Leveraging Flexible Hydro in Wholesale Markets

PRINCIPLES FOR MAXIMIZING HYDRO'S VALUE

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Executive Summary

Hydropower plays an important role in the clean energy landscape today, providing large amounts of renewable primary energy and operational flexibility. The 100+ GW of existing hydro provides approximately 7% of the nation's total electric generation and 39% of renewable generation, while providing operational flexibility that is invaluable to electric systems.

The need for clean, flexible generation sources will continue to grow in coming decades as the power sector transforms. To achieve 90% carbon-free electricity, the level of decarbonization needed to stabilize the global climate, the United States may need to add more than 1,000 GW of new renewable resources. Clean and flexible sources of power such as hydro will be needed to integrate these resources and continue to keep the system reliable while meeting decarbonisation objectives.

Further integration of hydro into RTO markets will become critical as hydro's "job description" shifts to provide more flexibility to integrate growing amounts of wind and solar generation. Although hydro operators and RTOs have made significant progress integrating hydro into markets, NHA members have indicated through our surveys and interviews that there is still work to be done if hydro is to competitively and efficiently procure the services needed to support the grid of the future. As the grid continues to evolve, RTO market rules will continue to develop to ensure the fair and cost-effective provision of these essential services.

In this whitepaper we explore how RTOs and hydro operators manage hydro assets in markets today, and provide examples of the experiences of NHA members. We then outline four principles for maximizing the value hydro and other assets provide within wholesale markets, with the goal of informing current and future RTO market rule development.

Principle 1: New energy and ancillary service (E&AS) market products may be needed as the fleet transforms and faces new flexibility challenges. RTOs are proactively preparing for future flexibility challenges through a series of initiatives to enhance existing market products and establish new products. Looking forward, evolution of the generation fleet and changing demand characteristics are likely to drive continued changes to wholesale market design, and continued market enhancements will be needed to properly utilize and compensate flexible resource such as hydro.

Principle 2: RTOs should allow hydro a range of energy market participation options. RTOs should allow hydro to participate in wholesale markets in a variety of ways, so hydro operators can provide the greatest value to the system while respecting the unique characteristics of their assets. Today, not all RTOs yet offer a full set of participation options, which may cause hydro to operate in ways that do not maximize their value. In particular, incomplete accounting of the operating and opportunity costs of flexible hydro assets when evaluating their offers may result in these resources being used inefficiently.

Principle 3: Hydro and other flexible resources should be properly compensated for any out of market dispatches. Through our interview and survey process, hydro operators noted that system operators frequently use their assets outside of standard day-ahead and real-time market products to help maintain reliability and balance the system. These actions can result in hydro and other flexible assets not being fully compensated for the services they provide, and can distort competitive market outcomes. More complete day-ahead and real-time markets can reduce the need for these out-of-market instructions. When these are unavoidable, uplift payments should be structured to fully compensate suppliers for their costs, including lost opportunity costs.

Principle 4: All assets, including hydro, should be accredited fairly for the resource adequacy value they provide. Hydro is a reliable resource with high resource adequacy value, as hydro can reliably generate when needed, effectively supporting the ability of systems to meet their mandated reliability requirements. System operators have developed a series of techniques to quantify hydro's resource adequacy value. A larger challenge is accurate accreditation of renewable and short-duration storage resources as the market share of these resources increases. Accurate accreditation is essential, both for reliability and economic efficiency. Over-crediting some resources would tend to reduce reliability and set capacity market prices artificially low for other resources. Under-crediting resources would tend to cause over-procurement and undue costs to customers. Over-crediting some resources relative to others would result in an inefficient resource mix and unfair compensation.

Continued improvements in RTO market design, informed by these four principles, will ensure that wholesale markets continue to provide power reliably and cost-effectively as the grid decarbonizes in coming years. These improvements will allow system operators to maximize the value they receive from flexible resources such as hydro, which are critical to enabling our decarbonized future.

I. Introduction and Purpose

Hydro is a flexible, zero-emission, and reliable and resilient generation source—all attributes that will become increasingly valuable as the system transforms to clean energy. The National Hydropower Association (NHA) commissioned this whitepaper to explore how hydro assets participate in RTO wholesale markets today, and how RTO market rules can encourage hydro to operate and invest in ways that maximize their value to the system. To that end, NHA and Brattle conducted interviews and surveys with NHA members regarding their experiences participating in and adjacent to RTO markets. Through their responses, NHA members expressed concerns that their hydro assets are increasingly being relied upon as a source of clean, flexible supply, but are not being adequately compensated for the value they provide or and/or the costs they are incurring.

This whitepaper:

- Reviews the valuable role of hydro today as the largest flexible renewable resource, and the increasingly important role hydro will play in the future;
- Describes the unique capabilities and constraints of hydro assets, and how wholesale markets leverage or accommodate these attributes;
- Presents examples provided by NHA members of their experience participating in wholesale markets across the U.S.; and
- Offers four RTO market design principles to incent value-maximizing hydro investment and operations.

This whitepaper aims to inform policymakers, RTO staffs, State regulators, FERC Commissioners and Staff, and hydro asset owners, and to motivate continued enhancements to wholesale market design to promote fair competition and compensation for all resources, including hydro.

This whitepaper does not address mechanisms to compensate hydro resources for their clean energy attributes, such as carbon pricing or eligibility for REC payments under clean energy mandates. While those are out of scope here, they are important context as part of a larger need to fully recognize all sources of value in order to signal efficient operational and investment decisions. Not doing so risks premature retirement of valuable resources, including existing hydro resources.

II. Hydro's Role in the Clean Energy Transition

Hydropower plays an important role in the clean energy landscape today, providing large amounts of renewable primary energy and operational flexibility. The need for these attributes will grow as the power sector continues to transform toward clean energy in the coming decades. To achieve 90% carbon-free electricity, the level of decarbonization needed to stabilize the global climate, the United States may need to add more than 1,000 GW of new renewable resources.[1,2] As NERC notes in its 2020 Long Term Reliability Assessment, the addition of these resources (in particular, wind and solar) will require complementary flexibility to ensure a reliable system.[3] This point is further emphasized by recent major RTO planning initiatives, including NYISO's "Grid in Transition" project and MISO's "Renewable Integration Impact Assessment."[4] While some of this flexibility need will be filled by emerging technologies such as battery storage, much of it will be met by utilizing existing energy resources in more flexible ways.[5]

As a flexible and renewable resource, hydro can both continue to provide zero-carbon energy and help integrate other intermittent renewables such as wind and solar. In order to fully unlock the value of hydro, market rules must incent and reward hydro for the flexibility value it provides while also accommodating its unique attributes.

Types of hydro facilities

Hydropower refers to electricity generation from water flowing through a turbine. Unlike many other types of generation, however, the specifics attributes are unique to each plant based on its hydrological circumstances and configuration. Hydro facilities can be divided into four general categories:

Reservoir hydro, the largest source of hydro in the United States, refers to hydro assets with dams and large reservoirs. Because of their reservoirs, these assets are dispatchable, meaning they can adjust

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1 On a nameplate capacity basis, this is on the order of ten times currently installed wind and solar capacity, or the entirety of generation capacity across all resource types.

2 See: "2035 The Report," University of California Berkeley Goldman School of Public Policy, June 2020, https://www.2035report.com/; "The Value of Inter-Regional Coordination and Transmission in Decarbonizing the US Electricity System," Brown & Butterud, Joule *5*, 1-20 January 20, 2021, https://doi.org/10.1016/j.joule.2020.11.013; "Net-Zero America: Potential Pathways, Infrastructure, and Impacts, Interim Report," E. Larson et al., Princeton University, December 15, 2020, https://acee.princeton.edu/rapidswitch/projects/net-zero-america-project/

3 NERC, "2020 Long Term Reliability Assessments," December 2020, pg 7.

4 See NYISO, "Reliability and Market Considerations for a Grid in Transition," 2019.

MISO Renewable Integration Impact Assessment documents available at: https://www.misoenergy.org/planning/policy-studies/Renewable-integration-impact-assessment/#nt=%2Friiatype%3AReport&t=10&p=0&s=Updated&sd=desc.

5 The deep decarbonization models referenced in Footnote 2 also include up to hundreds of GWs of battery storage.

their water flow and power generation in response to electricity system needs within environmental, water use and other constraints. Many reservoir hydro plants have a high degree of flexibility.

Run-of-river hydro utilizes river flow to provide generation subject to hydrological conditions. Run-of-river facilities have limited impoundments and, as such, depend upon river flow for generation. While there is seasonal variation in river flows, on a shorter term (e.g., days to weeks) their output is forecastable with a high degree of certainty. Run-of-river hydro facilities tend to be able to shift some generation from one hour to the next in response to electricity system needs due to their limited impoundments. Together, reservoir and run-of-river are sometimes referred to as "conventional hydro."

Pumped storage hydro refers to assets that use the gravitational potential energy of water to store electricity. Pumped storage consists of two connected reservoirs at different elevations. To store energy, the facility consumes electricity to pump water from the lower reservoir to the upper reservoir. To generate power, water is released from the upper reservoir and through spinning turbines to generate electricity on its path back to the lower reservoir. Like a battery, pumped storage does not generate electricity and instead allows energy to be stored and discharged when most valuable.[6] However, one important advantage of pumped storage over batteries is their ability to generate (or pump) at full capacity for significantly longer durations. Typical pumped storage facilities are capable of full loading for at least 6-10 consecutive hours and sometimes longer, while recently installed large-scale electrochemical batteries had average durations of 3.5 hours in California, and only 45 minutes in PJM.[7,8]

Wave and tidal hydro generates power through the natural motion of waves and tides. Given the very small amount of wave and tidal hydro deployed, we do not focus on this technology in this white paper.

More so than many other generation technologies, each hydro facility is unique. While these four categories are useful for distinguishing the various operational modes of hydro, real-world assets may exhibit characteristics of more than one category. For instance, the Niagara Power Project at Niagara Falls "includes two intake structures, two underground conduits and associated pump stations, a forebay, the Lewiston Reservoir, the Lewiston Pump Generating Plant, the Robert Moses Niagara Power Plant, and the Niagara Switchyard." Together the components of the Niagara Power Project provide 240 MW of pumping capacity and up to 2,675 MW of run-of-river/reservoir hydro generation.[9]

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6 Although, as with an electrochemical battery, there is an efficiency loss on the electrical energy.

7 "Pumped Storage Report," National Hydropower Association, 2018, https://www.hydro.org/wp-content/uploads/2018/04/2018-NHA-Pumped-Storage-Report.pdf.

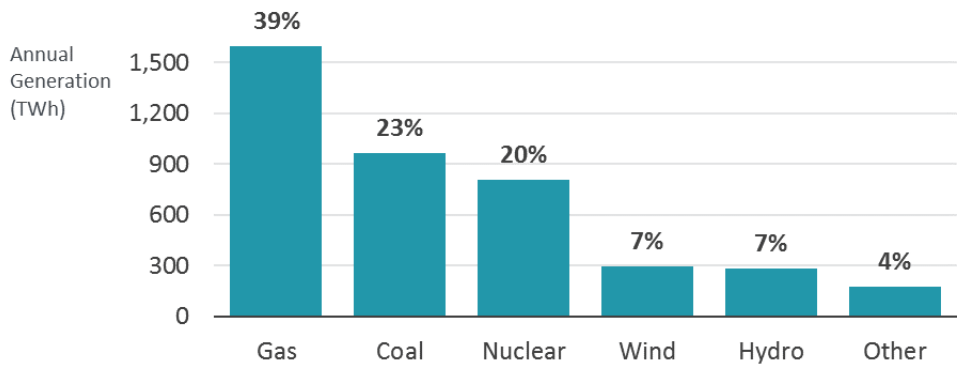
8 "Battery Storage in the United States: An Update on Market Trends," U.S. Department of Energy, July 2020, https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf.

9 Pumping capacity from SNL. "Niagra Power Project: Clean Energy for NY," New York State, https://www.nypa.gov/power/generation/niagara-power-project.

The clean energy and flexibility value of hydropower

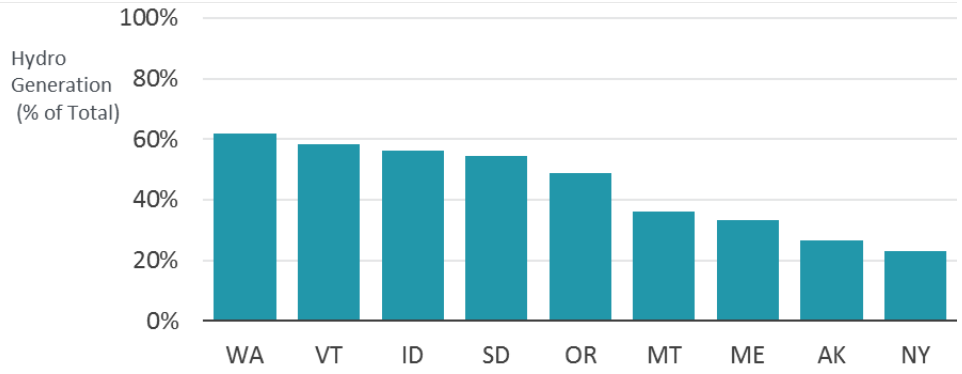
In 2019, 80 GW of conventional hydro and 22 GW of pumped storage were operational throughout the United States, generating approximately 300 TWh of electricity or 7% of the nation's total.[10] These 300 TWh made up 39% of the nation's renewable generation, and 19% of clean power.[11] As shown in Figure 1, hydro is currently the nation's second largest source of renewable generation, having been narrowly overtaken by wind in recent years. In some regions, hydro is the primary source of electricity generation: as shown in Figure 2, eight states derived at least 20% of their generation from hydro in 2019, with Washington State relying on hydro for 62% of its generation.

FIGURE 1: NATIONAL GENERATION BY RESOURCE TYPE (2019)



Source: Calculated from EIA Form 923 data.

FIGURE 2: HYDRO GENERATION BY STATE (% TOTAL, 2019)



Source: Calculated from EIA Form 923 data.

[10] Calculated from EIA Form 860 and Form 923 data.

[11] Calculated from EIA Form 923 data. Renewables include energy from conventional hydroelectric generation, pumped storage, wind, solar, wood and other biomass, and geothermal sources. Clean power includes energy from conventional hydroelectric generation, pumped storage, wind, solar, nuclear, and geothermal sources.

The 100+ GW of hydro installed today also provides a major source of operational flexibility that is invaluable to electric systems. At the end of 2019, 22 GW of pumped storage was operational across the United States (compared to about 1 GW of shorter-duration battery storage, although installations of that technology are growing rapidly).[12] Beyond pumped storage, the Department of Energy estimates that approximately 70% of the 80 GW of conventional hydro operates flexibly today.[13] These units provide flexibility benefits that many other resource types do not. Compared to steam turbines, flexible hydro resources can be started, stopped, and ramped much more quickly and economically.[14] Maximum ramp rates observed across RTOs are about twice as high as for hydro as gas-fired steam units, and large conventional and pumped storage hydro units regularly start and stop hundreds of times per year.[15]

Given their flexibility, hydro resources can provide a variety of valuable services to the grid. Figure 3 illustrates the grid services hydro and other generation technologies are capable of providing. RTOs have developed wholesale market products to procure each of these services.

Energy

- **Day-ahead energy** is generation scheduled in advance to meet day-ahead demand purchases. Run-of-river provides stable clean generation subject to hydrological conditions, and storage allows hydro to shift generation to meet seasonal and diurnal variations in demand. For example, reservoirs in the Northwest allow run-off from spring snowmelt to be stored until summer, when demand for electricity is typically greatest.[16] Flexible hydro such as pumped storage tends to pump during low-priced hours and generate during high-priced hours. In systems with large amounts of intermittent renewable generation, such as CAISO, pumped hydro is now sometimes scheduled to pump during the day to store excess solar generation.[17]
- **Real-time energy** is generation dispatched every five minutes to meet real-time changes in net demand. Real-time energy helps balance the system against changes in load or renewable generation that are not forecasted or purchased in advance, and increments and decrements can only be provided by flexible generators. Flexible hydro with storage and pumped storage hydro are capable of ramping up and down quickly enough to respond to real-time dispatch signals.

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[12] As well as a few hundred MW of other storage technologies including concentrated solar power, flywheels, and compressed air storage. Calculated from EIA Form 860 data.

[13] "Hydropower in the 21st Century." Alejandro Moreno. Director, Water Power Technologies Office. EEI Webinar on December 15, 2020.

[14] USBR p. 2.

[15] 2017 DOE Hydropower Market Report p. 78, 81.

[16] "Types of Hydroelectric Projects," Foundation for Water & Energy Education, 2020, https://fwee.org/nw-hydro-tours/how-the-northwest-hydro-system-works/types-of-hydroelectric-projects/.

[17] DOE Value of Hydro report p. 13.

Ancillary Services

- **Regulation** refers to supply resources that make very quick, small deviations to their output in order to balance supply and demand and maintain a consistent grid. As a flexible resource, hydro is well-suited to providing this service. In CAISO, hydropower makes up 15% of overall installed capacity, but provides up to 25% of regulation reserves.[18]
- **Spinning and non-spinning reserves** are capacity available on short notice to balance the system in the event of a contingency, such as a generation or transmission outage. In CAISO, hydro provides 60% of spinning reserves.[19]
- **Load-following or ramping reserves** are used to meet rapid changes in net load (i.e., load minus solar and wind generation), especially those that occur unexpectedly. The quick-ramping abilities of hydro with storage and pumped hydro allow these resources to provide this service, and these resources are increasingly relied on to provide these services in places like CAISO, where net load ramps are becoming more extreme due to solar penetration.[20] Not all RTOs yet have a formal product for load-following or ramping reserves, as they have not had to historically, but MISO and CAISO have and SPP is considering it.
- **Reactive power and voltage support** is used to provide voltage control and thus maintain reliable service and support the transfer of power flows on the network.
- **Black start** capability is used to establish frequency following a blackout. Across the US, hydro represents 10% of overall installed capacity, but 40% of units retained for blackstarts.[21]

Resource Adequacy

- **Resource adequacy (aka "capacity" in some markets)** is the ability of a system to ensure sufficient supply to meet demand with all but a *de minimis* loss-of-load expectation. Dispatchability of hydro with storage and the long duration of pumped storage hydro make these resources valuable for resource adequacy.

[18] DOE Value of Hydro report p. 13.

[19] DOE value of Hydro report, p. 10

[20] DOE Hydro in the 21st Century presentation.

[21] DOE value of hydro report, p. 10

FIGURE 3: RESOURCE CAPABILITIES TO PROVIDE VARIOUS GRID SERVICES

Product	Nuclear	Run-of-River Hydro	Pondage Hydro	Pumped Storage	Coal	Combined Cycle	Combustion Turbine	Wind	Solar	Battery Storage	Demand Response	Energy Efficiency
Day-Ahead Energy	✓	✓	✓	✓	✓	✓	O	✓	✓	O	O	O
Real-Time Energy	O	✓	✓	✓	✓	✓	O	✓	✓	O	O	O
Clean Energy	✓	✓	✓	O	X	O	O	✓	✓	O	O	✓
Regulation	X	O	✓	✓	✓	✓	O	O	O	✓	O	X
Spinning Reserves	X	O	✓	✓	✓	✓	✓	X	X	✓	O	X
Non-Spinning Reserves	X	X	✓	✓	X	✓	✓	X	X	✓	O	X
Load-following	O	O	✓	✓	O	✓	✓	O	O	✓	O	X
Reactive Power	✓	✓	✓	✓	✓	✓	✓	O	O	✓	X	X
Black Start	X	✓	✓	✓	O	✓	✓	X	X	O	X	X
Resource Adequacy	✓	✓	✓	✓	✓	✓	✓	O	O	O	✓	✓

Technical Capability to Provide Product

✓ Well-Suited

O Neutral

X Poorly-Suited

Accommodating hydro's constraints in wholesale market design

Along with the benefits listed above, hydro resources also have unique operational constraints that plant operators must respect and wholesale markets must appreciate. Annual and seasonal variations in hydrological cycles affect hydro availability, and water levels limit energy for flexible and pumped hydro. Environmental flow requirements can limit the ability of operators to dispatch some resources flexibly enough to provide certain services. Cascading systems of multiple plants in a series along a river come with their own constraints as releases from an upper dam control not only that plant's production, but also that of downstream run-of-river plants with a time delay. Some systems also have operational constraints associated with age; 70% of the nation's conventional hydro capacity was built over 50 years ago.[22] These mechanical limitations can, for example, cause damage to turbines that are being rapidly ramped or cycled on and off to provide regulation or other flexibility services.

[22] Calculated using EIA Form 860 data.

As hydro's "job description" changes to provide new types of flexibility services and in greater amounts to meet the needs of an evolving grid, these constraints will become more important, as will hydro's limitations. RTO market rules should seek to maximize participation from all resources, including hydro, to competitively and efficiently procure the services needed for the grid of the future under market rules that fairly compensate their services.

III. Four Principles for Maximizing Hydro's Value in Wholesale Markets

Over time, both hydro operators and RTOs have developed approaches to operating hydro assets in ways that provide value to the system. Several RTOs have ongoing or recently-completed initiatives to enhance market designs to support an evolving supply mix, including ERCOT's recent Future Ancillary Services project and subsequent developments to update its ancillary service markets, and NYISO's ongoing Grid in Transition effort to evaluate the potential impact of changing system conditions on energy, ancillary service, and capacity markets. [23,24] Alongside these initiatives, RTOs have explicitly acknowledged the importance of accommodating and valuing hydro. For example, in March of 2017, PJM issued a study on the "Evolving Resource Mix and System Reliability," in which it discussed the unique attributes of hydro and hydro's ability to provide reliability, resilience, and flexibility.[25]

However, NHA members indicated through surveys and interviews that there is still work to be done, as the unique characteristics of hydro resources can cause some frictions that other resources do not face, affecting the value hydro can provide. Additionally, some NHA members expressed concern that their assets are not always fully optimized or compensated for the flexibility services they provide. As the grid continues to evolve, RTO market rules will continue to develop to ensure the fair and cost-effective provision of these essential services. Below we provide four principles for maximizing the value hydro and other assets provide within wholesale markets, with the goal of informing current and future RTO market rule development.

[23] See: "Future Ancillary Services in ERCOT," ERCOT Concept Paper, 2013, http://www.ercot.com/content/news/presentations/2014/ERCOT_AS_Concept_Paper_Version_1.1_as_of_11-01-13_1445_black.pdf.

[24] See: "2019 Reliability and Market Considerations for A Grid in Transition," New York ISO, December 20, 2019, https://www.nyiso.com/documents/20142/2224547/Reliability-and-Market-Considerations-for-a-Grid-in-Transition-20191220%20Final.pdf/61a69b2e-0ca3-f18c-cc39-88a793469d50.

[25] "PJM's Evolving Resource Mix and System Reliability," PJM Interconnection, March 30, 2017, https://www.pjm.com/~/media/library/reports-notices/special-reports/20170330-pjms-evolving-resource-mix-and-system-reliability.ashx.

Principle 1: New energy and ancillary service (E&AS) market products may be needed as the fleet transforms and faces new flexibility challenges

As the power system decarbonizes, it is likely to face increased flexibility challenges. Integrating large amounts of variable and uncertain wind and solar generation will require balancing support from other resources. Electrification initiatives including vehicles and heating demand could exacerbate these problems if not well coordinated with system needs through real-time pricing. While flexibility challenges are growing, dispatchable fossil-fired generators—a traditionally large source of flexibility—are being displaced, often not turning on, and many retiring altogether. These phenomena will create a need for other resources, including hydro, to play an even greater role in ensuring sufficient system flexibility.

Wholesale markets coordinate reliable and economically efficient operation of the electric system. Today, wholesale energy markets efficiently schedule and dispatch supply to meet demand. The wholesale markets also procure various ancillary services to help balance supply and demand in real time and protect against unexpected contingencies. As system conditions change, energy and ancillary service markets can continue to meet system needs at least cost if the necessary products and quantities are properly defined, with participation rules that maximize competition. Under these conditions, accurate price formation will reward providers based on the value of services and the cost of alternatives, and thus encourage efficient operations. In fact, rewarding all services at competitive market prices also incents economically efficient investment as long as environmental externalities are recognized in some way.

RTOs are proactively preparing for future flexibility challenges by enhancing their existing market products and establishing new market products. In recent years, every RTO in North America has undertaken broad flexibility-related initiatives, tuning their market designs to meet their own specific conditions and needs, and taking advantage of technological and analytical advancements. Below are just a subset of the results of these initiatives:

- **CAISO** has recently introduced multiple products for the explicit purpose of compensating flexibility. In 2014, the CPUC developed a flexible resource adequacy product specifically for serving the evening ramp in net load as solar output decreases. This product serves alongside the traditional resource adequacy product. Since 2014, CAISO and the CPUC have continued to review and revise this product to meet system needs. In its current iteration, the product is designed to compensate any resources that can either meet or reduce ramping needs during each month's greatest 3-hour continuous ramping need.[26] Under this construct, hydro that is flexible enough to meet the 3-hour ramping need is distinguished from inflexible providers of resource adequacy, and paid for its greater flexibility value. In 2016, CAISO added a new

[26] California Public Utilities Commission, "2021 Filing Guide for System, Local, and Flexible Resource Adequacy (RA) Compliance Filings." R. 19-11-009. Issued October 2, 2020.

ancillary service for flexible ramping.[27] This product clears in both the 15- and 5-minute real-time markets, requiring that enough upward and downward ramping capability is available to meet 95% of uncertainty in net load over the subsequent 15- or 5-minute interval.[28] This ramping product rewards hydro flexible enough to adjust its output in real-time. Additionally, in 2014 CAISO expanded its geographical footprint through the creation of the Western Energy Imbalance Market (EIM). The EIM allows CAISO to schedule real-time energy trades between balancing authorities across the West, allowing (among other things) more flexibility for imports from the hydro-rich Northwest. New members have entered the EIM each year since its conception, with additional new entrants planned through 2023.[29] As of January 29th 2021, the EIM estimates that it has accrued $1.2 billion of cost savings since its inception.[30]

- **ERCOT** has established numerous mechanisms for ensuring sufficient flexibility in its market. In 2014, ERCOT introduced its Operating Reserve Demand Curve (ORDC), which introduces adders to energy prices to reflect the value of reserves in shortage conditions, and this rewards highly available resources and flexible resources that can maximize output when supply is scarce. ERCOT also explicitly adjusts procurements of ancillary services with growing wind and anticipated solar penetration. For example, ERCOT sets regulation up and down requirements to cover at least 95% of recently observed interval changes in net load (load minus wind and solar generation). ERCOT similarly sets non-spinning reserve procurements based on recently observed net load uncertainty and net-load ramping needs. ERCOT further adjusts these procurements upward to account for wind and solar additions beyond those online during the historical observation period.[31] While hydro is limited in the ERCOT footprint, to the extent it is able to provide reliable energy supply during scarcity periods, it is rewarded via the ORDC. Additionally, increased procurements of ancillary services may provide opportunity to hydro resources that are flexible enough to provide regulation and contingency reserves. ERCOT's experience at the forefront of wind penetration can serve as a model for other RTOs to refine product designs and increase the procurement of traditional ancillary services as renewables make up a greater share of the supply mix.

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27 "Flexible Ramping Product," California ISO, November 2016, http://www.caiso.com/informed/Pages/StakeholderProcesses/CompletedClosedStakeholderInitiatives/FlexibleRampingProduct.aspx.

28 "Flexible Ramping Product, Draft Final Technical Appendix, California ISO, January 25, 2016, http://www.caiso.com/Documents/Addendum-DraftFinalTechnicalAppendix-FlexibleRampingProduct.pdf.

29 "About Western Energy Imbalance Market," Western Energy Imbalance Market, 2021, https://www.westerneim.com/Pages/About/default.aspx.

30 "Benefits," Western Energy Imbalance Market, 2021, https://www.westerneim.com/Pages/About/QuarterlyBenefits.aspx.

31 "2021 ERCOT Methodologies for Determining Minimum Ancillary Service Requirements," ERCOT, December 8, 2020, http://www.ercot.com/content/wcm/key_documents_lists/181586/8_2021_ERCOT_Methodologies_for_Determining_Minimum_Ancillary_Service_Requirements.pdf.

- **MISO** introduced a 10-minute ramping product in 2016, to address unexpected (plus expected) ramping needs over that timeframe.[32] Another important feature of MISO's recent market design with respect to flexibility is the Extended Locational Marginal Price (ELMP), established in 2015 and upgraded to five-minute settlement in 2017. The ELMP allows quick-start units and demand response to set prices in the real-time market, inclusive of both their variable and commitment costs. This reduces *ex-post* uplift payments and leads to more efficient dispatch.[33] Other RTOs have also added mechanisms to provide similar pricing enhancements. As in CAISO, the ramping product provides an important new potential value stream for flexible hydro. Because the ELMP improves market price formation (by internalizing some of the commitment costs), it leads to more efficient dispatch of *all* resources, including hydro.
- **NYISO** is considering a holistic suite of market enhancements under its Grid in Transition effort, including carbon pricing, enhancements to energy and shortage pricing, enhancements to ancillary service products, and enhancements to their resource adequacy construct.[34] In particular, NYISO has proposed changing operating reserve demand curves to be more steep, such that shortage pricing reaches higher levels more quickly, better reflecting the value of flexible and reliable generators. While details of these market design updates are still forthcoming, valuing clean energy and flexibility attributes within market dispatch and settlement promises to benefit resources that can provide these attributes, such as hydro.
- **ISO-NE's** recent Energy-Security Initiatives project sought implementation of new day-ahead ancillary service markets that are co-optimized with ISO-NE's day-ahead energy procurements. Under that design, sellers of day-ahead ancillary services would sell a "call option" for energy settled against the real-time energy price. The establishment of day-ahead ancillary products should serve to more transparently and competitively compensate flexible resources such as hydro for the reliable supply of ancillary services they provide in ISO-NE.[35] Unfortunately, FERC rejected ISO-NE's proposed reforms in October 2020 and the day-ahead operating reserve service provided by hydro remains uncompensated.[36]

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[32] "Ramp Capability Product Development IR048," MISO, June 1, 2016, https://www.misoenergy.org/stakeholder-engagement/issue-tracking/ramp-capability-product-development/.

[33] "MISO Market Design Overview and Evolution," Yonghong Chen, MISO, March 29, 2019. https://curent.utk.edu/files/9315/5371/4823/19_03_29_Power_and_Energy_-_Chen.pdf.

[34] "Ancillary Services Shortage Pricing," Pallavi Jain, New York ISO, April 27, 2020, https://www.nyiso.com/documents/20142/12170360/Ancillary%20Services%20Shortage%20Pricing%20MIWG%2004272020.pdf/9e1730e1-c8d2-33eb-b3c4-8e2e7574534a.

[35] ISO New England, Compliance Filing of Energy Security Improvements Addressing New England's Energy Security Problems; Docket Nos. EL18-182-000. Filed before FERC April 15, 2020. https://www.iso-ne.com/static-assets/documents/2020/04/energy_security_improvements_filing.pdf

[36] U.S. Federal Energy Regulatory Commission. *Order Rejecting Proposed Tariff Revisions.* October 30, 2020. 173 FERC ¶ 61,106, Docket No. ER20-1567-000. https://www.iso-ne.com/static-assets/documents/2020/10/er20-1567-000_order_rejecting_esi_10-30-2020.pdf

- **PJM** recently implemented Reserve Pricing Reforms, which establish sloped demand curves for operating reserves, similar to ERCOT's ORDC.[37] PJM is also in the process of implementing "fast-start pricing" rules that would improve price formation when fast-start resources, or units that can turn on and ramp very quickly, are marginal. Under the proposed rules, these fast-start units could include their amortized commitment costs within their offer.[38] When fast-start units are marginal, they can set LMP at a price that includes commitment and startup costs. Although hydro does not qualify as a "fast-start" unit (all non-pumped storage hydro must self-schedule in PJM), all units, including hydro, may benefit from more accurate energy market pricing.
- **SPP** has just implemented a real-time imbalance market with balancing areas in its Western footprint, the Western Energy Imbalance Service (WEIS), in 2021. Previously SPP had operated a real-time imbalance market from 2007-2014 in its Eastern footprint, before its formation of the Integrated Marketplace we know today.[39] Like CAISO's EIM, SPP's real-time imbalance market offers a new revenue stream to out-of-RTO owners of flexible assets, including hydro. Further, SPP is in advanced stages of developing an uncertainty product.[40] The goal of this new ancillary service is to ensure sufficient flexible resources are available to manage renewable and other forecast uncertainty. As with the ramping products introduced in CAISO and MISO, this ancillary service will allow hydro to monetize its flexibility, and more efficiently contribute to the integration of intermittent renewable resources.
- **Ontario's Independent Electricity System Operator (IESO)** presented the high-level design from its Market Renewal program in 2019. Some of the main upgrades include an Enhanced Real-Time Unit Commitment (ERUC) process, which will better align with day-ahead scheduling and incorporate startup costs into the real-time market, as well as enhanced Single Schedule and Day-Ahead Markets which will incorporate start-up costs and locational pricing into commitment and dispatch decisions.[41] As with MISO's ELMP and PJM's "fast-start pricing," internalizing commitment costs can be expected to lead to more efficient dispatch for all resources, including hydro.
- **The Alberta Electric System Operator (AESO)** is also currently considering a variety of flexibility-related market design initiatives. Highlights include a review of distributed energy (DER) energy and ancillary service participation rules, further integration of energy storage

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37 "PJM Files Reserve Pricing Reforms for the Future of a Flexible, Reliable Power System," PJM, March 29 2019. https://www.pjm.com/-/media/about-pjm/newsroom/2019-releases/20190329-reserve-pricing-ferc-filing-news-release.ashx

38 "Fast Start Education," PJM, October 19, 2020, https://sdc.pjm.com/-/media/committees-groups/committees/mic/2020/20201019-fast-start/20201019-item-02-fast-start-education.ashx.

39 "Western Energy Imbalance Service Market," Southwest Power Pool, 2021, https://www.spp.org/weis.

40 "SIR19 Uncertainty Product," SPP, March 18 2020. https://www.spp.org/documents/61872/sir19%20hittr4%20implement%20uncertainty%20market%20product%20sppbod.pdf

41 IESO DAM High Level Design and IESO ERUC High Level Design.

into energy and ancillary service markets, a review of competiveness for reserves (with an emphasis on regulation), and evaluation of a switch from hourly to sub-hourly settlement.[42] These market design updates each contribute to the formation of prices that internalize flexibility, paving the way for increased compensation and better utilization of flexible resources such as hydro.

Looking forward, evolution of the generation fleet and changing demand characteristics are likely to drive continued changes to wholesale market design. One possible example is a market product for frequency response. Frequency response is the ability of the system to respond to sudden deviations in frequency, for instance following a contingency such as a generator outage. Frequency response can come in multiple forms:

- **Inertial Response** slows the rate of change of frequency following a contingency that suddenly upsets the supply-demand balance. Generators with synchronous spinning mass (e.g., hydro and fossil-fired turbines) provide Instantaneous Inertia naturally as their rotational kinetic energy transforms. Other, typically inverter-based, resources such as wind, solar, and battery storage could also provide smaller amounts of Supplemental Inertial Response through appropriate control logic.
- **Primary Frequency Response** quickly restores the frequency back toward 60 Hz. This service entails changing output in proportion to frequency deviation, by generators with governor control.
- **Fast Frequency Response** suddenly adds net supply and can be particularly helpful for curing larger frequency deviations. This service is implemented by either injecting power from ultra-fast-responding batteries, or by disconnecting demand when frequency is reduced below a certain threshold through opening their circuit breakers. The service is different from standard under-frequency load shedding (UFLS) in that it is provided by willing large customers that are compensated for providing it. Also, Fast Frequency Response is triggered at frequencies well above UFLS schemes.

Historically, the supply of frequency response has been abundant in many systems and, as a result, is not compensated.[43] However, frequency response could grow scarce as traditional inertial generators are displaced by inverter-based resources. In its 2017 "State of Reliability" report, NERC highlighted a long-term trend of declining frequency response in the Eastern Interconnect, illustrated in Figure 4, and postulated similar trends may be occurring in other interconnections.[44] NERC's most recent "State of

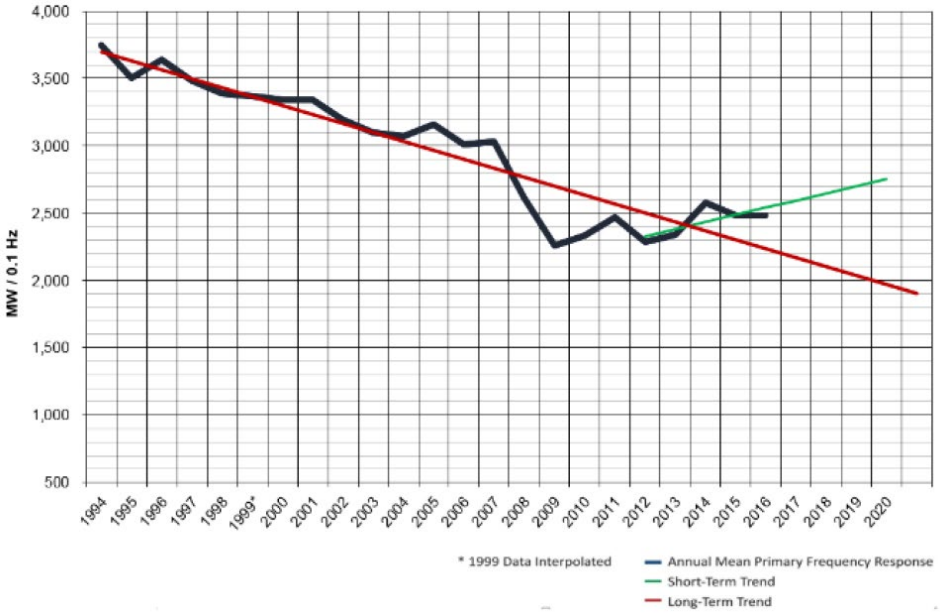
[42] "2020-2021 Market-Related Initiatives Schedule," Alberta Electric System Operator, https://www.aeso.ca/assets/Uploads/2020-2021-Market-Related-Initiatives-Schedule-FINAL.pdf.

[43] This is especially true in large systems such as the North American Eastern and Western interconnections.

[44] "State of Reliability," NERC, 2017, p. 139.

Reliability" report found stabilized or improving frequency response in each interconnect, marking a reversal of the long-term decline, but noted falling frequency response as a concern moving forward.[45]

FIGURE 4: EASTERN INTERCONNECTION FREQUENCY RESPONSE TREND



Source: NERC 2017 State of Reliability report

Hydro assets are unique in their ability to provide a combination of carbon free generation, in-market ancillary services, and other key out-of-market or uncompensated services such as frequency response, which are of particular concern for NHA members. Other sometimes under-compensated services mentioned by NHA members include volt-ampere reactive (VAR) support provided by pumped hydro (which is made whole in jurisdictions such as PJM, but not internalized by the market), inertia (which goes largely uncompensated), and black-start capability (which is compensated out-of-market in every US RTO except for ERCOT, which has an auction).[46]

Principle 2: RTOs should allow hydro a range of energy market participation options

Hydro operators have developed a variety of approaches to participating in wholesale markets in ways that provide value to the system while simultaneously respecting their unique operational constraints. NHA members described a range of offer strategies, including submitting price-based offer curves, energy-limited offers (allowing the RTO to schedule them subject to a daily energy constraint), and self-scheduling. RTOs should allow hydro to participate in wholesale markets in a variety of ways, so hydro operators can provide the greatest value to the system while respecting the unique characteristics of

[45] "State of Reliability," NERC, 2020, p. 30.

[46] HydroWires, Gracia et al., "Hydropower Plants as Black Start Resources," May 2019.

their assets, and fairly compensate them for the services they are asked to provide. Today, not all RTOs yet offer a full set of participation options, which may cause inefficiencies in how hydro can participate in their markets. Below we describe the approaches hydro operators take to participate in the markets, and we identify areas for further market rule enhancement by RTOs.

PARTICIPATION VIA SELF-SCHEDULING

Self-scheduling, in essence telling the RTO at what times and quantities an asset will generate power, allows hydro operators to maintain maximum operational control of their assets. Hydro assets with no flexibility in their generation, such as run-of-river assets, often self-schedule. However, limiting hydro participation to self-scheduling an otherwise flexible hydro asset can result in sub-optimal dispatch because the asset does not respond to market price signals. Absent efficient market signaling, a self-scheduled asset may generate at times and amounts that do not provide much value to the system or revenues to the asset owner. Self-scheduled assets also cannot set market prices, which can adversely affect price formation in markets with large amounts of hydro. RTOs should continue to allow assets to self-schedule but should also establish other attractive market participation methods that encourage assets to participate in ways that provide more value to the system.

PARTICIPATION VIA OFFER CURVES

A common way in which hydro operators participate in wholesale markets is by submitting price-based offer curves. These curves consist of price/quantity pairs that reflect the asset owner's willingness to generate power at a given price. Operators structure these offer curves to self-manage their water levels and operating constraints while also responding to market prices for energy and reserves. As hydro owners expressed through interviews and surveys, the ability to self-manage market participation is critical for hydro because RTOs are often unaware of, or unable to accommodate, complex hydro constraints directly within market dispatch and commitment software.

RTOs should allow all assets, including hydro, to submit price-based offer curves. However, some RTOs such as PJM do not yet allow conventional hydro assets to submit price-based offer curves, instead requiring these resources to self-schedule irrespective of market price.

Price-based offer curves for flexible hydro assets should be allowed to account for all components of operating costs, including opportunity cost. Opportunity costs reflect foregone expected earnings from using limited energy. For example, consider a pondage hydro unit with only one hour's worth of stored energy. Say the resource anticipates margins of $10/MWh in the morning and $50/MWh in the evening. If the resource is forced to offer at its variable cost, it will dispatch in the morning, netting $10/MWh of revenues. If it is allowed to offer at its opportunity cost, it will instead dispatch in the evening, netting

$50/MWh of revenues and providing greater value to the system by displacing more expensive marginal generation.

RTOs review offer curves submitted by suppliers with market power to ensure that their offers are competitive and reflect their true cost of providing energy. If submitted offers appear to be inconsistent with the unit's actual costs, market operators may mitigate offers to a price level administratively estimated by the market operator. Accurately estimating the operating costs of hydro assets is challenging both for RTOs and hydro operators. For example, hydro operators may not have fully quantified the costs of startup and wear-and-tear associated with frequent cycling of their assets.

Most RTOs allow flexible hydro units to include opportunity costs within their offer curves, but they take different approaches to estimating these opportunity costs. Rules permitting fair hydro resource owner estimation of lost opportunity cost is critical to maximizing the value of all energy-limited assets, including flexible hydro and batteries. Accurately calculating these costs can be challenging, because it requires developing an outlook of future prices and foregone revenues from using limited energy. It also requires hydro owners and RTOs to be able to communicate and accommodate changing system conditions on a timely basis. For instance, an NHA member in CAISO stated that while an unexpected daily change in water levels could impact generation potential, the resulting change in opportunity cost could take a week or more for CAISO to update.

Additionally, multiple NHA members expressed concerns that RTOs sometimes underestimate hydro opportunity costs, resulting in over-mitigation of hydro units. This in turn reduces revenues and the value the units provide to the system. Adequate flexibility for resource owners to reflect the lost opportunities they face should take precedence over administrative cost estimates that may not accurately reflect the true costs of hydro, including opportunity costs. Over-mitigation of resources may cause hydro owners to shift to participating via self-scheduling and reduce the potential value of these resources to the system. Because the operating costs of hydro assets can be challenging to calculate, asset owners and RTOs should work collaboratively to understand how the costs of operating these assets might change in a future in which hydro is increasingly used as a source of flexibility.

PARTICIPATION VIA ENERGY-LIMITED OFFERS

Some RTOs can account for the energy limitations of pumped hydro and energy-limited reservoir hydro when scheduling assets. Several survey participants expressed support for this option as a useful complement to self-management of reservoirs via self-scheduling or price-based offers. The RTO may be better positioned to optimally schedule hydro assets subject to their energy limitations than the hydro operator because they likely have greater visibility into electric system conditions and congestion patterns. However, RTOs have less visibility into other operating constraints of individual hydro resources, and therefore may schedule assets in ways that are infeasible due factors such as environmental constraints or cascading water constraints not represented in the RTOs' optimization or otherwise miss important opportunity cost considerations, as they change.

Take PJM as an example. PJM will co-optimize pumped-hydro storage into day-ahead energy and ancillary service products (PJM currently does not provide the ability to redispatch units in real time).[47] PJM performs this calculation over 24-hour time horizons each day, accounting for hydro parameters including pump efficiency factor, initial daily reservoir level (MWh), end-of-day target reservoir level (MWh), minimum and maximum reservoir levels (MWh), and minimum and maximum pumping (MW).[48]

For scheduling flexible hydro assets, RTOs should aim to account for energy limitations as well as any other operating factors, such as cascading flow challenges. Some participants may still choose, at times, to self-manage their assets via self-scheduling and override offer curves, or self-commit a resource, to retain more operational control, yet, at other times, may find enhanced RTO scheduling increases revenues because of transmission constraints and congestion that is difficult to forecast. In general, the more RTOs can incorporate hydro operating constraints into their dispatch algorithms, the more optimally these assets will be scheduled and the more value they will provide. This in turn will make hydro operators more willing to participate in RTO scheduling processes rather than participating via offer curves, and will increase the economic efficiency of system operations.

IMPROVED COORDINATION

Regardless of the mechanism hydro uses to participate, communication between hydro asset and grid operators is essential. In CAISO's analysis of its summer 2020 blackouts, it acknowledged the key role hydro played in ameliorating emergency conditions. Looking forward, CAISO states, "there should be increased coordination by communicating as early as possible the need for additional energy or active pump management ahead of stressed grid conditions […] to improve electric reliability."[49]

Principle 3: Hydro and other flexible resources should be properly compensated for any out-of-market dispatches

Through our interview and survey process, hydro operators noted that some system operators frequently use their assets outside of standard day-ahead and real-time market products to help maintain reliability and balance the system. These actions can result in hydro and other flexible assets not being fully compensated for the services they provide, and can distort competitive market outcomes. More complete day-ahead and real-time markets can reduce the need for these out-of-market instructions. When these are unavoidable, uplift payments should be structured to fully compensate suppliers for their costs, including lost opportunity costs.

[47] "PJM Operating Agreement," Schedule 1, Section 1.10 Scheduling, PJM, July 14, 2011, https://www.pjm.com/directory/merged-tariffs/oa.pdf.

[48] "Optimizing Hydroelectric Pumped Storage in PJM's Day-Ahead Energy Market," Anthony Giacomoni, Qun Gu, Boris Gisin, PJM, June 23, 2020, https://www.ferc.gov/sites/default/files/2020-06/T2-3_Giacomoni_et_al.pdf.

[49] "Root Cause Analysis: Mid-August 2020 Extreme Heat Wave," p. 6, January 13, 2021, http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf.

NHA members provided several examples of ways in which hydro assets are called upon to provide services outside of standard market dispatch procedures, including:

- RTOs issuing instructions for hydro to dispatch in ways that deviate from their planned schedules to shore up a reserve shortage or mitigate the effects of an unexpected contingency;
- RTOs requesting hydro to maintain a minimum or maximum generation level in order to provide system voltage support;
- RTOs utilizing hydro to provide synchronous condensing; and
- RTOs calling on hydro to provide energy for reliability reasons, such as maintaining Area Control Error (ACE).

RTOs generally compensate hydro and other assets for following out-of-market instructions via uplift payments. Uplift payments are designed to ensure that revenues cover costs any time dispatch instructions deviate from the resource operator's planned schedule and market revenues are insufficient to recover costs. This can occur, for example, if the system operator schedules a plant to turn on, but the energy revenues it earns do not cover its start-up costs, as energy prices are set by the marginal cost of providing energy, not the cost of committing units.

In general, RTOs seek to minimize uplift payments as these payments are not transparent and do not give other market participants an opportunity to compete to provide the services at lower costs, and they indicate price distortions. Overall, uplift payments make up a small fraction of total costs. In 2019, total ISO-NE uplift payments were $30 million, constituting only 0.3% of total wholesale costs (although the impact of out-of-market actions on market prices could be larger).[50] Between 2001 and 2019, PJM has reduced uplift payments fell from 8.5% of total billings to just 0.2% of total billings.[51] Despite these improvements, some level of uplift payments are unavoidable and consistent with marginal cost based pricing.[52]

However, uplift payments tend to be concentrated in a subset of units. In PJM, 10 organizations received 72.9% of uplift payments in 2019.[53] In some markets such as ISO-NE, pumped storage hydro provide significant out-of-market value and thus earn greater uplift payments due to this inherent flexibility than other resources. As shown in Figure 5 below, hydro units in ISO-NE regularly earn 50% or more of their total annual ancillary service revenues from uplift. At least two-thirds of hydro assets in ISO-NE receive uplift revenue and provide reserves and voltage control.

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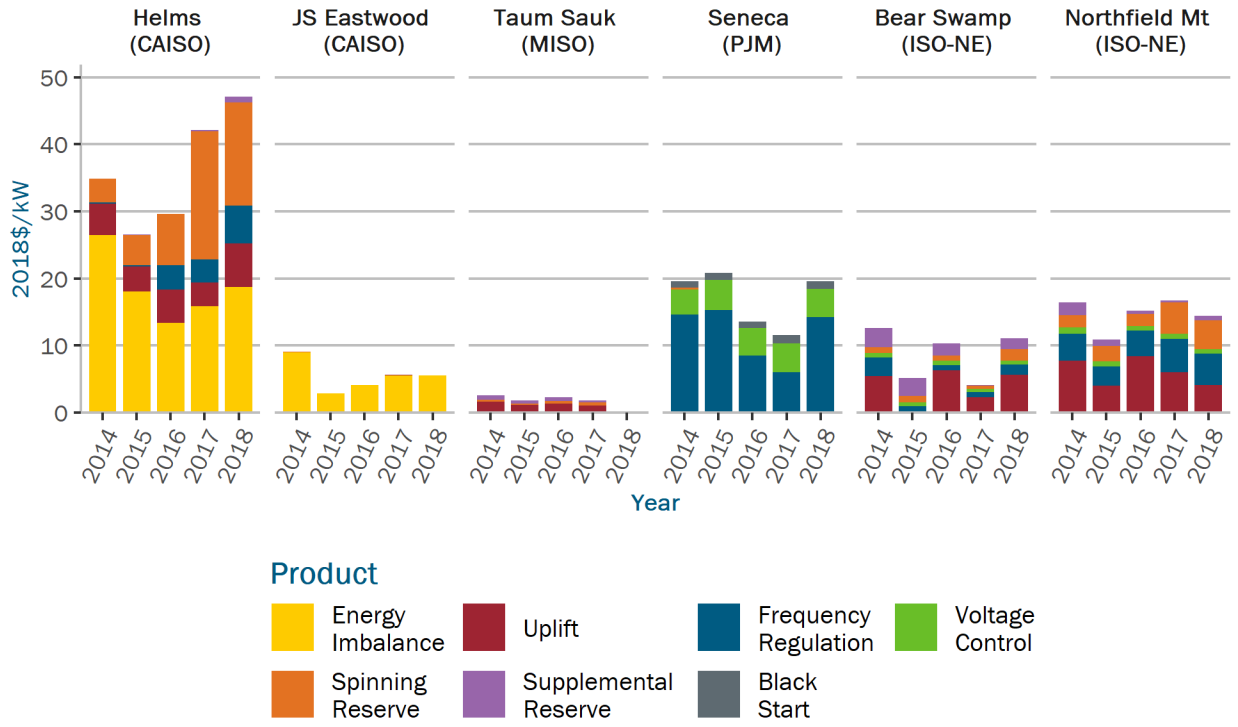
[50] "2019 Annual Markets Report," ISO New England, May 26, 2020, https://www.iso-ne.com/static-assets/documents/2020/06/a6_2019_annual_markets_report.pdf.

[51] PJM 2019 uplift payments were $88.6M and total billings were $39.2B., per 2019 state of the market. "Market Monitor Report," Joe Bowring, Monitoring Analytics, February 19, 2019, https://www.pjm.com/-/media/committees-groups/committees/mc/20190219-webinar/20190219-item-07-imm-report.ashx.

[52] "State of the Market Report for PJM," Monitoring Analytics, p. 239, March 12, 2020, https://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2019/2019-som-pjm-volume2.pdf.

[53] "State of the Market Report for PJM," Monitoring Analytics, p. 31, March 12, 2020, https://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2019/2019-som-pjm-volume2.pdf.

FIGURE 5: ANNUAL ANCILLARY SERVICE REVENUE STREAMS FOR SELECTED PUMPED STORAGE HYDROPOWER PLANTS



Source: 2020 DOE Hydropower Market Report

In some cases, more complete day-ahead and real-time markets can reduce the need for out-of-market instructions. NHA members expressed concerns regarding ISO-NE's lack of a day-ahead operating reserve market. Best practice is for RTOs to establish market products that competitively and transparently procure all needed grid services, including day-ahead operating reserves, rather than relying on uncompensated service or unnecessary out-of-market instructions and related uplift payments.

When out-of-market instructions are unavoidable, it is crucial that any uplift payments fully compensate suppliers for their costs, including lost opportunity costs. Several NHA members noted concerns that uplift payments are often insufficient to cover costs. Coupled with the fact that flexible hydro assets in some RTOs are frequently used for out-of-market purposes, insufficient uplift can materially affect their revenues.

However, some degree of uplift payments are unavoidable. It is therefore important that uplift payments to generators fairly compensate them for their costs – especially so for flexible hydro assets that are so frequently used for out-of-market purposes. RTOs differ in how they compensate units for uplift, but many NHA members suggested uplift payments in certain markets do not completely cover costs, including opportunity costs.

Principle 4: All assets, including hydro, should be accredited fairly for the resource adequacy value they provide

"Resource adequacy" refers to a system's preparedness to have enough supply to meet load all but a *de minimis* fraction of the time—with loss of load expectations of no more than one event in 10 years in most North American systems. To ensure resource adequacy, RTOs define requirements as capacity reserve margins above peak load or as the level of supply needed to achieve minimum reliability criteria, based on an assumed resource level support to meet those requirements. Accurate accreditation of resources is essential, both for reliability and economic efficiency. A resource's 'resource adequacy value', or capacity value, refers to the accreditation of resources' ability to help meet system reliability standards. Over-crediting some resources would tend to reduce reliability and under-compensate other resources. Under-crediting resources would tend to cause over-procurement and undue costs to customers. Over-crediting some resources relative to others would result in an inefficient resource mix and unfair compensation. Across regions, accreditation practices vary, but several issues are generalizable.

Hydro is generally a very reliable resource and therefore has high resource adequacy value. Generation from run-of-river hydro is generally stable and predictable hour-to-hour and day-to-day (although subject to annual and seasonal hydrological cycles), more so than other renewable resources such as wind and solar. Flexible hydro with ample reservoir capacity is dispatchable with high availability. Recent market outcomes provide evidence for hydro's reliability. In the summer of 2020, CAISO had to institute rolling load shedding when it could not meet demand. In its subsequent analysis of drivers of the load shed events, CAISO acknowledges that while the "reliability value of intermittent resources [solar and wind] is still over-estimated during the net peak hour," "RA [resource adequacy] hydro resources provided above their RA amounts and various hydro resources across the state managed their pumping and usage schedules to improve grid reliability."[54] This is in spite of the fact that 2020 was a considerably drier-than-average year.[55] To fairly accredit hydro and other reliable resources for the resource adequacy value they provide, RTOs and utilities must accurately accredit all resources, including variable wind, solar, and energy-limited battery storage. Over-crediting wind, solar, and battery storage can result in overestimating the overall system resource adequacy and reliability, and can result in reduced compensation for other resources for the resource adequacy value they provide. Installations of these resources are increasing rapidly, and, due to correlations in output among similarly weather-dependent (or diurnally varying) plants, their resource adequacy value is simultaneously eroding. Furthermore, resource adequacy value is becoming more challenging to characterize as loss-of-load risks shift from being concentrated in summer peak load hours to a broader set of hours due to

[54] Root Cause Analysis, p. 6.

[55] CAISO notes, "the statewide snow water content for the California mountain regions peaked at 63% of average on April 7, 2020." Root Cause Analysis, p. 22.

flexibility challenges caused by growth in wind and solar and emerging winter risks, including increased winter energy demand under winter heating electrification efforts.

Hydro also contributes to system resiliency, as it does not experience the types of fuel supply disruption risks faced by fossil generators. The inability of fossil plants to procure sufficient fuel played a major role in both the February 2021 Texas outages and the Northeast 2014 Polar Vortex. Fuel supply disruption risks are not yet commonly considered in RTO system planning or generator accreditation, despite evidence they are a major driver of system reliability. To the extent this oversight causes fossil units to be over-accredited, system operators may understate reliability and under-compensate hydro and other resilient resources.

To understand why the resource adequacy value of wind, solar, and short-duration battery storage resources falls as more is deployed, and the associated risks of over-accreditation, consider the stylized examples below. Figure 6 demonstrates the declining resource adequacy value of solar. In this example, adding 10 MW of solar to a system with peak demand of 135 MW reduces the peak by 5 MW, reflecting a 50% capacity value for solar. Tripling solar installation to 30 MW results in peak load hours shifting to later in the day, and peak demand is only reduced by 6 MW, reflecting a 20% capacity value for solar. As more solar is added, peak load shifts to later in the evening, until eventually solar's marginal peak load reduction is zero.

In the second example (Figure 7), consider the impact of four-hour duration battery storage on peak load. With a 10 MW battery, demand is shifted such that peak is reduced by a full 10 MW, 100% of the battery's capacity. With a 30 MW battery, only 23 MW of peak demand reduction is possible, 77% of the battery's capacity. Notice that after using the 30 MW battery to shift demand, the net demand profile has become almost completely flat. Once it flattens entirely, any incremental storage will no longer be able to reduce net demand, since reducing demand any one hour (discharging the battery) would require increasing it during another (charging the battery).

FIGURE 6: RESOURCE ADEQUACY CONTRIBUTION OF SOLAR – STYLIZED EXAMPLE

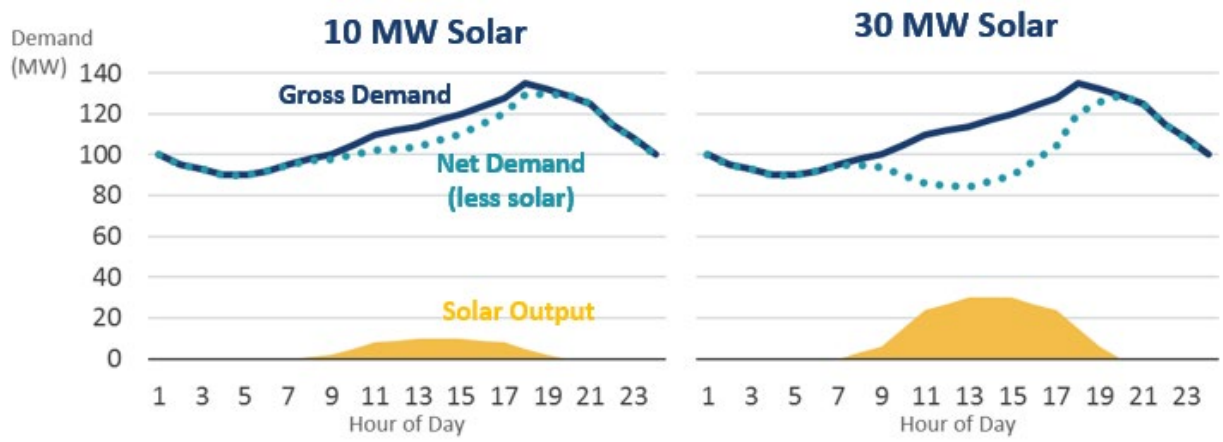
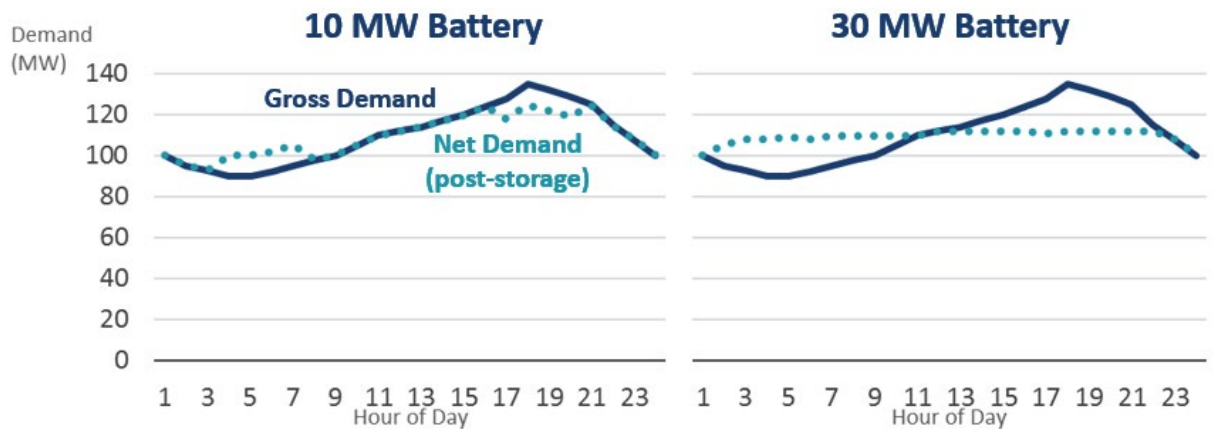


FIGURE 7: RESOURCE ADEQUACY CONTRIBUTION OF BATTERY STORAGE – STYLIZED EXAMPLE



Note: Example assumes four-hour duration battery storage with 100% round-trip efficiency.

In reality, quantifying resource adequacy value for variable and energy-limited resources is more complex than indicated by these stylized examples. Due to differences in location and technology, resources of the same type have different generation profiles. Furthermore, the marginal contribution of any one resource type to resource adequacy depends not only on the penetration of that resource type (as shown above), but on the penetration of each other resource types as well.

Today, many RTOs estimate the capacity contribution of variable and energy-limited resources using simplified methods that, for example, evaluate the resource's historical average output over certain specified calendar hours typically corresponding to peak loads. Such methods are generally appropriate for systems with low to moderate amount of intermittent renewables and storage, as the loss-of-load risk in such systems are generally concentrated in summer peak hours. However, these methods become less accurate as the amount of renewables and storage grows, and loss of load risks shift to a broader set of hours.

One increasingly prevalent approach to accrediting intermittent and energy-limited resources is effective load-carrying capacity (ELCC). A definition of ELCC is "the additional load met by an incremental generator while maintaining the same level of system reliability," where the level of system reliability is defined in relation to the statistical probability of loss of load.[56] Calculations of ELCC are require making assumptions about how other resources will perform during periods of peak demand. There are also debates around the most fair and efficient ways to perform the calculation. Resource quality varies across location, and so resource adequacy administrators must determine the appropriate geographic granularity to calculate ELCC. As penetration of certain intermittent and energy-limited technology resource classes grow, their ELCC ratings tend to decline, meaning the marginal ELCC of any given resource is less than the average ELCC of that type. For example, while small penetrations of 2-hour

[56] "Stochastic Modeling Status Report," Arne Olson, Andrew DeBenedictis, Ryan Jones, California ISO Workshop, February 10, 2012, https://www.caiso.com/Documents/Presentation_E3_LOLP_Model_Feb10_2012.pdf.

batteries might provide a higher reliability contribution, higher levels of penetration will face diminishing ELCC contributions as more peak load hours must be supported. Market administrators using ELCC for accreditation must then decide whether to assign marginal or average values to resources. For example, the CPUC assigns existing resources average ELCC, and new resources marginal ELCC for planning and contracting purposes. For hydro assets, it is important that ELCC calculations be done at the resource level, not as a "class average", due to the unique and idiosyncratic features of each hydro asset, such as the facility's amount of pondage capability.

System operators today take a variety of approaches to estimating the capacity value of hydro. PJM has proposed an ELCC approach to estimate the capacity value of all types of hydro, including run-of-river hydro, pumped hydro, and reservoir hydro with storage.[57] Other systems use different methods for different hydro technologies. NYISO uses "peak period" methods to assign capacity values to run of river hydro, but accredits large reservoir hydro based on their equivalent forced outage rate (the same approach used for conventional generation).[58] The Northwest Power Pool is currently proposing to use an ELCC approach for run-of-river hydro and is in the process of developing an approach for hydro with storage.[59]

Capacity accreditation does not readily capture more elusive characteristics such as flexibility and fuel security. Even if it did, capacity accreditation alone may not provide sufficient incentives for supply resources to perform when needed. Accreditation is therefore best complemented by shortage pricing in energy and ancillary service markets, which help reward the resources with the most valuable characteristics and performance attributes. RTOs have enhanced their shortage pricing mechanisms, particularly since FERC Order 719 in 2008 required RTOs to implement reserve constraint penalty factors (RCPFs).[60] ISO-NE also introduced capacity performance incentives to penalize capacity resources that under-perform during emergency events and reward resources that over-perform. PJM emulated this system in its new Capacity Performance construct. As part of its Reserve Pricing Reforms currently being implemented, PJM is also transitioning its RCPFs into operating reserve demand curves (ORDCs) that are similar to ERCOT's in its energy-only market.

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57 PJM, *PJM Manual 21a Initial Outline and Partial First Draft*, December 15, 2020. https://www.pjm.com/-/media/committees-groups/task-forces/ccstf/2020/20201218/20201218-item-03c-conceptual-draft-for-new-elcc-manual-21a.ashx

58 NYISO, *Manual 4: Installed Capacity Manual*, February 2021. https://www.nyiso.com/documents/20142/2923301/icap_mnl.pdf/234db95c-9a91-66fe-7306-2900ef905338

59 Gregg Carrington, NWPP, *NWPP Resource Adequacy Public Webinar*, January 29, 2021. https://www.nwpp.org/private-media/documents/Final_Public_Webinar_Slides_1.25.2021.pdf

60 U.S. Federal Energy Regulatory Commission, *Wholesale Competition in Regions with Organized Electric Markets*, October 17, 2008, https://cms.ferc.gov/sites/default/files/2020-04/E-1%281%29.pdf.

IV. Conclusions

Hydropower is an invaluable energy resource that can play a large role in the clean energy transition. The 100+ GW of hydropower operating in the United States today provides 300 TWh of electricity, 7% of the nation's total, and more than any other clean energy source besides wind power. Additionally, hydro provides needed flexibility. The 20+ GW of pumped storage online today dwarf all other types of energy storage, and, together with conventional hydro, provide diverse grid services, including dispatchable, clean real-time energy, day-ahead energy and resource adequacy, and ancillary services from regulation, to contingency reserves, to reactive power and black start capability. As the grid of the future evolves to incorporate more intermittent wind and solar resources, hydro's clean energy and flexibility benefits can play an essential role in enabling deep decarbonization.

To fully utilize hydropower in the clean energy transition, RTOs must work with hydro asset owners to continue to develop market rules that allow hydro to compete fairly with other resources, and incent and reward hydro's unique characteristics. Today, as system conditions begin to change, RTOs and hydro asset owners alike have begun to develop new market mechanisms and operational strategies to better utilize hydro's flexibility to provide a full range of grid services. While some of these efforts are well-aligned, our interviews and surveys of NHA members indicated that there is still work to be done to ensure hydro resources are able to overcome market frictions and contribute their full clean energy and flexibility value. The issues facing hydro asset owners are varied—from the current inability of RTOs to fully represent the constraints of some hydro systems in economic dispatch, to the reliance of RTOs on hydro for undercompensated out-of-market services, to suboptimal resource adequacy accreditation.

In this whitepaper we provide four principles to maximizing the value hydro and other assets provide within wholesale markets. We hope that these four principles, identifying and implementing new energy and ancillary service products, allowing variety in market participation, properly compensating (minimal) out of market dispatches, and fairly accrediting the resource adequacy value of *all resources*, can serve as a guide for RTOs and other industry participants supporting the clean energy transition. Through ensuring the accurate identification and fair compensation of emerging flexibility and clean energy needs, the power markets of the future offer the opportunity to fully unlock the value of hydro in the clean energy transition, supporting the transition to reliable, cost-effective, decarbonized energy systems.