



Value of Stored Energy

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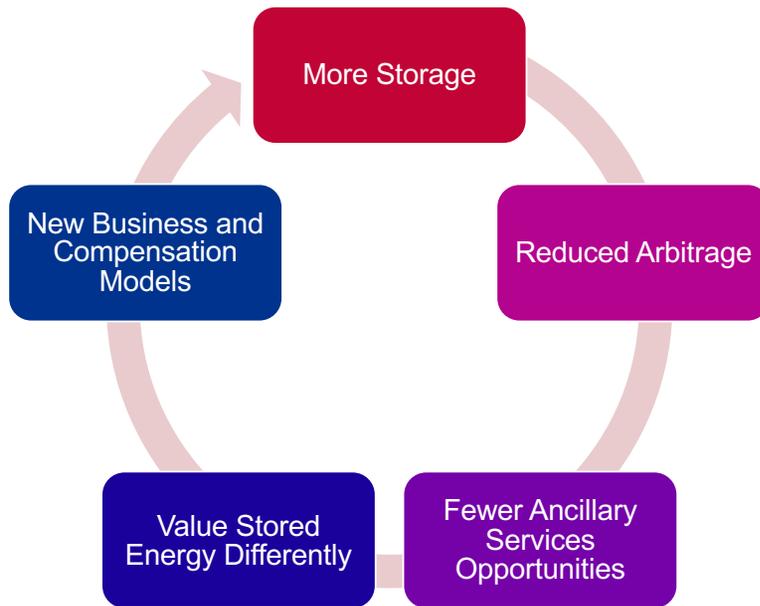
MDES Alliance Online Meeting, Jan 19 2026



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Energy Storage Is Becoming Essential — But Harder to Pay For



- Energy storage supports reliability, affordability, and resilience
- Historically, storage earned revenue through price arbitrage
- As storage deployment increases, arbitrage opportunities decline
- This creates a gap between **system value** and **market compensation**

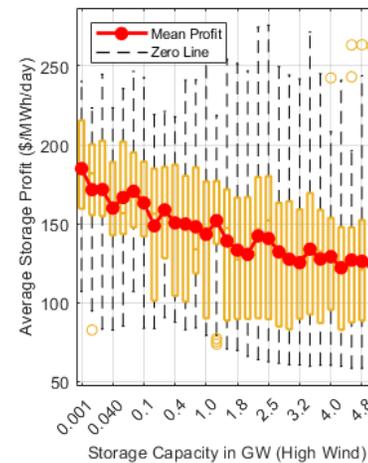
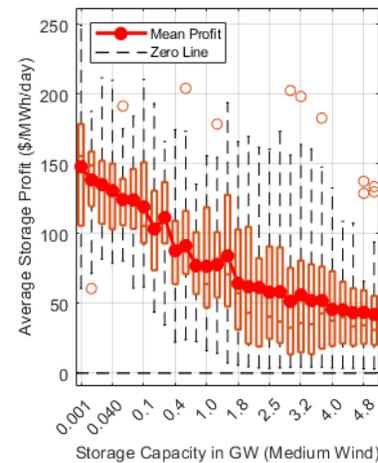
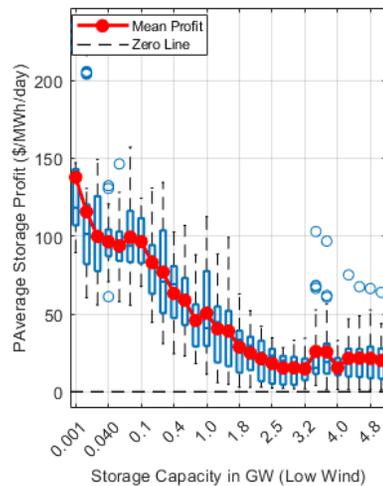
• ¹R. Sioshansi, P. Denholm, T. Jenkin and J. Weiss, "Estimating the Value of Electricity Storage in PJM: Arbitrage and Some Welfare Effects," *Energy Economics*, vol. 31, no. 2, pp. 269-277, 2009;
F.J. De Sisternes, J.D. Jenkins, A. Botterud, "The Value of Energy Storage in Decarbonizing the Electricity Sector," *Applied Energy*, vol. 175, pp. 368-379, 2016; S. Bhattacharya, T. Ramachandran, A. Somani and D. J. Hammerstrom, "Impacts of Energy Flexibility in Transactive Energy Systems With Large-Scale Renewable Generation," in *IEEE Access*, vol. 10, pp. 14870-14879, 2022

• ²A.Somani, et al., "An Assessment of Resource Drought Events as Indicators for Long-Duration Energy Storage Needs," PNNL-35955

• ³T. Kieper, et al. "The Contribution of Hydropower and Long-Duration Energy Storage to Grid Resilience During Extreme Weather and Electricity Market Scarcity Events," <https://www.techrxiv.org/doi/full/10.36227/techrxiv.174060198.84092808>

Impact of Increasing Penetration of Energy Storage on Arbitrage-based Revenue

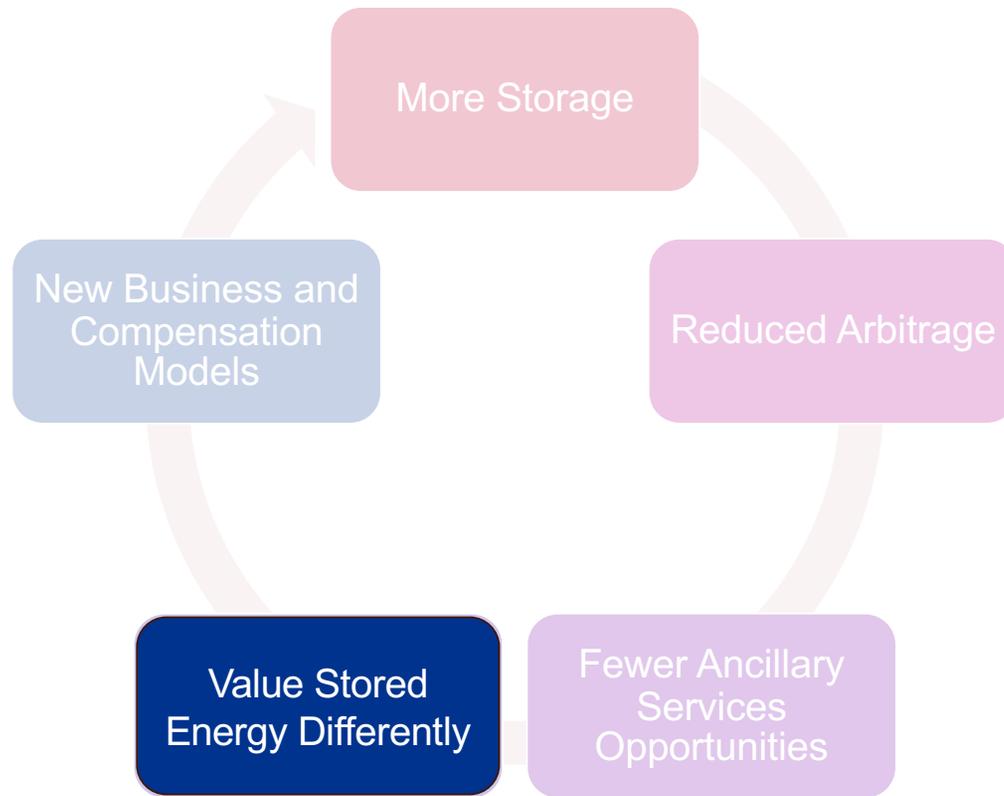
Storage reduces price volatility — which is good for the grid, but bad for arbitrage-based revenue.



Average energy storage profit under various wind and energy storage penetrations

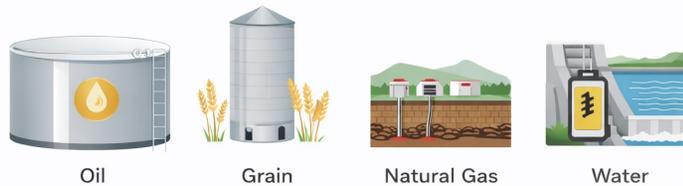
- Higher storage penetration → flatter prices
- Profits decline because storage stabilizes the system
- This is expected behavior, not a failure of storage

E3 on ERCOT shift from 2023 to 2024 - "We observe that *arbitrage* opportunity in both markets reduced in 2024. Moderate weather alongside more energy storage has contributed to this ..."



Why Do We Store Anything?

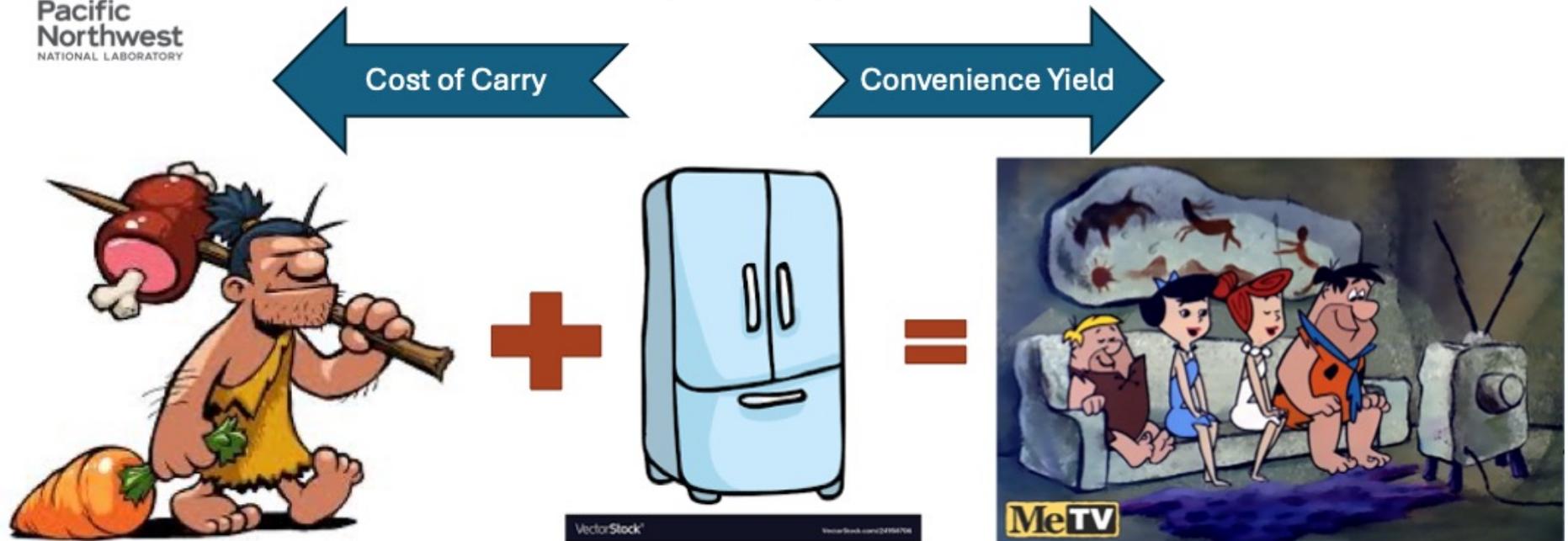
- Why do we store physical commodities?



- Storage isn't just valuable because of price differences
- **It's valuable because it reduces risk when supply is uncertain**
 - Flexibility when supply or demand changes suddenly
 - Protection against extreme events
 - Confidence that energy will be available when needed

Energy storage creates value even when it doesn't move power.

Convenience Yield: The Value of Having Energy When You Need It



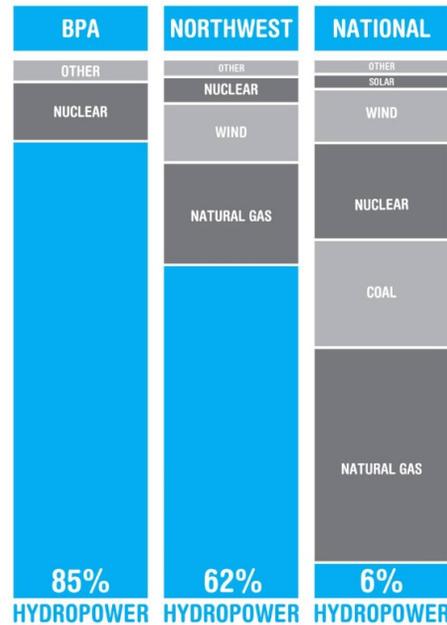
Having stored energy nearby provides:

- Faster response
- Greater reliability
- Lower system stress

Economists call this convenience yield

Source of MDES/LDES: Federal Columbia River Power System (FCRPS)

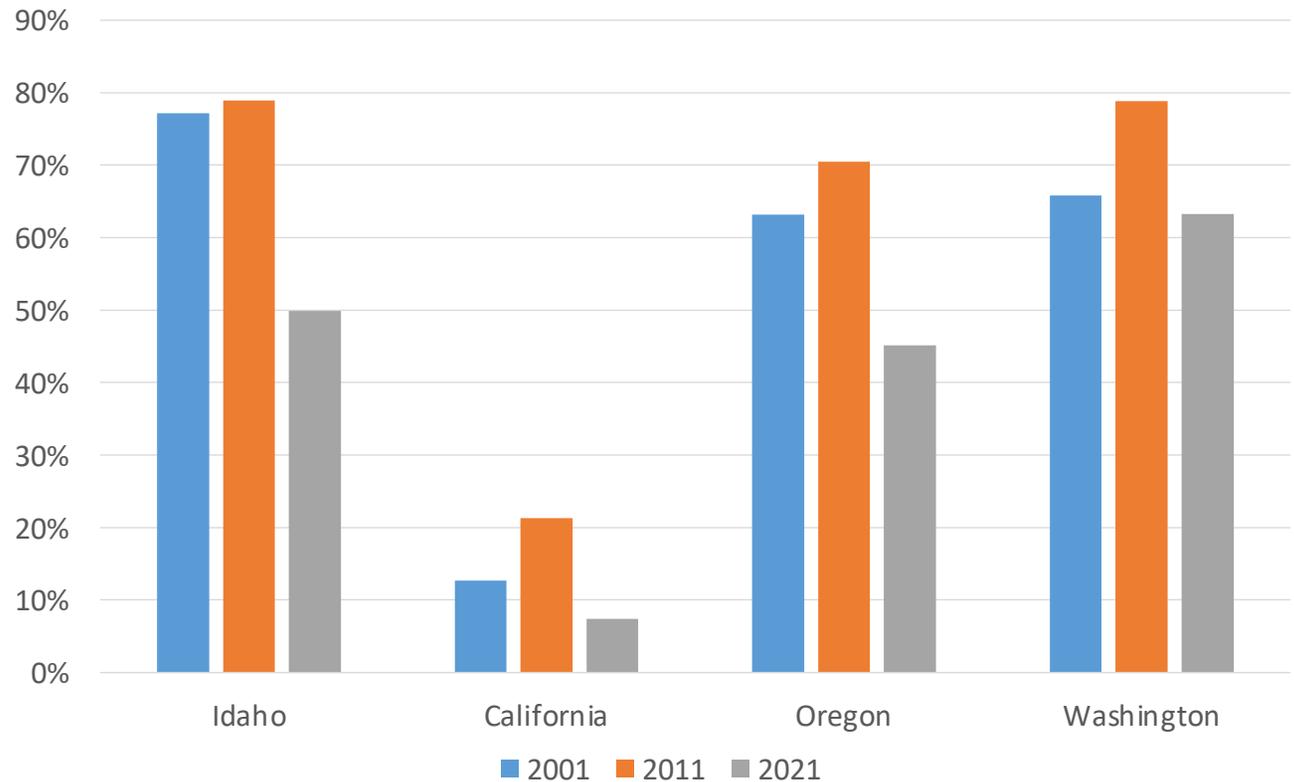
- The FCRPS is a multi-use system
- BPA markets power from 31 federally owned multipurpose dams on the Columbia and its tributaries that comprise the FCRPS provide about 60 percent of the region's hydroelectric generating capacity
- The dams operate to protect migrating fish, and they supply irrigation water to more than a million acres of land in Washington, Oregon, Idaho and Montana.



Hydropower is a major source of energy in the Western US, especially the Pacific Northwest

Hydropower Installed Capacity – MW (% of State Total)	
Idaho	75%
California	25%
Oregon	72%
Washington	80%

Hydropower's Contribution to Energy Demand (MWh)



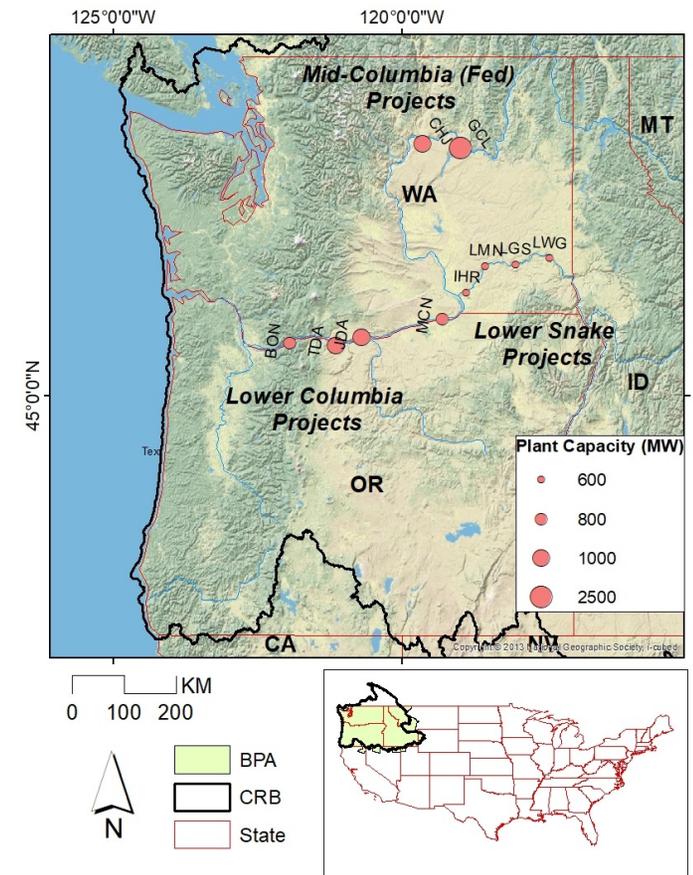
Hydropower flexibility during extreme events

Research questions:

- How do the Big 10 projects respond (shift energy) during extreme temperature events?
- How much flexibility do the Big 10 project have during these events?
- How does flexibility change seasonally and with the magnitude of extreme temperature events?

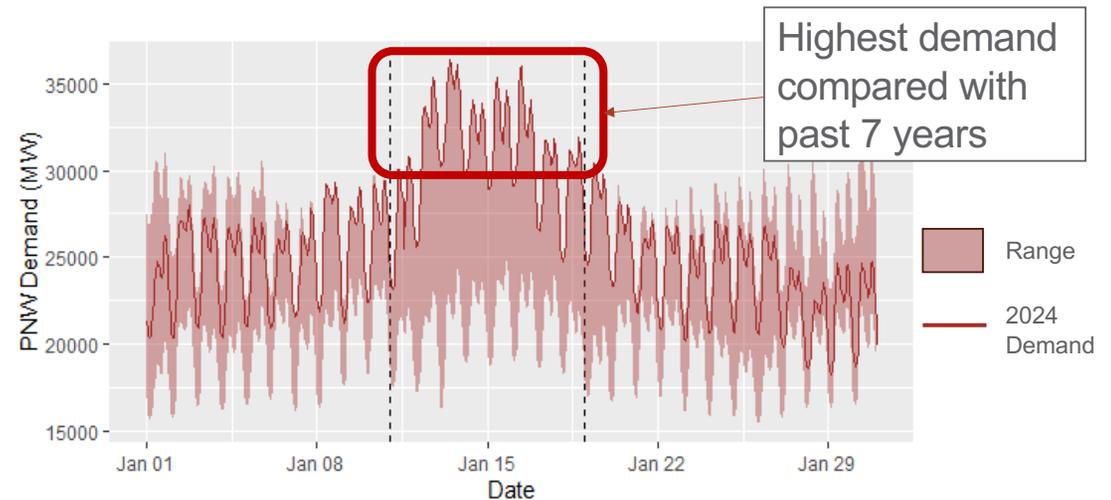
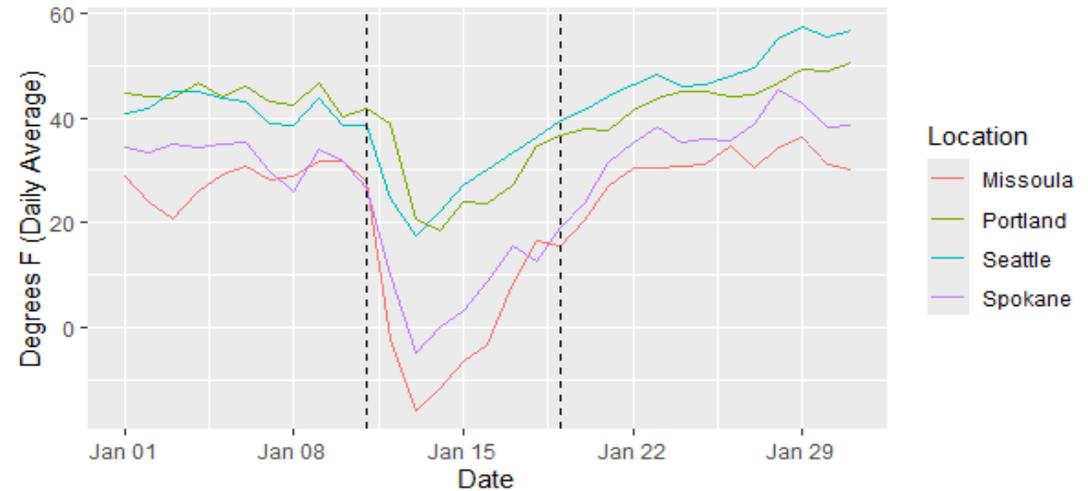
Definition of hydropower flexibility: BPA can conserve water (and thus potential energy) before extreme events (e.g., cold snaps) and increase power generation during the events. We quantify **flexibility** as the **surplus power generated during the event relative to the pre-event period and a control period; a higher surplus indicates greater flexibility.**

[Kieper et al, "The Contribution of Hydropower and Long-Duration Energy Storage to Grid Resilience During Extreme Weather and Electricity Market Scarcity Events." IEEE PES GM 2025](#)



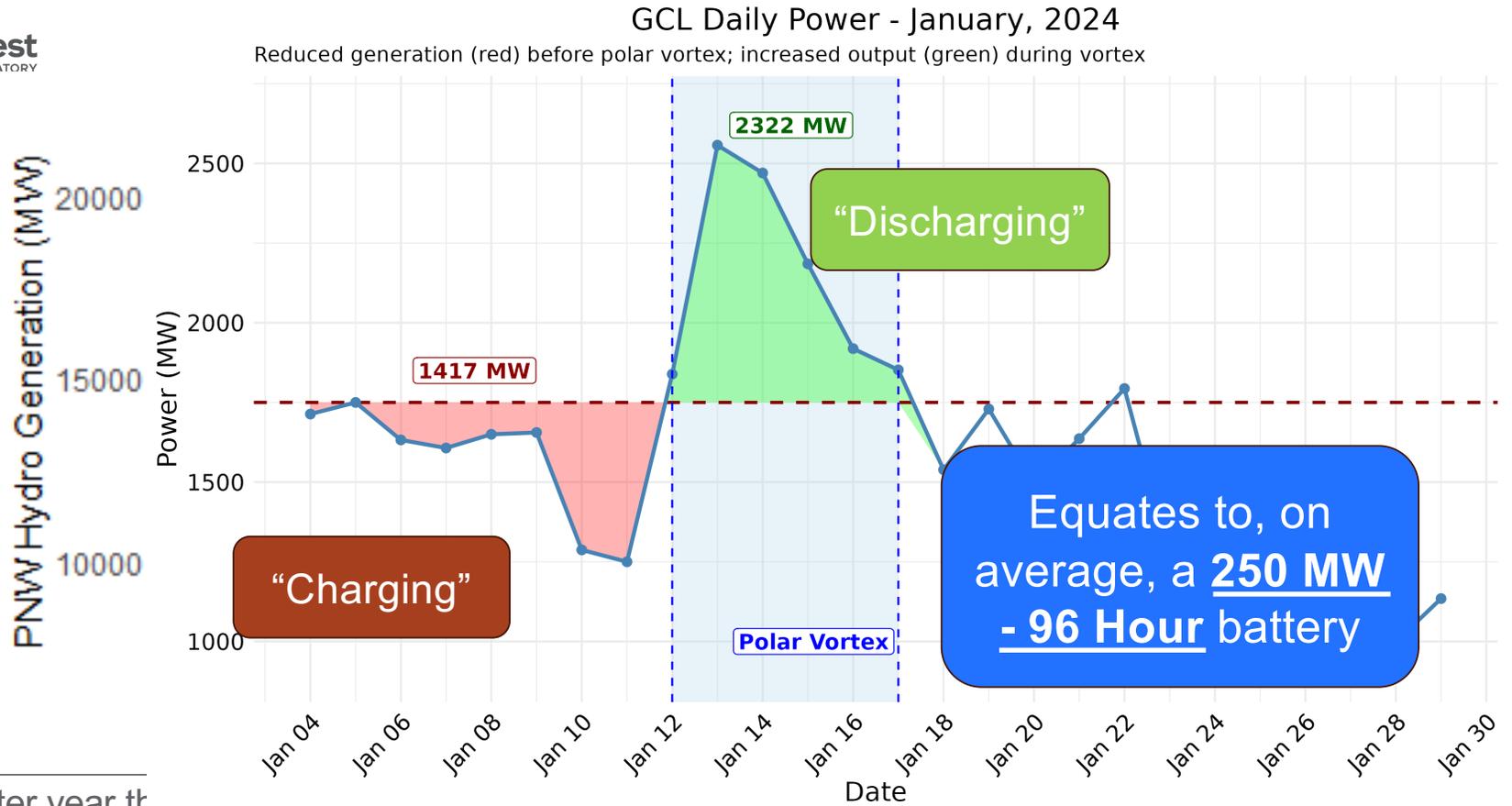
Polar Vortex January 11, 2024 – January 18, 2024

- Combination of:
 - extreme weather
 - high loads
 - lower-than-average water
 - electric and/or natural gas supply disruptions
- Extreme weather events also often correlate with **substantial drops in renewable generation**



Temperatures from NOAA Global Historical Climatological Network daily data. Demand data from EIA Electric Grid Monitor/EIA 930.

Figures show January 2024 generation (black line) and minimum and maximum January generation by period back to January 2017.



"Due to a low water year the operations are managing the river to minimum flows."²

Data source: EIA Electric Grid Monitor/EIA 930

¹ https://www.newsdata.com/clearing_up/briefs/bpa-reports-negative-net-revenues-for-q1-warns-q2-could-be-worse/article_c5a2a218-cd0b-11ee-a7a8-2b8f37c38589.html

² <https://www.bpa.gov/-/media/Aep/about/publications/news-releases/20240130-pr-02-24-federal-hydro-system-powers-region-through-arctic-blast.pdf>

— 2024 Hydro Generation

Assessing the Value of Hydro-based Stored Energy in the US' Pacific Northwest



The goal of this research was to measure how hydropower-based energy storage impacts market prices and alleviates grid stress

- We measured this impact through identifying and measuring the value of increasing reservoir storage volume, which can impact price formation in electricity markets. We measured the impact on
 - Real-time prices
 - The distribution of real-time prices
 - And risk premiums

What Is a Risk Premium?

A risk premium is what markets pay to protect against uncertainty in electricity markets:

- Large price spreads = high uncertainty
- Smaller spreads = more confidence in supply



The Value of Energy Storage: Empirical Analysis

The Value of Hydropower as a Grid-Scale Storage Resource: A Commodity Market Approach

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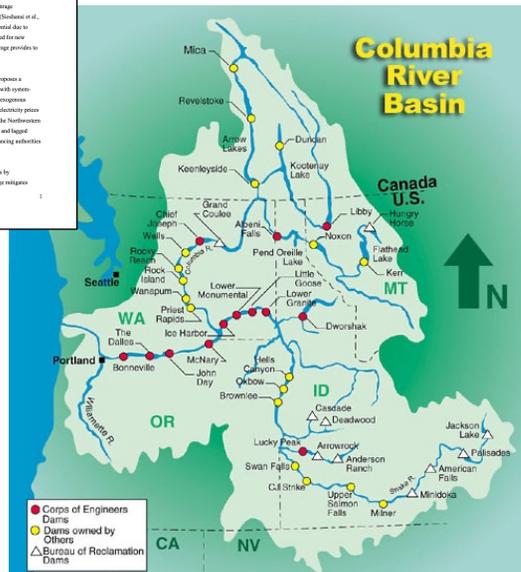
Abstract

Energy storage plays a critical role in modern power systems, providing services such as grid stability, frequency regulation, and load balancing. Currently, storage systems are restricted by offering these grid services and forgoing energy arbitrage—buying electricity when prices are low and selling when prices are high. However, as energy deployment expands, arbitrage profitability declines due to market saturation and increasing price differentials (Chowdhury et al., 2009; Li et al., 2020). In ERCOT, for example, 2024 saw reduced arbitrage potential due to moderate weather and increased energy capacity. This trend underscores the need for new business models that more fully recognize and compensate the value energy storage provides to the power system.

This paper presents empirical research on the full value of energy storage and proposes a commodity market-based framework to better align compensation mechanisms with operational benefits. We estimate hydropower as a proxy for grid-scale storage, using congestion variation to measure storage volume to estimate causal effects on (1) real-time electricity prices and (2) risk premiums, measured by the spread to real-time price spread, in the Northwestern United States between May 2022 and November 2024. Employing fixed-effects and spatial-dependent variable models, we control for unobserved heterogeneity across balancing authorities and capture dynamic price behavior.

We find that a 10% increase in reservoir storage volume reduces real-time prices by approximately 6% and lowers risk premiums by about 5%, indicating that storage mitigates

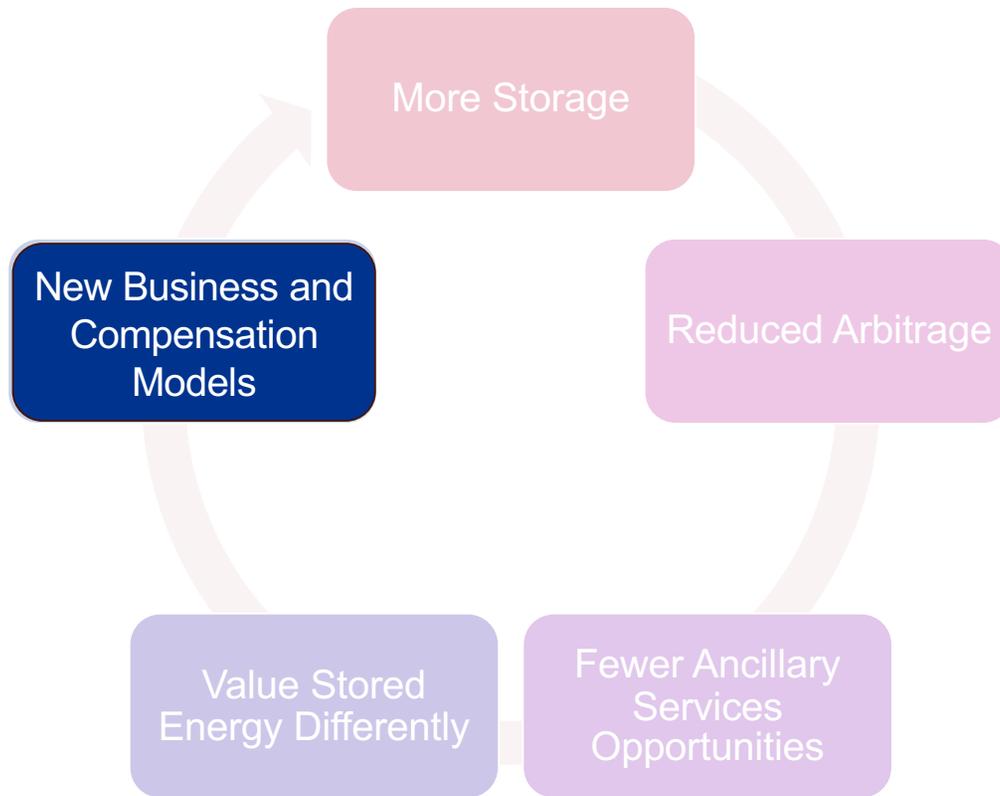
PNL 37702



Source: EIA

- We also found that a **10% increase in reservoir volume reduces price premiums (day-ahead minus real-time) by 5%**
- But storage can also affect other market dynamics, such as extreme prices during meteorologically-driven grid stress events (MDGSEs) and risk
 - We analyze the distribution of prices, finding that increases in reservoir storage volume reduce prices more at the upper end of the price distribution (~6%)
 - We analyze risk premiums, finding that increases in reservoir storage volume also reduce risk premiums (~5%)

Storage Matters Most When It Matters Most



MDES / LDES Valuation: Today vs. Future



MDES/LDES Asset Valuation Components

How Storage Is Valued Today

- Power delivery
- Ancillary services
- Arbitrage

What's Missing:

- Value of stored energy availability

MDES/LDES Valuation Drivers of Change

- **Need:** MDES/LDES reduce renewable curtailments and increase reliability.
- **Revenue:** Price arbitrage revenues decline with increasing MDES/LDES penetration.
- **Intrinsic Storage Value:** Industrial commodity storage assets deliver convenience yield for the cost of carry.

Quantify MDES/LDES full benefits



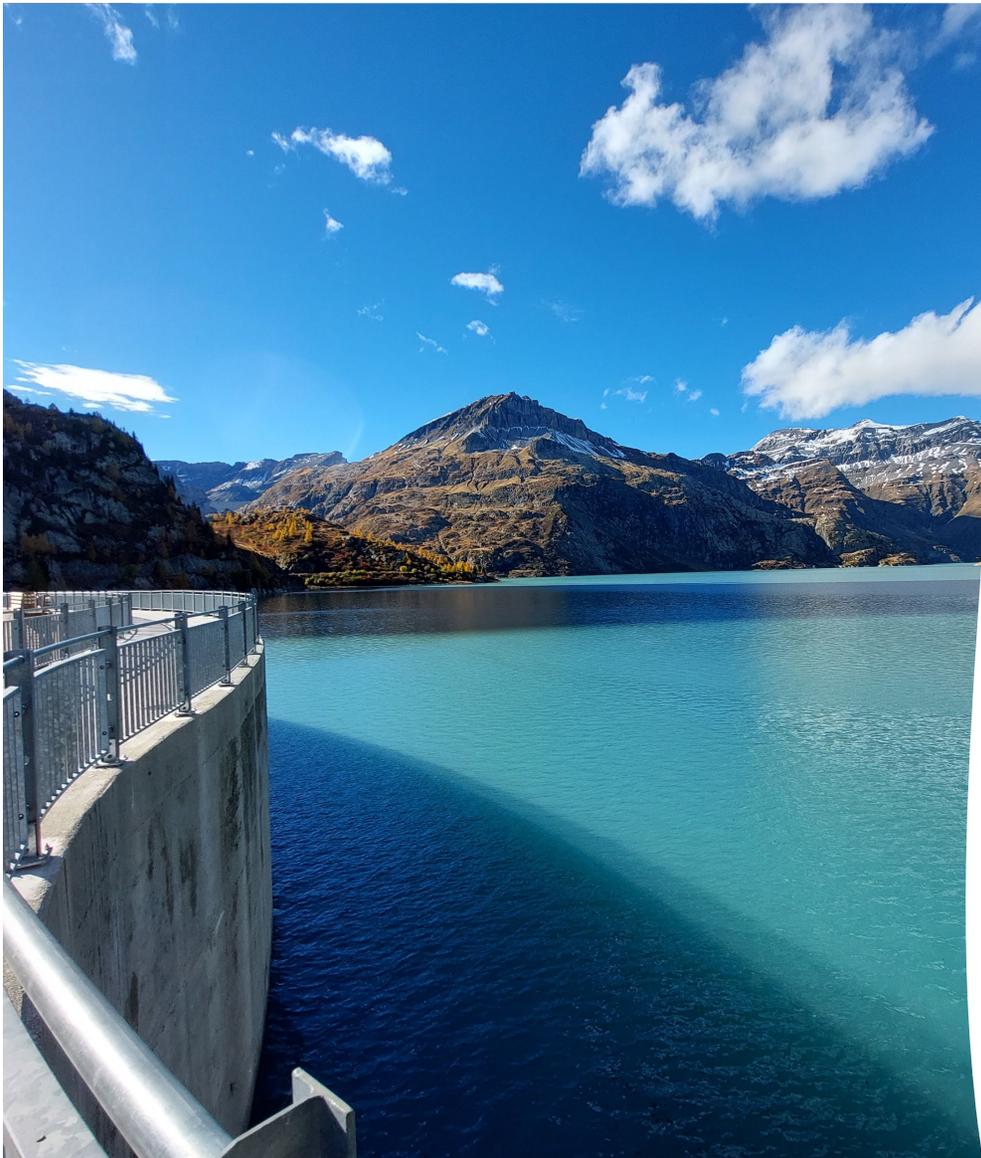
MDES/ LDES Asset Valuation Components

How Storage Must Be Valued in the Future

- Power
- Services
- Readiness and risk reduction

What Would a Stored Energy Product Do?

- A stored energy product should answer:
 - What problem is being solved?
 - When is the energy needed?
 - How much energy and for how long?
 - Does it reward *holding* energy, not just releasing it?



Longer-term flexibility

Swiss winter reserve



2022-23 - Swiss recognised long-duration energy storage needs.

January 2023 – Winter Reserve Ordinance entered into force. Federal Council awarded the contract for reserve power plants to DETEC - consisting of three hydropower reserves and aggregated poolers

Winter tenders:

For the winter of 2023/24, a total volume of 400 GWh was procured at an average price of 138.67 euros/MWh (previous year: 739.97 euros/MWh).

2024 Three Tranches - A total energy volume of 250 GWh (winter of 2023/24: 400 GWh) was procured at an average price of 66.12 €/MWh (previous year: 138.67 €/MWh).

1. 63 GWh were awarded at an average price of 53.17 €/MWh
2. 82 GWh at an average price of 68.2 €/MWh
3. 105 GWh were awarded at an average price of 72.28 €/MWh

Stored Energy Products Across Three Regions

Region	Stored Energy Products	Resource(s)	Eligibility	Driver for Product	Resource Owner Benefits	Future stored energy products
PJM	Dual-fuel “Stored Energy” ELCC class for Resource Adequacy	Gas CC/CT units	Operate onsite alternate fuel for two 16-hour periods across two consecutive winter days .	Triggered by empirical observations of event durations in 2014 Polar Vortex and 2022 Winter Storm Elliot. 2-day events most common.	Increase in RA payment	“Should a longer duration benefit arise, PJM will propose to update its ELCC Class definitions at that time” [1]
BPA (Pacific Northwest)	120-Hour Hydro Capacity metric (2023 White Book)	Li-ion batteries (Salem Smart Power Center), flywheels, thermal/demand-side storage, pumped hydro studies.	Average output from the 6 highest HLH hours/day × 5 days/week × 4 weeks/month → reflects sustainable multi-hour hydro capability.	Single-hour peaks misrepresent sustainable hydro capability; RiverWare is used to estimate usable hourly hydro output while meeting non-power constraints.	<i>Research ongoing</i>	2024 White Book: metric under revision to incorporate changing hydrology
Switzerland (Swissgrid & EICOM)	Winter Hydropower Reserve (WResO)	Storage hydropower, backup thermal/ CHP/ emergency generators	Storage hydropower must hold back ~300 GWh ± 100 GWh energy for Feb-May.	Triggered by 2022 European energy crisis; high winter import dependence and hydrological risk required an energy-based strategic reserve. Volume derived from adequacy simulations : worst-case 6–8-day winter energy deficit ≈ 300 GWh.	Annual tender for withheld hydro energy (e.g., 3 tranches in 2024/25 totaling 250 GWh). <i>Research ongoing</i>	<i>Research ongoing</i>

[1] Email correspondence from Sr. Director of Stakeholder Affairs; Rationale provided in ER24-99 Filing

Stored Energy as a Commodity

- **Why Power Markets Alone Don't Work**
 - Power markets reward discharge, based on arbitrage
 - They discourage holding energy for long periods
 - This creates incentives to empty storage too early
- **What Does It Mean to Treat Stored Energy as a Commodity?**
 - The product is *availability*, not generation
 - Value comes from reducing system risk
 - Compensation reflects insurance-like benefits
- This already exists in other commodity markets – oil, gas, etc.



Thank you



