Resource Adequacy and the Energy Transition in the Pacific Northwest

Final Report

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Project Overview

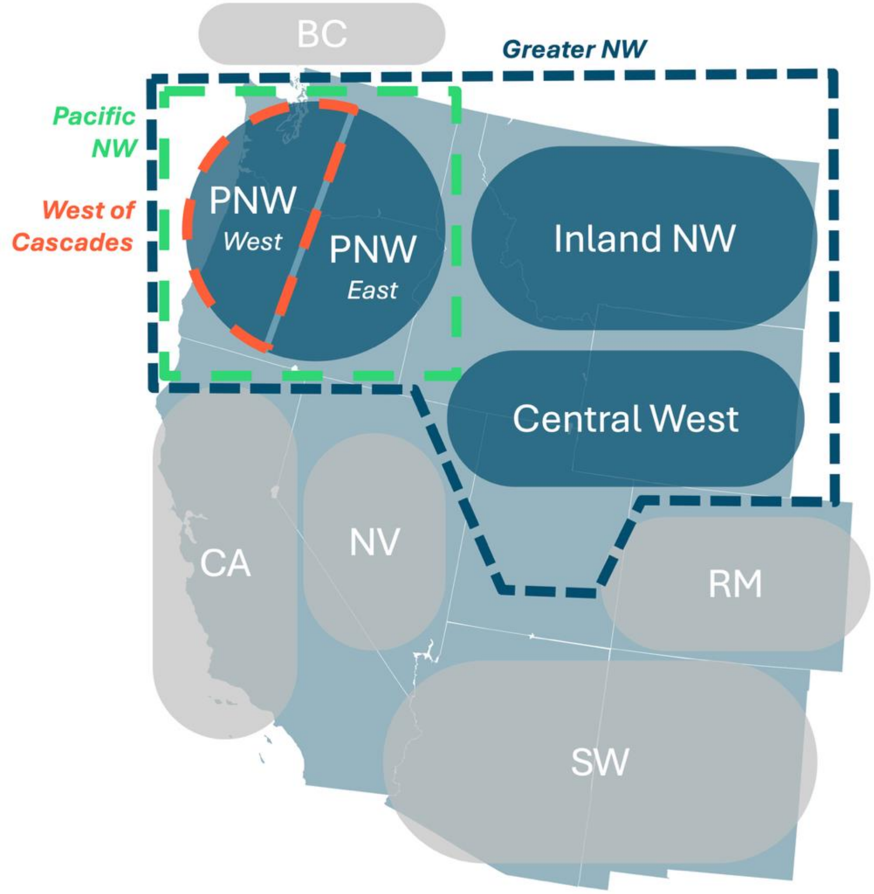
E3 was retained by regional utilities and generation owners to evaluate the state of resource adequacy in the Pacific Northwest today and into the future

	Key Study Questions	Key Outputs
1	What are near-term resource adequacy needs (2025-2030)?	• Near-term RA shortfalls • NW reliability event characteristics
2	What are the main barriers to meeting near- to intermediate-term needs?	• Pace of future vs. historical build rates • Challenges of developing new generation, transmission, and natural gas infrastructure • RA contributions of new resources
3	What are the long-term resource needs (2035-2045)?	• Least-cost portfolio optimization analysis • Technology and load growth scenarios
4	What is the role of new natural gas peaking capacity?	• Cost impact of allowing new gas capacity • Risk of asset stranding for new gas • Role of substitute emerging technologies
5	What are the needs in constrained NW load pockets?	• Growth in RA need in PNW and I-5 corridor • Modeled resource and transmission solutions

STUDY SPONSORS

- Puget Sound Energy
- Public Generating Pool
  - Chelan Public Utility District
  - Clark Public Utilities
  - Cowlitz Public Utility District
  - Eugene Water & Electric Board
  - Grant Public Utility District
  - Lewis Public Utility District
  - Seattle City Light
  - Snohomish Public Utility District
  - Tacoma Power
- Avista Corporation
- Benton Public Utility District
- Douglas Public Utility District
- Emerald People's Utility District
- Franklin Public Utility District
- Idaho Power
- Klickitat Public Utility District
- Mason Public Utility District No. 3
- Northwest & Intermountain Power Producers Coalition
- NorthWestern Energy
- Okanogan Public Utility District
- Pacific Public Utility District
- Portland General Electric

E3's methods combined quantitative LOLP modeling, optimal capacity expansion modeling, and qualitative research and interviews



Phase 1: Reliability Modeling
RECAP
Loss-of-load model

Planning reserve margin →
Technology ELCC curves →
← *Optimized portfolios*

Phase 2: Portfolio Modeling
RESOLVE
Investment model

+ **Loss of Load Probability modeling and Capacity Expansion studies performed for Greater NW region and two transmission-constrained subregions**
  - Key inputs include loads, resources, and hydro operations
  - Adequacy simulated across 2,500 years of hydro + load + solar/wind conditions
  - Key outputs are reliability metrics, capacity surpluses/shortfalls, and capacity contributions of individual resource types
+ **Quantitative modeling supplemented by research and stakeholder interviews on barriers to new resource development**

- Inputs are benchmarked to key industry sources such as PNUCC, WECC, WestTEC, BPA

Key Study Assumptions

Load forecasts aligned with PNUCC utility projections in 2030; for long-term load forecasts E3-developed reference and net-zero economywide scenarios

Current climate conditions modeled for both load and hydro generation, using **recent 30 years of hydro conditions from BPA** with **hydro operational constraints reviewed by regional hydro experts**

Probabilistic resource adequacy simulations of ~2,500 years of simulated weather (1979-2022) and hydro (1989-2018) conditions

1-day-in-10-year Loss-Of-Load Expectation (LOLE) reliability standard[1] applied, resulting in a **9% region-wide planning reserve margin** (Using the perfect capacity ("PCAP") method)

Marginal resource accreditation is used to inform economically-efficient market entry

Region-wide portfolio optimization assumes **regional coordination on energy, capacity, transmission, and clean energy markets** that support least-cost GHG reduction across the NW

E3 developed **resource costs including latest federal policy and near-term scarcity premiums for new generation** due to supply-demand imbalance for panels, turbines, transformers, and other equipment

1. E3's modeling calibrates the current system at 1-day-in-10-year LOLE to a 0.0008% normalized expected unserved energy (NEUE) target, which is then maintained for determining future need and ELCC contributions.

Key Findings

1. Accelerated load growth and continued retirements create a resource gap that grows to *9 GW of effective capacity by 2030* and *14-18 GW by 2035*
2. In the near-term, the region is not on track to fill this gap due to market and institutional barriers
3. In the long-run, it is possible to achieve deep carbon reductions while maintaining reliability and affordability by investing in a portfolio of energy efficiency, wind, solar, geothermal, and natural gas
4. New natural gas peaking capacity for backup use during low hydro or low renewable conditions is a robust long-term strategy across a wide range of future scenarios
5. There will be a growing need for new local delivery capability into Washington and Oregon, particularly in the I-5 corridor, either from new resources or transmission

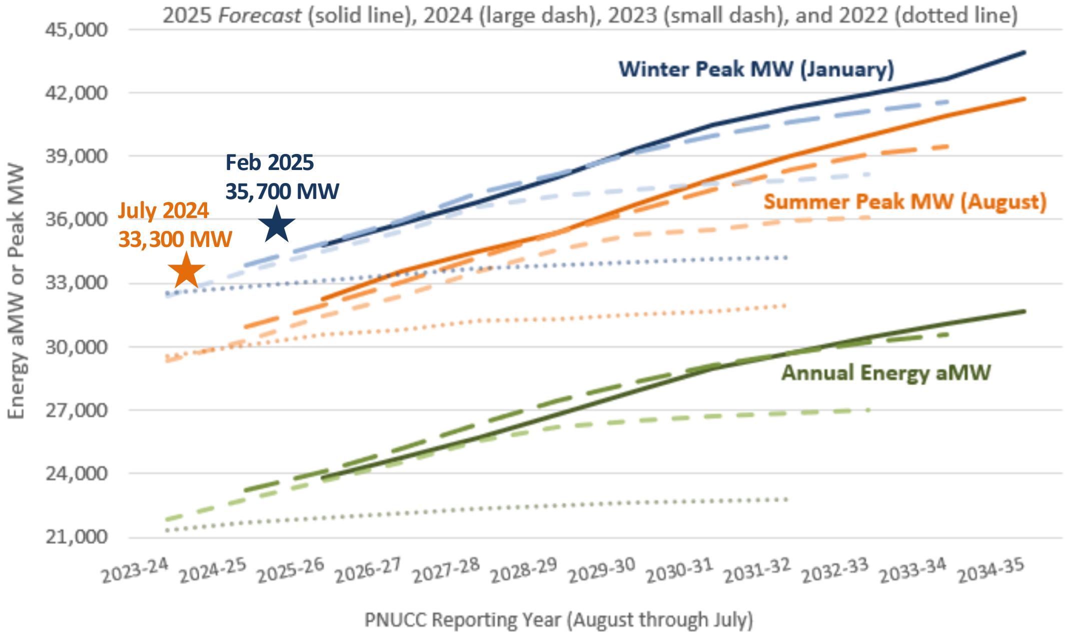
1. Near-term Resource Adequacy Needs

- How are loads and resources changing in the region?
- What is the resource need in 2030 and beyond?
- What are the characteristics of the NW reliability challenge?

Regional load forecasts continue to increase due to electrification, new large loads, and AC adoption

PNUCC 2025 Northwest Regional Forecast

Energy aMW or Peak MW Forecast



Growth Rates

Energy	10 year
2025 Forecast	3.2%
2024 Forecast	3.1%
2023 Forecast	2.4%
2022 Forecast	0.9%

Summer Peak	10 year
2025 Forecast	2.9%
2024 Forecast	2.7%
2023 Forecast	2.3%
2022 Forecast	1.0%

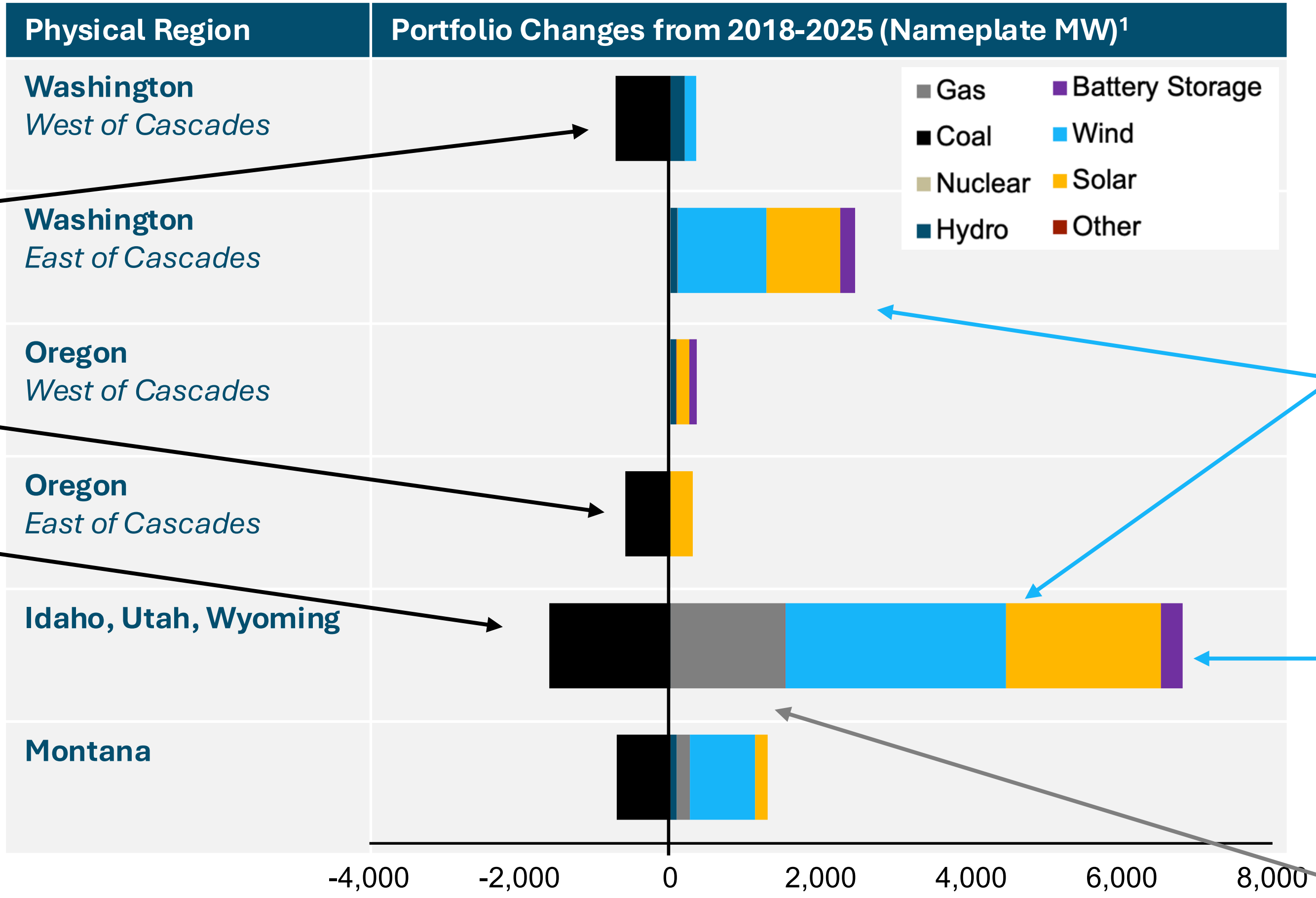
Winter Peak	10 year
2025 Forecast	2.6%
2024 Forecast	2.3%
2023 Forecast	1.8%
2022 Forecast	0.7%

Load growth acceleration is attributable to multiple distinct drivers, despite impact of energy efficiency

Driver	Near-term Impact
Economywide **energy efficiency**	Small load reductions in both seasons
Higher-than-expected **air conditioning adoption** after recent heat waves	Small-medium peak load growth in the summer
Policy-driven **electric vehicle adoption**	Medium peak load growth in both seasons
Population growth and new building construction	Medium peak load growth in both seasons
Anticipated **data center** interconnection	Large average and peak load growth in both seasons

- E3's load forecast used in this study, data center growth represents ~1.9 aGW by 2030, growing to ~3.1 aGW by 2045.

Most new resource additions since 2018 have been solar and wind, and most have been outside of Washington and Oregon



Coal retirements are reducing the quantity of firm capacity available in the region

Almost all new resources have been wind and solar

New resources are mostly being built in Wyoming and Utah

New firm capacity from coal to gas conversions

1. Based on WECC 2034 ADS and recent retirements)

E3's Renewable Energy Capacity Planning ("RECAP") model was used to study resource adequacy needs and capacity accreditation

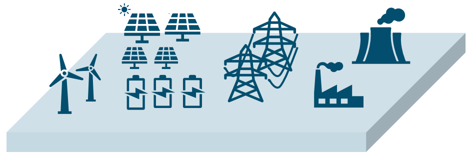
- **RECAP is a loss-of-load probability ("LOLP") model that has been used in dozens of jurisdictions to study the reliability dynamics of high-renewable electricity systems**
- **RECAP simulates the operations of the electricity system under thousands of scenarios to capture different conditions**
  - Including simulated forced outages events and variability for load, weather, hydro, and renewable output
- **Key RECAP outputs:**
  - System reliability metrics
  - Target Planning Reserve Margin (PRM)
  - Capacity shortfall
  - Capacity value (ELCC) of resources

Temperature and Load Artificial Neural Network Simulation

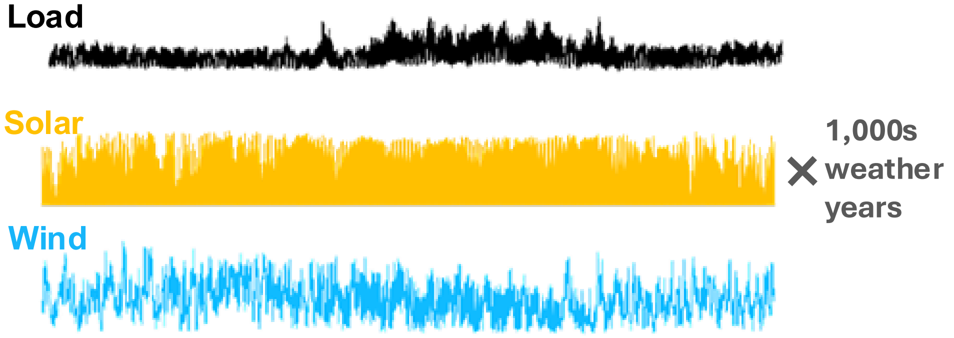
Capturing hourly load conditions under mild and extreme historical weather

Operational Module

Dispatching resources based on outage characteristics, weather dependency, state of charge availability, and demand-side management

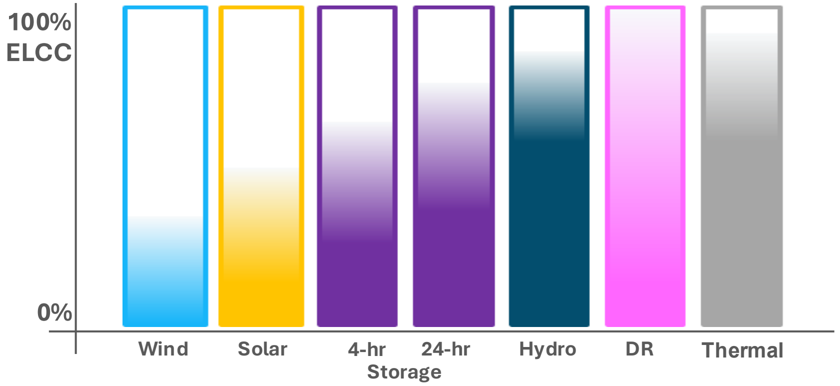


System Reliability: simulates the operations of the electricity system under thousands of scenarios to capture different conditions



Resource Capacity Value: measures resource's ability to contribute to reliability under a marginal or average ELCC methodology

Illustrative ELCC Values Across Technologies

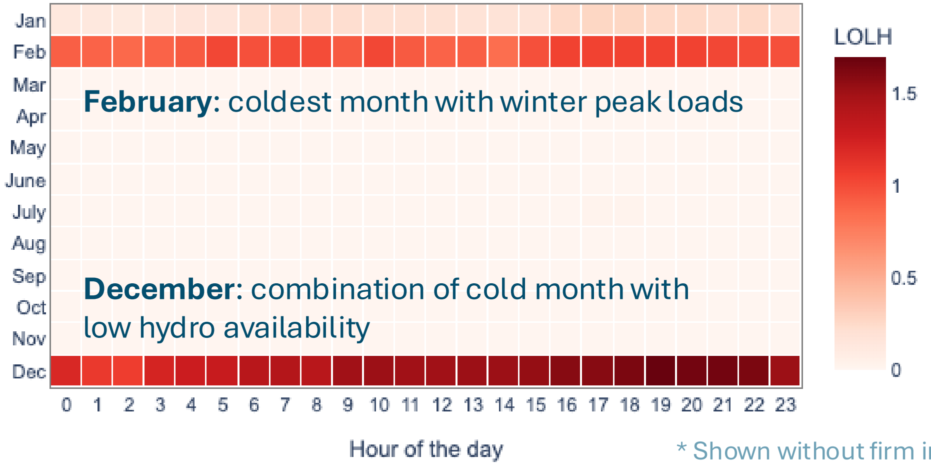


The region's biggest reliability challenge is a multi-day cold weather event that occurs during a low hydro year

- **About 50% of the region's energy comes from hydro, but its availability varies significantly from year to year**
  - Water variability is critical for resource adequacy in our region → low water years create winter reliability risk
- **Most shortfall events occur during the cold winter months**
  - Demand spikes while wind & solar produce less
- **Simulated reliability events can last multiple days (exceeding 50-100 hours)**

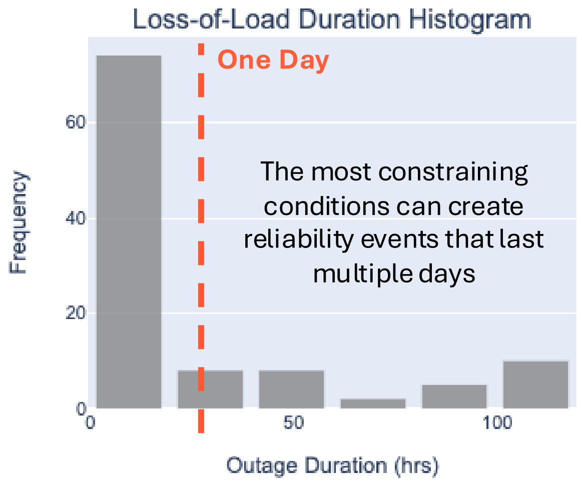
Addressing these events requires resources that can reliably deliver energy over long periods

Average Loss-of-Load Hours (LOLH) by Month x Hour*



* Shown without firm imports

Distribution of Loss-of-Load Events

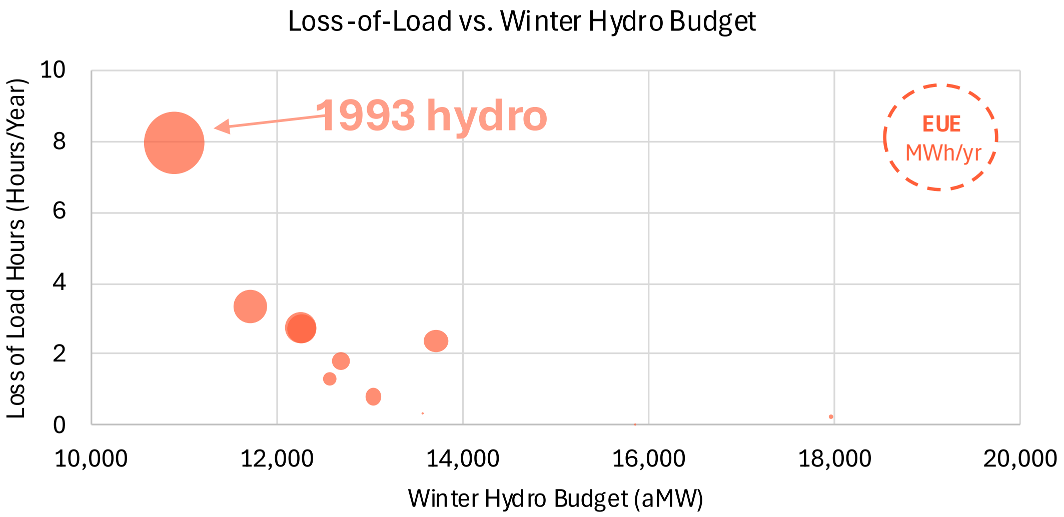


*** Greater Northwest, tuned to 1-day-in-10-year standard*

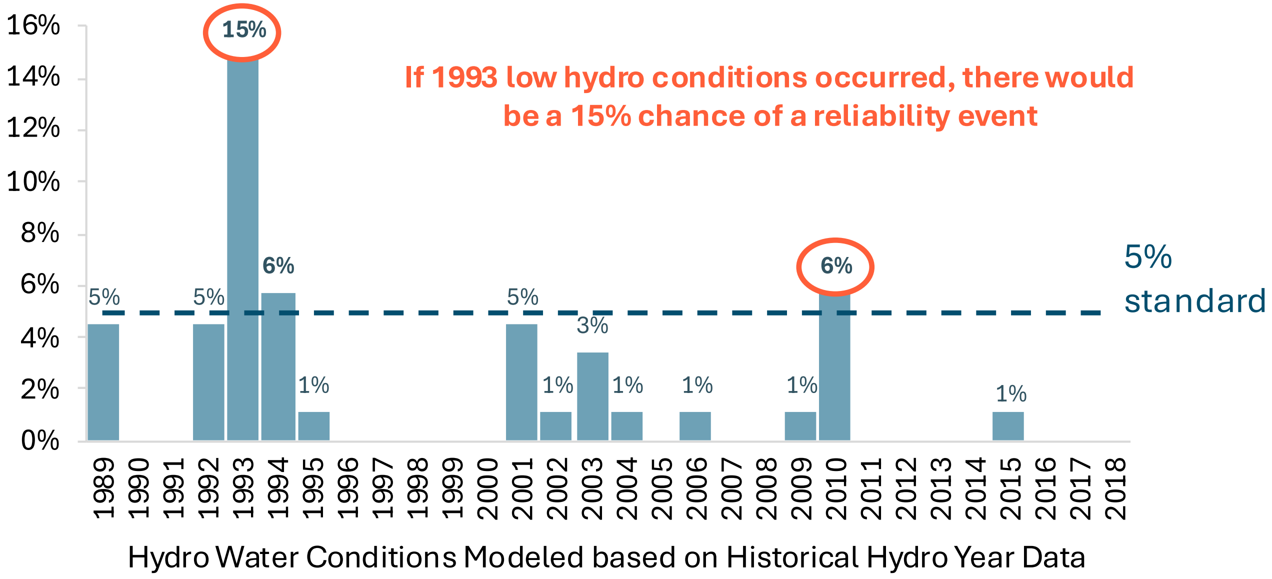
The vast majority of reliability events occur during years with very low hydro conditions

- E3 analysis used BPA hydro simulations for the 30-year period from 1989-2018
- Loss of load events are concentrated during the lowest hydro years (1989, 1990, 1992, 1993, 1994, 2001, 2010)
- January 2024 conditions were consistent with the very low hydro years simulated here

2025 Average Loss-of-Load Hours (LOLH) and Expected Unserved Energy (EUE) by Hydro Year

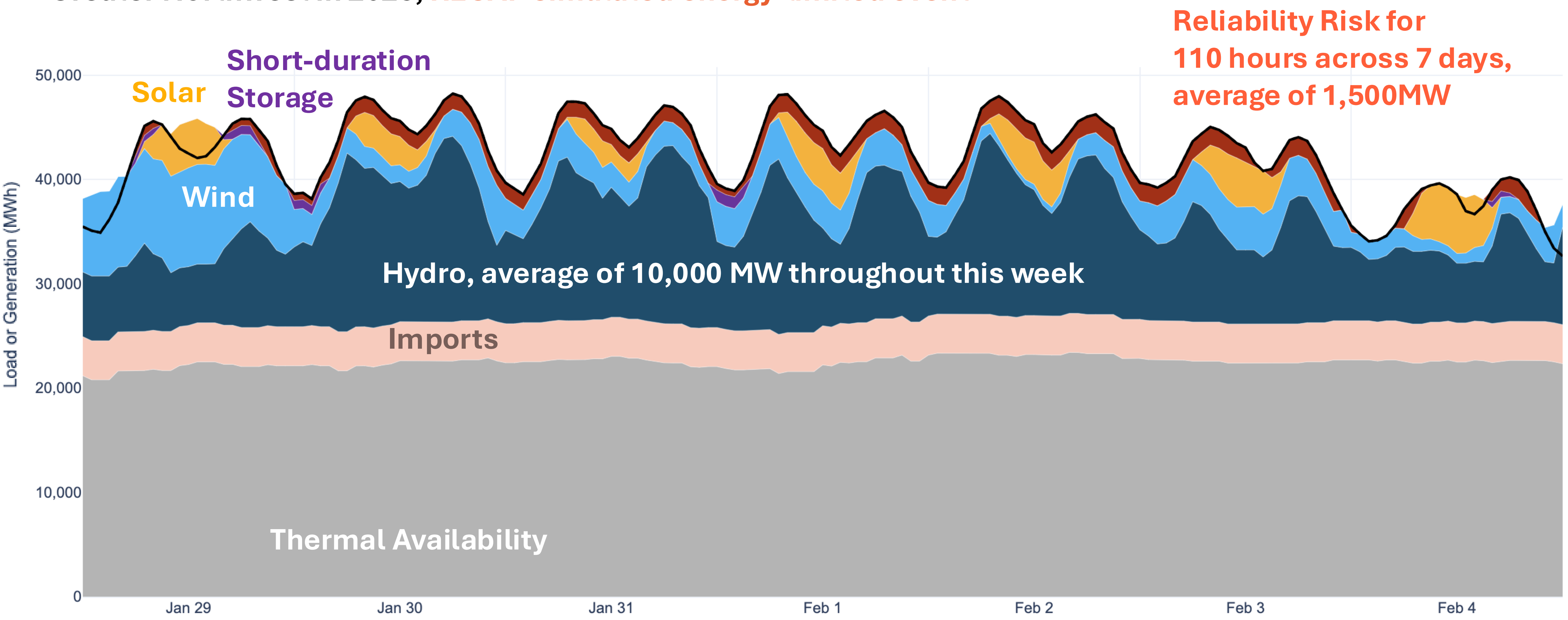


2025 Loss-of-Load Probability (LOLP) by Hydro Year



Resource availability example: February 2025 load levels simulated under 1996 temperatures + 1993 hydro conditions

Greater Northwest in 2025, RECAP simulated energy-limited event



Greater Northwest region faces a resource shortfall in 2026 and beyond

Greater Northwest Load and Resource Balance

Effective Capacity (ELCC) MW

Available resources includes firm imports from other regions

	2025	2026	2027	2028	2029	2030
Total Resource Need*	49,245	50,737	52,499	54,184	55,879	57,195
Existing Portfolio w/ Retirements	46,716	45,666	45,395	45,388	45,098	44,757
Firm Imports	3,750	3,750	3,750	3,750	3,750	3,750
Reliability Position Surplus (+) / Shortfall (-)	**+1,221**	**-1,321**	**-3,354**	**-5,046**	**-7,031**	**-8,689**
ELCC from "In-Development"** Firm Resources	-	296	407	580	770	1,114
ELCC from "In-Development" Wind, Solar and Battery projects	-	645	1,015	1,316	1,508	1,934

The region faces a power supply shortfall starting in 2026 that grows to almost 9 GW by 2030

In development resources amount to only 3 GW of effective capacity, leaving 6 GW shortfall

** Total Resource Need includes median peak load + 9% PCAP planning reserve margin as well as obligation to serve the Columbia River Treaty Regime*
*** In-development resources are based on WECC ADS 2034 facilities with confirmed project location, project name, or can be verified online*
**** Centralia unit 2's repower from coal to gas was not in the WECC ADS data source and is not included here; it would bring down the shortfall by ~700 MW in 2029 and 2030*

Key Finding #1: Near-term resource needs are significant

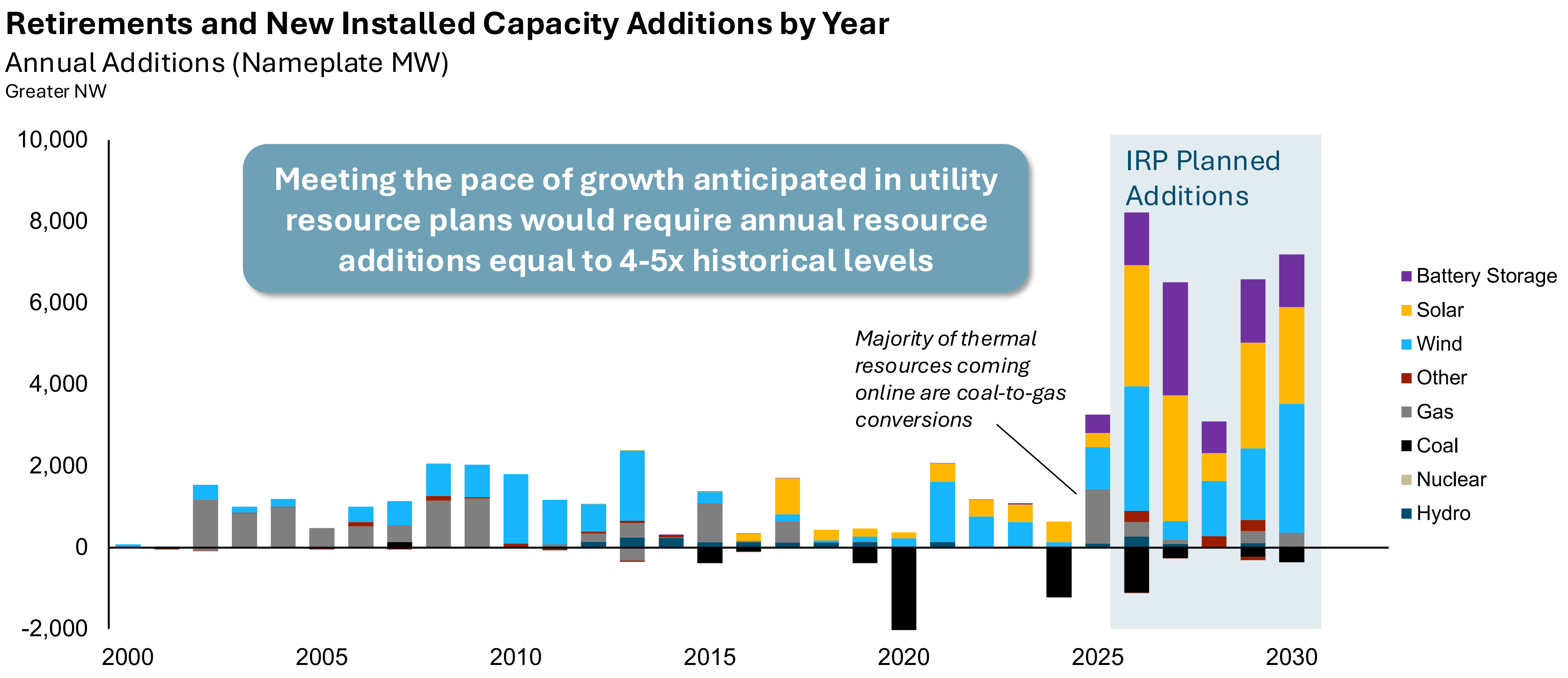
1. Accelerated load growth and continued retirements create a resource gap that grows to *9 GW of effective capacity by 2030* and *14-18 GW by 2035*

- Load forecasts continue to increase
- Retiring firm capacity is mostly being replaced with wind, solar, and batteries
- Few resources have been added in Washington or Oregon
- The region faces a multi-day reliability challenge driven by cold snaps and low hydro conditions

2. Barriers to Meeting Near-term RA Needs

- How do planned additions compare to historical trends?
- What are institutional barriers to building new resources?
- How do different resources contribute to meeting RA needs?

Planned additions would meet need through 2030, but require an unprecedented pace of resource development



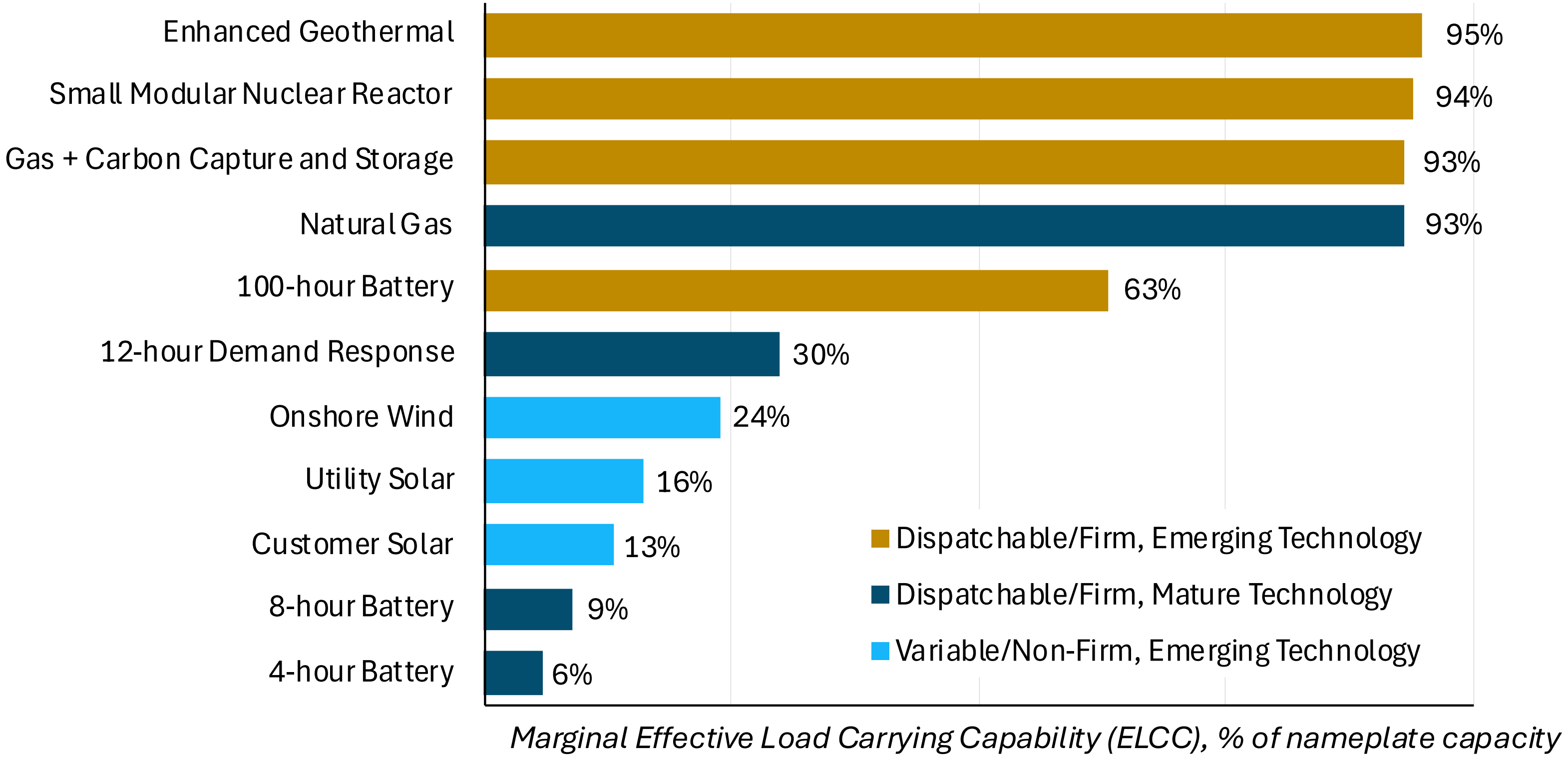
Utilities and developers identified transmission, regional accreditation uncertainty, and new firm capacity barriers as key challenges

Key challenge	Findings from stakeholder interviews	Potential Solutions
1. Transmission access faces physical and institutional constraints	• **Separate procurement and transmission planning processes** leading to chicken-and-egg challenges • **Lack of available firm transmission rights** for new resources • Difficult terrain and siting challenges	• **Improve regional transmission planning and interconnection** processes • **Streamlined siting** and state supported **land use planning**
2. Uncertain regional capacity accreditation metrics	• **WRAP is voluntary** and is just entering its binding phase • **Accreditation metrics are uncertain**	• Strengthen the WRAP program and **ensure fundamentals-based capacity + energy-informed accreditation**
3. Barriers to building new firm capacity	• Existing clean resources do not contribute significantly to resource adequacy and **“clean firm" options are not yet commercially available** • Natural gas is the only viable near-term firm capacity option, yet siting new gas plants and required infrastructure is extremely challenging and there are **perceived stranded asset risks** • Utilities are likely to be challenged by the **sheer volume** of new resources in their IRPs	• **New firm resources may be needed** if they do not set the region back on long-term carbon reduction goals • **“Clean firm” resources may need policy support to** speed commercialization

Generation resources differ in their ability to support regional resource adequacy needs

Reliability Contribution by Resource Type (2025)

Driven by loss of load events occurring primarily during wintertime multi-day low hydro conditions



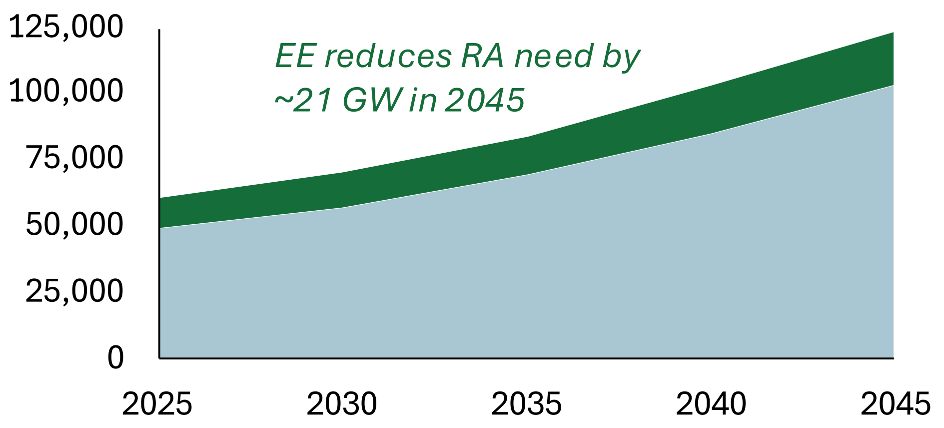
Many innovative "clean firm" technologies may emerge in the future, but none are ready for large-scale deployment in the near term

+ **Each resource is measured based on its ability to produce energy during critical conditions**
+ **Among commercially available resources:**
  - Wind and solar provide valuable clean energy, but cannot always produce energy when needed most
  - Short-duration energy storage and demand response cannot respond for the required duration
  - Natural gas plants provide high RA value but require additional infrastructure to ensure firm fuel supply

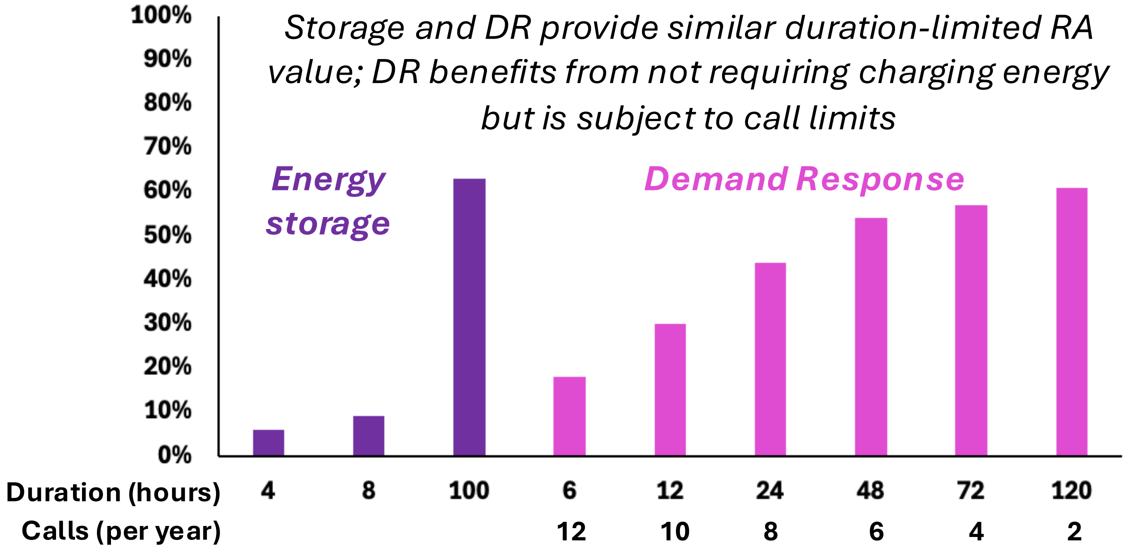
Demand side management strategies can help if tailored to address winter resource adequacy needs

- **Energy efficiency measures, such as building shell upgrades, lighting efficiency, and industrial energy efficiency, can partially offset the need for supply side resource additions to meet RA and clean energy policy needs**
  - Embedded efficiency in E3's load forecast grows by ~300-400 MW/yr 2025-2035 and 500-600 MW/yr 2035-2045
  - Continued investment in EE will be necessary to achieve this level of savings
- **Additional energy efficiency or demand response can help avoid some further RA investments, if tailored to the unique NW energy-based reliability challenge**
  - Hybrid heating could reduce RA need up to 7 GW in 2045
  - Demand response with extended duration
  - Large load demand flexibility
  - Flexible EV charging

Effect of EE Embedded in High Loads Forecast on RA Need (MW)



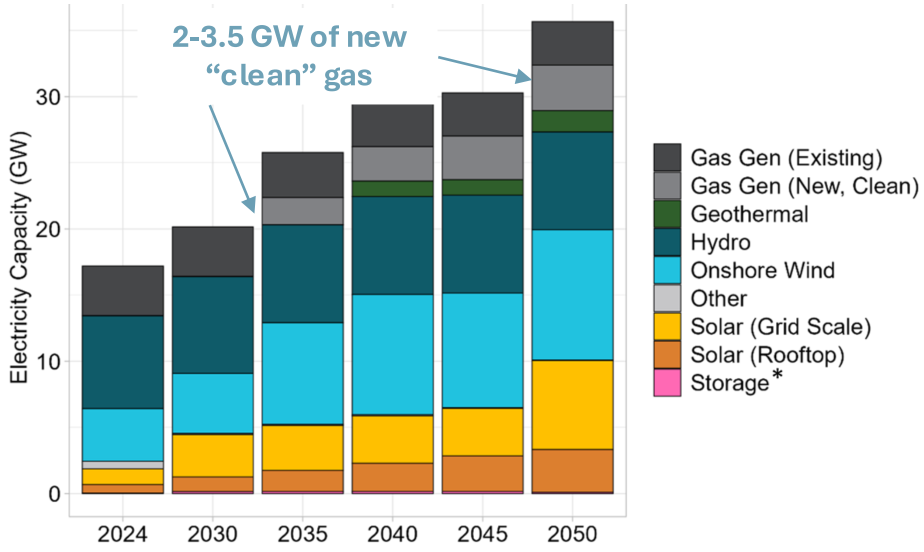
Effective Load Carrying Capability (%, 2025)



There are significant policy and regulatory barriers to investing in generating resources that are powered by fossil fuels

- **Oregon's Clean Energy Targets Bill (HB 2021) prohibits the construction of new natural gas generators of 25 MW or above**
  - Backup generators 24.9 MW and below are not prohibited and are favored by large data centers
- **Washington's Clean Energy Transformation Act (CETA) and Climate Commitment Act ("Cap-and-Invest") do not prohibit new natural gas plants but create significant uncertainty and stranded asset risk for new gas**
  - 2030 – Electricity must be GHG neutral
  - 2045 – Electricity must be 100% renewable or zero-carbon
- **Washington and Oregon utilities have not included fossil gas generation in recent IRPs**
  - Utility IRPs include peaking resources in future year plans (Avista: 669 MW by 2045, PSE: 1,558 MW by 2045)
- **Washington and Oregon energy strategy documents also identify the need for peaking resources**

Oregon Energy Strategy
Installed Capacity (Nameplate MW)



WA and OR State Energy Strategies
New Gas Capacity Modeled (Nameplate MW)*

Study	Type of Units	2035	2050
2025 OR	"Clean" gas	2 GW	3.5 GW
2021 WA (in-state)	"Unabated" gas	1 GW	3.5 GW
2021 WA (NW regional)	"Unabated" gas	6.3 GW	11 GW

WA and OR state energy strategies both include new peaking resources

* OR Energy Strategy (2025) data points use the "Reference" scenario.
WA Energy Strategy (2021) data points use the "Electrification" scenario.

Key Finding #2: The region is not on track to meet near-term needs

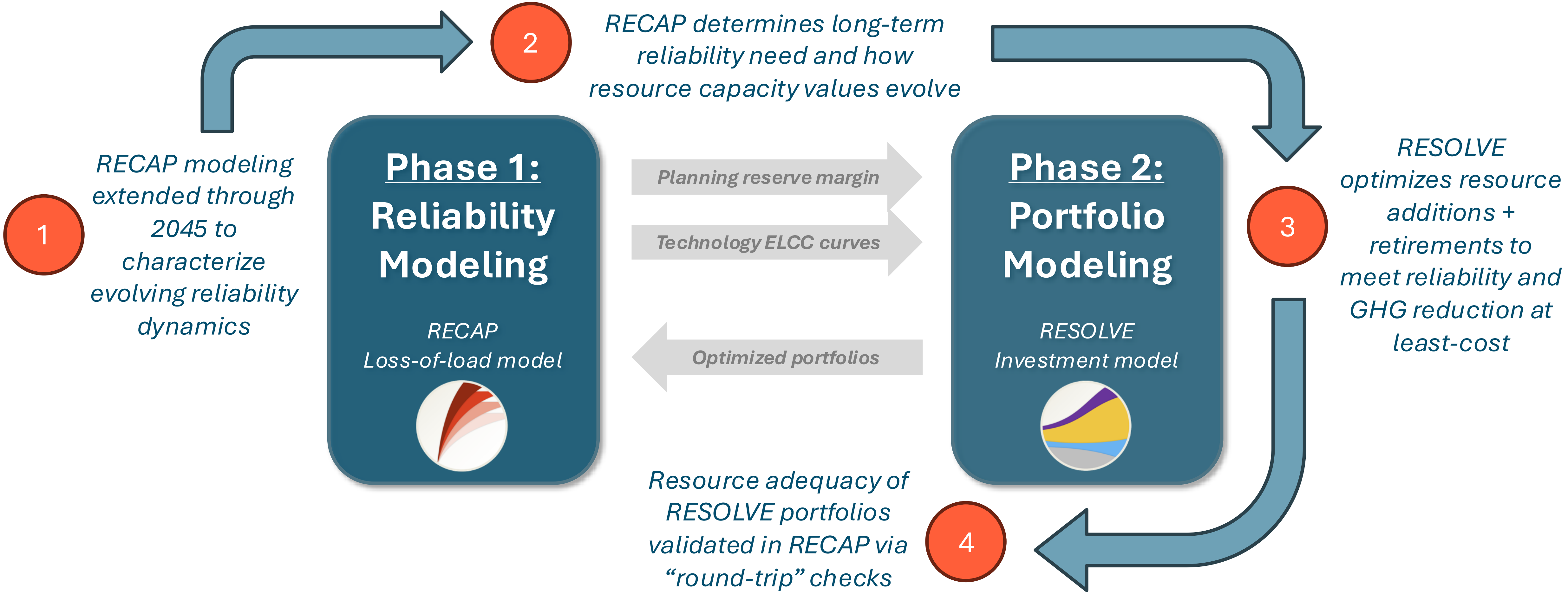
2. In the near-term, the region is not on track to fill the resource adequacy gap due to market and institutional barriers to resource development

- Planned resource additions are sufficient to fill the gap through 2030 but would require a pace of resource development that is unprecedented in the Northwest
- There are significant institutional barriers to accelerating build rates, including transmission interconnection, siting/permitting, uncertainty related to evolving regional capacity markets, and policy prohibitions
- Planned solar, wind, battery and demand response resources provide clean energy but limited RA value.
- There are significant policy and regulatory barriers to investing in new firm resources that are powered by fossil fuels

3. Long-term Resource Needs

- Portfolio optimization analysis through 2045
- Load, technology, and policy sensitivities
- Cost impacts
- Annual build rates

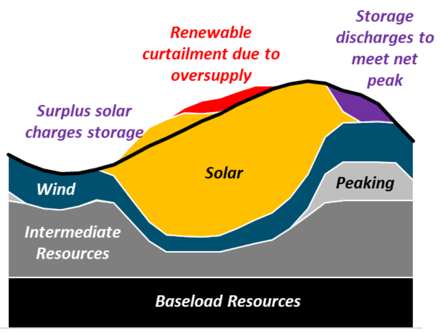
Near-term resource adequacy modeling expanded through 2045 to ensure reliability optimized portfolio expansion



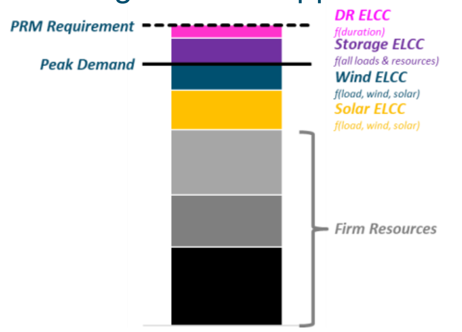
E3's RESOLVE optimal capacity expansion model was used to study long-term portfolio optimization

+ RESOLVE is a linear optimization model designed to study electricity systems with high renewable & clean energy policy goals
+ Optimization balances fixed costs of new investments with variable costs of system operations, identifying a least-cost portfolio of resources to meet needs across a long-time horizon
+ Has been used to study low-carbon portfolios in California, Pacific Northwest, Hawaii, New York, and other places

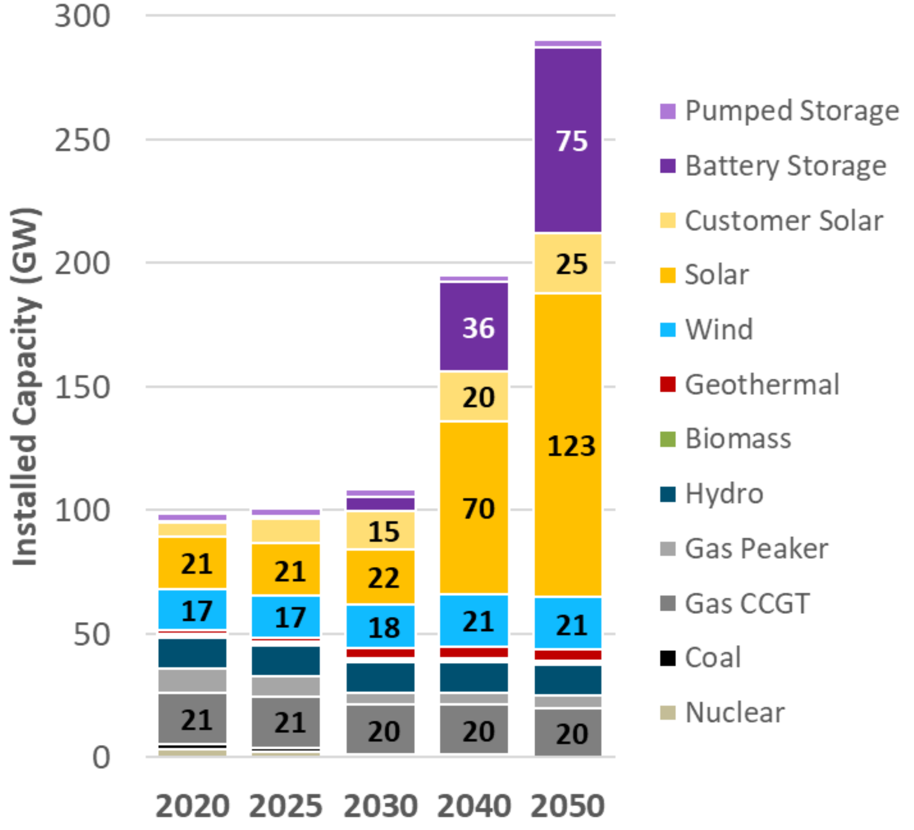
Operational module simulates hourly system operations for a sample of representative days



Reliability module ensures portfolio can meet load during extreme conditions using an ELCC approach



Least-cost plan co-optimizes investments and operations to meet clean energy policy targets, selecting from a diverse set of potential resources including wind, solar, storage, DSM, and natural gas

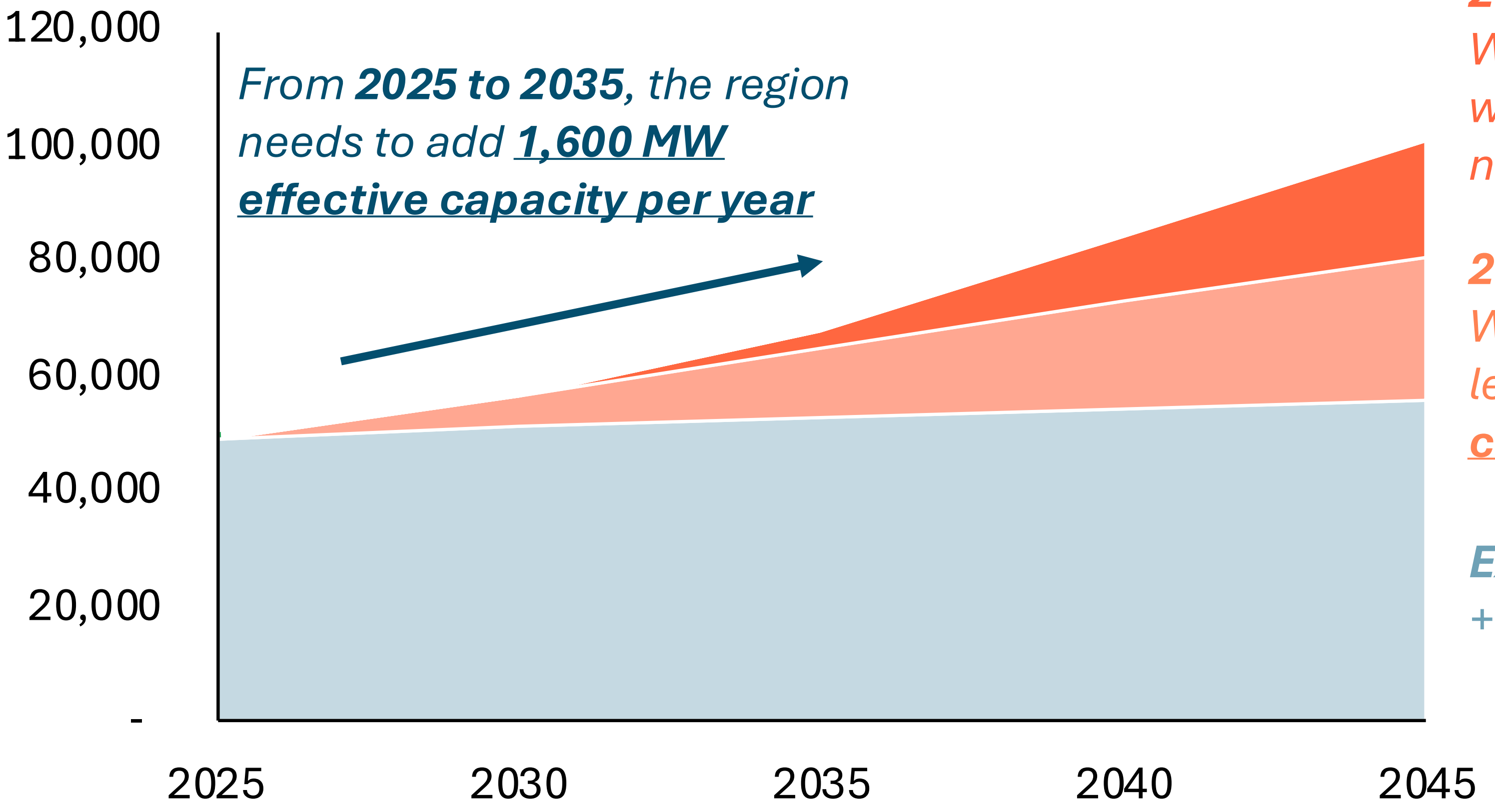


Example RESOLVE result from *Long-Run Resource Adequacy under Deep Decarbonization Pathways for California* (Calpine, 2019)

Resource adequacy need will accelerate in the 2030s to support electrification for economy-wide net zero emissions goals

Greater Northwest

Total Resource Need (Peak + 9% PRM), Effective (ELCC) MW



2035-2045 Needs: High Load Scenario
With high electrification to meet economy-wide net zero emissions, effective capacity need ***grows to 3,200 MW per year***

2035-2045 Needs: Reference Scenario
With continued electrification trends and legislated policies, effective capacity need ***continues at 1,600 MW per year***

Existing and In-development resources
+ 3,750 MW of winter firm imports

Near-term load forecasts aligned with PNUCC utility forecasts in 2030

Long-term load forecasts follow current market trends (reference) or are modeled to achieve net-zero emissions in the Greater Northwest (high load)

Portfolio optimization scenarios consider GHG policy, loads, and technology availability

The **Reference Load Scenario** assumes continued electrification trends and legislated policies.

The **96% GHG Reduction** cases are the focus of analysis. The achieved region-wide GHG reduction is **broadly aligned with existing WA and OR policies + voluntary goals** by utilities in other NW states.

The **100% GHG Reduction** cases are sensitivities beyond current state policies; these cases are designed to focus on the value of emerging technologies.

Policy Scenario	Load Scenario	Technology Scenario
96% GHG Reduction below 1990 levels	Reference	Mature Technologies Mature Technologies (No New Gas)
	High Loads	Mature Technologies Mature Technologies (No New Gas) Emerging Technologies (Long-Duration Storage) Emerging Technologies (Clean Baseload) Emerging Technologies (Clean Fuels) Emerging Technologies (No Combustion) Emerging Technologies (All) Emerging Technologies (All, Low Cost)
100% GHG Reduction	High Loads	Mature Technologies Emerging Technologies (Long-Duration Storage) Emerging Technologies (Clean Baseload) Emerging Technologies (Clean Fuels) Emerging Technologies (No Combustion) Emerging Technologies (All)

Technology scenarios consider resource needs and costs to meet RA and clean energy needs under **mature technologies**, **no new gas**, and scenarios with **emerging technologies** not yet commercialized at scale.

The **High Loads Scenario** reflects the high level of electrification needed to meet economy-wide net zero emissions and is the focus of the emerging technologies analysis.

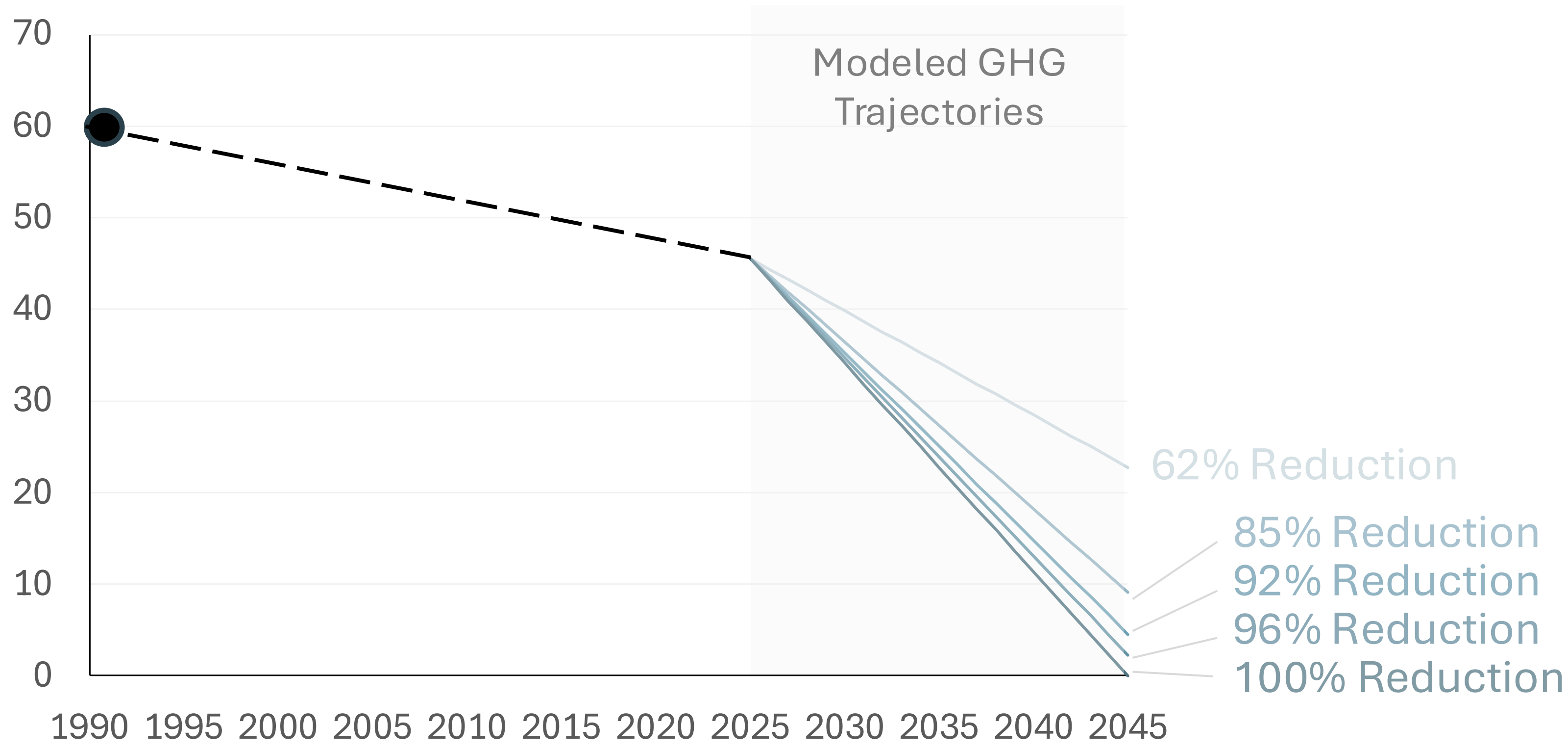
• Note: additional GHG reduction scenarios using mature technologies were studied for 0%, 62%, 84%, and 92% GHG reduction

Modeled greenhouse gas (GHG) trajectories

- GHG emissions reductions are relative to 1990 emissions of 60 MMT[1]
- GHG emissions in 2025 are benchmarked to statewide historical emissions
- Emission trajectories between 2025 and 2045 are linear
- GHG emissions target is applied to the entire GNW region in RESOLVE
- Emission reductions must accelerate to meet modeled targets

Greater Northwest **Reference Emissions and Modeled Greenhouse Gas Targets**

CO_2 emissions (MMT)

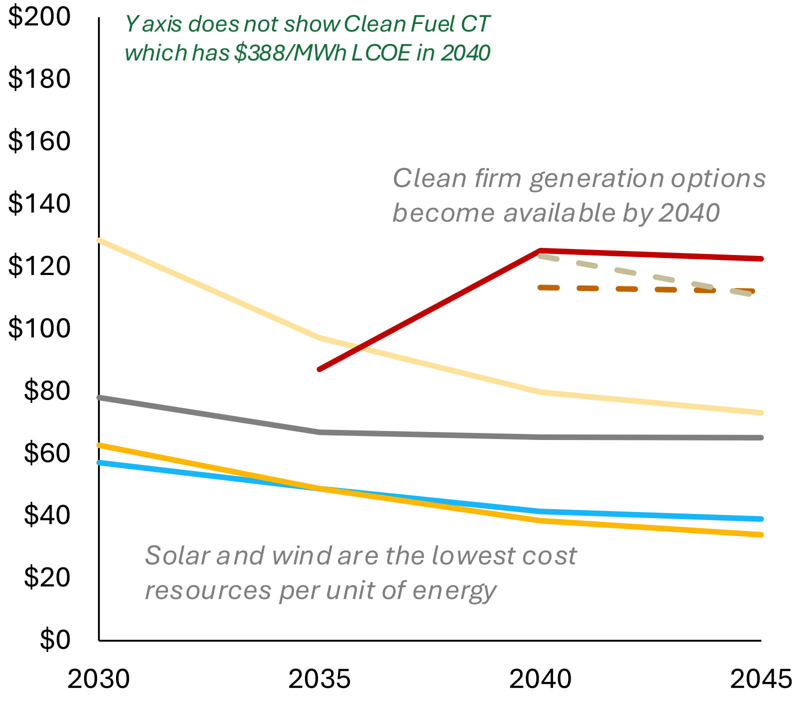


1. Resource Adequacy in the Pacific Northwest (2019)

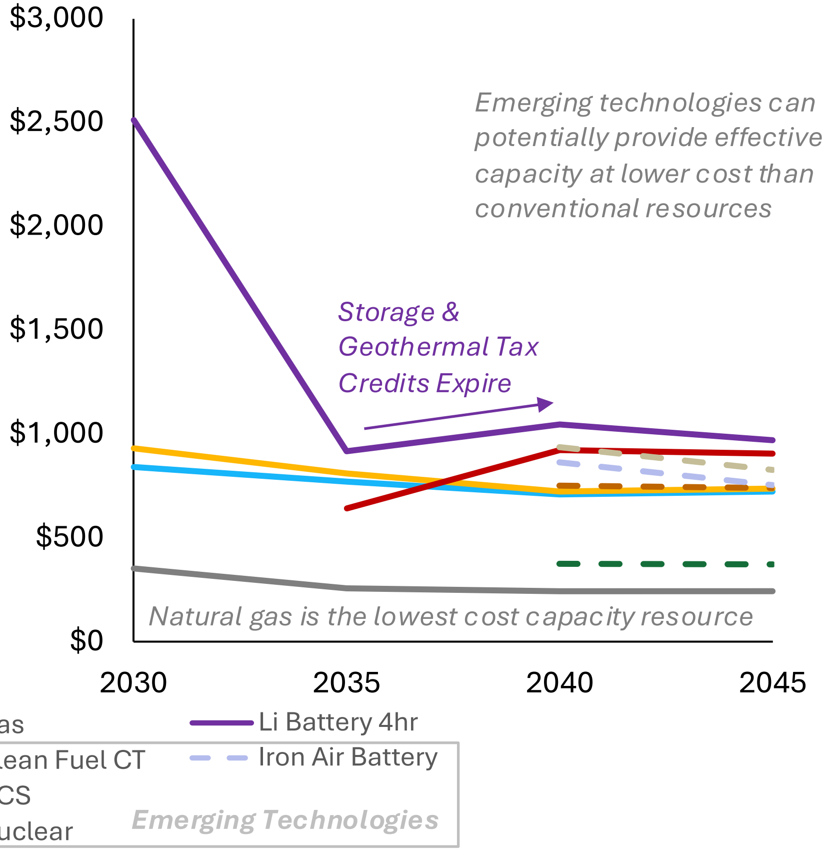
Resource cost assumptions reflect latest market trends and federal policies as of mid-2025

Cost of New Resources

Levelized Cost of Energy (2024$/MWh)[1]



Levelized Cost of Effective Capacity (2024$/kW-yr)[2]



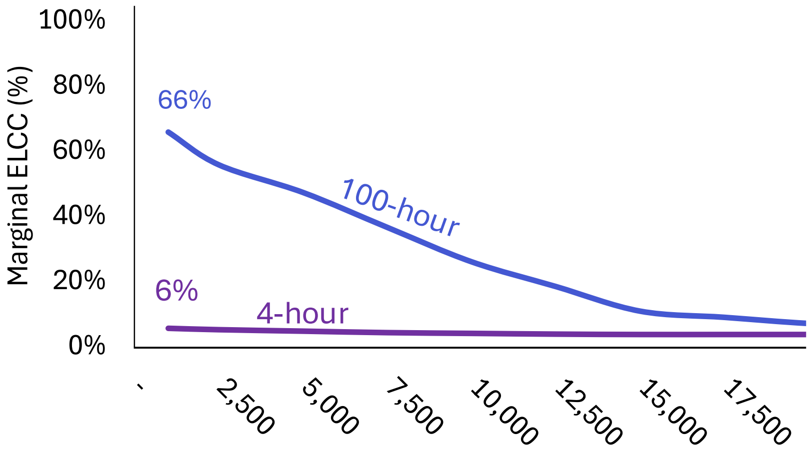
- **Cost trajectories reflect current market and policy outlook, including sunsetting of tax credits and supply chain bottlenecks**
- **Solar and wind costs modeled with continued declines, but larger penetrations face increasing interconnection costs and declining ELCCs**
- **"Clean firm" resources like geothermal, CCS, and nuclear are high cost but high value**

1. Levelized cost of effective energy (LCOE) only includes generation resources. Charts show average costs of candidate resources for the Greater Northwest developed in RECOST, E3's in-house discounted cash flow model. Solar and wind have increasing interconnection costs and declining resource capacity factors as a function of penetration.
2. Levelized cost of effective capacity (LCOC) includes both generation and energy storage resources. Solar, wind and batterieshave changing ELCCs as a function on penetration and portfolio interactive effects. LCOC use static ELCC values for thermal resources (93-95%). ELCC of 4-hr Li-ion change from 6% to 14%, solar from 16% to 11%, wind from 24% to 19%, and 100-hr Iron-Air Battery 63% to 77% reflecting the average ELCC of each resource type added in that year.

Storage ELCCs increase over time as the system grows and the influence of low hydro conditions is diluted

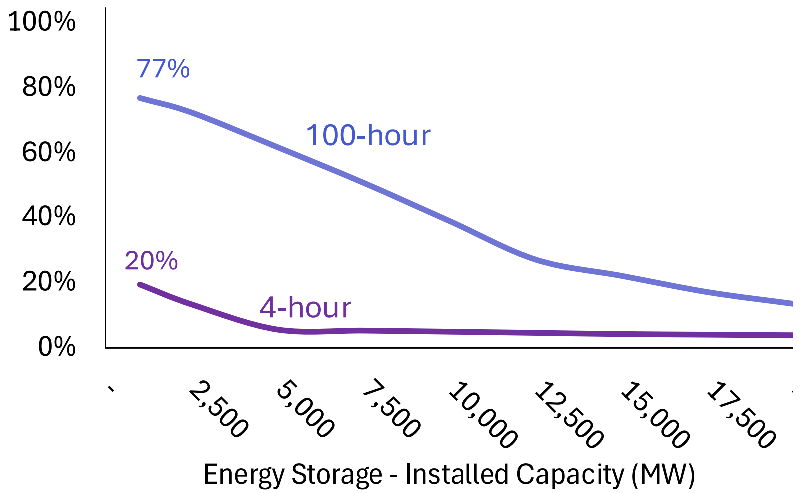
Marginal Effective Load Carrying Capacity of Energy Storage Additions (%)

2030



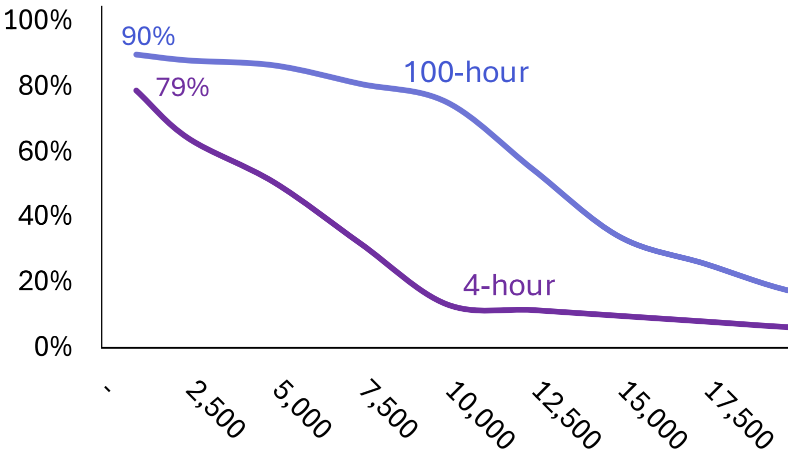
Today, short-duration storage is **ineffective at meeting multi-day reliability events** caused by extreme cold weather and very low hydro conditions

2035



By 2035, **storage ELCCs increase a bit** due to higher loads and higher wind and solar generation shifting the nature of loss-of-load events

2045



By 2045, with **2x load and 6x wind and solar** generation, ELCCs for both short and long-duration storage are much higher (High Load Scenario)

- Additions of any duration storage affects the marginal ELCC for all other storage, and ELCC curves do not saturate independently.
- The ELCCs come from the 96% GHG Reduction Scenario (High Load) which includes 28 GW wind and 13 GW solar by 2035, 63 GW wind and 62 GW solar by 2045

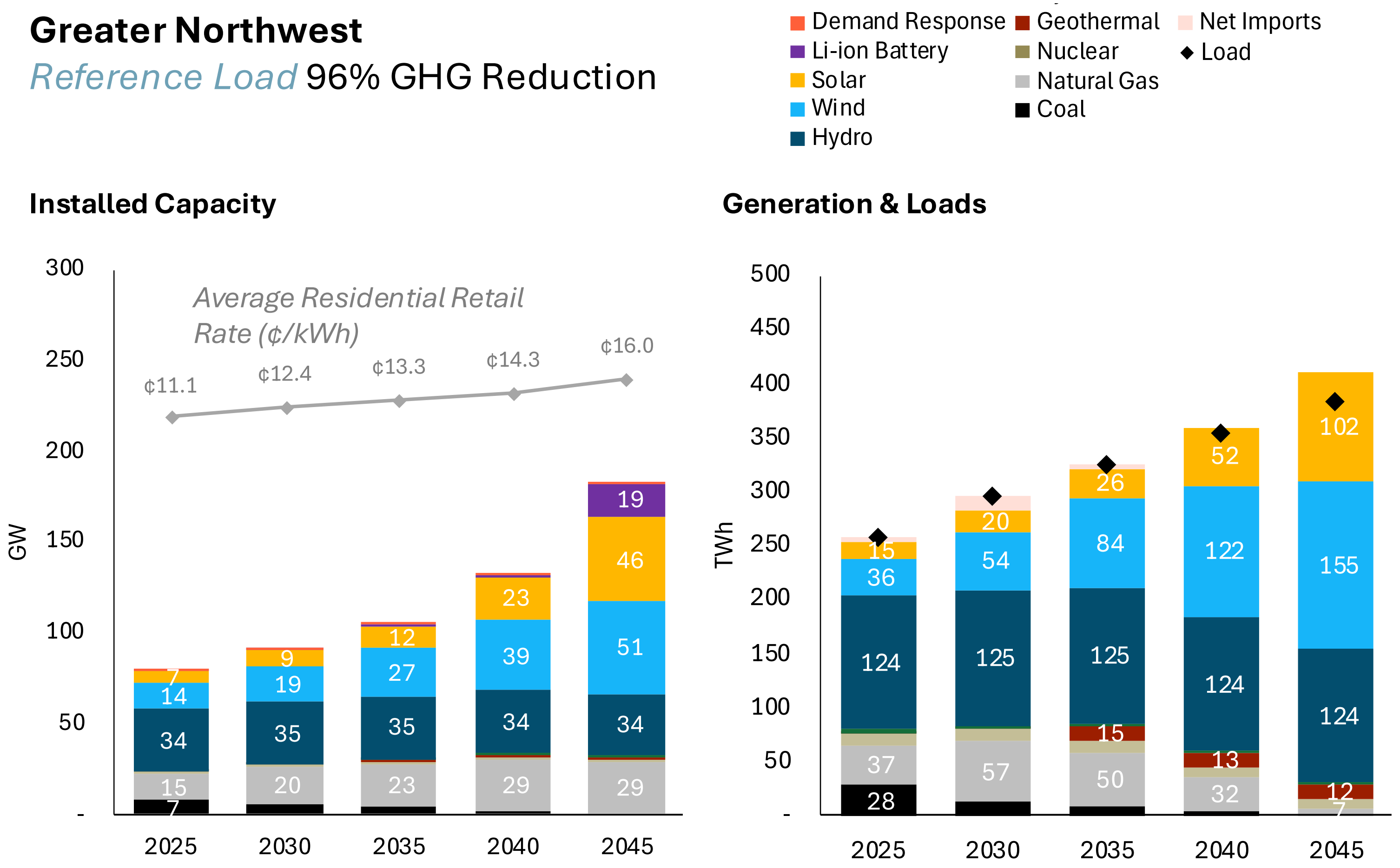
A portfolio of wind, solar, storage and natural gas is selected to meet clean energy and resource adequacy needs

Greater Northwest

Reference Load 96% GHG Reduction

Installed Capacity

Generation & Loads

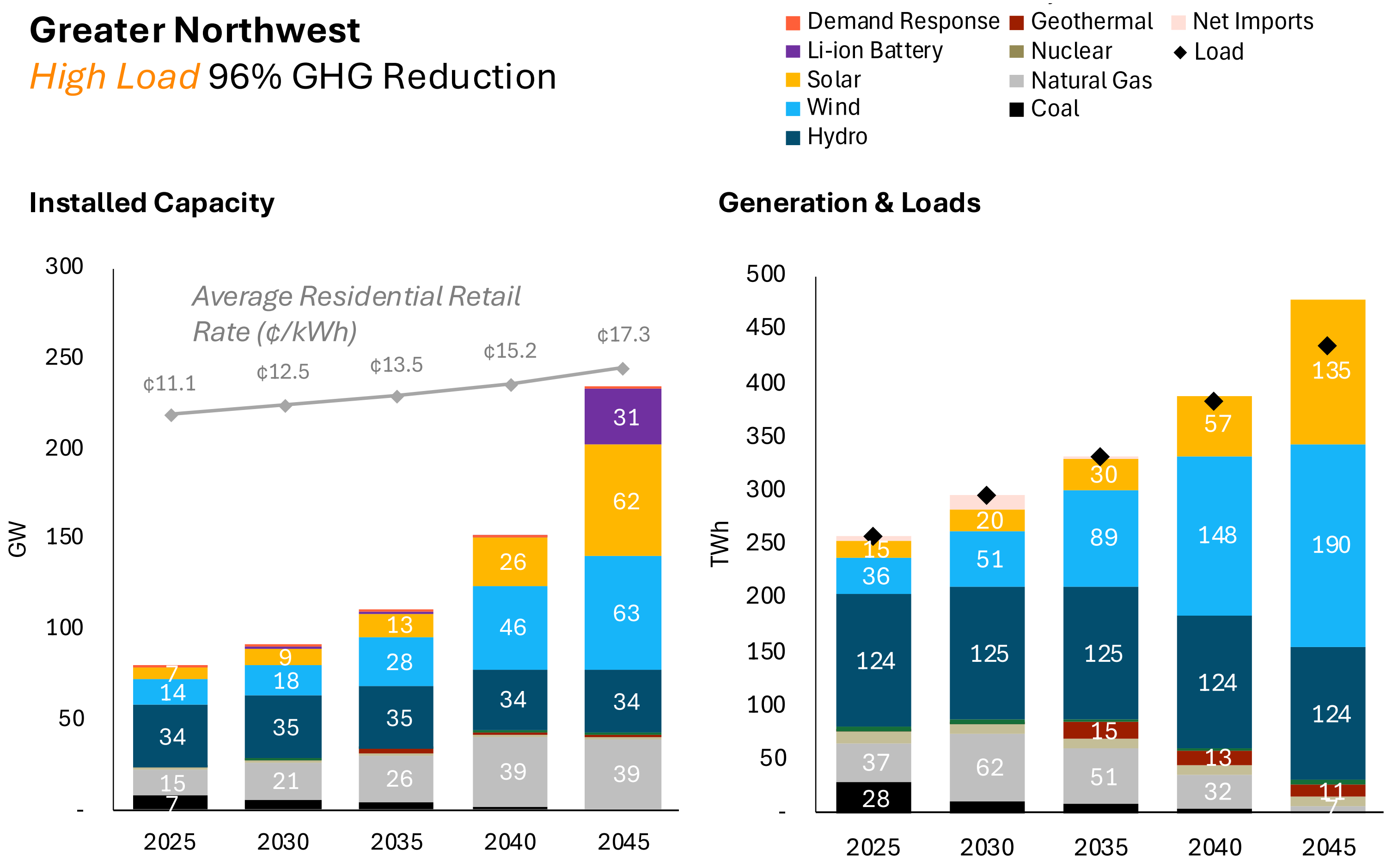


- Large increase in wind, solar, and gas is needed by 2035 to meet growing load and reduce emissions :
  - 13+ GW Wind
  - 5+ GW Solar
  - 8+ GW Natural Gas
- Storage selected, but not until 2040's, when RA value and renewable integration values increase
- Natural gas capacity is added as the reliability backstop, but additions of renewable generation reduce gas capacity factor over time
- Costs increase to serve new loads, but costs to achieve 96% GHG reduction is only slightly higher than cases with uncapped emissions

- Rate impacts shown in real 2024$ terms; some utilities may see significantly different impacts than these regional values
- Policies are modeled at least-cost, achieved on a regional basis
- Generation exceeds loads in years where the Greater Northwest is a net energy exporter

High load scenario shows similar portfolio, but with significantly more resources selected by 2045

Greater Northwest
High Load 96% GHG Reduction

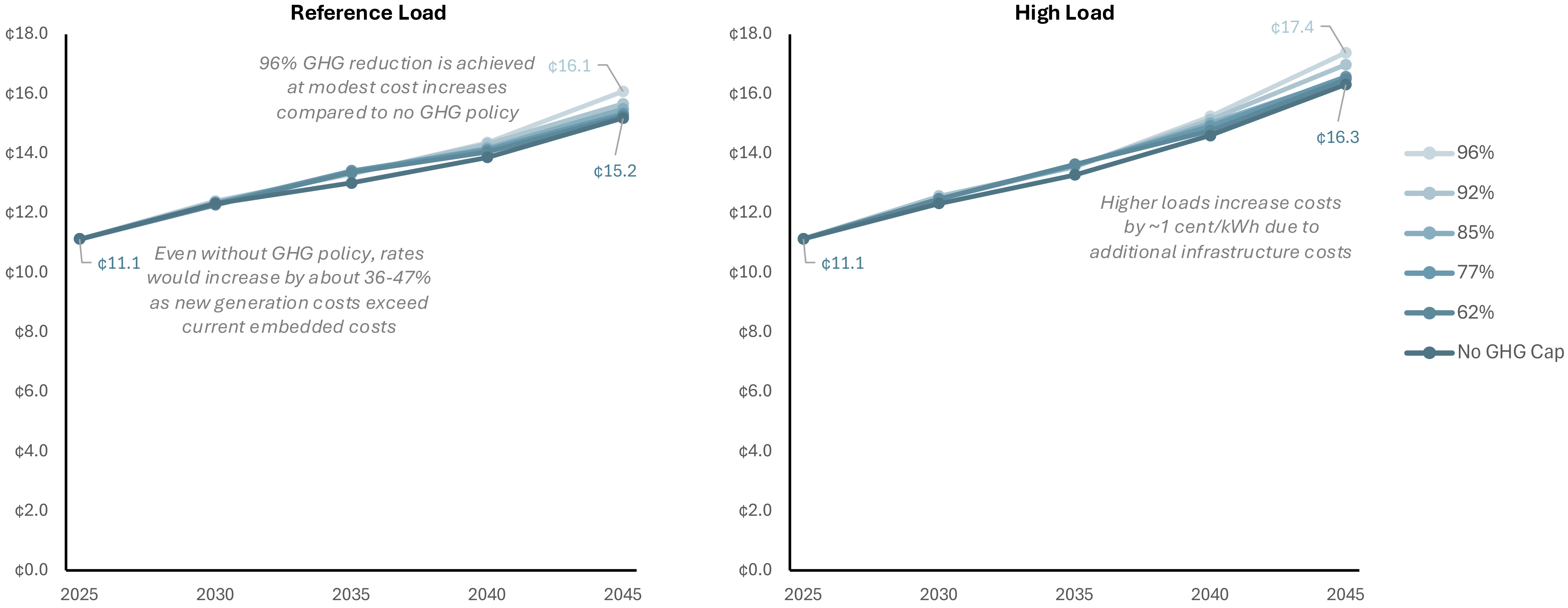


- **High load scenario shows large increase in resources needed**
  - Higher resource need primarily after 2035 as electrification to support a net-zero carbon economy increases
  - **Installed capacity** of generation and associated transmission interconnection grows **more than triples**
- **Annual generation nearly doubles from today**
- **Costs to meet high load scenario are slightly higher, reflecting increased needs for RA and GHG reducing infrastructure**

- Rate impacts shown in real 2024$ terms; some utilities may see significantly different impacts than these regional values
- Policies are modeled at least-cost, achieved on a regional basis
- Generation exceeds loads in years where the Greater Northwest is a net energy exporter

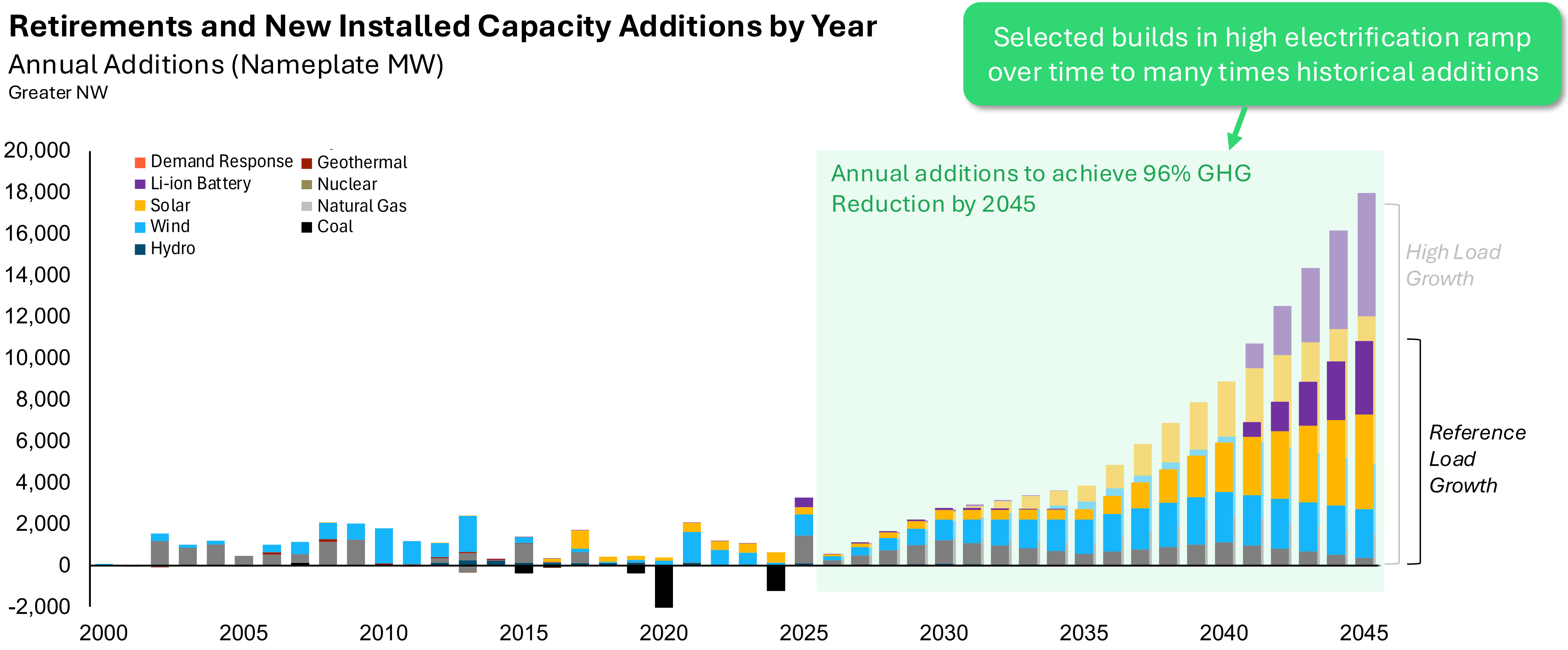
Rates increase in all scenarios, while incremental costs to achieve up to 96% GHG reduction regionwide are modest

Greater Northwest Average Residential Retail Rates (¢/kWh)
GHG Reduction Scenarios



- Rate impacts shown in real 2024$ terms; some utilities may see significantly different impacts than these regional values if they cannot access the regional diversity (for RA and clean energy) modeled in this study
- Policies are modeled at least-cost, achieved on a regional basis

Achieving current clean energy targets requires a massive increase in annual new capacity additions



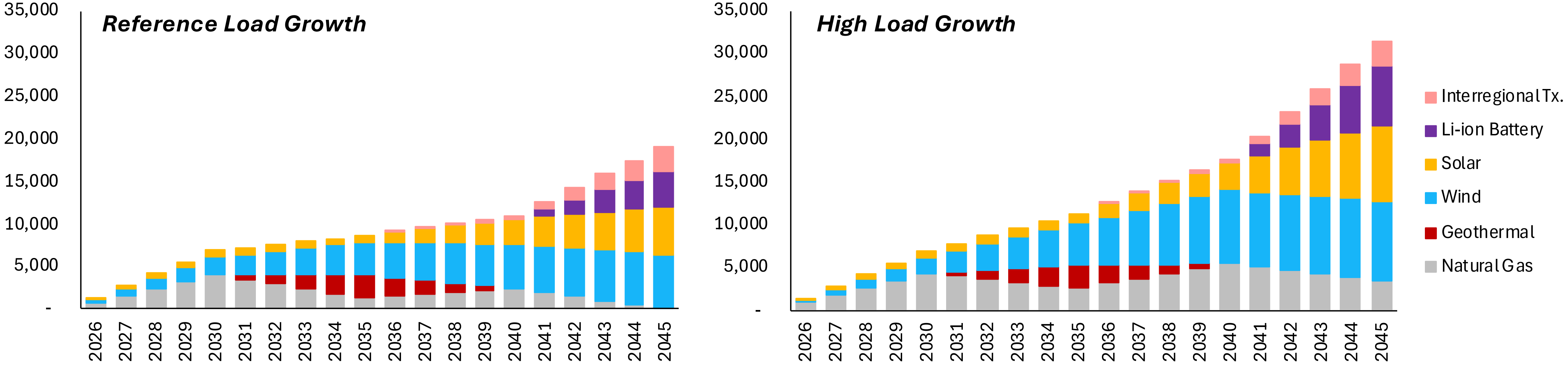
Annual capital investments increase to $11 billion/year by 2035 and nearly $32 billion/year by 2045

+ Annual regional capital investments in new resources grow rapidly across the planning horizon studied

- Natural gas investments peak in 2030 due to elevated turbine prices and again in 2040 when new gas is added to meet growing peak load
- Investments in solar and wind escalate substantially over time given
- Interregional transmission becomes important in the 2040 timeframe

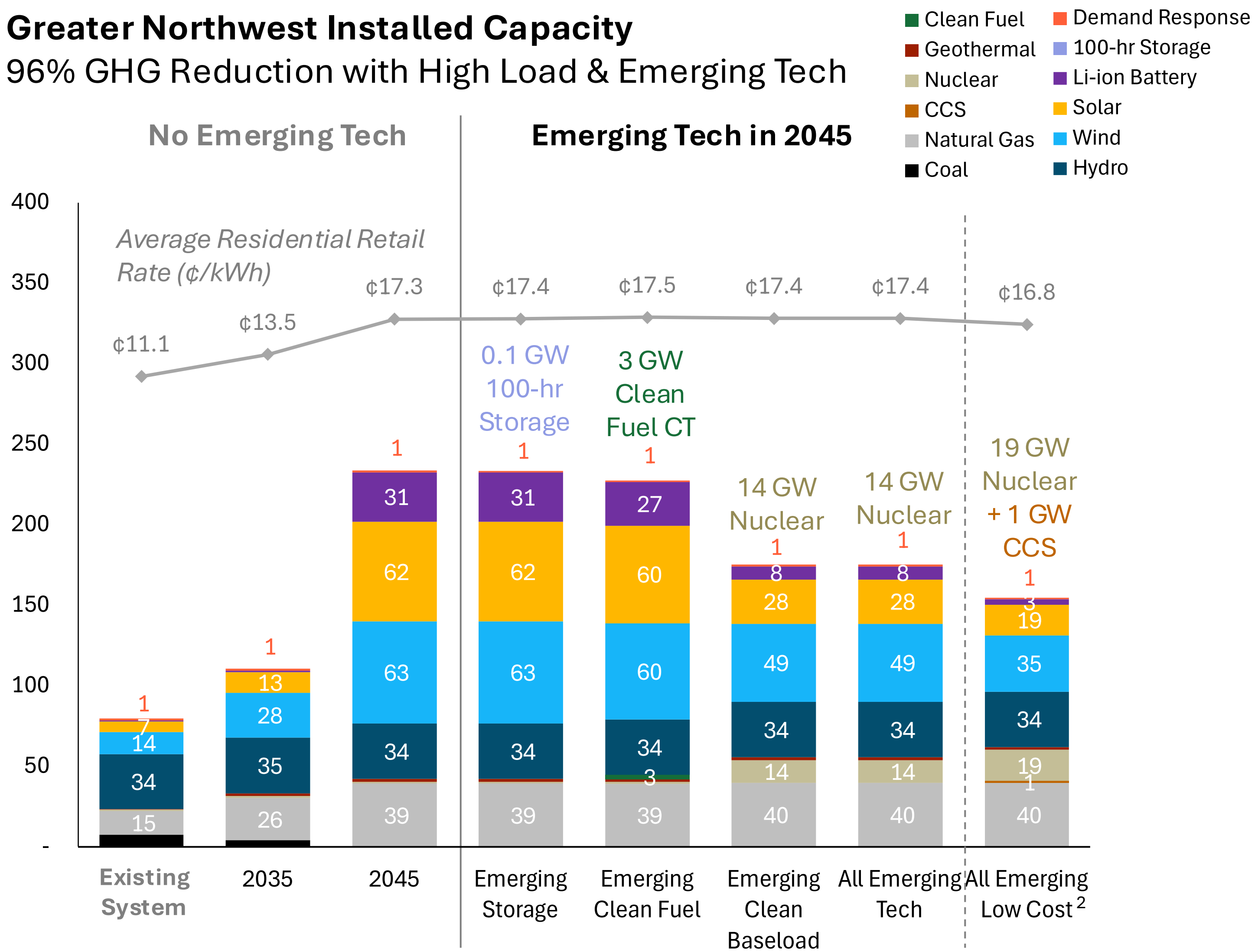
Capital Investments for Resource Additions

Annual Overnight Capital Costs (Million 2024$)



- Includes capital costs for new generation, new generation supporting transmission investments, and new gas power plant delivery pipelines only
- Does not include additional expected spending on utility T&D expenses nor utility or customer spending on electrification and other DSM/DER resources

Emerging technologies are selected at 96% GHG reduction but show limited ratepayer benefits absent a cost breakthrough



- Without emerging technologies, the model selects 31 GW of Battery Storage, 62 GW of Solar, and 63 GW of Wind to achieve 96% emissions reductions in 2045
- 14-19 GW of clean firm baseload, e.g., Nuclear SMR, economically substitutes a large portion of solar and wind
- The availability of Long-duration Energy Storage and Clean Fuels does not result in major portfolio changes to achieve 96% GHG reduction
- All 96% GHG reduction cases show the same or more natural gas builds when emerging technologies are made available

- Rate impacts shown in real 2024$ terms; some utilities may see significantly different impacts than these regional values
- Policies are modeled at least-cost, achieved on a regional basis
- Note that the level and type of emerging technologies selected is sensitive to cost assumptions; "Low cost" sensitivity modeled emerging technologies at ~30% lower cost

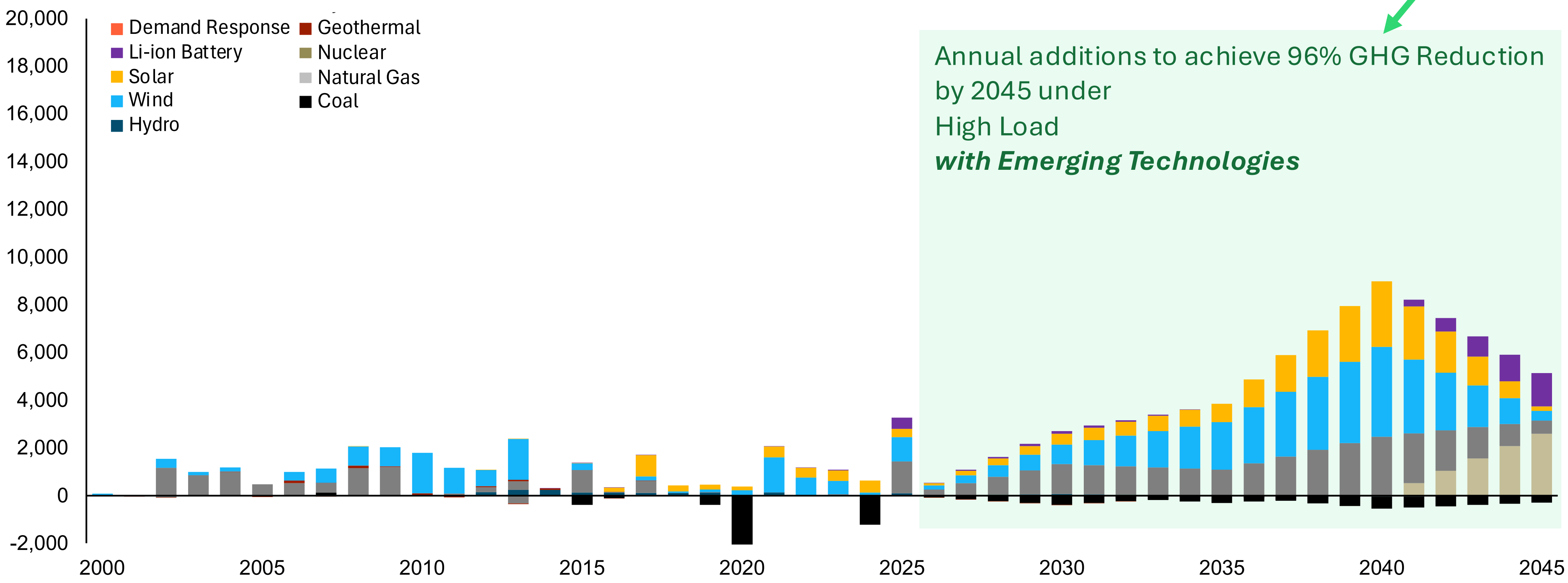
Emerging technologies can reduce the annual build rate required to meet reliability and clean energy goals

Availability of Emerging Technologies changes least-cost portfolio and significantly reduces build rate

Retirements and New Installed Capacity Additions by Year

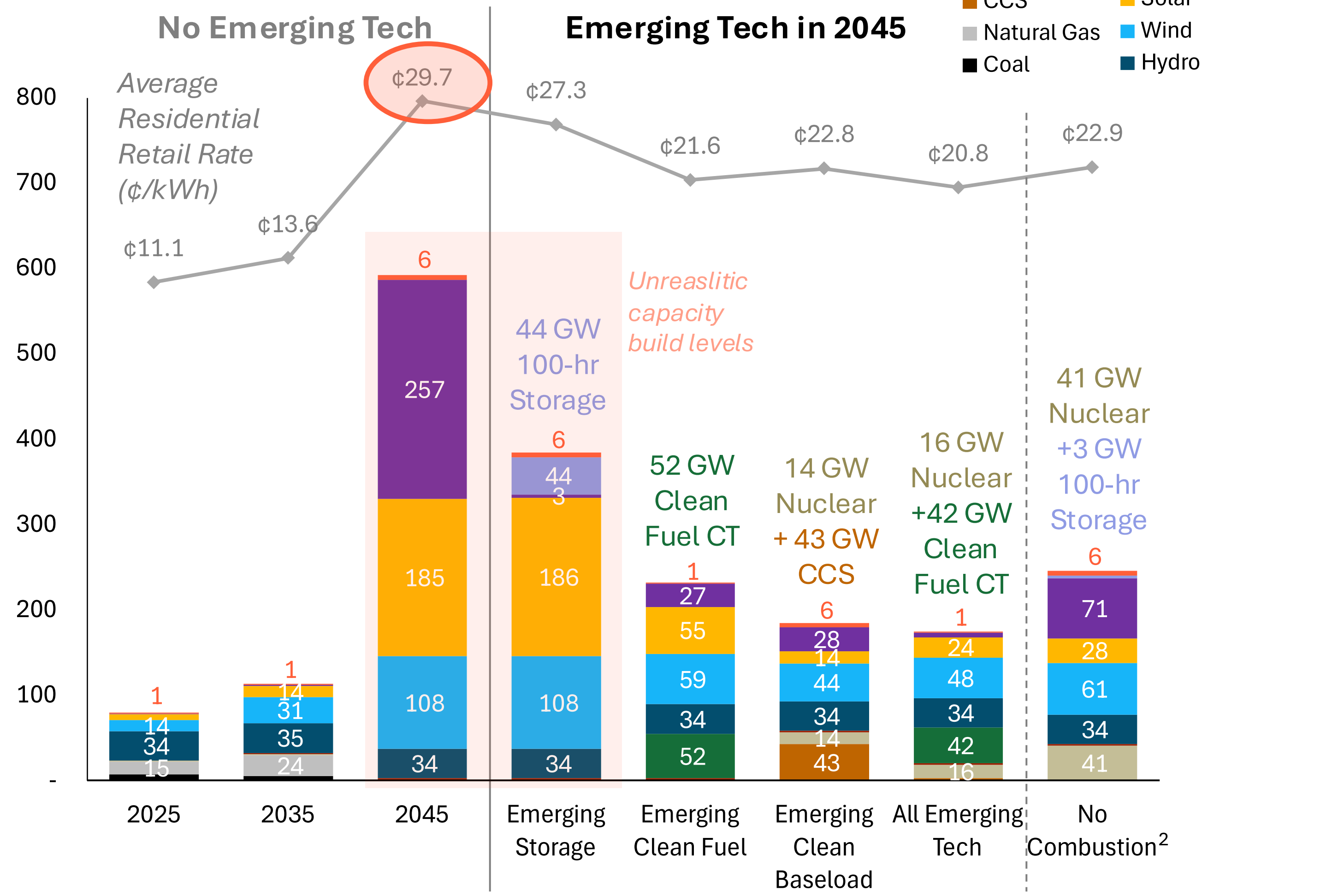
Annual Additions (Nameplate MW)

Greater NW



Achieving 100% carbon reductions is not feasible without at least one "clean firm" technology available at scale

Greater Northwest Installed Capacity
100% GHG Reduction with High Load & Emerging Tech

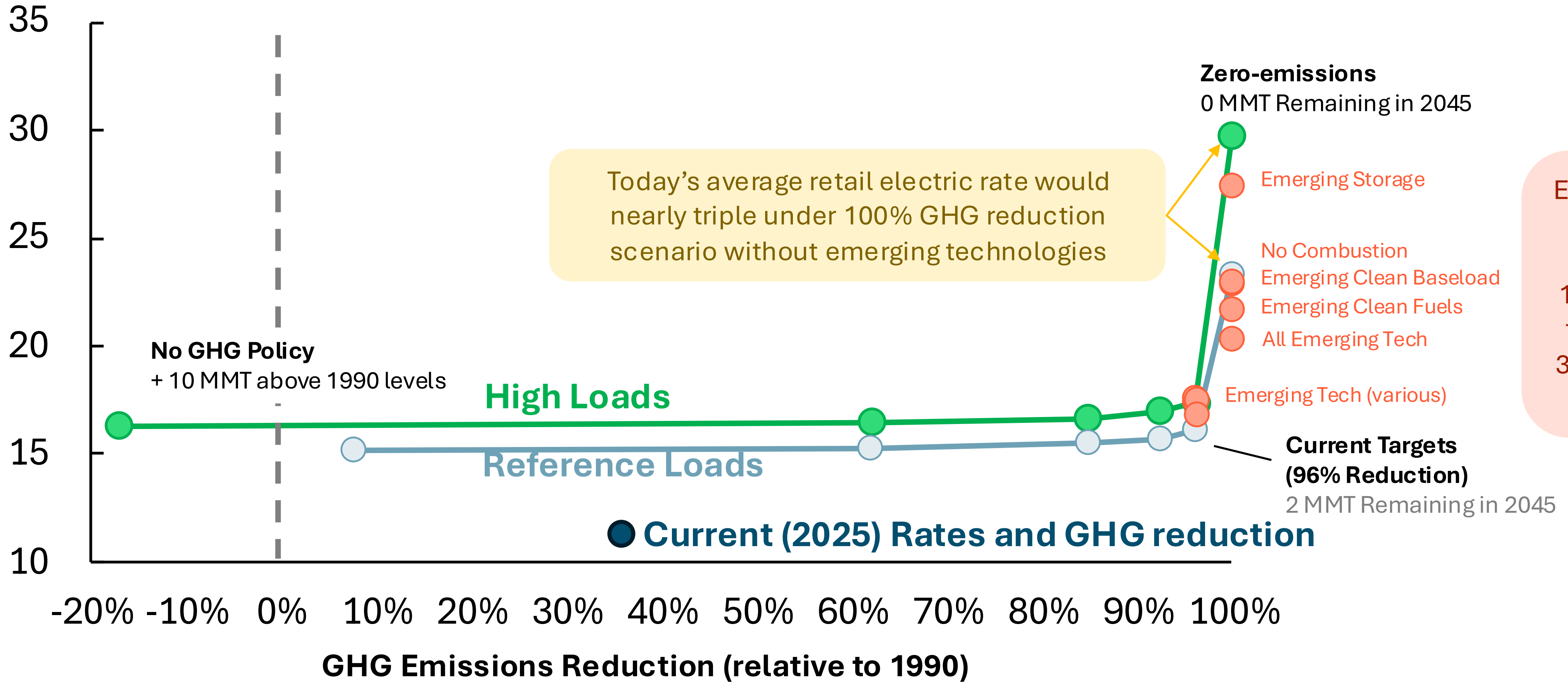


- Under 100% GHG reduction, all emitting coal and gas generators must retire or convert to zero-carbon fuels by 2045
- Achieving 100% reduction is not feasible without emerging "clean firm" technologies available at scale
- 44 GW of Long-Duration Energy Storage displaces almost all batteries, but very high levels of renewable builds are still required
- 57 GW of Clean Firm Baseload, such as Gas w/ CCS or Nuclear SMRs, offsets battery storage and renewables while replacing firm capacity previously provided by natural gas generation
- 42-52 GW of clean fuel powered combustion turbines displace fossil gas generation

- Rate impacts shown in real 2024$ terms; some utilities may see significantly different impacts than these regional values
- Note that the level and type of emerging technologies selected is sensitive to cost assumptions
- "No Combustion" sensitivity does not allow CCS, clean fuel CT, or gas in 2045

Average residential retail rates increase significantly to eliminate the last 2 MMT of GHG emissions

2045 Average Residential Retail Rates
(cents/kWh, 2024$)



Emerging technologies mitigate the rate impacts of achieving 100% GHG reduction, though costs are still 3-10 cents/kWh higher than 96% reduction

- Note: Emerging technologies are explored only in High Loads Scenario

Key Finding #3: A portfolio of new resources will be needed

3. In the long-run, it is possible to achieve deep carbon reductions while maintaining reliability and affordability by investing in a portfolio of energy efficiency, wind, solar, geothermal, and natural gas

- A balanced portfolio of new renewable generation, batteries and natural gas peaking capacity enables over 90% GHG reduction at a relatively low cost
- Emerging technologies are selected at 96% GHG reduction but provide limited ratepayer benefits absent a significant cost breakthrough
- 100% GHG reduction cannot realistically be achieved without one least one and likely multiple emerging technologies available at significant scale – 40+ GW
- Achieving the portfolios modeled requires overcoming institutional barriers (transmission, siting/permitting, etc.) to support a large increase in annual build rates compared to historical experience

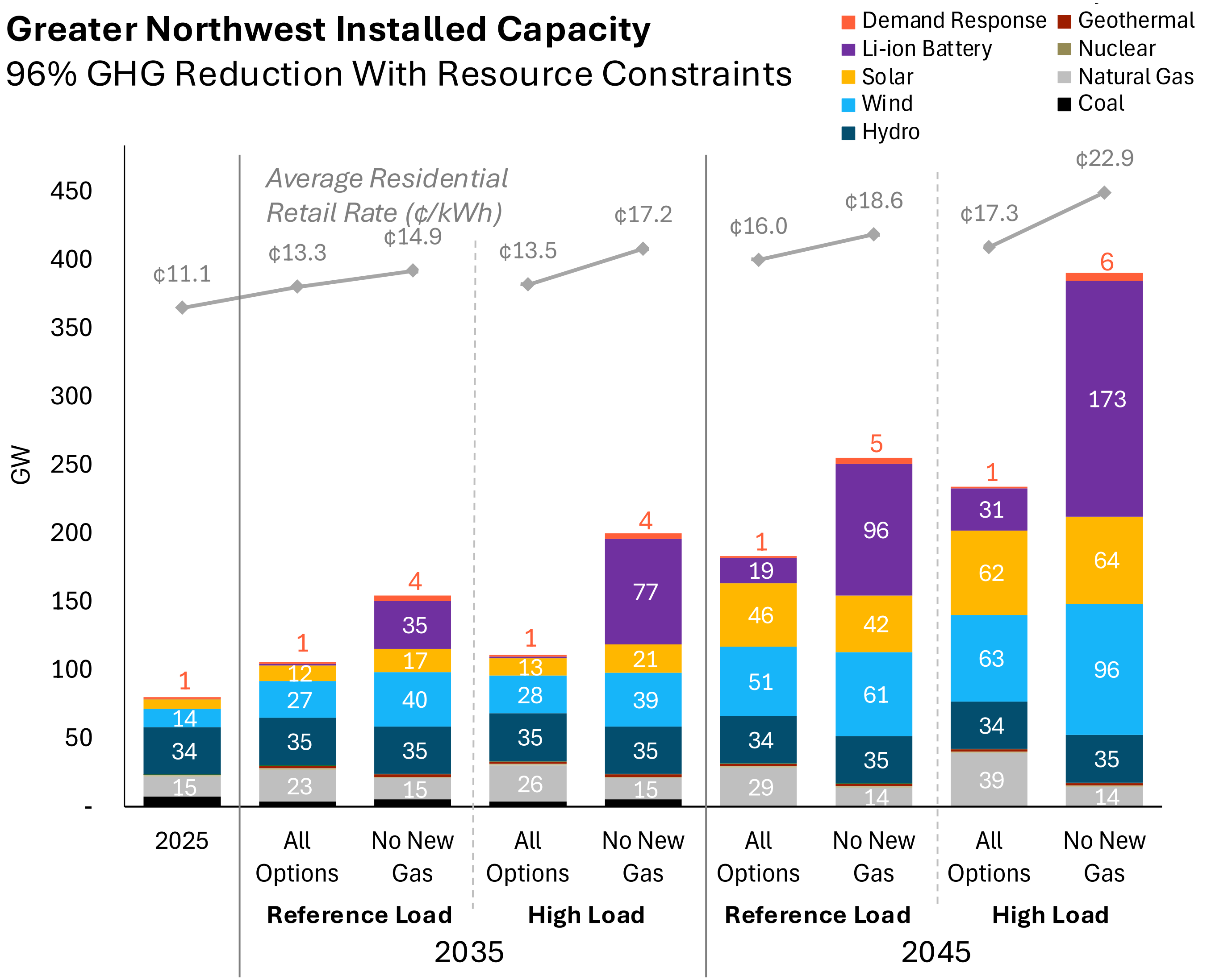
4. Role of New Natural Gas Generation

- What are resource needs + cost impacts without new gas?
- How robust is new gas selection across scenarios modeled?
- What is the risk that investments in new natural gas generation become stranded?
- How will new gas plants be utilized as the region decarbonizes?

Energy+Environmental Economics

If new natural generation is not allowed, costs and build requirements increase significantly

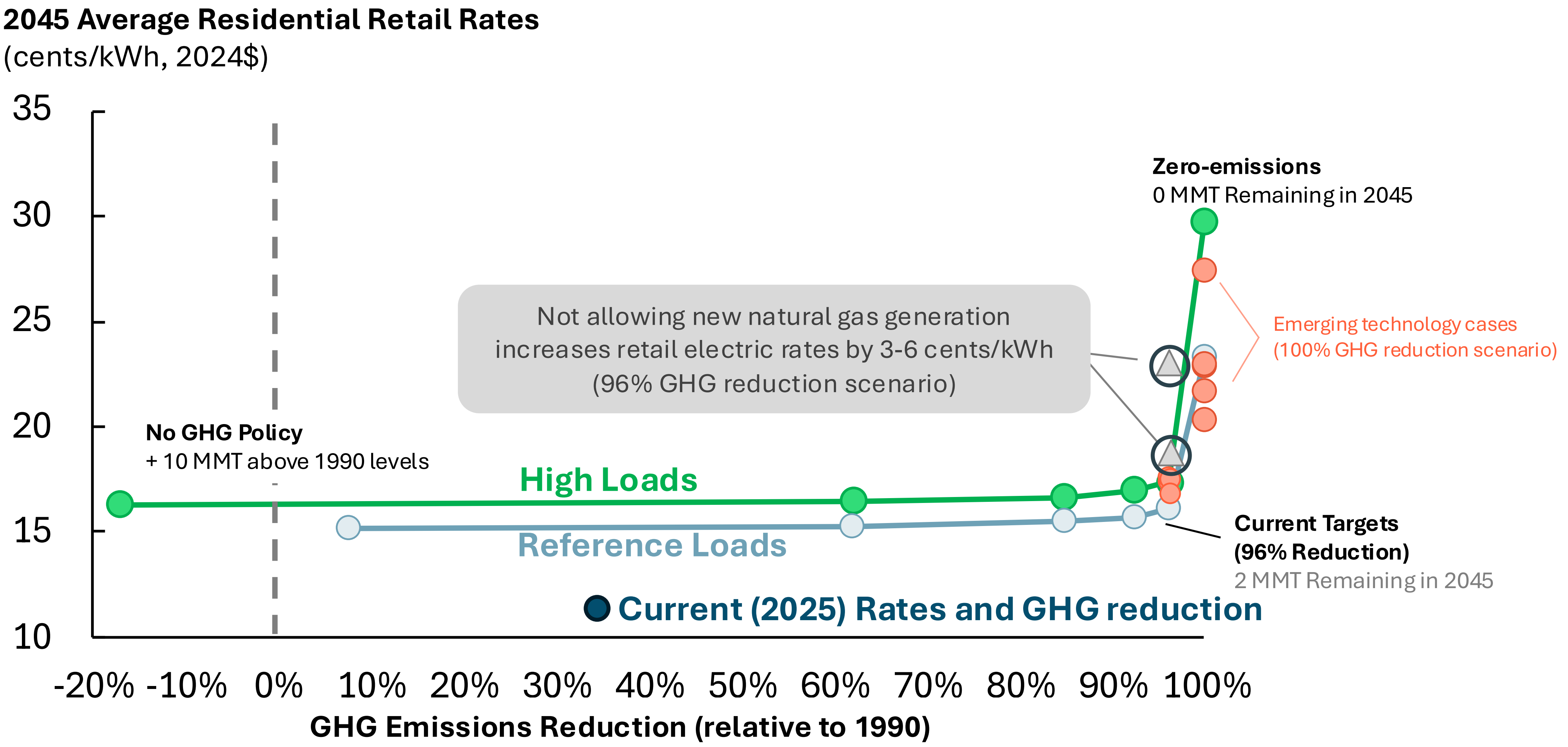
Greater Northwest Installed Capacity
96% GHG Reduction With Resource Constraints



- **In 96% GHG reduction cases with all resource options, new wind and solar decrease emissions by displacing generation from fossil resources while new natural gas capacity is added as a reliability backstop for extreme conditions**
- **Not allowing new gas generation requires tens to hundreds of GW of additional capacity**
  - In 2035, ~35-77 GW storage, 5-8 GW solar, and 11-13 GW of additional wind is required to offset 8-11 GW of new gas generation
  - In 2045, 196 GW of wind, solar and storage
  - Without new gas generation, retail rates increase by 3-6 cents/kWh under 96% GHG reduction case

- Rate impacts shown in real 2024$ terms; some utilities may see significantly different impacts than these regional values
- Policies are modeled at least-cost, achieved on a regional basis

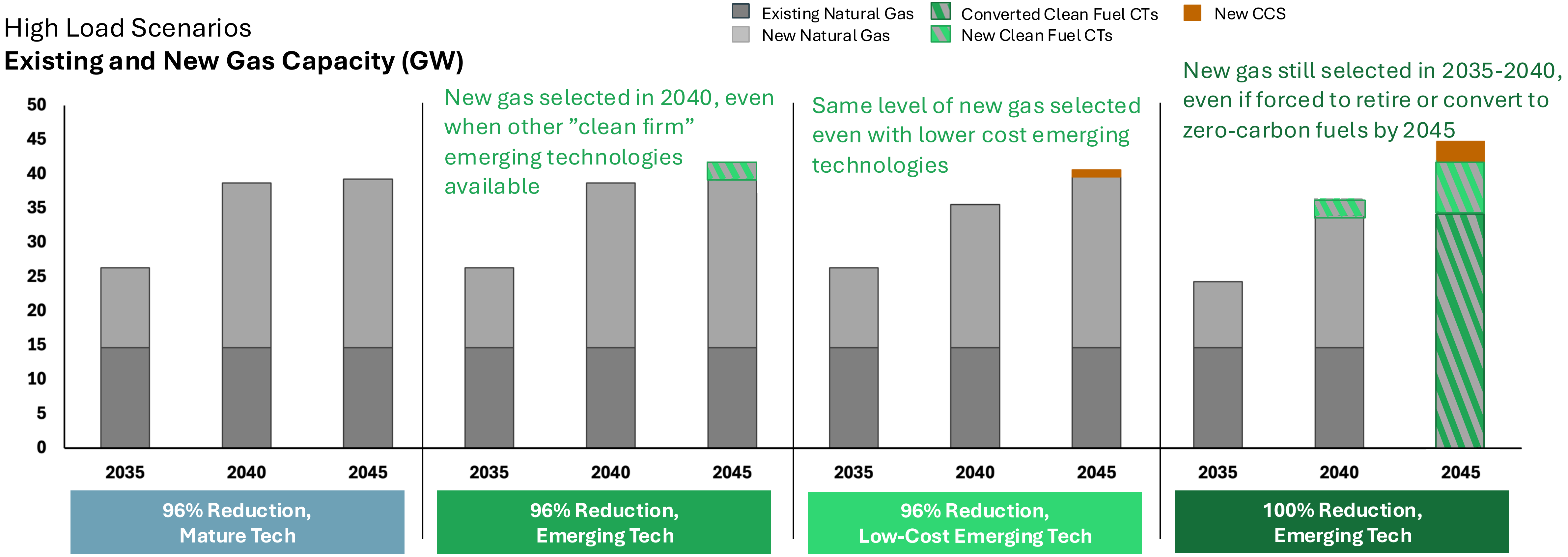
Not allowing new natural gas generation increases retail rates significantly compared to cases where new gas is allowed



Selection of new natural gas generation is robust across all scenarios and sensitivities, unless explicitly prohibited

High Load Scenarios

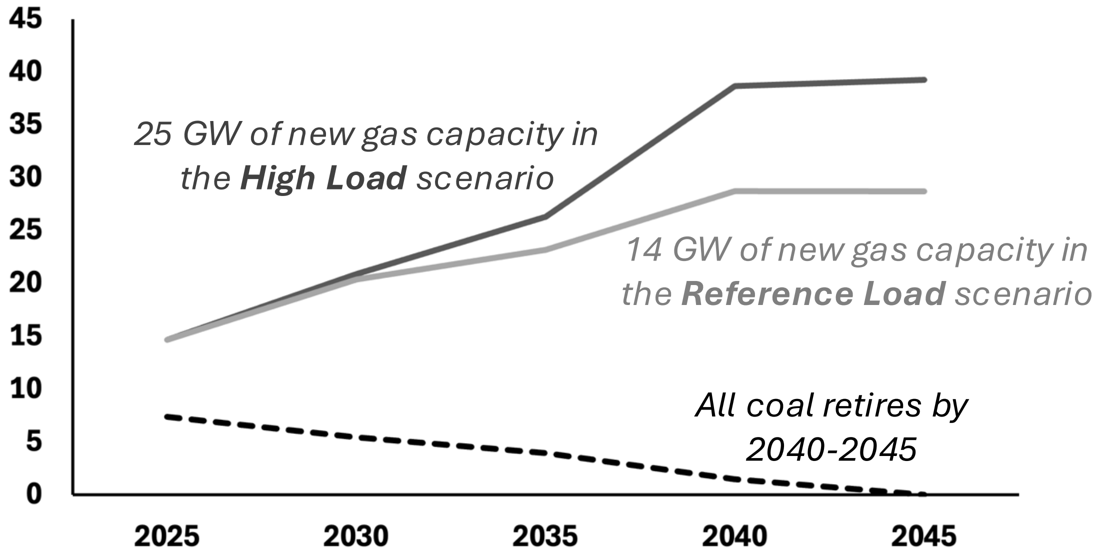
Existing and New Gas Capacity (GW)



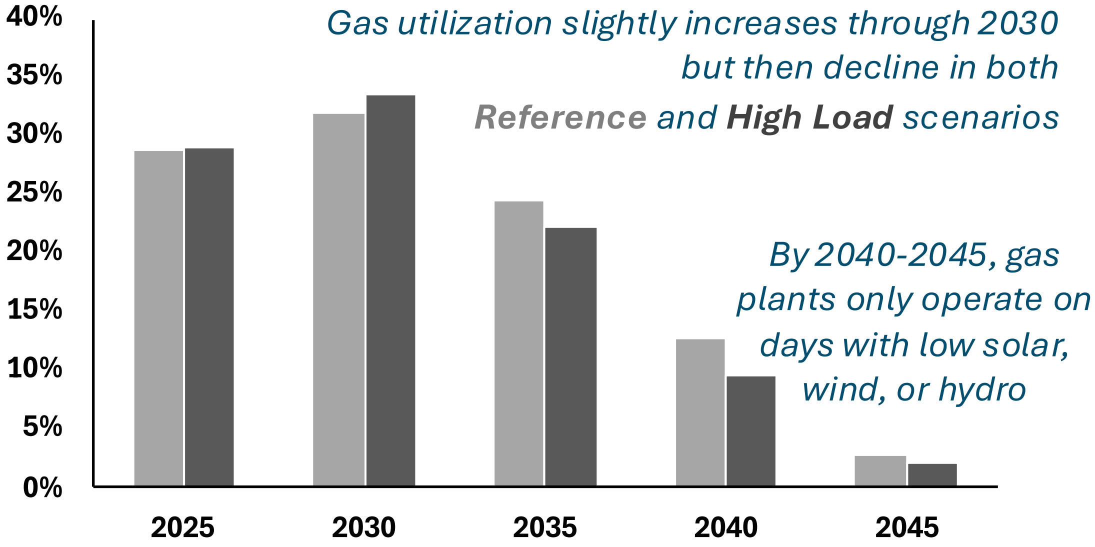
- **New natural gas capacity is added to maintain reliability in all scenarios where allowed**
- **Stranded asset risk eliminated if a small level of electric emissions are still allowed or an alternative zero-carbon fuel can be utilized (renewable natural gas, hydrogen, CCS)**

Natural gas plant utilization declines as clean energy policy drives solar and wind builds to reduce emissions

Natural Gas and Coal Capacity (GW)
Current Policy Targets, 96% GHG Reduction



Natural Gas Utilization (Annual Capacity Factor %)
Current Policy Targets, 96% GHG Reduction

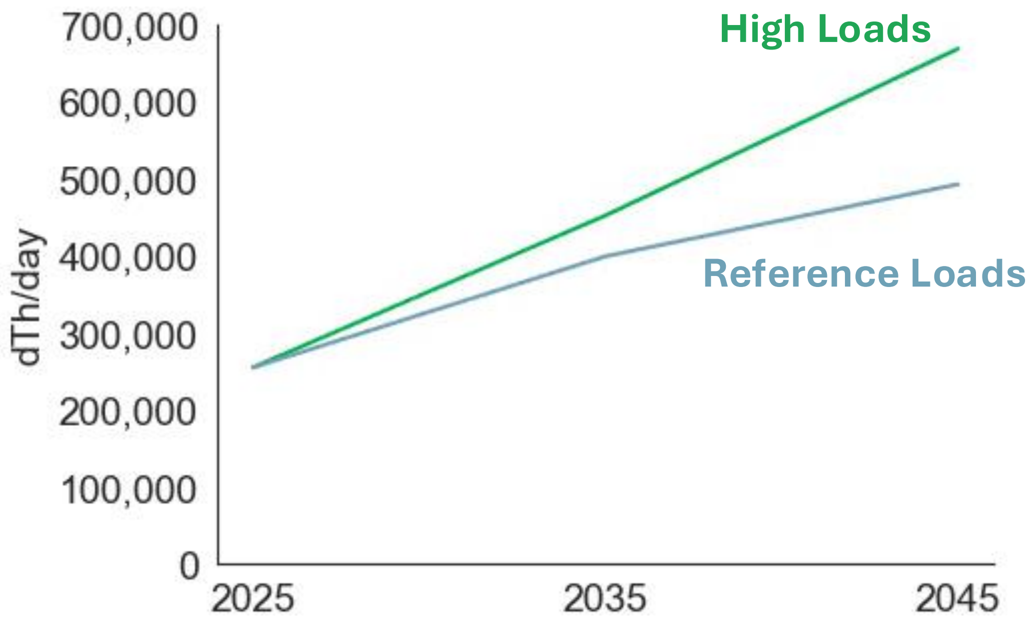


Clean energy additions drive emission reductions by displacing emitting generation, while gas capacity additions ensure sufficient backup firm power to serve loads when non-emitting energy is not available

Gas fuel delivery infrastructure needs for electricity generation increase significantly

+ **New natural gas generation requires firm fuel availability for resource adequacy provision**
  - New pipeline capacity (modeled in this study)
  - Backup on-site liquid fuel (potentially feasible, dependent on duration of fuel required)
+ **As electric loads grow, peak day gas throughput for electric generation more than doubles between 2025 and 2045**
  - Driven mostly by fuel switching from gas heating to electric heat pumps with resistance backup
+ **Further study required to assess combined throughput for electric generation and natural gas end use demands**
  - Hybrid heat pumps with gas backup may be a more efficient use of gas combustion, reducing the need for new power plants, pipelines, and T&D infrastructure

Natural Gas Peak Day Throughput (dTh/day, Electric Gen Only)
96% GHG Reduction



Key Finding #4: Gas peaking plants are a robust reliability strategy

4. New natural gas peaking capacity to provide energy during low hydro or low renewable conditions is a robust long-term strategy across a wide range of future scenarios

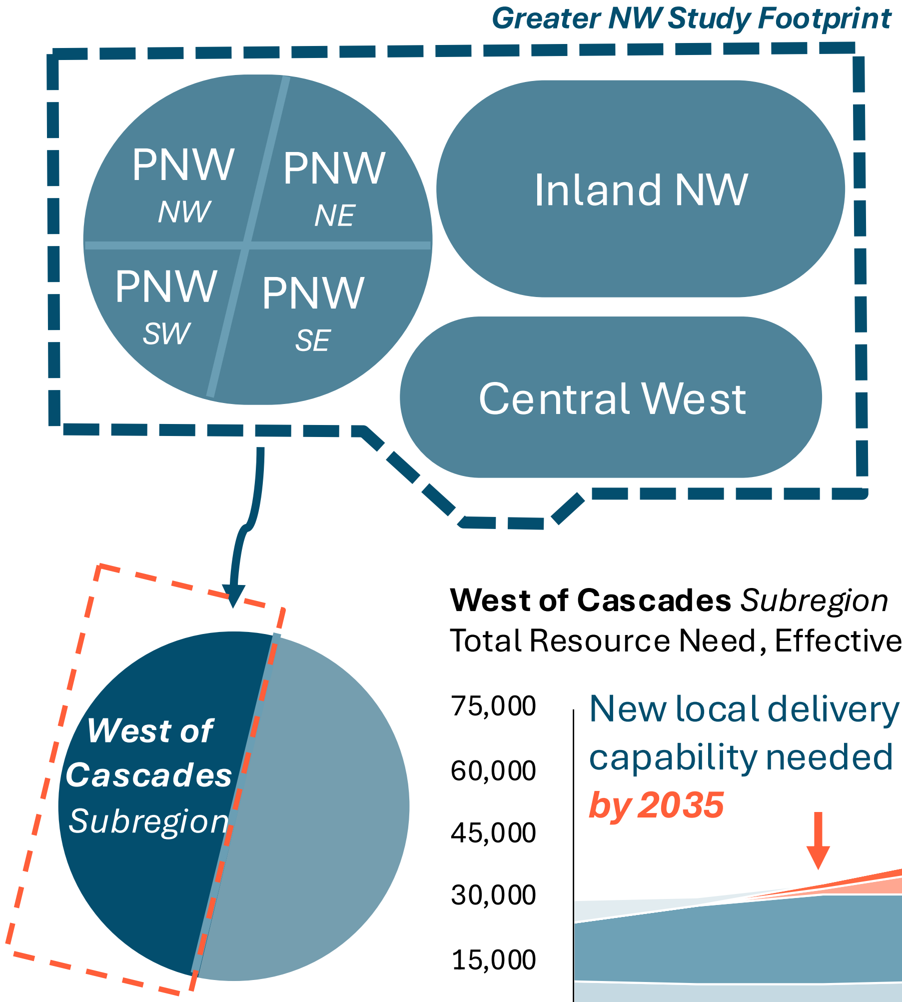
+ **Not allowing new natural gas peaking capacity leads to higher costs with no accompanying emissions benefits**
+ **New natural gas peaking capacity is selected across all scenarios unless prohibited**
  - **24-34 GW** of new natural gas capacity is selected under 96% GHG reduction, reducing retail electric rates by **3-6 cents/kWh**
  - Natural gas capacity is dispatched less frequently as clean generation is added, with capacity factors falling to 10-12% in 2040 and 2-3% in 2045
  - Even under a 100% GHG reduction scenario, new natural gas capacity is selected in 2040 only to be retired (or converted to zero-carbon fuels) in 2045

Pacific Northwest and Westside Resource Adequacy Needs

- As loads grow, when do resource adequacy needs in the Washington and Oregon load pockets exceed existing transmission capabilities?
- How much new local delivery capability is needed?
- What mix of resource and transmission solutions are selected by RESOLVE to meet sub-regional resource adequacy needs?

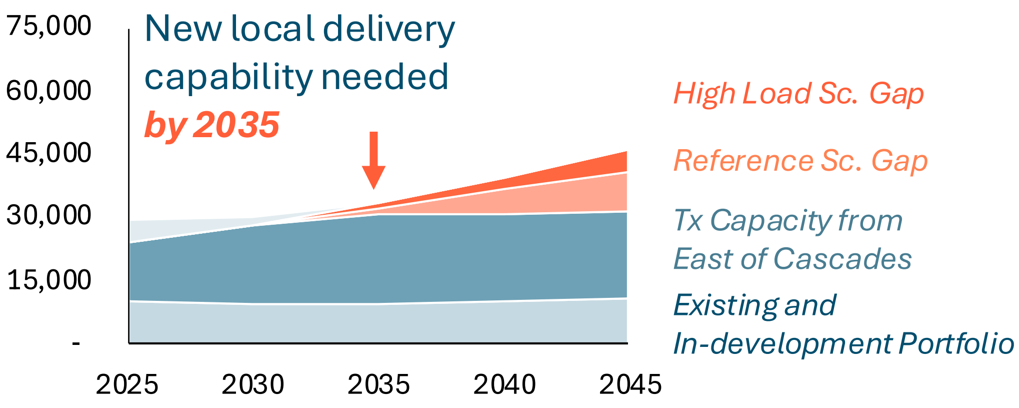
Energy+Environmental Economics

Subregional RA needs grow in OR/WA and West of the I-5 corridor as west coast population centers electrify

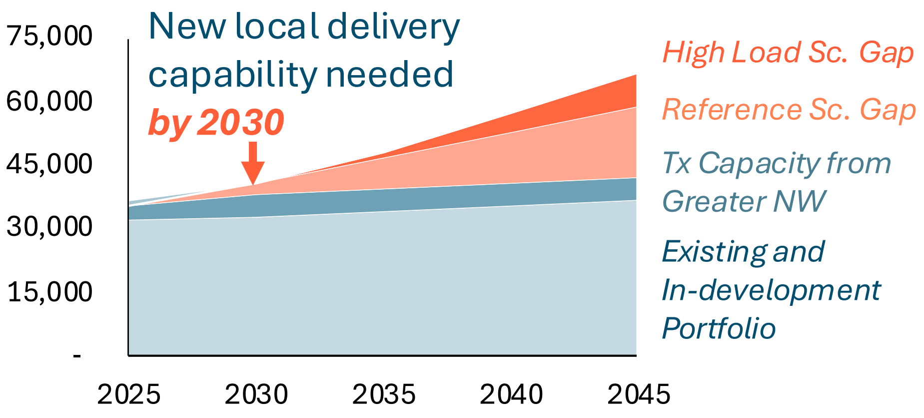


+ **Load in modeled subregions is growing faster than planned transmission upgrades, driving subregional RA needs**
+ **Subregional RA needs can be met by:**
  - **New inter-regional transmission**, which provides RA value to subregions and enables access to higher quality WY+MT wind resources
  - **New local resources in the subregions**, which was the only option by 2035 since new transmission is modeled starting in 2040

West of Cascades *Subregion*
Total Resource Need, Effective (ELCC) MW



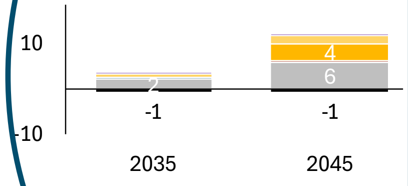
Pacific Northwest *Subregion*
Total Resource Need, Effective (ELCC) MW



New resources are distributed across the Greater Northwest alongside new transmission to meet subregional RA needs

96% GHG Reduction - High Load Scenario

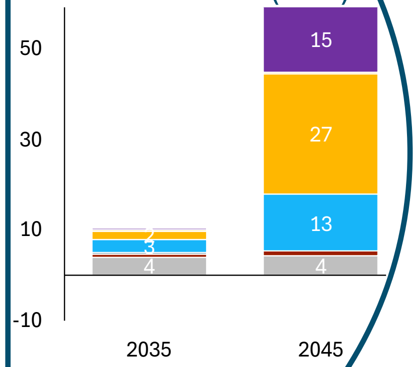
Pacific Northwest
West of Cascades
Resource Build (GW)



East to West Cascades
Tx Interface (MW)

2025	19,250
2035	**21,400 (+2,150)**
2045	**27,890 (+8,640)**

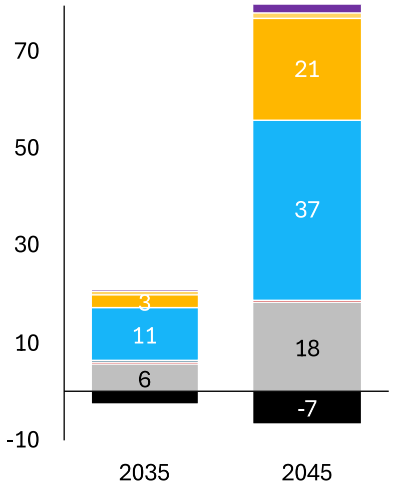
Pacific Northwest
East of Cascades
Resource Build (GW)



Inland Northwest & Central West
into Pacific Northwest
Tx Interface (MW)

2025	4,600
2035	**6,200 (+2,600)**
2045	**8,908 (+4,308)**

Inland Northwest & Central West
Resource Build (GW)



The West of Cascades subregion requires over 4 GW of new delivery capability by 2035 and 17 GW by 2045

The Pacific Northwest subregion requires over 11 GW of new delivery capability by 2035 and 31 GW by 2045

Results show RESOLVE's optimal solution to meet local needs, but those needs could be plausibly met by different combinations of local resources and transmission upgrades. For instance, siting batteries for local capacity values West of the Cascades is an alternative to the East of Cascades siting and upgraded cross-cascades transmission that RESOLVE selected.

Key Finding #5: Increased local delivery needed, especially west of the cascades

5. There will be a growing need for new local delivery capability into Washington and Oregon, particularly in the I-5 corridor west of the Cascades, either from new local resources or new regional transmission

+ **Amidst growing loads, the Pacific Northwest (OR+WA) and the West-of-Cascades subregions become locally constrained, requiring new delivery capacity**
  - Pacific Northwest (OR+WA) subregion: 11 GW of new local firm generation or transmission needed by 2035, 31 GW by 2045
  - West of Cascades subregion: 4 GW of new west-side firm generation or cross-Cascades transmission needed by 2035, 17 GW by 2045
+ **Local resource options are limited West of Cascades given low wind and solar availability**
  - Energy storage may be able to help meet some of the local need – further study is needed
  - 9 GW of new transmission selected implies 5-6 new cross-Cascades corridors

Recommendations

Energy+Environmental Economics

Key Findings

1. Accelerated load growth and continued retirements create a resource gap that grows to *9 GW of effective capacity by 2030* and *14-18 GW by 2035*
2. In the near-term, the region is not on track to fill this gap due to market and institutional barriers
3. In the long-run, it is possible to achieve deep carbon reductions while maintaining reliability and affordability by investing in a portfolio of energy efficiency, wind, solar, geothermal, and natural gas
4. New natural gas peaking capacity for backup use during low hydro or low renewable conditions is a robust long-term strategy across a wide range of future scenarios
5. There will be a growing need for new local delivery capability into Washington and Oregon, particularly in the I-5 corridor, either from new resources or transmission

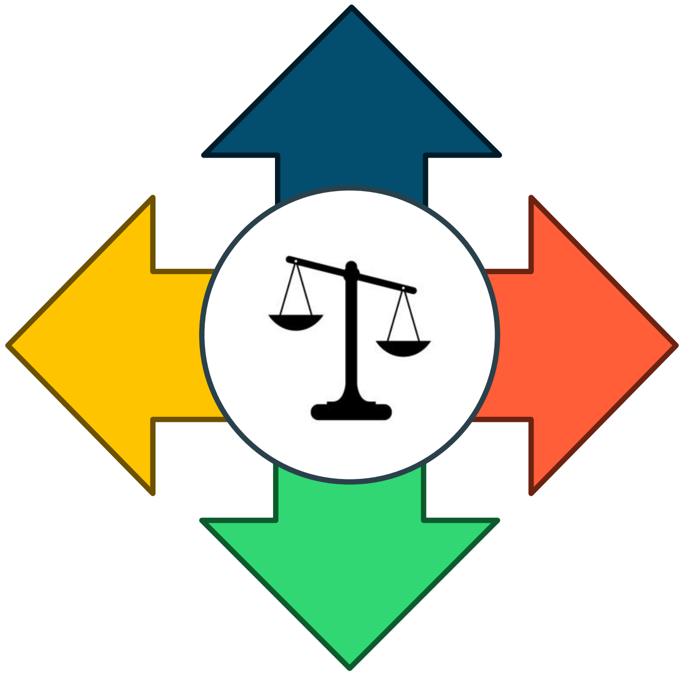
The region faces a balancing act across key objectives

Load Growth

Can the region build enough electricity infrastructure to support population growth, electrification objectives, and the economic benefits of large load development?

Reliability

Can the region build new capacity fast enough to maintain acceptable levels of resource adequacy?



Affordability

Can customer rate increases be minimized with the generation and transmission buildout necessary to support new loads and clean policy goals?

Clean Energy

Can the region meet near-term clean energy policy goals amidst rising loads? Are new GHG-emitting resources needed to maintain reliability?

Study results require key institutional changes to support the construction of modeled portfolios

DSM: continuation of historical EE+DR programs, new need to consider flexibility for data centers and electric vehicles

Siting and permitting: ensure efficient processes for siting new generation and transmission

Natural gas: coordinated development of new peaking capacity and expanded gas delivery system, joint planning for electric and gas end use demands

Emerging technologies: balance of federal funding, private capital, and state/utility support to commercialize new technologies

Transmission: efficient reformed interconnection processes, proactive transmission buildout, effective pathways for interregional line selection and cost allocation

Regional coordination: foundational to least-cost renewable integration

- **Energy markets** ensure efficient regional commitment and dispatch
- **Capacity markets** allow pooling of regional RA resources (e.g., WRAP), define regional and sub-regional RA needs, and send efficient market signals for entry/exit
- **Clean energy markets** support least-cost regional diversity and tradeable products instead of piecemeal BA-level planning

Phase 1 Near-Term Resource Adequacy Assessment: Recommendations

1. **Consider demand management strategies that can address winter resource adequacy needs:**
   - Develop all cost-effective energy efficiency, with an emphasis focus on load reduction during cold snap conditions
   - Consider DR programs that could minimize risk to residential customers should load shed conditions emerge
   - Carefully manage large load interconnections to align timing with available generation
2. **Firm up imports:**
   - Work with WRAP and others to enhance the availability of firm import capacity into the region, particularly during winter
3. **Prepare for potential emergency conditions:**
   - Mobilize existing backup generation to be available to meet regional needs if necessary
   - Expand gas-electric operational coordination to minimize fuel disruptions during critical conditions
   - Re-evaluate hydro emergency operations during extreme cold weather events, especially under low hydro conditions
   - Prepare utility load shedding practices to minimize disruption during a load shed event
4. **Address barriers to new resource development:**
   - Mobilize state government resources to help avoid potential project delays
   - Continue BPA interconnection reforms and state level transmission planning support
   - Streamline permitting practices and proactive land use planning activities

Phase 2 Long-Term Optimal Portfolio Evaluation: Recommendations (1 of 3)

1. **Continue to address barriers to new resource development**
   - Coordinated regional transmission planning to support proactive grid buildout and reduced interconnection challenges
   - Ensure policy support for the resources needed to meet reliability and clean energy needs
   - Continue to streamline resource permitting processes
2. **Address energy and capacity risks unique to the Pacific Northwest in regional programs**
   - Work with WRAP, NWPCC, WECC, and other regional organizations to ensure ongoing regional resource adequacy assessments appropriately capture the risk of energy shortfalls associated with low hydro conditions along with potential capacity shortfalls
3. **Consider strategic investments in new clean firm technologies**
   - Strategic investments in market transformation may help emerging "clean firm" technologies such as advanced nuclear, carbon capture and sequestration, enhanced geothermal, clean fuels or multi-day energy storage achieve commercialization
   - Policy actions should recognize the limited impact that Northwest entities alone are likely to have and leverage the potential for industry and geographical partnerships

Phase 2 Long-Term Optimal Portfolio Evaluation: Recommendations (2 of 3)

4. **Ensure that regional planning efforts appropriately consider the growing need for new delivery capability into the I-5 corridor**
   - West-side needs are more difficult to serve due to geographic barriers; however electric loads are expected to continue to grow on the west side due to building and transportation electrification policies and new large loads on top of organic population and economic growth
   - West-side capacity needs can be met with demand management programs, new supply resources, and/or new transmission; regional planning efforts should consider the cost and environmental tradeoffs among all these options
5. **Develop a coordinated process to consider electricity and natural gas delivery needs**
   - Northwest consumers currently rely on both electricity and natural gas to meet heating needs during severe cold weather events; electric reliability during these events will be dependent on natural gas combustion for the foreseeable future
   - Increased policy focus on building electrification may exacerbate this dependence due to higher peak electric loads, requiring investment in new gas delivery capability
   - A coordinated planning process should identify the lowest societal cost solutions for meeting the needs of consumers across the combined electricity and natural gas systems

Phase 2 Long-Term Optimal Portfolio Evaluation: Recommendations (3 of 3)

6. **Continue to support regional coordination and markets for energy, capacity, clean energy, and transmission**
   - Portfolio optimization modeling, including the conclusions of limited costs to reach 96% GHG reduction, assumes efficient and seamless regional markets
   - Organized regional wholesale energy markets support efficient commitment and dispatch
   - Organized regional capacity constructs capture load and resource diversity to reduce overall resource adequacy build requirements
   - Coordinated transmission planning is needed to identify new projects that support subregional resource adequacy needs and renewable energy interconnection and delivery
   - Regional clean energy markets support achieving clean energy policy goals at least-cost versus higher cost pathways where each utility is forced to meet its load with its own clean energy portfolio on an hourly basis