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Explained: Maintaining a Reliable Future Grid with More Wind and Solar

Maintaining reliability of the bulk power system, which supplies and transmits electricity, is a critical priority for electric grid planners, operators, and regulators. Based on the standards set by power system reliability entities, the U.S. grid has been and continues to be very reliable. Over the past decade, the average U.S. customer has only experienced about 15 minutes of outages per year due to supply limitations of the bulk power system.

Since the early 2000s, maintaining grid reliability has become more complex due to a variety of factors, including the changing generation mix, the creation of wholesale energy markets, and a growing number of extreme weather events.[1] Parts of the U.S. grid are already operating with significant amounts of wind and solar generation and in 2022, wind and solar generation provided 25%–40% of some regions' electricity generation.[2]

Extreme weather aside, maintaining reliability will require new capacity to address both growing electricity demand and retiring capacity. Based on the 2022 North American Electric Reliability Corporation (NERC) Long-Term Reliability Assessment,[3] the combination of growth in peak demand and retirements suggests a need for more than 100 gigawatts (GW) of new capacity by 2032.

In general, five categories of resources are expected to be deployed and used to meet the challenge of maintaining an adequate source of supply in the coming decade: new wind and solar resources, energy storage, demand response resources, continued use of thermal generators, and expanded transmission.

Contribution of Wind and Solar and the Evolving Planning Process

Large growth in variable renewable generation is expected in the coming decades due to the declining cost of variable

1 (FERC) Federal Energy Regulatory Commission 2022. "FERC Acts to Boost Grid Reliability Against Extreme Weather Conditions" June 16, 2022. https://elibrary.ferc.gov/eLibrary/filedownload?fileid=57afc1e8-d159-c747-97e1-816e84600000.

2 EIA (U.S. Energy Information Administration) 2022. "Electric Power Annual." https://www.eia.gov/electricity/annual/.

3 NERC 2022 Long-Term Reliability Assessment (December 2022) https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_2022.pdf.

renewable resources combined with policies and incentives at the local, state, and federal levels. Figure 1 shows projections from the National Renewable Energy Laboratory's Standard Scenarios,[4] including projected growth in capacity (top) and generation (bottom) in the coming decade, with wind and solar providing an estimated 47% of the nation's electricity in 2032.

As contributions of wind and solar have increased, planners have changed their approach to evaluating the contributions of various resources to maintain reliability.[6,7] Wind and solar cannot act as a one-to-one replacement for traditional hydropower and thermal generators, but they can provide some power during peak demand periods. Wind and solar plants are therefore "derated" based on their ability to contribute during periods of highest risk of an outage. And the periods of highest risk are changing in the evolving grid. For example, as more solar is deployed and it serves a greater fraction of the mid-day load, the highest risk periods shift to later in the day when less solar generation is available. Much of the United States has not reached this point yet, but California has observed a substantial decrease in the ability of solar to meet the "net load peak" (total load minus the contribution from wind and solar). System operators have also needed to change how they balance supply and demand in real time to deal with the variability and uncertainty of these resources, as some regions have achieved 70% of instantaneous generation from wind and solar during some periods.[8,9]

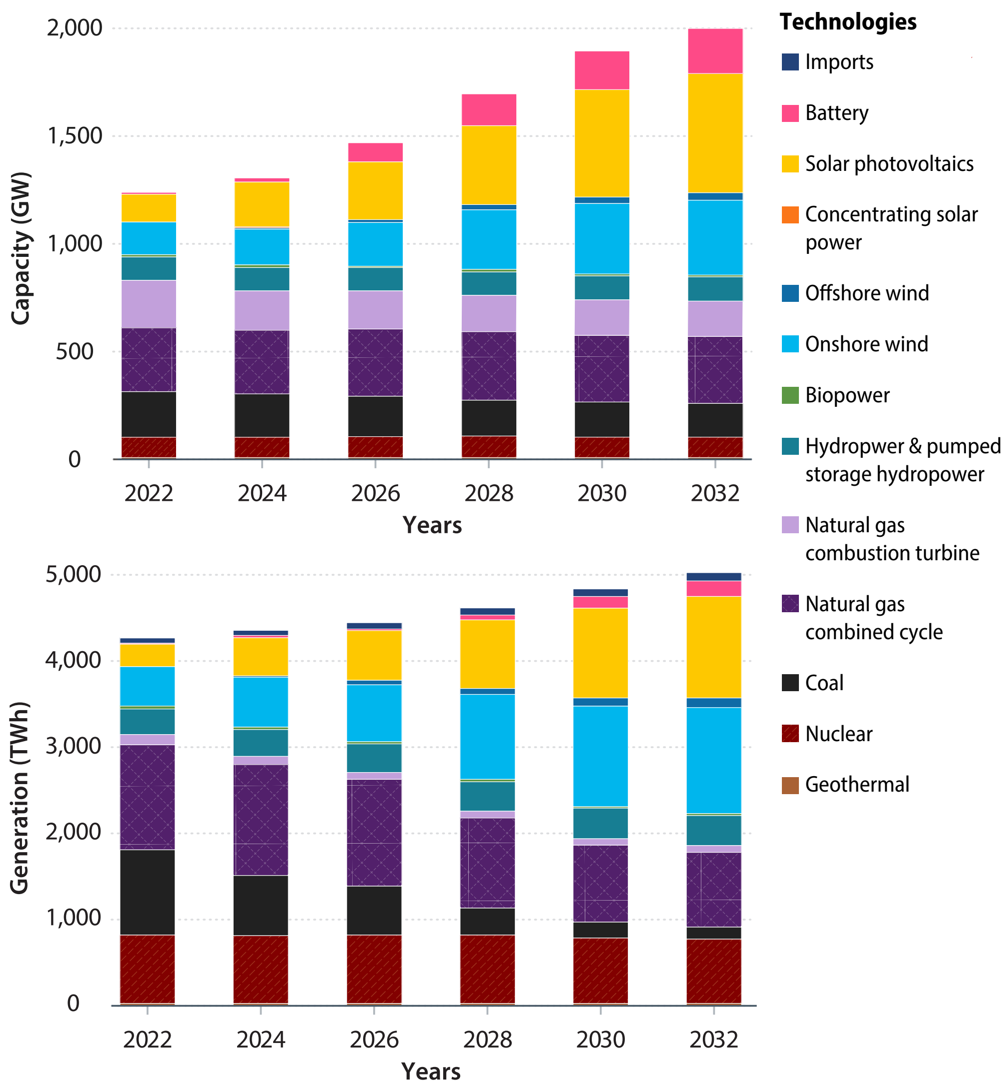

Figure 1. Projected growth in generation resources from the National Renewable Energy Laboratory (NREL) Standard Scenarios[5]

The ability of wind and solar to provide energy during peak periods has been incorporated into the planning process in most regions of the United States, and it is well understood that a mix of resources will be required to maintain reliability.[10]

The Increasing Role of Energy Storage

Energy storage is expected to play an increasing role in meeting peak demand as declining costs, incentives, and mandates[11] have led to significant growth in storage and projections of accelerated growth in the future (as demonstrated in Figure 2, which

[4] "Scenario Viewer: Data Downloader," NREL, https://scenarioviewer.nrel.gov/.

[5] Results are from the Standard Scenarios Mid-Case. See "Standard Scenarios," NREL, https://www.nrel.gov/analysis/standard-scenarios.html.

[6] Energy+Environmental Economics 2020. *Capacity and Reliability Planning in the Era of Decarbonization: Practical Application of Effective Load Carrying Capability in Resource Adequacy*. https://www.ethree.com/wp-content/uploads/2020/08/E3-Practical-Application-of-ELCC.pdf.

[7] EPRI (Electric Power Research Institute) 2022. *Resource Adequacy for a Decarbonized Future: A Summary of Existing and Proposed Resource Adequacy Metrics*. https://www.epri.com/research/products/000000003002023230.

[8] EIA 2022. "Electric Power Annual." https://www.eia.gov/electricity/annual/

[9] SPP (Southwest Power Pool) 2022. *Southwest Power Pool 2021 Annual Report*. https://spp.org/documents/68651/spp%202021%20annual%20report.pdf and CAISO (California ISO) 2022. *2021 Annual Report on Market Issues and Performance*. http://www.caiso.com/Documents/2021-Annual-Report-on-Market-Issues-Performance.pdf.

[10] ESIG (Energy Systems Integration Group) 2023. *Ensuring Efficient Reliability: New Design Principles for Capacity Accreditation*. https://www.esig.energy/new-design-principles-for-capacity-accreditation.

[11] DSIRE (Database of State Incentives for Renewables and Efficiency). *Energy Storage Targets* (August 2021), https://ncsolarcen-prod.s3.amazonaws.com/wp-content/uploads/2021/08/DSIRE_Storage_Targets_August2021.pdf.

shows projections from the U.S. Energy Information Administration).[12]

Storage works particularly well in summer peaking systems with increasing deployments of solar energy. Solar reduces the duration of the peak net load period and increases the ability of shorter-duration storage (and flexible loads) to meet the peak demand. Figure 3 illustrates how solar and storage can work together, with solar addressing the first part of the summer peak and storage meeting the second part. In systems with winter peaks, the longer peak period and limited contribution of solar may necessitate longer-duration storage.[14]

The benefits of energy storage can be obtained from stand-alone grid storage or in the form of hybrid generators, which combine electricity generation and storage technologies at a single location.[15] In 2021, 45% of all proposed solar power plants incorporated storage.[16]

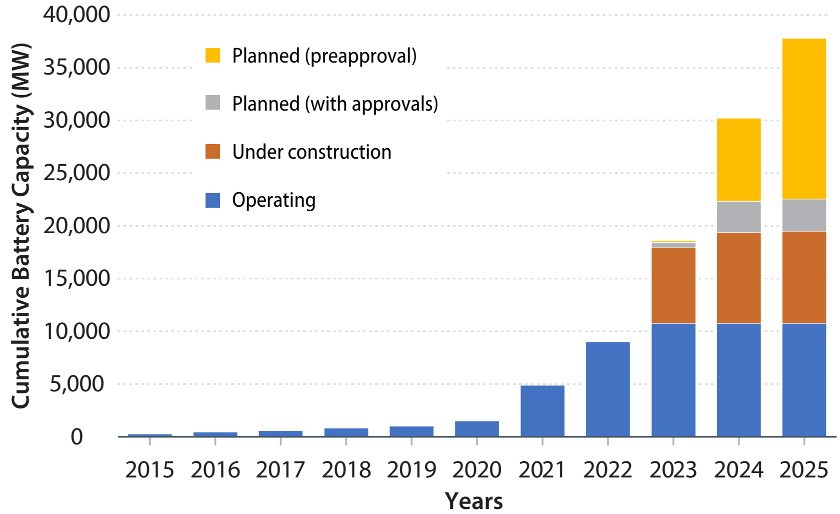

Figure 2. Operational and planned storage[13]

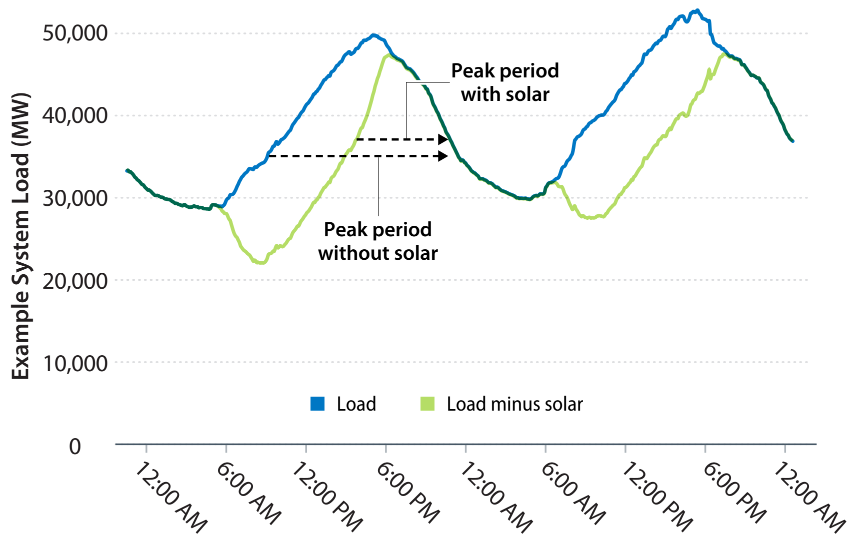

Figure 3. Increased PV contribution reduces peak-period duration. Example in a system with 17% annual PV contribution

The Potential Role of Demand Response

Rather than building new capacity, utilities and other entities can provide incentives to electricity users to reduce their demand with more efficient appliances, or to shift their demand to parts of the day with lower demand, thus reducing the overall need for capacity. Such programs can be cost-effective as long as the cost of incentive payments is less than the cost of building and operating new generation capacity. Advanced technologies can enable aggregations of smaller demand response resources including customer-sited storage and electric vehicles to be controlled like a power plant and contribute to system reliability. Other technologies can enable differentiation of the value of different electricity loads, potentially increasing reliability for critical loads (e.g., hospitals) while decreasing costs (compared to generation-only resource portfolios).

The Continued Role of Traditional Capacity Resources

While variable generation, new storage, and demand response may provide a significant fraction of new energy and capacity resources, it is important to note the role of traditional thermal and hydropower assets to meet peak demand in the coming decade. Figure 4

[12] EIA. "U.S. Battery Storage Capacity Will Increase Significantly by 2025" (December 8, 2022), https://www.eia.gov/todayinenergy/detail.php?id=54939.

[13] Data are as of June 2023 from EIA. "Preliminary Monthly Electric Generator Inventory (based on Form EIA-860M as a supplement to Form EIA-860)," https://www.eia.gov/electricity/data/eia860m/. Data includes the battery component of solar+battery projects. CAISO accounts for the largest share of capacity, but other areas—including ERCOT, MISO, and PJM—also have a significant amount of queued solar+battery projects.

[14] Denholm, Paul, Wesley Cole, and Nate Blair. 2023. *Moving Beyond 4-Hour Li-Ion Batteries: Challenges and Opportunities for Long(er)-Duration Energy Storage*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A40-85878. https://www.nrel.gov/docs/fy23osti/85878.pdf.

[15] Murphy, C. A., A. Schleifer, and K. Eurek 2021. "A Taxonomy of Systems that Combine Utility-Scale Renewable Energy and Energy Storage Technologies." *Renewable & Sustainable Energy Reviews* 139:110711. https://doi.org/10.1016/j.rser.2021.110711.

[16] Bolinger, Mark, Will Gorman, Joe Rand, Ryan Wiser, Seongeun Jeong, Joachim Seel and Cody Warner 2022. *Hybrid Power Plants: Status of Operating and Proposed Plants, 2022 Edition*. Lawrence Berkeley National Laboratory. https://emp.lbl.gov/sites/default/files/hybrid_plant_tracking_2022_0.pdf

shows the projected mix of resources meeting peak demand in just the coming decade from NREL's Standard Scenarios. The figure demonstrates the importance of storage and solar meeting summer demand, and it captures the modest contribution of wind (and solar in the winter) to meeting peak demand accounted for in planning processes.

With the growth in variable generation, we will likely see an increasing split in the role of different generation resources. Historically, plants could be split into two broad categories: those that provide both energy and capacity as needed and peaking plants that provide primarily capacity. The introduction of variable generation introduces a third type of resource that provides primarily energy (and limited capacity) and requires new approaches to maintain reliability and low-cost electricity.

Much of the anticipated growth in energy supply is from variable generation resources and the role of existing (and new) fossil-fueled plants may shift to primarily providing a source of capacity. This means fossil plants would remain available but only run as needed to maintain reliability, rather than generating electricity most the time.

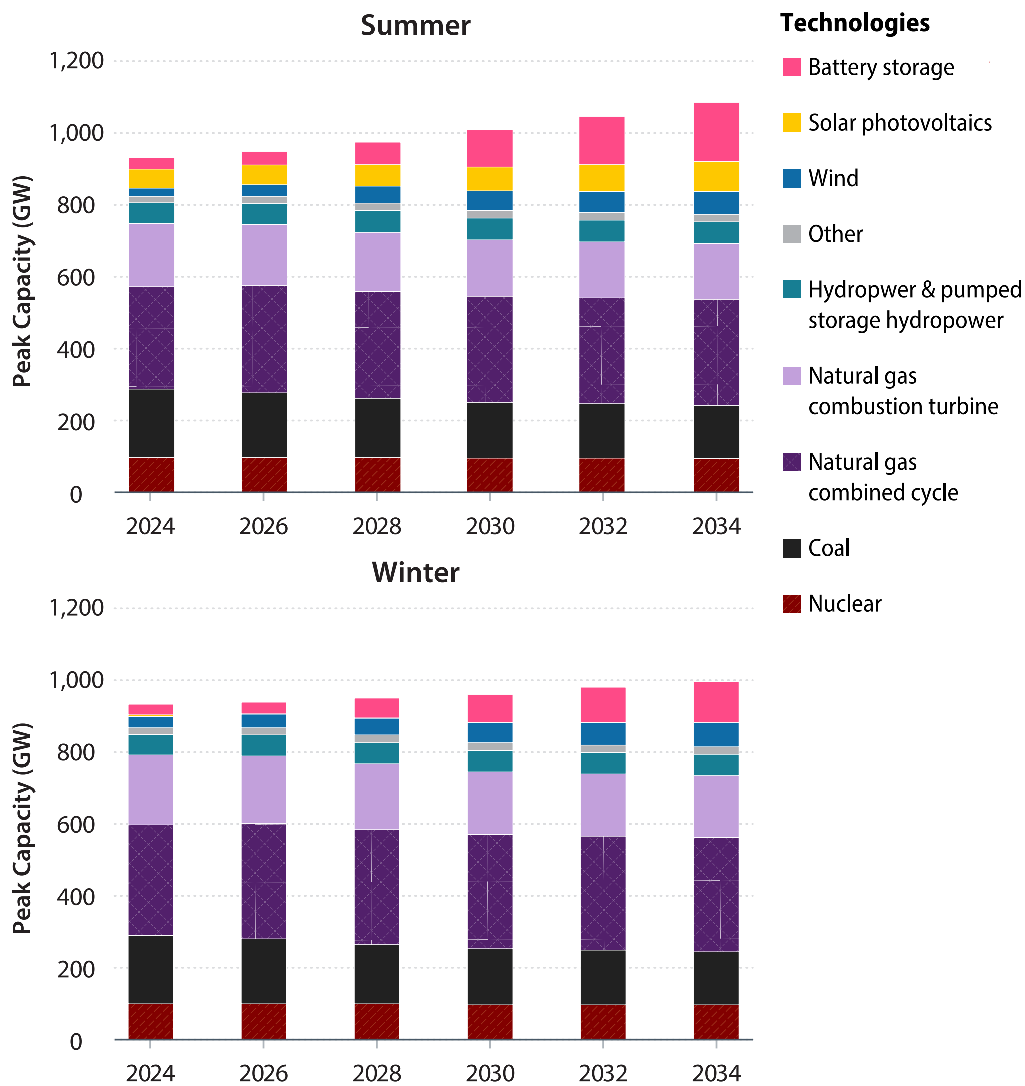

Figure 4. Projected mix of resources meeting the peak demand in the coming decade

The Critical Role of Transmission

Much of the planned capacity of all forms relies heavily on additional transmission capacity. Multiple studies have demonstrated that additional transmission capacity could provide significant benefits to providing reliability (in addition to the economic benefits of lower-cost electricity).[17]

These reliability benefits can be provided largely by geographic and resource diversity, as demonstrated by extreme weather events in 2020 (California heat wave) and 2021 (Texas winter storm), when limited interregional transfers contributed to outages (learn more about the causes of the recent major blackouts).

What are the challenges—both known and unknown—of maintaining grid reliability in the future?

Future challenges in maintaining reliability arise from both the ability to procure, build, and use the resources outlined above and the evolving threats from climate change-driven extreme weather. A detailed discussion of these challenges is provided by Carvallo et al.[18]

The total reliability contribution of existing and new generation, transmission, storage, and demand resources needs to be sufficient to replace any retiring generators. The build-out of any new resources needed may be delayed due to unforeseen supply chain, siting, interconnection, permitting,[19] or other challenges.

[17] LBNL (Lawrence Berkeley National Laboratory) 2022. "Regional and Interregional Transmission Have Significant Economic Value" August 1, 2022. https://emp.lbl.gov/news/regional-and-interregional-transmission-have and NREL. "Interconnections Seam Study," https://www.nrel.gov/analysis/seams.html.

[18] Carvallo, Juan Pablo, Nan Zhang, Benjamin D. Leibowicz, Thomas Carr, Sunhee Baik, and Peter H. Larsen 2023. *A Guide for Improved Resource Adequacy Assessments in Evolving Power Systems: Institutional and Technical Dimensions.* https://eta-publications.lbl.gov/sites/default/files/ra_project_-_final.pdf.

[19] PJM. *Energy Transition in PJM: Resource Retirements, Replacements and Risks* (February 24, 2023), https://www.pjm.com/-/media/library/reports-notices/special-reports/2023/energy-transition-in-pjm-resource-retirements-replacements-and-risks.ashx.

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One of the greatest uncertainties in maintaining reliability is the potential growth in climate change-driven extreme weather, including the duration, magnitude, and frequency of events.[20] Electrification of applications served largely by fossil fuels could accelerate the growth in winter peaks. Longer winter peaks and lack of solar output reduce the ability of shorter-duration energy storage to cover peak demand periods.[21] There is also an increasing need to consider resilience and the limitations of traditional reliability metrics in the face of growing frequency and intensity of extreme weather.

Maintaining reliability in the future will require addressing the supply deficiencies that led to recent extreme weather events like the California heat wave and Texas winter storm. That need includes addressing the performance of all generation resources in extreme heat and cold. Recent events have also demonstrated the limitation of assuming generator outages are largely independent and have also demonstrated that no generator is 100% reliable. Planners and regulators are increasingly examining how to maintain the abilities of plants of all types to operate during extreme weather conditions.

Finally, updated and additional planning processes may be needed to address uncertainties related to maintaining reliability. Such processes include continual advancements in methods to assess how new and existing resources can support the reliability of the power system, and improved market design and policies to procure or incentivize reliability in the most cost-effective, timely and equitable manner.[22]

Learn about reliability of the current grid by visiting https://www.nrel.gov/fy24osti/87297. Learn about causes of the recent major blackouts and what is being done in response by visiting https://www.nrel.gov/docs/fy24osti/87308.

Want to learn even more? Take a deeper dive into grid reliability by visiting https://www.nrel.gov/docs/fy24osti/85880.

[20] FERC 2022. "FERC Acts to Boost Grid Reliability Against Extreme Weather Conditions" June 16, 2022. https://elibrary.ferc.gov/eLibrary/filedownload?fileid=57afc1e8-d159-c747-97e1-816e84600000.

[21] Redefining Resource Adequacy Task Force. 2021. *Ensuring Not Only Clean Energy, but Reliability: The Intersection of Resource Adequacy and Public Policy*. https://www.esig.energy/download/ensuring-not-only-clean-energy-but-reliability-the-intersection-of-resource-adequacy-and-public-policy/.

[22] Carvallo, Juan Pablo, Nan Zhang, Benjamin D. Leibowicz, Thomas Carr, Sunhee Baik, and Peter H. Larsen 2023. *A Guide for Improved Resource Adequacy Assessments in Evolving Power Systems: Institutional and Technical Dimensions*. https://eta-publications.lbl.gov/sites/default/files/ra_project_-_final.pdf

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