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PNW ELCC Sensitivity Analysis

Technical Report – August 2026

Contents

Study Objectives and Scope

01

Establish near-term system resource adequacy model

Measure resource adequacy metrics and system risk across modeling methods and input assumptions.

02

Calibrate & accredit

Calibrate each case to a 0.1 LOLE target and calculate ELCC for solar, wind, storage, and thermal resources using each sensitivity setup.

03

Explore modeling impacts on ELCC

Identify how modeling choices affect accreditation results so to align on best practices and identify shortfalls.

ELCC CALCULATED FOR EACH RESOURCE x 8 Sensitivities

Solar	Wind	4-hr BESS	8-hr BESS	24-hr Storage	Combustion Turbine

Principal Takeaway:

The settings we choose, model assumptions, and model topology affect accreditation outcomes for resources. These settings should be transparent, their impact should be clear, and methods agreed upon.

Modeling Method Case Matrix

This sensitivity matrix quantifies how PNW resource ELCCs are sensitive to various modeling assumptions. Each of the assumptions, hydro dispatchability, correlated water and weather, storage dispatch behavior, cold weather outage risks on new thermal generators, and including neighbor-region support, drive a different risk landscape and a different accreditation result.

MODELING ASSUMPTION	Baseline	1	2	3	4	5	6 Combined PNW	7 Neighbors
Hydro Dispatchability	Load following	Moderate	High				High	High
Weather / water correlation	Un-correlated			Correlated			Un-correlated	Un-correlated
Battery operations	Energy arbitrage				Reliability		Hybrid arbitrage + Reliability	Hybrid arbitrage + Reliability
Thermal outages	Random					Correlated	Random	Random

Highlighted rows — hydro operations and weather/water correlation are key drivers.
For all cases, we assume storage does not provide A/S to measure energy shifting value only.

Baseline Changed from Baseline

Case Description and Starting Metrics per Case

Case	Label	Description / resources assessed	LOLE target (d/yr)	EUE target (MWh/yr)
Baseline	Baseline	Load-following hydro · un-correlated weather/water · battery energy arbitrage · random thermal outages · **Resources: All**	0.11	416
Case 1	Moderate Hydro Dispatch	Moderate hydro dispatchability based on consecutive flex up days in EIA 930; **Resources: All**	0.1	150
Case 2	High Hydro Dispatch	High hydro dispatchability based on consecutive flex up days in EIA 930; **Resources: All**	0.1	140
Case 3	Correlated Water/Weather	Correlated water + weather years; **Resources: All**	0.11	201
Case 4	Battery Reliability Mode	Marginal battery held at 100% SOC except to avoid load shed; all else = Baseline · **Resources: Only evaluated 1 GW storage levels**	0.1	416
Case 5	Cold Weather Outages (CWO)	Cold-weather outage adder on marginal CT (+10% / +30% fail chance at extreme cold); all else = Baseline · **Resources: New CT only (Base / 10% CWO / 30% CWO)**	0.14	824
Case 6	Combined PNW	High hydro dispatch + un-correlated water + hybrid arbitrage/reliability battery + random outages · **Resources: Storage only**	0.1	134
Case 7	Neighbors	Neighbor modeling (CAISO + Greater NW; BCHA/DSW import support) + high hydro dispatch + hybrid battery · **Resources: Storage only**	0.1	110

Calibration and ELCC Approach

1. Firm import assumptions from BCHA or California were assumed in most cases
   - Only case 2, 6, and 7 assumed different base firm import assumptions, discussed in the next slide.
2. Firm imports were layered on top of the base assumptions to reach 0.1 LOLE as the calibration target
3. In all cases, firm imports were removed after the candidate resource was added until returning to the target LOLE (or EUE at 0.1 LOLE)

Firm Imports, Proxy Imports, and Case Differences

Firm Imports

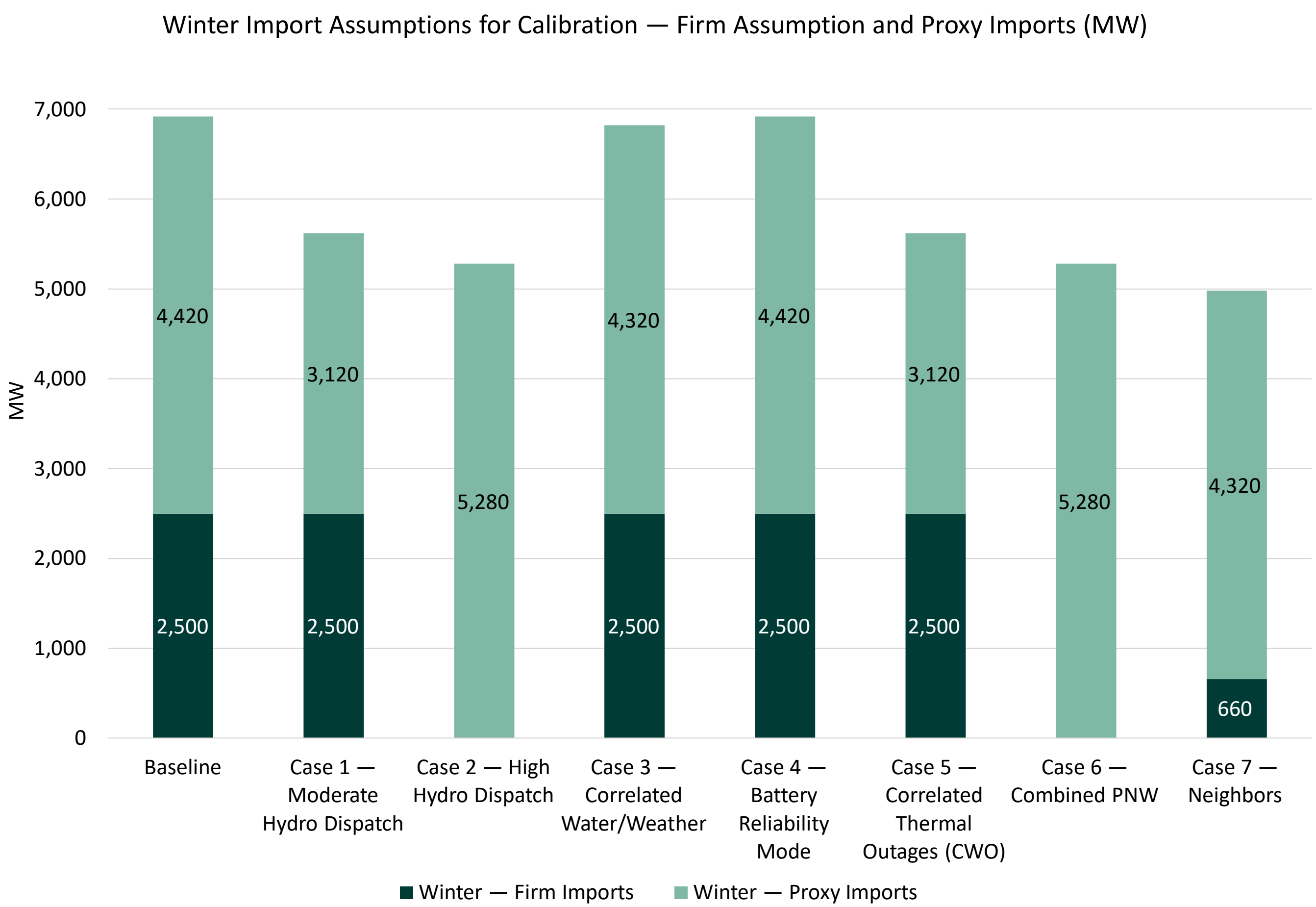
- Firm imports intended to represent reasonably available imports given most cases did not model wide-area neighbors
- Case 2 & 6 using high hydro dispatchability removed all firm import assumptions

Proxy Imports

- These represent high priced "perfect" generators to reach 0.1 LOLE
- In all cases, the ELCC of a resource was measured against the reduction in proxy imports it enabled

Case 7 - Neighbors

- Case 7 was intentionally made more unreliable as a starting point by scaling load across all regions.
- Proxy imports were then added to measure against the candidate resources (discussed later in slide 20)



Calibration and Import Takeaways

Hydro Dispatchability

- Resource adequacy **modeling of hydropower needs greater real-world validation for hydropower dominated systems.** Higher dispatchability reduced 'proxy imports' needed to calibrate the system to 0.1 LOLE.
- Increased hydro dispatchability means that hydropower may be competing to resolve similar events that storage can resolve
- Cascading hydropower and strict adherence to environmental requirements was not assessed. Enabling conservation of water resources for extreme events was only modeled using flexibility budgets.

Modeling Neighbors

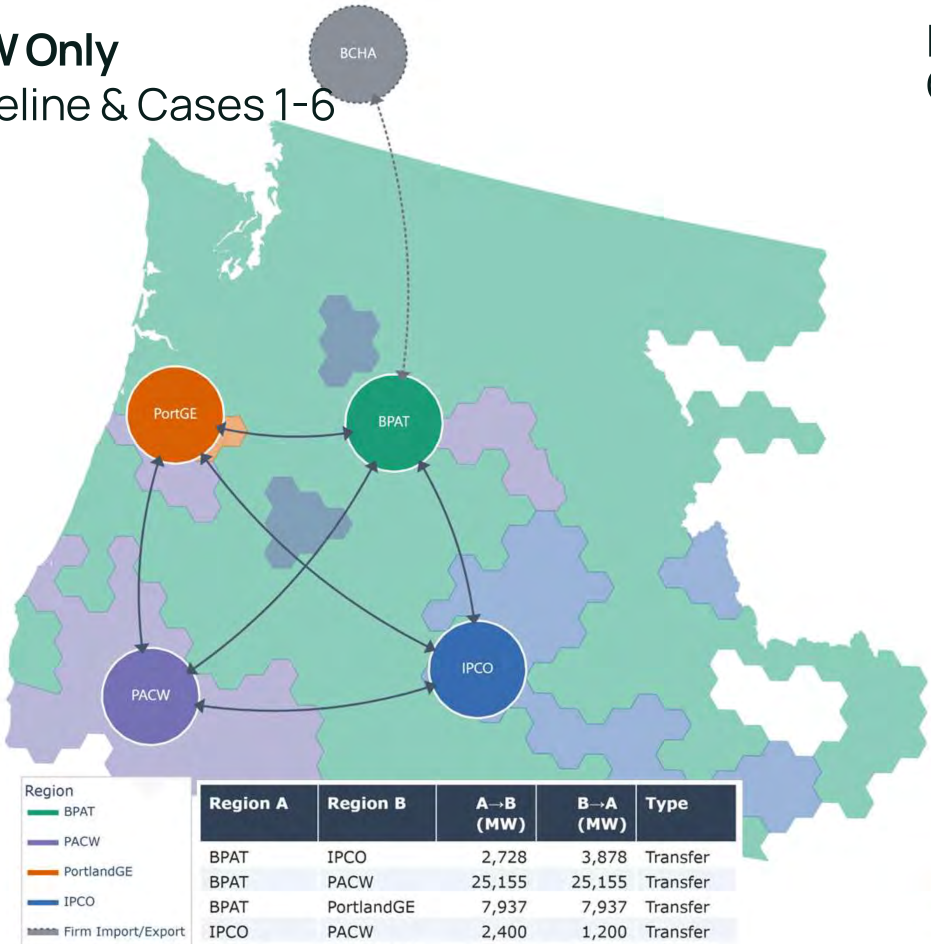
- Modeling CAISO, NWMT_WAUW, and PACE in detail alongside the PNW region revealed significant load diversity and benefits.
- The PNW still required some representation of British Columbia import availability in winter and summer.
  - All **future work must model British Columbia plus the Pacific Northwest in detail** to better capture their dynamics.
- We recommend **full WECC-wide resource adequacy modeling is needed to truly represent the load diversity, resource diversity, and import dynamics** that both reduce risks and minimize hydropower generation risks during drought years.

Import Dependency

- The **PNW is highly import dependent, particularly in drought years**. Whether that is leverage imports to manage water budgets in the model, charge storage, or meet peak demand due to hydropower capacity limits, imports play a significant role.

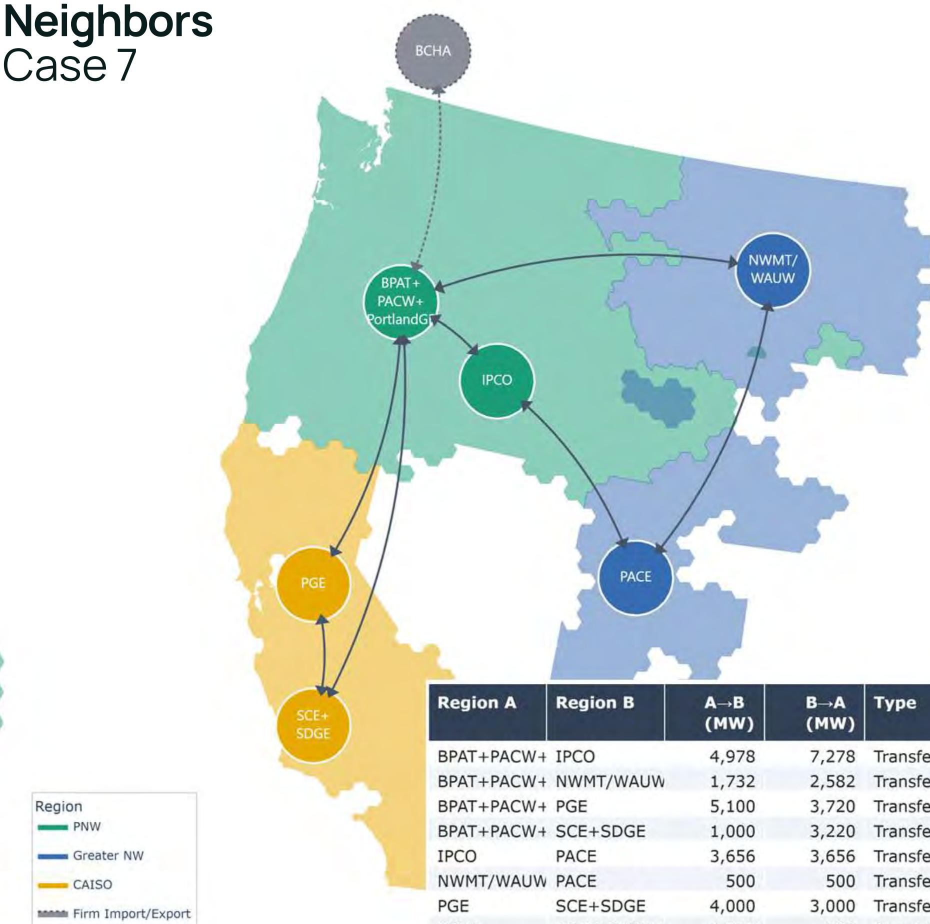
PNW Only & Neighbors Topology

PNW Only
Baseline & Cases 1-6



Region A	Region B	A→B (MW)	B→A (MW)	Type
BPAT	IPCO	2,728	3,878	Transfer
BPAT	PACW	25,155	25,155	Transfer
BPAT	PortlandGE	7,937	7,937	Transfer
IPCO	PACW	2,400	1,200	Transfer
IPCO	PortlandGE	1,000	1,050	Transfer
PACW	PortlandGE	3,809	3,809	Transfer
BCHA	BPAT	1,250	660	Firm I/E

Neighbors
Case 7



Region A	Region B	A→B (MW)	B→A (MW)	Type
BPAT+PACW+	IPCO	4,978	7,278	Transfer
BPAT+PACW+	NWMT/WAUW	1,732	2,582	Transfer
BPAT+PACW+	PGE	5,100	3,720	Transfer
BPAT+PACW+	SCE+SDGE	1,000	3,220	Transfer
IPCO	PACE	3,656	3,656	Transfer
NWMT/WAUW	PACE	500	500	Transfer
PGE	SCE+SDGE	4,000	3,000	Transfer
BCHA	BPAT+PACW+	1,250	660	Firm I/E

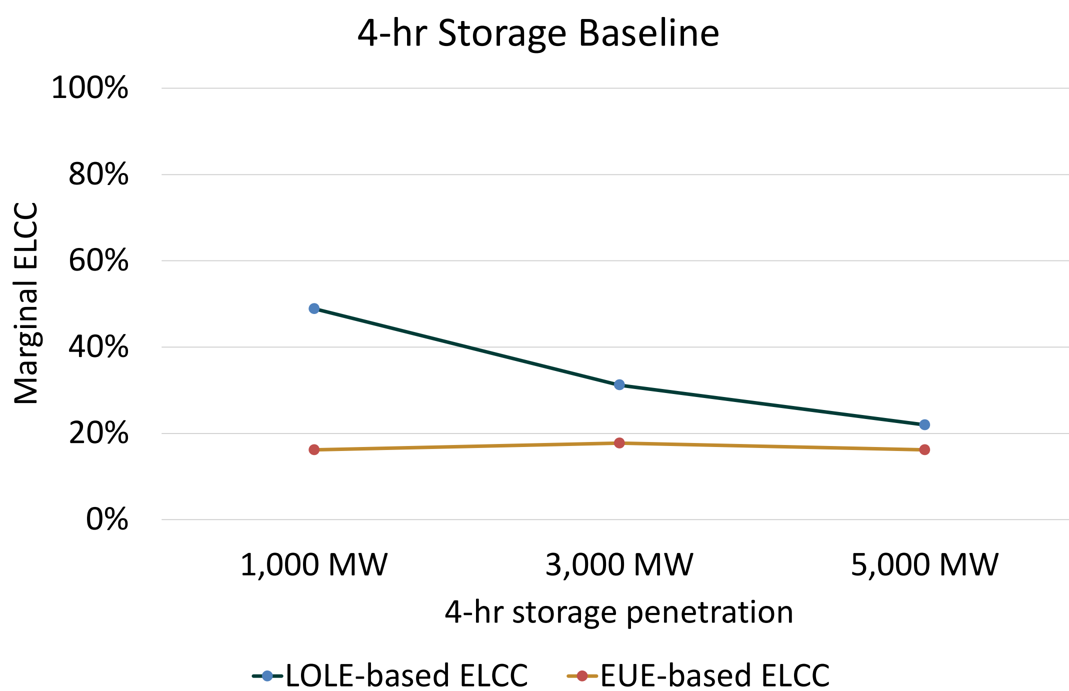
*SCE+SDGE includes PDCI with S→N transfer limit of 1,000 MW

Loss of Load Expectation (LOLE) and Expected Unserved Energy (EUE) Accreditation

- Loss of Load Expectation = Shortfall Frequency Metric
- Expected Unserved Energy = Shortfall Magnitude Metric
- Storage is inadequately valued using a single metric, so we calculated ELCC using both based on EUE at LOLE = 0.1

Key Findings

- LOLE-based ELCC > EUE-based ELCC
- At higher penetration, energy limitations, not capacity, drive converging ELCC values
- 4-hr storage accreditation ranges from 14% to 50% at 1,000 MW

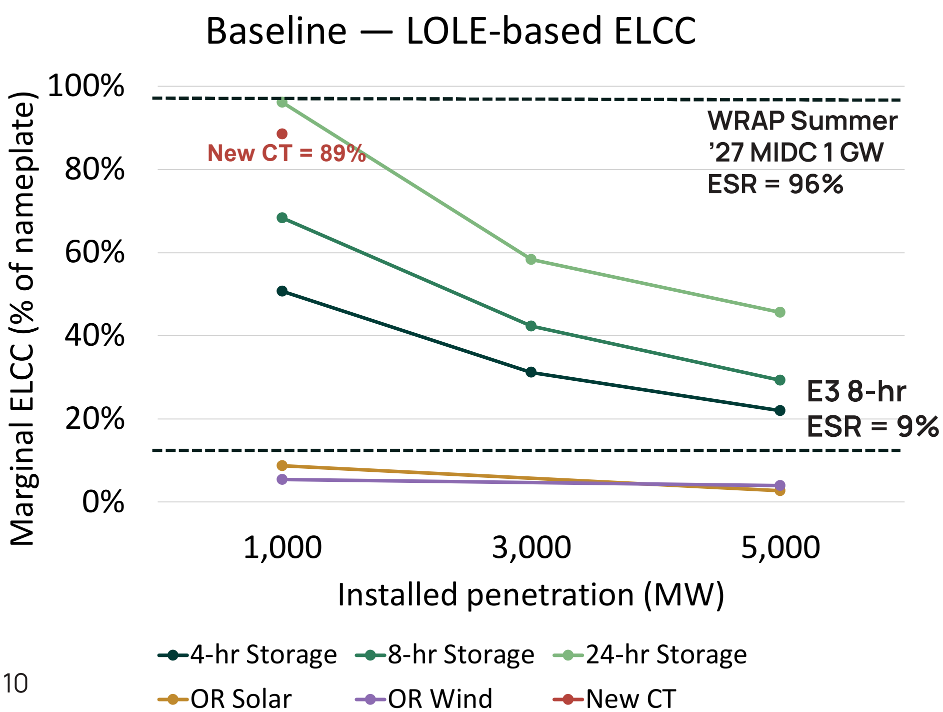


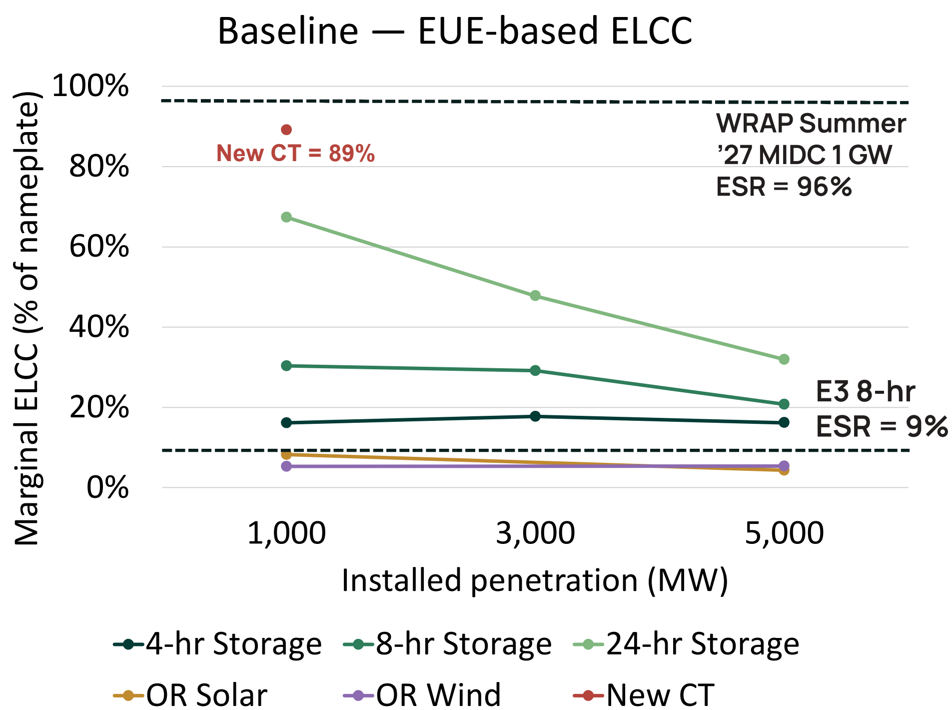
ELCC Results

Baseline & Cases 1 - 6

Baseline ELCC Results

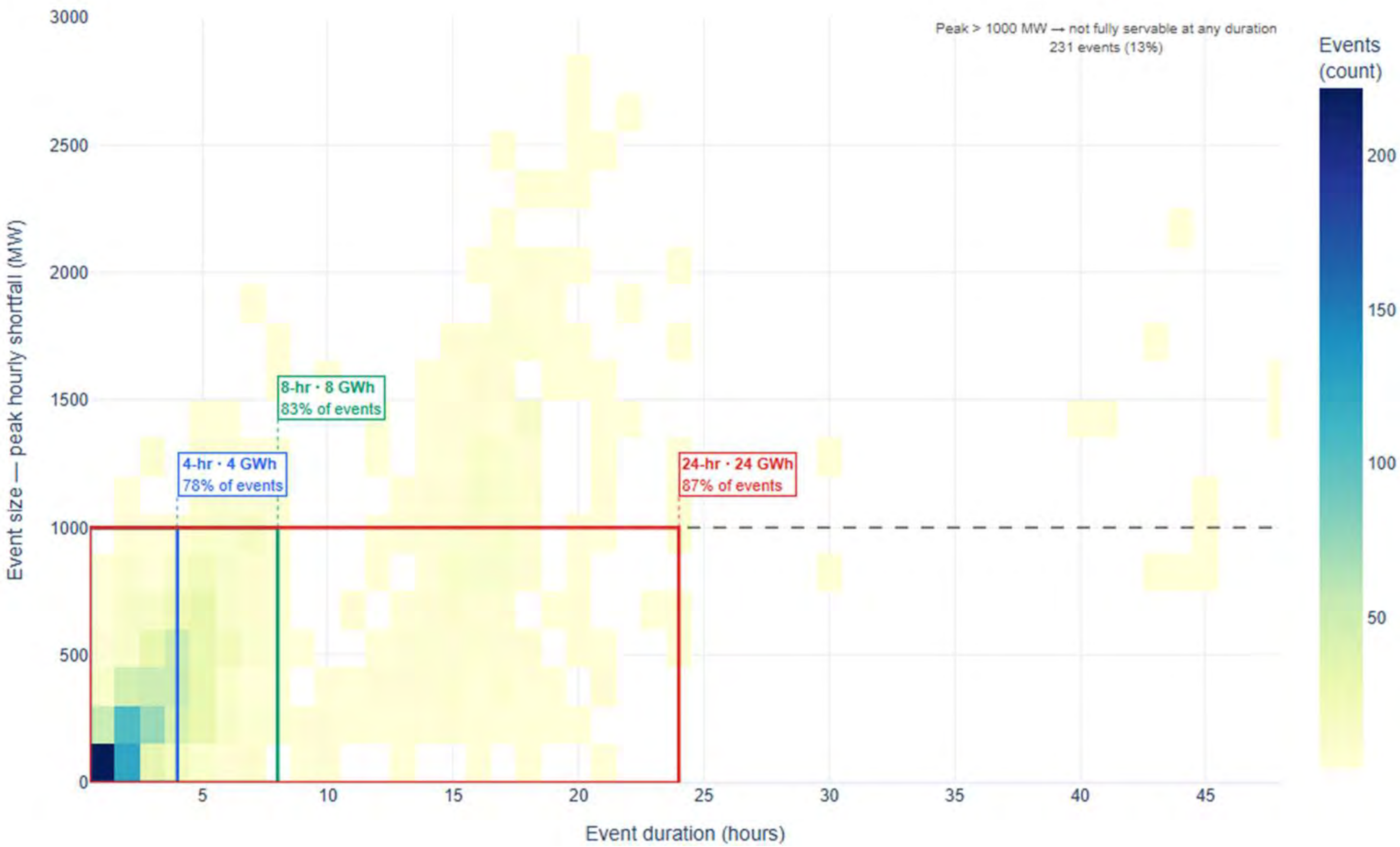
- Baseline simulates uncorrelated water/weather and requires significant proxy imports for calibration
- Storage ELCC values decline as penetration grows across all durations (expected)
- Longer-duration storage retains higher accreditation at higher penetration
- Our values fall between those reported in the WRAP and the Northwest Utilities (E3) studies





Baseline Event Count and Storage Size Coverage

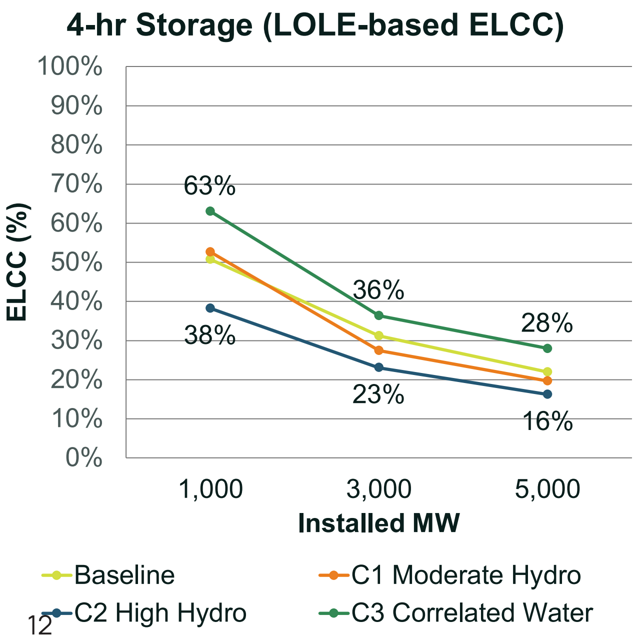
- Shortfall events in the Baseline system are predominantly <24 hours (87% of all events).
- Once storage is deployed above 1,000 MW however, the risks shift towards longer duration events and reduced accreditation.
- Results that share details on the size, frequency, and duration of shortfall events are needed.
- This will inform better procurement of storage resources.

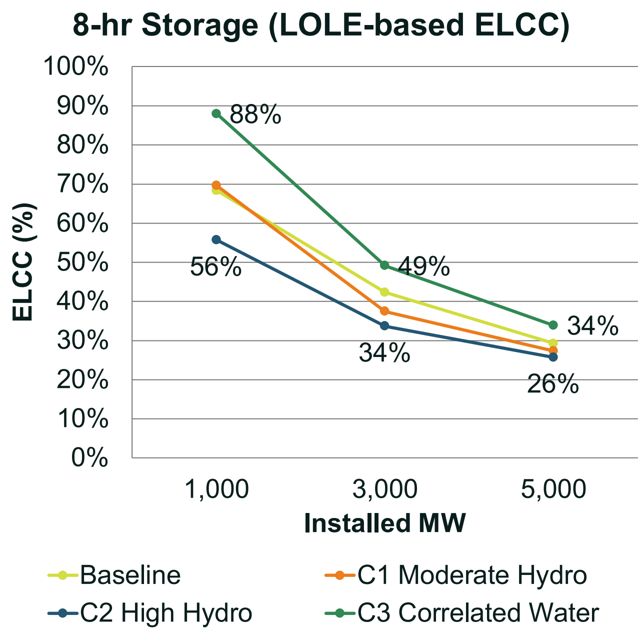


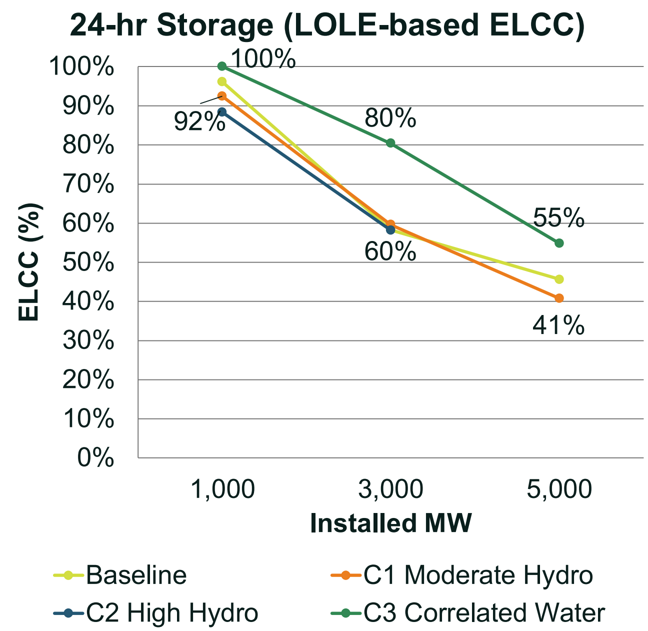
Baseline & Cases 1–3

Effect of Hydropower Assumptions on Storage LOLE-based ELCC

- Increasing hydropower dispatchability changes storage ELCC.
  - Increased dispatchability (from load-following mode) can compete with storage, even while shaping shorter duration events.
  - Higher hydropower dispatchability reduces calibration resource need. There could be an accreditation method effect on ELCC values based on how calibration is done.
- Correlated water/weather surfaces risk that is more manageable with 4, 8 and 24-hr storage resulting in higher accreditation for all cases.



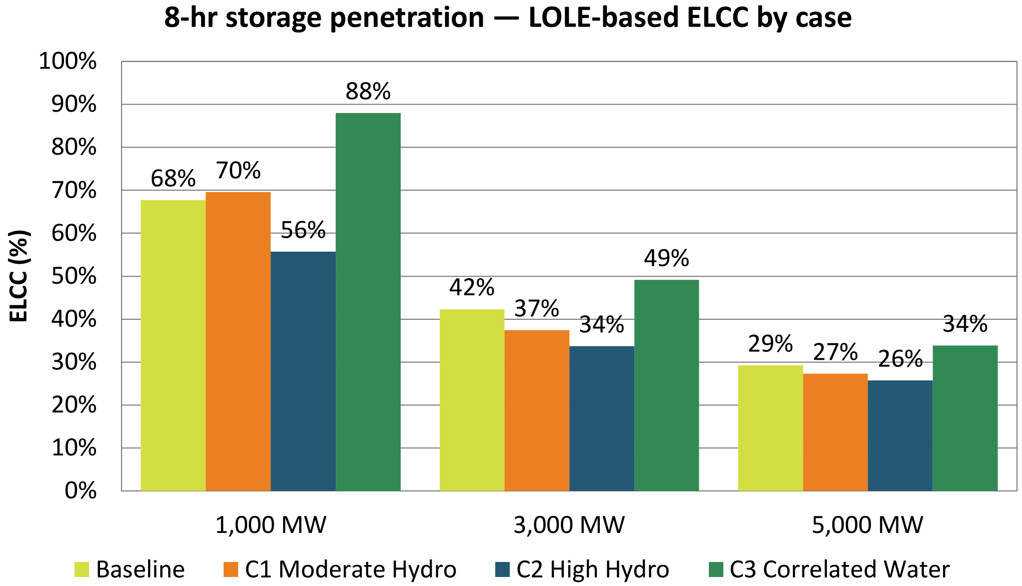


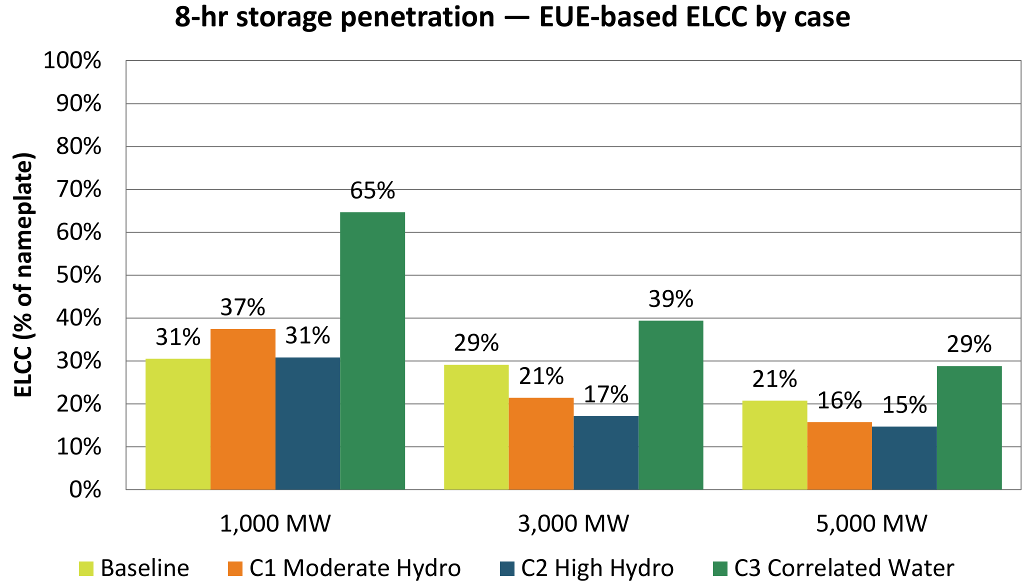


*ELCC estimate errors is +/- 2% so many cases show functionally the same ELCC value

Effect of Hydropower Assumptions – LOLE-based vs EUE-based ELCC

- Baseline versus Correlated Water cases show correlated water and weather modeling results in persistently higher ELCC values even as storage penetration grows.
- For all storage durations and accreditation methods, **higher hydropower dispatchability lowered ELCC values of storage in most cases.**

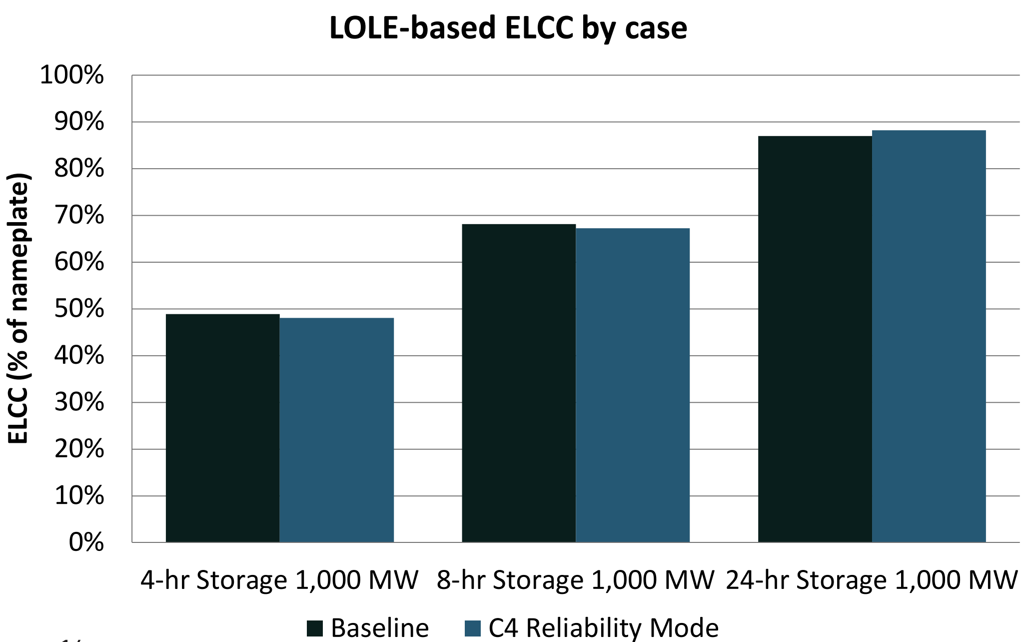


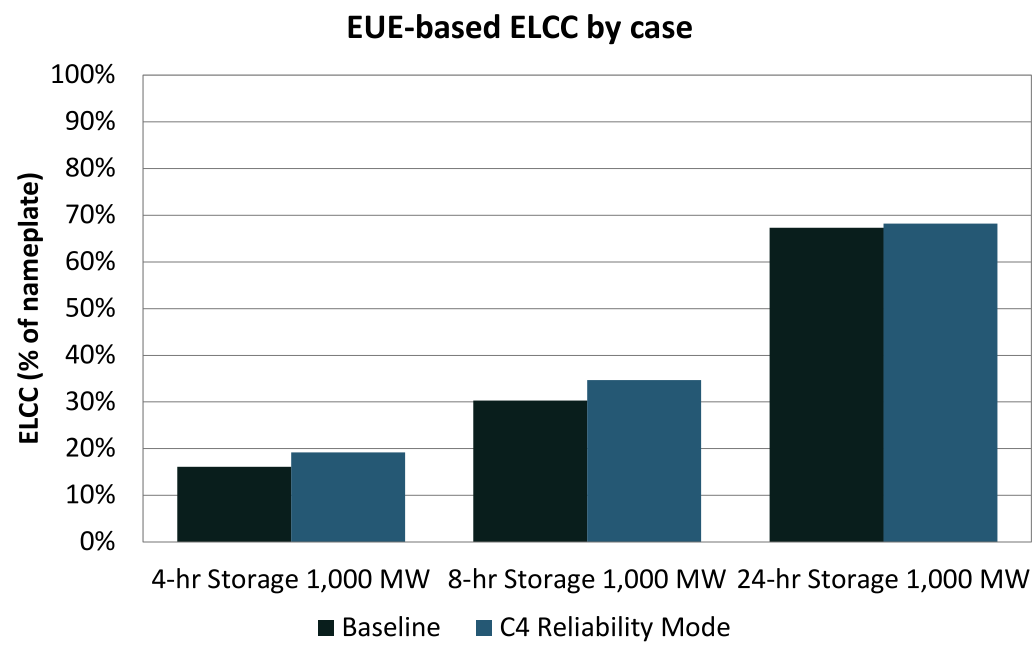


*ELCC estimate errors is +/- 2% so many cases show functionally the same ELCC value

Preserving Storage State of Charge Effect on ELCC

- Preserving storage state of charge (SOC) using reliability mode revealed minimal changes
- Since accreditation is focusing on reliability value for storage, but timing to charge up is important, the combined and neighbors case use a hybrid economic + reliability mode.





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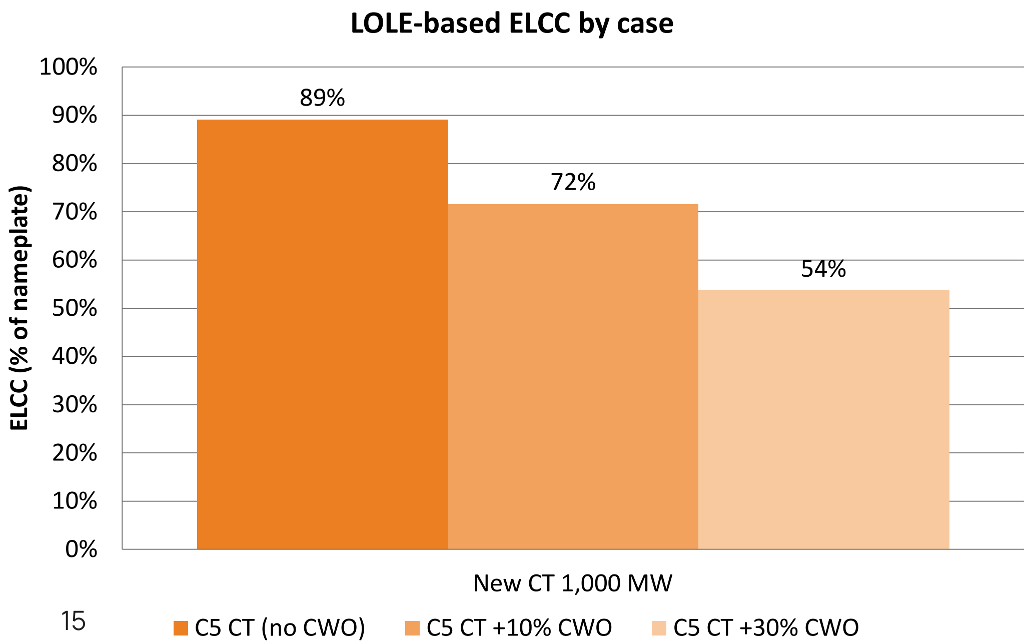
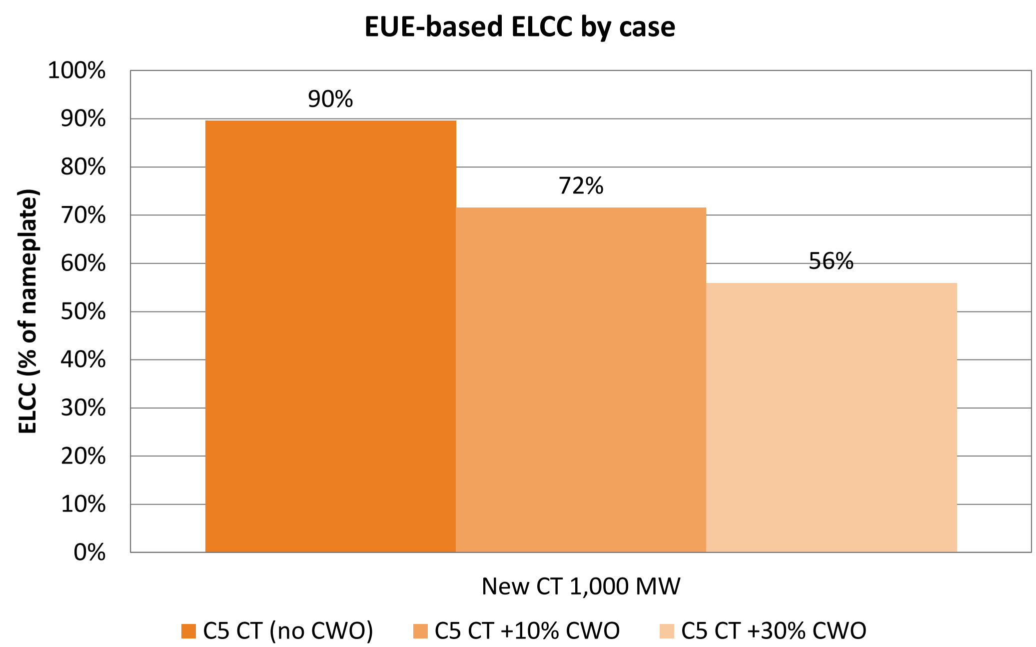
Effect of Cold Weather Outage Sensitivity on CTs

- Notably, limited historical NERC GADS data is available that shows increased cold weather outage in the Pacific Northwest
  - Natural gas storage is critical to the PNW. A lack of firm fuel resources could create correlated outage risks.
  - This case explores two 'what if' scenarios on the ELCC of new CT units with a 10% and 30% increased outage rate.
  - **If cold weather outage sensitivity exists for new units; CT accreditation would drop to 50 – 70% depending on severity.**





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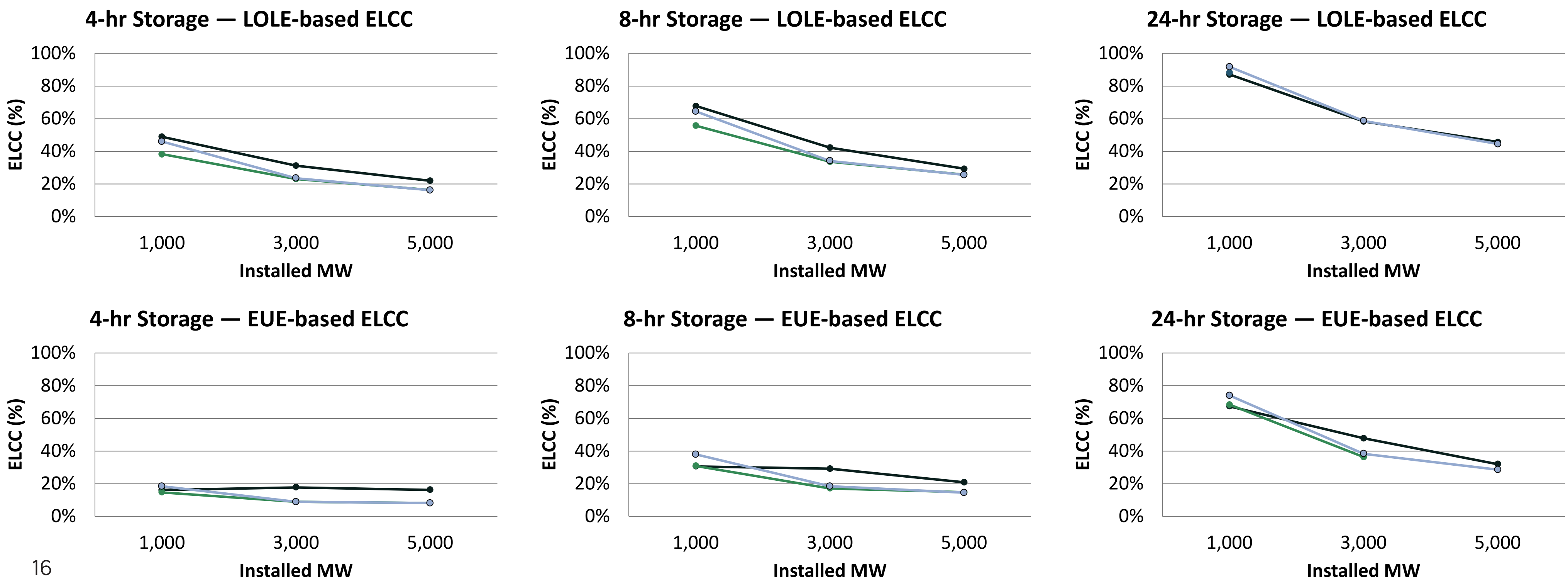
Combining Sensitivity Assumptions (Case 6)

- Case 6 models uncorrelated water, high hydro dispatchability, and hybrid economic + reliability storage
- Results confirm higher hydro dispatchability lowers accreditation
- **EUE-based accreditation < LOLE-based accreditation for storage**

Legend
Baseline
C2 High Hydro
C6 Combined



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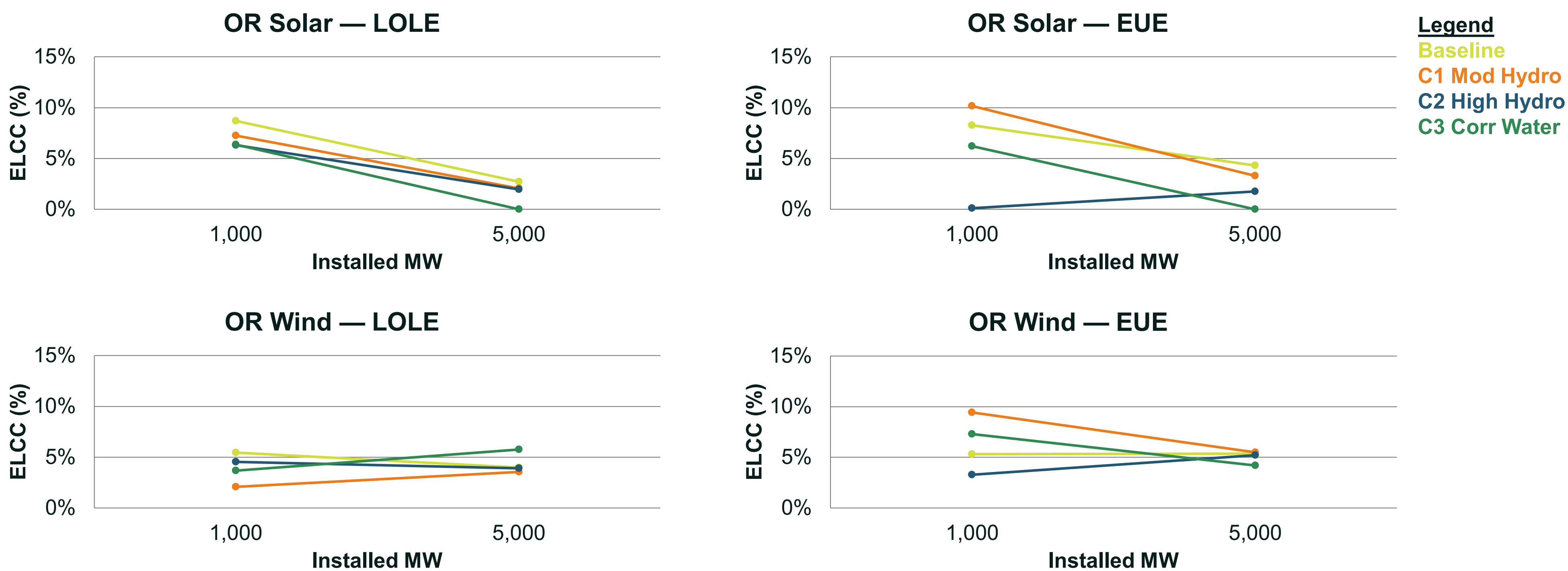
Solar and Wind ELCC Sensitivity Case Results

- Across all cases and penetration levels modeled (Baseline and 1 – 3), PNW solar and wind (Oregon siting) has ELCC values <10%.
- Portfolio effects of hybrid renewable + storage or effects of renewables on hydropower dispatch will be embedded in the Phase 2 expansion planning.



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ELCC Results

Baseline & Case 7

Baseline vs Case 7

Case 7 – Modeling Neighbors RA Risk Comparison to Baseline

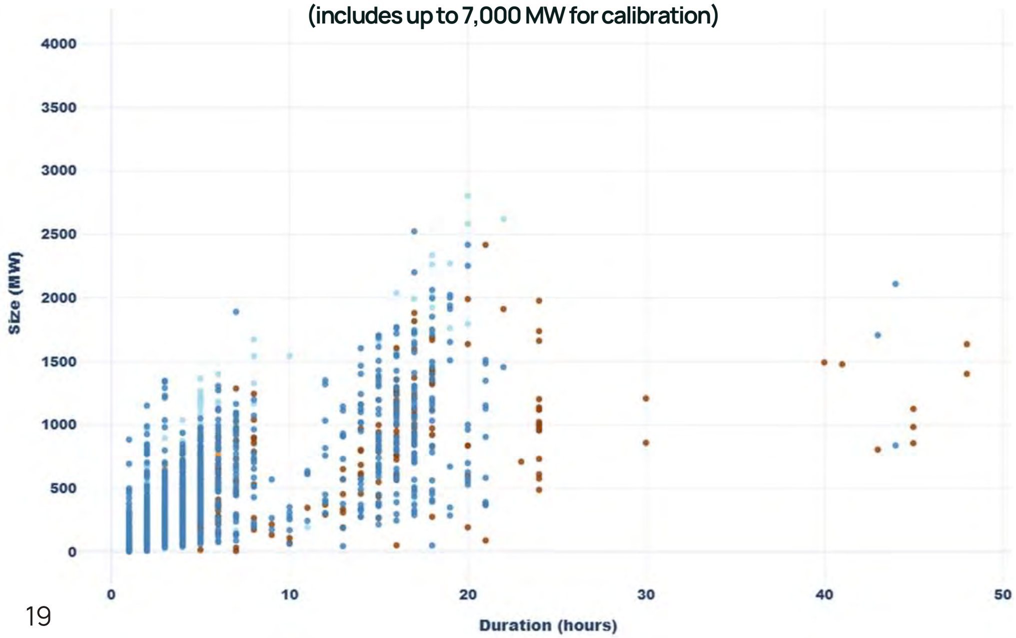
2026 Results for Neighbor Modeling Shows Elevated PNW Risk

- PNW LOLE = 0.3 days/year, higher than our 0.1 LOLE target
- Neighbors provide support, such as reducing event durations, but event frequency remains challenging.
- The two size, frequency, and duration plots show the PNW "at criterion" in the Baseline, but with far greater long duration event exposure than when modeling neighbors. This has implications for the value of storage.

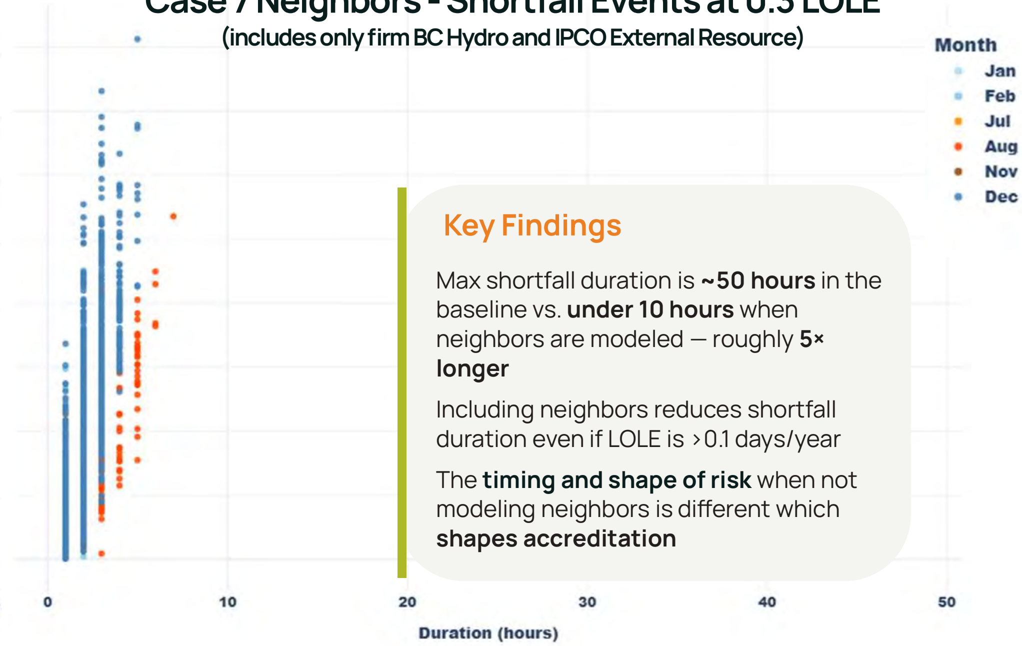
Case 7 ELCC Method for Using Proxy Imports to Measure ELCC

- Increased regional risk by scaling load +5%
- Added proxy generators, brought back to 0.1 LOLE
- Add candidate resource (e.g., 5 GW 8-hr storage)
- MW of removed proxy generators back to criterion = ELCC

Baseline - Shortfall Events at 0.1 LOLE
(includes up to 7,000 MW for calibration)



Case 7 Neighbors - Shortfall Events at 0.3 LOLE
(includes only firm BC Hydro and IPCO External Resource)



Key Findings

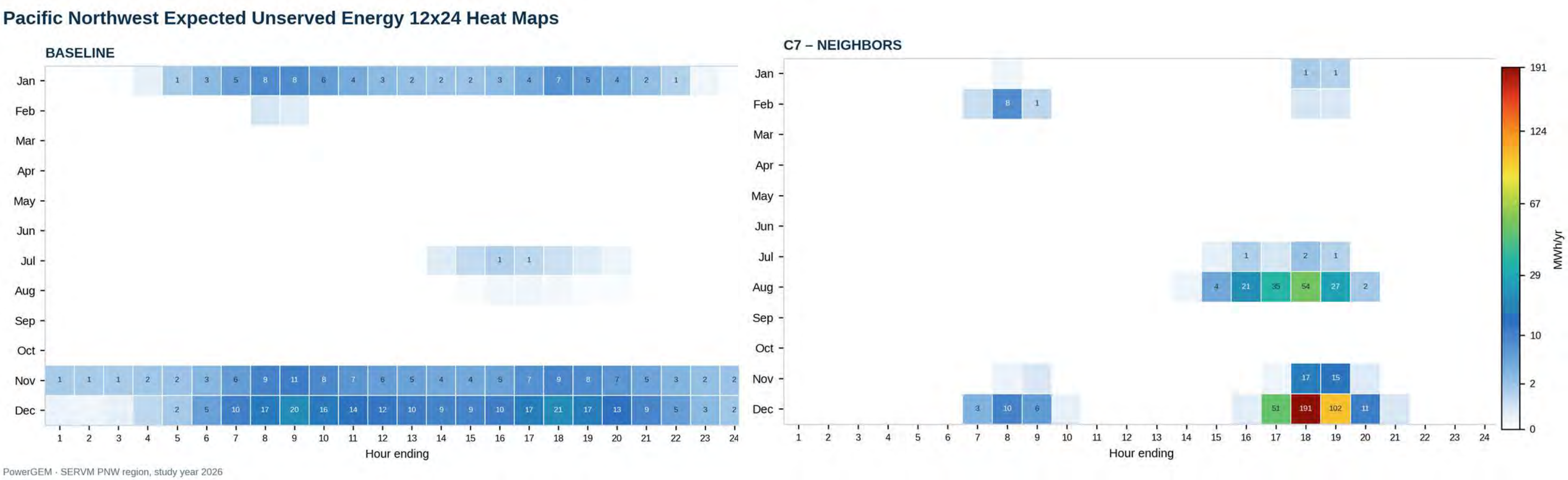
Max shortfall duration is **~50 hours** in the baseline vs. **under 10 hours** when neighbors are modeled — roughly **5× longer**

Including neighbors reduces shortfall duration even if LOLE is >0.1 days/year

The **timing and shape of risk** when not modeling neighbors is different which **shapes accreditation**

PNW Only & Neighbors Topology Shortfall Risks

Modeling neighboring regions in detail changes shortfall duration, timing, and magnitude
- The timing and duration of risk fundamentally changes the accreditation value for storage



Case 7 – Modeling Neighbors Load Diversity

Neighbors in Case 7 Show Substantial Load Diversity

- This indicates high RA value from enabling interregional sharing
- Market constructs that do not block interregional coordination will reduce RA risks and buoy storage accreditation.
- Not modeling the southwest in greater detail was a limitation of this study. Leveraging NW and SW diversity can enhance the value of storage and transmission.

Coincident Peak Load Correlation Between Case 7 Neighbors

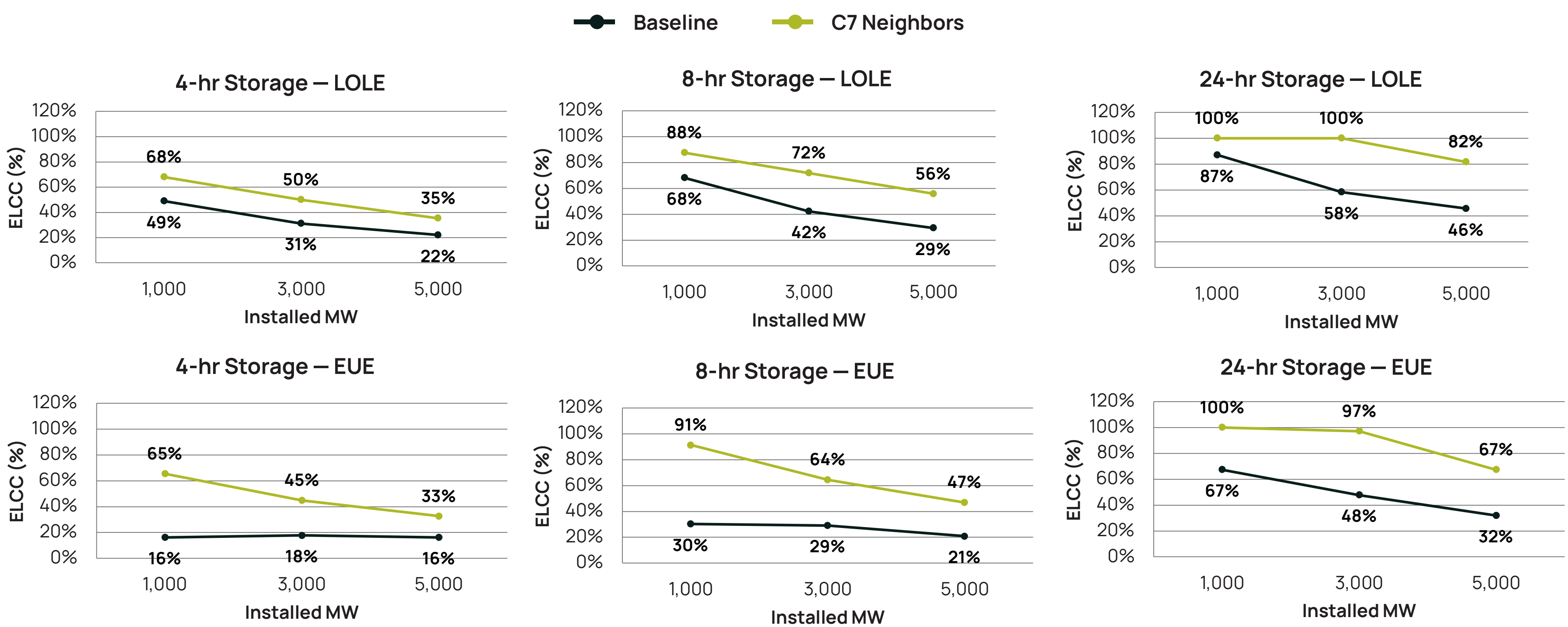
	BPAT	PACW	PortlandGE	IPCO	NWMT	PACE	PGE	SCE	SDGE
BPAT	100%	76%	77%	71%	70%	72%	76%	58%	55%
PACW	81%	100%	98%	86%	85%	85%	90%	75%	62%
PortlandGE	75%	88%	100%	70%	69%	73%	90%	69%	69%
IPCO	65%	93%	91%	100%	92%	94%	97%	77%	54%
NWMT	80%	89%	79%	82%	100%	87%	91%	74%	56%
PACE	67%	93%	86%	88%	91%	100%	98%	89%	63%
PGE	44%	78%	83%	77%	84%	80%	100%	87%	82%
SCE	43%	82%	74%	70%	77%	80%	90%	100%	93%
SDGE	44%	65%	54%	58%	60%	63%	81%	91%	100%

Lower correlation (green) indicates greater load diversity; higher correlation (red) indicates coincident peaks.

Case 7 – Modeling Neighbors ELCC Results vs Baseline

Modeling neighbors results in an increase in Storage ELCC for all duration types and accreditation metrics

- Interregional transmission and resource sharing improves the value of storage shifting energy over time and meeting peak capacity.
- Modeling a wider area reduces hydropower drought risks found in the uncorrelated water simulations



Summary

Takeaways and Recommendations

ELCC Sensitivity to Modeling Assumptions

Hydro assumptions greatly affect storage accreditation

Higher hydro dispatchability competes with storage on the same events and lowers storage ELCC; correlated water/weather surfaces risk that storage manages well, raising accreditation across all durations.

Accreditation Should Measure Benefits Based on Multiple Resource Adequacy Metrics

LOLE-based ELCC consistently exceeds EUE-based ELCC — 4-hr storage spans 14–50% at 1,000 MW depending on case and metric. Uncorrelated water mixing droughts with high net load drives the sharpest divergence between LOLE and EUE-based accreditation.

Local Renewables (Oregon Solar and Wind) Show Low Accreditation in All Cases

Oregon-based solar and wind offer consistently low values (<10% ELCC). Their primary role will be to work together with storage to take pressure off the hydropower system, especially during drought years.

Sensitivity to cold weather outages drastically reduces new combustion turbine ELCCs

If new natural gas combustion turbines exhibit cold weather outage sensitivity of 10% to 30% increase in forced outage rates below -5 degrees Fahrenheit, accreditation drops from 90% to 70% and 50%.

ELCC Sensitivity to Modeling Neighbors

1. **Interregional sharing shows higher storage value at higher penetrations**
   Modeling CAISO, NWMT_WAUW, and PACE lets storage shift energy across diverse regional peaks, lifting accreditation across every duration.

2. **Load and resource diversity is significant**
   Case 7 neighbors show low coincident-peak correlation — market constructs that do not block interregional coordination directly reduce RA risk.

3. **Wider-area modeling supports the PNW during drought risk**
   Neighbor support offsets the hydropower drought risk seen in uncorrelated-water runs. British Columbia and the Southwest were not modeled in detail, so the diversity benefit is likely understated.

8-HR STORAGE LOLE-ELCC UPLIFT VS BASELINE

+19% → +30%

across 1 GW, 3 GW, and 5 GW penetration levels

8-HR STORAGE EUE-ELCC UPLIFT VS BASELINE

+13% → +35%

energy-limitation is mitigated and storage EUE value is higher

Recommended Path Forward

1. **Storage and Thermal accreditation is the most sensitive to modeling methods (e.g., hydropower dispatchability, correlation, cold weather outages). Storage is most sensitive to calibration methods and topology (firm imports, neighbor modeling, etc.).**
   - Wind, solar, thermal accreditation all have close results across cases and methods.
   - Cold weather outage risks due to fuel supply disruptions (NG storage risks) or non-firm fuel arrangements could drastically reduce new gas accreditation value.

2. **Multi-value accreditation represents the multiple-dimensions of storage. Frequency and magnitude both matter.**
   - LOLE-based accreditation and EUE-based accreditation in isolation are inadequate.
   - Recommended that both are reported and some hybridized approach is leveraged to reflect the value storage provides in reducing event frequency.

3. **Energy availability for storage to charge from is crucial to accreditation, including benefits of neighbors.**
   - Focus efforts on representing imports and interregional transfers in more detail in resource adequacy modeling.
   - Results support pursuing hybrids where energy can be better optimized through storage.
   - Recognize the value storage can provide if hydro maximum output is limited but energy is available.
   - Evaluate how significant renewable energy deployment or greater interregional coordination can optimize water for hydropower prior to extreme events.

Additional Details

Hydropower Modeling in SERVM

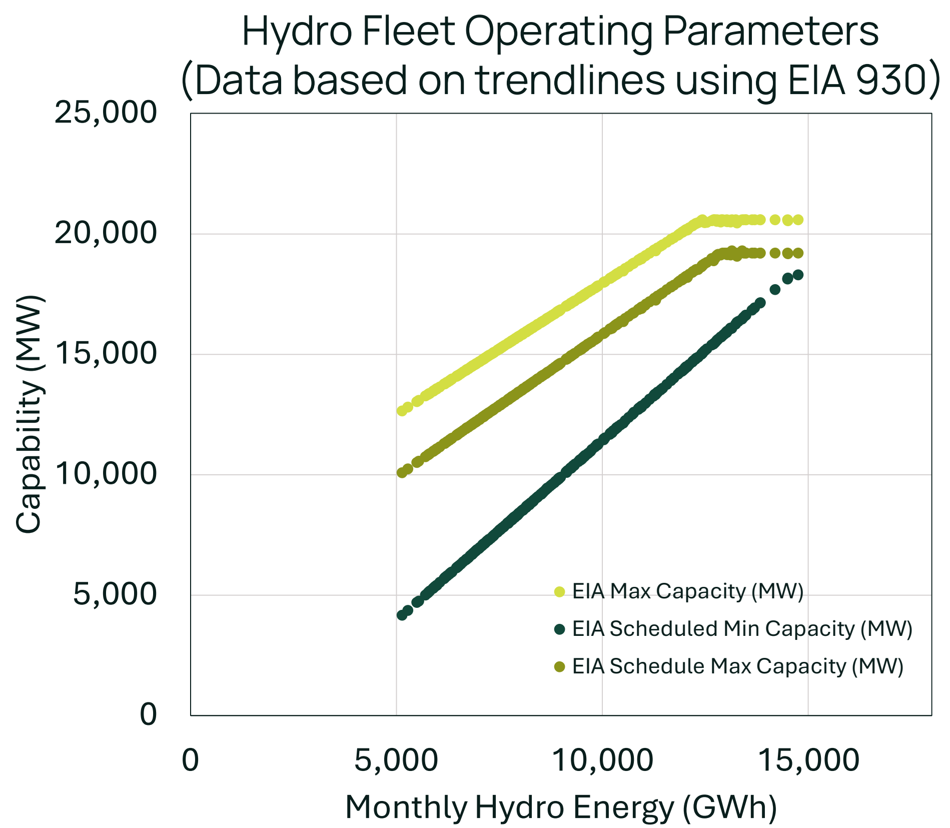
POWERGEM

SERVM Hydro Modeling Details

Operating Parameters:
1. EIA 930 hourly hydro for hydro aggregate fleet
2. Historical data used to develop trends versus monthly energy

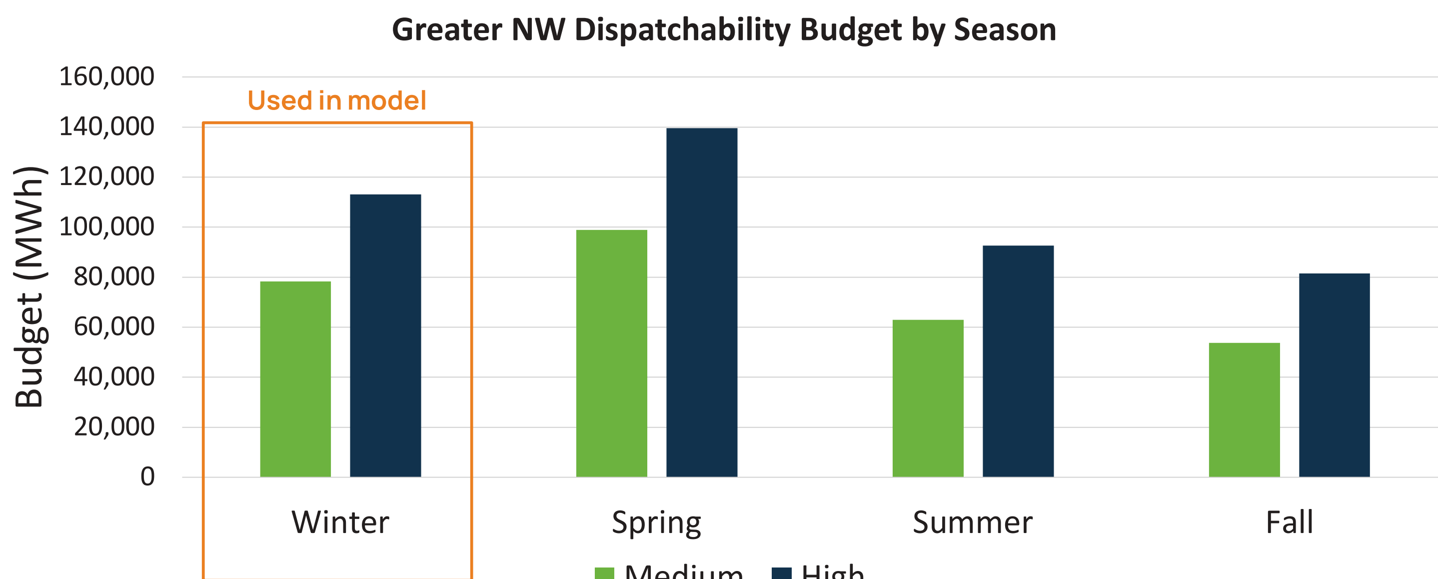
Hydro Scheduling Algorithm
Load-following and peak shaving
 a) Scheduled hourly within operating parameters
 b) Seeks to minimize net load as priority
 c) Seeks to reduce (shave) peaks

Key Point: The basic load following algorithm is not responsive to storage signals and only has flexibility when assigning monthly energy over each day. Nor is it based on streamflow data.



Moderate Hydro Dispatchability Details

- Observed hydro generation deviations to median were derated relative to inherent SERVM monthly scheduling logic.
- Budgets were developed for the moderate hydro dispatchability case using single day deviations



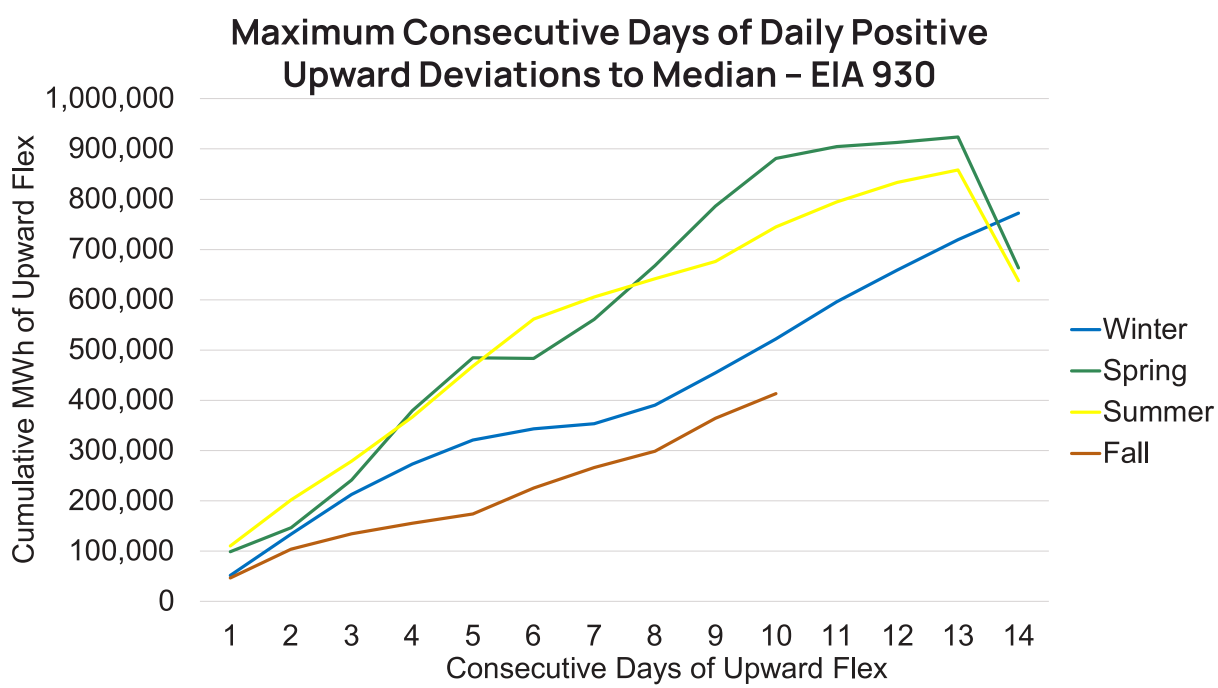
Additional notes:
1. Increased dispatchability is modeled based on observed deviations to median daily energy by month in EIA 930 data and derated by inherent SERVM scheduling flexibility.
2. Budgets are drawn down when used and must replenish by dispatching hydropower down in future hours. They can run out to reflect system constraints.
3. Only a single value for budgets is allowed in SERVM. The Winter value was chosen to bridge between very high spring and lower summer/fall conditions.

High Hydro Dispatchability Details

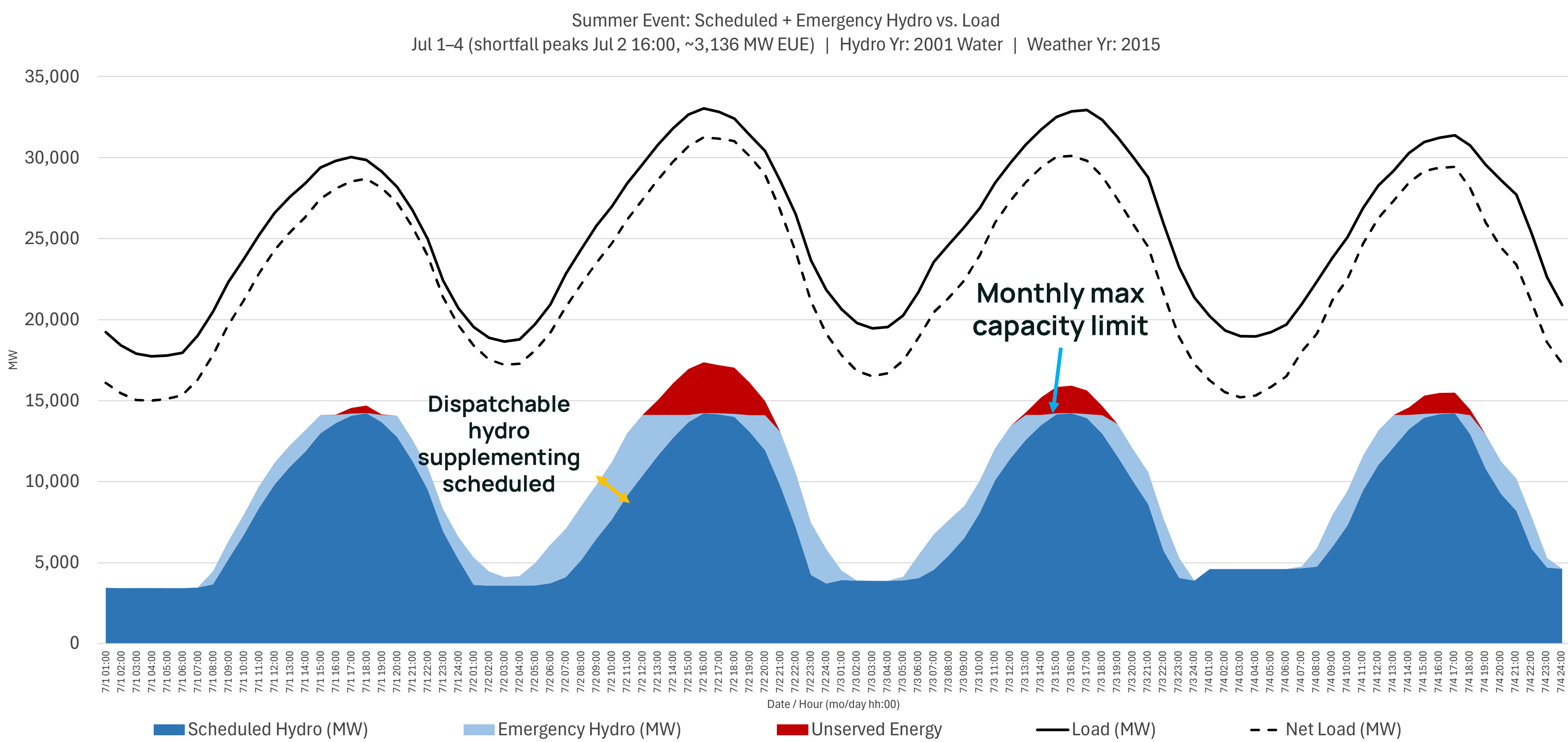
- Additional review using EIA 930 data for consecutive days when hydro energy is above median monthly data reveals higher possible upward deviations.
- The flexibility budget and max capacity range (daily flow range) were both increased for this case to maximize hydro representation while maintaining observed historical limits.

High Hydro Dispatchability Effect

- Hydro in BPAT was given 500,000 MWh
- Hydro in PACW & IPCO were given 60,000 MWh each
- Total flex capability is ~5x the moderate case and schedule hydro maximum is ~2 GW higher

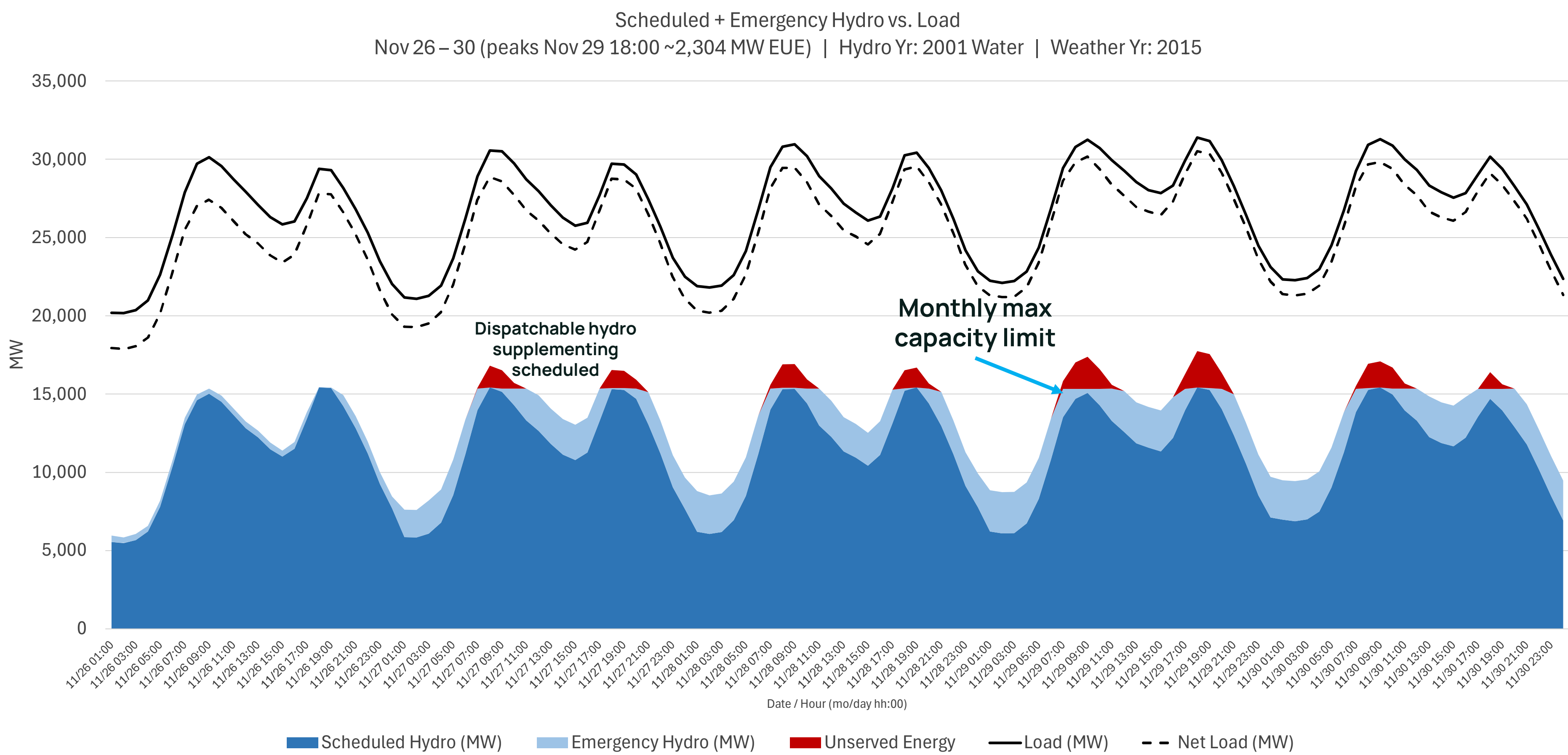


SERVM Dispatchable Hydro in Action



The goal of this approach is to allow for a controllable level of response to outages, storage signals, and load while linking back to input constraints.

SERVM Dispatchable Hydro in Action

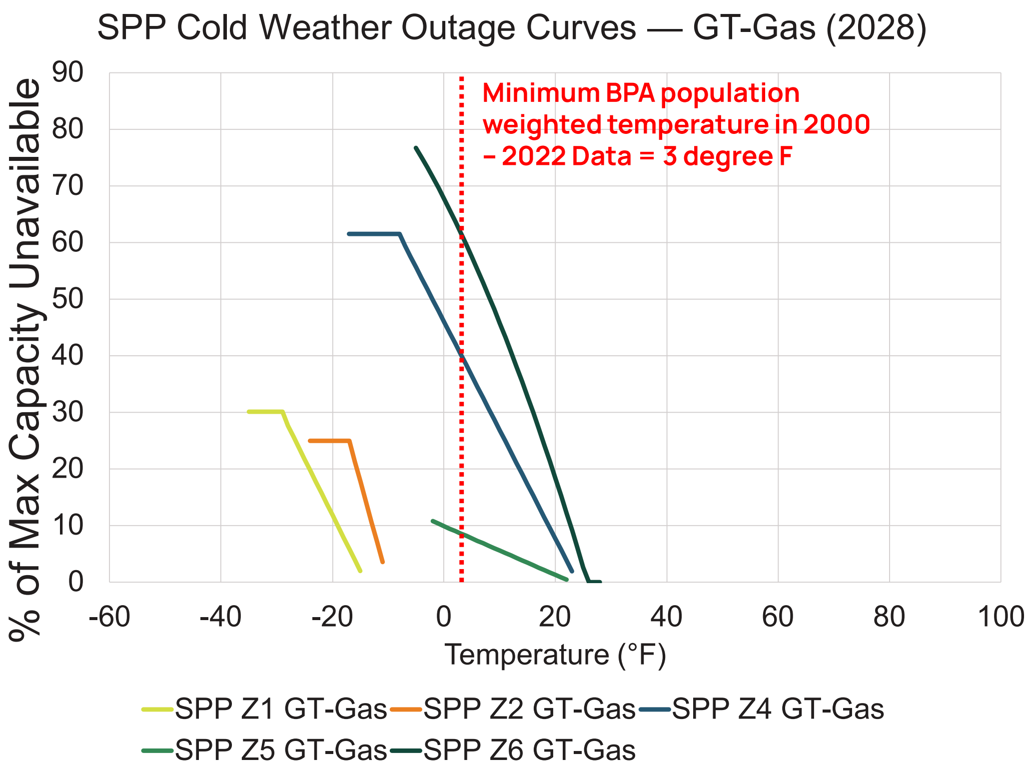


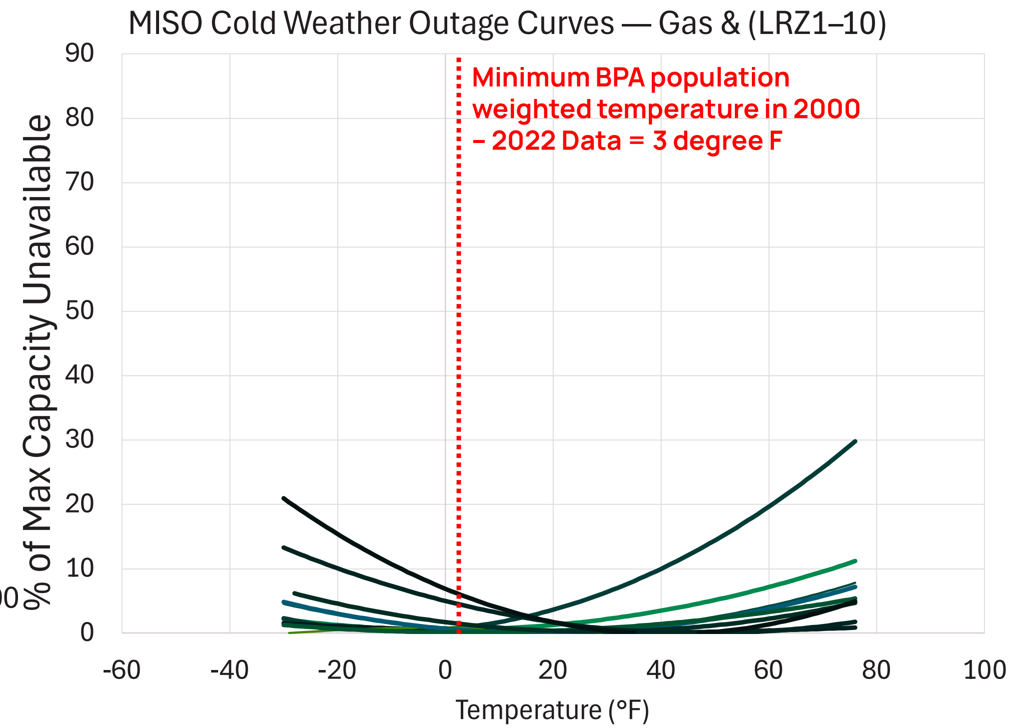
The goal of this approach is to allow for a controllable level of response to outages, storage signals, and load while linking back to input constraints.

Additional Details

Cold Weather Outage Modeling

Cold Weather Outage Curves from Other Regions

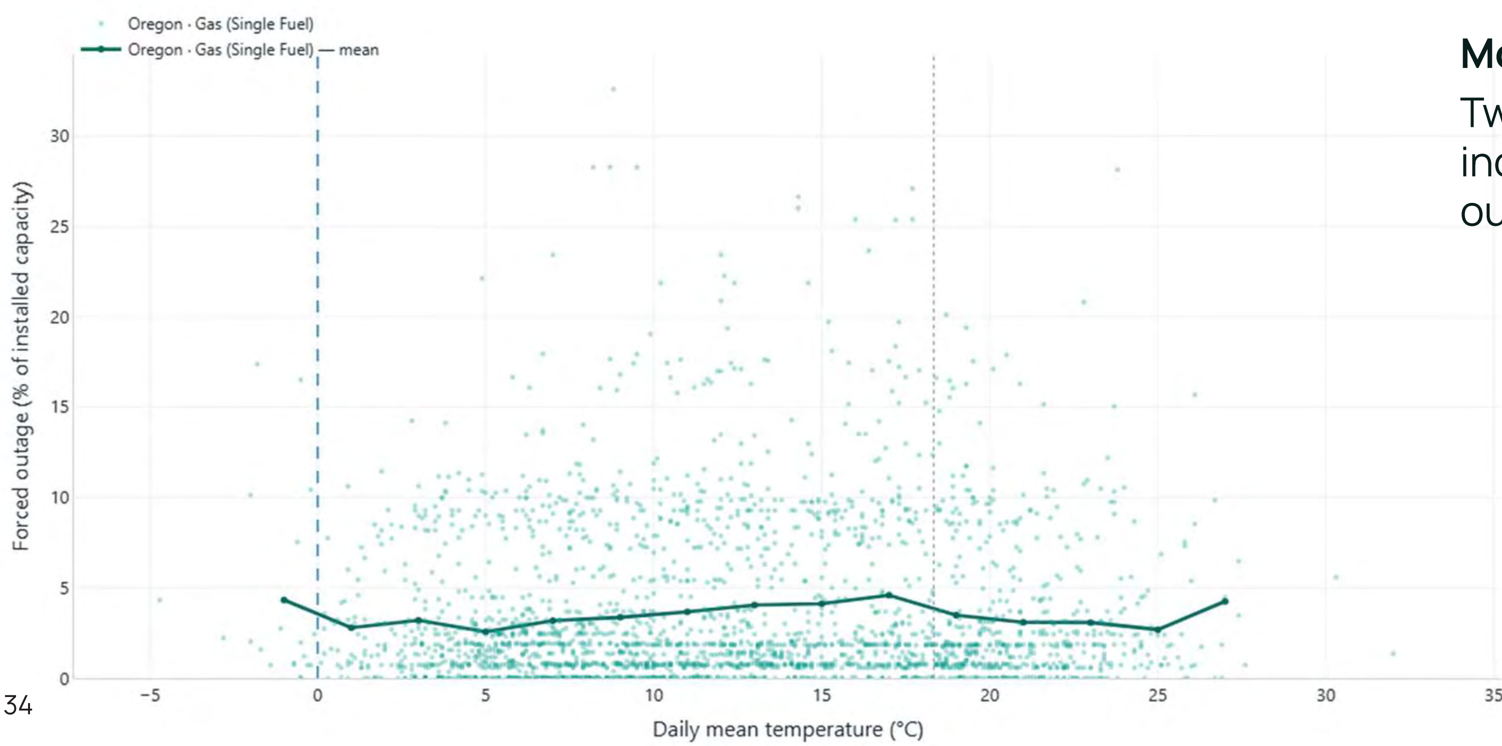




Key Point: There is limited history in the PNW for cold weather outages as discussed before and limited extreme cold weather events (based on population weighted avg). Between SPP and MISO regions (each curve), outage levels on CTs can vary dramatically (1% to 60%) based minimum temp in BPA data.

Anonymized NERC GADS Data vs Temperature - Oregon

- Used anonymized GADS data by region and fuel from NERC ITCS (2016 – 2022)
    - No strong trends observable based on daily mean temperatures for single-fuel gas fleet
    - Data points for temperature extremes are sparse in the 2016 – 2022 record used.



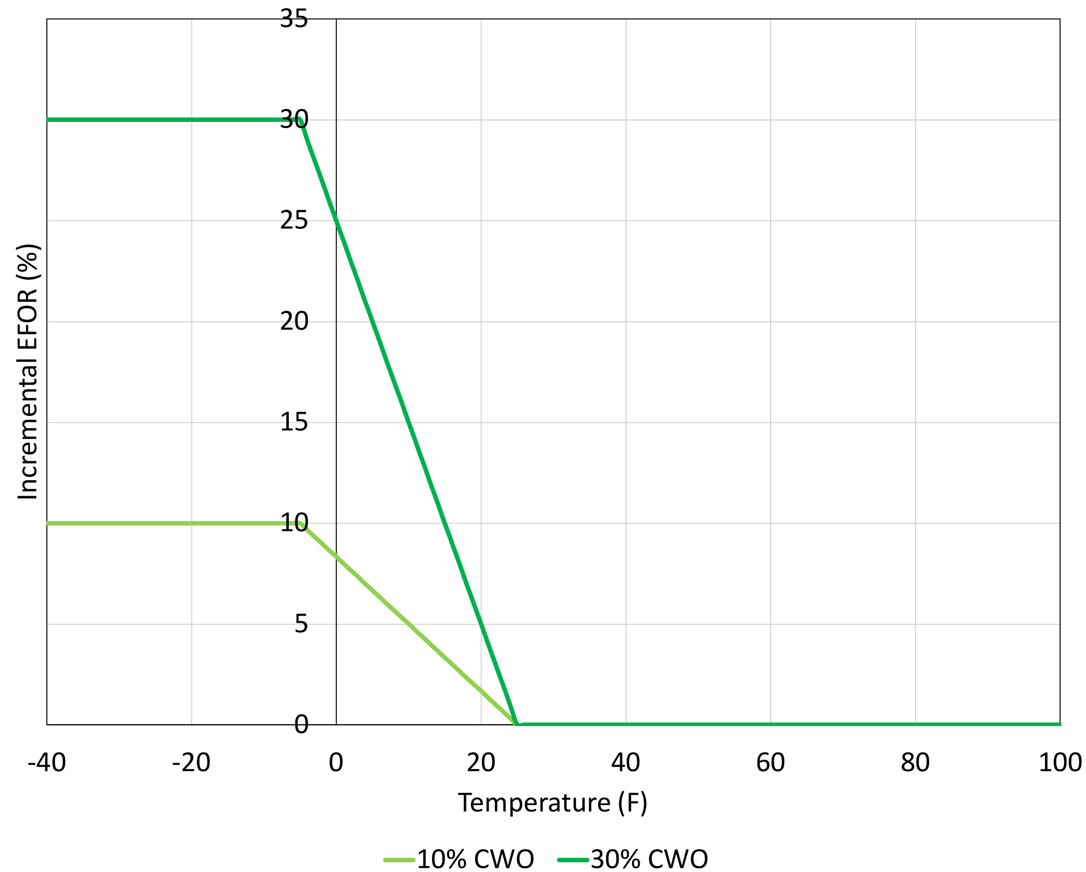
Modeling Approach

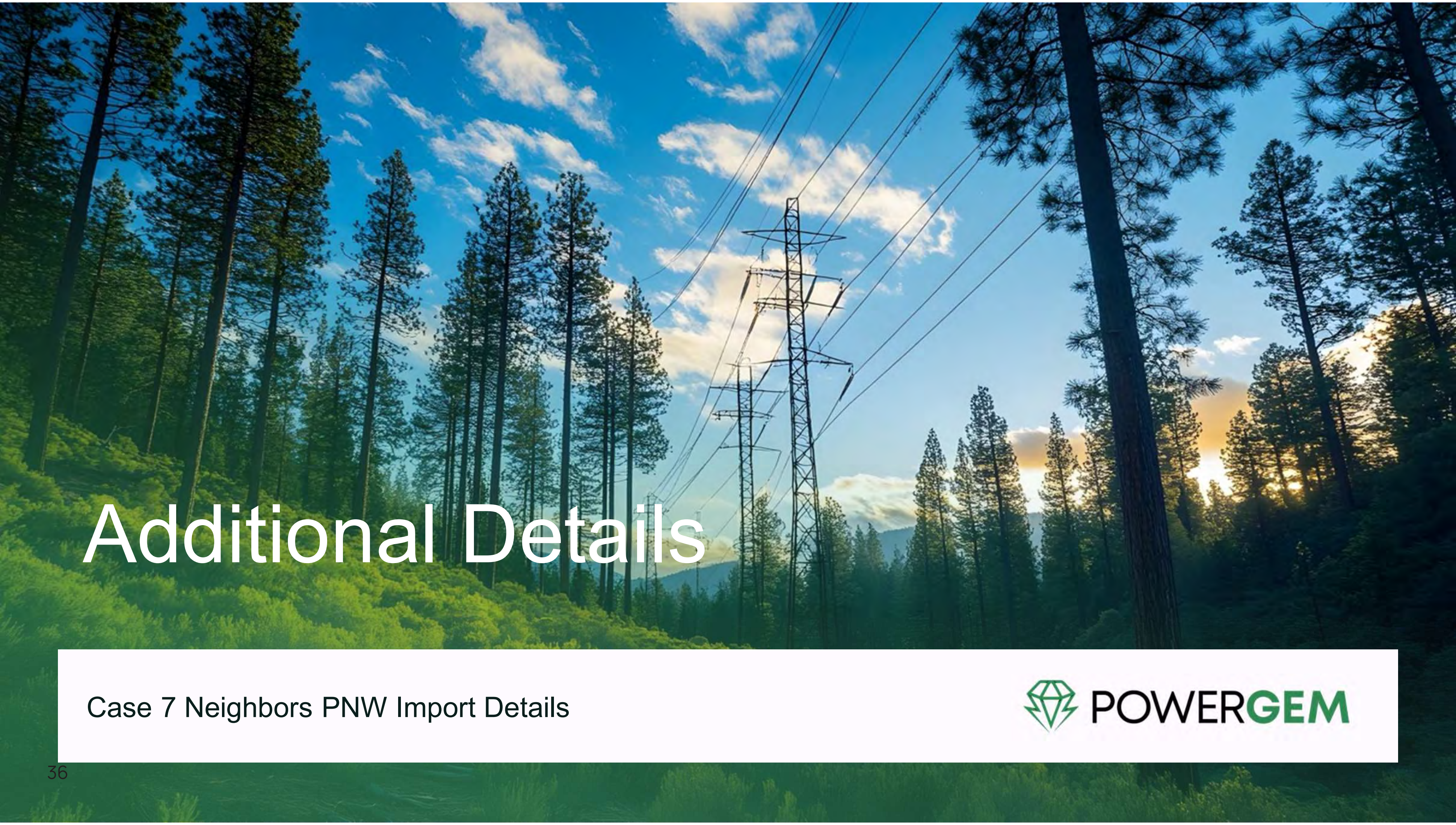
Two 'what if' ELCC analyses wit incremental cold weather outage sensitivity.

- 10% maximum increase in outage rate
- 30% maximum increase in outage rate

Cold Weather Outage Sensitivity Setup

- Incremental CT units (3 x 333 MW) were assigned a 10% and 30% cold weather outage incremental EFOR curve
- As a function of temperature, the forced outage rate for each unit increases up to a maximum value (by -5 degrees F)
- Curves are based on representing a spread of cold weather sensitivity from public SPP and MISO data
- **These cases answer:**
  - “What is accreditation if incremental natural gas CTs in the PNW face fuel supply disruptions or are sensitive to winter conditions”





Additional Details

Case 7 Neighbors PNW Import Details

POWERGEM

Net Imports Probability versus Load Level

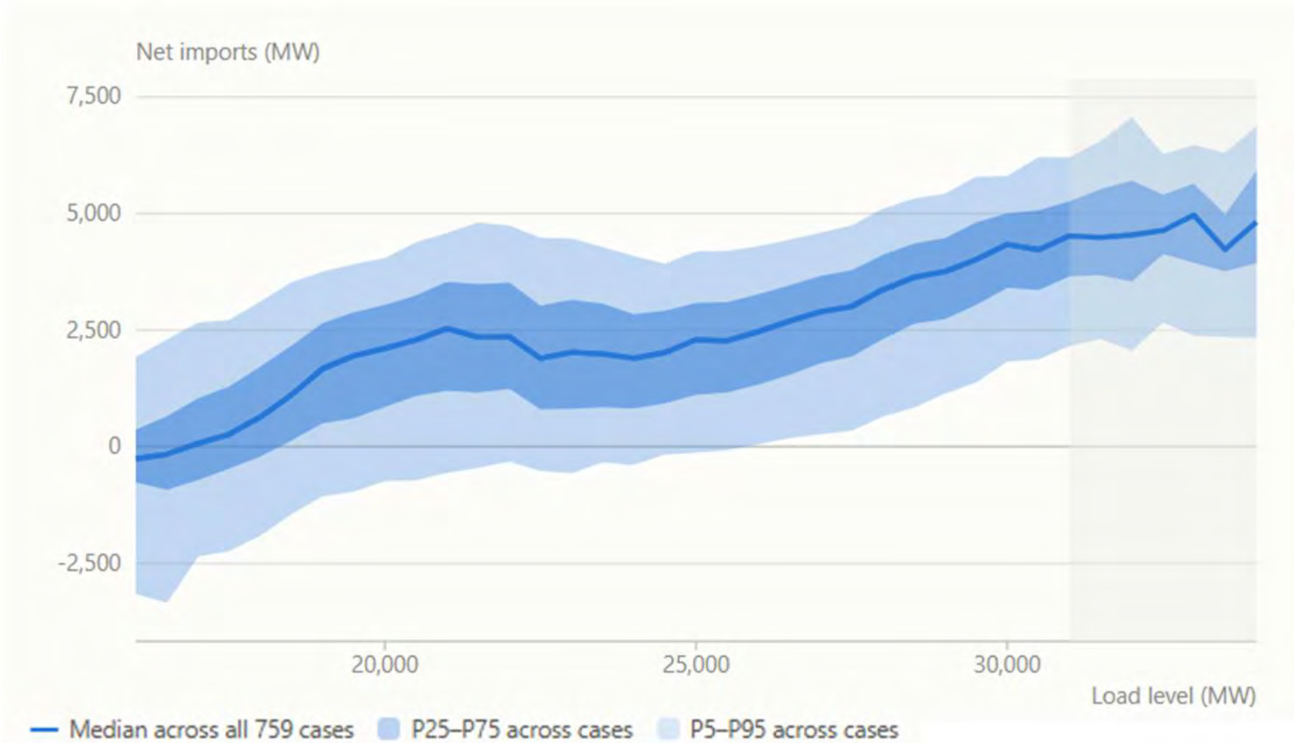
Net imports into PNW are modeled dynamically based on neighboring regions availability, price, and PNW need

Results show that in wet years (high hydro), net imports are lower, but even with high water high load-levels in the PNW match with high net imports

Modeling neighbors directly enables quantifying the availability of imports. In this case, net imports in the highest load hours ranges 2,300 to 6,900 MW

This data will be incorporated into the expansion planning (phase 2) work to represent imports within the capacity expansion model.

Net Imports vs PNW Load Level – Case 7 Neighbors



*In case 7, only CAISO, NWMT, WAUW, and PACE are modeled. This means net import availability, particularly during peak load hours is a conservative estimate since British Columbia and the full southwest and rocky mountain region are not modeled