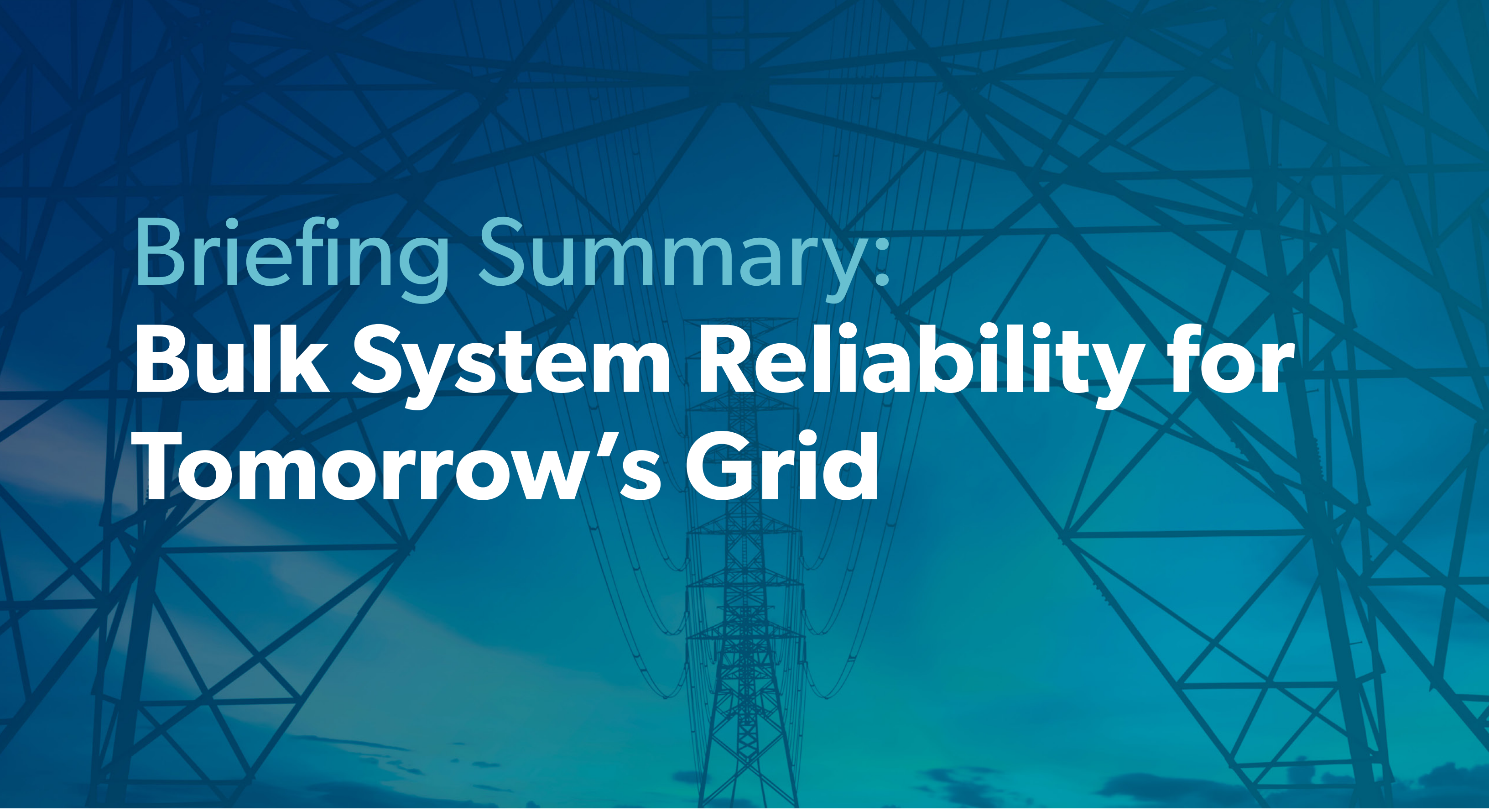

Briefing Summary: Bulk System Reliability for Tomorrow's Grid

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The electric grid is in transition. It is continuing a shift from fossil fuel-based systems of energy production to renewable energy sources and energy storage resources. Meanwhile, growth in demand is starting to accelerate, and grid reliability challenges are on the rise, prompting questions about the nature and pace of reforms needed to ensure reliability during the transition.

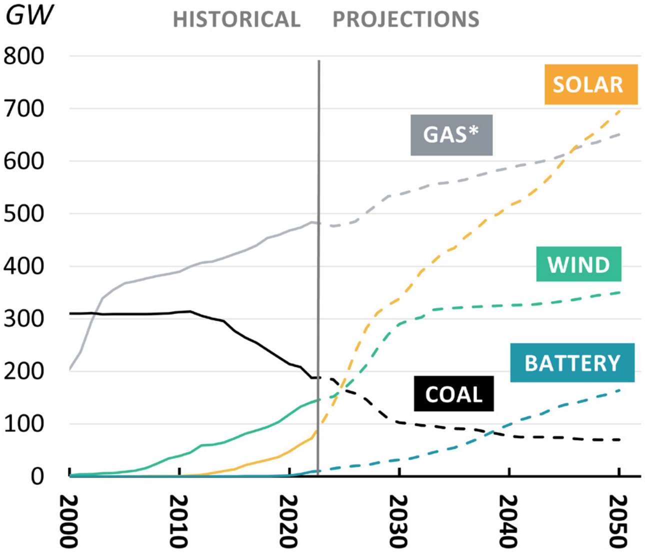
We investigated these reliability questions on behalf of the Center for Applied Environmental Law and Policy in a detailed report, which is summarized in this briefing.

In this investigation, we concluded the following:

- The grid transition is driven by combined effects of rapidly declining cost of clean energy, customer preferences, state and federal clean energy policies, as well as EPA regulations, together with other factors. *(continued on next page)*

- The transition offers both challenges and abundant solutions to address challenges, shifting the focus of grid reliability management practices.
- A comprehensive suite of reliability reforms is needed to address the transition challenges regardless of EPA regulations.
- Examples of such reliability reforms are in place or underway at various grid operators. Acceleration of these reforms should be a priority to ensure reliability during the transition.
- For specific cases in which EPA regulations are a major driver of transition-related challenges and reliability reforms do not keep pace, regulatory flexibility can be utilized to address reliability needs while meeting EPA regulations.

FIGURE 1: HISTORICAL AND PROJECTED ELECTRICITY GENERATION CAPACITY BY SELECTED TYPE



Source: U.S. Energy Information Agency

CHANGING RELIABILITY STRENGTHS & CHALLENGES

Shifting stress periods:

Clean supply is available in ever-greater abundance during traditional peak demand periods, but less available during other periods.

New constraints:

Flexible short-duration batteries are being deployed rapidly, but are largely exhausted during long-duration winter reliability challenges that are becoming increasingly prevalent.

New inverter configurations:

Poorly-configured inverters used by renewable or battery plants can cause reliability challenges, even though available inverter technology can provide abundant reliability support when fully integrated into the utility's systems and protocols.

Value of flexibility:

The output from wind and solar generators is nearly zero marginal cost, but their variability and uncertainty pose new challenges for operators who must balance supply and demand under all conditions. At the same time, technology advancements in storage and demand-side resources promise to unlock new, low-cost sources of flexibility.

Value of transmission:

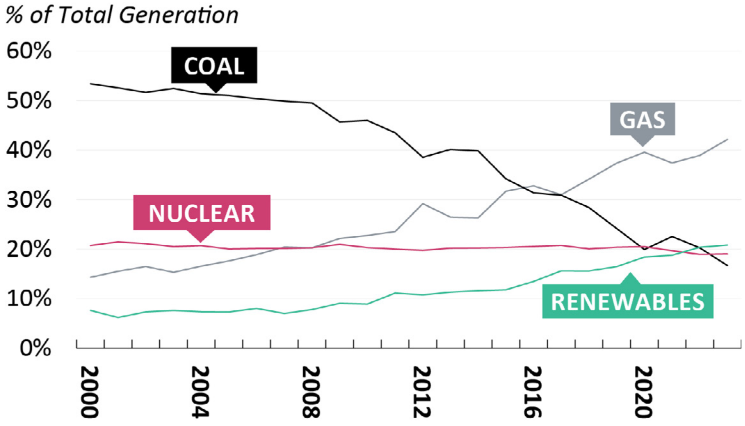
Low-cost renewables are often remote from demand centers. Meanwhile, neighboring grids can offer mutual support for balancing supply and demand by increasing their interconnectivity. In both cases, transmission expansion is increasingly valuable, and new technologies can help achieve it at lower cost.

1. The Resource Mix is Changing While Growth in Electricity Demand is Starting to Accelerate

Utilities across the country are adding clean energy goals to their existing objectives of reliability and cost effectiveness while the cost of new clean supply has been falling rapidly. Aging generators struggle to compete, especially as EPA regulations for clean air and water get stricter. The result is a shift in the primary sources of electricity generation over the last two decades, shown in Figure 2 below, with consistent growth in renewable and natural gas generation and declines in coal generation.

Coal power has seen declining market share since 2000. Coal now provides less electricity than nuclear or renewable generation.

FIGURE 2: SHARE OF ELECTRIC ENERGY GENERATED BY RESOURCE TYPE



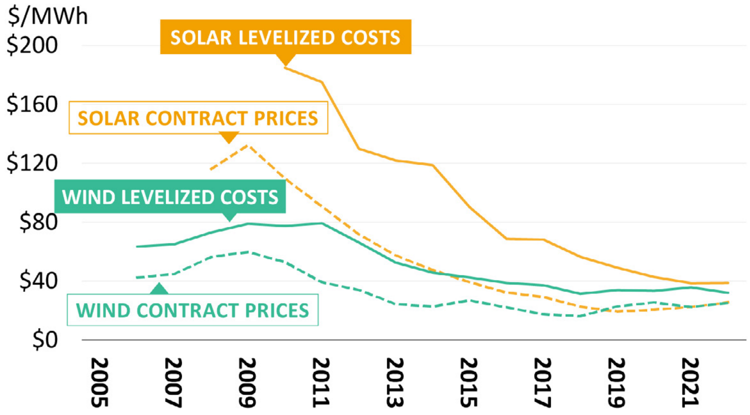
Source: *U.S. Energy Information Agency*

Since 2010, the cost of new wind and solar generation has fallen by well over half

Figure 3 illustrates the extent of the decline in clean energy costs. Prices of long-term purchase contracts for new wind and solar generators now average around $25/MWh (i.e., 2.5¢ /kWh). These cost declines are due to: [i]

- Decreases in capital cost as equipment manufacturing and generator size has scaled up;
- Increases in generator efficiency and reduced operating cost; and
- More efficient permitting and installation.

FIGURE 3: HISTORICAL SOLAR AND WIND LEVELIZED COSTS AND CONTRACT PRICES

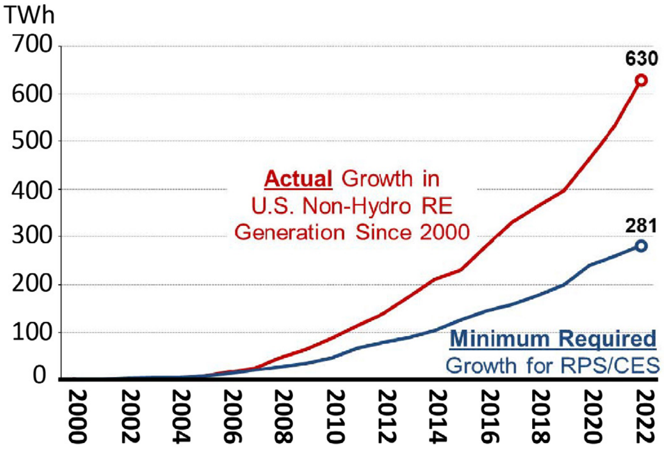


Source: *Lawrence Berkeley National Laboratory and U.S. Department of Energy*

Customers and Many State and Local Governments Favor Clean Power

29 states have requirements for renewable generation purchases (called renewable portfolio and clean energy standards, or RPS and CESs).[ii] As shown in Figure 4, these requirements account for about half of 2022 clean-energy generation. Meanwhile, municipal-led supply arrangements called Community Choice Aggregations are growing. Voluntary long-term corporate procurements also motivate new clean energy supply, representing approximately 17% of new wind and solar generation built in 2022. Other voluntary renewable purchases, such as residential customers in clean-energy retail choice programs in applicable states, also contribute.[iii]

FIGURE 4: RENEWABLE DEPLOYMENT EXCEEDS STATE GOALS



Source: *Lawrence Berkeley National Laboratory*

Coal Generation Faces Headwinds

The competitiveness of coal generation has been challenged for decades, with the share of electricity from coal falling since 2000 (Figure 2). Retirements began in earnest in the last decade, and are expected to continue (see Figure 1 on page 2). The retirements are not driven by a single factor, but rather are due to several concurrent competitive pressures, including:[iv]

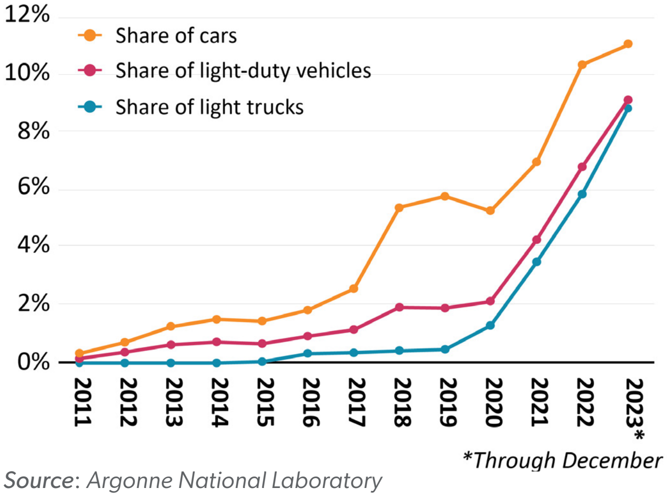
- Rising cost to operate aging plants;
- Sustained low prices for competing gas and renewable generation;
- State and federal clean energy policies (e.g., the Production Tax Credit, state Renewable Portfolio Standards, etc.); and
- Stricter emissions standards, such as the Mercury and Air Toxics Standards (MATS), the Coal Combustion Residuals (CCR) rule, and the Cross-State Air Pollution Rule (CSAPR).

Growth in Electricity Demand is Starting to Accelerate

Stagnating growth in electricity demand has been a feature of the last decade, contributing to the challenging economics of aging generators.[v] Nonetheless, an acceleration of electricity demand growth, in some places rapidly, is expected. Sources of demand growth include data centers, expansion of electric heat pumps, electric vehicles, and reshoring of manufacturing.[vi]

This new trend is expected to increase the need for new generation resources and transmission. In some cases, the technology underlying the demand growth features greater controllability and flexibility than traditional electricity loads. This capability can be used to mitigate the very challenges caused by demand growth and provide a valuable new source of grid flexibility.[vii] For example, home electric vehicle charging can be scheduled flexibly overnight to respond to grid needs since typical commutes do not require a full night to recharge.

FIGURE 5: ELECTRIC VEHICLES SALES SHARE OF TOTAL



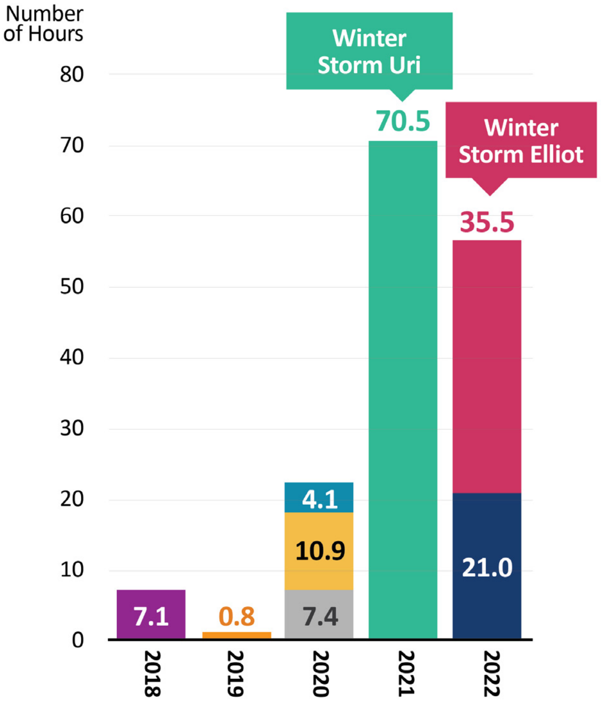
Source: *Argonne National Laboratory*

The Impact of Extreme Weather is Growing

Figure 6 shows that the frequency and magnitude of grid emergencies appears to be increasing due to extreme weather.

- Extreme hot and cold temperatures are increasingly leading to rotating power outages caused by the correlated unavailability of generation resources due to equipment failures and lack of access to fuel.
- This has led to efforts to improve gas-electric coordination and the winterization of generators of all types.[viii]

FIGURE 6: HOURS OF ROTATING POWER OUTAGES BY EVENT IN THE U.S. SINCE 2018

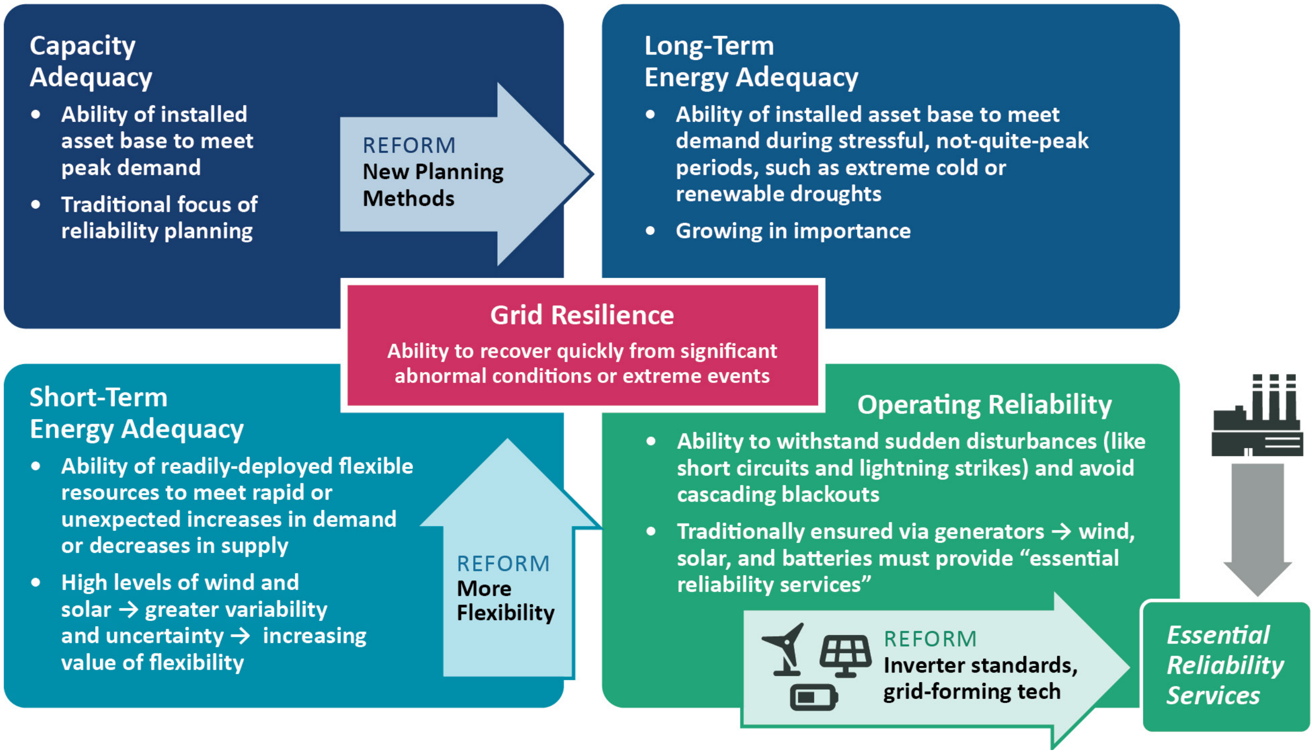


Source: *North American Electric Reliability Corporation*

2. Grid Reliability Reforms are Underway, as Warranted by the Clean Energy Transition

The regional electric grid, consisting of bulk transmission lines that cross the country, is necessary to provide the electric service that customers depend on. Reliability is the ability to ensure electricity is available continuously. The North American Electric Reliability Corporation (NERC), empowered with federal authority to coordinate and ensure regional reliability, defines several distinct characteristics of regional grid reliability. To illustrate how reliability changes during the clean-energy transition, we highlight four such reliability characteristics, as summarized in Figure 7.[1] We add "resilience," the ability to recover quickly from abnormal conditions, as a consideration that is present across all four reliability characteristics.

FIGURE 7: FOUR CHARACTERISTICS OF RELIABILITY ARE EVOLVING AND REQUIRE REFORMS



Capacity Adequacy

- Ability of installed asset base to meet peak demand
- Traditional focus of reliability planning

REFORM
New Planning Methods

Long-Term Energy Adequacy

- Ability of installed asset base to meet demand during stressful, not-quite-peak periods, such as extreme cold or renewable droughts
- Growing in importance

Grid Resilience

Ability to recover quickly from significant abnormal conditions or extreme events

Short-Term Energy Adequacy

- Ability of readily-deployed flexible resources to meet rapid or unexpected increases in demand or decreases in supply
- High levels of wind and solar → greater variability and uncertainty → increasing value of flexibility

REFORM
More Flexibility

Operating Reliability

- Ability to withstand sudden disturbances (like short circuits and lightning strikes) and avoid cascading blackouts
- Traditionally ensured via generators → wind, solar, and batteries must provide "essential reliability services"

REFORM
Inverter standards, grid-forming tech

Essential Reliability Services

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[1] NERC defines "adequacy" and "operating reliability" as the two aspects that define reliability. See NERC, Reliability Terminology, August 2013, accessed November 9, 2023.

NERC further differentiates capacity adequacy, long-term energy adequacy, and operational energy adequacy in NERC, Ensuring Energy Adequacy with Energy Constrained Resources, December, 2020, pp. 3-4.

Grid Operators are Pursuing Necessary Reliability Reforms

As we catalog in Section IV.F of the full report, Bulk System Reliability for Tomorrow's Grid, the nation's grid operators and regulators are pursuing an array of reforms across the four aspects of reliability summarized above. The following examples illustrate the types of reliability reforms currently underway.

- **Resource adequacy reforms:** in response to the clean-energy transition, resource adequacy planners across the country are in the process of expanding their analyses to evaluate every hour of the year, rather than just peak conditions, an approach known as long-term energy adequacy planning. This includes all of the regional grid operators—i.e., the Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs)—and many utilities. The first component of this reform is a method to calculate the capacity value of supply resources called Effective Load Carrying Capability (ELCC).[ix] ELCC calculates the capacity value of a resource by comparing patterns in its generation output to patterns in anticipated resource shortfall risk during all hours of the year. Because the presence of wind and solar generation tends to shift the system's peak net demand (i.e., peak demand minus variable wind and solar output) and reliability risk to hours with less wind and solar (such as early evening), an ELCC-based resource adequacy analysis can better measure the (often diminishing) adequacy value of renewable resources as their share of supply increases.[x]
- **Short-term energy adequacy reforms:** the marginal cost of wind and solar output is nearly zero, but its availability is variable and subject to uncertainty. Grid operators, who must continuously balance supply and demand in real-time, have long been accustomed to working with variability (e.g., in demand for power) and uncertainty (e.g., due to sudden failures of large conventional generators).[xi] Even for significant initial deployments of wind and solar power, grid operators use these existing tools to take advantage of nearly all of the production of such generators. However, with significant further expansion of wind and solar power on the horizon, operators are now re examining and improving their existing methods to manage increasing variability and uncertainty.

> ***All the ISOs/RTOs recently have either increased the quantity of operating reserves or introduced new types of flexibility reserves to address the variability and uncertainty of increasing shares of renewable generation.***[xii]

- **Operating reliability reforms:** the Federal Energy Regulatory Commission (FERC), NERC, grid operators, and utilities are all pursuing significant enhancements to requirements on the dynamic capabilities of the power inverters that are used by wind, solar, and battery facilities.[xiii] Interconnection requirements already mandate that inverter-based resources provide some essential reliability services, such as reactive power for voltage control, and that they stay connected to the grid during stability challenges such those caused by lightning strikes and short circuits.[xiv] However, these do not address all the essential reliability services, and ambiguities in implementation or other gaps in requirements can cause reliability challenges.[xv]

The reforms, such as through FERC Order 901, will lead to requirements that address remaining ambiguities and other gaps that have led to inverter-based resources (IBRs) failing to perform adequately during stability challenges.[xvi] In many cases, system operators are expected to go further and specify the provision of other essential reliability services. So-called "grid forming" inverter technology is now commercially available to provide a full suite of such reliability services, including inertial response and voltage disturbance performance—although grid codes have not yet been developed in the U.S. to enable and mandate these IBR-based reliability services.[xvii]

TABLE 1: EXISTING RELIABILITY TOOLS WILL SHIFT IN IMPORTANCE AND EVOLVE TO MATCH EVOLVING SYSTEM NEEDS

	Shifting Challenges and Strengths	Shifting Solutions	Resilience Solutions
Capacity Adequacy and Long-Term Energy Adequacy	• More variability in potential scarcity conditions, such as extreme cold weather and renewable droughts • Increased demand for electricity, including more controllable demand	• Shift to year-round adequacy evaluations, new metrics • Improved precision of probabilistic reliability models, longer weather histories	• Potential to incorporate non-probabilistic scenario-based planning of extreme weather for resilience
Operational Energy Adequacy	• More variability and uncertainty • Potential to unlock new sources of flexibility among customer-side resources, batteries, and curtailed renewables	• More sophisticated operational tools, including forecasting • New ancillary services for ramping and other flexibility services to operate and retain or attract flexible resources • Improved pricing of flexibility services in ISOs/RTOs	• Explicit planning for low probability drops in renewable output
Operating Reliability	• Faster dynamics and more responsive resources • More computer-mediated transient responses and need to manage configurations and models • Resources can provide services all the time at lower cost	• Greater role for stability • Potentially more synchronous condensers • More HVDC for long-haul access to remote, low-cost resources and stability improvement	• Designing the system for recovery from abnormal conditions via grid-forming inverters

Existing Resource Adequacy Mechanisms Adapt in Response to Reliability Needs

Resource adequacy is the ability of the installed base of supply resources to meet demand even under challenging conditions of exceptionally high demand and/or high unavailability of supply. Resource adequacy planning and investment processes are run on a regular basis to ensure that reliability targets are met in practice, and that shortfalls in supply are therefore minimized.

The resource adequacy assurance processes vary somewhat across North America by utility and grid operator. Traditionally-regulated utilities typically conduct an open integrated resource planning process to support decisions to invest in or retire supply resources. The ISOs/RTOs, such as PJM and CAISO, also conduct such resource adequacy planning, and place resource requirements on member utilities. In restructured states, such as Ohio or Maine, the ISO/RTO planning process is the primary way that resource adequacy is assured. MISO, PJM, and the Northeastern RTOs also feature capacity auctions in which suppliers trade with utilities and other buyers so the latter can meet their requirements.

When supply becomes tight, either due to growth in demand or because existing supply becomes uneconomic, the resource adequacy process is designed to identify the tightness years ahead of time, and adapt accordingly. In the case of a traditionally-integrated utility, it will identify supply options that can be procured within the necessary timeframe (e.g., demand response, battery deployment, or off-system purchases if there is less time, or deployment of new generation if there is sufficient time), then select those that best meet the planning objective (typically cost effectiveness). In the case of a forward capacity market, such as PJM or ISO New England, the tightness will manifest in a high auction clearing price several years ahead of the target year. These high prices will in turn incentivize changes in investment plans, ranging from delayed retirements to investment in new generation.

Reforms Pave the Way for Quicker Deployment of Grid Assets

As described in Section IV.E of the report, after many decades with relatively little policy attention, lawmakers in many states are recognizing the need for more consistent and predictable timelines for siting of grid assets, especially in light of the shift to renewable energy. Many states have passed legislation in pursuit of this goal, in some cases helping break ground on significant transmission projects.

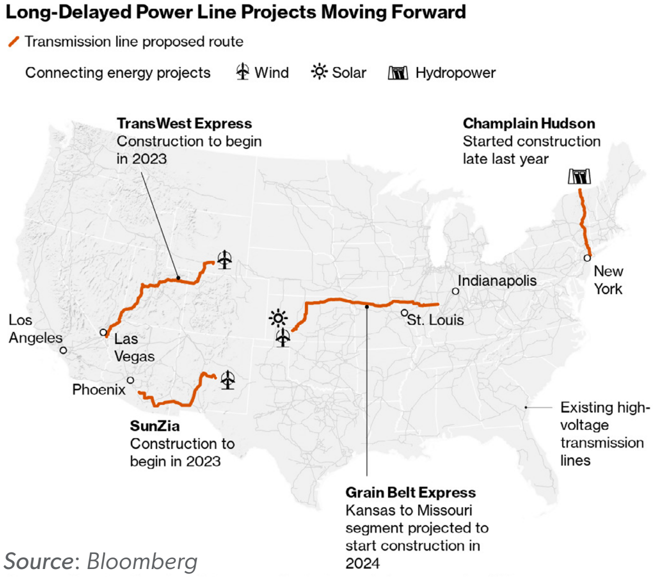
The federal government has also taken a variety of steps to facilitate siting and development of grid assets:[xviii]

- The 2021 Bipartisan Infrastructure Law strengthened existing federal authority over transmission siting in designated National Interest Electric Transmission Corridors. *(continued on next page)*

- The Department of Energy (DOE) proposed easing environmental reviews for certain transmission upgrades and rebuilds (as well as storage and solar projects) on federal land.
- The Bipartisan Infrastructure Law and the Inflation Reduction Act together included tens of billions of dollars in funding to support transmission siting and development.
- The Biden administration says they have helped facilitate breaking ground on ten new high-capacity transmission projects since 2021, connecting 19.5 GW of new generation.

Americans for a Clean Energy Grid and Grid Strategies have identified 36 projects totalling approximately 132 GW of transmission capacity that are in "ready to go" status.[xix]

FIGURE 8: TRANSMISSION PROJECTS MOVE AHEAD AFTER YEARS OF PERMITTING



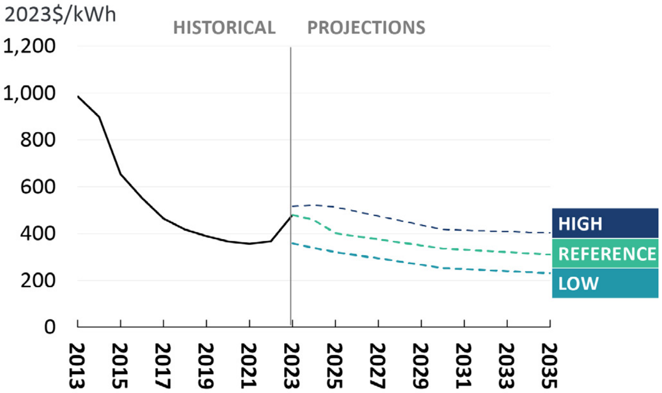
Source: *Bloomberg*

Transition-Enabling Technologies Continue Maturing

The temporal variability of wind and solar output is, at moderate levels, comparable to the variability of electricity demand, and can be handled similarly. However, at high deployment levels, system flexibility gains higher value and serves to enable full leverage of low-cost wind and solar output.

- Like wind and solar power, energy storage costs have also declined rapidly, and are expected to continue to decline (Figure 9). Battery deployments in the U.S. exceeded 17,000 MW as of 2023, up from just 2,000 MW in 2020.[2]
- Distributed energy resources such as rooftop solar power and building-integrated battery systems enable society to increase dependence on electricity for heat and transport while maintaining access to an energy source other than the grid.
- A new, more controllable form of high-voltage direct current (HVDC) transmission technology features several advantages, including superior stability, controllability for efficient operations, and the ability to transmit more power over smaller and longer

FIGURE 9: THE INSTALLED CAPITAL COST OF BATTERY ENERGY STORAGE IS EXPECTED TO CONTINUE TO DECLINE



Source: *BNEF and National Renewable Energy Laboratory*

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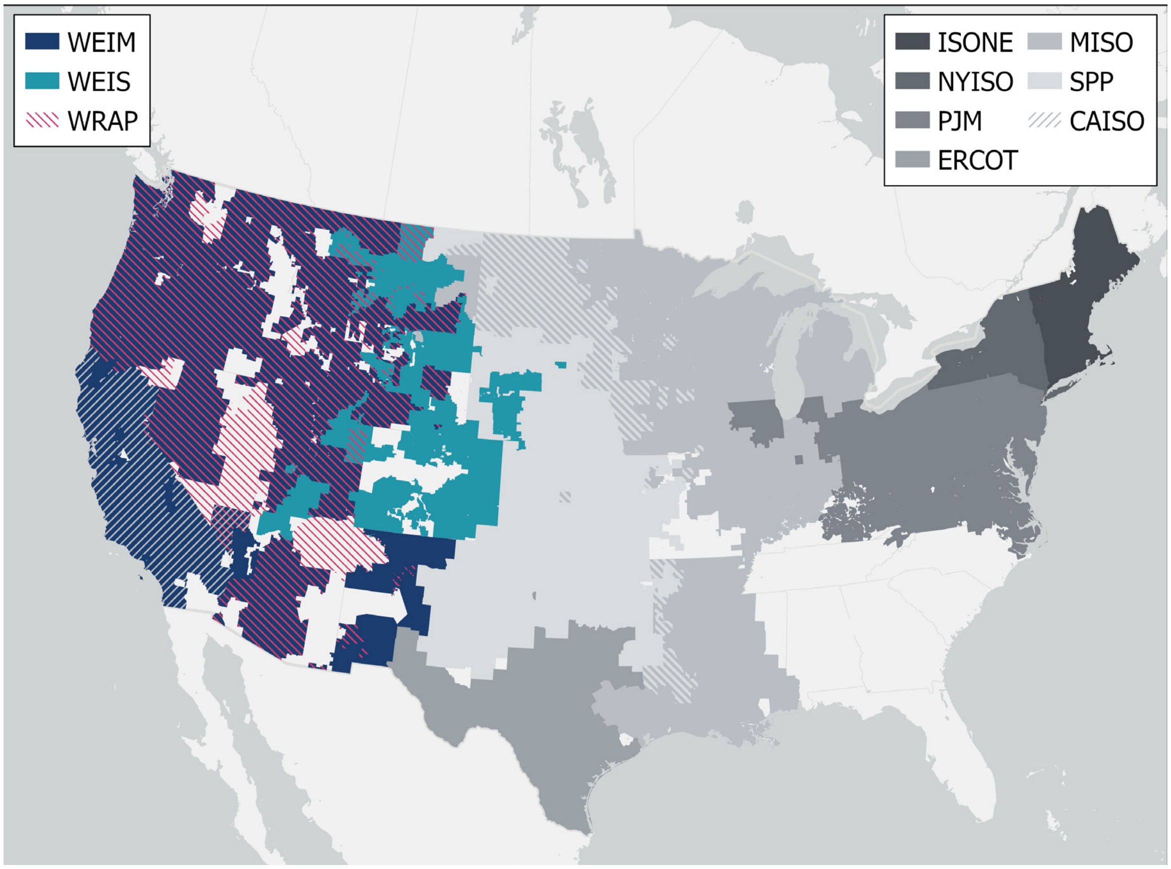
[2] 17 GW refers to planned battery storage capacity with online date in 2023, according to EIA Form 860M data; EIA, "Preliminary Monthly Electric Generator Inventory (based on Form EIA-860M as a supplement to Form EIA 860)," November 22, 2023, October 2023 data, accessed November 28, 2023; EIA, "Electric Power Annual," 2023, Table 4.08. C. Usage Factors for Utility Scale Storage Generators, accessed November 28, 2023.

corridors. This so-called "voltage-source converter" or VSC HVDC technology has been deployed in rising quantities worldwide, especially in Europe.[3]

- Regional wholesale markets are continuing to expand, accruing billions in benefits for customers and reliably facilitating integration of large amounts of variable wind and solar power.[4] See the Western Energy Imbalance Market (WEIM), Western Energy Imbalance Service (WEIS), and Western Resource Adequacy Program (WRAP) portions of the map in Figure 10 below, none of which existed prior to 2014.
- Grid-Enhancing Technologies (GETs) allow operators to increase utilization of existing transmission infrastructure, moving more power without the need to build new transmission.[5] By optimizing the flow of electricity over existing transmission lines, GETs such as dynamic line ratings, topology control, and advanced flow control can potentially allow more than twice the amount of new renewables to be interconnected relative to conventional transmission planning approaches.

FIGURE 10: CENTRALIZED WHOLESALE MARKETS (WEIM AND WEIS) AND RESOURCE ADEQUACY POOL (WRAP) HAVE ALL EXPANDED ACROSS THE WEST SINCE 2014



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[3] Johannes P. Pfeifenberger, et al. The Operational and Market Benefits of HVDC to System Operators, September, 2023.

[4] EIA, Electric Retail Service Territories, December 9, 2022, accessed November 30, 2023; WEIM, "About," 2023, accessed November 30, 2023; SPP, Western Energy Imbalance Service Market, 2023, accessed November 30, 2023; Western Power Pool (WPP), "WRAP Area Map," April 5, 2023, accessed November 30, 2023.

[5] DOE, Grid-Enhancing Technologies: A Case Study on Ratepayer Impact, February 2022.

3. Flexibilities in EPA Regulations Can Meet Environmental Goals While Serving Reliability if Reforms are Outpaced

Despite being only one of many contributors to coal plant retirements, environmental regulations could accelerate the pace of such retirements. While many enabling technologies are available to facilitate grid transition, and the relevant reliability reforms are well underway, EPA regulations could hypothetically accelerate system needs faster in some areas than reforms are adapting there. It is therefore instructive to understand what compliance flexibilities already exist in EPA regulations to deal with such possibilities.

Environmental regulations typically specify standards for emissions (e.g., rates per unit of fuel use or quantities per hour or per year), compliance deadlines, and multiple compliance options with varying degrees of costs and effectiveness. The various forms of compliance options and flexibilities allow plant owners, state regulators, and system planners to develop cost-effective compliance plans that meet the standard while preserving system reliability. The key types of compliance flexibilities in U.S. federal environmental regulations that tend to reduce adverse impacts on electric grid reliability can be summarized into four general categories:

Key Flexibilities in EPA Regulations

1	2	3	4
Emissions standards instead of a mandate to reduce generation output or retire a power plant	Multiple compliance options including emissions allowance purchases, fuel conversion, and installation of control equipment that would allow power plants to continue operating during periods with high reliability needs	Multi-year advance notice to implement compliance plans	Emergency exemptions as a last resort option for maintaining grid reliability

In sum, many factors are at play in the changing supply mix and the evolving grid. Our review of industry studies indicates that, even without environmental regulations, these other factors will continue to drive industry change and the need to address grid reliability challenges. In particular, when decisions are made to retire a generator, they are made based on the combined effects of all factors that impact the generator's economic outlook. To be sure, EPA regulations can be an important accelerator of the clean energy transition. In specific cases, reforms to address emerging challenges and solutions could proceed more slowly than the exigencies of the transition. To the extent that reliability concerns remain, the existing flexibility in EPA regulations can be an important tool for maintaining grid reliability while achieving environmental objectives.

APPENDIX A: NOTES AND SOURCES

Figure 1: *Under EIA Annual Energy Outlook projects, the category "gas" combines capacity from combined cycle, combustion turbine/diesel, and natural gas/oil steam plants; capacity equal to installed summer capacity (for conventional generators) or nameplate capacity (for wind, solar, and battery resources) for use in the electric power sector; figure excludes capacity from conventional hydropower, nuclear, storage, geothermal, and biomass sources; see U.S. Energy Information Administration (EIA), Monthly Energy Review, 2023, Table 7.2b; EIA, Annual Energy Outlook (AEO) 2023, March 16, 2023, Table 9, Table 16.

Figure 2: 2023 data represents net generation from January through August 2023; EIA, Monthly Energy Review, November 2023, Table 7.2b.

Figure 3: Values all correspond to new wind and solar generators. Contract prices are average market-based contract prices from surveys. Dollars are expressed in nominal terms; LBNL, Utility-Scale Solar 2023 Edition, October 2023; DOE, Land-Based Wind Report, 2023.

Figure 4: "RE" stands for renewable energy, and "CES" stands for Clean Electricity Standards; Galen Barbose, U.S. State Renewables Portfolio & Clean Electricity Standards: 2023 Status Update, June 2023.

Figure 5: "PEV" stands for plug-in electric vehicles, "LT" stands for light truck, "LDV" stands for light-duty vehicle; Argonne National Laboratory, "Light Duty Electric Drive Vehicles Monthly Sales Update," 2023, accessed December 14, 2023.

Figure 6: NERC, 2023 State of Reliability Technical Assessment: Technical Assessment of 2022 Bulk Power System Performance, June 2023, p. 39.

Figure 7: See Section III and Section IV of the full report, Bulk System Reliability for Tomorrow's Grid.

Figure 8: Brian Eckhouse, et al., Billion-Dollar Power Lines Finally Inching Ahead to Help US Grids, Bloomberg, March 6, 2023.

Figure 9: Historical data for battery facilities are based on Bloomberg battery pack cost estimates plus a cost-adder of $206/kWh in 2023$ which accounts for additional component (battery management systems, balance of system, inverters, etc.) and soft costs (taxes, overhead, developer costs, etc.) for the remainder of facility costs; projections of battery facility costs are NREL 2023 Annual Technology Baseline estimates for 4-hour, utility-scale lithium ion battery storage. See BNEF, Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh, November 27, 2023; NREL, 2023 ATB, 2023.

Figure 10: EIA, "Electric Retail Service Territories," December 9, 2022, accessed November 30, 2023; WEIM, "About: Active Participants," 2023, accessed November 30, 2023; CAISO, "EDAM: Extended Day Ahead Market," accessed November 29, 2023; SPP, "Western Energy Imbalance Service Market," 2023, accessed November 30, 2023; SPP, "Markets +," accessed November 30, 2023; Western Power Pool, "WRAP Area Map," November 21, 2022, accessed November 30, 2023.

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- The brief reflects the analyses and opinions of the authors and does not necessarily reflect those of The Brattle Group's clients or other consultants. We appreciate valuable comments and suggestions from Johannes Pfeifenberger and Peter Fox-Penner.
- The analyses and market overviews provided in this presentation are necessarily based on assumptions with respect to conditions or events which may or may not arise or occur in the future. While we believe these assumptions to be reasonable for purposes of preparing our analysis, they are dependent upon future events that are not within our control or the control of any other person. Actual future outcomes can and will differ, perhaps materially, from those evaluated in these projections.
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ENDNOTES

i National Renewable Energy Laboratory (NREL), 2023 Electricity Annual Technology Baseline Data, 2023; LBNL, "Utility-Scale Solar 2023 Edition Data File," 2023, accessed December 4, 2023.

ii Galen Barbose, U.S. State Renewables Portfolio & Clean Electricity Standards: 2023 Status Update, June 2023.

iii Municipal procurement data from NREL, Status and Trends in the Voluntary Market (2022 Data), September 20, 2023. Installed capacity additions with corporate buyers from Clean Energy Power, 2022 Corporate Buyers Report, January 2023, p. 41; Total increase in wind and solar capacity in 2022 from EIA, Monthly Energy Review, 2023, Table 7.7b; EPA, "Community Choice Aggregation," October 27, 2023, accessed December 4, 2023.

iv Metin Celebi, et al., A Review of Coal-Fired Electricity Generation in the U.S., The Brattle Group, April 27, 2023.

v See historical near-term forecasts of peak load; NERC, 2023 Long-Term Reliability Assessment, December 2023, Supplemental Charts and Graphs, Table F.

vi NERC, 2023 Long-Term Reliability Assessment, December 13, 2023, Supplemental Charts and Graphs, Table H; John Wilson and Zach Zimmerman, The Era of Flat Power Demand is Over, Grid Strategies, December 2023; EPRI, Reindustrialization, Decarbonization, and the Prospects for Demand Growth, 2023; McKinsey & Company, Investing in the rising data center economy, January 17, 2023; Jared Anderson, et al., Power of AI: Wild predictions of power demand from AI put industry on edge, S&P Global, October 16, 2023; The White House: Office of Science and Technology Policy, "FACT SHEET: Climate and Energy Implications of Crypto-Assets in the United States," September 8, 2022, accessed December 4, 2023; DOE, "Regional Clean Hydrogen Hubs," accessed December 4, 2023; Robert Walton, Pot, EVs, data to lead electricity demand growth: Morningstar, Utility Dive, December 5, 2018; Jeremy David and Howard Herzog, The Cost of Carbon Capture, Massachusetts Institute of Technology, October 2011; Trieu Mai, et al., Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States, NREL, 2018.

vii NREL, Electrification Futures Study: Operation Analysis of U.S. Power Systems with Increased Electrification and Demand-Side Flexibility, May 2021, p. 55.

viii National Association of Regulatory Utilities Commissioners (NARUC), Memorandum on the Creation of the Gas-Electric Alignment for Reliability (GEAR), 2023; FERC and NERC, FERC, NERC Encourage NAESB to Convene Gas-Electric Forum to Address Reliability Challenges, July 29, 2022; FERC, 182 FERC ¶ 61,094, February 16, 2023, Order Approving Extreme Cold Weather Reliability Standards EOP-011-3 and NERC, EOP-012-1 and Directing Modification of Reliability Standard EOP-012-1; NERC, Reliability Guideline: Natural Gas and Electrical Operational Coordination Considerations, March 22, 2023; North American Energy Standards Board (NAESB), Gas Electric Harmonization Forum Report, July 28, 2023; FERC, FERC Approves Final Rule to Improve Gas-Electric Coordination, April 16, 2015.

ix Except ERCOT, which does not do centralized long-term adequacy planning. See, Tongxin Zheng, Resource Capacity Accreditation (RCA) Overview and Roadmap, ISO New England (ISO-NE), October 2023; California Public Utilities Commission (CPUC), Decision Requiring Procurement to Address Mid-Term Reliability (2023-2026), June 24, 2021, p. 13; PJM, "Effective Load Carrying Capacity (ELCC)," accessed November 29, 2023; CPUC, 2020 Qualifying Capacity Methodology Manual, November 2020, pp. 13-14; MISO, "Planning Year 2022-2023 Loss of Load Expectation Study Report," 2022, accessed December 2, 2023, pp. 19-20; Astrapé Consulting, Duke Energy Carolinas and Duke Energy Progress Effective Load Carrying Capability (ELCC) Study, April 25, 2022, pp. 4-18; Georgia Power, 2023 Integrated Resource Plan Update, October 2023, p. 12; Arizona Public Service Company, 2023 Integrated Resource Plan, November 2023, p. 66; Public Service Company of Colorado, Our Future Energy: Destination 2030, March 31, 2021, p. 213-214; Astrapé Consulting, Dominion Energy South Carolina 2023 Planning Reserve Margin Study, January 27, 2023, p. 28; Tennessee Valley Authority, 2019 Integrated Resource Plan Volume I: Final Resource Plan, 2019, pp. D-7 – D-9.

x L. L. Garver, Effective Load Carrying Capability of Generating Units, IEEE Transactions on Power Apparatus and Systems, Aug. 1966, vol. PAS-85, no. 8, pp. 910-919. For general background on ELCC see Nick Schlag, et al., Capacity and Reliability Planning in the Era of Decarbonization, Energy + Environmental Economics, August 2020. For detailed information on ELCC calculations and conceptually related studies, see Astrapé Consulting, "Our Publications," 2023, accessed December 17, 2023; NERC, Considerations for Performing an Energy Reliability Assessment: ERATF White Paper, March 2023, pp. 1-3.

xi E.g., NERC requires grid operators to maintain operating reserves to manage uncertainties while meeting the need to rapidly balance supply and demand. In its 2014 paper on Essential Reliability Services, NERC describes operating reserves as follows: "ORs ensure a sufficient amount of resources are available to address load and generation imbalance. Some types of ORs include regulation, load following, and contingency reserves," and then describes each type as follows: "***Regulation***: Used to manage the minute-to-minute differences between load and resources and to correct for unintended fluctuations in generator output"; "***Load Following***: Follow load and resource imbalance to track the intra- and inter-hour load fluctuations within a scheduled period"; "***Contingency Reserves***: Resources that are slated to provide contingency reserve services are utilized during a contingency event, and contingency reserves ensure resources are available to replenish the amount of output used during the event, thus returning the system to the level of balance before the event." NERC, Essential Reliability Services Task Force, October 2014, p. 3.

xii E.g., Following Winter Storm Uri, ERCOT updated the operating reserve demand curve used to procure operating reserves, see ERCOT, 2022 Biennial ERCOT Report on the Operating Reserve Demand Curve, October 31, 2022, p. 6. ERCOT also increased reserve procurement after implementing Contingency Reserve Services, see Carrie Bivens, IMM Concerns with the AS Methodology and Recommended Improvements, September 22, 2023, p. 4. CAISO calculates day-ahead reserve requirements based on the maximum of A) 6.3% of load forecast B) largest single contingency and C) 15% of forecasted solar production (similar calculation for real-time reserves), day-ahead reserve procurement in 2022

ENDNOTE

increased by an average of 3% relative to prior year, see CAISO, 2022 Annual Report on Market Issues & Performance, July 11, 2023, p. 146. In 2021, MISO proposed raising the price cap of its ORDC (while maintaining same maximum quantity procured at the foot), while this reform does not directly increase the quantity procured, it could incentivize greater resource participation in operating reserves due to higher revenue opportunities, MISO, Scarcity Pricing Evaluation, May 2021, pp. 16-17; PJM implemented an increase on all operating reserve requirements until further notice but is concurrently pursuing additional reforms, see PJM, Synchronized Reserve Requirement Reliability Update, May 18, 2023, p. 1; PJM, Reserve Certainty Problem/Opportunity Statement, August 24, 2023, pp. 1-4.

ERCOT, Introduction to FFR Advancement and ERCOT Contingency Reserve Service (ECRS) Projects), June 16, 2022, p. 6; ERCOT, Board Report on Creation of ERCOT Contingency Reserve Service and Revisions to Responsive Reserves, February 12, 2019; HB 1500 requires ERCOT to implement a new ancillary product called Dispatchable Reliability Reserve Service by December 2024; Texas Legislature, H.B. No. 1500, June, 2023, pp. 20-21; Kenan Ögelman, DRRS Discussion, ERCOT, July 27, 2023, pp. 1-7; CAISO, "Flexible ramping product," 2023; CAISO, "Revised Final Proposal: Day-Ahead Market Enhancements, May 1, 2023, p. 5; MISO, BPM 002, September, 30, 2022, pp. 52-55; PJM, Manual 11, November 15, 2023; CAISO, Day-Ahead Market Enhancements, May 2, 2023.xiii NERC will reform its performance requirements for inverter-based resources and consider commissioning requirements to confirm that new such resources are configured properly. NERC will also "develop two Reliability Standard Projects…to produce performance and post-disturbance analytical expectations that will address the systemic IBR performance issues and support a more reliable IBR fleet." See NERC, Inverter-Based Resource Performance Issues Report, November 2023, Findings from the Level 2 Alert, p. v.; FERC issued Order 2023 in July 2023 mainly to require reforms to the interconnection process at the ISOs/RTOs. However, the order also includes revisions to new interconnection agreements that require inverter-based resources to better contribute to stabilizing the grid during disturbances. See FERC, 185 FERC ¶ 61,042, October 19, 2023, Reliability Standards to Address Inverter-Based Resources and FERC, 184 FERC ¶ 61,054, July 28, 2023, Improvements to Generator Interconnection Procedures and Agreements.

[xiii] NERC will reform its performance requirements for inverter-based resources and consider commissioning requirements to confirm that new such resources are configured properly. NERC will also "develop two Reliability Standard Projects…to produce performance and post-disturbance analytical expectations that will address the systemic IBR performance issues and support a more reliable IBR fleet." See NERC, Inverter-Based Resource Performance Issues Report, November 2023, Findings from the Level 2 Alert, p. v.; FERC issued Order 2023 in July 2023 mainly to require reforms to the interconnection process at the ISOs/RTOs. However, the order also includes revisions to new interconnection agreements that require inverter-based resources to better contribute to stabilizing the grid during disturbances. See FERC, 185 FERC ¶ 61,042, October 19, 2023, Reliability Standards to Address Inverter-Based Resources and FERC, 184 FERC ¶ 61,054, July 28, 2023, Improvements to Generator Interconnection Procedures and Agreements.

IEEE, Standard 2800-2022, April 22, 2022. ISO-NE, MISO, and NYISO are among the grid operators proposing to require conformance with IEEE standard 2800. See Brad Marszalkowski, PP5-6 Updates: Updates for the Clean Energy Transition, Adoption of IEEE 2800 and Improvements to Modeling of Inverter-Based Resources, ISO-NE, September 19, 2023; MISO, Inverter-Based Resource performance Requirements, Interconnection Process Working Group, March 14, 2023; Keith Burrell, Overview of Industry Activities Related to Inverter-Based Resources and IEEE 2800, NYISO, February 8, 2023.

[xiv] From FERC Orders 827 and 842, inverter-based resources must provide primary frequency response and be capable of providing steady-state voltage regulation. See FERC, 155 FERC ¶ 61,277, June 16, 2016, Reactive Power Requirements for Non-Synchronous Generation Under; FERC, F162 FERC ¶ 61,128, February 15, 2018, Essential Reliability Services and the Evolving Bulk-Power System—Primary Frequency Response.

[xv] NERC, 1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report, June 20, 2017, Southern California 8/16/2016 Event; NERC and WECC, 900 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report, February 2018, Southern California Event: October 9, 2017; NERC, Panhandle Wind Disturbance, August 2022; NERC, 2022 Odessa Disturbance, December 2022; NERC, 2022 California Battery Energy Storage System Disturbances, September 2023, p. iv.; NERC, Inverter-Based Resource Performance Issues Report: Findings from the Level 2 Alert, November 2023. For more examples and details, see NERC, Quick Reference Guide: Inverter-Based Resource Activities, June 2023.

[xvi] FERC issued Order No. 901 in October 2023, which, among other things, requires NERC to establish reliability standards that prohibit the misoperation of new and existing inverter-based resources as observed in recent NERC reports.

[xvii] From NERC: "GFM [grid forming] technology is commercially available and field-proven for transmission-connected applications, particularly for BESS (including standalone BESS in ac-coupled hybrid plants) as well as dc-coupled solar photovoltaic (PV)+BESS applications." NERC, White Paper: Grid Forming Functional Specifications for BPS-Connected Battery Energy Storage Systems, September 2023. For examples, see Bella Peacock, World's largest 'grid-forming' battery to begin construction in Australia, PV Magazine, August 10, 2021; and David Bissell, Hybrid Solar and Storage in Hawaii, T&D World, July 1, 2019.

[xviii] Boris Shkuta, et al., Electricity Transmission Provisions in the Bipartisan Infrastructure Bill, Bracewell LLLP, November 18, 2021. DOE, National Environmental Policy Act Implementing Procedures: Proposed Rule, November 16, 2023. The White House, Fact Sheet: The Biden-Harris Administration Advances Transmission Buildout to Deliver Affordable, Clean Electricity, November 18, 2022; The White House, Fact Sheet: Biden-Harris Administration Announces Historic Investment to Bolster Nation's Electric Grid Infrastructure, Cut Energy Costs for Families, and Create Good-paying Jobs, October 20, 2023; Grid Deployment Office, "Transmission Facilitation Program First Round Selections," accessed December 12, 2023.

[xix] Zachary Zimmerman, et al., Ready-To-Go Transmission Projects 2023, Americans for a Clean Energy Grid and Grid Strategies, September 2023, pp. 4-6.