Hydropower at Risk

How Challenges to America's First Renewable Resource Threaten Grid Reliability and Resilience

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Problem Statement

Despite the clear value of hydropower and its role in balancing the grid, the future of the existing fleet is at risk. Not enough has been done to address the challenges that push hydropower and pumped storage operators towards early retirement, including an antiquated licensing and relicensing process, lack of federal tax parity with other renewables, and inadequate compensation in wholesale markets.

Inaction on these issues has created an expensive, risky, and generally inhospitable landscape for hydropower compared to other renewables, jeopardizing the existence of 451 FERC licensed water power facilities totaling 15,700 MW in capacity that are set to expire between 2020-2035.[1] This is nearly 40% of the non-federal fleet. Under the status quo, many of these plants may choose to surrender these licenses, disrupting grid stability and creating a new demand for similarly situated resources like natural gas. This scenario leads to an increase in both emissions and electricity costs.[2] Moreover, these inadequacies in federal and market policy have also stifled the expansion of new hydropower by causing major project delays and discouraging private investment. To fully decarbonize the energy sector while ensuring reliable and resilient electricity in the United States, policymakers and market designers must address these challenges in support of hydropower.

Policy Solutions

To address the threat to grid reliability and resilience posed by the wave of upcoming hydropower license expirations, the following solutions should be adopted:

1. Congress should streamline the process for licensing and relicensing hydropower facilities with the Federal Energy Regulatory Commission by:
    a) Clarifying that mandatory conditions relate only to project effects, rather than unrelated requirements, and that licensees are authorized to conduct routine, non-substantial maintenance and repairs without a license amendment
    b) Improving interagency coordination and process discipline at the federal and state levels including the development of a consolidated schedule, joint study plans, and a process to resolve inconsistent licensing conditions; and
    c) Remedying the America's Water Infrastructure Act of 2018 by expediting the timeline for licensing new generation at existing non-powered dams and qualifying pumped storage facilities.
2. Congress should reform the tax code to provide incentives for environmental and dam safety improvements to the existing hydropower fleet.
3. When implementing the Inflation Reduction Act, the Internal Revenue Service and Department of Treasury should provide hydropower tax parity with other renewable resources like wind and solar, including investments to repower the existing fleet.
4. Regional Transmission Organizations and Independent Service Operators should ensure that hydropower is accurately valued and fully compensated for its contributions to the grid by:
    a) Developing new products and models that better compensate hydropower generators for their load carrying capability as variable renewables expand, and
    b) Allowing hydropower operators to recover opportunity costs for providing essential grid services (e.g., ancillary services like reserves) in lieu of generating power; and
    c) Minimizing out-of-market uplift payments for essential grid services that are key to reliability and resilience.

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[1] 2023 Hydropower Markets Report Section 1.5

[2] How Today's Hydropower Impacts Tomorrow's Grid: Counterfactual Scenarios Showing Grid Impacts if Hydropower Goes Away Section 6 (2023)

Introduction

The United States electric grid is undergoing a rapid transition away from fossil fuels in favor of renewable energy. Driven by a rising demand for electric power, total grid capacity is expected to double from 2022 to 2050, met by a 380% increase in renewable capacity.[3]

Historic federal investments in clean energy generation and zero fuel costs are accelerating this growth. Meanwhile, over 83GW of fossil-fired and nuclear generators are anticipated to retire from now through 2033.[4] The combination of these three trends – significant retirements of baseload fossil generation, strong growth of variable renewables, and increasing electricity demand – are straining the U.S. electric grid. Magnified by prolonged extreme weather, these challenges threaten system reliability and resilience for millions across the country.[5] Yet, as policymakers and regulators search for solutions, the nation's oldest and most capable source of renewable energy is often overlooked: hydropower.

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Hydropower has been the backbone of clean energy since the 1880s, faithfully serving as the single largest generator of renewable electricity in the U.S. for most of its history. Today, hydropower remains a significant contributor to the supply of electricity, accounting for 6.2% of total U.S. generation and 28.7% of renewable generation.[6] In 2022, the conventional hydropower fleet generated enough energy to power 25 million homes. In addition, pumped storage hydropower, a type of long-duration energy storage that moves water between two reservoirs, accounts for 96% of all utility-scale energy storage capability in the U.S.[7] This is because, unlike other technologies, the 22 GW of pumped storage capacity across the country can store 8-12 hours or more of continuous power. Together, conventional hydropower and pumped storage represent over 100 GWs of carbon-free, flexible capacity.

Now, as the grid changes, so too does the role of water power. Although no longer the largest source of clean energy, hydropower and pumped storage still provide irreplaceable benefits to the U.S. bulk electric system and have a pivotal role to play in the energy transition. For one, water power is the only source of carbon free energy that offers flexible, baseload power when the sun is not shining, and the wind is not blowing. Reservoirs containing clean, dispatchable operating reserves of hydroelectricity keep the lights on when other resources falter. As a result, hydro is naturally suited to complement the expansion of variable renewables. Hydropower also offers a wide range of grid scalable ancillary services that strengthen the overall reliability of our electric system. Many of these services, like voltage control and frequency response, are made possible by the unique attributes of hydropower not found in other sources of renewable energy. These strengths of water power protect our electric infrastructure from the everyday operational challenges that most people never see. They are also crucial in the face of extreme adversity. From natural disasters to malicious attacks on electric infrastructure, hydropower has the capability to improve preparedness, mitigate damage and even restore systemwide power after a total blackout. Millions of people across North America depend on hydropower to provide security against these unexpected threats. Without it, the U.S. grid is less reliable, less resilient, and less renewable.

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[3] U.S. Energy Information Administration, Annual Energy Outlook (2023)

[4] North American Electric Reliability Corporation, Long-Term Reliability Assessment (2023), p.6

[5] NERC has identified a significant portion of the country as at elevated risk of power outages due to long-duration extreme weather. Id.

[6] There are over 2000 hydro plants across the country, with a total generating capacity of around 80GW. U.S. Department of Energy, Hydropower Market Report (2023), p.2

[7] There are 43 plants totaling 22GW of capacity. Id.

The Value of Hydropower to an Evolving Grid

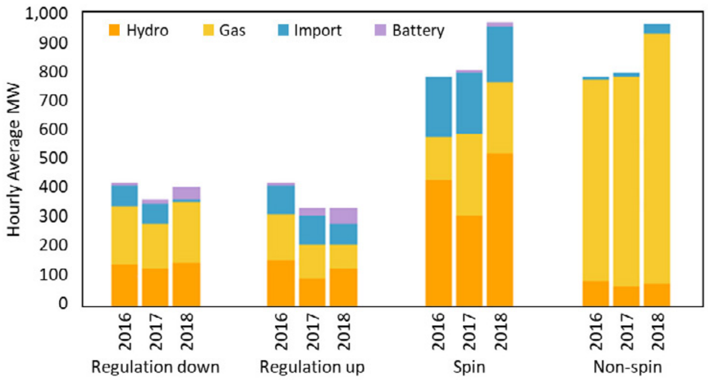
HYDRO AND GRID RELIABILITY

Put simply, a reliable grid is one that ensures the light switch always works, no matter when you flip it. In spite of common disturbances, a reliable grid will continue to provide stable and adequate power. The Federal Energy Regulatory Commission (FERC) is responsible for approving, overseeing, and enforcing reliability standards for the bulk-power system.[8] Best practices for grid operators and wholesale markets have come to reflect the need for reliable operation and resource adequacy. The FERC has defined six ancillary services that serve this purpose:

1. Scheduling, system control, and dispatch service
2. Reactive supply and voltage control from generation sources service
3. Regulation and frequency response service
4. Energy imbalance services
5. Operating reserve – spinning reserve service
6. Operating reserve –supplemental reserve service[9]

The unique characteristics of hydropower make it a versatile resource compared to other zero-emission renewables. For one, reservoir hydropower is a firm source of operating reserves. The water impounded behind a hydro dam serves as a large supply of easily dispatchable energy. By regulating the flow of water, hydropower can quickly access these reserves to adjust to grid demands and maintain reliability. This flexibility allows operators to either dispatch power into the grid by ramping up production or curtail power by ramping down, all in as fast as 10 minutes.[10] In fact, hydropower resources provide one-hour ramping at a greater average frequency per installed megawatt than the natural gas fleet, demonstrating its key role in flexibility.[11] At the same time, conventional hydropower is also a baseload resource, capable of consistently generating electricity at a stable rate to meet demand 24/7. So long as water is flowing, power is being generated. Even in the face of severe drought, hydropower still maintains 80% of its average generation.[12] This dependability of flow is just as important as the flexibility of operating reserves. Of all the forms of renewable energy, only hydropower possesses both of these capabilities interchangeably.

Another benefit of hydropower is its direct, synchronous connection to the electrical grid. Synchronous generators, like those used in hydropower plants, contribute to the physical inertia of the power system, which is crucial for grid reliability. Hydro and pumped storage use turbines to spin generators, creating a rotational inertia that builds a natural resistance to changes in frequency. Wild fluctuations in frequency can damage electrical equipment and cause blackouts. When disruptions like loss of generation or transmission cause sudden imbalances in frequency, the collective inertia of grid connected synchronous generators dampen these oscillations to maintain a healthy 60hz. Hydropower is a large supporter of that grid scale inertia. For instance, in CAISO, hydropower resources provide up to 60% of the total spinning reserve requirements and up to 25% of total regulation reserve requirements, despite making up only 10% of CAISO's generation capacity.[13] This heavy reliance on hydro for reliability illustrates its continued relevance in the evolving energy mix.



PNNL, Hydropower Value Study: Current Status and Future Opportunities (2021)

Spinning mass generators like hydro and pumped storage are also important contributors to the supply of reactive power, an alternative to real power that provides voltage control along local transmission lines. Voltage is the force that pushes electricity through the power lines and towards its destination.

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[8] Federal Power Act (1920), Section 215

[9] Promoting Wholesale Competition Through Open Access Non-Discriminatory Transmission Services by Public Utilities; Recovery of Stranded Costs by Public Utilities and Transmitting Utilities, Order No. 888, FERC Stats. & Regs. ¶ 31,036 (1996)

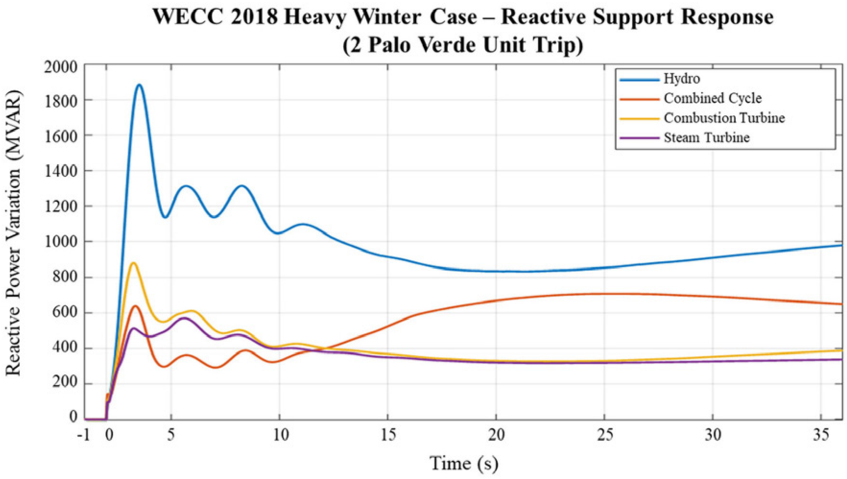
[10] Pacific Northwest National Laboratory, Hydropower's Contributions to Grid Resilience (2021), p. 3.1

[11] U.S. Department of Energy, Hydropower Markets Report (2023), Section 5.7

[12] Pacific Northwest National Laboratory, In the Face of Drought Hydropower Still Delivers Electricity (2022)

[13] Pacific Northwest National Laboratory, Hydropower Value Study: Current Status and Future Opportunities (2021), p. 21

In vast regions with long transmission lines, like the Western Interconnect (WI), an ample supply of reactive power is absolutely essential for the reliable transmission of real power.[14] This is especially true during a generator outage, when other resources increase real power output to meet load and pack that power into the transmission system for export. By adjusting the excitation of the magnetic field within the generator rotor, hydroelectric operators can regulate voltage output to either produce or consume reactive power, depending on the needs of the grid. Although reactive power management can be provided by a variety of resources, hydropower is uniquely equipped for this purpose for several reasons. First, hydropower often operates below full capacity, with a national average capacity factor of 36%.[15] This characteristic is quite uncommon for a baseload resource. Although this may seem disadvantageous, it actually allows a greater portion of the remaining capacity to be used for reactive power support. Moreover, in some cases, hydro operators accommodate for reactive power by running select generator units within a single hydro facility at a lower power factor than others.[16] The inherent versatility of running multiple generators differently within one hydro powerhouse allows hydropower to react and adapt to grid contingencies, like extreme weather, dynamically. This, in turn, secures reliable energy for customers.



PNNL: Hydropower's Contributions to Grid Resilience (2021)

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[14] Pacific Northwest National Laboratory, Hydropower's Contributions to Grid Resilience (2021), p. viii

[15] Energy Information Administration, Capacity Factors for Utility Scale Generators Primarily Using Non-Fossil Fuels, Table 4.08.B.

[16] Pacific Northwest National Laboratory, Hydropower's Contributions to Grid Resilience (2021), p. 3.15

Like conventional hydropower, pumped storage hydropower (PSH) contributes greatly to grid reliability through flexibility, dispatchability, spinning mass generation, and voltage control. However, as a novel and mature energy storage technology, pumped hydropower brings additional benefits to grid reliability that are often underrecognized, like energy arbitrage. In times of surplus energy supply, pumped storage is a net consumer of electricity, using the extra power available on the grid to pump water uphill to an elevated reservoir. Excess supply can happen when there are discrepancies between scheduled energy deliveries and actual demand in day ahead markets, creating an imbalance. Pumped storage can create value from this wasted energy in real time by effectively storing it as potential energy in the form of water, like a wet battery. When prices rise again with demand, the water is released into the lower reservoir to produce electricity at a net profit. This process not only captures optimal prices, but also improves grid reliability by mitigating transmission congestion and replenishing long-duration energy storage (LDES) reserves.[17] The scale of these reserves is another major asset to grid reliability that only pumped storage can provide.

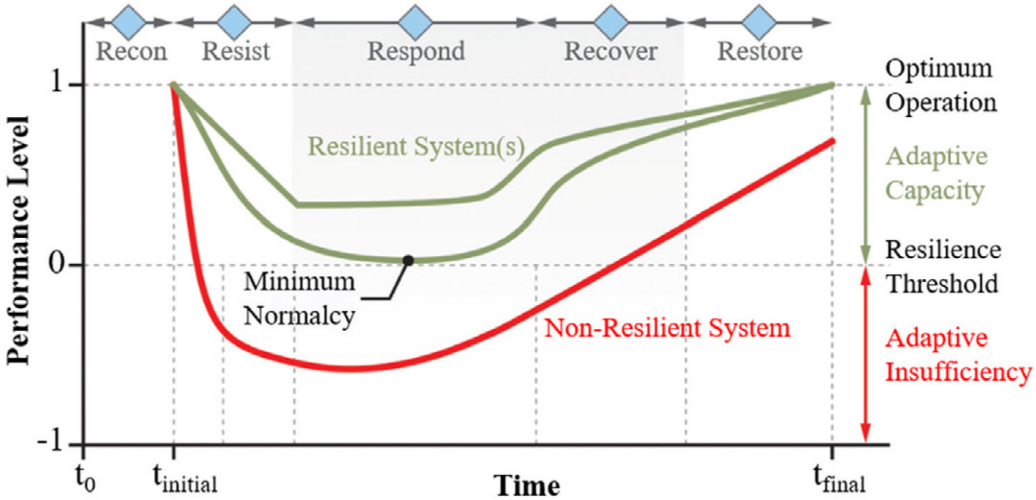
> **Pumped storage represents 96% of all utility-scale energy storage capability in the U.S., enabled by reserves that can be dispatched to continuously meet load for 8-12 hours or more.[18]**

This means that, while overall battery storage capacity may be larger than PSH, individual batteries are still completely empty after just 1-2 hours. This makes pumped storage hydropower the clear choice for grid-scale operating reserves when reliability is jeopardized for a prolonged period of time. Gaps in adequate power supply can occur for a variety of reasons such as fuel supply disruptions, missed load forecasts, variable renewable output and system transients. To support reliability and meet load for as long as possible through these events, the grid needs pumped storage hydropower.

HYDRO AND GRID RESILIENCE

Grid resilience is not as well understood as grid reliability.[19] Although often lumped together, these two metrics of a stable grid are distinct. A resilient grid is one that can rapidly recover from uncommon or extreme disturbances to reduce the likelihood of long-duration outages over large service areas.[20] Unlike the mundane hiccups of everyday operations, these sudden losses of power due to extreme weather, sea-level rise, pandemics, cyberattacks etc. can overwhelm normal reliability provisions.

When this happens, there are direct costs to the health of the power system, its customers, and society at large. These costs include property damage, loss of business, and loss of life, often exceeding billions of dollars.[21] Resilient generators, like hydropower, reduce the severity of this damage and actively accelerate recovery time. Resilience, then, can be measured as a function of time and intensity throughout the course of an emergency event.[22] To address the rising threat of unexpected grid contingencies driven by factors like climate change, wholesale markets and operators must consider resilience as well as reliability when procuring resources and services.



PNNL: Hydropower's Contributions to Grid Resilience (2021)

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[17] Argonne National Laboratory, Pumped Storage Hydropower: Benefits for Grid Reliability and Integration of Variable Renewable Energy (2014), Table 5

[18] U.S. Department of Energy, Hydropower Markets Report (2023), p.17

[19] National Academies of Sciences, Engineering, and Medicine, Enhancing the resilience of the nation's electricity system (2017), National Academies Press, Washington, D.C.

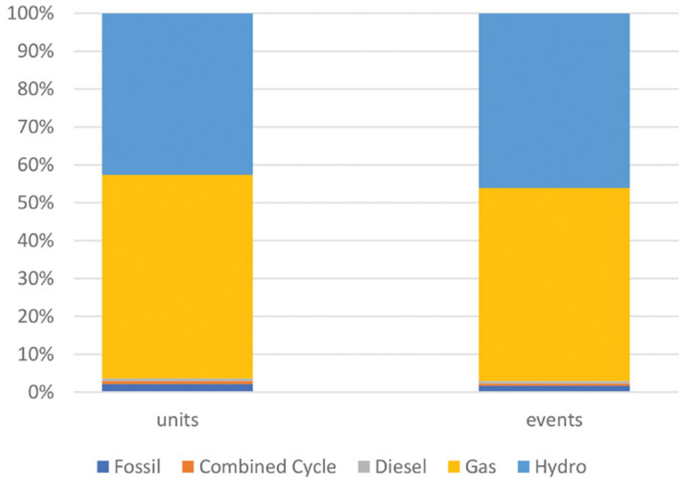
[20] U.S. Department of Energy, Energy Resilience

[21] NOAA National Centers for Environmental Information, U.S. Billion-Dollar Weather and Climate Disasters (2024) https://www.ncei.noaa.gov/access/billions

[22] Pacific Northwest National Laboratory, Hydropower's Contributions to Grid Resilience (2021), p. vi

Hydropower is a pillar of bulk electric system resilience, minimizing the adverse effects of grid disturbances and accelerating a return to normal operating conditions. Many attributes of hydro that contribute to reliability are also useful for resilience, assisting at various temporal stages along the resilience curve. Reservoir operating reserves allow for the storage of energy for unforeseen challenges before they even occur, without concern about future fuel delivery like natural gas generators. As emergencies begin to unfold, the rotational inertia inherent in spinning mass turbines help buffer the sudden variations in frequency due to loss of generation. Dispatchable, flexible hydropower then allows operators to catalyze a fast recovery, ramping up the generation of power and deploying it through the transmission system. All of these capabilities help soften the blow and, if possible, prevent major system damage. However, during extreme grid events, conditions that exceed standard reliability planning and overwhelm early-stage resilience can sometimes result in total blackouts. When this happens, a hydropower capability known as black start is key to restoring the full functionality of the bulk electric system.

Black start refers to the ability to restart a power plant without relying on the external electric power grid.[23] Although it represents less than 6.2% of U.S. electricity generation capacity, hydro is responsible for approximately 40% of black start resources.[24] Reservoir hydropower and pumped storage are uniquely positioned to provide black start because water is a simple, easily accessible source of reserves. Unlike with fossil fuel combustion plants, there is no need to prepare fuel, provide cooling, or reach a certain thermal threshold before you can generate electricity. This allows for hydropower generators to restart quickly with only a small amount of auxiliary power, such as the small diesel generators often already present on site to manage spillway gates.[25] As a result, hydropower can re-energize in the middle of a total blackout, creating a lifeline of resilience for the grid.[26] Transmission operators can then configure a "cranking path" to send that electricity out to non-black start generators, thereby starting the recovery process. Other attributes of hydropower and pumped storage like rapid ramping times and direct transmission interconnection accelerate the black start process, quickly generating energy and distributing it through the cranking paths. Furthermore, the size and significant inertia of these facilities also give hydro a high tolerance to swings in system frequency, a big challenge when bootstrapping a dysfunctional grid.[27] No other utility-scale renewable energy resource is capable of black start at all, let alone the rapid black start needed to reduce downtime and maximize grid resilience. Without hydropower, fossil fuel resources are the sole contributors of black start and cannot be replaced without jeopardizing resilience. With hydro, we can continue to grow the variable renewable fleet and retire fossil fuels, knowing our power system remains secure.



ORNL: Hydropower Plants as Black Start Resources (2019)

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[23] Oak Ridge National Laboratory, Hydropower Plants as Black Start Resources (2019), p. 1.1

[24] Pacific Northwest National Laboratory, Hydropower's Contributions to Grid Resilience (2021) p. 1.2

[25] Oak Ridge National Laboratory, Hydropower Plants as Black Start Resources (2019), p. iii-v

[26] Idaho National Laboratory, Enhancing Local Grid Resilience with Small Hydropower Hybrids (2022), Table 1-1

[27] Oak Ridge National Laboratory, Hydropower Plants as Black Start Resources (2019), p. iii-v

HYDRO AND THE CLEAN ENERGY TRANSITION

It is clear that variable renewable adoption is accelerating at an unprecedented rate, with 33.8GW of new clean power capacity commissioned in 2023 alone.[28] It is also apparent that this growth has presented challenges for grid operators. Integrating high levels of intermittent resources into the bulk electric system increases uncertainty in load forecasting, impacting short- and long-term capacity planning.

In the short term, sudden changes in weather can upset the predictions of a day-ahead energy market, leaving load unserved. Climate change has made this weather more volatile which, in turn, has made variable renewable output harder to forecast. In the long term, increased solar penetration is completely changing the demand curve for electricity. As more solar comes online, electricity will become more abundant during mid-day. This pushes peak load into the evening, creating a steep ramp-up in in demand for dispatchable resources at that time. This phenomenon, known as the "duck curve," is reshaping capacity accreditation criteria across ISOs/RTOs. In regions with more solar, it is no longer useful to simply aggregate nameplate capacity as a measurement of resource adequacy. New concepts like Effective Load Carrying Capability (ELCC), for instance, have been introduced to reflect the diminishing marginal benefits of solar buildout past a certain time of day.[29] Thankfully, hydropower can fill the gaps created by solar and fortify long-term capacity planning. By providing load-following, quick ramping energy to the grid just as the sun sets, conventional and pumped storage hydropower create a complimentary balance to any renewable portfolio without increasing emissions.

> **In fact, the current fleet of dispatchable hydropower can supply enough operating reserves for the integration of 137GW of new VERs that otherwise would have been supported by fossil fuels.[30]**

Moreover, as climate change makes weather more volatile, the baseload generation of hydropower is actually expected to increase.[31] Thus, to ensure adequate long-term capacity planning in the face of climate change while amplifying the expansion of variable renewables, the grid needs hydropower.
Furthermore, as asynchronous resources like wind and solar continue to serve a greater amount of total load, and synchronous fossil generators retire, the demand for ancillary services like frequency regulation and voltage support will only grow. While there have been developments in inverter-based resources (IBR) to provide these services, they are rife with known performance issues.[32] IBRs lack the inherent resilience of inertia driven motors because they are computerized and require power to receive and read commands. This makes them unreachable during blackouts and brownouts, as well as prone to miscommunication. Synchronous generators, on the other hand, are interconnected via AC transmission lines by the physics of rotational speed and do not require external power to respond to change. Any generator on the synchronized transmission system can monitor and respond to changes in frequency, all in real time. Most existing and planned transmission infrastructure in the U.S. is AC and will remain dependent upon synchronous generation for the foreseeable future. Fortunately, hydropower and pumped storage are mature technologies that already provide the ancillary services needed to stabilize the grid without compromising emissions. As we continue the transition towards carbon-free energy, we are reliant upon hydropower to ensure grid reliability.

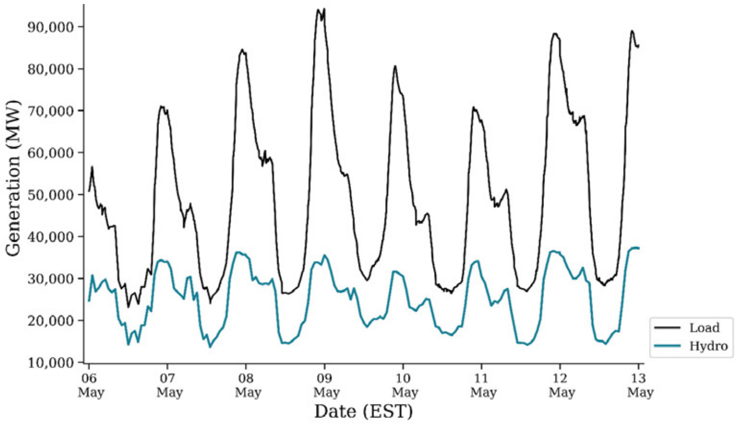

Figure 50 U.S. Western Interconnection hydropower generation and net load during a week with high curtailment

NREL: The North American Renewable Integration Study: A U.S. Perspective[33]

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[28] American Clean Power, Annual Market Report (2023)

[29] Electric Reliability Council of Texas, Effective Load Carrying Capability Study Final Report (2022)

[30] National Renewable Energy Laboratory, The Role of Hydropower Flexibility in Integrating Renewables in a Low-Carbon Grid (2023), p.9

[31] Pacific Northwest National Laboratory, Multi-scale impacts of climate change on hydropower for long-term water-energy planning in the contiguous United States (2024)

[32] The NERC 2023 State of Reliability Overview found that poor solar PV inverter performance during the 2022 Odessa Disturbance led to 1700MW of solar PV generation in the Texas interconnect.

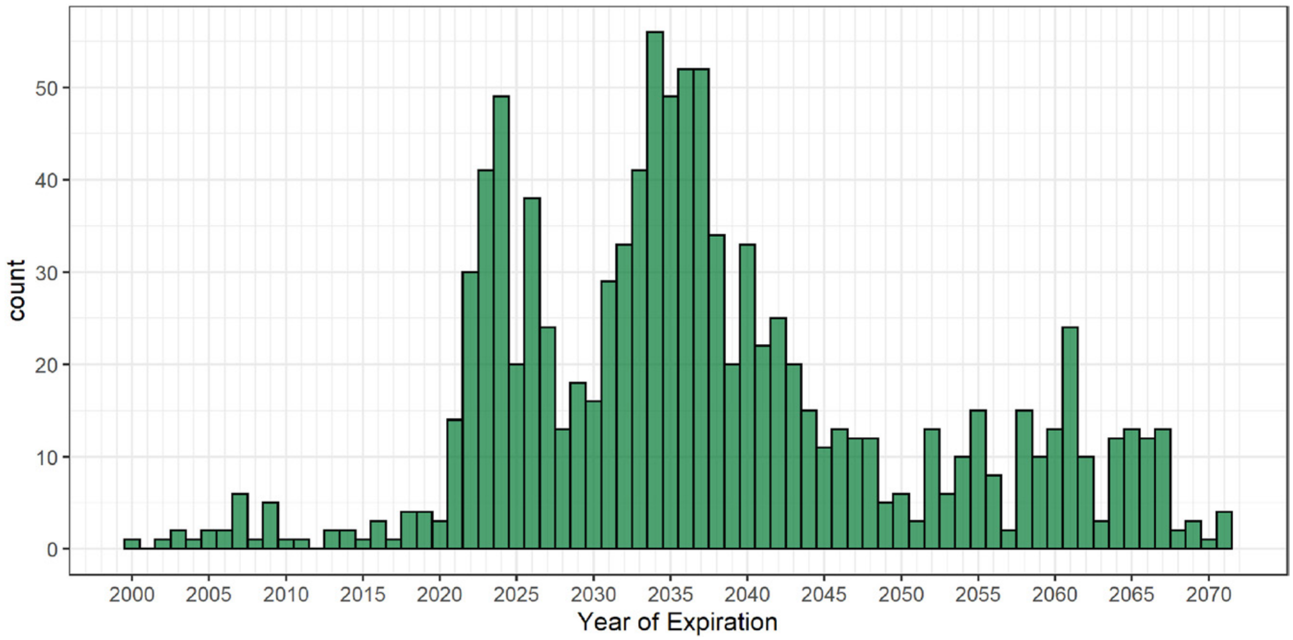
[33] National Renewable Energy, The North American Renewable Integration Study: A U.S. Perspective (2021)

Hydropower at Risk: License Expirations and Other Threats to the Grid

LICENSING AND RELICENSING

There are serious obstacles to the preservation and expansion of hydropower in the United States today. One of the biggest challenges is the licensing and relicensing process. We are currently approaching a wave of hydropower and pumped storage license expirations across the country, with 451 active FERC licenses totaling 15700 MW in capacity set to expire between 2020-2035.[34] Facing license expiration, a third of polled owner/operators have said they are considering license surrender and decommission.[35] In fact, many have already done so, shuttering the operation of 68 facilities with a combined capacity of 322 MW from 2010-2022 alone, citing economic infeasibility and risk of relicensing.[36] This is part of a broader upward trend in license surrenders since 2004 that coincides with the rising wave of expirations, suggesting that, unless something changes, hydropower operators may continue to surrender their licenses when faced with renewal.[37]

The upward trend in surrenders is, in large part, the result of a cumbersome licensing process. Relicensing takes on average seven to ten years to complete and can cost millions of dollars, depending on factors like project size, environmental complexity, and stakeholder negotiations.[39] The Federal Power Act (FPA) requires FERC to balance energy and non-energy values alike when assessing stakeholder needs throughout the licensing process. This widens the scope of analysis for a project and requires additional research and paperwork, like environmental



[38]Estimated capital costs of fish exclusion technologies for hydropower facilities (2024)

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[34] FERC Complete List of Active Licenses Updated 8/13/2024

[35] Kleinschmidt Group, Ear to the River Survey (2022)

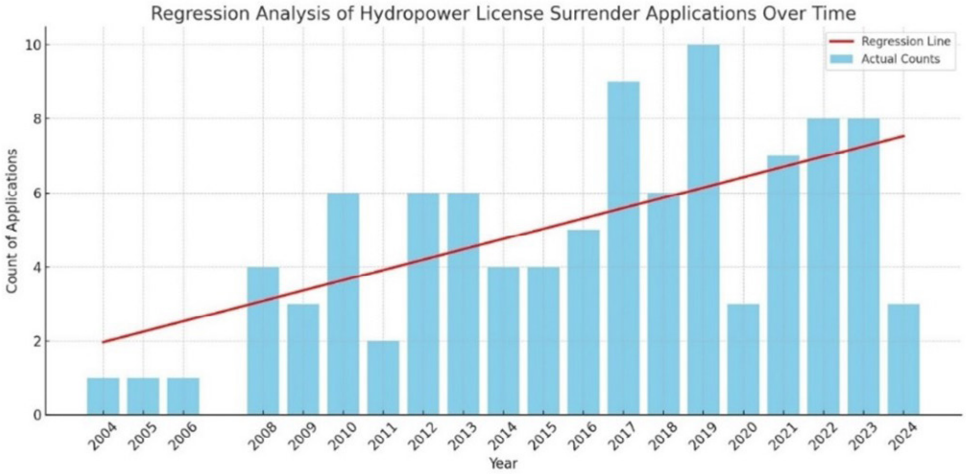
[36] U.S. Department of Energy, U.S. Hydropower Market Report (2023), Section 1.5

[37] Oak Ridge National Laboratory, Hydropower Relicensing and License Surrender dataset (2024). Regression analysis using Python: (P-value= 0.0027, Standard Error = 2.04, R2= 0.40)

[38] Paul G. Matson, et al., Estimated capital costs of fish exclusion technologies for hydropower facilities, Journal of Environmental Management (2024), Volume 351

[39] National Renewable Energy Laboratory, Oak Ridge National Laboratory, An Examination of the Hydropower Licensing and Federal Authorization Process (2021), Executive Summary

assessments and impact statements, well before developers can break ground. Progress at this stage is partially dependent upon agency bandwidth, which can bottleneck the development process if the government agency is understaffed or has new personnel. Furthermore, statutory requirements from laws like the Endangered Species Act, National Environmental Policy Act, and Clean Water Act exacerbate these challenges by introducing additional actors like state governments and municipalities into the decision-making process. Coordination between local, state, and federal agencies across several policy areas is complex, and ultimately, elongates the licensing/relicensing process. Faced with the uncertainty of these convoluted regulations, many operators of existing facilities are simply hanging up the towel after their 50-year license expires. Without license reform, the threat of hydropower stagnation and subsequent mass retirements will persist, deepening the precariousness of our transitioning grid. In addition to harming the existing fleet, protracted licensing proceedings also discourage investment into new hydropower and pumped storage. For developers, the economic uncertainty of licensing costs creates major risks. This burden is especially heavy on smaller hydropower developers who do not have the economies of scale to absorb these costs. For investors, the potential for regulatory delays and setbacks obfuscates the timeline for a return-on-investment. In fact, 91% of private equity investors, banks, and venture capitalists cite extended licensing timelines as a reason to avoid investment in early-stage projects.[40] While some developers can mitigate these risks by presenting diverse project portfolios, small hydropower projects are often done one at a time and, consequentially, cannot reliably access private equity. These limitations stifle the growth of hydro and the expansion of its benefits to the grid.



ORNL Hydropower Relicensing and License Surrender (2024) + Regression Analysis

Fortunately, solutions have been proposed to modernize the hydropower licensing process. There are currently two bipartisan license reform bills pending in the House and Senate designed to improve interagency coordination and establish firm deadlines on major milestones in the licensing process. Both the Community and Hydropower Improvement Act (S. 1521) and the Hydropower Clean Energy Future Act (H.B. 4045) are supported by a wide coalition of stakeholders including industry, environmental NGOs, unions, and Tribes. These bills would greatly improve the current regulatory landscape.

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[40] National Renewable Energy Laboratory, Hydropower Investment and Public-Private Ecosystem Assessment (2024), p.29, Figure 18

MARKET COMPENSATION

Hydropower is not always compensated for the essential grid stability it provides.[41] While many ISOs/RTOs have modified their resource adequacy constructs to recognize the value of reliability, less has been done to reimburse resilience. Flexibility characteristics, like spinning mass reserves and quick ramping, are receiving new compensation mechanisms like uncertainty pricing, enhanced co-optimized ancillary and energy markets, and fast-start pricing in markets across North America.[42] This has been a direct response to the reliability challenges caused by VER expansion and load growth in those regions. However, essential features of hydropower resilience like frequency response, voltage control, inertia, and black-start are still largely compensated out-of-market or not at all. These capabilities prevent cascading blackouts and, if necessary, can reboot the grid from scratch. Yet, in many cases, compensation for these vital resilience measures is limited to uplift payments that do compensate suppliers for their full costs, including opportunity costs and maintenance costs.

For instance, hydro operators may be called upon to cap real power generation in order to provide reactive power for voltage support. Deviations from standard dispatch cause operators to lose money and can put extensive wear on equipment. They are also more common than often realized. In ISO-NE, hydro units regularly earn 50% or more of their total annual ancillary service revenues from uplift.[43] The lack of market products for these services distorts market signals and elevates uncertainty for investors and developers seeking to turn a profit through the sale of electricity. It also further discourages operators of existing facilities from taking on relicensing costs. To maximize hydropower's potential, markets must be designed to value both reliability and resilience.

TAX PARITY WITH OTHER RENEWABLES

The Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA) have transformed the energy landscape. These laws include several provisions that encourage investment in new hydropower and refurbishment of the existing fleet. First, the BIL, passed in November 2021, provides over $750M in incentive payments to owner/operators for electricity produced, for capital improvements to efficiency, environmental improvements, and grid resiliency measures. As of Spring 2024, over $100M has already been distributed, with awardees ranging from large scale power producers and utilities to small hydro co-ops and family-owned plants. Similarly, in August 2022, the IRA was signed into law, creating several new clean energy tax credits designed to encourage private investment in renewable generation. The production tax credit (PTC) provides up to $27.50 per megawatt-hour for projects beginning construction before 2025, while the investment tax credit (ITC) provides up to 50% of the project cost for facilities beginning construction before 2025.[44] These credits are explicitly made available to hydropower and pumped storage, as well as other renewables like wind and solar.

Although these laws create extraordinary opportunity, it is not extended equally to all carbon-free resources. The unique attributes of existing hydro infrastructure allow it to serve many purposes beyond electricity generation, including flood control, irrigation, water supply, and recreation. Balancing these various responsibilities requires continuous upkeep to ensure dam safety, environmental stewardship, and reliable grid interconnection. However, these needs are not reflected in the tax code, which only provides ITCs for relatively new projects. While production tax credits help incentivize the maintenance of existing electricity generators, they are designed with only megawatt-hour output in mind and cannot alone support the wide-ranging demands of hydro's job description. This discrepancy gives other renewables that are not as intertwined with multipurpose infrastructure a tax advantage, creating an uneven investment landscape that could accelerate the existing trend in hydropower retirements. To increase the economic viability of existing facilities, hydropower must achieve tax parity with other renewables.

To address this threat to reliability and resilience, two bipartisan pieces of legislation have been introduced in the House and Senate proposing a 30% ITC for asset owners to make dam safety upgrades and environmental improvements at their facilities. These bills, both scored at less than $1B by the Congressional Budget Office, will support activities like adding or improving fish passage, maintaining, or improving water quality, upgrading, or replacing floodgates and spillways, and maintaining river sediments. In doing so, the Maintaining and Enhancing Hydroelectricity and River Restoration Act of 2023 (H.B. 6653 and S. 2994) puts all carbon-free energy on equal footing, allowing the value of hydropower to reflect its unique contributions to the grid.

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[41] The Brattle Group, Leveraging Flexible Hydro in Wholesale Markets (2021)

[42] Id. at p. 12

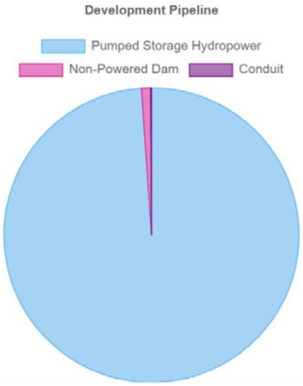
[43] Id. at p.18

[44] U.S. Department of Energy, Inflation Reduction Act Tax Credit Opportunities for Hydropower and Marine Energy (2022)

Hydropower Potential: Expanding Grid Stability

PUMPED STORAGE

While water power may be the oldest form of renewable energy in the United States, the potential for growth remains strong. There are currently 86 GW of capacity in the development pipeline, a majority of which is attributable to pumped storage.[45] In fact, the growth in pumped storage development has outpaced DOE projections, suggesting a strong market appetite despite large hurdles in the regulatory space.[46] This is because, in terms of large, utility-scale energy storage, pumped storage is remarkably cost effective. For a 1000 MW, 10-100-hour system, pumped hydro outperforms all forms of chemical battery storage in terms of $/kWh.[47] This allows for a quicker return on investment once the asset is up and running. Beyond cost, pumped storage is also a mature technology with an existing market, unlike proposed alternatives like hydrogen and compressed air. The persistent demand for more long-duration energy storage reflects the needs of a strained grid system, where dispatchable reserves are an increasingly valuable commodity in the wholesale marketplace. So long as the aforementioned trends in load and generation continue, pumped storage will remain a viable opportunity for investors and developers seeking to serve customers.



ORNL Development Pipeline Dataset (2024)

In addition to being proven, pumped storage is simultaneously innovative. Projects currently under construction like Lewis Ridge in Bell County, Kentucky are demonstrating how pumped storage can provide new solutions for our transitioning grid. By transforming former coal mining land into 287 MW of clean energy storage for thousands of customers across 16 states, this Rye Development project shows the promise of pumped storage for energy communities transitioning away from fossil fuels.[48] Many new pumped storage projects are also closed loop and are disconnected from natural waterways, reducing the duration and scope of environmental impact.[49] With 56 other projects across 20 states still in the pipeline, the potential to expand these benefits remains.

NON-POWERED DAMS

Non-powered dams are another source of hydropower expansion. Although there are over 90,000 dams in the United States, less than 3% generate electricity, with most of these dams serving multiple use cases.[50] The untapped power potential of these dams is anticipated to be upwards of 12GW, 8GW of which is concentrated into just 100 dams.[51] Although this is not a massive amount of power, the impactful role small hydropower can play in localized reliability and resilience, especially for rural communities, is often underestimated.[52] As innovation around distributed resources and microgrids accelerates, the potential for non-powered dams to become providers of black start and other restoration services can transform a community. Adding power generation to existing dams also has little negative environmental impact, given the prior existence of an impounded reservoir.[53] In fact, it can breathe new life into dilapidating infrastructure that may otherwise present safety and environmental challenges. Yet, retrofits to these nonpowered dams make up just 738.7 MW of the 86 GW of projects in the current development pipeline. In fact, of the top 100 dams with the highest potential capacity, less than 15% of them have actually been developed.[54] Many of these dams are

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[45] Oak Ridge National Laboratory, Hydropower Development Pipeline Dataset (2024)
[46] U.S. Department of Energy, Hydropower Vision Report (2016), Executive Summary
[47] U.S. Department of Energy, Grid Energy Storage Technology Cost and Performance Assessment (2022), p. vii
[48] Office of Clean Energy Demonstrations, Program on Current and Former Mine Land Selections for Award Negotiations, (2024)
[49] Pacific Northwest National Laboratory, A Comparison of the Environmental Effects of Open-Loop and Closed-Loop Pumped Storage Hydropower (2020), p.
[50] U.S. Department of Energy, Hydropower Market Report (2023) Section 2.1
[51] Oak Ridge National Laboratory, An Assessment of Energy Potential at Non-Powered Dams in the United States (2012)
[52] Idaho National Laboratory, Enhancing Local Grid Resilience with Small Hydropower Hybrids (2022), Key Takeaways
[53] Environmental Protection Agency, Inventory of Greenhouse Gases and Sinks (2023), Flooded Lands Remaining Flooded

owned by the U.S. Army Corp of Engineers, whose commitment to the public interest and decentralized office structure often complicate development. But, with 60 nonpowered dam retrofits across 19 states still in the pipeline, conventional hydro is poised to expand.

MARINE ENERGY

Finally, marine energy is an emerging technology sector that represents an entirely new route for the expansion of water power. Generating clean power from waves, tides, currents, and other water-based resources, marine energy is rapidly maturing, with a number of systems entering commercialization in both U.S. and international markets. Investment is motivated, in part, by the large power potential of the ocean. The total marine energy technical resource in the fifty states is estimated to be 2,300 terawatt hours per year (TWh/yr.), equivalent to roughly 56% of 2019 U.S. electricity generation.[55] Furthermore, unique attributes of marine energy like siting proximity to coastal load centers, rural and remote deployment, and predictability of generation provide clear and competitive benefits to the emerging, off-grid "Blue Economy." This term describes a variety of markets that would benefit from offshore power production including research academia, national defense, rural, remote, and underserved communities. Eventually, marine energy could achieve utility-scale grid power production to sell in wholesale markets, similar to offshore wind. As with other technologies, support from the U.S. Federal Government for critical technology RDD&D, along with aligning regulatory processes to development stage and implementation of appropriate incentives, are key to igniting commercialization of the domestic marine energy sector.

Conclusion

As the United States continues its transition toward a more sustainable energy landscape, hydropower remains an underappreciated cornerstone capable of reinforcing grid reliability and resilience, as well as facilitating the integration of variable renewable energy resources. Despite its proven flexibility, dispatchability, and essential role in both base and peak load scenarios, hydropower faces significant challenges that jeopardize its potential to support a decarbonized energy future. The burdensome licensing and relicensing processes, lack of equitable market compensation, and insufficient tax incentives have stymied both the preservation and expansion of this vital resource. To harness the full potential of hydropower, policymakers and industry stakeholders must address these barriers.

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[54] Oak Ridge National Laboratory Non-Powered Dam Potential (2012) dataset and Oak Ridge National Laboratory Hydropower Development Pipeline (2024) dataset.

[55] National Renewable Energy Laboratory, Marine Energy in the United States: An Overview of Opportunities (2021)