ENERGY STRATEGIES

LOWER SNAKE RIVER DAMS POWER REPLACEMENT STUDY

Regional power system planning assessment of the technical feasibility and cost implications of replacing the Lower Snake River dams with clean energy portfolios

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Full Summary Slides

Study commissioned by the NW Energy Coalition

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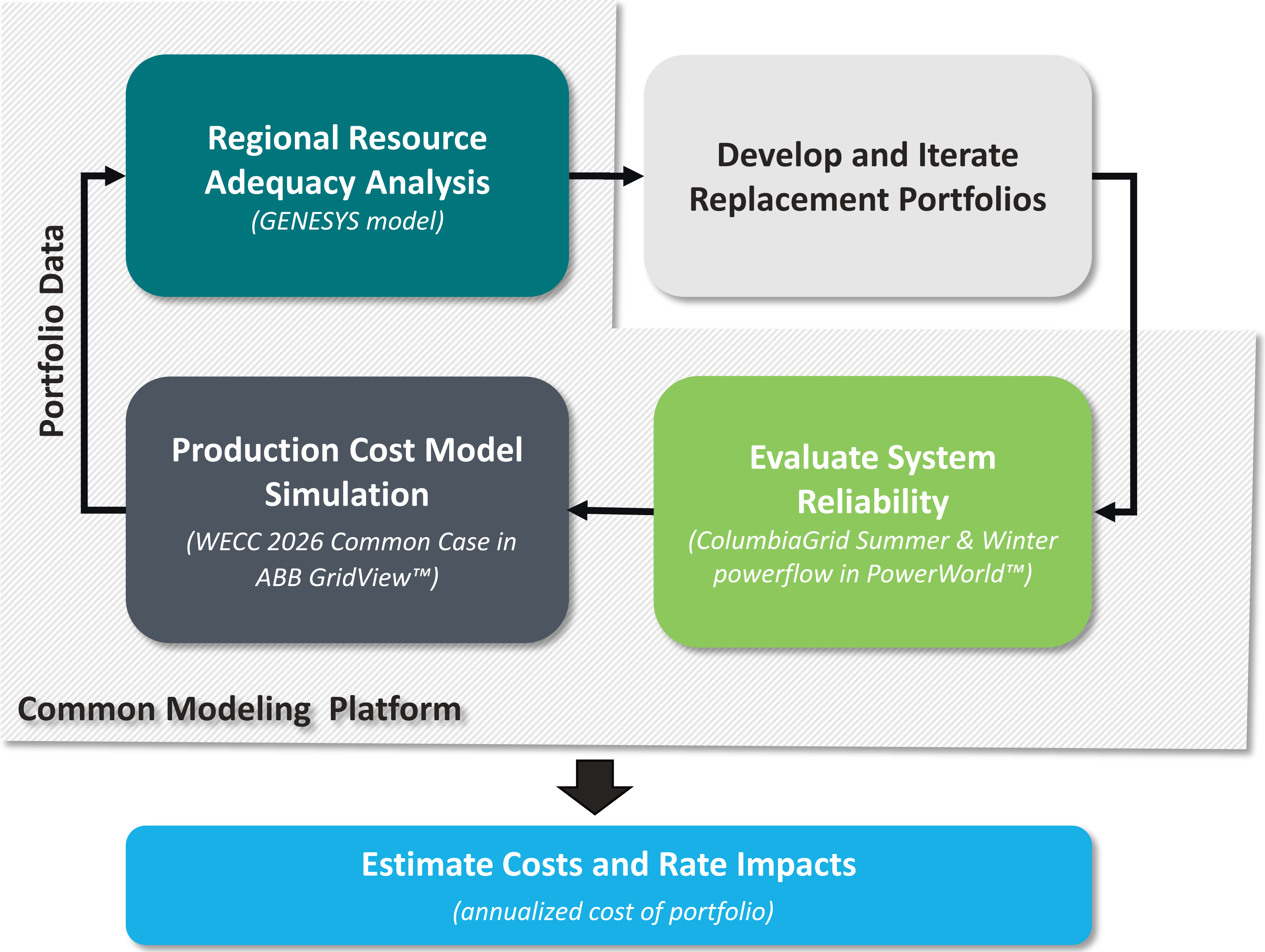
SUMMARY

STUDY OVERVIEW

- **Wide-ranging power planning study evaluating the technical feasibility of replacing the Lower Snake River (LSR) Dams with a clean energy portfolio of resources while ensuring the continued reliability, stability, and adequacy of the Northwest power system**
- **Relied on sophisticated and regionally-vetted tools and planning criteria to test the ability of replacement portfolios to achieve "like-for-like" replacement of the grid-services supplied by the LSR Dams**
  - ❖ Used conservative planning assumptions and criteria whenever possible to ensure replacement portfolios provide adequate replacement capabilities
- **Analyses consider three thematic portfolios: (1) demand-side focused theme ("Non-Generating Alternative" portfolios), (2) balanced theme that included wind and solar generation ("Balanced" portfolios) and (3) a gas-only approach ("All Gas" portfolios)**
  - ❖ Portfolios were not optimized for emission or cost performance, but the level of clean energy resources was adjusted to meet planning criteria and study goals
  - ❖ Compared portfolios with a "business-as-usual" Reference Case to calculate regional-level changes to technical planning metrics, total system cost, and emissions

STUDY FRAMEWORK



- **Coordinated modeling framework used three modeling tools to assess replacement portfolio impacts to reliability, resource adequacy, operations, and cost**
- **Initial portfolios were developed, tested, and then adjusted iteratively before final portfolios were analyzed for their cost impacts**
- **100% clean replacement portfolios included “Plus” versions that ramped-up the level of clean energy resources**
- **Modeling resulted robust comparisons for all replacement portfolios with Reference Case**

SUMMARY

REPLACEMENT PORTFOLIOS AND RESULTS

DR = demand response
EE = energy efficiency
NGCC = natural gas-fired combined cycle
Recip = reciprocating engine

All are changes relative to Reference Case that retains the LSR Dams		Replacement Portfolios					GHG Reduction Policy Sensitivity		
		NGA	NGA *Plus*	Balanced	Balanced *Plus*	All Gas	NGA *Plus*	Balanced *Plus*	All Gas
Replacement Resources	Demand-side	~1,000 MW DR 320 aMW EE	~1000 MW DR 880 aMW EE	~500 MW DR 160 aMW EE	~500 MW DR 160 aMW EE	-	~500 MW DR 160 aMW EE	~500 MW DR 160 aMW EE	-
	Resource-side	-	-	500 MW wind 250 MW solar	1,250 MW wind 750 MW solar	500 MW NGCC 450 MW recip	500 MW wind 250 MW solar	1,250 MW wind 750 MW solar	500 MW NGCC 450 MW recip
	Capacity Market	100 MW	100 MW	-	-	-	100 MW	-	-
Portfolio Performance	Resource Adequacy (Δ LOLP%)	-1.1%	-2.1%	-0.4%	-1.3%	-0.3%	-2.1%	-1.3%	-0.3%
	Δ Reliability	All met NERC/WECC criteria, but for one reliability issue identified in all replacement portfolios (mitigated w/ transmission upgrade and cost captured)							
	Δ GHG Regional Emissions (%)	+5%	+2%	+5%	+1%	+8%	0%	-2%	+5%
Costs	Δ Total Annual Cost ($M/year)	$421	$1,191	$396	$464	$535	$1,224	$501	$581
	Δ Region Revenue Requirement in 2026 (%)	+2.7%	+7.6%	+2.5%	+3.0%	+3.4%	+7.6%	3.21%	+3.7%
	Δ Levelized Monthly Bill ($/Month)	$1.16	$3.28	$1.09	$1.28	$1.47	$3.37	$1.38	$1.60

KEY STUDY FINDINGS

1. **A portfolio of reasonably available clean energy resources, including solar, wind, energy efficiency, demand-response, and energy storage can effectively replace the most important power attributes the four LSR Dams are forecasted to contribute to the Northwest region.**
   - The clean energy portfolios had superior performance to an all gas replacement alternative in terms of resource adequacy, emissions, and total cost.
   - The resource levels required for replacement are readily available in the region.
2. **The total costs of the clean energy replacement portfolios, particularly the balanced portfolios that include both new wind/solar and demand-side measures, are relatively small compared to the total projected costs of the Northwest power system.**
   - The portfolios increase the region's costs by 2-3% after accounting for changes in operational costs, transmission costs, and the costs of new resources and programs associated with the portfolio.
3. **When a balanced clean energy replacement portfolio is implemented in conjunction with greenhouse gas reduction policy, substantial <u>reductions</u> in emissions can be achieved without the LSR Dams.**
   - Absent such policy, the balanced portfolio has a minor impact on greenhouse gas emissions (about 1%) compared to expected emissions with the LSR Dams in service.
4. **The clean replacement portfolios met transmission reliability criteria under peak summer and winter conditions and did not create any new reliability issues (but for one minor exception)**
   - The exception was identified for all portfolios and was addressed through a minor transmission upgrade.
5. **The clean replacement portfolios provide the region with enhanced resource adequacy compared to the LSR Dams, reducing the likelihood of the region not having sufficient power to meet peak demands.**
   - New gas-fired generation is not required to address regional capacity needs that arise when the LSR Dams are removed.

OUTLINE

1. INTRODUCTION & BACKGROUND

STUDY SPONSORS AND PURPOSE

- **The NW Energy Coalition sponsored this study investigating the technical feasibility and cost of replacing the four Lower Snake River (LSR) Dams with a portfolio of resources and technologies that minimize increases to the region's GHG emissions while preserving a reliable and adequate regional power system**
  - The driver of the analysis stems from decades of concern as to how the LSR Dams may impact endangered salmon and steelhead species in the Columbia River Basin and the need for an assessment of the feasibility, costs, and benefits of replacing LSR Dam hydropower with other resources
- **The study seeks to help Northwestern stakeholders develop a deeper understanding of the options for replacing the grid services the LSR Dams provide the regional power system, while also establishing a framework for conducting this analysis using models and metrics familiar to the Northwest region**
  - This study's scope is limited to the regional power system and is not a benefit-cost analysis evaluating *if the dams should be replaced.* Rather, the study assumes replacement and looks at the implications and tradeoffs associated with different portfolios
- **The purpose of this assessment is not to determine if dam removal is the most appropriate or best option given myriad issues that impact such a decision**
  - The study does not take a policy position and is an independent assessment of technical planning issues

The project was sponsored by the NW Energy Coalition (NWEC) and the views contained in these materials do not necessarily reflect those of the project sponsor.

STUDY SCOPE FOCUSED ON POWER SYSTEM

What the study IS:

- Focused on **power system analysis** and the evaluation of energy-system attributes of the dams and conceptual replacement portfolios
- **Demonstration** of the types of planning analyses that can be undertaken to evaluate potential replacement portfolios
- Leverages **regionally-vetted planning tools** and **advanced hydro modeling** to accurately analyze the forward-going value of the dams
- An independent assessment focused on developing **analytical frameworks** and objectively evaluating the feasibility of low carbon energy replacement portfolios
- **Focused on the Pacific Northwest** region while representing the entire WECC in most models

What the study is NOT:

- An optimization designed to identify *the* most cost-effective replacement portfolio
- A detailed evaluation of long-term regional carbon policy effectiveness or implementation strategies
- Designed to capture the full range of costs and benefits associated with dam removal related to fisheries, transportation, irrigation, and recreation
- A policy position on whether the dams should or should not be removed – the study is technically focused.

CORE QUESTIONS

The study sought answers to four key questions:

1. **Can an energy portfolio replace the LSR Dams without compromising the region's reliability and resource adequacy while minimizing or eliminating increases to regional GHG emissions?**
   - How might these replacement portfolios change under different future scenarios?
2. **If replacement portfolios of energy storage, renewable resources, and clean market purchases cannot (alone) replace the LSR Dams, what incremental infrastructure (e.g. additional transmission, substation equipment, gas-fired resources) might be required to fill the gap?**
3. **At what approximate cost might the replacement portfolios be achieved?**
4. **What additional value might the replacement portfolios offer?**
   - For example: Additional capacity under stressed conditions, impact on Northwest energy prices, a better match to seasonal changes in monthly or daily demand?

STUDY PRINCIPLES

- **Rely on existing authoritative data sources, models, and planning metrics**
  - Leverage standard, fully vetted models and metrics familiar to stakeholders in the Northwest and used by regional and utility planners
  - Capture unique characteristics of NW hydro system in ways with which the region is familiar
- **Do not seek to fully optimize the replacement portfolios for economic or environmental efficiency.**
  - Conduct analyses iteratively, allowing for linkages and feedback between study types when developing the replacement portfolios
- **Focus the geographical scope on the Northwest power system footprint**
- **Create common databases and assumptions across study phases and modeling platforms**
  - For example, major announced coal retirements in region are to be reflected in reliability, adequacy, and operational assessments

PLANNING IN THE NORTHWEST

- **The Northwest power system is analyzed and planned by several entities that, in addition to decades of experience, each have a unique scope, charter, and perspective.**
- **Investor-owned utilities and municipalities/co-ops also conduct planning for generation and transmission**

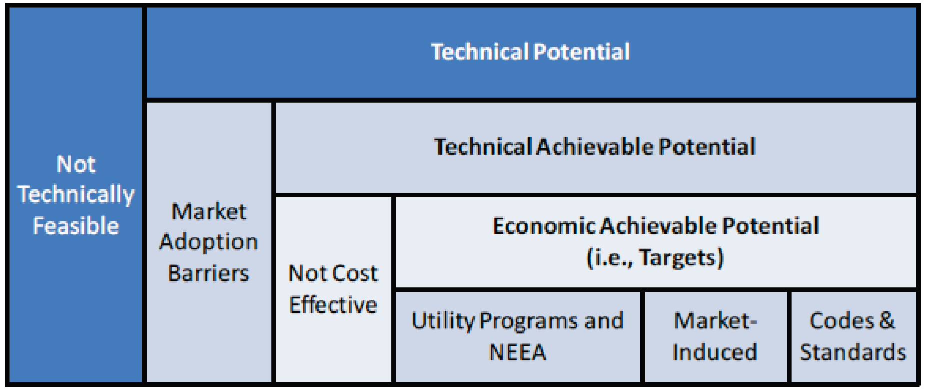
Organization	Bonneville Power Administration	ColumbiaGrid	Northwest Power and Conservation Council
Role/responsibility	Federal power marketing administration transmitting power from federal hydro resources, including the four Lower Snake River dams	Conducts reliability, economic, and public policy regional transmission planning under FERC Order 1000 for utility members, including BPA	Creates regional conservation, power plan, and fish/wildlife program every 5-years as required under the Northwest Power Act. Plan guides BPA's resource decision and allows explicit state input.
Relevance to study footprint and scope	Analysis captures generation assets and transmission in BPA's control area	Analysis captures generation and transmission for utilities that are members of ColumbiaGrid	Study scope based on NWPCC footprint
Planning analyses relevant to this study	10-year Transmission Plan BPA White Book	2017 System Assessment	7th Power Plan Power Supply Adequacy Assessment
Data/models used in this study	Data captured through input to WECC, ColumbiaGrid, and NWPCC	2026 Heavy Summer Case 2026-27 Heavy Summer Case	GENESYS

NWPCC Seventh Plan and Importance to LSR Study

- **NWPCC develops a plan to ensure the region's power supply and acquire cost-effective resources with energy efficiency as the highest priority over a 20-year time horizon**
  - Evaluates 800 possible futures and 20 different scenarios to determine resource adequacy needs
  - Seventh Power Plan (7th Plan) was adopted in 2016; updated every 5 years
  - Must balance power system needs with wildlife/fish issues
- **This study's "Reference Case" utilized 7th Plan's near-term Action Plan as a starting point**
  - Action Plan implements the 7th Plan targets
  - Reference case for LSR Study included the demand response targets called for in the Action Plan
- **LSR Study Replacement Portfolios relied on 7th Plan's technical and economic achievable potential to set upper limits on some resource additions and to estimate costs**
  - Replacement portfolios limited to acquiring no more than the NWPCC's energy efficiency and demand response technically achievable levels by 2026
  - 7th Plan undertook significant analysis to determine levelized costs for energy efficiency, demand response and natural gas resources, which were utilized in the LSR Study
  - However, wind, solar and battery storage cost estimates were gathered separately to reflect significant cost declines since the 7th Plan was adopted
- **7th Plan utilizes a "Frozen-Efficiency" demand forecast to avoid double counting of energy efficiency potential**
  - Assumes that the efficiency level is fixed and does not change during the study period
  - If a known future federal standard exists, that is considered a reduction in future demand rather than future energy efficiency "potential"

SEVENTH NORTHWEST POWER PLAN

7th Plan Conservation Potential Methodology

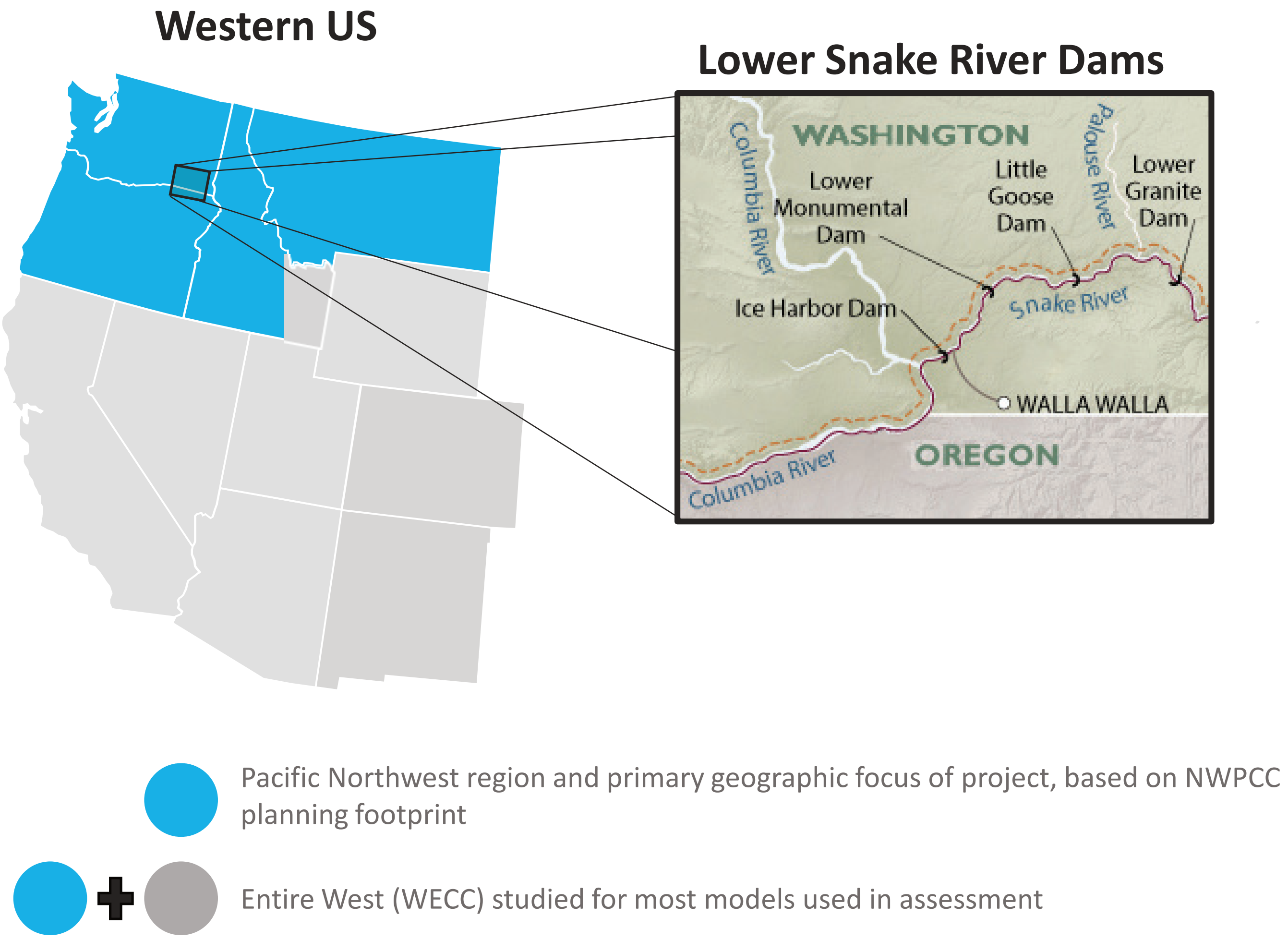


NWPCC Seventh Power Plan: *https://www.nwcouncil.org/energy/powerplan/7/plan/*

PLANNING CRITERIA

- **Assessment leverages established regional planning criteria and targets as the basis to evaluate the technical feasibility of replacement portfolios**
- **Resource adequacy criteria: Northwest Power and Conservation Council (NWPCC) adopted a resource adequacy standard in 2011 to assess the adequacy of the Northwest's power supply**
  - Loss-of-load probability (LOLP) that is **less than 5% for five years into the future**
  - NWPCC is currently considering other alternatives, so we have broadened the metric for this analysis
- **Reliability criteria: NERC Transmission Planning (TPL) Standards are the guiding criteria, along with applicable WECC guidelines**
  - ColumbiaGrid, BPA, and all transmission operators, use these standards when conducting their respective assessments
- **System Costs and emissions: Costs and emissions are not a "hard constraint", although we seek to evaluate how the portfolios can minimize impact to these two criteria while adhering to the criteria above**
  - Considers regional-level cost impacts using system annual revenue requirement
  - All new costs are incremental to the NWPCC 7th Power Plan levels
  - Mirrors residential rate-analysis conducted by the NWPCC in its 7th Plan
  - Does not seek to evaluate impacts of any specific carbon reduction policy, such as those being considered by Oregon and Washington, although it does broadly consider how assigning a proxy cost to carbon emission could change the emission and cost effects of the replacement portfolios

GEOGRAPHIC SCOPE OF STUDY



- **Three models were used to evaluate Pacific Northwest region**
  - ❖ Two of these models represent the entire WECC-footprint, while the third represents ties and market purchases with neighboring areas
  - ❖ British Columbia and Alberta are factored in within all three models
- **Lower Snake River Dams are modeled explicitly**
- **Replacement portfolios are modeled with high-granularity (e.g. new resources sited at specific substations, demand response assigned to appropriate load types)**
- **Study defined the "Northwest region" consistent with the planning scope adopted by the NWPCC**

2. ANALYTICAL APPROACH

ANALYSIS CONDUCTED IN THREE PHASES

Identify and quantify grid services provided by LSR dams

- Estimate value LSR dams might provide NW region in future
- Analysis focused on resource adequacy as driver for resource additions
- Qualitative review of other attributes

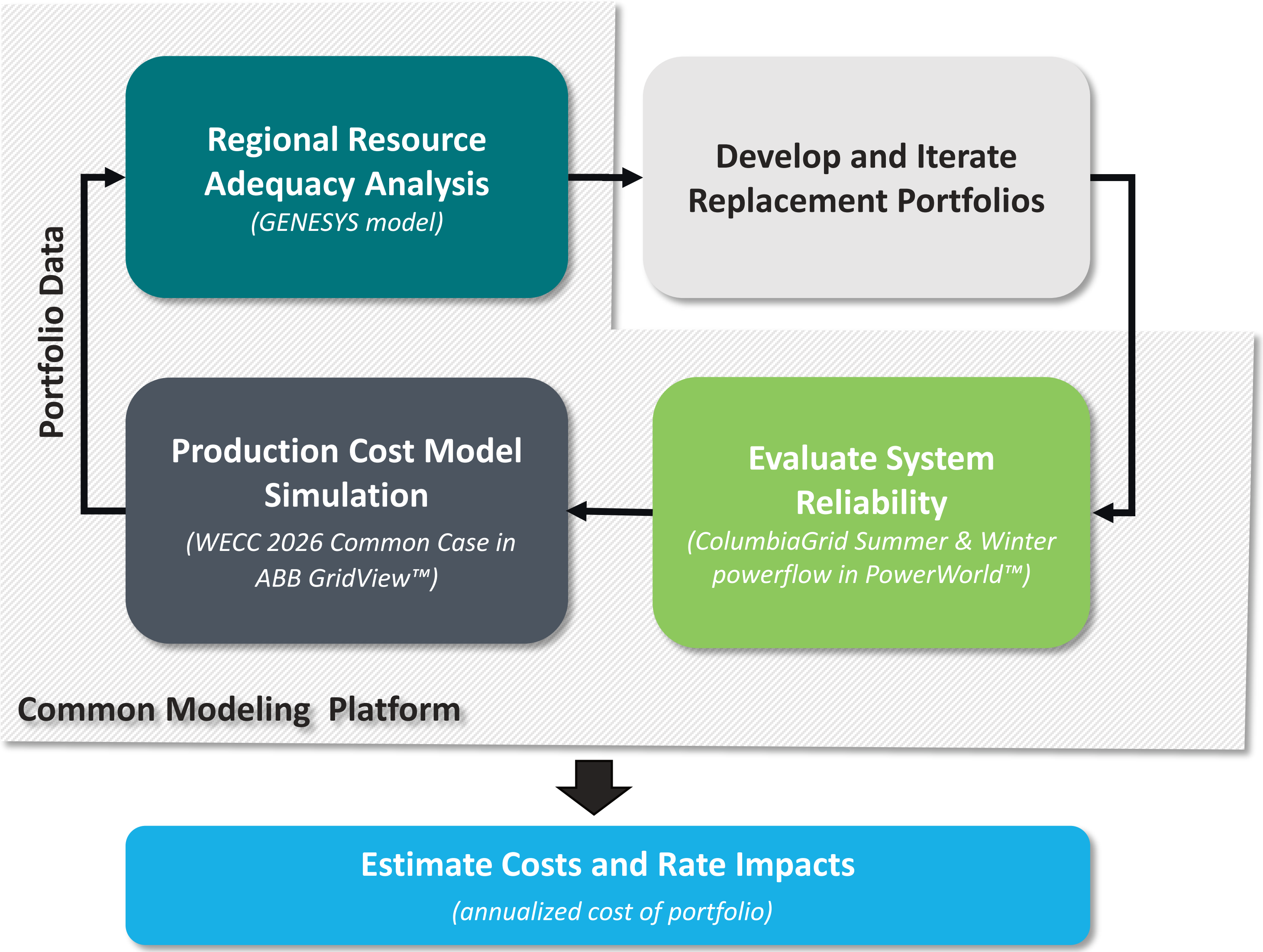
Develop energy replacement portfolios that provide similar grid services

- Portfolios to meet reliability, energy, and capacity needs are iterated to achieve power system and emission objectives
- Low/no carbon resources were preferred
- Ultimately led to development of three primary portfolios – two clean portfolios and one all-gas portfolio

Assess the cost implications of the replacement portfolios

- Cost analysis is comparative, looking at fixed and variable annualized costs to implement portfolios
- Production cost modeling used to evaluate changes to operating costs and impacts on market prices
- High-level rate impact analysis compiled based on 7th Plan assumptions

MODELING FRAMEWORK

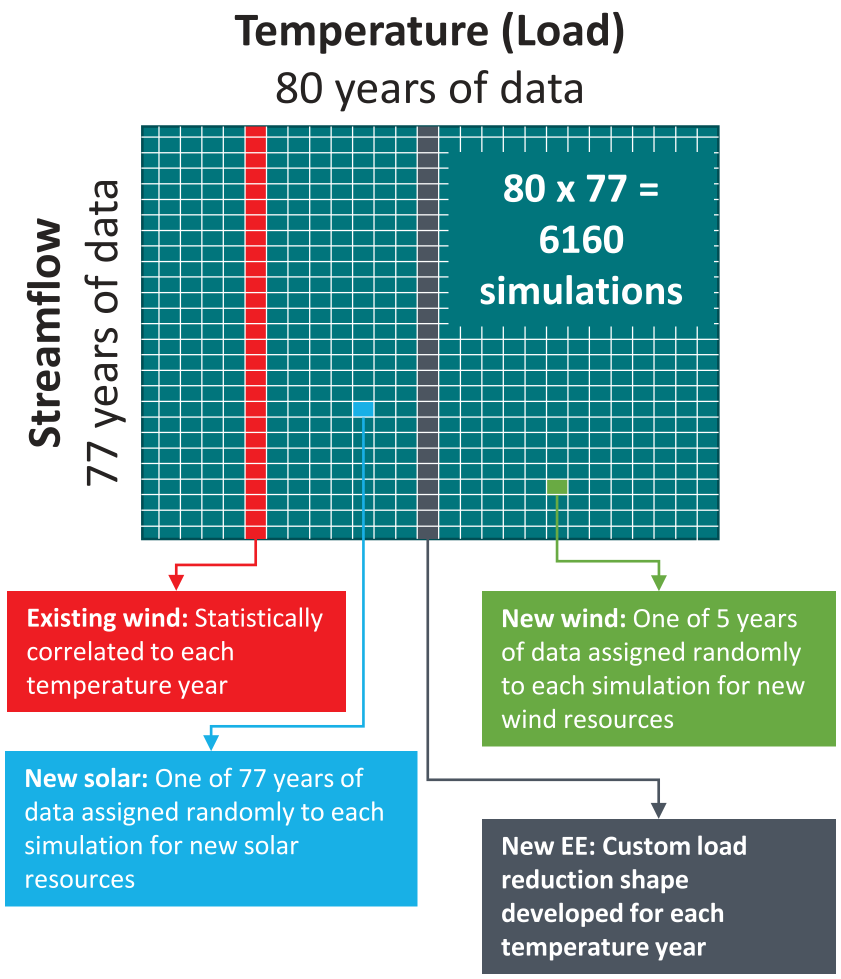


Key Study Metrics

- **Loss of Load Probability** (LOLP)
- **Expected Unserved Energy** (EUE)
- **Steady-state reliability** (overloads, voltage, reactive power)
- **Transient stability** (frequency response, system stability)
- **Operating costs** ($)
- **Regional GHG emissions** (tons)
- **Annual revenue requirement** ($/yr)
- **Typical residential bill** ($/month)

GENESYS (Generation Evaluation System) MODEL

- **Simulates operation of the Pacific Northwest power system to assess the adequacy of the power supply**
- **Used by the NWPCC, BPA, and other regional stakeholders for numerous purposes including resource adequacy assessments, hydro flow studies, and economic analysis of hydro dispatch changes**
- **Hourly simulation model with detailed representation of Northwest hydro system that stochastically considers:**
  - Temperature variation (load)
  - Wind generation
  - Streamflow (hydro conditions)
  - Thermal forced outage
- **Represents hydro system constraints (e.g. environmental requirements), transmission, and external market supply**
- **See NWPCC website for details on model**
  - https://www.nwcouncil.org/media/7150541/p1.pdf
  - https://www.nwcouncil.org/energy/saac/GENESYS



PRODUCTION SIMULATION MODEL

- **Performed nodal security constrained economic dispatch modeling with ABB's GridView™ software**
  - ❖ Software platform used by WECC and ColumbiaGrid – also used by BPA for certain assessments
  - ❖ NWPCC uses similar modeling platform to develop market price forecasts and assess system operation
  - ❖ Incorporates detailed supply, demand, and (nodal) transmission system models for large-scale transmission grids
- **This study's Reference Case based on modified WECC 2026 Common Case dataset, which represents the expected loads, resources and transmission topology 10 years in the future**
  - ❖ Removed Northwest Resource Adequacy ("NW RA") placeholders for synergy with NWPCC GENESYS assumptions
  - ❖ Updated Rock Island, McNary, John Day, The Dalles, Bonneville, Wanapum, and Grand Coulee hydro modeling
  - ❖ Implemented general wind and solar curtailment prices based on REC & PTC pricing estimates (-$15/MWh & -$25/MWh, respectively)
  - ❖ Implemented historically-based hourly shapes for the DC interties between the Western & Eastern Interconnections
  - ❖ Activated GridView 7-day Look Ahead logic to improve dispatch
  - ❖ Implemented recent planned retirements and replacements in the Southwest region

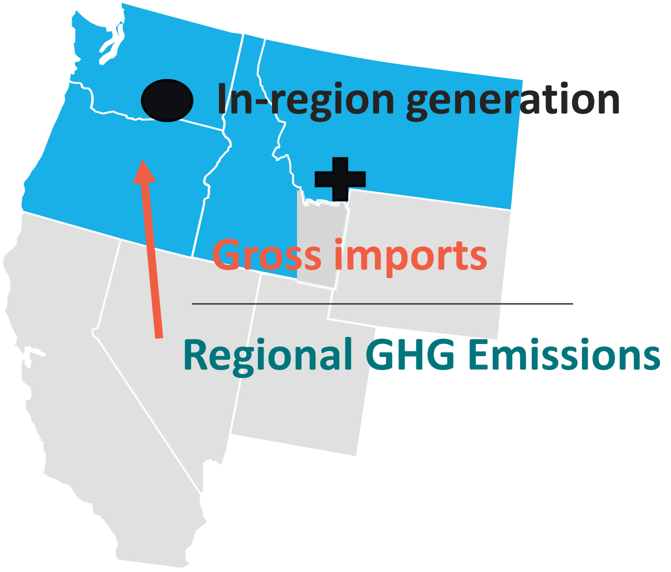
GridView Inputs and Outputs

POWER FLOW MODEL

- **PowerWorld: Used by power system engineers to simulate single snap-shot condition of grid, evaluating ability of system to remain within reliable operating limits before and after contingencies**
  - Model commonly used by transmission planners in the Northwest
- **The best available data source for this study is ColumbiaGrid's most recent System Assessment (3/21/2017)**
  - Studied two stressed system conditions in 2027 timeframe: 2027 Heavy Summer and 2027-28 Heavy Winter (3/21/2017 Posting)
  - Included power flow contingency definitions
  - Dynamics data included, but no switching data to perform simulations
- **Energy Strategies made modifications to Base Cases in order to create a more reasonable starting point for the assessment**
  - Reference Case includes the Lower Snake River Dams, but the output of the dams was adjusted based on historical operation during system peak to provide a more realistic perspective of what is needed, from a reliability standpoint, to replace the Lower Snake River Dams
  - Case was also updated to align assumptions between other 10-year models (production cost model and GENESYS) – redispatch across the system was minimized whenever possible to maintain alignment with the Base Cases
- **Replacement portfolio cases were built from the Reference Case and include removal of the Lower Snake River Dams and the addition of resources or demand-side measures detailed in the Replacement Portfolios**
  - New demand response and energy efficiency resulted in load adjustments based on specific load types
  - New resources added and dispatched to reasonable levels

GHG ACCOUNTING METHOD

- **Carbon emission accounting based on a regional footprint consistent with the planning scope of the NWPCC**
- **Accounting includes:**
  1. Emissions from generation within or contracted by utilities in the region based on simulated generation from fossil generation and unit-specific emission rates; **and**
  2. Captures emissions from "unspecified" economic imports into region, based on a per MWh emission rate of 944 lb/MWh (0.428 tonne/MWh)
- **Method applied consistently to Reference Case and replacement portfolios to track the relative change in the region's GHG emissions across studies**



3. REFERENCE CASE AND REPLACEMENT PORTFOLIOS

OVERVIEW OF REPLACEMENT PORTFOLIOS

1. **Reference Case:** LSR Dams remain and system reflects existing state energy policy, 10-year plans for generation and transmission, 5 Year Action Plan from NWPCC 7th Plan for demand response, and 7th Plan 10-year levels of energy efficiency
2. **Non-Generating Alternative (NGA) Portfolio:** LSR Dams are replaced primarily with feasible levels of demand-side resources including demand response, energy efficiency, battery storage, and incremental capacity market purchases
3. **Balanced Portfolio:** LSR dams are replaced with a more balanced portfolio of demand response, energy efficiency, wind and solar generation
4. **All Gas Portfolio:** LSR Dams are replaced with a mix of combined-cycle and reciprocating engine gas-fired generators

- ✓ **“Plus” versions of Balanced and NGA portfolios included ramped-up levels of clean energy resources to create more data points on portfolio performance**
- ✓ **GHG reduction policy sensitivity captures performed on “Plus” portfolios and All Gas portfolio to capture the impact GHG policy might have on replacement strategies**

REFERENCE CASE

Is this study about the replacement of these coal plants, under the cover of being replacement of LSR dams?

- **Reference Case assumptions made consistent across <u>three study tools</u>**
- **Case reflects:**
  - ❖ Announced and anticipated coal retirements across West
  - ❖ Renewable resources to achieve existing statutory standards – assumes no incremental RPS or decarbonization policy for the Northwest region
  - ❖ Demand response deployment consistent with NWPCC 7th Plan 5-Year Action Plan
  - ❖ Load and EE for RA analysis: Based on results from the NWPCC 7th Plan Regional Portfolio Model "2026 Frozen Efficiency Medium Load" games

Major Regional Retirements

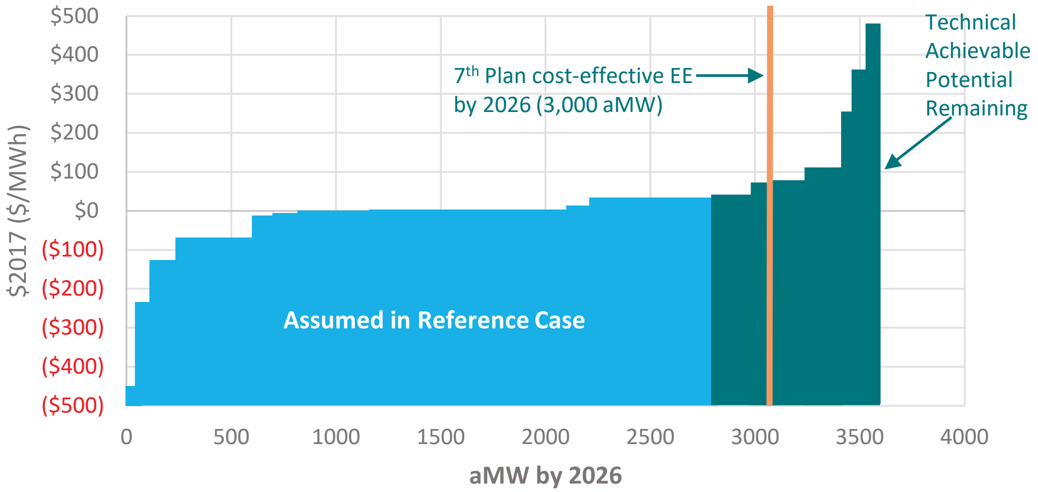
Boardman	585 MW	2020
Colstrip 1 & 2	614 MW	2022
Centralia 1 & 2	1,340 MW	2020 & 2024
North Valmy 2	268 MW	2019

Significant New Transmission in Region

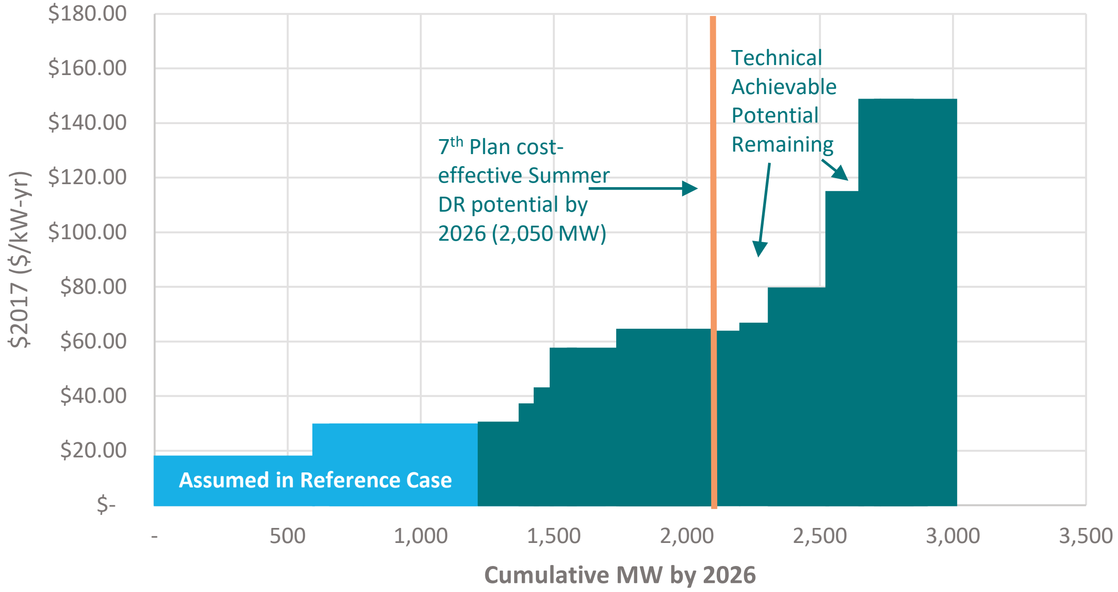
Boardman to Hemingway (B2H)
Gateway West and South
Wallula – McNary
West of McNary Reinforcement (Big Eddy – Knight)

I-5 Corridor upgrade not included in Reference Case

Energy Efficiency Supply Curve (aMW)

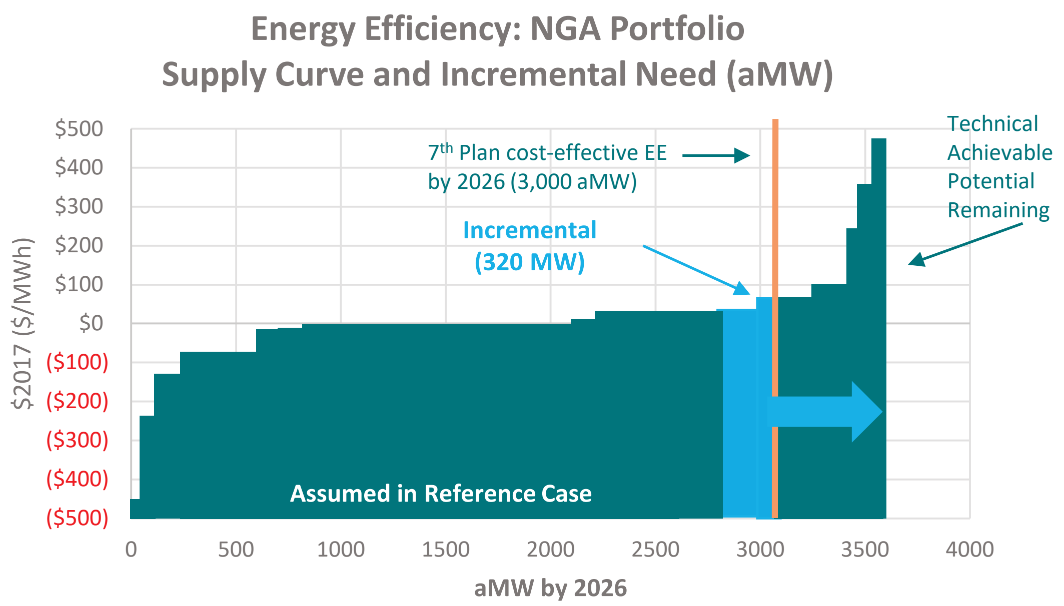


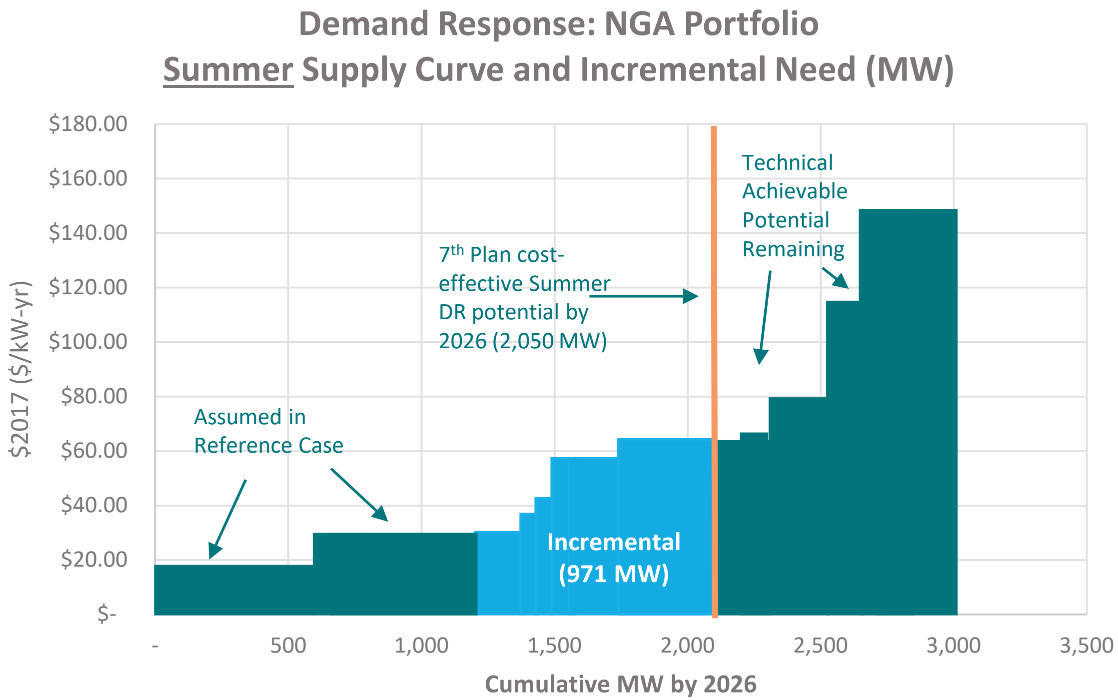
Demand Response Summer Supply Curve (MW)



NON-GENERATING ALTERNATIVE (NGA) PORTFOLIOS

- **Represents a future in which cost-effective energy efficiency and demand response are achieved**
  - ❖ Cost effectiveness criteria based on NWPCC 7th Plan
  - ❖ NGA Plus portfolio considered the effect of developing all technically achievable energy efficiency
- **100 MW of new energy storage added near Portland metro area and 100 MW increase in potential for market purchases from California for winter capacity needs**
- **No incremental gas-fired resources added**

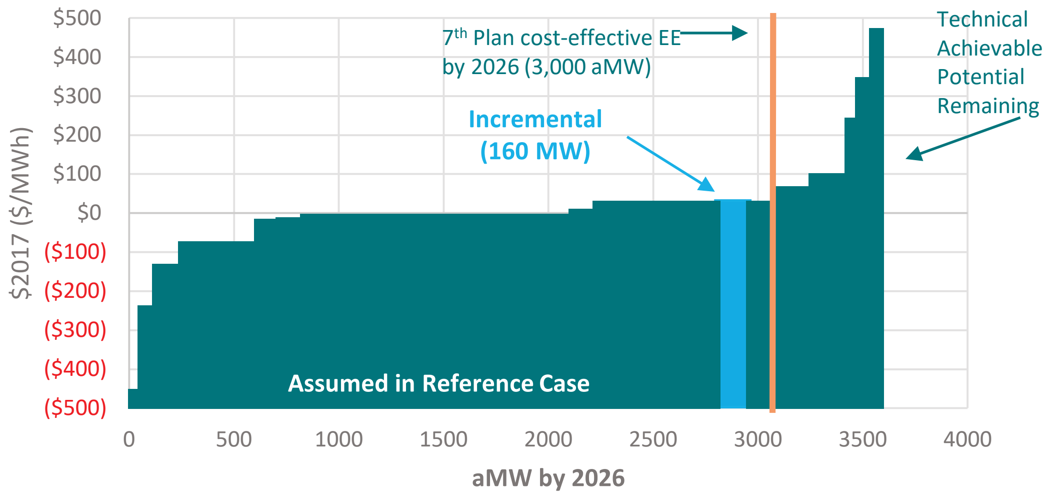




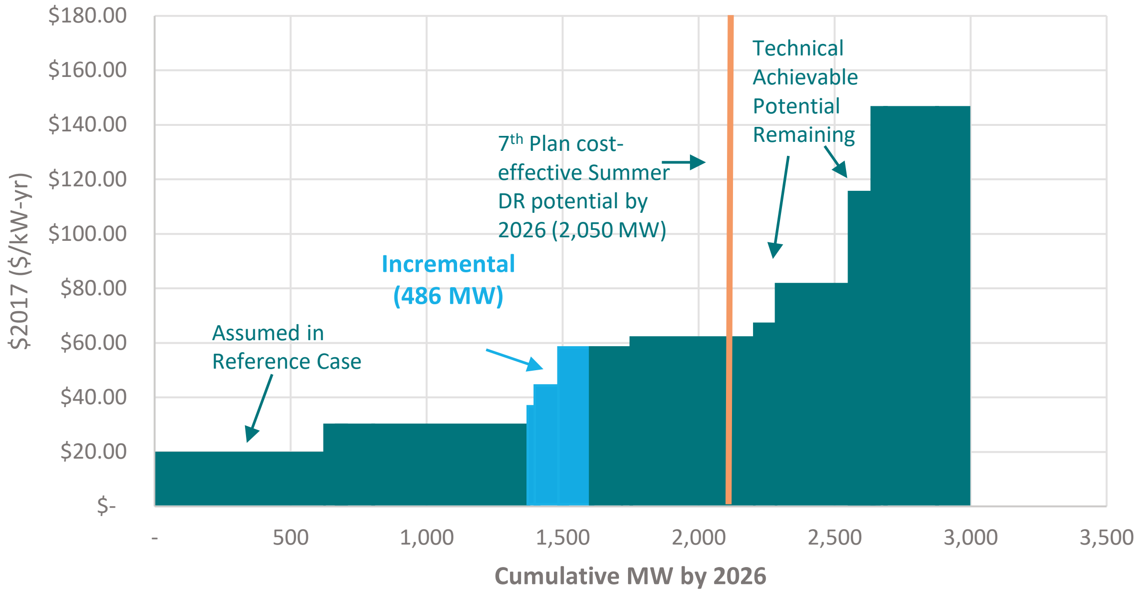
BALANCED PORTFOLIOS

- **Represents a future in which half *of* cost-effective energy efficiency and demand response are achieved**
- **Portfolios featured a range of additional renewable resources**
  - Balanced portfolio included 500 MW of Montana wind and 250 MW of Idaho solar
  - "Plus" portfolio increased these levels of renewables by 750 MW and 500 MW, respectively
- **No incremental energy storage and no incremental market purchases for capacity and incremental gas-fired resources**

Energy Efficiency: Balanced Portfolio Supply Curve and Incremental Need (aMW)



Demand Response: Balanced Portfolio Summer Supply Curve and Incremental Need (MW)



ALL GAS PORTFOLIO

- **Studied for comparison purposes and because All Gas approach has been proposed in past**
- **Future assumes that 950 MW of gas-fired generation sited southwest of LSR dams at major power hub**
  - ❖ Area has significant high-voltage transmission, major gas pipelines
  - ❖ Existing gas-fired generation in the area
- **No other market purchases, resource additions, or incremental achievement of energy efficiency or demand response**

Generation Additions

Natural-gas combined cycle	McNary 500 kV	500 MW	Modeling assumptions roughly consistent with existing Hermiston Power Project
Reciprocating engine	McNary 230 kV	458 MW (24x18.3 MW)	Modeling assumptions roughly consistent with Port Westward units

GHG POLICY SENSITIVITY

- To capture the effect that policies like a carbon tax or cap-and-trade might have on any potential replacement portfolios the study included sensitivities that layered proxy modeling for these policies on top of the replacement portfolios
- In study results, GHG policy sensitivities indicated by "+ GHG" in portfolio name
- Calculation of system operating costs assumes revenue neutral GHG policy, with 100% of revenues being returned to customers

Modeling Parameters for Carbon Reduction Policy Sensitivity

Element	Assumption	Application	Source
Carbon Price	$33.9/metric ton	Incremental cost applied to all carbon emissions from generators in Washington or Oregon	Planning price used by CAISO to reflect AB-32
Import Adder Price	$14.509/MWh	Cost of importing "unspecified" emissions (0.428 metric ton CO_2e/MWh) into control areas within Washington or Oregon, except for imports from California and British Columbia	Consistent with rules established by California Air Resources Board for importing "unspecified" emissions into California

SUMMARY OF REPLACEMENT PORTFOLIOS

Resources	Portfolios				
	NGA	NGA *Plus*	Balanced	Balanced *Plus*	All Gas
Demand Response	971 MW (summer) 1,039 MW (winter)	971 MW (summer) 1,039 MW (winter)	485.5 MW (summer) 519.5 MW (winter)	485.5 MW (summer) 519.5 MW (winter)	-
Energy Efficiency	320 aMW	880 aMW	160 aMW	160 aMW	-
Battery Storage	100 MW	100 MW	-	-	-
Wind	-	-	500 MW (MT)	1,250 MW (MT)	-
Solar	-	-	250 MW (ID)	750 MW (ID)	-
Gas – Combined Cycle	-	-	-	-	500 MW
Gas – Reciprocating Engine	-	-	-	-	450 MW
GHG Policy Sensitivity	No	Yes	No	Yes	Yes

- **To meet the study objectives (low costs, low carbon), the initial portfolios were augmented into "*Plus*" versions where resources consistent with a portfolio's theme were added to the original portfolio to test their effectiveness at reducing emissions while maintaining reliability**
- **In addition to this, the GHG reduction policy sensitivity was layered onto the "Plus" portfolios**
- **In total, eight different replacement portfolios were studied**

4. VALUE OF THE LOWER SNAKE RIVER DAMS

VALUE TO THE SYSTEM

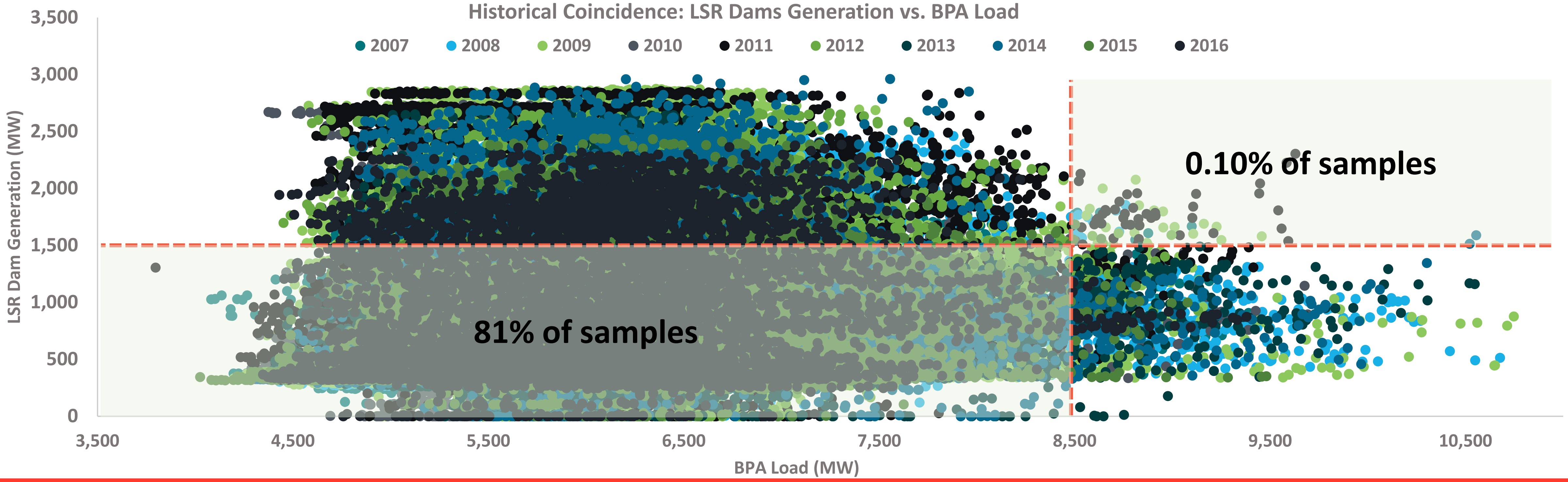
- **Certain power system attributes were assumed to retain their historical value going forward, others fell outside of the scope of the analysis, and others were studied using regionally vetted planning models and methods**
- **This table summarizes how the attribute was or was not addressed in the assessment**

Power System Attribute	Forecasted Value of the LSR Dams	Analytical Approach
Resource Adequacy	• The LSR dams provide significant capacity to the NW system. When they are removed, the region loss-of-load probability (LOLP) increases to 8%, well above the 5% planning target	• Analyzed the ability of replacement portfolios to makeup this lost capacity using Council's GENESYS model • Goal was to return region to pre-removal adequacy levels, going beyond regional adequacy targets
Energy	• Historically, the LSR dams provide about 1,000 aMW of generation annually. This value is assumed to continue into the future and the study did not capture any potential climate-driven energy increases/reductions.	• The ability of the replacement resources and existing regional resources to make up the lost energy value of the LSR dams is analyzed through production cost modeling to evaluate impacts to regional dispatch, energy shortfalls, imports, operating costs and power prices
Operating and Contingency Reserves	• Contingency: The exact amount of contingency reserves provided by the LSR Dams is not published • Operating (regulation and balancing): Not quantified due to a lack of sub-hourly generation data that would indicate the LSR dams role in providing contingency reserves	• Both GENESYS and GridView model contingency reserve requirements as an explicit constraint and any violations of this constraint will be captured in the modeling • The NWPCC does not consider regulating reserves in its long-term resource making decisions so they were not accounted for in this analysis • Balancing reserves were captured as constraints in the NWPCC TRAPEZOIDAL ("TRAP") model, which feeds into GENESYS
Transmission Reliability	• Provides Reactive supply, voltage control, frequency response	• Determined by reliability analysis comparing pre-retirement case with cases with replacement portfolios designed to ensure that these services are maintained within established reliability requirements

maximum output of 3003 MW is NEVER reached
only in .1 % of samples was a taxed BPA system getting over 50% capacity utilization of LSR dams

CAPACITY VALUE

- **The LSR Dams have a combined maximum output of 3,003 MW, but due to the fuel (water) dependent nature of the generation as run-of-river facilities, output varies widely throughout the year**
- **Thus, the actual capacity value of the dams (or any resource) is dependent on its ability to generate power during times of system need (peak)**

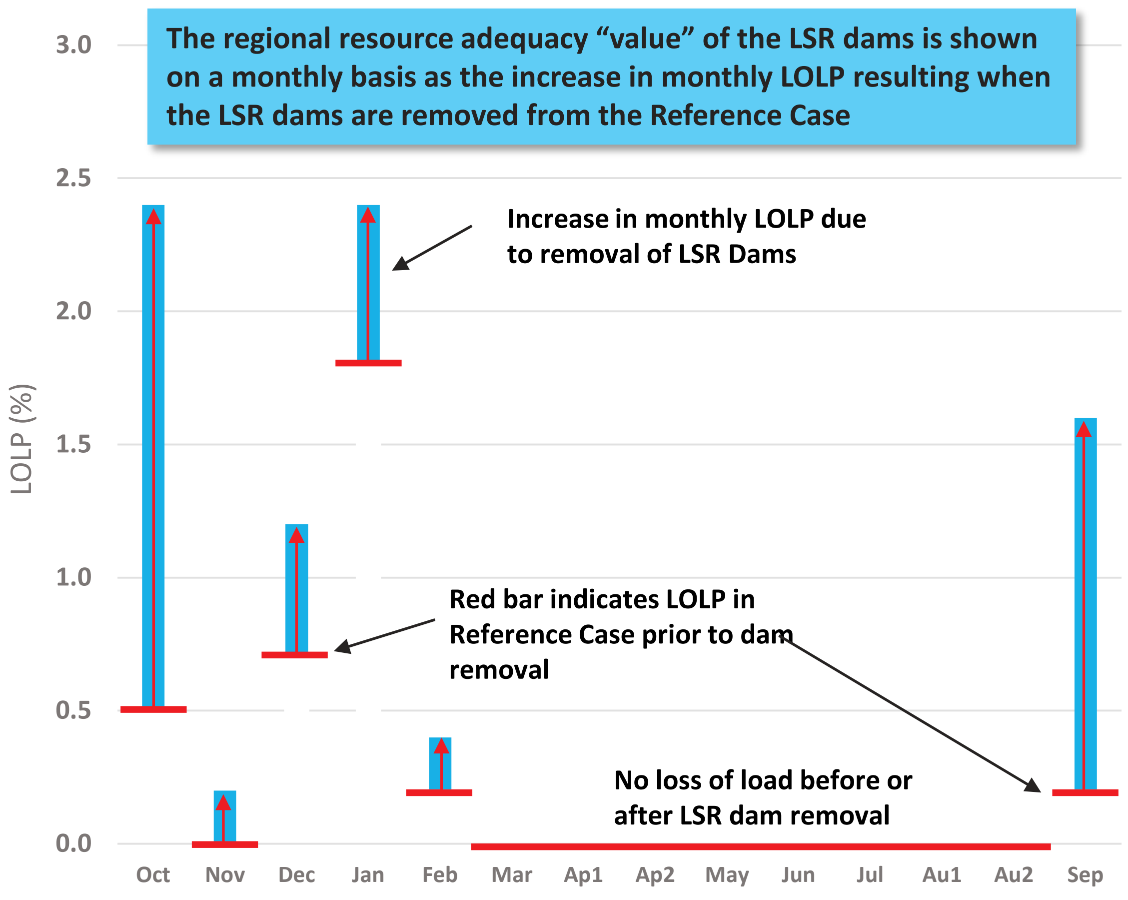


CAPACITY VALUE

Interesting to note that Sept-Oct is also
where BPA Hydro most nearly matches Load
see next slide

- **The historical observation on the prior slide is confirmed through GENESYS modeling, which considers the LSR Dam's potential for sustained output during stressed system conditions**
- **Removing the LSR Dams from the planned system causes annual LOLP to increase from 3.4% to 8%**
  - This is above the regional standard of 5%
  - Expected unserved energy (EUE) increases 1,172 MWh
- **The LSR Dams provide their most valuable contribution to the system's adequacy in October and September**
  - LSR Dam's contribution during that winter peaking period is limited as indicated by the smaller increases in the likelihood of losing load in January and December (when the LSR Dams are removed)
- **To return system to Reference Case-level adequacy, resource additions are needed**

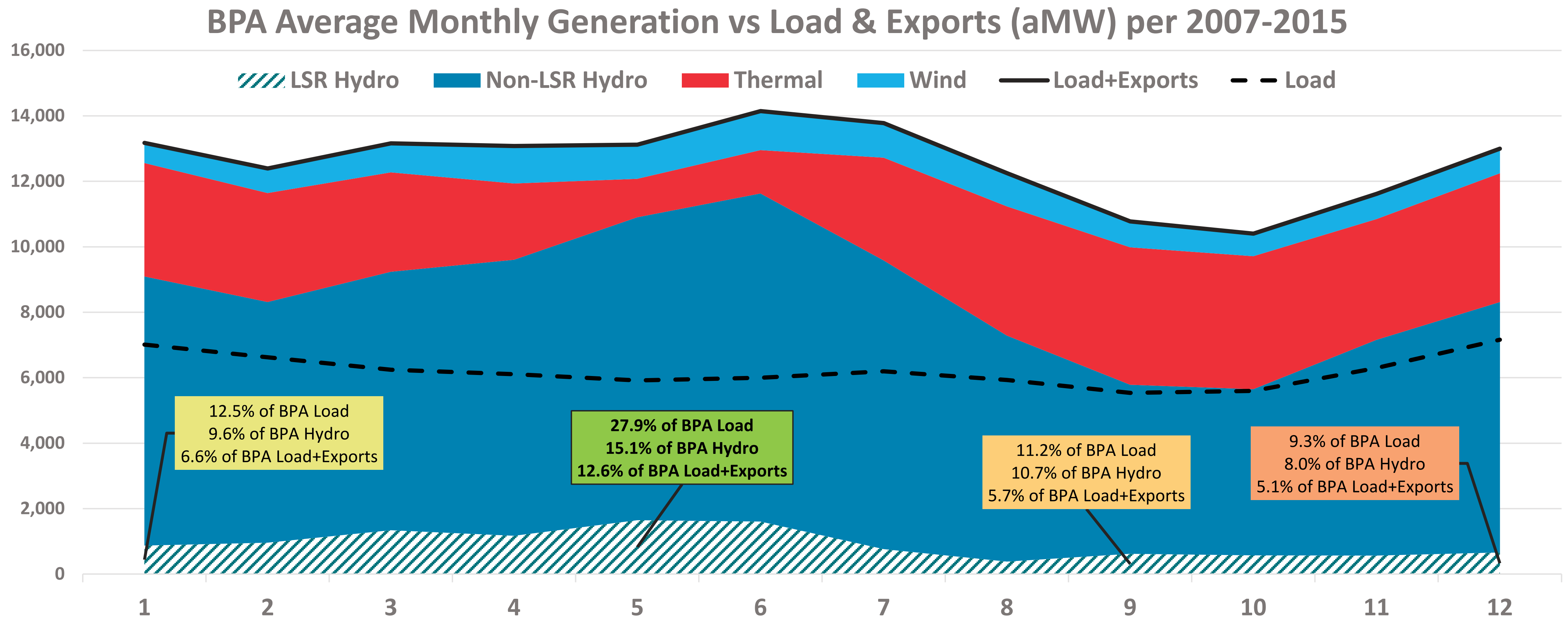
Monthly Loss of Load Probability (LOLP, %)



Value of the LSR Dams

ENERGY VALUE

Especially in Sept-Oct when LSR are "Most Valuable" (previous slide), note how little LSR produces compared to size of Export



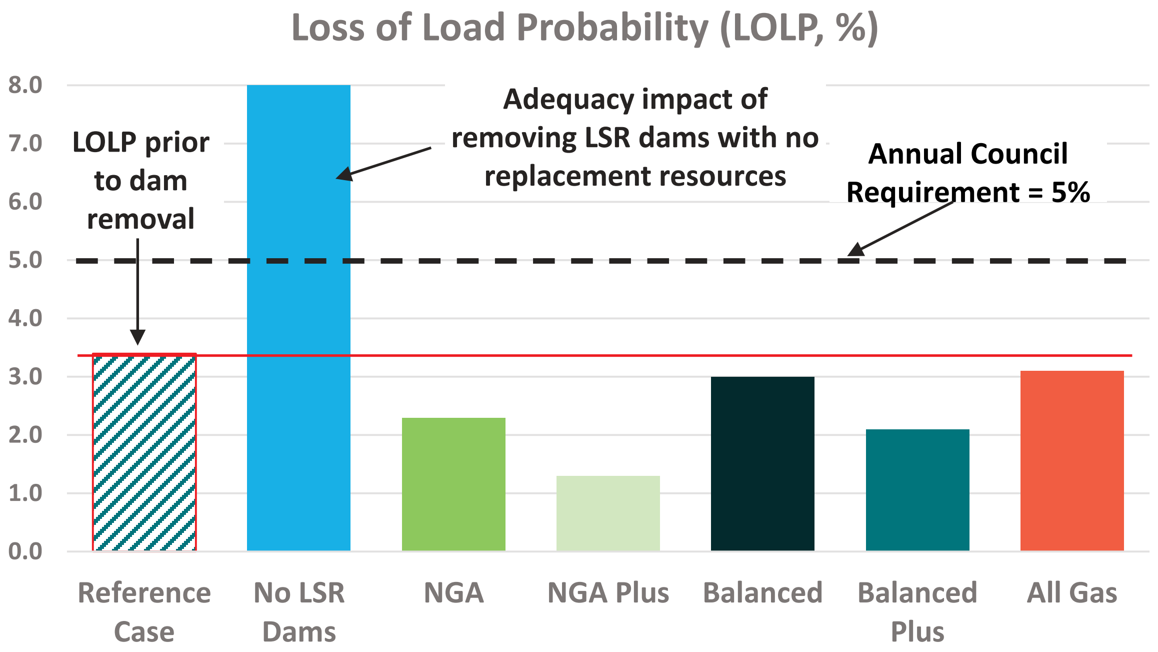
- **The LSR Dams' energy value has been greatest in the spring and earlier summer months, and lowest in August and mid-winter**
- **This timing is generally opposite of when power is most valuable in the Northwest and the effect is captured in the production cost model**

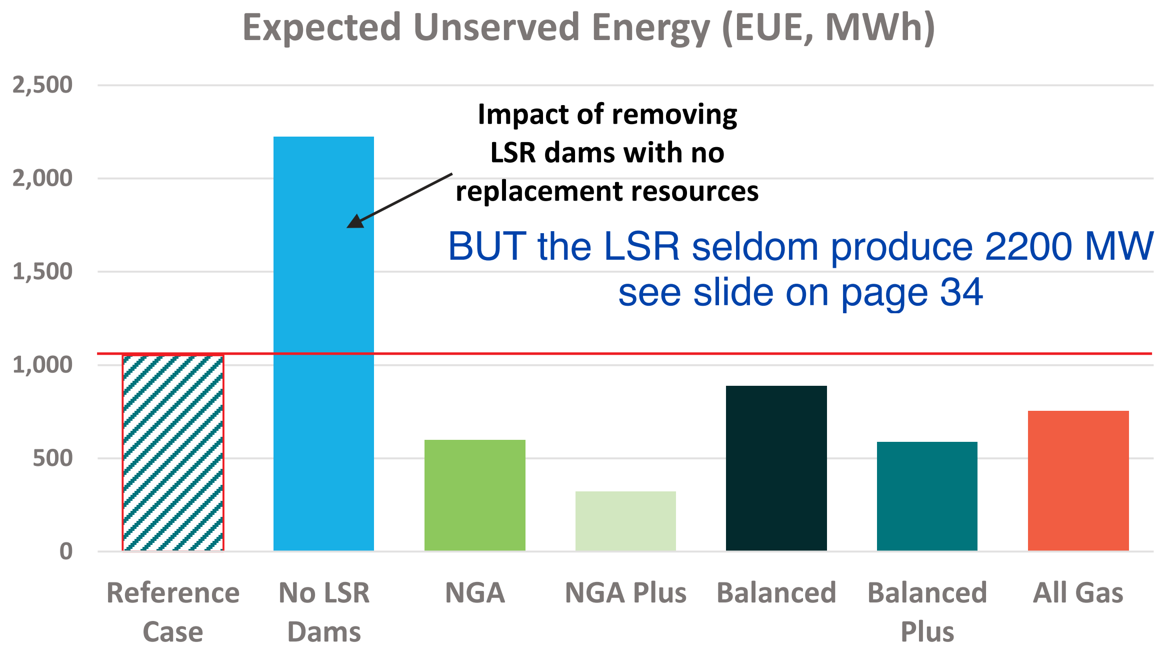
5. REPLACEMENT PORTFOLIO PERFORMANCE

- **Adequacy Assessment**
- Reliability Assessment
- Operations and Emissions Assessment
- Annualized Cost Impact

RESOURCE ADEQUACY

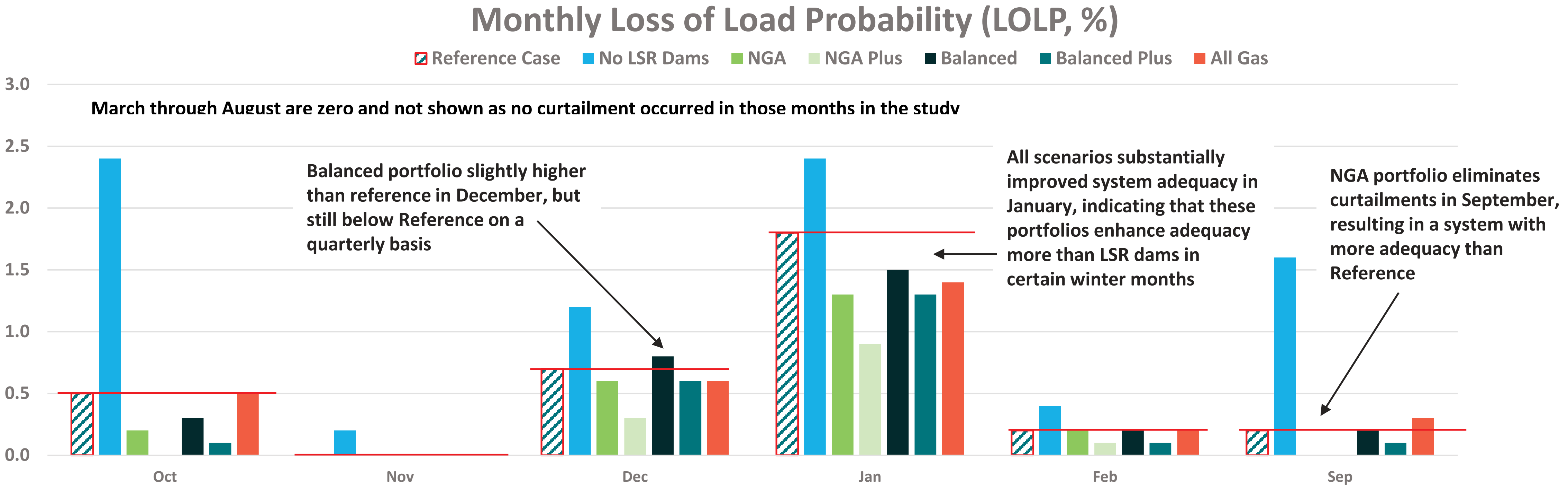
- **The target for system adequacy was established as the LOLP prior to dam removal instead of the NWPCC standard of 5%**
  - This assumption is conservative and results in portfolios that are well below the 5% planning standard
- **All three replacement portfolios achieved annual LOLP and EUE values substantially lower than the 5% LOLP standard and also below the Reference Case value, indicating that the likelihood and magnitude of load curtailments is lower in the replacement portfolio scenarios relative to the Reference case with the LSR dams**
- ***"Plus"* replacement portfolios substantially overachieved in terms of system adequacy and enhances regional adequacy**





RESOURCE ADEQUACY

- **Although not defined by the NWPCC standard, shifting the likelihood of curtailment from one month to another is not acceptable from an adequacy planning perspective**
    - ❖ To mitigate against this, a more conservative and granular monthly LOLP criteria was used to evaluate the replacement portfolios
- **The replacement portfolios achieved monthly LOLP values lower than or equal to the Reference case values, indicating that that the likelihood of curtailments decreased (or stayed roughly the same)**
    - ❖ Critical months such as December and January are roughly at or below the Reference Case level, and no new curtailment risk introduced in high-load months such as August



5. REPLACEMENT PORTFOLIO PERFORMANCE

- Adequacy Assessment
- **Reliability Assessment**
- Operations and Emissions Assessment
- Annual Cost Impact

RELIABILITY ANALYSIS KEY ASSUMPTIONS

Changes to Base Cases to create Reference Cases

Topology Changes
- Updates to mimic ColumbiaGrid's final 2017 System Assessment
- Retired Colstrip 1-2 & North Valmy 2
- Removed I-5 upgrade

System Redispatch	Summer	Winter
LSR Hydro	↓	↓↓
Non-LSR Hydro	-	↑
Thermal	↑	↓
Canada → NW	-	-
NW → CA	-	↓

Changes to Reference Cases to Create Scenario Cases

Demand Response: Adjusted loads proportionately per load type (agricultural, industrial, commercial, and residential) and impact to system peak	**Summer & Winter** (Different Contributions)
Energy Efficiency: Scaled down all conforming load by impact to system peak	**Summer & Winter** (Same Contribution)
Market Purchases: Reduce export to California	**Winter Only**
Additional Resource Updates ➢ Removed LSR dams ➢ New battery dispatched at full capacity - POI at Troutdale 500kV, Oregon ➢ New Combined-cycle gas: Hermiston Power Project duplicate – POI at McNary 500kV, Oregon ➢ New Reciprocating engines: Port Westward duplicates – POI at McNary 230 kV, Oregon ➢ New wind: full output scheduled to Northwest – POI at Judith Gap, Montana ➢ New solar: full output scheduled to Northwest – POI at Bennet Mountain substation in southern Idaho	**Summer & Winter**

STEADY-STATE CONTINGENCY ANALYSIS

- **Purpose of steady-state contingency analysis is to evaluate system's ability to remain within acceptable standards before and after system contingencies (e.g., generator trips, line trips)**
  - ❖ Scope of assessment typically looks for thermal overloads, voltage issues, and voltage stability limits
  - ❖ Thermal overloads occur when facilities exceed their applicable rating, voltage issues occur when there are significant voltage changes (up or down) at a bus
- **Contingency Analysis assumptions based on ColumbiaGrid 2017 System Assessment**
  - ❖ Contingency List and Remedial Action Schemes (or Special Protection Scheme)
- **Pre-existing issues and screening logic used to isolate LSR Dam removal-driven reliability issues:**

IF	THEN
Reference Cases' issues persisted in replacement portfolio cases…	Noted as an existing planning issue with mitigation scope that could be affected by the replacement portfolio
New issues were identified in replacement portfolio cases…	Mitigation was developed as part of the replacement portfolio

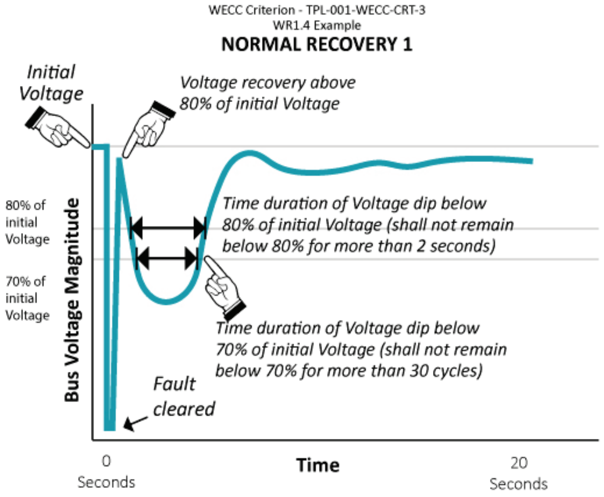
STEADY-STATE CONTINGENCY ANALYSIS RESULTS

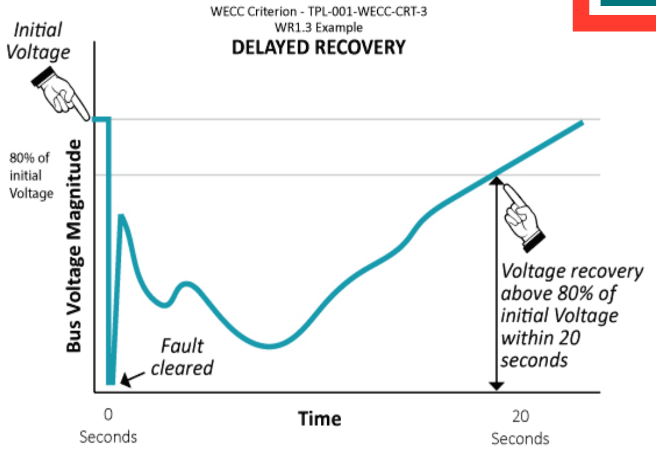
- **There were no incremental WECC voltage criteria violations caused by implementing the replacement portfolios**
- **Four potential post-contingency thermal overloads were identified & addressed through data revisions to line ratings, modeling of RAS, or through planned facilities not modeled in the assessment – mitigations noted in the table below**
- **The remaining issue is the overloaded Stevens – Snyder – White Bluffs 115 kV line which was assumed to be addressed through the addition of a second 115 kV line at a total cost of $10 million**
  - Annual revenue requirement of added transmission is less than $1 million and, given relatively small value, cost was not included in overall cost of portfolios
  - Key cost assumptions: 7 miles of new 115 kV, ~$740k/mile, new line positions at existing substations, 40-year life, 100% debt financed at 5%, 30-year debt period

Season	Branch and Mitigation	Most Severe Contingency	Loading % By Case		Loading % By Scenario Case (& Change in Loading % from Ref Case)				
			Base	Reference	Balanced	Balanced Plus	NGA	NGA Plus	All-Gas
Heavy Summer	Ahsahka - Orofino 115kV Line # 1 ***Mitigated by RAS per ColumbiaGrid report (p. 41)***	[redacted]	[redacted]	[redacted]	[redacted] (+19%)	[redacted] (+34%)	[redacted] (+9%)	[redacted] (+9%)	[redacted] (+7%)
Heavy Summer	Ashe - White Bluffs 230kV Line # 1 ***Mitigated by updated rating from BPA***	[redacted]		[redacted]	[redacted] (+14%)	[redacted] (+14%)	[redacted] (+15%)		
Heavy Summer	Horn Rap - Red Mountain 115kV Line # 1 ***Mitigated by BPA planned reconductor***	[redacted]	[redacted]	[redacted]	[redacted] (+6%)	[redacted] (+3%)	[redacted] (+6%)	[redacted] (+2%)	[redacted] (+1%)
Heavy Summer	Snyder - Stevens 115kV Line # 1	[redacted]	[redacted]	[redacted]	[redacted] (+8%)	[redacted] (+7%)	[redacted] (+8%)	[redacted] (+4%)	[redacted] (+7%)
Heavy Summer	Snyder - White Bluffs 115kV Line # 1		[redacted]	[redacted]	[redacted] (+8%)	[redacted] (+6%)	[redacted] (+7%)	[redacted] (+2%)	[redacted] (+7%)
Heavy Winter	Franklin 230/115kV Transformer # 1 ***Mitigated by moving new Gas CC to different McNary bus section***	[redacted]		[redacted]					[redacted] (+46%)

TRANSIENT STABILITY ANALYSIS

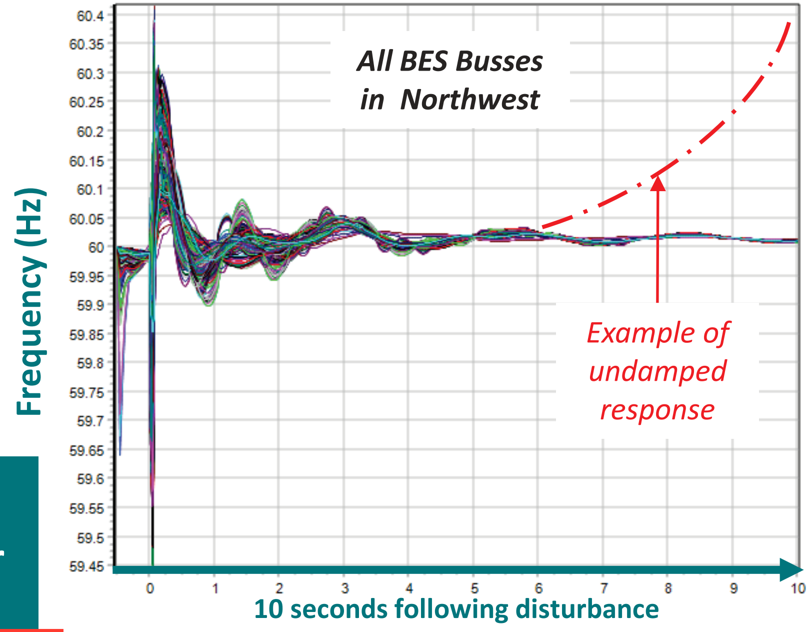
- **Studied three phase faults on each side of nineteen 500 kV lines**
  - ❖ Total of 38 simulations on the Reference Case and all scenario cases
  - ❖ Lines in eastern Washington, Oregon, and tie with Colstrip
  - ❖ No data publicly available to simulate breaker failures or double-line contingencies
- **Analysis of the simulation results for all studies indicated there were no WECC criteria violations**
  - ❖ WECC Transient Stability Criteria (TPL-001-WECC-CRT-3.1) (Voltage swing, Controlled damping and oscillations, Retain system synchronism)

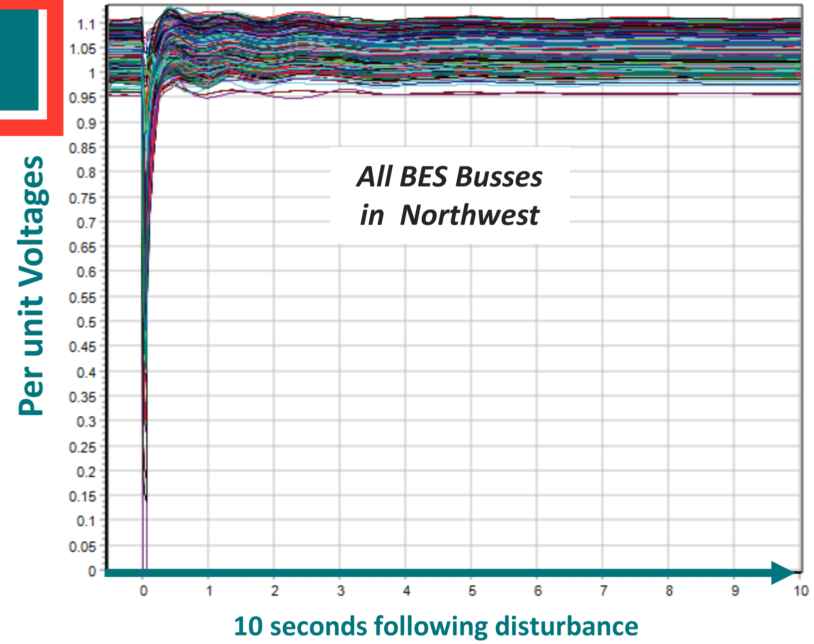




Balanced Portfolio performance under major contingency

Sample - other results have similar profiles



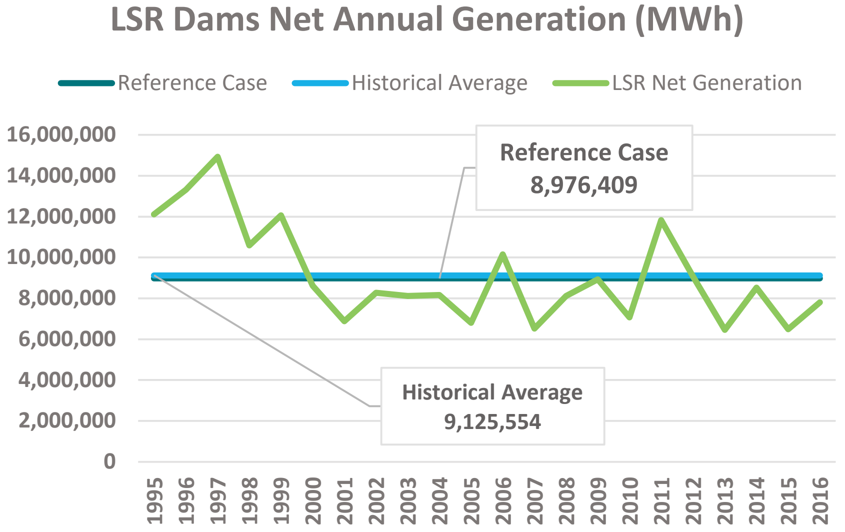


ENERGY STRATEGIES

5. REPLACEMENT PORTFOLIO PERFORMANCE

- Adequacy Assessment
- Reliability Assessment
- **Operations and Emissions Assessment**
- Annualized Cost Impact

LSR DAMS AND PORTFOLIO ENERGY OUTPUT



- **Nodal production simulation modeling is representative of a "median" future and is not designed to stochastically capture impact of all variables within single study**
  - The modeled energy generated by the LSR dams in the Reference Case is comparable to the historical annual average generation for 1995 - 2016
- **The resources in the replacement portfolios do not replace all ~9,000 GWh of modeled energy generated by the dams with new generation and as a result, the model sourced incremental power from varying levels of in-region thermal generation, reductions in exports, and increases in imports**
- **The Balanced *Plus* and NGA *Plus* portfolios replace 86% and 73% of the lost energy and are most effective at mitigating increases to the region's GHG emissions**

Portfolio	LSR Dams	New Wind	New Solar	New DR+EE	New BESS	New Gas	TOTAL	% Energy From Portfolio
Reference	8,976,409	0	0	0	0	0	**8,976,409**	---
All Gas	0	0	0	0	0	2,624,028	**2,624,028**	**29%**
All Gas + GHG Policy	0	0	0	0	0	1,321,673	**1,321,673**	**15%**
Balanced	0	1,916,947	579,370	1,191,724	0	0	**3,688,040**	**41%**
Balanced Plus	0	4,789,169	1,736,860	1,191,772	0	0	**7,717,802**	**86%**
Balanced Plus + GHG Policy	0	4,792,359	1,734,863	1,191,943	0	0	**7,719,165**	**86%**
NGA	0	0	0	2,391,174	-72	0	**2,391,102**	**27%**
NGA Plus	0	0	0	6,508,404	100	0	**6,508,504**	**73%**
NGA Plus + GHG Policy	0	0	0	6,508,364	-100	0	**6,508,264**	**73%**

Portfolio energy in MWh

IMPACTS TO IMPORTS/EXPORTS

- Removing the LSR dams generally increased the amount of annual gross imports and decreased the amount of gross exports, with the net effect being varying reductions in regional net exports
- The Balanced Plus and NGA Plus portfolios limited the reduction to net exports due to (1) amount of energy in those portfolios and (2) the timing at which that energy was available relative to the LSR Dam generation

Portfolio	Annual Gross Imports (GWh)	Δ Import (GWh)	Annual Gross Exports (GWh)	Δ Export (GWh)	Annual Net Exports (GWh)	Δ Export (GWh)	Δ Export (%)	Δ Export (aMW)
Reference	13,181	0	26,510	0	13,329	0	**0%**	**0**
Balanced	14,319	1,138	25,781	-729	11,462	-1,867	**-14%**	**-213**
Balanced Plus	13,908	727	26,888	379	12,980	-349	**-3%**	**-40**
Balanced Plus + GHG Policy	17,971	4,790	24,648	-1,862	6,677	-6,652	**-50%**	**-759**
NGA	13,972	791	24,799	-1,711	10,827	-2,502	**-19%**	**-286**
NGA Plus	13,514	333	26,190	-320	12,676	-653	**-5%**	**-75**
NGA Plus + GHG Policy	18,601	5,420	24,521	-1,989	5,920	-7,409	**-56%**	**-846**
All-Gas	14,393	1,212	25,386	-1,123	10,993	-2,336	**-18%**	**-267**
All-Gas + GHG Policy	19,291	6,110	22,427	-4,082	3,136	-10,193	**-76%**	**-1164**

- The GHG Policy sensitivities had the effect of increasing the marginal power price in the region as the cost of carbon is internalized by thermal units, which (1) increased the in-region value of low-carbon resources that would have otherwise been exported and (2) increased the cost of dispatching thermal generators for export.

Not including LSR Comp hatcheries or LSR dam O&M, so not capturing cost savings greater than loss of net exports.

SYSTEM OPERATING COSTS

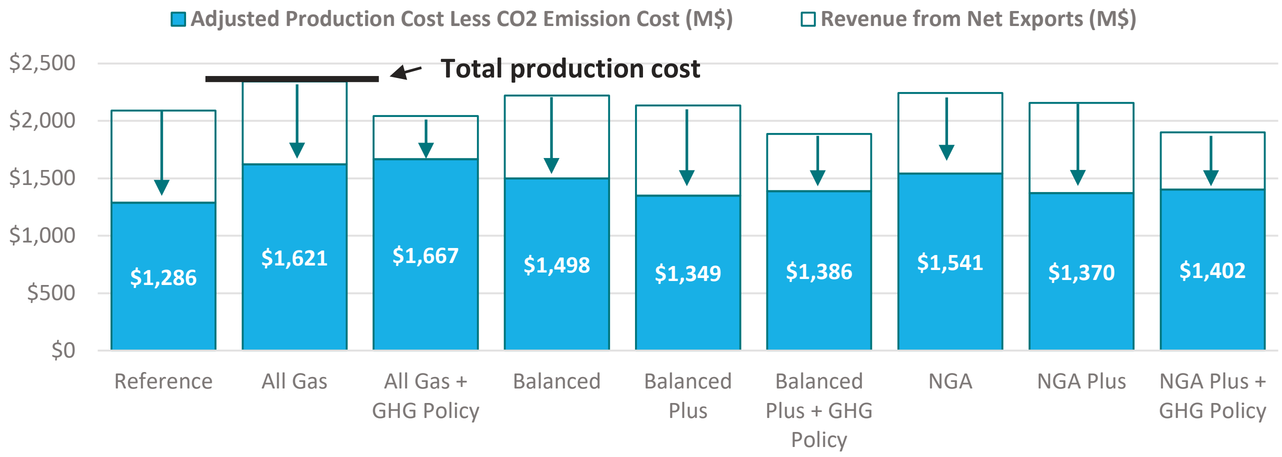
- **Total operational cost to serve load in Northwest region approximated through adjusted production cost metric where:**

Adjusted Production Cost for Region = **Production cost of generators in region** − **Revenue from net exports**

- **Captures total annual operating costs (including fuel), for all generation physically within or contracted/owned by utilities within the study footprint**
- **Revenue from exports approximates how operating costs would be offset by sales to neighboring regions at that region's marginal power price (LMP)**
  - Export revenue nets out cost of gross imports
- **The NGA and Balanced replacement portfolios cause Northwest operating costs to increase by 16-20% as energy is made up with purchases, new generation, and decreases in exports**
- **The "Plus" portfolios have more zero-marginal cost energy and impact the region's operating costs by a much lower 5-7%**

What is LMP and how does it relate to the Surplus Market price?

Adjusted Production Cost (M$) by Portfolio



GHG EMISSIONS

Carbon Sequestration of forests with salmon, far exceeds these puny CO2 emission numbers.

- **During median hydro years with minimal spill/curtailment of clean energy resources, such as the year modeled in this operational study, certain portfolios that did not replace most of the LSR Dams' energy output caused increases in GHG emissions**
  - In years of hydro surplus, these portfolios may contain sufficient clean energy to avoid increases in emissions
- **However, the "Plus" replacement portfolios had sufficient energy to mitigate impacts to regional GHG emissions, limiting the increase to ~1%**
  - Note the portfolio was not optimized for this purpose additional clean energy could fully mitigate the emission increase
- **The GHG Policy sensitivity for these two portfolios had the effect of reducing GHG emissions to points *below* that of the Reference Case**
  - This suggests that substantive regional decreases in GHG emissions are feasible so long as the LSR Dams are replaced with a clean energy portfolio that is realized following implementation of a GHG reduction policy
- **The All-Gas portfolio, even when combined with a Regional GHG policy, results in substantial increases to regional emissions**

Portfolio / Sensitivity	Total CO_2 Emissions Including Annual Gross Imports (Short Ton)	Δ (Short Ton, annual)	Δ (%)	Emission Intensity (ton/MWh)
Reference	43,299,426	0	0%	0.18
Balanced	45,327,168	2,027,741	5%	0.19
Balanced Plus	43,659,702	360,275	1%	0.19
Balanced Plus + GHG Policy	42,491,591	-807,836	-2%	0.18
NGA	45,566,562	2,267,136	5%	0.20
NGA Plus	44,267,489	968,063	2%	0.19
NGA Plus + GHG Policy	43,351,769	52,342	0%	0.19
All-Gas	46,928,920	3,629,493	8%	0.20
All-Gas + GHG Policy	45,357,456	2,058,030	5%	0.20

IMPACT TO POWER PRICES

- **All replacement portfolios had consistently small impacts on power prices**
- **Average LMPs at key trading hubs increased between $0.80/MWh and $1/MWh depending on the hub and replacement portfolio (without the GHG Policy sensitivity)**
- **All Gas Replacement Portfolio caused prices to increase nominally higher than the other two portfolios**
- **Balanced Portfolio resulted in the smallest price increase**

"COB|Mid-C" LMP ($/MWh)	On-Peak (Avg.)	Off-Peak (Avg.)	Average
Reference	$39 | $37	$34 | $33	$37 | $36
All Gas	$40 | $38	$35 | $34	$38 | $37
All Gas + GHG Policy	$52 | $50	$48 | $46	$51 | $49
Balanced	$40 | $38	$35 | $34	$38 | $37
Balanced Plus	$39 | $38	$35 | $33	$38 | $36
Balanced Plus + GHG Policy	$52 | $50	$48 | $46	$50 | $48
NGA	$40 | $38	$35 | $34	$38 | $37
NGA Plus	$39 | $38	$35 | $33	$38 | $36
NGA Plus + GHG Policy	$51 | $49	$48 | $46	$50 | $48

- **These small increases in price reflect the impact of losing the energy from the LSR Dams since the portfolios did not replace all of the energy lost with equally low marginal cost resources, the LMPs at key market hubs increase.**
- **The GHG Policy sensitivity cases have $12-13/MWh prices increases, which indicates that market prices will increase when fossil-fired generators internalize their carbon cost and set the marginal price for power**

GHG POLICY SENSITIVITIES

This report is really about the cost of GHG reduction, it uses the LSR dam removal for cover which when replaced fully by loss of exports has no GHG effect.

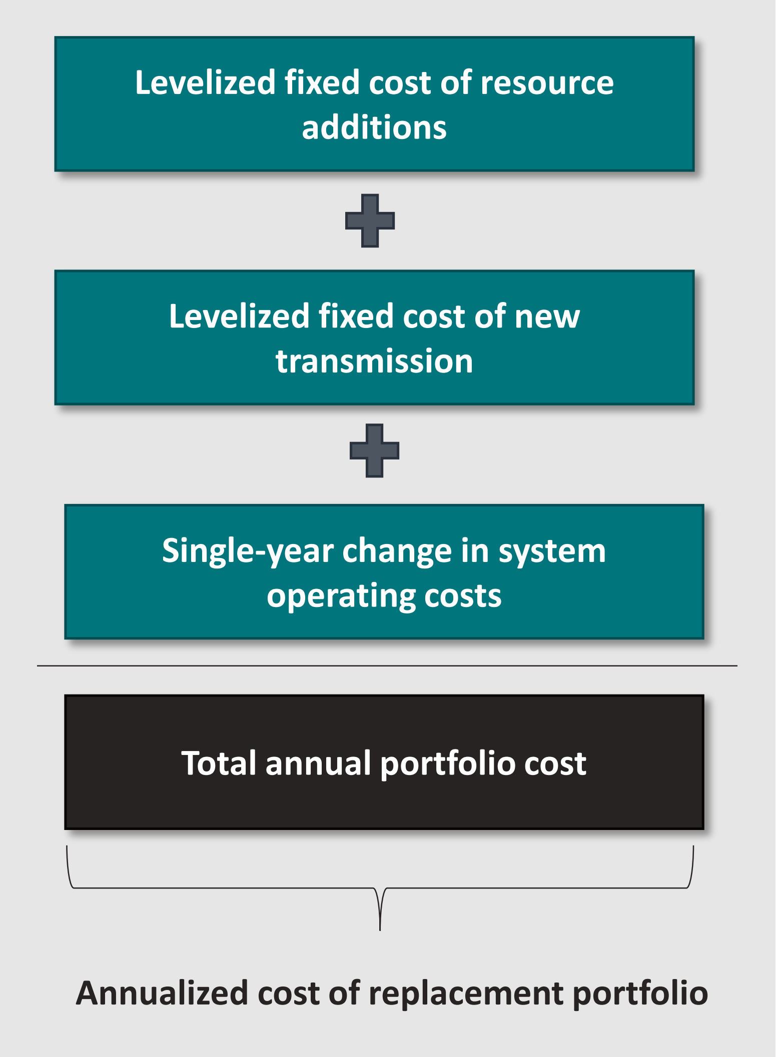
- **The study used a conservative approach to modeling GHG policy, assigning imports into control areas within Washington or Oregon an assumed "unspecified" import rate (0.428 metric ton CO_2e/MWh) even if those imports were from remote thermal resources that may be owned by the utilities**
- **The study also considered applying the full carbon price to these remote but contracted/owned out-of-state resources (e.g. "specified resources")**
- **This approach caused major decreases in regional GHG emissions, on the order of 20% from the Reference Case for certain portfolios, mainly from the coal-to-gas generation shift**
  - ❖ The operational cost increase works out to a GHG abatement cost of ~$30/ton, which is in line with recent studies
  - ❖ GHG policy modeling not the focus of this study
- ❖ **While the study still relied on the conservative approach, the analysis tells us that the emission impact of LSR Dam replacement is small (~1% for some portfolios) relative to the potential reductions that are achievable through GHG policy that impacts remaining coal generation in the region**

Portfolio and Sensitivity	Change in GHG Emissions (%)	Operational Cost ($M)
Reference	0%	$1,286
All Gas + GHG	5%	$1,667
All Gas + GHG ("specified resource" modeling)	-17%	$1,945
Balanced Plus + GHG	-2%	$1,386
Balanced Plus + GHG ("specified resource" modeling)	-24%	$1,638
NGA Plus + GHG	0%	$1,402
NGA Plus + GHG ("specified resource" modeling)	-22%	$1,673

5. REPLACEMENT PORTFOLIO PERFORMANCE

- Adequacy Assessment
- Reliability Assessment
- Operations and Emissions Assessment
- **Annualized Cost Impact**

COST ANALYSIS FRAMEWORK



- **Cost analysis calculates the incremental cost of each replacement portfolio on an annualized basis**
- **Resource and transmission capital costs are based on estimates derived from industry-vetted projections**
  - Captures costs associated with fixed capital costs, fixed O&M and financing with common industry valuation periods
  - Solar/wind/storage reflect reasonable cost reductions between today and installation date
- **Changes in regional operational costs are captured through production cost modeling studies**
  - Single-year change for a median study case is reasonable proxy for "average" conditions over an extended period
- **Cost analysis does not seek to evaluate the cost effectiveness of removing the dams, nor does it capture all potential replacement options**
  - For example, the costs of removing the dams is not included in the analysis, nor are a number of energy and non-energy system benefits and the benefits (savings) of removing dams from avoided capital and maintenance expenditures

ASSUMPTIONS AND METHODOLGY

Resource Type	Replacement Portfolio Cost Assumption
Demand Response	7th Plan documentation
Energy Efficiency	
Renewable Resources	Energy Strategies-derived costs based on multiple industry cost estimates
Battery Storage	Energy Strategies-derived costs based primarily on Lazard Levelized Cost of Storage Report v3.0
Gas CC	7th Plan documentation
Gas CT	

- **Wind, solar and battery storage levelized fixed costs were calculated using the 2017 WECC Capital Cost Model, with some modifications**
  - Publicly vetted cash flow model created for WECC's long-term transmission expansion planning process
  - Allows users to input unique assumptions for generation resources
    - Energy Strategies updated the resource capital cost assumptions in the model to account for recent estimates customized for the Northwest
- **All resources, transmission, and operational costs embedded in Reference Case are considered sunk costs**
  - This includes 5-year Action Plan for demand response and energy efficiency from NWPCC 7th Plan

2017 WECC Capital Cost Pro-Forma Model

Capital Cost
- Energy Strategies-defined input in $/kW
- Includes Progress Multiplier to capture future cost declines

\+

Property Tax and Insurance
- Assumes 1% property tax and no insurance cost

\+

(ITC Value)
- Assumes 10% ITC on 95% of capital for solar
- Not applicable for wind

\+

O&M
- Fixed over 25-yr life of asset

=

Levelized Fixed Cost ($/kW-yr)

2017 WECC Capital Cost Proforma Model can be found at this link

Annualized Cost Impact

COST ASSUMPTIONS SUMMARY

- **All costs are in AC installed-capacity for year 2026 installation and are shown in 2017 dollars**
- **Assumed no incremental cost for transmission as levels modeled in this study would not require incremental transmission capacity investment beyond what is included in the Reference Case transmission system**
- **Storage cost based on Lazard (COS v3.0) 2018 cost estimate of ~$1,200/kW with 37% reduction by 2026**
- **Solar costs assume 10% ITC value in 2026**
- **Thermal generators from 2025 installation year costs from 7th Plan with proxy capacity contract cost of $2.50/kW-month, which is based on CAISO NP-15 System RA contracted prices for 2017**

Thermal Generation or Capacity Market Cost

Resource Type	Capital Cost ($/kW-ac)	Levelized Fixed Cost ($/kW-year)
Gas Combined Cycle	$1,498	$213
Gas Reciprocating Engine	$1,416	$206
Capacity Contract (Market)	$30/kW-year	---

Renewable/Storage Cost

Resource Type	Capacity Factor (%)	Installed cost ($/kW-ac)	Levelized Fixed Cost ($/kW-year)	Levelized Cost of Energy ($/MWh)
Wind (Montana)	44%	$1,639	$205	$53.24
Solar, Single-axis Tracking (Idaho)	26%	$1,400	$127	$59.10
Li-ion Battery (4-hr)	---	$753	$141	---

Demand-side Cost Assumptions

Resource Type (incremental to Reference Case)	Resource Potential	Average Levelized Fixed Cost ($/kW-year)	Average Levelized Cost of Energy ($/MWh)
Cost Effective Energy Efficiency	320 aMW	---	$28
50% of Cost Effective Energy Efficiency	160 aMW	---	$24
Technical Achievable Potential Energy Efficiency	880 aMW	---	$132
Cost Effective Demand Response	~1000 MW	$68	---
50% of Cost Effective" Demand Response	~ 500 MW	$29	---

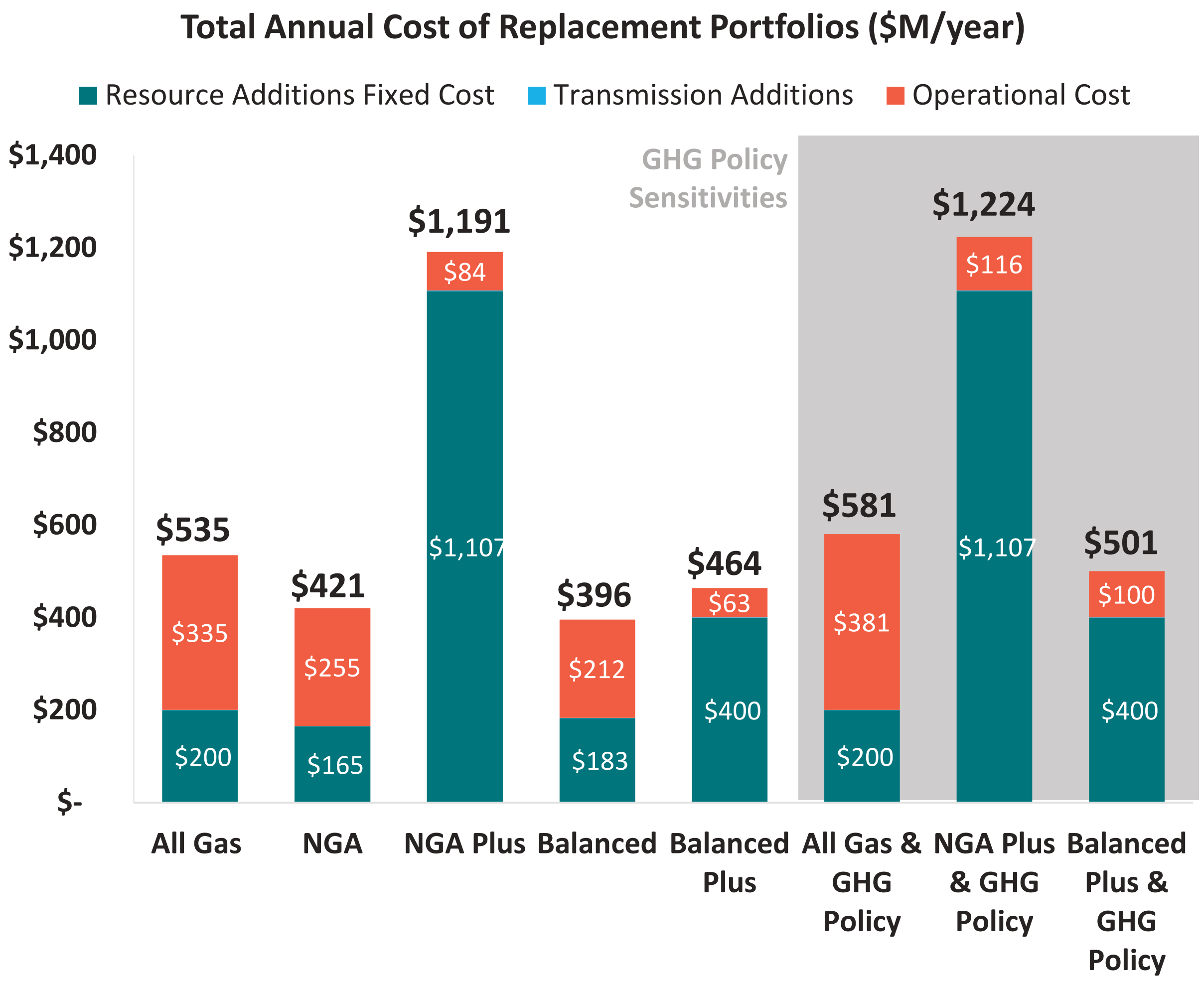
REPLACEMENT PORTFOLIO DETAILS

Resources	Portfolio Fixed Cost (Millions, $2017/year)				
	NGA	NGA *Plus*	Balanced	Balanced *Plus*	All Gas
Demand Response	**$68**	**$68**	**$15**	**$15**	-
Energy Efficiency	**$80**	**$1,022**	**$34**	**$34**	-
Battery Storage	**$14**	**$14**	**-**	-	-
Wind	-		**$103**	**$256**	-
Solar	-		**$32**	**$95**	-
Gas – Combined Cycle	-		-		**$107**
Gas – Reciprocating Engine	**-**		-		**$93**
Capacity Contract (Market)	**$3**	**$3**			
Total Annual Fixed Cost	**$165**	**$1,106**	**$183**	**$400**	**$200**

- **Fixed costs of most replacement portfolios vary between $165-400 million/year**
- **The NGA Plus replacement portfolio includes all technically achievable energy efficiency and the remaining 880 aMW of this resource comes at a very high average cost of $132/MWh, which drives up the portfolio's total resource cost by exhausting the stock of energy efficiency**

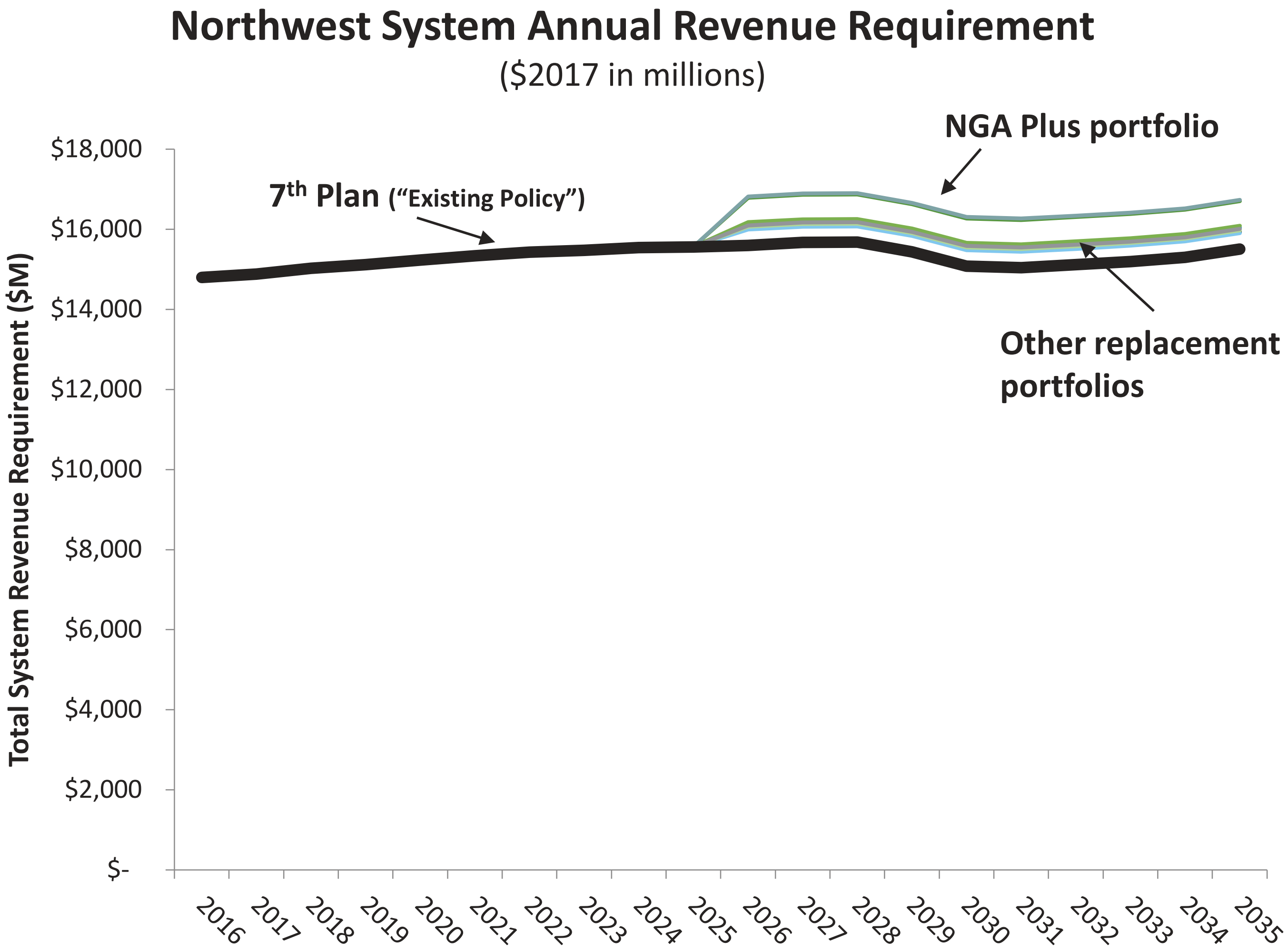
INCREMENTAL COST OF REPLACEMENT

- **All Gas portfolios have greater increases in operating costs as compared to clean portfolios**
  - On average, All Gas portfolio costs $110 million per year more than the clean replacement portfolios (excluding the NGA Plus option)
- **NGA and Balanced portfolio are similar in total cost**
  - NGA Portfolio has a slightly lower fixed costs from resource additions, but higher operating costs
  - Balanced Portfolio has higher fixed costs, but lower operating costs
- **Transmission addition costs are insignificant relative to total costs for all portfolios**
  - Less than $1M/yr
- **Balanced Plus portfolio is about 17% more costly than the Balanced portfolio, but has the benefit of relative reductions in carbon emissions**
  - The GHG reduction policy sensitivity further emphases this effect, although the incremental carbon reductions come at a lower abatement cost due to the efficiency of the carbon policy (relative to the incremental resource additions)

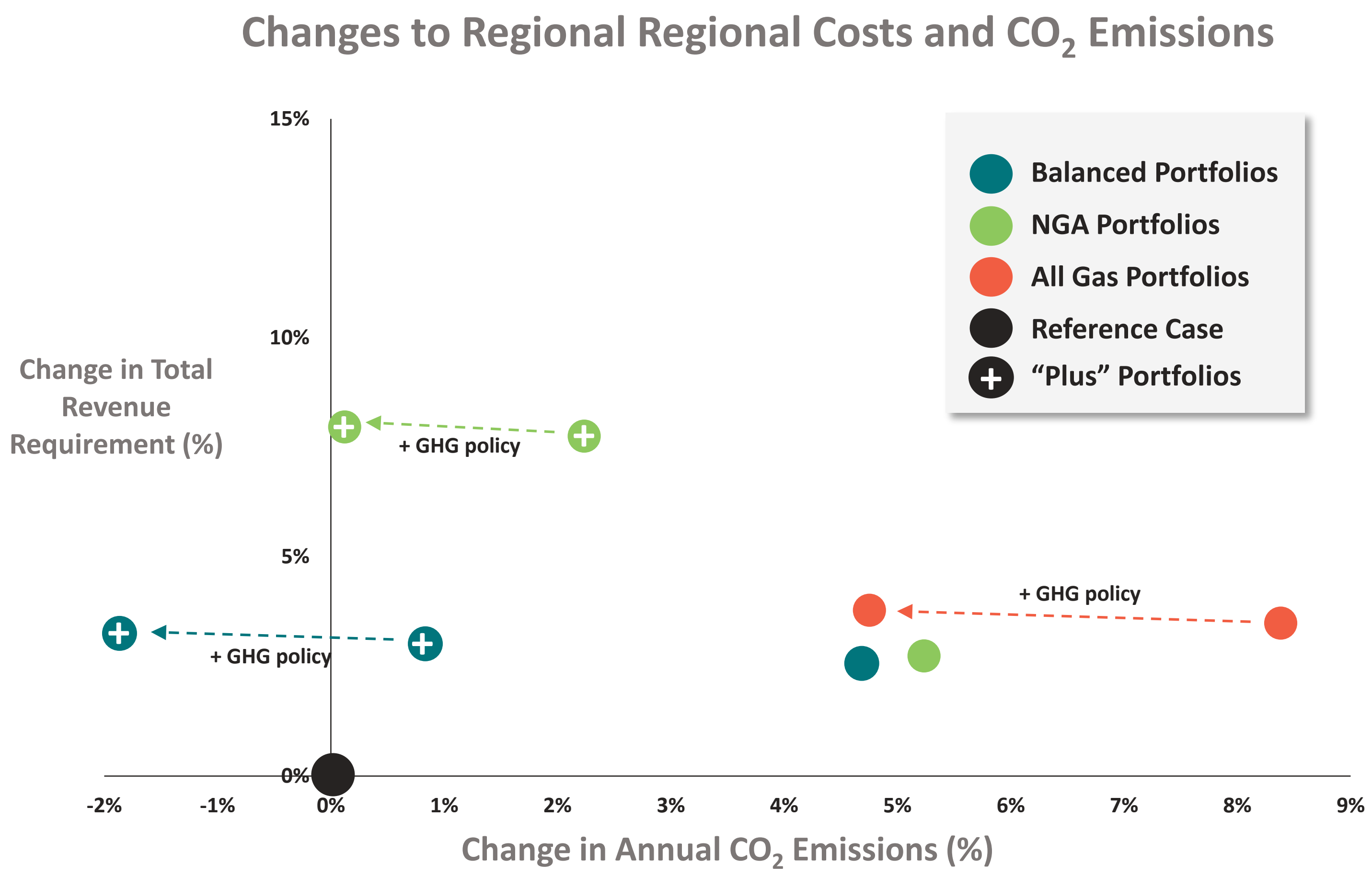


ESTIMATED REVENUE REQUIREMENT IMPACT

- **7th Plan calculates Northwest system revenue requirement of $15.6 billion (in 2017$) for 2026**
  - Includes cost of operating/maintaining LSR dams, so decrease in revenue requirement, a benefit, is not captured (while we do capture the cost or replacing the power)
  - Excludes implicit carbon cost
- **NGA and Balanced portfolio estimated to increase the going-forward average revenue requirement by ~2.6%, starting in 2026**
  - All gas portfolios would increase costs by 3.6%
- **Balanced Plus scenario results in 3% increase, with the GHG reduction policy further increasing this cost by 0.25%**
- **NGA Plus is highest cost portfolio with 7.8% increase**



COSTS AND EMISSIONS SUMMARY



- The initial Balanced, NGA, and Gas portfolios did not meet the study goal of mitigating increase in carbon emissions
- When the Balanced portfolio was modified to include additional renewable resources and then modified further to include a regional GHG policy, carbon emissions are fully mitigated at a relatively low incremental cost
- The effect was similar for the NGA case, but because the incremental energy efficiency had a high cost, the iteration of the portfolio had a much higher carbon abatement cost as reflected by the increase in the regional revenue requirement
- The All Gas portfolio started with much higher emissions and while the GHG policy was effective at reducing those emissions, the portfolio was still more costly and higher emitting than the Balanced portfolio
- An optimized portfolio may result in an finely tuned balance between emissions and cost tradeoffs
  - ❖ For example: If the Balanced portfolio was optimized to include slightly more conservation, emission reductions may be further mitigated at a lower cost

Annualized Cost Impact

RESIDENTIAL BILL METRIC

Replacement Portfolio	Change in Levelized Residential Electric Bill ($) ($/month/household)	Change in Residential Electric Bill (%)
Reference Case	---	---
All Gas	$1.47	1.4%
All Gas + GHG Policy	$1.60	1.6%
NGA	$1.16	1.1%
NGA Plus	$3.28	3.2%
NGA Plus + GHG Policy	$3.37	3.3%
Balanced	$1.09	1.1%
Balanced Plus	$1.28	1.2%
Balanced Plus + GHG Policy	$1.38	1.3%

- Bills levelized over 20-year period for comparison with Reference Case and 7th Plan
- Assumes NWPCC 4% discount rate
- All are 2017 dollars
- Reference Case corresponds to NWPCC Existing Policy scenario and captures full system ongoing costs for 20-years

- **Bill impact analysis based on methodology used by NWPCC for 7th Plan**
  - Assumes that 47% of total revenue requirement is paid for by residential customers
  - Kept constant NWPCC projections for total households in region and assumption that residential share is split equally among the number of forecasted households
  - Captures effects of incremental conservation
- **Relative to total monthly residential bill analysis from the 7th Plan, increases in monthly bill metric for the least costly portfolios are in the 1-3% range, which translates to approximately $1-2 dollars per month per household on a 20-year levelized basis**
  - On a non-levelized basis, bill impacts are in the 2-3% range starting in 2026
- **Calculation was also performed on a 30-year levelized basis to capture additional costs beyond 2035**
  - For most portfolios, this increased the levelized average residential bill by ~0.5%, or roughly $0.43/month

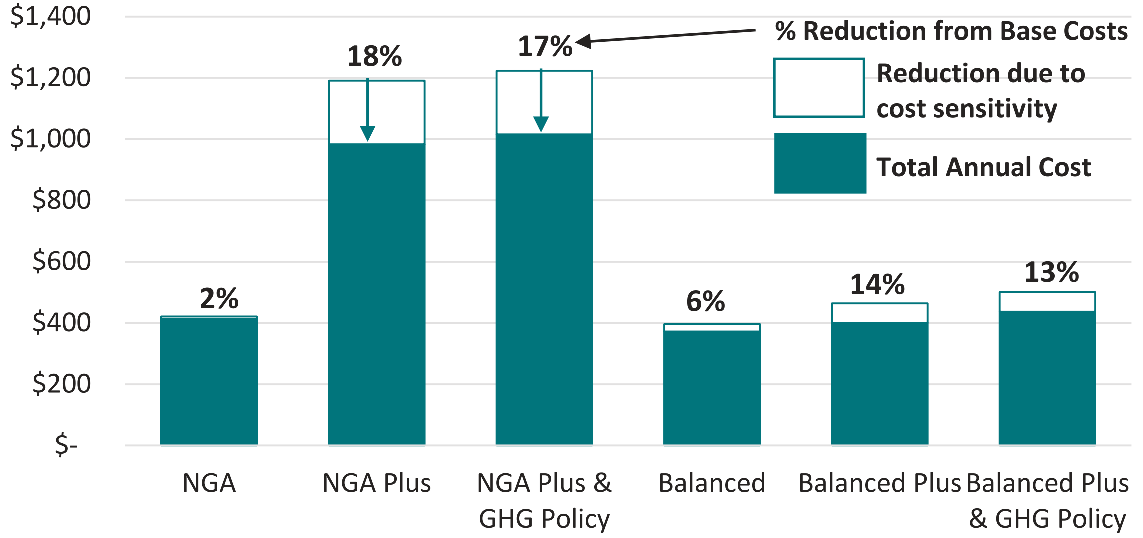
COST SENSITIVITIES

- **Evaluates impact of potential capital cost reductions for certain technologies**
  - Energy Efficiency reduced **20%** relative to Base Case for full technical achievable potential (high cost conservation) to capture technological advances or new conservation that may bring down the costs of conservation
  - Wind, solar, and battery storage reduced 20%, 30%, and 40%, respectively, reflecting the relative maturity of the technologies
- **Based on these assumptions, the low cost sensitivity has a small effect on *total costs* except for the NGA Plus alternative**
  - NGA Plus included all technically achievable energy efficiency and when the cost for that conservation was decreased the savings were pronounced (17-18% reduction in total costs)
  - For the Balanced Portfolio, fixed capital costs made up only a portion of the total costs so 10-20% reductions in capital costs translated to 6-14% of total cost reduction

Summary of Resource Installed Cost Changes (2026 installation, 2016$)

Resource Type	Base Cost	Reduction (%)	Low Cost Sensitivity
Wind (Montana)	$1,639/kW	**20%**	$1,311/kW
Solar, Single-axis Tracking (Idaho)	$1,400/kW	**30%**	$980/kW
Li-ion Battery (4-hr)	$753/kW	**40%**	$452/kW
Technical Achievable Potential Energy Efficiency	$132/MWh	**20%**	$106/MWh

Total Annual Cost of Replacement Portfolios for Cost Sensitivities ($M/year)



ENERGY STRATEGIES

6. FINDINGS

REPLACEMENT PORTFOLIOS AND RESULTS

DR = demand response
EE = energy efficiency
NGCC = natural gas-fired combined cycle
Recip = reciprocating engine

All are changes relative to Reference Case that retains the LSR Dams		Replacement Portfolios					GHG Reduction Policy Sensitivity		
		NGA	NGA *Plus*	Balanced	Balanced *Plus*	All Gas	NGA *Plus*	Balanced *Plus*	All Gas
Replacement Resources	Demand-side	~1,000 MW DR 320 aMW EE	~1000 MW DR 880 aMW EE	~500 MW DR 160 aMW EE	~500 MW DR 160 aMW EE	-	~500 MW DR 160 aMW EE	~500 MW DR 160 aMW EE	-
	Resource-side	-	-	500 MW wind 250 MW solar	1,250 MW wind 750 MW solar	500 MW NGCC 450 MW recip	500 MW wind 250 MW solar	1,250 MW wind 750 MW solar	500 MW NGCC 450 MW recip
	Capacity Market	100 MW	100 MW	-	-	-	100 MW	-	-
Portfolio Performance	Resource Adequacy (Δ LOLP%)	-1.1%	-2.1%	-0.4%	-1.3%	-0.3%	-2.1%	-1.3%	-0.3%
	Δ Reliability	All met NERC/WECC criteria, but for one reliability issue identified in all replacement portfolios (mitigated w/ transmission upgrade and cost captured)							
	Δ GHG Regional Emissions (%)	+5%	+2%	+5%	+1%	+8%	0%	-2%	+5%
Costs	Δ Total Annual Cost ($M/year)	$421	$1,191	$396	$464	$535	$1,224	$501	$581
	Δ Region Revenue Requirement in 2026 (%)	+2.7%	+7.6%	+2.5%	+3.0%	+3.4%	+7.6%	3.21%	+3.7%
	Δ Levelized Monthly Bill ($/Month)	$1.16	$3.28	$1.09	$1.28	$1.47	$3.37	$1.38	$1.60

CORE QUESTIONS

Can an energy portfolio replace the LSR Dams while minimizing or eliminating increases to regional carbon emissions?

- ❖ How might these replacement portfolios change under different future scenarios?

- **Yes – a portfolio of clean energy resources, including solar, wind, energy efficiency, demand response, and energy storage, can effectively replace the most critical power attributes the four LSR Dams contribute to the Northwest region.**
  - ❖ Clean resources required for this replacement, such as energy efficiency and renewable power, are or will be reasonably available within the region.
- **When a balanced portfolio is implemented in conjunction with greenhouse gas reduction policy, substantial reductions in emissions can be achieved without the LSR Dams.**
  - ❖ GHG policy-driven reductions of emissions are much larger, in proportion, to LSR Dam emission impacts.
  - ❖ Given the cost-effectiveness of the carbon policy in reducing carbon emissions, an optimal replacement strategy may rely less (or not fully) on resource-specific replacements and more on broad policy measures to mitigate against carbon emissions – such a strategy could reduce costs of replacement.
- **Absent such policy, the balanced portfolio has a minor impact on GHG emissions (about 1%) compared to expected emissions with the LSR Dams in service.**
  - ❖ Did not study cost of reducing emissions impact below 1%, but analysis indicates it is feasible even absent GHG policy

FINDINGS

CORE QUESTIONS

What is the
ISSUE?
Transmission line
$1 million

If replacement portfolios of energy storage, renewable resources, and clean market purchases cannot (alone) replace the LSR Dams, what incremental infrastructure (e.g. additional transmission, substation equipment, gas-fired resources) might be required to fill the gap?

- **The reliability analysis revealed one reliability issue that was mitigated at a relatively low cost compared to the total cost of the replacement portfolio.**
  - Based on the scope, this was the only infrastructure (beyond the portfolios themselves) that would be required.
  - Issued was identified in All Gas portfolio as well.
  - After addressing the issue, the clean replacement portfolios met reliability criteria under peak summer and winter conditions and did not create any new reliability issues.
- **Gas-fired generation is not required to address regional capacity needs that arise when the LSR Dams are removed.**

CORE QUESTIONS

At what approximate cost to Northwestern residential ratepayers might the replacement portfolios be achieved?

- **The total costs of the clean energy replacement portfolios, particularly the balanced portfolios that include both new wind/solar and demand-side measures, are relatively small compared to the total projected costs of the Northwest power system.**
  - Implementing the replacement portfolios results in system cost increases, starting in 2026, on the order of 2-3%, accounting for the cost of the incremental resources/programs, the change in cost of system operation (including increased market purchases), and the cost of any new transmission to address minor reliability issues
- **Compared to business-as-usual, on a levelized basis the impact of implementing the portfolios studied translates to a roughly $1-2 dollar increase to the month bill metric calculated for a typical residential customer in the Northwest**
  - Bill metric increases 2-3% from forecasted Reference Case levels starting in 2026
- **Reductions in the cost of technologies like wind, solar, and conservation would decrease these costs**

CORE QUESTIONS

What additional value might the replacement portfolios offer?

- **The replacement portfolios provided the region with enhanced resource adequacy compared to the LSR Dams**
  - ❖ They decreased the likelihood of load curtailments annually and in almost all months
- **The clean energy portfolios had superior performance to an all gas replacement alternative in terms of resource adequacy, emissions, and total cost.**
- **Additional value not quantified in this analysis:**
  - ❖ Energy Prices: The replacement portfolios increase prices at regional power trading hubs, which will benefit those seeking to sell power at those locations and it would provide additional revenue for other hydro generation resources sold into the market
  - ❖ Fuel security and diversity: While aspects of the clean energy replacement portfolios are weather dependent (like the LSR Dams), they help to diversify the Northwest's system by relying less on hydropower and more on wind/solar, which could be more valuable in low and very high hydro conditions
  - ❖ Transmission relief: The NGA portfolios modeled a 100 MW battery storage facility, which could provide support to the South of Allston transmission constraint

AREAS OF ADDITIONAL STUDY AND CONSIDERATION

- Identifying the most cost effective, environmentally efficient, and robust/adequate replacement portfolio will require scenario-based optimization studies. An effort to do so by the region may lead to a more cost effective and environmentally efficient outcome than the portfolios considered in this analysis.
- Future studies should gather and incorporate detailed cost estimates surrounding planned, long-term capital and maintenance costs that could be avoided if the dams were removed and replaced, the cost of fish programs that could potentially be avoided, as well as any incremental costs required to breach the dams.
- The region should consider the issue in combination with other evolving policy, climate, and economic factors.
- The impacts of decarbonization policy needs additional investigation – an optimal portfolio may be partly made up of physical resources and GHG reduction policy.
- The study used conservative assumptions with regards to resource adequacy and capital costs and relaxing these assumptions should be considered.
- The study did not consider the impacts of high renewable penetration levels in neighboring regions, such as California, nor did it consider the implications of changes to natural gas prices, load forecast, and other key variables.
- The residential bill analysis was done at a regional level and more granular impacts should be considered
- An assessment to evaluate the impact, if any, that the removal and replacement of the LSR Dams might have on path transfer capabilities would be important to identify.

ACKNOWLEDGEMENTS

- **The following organizations generously provided data, modeling tools and/or feedback on preliminary study results and the authors of this report very much appreciate their efforts:**
    - ❖ Northwest Power and Conservation Council
    - ❖ ColumbiaGrid (and its members)
- **These organization have not, however, participated in the project and their role in providing data, tools, or review is not an endorsement or support of the project and/or its findings**
- **Additionally, the NW Energy Coalition and its partner organizations provided valued input in establishing the scope of the assessment and in reviewing the final results**

ENERGY STRATEGIES

THANK YOU

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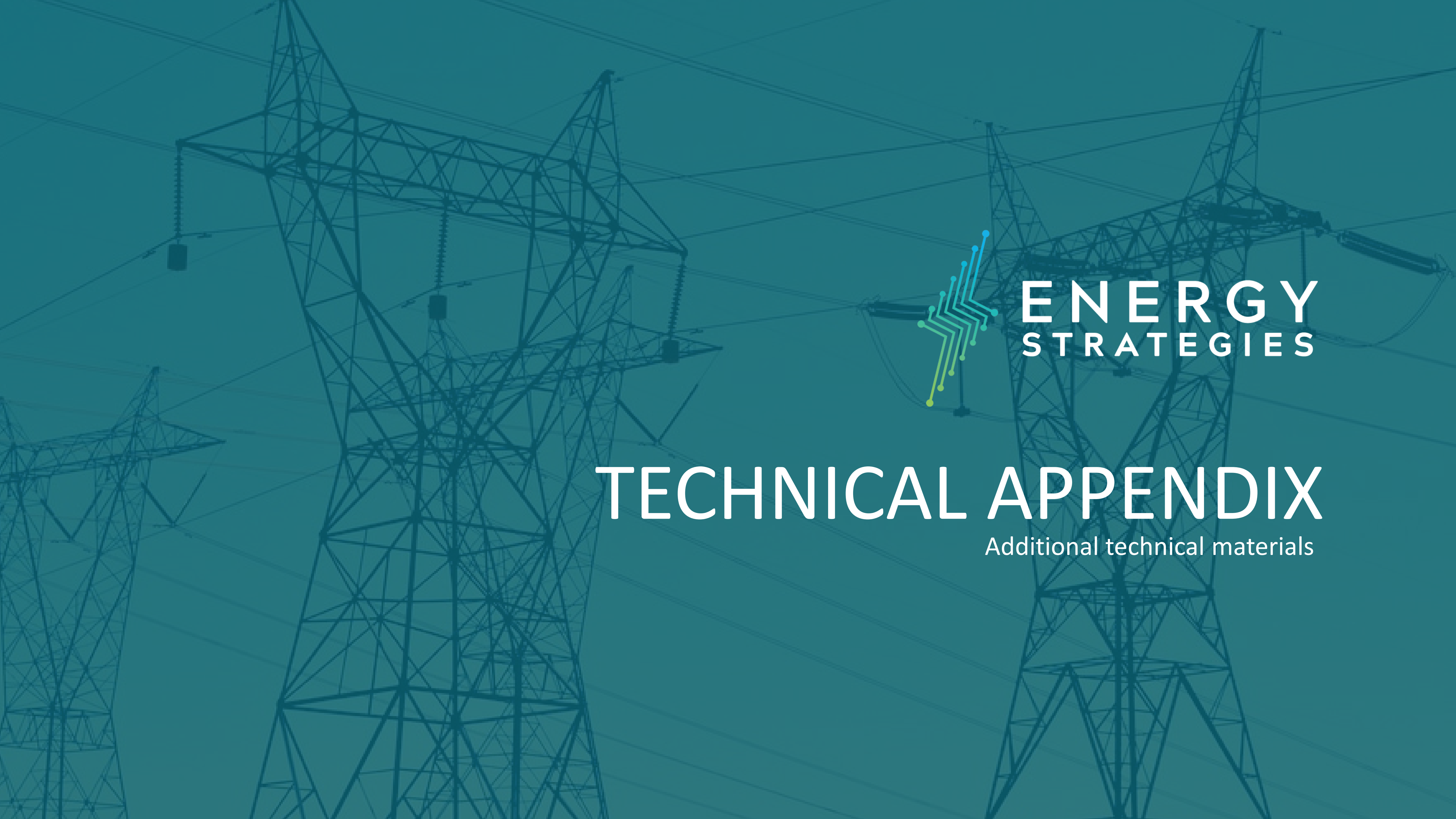


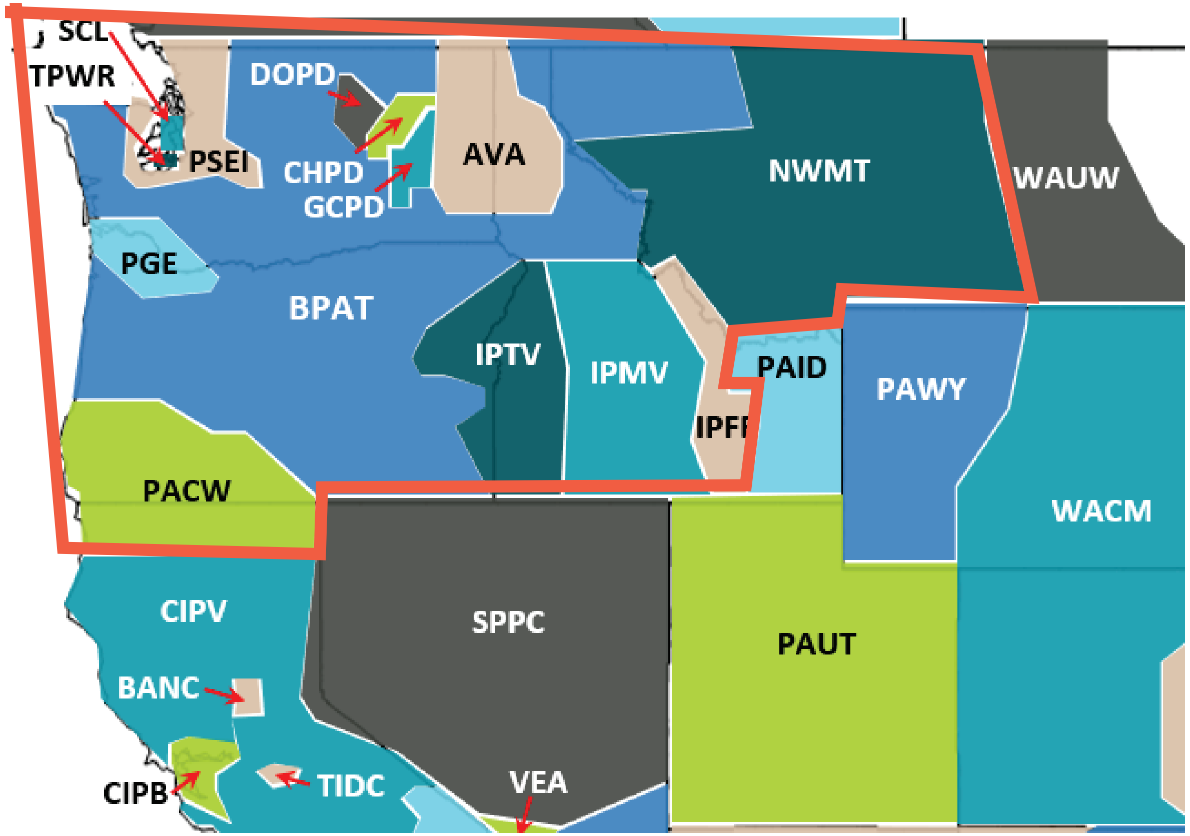
ENERGY STRATEGIES

TECHNICAL APPENDIX

Additional technical materials

STUDY AREA FOOTPRINT

NWPCC Balancing Authority Areas
AVA
BPAT
CHPD
DOPD
GCPD
IPFE
IPMV
IPTV
NWMT
PACW
PGE
PSEI
SCL
TPWR



RELIABILITY ANALYSIS KEY ASSUMPTIONS (CONT.)

Summer Case Dispatch/Flow Totals (MW) – Pacific Northwest Region

	Base Case	Reference Case	NGA	NGA Plus	Balanced	Balanced Plus	All Gas Scenario
LSR Hydro	2,291	1,497	-	-	-	-	-
Non-LSR Hydro	21,424	21,793	21,693	21,788	21,737	21,683	21,873
Thermal	5,892	6,212	6,212	5,672	7,022	5,334	6,682
Canada->NW	2,296	2,296	2,296	2,296	2,296	2,296	2,296
PDCI N->S Flow	1,240	1,240	1,240	1,240	1,240	1,240	1,240
COI N->S Flow	2,678	2,711	2,648	2,634	2,653	2,568	2,715
New Thermal	-	-	-	-	-	-	958
New DR	-	-	971	1,715	486	486	-
New EE	-	-	425	425	212	212	-
New Battery	-	-	100	100	-	-	-
New Wind	-	-	-	-	500	1,250	-
New Solar	-	-	-	-	250	750	-

RELIABILITY ANALYSIS KEY ASSUMPTIONS (CONT.)

Winter Case Dispatch/Flow Totals (MW) – Pacific Northwest Region

	Base Case	Reference Case	NGA	NGA Plus	Balanced	Balanced Plus	All Gas Scenario
LSR Hydro	3,080	1,590	-	-	-	-	-
Non-LSR Hydro	23,330	24,056	23,906	24,056	24,004	23,961	23,999
Thermal	8,580	7,920	7,920	7,027	7,920	6,949	8,090
Canada->NW	-1,506	-1,506	-1,506	-1,506	-1,506	-1,506	-1,506
PDCI N->S Flow	384	-	-	-	-	-	-
COI N->S Flow	1,043	313	210	197	98	40	-119
New Thermal	-	-	-	-	-	-	958
New DR	-	-	1,040	1,784	520	520	-
New EE	-	-	425	425	212	212	-
New Battery	-	-	100	100	-	-	-
New Wind	-	-	-	-	500	1,250	-
New Solar	-	-	-	-	250	750	-

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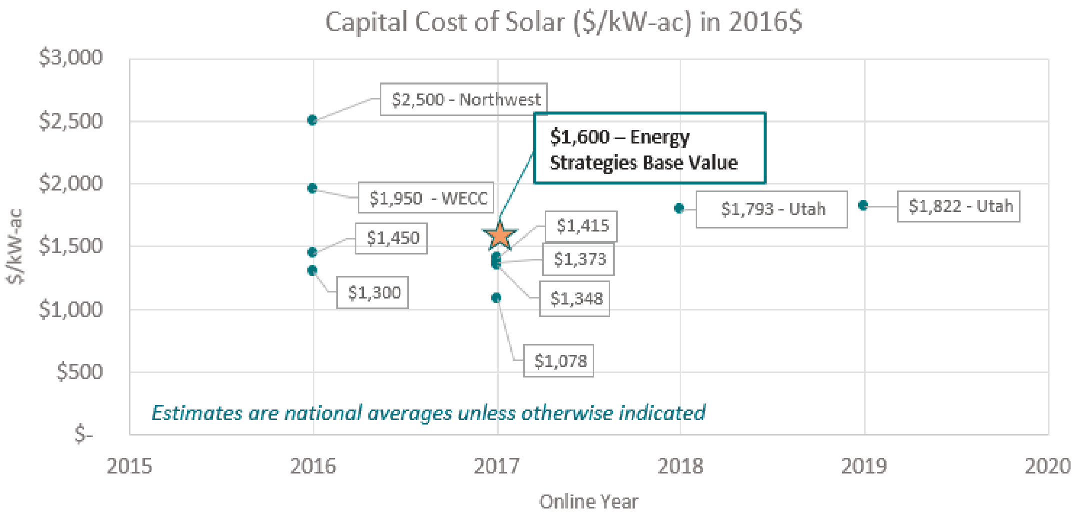
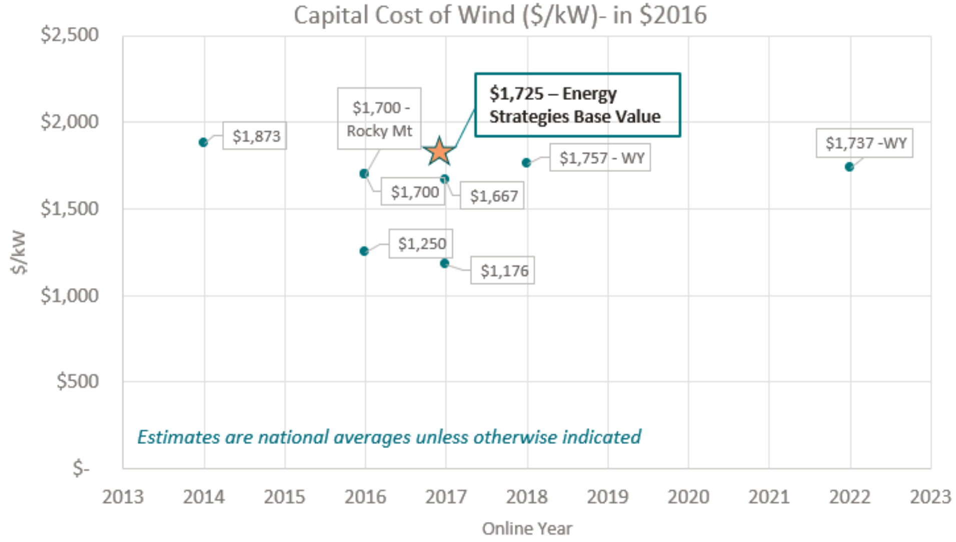
313 Export was felt to be realistic, dropping it to zero did not seem realistic, something should be flowing to the South even during the most stressed Winter day.

RESOURCE COST ASSUMPTIONS





Sources are documented in the report and include: National Renewable Energy Lab, Lawrence Berkeley National Lab, Lazard, E3, Black & Veatch, and Integrated Resources Portfolios such as PacifiCorp and Idaho Power. Cost estimates figures were all adjusted for 2016 dollars to match the parameters of the WECC proforma model.