U.S. DEPARTMENT OF ENERGY

The Future of Resource Adequacy

Solutions for clean, reliable, secure, and affordable electricity

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Executive Summary

A clean, affordable, reliable, secure, and resilient power system is a critical priority for the United States. It is essential to American households and communities, and fundamental to the nation's economy. It is also a key national strategy to address climate change and meet our targets to reduce greenhouse gas emissions by 50% - 52% from 2005 levels by 2030 and a net-zero emissions economy by 2050.[1]

The power system is at a time of rapid change. After a decade of nearly zero growth, electricity demand is increasing and is expected to accelerate over the next ten years due to the expansion of industries like data centers, robust investment in new and existing manufacturing sectors like semiconductors and batteries, and deployment of electric vehicles.[2] Power supply is evolving, with older fossil fuel units retiring and new deployment of clean energy capacity, most significantly from wind, solar, and battery storage. Aging transmission and distribution infrastructure needs to be modernized. Physical and cybersecurity attacks against energy infrastructure continue to threaten energy security; cybersecurity threats particularly have become more sophisticated, frequent, and severe. Supply chain availability is another risk, as demand for foundational grid equipment like transformers currently far exceeds supply.[3] At the same time, the worsening effects of climate change are increasing the threat to power sector reliability through more frequent, intense, and uncertain extreme weather. The demand for more generation and the rise of new technologies also creates and adds to existing supply chain concerns related to both availability and supply chain security.

Relying solely on additional fossil fuel resources as the default option to meet reliability needs is risky. Reliability is a system attribute – no individual resource is perfectly reliable. Any single technology approach to addressing the combination of challenges is risky, partly due to substantial fuel delivery and availability issues that lead to correlated failures which can jeopardize the entire system during extreme weather.

A portfolio approach that takes advantage of the full range of technology, planning, and operational solutions best ensures reliable, clean, secure, and affordable power. These solutions encompass all parts of the electricity system, including:

1. **Generation and Storage**. New deployment of technologies such as long-duration energy storage, hydropower, nuclear energy, and geothermal will be critical for a diversified and resilient power system. In the near term, continued expansion of wind and solar can enhance resource adequacy, especially when paired with energy storage. Natural gas generators should proactively develop the ability to use clean hydrogen or be retrofit with carbon capture systems for low-to-zero carbon operation. Investments in and expansions of existing clean energy generators like hydropower and nuclear energy can prevent premature retirements of facilities and support near term needs.

2. **Grid Enhancement and Expansion**. Expanding transmission capacity supports resource adequacy through enabling new generation and power transfer within and between regions. Transmission capacity is critical to facilitating the interconnection of energy generation in queues across the country. Reconductoring existing transmission lines, especially with advanced conductors and cabling, can expand transmission capacity on existing rights of way.

Interregional transmission can enable neighboring utilities and regions to share resources when needed and take advantage of greater diversity in resources — especially valuable during extreme weather events. In the near term, deployment of grid enhancing technologies—a collection of advanced sensors, controls, and analytical tools—helps maximize electricity transmission through existing lines.

3. **Demand Resources**. Accelerating energy efficiency programs and distributed energy resources provide critical tools to support reliability. In the near-term, programs supporting continued deployment of energy efficient end-use technologies can cost-effectively reduce overall demand for power and can be especially valuable when targeted towards demand reduction during typical grid stress periods. Demand response measures provide additional flexibility, whether through simple and low-cost traditional measures or more aggregated demand response programs. Distributed generation and storage resources such as rooftop solar, behind-the-meter batteries, and electric vehicles with advanced bidirectional charging systems can provide cost-effective energy and capacity, particularly when combined as virtual power plants.

Methods used to assess resource adequacy and how each technology contributes to it need to evolve and are continually improving. System operators and stakeholders are developing better tools, data, and methods for understanding and assessing system needs to help determine the best set of resources to meet complex and fast-changing resource adequacy needs at lowest cost while providing secure and resilient solutions. Emerging market-mechanisms and business models can drive new investments and incentivize operational decisions that enable capacity to meet demand.

The opportunity to invest in the broad suite of technological, analytical, and operational solutions has never been greater. The Inflation Reduction Act (IRA) and the Bipartisan Infrastructure Law (BIL) together make hundreds of billions of dollars available to develop and deploy these solutions in the form of tax credits, loans, investments, and other innovative programs. Clean energy demonstrations are accelerating cost reductions and supporting infrastructure build out for new technology solutions, lowering the risk for the next wave of deployments. These incentives provide motivation to accelerate exploration of all the solutions available and make deploying a much broader set of solutions far more economically attractive, secure, resilient, and realistic. With this portfolio of policies and technologies in hand, and unprecedented resources to support their deployment, the U.S. power system is well-positioned to ensure resource adequacy while increasing clean electricity and reducing greenhouse gas emissions.

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Introduction

A robust power system is critical to the Nation's economic, energy, and national security. The power system is also a cornerstone of broader strategies to address climate change and is anticipated to deliver significant greenhouse gas emissions reductions through deployment of new clean electricity generators, demand reduction measures, and increased electrification of transportation, buildings, and industrial processes.[1] Recent legislation including the Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA) are providing unprecedented funding to support grid infrastructure and the accelerated deployment of clean electricity, through tax credits, loans, and other programs. Altogether these laws are projected to double the share of clean electricity by 2030.[4]

The confluence of these factors means we are increasingly relying on the power sector to deliver clean, reliable, secure, affordable electricity and support beneficial economic growth. Power system operators must continue maintaining essential system reliability and defending against evolving threats while this transition is underway.

The power system can continue to provide reliable power while meeting new demand, accelerating clean electricity, and maintaining affordability though the array of opportunities provided by BIL and IRA together with the full range of technology, planning, and operational solutions available.

The technologies and solutions supported by BIL and IRA can help address reliability issues facing the power sector. The North American Electric Reliability Corporation (NERC) 2023 Long Term Reliability Assessment outlines these issues, focusing on resource adequacy as a key element of reliability.[2] Resource adequacy is making sure we have enough electricity available at the right time and in the right place to keep the lights on and keep the economy running.[i,ii] These issues are summarized below.

Growth in electricity demand – both annual demand for energy and peak demand – is increasing sharply. Tax credits and other incentives from BIL and IRA are spurring adoption of electric vehicles (EV) and other electrification technologies. The BIL and IRA along with the CHIPS and Science Act have driven a wave of investments in manufacturing such as batteries and semiconductors, reflecting significant economic growth.[5] Increased demand for advanced computation and artificial intelligence applications is driving investments in new data centers.[6] As a result, there is anticipated to be, for the first time in a decade, significant acceleration of electricity demand.[7] For example, PJM Interconnection LLC's (PJM) ten-year projection for net energy load growth has increased from 1.4% per year in 2023 to 2.3% in 2024.[8]

Concurrently, the increasing threat of extreme weather events due to climate change is exacerbating risks of over-reliance on fossil fuels while also increasing electricity demand**.** Extreme weather events are increasing in severity, extent, and frequency as the impact of climate change intensifies.[9] The number and cost of weather-related disasters has increased dramatically over the last few decades, and

[i] The full NERC definition of adequacy and analysis in the long term reliability assessment includes both capacity and energy risk assessments. See: https://www.nerc.com/pa/Stand/Glossary%20of%20Terms/Glossary_of_Terms.pdf

[ii] Other key elements of reliability include operational reliability and resilience. This paper focuses on resource adequacy as a core issue due to its central role in resource planning. More information on other aspects of reliability: https://www.nrel.gov/docs/fy24osti/85880.pdf

in 2023 the United States experienced 28 weather and climate disasters each causing over $1 billion in damages.[10] Extreme weather stresses the power system and its ability to generate and deliver electricity. For example, heat waves and associated droughts increase cooling demands while decreasing the available capacity of fossil fuel and thermal plants.[11] Extreme cold temperature events impact vulnerable equipment and facilities and tighten fuel supply, which affects generator availability and grid reliability. For example, during Winter Storm Elliot in 2022, natural gas production in the Appalachian region dropped by 23% to 54% leading to outages of natural gas electricity generators.[12] Similarly, during Winter Storm Uri, 87% of unplanned generation outages due to fuel issues were related to natural gas, and roughly 43% of natural gas production declines were caused by freezing temperatures and weather.[13] NERC has noted that a significant fraction of the country is at elevated risk of power outages under extreme temperatures and prolonged severe weather conditions in part due to natural gas supply risks.[2]

Older plants, primarily inefficient fossil fuel plants, are retiring. Most coal-fired power plants operating in the United States were built in the 1970s and 1980s. Aging power plants, competition from lower-cost resources, such as wind and solar and efficient natural gas generators, and environmental regulations have led to increasing retirements of these coal-fired facilities.[14] Altogether there have been over 177 gigawatts (GW) of combined retirements from fossil fuel and nuclear energy resources over the last decade, and there are over 72 GW of retirements planned over the next ten years.[15] Similarly, the transmission and distribution infrastructure is aging, increasing risks of failure as this infrastructure approaches the end of typical 50 to 80 year lifecycles.[16]

Grid planners, investors, and policymakers can plan for and pursue the full range of technology, planning, and operation solutions available today to affordably meet resource adequacy needs in the near term and over the next decades. The combination of rapid growth in electrical demand, unprecedented federal support for energy infrastructure upgrades, and the availability of a range of current and emerging technology solutions creates an opportunity to invest in a modernized power system. This includes not just new generation resources, but also investments in the transmission system and leveraging distributed resources, such as energy efficiency and demand flexibility. As approaches for assessing resource adequacy evolve, modernizing the power system can ensure that solutions are matched with the specific emerging needs of a highly decarbonized and electrified power system and allow faster deployment of the right combination of technologies in the right locations at the right time to maintain and enhance resource adequacy (Figure 1).

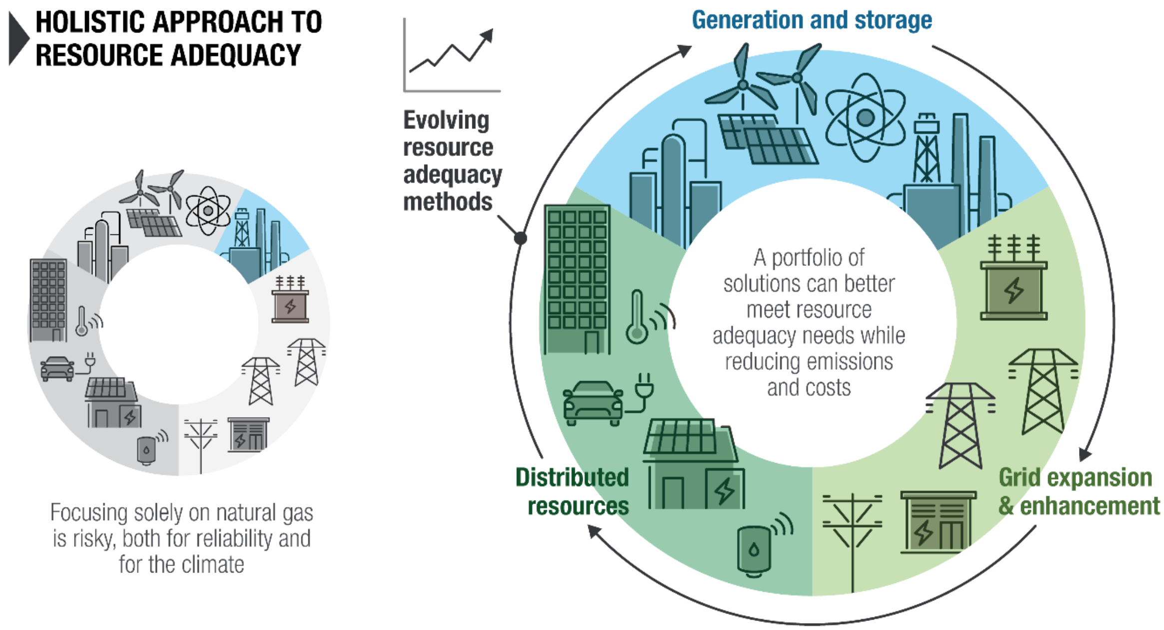

Figure 1. Groups of solutions to meeting growing resource adequacy needs in the power sector over the next decade.[17]

This paper summarizes the opportunities in meeting the resource adequacy needs for a clean, reliable, and affordable power system; reviews the expanding menu of available technology options; and highlights many of the federal incentives available to accelerate adoption and use of these technology and operational solutions. By leveraging all these options, we can support expanded technology and operational solutions, meet the needs of a growing economy and new manufacturing, and maintain our historically high level of power system reliability, while decreasing emissions and keeping costs low for Americans.

Resource adequacy is a system-wide attribute requiring a holistic approach

Due in part to the complexity of the power system, the reliability of the power grid is intrinsically a system-wide property that cannot be ensured by any individual resource or technology in that system. This is particularly true for resource adequacy, which measures the total contributions from supply- and demand-side resources to meet aggregate electrical demand. Different resource types can contribute to resource adequacy, and these contributions can change over time due to evolving system needs and interactions between resources in the portfolio. Planning best practices should consider the differences between resources and compare *portfolios* in terms of their resource adequacy contributions—along with how these portfolios contribute to other reliability services and other key power system characteristics such as affordability, security, resilience, and emissions.

The varied, dynamic, and complex ways different technologies can meet reliability complicates resource adequacy planning and challenges the notion that resources can be simply characterized as "firm" or not. Best planning practices should also account for the differences between resources and anticipate how they might change over time.

While this report highlights individual technology options for addressing resource adequacy needs, the options must be considered as parts of a portfolio of technologies that together provide sufficient and timely quantities of power. Recognizing that there is no perfectly reliable resource and that there is added risk from exposure to common points of failure, this system-wide approach considers the benefit of a diverse portfolio of resources to mitigate the risk of single points of failure and over-reliance on a single resource type. For example, diversifying the portfolio of resources can help lower exposure to natural gas supply risks during extreme weather while also reducing emissions and potentially lowering costs to customers.

The concept of capacity credit is used to quantify the contributions to resource adequacy of individual options of any resource type within a particular electric system. It is measured either in terms of capacity or as the fraction of its nameplate capacity (%), and it indicates the amount or portion of the nameplate capacity that is reliably available to meet load during times of highest system stress.[18] This is sometimes also referred to as firm capacity.

A resource's capacity credit can depend on its generation profile and how well that profile correlates with demand profiles and other resources' generation profiles, particularly during periods of high system stress such as peak demand hours. As a result, capacity credit can vary significantly across regions and technologies. For example, NERC estimates a range of 12% to 47% for wind's summer on-peak capacity contribution across reliability regions and a range of 40% to 99% for solar.[iii] Similarly, the contribution of storage technologies to resource adequacy can depend on the duration of storage, how storage is dispatched, and the expected length and nature of stressful periods.

The capacity credit concept applies to thermal generators such as fossil and nuclear to account for the risk of correlated outages and other derates in capacity. Under today's most commonly used methodologies, these resources have typically been given high capacity credit. However, outage rates for these thermal resources depend on weather or other external conditions as shown in Figure 2. During extreme weather conditions, which already are occurring more frequently and with higher intensity as discussed above, outage rates increase concurrently with increased electricity demand for cooling or heating. For example, as reported by the Federal Energy Regulatory Commission (FERC) in their report on Winter Storm Elliot, there have been five events since 2011 which featured significant levels of unplanned outages due to mechanical freezing and fossil fuel issues.[19] Resource adequacy planning requires considering these correlated thermal outages and their occurrence during extreme demand hours.

[iii] Other reliability, planning, or market entities can use different assumptions and methods for estimating capacity contributions that would yield different results than those shown. For example, the reported values here are averages, other planning entities may use marginal values, which can result in significantly lower values. https://www.nrel.gov/docs/fy24osti/85880.pdf

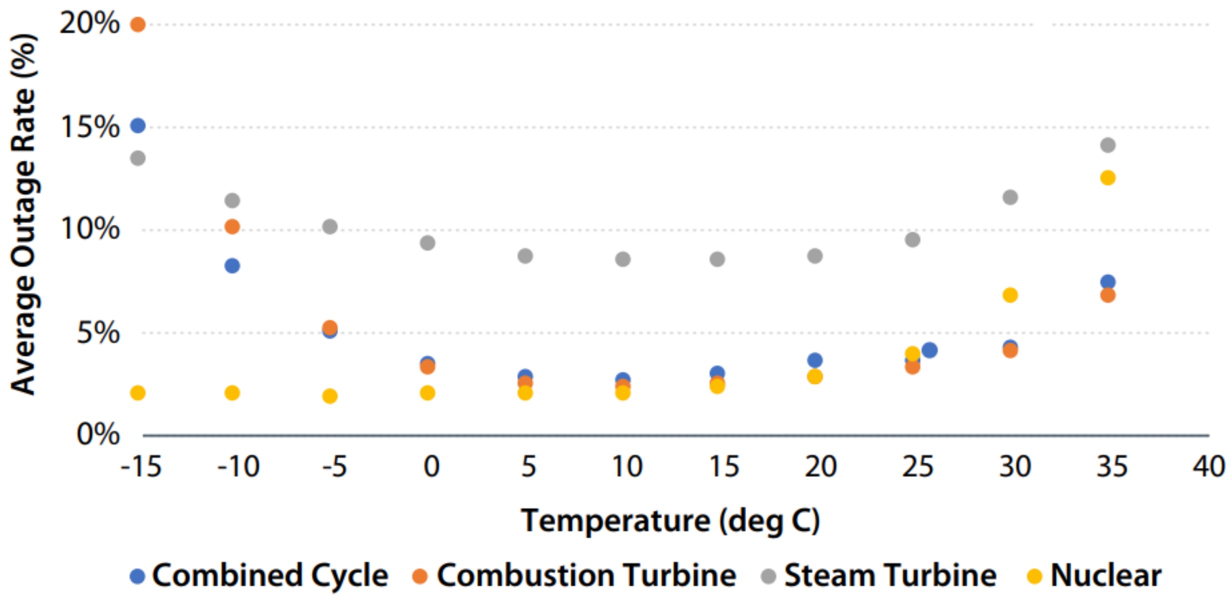

Figure 2. Historical outage rates for fossil and nuclear power plants as a function of temperature.[20]

A recent example demonstrates how portfolios of technologies with varying individual contributions to resource adequacy can, in whole, provide reliable, affordable systems. Xcel Energy in Minnesota plans to retire the 1,879 megawatt (MW) Sherco coal facility in phases through 2030.[21] Initially, Xcel proposed to replace the Sherco plant with a new large natural gas combined cycle facility in the same location. However, after public comment, Xcel removed the proposed natural gas combined cycle facility and instead proposed building two smaller combustion turbines that would operate less frequently along with reusing the interconnection point to build 710 MW of new solar, a novel 10 MW/1000 MWh long duration storage facility, and transmission lines to facilitate interconnection of up to 1.2 GW of new wind resources.[22,23] Xcel stated the revised plan "is projected to reduce customer costs over the planning period, achieve substantially greater carbon reduction, and allow us to move faster in pursuing a more renewable and carbon-free generation system, all while preserving reliability…"[24] This demonstrates how portfolios of multiple resources can provide equivalent resource adequacy and other reliability services while reducing emissions and customer costs.

Opportunity to meet resource adequacy needs with a full array of solutions

Meeting the moment requires that grid planners explore the full suite of options available. A broad portfolio of solutions can support resource adequacy while reducing emissions and maintaining security and affordability for consumers.

Building new unabated natural gas plants has often been the first response during grid planning to meet resource needs for several reasons, including their general flexibility, low cost, and high capacity credit, as well as familiarity with the technology. However, it is only one tool in the toolkit and has the potential to result in higher costs and unexpected lower reliability during extreme weather events than alternative options. A more expansive look at options available to planners to meet reliability and resource needs in the power sector should include:

1. **Generation and storage**: Maintaining and expanding existing clean generating resources can allow nuclear energy and hydropower plants to continue to contribute to resource adequacy, while producing emissions-free power and avoiding the need for replacement capacity. Accelerated deployment of low-cost wind and solar capacity can also contribute to resource adequacy – especially solar in locations where the solar has high capacity credit or when it is hybridized with co-located energy storage.[25] Standalone energy storage technologies are seeing rapid growth[26] and can provide near-term boosts to resource adequacy. Other opportunities to increase generation using existing infrastructure are available, such as powering non-powered dams. Planning for new clean generation sources with high capacity credit such as hydropower, geothermal, nuclear energy, and fossil plants with carbon capture can begin today for longer term deployment. Long duration energy storage technologies are beginning to be deployed and can help meet resource adequacy needs over the coming decade, especially when used to balance variable supply and demand.

2. **Grid expansion and enhancements:** Expanding and making the most efficient use out of the existing grid can increase transmission capacity, accommodate additional generator deployment, manage congestion, and improve operational flexibility, which contributes to resource adequacy by ensuring that the power system can deliver electricity at all times.[27] In the near term, deployment of grid enhancing technologies (GETs)—a collection of advanced sensors, controls, and analytical tools—helps maximize electricity transmission through existing lines. Other solutions such as reconductoring existing transmission lines with advanced conductors and cabling can expand transmission capacity on existing rights of way while avoiding the costs and delays associated with permitting and building new transmission lines. In the long term, expanding regional and interregional transmission improves resource adequacy and enhances the value of existing generators through sharing resources across broader geographies, which is especially valuable during extreme conditions.[28]

3. **Distributed resources:** Accelerating energy efficiency programs and procuring grid services from distributed energy resources (DERs) can help grid operators balance supply and demand and reduce demand on the bulk power system during peak hours. Utility programs that increase energy efficiency can cost-effectively reduce overall demand for power, for example by encouraging replacement of old appliances with energy-efficient smart devices (e.g., water heaters, heat pumps). Energy efficiency can be targeted to reduce demand at high-stress periods. Flexible demand in residential, commercial, and industrial settings can be shifted or reduced in response to grid operator signals or through innovative rate structures. In addition to demand, networks of distributed generation and storage from devices such as rooftop solar and behind-the-meter batteries, especially when paired with controls such as Distributed Energy Resource Management Systems (DERMS), advanced distribution management systems (ADMS), and building automation, can provide both flexibility and visibility to grid operators and customers. When aggregated over a sufficiently broad collection of resources, locations, and loads, such DERs can provide cost-effective dispatchable, utility-scale energy and capacity as

virtual power plants (VPPs), which can enhance resource adequacy similar to adding new generation.

Certain technology solutions can be more rapidly deployed

Some technology options are beneficial because they can be implemented more quickly than other more traditional solutions. For example, energy storage can generally be added at the site of existing generators, increasing capacity value while using the same interconnection point. In 2022, adding two 230 MW battery systems to the existing Desert Sunlight Solar PV generator required only 10 months from signing the power purchase agreement to commercial operations and added almost $50 million a year worth of capacity value.[29]

Similarly, reconductoring, the process of upgrading the conductor core of existing transmission lines with advanced materials, re-uses towers and rights of way, speeding capacity expansion compared to building new transmission. GETs such as dynamic line ratings can be deployed to increase capacity on existing transmission lines in a year or less. Demand resources, such as smart thermostats and enrollments in a demand response program and VPPs deployments, do not have the lengthy siting and permitting steps necessary for other large energy infrastructure and can be deployed in the near term. In addition to these near-term solutions, there is value in planning for long-term needs, which expands the solution set.

Unprecedented federal support for resource adequacy solutions

The BIL and IRA offer a historic amount of federal support and incentives for clean power and electricity infrastructure. These programs are generally available through the end of the decade.

- **Tax Incentives** – New and expanded tax credits from the IRA can significantly reduce the cost of investment in certain technology solutions. For example, the new technology neutral clean electricity investment tax credit can be worth up to 30% to 50% of the installation cost of eligible new zero-emitting generating capacity like renewables, nuclear energy, and energy storage. Tax incentives for consumers and businesses will accelerate deployment of efficiency technologies and distributed energy resources like rooftop solar, battery storage systems, and bidirectional EV chargers.[30]

- **Loans** – Federal loans and loan guarantees are available to provide low-cost financing to a wide variety of technology solutions. For example, DOE's Energy Infrastructure Reinvestment program can provide loan guarantees to projects that retool, repower, repurpose, or replace energy infrastructure that has ceased operations or enable operating energy infrastructure to avoid, reduce, utilize, or sequester air pollutants or greenhouse gas emissions. This can be used for a variety of purposes such as uprating energy infrastructure so it can restart or operate more efficiently at higher output;
  replacing retired generating resources with clean energy; or building new facilities for clean energy that use legacy energy infrastructure such as existing points of interconnection.[31]

- **Direct Financial Assistance** – A wide variety of other programs are available to help deploy resource adequacy solutions. For examples DOE's Grid Resilience and Innovation Partnership (GRIP) program has $10.5 billion to support projects that use innovative approaches to transmission, storage, and distribution infrastructure to enhance grid resilience and reliability.[32]

DOE's $6 billion Civil Nuclear Credit program and $750 million Hydroelectric Incentive program support investments in maintaining and enhancing existing clean generators.

Altogether, these funding opportunities and incentives provide a massive opportunity to invest in resource adequacy solutions over the next ten years. These opportunities are further detailed in Tables 1-3 in the sections below.

New generation and storage resources and a diversified energy mix

Maintaining resource adequacy with growing demand and retiring generators requires building and procuring a portfolio of resources, while not relying too heavily on any one technology. A portfolio of resource adequacy measures can be more effective than focusing on any given technology and can minimize risks associated with relying on any one technology. Below, this report reviews the suite of generation and energy storage technology options that can contribute to a portfolio approach. Near term solutions can be deployed while planning for longer-term solutions. At the same time, investments in the existing fleet of clean generation technologies like nuclear energy and hydropower ensure that these resources continue to contribute to resource adequacy needs.

Natural gas supporting clean electricity systems

Today's grid has large quantities of natural gas generation resulting from an extensive buildout of gas plants in the 2000s and 2010s.[33] As a result, gas has grown to become the largest source of electricity generation in the United States, providing over 40% of total electricity generation in 2023.[34] Natural gas generators have traditionally provided a significant source of firm capacity and are also an important source of flexible generation complementing variable wind and solar generation.

However, natural gas generators account for over 40% of power sector greenhouse gas emissions, as well as indirect methane emissions from upstream fuel production and processing and transport.[35] Building new natural gas plants without a strategy to address emissions risks infrastructure lock-in and stranded assets. To help address these concerns, new gas capacity should be capable of achieving and supporting clean electricity systems. For example, gas generators should be designed to operate flexibly and at lower capacity factors to effectively support systems with increasing amounts of variable wind and solar generation. Plant designs that are more modular and flexible can reduce the extent of stranded assets and better support ramping, operating reserves, and other operational needs. Generators that can operate using low greenhouse gas hydrogen or be built or retrofit with carbon capture systems are better positioned to reduce their greenhouse gas emissions over the long term and less likely to become stranded assets.

With a large and growing share of total generation nationwide coming from natural gas plants, the contribution of new gas plants to resource adequacy has become less certain. While gas can be flexible under normal operating conditions, over-reliance on one generation source increases risks to reliability during extreme weather events through correlated failures such as fuel supply challenges. These challenges were seen most recently during winter storms Elliott and Uri[36] and demonstrate the value and need for winterization of gas assets and enhanced electric-gas coordination and information sharing.[37] Planning for a broader portfolio of resources reduces these risks and provides for a path consistent with achieving a 100% clean electricity system.

Natural gas is also not always the most cost-effective resource to provide resource adequacy. Investment is surging in new battery storage resources, which can provide significant resource adequacy value in systems that experience relatively short periods of stress, such as during steep summer evening peaks. Portfolios of clean energy resources can increasingly provide similar services – including resource adequacy contributions – as gas plants at lower costs.[38]

Wind and solar

Increased deployment of wind and solar technologies can provide low-cost clean energy and help support resource adequacy. Although wind and solar typically have lower capacity credit, adding capacity of different resource types increase a system's resource adequacy. Easing the barriers to deployment of variable renewable technologies—through reducing interconnection costs and delays[39] and solving siting challenges[40]—would increase the rate of capacity deployment and increase the total contributions to resource adequacy from variable renewables.

In addition to increasing variable renewables' nameplate capacity, there are other ways to maximize their resource adequacy contributions or increase their capacity credit. These include hybridization with storage or other generation resources. Hybridization can reduce the interconnection challenges and yield generation profiles that are more aligned with demand peaks. Grid-friendly technology designs can also help increase variable renewables' capacity credit. Examples include west-facing orientation or use of more tracking systems for solar photovoltaic or low wind speed turbine designs. Winterization or other mechanisms to increase availability during extreme weather can also help variable renewables—and all resources—better serve demand during stressful periods.

Beyond plant level improvements, there are system-wide advancements, as well as operational and planning improvements like advanced forecasting, that would increase variable renewables' capacity credit and overall system resource adequacy. More coordinated generation and transmission planning and deployment across regions would increase load diversity, reduce variability, and enable resources (of any type) to contribute to multiple regions' resource adequacy needs. Such interregional coordination could require different institutional forms, such as the Western Resource Adequacy Program, but could offer substantial benefits. [41]

Energy storage

Energy storage deployment is accelerating and currently providing capacity during peak times to support resource adequacy.[42] Through 2020, only 1.5 GW of battery storage was in operation. By the end of 2023 operational battery storage reached over 15 GW, and it could reach over 40 GW by the end of 2025 based on planned deployments (Figure 3). While current battery storage typically ranges from 1 to 4 hours in duration, energy storage contributes more to meeting peak demand with increasing capacity credit as duration approaches 4 hours. Because additional solar deployment generally shortens the remaining summer peak demand, it enables shorter duration storage to cover an increasingly larger fraction of peak demand. This synergistic effect increases the potential of energy storage capacity value in summer peaking systems. This also highlights how capacity credit of a given technology can change over time.[43]

It is becoming increasingly common to pair renewable generation with storage, providing additional deployment and operational synergies. By the end of 2022, hybrid plants alone added 5.3 GW of storage capacity and 15.2 GWh of energy storage.[44] The amount of hybrid capacity in the interconnection queue as of 2022 is 358 GW, which is more than double the amount in 2020.[44] Hybrid arrangements help variable generators provide greater contributions to resource adequacy and can be deployed more rapidly than standalone storage systems when combined with existing generator resources. For example, if located at an existing generator or attached to an existing proposed project, a hybrid storage system generally does not have to re-enter the interconnection queue and may fit within the boundaries of the existing generators,[45] cutting down on one of the biggest hurdles to greenfield deployment.

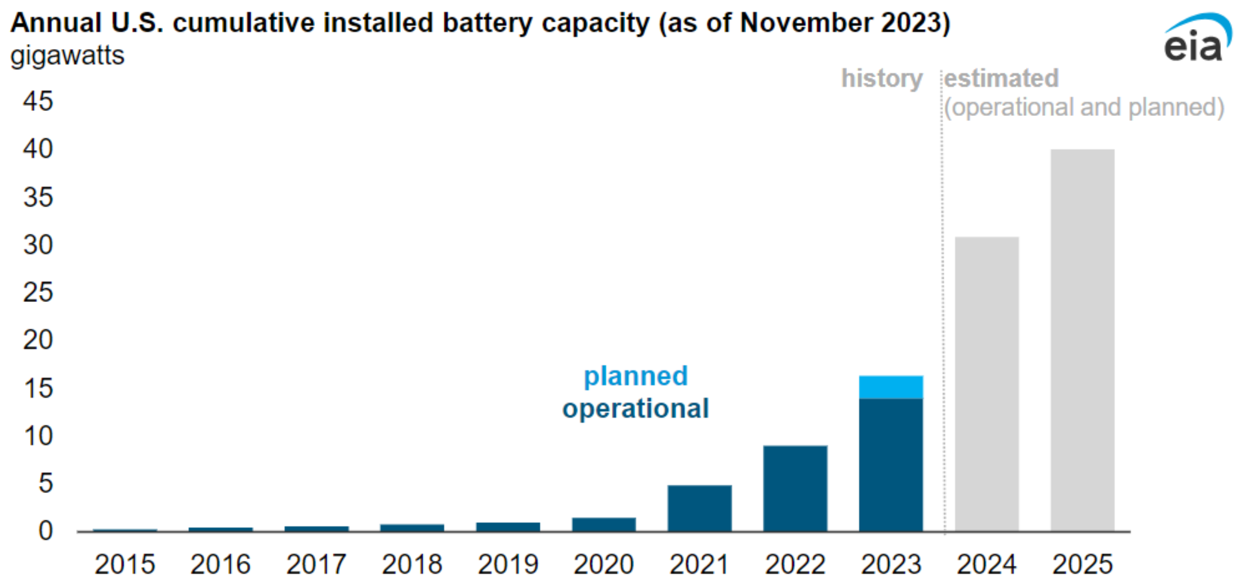

Figure 3. Total power sector battery capacity historical and projected through 2025. Battery capacity is projected to more than double by 2025 representing rapid deployment of storage and its growing potential to contribute to meeting resource adequacy needs.[46]

Long duration storage

Long Duration Energy Storage (LDES) will be key to providing flexibility and reliability in a future decarbonized power system. LDES includes a set of diverse technologies that share the goal of storing energy for long periods of time for future dispatch. The form of energy that is stored and released, as well as the duration of dispatch is highly variable across technologies. DOE includes systems with duration of dispatch of 10 hours or more as LDES and identifies two types of LDES, including inter-day LDES (i.e., power shifted by 10–36 hours) and multi-day / week LDES (i.e., power shifted by 36–160 hours).[47]

Pumped storage hydropower (PSH) facilities are mature LDES technologies with a combined generation capacity of 22 GW with an estimated median storage duration of 12 hours.[48] By the end of 2022, 96 PSH projects were in the U.S. development pipeline with an additional combined power storage capacity of 91 GW.[48] Most of the proposed projects have closed-loop configurations, which allow more siting flexibility and have generally lower environmental impacts on aquatic and terrestrial resources than open-loop facilities, and some developers are exploring storage durations beyond the typical 8-12 hours.

Cost-effective LDES technologies can enable high renewable pathways, lower the cost of grid expansions, improve grid resilience, reduce the need for new natural gas buildout, and diversify domestic energy storage supply chains. The DOE's *Pathways to Commercial Liftoff: Long Duration Energy*

Storage Report on LDES found that pathways that deploy LDES are $10-20 billion cheaper than those that do not, based on system savings in operating costs from reduced renewable curtailment and fuel spend, as well as reduced capital investment for dispatchable firm generation.[47]

LDES demonstrations have gained momentum with $325M of projects announced through the DOE's Office of Clean Energy Demonstration,[49] as well as a conditional commitment to loan to a LDES manufacturing facility from DOE's Loan Program Office.[50] However, accelerated commercialization of LDES relies on action across organized wholesale electric markets, state regulators, and policymakers to adopt market standards and policies that value the reliability and flexibility services that LDES technologies provide. State utility regulators and utilities standardizing a methodology for longer-term, integrated modeling could improve their valuation of the resource adequacy benefits of LDES.

Example: California's LDES program is investing up to $300 million in projects to increase resiliency and reliability of its grid as the state accelerates its deployment of renewables. The longest duration of storage announced is a 5MW/500MWh iron-air battery that is capable of discharging energy to the grid for 100 hours. This project will be built at a substation in Mendocino county and provide reliability and resilience to the system.[51]

Clean firm resources

Clean firm generators are low or zero emitting resources with generally high capacity credit. These include technologies like nuclear energy, geothermal, hydropower, and fossil resources with carbon capture equipment. These resources can provide reliability services such as maintaining grid voltage and frequency stability. New builds for these technologies can have long lead times, so planning processes need to begin in the near term for resources to be available within the next decade and for construction to begin before the relevant tax credits expire. Additional near-term opportunities for these resources include adding power generation to existing dams, increasing generating capacity at existing hydropower and nuclear energy facilities, and investing in improved efficiencies or extending lifetimes at existing facilities. Many of these resources are also available around the clock and are increasingly being considered to provide electricity to customers who are looking for 24/7 clean power for specific industries such as data centers, semiconductor fabrication facilities, or electrolyzers to produce clean hydrogen.

Example: The Douglas County Public Utility District is installing a 5-MW electrolyzer near the Wells hydropower plant (774 MW) in Washington which scheduled to start production in June 2024. The District also plans to closely couple hydropower and electrolyzer operations.[48]

Hydropower

At the end of 2022, there were over 117 new hydropower facilities with a combined capacity of 1.2 GW proposed or under construction.[48] Most of these projects are additions of hydropower to existing non-powered dams (NPDs) – dams that exist but do not already produce electricity. The United States has more than 80,000 non-powered dams, which already provide a variety of services ranging from water supply to inland navigation. Many of the monetary costs and environmental impacts of dam construction have already been incurred at NPDs, so adding power to the existing dam structure can often be achieved at lower cost, with less risk, and in a shorter timeframe than new dam construction. Analysis indicates there is 12 GW of development potential for non-powered dams.[52] Other types of low-impact hydropower include conduit units, which add hydropower generators to existing water infrastructure such as pipelines or irrigation systems, or new stream reach development which uses weirs and intake structures and does not involve creating a new dam or reservoir.

Example: Data center operator Iron Mountain announced a power purchase agreement with Rye Development to add up to 150 MW of new hydropower capacity to currently unpowered dams across Pennsylvania and West Virginia.[53]

Nuclear Energy

Nuclear reactors provide clean firm capacity that also helps maintain grid voltage and frequency stability. Nuclear generation efficiently uses land and existing transmission infrastructure and new deployment can maintain high-quality, high-paying jobs from retiring fossil assets.[54,55] There is significant potential for new nuclear reactor deployment at retiring or retired coal facilities—an estimated 80% of retired and existing coal sites could host an advanced nuclear energy facility, representing a total potential generating capacity of 260 GW.[56] This can unlock cost and timeline savings through re-use of electrical and interconnection infrastructure.

For the current fleet, plant owners and system operators can support investments in uprates, upgrades, and improvements that increase asset lifespan or power output. For new reactors, planning for capacity can begin in the near-term, including but not limited to: considering nuclear in utility IRPs, placing reactor orders, applying for early site or reactor design permits – even if plans are for assets that will not be online until the 2030s – and investing in supply chain and fuel production and enrichment infrastructure. Developing an early committed orderbook of new advanced reactor designs, possibly via a consortium model where multiple utilities or customers use the same reactor design, is one critical method to support cost and risk reductions by accelerating progress towards Nth-of-a-kind reactor costs. [57]

DOE investments and programs are supporting deployment of new reactors. DOE's Office of Clean Energy Demonstrations is investing $2.5 billion to support design, licensing, construction, and operation of two new nuclear energy technologies through the Advanced Reactor Demonstration Projects.[58] The HALEU Availability Program will acquire the initial High Assay Low-Enriched Uranium (HALEU) fuel necessary for advanced reactor designs and ultimately ensure a robust domestic supply of this fuel source.[59]

Example: Green Energy Partners, a US data center and energy developer, plans to use nuclear reactors to provide power for 30 new data centers in Virginia and provide Virginia with green hydrogen for data center backup. The company bought 641 acres of land adjacent to Dominion Energy's Surry Nuclear Power Plant and plans to invest $6.45 billion in developing the property over the next 13 years. In February 2024, Surry County supervisors voted to approve rezoning of the site. Initially, data centers on the site will be powered from existing grid resources, but the company plans to develop four to six small modular reactors to provide reliable power to the complex.[60,61]

Geothermal

Geothermal provides clean firm capacity with the potential to load-follow variable renewables, capitalizing on and transitioning existing technology, supply chains, and a workforce built originally for fossil fuel extraction. Next-generation geothermal technologies use human-made reservoirs to create the right conditions by injecting fluid into hot rocks. These new engineering capabilities are currently being demonstrated and ultimately can expand the availability of geothermal resources into new regions and increase the total possible geothermal resource available.[62]

DOE investments are supporting wider deployment of geothermal technologies. For example, the Geothermal Technologies Office is supporting three enhanced geothermal system demonstration projects with $60 million dollars provided through the BIL.[63]

Example: In November 2023, Google announced that, in partnership with Fervo Energy, they developed a 3.5 MW pilot demonstration of an Enhanced Geothermal System that used standard oil and gas technology to create and exploit a new geothermal reservoir. Google has signed further advanced commitments for future, larger plants with similar designs.[64] In September 2023, Fervo Energy broke ground on its 400 MW Cape Station project in Utah which is scheduled to start delivering power in 2026 reaching full capacity in 2028.[65]

Federal Opportunities and Programs for Generation and Storage

Table 1. *Select major federal opportunities to support private sector deployment of generation and storage resources and to maintain existing clean firm resources.*

Category	Item	Description
Tax Credits[30]	Clean Electricity Production Tax Credit (§45Y)	An inflation adjusted $27.5/MWh tax credit for the first 10 years of zero emission electricity production. Two 10% bonuses are available for eligible projects located in energy communities or meeting domestic content criteria.
	Clean Electricity Investment Tax Credit (§48E)	A 30% tax credit on investment in zero emission technologies. Two 10 percentage point bonuses are available for eligible projects located in energy communities or meeting domestic content criteria. Energy storage technologies are also eligible.
	Carbon Oxide Sequestration Tax Credit (§45Q)	Up to $85 per metric ton of sequestered carbon dioxide for the first 12 years of operations.
Loans	Innovative Energy Loan Program (1703)[66]	Offers loan guarantees to support deployment of innovative or significantly improved clean energy technologies.
	Energy Infrastructure Reinvestment Loan Program (1706)[66]	Up to $250 billion in loan guarantees available to projects that retool, repower, repurpose, or replace Energy Infrastructure that has ceased operations or enable operating energy infrastructure to avoid, reduce, utilize, or sequester air pollutants or greenhouse gas emissions.
	Empowering Rural America Program[67]	$9.7 billion in loans available for rural electric coops through USDA Rural Utilities Service, including clean energy generation and storage projects.
Direct Support	Civil Nuclear Credit Program [68]	Up to $6 billion to help preserve the existing nuclear fleet at risk of retirement due to economic factors.

	Hydroelectric Incentive Programs[69]	More than $750 million through three programs to support production, efficiency improvements, and enhancements at existing hydropower facilities.
Technical Assistance	Hydropower Technology Development[70]	Opportunity for hydropower developers, system operators, utilities, and other stakeholders to receive technical assistance on the development of hydropower hybrids and pumped storage hydropower
	State Technical Assistance Program[71]	Targeted national lab technical assistance for state energy offices and regulators, including support for resource adequacy planning

Grid enhancements and expansions

The transmission network and other grid infrastructure necessary to move power to meet demand is a critical component of resource adequacy. In addition to accessing and connecting new generation sources, transmission enables neighboring utilities and regions to share power when needed, especially during periods of high stress. To maximize the transmission system's ability to contribute to resource adequacy, the transmission network needs to expand while more efficiently using existing lines and rights of way.

New Transmission

Transmission capacity can provide substantial resource adequacy benefits, as new lines enable more flexible generation sharing and reduce the need for new generation.[27] DOE's National Transmission Needs Study concluded that there is a pressing need to build additional transmission infrastructure and that nearly all regions in the United States would gain improved reliability and resilience from additional transmission investments. For example, in 2022 the value of new interregional transmission lines is concentrated into a small portion of total hours coinciding with extreme weather events.[72]

Some regions have acute reliability and resilience needs, which additional interregional transmission deployment can address (Figure 4).[27] The resilience value of interregional transmission is of particular importance because all generators face the risk of unplanned outages due to extreme weather, and increased interregional transmission enables unaffected generators to help neighboring regions meet their resource adequacy needs. Planning now for interregional capacity expansion can help meet demand in the next decade.

Examples: The projects selected for capacity contracts via the BIL's Transmission Facilitation Program exemplify intraregional and interregional transmission expansion that supports resource adequacy. For example, the Southline project will increase transfer capability between New Mexico and Arizona, giving load centers with growing needs in Arizona access to diverse new generation resources while also opening new opportunities for energy to flow further west to California. Similarly, the Cross-Tie project will provide a new path for generation resources in the interior West and Midwest to deliver energy across the Western Interconnection. These projects will not only increase reliability and decrease congestion, but are also designed to increase access to renewable energy sources.

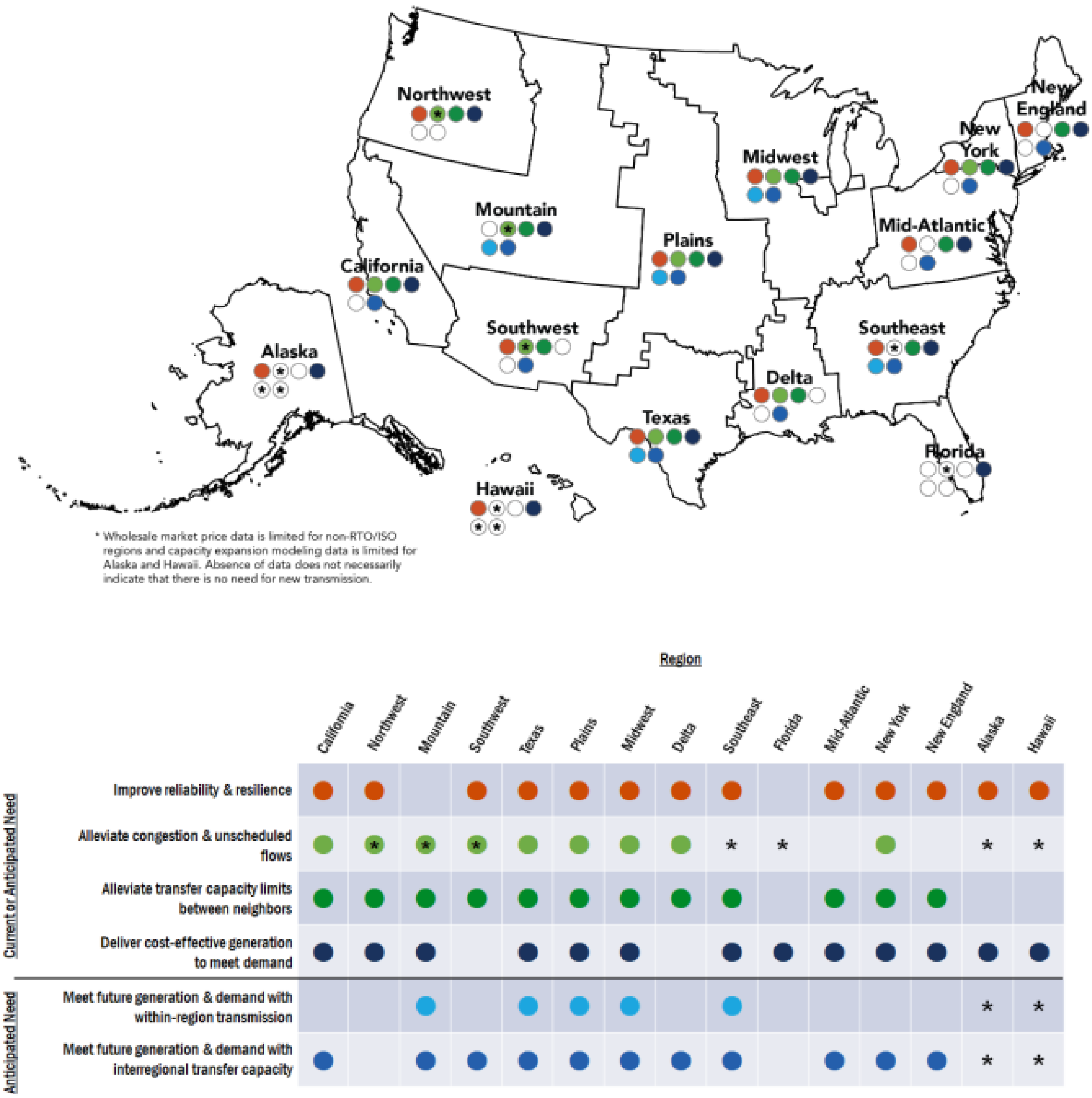

Figure 4. Summary of current and future transmission needs identified in DOE's Transmission Needs Study by geographic region. The study identified that all regions would gain improvements in reliability and resilience with increased transmission deployment.[27]

Reconductoring

Reconductoring existing transmission lines, particularly with higher capacity advanced conductors, can quickly expand grid capacity to interconnect new generation and improve resource adequacy. Advanced conductors are conductors made with composite cores rather than traditional steel cores and can increase power capacity with improved efficiency. Reconductoring with conventional materials can increase line capacity and using advanced conductors can as much as double transmission line capacity. Reconductoring can be done without requiring new rights of way, and can be deployed on certain types of existing infrastructure in 1-3 years to meet near-term grid capacity needs. Reconductoring is particularly useful from a resource adequacy perspective when deployed on inter-regional transmission links that are more likely to have resources on either side to transfer in times of system stress.

Other promising innovative conductor types include enhanced steel core conductors that have higher capacity and efficiency benefits at a lower cost than composite core conductors—though usability in reconductoring efforts varies based on sag clearance requirements. Nearly 20% of U.S. transmission lines could be ripe candidates for advanced reconductoring.[73] Utilities can evaluate advanced conductors during ongoing reconductoring initiatives and in current planning and investment processes to address near-term and expected long-term capacity needs and make efficient use of capital investments.

Example: In Texas, American Electric Power (AEP), the largest transmission utility in the United States, replaced 240 miles of aging conventional conductors with advanced composite core conductors from 2012-2015 to achieve a ~2x capacity increase.[74]

Grid Enhancing Technologies

Using readily available, low-cost GETs to expand grid capacity can be much faster than building new transmission. GETs include a range of hardware and software technologies that enhance or optimize existing grid infrastructure to improve system utilization, flexibility, and reliability. Dynamic line rating (DLR), advanced power flow control (PFC), and topology optimization are three types of GETs that can improve utilization of existing transmission infrastructure to increase effective capacity and support resource adequacy priorities.

- **Dynamic line ratings** (DLR) adjust transmission line ratings based on local environmental and conductor conditions (e.g., wind speed) to determine how much power can be safely carried through a transmission line, providing a more accurate assessment of a line's safe carrying capacity versus conventional static ratings based on conservative assumptions.
- **Advanced power flow controls** (PFC) consist of devices that can efficiently reroute power from overloaded lines to lines with available capacity.
- **Topology optimization** is software that determines optimal grid configurations to route power flow away from congested and/or overloaded transmission lines.

These GETs—individually and in combination—are low-cost, readily available technologies that can frequently be deployed in 1-3 years because they leverage existing infrastructure, do not require new rights of way, and can be implemented without system outages. Beyond unlocking grid capacity to bring on more generation and serve higher loads, these GETs can reduce congestion costs for ratepayers and improve system reliability by reducing overloading lines and improving system visibility. These GETs have been successfully deployed widely internationally and in some parts of the United States. Utilities and grid operators can integrate GETs into grid planning and investment processes today to accelerate deployment, address near-term grid needs, and improve the efficient use of existing infrastructure.

Example: In 2022, Pennsylvania Power and Light (PPL) Electric deployed DLR for real-time and market operations. The DLR system was installed in ~1 year without system outages and at a cost less than $300,000. The deployment resulted in increasing average capacity ratings by ~18-19%, avoiding ~$50 million in costs of reconductoring and rebuilding alternatives, and saving customers an estimated $23 million in annual congestion costs.[75]

Example: Alliant Energy leveraged topology optimization software to reconfigure power flows on transmission lines in Midcontinent Independent System Operator (MISO). The reconfigurations reduced congestion by 18% (a cumulative $13.7 million in savings) since October 2021 when the program was started. The software identified an additional 36% of congestion that could have been avoided if the recommended reconfiguration solution had been implemented.[76]

Federal Opportunities and Programs for Grid Enhancements and Expansions

Table 2. *Select major federal opportunities to support private sector deployment of grid enhancements and expansions.*

Category	Item	Description
Loans and Financing Programs	Transmission Facilitation Program[77]	$2.5 billion in commercial support for qualified transmission projects through tools such as capacity contracts, public-private partnerships, and loans.
	Transmission Facility Financing Program[78]	$2 billion to pay for the costs of direct loan for the construction and modification of transmission facilities.
	Innovative Energy Loan Program (1703)[66]	Offers loan guarantees to support clean energy deployment of innovative or significantly improved technologies. Can fund transmission projects.[79]
	Energy Infrastructure Reinvestment Loan Program (1706)[66]	Up to $250 billion in loan guarantees available to projects that retool, repower, repurpose, or replace Energy Infrastructure that has ceased operations or enable operating energy infrastructure to avoid, reduce, utilize, or sequester air pollutants or greenhouse gas emissions.
	Empowering Rural America Program[67]	$9.7 billion in loans available for rural electric coops through USDA Rural Utilities Service, including for grid enhancements.
Direct Support	Grid Resilience and Innovation Partnerships (GRIP) program[80]	$10.5 billion in grant funding for grid investments, including for transmission and GET technology solutions.
Other Programs	National Interest Electric Transmission Corridors (NIETC)[81]	Special designation that enables DOE and the FERC to use financing and permitting tools to spur construction of transmission projects within a NIETC.
Technical Assistance	Grid Resilience Assistance[82]	Technical and other assistance available to support state, Tribal, territory, and industry needs to support

		grants to enhance electric grid resilience against extreme weather, wildfire, and other natural disasters.
	State Technical Assistance Program[71]	Targeted national lab technical assistance for state energy offices and regulators, including support for resource adequacy planning.

Distributed Resources

Resource adequacy planning traditionally focuses on building centralized power supply to meet a fixed amount of forecasted demand. However, resources on the distribution grid provide critical tools to flex demand to better match supply as the power system evolves. This includes both traditional energy efficiency programs that reduce overall demand and VPPs that provide demand flexibility or energy export from distributed generation and storage DERs. These resources are important tools to evaluate and pursue to meet resource adequacy needs.

Energy Efficiency

Investments in energy efficiency technologies and programs reduce overall annual electricity demand. In addition, energy efficiency investments generally reduce demand during peak periods. This means energy efficiency investments contribute to resource adequacy by reducing the need to procure and deliver electricity during grid stress. Increased adoption of efficiency technologies overall significantly reduce electricity system demands and result in cost savings. Analysis of accelerated deployment of building decarbonization measures and technologies demonstrated that energy efficiency measures alone in residential and commercial buildings could result in billions of dollars of avoided costs in the power sector due in part to avoided investments in power sector infrastructure.[83] Case studies of specific regions demonstrated that deployment of a set of efficiency measures and technologies could result in a peak load reductions in 2030 of 24% to 33%.[84] Combined with other demand flexibility measures, energy efficiency could reduce national peak demand by 42 to 116 GW by 2030.[85]

Widespread deployment of specific technologies individually can have significant impacts on resource adequacy needs. DOE examined the impact of mass-deployment of geothermal heat pumps across residential and commercial buildings, accompanied with ventilation and weatherization upgrades, and found a summer peak load reduction of 3% to 28% due to higher cooling efficiencies compared to traditional air conditioners.[86] Geothermal heat pumps also provide significant reliability benefits because they use consistent temperatures found underground and as a result do not have operational efficiencies affected by extreme air temperatures.

Examples: PacificCorp's 2023 IRP forecasted a 14.9% increase in system peak demand over the 2021 IRP and uses incremental cost-effective energy efficiency to deliver nearly 800 MW of peak demand reductions in the near term through 2026.[87]

In ISO-New England's 2023 Capacity Auction for 2026/27 peak demand, nearly 10% of the cleared capacity was from demand resources, including energy efficiency, load management and distributed generation.[88]

Virtual Power Plants: Demand Flexibility & Distributed Generation and Storage

Demand flexibility can contribute to resource adequacy. Time-varying rates, such as real-time, time-of-use, and critical peak pricing, give retail customers an incentive to shift consumption outside of peak hours, potentially reducing peak demands, thereby providing effective capacity.[iv] Flexible demand from DERs such as demand response programs can be managed through mechanisms such as managed EV charging, smart thermostat demand response, commercial demand response, and other programs. Potential DERs include EV charging infrastructure and EVs, HVAC systems, smart water heaters, commercial and industrial loads, pool pumps, batteries,[v] distributed solar resources such as rooftop solar panels, and a wide variety of other connected devices.

VPPs are aggregations of DERs that provide a variety of utility-grade grid services, including boosting resource adequacy, by orchestrating demand from DERs at flexible times (e.g., EV chargers, water heaters, commercial and industrial loads) or DERs that generate and store electricity (e.g., distributed solar and battery systems). VPPs are deployed across the country today, with a cumulative 30-60 GW of capacity. With rapid adoption of distributed energy resources and the need to serve rising peak demand, VPPs have the potential to address 10% - 20% of peak demand by 2030 and save approximately $10B per year in grid spending nationally.[89]

VPPs can have shorter deployment timelines than bulk power assets because they require less siting, permitting, and construction effort. Procuring new peaking capacity from a VPP can be up to 60% less expensive for a utility than traditional resources such as peaker plants due to savings from deferred transmission and distribution upgrades and avoided fuel costs.[90] Beyond financial impacts, VPPs have the potential to increase the efficiency of existing and new grid infrastructure and empower communities.

DOE is accelerating use of VPPs to support grid needs. The Office of Clean Energy Demonstrations Distributed Energy Systems program has $50 million for projects that design and operate distributed energy systems that integrate high levels (>25% of peak demand) of variable clean energy resources. Projects will demonstrate aggregated approaches that integrate utility planning, sensors, communications and control infrastructure, and solutions to long-term operations.[91]

[iv] Advantages of time-varying rates over VPPs for load reshaping including simplicity to implement within existing ratemaking frameworks; disadvantages include less dexterous control over demand and – in some cases – secondary peaks created immediately before and/or after on-peak price windows.

[v] While demand flexibility typically involves DERs that *consume* energy, batteries that *dispatch* energy that stays behind the meter (BTM) to serve on-site loads have the effect of dropping demand on the grid and therefore deliver demand flexibility.

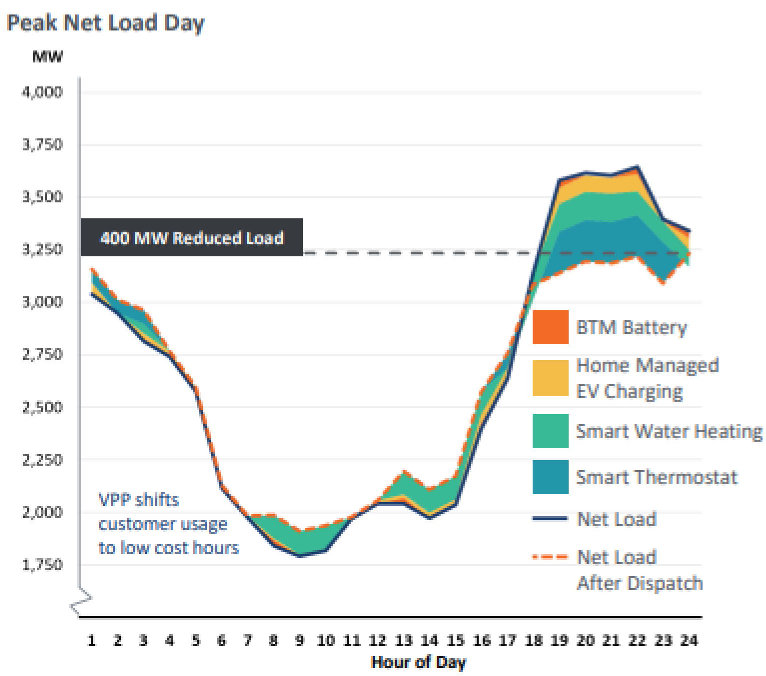

Figure 5. Example of a modeled 400 MW reduction in a peak load day due to an aggregation and control of distributed resources such as batteries and demand response through a VPP. Reproduced with permission.[90]

When aggregated into utility-scale VPPs, distributed generation and storage systems—in particular, distributed solar with batteries—can provide resource adequacy to utilities with lower siting, construction, and/or transmission interconnection hurdles than experienced with bulk power system resources.

Examples:

- *Utility-financed smart water heaters and smart thermostats:* Roanoke cooperative provides and/or finances smart electric water heaters and smart thermostats to customers at low, no, or even negative cost who enroll in a VPP as part of their Smart Grid Technology for Member-Owners program.[92]
- *Solar and storage VPP in wholesale markets:* Sunrun bid capacity into ISO New England in 2019 and delivered over 1.8 GWh of power in the summer of 2022 from home solar and battery systems during peak hours.[93]

Federal Opportunities and Programs for Distributed Resources

Table 3. *Select major federal opportunities to support private sector deployment of distributed resources.*

Category	Item	Description
Tax Credits[30]	Tax incentives for efficiency technologies (§§48, 45L, 25C, 25D, 179D)	Tax credits and deductions available for the installation of energy efficiency equipment such as heat pumps, and for the construction and retrofit of efficient homes and businesses.

	Residential Clean Energy Credit (§25D)	30% investment tax credit available for individuals that install distributed energy resources such as rooftop solar and home battery storage systems.
	Tax incentives for vehicle electrification (§§30C, 30D, 25E, 45W)	Tax credits available for individuals and businesses that purchase eligible electric vehicles and that install charging equipment in eligible locations.
Loans	Innovative Energy Loan Program (1703)[66]	Offers loan guarantees to support clean energy deployment of innovative or significantly improved technologies. Can fund VPP deployment such as Project Hestia.[94]
Direct Support	Home Energy Rebates[95]	$8.8 billion for states to provide rebates on select home energy efficiency and electrification projects.
	Greenhouse Gas Reduction Program[96]	$27 billion EPA program including a $7 billion Solar for All competition to expand solar deployment to low-income and disadvantaged communities.
	Energy Efficiency Revolving Loan Fund Capitalization Grant Program[97]	$250 million to provide capitalization grants to States to establish a revolving loan fund under which the state provides loans and grants for energy efficiency audits, upgrades, and retrofits to increase energy efficiency and improve the comfort of buildings.
Technical Assistance	Technical Assistance for the Adoption of Building Energy Codes[98]	$1 billion for states and local governments with code making authority to adopt traditional and innovative building energy codes to reduce energy use in new and existing residential and commercial buildings.
	State Technical Assistance Program[71]	Targeted national lab technical assistance for state energy offices and regulators, including support for resource adequacy and distributed resource planning.

Evolving resource adequacy methods

In addition to deploying new technology solutions for resource adequacy, the methods for assessing resource adequacy need to significantly advance to meet the needs of the emerging power system with increasing amounts of clean electricity and electrified loads. For example, resource adequacy assessments have historically only focused on capacity needs for certain hours of the year – typically peak demand days in the summer or winter. With increasing amounts of variable wind and solar combined with energy storage, it is necessary to instead model chronological hour-by-hour operations of the system to accurately capture a wider range of possible stressed system conditions and to account for energy storage charging and discharging behavior. Similarly, understanding and modeling of when extreme weather conditions may cause correlated outages among natural gas resources may change the hours of greatest concern for maintaining reliability.

With the increasing importance of deploying a full portfolio of resources and approaches to provide resource adequacy, planners and regulators can benefit from more sophisticated resource adequacy evaluation methodologies that can account for interactions between different types of resources and loads. Select key areas of evolution in best practices and emerging methodologies in assessing resource adequacy identified in recent studies[99,100,101] include:

- **Chronological hourly assessments**. Methods that only look at the peak hour of the year or season, or on a few select top load hours, are insufficient as peak demand may no longer predict the times when the power system is most stressed. Chronological hourly simulations are the current best practice, with sub-hourly analysis, when possible, for more accurate characterization of system needs.
- **Probabilistic approaches to setting reliability standards**. Older approaches to resource adequacy often use administratively set targets – such as a prescribed reserve margin – for planning purposes. With a wider variety of resource technologies contributing to the grid today and into the future, grid planners can replace simpler, administrative targets with metrics based on probabilistic methods. Probabilistic modeling can establish better relationships between resource adequacy targets and specific reliability metrics, and many different resource adequacy and reliability metrics can be assessed to inform the planning process. These methods can be used to create a larger sample size of potential events that would cause stressed system conditions, which drive resource adequacy shortfalls but are relatively rare.
- **Improved weather, load, and resource performance data**. Representation of weather dependencies and weather data needs to improve, as current practices can hinder appropriate assessments under high wind and solar futures and climate change. Resource adequacy assessments are more robust when greater number of weather conditions are considered, and climate change requires extending these conditions beyond the historical record. Correlated, weather-dependent outages of all resources should be accounted for in resource adequacy modeling, including thermal resources that can experience outages during extreme temperatures. Ideally, sufficient data should be used to capture real-world resource performance in a range of external conditions.
- **Integrating demand side resources into the planning process**. Some approaches consider demand side resources as a part of load forecasting in a process that is separate from the resource adequacy assessment. It is important to explicitly model demand resources in evaluations of system reliability rather than simply as a load modifier. This allows for better understanding of the capacity contributions of these resources (rather than hiding those contributions in load reductions or shifts) and allows for optimizing the dispatch of flexible demand resources. Properly characterizing the capacity contributions of specific demand side resources could support the use of VPPs as capacity resources in organized markets.
- **Refine the characterization of transmission.** Some assessments do not fully consider transmission or possible transmission constraints in resource adequacy assessments. Planners can undertake more detailed modeling to understand transmission capacity for bilateral trading with neighboring regions and the limits of these resource transfers during critical periods, such as by including weather-sensitive dynamic line ratings. Regional entities can assist in developing area-wide assessments that reflect transmission availability and needs.

- **Improve capacity credit assessment of all resources**. Resource contributions to resource adequacy are not static and change over time with changing system conditions and changing energy supply mix. Effective load carrying capacity (ELCC) is a common metric used to measure the marginal capacity credit of renewable resources like wind and solar. Use of the ELCC metric is very important to assess the declining marginal contributions of adding more of the same type of resource to a portfolio, as well as potential synergistic impacts between resources such as solar and battery storage, and demand side resources. ELCC can be further applied to fossil plants, hydropower, transmission, and demand resources, and can provide a better standard for comparisons across resources.

Addressing Barriers to Deployment

To maintain reliability while achieving clean energy and emissions goals, continued efforts of grid operators, planners, and regulators are critical to address several potential regulatory, market, or other technology adoption barriers. These include:

- **Interconnection**. New generation resources are facing increasing delays due in part to the large number of projects seeking interconnection—known as interconnection queues—and the sometimes lengthy assessments required before interconnection is approved.[102] Modernizing the interconnection process and looking for better ways to re-use existing points of interconnection can both speed deployment of resources that can contribute to resource adequacy and make most efficient use of the existing system. DOE's Interconnection Innovation e-Xchange (i2X) has released a draft roadmap laying out a number of solutions addressing underlying causes of interconnection delays from workforce availability to tools and methods used in interconnection studies.[103] FERC Order No. 2023 reforms the processes that transmission providers use to study and interconnect generating facilities.[104] Transmission providers, including RTOs and ISOs, are now required to propose how they would implement the requirements outlined in FERC Order No. 2023.
- **Regulatory consideration.** Regulatory decisions for solutions like interregional transmission and GETs do not always include a full cost-benefit analysis, with the result that they are often not selected for investment in situations where they would have been a better solution. Regulatory decisions, including in the context of utility Integrated Resource Plans (IRPs), must utilize evolving resource adequacy evaluation methods and account for the full set of available resources that can provide resource adequacy. Divided regulatory authority between state jurisdiction of the distribution system and federal jurisdiction of the interregional transmission system can pose a challenge to holistic system planning, given that both distributed and utility scale resources will play a role in providing resource adequacy in the future. Further, successful interregional coordination on transmission planning and development requires addressing planning authority and cost allocation issues but is necessary to better connect the nation's electricity infrastructure and maximize the technological resource adequacy tools available. FERC's transmission planning Notice of Proposed Rulemaking laid out several proposed reforms to improve regional, and interregional, coordination with respect to transmission planning.[105]

- **Markets**. Utilities, balancing authorities, and markets need to update their resource adequacy frameworks to ensure that resources are valued and compensated in proportion to the value they provide to the system. Numerous utilities and grid operators throughout the country are already moving toward new and more sophisticated ways to value the resource adequacy attributes of specific resources within their evolving systems, including adopting ELCC methodologies for capacity accreditation.[vi] New and improved standards and communication protocols can integrate more distributed resources into utility planning and operation and organized wholesale electricity markets.

- **Permitting and supply chains.** Serving the new load coming on to the system while transitioning to a low carbon resource mix will require deploying large quantities of new generation, transmission, and demand resources. Local, state, and federal permitting processes will have to accommodate and ultimately approve large quantities of projects while ensuring reasonable engagement with surrounding communities without creating unnecessary hurdles that cause delays and increase costs. Similarly, supply chains must grow to build and secure all the new resources that will be needed. Numerous generation, storage, and grid component manufacturing facility investments have already been announced following the passage of BIL and IRA.

Conclusion

The technologies, approaches, and supporting resources outlined above present a significant opportunity to meet resource adequacy needs, power the economy, and maintain affordability for households and businesses. The path ahead will require significant investment and deployment to ensure that the electric grid can serve growing future electricity loads, while allowing for managed retirements of the most polluting generation resources. A portfolio approach can best meet this challenge and avoid a narrow focus on the most familiar technologies of the past. An overreliance on natural gas and other fossil fuel technologies risks locking in climate-warming emissions, while failing to address critical reliability risks that already exist today, as highlighted by recent extreme weather events around the country. Rather, the moment calls for embracing a diverse mix of tools and harnessing both new and existing technologies that together can provide better electricity service to customers around the country. The numerous available technologies described here can be combined into countless portfolios to serve the grid of the future reliably, sustainably, and affordably.

As improvements are made to streamline the deployment of clean technologies that enhance resource adequacy, utilities and grid planners can consider the full menu of technology solutions to meet the needs of a clean, reliable, and affordable power system. The unprecedented availability of tax credits and other funding opportunities through the BIL and IRA creates a compelling environment for exploring all of these opportunities. Utilities have both the opportunity and the means to plan and deploy a variety of clean technologies to maintain and improve resource adequacy along the path toward the sustainable electric grid of the future.

[vi] For example see: *Effective Load Carrying Capability (ELCC).* PJM. https://www.pjm.com/planning/resource-adequacy-planning/effective-load-carrying-capability

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