberate efforts to diversify supply chains, reduce overreliance on top-tier suppliers, and expand regional manufacturing capacity. Finally, the global workforce must scale in parallel, with modernized training programs that align skills development with every stage of transmission project delivery—from design and engineering to factory work and field installation.

The Technology Promise for Transmission, Distribution, and Pipelines

In both grid and pipeline sectors, the past few years have been characterized by a rapid adoption of technologies that promise to make infrastructure smarter, safer, and more efficient—delivering more energy, faster, with fewer emissions and lower costs.

Transmission & Distribution. Utilities are rapidly scaling deployment of advanced conductors such as ACCC (Aluminum Conductor Composite Core) to double line capacity, reduce thermal losses, and avoid costly rebuilds. As of 2025, more than 1,350 global projects have integrated these high-performance conductors, many retrofitted onto existing towers to bypass siting constraints. U.S. utilities are using them to accelerate capacity additions and harden corridors against rising load and extreme weather. Grid-enhancing technologies (GETs), including dynamic line ratings (DLR), topology optimization software, and modular power flow controllers, are also gaining traction. These tools promise to unlock up to 30% more capacity on existing lines using real-time telemetry and analytics, offering a near-term solution to congestion, renewable curtailment, and delays in large-scale buildouts.

Regulatory bodies are responding. So far, the National Association of Regulatory Utility Commissioners (NARUC), along with multiple state legislatures, has called for continued funding, valuation frameworks, and integrated resource plan integration for transmission-enhancing technologies. California, Virginia, Minnesota, and New Mexico now require utilities to evaluate GETs in transmission planning. Planners are also taking note: the California Independent System Operator's (CAISO's) 2024–2025 transmission plan, for example, prioritizes advanced conductors as a lower-cost pathway to meet reliability and interconnection targets.

Industry is also adapting. This year, Ameren Illinois reached a regulatory settlement to integrate GETs and storage into its planning process, combining digital and physical assets to manage constraints. And in New York, National Grid is using utility-owned batteries as "storage-as-transmission" to mitigate congestion and improve renewable integration. Still, challenges remain. Standardization, integration with ISO markets, limited sensor coverage, and persistent equipment lead times all temper full-scale deployment.

Pipelines. Parallel innovation is transforming the gas pipeline sector. Internet of Things (IoT)-enabled smart pipeline networks are rapidly becoming the industry standard, leveraging sensor arrays and artificial intelligence for predictive maintenance and real-time leak detection—capabilities that can reduce maintenance costs by up to 30%. Modular and prefabricated pipeline sections, currently expanding at an annual rate of 8% to 10%, accelerate deployment and mitigate quality risks, particularly for remote projects.

Security and monitoring technologies are also advancing rapidly. Operators such as Enbridge and Chevron are implementing advanced supervisory control and data acquisition (SCADA) systems, blockchain-secured data protocols, and real-time anomaly detection tools to comply with new federal safety and cybersecurity requirements. Enhanced in-line inspection (ILI) and non-destructive evaluation (NDE) techniques are increasingly being codified in industry training and standards programs as of 2025.

Wyoming wind to Nevada and California. In the eastern U.S., PJM approved a $6.7 billion regional plan in February 2025—its largest to date—encompassing a new 765-kV backbone to alleviate congestion associated with data centers and electrification. Texas followed suit in April with its first 765-kV line under the Permian Basin Reliability Plan, a major undertaking that marked ERCOT's shift toward extra-high-voltage infrastructure. Other major HVDC projects moving forward include SunZia (3,000 MW, New Mexico to Arizona), Grain Belt Express (4,000 MW, Kansas to Indiana), SOO Green (2,100 MW, Iowa to Illinois via rail corridors), and New England Clean Energy Connect (1,200 MW, Quebec to Maine). Meanwhile, MISO's $10.3 billion Tranche 1 buildout continues, with Tranche 2 planning active in 2025, and SPP has approved $1.6 billion in new regional lines to support wind integration and resilience.

Distribution Grid: Modernizing the Last Mile

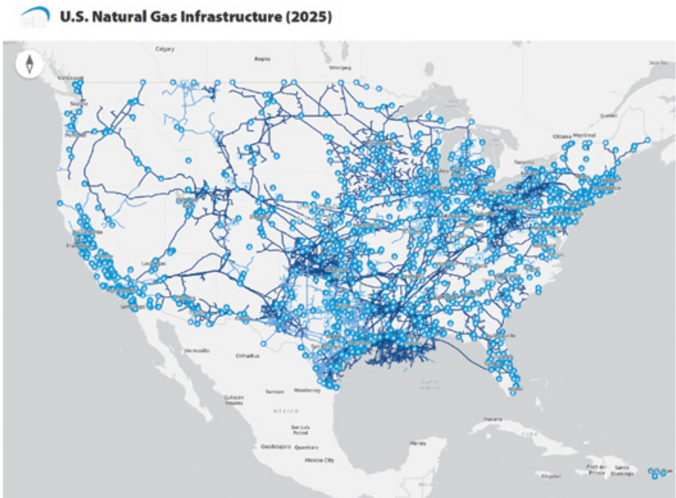
In response to mounting reliability concerns and the demands of a changing energy landscape, utilities invested a record $50.9 billion in distribution infrastructure in 2023, a sharp increase over prior years. For 2024, the most recent data indicate that total capital investment in the U.S. power sector reached an all-time high of approximately $179 billion, with about 42% of that—roughly $75 billion—allocated to transmission and distribution systems combined. A key driver has been the urgency to accommodate rising distributed energy resources (DERs)—rooftop solar, batteries, and electric vehicles—as well as nontraditional large loads emerging behind utility meters, such as AI clusters, cryptominers, and industrial fleets. Many of these loads connect directly to distribution feeders, bypassing ISO interconnection queues.

Federal support has been pivotal. The DOE directed about $14 billion in grants and formula funding—much of it from the IIJA—toward grid modernization, with $2.2 billion specifically earmarked for projects that harden distribution lines and boost DER integration. Projects funded through these programs supported reconductoring, automation, and targeted capacity upgrades in vulnerable and high-growth load areas.

According to the NC (North Carolina) Clean Energy Technology Center, all 50 states, plus the District of Columbia and Puerto Rico, took some form of policy or deployment action on distribution modernization in 2024—resulting in 822 recorded actions. Among key priorities last year were the establishment of distribution system planning (DSP) rules, cost-sharing frameworks for interconnection-related upgrades, and state-led evaluations of virtual power plants (VPPs). Ten of the most active states—led by New York, Massachusetts, Michigan, and New Jersey—approved major utility grid plans, adopted multi-gigawatt energy storage targets, and launched new demand-side management (DSP) dockets aimed at proactive, locationally aware investment.

Utilities, meanwhile, report modernizing operations through increased deployment of advanced distribution management systems (ADMS), DER management systems (DERMS), and feeder-level controls. So far, pilots in states including Minnesota and California are already testing advanced time-varying rates and critical peak pricing as tools to improve load management and unlock DER flexibility (see sidebar "The Technology Promise for Transmission, Distribution, and Pipelines").

However, here too, persistent challenges remain. Experts note that many



6. A dense web of natural gas infrastructure underpins the U.S. power sector. Icons represent gas-fired generation facilities (circle with flame) and underground storage sites (tank with flame). Dark blue lines indicate interstate pipelines, while light blue lines represent intrastate pipelines. The clustering across the Gulf Coast, Midwest, and Eastern U.S. highlights critical nodes in the gas-power nexus. Source: U.S. Energy Information Administration, U.S. Energy Atlas (May 2025)

utilities lack full hosting capacity data, real-time system visibility, or the workforce needed to design and integrate modern distribution technologies at scale. For now, as the NC Clean Energy Technology Center notes, many states are examining performance-based regulation tools and launching integrated distribution system planning frameworks. These developments, combined with the tapering of near-term federal grant funding, suggest that future progress will increasingly depend on how effectively utilities and regulators adapt their planning, rate design, and digital infrastructure to manage a more distributed, two-way power system.

Keeping Dispatchable Power Online—and Fueled

While investments in transmission and distribution remain critical, experts are also increasingly flagging an urgent need to reinforce the infrastructure underpinning dispatchable generation—a near-term reliability pillar that, in many regions, may prove indispensable. "There are states where you can't build certain types of generation," NERC's Moura explained to *POWER*. "There are areas where you have a lot of generation. Transmission is an obvious solution as one option," he said, "but there are local solutions as well." Natural gas is among the most readily available, "but you can't really even think about building natural gas without thinking about the gas pipeline infrastructure," he added. "So whether that means storage, more pipeline, and other options—even oil backup—I think that is a critical component. All that infrastructure, we see, needs to be increased as we progress forward."

In 2024, natural gas supplied 43% of U.S. electricity generation (Figure 6), drawn from a gas-fired fleet of about 567 GW. That dominance is only slated to grow. Rystad Energy in January suggested U.S. utilities are planning 17.5 GW of new gas-fired capacity—marking the highest level of project activity since 2017. Newer industry projections hover around 46 GW of additions over the next five years, while a recent *POWER* analysis of utility earnings statements suggests the actual buildout may be higher still.

But as demand for natural gas surges, the physical system that supports it will be strained. "According to EIA [the U.S. Energy Information Administration], in 2024, U.S. natural gas consumption averaged a record 90.3 billion cubic feet per day (Bcf/d) and set new winter and summer monthly records in January and July," Amy Andryszak, president and CEO of the Interstate Natural Gas Association of America (INGAA), said in testimony before a House subcommittee in April. Last year, the U.S. added a record 17.8 Bcf/d of new pipeline capacity, including the Mountain Valley Pipeline and the Matterhorn Express. However, federal data shows that most of those additions supported LNG exports or upstream congestion relief—not power markets. According to the EIA, only 0.9 Bcf/d of that total came from interstate pipelines—down from 65% of additions in 2017—while 5.2 Bcf/d was intrastate, nearly all concentrated in Texas and Louisiana to serve Gulf Coast LNG demand.

Gas consumption will be even higher in 2025 and 2026, Andryszak noted. "A Goldman Sachs analysis shows an additional 47 GW of electric generation capacity will be required to support data center power demand growth by 2030, and it estimates 60% will come from gas and 40% will be derived from renewables. That equates to an additional 3.3 Bcf/d of natural gas pipeline capacity to meet the demand growth from data centers by 2030." Meanwhile, "Calculations by S&P Global suggest additional gas demand could be as high as 6 Bcf/d by 2030," she said. "It is self-evident that we will not meet this scale of growing demand for natural gas without adding new pipeline and storage capacity, and the status quo regulatory regime that discourages investment in infrastructure will not get us there."

Even where pipeline expansion is technically feasible, projects often face delays due to permitting, environmental review, land acquisition, and local opposition—issues that are compounded by rising material costs and increasing project management complexity. The sector is also grappling with its own supply chain challenges, driven by global competition for critical components, transportation bottlenecks, labor shortages, and ongoing disruptions in the availability of specialized equipment and materi-

On peak days, natural gas storage withdrawals support more than 21,000 GWh of electricity, equivalent to 144 times the output of all U.S. battery and pumped hydro storage combined.

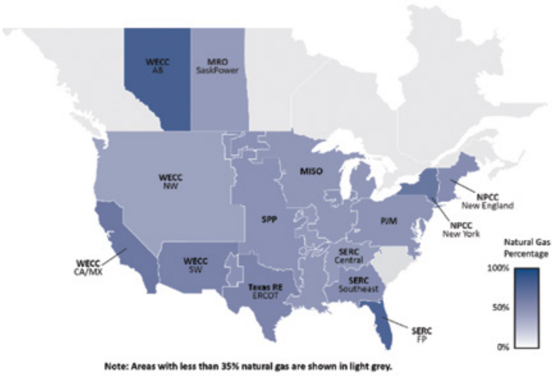
als. Additionally, regulatory uncertainty, evolving climate policies, and financing risks can further complicate and delay project development.

Storage Shortfalls and Systemic Gaps Threaten Gas Reliability

Gas-fired generation projects face their own set of challenges. As *POWER* recently reported, surging demand for gas-fired generation is straining the turbine supply chain, driving up prices and extending lead times for new combustion turbines to as much as four to five years. All three major original equipment manufacturers have reported record turbine order backlogs, prompting a return to reservation fees and production slot agreements to secure manufacturing capacity. Developers now often must commit funding well before siting or interconnection is finalized adding to project financial and operational risks.

But the natural gas sector is also grappling with serious natural gas storage constraints. The American Gas Association (AGA) underscored in an April 2025 report, the power sector already leans heavily on gas storage: On peak days, natural gas storage withdrawals support more than 21,000 GWh of electricity, equivalent to 144 times the output of all U.S. battery and pumped hydro storage combined. And, while storage is rarely included in capacity accreditation or state-level energy planning, dozens of new gas-fired power plants under development across the U.S. are sited in high-demand areas with little or no adjacent storage infrastructure. Compounding this is that seasonal patterns are also shifting. Electric-sector gas consumption now peaks in summer, compressing refill windows even more and straining traditional planning assumptions.

The key concern is that underground storage capacity has grown at just 0.1% per year since 2014—far slower than increases in gas production, pipeline expansions, or demand from gas-fired generation. Over the past five years, underground storage utilization in the East, Midwest, and Mountain states has approached or exceeded 90% heading into the winter heating season. At the same time, daily Henry Hub price volatility has surged, averaging 71% between 2020 and 2024 compared to 43% in the preceding five-year period, pointing to storage's diminished traditional role as a physical and financial buffer against market shocks and extreme weather demand.



	Natural-Gas-Fired Generation	
	Peak Winter Capacity	Contribution to Total Winter Resource Mix
MISO	62.3 GW	45%
MRO-SaskPower	2.4 GW	43%
NPCC-New England	15.0 GW	51%
NPCC-New York	24.5 GW	66%
PJM	84.4 GW	47%
SERC-Central	22.0 GW	43%
SERC-Florida Peninsula	49.8 GW	80%
SERC-Southeast	31.9 GW	50%
SPP	29.9 GW	48%
Texas RE-ERCOT	55.3 GW	57%
WECC-AB	13.9 GW	83%
WECC-CA/MX	37.8 GW	65%
WECC-NW	33.6 GW	39%
WECC-SW	18.1 GW	58%

7. This map from the North American Electric Reliability Corporation (NERC) illustrates the contribution of natural gas–fired generation to each region's winter peak capacity. Courtesy: NERC, March 2025 Reliability Insights.

According to AGA, "Despite the proven value of natural gas storage facilities to the energy system, several structural and regulatory challenges continue to limit the system's overall effectiveness." Chief among these are lengthy, uncertain permitting processes, which could stretch several years from concept to operation, along with land-use opposition and overlapping federal and state reviews that discourage early-stage investment. In many cases, developers face unclear cost recovery pathways, especially in deregulated power markets, where storage receives little or no compensation for providing backup capacity or fast-ramping flexibility. And, even in regulated regions, rate cases may not fully reflect the resilience and system-wide benefits storage provides. At the same time, many older storage facilities suffer from limited withdrawal capability, reducing their usefulness for fast power-sector ramping. These factors create a disconnect between the operational importance of storage and its perceived market value—a mismatch that, AGA warns, could leave the power system vulnerable as demand rises and clean energy integration deepens.

AGA President and CEO Karen Harbert warned, "America's natural gas system requires expanded storage capacity that is flexible and responsive to help enable our system to reliably meet increasing demand from power generation, data centers, and a reshoring of American manufacturing." Without targeted policy action, the AGA said, the U.S. risks "service interruptions during extreme weather, price shocks for consumers, and impacts on grid reliability"—especially as renewable integration further amplifies the need for fast-ramping, on-demand fuel reserves.

Finally, experts point to another persistent systemic blind spot: Because natural gas and electric planning remain largely siloed, the risk of fuel supply disruptions during periods of peak power demand is increased. A joint review by FERC, NERC, and regional entities of January 2025 arctic events, which comprised Winter Storms Blair, Cora, Demi, and Enzo, underscored the need for better coordination, citing misaligned scheduling, limited real-time transparency, and inadequate data sharing—especially in intrastate gas systems—as persistent barriers that hinder generators' ability to secure timely fuel deliveries. The report calls for more formalized cross-sector planning, shared risk modeling, fuel availability surveys, and scheduling reforms.

NERC has consistently highlighted the growing operational risk (Figure 7) posed by the rising reliance on gas-fired generation, especially in regions where pipeline constraints, wellhead freeze-offs, and electricity-dependent gas infrastructure can challenge deliverability during extreme weather. It warned that planning coordination between gas and electric systems remains insufficient, and that both systems would benefit from regulatory reforms, improved communication protocols, and aligned market schedules during extreme weather. The designated reliability organization, notably, has expressed strong support for new efforts, such as the Gas Electric Reliability for America (GERA) task force, while also calling for deeper coordination across policy, market, and infrastructure domains to ensure winter readiness and system-wide resilience.

Persistent Uncertainties

The behemoth task of modernizing and expanding the interconnected power system ultimately hinges on two things: investment and people. Despite unprecedented federal support through the IIJA and IRA, the U.S. still lacks a coherent financing model for long-term grid infrastructure. Transmission, dispatchable generation, and fuel supply all rely on state-level rate cases—a process increasingly mismatched with the speed of electrification and market volatility. As Deloitte noted in its 2025 industry outlook, delays in cost recovery are already inflating electricity prices, and some utilities are piloting large-load tariffs to shift grid upgrade costs onto data centers and industrial users. The bigger question is looming: Who pays for the grid of the future—and will regulators adapt in time?

Because natural gas and electric planning remain largely siloed, the risk of fuel supply disruptions during periods of peak power demand is increased.

The urgency is mounting, driven by intensifying global competition and shifting energy geopolitics. In China, permitting and investment decisions flow through centralized five-year plans, allowing ultra-high-voltage lines to be built in just a year and a half—compared to eight or more in the U.S. and Europe, where permitting remains a core obstacle. The European Union mandates coordinated cross-border planning and ties grid operator returns to performance. By contrast, even the most ambitious U.S. reforms are still years away from impacting the industry, and face legal headwinds and constant political churn.

"We have this very big mountain to climb in terms of investment because we need to push more electrons to the grid," Anthony Allard, executive vice president and managing director of Hitachi Energy in the U.S., told *POWER* in March. "The grid, on top of that, needs to be reliable and resilient." What's missing, he added, is a 20- to 30-year vision that gives the private sector confidence to act. "Once this planning is available, then the private sector can come in and say, 'Let's find ways with the right type of project and the right type of capital to be able to execute on that,' " Allard said.

The next big bottleneck will be finding skilled labor. According to the International Energy Agency, the global power sector will need 1.5 million more workers by 2030 just to meet current transmission and distribution targets—a gap that threatens to stall both grid projects and domestic equipment manufacturing. "We need to invest a lot in people. We need the workforce to grow, and that's a real concern for the entire industry," Allard noted. ■

*—**Sonal Patel** is a POWER senior editor.*

Decentralized Power That's Central to the Energy Transition

Resilience, sustainability, cost savings, and more are behind the increasing adoption of microgrids, as a variety of industries and enterprises seek greater control of their energy supply.

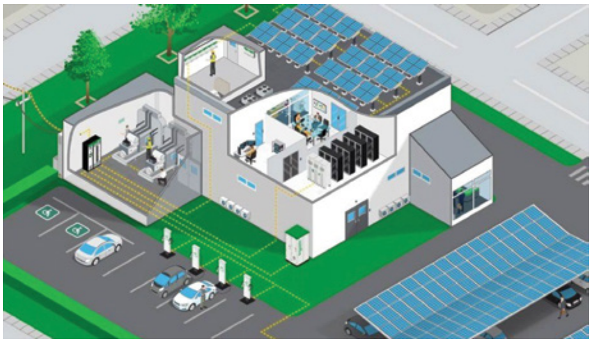
Darrell Proctor

Microgrids have been an integral part of the energy transition, supporting the growth of decentralized power generation. The legacy of power generation has been large, centralized power plants, providing electricity to a wide area. The advent of microgrids brought energy to areas without transmission lines, and they're now an important source of backup power, in many cases supporting critical operations in need of a constant, reliable supply of electricity. Some microgrids use fossil fuels, including natural gas and diesel, and the systems have helped support renewable energy by utilizing solar and wind power, along with battery energy storage systems (BESS).

Organizations of all kinds are turning to microgrids and distributed energy resources not only for onsite power but also for financial and sustainability benefits. Government agencies, military bases, nature preserves, agricultural enterprises, and more are utilizing microgrids to gain control over energy costs, and to have power in remote areas where access to energy is limited or nonexistent.

"Unlike traditional grids that rely on large, centralized power plants, microgrids operate as self-contained networks that can generate, store, and use electricity onsite. This ability allows them to maintain operations independently from the main grid during power outages or when energy demand surges, helping balance the larger grid," said Bin Lu, executive vice president of Power Products at Schneider Electric (Figure 1). "Microgrids also offer the flexibility to integrate renewable energy sources, like solar and wind, as well as battery storage, adding a layer of energy resilience and independence while helping meet decarbonization goals.

"Beyond supporting energy needs and sustainability goals, the deployment of microgrids is also a compelling economic opportunity," said Lu. "By generating and storing energy locally, organizations and communities gain control over energy costs, reduce reliance on external power, and can even sell surplus power back to the main grid. For facilities managing high-demand operations, such as data centers, these capabilities add reliability while also supporting sustainability by using renewable power."



1. *This rendering of a microgrid designed by Schneider Electric shows technologies including solar power, which are used to power the building along with the chargers for electric vehicles in the parking lot. Courtesy: Schneider Electric*

Brandon Young, CEO at Texas-based electricity company Payless Power, told *POWER*: "Microgrids are revolutionizing the energy world behind the scenes, and their significance is only increasing as we continue to add more renewable energy to the mix. Microgrids are basically local energy systems that can operate both in synchronization with the traditional grid and in isolation from it. That double-duty capability gives them a clear advantage when it comes to energy resilience—especially during blackouts, extreme weather, or times of peak demand when the centralized grid is maxed out."

Young continued, "What's making microgrids so attractive in the energy landscape today is the simplicity with which they can be used to incorporate distributed renewable resources like solar panels, wind turbines, and battery storage into the mix. We've all heard the problem of intermittency with renewables—how the sun doesn't always shine and the wind doesn't always blow. Microgrids solve that problem by using energy management systems and storage technologies to level out the ups and downs, delivering power when and where it's needed. Microgrids are, in effect, shock absorbers for the larger grid, leveling out the system as more variable generation comes online."

Scalable, Integrable Solutions

Alex Ince-Cushman, co-founder and CEO at Branch Energy, a renewable energy and energy storage group, told *POWER*: "Microgrids are arguably the most scalable, integrable solutions there are for reducing pressure on the main grid. Additionally, intelligent control and management systems enable microgrid controllers to be in smooth communication with the main grid. This communication not only allows microgrids to function efficiently but also optimizes energy utilization overall, enhancing grid stability.

"Microgrids can act as a load-balancing mechanism for our grid by reducing demand during peak times and sending excess power back to the grid. By smoothing out fluctuations and managing local energy generation, microgrids reduce strain on the main grid and maintain overall stability," said Ince-Cushman. "Having a constant, reliable backup has typically been considered an added cost for most businesses. Generators are costly for installation and maintenance, but keep power running when it goes down, pretty similar to a microgrid. Microgrids, however, are much cheaper and have an added value proposition from the solar savings to load shifting and avoided service costs."

Dane Labonte, an energy management consultant with Stantec, told *POWER*, "The key feature of a microgrid is that it's an energy system that can disconnect from the broader electricity grid and operate independently. In the microgrid world, disconnecting from the electricity grid is referred to as 'islanding.' Basically, a microgrid has the ability to operate connected to the grid or as an independent island."

Labonte, whose group is a global company that provides consulting services in sustainable engineering, architecture, and environmental consulting, continued: "To operate as an island, a microgrid relies on a sophisticated protection and control strategy, as well as a microgrid controller that provides the 'brains' for coordinating multiple energy resources. Beyond these key points of islanding and controllers, microgrids can have very different technical designs, but a core objective of any microgrid project is to enhance energy resilience."

Young said microgrids also represent a "philosophical shift" in the energy landscape. "We're moving away from a one-way energy model where power is being sent from central plants to consumers, to a more dynamic, decentralized model where consumers can also be producers—thanks to solar panels, home batteries, and other distributed energy technologies. Microgrids allow these assets to be controlled in real time, making the grid more efficient, flexible, and responsive.

"One of the more fascinating trends is how microgrids are being leveraged to support community-scale resilience," said Young. "Hospitals, schools, military installations, and even entire neighborhoods are employing microgrids as a backup power supply, but more importantly as a source of energy for extended periods of time. Microgrids in wildfire, hurricane, or ice storm zones can island from the primary grid and continue to supply reliable power. That's a public safety and critical service continuity game-changer."

2. The Monarch Compute Campus in West Virginia is a hyperscale data center complex. It is part of the Mountaineer GigaSystem project. Officials have said hydrogen to power the campus microgrid could be produced using natural gas, which is abundant in the state as it sits within the Marcellus and Utica shale plays. Courtesy: Fidelis Energy

> ***"Microgrids in wildfire, hurricane, or ice storm zones can island from the primary grid and continue to supply reliable power. That's a public safety and critical service continuity game-changer."***
>
> —Brandon Young, CEO of Payless Power.

Those attributes are among the reasons that lawmakers in several states have worked to support development of microgrids, particularly recently as officials look at the economic impacts of data centers. Tech companies want onsite power generation for their energy-intensive operations, so they don't have to rely on the power grid and can get projects built more quickly.

West Virginia lawmakers recently passed legislation to streamline and simplify the permitting process for microgrids—what officials called the "Power Generation and Consumption Act." The law is intended to support development of microgrids using both renewable energy and fuels such as natural gas and even coal.

Patrick Morrisey, the state's governor, said, "The Power Generation and Consumption Act will make West Virginia the most attractive state in the country for data centers and help America better compete with China in the technology arms race of the future. Combined with the one-stop shop permitting bill, companies will now be able to quickly build, expand, and increase job creation right here in West Virginia."

The state already is working with Texas-based Fidelis New Energy, an energy infrastructure group, on a hydrogen microgrid project in Mason County. The proposed $5 billion Monarch Compute Campus (MCC) is a hyperscale data center complex (Figure 2), offering 2,000 MW of capacity on a 1,100-acre site. It is part of the company's larger Mountaineer GigaSystem project, a 2,300-acre site that includes the Monarch campus along with an expansion of that installation. Officials have said hydrogen for the project could be produced using natural gas, which the state has in abundance as it sits within the Marcellus and Utica shale plays.

Schneider's Lu said his company in 2023 partnered with Middle Tennessee Electric (MTE) to deploy MTE's Energy Control Center (ECC)-based microgrid in Lebanon, Tennessee. The microgrid added 60 kW of solar PV, a 250-kW/224-kWh BESS, and an ECC for integrated source/load management. At a loss in utility power, the generator would restore power to the site within 10 seconds.

Said Lu: "The microgrid combines behind-the-meter energy sources and dynamic load management to increase the number of power sources and extend outage duration in cases of extended outage. In short-duration power outages, the microgrid controller prevents the generator from starting and provides battery power to the site. When available, solar PV compliments BESS power. If the outage duration doesn't surpass the BESS charge level, the diesel generator can be bypassed.

"During an extended outage, the microgrid controller activates the generator when the BESS reaches a minimum SoC [state of charge], supporting the site and recharging the BESS. Once the BESS replenishes to a usable SoC, the controller switches to BESS power, repeating this cycle to reduce diesel consumption. The project is one of the first multi-source [generator, solar PV, BESS] commercial microgrids in Tennessee, and is intended as both a functional/pilot project for MTE customers," said Lu.

DERs and Control Technologies

Karina Hershberg, associate principal with PAE Engineers, said, "The key potential benefits of microgrids are energy resilience, operating cost reduction, and sustainability. Achieving all these outcomes depends heavily on the distributed energy resources [DERs] in the system and the system's operating parameters. However, it is absolutely possible to achieve all these outcomes with currently available DER and control technologies.

"At its core level, a microgrid is simply energy generation and storage used to operate grid-connected and grid-disconnected systems. Multiple technologies meet these criteria, but since most microgrids are intended to fulfill an energy resilience purpose, the best DERs are the ones that can be locally supported," said Hershberg. "For example, a diesel generator can be paired with a fuel storage tank as the generation and storage resource. But the fuel storage tank requires refueling inputs from external supply chains, which may or may not be functional in a major emergency [icy roads in a winter storm, for example]. By comparison, PV with a battery energy storage system is also a generation with storage pairing. Yet, the electricity generation comes from a local source—the sun—therefore, the system is more independent and ultimately more resilient."

Hershberg continued: "The same logic can be applied to other DER options. Both natural gas and propane generators rely on external supply chains for their energy resources. A common argument in favor of natural gas is that the system is more robust since the infrastructure is underground. However, there are still examples of these systems being impacted by wildfires and winter storms [not to mention leaks or other system failures]. Whereas a small-scale biomass generator, for example, sited in an area with local biomass resources and existing biomass infrastructure [local mills or other processing facilities, forest management practices, etc.], can support a biomass DER with entirely locally sourced resources. Another locally sourced example is microhydro, which can include solutions that go inside municipal water pipes [for example, InPipe], which turns an existing water infrastructure resource into an energy resource as well."

Hershberg said that in PAE designs, the company will "often structure locally 'refueled' DERs [such as PV with BESS] as the first layer of support in the system. There can be advantages to diesel and natural gas generators depending on the application, so we may include these as a second layer of resilience. DERs such as PV with BESS, microhydro, and so on will then be able to support most outage conditions, in addition to providing the more day-to-day benefit of load flexibility. The diesel generator is then reserved for additional support in only the most catastrophic situations.

"The main summary is that, often, the best energy technology is the one where the 'fuel' can be locally sourced and the systems can provide off-grid and on-grid benefits," said Hershberg. "The optimal options for many projects are batteries with PV and possibly site-specific options for small-scale biomass and microhydro."

An example of a PAE project is the company's "Living Building" in Portland, Oregon (Figure 3). The five-story office building in the city's downtown utilizes solar PV and battery energy storage. Its functionality includes optimized use of onsite solar, grid-responsive BESS discharge, and resilience, said Hershberg, with the building seismically resilient to a Category 4-level earthquake.

3. The "Living Building" in Portland, Oregon, utilizes solar power and battery energy storage to provide electricity for the five-story office building. Courtesy: PAE Engineers

Ince-Cushman said, "There are clear candidates for microgrids—like data centers, hospitals, and industrial sites—but the truth is, nearly every building benefits from having a battery. Whether it's cutting energy costs, improving resilience, or supporting the grid, batteries make buildings smarter and more self-reliant. Microgrids built around storage are quickly becoming the default solution, not the exception."

> ***"There are clear candidates for microgrids—like data centers, hospitals, and industrial sites—but the truth is, nearly every building benefits from having a battery."***
> —Alex Ince-Cushman, co-founder and CEO at Branch Energy.

Military Applications

Labonte said, "In recent years, there have been incredible cost reductions in energy resources costs, particularly solar PV and battery energy storage, which are creating new opportunities for microgrid projects. But achieving high levels of energy resilience usually requires traditional thermal generation assets as well. Finding the right mix of energy resources is project specific.

"When planning a microgrid project, we try to understand a client's goals across three interconnected categories: energy resilience goals, financial goals, and sustainability goals," said Labonte. "With the technology currently available, there are trade-offs across these goal categories. So, finding the 'best' mix of energy resources requires understanding the project's specific goals and priorities."

The best mix of energy resources has been a focus for groups that include the U.S. military (Figure 4). The U.S. Air Force and the Department of Defense (DoD) recently said a collaboration that includes GE Vernova, Sage Geosystems, Energy Systems Group, and the University of Utah would look at ways to use geothermal energy for future microgrids at military bases. The Air Force and the DoD's Chief Digital and Artificial Intelligence Office (CDAO) has previously discussed developing utility-scale geothermal power plants in the U.S. and elsewhere to supply military bases with electricity.

Energy Systems Group said the team was selected through the CDAO's solicitation process known as the Tradewinds Solutions Marketplace, which is designed to accelerate the procurement and adoption of mission critical technologies, such as artificial intelligence, machine learning, and resilient energy technologies. "The U.S. Air Force leveraged the Tradewinds solicitation process to quickly collaborate with innovative American companies to build resilient, next-generation geothermal technologies at our bases, using private capital instead of taxpayer dollars," said Kirk Phillips, director of the Air Force Office of Energy Assurance.

Officials said Energy Systems Group would lead the collaboration and focus on designing power plants for DoD. Sage Geosystems would supply its pressure geothermal technology, which typically utilizes two wells in an injection and production pattern. GE Vernova has said its geothermal conversion technology could provide as much as 5 MW of continuous power to DoD sites. The Energy and Geoscience Institute at the University of Utah, along with Sage, would provide geothermal assessment knowledge, and Sage would handle drilling activities. GE Vernova would deliver power conversion, microgrid design and control, and also hydrogen generation and storage. Energy Systems Group would lead development of the project collaboration.

"We are excited to play a role in helping unleash America's energy dominance with secure, plentiful, geothermal energy," said Steve Smith, Energy Systems Group's vice president of Federal Business. "We are honored to lead this innovative team that brings a wide range of technology and experience to help the DoD safeguard mission-critical operations."

The White Sands Missile Range in New Mexico in February celebrated the launch of a hybrid microgrid that will provide backup power to four groundwater wells at the site. The microgrid is designed to ensure power outages will not impact potable water service to the garrison's main post. The $10.9 million hybrid microgrid includes a 700-kW solar photovoltaic array, a 500-kW natural gas generator, and a 500-kW lithium-ion BESS.

4. The U.S. military is using microgrids to ensure a steady power supply at its bases. Source: U.S. Marine Corps

"This new solar and natural gas microgrid is a major step towards ensuring White Sands Missile Range remains mission ready even during power disruptions," Garrison Commander Col. Donyeill Mozer said in a statement. "Having an alternative energy source strengthens our ability to operate without interruption. This project showcases our commitment to innovation and sustainability."

The DoD calls White Sands the "premiere missile, munitions, and artillery test range." The base is used by the Air Force, Navy, NASA, the National Reconnaissance Office, and the Defense Threat Reduction Agency. The U.S. Army has mandated that each of its sites be capable of operating for at least 14 days with its own water and energy services. "By integrating solar energy with natural gas, we are not just improving reliability, we are also taking steps towards a more energy efficient and environmentally responsible future," Mozer said of the microgrid, which was designed and built by Hannah Solar Government Services-Ameresco (HSGS-Ameresco).

"This microgrid project is a great example of how innovative energy solutions can enhance the resilience and efficiency of critical infrastructure," said Nicole Bulgarino, president of Federal Solutions and Utility Infrastructure at Ameresco. "Our collaboration with White Sands Missile Range has resulted in a robust system that ensures continuous operation and supports the mission readiness of the installation. We are proud to contribute to a more sustainable and secure energy future."

"I am really proud of the fact that our company is dedicated to providing energy security for America and especially for our Army and our military," said Dave McNeil, CEO and president HSGS-Ameresco. White Sands also is home to the Army's first fully sufficient hydrogen-powered nanogrid, which is a smaller version of a microgrid. The nanogrid includes solar panels, an atmospheric water generator, and an electrolyzer to split the hydrogen from water. It also has a fuel cell, low-pressure hydrogen storage, and battery energy storage.

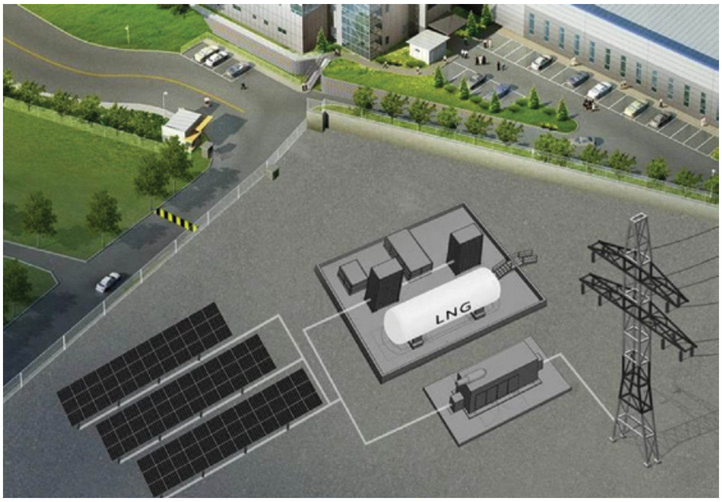
Creating a Mobile Microgrid

GM Energy, an energy products vision of the Michigan-based automaker, recently said the company is promoting sales of electric vehicles (EVs) with bidirectional charging to customers in areas prone to power outages—in essence, creating a mobile microgrid. The company specifically noted its efforts in California, in territory served by Pacific Gas & Electric (PG&E). GM said the vehicles would help customers during blackouts, and said the EVs also could provide services for the power grid.

Aseem Kapur, chief revenue officer at GM Energy, said the company is targeting areas in California, Michigan, Texas, Florida, Washington, and New York. The company said it currently has eight EVs with bidirectional capabilities.

Kapur said with GM Energy's vehicle-to-home system, which includes 10.6-kWh to 35.4-kWh stationary storage systems, a microgrid configuration can be supported. Kapur said solar power also could be added to the system. GM Energy is participating in pilot projects with PG&E, DTE Energy in Michigan, and Southern California Edison to test the bidirectional technology.

Crowley, the longest-serving U.S. logistics provider in Puerto Rico, in April said it is enhancing the resiliency of its Isla



5. *Crowley, a U.S. logistics provider, is enhancing the resiliency of its Isla Grande logistics terminal in San Juan, Puerto Rico, with the installation of a microgrid fueled by liquefied natural gas. Courtesy: Crowley*

> ***"One area where microgrid technologies offer huge benefits are for remote off-grid communities."***
>
> —Dane Labonte, energy management consultant with Stantec.

Grande logistics terminal in San Juan with the installation of a microgrid fueled by liquefied natural gas (LNG). The system is expected to provide a reliable power supply to support the terminal's daily operations, such as powering its terminal equipment, refrigerated containers, and administrative and maintenance facilities.

"This LNG-fueled microgrid is a transformative investment that ensures our logistics terminal in San Juan can maintain seamless operations regardless of external conditions," said Matt Jackson, vice president of advanced energy at Crowley. "It exemplifies our focus on delivering innovative energy solutions that enhance reliability and operational resilience for our customers and the communities we serve."

The microgrid is set for completion in early 2026 (Figure 5). Crowley said the project advances the company's long-term power reliability at its San Juan terminal, and also showcases how the microgrid service provides industrial or commercial operators with a highly resilient energy solution that delivers cost savings and a reduced carbon footprint.

Remote, Off-Grid Communities

"One area where microgrid technologies offer huge benefits are for remote off-grid communities," said Labonte. "These are usually either small communities or mining sites that aren't connected to the broader electricity grid and have typically relied on diesel generators. These sites' electricity systems have always been functional islands, but they benefit greatly from advancement of microgrid controllers and emerging DERs that offer new opportunities for energy system design. Stantec supported the Gull Bay microgrid project in northern Ontario, which was the first of its kind microgrid in Canada that integrated solar PV and batteries with existing generators using a microgrid controller. The project was able to greatly reduce the communities' reliance on diesel and offer greater energy resilience."

Churches in Georgia also are using microgrids, enabling EV charging and more for community members. The African Methodist Episcopal (AME) Church Sixth District has a program to create microgrids at churches across the state, starting with a goal of installing five systems by 2026. Officials said there are 482 church locations in Georgia that could eventually deploy microgrids. The AME Church said the program, which started development in 2023, is part of its commitment to environmental stewardship.

The project includes the installation of solar panels, EV charging stations, and BESS, as well as implementing energy efficiency measures. The bidirectional charging technology used in the program allows the churches to serve as energy hubs and resiliency centers for their local communities. That includes having reliable power to charge medical equipment, store medicines, and for community members to seek shelter in an emergency.

Church officials said each system is expected to offset more than 93% of each church's annual energy usage, and would pay for itself after eight years. The systems are expected to have a useful life of more than 25 years. Officials said the Sixth District's 482 church sites in total represent about 34 GWh of potential annual power production capacity.

Engineering firm WSP partnered in a project at PortMiami in Florida, implementing technologies to help electrify the port's operations along with supporting decarbonization efforts. The project, called the largest of its kind on the U.S. East Coast, enables cruise ships to connect to a shore power system, essentially a microgrid configuration that enables the ships to be powered while in port. That eliminates the need for vessels to keep their engines running while berthed, resulting in a significant reduction in polluting emissions from the ships.

WSP is the engineer of record for the project, working with PortMiami, Florida Power and Light, cruise lines, and others. "Designing a single project for this many cruise ships and that offers such tremendous flexibility is like trying to hit a home run out of the park," said Mark Valenti, senior vice president and southeast regional maritime leader at WSP in the U.S. "It really is the first of its kind." PortMiami is one of the largest cargo and passenger ports in the U.S, generating $61 billion annually.

Valenti told *POWER* the system "is crucial for achieving decarbonization goals by reducing air pollutants such as particulate matter, nitrogen oxides, and carbon dioxide. The cruise industry at ports has seen substantial reductions in these pollutants using shore power, as highlighted by recent EPA [Environmental Protection Agency] studies. This not only improves air quality but also benefits the health of port neighbors by reducing noise pollution."

Grace Patino, a WSP senior vice president and electrical engineer, said systems like microgrids and other measures that support electrification are important, including for seaports. "Electrification technologies can help utilities manage electricity and support grid flexibility in a number of ways," said Patino, noting demand management programs and more. "Battery storage systems can store excess electricity generated during off-peak times and release it during peak demand. This helps utilities manage fluctuations in electricity consumption and provides a reliable backup power source for critical operations, such as those at ports." Patino said this also helps with integration of renewable energy resources, and will "support the transition to a more sustainable and resilient energy system."

Software and Energy Storage

Gary Wong, Global Segment Leader of Power, Utilities, and Infrastructure at AVEVA, said microgrids provide a great opportunity to discover how software and data-gathering support power generation and a host of energy sector technologies, including battery energy storage. "We're seeing a lot of battery energy storage," said Wong, who spoke with *POWER* at the recent AVEVA World summit in San Francisco. "Software that looks at microgrids, that compiles the data, provides more visibility into operations. We need to have that ability to gain more visibility into how different technologies impact the grid. Storage is providing more flexibility," which he said benefits both microgrids and the larger power grid.

"We can have connected communities," said Wong. "We have the technology to make the power supply more resilient. We can monitor every electron, and we're starting to see more data being shared."

Andy Sofranko, vice president of Engineering at REC Solar, said, "Microgrids that leverage reliable, renewable energy generation sources—like solar—have emerged as a lucrative investment for commercial entities of all sizes in recent years. Efforts to lower emissions and guard against volatile energy prices and outages caused by extreme weather are driving this trend. Bundling solar with microgrids is a particularly ideal approach for companies or sites that are averse to running on diesel generation and are looking for a more sustainable resiliency solution."

Sofranko, like Wong, said operators also should "consider the software and energy management capabilities of any energy storage system you intend to deploy at a microgrid. Ideally, your system can intelligently manage its connection to the grid and to your solar array or other renewable generation asset. In this way, you can make the most of stored clean energy and feed excess into the grid when needed or, conversely, draw power from the grid when renewable generation is insufficient. Similarly, the system should be equipped with off-grid functionality, meaning the microgrid can operate independently from the primary power grid when needed. This is important during power outages and instances of grid instability as it can provide a consistent power source to critical energy loads via stored power."

> ***"Microgrids that leverage reliable, renewable energy generation sources—like solar—have emerged as a lucrative investment for commercial entities of all sizes in recent years."***
>
> —Andy Sofranko, vice president of Engineering at REC Solar.

Sofranko told *POWER*, "Put simply, microgrids can help reduce energy costs by reducing a site's exposure to volatile utility prices. Pairing energy storage with a solar array in a microgrid makes it easier to self-consume onsite generated solar energy when utility prices are the highest in a given region. This will vary based on the utility market, time of year, size of the energy load, and other factors, but microgrids equipped with intelligent energy management software can help navigate these signals and facilitate lower prices—all while helping a site make the most of the clean energy it generates."

Sofranko said the microgrid technology at Blue Lake Rancheria, a federally recognized Native American tribal government and community located in a remote region of Humboldt County, California, provides an example of the benefits of such systems. Sofranko said the tribal community is committed to achieving net-zero carbon emissions by 2030 through a range of solutions including EV charging, advanced energy efficiency, and multiple microgrids.

REC Solar built, operates, and supports a nearly 500-kW, ground-mounted solar array adjacent to the property's hotel and casino. "The solar plus energy storage cuts energy costs when the grid is up and powers up to 50% of operations when the grid is unavailable," said Sofranko. "During outages, such as public safety power shutoffs [usually called for during periods of wildfire danger], the Blue Lake tribe uses its microgrid—developed in conjunction with Siemens and the Schatz Energy Research Center—to power its Red Cross emergency center operations and provide critical power to its broader Northern California community."

The energy experts who spoke with *POWER*, including Sofranko, agreed that microgrids are an ideal investment for any company, group, or site that requires access to stable, reliable, uninterrupted power. Sofranko continued: "Critical infrastructure like data centers, hospitals and healthcare facilities, cybersecurity operations, and military installations frequently deploy microgrids. Regional energy trends and weather patterns also come into play, with states and communities prone to outages, high energy prices, and grid stability turning to microgrids for backup power and cost-saving benefits. In these markets, the use case for microgrids can expand beyond just supporting critical infrastructure to include any large-scale business operation that wants to improve its overall power reliability to keep operations running for customers or to mitigate business disruptions."

Said Payless Power's Young: "Last but not least, microgrids are not just a technological innovation—they are a strategic move toward energy independence, climate resilience, and people empowerment. Now, the agenda has to shift to scaling the systems, lowering their costs, and making them universally available so that not just the high-end communities but all communities can take advantage of this transition." ■

*—**Darrell Proctor** is a senior editor for POWER.*


TO ADVERTISE IN
POWER
Contact your Sales Representative for More Information:
ELLEN NYBOER | Eastern U.S./Canada
enyboer@accessintel.com | 713-343-1893
CHRIS HARTNETT | Western U.S./Canada
chartnett@accessintel.com | 404-634-5123
PETRA TRAUTES | Europe
ptrautes@accessintel.com | +49 172 6606303


To Advertise in POWER
Classifieds or Hot Products
CONTACT: Ellen Nyboer
PHONE: 713-343-1893
EMAIL: ENyboer@accessintel.com

The Risk of Political Rebranding in the Clean Energy Industry

Stamatis Astra

The U.S. solar industry has increasingly begun to rebrand itself as "MAGA-friendly," emphasizing cost savings, energy independence, and job creation over climate concerns. This shift marks a departure from its traditionally left-leaning roots, as companies attempt to appeal to conservative consumers and policymakers.

Some solar companies have changed their messaging to align with Trump-era rhetoric, promoting solar as a tool for reducing reliance on foreign energy. Others have downplayed environmental activism in favor of branding themselves as pragmatic, business-friendly alternatives.

When Changing the Message Hurts

Companies that shift their messaging to align with political winds—whether left or right—often find themselves alienating audiences and facing severe reputational and financial consequences. Bud Light learned this lesson last year when a partnership with a transgender influencer went viral, sparking boycotts and costing the brand $1.4 billion in sales.

Target has experienced similar turmoil from both sides of the political spectrum. The retailer first upset right-leaning consumers with its high-profile "Pride" collection, then frustrated other customers by scaling the collection back. This resulted in billions in losses and the company's stock facing a heavy drop. More recently, its decision to abandon long-held diversity, equity, and inclusion (DEI) values has angered progressive consumers, resulting in not only declining sales, but also a lawsuit in which stakeholders are suing Target for failing to warn against the potential risks of these messaging shifts.

Considering that we live in an era of extreme polarization, it's no surprise that brands wading into politics risk alienating a segment of their audience. But I don't believe the core issue is that consumers inherently dislike political statements; rather, the problem is inconsistency. When a company builds its brand identity around certain values, any attempt to pivot can feel like a betrayal.

What About Green Energy?

So, what does that mean for renewable energy companies trying to survive under Trump 2.0? Again, for decades, the green energy sector has been politically aligned with the left, with climate change discussions often framed as a Democratic issue. That began to shift with the current administration's unfriendly stance toward renewable energy.

In response, the clean energy industry has started emphasizing affordability over environmental benefits, attempting to rebrand itself as a fiscally conservative, cost-saving solution, rather than a climate-focused movement. The Solar Energy Industries Association even has a new slogan, "American Energy DOMINANCE," which matches some of Trump's rhetoric about U.S. energy initiatives.

While this strategy of matching the current party line might help appeal to a broader audience, it also carries significant risks. If solar companies now attempt to win over conservative support by downplaying environmental concerns, they run the risk of alienating progressive supporters.

Pivoting Without Losing Your Audience

So, is there a way for brands to change their spoken values without jeopardizing their customer base? That's the challenge the solar industry—and any company tempted to go political—must navigate carefully.

A key starting point is understanding your audience and making sure your messaging is what they're actually looking for. Artificial intelligence–powered sentiment analysis, customer surveys, and social media monitoring can help brands identify their customers' attitudes and refine messaging accordingly. Whether your customers are motivated by lower energy bills, energy independence, or environmental sustainability, develop marketing and public relations campaigns that match those motivations.

Next, think less about who is in office and more about using consistent messaging to build trust. Companies that change their messaging every election cycle risk appearing opportunistic rather than principled. Instead, stick to your core beliefs and established tone. If the company and its spokespeople are generally bold and don't mind picking fights, then stick with what has worked. If you're focused on a more neutral stance, continue to identify and brand yourself based on unifying themes that resonate across ideological lines, like job creation and economic growth.

If for whatever reason you do feel like you have to make a change, take it slow to avoid messaging whiplash for your customers. While aligning with a new audience may seem like a great opportunity for growth, sudden changes—even toward a more neutral stance—can backfire if they contradict years of branding. Rework messaging gradually, ensuring it remains consistent with your core mission.

Of course, even the most carefully planned messaging strategies can misfire. When backlash occurs, how a company responds can determine whether the damage is temporary or lasting. Rather than reacting defensively, brands should acknowledge concerns, clarify their position, and, if necessary, make adjustments without undermining their credibility. For instance, if a green energy company faces criticism for downplaying its environmental commitments, it can reinforce the idea that affordability and sustainability are not mutually exclusive. Handled the right way, value-based statements don't have to threaten your profitability in the long term.

For green energy, surviving political shifts requires a delicate balance between adaptability and consistency. Companies that maintain consistent messaging and know how to appeal to their existing customers rather than chasing political trends will be far better positioned for long-term success. ■

*—**Stamatis Astra** is co-founder and Chief Business Officer of Intelligent Relations.*