Role of Hydropower to Meet Regional Needs

+ **Hydropower resources provide unique system benefits to support system needs in the region**

System Benefit	Hydropower Capabilities	Value Over Time
Capacity for Resource Adequacy	• Hydropower provides significant RA capacity through its maximum expected generation (CA) or sustained peaking capability (NW)	• RA will be ***highly valuable across the planning horizon***
Carbon Free Energy	• Hydropower's carbon-free energy comes at low-cost without any new transmission needs or development risk • Hydro energy also provides the financial benefit of avoiding natural gas fuel costs	• Carbon-free energy will be ***increasingly valuable*** to both CA and the NW as clean energy policy targets become more stringent
Reserves and Flexibility	• Hydro provides a zero-emissions source of ancillary services (spin, regulation, etc.) and ramping capabilities to integrate variable renewable energy • Flexibility may change as a function of time of year and water availability	• Renewable integration value will be ***increasingly valuable***, though batteries can provide some similar services
Other Essential Reliability Services (ERS)	• Hydro also provides key reliability services (reactive power, inertia, blackstart, etc.), including some that cannot currently be provided by asynchronous generators	• ERS will be ***increasingly valuable*** as other synchronous generators retire

Not calculated in RESOLVE but will be described qualitatively in project report

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An In/Out Modeling Approach Calculates Replacement Resources + Cost

+ **RESOLVE analysis will use in/out cases of the Lower Snake River Dams to determine the costs of replacement**

RESOLVE Run A **without** Lower Snake River Dams		RESOLVE Run B **with** Lower Snake River Dams		*NOTE: all cost results will be shown in real 2022 dollars.*
$ NPV A	-	$ NPV B	=	LSR Dam Replacement Cost
Resource Additions	-	Resource Additions	=	LSR Dam Replacement Resources

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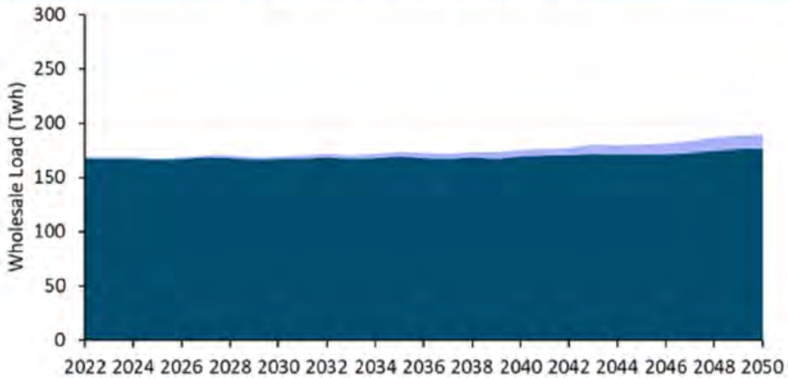
RESOLVE Scenarios

+ **Four core scenarios are based on two key variables:**
  - **Decarbonization policy**: impacts remaining electric sector emissions and electrification loads
    - **100% clean retail sales**: annual target for RPS + zero-carbon power vs. retail sales (allows emitting generation to cover losses and be offset by exports)
    - **0 MMT**: requires complete elimination of NW emitting generation or imports ("absolute zero" emissions)
  - **Technology availability**: impacts resources available to support reliability + policy goals
    - **Baseline**: includes mature technologies + new dual fuel (natural gas and H2) plants
    - **Emerging Tech**: baseline + gas w/ carbon capture and storage, offshore wind, and nuclear SMR
    - **Limited Tech:** baseline but excludes either 1) all new combustion plants, 2) no new natural gas plants but some new H2-only plants allowed

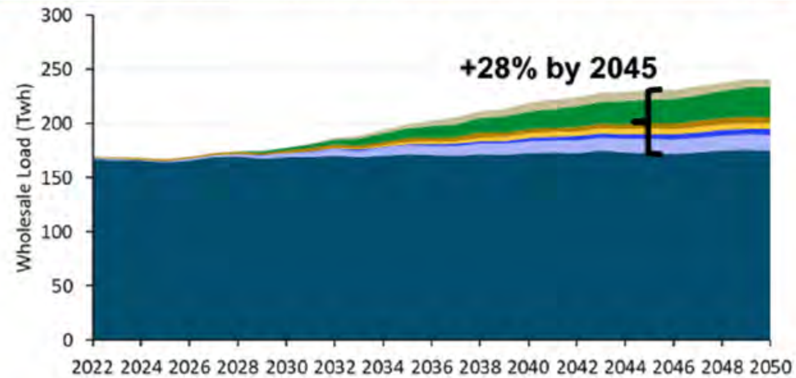
	Scenario Name	Loads	Clean Energy Policy	Technology Availability	Removal Year
0	No Policy Reference	Baseline	None	Baseline	2032
1	Baseline	Baseline	100% retail sales by 2045	Baseline	2032
1a	Baseline (no carbon price)	Baseline	100% retail sales by 2045	Baseline	2032
1b	*Baseline (early LSR removal)*	*Baseline*	*100% retail sales by 2045*	*Baseline*	2024
2	Deep Decarb	High Electrification	0 MMT by 2045	Baseline	2032
2a1	Deep Decarb – no new combustion	High Electrification	0 MMT by 2045	Limited Tech (no new combustion)	2032
2a2	Deep Decarb – no new gas, H2 allowed	High Electrification	0 MMT by 2045	Limited Tech (no new gas, H2 allowed)	2032
2b	Deep Decarb – emerging tech	High Electrification	0 MMT by 2045	Emerging Tech	2032

Electrification Load Growth (Annual GWh)

Base Forecast for Core NW



High Electrification Load Forecast for Core NW



Core NW Baseline | LDV | HDV | Residential SH | Residential non-SH | Commercial | Industrial

+ **Base load forecast is from NWPCC 2021 Plan benchmarked to E3's boundary of Core NW**
  - Includes EE+DR in the Power Plan + incremental selectable EE+DR

+ **High Electrification scenario takes Washington's State Energy Strategy high electrification load and then scales up and benchmarked to the Core NW**
  - Electrification grows across all sectors, most noticeably in commercial and transportation to meet state's net-zero emissions by 2050
  - Commercial and residential SH electrification indicates a switch to high electric resistance & heat pump adoption which will significantly impact load profiles and ultimately peak load

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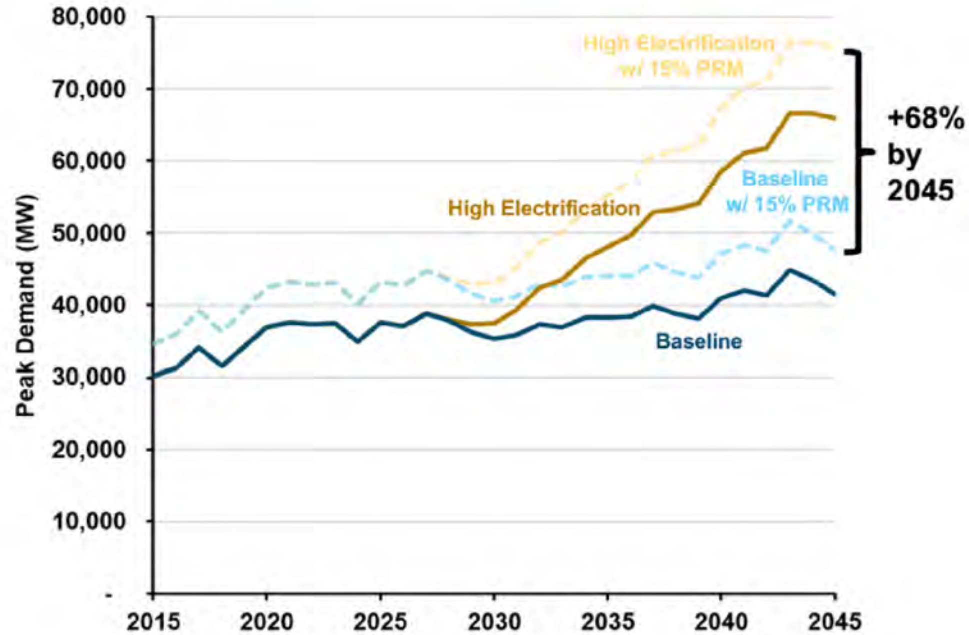
Electrification Load Growth (Peak Demand)

- **Peak demands increase higher than annual energy due to the winter "peak heat" challenge**
  - Heat pump efficiency declines as temperatures decrease
- **Peak electric demand growth is consistent with replacing peak NW gas needs with electric peaking capacity**
- **Peak demands could be lower with:**
  - Aggressive additional building shell retrofits
  - Replacement of electric resistance heating with cold-climate heat pumps
  - Less electric resistance heating (vs. assumed in the WA State Energy Strategy analysis)
  - Gas/electric hybrids heat pumps



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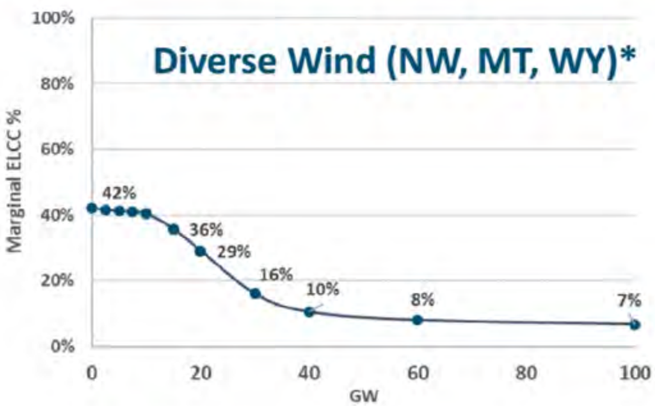
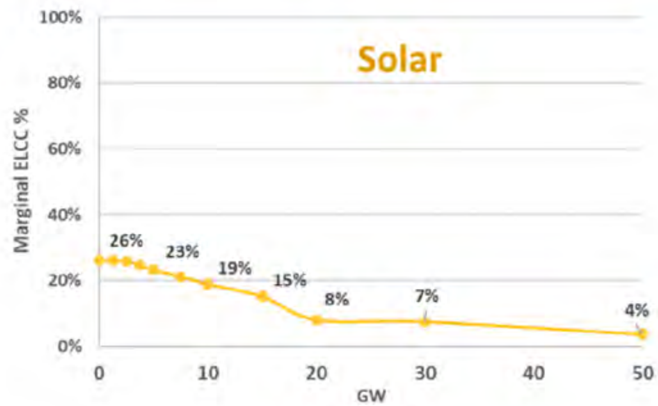
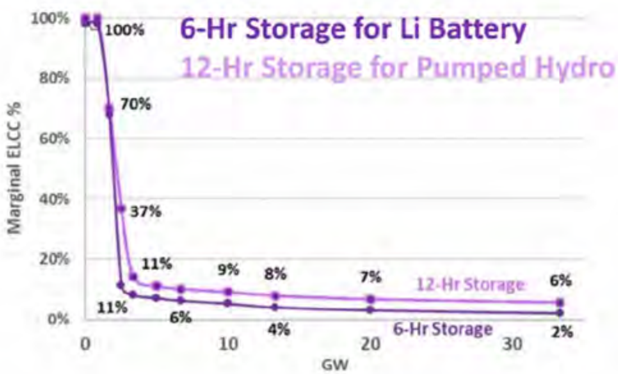
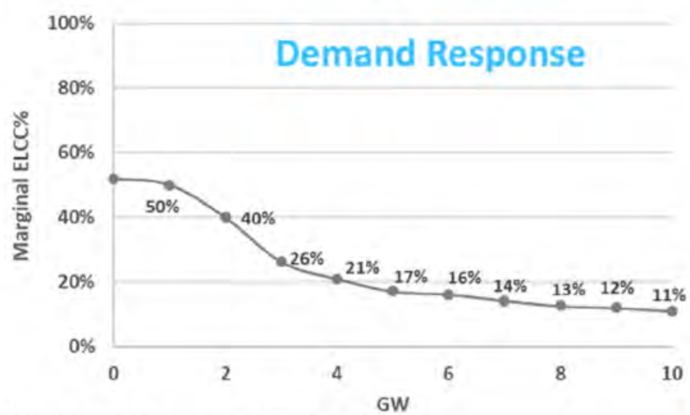
Incorporating Declining Capacity Contributions of Renewables, Storage, and DR









- A reliable electric system requires enough capacity to meet peak loads and contingencies
- This study incorporates information from E3's 2019 report *Resource Adequacy in the Northwest* about the effective capacity contribution of renewables, storage and DR at various penetration levels

* The offshore wind sensitivity in this study assumed the same ELCC curve as modeled for diverse on-shore wind resources in the Resource Adequacy in the Northwest report.

ELCC = Effective Load Carrying Capability = firm contribution to system peak load

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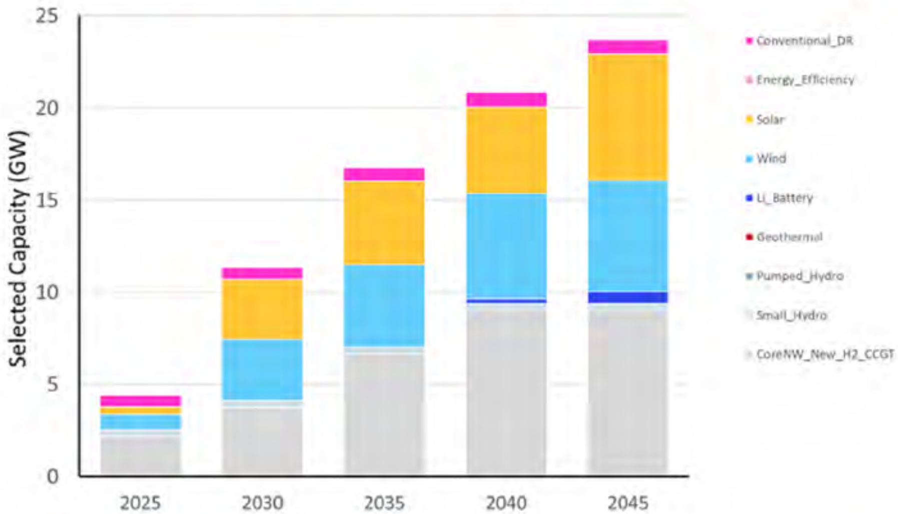
Summary of RESOLVE Results

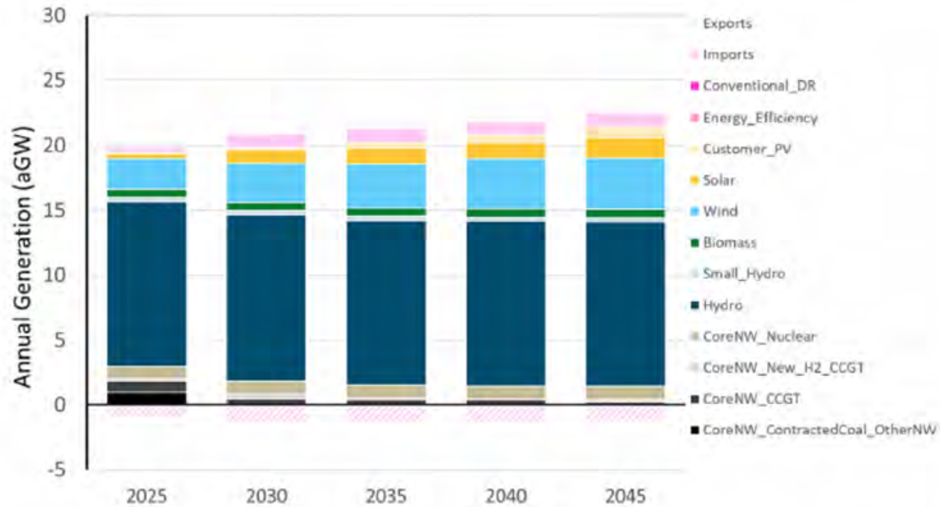
+ **Resource needs are primarily driven by resource adequacy needs**
  - Renewables, storage, and DR support RA needs but face declining ELCCs
  - "Clean firm" capacity is selected when available: new H2 plants, natural gas to H2 retrofits, and/or nuclear SMRs
+ **Coal retirement + carbon pricing drive ~7 GW of solar and wind additions by 2030, which reduce GHG emissions and push the region to a >100% clean retail sales**
  - However, under a 100% clean as % of retail sales definition, some GHG emissions are allowed to remain
+ **Deep decarbonization scenarios require significantly more resources to meet peak and energy needs**
  - High electrification peak impacts drive very large additional RA needs to replace gas system winter peak heat provision at a high cost to the electric system
+ **Reaching a zero-emissions electric system with high electrification and reasonable levels of renewable additions requires new technologies such as hydrogen combustion turbines or nuclear SMRs**
  - If nuclear SMRs become viable, they are likely to provide significant GHG-free energy by 2035-2045
  - Otherwise, additional renewables backed by dispatchable hydrogen plants are needed

S1: Baseline – 100% Clean Retail Sales

With Carbon Price

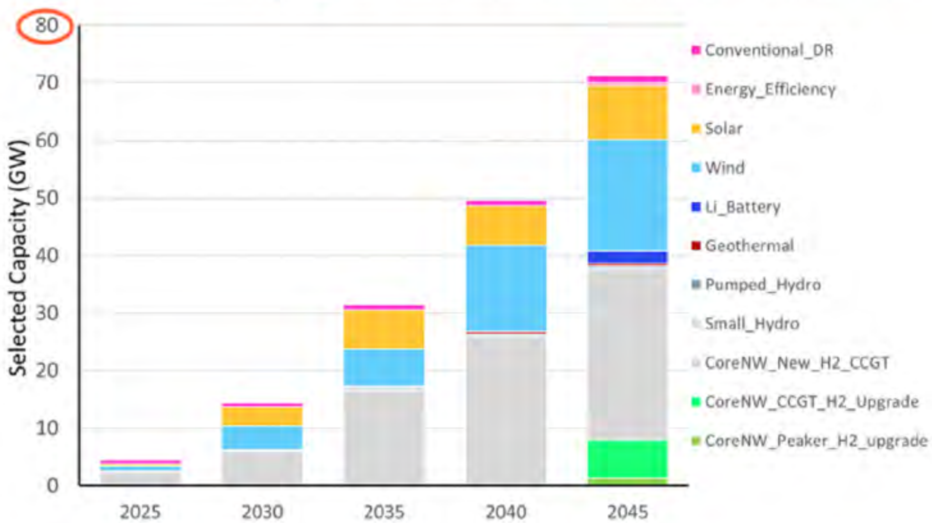
+ **With a 100% Clean Retail Sales requirement by 2045, forced coal retirements, and a carbon price, resource adequacy is the most binding constraint, followed by CES**
  - New build of dual fuel plants (gas + H_2) needed to provide reliability; these plants burn gas first, then H2 in 2045
  - Region reaches near-100% clean retail sales by 2025 then exceeds 100% with carbon price driving more solar + wind
    - However, GHG emissions still remain in 2045 per retail sales interpretation of policy (i.e. for line losses + exported clean energy)
  - Core NW continues to be a net exporter through 2045

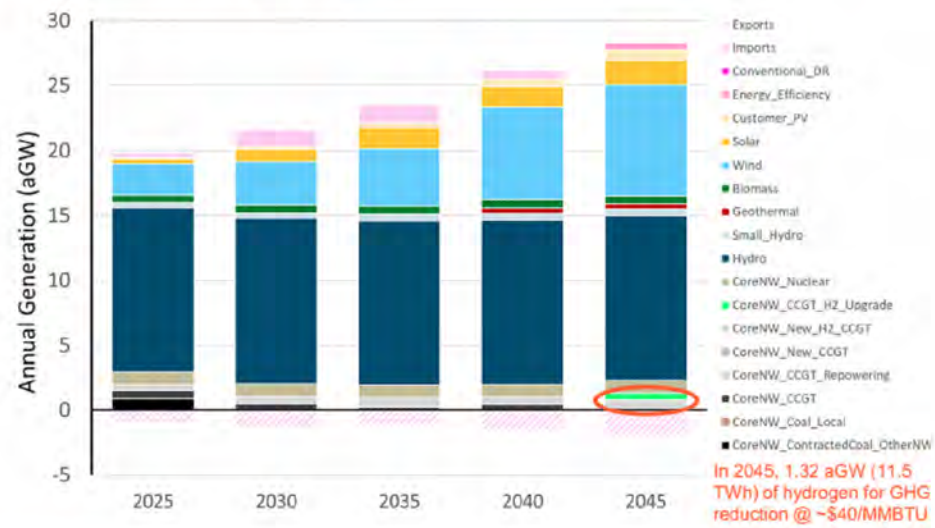




S2: Deep Decarbonization

+ **With a 0 MMT GHG target by 2045 and higher energy + peak loads, both resource adequacy and GHG reduction drive incremental resource needs**
  - Much higher build of new resources (e.g. ~70 GW in 2045 vs. ~23 GW in 100% clean w/ baseline load scenario)
  - Existing gas plants are forced to stop burning gas in 2045 and are retrofitted to combust H_2
  - Additionally, new dual fuel (H2 + gas) plant is still selected, with fuel switching to entirely H2 in these plants by 2045
    - Hydrogen combustion required to meet zero emissions on low renewables/low hydro days





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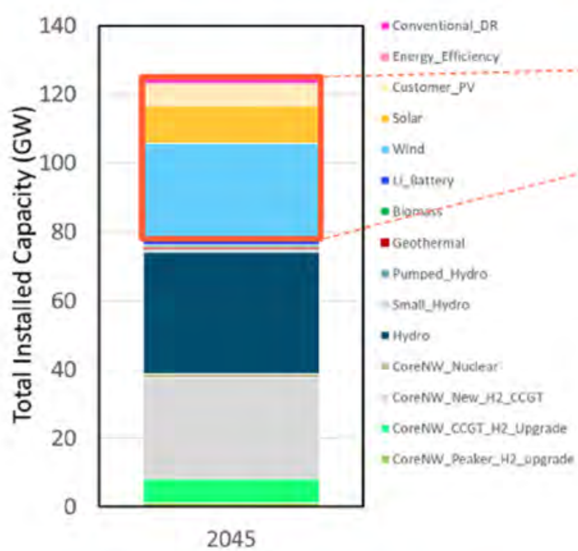
S2: Deep Decarbonization – Resource Adequacy Needs

Solar, wind, batteries, and DR provide limited resource adequacy value in the Northwest, requiring "clean firm" capacity backup

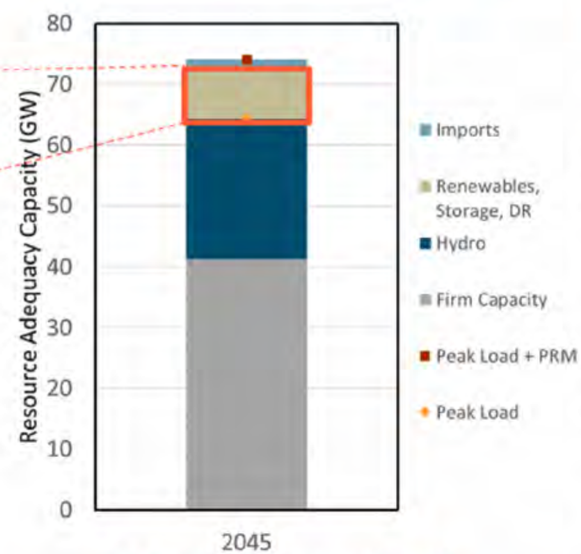
2045 Deep Decarbonization Scenario Results

Installed Nameplate Capacity (GW)



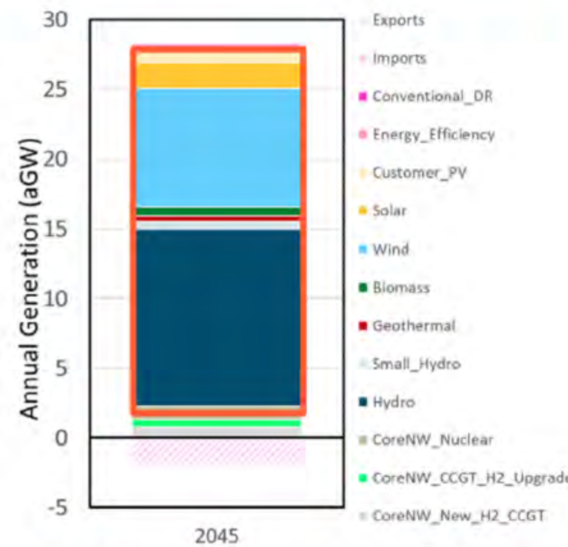
Renewables, storage, and DR provide significant installed MW...

Resource Adequacy Capacity (GW)



... but declining ELCCs mean their RA contributions become limited, requiring "clean firm" capacity backup (hydrogen in this case)...

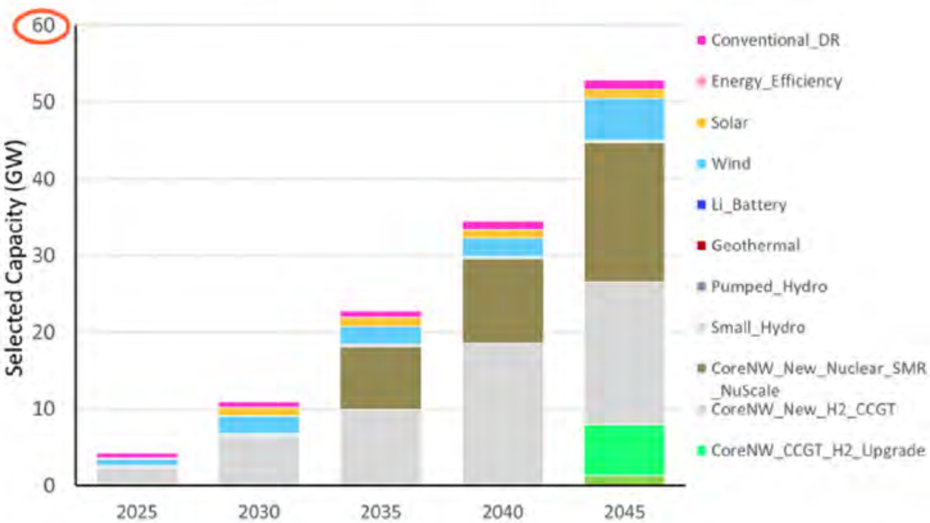
Annual Generation (TWh)

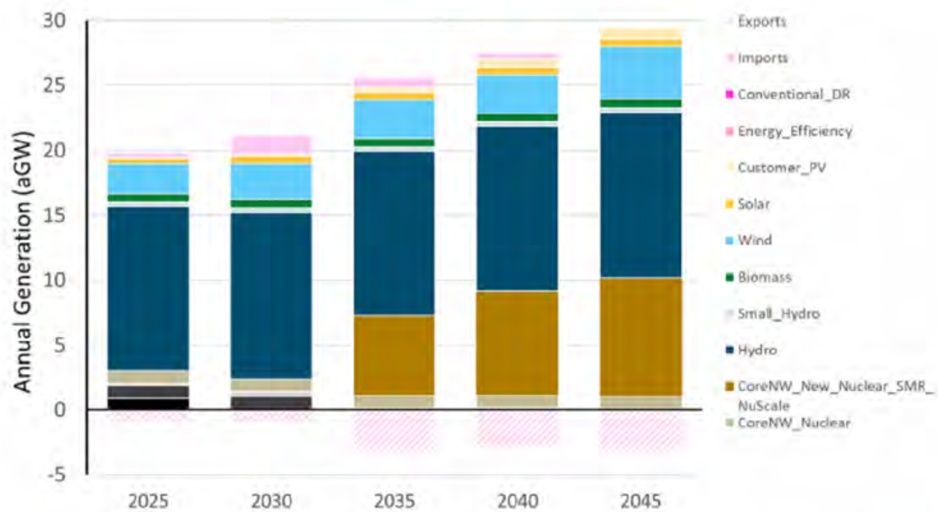


...due to high costs, hydrogen generation is limited to low hydro, low renewable periods; renewables + hydro + nuclear provide 95% of annual energy

S2b: Deep Decarbonization – Emerging Technology

+ **With nuclear SMR available, renewable energy build is minimized**
  - Lower build of new resources (~50 GW in 2045 vs. ~70 GW in the S2 Deep Decarb case)
  - Large buildout of nuclear SMR and new + retrofitted hydrogen plants provide RA capacity needs
  - Nuclear SMR provides zero-carbon energy for Northwest and results in increased exports to other regions
    - No expensive hydrogen generation is required to meet zero emissions goal on modeled RESOLVE days





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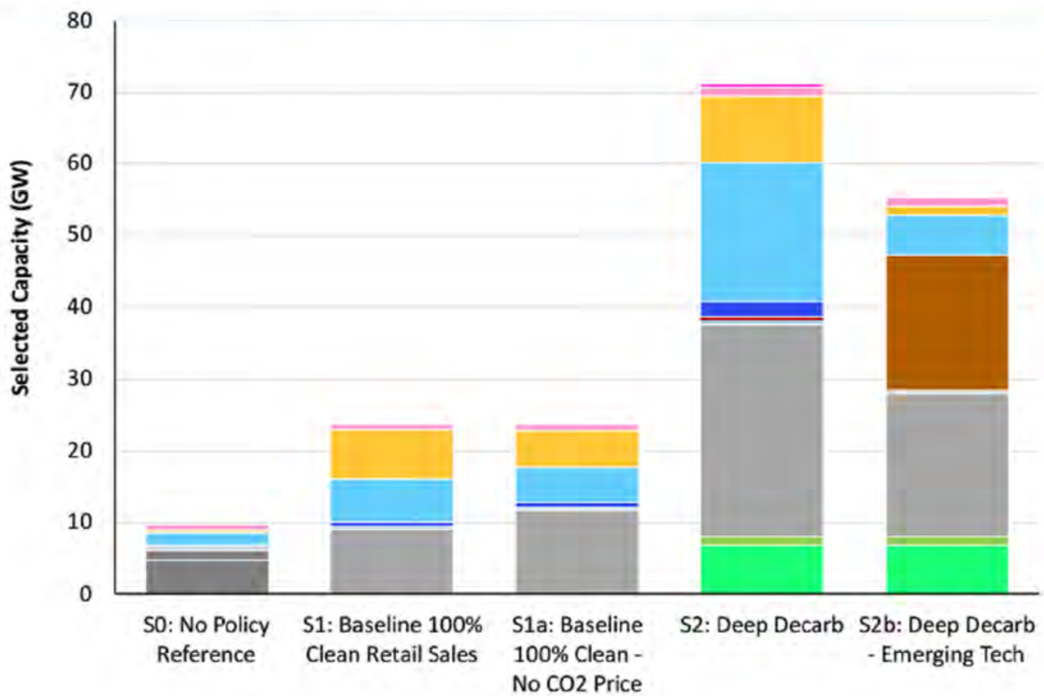
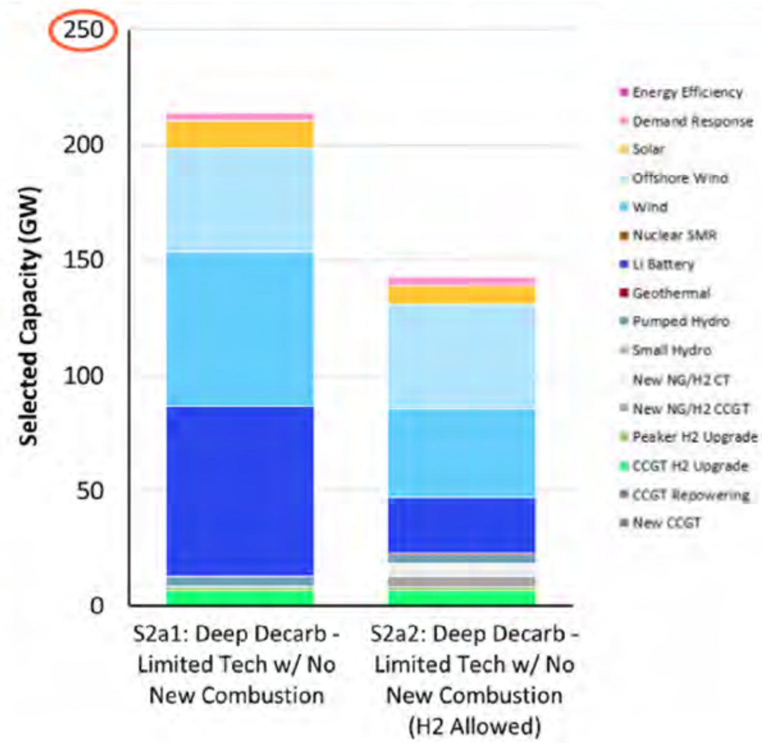
Comparison of 2045 Cumulative Selected Capacity

Baseline and Emerging Technology Scenarios



Limited Technology Scenarios



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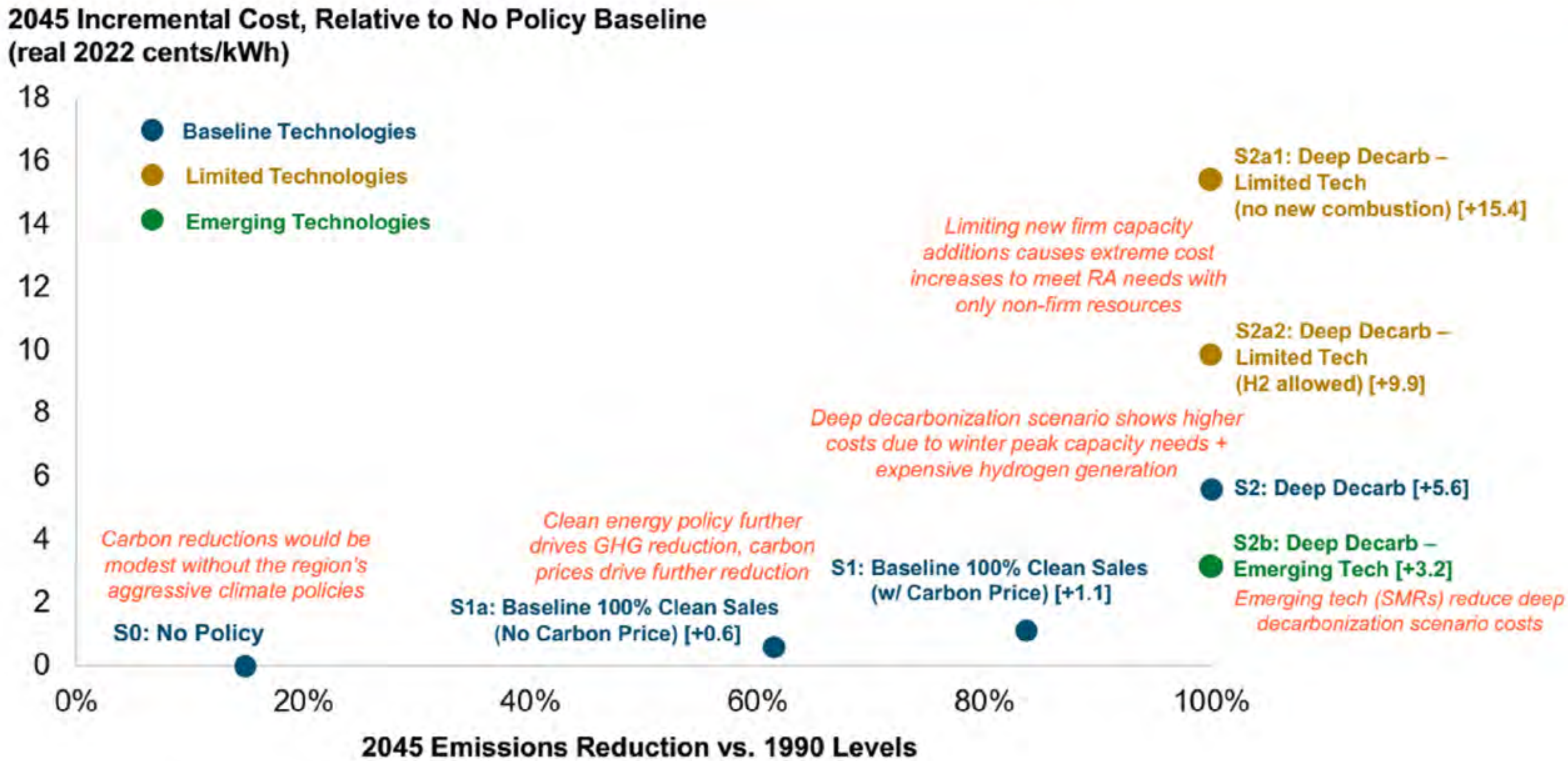
Decarbonization Scenarios Cost Impacts



NOTES:
- 2020 average retail rates for OR and WA were 8-9 cents/kWh; 1990 electric emissions were ~33 MMT
- High electrification scenarios would avoid natural gas infrastructure costs, which would offset some of the electric peaking infrastructure cost increase

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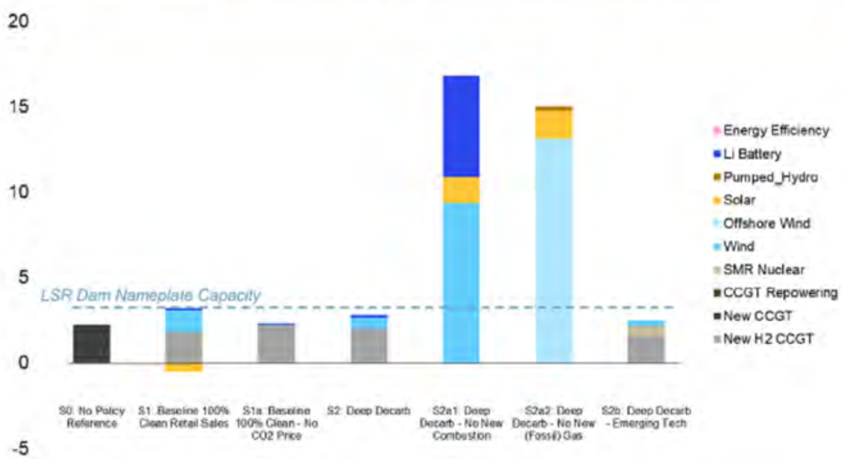
Summary of No LSR Dam RESOLVE Analysis

		2035		2045		
	NPV Increase ($M NPV)	Cost Increase (real 2022 $M)	Resource Needs (GW)	Cost Increase (real 2022 $M)	Resource Needs (GW)	Notes
S0: No Policy Reference	**$2,992**	$452	+ 2.3 GW NG CCGT + 0.2 GW wind	$415	+ 2.1 GW NG CCGT + 0.5 GW wind	Replacement costs driven by RA needs and energy redispatch
S1: 100% Clean Retail Sales	**$3,264**	$433	+ 1.8 GW NG/H2 CCGT - 0.5 GW solar + 1.3 GW wind + 0.1 GW li-ion battery	$478	+ 2.1 GW NG/H2 CCGT + 0.5 GW wind	Replacement costs slightly higher than no policy, but increase is limited since CES is not binding
S1a: 100% Clean Retail Sales (no carbon price)	**$3,102**	$444	+ 2.2 GW NG/H2 CCGT + 0.1 GW li-ion battery	$450	+ 1.9 GW NG/H2 CCGT + 2.2 GW solar + 0.8 GW wind	CES binds, increasing 2045 solar + wind replacement, but offset by lower avoided carbon cost
S2: Deep Decarb	**$5,662**	$490	+ 2 GW NG/H2 CCGT + 0.6 GW wind + 0.2 GW li-ion battery	$1,055	+ 2.1 GW NG/H2 CCGT + 1.5 GW li-ion battery + 0.01 GW energy efficiency + 1.8 TWh hydrogen gen	Replacement costs increases due to 2045 GHG-free energy replacement w/ expensive H2 generation
S2a1: Deep Decarb, Limited Tech (no new combustion)	**$21,879**	$2,591	+ 9.4 GW wind + 1.5 GW solar + 0.01 GW energy efficiency + 0.3 GW pumped hydro + 6 GW li-ion battery	$3,279	+ 6.7 GW wind + 1 GW solar + 0.01 GW energy efficiency + 10 GW li-ion battery	Meeting high electrification RA needs without firm capacity available drives extremely high replacement cost
S2a2: Deep Decarb, Limited Tech (no new gas, H2 allowed)	**$17,223**	$2,293	+ 13 GW offshore wind + 1.6 GW solar + 0.01 GW energy efficiency + 0.3 GW li-ion battery	$2,617	+ 10.9 GW wind + 1.4 GW solar	Meeting high electrification RA needs without firm capacity available drives extremely high replacement cost… reduced slightly by 10 GW of new H2 only-gas allowed
S2b: Deep Decarb, w/ Emerging Tech	**$2,909**	$407	+ 1.5 GW NG/H2 CCGT + 0.6 GW nuclear SMR + 0.6 GW wind	$429	+ 1.4 GW NG/H2 CCGT + 0.7 GW nuclear SMR + 0.7 GW wind	Replacement costs reduced with low-cost nuclear SMR available

Cost increases account for replacement energy, capacity, and reserves as well as avoided LSR capital + expense, but do not include any costs for breaching the dams, which would be an additional cost.

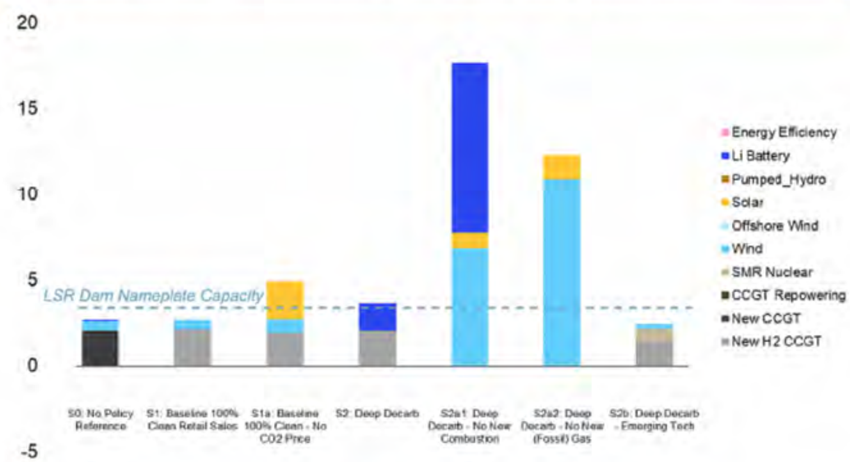
Replacement Resource Needs

LSR Dam Replacement Portfolio in 2035 (GW)



+ **2035 replacement is driven by resource adequacy needs**
  - Firm gas, H2, or nuclear provide replacement RA capacity
  - Scenarios without firm capacity require RA to be replaced by very large amounts of wind, solar, and batteries

LSR Dam Replacement Portfolio in 2045 (GW)



+ **2045 replacement is driven by both resource adequacy and clean energy needs**
  - Firm gas, H2, or nuclear provide replacement RA capacity; additional solar, wind, nuclear, and/or hydrogen generation replace clean energy output
  - Scenarios without firm capacity require RA to be replaced by very large amounts of wind, solar, and batteries

Replacement Resource Costs

+ **Replacing the Lower Snake River dams' energy and firm capacity results in significant costs**
  - LSR dams generation costs are $17/MWh, while 2045 replacement resources cost ~$85-190/MWh
+ **BPA customer costs would increase by ~0.7-1.8 cents/kWh**
  - An increase of ~20-50% compared to current estimated BPA generation rate of 3.5 cents/kWh
+ **Limited technology cases drive extreme replacement costs due to very high capacity value in these scenarios**

Incremental LSR Dam Replacement Resource Costs

Lower Snake River Dams All-in Generation Costs (2022 $/MWh)	Current BPA Generation Rate (cent/kWh)
$17/MWh	3.5 cent/kWh

Scenario	2045 Costs to replace LSR Generation* (real 2022 $/MWh)	2045 Incremental Tier I BPA Customer Costs** (real 2022 cents/kWh)
S0: No Policy Reference	$85/MWh	+ 0.7 cents/kwh
S1: 100% Clean Retail Sales	$95/MWh	+ 0.8 cents/kwh
S1a: 100% Clean Retail Sales (no carbon price)	$90/MWh	+ 0.8 cents/kwh
S2: Deep Decarb	$189/MWh	+ 1.8 cents/kwh
S2b: Deep Decarb, w/ Emerging Tech	$87/MWh	+ 0.7 cents/kwh
Outlier cases:		
S2a1: Deep Decarb, Limited Tech (no new combustion)	$535/MWh	+ 5.6 cents/kwh
S2a2: Deep Decarb, Limited Tech (no new gas, H2 allowed)	$427/MWh	+ 4.5 cents/kwh

* Replacement $/MWh costs are calculated as CoreNW revenue requirement increase with LSR dams removed divided by the annual MWh of the LSR dams. These costs includes replacement of the LSR dam energy, capacity, and reserve provision. A significant portion of the costs is capacity costs to replace the dams' RA capacity contributions.

** Incremental BPA customers costs calculated as the incremental annual revenue requirement divided by BPA's Tier 1 annual sales (~58,686 GWh/yr per FY2022 BPA forecast)

Next steps

- Update slides w/ final RESOLVE runs
- May 6 meeting to brief w/ DOE staff
- Final (word) project report by June 1

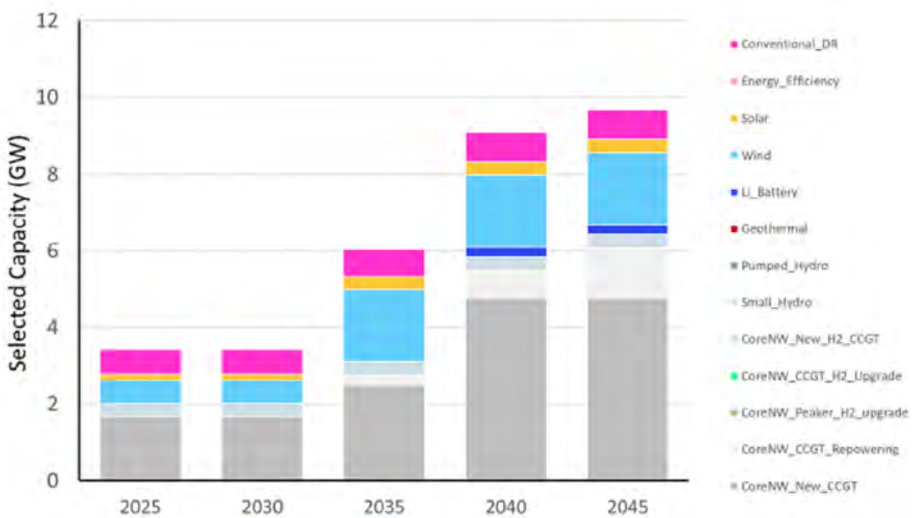
Energy+Environmental Economics

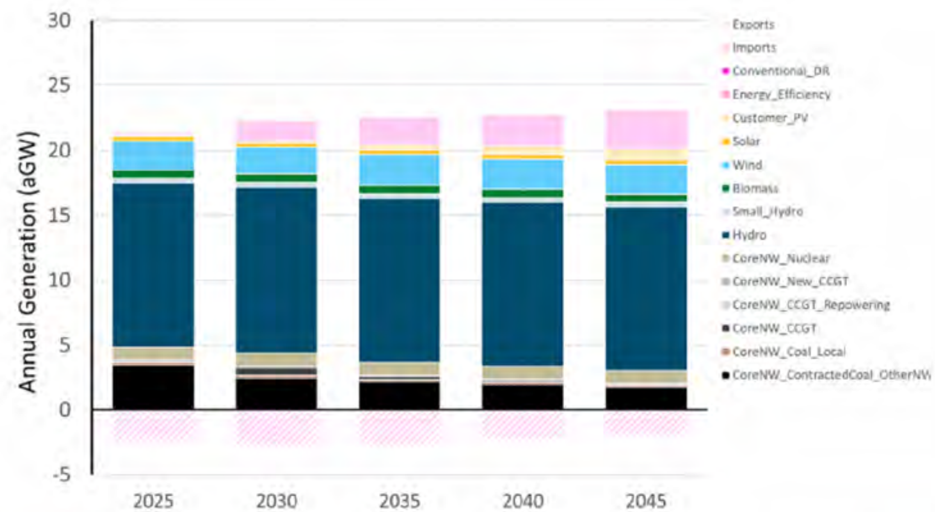
Appendix

S0: No Policy Reference

+ Without policy constraints, economics are the key driver of new resource needs

- Incremental RA need is met with DR and renewables, but is generally limited without forced coal retirements
- Coal and gas are allowed to remain online through 2045; coal remains online in 2045 to provide energy and capacity even with economic retirements allowed
- Core NW is a net exporter until 2040





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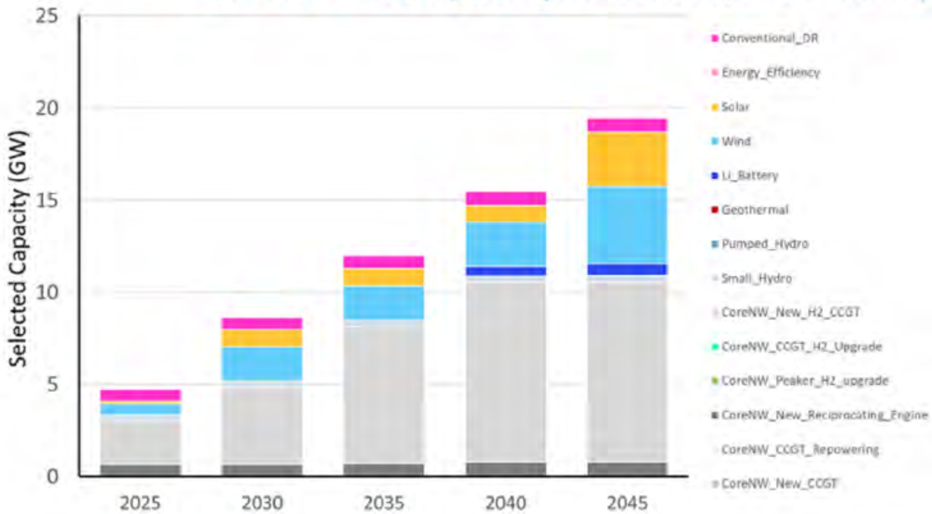
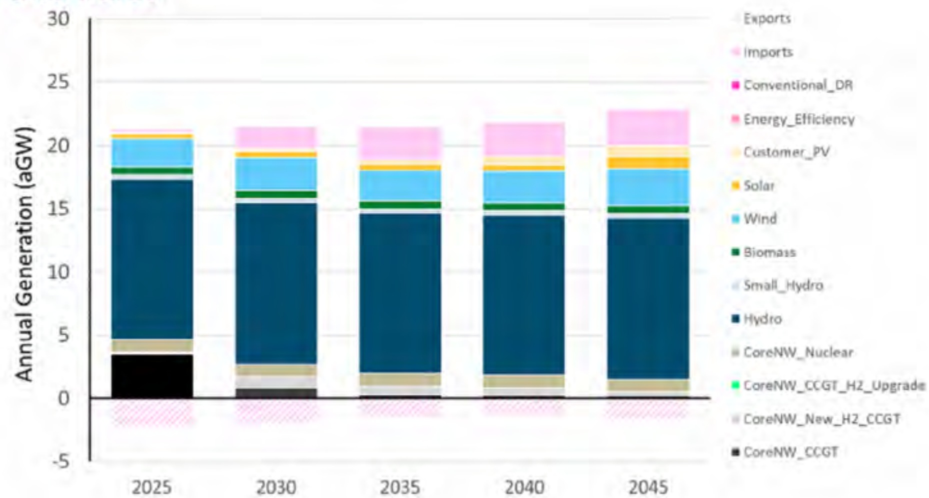
S1a: Baseline – 100% Clean Retail Sales

Without Carbon Price

+ **With a 100% Clean Retail Sales requirement by 2045, forced coal retirements, both resource adequacy and the 100% clean target drive resource needs**
  - New build of dual fuel plants (gas + H_2) are needed to provide reliability. These plants can burn gas until emissions constraints become binding, and then can switch to using H_2
  - With no carbon price, there is less solar + wind added across the planning horizon
    – GHG emissions remain per retail sales definition (i.e., for line losses + exported clean energy)
  - Core NW is net exporter prior to 2035, and a net importer afterwards





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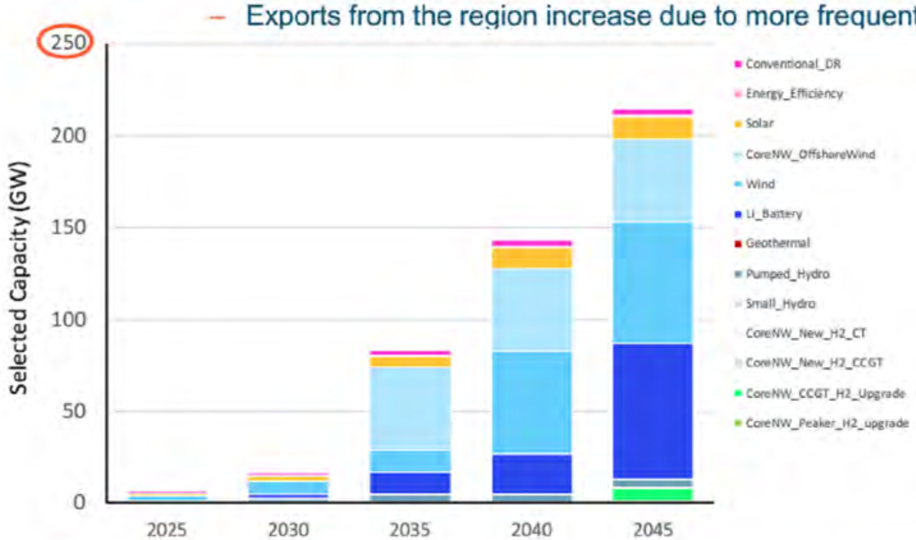
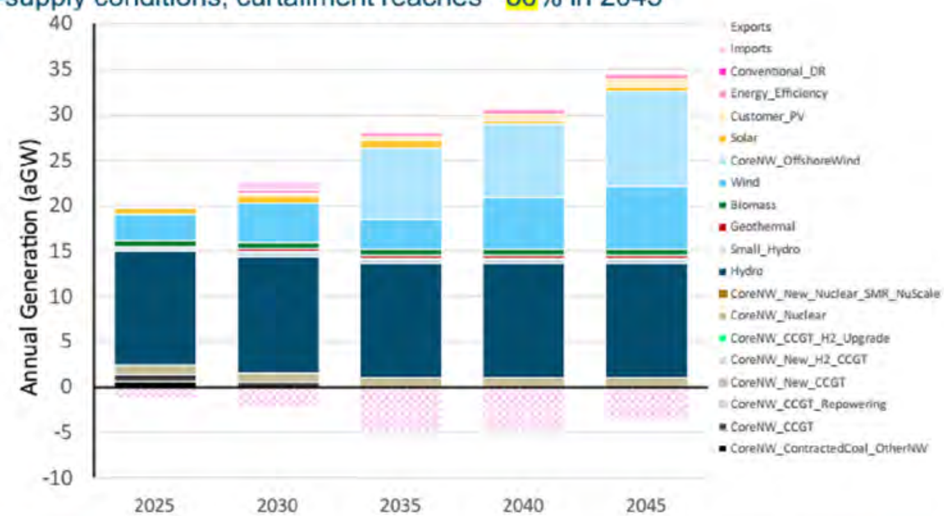
S2a1: Deep Decarbonization – Limited Tech w/ No New Combustion

- **Without new natural gas or H2 combustion turbines to meet growing resource adequacy needs, a large overbuild of onshore wind, offshore wind, and battery storage are selected**
  - Even higher build of new resources (~215 GW in 2045 vs. ~70 GW in the S2 Deep Decarb case)
  - Existing gas plants are forced to stop burning gas in 2045 and are retrofitted to combust H_2
  - Onshore wind, offshore wind, and battery storage are selected over additional solar since wind and storage are slightly more efficient at providing incremental RA
    - Exports from the region increase due to more frequent over-supply conditions, curtailment reaches ~60% in 2045





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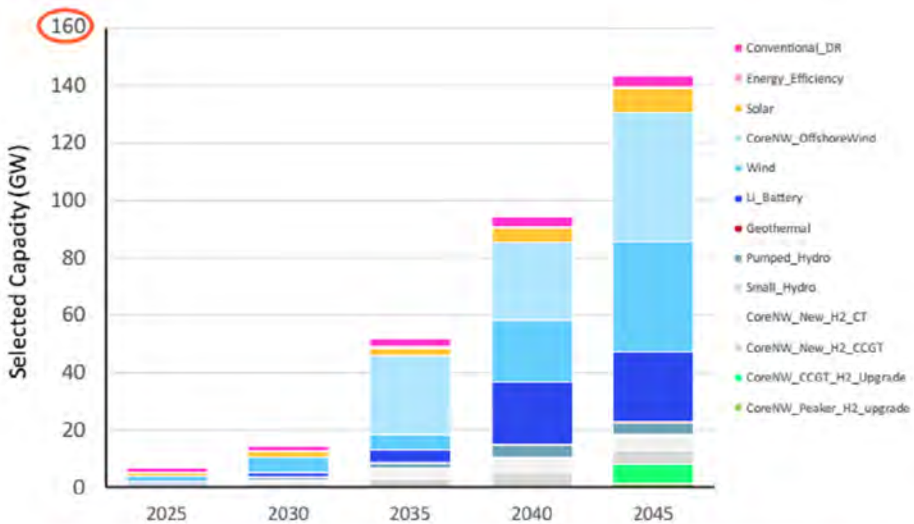
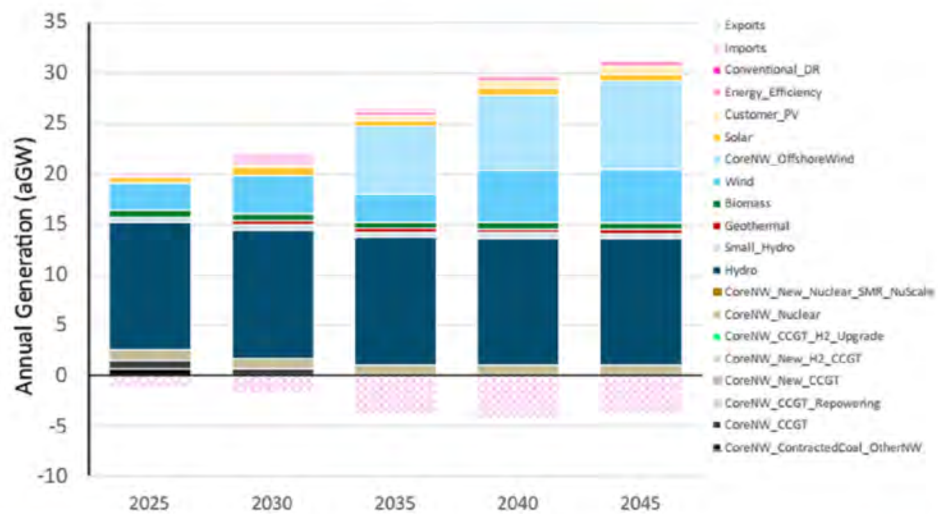
S2a2: Deep Decarbonization – Limited Tech w/ No New Gas (H_2 Allowed)

- **With 10 GW of new H_2 combustion turbines available, a combination of new H_2 turbines and onshore wind, offshore wind, and battery storage overbuild are selected to meet resource adequacy needs**
  - Very high build of new resources (~143 GW in 2045 vs. ~70 GW in the S2 Deep Decarb case)
  - Allowing 10 GW of new H_2 in 2045 helps bring down new resource build from ~215 GW (in S2a1) to ~143 GW





LSR dams annually save 0-2 MMT of CO2 emissions

Core NW million metric tons (MMT) of CO_2 emissions difference in cases with LSR and after LSR removal in 2032

Year	No Policy Reference	Baseline	Baseline (no carbon price)	Deep Decarb	Deep Decarb – limited tech (no new combustion)	Deep Decarb – limited tech (no new gas, H2 allowed)	S2b - Deep Decarb - emerging tech
2035	2.0	1.5	0.3	0.7	-	(0.3)	(0.0)
2040	1.7	(0.1)	0.6	-	-	-	-
2045	1.7	(0.1)	0.6	-	-	-	-

Final results will include additional GHG emissions analysis

Hydropower provides direct and indirect grid benefits

Grid Benefit	Captured in RESOLVE
Energy (MW)	☑
Instantaneous and Sustained Capacity (MW)	☑
Reserve Carrying Capability (MW)	☑
Fast Ramping	☑
Voltage and Reactive Support	☒
Frequency and Inertial Response	☒
Blackstart Capability	☒
Short-Circuit and Grounding Contribution	☒
Voltage and Frequency Excursion Ride-Through	☒
Participation in Remedial Action Schemes	☒

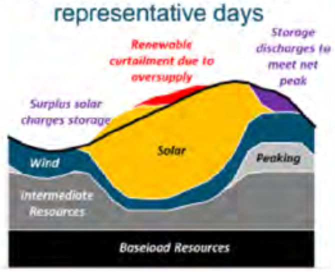
+ **Hydroelectric generation produces additional benefits not directly captured in E3's RESOLVE model**
  - Those benefits are described qualitatively in these slides
+ **Most ancillary benefits can be provided by any turbine-based generation resources …**
  - However, hydropower supplies benefits without the emissions cost of conventional thermal resources
  - Hydropower is uniquely suited to overhead-dependent grid services like dynamic reactive power support
+ **Hydropower's ancillary benefits are a key contributor to the stability and reliability of the region**

RESOLVE: Optimal Capacity Expansion Under Aggressive Clean Energy Goals

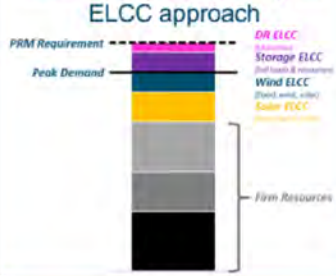
+ RESOLVE is a linear optimization model explicitly tailored to the study of electricity systems with high renewable & clean energy policy goals

+ 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

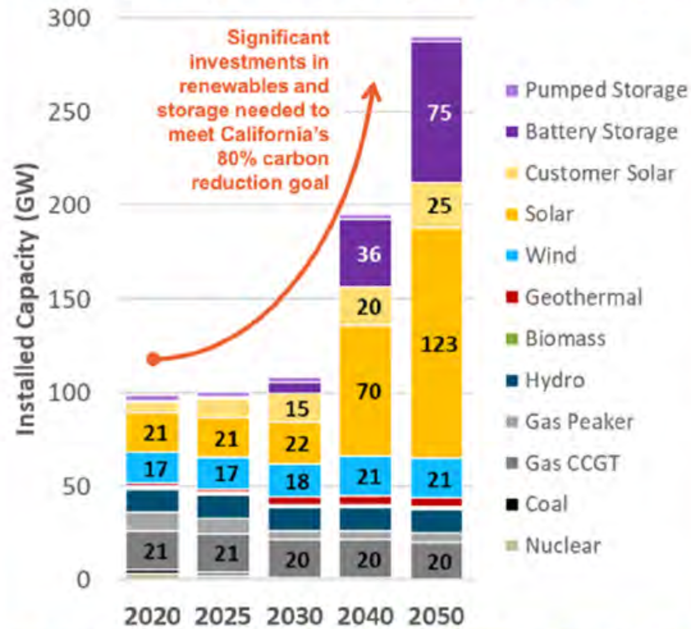
Operational module simulates hourly system operations for a sample of representative days



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



Least-cost plan cooptimizes 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)

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RESOLVE Co-optimizes Investment and Operational Decisions

+ **RESOLVE allows portfolio optimization across a long-time horizon (20-30 years)**
  - Investments made in multiple periods
+ **Operational detail directly informs investment decisions to economically address primary drivers of renewable integration challenges**
+ **Fixed costs capture capital, financing, and fixed O&M associated with new infrastructure and economically retiring resources**
+ **Optimization is constrained by many factors, including:**
  - Hourly load
  - RPS target
  - Planning reserve margin
  - GHG limit

RESOLVE Objective Function

+ **Fixed Costs of New Resources**
  + Generation (thermal, hydro, renewables)
  + Energy storage
  + Demand response
  + Energy efficiency
+ **Fixed Costs of New Transmission**
+ **System Operating Costs**
  + Fixed & variable O&M
  + Start costs
  + Fuel costs
  + Carbon
  + Hurdles

Technology Availability

Technology Scenarios

	Baseline	Emerging Tech	Limited Tech* (No New Gas)	Limited Tech* (No New Combustion)
Solar	Available	Available	Available	Available
Wind	Available	Available	Available	Available
Battery storage	Available	Available	Available	Available
Pumped storage	Available	Available	Available	Available
Demand Response	Available	Available	Available	Available
Energy Efficiency	Available	Available	Available	Available
Small Hydro	Available	Available	Available	Available
Geothermal	Available	Available	Available	Available
Offshore wind (floating)	Unavailable	Available	Available	Available
Natural gas to H2 retrofits	Available	Available	Available	Available
New duel fuel natural gas + H2 plants	Available	Available	Unavailable	Unavailable
New H2 only plants	Unavailable	Unavailable	Available	Unavailable
Gas w/ 90-100% carbon capture + storage	Unavailable	Available	Unavailable	Unavailable
Nuclear Small Modular Reactors	Unavailable	Available	Unavailable	Unavailable

Unavailable | Available

* Limited tech scenarios consider scenarios of no new gas plants and no emerging technologies. For these scenarios to be feasible, additional renewable capacity on new transmission lines was made available.

+ Mature Technologies

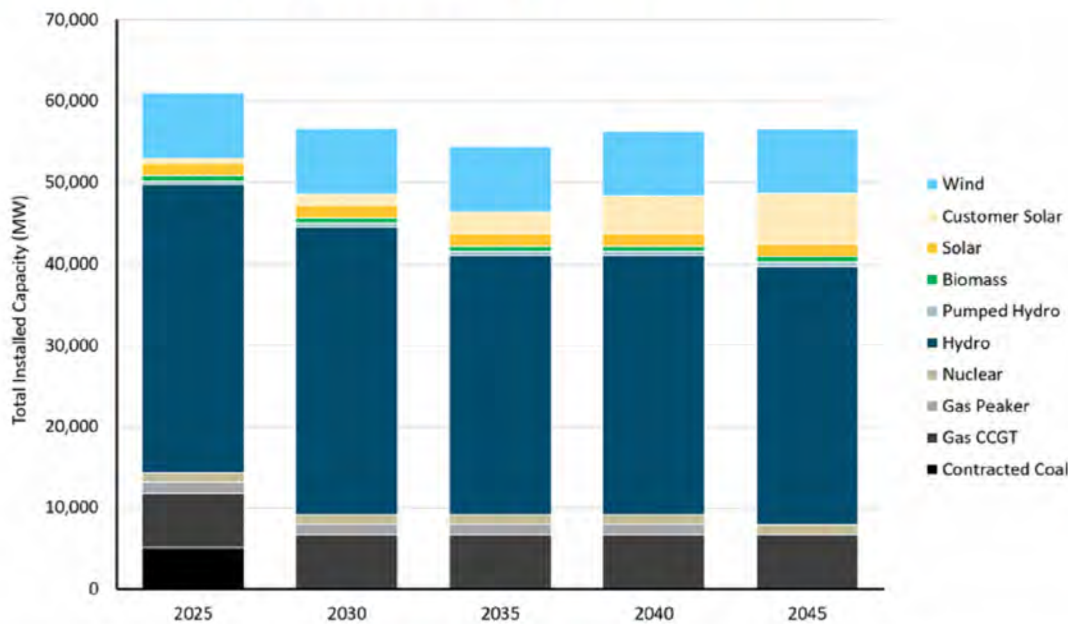
- Renewables provide low-cost form of zero-carbon energy w/ limited capacity value
  - Solar, wind (onshore)
- Storage resources support renewable integration but show limited value in the Northwest with the large hydro fleet
  - Battery storage, pumped hydro
- Demand response supports peak reduction but faces same ELCC decline as batteries; energy efficiency supports energy reduction but increasingly competes against low-cost renewables
- Geothermal is expensive and limited but provides "clean firm" capacity
- Small hydro potential is very limited

+ Emerging technologies

- "Clean peakers" such as new H2, new NG+H2, or NG→H2 retrofits provide low-cost form of capacity with very high energy cost (when burning hydrogen)
- Gas w/ CCS provides a moderately high cost source of energy and capacity
- Nuclear SMR provides moderately high capital cost but low operating cost source of firm zero-carbon energy
- Floating offshore wind can address onshore resource / land constraints, but is generally higher cost than onshore wind for same capacity factor

Baseline Resources

+ **Baseline resources are the same across most* scenarios**
  - Includes limited amount of near-term planned additions, continued customer PV growth, and planned/mandated coal retirements
  - Result slides show incremental capacity additions on top of this baseline



* This baseline used in S1 and S2 scenarios. No policy case does not force coal retirements as shown here per WA+OR law. No LSR cases have 3.4 GW of LSR hydro removed.

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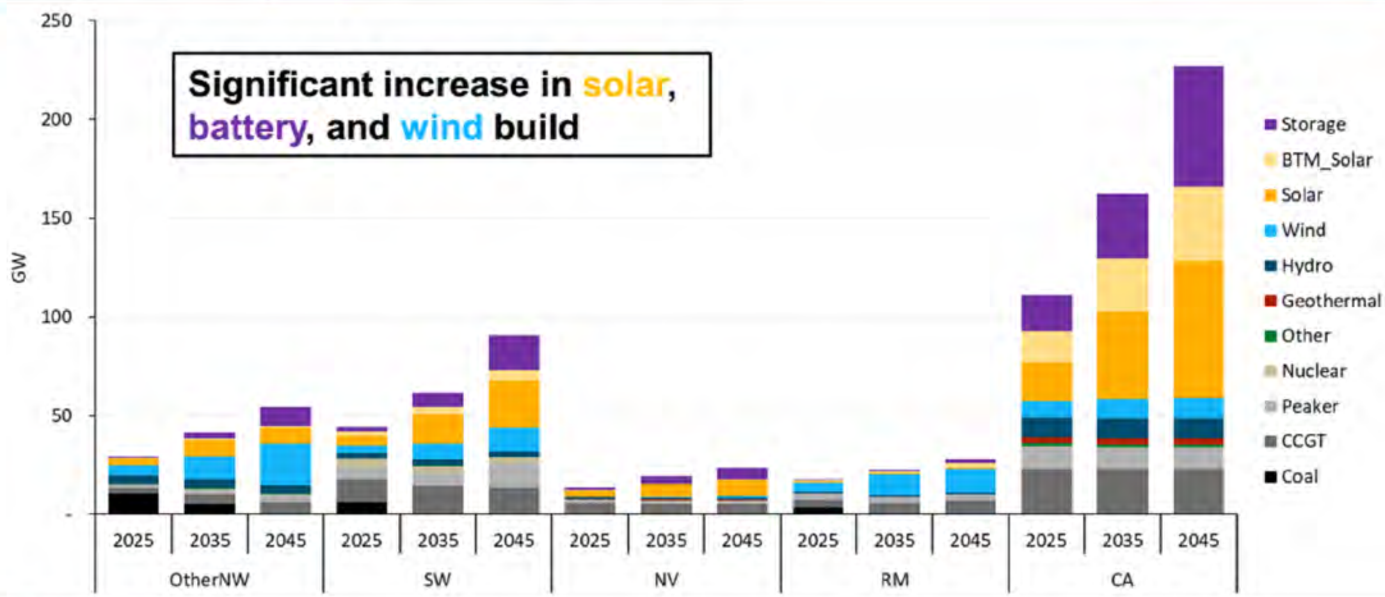
External Zone Installed Capacity Portfolio

+ **There is a significant increase in solar and battery capacity installed capacity due to the more aggressive RPS targets, assumed electrification, and the decline of technology cost forecasts**
  - Load is based on 2018 Electrification Futures Study and E3 internal incremental electrification impact assumptions

Total Installed Capacity for External Zones



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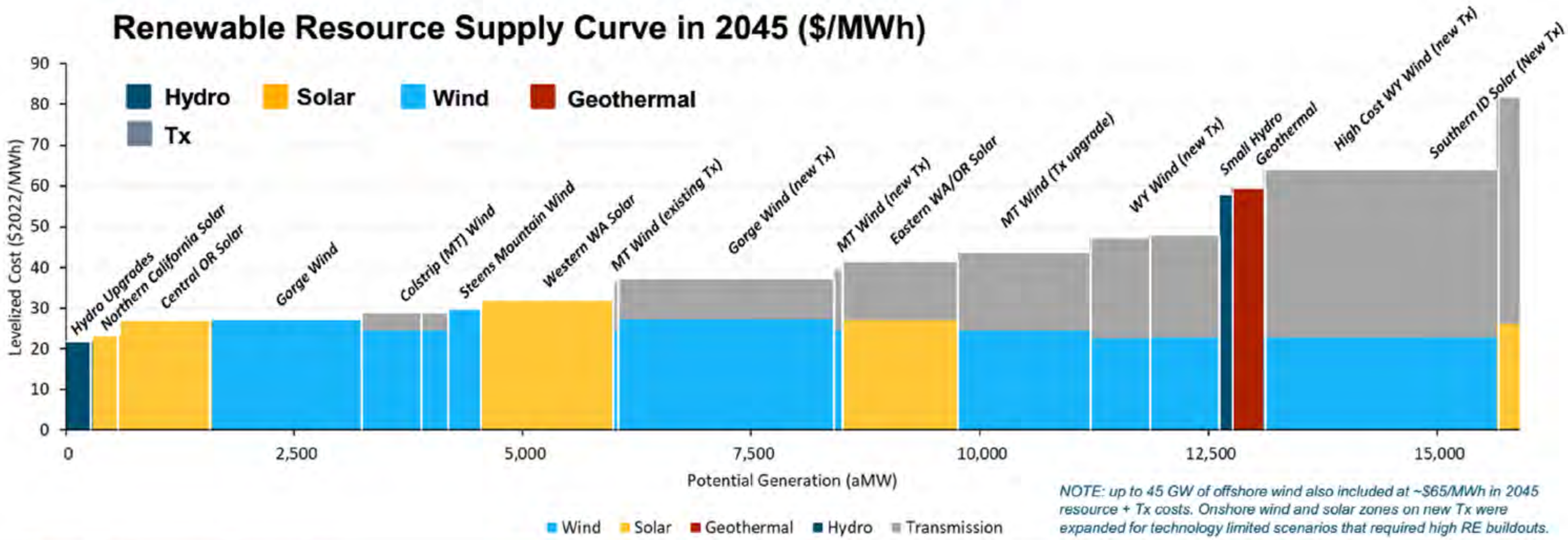
New Resource Options
Renewables

+ The following supply curves integrate Tx costs that RESOLVE sees
+ Certain solar resources (i.e., Western WA solar) might require new transmission lines to bring the supply to load centers, which is not captured currently

Renewable Resource Supply Curve in 2045 ($/MWh)



NOTE: up to 45 GW of offshore wind also included at ~$65/MWh in 2045 resource + Tx costs. Onshore wind and solar zones on new Tx were expanded for technology limited scenarios that required high RE buildouts.

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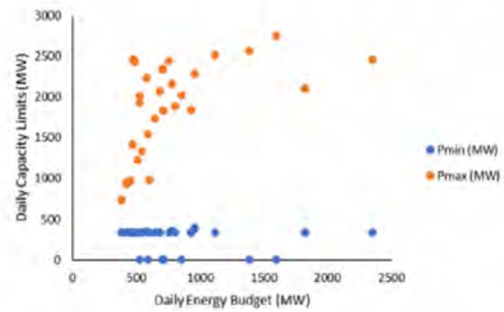
Hydro Operating Data

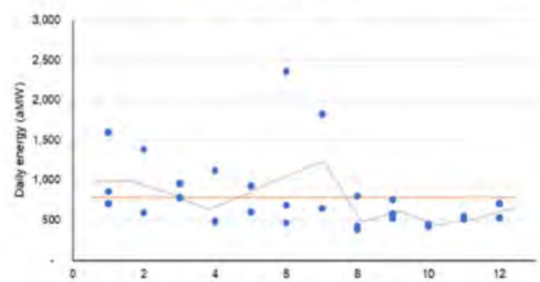
- **Key RESOLVE inputs (for each representative RESOLVE day)**
  - Max generation MW
  - Min generation MW
  - Daily MWh hydro budget
  - Ramp
- **Hydro operating data is parameterized using representative conditions for 3 low/mid/high historical years (2001, 2005, 2011)**
  - Lower Snake River and Lower Columbia River dams were adjusted per BPA hydro modeling w/ latest fish spill constraints

LSR Hydro

Ramp Rates

Hydro Resource	1-hr	2-hr	3-hr	4-hr
LSR_Hydro	36%	43%	45%	48%

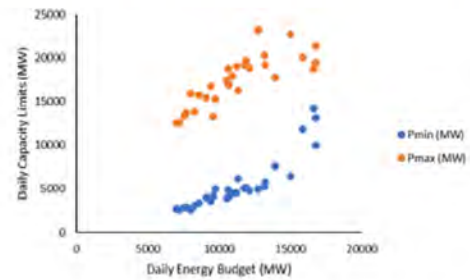


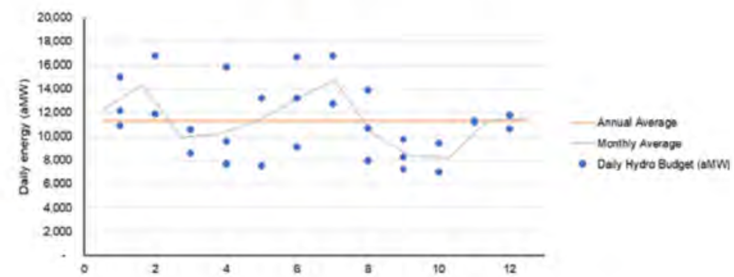


Non-LSR NW Hydro

Ramp Rates

Hydro Resource	1-hr	2-hr	3-hr	4-hr
CoreNW_Hydro	14%	23%	30%	34%





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Key Data Sources

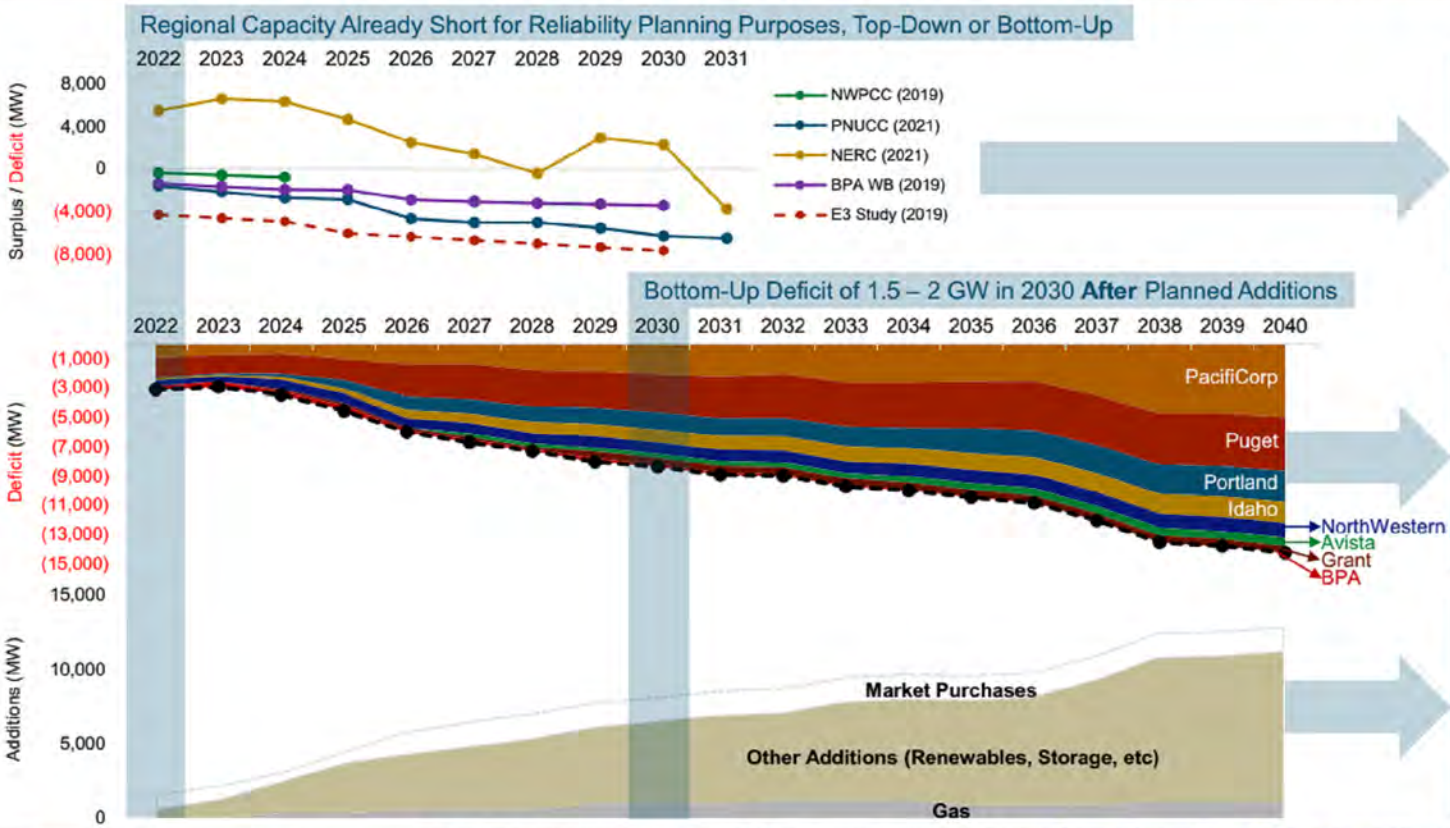
Inputs	Data Source
Demand Forecast	PNW Load Forecast Benchmarked to 2021 NWPCC Power Plan Non-PNW from E3 2021 2e WECC AURORA Cases High Electrification Sensitivity – benchmarked to Washington State Energy Strategies high electrification scenario extrapolated to CoreNW loads
Baseline Portfolio – WA + OR	WECC Anchor Data set
Baseline Portfolio – External Zones	E3 2021 2e WECC AURORA Cases
Technology Operating Characteristics	Per 2019 E3 Energy Northwest Study, except for updated hydro operating assumptions per BPA input (including new fish spill constraints)
Existing Resource Cost	Per 2019 E3 Energy Northwest Study
Candidate Resource Cost	E3 2022 Pro Forma (based on NREL 2021 ATB and Lazard v 7 reports)
Renewable Profiles	Per 2019 E3 Energy Northwest Study
Fuel Price Forecast	E3 updated coal (EIA), gas (E3 Market forecast team), hydrogen (E3 Electrolysis Calculator), uranium (Energy Northwest), bio (PSE), and carbon price (California)
Renewable and Battery ELCC	Per 2019 E3 RECAP study
CES Policy Case	Updated to load weighted avg based on OR and WA 100% trajectories

Policy Landscape: Washington, Oregon, California

	RPS or Clean Energy Standard?	Coal Prohibition?	Cap-and-Trade?	New Gas?	Economy-Wide Carbon Reduction?
WA	✓ Carbon neutral by 2030, 100% carbon free electricity by 2045	✓ Eliminate by 2025	✓ Cap-and-invest program established in 2021, SCC in utility planning	✓	✓ 95% GHG emission reduction below 1990 levels and achieve net zero emissions by 2050
OR	✓ 50% RPS by 2040, 100% GHG emission reduction by 2040, relative to 2010 levels	✓ Eliminate by 2030	✓ Climate Protection Plan adopted by DEQ in 2021 (power sector not included)	✕ HB 2021 bans expansion or construction of power plants that burn fossil fuels	✓ 90% GHG emission reduction from fossil fuel usage relative to 2022 baseline
CA	✓ 60% RPS by 2030, 100% clean energy by 2045	✓ Coal-fired electricity generation already phased out	✓	✕ CPUC IRP did not allow in recent procurement order	✓ 40% GHG emission reduction below 1990 levels by 2030 and 80% by 2050

PNW Capacity Need vs. Planned Additions

By 2030, the region faces a significant need not adequately met by currently planned additions, which are themselves optimistic



Top-Down Regional Assessments

3 – 8 GW capacity need by 2030, with different assumptions for capacity credit (especially hydro) driving differences in results

Bottom-Up Utility IRP Review

8.4 GW capacity need by 2030 **before** planned additions; PacifiCorp and Puget Sound Energy have the greatest need

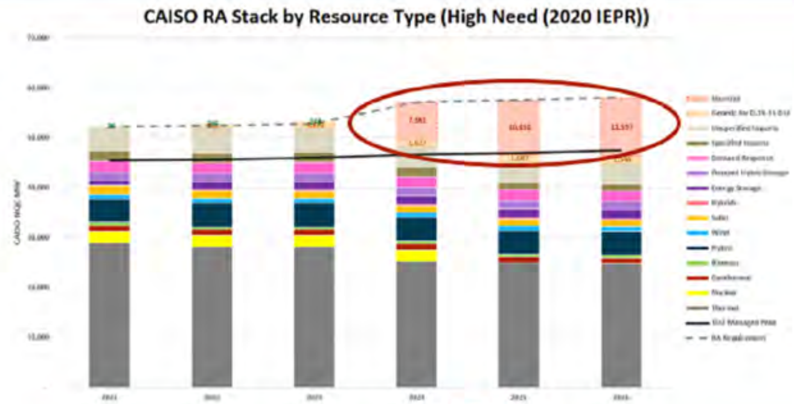
IRP Planned Additions

~6.5 GW effective capacity additions by 2030 (up to ~14 GW nameplate capacity), **significantly exceeding average capacity expansion rate for 2010-2020 (~1 GW/year)**

Note: E3 top-down assessment utilizes RECAP modeling results from E3's 2019 study Resource Adequacy in the Pacific Northwest. E3 study further shapes the annual capacity need based on proposed coal retirements schedules (as of Oct 2019). E3's capacity deficit does not include any planned additions. Bottom-Up Deficit excludes market purchases.

CAISO Shows a Large Near- to Mid-term Capacity Need

- **CPUC issued a 3.3 GW procurement order for 2021-2023 in 2019**
- **Then in August 2020, the CAISO faced two consecutive days where rolling blackouts were required**
- **In June 2021, the California PUC issued another historically large procurement order to address key "mid-term" resource adequacy needs for the CAISO system**
  - DCPP retirement removes ~2.2 GW of firm capacity
  - Once-through-cooling gas plant retirements remove another ~3.7 GW of capacity
  - Recent drought years have reduced hydro capacity value by ~1 GW
  - The historical 15% PRM is now seen as insufficient to support CAISO RA needs amongst shifting peak loads and a changing climate
- **2021 CPUC Procurement Order: 11.5 GW of new RA capacity to be procured by 2026**



CPUC Mid-Term Reliability Procurement Order

Type of Resource	2023	2024	2025	2026	Total
Zero-emissions generation, gen paired w/ storage, or DR resources[1]	-	-	2,500	-	2,500
Firm and / or dispatchable zero-emitting resources	-	-	-	1,000	1,000
Long-duration storage resources[2]	-	-	-	1,000	1,000
Total	2,000	6,000	1,500	2,000	11,500

(1) The zero-emissions resources required to replace Diablo Canyon must be procured by 2025, but may occur in any of the years 2023-2025; therefore, the columns to not add to the total.
(2) LSEs may request an extension by Feb 1, 2023 up to 2028 for the LLT resources.

CPUC Decision D.21-06-035:
https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M389/K603/389603637.PDF

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Energy+Environmental Economics

Thank You

Questions, please contact:

Aaron Burdick, aaron.burdick@ethree.com

From: Koehler,Birgit G (BPA) - PG-5
Sent: Monday, February 7, 2022 10:59 AM
To: Petty,Robert J (BPA) - PGP-5
Subject: FW: potential project under the E3/BPA contract
Attachments: E3 Proposal - BPA Lower Snake River Power Study 2022-02-07.pdf

Deliberative; FOIA-exempt

I was surprised at the first big project they put in their proposal. That's a lot to get done in short order.

From: Jack Moore <jack@ethree.com>
Sent: Monday, February 7, 2022 10:23 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Arne Olson <arne@ethree.com>; Kushal Patel <kushal.patel@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Subject: [EXTERNAL] RE: potential project under the E3/BPA contract

Hi Birgit,

Thank again for the opportunity to discuss working with you on this. We've put together our proposed work in the attached document. Please let us know if you have any questions over email; otherwise, we can discuss tomorrow on the call.

Thanks!
Jack

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Tuesday, February 1, 2022 3:38 PM
To: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Kushal Patel <kushal.patel@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Subject: RE: potential project under the E3/BPA contract

Hello Arne, Kushal, and Jack,

Thanks for the conversation today. We look forward to hearing your thoughts after you've had time to confer, and don't hesitate to be in touch by email if you have questions in the meantime.

As far as meeting next Tuesday, we got lucky on calendars at our end. Do you want to pick a time before calendars fill up? At the moment, we at BPA are free 10-1:30 and 2-4. How do your calendars look?

Cheers,
Birgit

From: Jack Moore <jack@ethree.com>
Sent: Tuesday, February 1, 2022 9:06 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Arne Olson <arne@ethree.com>; Kushal Patel <kushal.patel@ethree.com>
Subject: [EXTERNAL] RE: potential project under the E3/BPA contract

Thanks, Birgit. That sounds good—I look forward to talking this afternoon with you

---

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, January 31, 2022 4:56 PM
To: Jack Moore <jack@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Arne Olson <arne@ethree.com>; Kushal Patel <kushal.patel@ethree.com>
Subject: RE: potential project under the E3/BPA contract

Hello Jack,

Wonderful that you are interested in this study. Given that time is tight, let's talk tomorrow. (You'll get me out of a meeting that I'll be happy to miss.) I'll send a meeting invitation shortly to reserve the time.

And yes, we will work on the contracting paperwork right away. Eve did started on that and reached out to our contracting office already.

We'll talk tomorrow then,
Birgit

From: Jack Moore <jack@ethree.com>
Sent: Monday, January 31, 2022 4:21 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Arne Olson <arne@ethree.com>; Kushal Patel <kushal.patel@ethree.com>
Subject: [EXTERNAL] RE: potential project under the E3/BPA contract

Hi Birgit,

Thanks for reaching out to us. We'd definitely be interested discussing this more with you and coming up with an approach that is a good fit for what you need and in this timeline—which you are right, may affect how we should approach it.

Is there a good time for you to talk this week? Tomorrow 2-2:30 and Wed 11:30-12 both look open for us.

In parallel, to make the best use of the time until April, I think it's probably good to start the contracting process going so that we can begin efficiently and not need to wait. James, please let me know if you or Steve need anything from us to get things moving on that front.

Thanks!
Jack

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, January 31, 2022 11:01 AM
To: Jack Moore <jack@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: potential project under the E3/BPA contract

Good morning Mr. Moore,

Trevor Downen gave me your name as a contact for the IDIQ contract. We have another project that we hope you will be interested in.

We are looking for help with a study to identify one or more portfolios of resources that could potentially replace the full services the lower Snake River dams are able to supply. While BPA has the capability to do this study ourselves, we are looking for a third party to perform the study to minimize the appearance of bias in a BPA-led study. There is a tight turn-around in that we would like to have the information in April, and perhaps the timeline informs/constrains the scope.

You will find a short description of what we are looking for in the attachment. I'm happy to discuss further. When it comes to the nitty-gritty of adding this to the E3/BPA contract, I'll ask Eve James and Steve Bellcoff to work with our contracting office and with staff your organization as appropriate.

We certainly hope E3 is available and interested in performing this study! I look forward to hearing from you, and would be happy to discuss if you need more information before letting us know your interest.

Cheers,
Birgit

-.-
Birgit Koehler, Ph.D.
Deputy Vice President of Power Generation Asset Management
Bonneville Power Administration
(503) 230-4249
bgkoehler@bpa.gov

Bonneville Power Authority

The Role the Lower Snake River Projects

February 7, 2022

Arne Olson

44 Montgomery Street, Suite 1500
San Francisco, CA 94104

Arne@ethree.com

415-381-5100

Energy+Environmental Economics

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Introduction

We appreciate the opportunity to present this proposal to the Bonneville Power Authority (BPA). **Energy and Environmental Economics, Inc. (E3)** is a 100-person energy consulting firm with offices in San Francisco, Boston, New York, and Calgary. Founded in 1989, E3 helps utilities, regulators, policy makers, developers, and investors make the best strategic decisions possible in this period of transition in the electric and gas sectors. Many of E3's projects center around rigorous and transparent modeling analyses that provide a foundation for our strategic advising. Because E3 works with clients from all sectors of the electricity industry across the U.S., we provide a 360-degree understanding of markets, planning, policy, regulation, and environmental factors. Just as important, we are committed to delivering clear, unbiased analyses that help clients make informed decisions often in complex and multi-stakeholder contexts.

E3 has a 30-year track record of completing hundreds of large, analytically complex, multi-stakeholder projects on schedule, within budget, and with exceptional attention to detail. E3's success stems in large measure from its employees, project management, and organizational style. Throughout the organization, from top to bottom, E3 professionals relentlessly pursue objective, technically supportable answers. We believe this will be particularly important with this scope of work for BPA. All key E3 staff have deep expertise in the energy industry, from policy to markets, from finance to business model development, and from technology to economics, with a pragmatic eye toward real-world constraints. E3's project management style gives teams the freedom to create great products while also drawing on the support of the entire resource pool at E3, including our most senior experts.

E3 Operates at a Unique Nexus Across Multiple Clients in the Energy Stakeholder Spectrum

E3 completes over 300 projects per year on behalf of the industry's most diverse client base. Our integrity and reputation for providing high-quality, unbiased work, earned over many years of successful projects, especially in the Pacific Northwest has enabled us to occupy a unique niche in the energy industry: one where we are able to credibly advise a wide array of diverse clients such as investor-owned utilities, public power agencies, federal and state government agencies, independent system operators, power producers, and environmental advocacy organizations on a wide range of energy issues. This expansive breadth of project and client engagement has afforded us the opportunity to understand the perspectives of several different types of utility and energy industry stakeholders. This breadth, which we believe is unmatched by our competitors, speaks to the enthusiasm and dedication of our staff and the respect clients have for E3's high-quality, unbiased analysis.

Scope of Work

Task 1: Top Down and Bottom Up Capacity Need Analysis Highlighting the Role/Need of Hydropower

In this task E3 would perform analysis to level set how :

- Resource analysis of CA, WA, and Oregon from now until 2050
- Analysis of 100% renewable and carbon free mandates in CA, WA, and OR coupled with a technical analysis of achieving those stated goals
  - What does the actual path to 100% look like with technologies that are currently commercially viable and what is the role of hydropower along that pathway?
- Summarize and update research done to date on capacity shortfalls across the West highlighting the role of hydropower

E3 has performed this type of research and analysis a number of times for various clients and is well positioned to deliver a high quality work product under this task. We plan to break this task into two parts.

The first part is performing a holistic analysis from both a top-down and bottom-up perspective on the clean energy goals and targets in the Pacific Northwest, what the plan and potential key decision points are on the techno-economic implementation pathways to achieve those goals, and what the planned and expected resource mix looks like over the next 15- to 30-years based on existing analysis and research. The top-down approach would look at the clean energy targets and work backwards in terms of the ranges around the type, magnitude, and timing of resources needed to meet those targets.

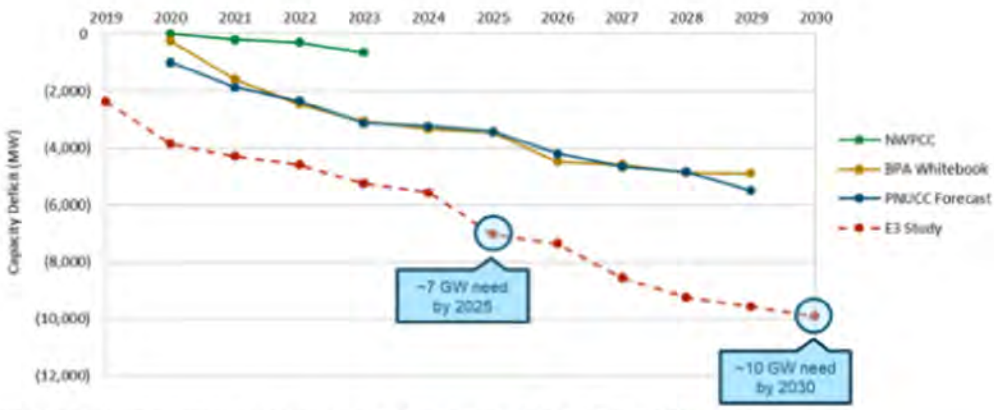
We would also include in that analysis potential alternative implementation pathways including an in-depth analysis on the key implementation barriers and challenges to meet each state's clean energy targets. The bottom up analysis would look at the resource mix in terms of what is likely in the near-term (~5-year horizon) based on existing interconnection queues, existing transmission capacity, and new resource build expectation along with existing resource retirement dates as well as the procurement targets and mechanisms by utilities and other off-takers. We would then analyze the utility IRPs and other key resource plans such as the California Public Utilities Commission to determine whether these add up to what is required to meet the longer-term clean energy targets in each state focusing on the medium to longer term (~5 to 30 year horizon). We would then highlight, examine, and provide narrative around any observed gaps, discrepancies, or other issues that arise from this research and analysis in the context of the Lower Snake River projects.

The second part of this task would be to summarize and update the research done on the capacity shortfalls across the West again both on a top down and bottom up basis similar to the work E3 has performed in the past. An example of this kind of analysis[1] can be seen below. This analysis demonstrated an almost 10 GW capacity need by 2030 that among other things highlighted the challenges of filling that

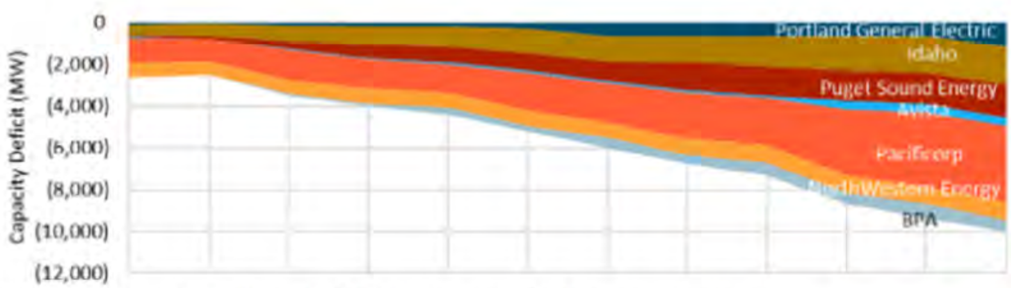
[1] https://www.ethree.com/wp-content/uploads/2019/12/E3-PNW-Capacity-Need-FINAL-Dec-2019.pdf

need with new resources. Since this analysis was performed E3 believes the capacity need has grown as well as the competition and cost for clean energy resources to fill that need. We believe this will demonstrate how the region is going to be need all carbon free resources in both the near and longer term in the context both the reliability needs in the shorter to medium term and the achievement of clean energy and decarbonization goals in the longer term.

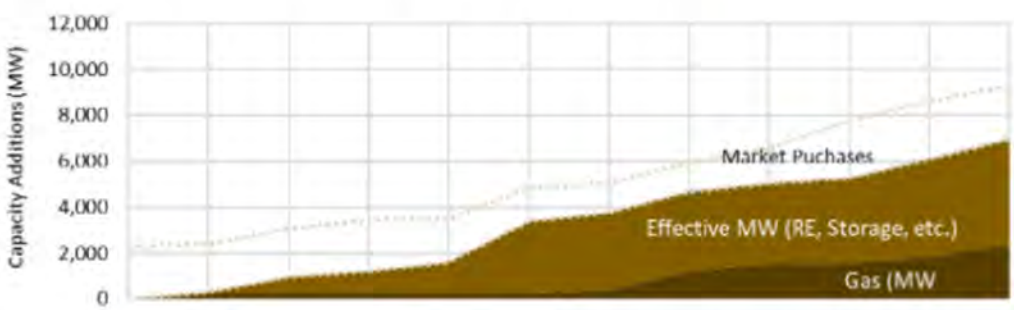
Capacity Needs of the Pacific Northwest — 2019 to 2030



E3's "top-down" regional assessment finds a capacity need of approximately 7 GW by 2025 and 10 GW by 2030



E3's "bottom-up" review of utility IRPs identifies 10 GW of capacity need by 2030, before planned additions



E3's review of IRP planned resource additions finds only ~7 GW of effective capacity additions, with 2.3 GW of market purchases generally not addressing regional need

Deliverables:

- Multiple PowerPoints and materials tailored to the various stakeholders that summarizes this analysis

Timeline:

- The proposed timeline would be to complete the work by Q3 2022 with an initial draft for the client to review by mid-April 2022.

Budget Estimate:

- E3 proposes to perform this work on a Time and Materials basis under our BPA rates with a not to exceed budget of **$35,000**

Task 2: RESOLVE Analysis

In this task E3 would perform the modeling and analysis along the lines specified by BPA below:

BPA needs an analysis of the region's future power benefits[2] picture if BPA lost this dispatchable, carbon-free hydropower output.

- *Capabilities include:*
  - *Energy*
  - *Capacity, instantaneous and sustained*
  - *Reserves carrying capability*
  - *Fast ramping*
- *Assess what combination of resources would provide these characteristic*
  - *This could include scenarios with different combinations of resources*

Outputs:

- *Portfolio(s) of resources*
- *Full Costs of resources (including transmission and fuel (e.g. gas would need pipeline and storage infrastructure costs included))*
- *Carbon emissions*
- *Reliability*
- *Timing (how fast could replacement resources be sited and producing energy)*
- *Feasibility (e.g. siting constraints, supply chain availability, transmission constraints, availability of balancing services to integrate variable renewable resources)*

Timeline: Draft[3] would need to be completed by April 2022 with a final report provided before July 31, 2022.

[2] This study would focus on replacing the power supply/reliability characteristics only and not look at navigation or irrigation uses of the projects. It would also not lean on existing resources in the region (such as coal or gas) to make up for the lost capability of the Columbia River System.

[3] Draft report preferred in April, but at a minimum need information in a presentation

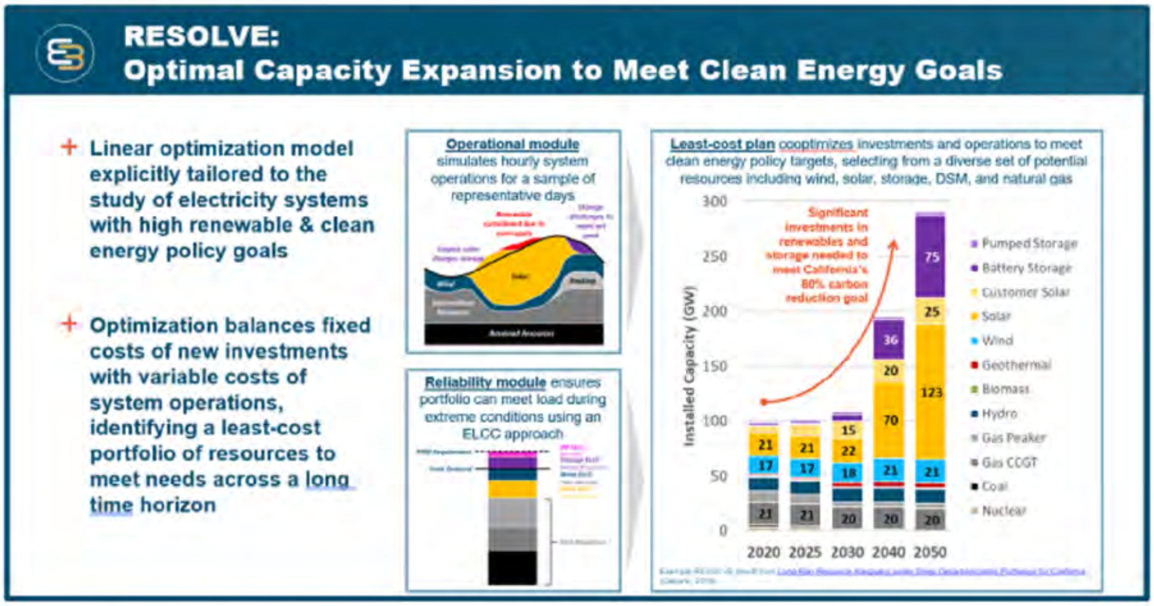
To evaluate the system-level value of the Lower Snake River projects, E3 would utilize its RESOLVE modeling tool which has been used for a number of studies in the Pacific Northwest as well as various IRP processes including for the California Public Utilities Commission's IRP process.

RESOLVE is an electricity sector capacity expansion and dispatch model developed by E3. E3 will use the RESOLVE model to estimate least-cost resource portfolios with and without the Lower Snake River projects. This will provide insight around how the Lower Snake River projects fits into a least cost, reliability power system in the Pacific Northwest under various scenarios including meeting the ambitious clean energy policies at the state and Federal levels.

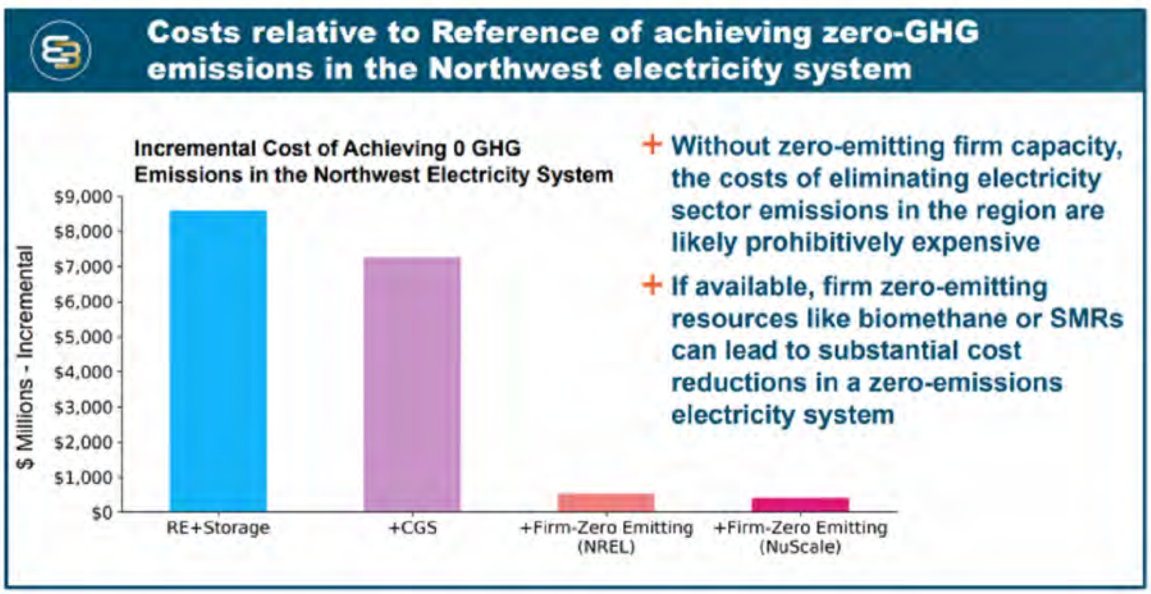
RESOLVE is well-suited to this task, as it is a resource investment model that identifies optimal long-term generation and transmission investments in an electric system, to develop a least-cost resource portfolio. The analysis will be conducted under a range of scenarios, including but not limited to a "current policy" scenario and scenarios that might call for additional procurement beyond current targets to meet additional state goals, such as RPS and reliability needs. The team will also conduct sensitivity analysis to investigate the impact of conservative and optimistic technology price forecast on the optimal portfolio. RESOLVE's optimization capabilities allow it to select from among a wide range of potential new resources including renewables, energy storage, demand-side solutions, and imports. The following are an example of the scenarios and sensitivities we could run in consultation with the BPA team.

- No policy case as a reference case
- Multiple state policy implementation cases
- Net Zero case
- Absolute Zero case
- Various technology breakthrough cases

E3's RESOLVE analysis would focus on the Pacific Northwest Region, which E3 has analyzed extensively for various stakeholders (utilities, trade organizations, etc.) and for which E3 has deep understanding of the system- and resource-specific dynamics that inform this type of analysis.



See below an example how different cases can highlight the role of different generation resources like the Lower Snake River projects in different future states of the world using our RESOLVE model[4]. Note, this example is from analysis performed in the context of examining small modular nuclear reactors in the Pacific Northwest.



[4] https://www.ethree.com/wp-content/uploads/2020/02/E3-Pacific-Northwest-Zero-Emitting-Resources-Study-Jan-2020.pdf

Deliverables:

- Multiple PowerPoints and materials tailored to the various stakeholders that summarizes this analysis

Timeline:

- The proposed timeline would be to complete the work by Q3 2022 with an initial draft for the client to review by late-April 2022.

Budget Estimate:

- E3 proposes to perform this work on a Time and Materials basis under our BPA rates with a not to exceed budget of **$100,000**

Team

Arne Olson, Senior Partner. Mr. Olson leads E3's resource planning practice. Since joining E3 in 2002, he has led numerous analyses of how renewable energy and greenhouse gas policy goals could impact system operations, transmission, and energy markets. In 2013, he led the technical analysis and drafting of the landmark report *Investigating a Higher Renewable Portfolio Standard for California*, prepared for the five largest utilities in California. Since that time, he has overseen numerous studies of deeply decarbonized and highly renewable power systems in California, Hawaii, the Pacific Northwest, the Desert Southwest, New York, South Africa, and many other regions. Mr. Olson's clients have included most of the major utilities and market participants in the West, including the California Independent System Operator, Pacific Gas & Electric, Southern California Edison, Puget Sound Energy, PacifiCorp, Arizona Public Service, Sacramento Municipal Utilities District, Los Angeles Department of Water and Power, the Bonneville Power Administration, Calpine, NextEra, NRG, TransAlta and many others. He also works extensively with government agencies and industry organizations such as the California Public Utilities Commission, California Energy Commission, Oregon Public Utilities Commission, the Western Electric Coordinating Council, and the Western Interstate Energy Board. Mr. Olson earned an M.S. in International Energy Management and Policy from the University of Pennsylvania and the Institut Français du Pétrole, and bachelor's degrees in Statistics and Mathematical Sciences from the University of Washington.

Kushal Patel, Partner Mr. Patel helps leads E3's asset valuation and strategy. He is the primary lead on work with technology companies, investor owned utilities, project developers, asset owners, investors, and financiers. This work involves a variety of strategic, asset valuation, and financial issues and requires extensive analysis of both wholesale and retail energy markets. Mr. Patel also supports state agencies and regulatory bodies as well as policymakers on a host of issues such as rate design, distributed energy resource (DER) deployment, and utility business model analysis. With over 20 years of experience in the energy sector, Mr. Patel has worked on a wide array of engagements for a diverse client base across of number of areas such as utility strategy, resource planning, electricity procurement, asset valuation, general rate cases, due diligence services, technology assessment, policy impact analysis, and others. Before joining E3, Mr. Patel was the Director of Corporate Development and Project Finance at a rapidly growing solar and energy efficiency engineering, procurement, and construction company in Washington, DC. Mr. Patel also has direct project financing experience for residential to utility-scale solar PV projects, along with other finance activities such as debt/equity structuring and revolving lines of credit. Before that, Mr. Patel worked in the Energy Practice at NERA Economic Consulting as part of the Oliver Wyman Group in New York City and Washington, DC. Mr. Patel received an M.S. in Engineering Management from Dartmouth College, an M.S.

in Accountancy from the George Washington University School of Business, and a B.A. in Engineering Sciences and Economics and a B.E. in Materials Science from Dartmouth College.

Sandy Hull, Director Mr. Hull joined E3 in 2017 after receiving his Master of Business Administration from Duke University, with concentrations in Energy Finance and Strategy. His areas of expertise include market analysis and valuation, distributed energy resources, and energy policy. At E3, he has assessed market risk for solar development with Community Choice Aggregator (CCA) offtakers and has supported the valuation of energy storage and gas generation assets for project developers and private equity investors. He has also contributed to integrated resource planning efforts, analysis of transmission rate design, and research on renewable energy integration in Canada. Before joining E3, Mr. Hull served as a Senior Consultant in the energy and finance practices at Bates White Economic Consulting. His prior work includes due diligence and strategic support for private equity investors, wind project developers, and corporate power purchasers. He has extensive experience with the valuation of wind-power investments in Mexico and the derivative portfolios of institutional investors. Mr. Hull has worked with stakeholders across the energy industry and is passionate about the intersection of energy policy, technology, and finance.

Nate Miller, Associate Director Mr. Miller joined E3's Asset Valuation team in 2019. With a background in energy economics and finance, he is skilled in financial modeling, energy market analysis, investor due diligence, risk analysis, resource contracting, and project financing. Prior to joining E3, Mr. Miller spent six years in Washington, DC as an advisor to investors, developers, utilities, and policymakers on power project planning, development, and financing. He has advised on over 10 GW of generation assets in 16 countries covering a range of technologies, including oil and gas, geothermal, solar, wind, biomass, and energy storage. In the U.S., Mr. Miller has advised some of the largest developers and investors in the country on asset value and due diligence for the acquisition and development of renewable power portfolios and energy storage assets. He was also a core member of E3's transaction advisory team for the solicitation, evaluation, and negotiation of competitive bids to reform or sell Santee Cooper, a publicly-owned electric utility in South Carolina valued at ~$9 billion. Mr. Miller holds a B.A. with honors in International Relations and Economics from Pomona College and a M.A. with honors in Energy and International Finance from the John Hopkins University School of Advanced International Studies (SAIS).

Relevant Qualifications

Arizona Public Service, Integrated Resource Plan and Corporate Strategy Advisory Support (2019-2020). In the lead-up to filing its 2019 Preliminary IRP, APS retained E3 to provide strategic support in several functions. E3 worked with APS internally to help align the scope and focus of the IRP with long-term corporate strategic efforts to shift focus towards clean energy and customer preferences and also led a stakeholder process to facilitate dialogue and collaboration. To facilitate APS' engagement with its stakeholders, E3 developed an IRP screening tool that allowed stakeholders to design and test the impacts of a wide range of alternative scenarios on APS' future portfolio. Working collaboratively with APS and stakeholders, E3 led a series of workshops to facilitate discussion between the two groups, providing stakeholders with an active platform to provide feedback to APS. In addition to the external stakeholder engagement process, E3 also supported efforts to achieve internal alignment around their announced zero carbon goals which included the development of this public report.

Arizona Public Service Resource Planning and Coal Plant Cost Recovery Analysis (2016-Present): E3 has been supporting APS in developing and evaluating its resource plans to meet its 100% decarbonization goals for several years. As part of this support, we have been analyzing coal operational strategies to support lower carbon portfolios, as well as the necessary regulatory cost recovery mechanisms required to keep the utility whole. E3 provided analysis that was submitted into APS's most recent rate case to support securitization as an option for coal plant stranded cost recovery. E3 has also been supporting discussions within the utility around strategy for exiting coal and the elements of just transition that are required such as considerations for environmental justice, local economy, etc.

Market Advisory Services on the Sale of Santee Cooper, South Carolina Dept. of Administration, 2019 – 2020. After a competitive national process, E3 was selected by the South Carolina Dept. of Administration to advise the State on the potential sale of Santee Cooper following the state-owned utility's accumulation of $4 billion in debt from its failed investment in the V.C. Summer nuclear generating station. As the only energy consulting firm selected, E3 is worked alongside a law firm and a financial services firm to advise the State on three possible options: selling all or a portion of Santee Cooper to a third party; a management agreement for a third party to operate Santee Cooper; and a restructuring proposal submitted by Santee Cooper itself. E3's support to the State included:

- Development of a standalone economic model of Santee Cooper's electric utility business – including dynamic dispatch of generation resources by year with additions and retirements, capital and operating costs, financing, taxes, annual revenue requirements, and forecasted average rates by customer class – for each of the three ownership structures under consideration
- Due diligence of Santee Cooper's existing system, rate setting methodology, assets in service, financing plans, and proposed future generation plans
- Responding to bidder Q&A; evaluating bids, including resource plans, financial offers, regulatory requirements, and projected rates and risks to rgffffffffffffffffffffffffffffffffffffffffffffffffffffffffzatepayers; and negotiating with bidders to improve offer terms, in coordination with legal and financial advisors to the State.

Salt River Project (SRP) Integrated System Plan Development (2019-Present) E3 was retained by SRP to develop the company's first Integrated System Plan (ISP) to coordinate currently disparate planning processes to ensure alignment with the Corporate Objectives including Reliability, Affordability and Sustainability. E3 is working closely with an internal team at SRP to develop a new planning framework that integrates supply-side resource planning, transmission planning, distribution planning and customer program design, and even touches on areas such as rate design to ensure that investment and operational decisions at each level are informed by a common understanding of potential future states of the world and a common set of data inputs and assumptions. To inform this pathbreaking work, E3 has conducted over 25 interviews with SRP personnel at multiple levels from planning Managers and Directors up to the Assistant General Managers and the General Manager. SRP expects to launch its inaugural ISP under the new process in late 2021.

Xcel Energy Upper Midwest Integrated Resource Plan Support (2019). As part of its 2019 Integrated Resource Plan, Xcel Energy retained E3 to conduct two independent analyses to support its IRP: (1) an economy-wide study for the state of Minnesota examining what would be needed to meet deep decarbonization goals throughout the economy (e.g. 80% reductions by 2050); and (2) a portfolio optimization and reliability analysis for Xcel's portfolio to examine the costs of meeting the utility's carbon reduction goals (80% reductions by 2030; 100% carbon-free by 2050). E3's statewide pathways study provided Xcel with a novel perspective on future electricity loads in the context of an economy-wide carbon reduction effort, showing how decarbonization measures such as building and transportation electrification could lead to significant long-term increases in load. These findings were used to inform a sensitivity analysis conducted within Xcel's internal IRP modeling.E3's portfolio and reliability analyses were conducted in parallel with Xcel's internal work to develop a forward-looking resource plan, testing the notion that an independent expert using advanced industry-standard methods would come to similar conclusions. E3 used RECAP for sophisticated loss-of-load-probability analysis and RESOLVE for optimal capacity expansion to design reliable, least-cost portfolios to meet carbon reduction goals, ultimately corroborating the findings in Xcel's plan.

Sacramento Municipal Utilities District, 2030 Zero Carbon Study (2020-2021). Building on prior analysis supporting SMUD's 2018 IRP, E3 worked with SMUD to study electric sector pathways to carbon neutrality by 2030 as required by SMUD's Climate Emergency Resolution. The results of the study were synthesized in a public-facing report and presented to SMUD's Board in March 2021. The study detailed key aspects of the 2030 target including: how carbon neutrality should be defined, which accounting methodology should be used to set the targets, whether existing or proven cleantech can accomplish the 2030 goal within reasonable costs and resource build rates, how emerging technologies like DERs, long-duration storage, and hydrogen can and aide in reaching the goal or reducing costs, and most importantly, how to achieve SMUD's goals while maintaining strict reliability. The analysis informed SMUD's proposed plan to achieve the goals set forth by the Board, which includes retirement of several of SMUD's aging gas generators, repurposing several of its more efficient gas generators as a carbon-free resources, and investing heavily in renewables, storage, and DERs.

Sacramento Municipal Utilities District, Integrated Resource Planning Technical Support (2018-2020). SMUD retained E3 as a technical consultant to provide ongoing analytical support to its IRP team. In SMUD's 2018 IRP, E3 led analysis to evaluate a range of long-term greenhouse gas goals (90-100%

emissions reductions by 2040) as well as impacts of vehicle and building electrification measures. E3 developed a highly customized rendering of the SMUD system in RESOLVE, completing long-term capacity expansion analysis to identify optimal portfolios of renewable, conventional and energy storage resources to meet SMUD's electric energy and reliability needs over time. E3 subsequently coordinated with SMUD's own analytical team to translate the resulting portfolios into inputs for SMUD's production cost modeling using PLEXOS. E3's analysis found that SMUD's "SD9" goal of 90% carbon reductions by 2040 can be met or exceeded using existing technology at a relatively modest cost to SMUD's customers but that retiring all natural-gas generation would be prohibitively expensive and may not meet customer expectations for reliable electric service. E3 presented the findings of our analysis to SMUD's Board of Directors in a public meeting in June 2018.

NYSERDA CLCPA Support (2019-Present). E3 is supporting NYSERDA in its analysis to inform the Climate Action Council's Scoping Plan. E3 has developed initial scenarios showing how New York could achieve carbon neutrality as outlined in the Climate Leadership and Community Protection Act (CLCPA). This work includes a detailed analysis of buildings, transportation, industry, electricity generation, non-combustion, and negative emissions using E3's suite of modeling tools (PATHWAYS, RESOLVE, and RECAP). E3's work includes detailed modeling of the CLCPA electric sector targets, including the 70x30 and 100x40 goals as well as technology-specific targets such as the 9 GW offshore wind target.

California Public Utilities Commission Integrated Resource Plan Support (2016-present). E3 has been assisting the California PUC in its administration of the state's IRP program, mandated by the passage of SB 350 in 2016. E3 has worked with CPUC staff to develop the structure of the IRP program including a two-year modeling cycle in which Staff prepares a system-wide plan and Load-Serving Entities prepare plans for their own loads in alternate years. E3 helped the CPUC design an optimal "Reference System Plan" for the combined utilities that complies with policy requirements including a 60% RPS by 2030 and 40% reductions in greenhouse gas emissions by 2030, while capturing the operational and reliability challenges encountered at high penetrations of variable renewable generation. As part of this process, E3 evaluated dozens of scenarios reflecting alternative assumptions about resource costs, the availability of pumped hydro and out-of-state wind, the ability of end-use loads to operate flexibly, and a variety of other input parameters. The CPUC adopted the Reference System Plan in February 2018. E3 is currently assisting the CPUC in developing the second Reference System Plan, expected to be approved in early 2020.

Public Service Company of New Mexico (PNM) 2020 Integrated Resource Plan Support (2019-2021). Prior to developing its 2020 IRP, PNM had established a corporate goal to achieve a carbon-free electricity portfolio by 2040. E3 provided technical and strategic support to PNM's planning team to create a plan that fulfills that commitment. E3's primary role in the IRP process was as lead author of the IRP document – including the writing of the IRP narrative, creation of supporting figures and graphics, and compilation of detailed technical appendices. Throughout the process, E3 also provided guidance to PNM during scenario development, reviewed and validated inputs and outputs from the Encompass and SERVM models, and supported stakeholder outreach efforts. PNM's 2020 IRP, released to the public in January 2021, provides one of the first roadmaps for a utility to achieve a transition to a carbon-free generation portfolio, along with a detailed action plan set against the context of that transition.

Nova Scotia Power Incorporated (NSPI) Integrated Resource Plan (2018-ongoing). NSPI retained E3 to assist in developing an Integrated Resource Plan that considers alternative resource options to meet provincial and federal greenhouse gas goals while maintaining reliable and affordable electricity service. E3's support includes: (1) Developing a Resource Options study to characterize the cost, performance and resource potential for a variety of resource options available to Nova Scotia Power including solar, wind, hydro, conventional and energy storage resources; (2) preparing a Planning Reserve Margin (PRM) study to identify the capacity needed for NSPI to meet long-run electric reliability requirements as well as the Effective Load-Carrying Capability (ELCC) of each candidate resource, using E3's RECAP model; (3) developing a Portfolio study that identifies optimal portfolios of demand-side and supply-side resources, including remote resources paired with new high-voltage transmission lines, to meet year-by-year GHG targets while meeting the PRM requirement, using E3's RESOLVE model in conjunction with NSPI's PLEXOS LT; (4) an operability study to identify any additional capability beyond that identified by RESOLVE to meet operational needs, particularly those associated with higher levels of wind penetration, using PLEXOS ST; and (5) stakeholder and regulatory support throughout the process including in-person presentations to stakeholder workshops and expert witness in front of the Nova Scotia Utility and Review Board as needed.

El Paso Electric (EPE) Integrated Resource Plan (2020-2021). E3 provided a broad range of IRP support services for EPE including developing resource options and data inputs, conducting a Planning Reserve Margin and ELCC study using RECAP, optimizing EPE's portfolios over the 2021-2045 period reflecting New Mexico's Renewables Portfolio Standard and Energy Transition Act as well as EPE's own goal of 80% carbon reductions by 2035, studying the operability of EPE's system under high levels of wind and solar generation, and developing regulatory strategies for cost allocation and procurement given EPE's multi-state service area. E3 has also been heavily involved in EPE's stakeholder outreach and communication strategy, leading multiple stakeholder workshops and contributing to a substantial improvement in EPE's stakeholder relations.

Analysis of Competitive Bids for New Generation Procurement, El Paso Electric Company (2018). E3 supported El Paso Electric Company in evaluating responses to its competitive RFP to procure new generation resources. El Paso received bids for a range of renewable, thermal, and storage resources with different operational characteristics and costs. E3's work supported and concurred with analysis performed independently by El Paso staff, which led to the utility's selection of bids for over 200 MW of utility-scale solar and 100 MW of battery storage to its system over the next five years, in addition to 225 MW of new natural gas capacity.

New York Energy Storage Peaker Replacement Study (2019). After developing the New York State Energy Storage Roadmap (2018) with a senior-level team at the New York State Energy Research and Development Authority (NYSERDA) and Department of Public Service (DPS), E3 was retained to evaluate the potential for energy storage to replace fossil-fuel peaking units across the state. E3 performed a statewide, unit-by-unit analysis of all simple-cycle and regenerative combustion turbine (SCCT) units to identify potential candidates for repowering or replacement with energy storage and/or clean resources. E3's methodology involved developing hourly historical operations and emissions profiles for all peaker units and then feeding this data into RESTORE, E3's energy storage dispatch optimization tool to assess whether replacement with energy storage might be possible. Overall, E3 found that at least 275 MW of peaking units, or about 6% of total fleetwide rated capacity, could be replaced by six-hour energy storage, and that over 500 MW of peaking units could be replaced by eight-hour storage. The findings were published in the report "The Potential for Energy Storage to Repower or Replace Peaking Units in New York State," filed at the Public Service Commission in July 2019.

Confidential Client SERC Market Overview (2021). E3 supported an investor by conducting top-down and bottom-up analysis of the SERC market. E3 prepared an overview of market trends in SERC, including analysis of the policy and regulatory landscape, load-resource balance trends, and key supply-side sensitivities likely to shape investment opportunities in the near and long term. To apply this expertise to the client's investment hypothesis, E3 analyzed specific offtakers to create a ranking of potential counterparties based on expected capacity need, willingness to contract, and additional sensitivities. To screen potential assets for investment, E3 prepared a plant benchmarking analysis across various criteria, including plant economics, contract terms, and other quantitative and qualitative factors.

Confidential Midwest Utility, Deep Decarbonization Pathways Analysis (2020). E3 worked with a vertically integrated utility located in MISO to perform an assessment of long-term decarbonization pathways and the impacts that this would have on the utility's generation portfolio. The utility currently has a coal-heavy portfolio and enlisted E3's support in studying the impacts of potential state decarbonization policies on the utility's assets. E3 performed a comprehensive decarbonization analysis and relied on three in-house models during this project: (1) PATHWAYS, its economy-wide energy accounting model; (2) RECAP, its loss-of-load probability model; and (3) RESOLVE, its least-cost capacity expansion model. E3 used PATHWAYS to examine different strategies to meet a potential statewide decarbonization goal, including a high electrification scenario with significant acceleration of electric vehicle and heat pump adoption. The study team then downscaled the statewide load forecast to the utility's service territory and leveraged RECAP to assess the impacts of changes in both the timing and magnitude of system loads on the utility's reliability needs. Using an ELCC-based framework, E3 also used RECAP to determine the reliability contributions of wind, solar, and battery storage. The ELCC analysis served as an input into E3's capacity expansion modeling, in which E3 examined a wide range of potential emissions targets in the electric sector, with a detailed assessment of the role of firm capacity in meeting increasingly stringent emissions limits, all the way to up a 100% decarbonized system. Lastly, E3 developed a summary report of key findings to inform the utility's long-term strategy and decision-making.

Electrodes Holdings, California Storage Analysis (2021). E3 provided recommendations and analysis for a client's BTM storage DRESA contracts with a utility in Southern California. We wrote a written report on the California landscape of BTM storage, including details on storage market participation and the impacts of recent regulatory proceedings on the market. E3 also provided strategic recommendations for the existing DRESA contracts that the portfolio is under, by providing specific points of the contract that could benefit the utility and the portfolio by increasing revenues. Finally, E3 performed a detailed portfolio valuation for both the short term and long term for the portfolio. We forecasted revenues for various scenarios and from different revenue streams - including DRAM, energy and AS. Detailed dispatch shapes and revenue streams were provided to the client.

Confidential Independent Power Producer, Market Overview (2021). In 2021, E3 supported an independent power producer seeking insight into the battery storage market in California. E3 conducted a market overview of high-level trends in California and WECC, with a focus on recent trends in battery storage procurement and development. To complement this analysis, E3 provided and dissected battery storage revenue forecasts and power price forecasts for California. Together, the market overview and forecasts provided a comprehensive analytical foundation for participation and value capture in the California battery storage market.

Confidential Infrastructure Fund, Due Diligence and Transaction Support for a Potential Investment in an Energy Storage Platform (2020). E3 supported an infrastructure fund as part of an M&A process to acquire a storage development platform by providing storage revenue forecasts for a standalone energy storage portfolio in California, performing market analysis of key value drivers and trends, assessing the relative strengths and weaknesses of the sponsor's business model and development strategy, and evaluating the commercial viability and attractiveness of the sponsor's project pipeline. E3 analyzed the terms and incentives of energy storage PPAs, risks to realizing merchant revenues and the potential recontacting opportunities. In assessing the sponsor's business model, E3 found that competitive advantages such as repurposing interconnection sites or strategic relationships with battery manufacturers were crucial to success in California's highly competitive energy storage market.

Confidential Multinational Developer, Strategic Support in North American Energy Storage Opportunities (2020). E3 characterized, sized, and analyzed the opportunities for front of meter energy storage to inform a large multinational developer's capital allocation strategy in this emerging sector. E3 provided a detailed summary of the U.S. market for battery storage and how it is forecasted to evolve in the 2021-2030 timeframe by outlining the drivers of battery storage procurement, including state mandates, federal tax credits, falling costs, and the evolving fundamental needs of the grid in the context of various federal and state regulations and market participation rules. Battery storage can be fully contracted under a tolling contract, paired with solar as part of a bundled PPA with offtaker or owner dispatch rights, or contracted via resource adequacy (RA), i.e. capacity contracts with residual merchant value retained by the asset owner. Each of these contract structures has different implications for revenue certainty and timing. Within contract structures, specific pricing terms may also shift risk between the offtaker and asset owner. For example, early solar and storage PPAs have often priced energy in simplified "solar+" terms with a dollar-per-megawatt-hour adder for the dispatch flexibility provided by storage. However, specific value streams provided by storage have begun to be priced in more complex ways to meet offtaker needs and risk preferences. Hence, E3 also summarized the archetypal standalone and hybrid storage configurations and contract structures that are expected to be competitive over the next decade. Finally, E3 helped inform the developer's market and pipeline strategy by forecasting where and when such archetypical projects will be in demand, and which asset characteristics (e.g. siting, cost, contract terms, etc.) will differentiate the most competitive projects.

Confidential Solar and Energy Storage Developer, Energy Storage Strategic Support in ERCOT (2020). E3 supported a solar and energy storage developer in evaluating the three potential sites in ERCOT for developing stand-alone storage and storage paired with PV by providing storage revenue forecasts under various sensitivities, including congestion and grid charging sensitivities, and providing sizing and project configuration suggestions. E3 found that the bulk of potential energy storage revenues come from ancillary service products, namely RRS and regulation markets and a 1-hour stand-alone battery has the highest IRR while a 2-hour stand-alone battery shows the highest NPV. E3 also found that allowing the battery to charge from the grid occasionally only improves the overall revenues slightly because solar can provide most of the charging needs for capturing high-price hours. And locating in a zone with congestions from solar and wind overgeneration increases the storage revenues slightly.

Confidential Solar and Energy Storage Developer, Bid Support for Georgia Power RFP (2020). E3 supported a project developer seeking to bid solar-plus-storage hybrid projects into Georgia Power's 2020 RFP process by analyzing the cost and value of different storage configurations. E3's work quantified the value of different solar integration services defined by Georgia Power such as "smoothing" and "firming" of solar output and the cost of performing these services by a combination of solar inverter management and battery storage operations. E3's work directly informed the developer's storage sizing for multiple bid variations into this RFP.

California Energy Storage RFO Support (2019-2020). E3 has supported numerous technology firms and project developers to assess the potential value of their storage technologies for utilities with respect to grid operation, long-term procurement and planning, and integration of renewable resources. E3 is actively supporting companies in developing projects and bidding into California utility energy storage RFOs. In addition, E3 has provided portfolio procurement support to Community Choice Aggregators, including East Bay Community Energy and San Jose Clean Energy, to meet California's ambitious carbon policy goals while preserving system reliability. E3's deep understanding of load serving entities and their regulatory and financial incentives directs clients to target their solutions to those applications with the highest potential value and likelihood of adoption.

National Grid Ventures, Pumped Storage Analysis. E3 provided technical analysis and regulatory support for the 1,200 MW Goldendale pumped storage project proposed in Washington as well as the 400 MW Swan Lake pumped hydro project in Oregon both being developed by National Grid Ventures. E3 performed production simulation to quantify the benefits of pumped storage for integrating higher penetrations of renewable energy in the Western U.S. E3 also quantified the significant value of long duration storage in preventing curtailment of excess solar generation and evaluated the benefits of pumped storage for the operation of the bulk transmission system in Washington, Oregon, and California.

Confidential Battery Manufacturer, Battery Revenue and Market Analysis (2018-2019). E3 produced an analysis for a vanadium flow battery (VFB) manufacturer evaluating the comparative revenues and net market value of VFB and Lithium-Ion (Li-ion) battery technology in California ISO's NP-15 and SP-15 markets. Estimated benefits include revenues from the day-ahead energy market, ancillary services market (regulation, spinning, and non-spinning), capacity payment (e.g. resource adequacy), and potential transmission and distribution deferral values. Future market prices are forecasted using a combination of a bottom-up production simulation model and historical statistical analysis. The operation of VFB and Li-ion batteries are simulated through RESTORE, an E3 in-house energy storage optimal dispatch model. Battery operation rules are modeled in detail based on the discussion with the battery manufacturer. The study found that VFB and Li-ion with the same usable power and energy capacity provide comparable values to the system. Li-ion has higher round-trip efficiency than VFB, but the advantage Li-ion has in efficiency is offset by constraints in providing regulation services due to degradation concerns. 4-hour duration of VFB and Li-ion are close to cost-effective in 2018 under base case assumption. The base case assumes energy prices that reflect the current policy, and battery located at somewhere that has average RA prices and T&D deferral values. With the potential price declines, they can be cost-effective in the near future.

Energy Storage Market Analysis, Business Model Review, and Strategic Advice – Macquarie Capital (2016, 2018 – 2019). E3 provided analytical services, strategic advice, and market analysis support for Macquarie Capital to assess and diligence a potential $200M investment in a 50 MW distributed storage project being developed by Advanced Microgrid Solutions, Inc. (AMS) in the Los Angeles Basin. E3 performed detailed analytical simulations to verify the storage company's internal modeling of the benefits, costs, and value proposition of behind-the-meter customer sited storage assets (built on the Tesla battery pack platform) that could provide a number of different services. E3 also modeled the potential revenue streams the storage project could access over a 20-year period, which involved in-depth analysis of the project and the underlying business model as well as forecasting wholesale and retail electric markets that the project could access over its operational lifetime. Additionally, E3 provided an investment grade financial analysis and report for the project's investors and potential lenders. E3's work was a key piece of the financial due diligence where the result was a decision to extend a $200M financing arrangement with AMS to take ownership of the project. This represents the first behind-the-meter storage project to be project financed. E3 followed up this work by supporting Macqaurie Capital's Q1 2019 sale of 50% of its equity stake in the project to SUSI Partners.

Eagle Crest Pumped Storage Project (2013-2016). E3 provided technical analysis and regulatory support for the 1,300 MW proposed pumped storage project in Southern California. E3 performed stochastic production simulation to quantify the benefits of pumped storage for integrating higher penetrations of renewable energy in California. E3 quantified the significant value of long duration storage in preventing curtailment of excess solar generation. E3 also evaluated the benefits of pumped storage for the operation of the bulk transmission system in Southern California.

New York Energy Storage Roadmap – NYSERDA (2017 – 2018). E3 worked with a senior-level DPS and NYSERDA team to support the development of an Energy Storage Roadmap for New York State. The Roadmap charts a path forward to achieve Gov. Cuomo's goal to install 1,500 megawatts of energy storage by 2025, including $350 million in statewide market acceleration incentives to fast-track the adoption of advanced storage systems. In developing the Roadmap, E3 used its RESTORE Energy Storage Dispatch Model to perform in-depth economic analysis of a broad range of storage project configurations across customer, distribution and bulk system market segments. This analysis informed the Roadmap's recommendations and evaluated how they improve project economics and bankability. E3 supported the Roadmap's development through strategic advising, analysis, and stakeholder outreach. In December 2018, following months of stakeholder engagement on the Roadmap, DPS established a longer-term storage target of 3000 MW by 2030 –– the largest target among all U.S. states.

From: James,Eve A L (BPA) - PG-5
Sent: Wednesday, July 20, 2022 7:10 AM
To: Baskerville,Sonya L (BPA) - AIN-WASH
Cc: Koehler,Birgit G (BPA) - PG-5
Subject: RE: [EXTERNAL] RE: E3 briefing request

Sounds good- I'll confirm with E3.

From: Baskerville,Sonya L (BPA) - AIN-WASH <slbaskerville@bpa.gov>
Sent: Wednesday, July 20, 2022 7:09 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: [EXTERNAL] RE: E3 briefing request

Okay. Let's go with the 8:00a pacific/11:00a eastern slot on Monday. I will announce on the markets call today that I intend to send a save the date for that briefing later today. Thanks!

Sonya Baskerville
BPA National Relations
(b)(6) [redacted] m

On Jul 20, 2022 9:56 AM, "James,Eve A L (BPA) - PG-5" <eajames@bpa.gov> wrote:
Hi Sonya- these times are PDT. I will let E3 know to hold the Mon 7/25 timeslots.

From: Baskerville,Sonya L (BPA) - AIN-WASH <slbaskerville@bpa.gov>
Sent: Tuesday, July 19, 2022 9:29 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: [EXTERNAL] RE: E3 briefing request

Sorry, somehow I misses this email yesterday and today!

Let's go with one of these:
Mon 7/25: 8-9, 10-11, 12-2 (Arne only, Aaron OOO)

Are these times eastern?

Sonya Baskerville
BPA National Relations
(b)(6) [redacted] m

On Jul 19, 2022 7:11 PM, "James,Eve A L (BPA) - PG-5" <eajames@bpa.gov> wrote:
Hi Sonya- let me know if there is still interest from Congressional staff for an E3 briefing and what times from E3's availability below would work.

Thanks!

Eve

From: James,Eve A L (BPA) - PG-5
Sent: Monday, July 18, 2022 2:00 PM
To: Baskerville,Sonya L (BPA) - AIN-WASH <slbaskerville@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 (bgkoehler@bpa.gov) <bgkoehler@bpa.gov>
Subject: FW: [EXTERNAL] RE: E3 briefing request

Hi Sonya- Let us know if any of these times work for Congressional briefings:

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, July 18, 2022 1:45 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: [EXTERNAL] RE: E3 briefing request

Got it. Sharing Tue-Thurs availabilities:

- Week of 7/18: Arne out, only Aaron available
  - Tue 8:30-9:30
  - Wed 10:30-noon
  - Thurs 10-1
- Week of 7/18: Aaron out, only Arne available
  - Tue 12-1
  - Wed 8-9, 10-1
  - Thurs – unavailable
- Week of 8/1: Arne out until Fri, only Aaron Tue-Thurs
  - Tue 8:30-10:30, 11-2
  - Wed 8-9, 10-12
  - Thurs 8-9, 10-1

All the best,
Aaron

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, July 18, 2022 12:39 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: [EXTERNAL] RE: E3 briefing request

Chiming in since Eve might be at lunch. This morning was for the executive branch (CEQ, departments, and fed agencies). The thread below talks about briefings for Congressional staff.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, July 18, 2022 12:36 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: [EXTERNAL] RE: E3 briefing request

Confirming this was today's briefing, right? So you don't need further availability?

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, July 15, 2022 6:27 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: E3 briefing request

Thanks Aaron - could you also provide any availability on Tues- Thursdays? The problem is the first week of August is right before the recess so can be hectic.

Thanks,
Eve

On Jul 15, 2022 4:40 PM, Aaron Burdick <aaron.burdick@ethree.com> wrote:
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- Fri 7/29: both unavailable
- Mon 8/1: 8:30-2pm (Aaron only, Arne OOO)
- Fri 8/5: 8:30-11 (both Aaron and Arne)

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
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To: Arne Olson <arne@ethree.com>; Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: E3 briefing request

Hi Aaron and Arne-
We've been contacted from several Congressional staff that they would like to have the E3 briefing rescheduled. Could you provide times that work for you- typically Mondays and Fridays and lunch times (eastern time) tend to work best.

Thanks,
Eve

From: James,Eve A L (BPA) - PG-5
Sent: Wednesday, July 20, 2022 6:58 AM
To: Aaron Burdick; Koehler,Birgit G (BPA) - PG-5
Cc: Arne Olson
Subject: RE: [EXTERNAL] RE: E3 briefing request

Thanks Aaron- it looks like the meeting is coalescing on one of these timeslots: Mon 7/25: 8-9, 10-11, 12-2 (Arne only, Aaron OOO)

Do those times still work for Arne (and I'm assuming these are all PDT)?

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, July 18, 2022 1:45 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
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Thanks Aaron - could you also provide any availability on Tues- Thursdays? The problem is the first week of August is right before the recess so can be hectic.

Thanks,
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On Jul 15, 2022 4:40 PM, Aaron Burdick <aaron.burdick@ethree.com> wrote:
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Thanks,
Eve

From: Koehler,Birgit G (BPA) - PG-5
Sent: Wednesday, July 20, 2022 9:35 AM
To: James,Eve A L (BPA) - PG-5
Subject: RE: [EXTERNAL] RE: E3 briefing request

I'll skip my other meetings. This would be the priority for me.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, July 20, 2022 9:04 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: [EXTERNAL] RE: E3 briefing request

Sonya is trying to schedule Mon 7/25 8 – 9 PDT (11 EDT) let me know if that time is a problem.

Thanks,
Eve

From: James,Eve A L (BPA) - PG-5
Sent: Wednesday, July 20, 2022 6:58 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: [EXTERNAL] RE: E3 briefing request

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Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: [EXTERNAL] RE: E3 briefing request

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To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: E3 briefing request

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On Jul 15, 2022 4:40 PM, Aaron Burdick <aaron.burdick@ethree.com> wrote:
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- Fri 8/5: 8:30-11 (both Aaron and Arne)

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Aaron

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Sent: Thursday, July 14, 2022 3:35 PM
To: Arne Olson <arne@ethree.com>; Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5

<bgkoehler@bpa.gov>
Subject: E3 briefing request

Hi Aaron and Arne-
We've been contacted from several Congressional staff that they would like to have the E3 briefing rescheduled. Could you provide times that work for you- typically Mondays and Fridays and lunch times (eastern time) tend to work best.

Thanks,
Eve

From: Koehler,Birgit G (BPA) - PG-5
Sent: Thursday, June 2, 2022 1:14 PM
To: Aaron Burdick; James,Eve A L (BPA) - PG-5
Cc: Arne Olson
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

If I were texting, I'd insert the thumbs-up emoji.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 1:01 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Ok. Seems more appropriate in a footnote to me. How about I add this footnote to slide 17? "Replacement resource costs are calculated assuming project financing per E3's pro forma calculator, rather than assuming upfront congressional appropriation."

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Thursday, June 2, 2022 12:54 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

...based on assuming that replace resource projects are financed rather than paid for upfront using $X billion appropriations of cash from congress
Yes, this is exactly what were meant. If you have a better way to phrase it than the current text, that's great.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 12:48 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Thanks. Follow up question below. We're working on pulling the 2C scenario "as much as" cost metrics. Hoping to complete that and send later today.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 2, 2022 12:32 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Thanks Aaron- how about replace that statement then with "E3 assumed transmission would be built as needed for renewable additions" to be clear of what transmission builds are in the study (please keep the suggested addition in italics about Congressional approval to breach the dams). We keep getting questions around Tx build outs.

Other comments below.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 12:25 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Re: slide 3, I also don't get this one: "E3 assumed the region is building the transmission needed even if the dams are not breached."

We assume transmission would be built as needed for renewable additions, etc. But we don't assume that any transmission needed for dam replacement would be built if the dams aren't getting replaced... Let me know if I am misunderstanding something.

Aaron

From: Aaron Burdick
Sent: Thursday, June 2, 2022 12:21 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

A few specific responses and one question response needed to proceed:

- Slide 15: yes, this is H2 generation. Adjusted and added footnote to clarify.
- Slide 17: you suggested adding "if region funds through debt financing over 50 years rather than upfront appropriations from Congress". Our resource cost inputs are developed using E3's pro forma project financing model that is based primarily on PPA off-taker prices for new resource additions. The debt vs. equity ratios depend on the technology (E3 developed this dataset based on the NREL Annual Technology Baseline), but they all assume a blend. Financing lifetimes change depending on the technology.
  That makes sense, maybe it should read "if region funds through debt financing rather than upfront appropriations from Congress"

Do you mean that annual costs would be $XM per year based on assuming that replace resource projects are financed rather than paid for upfront using $X billion appropriations of cash from congress? Are you just trying to have us state that the costs assume project financing for replacement resources?

- Slide 17: "by 2045" vs "after 2045". I prefer "by" since it implies costs before 2045 as well. "After" to me implies the costs are only occurring after 2045. By works- I meant to put the added words after the text 2045
- Question re: slide 3 feedback:
    - BPA said:
        - Bullet 2: How much would it cost to replace the power benefits of the four Lower Snake River dams, in E3's study?
            - 2a: Given the trends towards aggressive carbon reduction policies, total costs would be $X.X billion in upfront capital costs, with ~XXX million per year for operational cost, absent breakthroughs in not-yet-commercialized emerging technologies. $46 billion total net present value (NPV) costs
                - QUESTION: when we just showing the S1 baseline, no range was needed. Seems like we either need to say "increase AS MUCH AS" or provide a range for the 3 deep decarb scenario we ran. Should I use "as much as" per the prior version's use for the third bullet on public power cost increases? Yes- that works
            - 2b: With today's carbon reduction policies, total costs would be $2.8 billion in upfront capital costs, with ~$110 million per year for operational cost. $7.5 billion total NPV costs

Thanks,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, June 1, 2022 8:45 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Good Morning-
For some reason I wasn't able to successfully save the PDF of your slide deck with my comments on the slides so I'm attaching a PPT with 2 slides that have some notes and suggestions for your consideration. We also started working on a handful of slides on BPA's perspective for either introduction or after your slides (I'm currently leaning on takeaways once you present the results). We are hoping to send materials to DOE by the end of the week to get their OK to set up a meeting with CEQ so a fast turn-around would be helpful. I'm attaching a rough draft of the slides we are currently working on (it's still a work-in-progress) so you can get an idea of what we are thinking.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, May 27, 2022 5:40 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

One minor tweak made on slide 9. Please use this updated version.

All the best,
Aaron

From: Aaron Burdick
Sent: Friday, May 27, 2022 5:25 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Updated deck is attached.

We noted 700-900 aMW for now on slide 3, pending any further data/guidance on this (though we've still modeled 706 aMW in our RESOLVE cases).

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, May 27, 2022 3:59 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

I was pulling some data and see that the 1,030 aMW number in the EIS is in reference to the No Action Alternative baseline. Most folks are out of the office by now for the holiday weekend so I'll make sure on Tuesday I get the correct LSN gen data. Some white book data I was looking at had the LSN gen ~940 aMW but I want to make sure it has the correct spill operation.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, May 27, 2022 11:32 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

We're nearing a second draft. Can we meet briefly after lunch to discuss how we've integrated the BPA feedback and confirm any open questions? Are you free at 2pm?

Aaron

From: Aaron Burdick
Sent: Thursday, May 26, 2022 8:32 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>

Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Thanks Eve. I'll work from this version as I make updates today and tomorrow. I'll follow up by end of day with any questions.

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, May 25, 2022 4:20 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Attached are some "notes" for you to consider in the presentation. You can copy and paste into your template slides for the suggestions you like- feel free to edit and reword as needed. We will find out on Thursday if the presentation materials are needed on Friday so hopefully we can keep making progress on this. We had hoped to use a single presentation for CEQ and the broader public but realized we need to go to a higher level and focus on some different points with CEQ. The attached presentation is focused on CEQ as an audience.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, May 25, 2022 11:59 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Johnson,G Douglas (BPA) - DK-7 <gdjohnson@bpa.gov>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Eve – thanks for the note on that. I wasn't quite following the logic of how those first couple slides fit into the flow, so will await your further thoughts.

Douglas – thanks for your feedback. I will work to incorporate as we update over the next couple days.

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, May 25, 2022 8:46 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Johnson,G Douglas (BPA) - DK-7 <gdjohnson@bpa.gov>
Subject: RE: BPA-E3

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Cc: Arne Olson <arne@ethree.com>
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DELIBERATIVE FOIA EXEMPT

Sure. See attached.

Aaron

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Cc: Aaron Burdick; Diffely,Robert J (BPA) - PGPL-5; Koehler,Birgit G (BPA) - PG-5 (bgkoehler@bpa.gov); Arne Olson
Subject: FW: BPA-E3
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Meeting number (access code): [redacted]

Meeting password: 5UKeHJ2kK@2

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Join by phone

+1-415-527-5035 US Toll

Global call-in numbers

Join from a video system or application

Dial [redacted]@mybpa.webex.com

Need help? Go to https://help.webex.com

From: James,Eve A L (BPA) - PG-5
Sent: Wednesday, June 1, 2022 8:45 AM
To: Aaron Burdick; Koehler,Birgit G (BPA) - PG-5
Cc: Arne Olson
Subject: RE: BPA-E3
Attachments: LayPersonPPT_5-31_eajcomments.pptx; BPA bottom line perspective from the E3 study kps 6 1.pptx

DELIBERATIVE FOIA EXEMPT

Good Morning-
For some reason I wasn't able to successfully save the PDF of your slide deck with my comments on the slides so I'm attaching a PPT with 2 slides that have some notes and suggestions for your consideration. We also started working on a handful of slides on BPA's perspective for either introduction or after your slides (I'm currently leaning on takeaways once you present the results). We are hoping to send materials to DOE by the end of the week to get their OK to set up a meeting with CEQ so a fast turn-around would be helpful. I'm attaching a rough draft of the slides we are currently working on (it's still a work-in-progress) so you can get an idea of what we are thinking.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, May 27, 2022 5:40 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

One minor tweak made on slide 9. Please use this updated version.

All the best,
Aaron

From: Aaron Burdick
Sent: Friday, May 27, 2022 5:25 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Updated deck is attached.

We noted 700-900 aMW for now on slide 3, pending any further data/guidance on this (though we've still modeled 706 aMW in our RESOLVE cases).

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, May 27, 2022 3:59 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

I was pulling some data and see that the 1,030 aMW number in the EIS is in reference to the No Action Alternative baseline. Most folks are out of the office by now for the holiday weekend so I'll make sure on Tuesday I get the correct LSN gen data. Some white book data I was looking at had the LSN gen ~940 aMW but I want to make sure it has the correct spill operation.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, May 27, 2022 11:32 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

We're nearing a second draft. Can we meet briefly after lunch to discuss how we've integrated the BPA feedback and confirm any open questions? Are you free at 2pm?

Aaron

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DELIBERATIVE FOIA EXEMPT

Thanks Eve. I'll work from this version as I make updates today and tomorrow. I'll follow up by end of day with any questions.

All the best,
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DELIBERATIVE FOIA EXEMPT

Eve – thanks for the note on that. I wasn't quite following the logic of how those first couple slides fit into the flow, so will await your further thoughts.

Douglas – thanks for your feedback. I will work to incorporate as we update over the next couple days.

Aaron

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Meeting password: (b)(6) [redacted]

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Join by phone

+1-415-527-5035 US Toll

Global call-in numbers

Join from a video system or application

Dial 27627102796@mybpa.webex.com

Need help? Go to https://help.webex.com

Small Edit Suggestions:

Global Comment: lower is not part of the name of the river and should not be capitalized when in the middle of a sentence. Some places it is correct like Slide 6, others it is capitalized.

Slide 1: Please put "power" in front of replacement so clear not including navigation, irrigation, etc..

Slide 2: Please put "power" in front of services (bottom right corner) so clear not including navigation, irrigation, etc..

Slide 3- This slide had most comments so it is the next slide with text box suggestions

Slide 5- Under "Annual Carbon-Free Energy" please put same range as slide 3 (0.7 – 0.9 GW), Also beside Tx Reliability services maybe a bracket to the right that says some of these services are provided by the replacement resources but others may need to be purchased at additional cost

Slide 14- For scenario 2a: Did you mean to put TWh when others are in GW? One is a rate and one is capacity number. See our suggestion for footnote. If this is the energy of H2 for the 2.0 GW dual fuel number maybe it should get deleted or a sub-bullet under dual fuel but doesn't belong in a separate line item? It's confusing. Under table suggest for a footnote explaining 1 GW = 1,000 MW and if keep TWh then 1 TWh = 1.1 GW of generation every hour of the year

Slide 15: For 3rd table next to chart- "retail" should be added before rates? Or you could put "retail" before the word costs (Public Power Retail Costs). For the 3rd footnote bullet suggest wording "% increase versus average retail rates assumes 8.5 cents/kWh retail rates (estimated from OR and WA average retail rates)"

Slide 17: Bullet 1- sub-bullet 2 : suggest adding after 2045 "if region funds through debt financing over 50(is 50 correct?) years rather than up front appropriations from Congress"

Bullet 1- sub-bullet 4: Maybe use per year per household as metric instead of cents/kWh - maybe add percentage in parenthesis and info on total number of customers or households again to match slide 3

Slide 18 Title: Is "Important Considerations" a better term so it doesn't seem like an after-thought?

What would it take to replace the output of the four Lower Snake River Dams?

Key Study Conclusions

+ **What energy services are lost if the dams are breached?**
  - 3,483 MW of nameplate capacity, including

    For bullet 1b is it possible to add some lay-person context e.g. XX households or city the size of Portland?

    weather events
  - ~700-900 annual average MW of low-cost, zero-carbon energy as well as operational flexibility services

+ Bullet 2: How much would it cost to replace the power benefits of the four Lower Snake River dams, in E3's study?
  2a: Given the trends towards aggressive carbon reduction policies, total costs would be $X.X billion in upfront capital costs, with ~XXX million per year for operational cost, absent breakthroughs in not-yet-commercialized emerging technologies. $46 billion total net present value (NPV) costs
  2b: With today's carbon reduction policies, total costs would be $2.8 billion in upfront capital costs, with ~$110 million per year for operational cost. $7.5 billion total NPV costs

+ **What are th**

  Bullet 3: How many customers or households does this number represent? E.G. Public power costs increase by 9% or ~$125 per year, per household, for XX households (baseline scenario) [E3 was it households or customers? We want to quantify # of people affected. Please also reverse two sub-bullets to match order in Bullet 2. Deep carbon goes first]
  - Public
  - Public breakth

nt	Nameplate Capacity (MW)
wer anite	930
tle	930
ntal	930
or	693

Total = 3,483 MW

+ **What resources are needed to replace the dams?**
  - A combination of energy efficiency, renewable generation (wind), and "clean firm" capacity additions (such as dual fuel natural gas + hydrogen plants, advanced nuclear, or gas with carbon capture and storage)
  - Battery storage cannot cost-effectively replace hydro capacity in the Northwest due to charging limitations during energy shortfall events

+ **What is the timeline necessary to add the resources that would be required?**
  - E3 estimate 10 years if

    Bullet 5: sub bullet- E3 estimates that adding renewable energy and firm capacity additions would take approximately 5 years ***after congressional approval to breach the dams*** and possibly up to 10 years if additional new transmission was required. E3 assumed the region is building the transmission needed even if the dams are not breached.

27691309(01).pdf

The Bottom Line

Bonneville perspective on E3 study

B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

Would conclusions in the E3 study change the decision for the Columbia River System Environmental Impact Statement ?

- **No.** In fact, the E3 study **confirms** the decision.
- The E3 study provides an updated picture of the energy landscape:
  - **Policy decisions** and legislation in the region are having a very real-world effect to the amount of resources available to provide firm capacity to avoid power shortages. Specifically, fossil-fuel based resources, such as coal plants, are being removed. This is happening now.
  - Compounding the situation from removing fossil fuel resources, decarbonizing the region will result in **increased electricity use** in transportation (such as electric vehicles) and heating/cooling buildings (changing from gas to electric).
  - The E3 study also considers the **availability of emerging technology** in future scenarios. Even considering emerging technology such as battery storage, the region would face power shortages if the four lower Snake River dams are breached, given the path towards deep carbonization of the energy sector.

What power benefits do the four lower Snake River dams provide?

Reliable power to avoid blackouts

- For region and for BPA
- For regional human health and safety issues

Carbon-free power to fight climate change

- In the Northwest, the hydropower system provides carbon-free power
- Hydropower system enables addition of variable renewable resources, such as wind and solar, to the region

- 3,483MW in nameplate capacity
  – historically generation has peaked at XXX MW
- More than 2,000 MW of sustained peaking capabilities during cold winter weather events to **avoid power shortages**
- A quarter of Bonneville's current reserves holding capability which is **important for integrating variable generating resources** such as wind and solar
- **Essential transmission reliability** services such as voltage support, reactive power, inertia, black start, etc…

Maintaining these carbon-free assets is an important component of shifting to a cleaner electricity grid. Loss of these assets, or reductions in their flexibility, while there are still fossil fuel generators on the grid will **increase the timeframe and costs associated** with shifting to a carbon-free electricity sector.

While it is *feasible* to replace power benefits of the lower Snake River dams, it is not *cheap, fast, or easy.*

- **Not cheap**
  - XXX for public power total, assuming paid for with debt spread over 50 years.
  - XXX for each public power household per year
  - XXX households affected
- **Not fast**
  - Up to XXX years total
    - XXX for Congressional approval
    - XXX to replace the capacity resources
    - XXX to build transmission, which includes providing compliance with the National Environmental Policy Act, siting, permits, etc.
- **Not easy**
  - Policy requirements to reduce emissions is removing resources fossil fuel resources from the grid. Removing the four lower Snake River dams significantly **adds to the deficit of resources** in the region.

Acquiring replacement resources could require **building new renewable resources at an unprecedented rate.**

While it is *feasible* to replace power benefits of the lower Snake River dams, it is not *cheap, fast, or easy.*

- Replacing the lost power with new resources would require roughly X acres (about X square miles) of land.
- Such a large build out of capacity would likely result in additional, but currently unknown impacts to natural and cultural resources.
- Environmental issues associated with extensive builds of renewable resources include mining metals for batteries and solar infrastructure, which introduce land use issues and toxins into the environment.
- Relying on emerging technologies is risky -- timeline of development is highly uncertain and some may never mature to commercially viable.
- Supply chain issues impact rate of developing resource replacements.

Diablo Canyon-like map

Comparison to NWEC study

- The Northwest Energy Coalition study incorrectly describes the capacity of the four lower Snake River dams as 1,000 MW, when in fact, the nameplate capacity is 3,483MW and sustained capacity is over 2,000 MW.
  - The region regularly calls upon more than 2,000 MW of sustained peaking capabilities, to **avoid power shortages** during the winter
- Baseline for the NWEC study assumes that BPA purchases 300 MW from the market to provide firm power.
  - While BPA sometimes purchases power to serve its customers, the availability during times of high demand (winter cold snaps or summer heat events) there often is not enough power on the market, and other utilities may be declaring energy shortage emergencies.
- The NWEC study understates the benefits that the four lower Snake River dams provide in terms of grid stability – ancillary services required to keep the lights on.
  - In addition to providing sustained peaking capacity the lower Snake River dams provide generation reserves that can provide additional generation on short notice for grid stability and to integrate other variable resources such as wind and solar.

From: Koehler,Birgit G (BPA) - PG-5
Sent: Wednesday, May 25, 2022 9:09 AM
To: James,Eve A L (BPA) - PG-5
Subject: RE: BPA-E3

I forgot about the seasonality. In the winter any reserves can be put on there

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, May 25, 2022 9:08 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: BPA-E3

I think he means contingency reserves which aren't used as frequently as the balancing. But I would have to check because I think that is correct during fish spill season but not winter time.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, May 25, 2022 9:05 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: RE: BPA-E3

Am I confused. Aren't balancing reserves a part of operating reserves?
Balancing + contingency = operating?

Maybe my brain is off this morning. That is certainly a possibility.

From: Johnson,G Douglas (BPA) - DK-7 <gdjohnson@bpa.gov>
Sent: Wednesday, May 25, 2022 9:02 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

Thanks for sharing. A few thoughts below:

Slide 3, bullet 3: My understanding is that the LSRDs are used for operating reserves. While this does free up other facilities for balancing reserves, we need to be clear on that. Breaching advocates jump on it when they see us claiming LSRDs are involved directly in renewable integration/balancing.

Slide 13: We talk about transmission costs for "essential reliability services" not being considered. Do the costs include ANY estimated transmission costs? I would assume any build out of renewables and other resources to replace the LSRDs would need additional transmission to interconnect. Is that a correct assumption?

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Sent: Tuesday, May 24, 2022 4:44 PM

To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
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To: Aaron Burdick; Koehler,Birgit G (BPA) - PG-5
Cc: Arne Olson
Subject: RE: BPA-E3
Attachments: LayPersonPPT 5 25 mid-afternoon.pptx

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Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, May 25, 2022 11:59 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
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Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Eve – thanks for the note on that. I wasn't quite following the logic of how those first couple slides fit into the flow, so will await your further thoughts.

Douglas – thanks for your feedback. I will work to incorporate as we update over the next couple days.

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
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Hi Aaron-
I received from feedback that the "Bottom-Line Up Front" and Conclusion slides need some more work so we'll send another draft hopefully later this morning. The comments on the middle section of the deck should be fine for you to incorporate.

Thanks,
Eve

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Sorry for the additional email – in response to the question about slide 4 – I think a brief description of capacity, energy, nameplate capacity, etc., would help. We can also plug in a couple of bullets from our news releases about the LSRD contribution to keeping the lights on during the cold snap and severe weather in winter 2021 and the June 2021 heat dome event.

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Title slide

What it would take to replace the output of breachi ... ams

are exaggerating by only putting out the nameplate. Others are saying 1,000 --we need to put our sustained capacity number up front to counter that narrative accurately

- What are we losing?
  - 3,483 MW of nameplate capacity, including more than 2,000 MW of peaking capability to avoid power shortages during cold weather events
- How much would it cost to replace benefits of the four lower Snake River dams?
  - Upfront costs: $XXX (with today's carbon policy)
  - Total cost per year after that: $XXX
  - These costs could quadruple with aggressive carbon reduction policies and absent breakthroughs in commercial-scale technology

E3 please fill in these numbers, first number is construction, second is O&M and fuel? Use S1

Plant	Nameplate Capacity (MW)*
Lower Granite	930
Little Goose	930
Lower Monumental	930
	693
	Total = 3,483

- What are the rate impacts to public power customers?
  - Public power costs increase by 9% or $100 per year (with today's carbon policy)
  - Public power costs increase by 65% or $850 per year (with aggressive carbon reduction policies and absent breakthroughs in commercial-scale technology)

E3, are these numbers right? The second set is about 7 times the % but 8.5 times the $. Is it a rounding issue? We copied from your slide deck

- How long would it take to replace the services from breaching the four lower Snake River dams?
  - It would take up to a decade or more to bring new resources on-line once a decision to breach the dams has been reached.

Does E3 have anything more definitive on timeline, including transmission?

What services need to be replaced if the four lower Snake River dams are breached?

- What are the services we need to replace, and what is the cost of each?
  - Energy
  - Instantaneous and sustained capacity
  - Reserve carrying capacity
  - Fast ramping

These costs are included in model results XX MW XX$ from previous slide

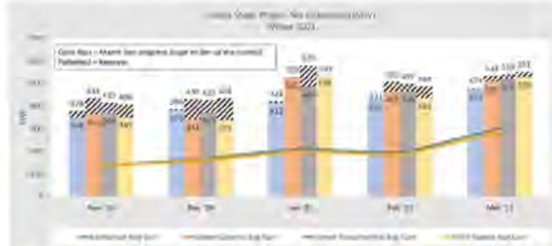
  - Transmission grid reliability services:
    - Voltage and reactive power: XXX MW for $XXX
    - Frequency and inertial response: XXX MW for $XXX
    - Blackstart capability: XXX MW for $XXX
    - Short-Circuit and Grounding Contribution: XXX MW for $XXX
    - Voltage and Frequency Excursion Ride-Through XXX MW for $XXX
    - Participation in Remedial Action Schemes: XXX MW for $XXX

Does E3 have cost estimates for these?
DOE said these are small costs compared to power services, and some are provided by the replacement resources. If we can't quantify them, we omit the costs and the bracket. But we should still list the services. Then we could also remove all mention of costs in the upper section of this slice since that was on the previous slide, i.e. remove the green text

	city
Lower Granite	930
Little Goose	930
Lower Monumental	930
Ice Harbor	693
	Total = 3,483

Lower Snake River Dams' Capabilities

- Lower Snake River Dams are ~10% of the Northwest hydro capacity and provide **low cost**, reliable, **carbon-free energy**, and high flexibility
- Provide **more than 2,000 MW** of sustained peaking capabilities during the winter, as shown in the bar graph to the right
- Provide a quarter of Bonneville's current reserves holding capability which is **important for integrating variable generating resources** such as wind and solar.
- Also provide **essential transmission reliability** services such as voltage, reactive power, inertia, black start, etc...



The solid bars show what was generated in winter 2020-2021, and the patterned bars shows additional available capacity. As the graph shows, it's not atypical to call on more than 2,000 MW of peaking capacity in the winter to avoid a power shortage, even sometimes more than 2,200 MW.

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About the E3 study

- E3 conducted an independent analysis of replacing the power output from the four lower Snake River dams in the context of Pacific Northwest resource requirements.
- BPA contracted E3 to conduct the study, which includes independent analysis about the value of the four lower Snake River dams to the Northwest energy system, including the **cost** and **resource requirements** for replacement.
- This study takes a regional view of electricity supplies and uses E3's RESOLVE electricity planning model to optimize electricity resource requirements for the Northwest through 2045.

What's new in this study compared to CRSO EIS

Updated resource pricing and included emerging technology. The study uses an optimizer to determine the least-cost replacement resources for the four lower Snake River dams subject to **policy** and **reliability** constraints.

- **Policy example**: E3's modelling considers the effects of regional policy decisions and legislation to reduce carbon emissions
  - Includes aggressive clean energy laws which remove fossil fuel-based power resources from the grid all along the west coast (such as retiring coal plants)
  - Compounding the situation from removing fossil fuel resources, decarbonizing the region will result in increased electricity use in transportation and building heating/cooling

- **Reliability example**: The E3 modelling considers multiple variables – not just cost. For example, the modelling considers how much capacity a resource actually has, and then prioritizes it based on its ability to provide reliable electricity when needed.
  - During extended cold-weather periods the wind isn't always blowing and the sun goes down at night
  - Even if those resources are the cheapest, the optimizer doesn't choose them because the capacity is not always available to provide power when needed

Transition slide. Does not need to say much

E3's modeling (called RESOLVE) occurred in two steps.

The first step looked at the energy landscape of the Northwest to provide critical context for the study of lower Snake River dam breaching.

Energy Policy Landscape: policy decisions in the region require reducing carbon emissions

Policy Landscape: Washington, Oregon, California

	RPS or Clean Energy Standard?	Coal Prohibition?	Cap-and-Trade?	New Gas?	Economy-Wide Carbon Reduction?
WA	✓ Carbon neutral by 2030, 100% carbon free electricity by 2045	✓ Eliminate by 2025	✓ Cap-and-invest program establishe in 2021, SCC in utility planning		✓ GHG emission ion below 1990 s and achieve ro emissions by 2050
OR	✓ 50% RPS by 2040, 100% GHG emission reduction by 2040, relative to 2010 levels	✓ Eliminate by 2030	✓ Climate Protection Plan adopted by DEQ in 2021 (power sector not included)	× HB 2021 bans expansion or construction of power plants that burn fossil fuels	✓ 90% GHG emission reduction from fossil fuel usage relative to 2022 baseline
CA	✓ 60% RPS by 2030, 100% clean energy by 2045	✓ Coal-fired electricity generation already phased out	✓	× CPUC IRP did not allow in recent procurement order	✓ 40% GHG emission reduction below 1990 levels by 2030 and 80% by 2050

E3, when you say "gas" it is not clear if you mean natural gas or any gas including hydrogen. Best to always be clear.

Added from technical presentation since thought it added valuable context

Key Modeling Assumptions of E3 Study

Element	Study Approach	Impact on Dams Replacement Needs
Study Years	• 2025 through 2045, including fuel price forecasts and declining renewable + storage costs	Considers long-term needs
Clean Energy Policy Scenarios	• Aggressive OR+WA legislation reflected, including coal retirements + carbon pricing • Two electric emissions scenarios considered: 1. 100% clean retail sales (~85% carbon reduction*) 2. Zero-emissions (100% carbon reduction)	Clean energy policy requires long-term **replacement of LSR dams with GHG-free energy**
Load Growth Scenarios	• Two load scenarios: 1. **Baseline** (per NWPCC 8th Power Plan) 2. **High electrification** load growth (to support economy-wide decarbonization)	Higher load scenarios **increase the value of LSR dams energy + firm capacity**
Reliability Needs PSM(-E39 EAJ1	• Modeling ensures reliability needs during extreme conditions (e.g. high loads + low hydro) Captures ability (and limits) of renewables, battery storage, and demand response to support system reliability	Reliability needs require **replacement of LSR dams firm capacity contributions**
Consideration of Emerging Technologies	• Broad range of dam replacement technology options considered: • **Baseline technologies**: solar, wind, battery + pumped storage, energy efficiency, demand response, dual fuel natural gas + hydrogen combustion plants • **Sensitivities:** • **Emerging technologies** • **No New Combustion**	**Technology available for LSR dams replacement** determines cost + feasibility
Distributed Energy Resource Options	• Energy efficiency, demand response, and customer solar embedded into modeling inputs • Additional energy efficiency and demand response can be selected	**Demand resource can help replace LSR dams**, though low-cost supply is limited

* A 100% clean retail sales target allows emissions for electric generation beyond that needed to serve "retail sales", i.e. losses during transmission to retail loads and exported energy

Scenarios in E3 Study

The study uses these two scenarios to represent bookends of how electricity use will change in the region to achieve carbon reduction goals

- Scenario1: 100% Clean Retail Sales
  - E3 how would you describe this to your next door neighbor? (we at BPA aren't even quite clear what is included)
  - Business-as-usual load growth
  - Can be achieved using existing mature technologies

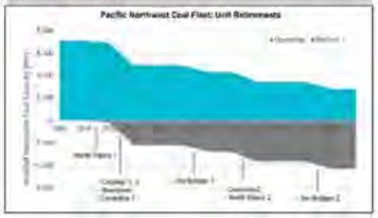
Scott, CEQ will be tuned in to "decarbonization" as it is a big issue for the Biden administration

- Scenario 2: Deep Decarbonization and Electrification
  - Zero carbon emissions remain in 2045
  - Electricity use increases to replace carbon emissions from other sectors of the economy such as transportation (e.g. electric cars replacing gas-power cars)
  - Emerging technologies are key to meeting higher winter reliability needs with carbon-free power (three variations represented by 2a, 2b, and 2c)

Key points for understanding the regional analysis (without breaching the four lower Snake River dams)

- Regional policy requirements and legislation to reduce emissions are removing resources fossil fuel resources from the grid. This is happening now, even without breaching the four lower Snake River dams.
- Consequently, with retiring coal and gas plants, the region is ***already*** facing resource adequacy issues.

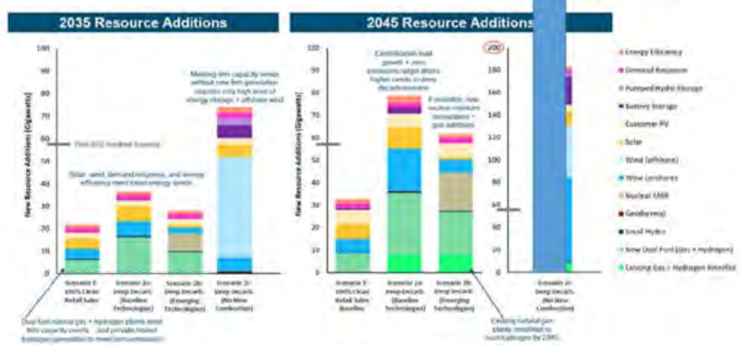
Blue area above the line shows coal plant nameplate capacity in the Pacific Northwest. The gray area below the line shows planned retirements as of 2021. Carbon policy changes and utility IRP decisions may accelerate or slow these retirements.



From Council's power plan (8th power plan, i.e. 2021 plan)

The graph shows the concepts from the previous slide: Without breaching the lower Snake River Dams, all scenarios show large levels of new resource additions for the region due to fossil-fuel plant retirements and increased electric demand

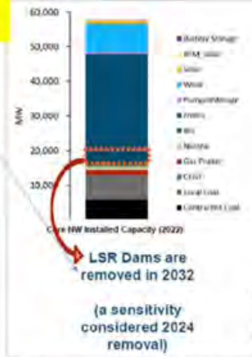
E3, please make this to scale. People won't notice the small circle on the scale. It looks effective if this one bar shoves the text out of the way to stick up high



After the first modeling step, which showed the regional energy landscape, the second step in modeling analyzes breaching the lower Snake River dams

Transition slide.
Also note, throughout presentation, please use "breach" instead of "remove" when referring to the dams. Critical distinction is that we are not removing the whole dams.

The left box above shows the second step in the modeling. The difference between the first and second steps shows how many more new resources would the region need, and at what cost if the lower Snake River dams were breached?



This graph shows the reduction in regional resources to reflect the loss of generation from the lower Snake River dams.

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Total Cost of Replacement Resources for the Lower Snake River Dams (assuming debt financing so costs are spread over 50? years)

- Costs are expected to fall on Bonneville Power Administration's public power customers
  - Could **increase public power retail costs** by up to 65%
  - Could **raise residential electricity costs** by up to $850 per year

This slide is total costs that CEQ will relate to

	Total Costs	Annual Cost Increase			Incremental Public Power Costs (% increase vs. ~6.5 cents/kWh NW average rates)
	2022 Net Present Value	[illegible]	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$3.3 billion	-	$434 million	$478 million	0.6 cents/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam removal)	$7.2 billion	$495 million	$466 million	$509 million	0.6 cents/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$5.0 billion	-	$496 million	[illegible] million	1.5 cents/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$3.0 billion	-	$415 million	$428 million	0.7 cents/kWh [+8%]
Scenario 2c: Deep Decarb. (No New Combustion)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Don't say Outlier case

NOTES:
- Cost increases account for replacement energy, capacity, and reserves as well as avoided LSR capital + expense, but do not include any costs for breaching the dams, which would be an additional cost.
- NPV and annual cost increase are shown for the Northwest Region as a whole, but the incremental costs are calculated relative to the BPA Tier 1 annual sales for public power customers.
- % increase versus average rates assumes OR + WA average retail rates are ~6.5 cents/kWh. This does not include additional rate increases driven by higher loads or clean energy needs that increase regional rates as shown in the earlier 2045 incremental cost chart.
- Annual residential customer cost impact assumes 1,280 kWh/month for average residential customers in Oregon and Washington (current ~1,000 kWh/month average + 28% from electrification load growth).

Cost of Generation of Replacement Resources for the Lower Snake River Dams (using utilities' metric of $/MWh)

- Even in the best case scenario, replacement power would cost several times as much as the current cost of generation from the lower Snake River dams.
- Replacement resources for the four lower Snake River dams range in costs from $77/MWh to over $500/MWh, depending on carbon-reduction policies and the availability of emerging technology.

Incremental LSR Dam Replacement Resourc

	Lower Snake River Dams All-in Generation Costs (2022 $/MWh)
	[illegible]
	$17/MWh w/ LSRCP*

Scenario	2045 Costs to replace LSR Generation** (real 2022 $/MWh)
S0: No Policy Reference	[illegible]
S1: 100% Clean Retail Sales	[illegible]
S1a: 100% Clean Retail Sales (no carbon price)	[illegible]
S1b: 100% Clean Retail Sales (2024 dam removal)	[illegible]
S2: Deep Decarb	[illegible]
S2b: Deep Decarb, w/ Emerging Tech	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

This slide is cost/MWh that DOE will relate to. Also it matches well with NGO studies that claim it is cheap to buy power, citing cost/MWh

E3 please take out scenarios not used in public deck for this table

Land use considerations – large footprint for replacement resources

- Replacing the lost power with new resources would require roughly ___ acres (about ___ square miles) of land.
- Such a large build-out of capacity would likely result in additional, but currently unknown impacts to natural and cultural resources, which may include vegetation, wildlife habitat, archeological resources, and traditional cultural properties (such as sites or land features that are important to tribes).
- Impacts from mining minerals for new technology may also impact availability of new resources

E3, can you produce this map? BPA is not producing it.

We would like to see a map of (land-use) footprint needed for replacement resources, overlayed. Maybe Seattle map? Or LSN dam area?
Table to the right is not meant for display but instead for generating the map.
Seattle is 142.55 square miles for reference (not sure if metro area)
Potentially use different boxes to show how much of Seattle gets covered for the different scenarios? Might take some experimenting.

Sample map at the right is one that our execs sent us as an example

Year	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Reliability Metric	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	PRM
Gas (MW)	2100	1800	2200	2000			1500 (H2)
DR (MW)							
Solar (MW)		-500			1500	1600	
Batteries (MW)		100	100	200	6000	300	
Wind (MW)	200	1300		600	9400		600
Offshore Wind (MW)						13000	
Pumped Storage (MW)					300		
Conservation (MW)					10	10	
SMR (MW)							600
Wind (Sq Miles)	7.8	50.8	0.0	23.4	367.2	0.0	23.4
Offshore Wind (Sq Miles)						1204.4	
Solar (Sq Miles)		-1.3	0.0	0.0	4.0	4.3	0.0

Conclusion and summary

- The study considers two important factors in replacing power from the four lower Snake River dams:
  - Power must **provide firm capacity** (reliable energy that is available at all times) to avoid power shortages
  - Power must be **free of greenhouse gases** to meet regional carbon policies

- Policies and laws to decarbonize the region will **increase electricity use** (electric cars, replacing gas appliances, etc.)

- Acquiring replacement resources could require **building new renewable resources at an unprecedented rate.**
  - This would also require building transmission to bring the power from new resources to utilities (E3 one of your slides had current resource build rate for NW- maybe add that here?)

- Replacing the dams comes at a **substantial cost** for new resource replacement
  - This would have a meaningful impact on the rates of Bonneville Power Administration's public power customers.

- The **availability of emerging technology** is a factor in achieving replacement recourses that are free of greenhouse gasses and the pace of development is highly uncertain.

- Loss of generation from the four lower Snake River dams, or reductions in their flexibility, while there are still fossil fuel generators on the grid will increase the timeframe and costs associated with shifting to a carbon-free electricity sector

E3: We would like that last sentence to stand out

Scott, this last bullet is important for our target audience

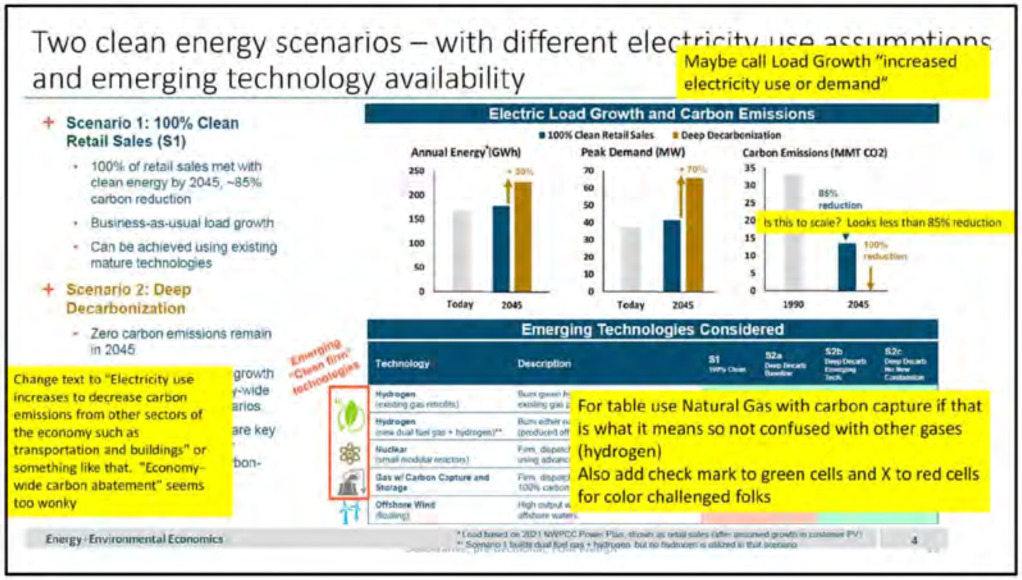
Appendix

- or slides we might save for a public presentation that can be more technical than the one we need asap for CEQ/DOE

Do we need to explain Capacity, energy, nameplate capacity?

Doug Johnson- thoughts on this for lay readers? Birgit thinks this is needed to ground reader –we'll keep this in the public version when we have more detail, but not in the CEQ version

It will provide a transition to next slide- study that E3 conducted sustained capacity was the most critical replacement needed from power perspective particularly for multi-day winter cold weather events



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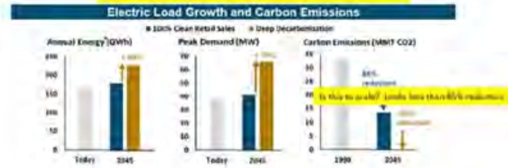
What's new in this study compared to CRSO EIS

The study uses these two scenarios to represent bookends of how electricity use will change in the region to achieve carbon reduction goals (see bar chart)

- Scenario1: 100% Clean Retail Sales
  - E3 how would you describe this to your next door neighbor?
  - Business-as-usual load growth
  - Can be achieved using existing mature technologies
- Scenario 2: Deep Decarbonization (3 variations in emerging technology availability)
  - Zero carbon emissions remain in 2045 (2045
  - High electrification load growth consistent with economy-wide carbon abatement scenarios
  - Emerging technologies are key to meeting higher winter reliability needs with carbon-free power

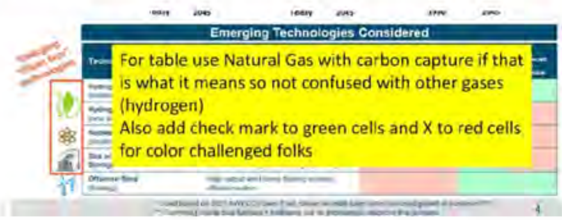
Maybe call Load Growth "increased electricity use or demand"



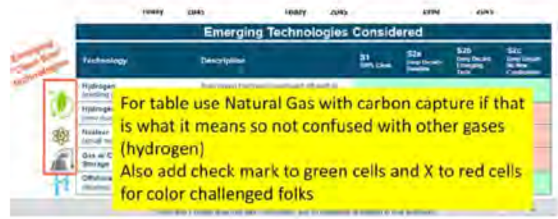
What's new in this study compared to CRSO EIS

Scenario 1 shows the impacts of carbon policy
Scenario 2 in three variations of emerging technology availability

The table below shows which resources can actually meet electricity demand(in green boxes), not just how much it costs. For example, the modelling considers how much capacity a resource actually has, and then prioritizes it based on its ability to provide reliable electricity when needed.



Two clean energy scenarios – with different electricity use assumptions and emerging technology availability

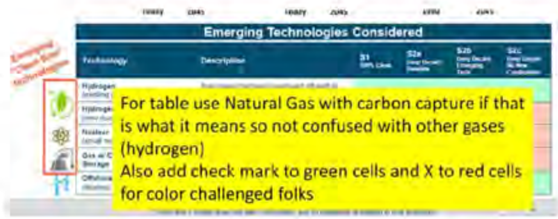


The table above shows which resources can actually meet electricity demand(in green boxes), not just how much it costs. For example, the modelling considers how much capacity a resource actually has, and then prioritizes it based on its ability to provide reliable electricity when needed.

Two clean energy scenarios – with different electricity use assumptions and emerging technology availability

The study uses these two scenarios to represent bookends of how electricity use will change in the region to achieve carbon reduction goals

- Scenario1: 100% Clean Retail Sales
  - E3 how would you describe this to your next door neighbor?
  - Business-as-usual load growth
  - Can be achieved using existing mature technologies
- Scenario 2: Deep Decarbonization (3 variations in emerging technology availability)
  - Zero carbon emissions remain in 2045 in 2045
  - High electrification load growth consistent with economy-wide carbon abatement scenarios
  - Emerging technologies are key to meeting higher winter reliability needs with carbon-free power

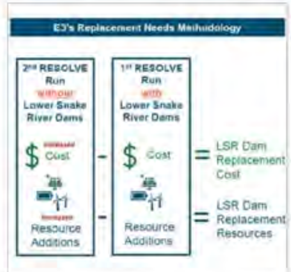


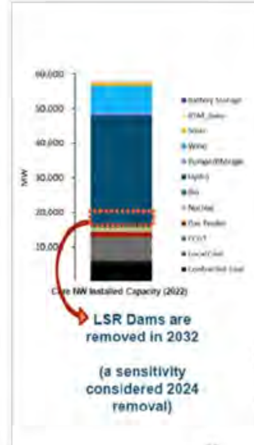
The table above shows which resources can actually meet electricity demand(in green boxes), not just how much it costs. For example, the modelling considers how much capacity a resource actually has, and then prioritizes it based on its ability to provide reliable electricity when needed.

Replacing the lower Snake River dam capabilities

- RESOLVE model determines replacement needs and cost by optimizing regional requirements with the dams, and then again without the dams
- The model does not consider **essential reliability** services for the transmission grid, such as voltage, reactive power, inertia, black start, etc.
- The RESOLVE model shows that, without the four lower Snake River dams, the region will experience increased costs and increased requirement for resources.

Electric Grid Benefit
GHG-free Energy Output (MWh) GHG-free energy displaces the costs and carbon emissions of NW coal + gas generation or imported power
Reliable Capacity (MW) Firm capacity contributions towards resource adequacy
Flexibility and Operating Reserves (MW) Sub-hourly ancillary service provision and renewable integration benefits



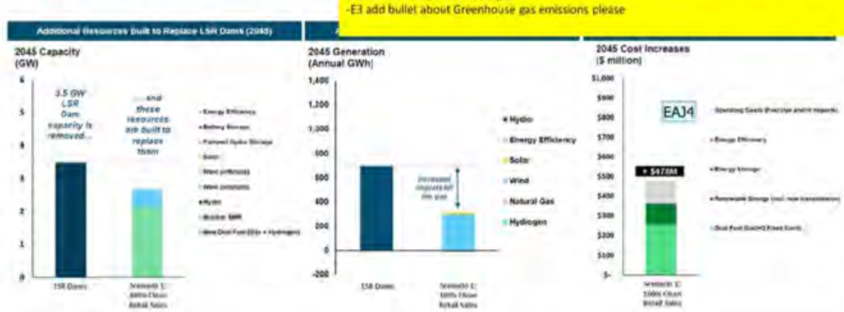


Scenario 1: 100% clean retail sales to replace lower Snake River dams

PSM(-E20 EAJ3 nneville's rates are structured to sell in long-term contracts the amount of electricity produced from a **low water year** since that can be assured. In average or high water conditions the system has additional power that Bonneville sells (often displacing fossil-fuel generators) to keep customer rates affordable.

- Capacity replaced with dual fuel natu
- Energy replaced by wind and net imp

Bullet point changes:
-capacity replaced with 2._ GW of dual fuel natural gas + hydrogen turbines and X GW wind
-Wind and imports provide the most energy but the gas plant is needed for meeting winter cold weather events to avoid power shortages
-E3 add bullet about Greenhouse gas emissions please



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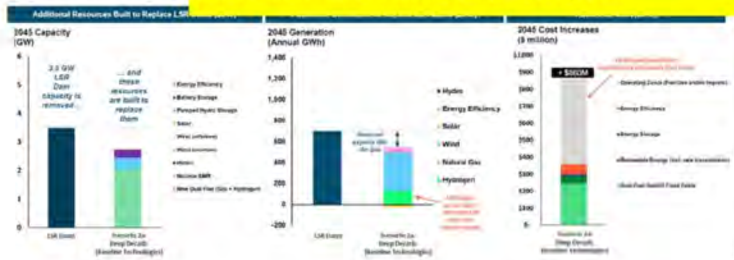
Scenario 2: deep carbonization/electrification (baseline technologies) to replace lower Snake River dams (does not eliminate all carbon emissions)

Bullet point changes:
-This scenario includes electric use increases for transportation and other sectors, however, natural gas is still permitted during high demand periods
-Hydrogen generation is a key feature in this scenario and is assumed to be available, though it is not commercially available today
-This scenario would cost $860 million dollars per year, note high hydrogen fuel costs
(the text in red is too small and wanted to highlight these points in the larger bullets)

+ Capacity replaced wi storage
+ Energy replaced by v



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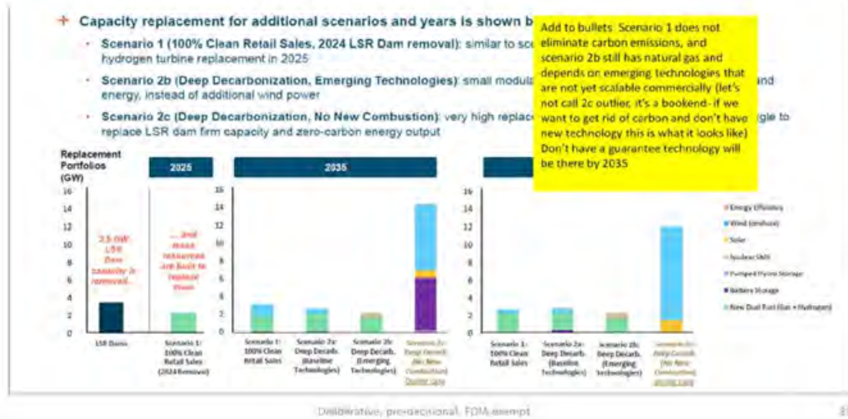
Comparing the scenarios: replacing four Lower Snake River dams' capacity



From: Koehler,Birgit G (BPA) - PG-5
Sent: Monday, May 23, 2022 3:15 PM
To: Pruder Scruggs,Kathryn M (BPA) - E-4
Cc: James,Eve A L (BPA) - PG-5
Subject: RE: BPA-E3

Katie,
We may need to have this presentation ready for a meeting on Tuesday. (And that's a meeting without us there to present, so it probably needs to get there by Friday so folks can ask us questions.)

Bottom line, we are suddenly under extreme pressure to get this done. We told E3 that you'd have it ready by the end of tomorrow. But if you have it partially done, it might be a good idea to share that so they know what they will be dealing with.

Birgit

From: Pruder Scruggs,Kathryn M (BPA) - E-4 <kpruder@bpa.gov>
Sent: Monday, May 23, 2022 11:23 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: BPA-E3

Thanks!

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, May 23, 2022 11:23 AM
To: Pruder Scruggs,Kathryn M (BPA) - E-4 <kpruder@bpa.gov>
Subject: FW: BPA-E3

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, May 23, 2022 10:50 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Sure. See attached.

Aaron

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, May 23, 2022 6:45 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>

Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Good morning Aaron,
Could you send us a Power Point for us to make suggestions on?

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, May 20, 2022 3:46 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Eve and Birgit,

See attached for the draft public summary deck. We hope to receive your feedback on Monday afternoon and discuss a path forward to finalizing this document shortly. Assuming the messaging aligns with your expectations of what the summary should cover, we can draft the 1-pager summary next week to align with the final public deck.

All the best,
Aaron

From: Aaron Burdick
Sent: Wednesday, May 4, 2022 5:12 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Hi Eve,

This all seems doable. Would the 1-2 pager exec summary from our word report also suffice? If not, we'll likely need a bit of additional budget if we need to create a separate PPT doc. We can discuss further tomorrow.

Thanks,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, May 4, 2022 2:30 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT
Hi Aaron-

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Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

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Cc: Aaron Burdick; Diffely,Robert J (BPA) - PGPL-5; Koehler,Birgit G (BPA) - PG-5 (bgkoehler@bpa.gov); Arne Olson
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Global call-in numbers

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Dia[redacted]@mybpa.webex.com

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From: Armentrout,Scott G (BPA) - E-4
Sent: Monday, May 23, 2022 9:18 AM
To: Koehler,Birgit G (BPA) - PG-5; Pruder Scruggs,Kathryn M (BPA) - E-4
Cc: James,Eve A L (BPA) - PG-5
Subject: RE: BPA-E3

Much appreciated. Thank you!

SCOTT G ARMENTROUT
Executive Vice President, Environment, Fish & Wildlife, SES | E-4
BONNEVILLE POWER ADMINISTRATION
bpa.gov | P 503-230-3076 | C (b)(6) [redacted]

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, May 23, 2022 9:16 AM
To: Armentrout,Scott G (BPA) - E-4 <sgarmentrout@bpa.gov>; Pruder Scruggs,Kathryn M (BPA) - E-4 <kpruder@bpa.gov>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: RE: BPA-E3

Good morning Scott,

Katie and I spent an hour on the phone this morning. She's also meeting with Eve later. Rob Diffely is working on a map. (We had mentioned that to E3, but it didn't show up in their ppt.) Qw have lots of things in motion.

Katie will put together a ppt that combines E3's info with our presentation style and clear messages. We'll let E3 put that back into their format (font, background, their look).

From: Armentrout,Scott G (BPA) - E-4 <sgarmentrout@bpa.gov>
Sent: Monday, May 23, 2022 7:22 AM
To: Pruder Scruggs,Kathryn M (BPA) - E-4 <kpruder@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
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Here is the Diablo – an example many of us liked......

An Assessment of the Diablo Canyon Nuclear Plant for Zero-Carbon Electricity, Desalination, and Hydrogen Production | Energy (stanford.edu)

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DELIBERATIVE, FOIA EXEMPT

Hi Katie,

Oh boy. Non-technical clearly is not E3's strong suit.

You may have your own idea of how to proceed with this. My first thought is to start a new ppt and copy over screenshots of the things we'd keep. This project may take closer work between you and power since E3 hasn't translated the technical into lay terms well for you to pick up. Timeline is pretty tight for this, as we want to get it to CEQ as soon as possible, ideally be ready to schedule something in the next couple of weeks.

We had given E3 suggestions Eve wrote out in the attached document we sent them. Here is the short version from my notes. (Credit to Scott for articulating these three bullets.)

- What are the 3-5 new things coming out of the study we didn't know before?
- What are the effects on BPA and our customers of not having the LSN gen
  - Cost, etc
- What are the regional effects?

Birgit

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Dial [redacted]@mybpa.webex.com

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From: James,Eve A L (BPA) - PG-5
Sent: Wednesday, May 25, 2022 8:46 AM
To: Aaron Burdick; Koehler,Birgit G (BPA) - PG-5
Cc: Arne Olson; Johnson,G Douglas (BPA) - DK-7
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Hi Aaron-
I received from feedback that the "Bottom-Line Up Front" and Conclusion slides need some more work so we'll send another draft hopefully later this morning. The comments on the middle section of the deck should be fine for you to incorporate.

Thanks,
Eve

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To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
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From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Friday, May 20, 2022 4:38 PM
To: Pruder Scruggs,Kathryn M (BPA) - E-4 <kpruder@bpa.gov>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Armentrout,Scott G (BPA) - E-4 <sgarmentrout@bpa.gov>
Subject: FW: BPA-E3

DELIBERATIVE, FOIA EXEMPT

Hi Katie,

Oh boy. Non-technical clearly is not E3's strong suit.

You may have your own idea of how to proceed with this. My first thought is to start a new ppt and copy over screenshots of the things we'd keep. This project may take closer work between you and power since E3 hasn't translated the technical into lay terms well for you to pick up. Timeline is pretty tight for this, as we want to get it to CEQ as soon as possible, ideally be ready to schedule something in the next couple of weeks.

We had given E3 suggestions Eve wrote out in the attached document we sent them. Here is the short version from my notes. (Credit to Scott for articulating these three bullets.)

- What are the 3-5 new things coming out of the study we didn't know before?
- What are the effects on BPA and our customers of not having the LSN gen
  - Cost, etc
- What are the regional effects?

Birgit

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, May 20, 2022 3:46 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>

Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Eve and Birgit,

See attached for the draft public summary deck. We hope to receive your feedback on Monday afternoon and discuss a path forward to finalizing this document shortly. Assuming the messaging aligns with your expectations of what the summary should cover, we can draft the 1-pager summary next week to align with the final public deck.

All the best,
Aaron

From: Aaron Burdick
Sent: Wednesday, May 4, 2022 5:12 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Hi Eve,

This all seems doable. Would the 1-2 pager exec summary from our word report also suffice? If not, we'll likely need a bit of additional budget if we need to create a separate PPT doc. We can discuss further tomorrow.

Thanks,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, May 4, 2022 2:30 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT
Hi Aaron-
I took some notes at an internal meeting where we were discussing future sharing of study information at a higher level since at some point this will go to a layperson audience. I thought it might be a helpful reference to share- we referenced some of the graphics and slide numbers from the presentation you had on this email.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, April 27, 2022 5:18 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

An abridged summary version of the draft results is attached. Let me know if you have any suggested changes prior to the executive briefing tomorrow.

Thanks,
Aaron

-----Original Appointment-----
From: Cooper,Suzanne B (BPA) - P-6 <sbcooper@bpa.gov>
Sent: Tuesday, April 26, 2022 2:44 PM
To: Cooper,Suzanne B (BPA) - P-6; James,Eve A L (BPA) - PG-5; Cook,Joel D (BPA) - K-7; Leady Jr,William J (BPA) - PG-5; Armentrout,Scott G (BPA) - E-4
Cc: Aaron Burdick; Diffely,Robert J (BPA) - PGPL-5; Koehler,Birgit G (BPA) - PG-5 (bgkoehler@bpa.gov); Arne Olson
Subject: FW: BPA-E3
When: Thursday, April 28, 2022 3:30 PM-4:30 PM (UTC-08:00) Pacific Time (US & Canada).
Where: Webex

-----Original Appointment-----
From: Cooper,Suzanne B (BPA) - P-6 <sbcooper@bpa.gov>
Sent: Tuesday, April 26, 2022 2:31 PM
To: Cooper,Suzanne B (BPA) - P-6; Cooper,Suzanne B (BPA) - P-6; James,Eve A L (BPA) - PG-5; Cook,Joel D (BPA) - K-7; Leady Jr,William J (BPA) - PG-5; Armentrout,Scott G (BPA) - E-4
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Meeting password: 5UKeHJ2kK@2

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Dial [redacted]@mybpa.webex.com

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Sent: Wednesday, May 4, 2022 2:30 PM
To: Aaron Burdick; Koehler,Birgit G (BPA) - PG-5
Cc: Arne Olson
Subject: RE: BPA-E3
Attachments: LaypersonOutline.docx

DELIBERATIVE FOIA EXEMPT

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Cc: Aaron Burdick; Diffely,Robert J (BPA) - PGPL-5; Koehler,Birgit G (BPA) - PG-5 (bgkoehler@bpa.gov); Arne Olson
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+1-415-527-5035,[redacted] US Toll

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+1-415-527-5035 US Toll

Global call-in numbers

Join from a video system or application

Dial 27627102796@mybpa.webex.com

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Title slide

How much does it cost to replace Lower Snake River Dam capabilities?

- Replacing the carbon-free energy, capacity, and operational benefits of the dams requires investment in new resources at increased total system costs
- Costs range between over $400 million to nearly $2 billion per year depending on available technologies and carbon reduction policies
    - Could **increase public power costs** by 8% (best case scenario with emerging tech) to 65%
    - Could **raise residential electricity costs** by ~$100 – 850 per year
- The above cost estimates do not include replacement of **all essential transmission reliability** services such as voltage, reactive power, inertia, black start, etc…
- New replacement resources and transmission take a long time to develop… E3 please rephrase or add any timeline info

Incremental LSR Dam Replacement Resource [illegible]	
	Lower Snake River Dams All-in Generation Costs (2022 $/MWh)
	$13/MWh w/o LSRCP
	$17/MWh w/ LSRCP
Scenario	2045 Costs [illegible] (real 202[illegible])
S0: No Policy Reference	[illegible]
S1: 100% Clean Retail Sales	[illegible]
S1a: 100% Clean Retail Sales (no carbon price)	[illegible]
S1b: 100% Clean Retail Sales (2024 dam removal)	[illegible]
S2: Deep Decarb	[illegible]
S2b: Deep Decarb. w/ Emerging Tech	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

E3 would need to take out scenarios not used in public deck for this table

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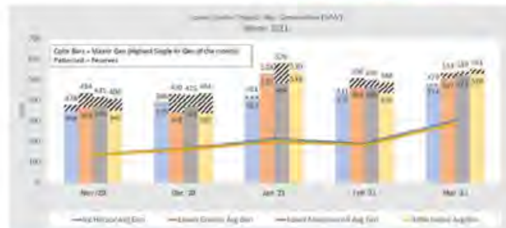
Lower Snake River Dam capabilities

- Lower Snake River Dams are ~10% of the Northwest hydro capacity and provide **low cost**, reliable, **carbon-free energy**, and high flexibility
- Provide **more than 2,000 MW** of sustained peaking capabilities during the winter
- Provide a quarter of Bonneville's current reserves holding capability which is **important for integrating variable generating resources** such as wind and solar.
- Also provide **essential transmission reliability** services such as voltage, reactive power, inertia, black start, etc...

Plant	Nameplate Capacity (MW)	Cost*
Lower Granite	930	
Little Goose	930	$15.71
Lower Monumental	930	$12.58
Ice Harbor	693	$15.84
	Total = 3,483 MW	**Avg = $17/MWh**

E3 need to delete "All-in" since it doesn't include a few other BPA program costs



https://www.bpa.gov/-/media/Aep/about/publications/news-releases/20210616-pr-08-21-lower-snake-river-dams-provided-crucial-energy-and-reserves-in-winter-2021.pdf

rative, predecisional, FOIA exempt 3

27691396(01).pdf

Do we need to explain Capacity, energy, nameplate capacity?

Doug Johnson- thoughts on this for lay readers? Birgit thinks this is needed to ground reader

Transition to next slide- study that E3 conducted sustained capacity was the most critical replacement needed from power perspective particularly for multi-day winter cold weather events

About this study

- E3 conducted an independent analysis of replacing the power output from the four lower Snake River dams in the context of Pacific Northwest resource requirements.
- BPA contracted E3 to conduct the study, which includes independent analysis about the value of the four lower Snake River dams to the Northwest energy system, including the **cost** and **resource requirements** for replacement.
- This study takes a regional view of electricity supplies and uses E3's RESOLVE electricity planning model to optimize electricity resource requirements for the Northwest through 2045.

What's new in this study compared to CRSO EIS

Updated resource pricing and included emerging technology. The study uses an optimizer to determine the least-cost replacement resources for the four lower Snake River dams subject to **reliability** and **policy** constraints.

- **Reliability example**: The E3 modelling considers multiple variables – not just cost. For example, the modelling considers how much capacity a resource actually has, and then prioritizes it based on its ability to provide reliable electricity when needed.
  - During extended cold-weather periods the wind isn't always blowing and the sun goes down at night
  - Even if those resources are the cheapest, the optimizer doesn't choose them because the capaci… not always available to provide power when needed
- **Policy example**: E3's modelling considers the effects of regional policy decisions and legislation to reduce carbon emissions
  - Includes aggressive clean energy laws which remove fossil fuel-based power resources from the grid all along the west coast (such as retiring coal plants)
  - Compounding the situation from removing fossil fuel resources, decarbonizing the region will result in increased electricity use in transportation and building heating/cooling

Maybe too much info but was trying to make the "reliability and policy constraints" language understandable to non-resource planners

Added from technical presentation since thought it added valuable context

Policy Landscape: Washington, Oregon, California

	RPS or Clean Energy Standard?	Coal Prohibition?	Cap-and-Trade?	New Gas?	Economy-Wide Carbon Reduction?
WA	✓ Carbon neutral by 2030, 100% carbon free electricity by 2045	✓ Eliminate by 2025	✓ Cap-and-invest program established in 2021, SCC in utility planning	✓	mission reduction below 1990 levels and achieve net zero emissions by 2050
OR	✓ 50% RPS by 2040, 100% GHG emission reduction by 2040, relative to 2010 levels	✓ Eliminate by 2030	✓ Climate Protection Plan adopted by DEQ in 2021 (power sector not included)	× HB 2021 bans expansion or construction of power plants that burn fossil fuels	✓ 90% GHG emission reduction from fossil fuel usage relative to 2022 baseline
CA	✓ 60% RPS by 2030, 100% clean energy by 2045	✓ Coal-fired electricity generation already phased out	✓	× CPUC IRP did not allow in recent procurement order	✓ 40% GHG emission reduction below 1990 levels by 2030 and 80% by 2050

Does this mean new Natural Gas? Best to always be clear

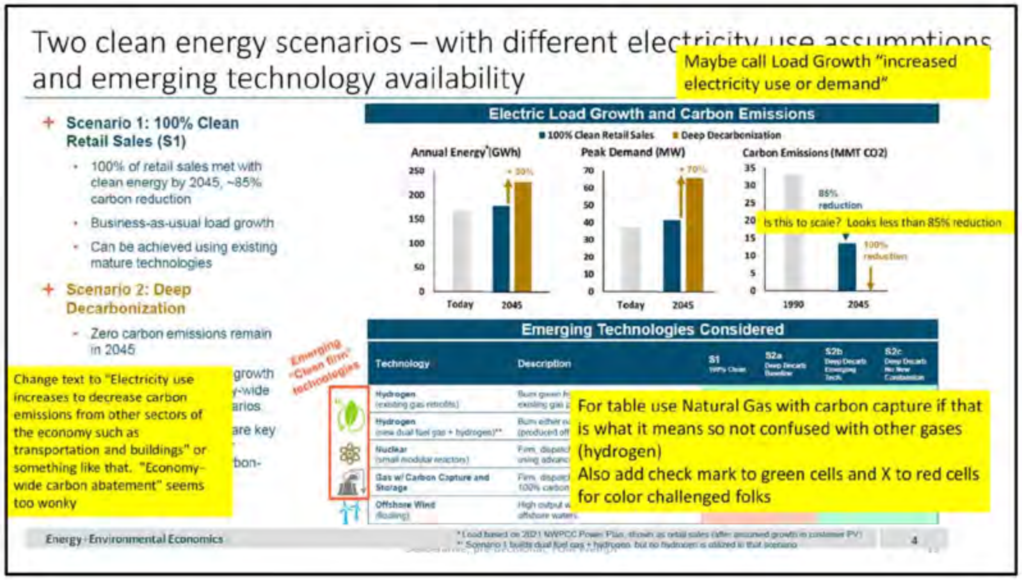
Modeling Step 1 is model scenarios without removing the lower Snake River dams, context of Pacific Northwest resource requirements in light of climate policies and changing resource mix from decarbonization/electrification

Or maybe add to Key modeling assumptions that

Key Modeling Assumptions

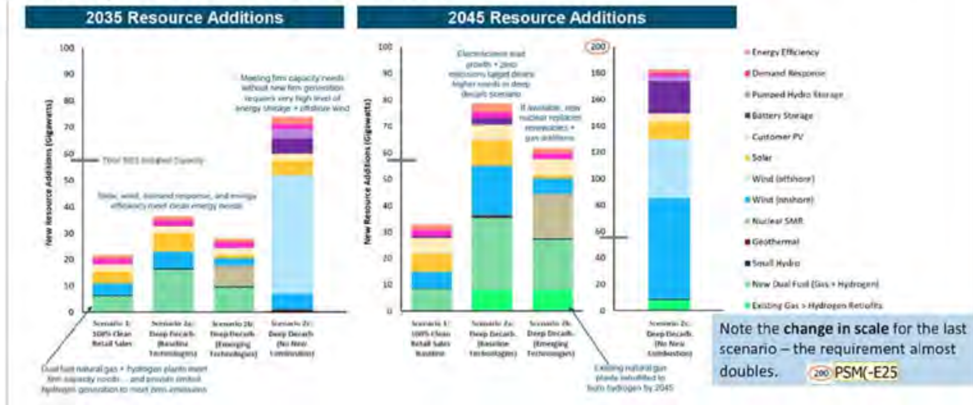
Element	Study Approach	Impact on Dams Replacement Needs
Study Years	• 2025 through 2045, including fuel price forecasts and declining renewable + storage costs	Considers long-term needs
Clean Energy Policy Scenarios	• Aggressive OR+WA legislation reflected, including coal retirements + carbon pricing • Two electric emissions scenarios considered: 1. 100% clean retail sales (~85% carbon reduction*) 2. Zero-emissions (100% carbon reduction)	Clean energy policy requires long-term **replacement of LSR dams with GHG-free energy**
Load Growth Scenarios	• Two load scenarios: 1. **Baseline** (per NWPCC 8th Power Plan) 2. **High electrification** load growth (to support economy-wide decarbonization)	Higher load scenarios **increase the value of LSR dams energy + firm capacity**
Reliability Needs PSM(-E39 EAJ1	• Modeling ensures reliability needs during extreme conditions (e.g. high loads + low hydro) Captures ability (and limits) of renewables, battery storage, and demand response to support system reliability	Reliability needs require **replacement of LSR dams firm capacity contributions**
Consideration of Emerging Technologies	• Broad range of dam replacement technology options considered: • **Baseline technologies**: solar, wind, battery + pumped storage, energy efficiency, demand response, dual fuel natural gas + hydrogen combustion plants • **Sensitivities:** • **Emerging technologies** • **No New Combustion**	**Technology available for LSR dams replacement** determines cost + feasibility
Distributed Energy Resource Options	• Energy efficiency, demand response, and customer solar embedded into modeling inputs • Additional energy efficiency and demand response can be selected	**Demand resource can help replace LSR dams**, though low-cost supply is limited

* A 100% clean retail sales target allows emissions for electric generation beyond that needed to serve "retail sales", i.e. losses during transmission to retail loads and exported energy



Two clean energy scenarios – with different electricity use assumptions and emerging technology availability
Maybe call Load Growth "increased electricity use or demand"
Scenario 1: 100% Clean Retail Sales (S1)
100% of retail sales met with clean energy by 2045, ~85% carbon reduction
Business-as-usual load growth
Can be achieved using existing mature technologies
Scenario 2: Deep Decarbonization
Zero carbon emissions remain in 2045
Change text to "Electricity use increases to decrease carbon emissions from other sectors of the economy such as transportation and buildings" or something like that. "Economy-wide carbon abatement" seems too wonky
Electric Load Growth and Carbon Emissions
100% Clean Retail Sales
Deep Decarbonization
Annual Energy* (GWh)
Peak Demand (MW)
Carbon Emissions (MMT CO2)
Today
2045
1990
85% reduction
100% reduction
Is this to scale? Looks less than 85% reduction
Emerging "Clean firm" technologies
Emerging Technologies Considered
Technology
Description
S1
S2a
S2b
S2c
Hydrogen
Hydrogen
Nuclear
Gas w/ Carbon Capture and Storage
Offshore Wind
For table use Natural Gas with carbon capture if that is what it means so not confused with other gases (hydrogen)
Also add check mark to green cells and X to red cells for color challenged folks
Energy+Environmental Economics

All scenarios show large levels of new resource additions for the region due to fossil-fuel plant retirements and increased electric demand (keeping lower Snake River dams)



Note the **change in scale** for the last scenario – the requirement almost doubles. (200) PSM(-E25

Even before we consider taking out the four lower Snake River dams…

- Regional policy requirements and legislation to reduce emissions is removing resources fossil fuel resources from the grid. This is happening now.

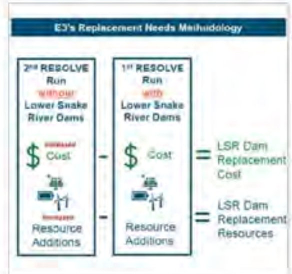
- Consequently, with retiring coal and gas plants, the region is ***already*** facing resource adequacy issues.

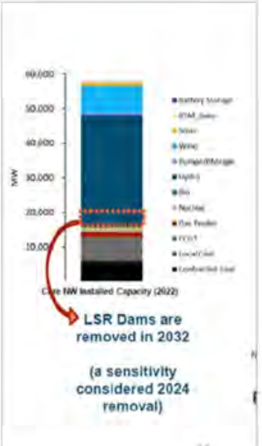
Placeholder for graphic showing coal retirements

Replacing the lower Snake River dam capabilities

- RESOLVE model determines replacement needs and cost by optimizing regional requirements with the dams, and then again without the dams
- The model does not consider **essential reliability** services for the transmission grid, such as voltage, reactive power, inertia, black start, etc.
- The RESOLVE model shows that, without the four lower Snake River dams, the region will experience increased costs and increased requirement for resources.

Electric Grid Benefit
GHG-free Energy Output (MWh) GHG-free energy displaces the costs and carbon emissions of NW coal + gas generation or imported power
Reliable Capacity (MW) Firm capacity contributions towards resource adequacy
Flexibility and Operating Reserves (MW) Sub-hourly ancillary service provision and renewable integration benefits



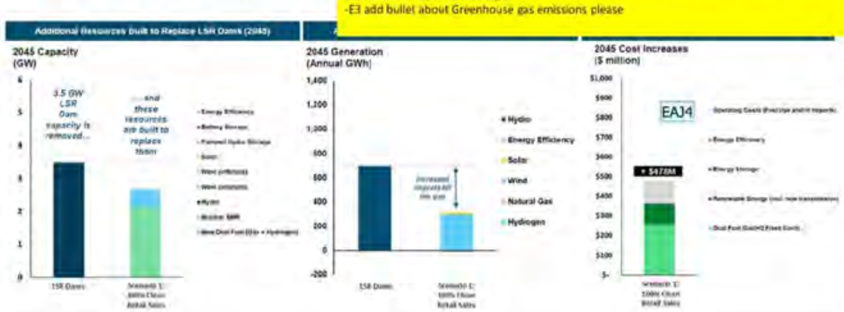


Scenario 1: 100% clean retail sales to replace lower Snake River dams

PSMC-E20 EAJ3 nneville's rates are structured to sell in long-term contracts the amount of electricity produced from a **low water year** since that can be assured. In average or high water conditions the system has additional power that Bonneville sells (often displacing fossil-fuel generators) to keep customer rates affordable.

+ Capacity replaced with dual fuel natu
+ Energy replaced by wind and net imp

Bullet point changes:
-capacity replaced with 2._ GW of dual fuel natural gas + hydrogen turbines and X GW wind
-Wind and imports provide the most energy but the gas plant is needed for meeting winter cold weather events to avoid power shortages
-E3 add bullet about Greenhouse gas emissions please



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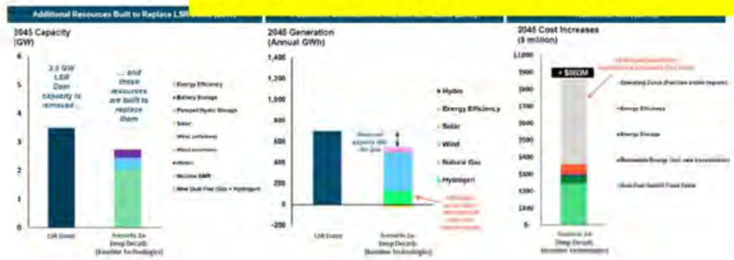
Scenario 2: deep carbonization/electrification (baseline technologies) to replace lower Snake River dams (does not eliminate all carbon emissions)

Bullet point changes:
-This scenario includes electric use increases for transportation and other sectors, however, natural gas is still permitted during high demand periods
-Hydrogen generation is a key feature in this scenario and is assumed to be available, though it is not commercially available today
-This scenario would cost $860 million dollars per year, note high hydrogen fuel costs
(the text in red is too small and wanted to highlight these points in the larger bullets)

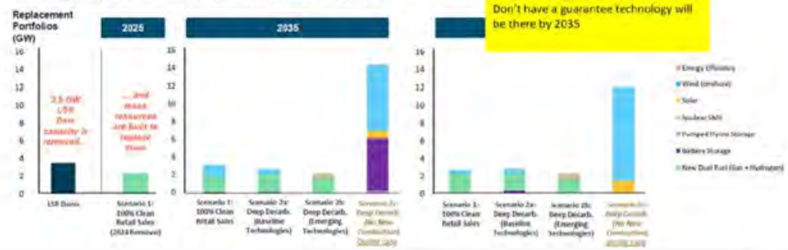
+ Capacity replaced wi storage
+ Energy replaced by v



Comparing the scenarios: replacing four Lower Snake River dams' capacity

- Capacity replacement for additional scenarios and years is shown b
  - **Scenario 1 (100% Clean Retail Sales, 2024 LSR Dam removal)**: similar to sce hydrogen turbine replacement in 2025
  - **Scenario 2b (Deep Decarbonization, Emerging Technologies)**: small modul and energy, instead of additional wind power
  - **Scenario 2c (Deep Decarbonization, No New Combustion)**: very high replac gle to replace LSR dam firm capacity and zero-carbon energy output

Add to bullets Scenario 1 does not eliminate carbon emissions, and scenario 2b still has natural gas and depends on emerging technologies that are not yet scalable commercially (let's not call 2c outlier, it's a bookend- if we want to get rid of carbon and don't have new technology this is what it looks like) Don't have a guarantee technology will be there by 2035



The cost of replacing power

- Replacing the greenhouse gas-free energy, capacity, and operational benefits of the dams requires investment in new resources at increased total system costs
  - Cost differences between scenarios driven by 2045 greenhouse gas PSM(-E26 EA17 rgy replacement and the availability of "clean firm" emerging technologies
- Costs are expected to fall on Bonneville Power Administration's public power customers
  - Could **increase public power costs** by 8% (best case scenario with emerging tech) to 65%
  - Could **raise residential electricity costs** by ~$100 –850 per year

	Total Costs	Annual Cost Increase			Incremental Public Power Costs (% increase vs. [illegible] NW average rates)
	[illegible] Net Present Value	[illegible]	[illegible]	[illegible]	[illegible]
Scenario 1: 100% Clean Retail Sales	$1.3 billion	[illegible]	$434 million	$478 million	0.8 cents/kWh (+9%)
Scenario 1: 100% Clean Retail Sales (2024 dam removal)	$7.2 billion	$495 million	$466 million	$509 million	0.8 cents/kWh (+9%)
Scenario 2a: Deep Decarb. (Baseline Technologies)	$5.0 billion	[illegible]	$490 million	[illegible]	1.5 cents/kWh (+18%)
Scenario 2b: Deep Decarb. (Emerging Technologies)	$3.0 billion	[illegible]	$415 million	$428 million	0.7 cents/kWh (+8%)
Scenario 2c: Deep Decarb. (No New Combustion)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

NOTES:
- Cost increases account for replacement energy, capacity, and reserves as well as avoided LSR capital + expense, but do not include any costs for breaching the dams, which would be an additional cost.
- NPV and annual cost increase are shown for the Northwest Region as a whole, but the incremental costs are calculated relative to the BPA Tier I annual sales for public power customers.
- % increase versus average rates assumes OR + WA average retail rates are ~6.5 cents/kWh. This does not include additional rate increases driven by higher loads or clean energy needs that increase regional rates as shown in the earlier 2045 incremental cost chart.
- Annual residential customer cost impact assumes 1,280 kWh/month for average residential customers in Oregon and Washington (current ~1,000 kWh/month average + 28% from electrification load growth).

Land use considerations

PSM(-E7

- Replacing the lost power with new resources would require roughly X acres (about X square miles) of land.

PSM(-E36

- Such a large build out of capacity would likely result in additional, but currently unknown impacts to natural and cultural resources, which may include vegetation, wildlife habitat, archeological resources, and traditional cultural properties (such as sites or land features that are important to tribes).

	E3						
	S0 No Policy	S1 100% Clean Retail Sales	S1a 100% Clean Retail Sales (no carbon price)	S2 - Deep Decarb	S2a1 - Deep Decarb no combustion	S2a2 - Deep Decarb no gas	S2a3 - Deep Decarb emerging tech
Year	2035	2035	2035	2035	2035	2035	2035
Reliability Metric	PRM	PRM	PRM	PRM	PRM	PRM	PRM
Gas (MW)	2300	1800	2200	2000			1500 (H2)
DR (MW)							
Solar (MW)		-500			1500	1600	
Batteries (MW)		100	100	200	6000	300	
Wind (MW)	200	1500		600	9400		600
Offshore Wind (MW)						13000	
Pumped Storage (MW)					300		
Conservation (MW)					10	10	
SMR (MW)							600
Wind (Sq Miles)	7.8	50.8	0.0	23.4	367.2	0.0	23.4
Offshore Wind (Sq Miles)						1204.4	
Solar (Sq Miles)		-1.3	0.0	0.0	4.0	4.3	0.0

If possible to get this done, if not we can delete. Maybe Seattle map? Or LSN dam area?
Info to the right. Seattle is 142.55 square miles for reference (not sure if metro area). Different boxes to show how much of Seattle gets covered.

E3 can you do this or Doug can BPA comms folks do this?

Conclusion and summary

- The study considers two important factors in replacing power from the four lower Snake River dams:
  - Power must **provide firm capacity** (reliable energy that is available at all times) to avoid power shortages
  - Power must be **free of greenhouse gasses** to meet regional carbon policies
- Policies and laws to decarbonize the region will **increase electricity use** (electric cars, replacing gas appliances, etc.)
- Acquiring replacement resources could require **building new renewable resources at an unprecedented rate.**
  - This would also require building transmission to bring the power from new resources to utilities (E3 one of your slides had current resource build rate for NW- maybe add that here?)
- Replacing the dams comes at a **substantial cost** for new resource replacement
  - This would have a meaningful impact on the rates of Bonneville Power Administration's public power customers.
- The **availability of emerging technology** is a factor in achieving replacement recourses that are free of greenhouse gasses and the pace of development is highly uncertain.

-

- Loss of the four lower Snake River dams, or reductions in their flexibility, while there are still fossil fuel generators on the grid will increase the timeframe and costs associated with shifting to a carbon-free electricity sector.

We like highlighting this point as a closing statement but leave it to E3 to word or decide style-wise how to incorporate

Deliberative; FOIA Exempt

High Level presentation needed that extracts the "so-whats?" in easily digestible pictures and words. For example, this might land on the desk of a legislator. Suggest starting a fresh ppt rather than tweaking the technical ppt. Extract tidbits that would be used by non-technical decision makers:

What is new here?:
Like graphic with blob areas (Slide 3) in regional model and map of LSN dams in particular from slide.

- CETA, faster coal out, west-wide regional resources updated
- Prices updated
- New technology for 2045? Basically describing the scenarios in lay terms, need better labels for the scenarios in graphics.
- Load growth due to electrification

What are ramifications of what's new?

- Slide 16 graphic of bar chart with all the scenario results need to rename scenarios into layperson labels. Currently shows 2045 year to show differences of renewable build outs- these are Core NW only correct? Would it be good to show year 2035 as well?
- Maps/graphics showing land impact of that many renewable build out (for same snapshot years as bar graphs- E.g. Diablo Canyon paper easy to digest graphics) Any comparisons to how much solar/wind currently exists?
- Any key pieces not covered in resolve (e.g. Tx related)
- other key challenges of building timeline (siting, supply chain, labor, TX, critical materials scarcity) Here close to graphics or at end as take-away? What would happen if you took the dams out 2032 in terms of build timeline?

With and without the LSRDs: Focus first on BPA and customers, then on region.
Similar to current Slide 20 with key points of cost to generate vs replacement cost. We are wholesaler though so need high level cost info that is meaningful - is it possible to translate to average residential increase in electric bill? +__% or __x cost

Key takeaway that without replacing the LSRDs with long term dispatchable capacity (NG, Hydrogen, SMR, NG currently only scalable technology in short-term) the costs and challenges (timing) are _not insignificant_ (annual costs, renewable builds, and land use)
GHG emissions takeaways. Mention impacts and maybe state take-away such as: Until all fossil-fuel generation is retired, renewables built to replace LSN instead of fossil-fuel plants means more CO2 emissions

Any peer review takeaway or put in appendix.
Appendix with more technical slides and details of scenarios in lay person names.

From: Koehler,Birgit G (BPA) - PG-5
Sent: Thursday, April 28, 2022 12:20 PM
To: Aaron Burdick; James,Eve A L (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5
Cc: Arne Olson
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Aaron,
You were spot on. In the EIS LOLP approach, we did not necessarily replace the full capacity *and* only a few coal retirements were in the base case.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, April 28, 2022 12:13 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Thanks Eve. I've now spelled out CES to avoid confusion. Regarding the replacement capacity, the no policy case is driven by 3.4 GW * 65% firm capacity contribution → 2.2 GW of firm capacity replacement. So, the EIS may have either assumed a lower firm capacity contribution or that the RA contributions of the dams do not need to be fully replaced. Maybe the latter if it was 2022 prior to the coal retirements, though I think most would argue the region is already in a capacity deficit position hence a full capacity replacement would be needed.

All the best,
Aaron

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Thursday, April 28, 2022 11:45 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

I have a couple of small comments for the presentation (so you know I did look at it!) and a comparison to the EIS for curiosity

Please remember to say what CES stands for.

Slide 18 on the No LSR results, remember to mention whether the additional costs are calculated as cumulative (NPV-like) or are annual costs

I just looked up our EIS result for MO3 (dam breaching and other measures). With least-cost replacements (combined cycle gas), we identified 1,120 MW need for 2022. Comparing that to S0, No policy, the E3 results have around 2,500 MW for 2035. That's a pretty dramatic difference, acknowledging that there are several contributors notably including coal retirements.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, April 27, 2022 5:18 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

An abridged summary version of the draft results is attached. Let me know if you have any suggested changes prior to the executive briefing tomorrow.

Thanks,
Aaron

-----Original Appointment-----
From: Cooper,Suzanne B (BPA) - P-6 <sbcooper@bpa.gov>
Sent: Tuesday, April 26, 2022 2:44 PM
To: Cooper,Suzanne B (BPA) - P-6; James,Eve A L (BPA) - PG-5; Cook,Joel D (BPA) - K-7; Leady Jr,William J (BPA) - PG-5; Armentrout,Scott G (BPA) - E-4
Cc: Aaron Burdick; Diffely,Robert J (BPA) - PGPL-5; Koehler,Birgit G (BPA) - PG-5 (bgkoehler@bpa.gov); Arne Olson
Subject: FW: BPA-E3
When: Thursday, April 28, 2022 3:30 PM-4:30 PM (UTC-08:00) Pacific Time (US & Canada).
Where: Webex

-----Original Appointment-----
From: Cooper,Suzanne B (BPA) - P-6 <sbcooper@bpa.gov>
Sent: Tuesday, April 26, 2022 2:31 PM
To: Cooper,Suzanne B (BPA) - P-6; Cooper,Suzanne B (BPA) - P-6; James,Eve A L (BPA) - PG-5; Cook,Joel D (BPA) - K-7; Leady Jr,William J (BPA) - PG-5; Armentrout,Scott G (BPA) - E-4
Subject: BPA-E3
When: Thursday, April 28, 2022 3:30 PM-4:30 PM (UTC-08:00) Pacific Time (US & Canada).
Where: Webex

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Global call-in numbers

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Dial (b)(6) [redacted]@mybpa.webex.com

Need help? Go to https://help.webex.com

From: Koehler,Birgit G (BPA) - PG-5
Sent: Monday, March 21, 2022 1:42 PM
To: Diffely,Robert J (BPA) - PGPL-5
Subject: RE: BPA-E3 Check-In

Well, I just checked Eve's email, and she said "Ryan E's group." And the email she attached referenced Ryan himself, so I'll send it to him.

From: Koehler,Birgit G (BPA) - PG-5
Sent: Monday, March 21, 2022 1:40 PM
To: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Subject: FW: BPA-E3 Check-In

Deliberative; FOIA-exempt
Rob, do you know who has been working with Eve on these? I think it might be Peter Williams. Eve is out most of the week, and Peter is out Mon-Wed. Who could review these for us?

Birgit

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, March 18, 2022 8:38 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Eve et al,

Sharing a summary spreadsheet of our historical hydro analysis from which we derived P-min (i.e. min gen), P-max, daily MWh budgets, and 1/2/3/4 hr ramp rate limits. We've included 1) P-min and P-mix using the historical monthly min and max, 2) the same but adjusted with the P-min guidance Eve provided for Dec-Feb (0 MW) and Apr-Aug (341 MW), and 3) the actual historical P-min and P-max on the RESOLVE representative days. 2 shows the highest hydro flexibility (is it too much?), followed by 1, then 3. We would appreciate your review of these values and any thoughts you have.

We have not adjusted the daily MWh by month/season as Eve notes below. Let's discuss on Monday (or our Tuesday check-in) if further adjustment or calibration is necessary. We're working on applying the same methods for the rest of the NW hydro system and will have those results by early-mid next week. We'd like to get the hydro assumptions sorted out by Wed-Thurs next week to stay on track.

Have a nice weekend!

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, March 18, 2022 3:56 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Deliberative; FOIA-exempt
Yes- those are the Min Gen MW requirements for grid stability during fish passage spill from April through August. Sorry I forgot to put the dates on the spreadsheet. Whenever the flows aren't high enough during that period to meet the minimum generation and the required fish spill the operation will be generate at minimum and spill the rest of the project flow.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, March 18, 2022 3:51 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Thanks Eve. I see the Min Gen MW values for LSN (LWG, LGS, LMN, and IHR) are ~341 MW and LCOL (MCN, JDA, TDA, BON) are ~220 MW. Can you confirm what months these apply to? Is this April through August? Or April through June with less constrained operations in the summer?

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, March 18, 2022 3:16 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Deliberative; FOIA-exempt
Next week is Oregon's spring break so my availability will be limited and I will be in the virtual office Friday. Attached is a spreadsheet with the spill parameter information that can be used to adjust the spill levels on the LSN and LCOL projects. I also included some snippets of the requirements and highlighted the assumptions I would use in modeling the adjustment. The summer spill in the CRSO EIS is actually lower than the 2005, 2011 operations so generation credit should be applied during summer spill and then the spring spill months have much higher levels so the generation needs to be decreased. 2001 historical data has no spill operation so the spill requirements will reduce generation from 4/3 – 8/31.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, March 18, 2022 12:27 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Thanks Eve. Very helpful. We do see 0 MW during winter months, so we won't remove those. We just have hourly generation data, without explicit callouts for outages.

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, March 18, 2022 12:00 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Deliberative; FOIA-exempt
Hi Aaron-
The lower Snake projects are able to operate to 0 generation by choice (not outage related) in Dec – Feb so do not remove the 0 MW data during those months as they are likely correct to optimize reservoir content to generate during peak load periods. During the summer months when the projects are operating at "minimum generation spill the rest" due to low flows, one unit loaded at each project results in a 4 dam generation total of ~320 MW. Does your dataset show If there were powerhouse outages in the historical time periods you are looking at?

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, March 18, 2022 11:42 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Quick question: we are doing some data quality checks on our historical hydro hourly data. Do you have a sense of the minimum generation for the 4 lower snake river dams? Clearly we'll remove a few 0 MW values we found, but am seeking your input on what a reasonable lower bound is for the 4 dams min gen, e.g. would they ever operate at a combined output of 50 MW or is that too small? 100 MW? 200 MW? Etc.

Thanks,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, March 17, 2022 10:07 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Deliberative; FOIA-exempt
Sounds good- let me know who would be best to talk through the parameter adjustments. I have some information that we used in an analysis to adjust some actual data when we were determining the cost of the new flexible spill program that was chosen as the spill operations for the CRSO EIS.

I also forgot to mention on my Tues email that I did confirm we would like to use the 2032 removal year as the primary assumption with 2024 as a scenario.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, March 16, 2022 5:38 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Thanks Eve for this information. Regarding the hydro data, I think the best path is to adjust the parameters from our hydro model, which will avoid misalignments between the historical data we use to develop WECC-wide hydro inputs (including the hydro beyond the core northwest region). We'll follow up in the next day or two with a draft set for your review.

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, March 15, 2022 5:05 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Deliberative; FOIA-exempt
Thanks for sending out the action items Aaron. Here's the information for the BPA bullets:
- The F&W cost in the CRSO EIS was $34,060,200 and spread evenly across the four plants results in a cost of generation:

FY2022 $/MWh

Plant	50-year Forecast with LSRCP
Lower Granite	$22.69
Little Goose	$15.71
Lower Monumental	$12.58
Ice Harbor	$15.84

Cost Calculation: The O&M budges used a flat 2% inflation rate. Capital numbers were based on modeled replacement needs influenced by asset risk so they varied year-to-year before levelizing. The capital replacement assumptions were inflated per asset using the 2021 BPA common planning assumptions for inflation (attached). Costs were levelized using BPA's nominal discount rate of 6.2% so the result is a levelized cost in real 2022 dollars.

Data availability: The hourly modeling data available is only for the 80 water year set which ends in 2008. We are working on adding another 10 years to the water year set which would include 2011 but that won't be completed in time for this analysis. Either a different wet year would need to be selected (e.g. 1996 or 1997) or if wet year cannot be changed than some sort of adjustment to the Pmin, Pmax, and the daily MWh budget could be made to adjust the historical data to reflect higher spill operations and less generation for fish passage season. Let me know which option you would prefer.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, March 15, 2022 12:09 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Capturing action items from today's meeting:

- **BPA** to share fish and wildlife costs for continuing LSR dam operations
- **BPA** to share cost calculation details (levelization, dollar year, etc.) for the $/MWh values provided
- **E3** to continue developing hydro constraints based on historical data and share w/ BPA in next couple days
- **BPA** to confirm availability of simulated hydro data w/ more recent biological operating constraints for the historical years currently being used in RESOLVE (calendar years 2001, 2005, and 2011)
- **E3** to incorporate today's discussion and share an updated scenario design for BPA review

All the best,
Aaron

From: Aaron Burdick
Sent: Tuesday, March 15, 2022 9:56 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; rjdiffely@bpa.gov
Cc: Jack Moore <Jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Hi all,

Suggested agenda for today's check in:

- **Costs**: confirm scope/use of $/MWh data provided
- **Operational constraints**: E3 is still developing our proposed Pmin, Pmax, daily MWh budgets to share w/ BPA, but it may be useful to discuss Eve's notes (fish constraints, GENESYS heuristics, etc.)
- **Scenarios**: present an initial set of scenario inputs and get BPA's feedback

All the best,
Aaron

-----Original Appointment-----
From: Aaron Burdick
Sent: Wednesday, March 2, 2022 4:53 PM
To: Aaron Burdick; Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; rjdiffely@bpa.gov; Angineh Zohrabian; Sierra Spencer
Subject: BPA-E3 Check-In
When: Tuesday, March 15, 2022 11:00 AM-12:00 PM (UTC-08:00) Pacific Time (US & Canada).
Where: https://ethree.webex.com/ethree/j.php?MTID=m228a4e26c5b763d73adb84c525782f42

Updating series from 30 mins to 1 hr.

Purpose: check-in on lower snake river dams analysis.

_~_

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From: James,Eve A L (BPA) - PG-5
Sent: Friday, March 18, 2022 3:16 PM
To: Aaron Burdick; Koehler,Birgit G (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5
Cc: Jack Moore; Arne Olson; Angineh Zohrabian; Sierra Spencer
Subject: RE: BPA-E3 Check-In
Attachments: SpringSpillRequirements.xlsx

Deliberative; FOIA-exempt
Next week is Oregon's spring break so my availability will be limited and I will be in the virtual office Friday. Attached is a spreadsheet with the spill parameter information that can be used to adjust the spill levels on the LSN and LCOL projects. I also included some snippets of the requirements and highlighted the assumptions I would use in modeling the adjustment. The summer spill in the CRSO EIS is actually lower than the 2005, 2011 operations so generation credit should be applied during summer spill and then the spring spill months have much higher levels so the generation needs to be decreased. 2001 historical data has no spill operation so the spill requirements will reduce generation from 4/3 – 8/31.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, March 18, 2022 12:27 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Thanks Eve. Very helpful. We do see 0 MW during winter months, so we won't remove those. We just have hourly generation data, without explicit callouts for outages.

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, March 18, 2022 12:00 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Deliberative; FOIA-exempt
Hi Aaron-
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due to low flows, one unit loaded at each project results in a 4 dam generation total of ~320 MW. Does your dataset show If there were powerhouse outages in the historical time periods you are looking at?

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, March 18, 2022 11:42 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Quick question: we are doing some data quality checks on our historical hydro hourly data. Do you have a sense of the minimum generation for the 4 lower snake river dams? Clearly we'll remove a few 0 MW values we found, but am seeking your input on what a reasonable lower bound is for the 4 dams min gen, e.g. would they ever operate at a combined output of 50 MW or is that too small? 100 MW? 200 MW? Etc.

Thanks,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, March 17, 2022 10:07 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Deliberative; FOIA-exempt
Sounds good- let me know who would be best to talk through the parameter adjustments. I have some information that we used in an analysis to adjust some actual data when we were determining the cost of the new flexible spill program that was chosen as the spill operations for the CRSO EIS.

I also forgot to mention on my Tues email that I did confirm we would like to use the 2032 removal year as the primary assumption with 2024 as a scenario.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, March 16, 2022 5:38 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Thanks Eve for this information. Regarding the hydro data, I think the best path is to adjust the parameters from our hydro model, which will avoid misalignments between the historical data we use to develop WECC-wide hydro inputs (including the hydro beyond the core northwest region). We'll follow up in the next day or two with a draft set for your review.

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, March 15, 2022 5:05 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Thanks for sending out the action items Aaron. Here's the information for the BPA bullets:

- The F&W cost in the CRSO EIS was $34,060,200 and spread evenly across the four plants results in a cost of generation:
  FY2022 $/MWh

Plant	50-year Forecast with LSRCP
Lower Granite	$22.69
Little Goose	$15.71
Lower Monumental	$12.58
Ice Harbor	$15.84

Cost Calculation: The O&M budges used a flat 2% inflation rate. Capital numbers were based on modeled replacement needs influenced by asset risk so they varied year-to-year before levelizing. The capital replacement assumptions were inflated per asset using the 2021 BPA common planning assumptions for inflation (attached). Costs were levelized using BPA's nominal discount rate of 6.2% so the result is a levelized cost in real 2022 dollars.

Data availability: The hourly modeling data available is only for the 80 water year set which ends in 2008. We are working on adding another 10 years to the water year set which would include 2011 but that won't be completed in time for this analysis. Either a different wet year would need to be selected (e.g. 1996 or 1997) or if wet year cannot be changed than some sort of adjustment to the Pmin, Pmax, and the daily MWh budget could be made to adjust the historical data to reflect higher spill operations and less generation for fish passage season. Let me know which option you would prefer.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, March 15, 2022 12:09 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Capturing action items from today's meeting:

- **BPA** to share fish and wildlife costs for continuing LSR dam operations
- **BPA** to share cost calculation details (levelization, dollar year, etc.) for the $/MWh values provided
- **E3** to continue developing hydro constraints based on historical data and share w/ BPA in next couple days
- **BPA** to confirm availability of simulated hydro data w/ more recent biological operating constraints for the historical years currently being used in RESOLVE (calendar years 2001, 2005, and 2011)
- **E3** to incorporate today's discussion and share an updated scenario design for BPA review

All the best,
Aaron

From: Aaron Burdick
Sent: Tuesday, March 15, 2022 9:56 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; rjdiffely@bpa.gov
Cc: Jack Moore <Jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Hi all,

Suggested agenda for today's check in:

- **Costs**: confirm scope/use of $/MWh data provided
- **Operational constraints**: E3 is still developing our proposed Pmin, Pmax, daily MWh budgets to share w/ BPA, but it may be useful to discuss Eve's notes (fish constraints, GENESYS heuristics, etc.)
- **Scenarios**: present an initial set of scenario inputs and get BPA's feedback

All the best,
Aaron

-----Original Appointment-----
From: Aaron Burdick
Sent: Wednesday, March 2, 2022 4:53 PM
To: Aaron Burdick; Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; rjdiffely@bpa.gov; Angineh Zohrabian; Sierra Spencer
Subject: BPA-E3 Check-In
When: Tuesday, March 15, 2022 11:00 AM-12:00 PM (UTC-08:00) Pacific Time (US & Canada).
Where: https://ethree.webex.com/ethree/j.php?MTID=m228a4e26c5b763d73adb84c525782f42

Updating series from 30 mins to 1 hr.

Purpose: check-in on lower snake river dams analysis.

-~-
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From:	James,Eve A L (BPA) - PG-5
Sent:	Tuesday, March 15, 2022 5:05 PM
To:	Aaron Burdick; Koehler,Birgit G (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5
Cc:	Jack Moore; Arne Olson; Angineh Zohrabian; Sierra Spencer
Subject:	RE: BPA-E3 Check-In
Attachments:	Inflation.csv

Deliberative; FOIA-exempt

Thanks for sending out the action items Aaron. Here's the information for the BPA bullets:

- The F&W cost in the CRSO EIS was $34,060,200 and spread evenly across the four plants results in a cost of generation:
  FY2022 $/MWh

Plant	50-year Forecast with LSRCP
Lower Granite	$22.69
Little Goose	$15.71
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Ice Harbor	$15.84

Cost Calculation: The O&M budges used a flat 2% inflation rate. Capital numbers were based on modeled replacement needs influenced by asset risk so they varied year-to-year before levelizing. The capital replacement assumptions were inflated per asset using the 2021 BPA common planning assumptions for inflation (attached). Costs were levelized using BPA's nominal discount rate of 6.2% so the result is a levelized cost in real 2022 dollars.

Data availability: The hourly modeling data available is only for the 80 water year set which ends in 2008. We are working on adding another 10 years to the water year set which would include 2011 but that won't be completed in time for this analysis. Either a different wet year would need to be selected (e.g. 1996 or 1997) or if wet year cannot be changed than some sort of adjustment to the Pmin, Pmax, and the daily MWh budget could be made to adjust the historical data to reflect higher spill operations and less generation for fish passage season. Let me know which option you would prefer.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, March 15, 2022 12:09 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Capturing action items from today's meeting:

- **BPA** to share fish and wildlife costs for continuing LSR dam operations
- **BPA** to share cost calculation details (levelization, dollar year, etc.) for the $/MWh values provided
- **E3** to continue developing hydro constraints based on historical data and share w/ BPA in next couple days
- **BPA** to confirm availability of simulated hydro data w/ more recent biological operating constraints for the historical years currently being used in RESOLVE (calendar years 2001, 2005, and 2011)

- **E3** to incorporate today's discussion and share an updated scenario design for BPA review

All the best,
Aaron

From: Aaron Burdick
Sent: Tuesday, March 15, 2022 9:56 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; rjdiffely@bpa.gov
Cc: Jack Moore <Jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Hi all,

Suggested agenda for today's check in:

- **Costs**: confirm scope/use of $/MWh data provided
- **Operational constraints**: E3 is still developing our proposed Pmin, Pmax, daily MWh budgets to share w/ BPA, but it may be useful to discuss Eve's notes (fish constraints, GENESYS heuristics, etc.)
- **Scenarios**: present an initial set of scenario inputs and get BPA's feedback

All the best,
Aaron

-----Original Appointment-----
From: Aaron Burdick
Sent: Wednesday, March 2, 2022 4:53 PM
To: Aaron Burdick; Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; rjdiffely@bpa.gov; Angineh Zohrabian; Sierra Spencer
Subject: BPA-E3 Check-In
When: Tuesday, March 15, 2022 11:00 AM-12:00 PM (UTC-08:00) Pacific Time (US & Canada).
Where: https://ethree.webex.com/ethree/j.php?MTID=m228a4e26c5b763d73adb84c525782f42

Updating series from 30 mins to 1 hr.

Purpose: check-in on lower snake river dams analysis.

-~-

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Year	InflationRa	InflationFactor
2021	0.01741	1
2022	0.019939	1.01741
2023	0.020586	1.037696
2024	0.020825	1.059059
2025	0.021016	1.081113
2026	0.021563	1.103834
2027	0.022661	1.127636
2028	0.02359	1.153189
2029	0.023874	1.180392
2030	0.024017	1.208573
2031	0.023292	1.2376
2032	0.022928	1.266426
2033	0.022839	1.295463
2034	0.022711	1.32505
2035	0.022669	1.355144
2036	0.022509	1.385863
2037	0.022318	1.417057
2038	0.022314	1.448683
2039	0.022301	1.481009
2040	0.022485	1.514037
2041	0.022256	1.54808
2042	0.022449	1.582533
2043	0.022719	1.618059
2044	0.022811	1.654821
2045	0.0228	1.692569
2046	0.022827	1.73116
2047	0.022887	1.770677
2048	0.023013	1.811202
2049	0.02314	1.852884
2050	0.023357	1.89576
2051	0.023357	1.94004
2052	0.023357	1.985353
2053	0.023357	2.031725

2054	0.023357	2.07918
2055	0.023357	2.127744
2056	0.023357	2.177442
2057	0.023357	2.2283
2058	0.023357	2.280347
2059	0.023357	2.333609
2060	0.023357	2.388115
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2062	0.023357	2.500977
2063	0.023357	2.559392
2064	0.023357	2.619172
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2092	0.023357	4.999483
2093	0.023357	5.116256
2094	0.023357	5.235757
2095	0.023357	5.358049
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2097	0.023357	5.611268
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2099	0.023357	5.876455
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2107	0.023357	7.068591
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2109	0.023357	7.40265
2110	0.023357	7.575554
2111	0.023357	7.752497
2112	0.023357	7.933572
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2114	0.023357	8.30851
2115	0.023357	8.502572
2116	0.023357	8.701167
2117	0.023357	8.904401
2118	0.023357	9.112381
2119	0.023357	9.325219
2120	0.023357	9.543029
2121	0.023357	9.765926

2122	0.023357	9.994029
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2124	0.023357	10.46634
2125	0.023357	10.71081
2126	0.023357	10.96098
2127	0.023357	11.21699
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2129	0.023357	11.74711
2130	0.023357	12.02148
2131	0.023357	12.30227
2132	0.023357	12.58961
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2138	0.023357	14.46024
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2144	0.023357	16.60881
2145	0.023357	16.99675
2146	0.023357	17.39374
2147	0.023357	17.80001
2148	0.023357	18.21576
2149	0.023357	18.64123
2150	0.023357	19.07663
2151	0.023357	19.52221

From: Koehler,Birgit G (BPA) - PG-5
Sent: Tuesday, March 22, 2022 3:49 PM
To: Diffely,Robert J (BPA) - PGPL-5
Subject: RE: BPA-E3 Check-In - 3-22 action items

Erin just called me. It looks like she has the hourly data from Riverware that Peter didn't think we had. Erin will get in touch with Aaron to verify that this is what they need.

From: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Sent: Tuesday, March 22, 2022 2:32 PM
To: Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: FW: BPA-E3 Check-In - 3-22 action items

FYI

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, March 22, 2022 12:57 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] BPA-E3 Check-In - 3-22 action items

Deliberative; FOIA-exempt

Action items from today's check in:

- **BPA** (Rob) to share previous trapezoid analysis re: hydro capacity value (***DONE! Thanks Rob!***)
- **E3** to update scenarios and defer sensitivity decisions until after first round
  - Proceed with scenarios 1, 2, 2a, and 2b for now, review results in April, then determine additional sensitivities to pursue
  - Move earlier removal sensitivity from scenario 2 to scenario 1
  - Consider replacing capacity value sensitivity with a no fish constraints case, pending data availability
- **BPA** to provide additional data regarding hydro operational impacts from spill requirements
  - Specifically, we are looking at *calendar* year 2001, 2005, and 2011 historical data and looking to understand how to adjust the Pmin/Pmax and daily MWh budgets for the LSR dams and any other related plants (lower Columbia)
  - If BPA can provide hourly plant-level (also fine if LSR dams are aggregated) generation for each of those years in A) a without fish constraint scenario, and B) a with fish constraint scenario, then E3 can adjust our data accordingly
  - If less granular data is available (e.g. more aggregated output and/or monthly or daily MWh budgets instead of hourly data), then E3 can still use that data to derive a heuristic from which to de-rate the P-max and/or daily MWh assumptions for the appropriate months

Many thanks,

Aaron Burdick, Associate Director

Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500 | San Francisco, CA 94104
818-807-6499 | aaron.burdick@ethree.com

From: James,Eve A L (BPA) - PG-5
Sent: Tuesday, July 26, 2022 9:34 AM
To: Koehler,Birgit G (BPA) - PG-5
Subject: RE: Clearing Up, Issue 2065

That makes sense- I'm not sure if there is any budget left that we added for presentations or not. It seems they would want to defend their RESOLVE model and analysis regardless for their business and future contracting prospects but happy to help make it happen if needed.

-----Original Message-----
From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Tuesday, July 26, 2022 9:31 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: RE: Clearing Up, Issue 2065

I have no problem paying them for this. I just note Liz? Sonya? email that we don't want it to look like it was motivated by us

-----Original Message-----
From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, July 26, 2022 8:37 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Leary,Jill C (BPA) - LN-7 <jcleary@bpa.gov>; Armentrout,Scott G (BPA) - E-4 <sgarmentrout@bpa.gov>; Godwin,Mary E (BPA) - LN-7 <megodwin@bpa.gov>
Cc: Baskerville,Sonya L (BPA) - AIN-WASH <slbaskerville@bpa.gov>; Zelinsky,Benjamin D (BPA) - E-4 <bdzelinsky@bpa.gov>
Subject: RE: Clearing Up, Issue 2065

We paid them to do the presentations on the study so I'm guessing that's what he is asking. I can touch base with him and Aaron on what $ and if we have some left in the presentation budget (though we had so many meetings I'm guessing we used that up).

-----Original Message-----
From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Tuesday, July 26, 2022 8:29 AM
To: Leary,Jill C (BPA) - LN-7 <jcleary@bpa.gov>; Armentrout,Scott G (BPA) - E-4 <sgarmentrout@bpa.gov>; Godwin,Mary E (BPA) - LN-7 <megodwin@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Baskerville,Sonya L (BPA) - AIN-WASH <slbaskerville@bpa.gov>; Zelinsky,Benjamin D (BPA) - E-4 <bdzelinsky@bpa.gov>
Subject: RE: Clearing Up, Issue 2065

I don't know what that means, but yes, it could include us paying for their time to write the response.

-----Original Message-----
From: Leary,Jill C (BPA) - LN-7 <jcleary@bpa.gov>
Sent: Tuesday, July 26, 2022 8:28 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Armentrout,Scott G (BPA) - E-4 <sgarmentrout@bpa.gov>; Godwin,Mary E (BPA) - LN-7 <megodwin@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>

Cc: Baskerville,Sonya L (BPA) - AIN-WASH <slbaskerville@bpa.gov>; Zelinsky,Benjamin D (BPA) - E-4 <bdzelinsky@bpa.gov>
Subject: RE: Clearing Up, Issue 2065

Birgit, do you know what "sponsoring E3" means? Do they mean have BPA pay for them to write the response?

-----Original Message-----
From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Tuesday, July 26, 2022 6:56 AM
To: Armentrout,Scott G (BPA) - E-4 <sgarmentrout@bpa.gov>; Godwin,Mary E (BPA) - LN-7 <megodwin@bpa.gov>; Leary,Jill C (BPA) - LN-7 <jcleary@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Baskerville,Sonya L (BPA) - AIN-WASH <slbaskerville@bpa.gov>; Zelinsky,Benjamin D (BPA) - E-4 <bdzelinsky@bpa.gov>
Subject: FW: Clearing Up, Issue 2065

I think Arne's suggestion to write a response to the Clearing Up article is a good idea. I too thought that the RNP critique had errors.

Do you agree?
Birgit

-----Original Message-----
From: Arne Olson <arne@ethree.com>
Sent: Monday, July 25, 2022 6:38 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Aaron Burdick <aaron.burdick@ethree.com>
Subject: [EXTERNAL] FW: Clearing Up, Issue 2065

FYI, see the critique from Renewables Northwest. Would BPA be interested in sponsoring us to write a brief, technical response? Each of these points is easy to rebut. They are mostly based on misunderstandings and mischaracterizations. Very annoying. We would keep it short and technical.

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From: NewsData <newsdata@newsdata.com>
Sent: Friday, July 22, 2022 4:26 PM
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Subject: Clearing Up, Issue 2065

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Cc: Baskerville,Sonya L (BPA) - AIN-WASH; Zelinsky,Benjamin D (BPA) - E-4
Subject: RE: Clearing Up, Issue 2065

We could write back saying that a response would be good, but asking what "sponsoring" means

-----Original Message-----
From: Koehler,Birgit G (BPA) - PG-5
Sent: Tuesday, July 26, 2022 8:29 AM
To: Leary,Jill C (BPA) - LN-7 <jcleary@bpa.gov>; Armentrout,Scott G (BPA) - E-4 <sgarmentrout@bpa.gov>; Godwin,Mary E (BPA) - LN-7 <megodwin@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
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Subject: RE: Clearing Up, Issue 2065

I don't know what that means, but yes, it could include us paying for their time to write the response.

-----Original Message-----
From: Leary,Jill C (BPA) - LN-7 <jcleary@bpa.gov>
Sent: Tuesday, July 26, 2022 8:28 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Armentrout,Scott G (BPA) - E-4 <sgarmentrout@bpa.gov>; Godwin,Mary E (BPA) - LN-7 <megodwin@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
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Subject: RE: Clearing Up, Issue 2065

Birgit, do you know what "sponsoring E3" means? Do they mean have BPA pay for them to write the response?

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Sent: Tuesday, July 26, 2022 6:56 AM
To: Armentrout,Scott G (BPA) - E-4 <sgarmentrout@bpa.gov>; Godwin,Mary E (BPA) - LN-7 <megodwin@bpa.gov>; Leary,Jill C (BPA) - LN-7 <jcleary@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
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Cc: Aaron Burdick <aaron.burdick@ethree.com>
Subject: [EXTERNAL] FW: Clearing Up, Issue 2065

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Sent: Tuesday, July 26, 2022 6:58 AM
To: Koehler,Birgit G (BPA) - PG-5; Godwin,Mary E (BPA) - LN-7; Leary,Jill C (BPA) - LN-7; James,Eve A L (BPA) - PG-5
Cc: Baskerville,Sonya L (BPA) - AIN-WASH; Zelinsky,Benjamin D (BPA) - E-4
Subject: RE: Clearing Up, Issue 2065

Absolutely agree. Scott

SCOTT G ARMENTROUT
Executive Vice President, Environment, Fish & Wildlife, SES | E-4 BONNEVILLE POWER ADMINISTRATION bpa.gov | P 503-230-3076 | C(b)(6) [redacted]

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From: Koehler,Birgit G (BPA) - PG-5
Sent: Tuesday, July 26, 2022 10:29 AM
To: James,Eve A L (BPA) - PG-5
Subject: RE: Confirming final project deliverables for each task

I can't think of any edits to the slide deck or final report. (I would hope that if we found something big, we could find a way for them to do it, on their own time or just using the wrong task, but I don't think that's likely.)

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, July 26, 2022 10:27 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: FW: Confirming final project deliverables for each task

Hi Birgit- do you think there is any need for Aaron to update the technical slide deck before closing out or are we good with the final report and public slide deck graphics? I think the Appendix slides in the public deck capture most of the more in depth materials we need from them and the final report as well but wanted to confirm with you before closing out.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, July 21, 2022 12:02 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: [EXTERNAL] Confirming final project deliverables for each task

Hi Eve,

Wanted to quickly ping you about thoughts on closing out Tasks 1-5 of the project, recognizing there is still some ongoing presentation support (Task 6). Specifically, do you want us to do additional work on the earlier slide decks for Tasks 1-3 before closing out and providing final approval on those tasks?

Let me know if/when we need to loop in the BPA contract administrator. I defer to you on how to manage that process.

Happy to chat briefly if you like.

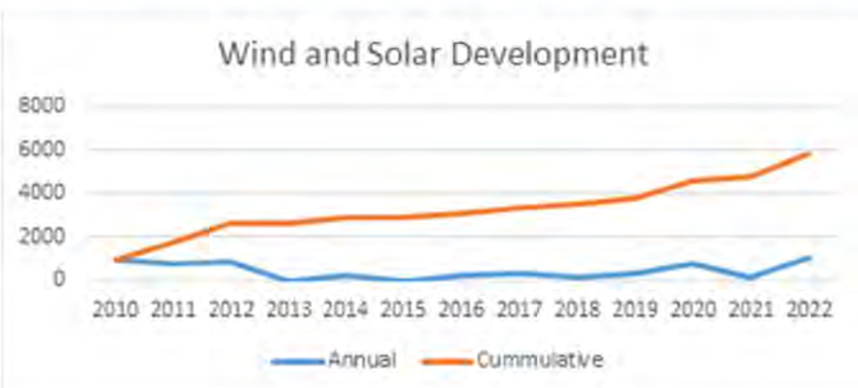
Thanks!

Aaron Burdick, Associate Director
Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500 | San Francisco, CA 94104
818-807-6499 | aaron.burdick@ethree.com

From: Diffely,Robert J (BPA) - PGPL-5
Sent: Thursday, April 28, 2022 8:42 AM
To: Arne Olson; James,Eve A L (BPA) - PG-5; Angineh Zohrabian; Riley,Erin A (BPA) - PGPR-5; Aaron Burdick
Cc: Koehler,Birgit G (BPA) - PG-5; Egerdahl,Ryan J (BPA) - PGPR-5; Sierra Spencer; Jack Moore
Subject: RE: Data for E3

NWEC chart

What wind and solar has actually been built (or under construction) in the past 12 years:



From: Arne Olson <arne@ethree.com>
Sent: Wednesday, April 27, 2022 4:01 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>; Sierra Spencer <sierra.spencer@ethree.com>; Jack Moore <jack@ethree.com>
Subject: [EXTERNAL] RE: Data for E3

FYI, Nancy Hirsh editorial in the Yakima Herald-Republic on replacing the dams. It doesn't have much in the way of specifics.

https://www.yakimaherald.com/opinion/commentary-replacing-dams-power-will-take-smart-planning/article_33c56e11-5ec6-572f-98ed-1d1eff5d6900.html

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, April 19, 2022 4:23 PM
To: Angineh Zohrabian <angineh.zohrabian@ethree.com>; Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>; Sierra Spencer <sierra.spencer@ethree.com>; Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>
Subject: FW: Data for E3

Deliberative; FOIA Exempt
This would be the "emergency capabilities" scenario set:

From: Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>
Sent: Wednesday, April 6, 2022 4:47 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: Data for E3

Deliberative; FOIA Exempt

Hi Eve,

I've attached the data removing spillway spill at the lower snakes.
Also made some plots for 2005 so you can see the difference, and added some hourly data from actual 2005 (Dataquery 2.0 (crohms.org))

Otherwise the run parameters are the same as before.

Data notes: The model was run on the FY, as indicated by the "trace" column. For CY I provided the Oct-Dec of the following FY trace. I did not correct the date to be continuous because this model simulation, generation is peaking during these dates in the datetime column:

Wednesday, December 6, 2023	Friday, December 8, 2023
Wednesday, January 3, 2024	Friday, January 5, 2024
Wednesday, February 7, 2024	Friday, February 9, 2024
Wednesday, July 3, 2024	Friday, July 5, 2024
Wednesday, August 21, 2024	Friday, August 23, 2024

Data dictionary:
"*.Power" = hourly generation in MW
"*.GN_Max_HK_ModelCap" = one hour capacity.
"*.Rsrv_DEC_Sim" = Dec reserves held at that project, or total if * is BPA
"*.Rsrv_INC_Sim" = Inc reserves held by that project, or total is * is BPA

Erin Riley
Operations Research Analyst
PGPR- Long Term Power Planning
Bonneville Power Administration

503-230-3717

From:	James,Eve A L (BPA) - PG-5
Sent:	Wednesday, June 29, 2022 12:41 PM
To:	Diffely,Robert J (BPA) - PGPL-5
Cc:	Koehler,Birgit G (BPA) - PG-5
Subject:	RE: Draft Exec Summary

Deliberative, FOIA exempt

Hi Rob-

I forgot to mention that Birgit and I have been reviewing with a "light-touch" since this is an independent E3 study. Any red-flag important catches or corrections we've been commenting on. Also, I know a lot of reports are coming in for review but due to the timing of trying to get this report finalized by Friday for public posting after the Council presentation this would be priority in terms of study review (Birgit correct me if I'm wrong).

Thanks,

Eve

From: James,Eve A L (BPA) - PG-5

Sent: Wednesday, June 29, 2022 12:30 PM

To: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>

Cc: Koehler,Birgit G (BPA) - PG-5 (bgkoehler@bpa.gov) <bgkoehler@bpa.gov>

Subject: FW: Draft Exec Summary

Deliberative, FOIA exempt

Hi Rob-

Here is a draft of the E3 report. If you could send me any edits/comments in "track changes" mode I would appreciate the feedback. I will be compiling comments from you and Birgit to send to E3 hopefully by Close of Business Thursday so they can incorporate and send the final report by Close of Business Friday. Sorry for the quick turnaround but we want to get this report finalized before the Council presentation next week and I will be out of the office that week.

Thanks,

Eve

From: Aaron Burdick <aaron.burdick@ethree.com>

Sent: Wednesday, June 29, 2022 12:14 PM

To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>

Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>

Subject: [EXTERNAL] RE: Draft Exec Summary

Deliberative, FOIA exempt

Eve,

Arne is still completing some edits, but I'm sending this "interim" draft version so you have the full report to start digging through. I'll send another version later today with all of Arne's edits, so suggest *E3 retains version control until later today when we share that version*, when it will transfer to BPA.

Note: Arne has made some changes to the exec summary, which I've keep tracked since you already reviewed that. I updated is response to your prior feedback (but did not track those changes).

All the best,
Aaron

From: Aaron Burdick
Sent: Tuesday, June 28, 2022 9:43 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Eve,

Status update: we're still working on a few remaining items in the draft and incorporating Arne's review. I'm hoping to send you the draft by mid-day tomorrow. Will either send of provide an update until then. I'm hoping we can get your review by end of day Thursday and update as needed on Friday before sharing the final version by Friday COB.

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Monday, June 27, 2022 3:36 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt
Hi Aaron-
Attached are some comments on the Executive Summary for your consideration.

Arne- I saw the Council's note on providing materials ahead of the July 7th meeting. Internally we were thinking that if we share the PPT this early we would need to be prepared to start fielding incoming questions and for the info to be shared with others. We're still working on some talking points for our communications staff and Account Executives. Also, just so you are aware there is a discussion with some of DC folks tomorrow so I was going to wait and email the Council staff tomorrow after that meeting if you don't mind. If you have concerns about waiting to share materials please let me know.

Thanks,
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From: Aaron Burdick <aaron.burdick@ethree.com>
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To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
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Deliberative, FOIA exempt

Hi Eve,

I'm leaving for a weekend trip and OOO the rest of the afternoon. I'm providing the draft executive summary but the rest of the report draft will need to wait until Tuesday next week. Hopefully this provides enough to make sure we're aligned. I'm also copying the TOC for the draft report to make sure you're aware what we're working on.

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All the best,

Aaron Burdick, Associate Director
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44 Montgomery Street, Suite 1500 | San Francisco, CA 94104

818-807-6499 | aaron.burdick@ethree.com

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Sent: Friday, June 24, 2022 3:25 PM
To: James,Eve A L (BPA) - PG-5
Subject: RE: Draft Exec Summary

I see one red flag edit already:

p. 2 below the graphs

~~When~~ If the dams are removed from the regional power system, RESOLVE was still able to meet the Northwest's clean energy policy goals and system reliability, however a large investment in replacement resources was found to be required at a substantial cost.

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Cc:	Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian; Arne Olson
Subject:	RE: Draft Exec Summary
Attachments:	E3_ExecSummaryDraft_062422-eaj bgk.docx

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Subject: [EXTERNAL] Draft Exec Summary

Deliberative, FOIA exempt

Hi Eve,

I'm leaving for a weekend trip and OOO the rest of the afternoon. I'm providing the draft executive summary but the rest of the report draft will need to wait until Tuesday next week. Hopefully this provides enough to make sure we're aligned. I'm also copying the TOC for the draft report to make sure you're aware what we're working on.

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All the best,

Aaron Burdick, Associate Director
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From: Koehler,Birgit G (BPA) - PG-5
Sent: Wednesday, July 27, 2022 2:16 PM
To: Arne Olson; James,Eve A L (BPA) - PG-5; Aaron Burdick
Subject: RE: E3 Response to Renewables Northwest Critique of 4 LSRD study

☺

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, July 27, 2022 2:11 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Subject: [EXTERNAL] FW: E3 Response to Renewables Northwest Critique of 4 LSRD study

FYI, we are on for the 5th. We'll try to get you a draft early next week, e.g., Monday afternoon.

Aaron, I will take the first crack at this and then pass to you for comment.

From: Mark Ohrenschall <marko@newsdata.com>
Sent: Wednesday, July 27, 2022 12:31 PM
To: Arne Olson <arne@ethree.com>; Dan Catchpole <dcatchpole@newsdata.com>; Steve Ernst <sernst@newsdata.com>
Subject: Re: E3 Response to Renewables Northwest Critique of 4 LSRD study

Hi Arne ...

Sure, we're happy to publish an E3 response to the Renewables Northwest piece in last week's Clearing Up.

We already have a column committed for this week (July 29); we can plan to run yours in our Aug. 5 issue, if that works for you.

As for guidelines, we prefer columns of up to 1,200 words (can be fewer), although it's not a hard-and-fast rule. Could you get it to us by end of the day Wednesday, Aug. 3?

Thanks for reaching out, and happy to answer questions/further discuss.

Mark O.

Mark Ohrenschall
Publisher/Editor-in-Chief
NewsData
www.newsdata.com
marko@newsdata.com
(b)(6) [redacted]

From: Arne Olson <arne@ethree.com>
Sent: Tuesday, July 26, 2022 6:18 PM
To: Mark Ohrenschall <marko@newsdata.com>; Dan Catchpole <dcatchpole@newsdata.com>
Subject: E3 Response to Renewables Northwest Critique of 4 LSRD study

Hi Mark and Dan,

E3 would be interested in publishing a response to the opinion piece that you ran for Renewables Northwest last Friday on our Lower Snake River dam replacement study. Their article is based on a number of misconceptions and misunderstandings that I think are important to clear up. Would you be interested/willing to publish an E3 response? If so, what would that look like and when would we need to get you a completed piece?

Thanks,

Arne

Arne Olson, Senior Partner
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44 Montgomery Street, Suite 1500 | San Francisco, CA 94104
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he/him/his

From: Koehler,Birgit G (BPA) - PG-5
Sent: Thursday, August 4, 2022 8:25 AM
To: Arne Olson; James,Eve A L (BPA) - PG-5
Cc: Aaron Burdick
Subject: RE: E3 Response to Renewables Northwest Critique of 4 LSRD study
Attachments: E3 Renewables-NW Response 2022-08-01, bk.docx

Hi Arne and Aaron,

This looks really good. I have only minor, minor edits/comments, which you may consider or ignore.

Eve is out this week.

Cheers,
Birgit

From: Arne Olson <arne@ethree.com>
Sent: Thursday, August 4, 2022 8:03 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Aaron Burdick <aaron.burdick@ethree.com>
Subject: [EXTERNAL] FW: E3 Response to Renewables Northwest Critique of 4 LSRD study

DELIBERATIVE FOIA EXEMPT

Hi Birgit and Eve,

Our attached is the response we sent to Clearing Up. Probably time for minor revisions today if you had any thoughts to share.

Thanks!

Arne

From: Arne Olson
Sent: Thursday, August 4, 2022 12:30 AM
To: Mark Ohrenschall <marko@newsdata.com>; Dan Catchpole <dcatchpole@newsdata.com>; Steve Ernst <sernst@newsdata.com>
Cc: Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: E3 Response to Renewables Northwest Critique of 4 LSRD study

Hi Mark,

Please find our Op Ed response attached. Please let me know if you have any questions or concerns about the piece.

Many thanks for agreeing to publish this!

Arne

From: Mark Ohrenschall <marko@newsdata.com>
Sent: Wednesday, July 27, 2022 12:31 PM
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Mark O.

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Subject: E3 Response to Renewables Northwest Critique of 4 LSRD study

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Thanks,

Arne

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Response to Renewable Northwest Op-Ed

August 6

Prepared by Arne Olson, Senior Partner, and Aaron Burdick, Associate Director

Renewable Northwest's op-ed in the July 22, 2022 edition of Clearing Up criticizes E3's Lower Snake River Dams Power Replacement Study which was prepared on behalf of the Bonneville Power Administration. The op-ed is critical of E3's modeling for "not fully capturing the value of existing renewables and battery storage" and not accounting for the impact of climate change on hydro and load. Unfortunately, the op-ed is simplistic and disappointingly betrays a lack of understanding of the dynamics of deeply-decarbonized and highly-renewable power systems.

It is true that the power output of the ~~Four~~ four ~~Lower~~ lower Snake River dams could readily be replaced with a combination of wind, solar, and battery storage – along with demand-side resources – under today's electricity market conditions and *if removal of the dams was the region's only policy objective*. The study prepared by Energy Strategies earlier this year for the Northwest Energy Coalition essentially models this scenario, finding replacement costs of $277-309 million per year or $8-9 billion NPV (albeit without replacing all of the dams' firm capacity)[1].

Comment [KG(-P1]: The river's name is simply Snake River, and we are talking about the lower portion of the river.

Comment [KG(-P2]: Do you want to clarify that Energy are only replacing the energy (and really only 70% of the energy)?

[1] https://nwenergy.org/issues/fish-wildlife/lower-snake-river-dam-replacement-study-energy-strategies/?utm_source=rss&utm_medium=rss&utm_campaign=lower-snake-river-dam-replacement-study-energy-strategies

By contrast, E3's study considers the resources needed to replace the dams *while also reducing carbon emissions to zero* or near zero by 2045, finding replacement costs of $450-800 million per year or $12-19 billion NPV. On these future power systems, the ability of wind and solar to contribute to resource adequacy, even when augmented with diurnal energy storage, is significantly diminished due to saturation. In fact, study after study has found that some form of "clean firm" generation – carbon-free generation that can run whenever needed – is necessary to achieve carbon emissions reductions beyond approximately 80% due to the limitations of variable renewables and short-duration storage.[2]

E3's study assumes that hydrogen-capable combustion turbines are available to fill this "clean firm" role in most scenarios. Other options are advanced nuclear, fossil generation with carbon capture, and long-duration energy storage. These emerging technologies dramatically reduce the cost of achieving deep decarbonization relative to scenarios without them. They also reduce the cost of replacing the Lower Snake River dams' generation, which requires replacing both the dams' GHG-free energy and their firm capacity contributions. E3's study not only fully captures the value of wind, solar and storage, but optimistically assumes that additional resources are available to complement them, resources that are not commercially available today. The scenario that did not allow any "clean firm" resources resulted in an unrealistically large renewable and battery buildout – and an astronomical cost for replacing the Lower Snake River dams.

The electricity sector's twin tasks of serving load reliably and reducing carbon emissions are intensified when considering electricity's role in achieving economy-wide decarbonization. Extensive electrification of transportation and building sector loads, called for in every deep decarbonization pathways study including Washington's 2021 State Energy Strategy[3], will significantly increase peak electricity demands, particularly during winter cold spells when much of the heating demand is currently met by natural gas.

[2] For examples, see https://www.sciencedirect.com/science/article/pii/S2542435118303866, https://issues.org/california-decarbonizing-power-wind-solar-nuclear-gas/

[3] https://www.commerce.wa.gov/growing-the-economy/energy/2021-state-energy-strategy/

While a warming climate, diminishing snowpack, and deteriorating load-resource balance will almost certainly lead to summertime reliability challenges in the Northwest over the next decade, meeting wintertime electric heating demands will be the largest reliability issue in the long run, even for southern systems such as California[4] and Texas[5]. Maintaining resource adequacy in the Pacific Northwest will require fully replacing the Lower Snake River dams' wintertime peaking capabilities. The op-ed disappointingly does not mention electrification or appear to consider its impact on regional electric loads.

Beyond these general remarks, specific responses are warranted in a few areas:

+ The op-ed takes issue with E3's use of a capacity expansion model, RESOLVE, which simulates operations over 41 representative days from each year and investment decisions over multiple decades, as opposed to an 8760-hour production simulation model. While the additional operational fidelity of modeling a full year is desirable, RESOLVE's operating days are carefully selected to accurately represent a wide range of system conditions, using multiple historical years of load, wind, solar and hydro conditions. Moreover, because fixed costs account for nearly 100% of the cost of replacement resources, optimization of capital deployment is the most important dynamic for this study to capture accurately. In fact, E3's use of RESOLVE responds to a criticism BPA received for *not* utilizing an optimal capacity expansion model in its 2020 Columbia River System Operations Environmental Impact Statement[6].

+ The op-ed suggests that a full-year production simulation model would be better able to capture the complementary nature of wind, solar, batteries, and hydro. In fact, RESOLVE's internal production simulation algorithms are fully capable of simulating these operational dynamics. Indeed, RESOLVE likely *over-optimizes* the joint dispatch of storage and renewable resources relative to hybrid resources with operational constraints caused by reliance on a single inverter, interconnection limit, or limitations

[4] https://www.ethree.com/wp-content/uploads/2019/06/E3_Long_Run_Resource_Adequacy_CA_Deep-Decarbonization_Final.pdf

[5] https://energy.utexas.edu/sites/default/files/UTAustin%20%282021%29%20EventsFebruary2021TexasBlackout%2020210714.pdf

[6] https://www.federalregister.gov/documents/2020/10/08/2020-22147/record-of-decision-columbia-river-system-operations-environmental-impact-statement

on charging from the grid. Neither RESOLVE nor full-year production simulation models can simulate the ability of various resources to contribute to resource adequacy. That's why RESOLVE uses results from a Loss-of-Load Probability model, E3's RECAP model which was used in our 2019 Study *Resource Adequacy in the Pacific Northwest*[7], to characterize the capacity contribution of various resources over time.

- E3's study is criticized for not selecting hybrid solar and storage resources, which have a very high effective load-carrying capability (ELCC) values for Idaho Power's system, to replace the dams. However, Idaho Power's and other IRP-related assessments of renewable ELCCs are focused on the value of those resources *today and in the near future*. Because there is very little solar and battery storage in the Pacific Northwest today, these resources have relatively high capacity value on strongly summer-peaking systems like Idaho Power's. However, it is well understood that as more variable and duration-limited resources are added to a power system, their marginal capacity contribution declines[8]. Because E3's study is optimizing the replacement resources on a system with zero or near zero carbon emissions, the baseline system includes tens of thousands of MW of wind and solar resources. The marginal capacity contribution from adding *even more* wind and solar to replace the output of the Lower Snake River dams is very small, hence RESOLVE finds it more cost-effective to add hydrogen-capable combustion turbines which are very effective at providing firm capacity even though their dispatch costs are high.

- The study is criticized for its assumption of a 15% planning reserve margin (PRM), which is said to be inconsistent with the Western Resource Adequacy Program (WRAP). E3's study models the entire region as if it were a single power system with all the load and resource diversity and frictionless transactions that entails; in effect E3 assumes a program like WRAP is in operation through the study period. Most importantly, the reserve margin and capacity contribution assumptions are held constant in the "with" and "without" cases, ensuring that the *reliability contribution of the dams themselves* is the key driver of the replacement resources, not the background reliability level for the region.

---

[7] https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

[8] https://www.ethree.com/wp-content/uploads/2020/08/E3-Practical-Application-of-ELCC.pdf

- The op-ed's criticism of E3's reliance on historical weather data to characterize the resource adequacy contribution of the dams is fair. Utilization of projected climate-altered weather and hydro conditions would likely have shown more reliability challenges in the summertime when the dams' peaking capability is reduced. To evaluate this possibility, E3 included a sensitivity case with the dams' peaking capability reduced from 2.3 GW to 1.0 GW. The replacement costs were estimated to be 14-33% lower than in the base scenarios.

  More importantly, this line of criticism ignores the fact that, in the long run, electrification of heating load is likely to drive up wintertime peak electric loads by 50% or even more. Serving load reliably during extreme cold weather events is expected to be the single biggest challenge for decarbonized energy systems around the world, a challenge against which wind, solar and short-duration batteries are largely ineffective.

Over the next few decades, the Northwest will have to face the challenge of both restoring salmon populations *and* decarbonizing its economy. It is essential that decisions about the future of the Lower Snake River dams be based on the best available information about how both of these challenges can be met.

Energy+Environmental Economics

BPA Lower Snake River Dams Power Replacement

Executive Summary

June 2022

Arne Olson, Sr. Partner
Aaron Burdick, Associate Director
Sierra Spencer, Sr. Consultant
Dr. Angineh Zohrabian, Consultant
Sam Kramer, Consultant
Jack Moore, Sr. Director

About this study

+ **BPA contracted with E3 to conduct an independent analysis of the electricity system value of the four lower Snake River (LSR) dams**
+ **E3 utilized our RESOLVE optimal capacity expansion model to identify least-cost portfolios of electricity resources needed to replace the electric energy and grid services provided by the dams through 2045**
+ **Replacement costs and emissions impacts are considered within the context of the Northwest region's aggressive, long-run decarbonization goals**

Key Study Questions:

- What **additional resources** would be needed to replace the power services provided by the LSR Dams through 2045?
- What is the **net cost to** BPA ratepayers?
- How do costs and resource needs change under **different types of clean energy futures**?
- How much does replacing the dams rely on **emerging, not-yet-commercialized technologies**?

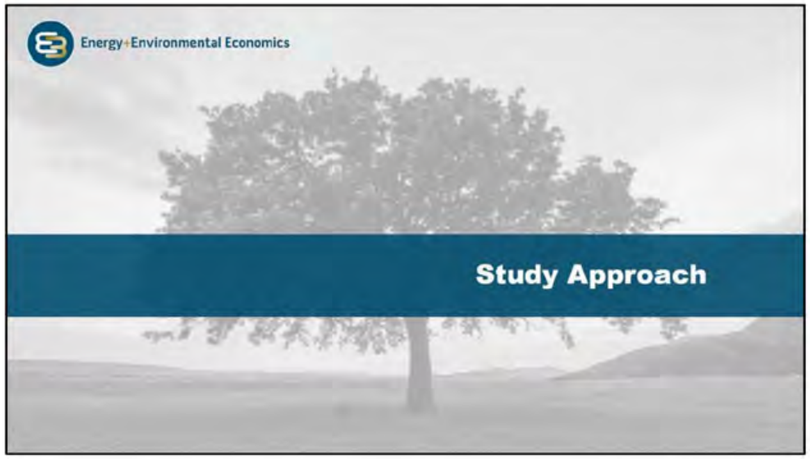
What would it take to replace the output of the four lower Snake River dams?

Key Study Conclusions

- **What energy services are lost if the dams are breached?**
  - 3,483 MW of nameplate capacity, including over 2,000 MW of firm peaking capability to avoid power shortages during extreme cold weather events
  - ~700-900[1] annual average MW of low-cost, zero-carbon energy (enough energy to support ~450,000 households or 1.7x the City of Portland) as well as operational flexibility services
- **How much would it cost to replace the power benefits of the four lower Snake River dams in E3's study?**
  - Given the trends towards aggressive carbon reductions policies, under a "deep decarbonization" scenario absent breakthroughs in not-yet-commercialized emerging technologies, total costs could be as much as $11 billion in upfront capital costs with up to $53 million per year for operational cost. Total net present value (NPV) costs could be as much as $46 billion.
  - With less load growth and less stringent long-term emissions reduction goals, total costs would be $2.8 billion in upfront capital costs with up to $110 million per year for operational cost. Total net present value (NPV) costs would be $7.5 billion.
- **What are the long-term rate impacts to ~2 million public power households in 2045?**
  - Public power costs could increase as much as 65% or $850 per year (deep decarbonization scenario absent emerging technology breakthroughs)
  - Public power costs increase by 9% or ~$125 per year (baseline scenario)
- **What resources are needed to replace the dams?**
  - A combination of energy efficiency, renewable generation (wind), and "clean firm" capacity additions (such as dual fuel natural gas + hydrogen plants, advanced nuclear, or gas with carbon capture and storage)
  - Battery storage cannot cost-effectively replace hydro capacity in the Northwest due to charging limitations during energy shortfall events
- **What is the timeline necessary to add the resources that would be required?**
  - E3 estimates that adding additional renewable energy and firm capacity additions would take approximately 5 years after congressional approval to breach the dams and possibly up to 10 years if additional new transmission was required. E3 assumed transmission would be built as needed for renewable additions.

Plant	Nameplate Capacity (MW)
Lower Granite	930
Little Goose	930
Lower Monumental	930
Ice Harbor	693

Total = 3,483 MW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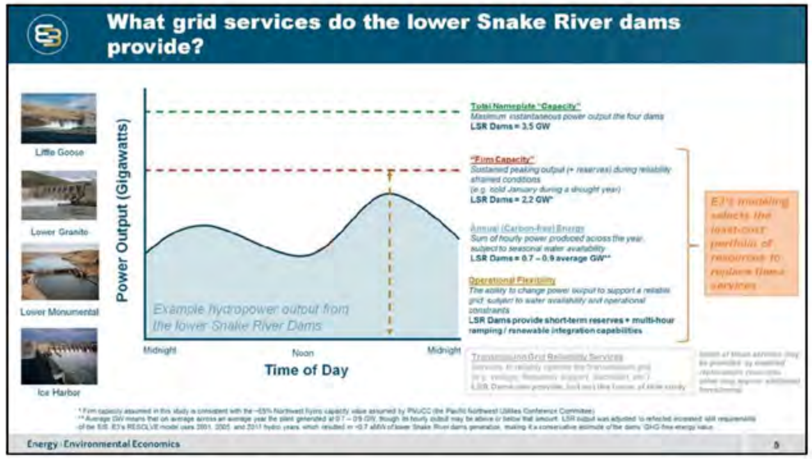
Study Approach


What grid services do the lower Snake River dams provide?
Little Goose
Lower Granite
Lower Monumental
Ice Harbor
Power Output (Gigawatts)
Example hydropower output from the lower Snake River Dams
Midnight
Noon
Midnight
Time of Day
Total Nameplate "Capacity"
Maximum instantaneous power output the four dams
LSR Dams = 3.5 GW
"Firm Capacity"
Sustained peaking output (+ reserves) during reliability strained conditions
(e.g. cold January during a drought year)
LSR Dams = 2.2 GW*
Annual (Carbon-free) Energy
Sum of hourly power produced across the year, subject to seasonal water availability
LSR Dams = 0.7 – 0.9 average GW**
Operational Flexibility
LSR Dams provide short-term reserves + multi-hour ramping / renewable integration capabilities
E3's modeling selects the
Energy+Environmental Economics

What's new in this study compared to the CRSO EIS?

The study uses an optimization model to determine the least-cost replacement resources for the four lower Snake River dams subject to A) policy and B) reliability constraints

+ **Least-cost optimization: includes updated resource pricing and new emerging technologies**
+ **Policy: E3's modeling considers the effects of regional policies such as Washington's Clean Energy Transformation Act (CETA) and Oregon's 100% clean electricity standard**
  - Aggressive clean energy laws drive coal power plant retirements, price carbon emissions, and require long-term **carbon emissions reductions** by 2045
  - Study includes significant **electrification** that increases demand for electricity to support carbon-reduction in other sectors such as transportation, buildings, and industry, consistent with Washington's Energy Strategy
+ **Reliability: E3's modeling captures the need for the Northwest system to meet peak load during extreme weather and low hydro conditions (known as "resource adequacy").**
  - Captures the abilities and limits of different technologies to serve load during reliability challenging conditions
    - E.g. during extended cold-weather periods with high load, low hydropower availability, and low wind and solar production
  - Resources with high energy production costs may be selected for reliability needs but then run sparsely only during extreme conditions (e.g. natural gas + hydrogen combustion turbines)
+ **LSR operations: incorporates preferred alternative operations selected in the EIS**
  - Increases spill from the dams, lowering available annual energy and changing operational flexibility

Policy Landscape: Washington, Oregon, California

+ The study includes the impacts clean energy policies in the Pacific states

	RPS or Clean Energy Standard?	Coal Prohibition?	Cap-and-Trade?	New Natural Gas?	Economy-Wide Carbon Reduction?
WA	✔ Carbon neutral by 2030, 100% carbon free electricity by 2045	✔ Eliminate by 2025	✔ Cap-and-invest program established in 2021. SCC in utility planning	✔	✔ 95% GHG emission reduction below 1990 levels and achieve net zero emissions by 2050
OR	✔ 50% RPS by 2040, 100% GHG emission reduction by 2040 relative to 2010 levels	✔ Eliminate by 2030	✔ Climate Protection Plan adopted by DEQ in 2021 (power sector not included)	✖ HB 2021 bans expansion or construction of power plants that burn fossil fuels	✔ 90% GHG emission reduction from fossil fuel usage relative to 2022 baseline
CA	✔ 60% RPS by 2030, 100% clean energy by 2045	✔ Coal-fired electricity generation already phased out	✔	✖ CPUC IRP did not allow in recent procurement order	✔ 40% GHG emission reduction below 1990 levels by 2030 and 80% by 2050

Modeling approach involves a three-step process

1. ***With the lower Snake River dams*, optimize long-term resource needs and operations for the Pacific Northwest**
   - Produces necessary resource additions and total system costs and emissions

2. ***Remove the lower Snake River dam generating capacity, then re-optimize* long-term resource needs and operations for the Pacific Northwest**
   - Produces a second set of resource additions and total system costs and emissions
   - All scenarios breach the dams in 2032, except for one 2024 breaching sensitivity

3. ***Calculate additional resources and investment + operational costs* required to replace the dams**
   - Calculated as the difference between steps 1 and 2 above

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Key Modeling Assumptions

Element	Study Approach	Impact on Dams Replacement Needs
Study Years	• 2025 through 2045, including fuel price forecasts and declining renewable + storage costs	Considers long-term needs
Clean Energy Policy Scenarios	• Aggressive OR+WA legislation reflected, including coal retirements + carbon pricing • Two electric emissions scenarios considered: 1. **100% clean retail sales** (~85% carbon reduction*) 2. **Zero-emissions** (100% carbon reduction)	Clean energy policy requires long-term replacement of LSR dams with GHG-free energy
Load Growth Scenarios	• Two load scenarios: 1. **Baseline** (per NWPCC 8th Power Plan) 2. **High electrification** load growth (to support economy-wide decarbonization) • Significant quantities of energy efficiency are embedded in all scenarios	Higher load scenarios increase the value of LSR dams energy + firm capacity
Reliability Needs	• Modeling ensures reliability needs during extreme conditions (e.g. high loads + low hydro) • Captures ability (and limits) of renewables, battery storage, and demand response to support system reliability	Reliability needs require replacement of LSR dams firm capacity contributions
Technologies Modeled, including "Emerging" Technologies	• Broad range of dam replacement technology options considered: • **Baseline technologies**: solar, wind, battery + pumped storage, energy efficiency, demand response, dual fuel natural gas + hydrogen combustion plants • **Sensitivities** include Emerging Technologies and Limited Technologies (No New Combustion) scenarios • Resource costs developed by E3 using NREL 2021 ATB, Lazard Cost of Storage v.7, NuScale Power (for small modular reactor costs)	Technology available for LSR dams replacement determines replacement cost
Distributed Energy Resource Options	• Energy efficiency, demand response, and customer solar embedded into modeling inputs • Additional energy efficiency and demand response can be selected	Demand resource can help replace LSR dams, though low-cost supply is limited

* A 100% clean retail sales target allows emissions for electric generation beyond that needed to serve "retail sales", i.e. losses during transmission to retail loads and exported energy

Scenarios

+ **Scenario 1: 100% Clean Retail Sales**
  - Northwest resources produce enough clean energy to meet **100% of retail electricity sales** on an annual average basis
  - Some gas generation is retained for reliability, but carbon emissions are reduced **85% below 1990 levels**
  - **Business-as-usual** load growth
+ **Scenario 2: Deep Decarbonization**
  - **Zero carbon emissions** by 2045
  - **High electrification** of buildings, transportation, and industry to reduce carbon emissions in other sectors
  - **Emerging technologies** become available to provide firm, carbon-free power

Emerging Technologies

Technology	S1 100% Clean	S2a Deep Decarb Baseline	S2b Deep Decarb Emerging Tech	S2c Deep Decarb No New Combustion
Mature technologies (solar, wind, battery + pumped storage, energy efficiency, demand response)	Available	Available	Available	Available
Hydrogen (existing natural gas retrofits)	Available	Available	Available	Available
Hydrogen (new dual fuel natural gas + hydrogen)	Available	Available	Available	Not available
Nuclear (small modular reactors)	Not available	Not available	Available	Not available
Natural Gas w/ Carbon Capture and Storage	Not available	Not available	Available	Not available
Offshore Wind (floating)	Not available	Not available	Available	Available

Available
Not available

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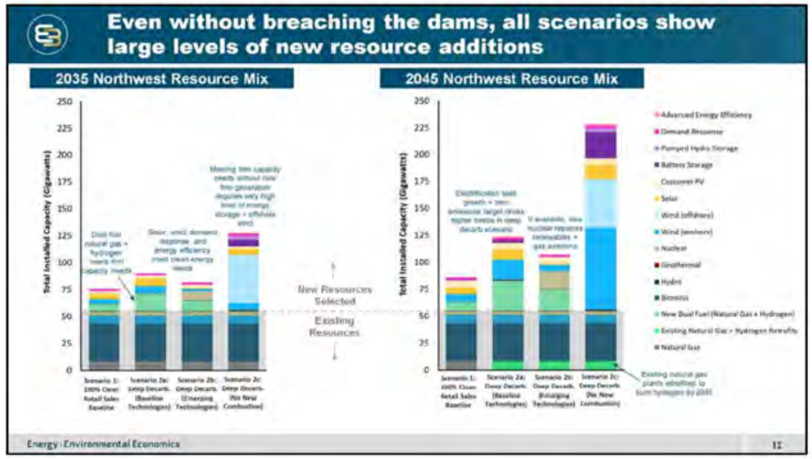
Northwest Resource Needs in Scenarios
With the Lower Snake River Dams



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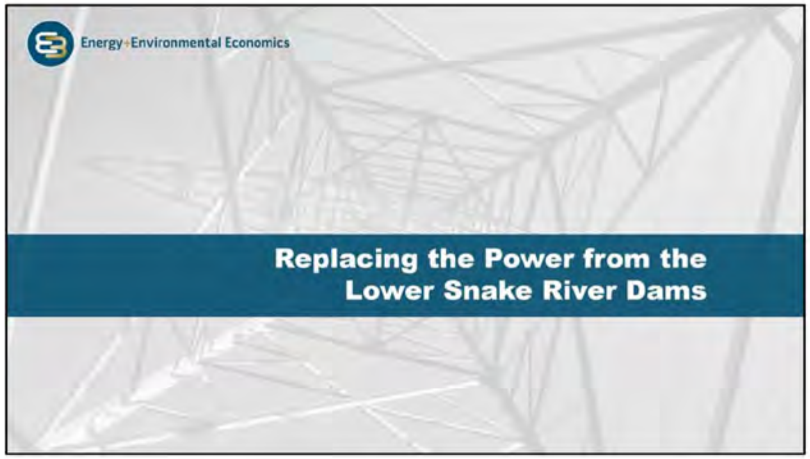
Energy+Environmental Economics
Replacing the Power from the
Lower Snake River Dams

Detailed Replacement Costs + Resource Needs

- RESOLVE selects an optimal portfolio of replacement resources including additional advanced energy efficiency, wind, solar, green hydrogen, and/or advanced nuclear
- Firm capacity is mostly replaced with ~2 GW of dual fuel natural gas + hydrogen turbines
  - These turbines may initially burn natural gas when needed during reliability challenged periods, but would transition to hydrogen by 2045 to reach zero-emissions
- If advanced nuclear is available, it replaces renewables and some of the gas plants
- The "no new combustion" scenario requires very large (~12 GW) buildout of renewable energy to replace the dams' firm capacity contributions

Scenario	Replacement Resources Selected, Cumulative by 2045 (GW*)
Scenario 1: 100% Clean Retail Sales	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
Scenario 2a: Deep Decarb. (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW [illegible] + additional H2 generation*
Scenario 2b: Deep Decarb. (Emerging Technologies)	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR
Scenario 2c: Deep Decarb. *(No New Combustion)*	+ 10.6 GW wind + 1.4 GW solar

* 1 GW = 1,000 MW
** Replacing LSR dams GHG-free energy at least-cost leads RESOLVE to generate an additional 1.2 TWh of hydrogen generation during low renewable conditions (or 0.14 average GW)

Total costs for replacing the lower Snake River dams

+ **Costs are expected to fall on Bonneville Power Administration's public power customers**
  - Costs could **increase public power retail costs** by up to 65%
  - Costs could **raise annual residential electricity bills** by up to $850/year

	Total Costs (real 2022 $)	Annual Cost Increase (real 2022 $)			Incremental Public Power Costs [% increase vs. ~8.5 cents/kWh NW average retail rates]
	Net Present Value in year of breaching	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$7.5 billion	[illegible]	$434 million	$478 million	0.8 cents/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$11 billion	$495 million	$466 million	$509 million	0.8 cents/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$11.5 billion	[illegible]	$496 million	$860 million	1.5 cents/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$7 billion	[illegible]	$415 million	$428 million	0.7 cents/kWh [+8%]
Scenario 2c: Deep Decarb. *(No New Combustion)*	*$46 billion*	*n/a*	*$1,853 million*	*$3,199 million*	*5.5 cents/kWh [+65%]*

Cost differences driven primarily by 2045 carbon policy and availability of emerging technologies

Costs increase over time as loads grow and carbon policy becomes more stringent

NOTES:
- Cost increases account for replacement energy, capacity, and reserves as well as avoided LSR capital + expense, but do not include any costs for breaching the dams, which would be an additional cost.
- NPV and annual cost increase are shown for the Northwest Region as a whole, but the incremental costs are calculated relative to the BPA Tier I annual sales for public power customers.
- % increase versus average retail rates assumes ~8.5 cents/kWh retail rates (estimated from OR and WA average retail rates). This does not include additional rate increases driven by higher loads or clean energy needs that increase regional rates as shown in the earlier 2045 incremental cost chart.
- Annual residential customer cost impact assumes 1,280 kWh/month for average residential customers in Oregon and Washington (current ~1,000 kWh/month average + 28% from electrification load growth).

Cost of generation for lower Snake River dams replacement resources (using common utility metric of $/MWh)

- The lower Snake River dams provide a low-cost source of GHG-free energy and firm capacity
- Even in a best-case scenario, replacement power would cost several times as much as the lower Snake River dams costs
- Compared to ~$13-17/MWh for the lower Snake River dams, replacement resources cost between $77/MWh to over $500/MWh, depending on the carbon-reduction policies and the availability of emerging technology

Incremental LSR Dam Replacement Resource Costs

Lower Snake River Dams All-in Generation Costs (2022 $/MWh)
$13/MWh w/o LSRCP*
$17/MWh w/ LSRCP*

Scenario	2045 Costs to replace LSR Generation** (real 2022 $/MWh)
S1: 100% Clean Retail Sales	$77/MWh
S1b: 100% Clean Retail Sales (2024 dam breaching)	$82/MWh
S2a: Deep Decarb	$139/MWh
S2b: Deep Decarb, w/ Emerging Tech	$69/MWh
S2a1: Deep Decarb, Limited Tech (no new combustion)	$517/MWh

* BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) fish hatcheries and satellite facilities. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat 2917) to offset fish and wildlife losses caused by construction and operation of the four lower Snake River projects.

** Replacement $/MWh costs are calculated as CoreNW revenue requirement increase with LSR dams breached divided by the annual MWh of the LSR dams assumed in E3's modeling (~700 aMW). These costs includes replacement of the LSR dam energy, capacity, and reserve provision. A significant portion of the costs is capacity costs to replace the dams' RA capacity contributions.

Key Conclusions

1. **Replacing the four lower Snake River dams comes at a substantial cost**
   1. Require 2,300 – 12,000 MW of replacement resources
   2. An annual cost of $480 million – $3.2 billion by 2045*
   3. Total net present value cost of $7 – 46 billion from 2032-2065
   4. Increase in costs for public power customers of $110 – 850 per household per year (an 8 – 65% increase) by 2045
2. **The biggest cost drivers for replacement resources are the need to replace the lost firm capacity and the need to replace the lost zero-carbon energy**
3. **Replacement resources become more costly over time due to increasingly stringent clean energy standards and electrification-driven load growth**
4. **Emerging technologies such as hydrogen, advanced nuclear, and carbon capture can prevent the cost of replacement resources from increasing over time, but the pace of their commercialization is highly uncertain**

* Replacement resource costs are calculated assuming project financing per E3's pro forma calculator, rather than assuming upfront congressional appropriation

Additional Important Considerations

- **Breaching the LSR dams risks delaying the region's achievement of its clean energy goals**
  - The development, permitting, and construction of replacement resources and transmission takes time
  - Even without breaching the dams, the pace of clean energy growth needed to reach regional policy goals is ~2-4 times as large as the historical 2010-2020 average of 600 MW/yr
- **Studies indicate that the region faces a near-term deficit of firm capacity resources**
  - This deficit grows over time as coal resources are retired and electrification loads are added
  - Removing the firm capacity of the LSR dams accelerates the need for new firm capacity
- **Land use impacts**
  - Even with the LSR dams, the Baseline and Deep Decarbonization scenarios shows ~2-4x increase in NW land use for renewable energy; the "no new combustion" scenario would lead to ~11x increase in land use
  - Breaching of LSR dams increases pressure on sensitive lands
- **Transmission impacts**
  - LSR dam replacement resources would require significant new transmission investment to deliver energy from new resources to load centers

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Thank you

Questions, please contact:
Arne Olson, arne@ethree.com
Aaron Burdick, aaron.burdick@ethree.com

Key Takeaways

Bonneville perspective on E3 study

Would conclusions in the E3 study change the decision for the Columbia River System Environmental Impact Statement?

- **No.** In fact, the E3 study **reinforces** the decision.
- The E3 study provides an updated picture of the energy landscape:
  - **Policy decisions** and legislation in the region are limiting the amount of resources available to provide firm capacity to avoid power shortages. Specifically, fossil-fuel based resources, such as coal plants, are being removed now.
  - Compounding the situation from removing fossil fuel resources, decarbonizing the region will result in **increased electricity use** in other sectors such as transportation (electric vehicles) and heating/cooling buildings (changing from gas to electric).
  - The E3 study also considers the **availability of emerging technology** in future scenarios. Even considering emerging technology such as small modular nuclear reactors, the region's risk of power shortages may increase if the four lower Snake River dams are breached, given the path towards deep decarbonization

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What power benefits do the four lower Snake River dams provide?

Reliable power to avoid blackouts

- For region and for BPA
- For regional human health and safety issues

Carbon-free power to fight climate change

- In the Northwest, the hydropower system provides carbon-free power
- Hydropower system enables addition of variable renewable resources, such as wind and solar, to the region

- 3,483MW in nameplate capacity
  – historically generation **has peaked at 3,431 MW**
- More than 2,000 MW of sustained peaking capabilities during cold winter weather events to **avoid power shortages**
- A quarter of Bonneville's current reserves holding capability which is **important for integrating variable generating resources** such as wind and solar
- **Essential transmission reliability** services such as voltage support, reactive power, inertia, black start, etc..

Maintaining these carbon-free assets is an important component of shifting to a cleaner electricity grid. Loss of these assets, or reductions in their flexibility, while there are still fossil fuel generators on the grid will **increase the timeframe and costs associated** with shifting to a carbon-free electricity sector.

While it is *feasible* to replace power benefits of the lower Snake River dams, it is not *cheap, fast, or easy.*

- **Not cheap**
  - Up to $2,000 million to $3,200 million per year for public power total, or $430 million to $480 million per year without decarbonization policies and with maturation of emerging technology (all assuming paid for with debt spread over 50 years)
  - Up to $850 per year for each public power household or $100 per year per household without decarbonization policies and with maturation of emerging technology
  - 2 million households affected
  - Social justice issue – lower income households would be disproportionally harmed by increased costs because a larger portion of their income goes to the electric bill
- **Not fast**
  - Up to **35 years total**
    - Practically, likely 5 to 10 years for Congressional approval, USACE NEPA analysis, and Congressional appropriations
    - Roughly 5 years to replace the capacity resources
    - Realistically 10 – 20 years to build transmission, which includes providing compliance with the National Environmental Policy Act, siting, permits, etc.
- **Not easy**
  - Policy requirements to reduce emissions are removing fossil fuel resources from the grid. Breaching the four lower Snake River dams significantly **adds to the deficit of resources** in the region.

Acquiring replacement resources could require **building new renewable resources at an unprecedented rate.**

B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

While it is *feasible* to replace power benefits of the lower Snake River dams, it is not *cheap, fast, or easy.*

- Replacing the lost power with new resources would require up to 500 square miles of land (or 50 square miles without decarbonization policies and with maturation of emerging technology).
- Such a large build out of capacity would likely result in additional, but currently unknown impacts to natural and cultural resources.
- Environmental issues associated with extensive builds of renewable resources include mining critical minerals e.g. for batteries and solar infrastructure, which introduce land use issues and toxins into the environment.
- Relying on emerging technologies is risky – timeline of development is highly uncertain and some may never mature to commercially viable.
- Supply chain issues impact rate of developing resource replacements.

Comparison to NWEC study

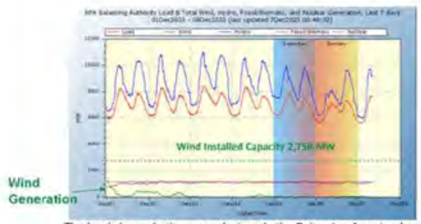
The Northwest Energy Coalition (NWEC) study looks at replacing some (but not all) of the capability of the four lower Snake River dams. Unlike the E3 and the CRSO EIS, **the NWEC study is not a reliability study that maintains regional resource adequacy.** NWEC's study relies on their 2018 assessment of regional reliability, which does not include the latest information about coal-plant retirements in the region.

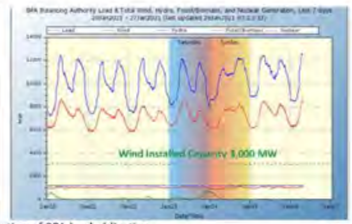
- The NWEC study **incorrectly describes the capacity** of the four lower Snake River dams as 1,000 MW, when in fact, the nameplate capacity is 3,483MW. and sustained capacity is over 2,000 MW.
  - The region regularly calls upon more than 2,000 MW of sustained peaking capabilities, to **avoid power shortages** during the winter, and has provided peak generation up to 2,838 MW in winter.
- Baseline for the NWEC study **assumes** that **300 MW of market purchases** provide firm power.
  - While BPA sometimes purchases power to serve its customers, during times of high demand (winter cold snaps or summer heat events) there often is not enough power on the market, and other utilities may be declaring energy shortage emergencies.
- The NWEC study **understates the benefits** that the four lower Snake River dams provide in terms of grid stability – ancillary services such as generation reserves required to keep the lights on.
  - In addition to providing sustained peaking capacity the lower Snake River dams provide generation reserves that can provide additional generation on short notice for grid stability and to integrate intermittent resources such as wind and solar. These projects also provide voltage support and inertia that help maintain the stability and reliability of the grid.
  - The NWEC study only replaces 80% of the lower Snake River dam ramping capability.

B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

Comparison to NWEC study

- NWEC study assumes wind output will be available, but **wind is as variable as the weather**.
- Specifically, historical wind generation should not be treated as around-the-clock firm generation, as stated in the NWEC study. In the northwest, wind generation is typically low during cold snaps and heat waves.
- Two examples below, from Jan 2020 and Dec 2021 show **extremely low wind during cold snaps** (Green Line).





The load shown in these graphs is only the Balancing Area load portion of BPA load obligations.

Deliberative, FOIA Exempt

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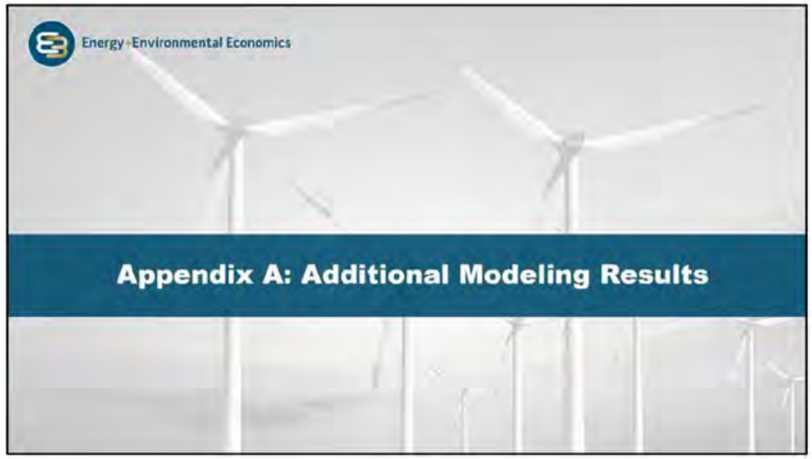
Closing Thought

- Any consideration of dam breaching must be informed **best available information** on the objective **costs** associated with replacing the full capabilities of those dams, including:
  - Peaking capabilities
  - Transmission considerations
  - Reliability (ability to keep the lights on)
  - Land use
  - Affordability for homes and businesses
- Keep in mind that breaching, or reducing flexibility, while there are still fossil fuel generators on the grid will:
  - **Increase the time** for shifting to a carbon-free electricity sector
  - **Increase the costs** for shifting to a carbon-free electricity sector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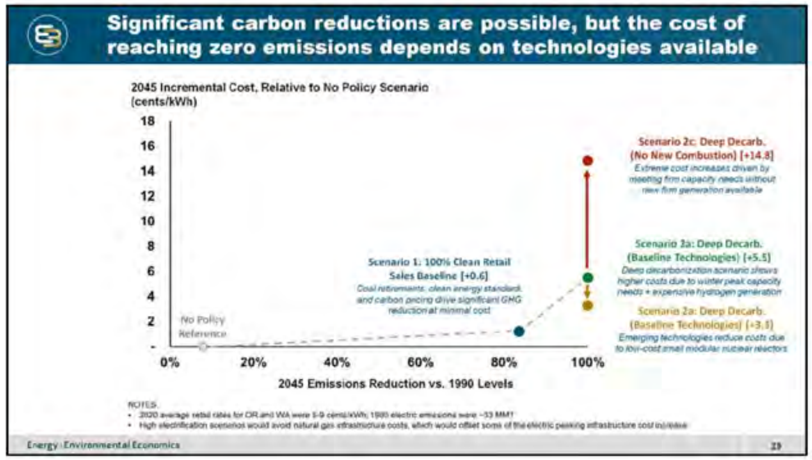
Appendix A: Additional Modeling Results


Significant carbon reductions are possible, but the cost of reaching zero emissions depends on technologies available
2045 Incremental Cost, Relative to No Policy Scenario (cents/kWh)
18
16
14
12
10
8
6
4
2
-
No Policy Reference
Scenario 1: 100% Clean Retail Sales Baseline [+0.6]
Coal retirements, clean energy standard, and carbon pricing drive significant GHG reduction at minimal cost
Scenario 2c: Deep Decarb. (No New Combustion) [+14.8]
Extreme cost increases driven by meeting firm capacity needs without new firm generation available
Scenario 2a: Deep Decarb. (Baseline Technologies) [+5.5]
Deep decarbonization scenario shows higher costs due to winter peak capacity needs + expensive hydrogen generation
Scenario 2a: Deep Decarb. (Baseline Technologies) [+3.1]
Emerging technologies reduce costs due to low-cost small modular nuclear reactors
0%
20%
40%
60%
80%
100%
2045 Emissions Reduction vs. 1990 Levels
NOTES:
2020 average retail rates for OR and WA were 5-9 cents/kWh; 1990 electric emissions were ~33 MMT
High electrification scenarios would avoid natural gas infrastructure costs, which would offset some of the electric peaking infrastructure cost increase
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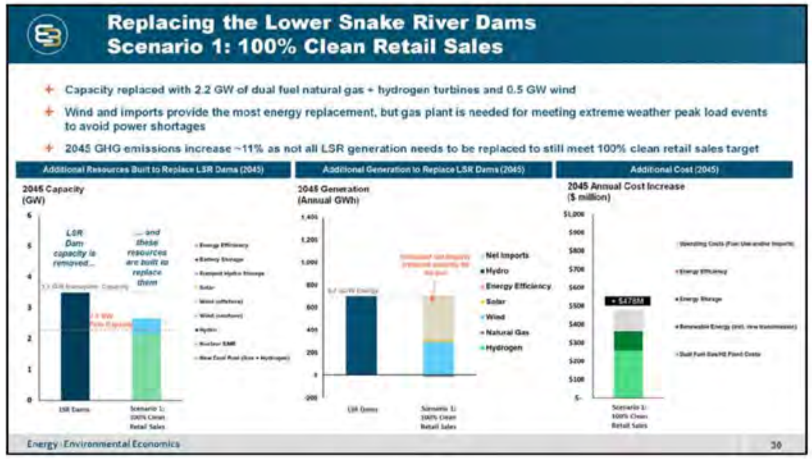

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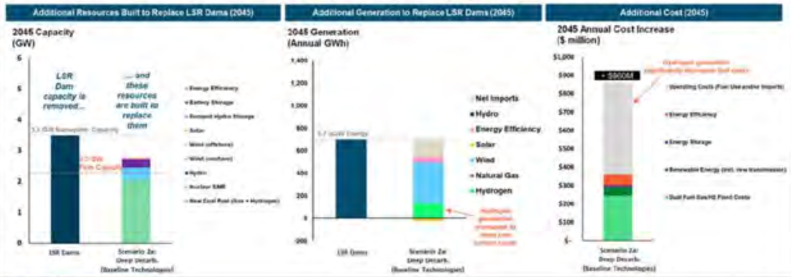
Replacing the Lower Snake River Dams
Scenario 2: Deep Decarbonization (Baseline Technologies)

- Scenario includes electric load increases for transportation and other sectors
- In 2045, hydrogen generation is a key replacement resource and is assumed to be available, though not commercially available today
- This scenario would cost $860 million dollars per year in 2045, driven by high hydrogen fuel costs (~$40/MMbtu)

Additional Resources Built to Replace LSR Dams (2045)	Additional Generation to Replace LSR Dams (2045)	Additional Cost (2045)



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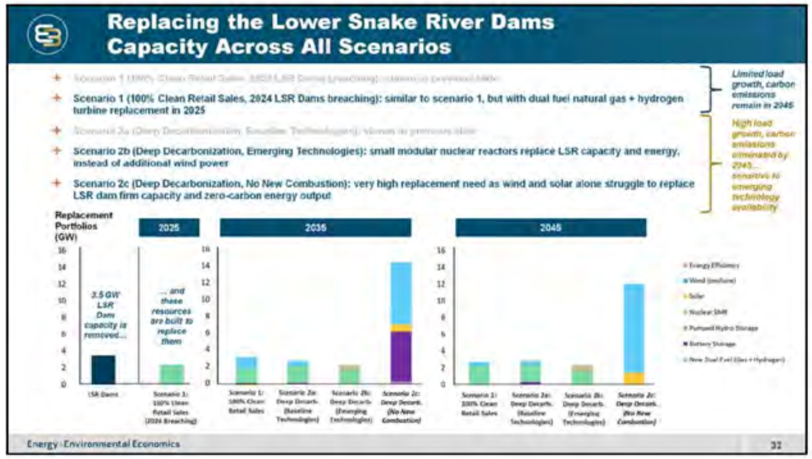

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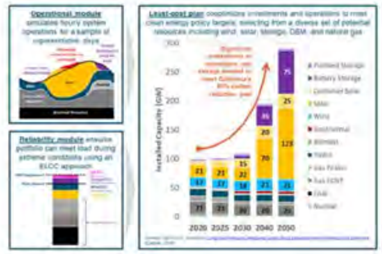
Appendix B: Additional Modeling Inputs

RESOLVE optimizes investments to meet clean energy targets reliably

RESOLVE is an optimal capacity expansion model specifically designed to identify least-cost plans to meet reliability needs and achieve compliance with regulatory and policy requirements

- **Linear optimization model explicitly tailored to study challenges to arise at high penetrations of variable renewables and energy storage**
- **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**



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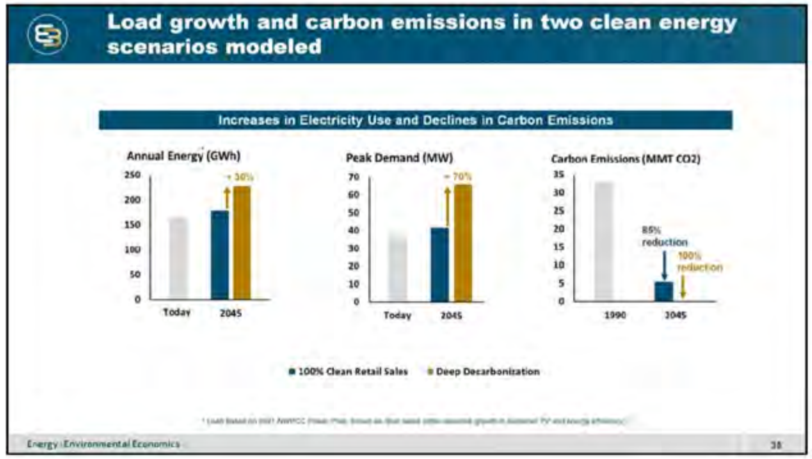
Load growth and carbon emissions in two clean energy scenarios modeled
Increases in Electricity Use and Declines in Carbon Emissions
Annual Energy (GWh)
250
200
150
100
50
0
Today
2045
+ 30%
Peak Demand (MW)
70
60
50
40
30
20
10
0
Today
2045
+ 70%
Carbon Emissions (MMT CO2)
35
30
25
20
15
10
5
0
1990
2045
85% reduction
100% reduction
100% Clean Retail Sales
Deep Decarbonization
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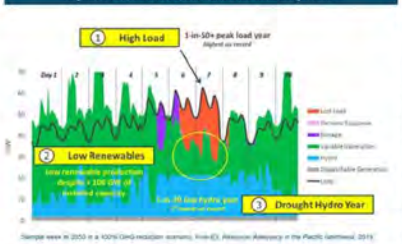
Resource Adequacy Resource Options

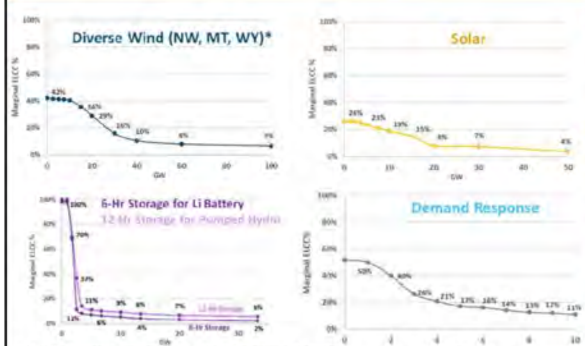
- RESOLVE resource adequacy constraint requires capacity to meet peak demand + a 15% planning reserve margin
  - PRM constraint is "installed capacity" (ICAP) based for firm resources and uses ELCC for non-firm resources
- The nature of the Northwest reliability risk limits the ability of battery storage to provide reliable capacity contributions
  - Storage and hydro show "antagonistic" interactions, which limit energy storage reliability value in "energy-limited" conditions where energy storage resources are unable to charge (with low hydro and renewable output) and run out of discharge (during extended energy shortfall events)

Key Drivers of Future Pacific Northwest Reliability Events



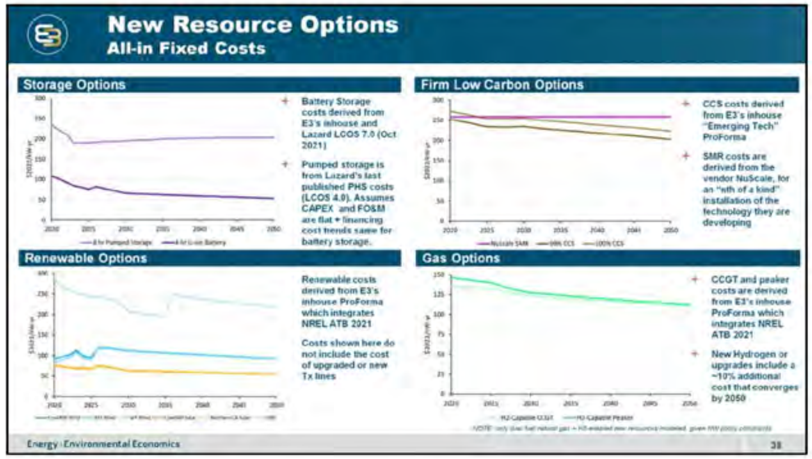
Resource	RA Capacity Contributions
Hydro	80%, based on sustained winter peaking capacity in critical water year conditions (per BPA/PNUCC). WRAP method is still evolving
Battery storage	Sharply declining ELCCs (due to hydro-interaction effects)
Pumped storage	Sharply declining ELCCs (due to hydro-interaction effects)
Solar	Declining ELCCs
Wind	Declining ELCCs
Demand Response	Declining ELCCs
Energy Efficiency	Limited potential/vs. cost
Small Hydro	Limited potential
Geothermal	Limited potential
Natural gas to H2 retrofits	Clean firm, but not fully commercialized
New dual fuel natural gas + H2 plants	Clean firm, but not fully commercialized
New H2 only plants	Clean firm, but not fully commercialized
Gas w/ 90-100% carbon capture + storage	Clean firm, but not fully commercialized
Nuclear Small Modular Reactors	Clean firm, but not fully commercialized

Incorporating Declining Capacity Contributions of Renewables, Storage, and DR



ELCC = Effective Load Carrying Capability = firm contribution to system peak load

- A reliable electric system requires enough capacity to meet peak loads and contingencies
- This study incorporates information from E3's 2019 report *Resource Adequacy in the Northwest* about the effective capacity contribution of renewables, storage, and DR at various penetration levels


New Resource Options
All-in Fixed Costs
Storage Options
Battery Storage costs derived from E3's inhouse and Lazard LCOS 7.0 (Oct 2021)
Pumped storage is from Lazard's last published PHS costs (LCOS 4.0). Assumes CAPEX and FO&M are flat + financing cost trends same for battery storage.
Firm Low Carbon Options
CCS costs derived from E3's inhouse "Emerging Tech" ProForma
SMR costs are derived from the vendor NuScale, for an "nth of a kind" installation of the technology they are developing
Renewable Options
Renewable costs derived from E3's inhouse ProForma which integrates NREL ATB 2021
Costs shown here do not include the cost of upgraded or new Tx lines
Gas Options
CCGT and peaker costs are derived from E3's inhouse ProForma which integrates NREL ATB 2021
New Hydrogen or upgrades include a ~10% additional cost that converges by 2050
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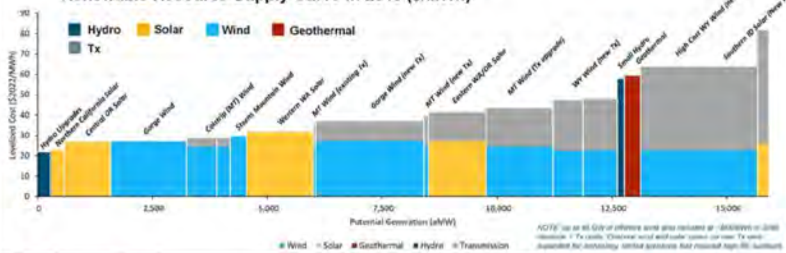
New Resource Options
Renewables

- The following supply curves integrate Tx costs that RESOLVE sees
- The "no new combustion" scenario required increases the supply of wind on new transmission (Northwest, MT+WY, and offshore) to enable a feasible solution

Renewable Resource Supply Curve in 2045 ($/MWh)



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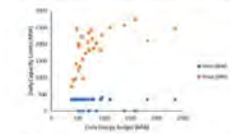
Hydro Operating Data

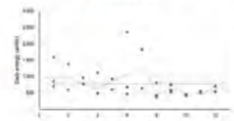
- Key RESOLVE inputs (for each representative RESOLVE day)
  - Max generation MW
  - Min generation MW
  - Daily MWh hydro budget
  - Ramp
- Hydro operating data is parameterized using representative conditions for 3 low/mid/high historical years (2001, 2005, 2011)
  - Lower Snake River and lower Columbia River dams were adjusted per BPA hydro modeling w/ latest fish spill constraints
- Hydro firm capacity contribution is assumed to be 65% of nameplate, per PNUCC methodology (based on BPA 10-hr sustaining peaking capacity)

LSR Hydro

Ramp Rates

Hydro Resource	1-hr	2-hr	3-hr	4-hr
LSR_Hydro	36%	43%	45%	48%

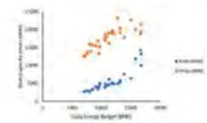


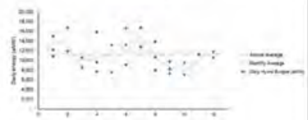


Non-LSR NW Hydro

Ramp Rates

Hydro Resource	1-hr	2-hr	3-hr	4-hr
CoreNW_Hydro	14%	23%	30%	34%





From:	Bellcoff,Steve (BPA) - PGPR-5
Sent:	Monday, April 18, 2022 11:05 AM
To:	Diffely,Robert J (BPA) - PGPL-5; Aaron Burdick; James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5
Cc:	Angineh Zohrabian; Arne Olson
Subject:	RE: Recent BPA Tier 1 sales

I don't have exactly that at my figure tips, and the person that compiles this information regular is out until tomorrow (Tuesday)

The latest set of data that I could find was for FY2015, and is what we use in out Bond Reports, and it is summarized in aMW.
Tier 1 Load Following = 3,045.994
Slice = 1,861.807
Block = 1,831.993
Total Tier 1 Delivery = 6,739.795 aMW

I have already reached out to try and get the latest information.

Steve

Steve Bellcoff
Long Term Power Planning, PGPR
BONNEVILLE POWER ADMINISTRATION
srbellcoff@bpa.gov | P 503-230-3319 | C (b)(6) [redacted]

From: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Sent: Friday, April 15, 2022 2:15 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Cc: Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Recent BPA Tier 1 sales

Steve,
Can you assist our contractor on this?

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, April 15, 2022 2:14 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>

Cc: Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] Recent BPA Tier 1 sales

We are refining our cost metrics for the RESOLVE results. Can you please share a recent year or near-term year annual Tier 1 sales in GWh? We can use this to estimate the share of the total CoreNW system that represents BPA customers that would feel the impact of the no LSR dam scenario costs.

Thanks!

Aaron Burdick, Associate Director
Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500 | San Francisco, CA 94104
818-807-6499 | aaron.burdick@ethree.com

From: Bellcoff,Steve (BPA) - PGPR-5
Sent: Wednesday, April 20, 2022 9:16 AM
To: James,Eve A L (BPA) - PG-5
Cc: Koehler,Birgit G (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5; Neuls,Esther T (BPA) - PGPR-5; Egerdahl,Ryan J (BPA) - PGPR-5
Subject: RE: Recent BPA Tier 1 sales

Eve

Just wanted to follow up on this since I did get some updated actuals information

I had given the following for FY2015, and is what we use in out Bond Reports, and it is summarized in aMW.
Tier 1 Load Following = 3,045.994
Slice = 1,861.807
Block = 1,831.993
Total Tier 1 Delivery = 6,739.795 aMW

Updating that with a lot more recent
FY2021
Tier 1 Load = 57,421 GWhr (or 6,554.9 aMW)

Both FY2015 and FY2021 end very similar to what was forecasted in the numbers that Esther had supplied.

Steve

From: Bellcoff,Steve (BPA) - PGPR-5
Sent: Monday, April 18, 2022 12:40 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: RE: Recent BPA Tier 1 sales

Okay I think we may have a mix but probably need to confirm what was wanted.
What Esther supplied (after Mark and Rob conversation) is the forecasted Tier 1 Sales that could be made under critical water.
So this is not Actuals, but the forecasted of what could be sold as Tier 1 under Critical water.
Not what we actually sold or under anything for better water conditions.

Steve

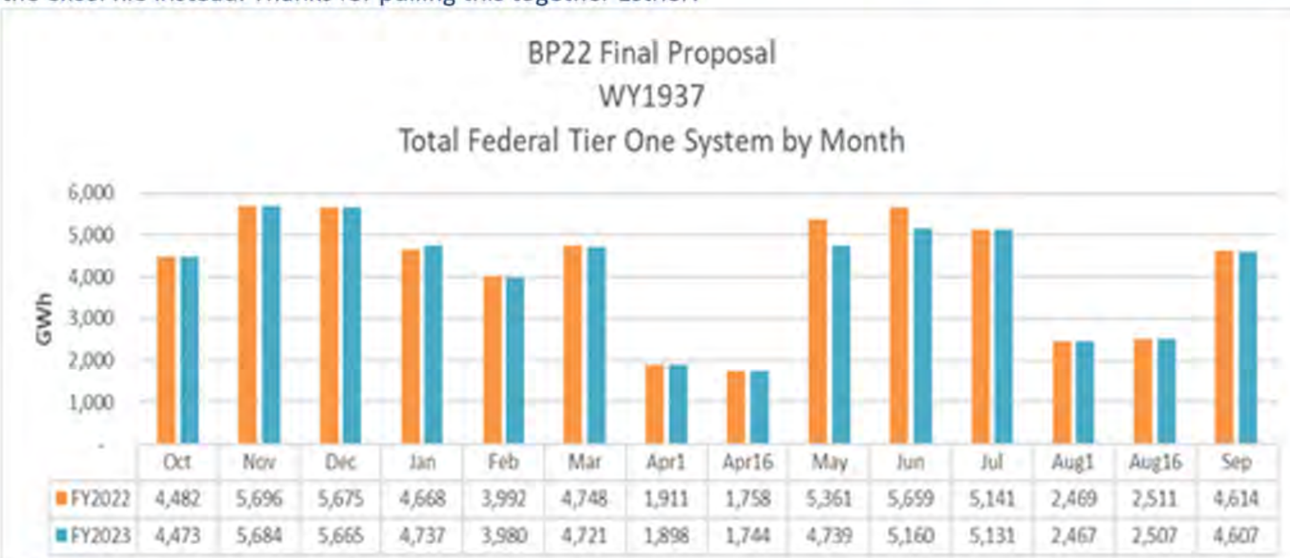
From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Monday, April 18, 2022 11:49 AM
To: Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Subject: FW: Recent BPA Tier 1 sales

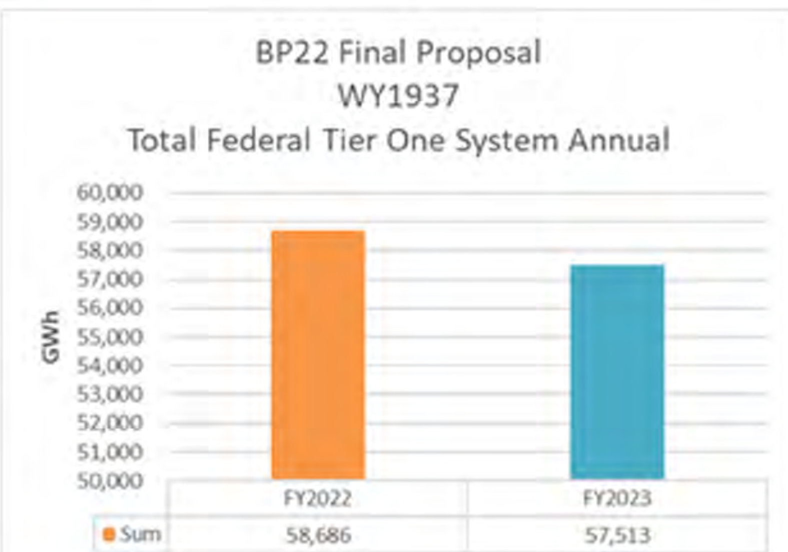
I meant to have you on this CC list as well but see I accidentally left you off. Sorry about that! Esther sent this on Friday- let me know if you have any concerns on what she sent.

Thanks!

From: James,Eve A L (BPA) - PG-5
Sent: Friday, April 15, 2022 3:48 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; **Cc:** Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Recent BPA Tier 1 sales

Hi Aaron-
Please see below for the FY2022 and 2023 data based on our most recent BP22 Final Proposal. Let us know if you'd like the excel file instead. Thanks for pulling this together Esther!





27691998(01).pdf

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, April 15, 2022 2:14 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] Recent BPA Tier 1 sales

We are refining our cost metrics for the RESOLVE results. Can you please share a recent year or near-term year annual Tier 1 sales in GWh? We can use this to estimate the share of the total CoreNW system that represents BPA customers that would feel the impact of the no LSR dam scenario costs.

Thanks!

Aaron Burdick, Associate Director
Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500 | San Francisco, CA 94104
818-807-6499 | aaron.burdick@ethree.com

From: Koehler,Birgit G (BPA) - PG-5
Sent: Tuesday, April 19, 2022 3:53 PM
To: Diffely,Robert J (BPA) - PGPL-5; James,Eve A L (BPA) - PG-5
Subject: RE: TIER 1 System

Wow, that's a lot!

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, April 19, 2022 1:32 PM
To: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: TIER 1 System

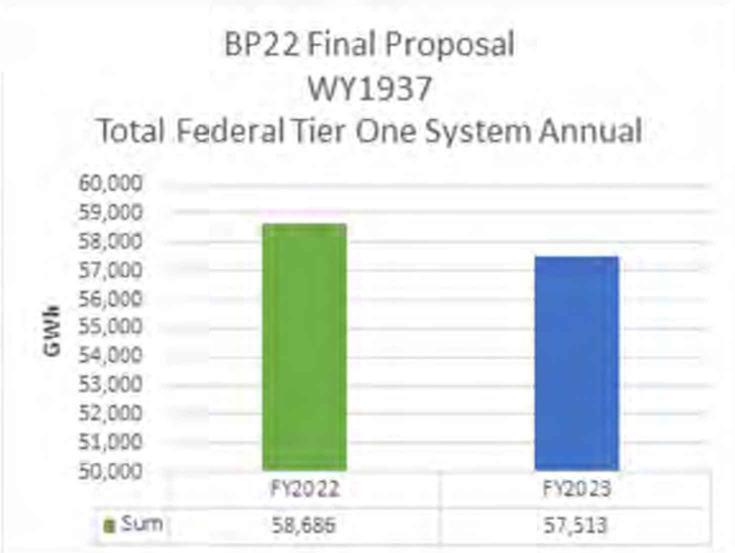
Thanks Rob. With that update the % increase went from 14-37% to 20-50%, based on an updated range of 0.7-1.8 cent/kWh impact.

All the best,
Aaron

From: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Sent: Tuesday, April 19, 2022 1:26 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: TIER 1 System

For the TIER 1 system, E3 can use FY2022 of 58,686 GWhrs. The difference between the two is primarily the 2 year refueling cycle of CGS.

Rob



-----Original Appointment-----
From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, March 2, 2022 4:54 PM
To: Aaron Burdick; Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5; Angineh Zohrabian; Sierra Spencer
Subject: BPA-E3 Check-In
When: Tuesday, April 19, 2022 11:00 AM-12:00 PM (UTC-08:00) Pacific Time (US & Canada).
Where: https://ethree.webex.com/ethree/j.php?MTID=m228a4e26c5b763d73adb84c525782f42

Updating series from 30 mins to 1 hr.

Purpose: check-in on lower snake river dams analysis.

-~-

-- Do not delete or change any of the following text. --

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Join by meeting number
Meeting number (access code): [redacted]
Meeting password: c5BSkxM2Sm8

Tap to join from a mobile device (attendees only)
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Join by phone
+1-408-418-9388 United States Toll
Global call-in numbers

Join from a video system or application
Dial [redacted]@ethree.webex.com
You can also dial 173.243.2.68 and enter your meeting number.

If you are a host, click here to view host information.

Need help? Go to https://help.webex.com

From:	Diffely,Robert J (BPA) - PGPL-5
Sent:	Friday, March 25, 2022 11:12 AM
To:	Aaron Burdick; James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5
Cc:	Jack Moore; Arne Olson; Angineh Zohrabian; Sierra Spencer
Subject:	RE: Trap Results for the preferred and Mo3

I will get back to you soon on this.

Rob

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, March 25, 2022 11:07 AM
To: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: Trap Results for the preferred and Mo3

DELIBERATIVE; FOIA EXEMPT

Hi Rob,

Can you provide more background info here? Is one of these scenarios without the LSR dams (the MO3 case) and one with (the PA case)? The differences in 10hr peaking capacity are ~3-5 GW, which is more than the LSR dam nameplate, so there must be something else going on too.

As a baseline we are planning to use the latest PNUCC (whitebook based) regional hydro value (65%) and apply it to the LSR dams and to the NW hydro non-LSR dams. The no LSR dam case will simply have the LSR MW * PNUCC 65% firm capacity value removed, with the need to replace that level of firm capacity other resource additions. Do you have any concerns with this approach or suggestions to use a more LSR-specific capacity value based on the data you provided?

Many thanks,
Aaron

From: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Sent: Tuesday, March 22, 2022 12:03 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: Trap Results for the preferred and Mo3

Please let me know if you have questions.

From:	James,Eve A L (BPA) - PG-5
Sent:	Tuesday, July 12, 2022 3:01 PM
To:	Aaron Burdick; Koehler,Birgit G (BPA) - PG-5
Cc:	Arne Olson
Subject:	RE: Updated PPT and Report

Thanks Aaron- the BPA website has just been updated with the corrected file versions.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, July 12, 2022 1:56 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] Updated PPT and Report

Birgit,

Per the email I just sent on the NWPCC thread, we found a small error in slide 14 of the PPT and figures 1/14 in the report. One of the stacked bars did not copy over properly.

Updated final versions attached.

I apologize we caught this today instead of last night, but please replace the posted versions with these.

Aaron Burdick, Associate Director
Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500 | San Francisco, CA 94104
818-807-6499 | aaron.burdick@ethree.com

From: Koehler,Birgit G (BPA) - PG-5
Sent: Friday, April 29, 2022 1:23 PM
To: Cooper,Suzanne B (BPA) - P-6; James,Eve A L (BPA) - PG-5
Cc: Leady Jr,William J (BPA) - PG-5
Subject: RE: follow-up on E3

Thanks for the bullets, Suzanne.

We mentioned to E3 a couple weeks ago that we will need to find a way to make this more digestible for CEQ and some of the DOE folks. Arne said something about "workshopping" the presentation. So they won't be surprised if we give them input. That said, I also want to make sure that the final presentation doesn't look like BPA massaged the message.

From: Cooper,Suzanne B (BPA) - P-6 <sbcooper@bpa.gov>
Sent: Friday, April 29, 2022 1:10 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Leady Jr,William J (BPA) - PG-5 <wjleady@bpa.gov>
Subject: RE: follow-up on E3

Thanks for adding me, Birgit. I started an email earlier but couldn't finish before meetings. I was going to ask for your help in matching up the figures from E3's slide to what was in the email chain – this latest information clarifies the first bullet.
Joel is going to be setting up an internal meeting – possibly this afternoon – to discuss recommendations for E3 to make their analysis more digestible to the intended audiences.

Figures from E3's slide:

- $17/MWh LSR dam generation cost -> SOLVED below
- $85 – 190/MWh replacement resource costs -> fact from E3 analysis (could characterize as 5x to 11x the generation cost of LSRDs)
- 0.7 – 1.8 cents/kWh "BPA customer cost increase" for replacement resources -> calculation by E3 that may be better characterized as to what it represents; would be nice if they could stick with a single unit of measure
- 20-50% increase to current "generation rate" of 3.5 cents/kWh -> calculation by E3, unclear what it represents

---

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Friday, April 29, 2022 9:50 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Leady Jr,William J (BPA) - PG-5 <wjleady@bpa.gov>; Cooper,Suzanne B (BPA) - P-6 <sbcooper@bpa.gov>
Subject: RE: follow-up on E3

Deliberative; FOIA-exempt

Ah, so we did use both in one location or another. Then I would suggest we use both. I don't think we need to make a big deal of the LSRCP but simply be clear on when it is or isn't included, such as how I showed it earlier.

Bill, does that seem reasonable to you? You had responded to Eve that you liked including the LSRCP. But I do think it is nice to show what the generation-related only (so O&M, capital) costs are. I took Suzanne off the thread earlier when I was getting into details, but am adding her back now. My suggestion is to show it this way. (See screenshot further below for context)

LSR Dam all-in Generation costs (2022 $/MWh)
$13/MWh without LSRCP *
$17/MWh with LSRCP

* add footnote about LSRCP

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, April 29, 2022 9:34 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Leady Jr,William J (BPA) - PG-5 <wjleady@bpa.gov>
Subject: RE: follow-up on E3

Deliberative; FOIA-exempt

Birgit-
That is correct- the CRSO EIS has a table 3-112 that summarizes the average cost of generation at the projects in the CRSO EIS. We initially started thinking we would use those numbers - not the all in costs (no Fish and Wildlife, residential exchange, or other BPA overheads allocated to the facilities). Financing (debt service) was ignored, so Capital numbers were effectively treated like expense. However, $34,060,200 LSRCP budget cited in the EIS (page 3-864) was taken out of MO3 For comparison with the other MOs that did have the LSRCP budget spread evenly across the 4 projects so we used that assumption with E3 as well. We can display both numbers as suggested if we want to highlight that program would go away without the dams.

Thanks,
Eve

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Friday, April 29, 2022 9:16 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Leady Jr,William J (BPA) - PG-5 <wjleady@bpa.gov>
Subject: RE: follow-up on E3

Deliberative; FOIA-exempt

Eve,
I did some digging.
The latest SAMP has cost of generation on the LSN at $12.50/MWh (I looked up the draft copy in my email. We would want to check the final version)

The (not weighted) average in your table is $16.71
The LSRCP $34,060,200 divided into about 1000 aMW and 8760 hours is $3.89

So that is almost certainly the explanation between Joel's expectation of $12.50/MWh versus the number in the table we gave E3.

That brings us to the big question: Should we change what E3 displays to $12.50?

Looking back at the slide, the solution might be easy. Use both. I know why we are using the number w LSRCP because we think it will go away if the generation goes away. But it is nice to highlight that the actual cost of generation is even lower. And some of the savvy readers will think the LSRCP might not go away, so might be interested in that lower number too.

If we want to use both, the change is easy. E3 only used these numbers to give verbal estimates of what the % impact is. So there was no other number on the slide to change. Do you remember where in the EIS we used these numbers? I think it might have been only in comment responses. If that's the case, it does give us a little leeway on how we use it. (Sure, Jill will have an opinion, but I expect more flexibility if it wasn't in the body of the EIS.)

LSR Dam all-in Generation costs (2022 $/MWh)
$13/MWh without LSRCP *
$17/MWh with LSRCP

* add footnote about LSRCP

And minor separate point, we could clarify the description in the blue circle. I think we said it was the Tier-1 rate.

Incremental LSR Dam Replacement Resource Costs

	Lower Snake River Dams All-in Generation Costs (2022 $/MWh)	Current BPA Generation Rate (cent/kWh)
	$17/MWh w LSRCP 13	3.5 cent/kWh

Scenario	2045 Costs to replace LSR Generation* (real 2022 $/MWh)	2045 Incremental Tier I BPA Customer Costs** (real 2022 cents/kWh)
S0: No Policy Reference	$85/MWh	+ 0.7 cents/kwh
S1: 100% Clean Retail Sales	$95/MWh	+ 0.8 cents/kwh
S1a: 100% Clean Retail Sales (no carbon price)	$90/MWh	+ 0.8 cents/kwh
S2: Deep Decarb	$189/MWh	+ 1.8 cents/kwh
S2b: Deep Decarb, w/ Emerging Tech	$87/MWh	+ 0.7 cents/kwh
S2a1: Deep Decarb, Limited Tech (no new combustion)	$535/MWh	+ 5.6 cents/kwh
S2a2: Deep Decarb, Limited Tech (no new gas, H2 allowed)	$427/MWh	+ 4.5 cents/kwh

eplacement $/MWh costs are calculated as CoreNW revenue requirement increase with LSR dams removed divided by the annual h of the LSR dams. These costs includes replacement of the LSR dam energy, capacity, and reserve provision. A significant portion ie costs is capacity costs to replace the dams' RA capacity contributions.
icremental BPA customers costs calculated as the incremental annual revenue requirement divided by BPA's Tier 1 annual sales 3,686 GWh/yr per FY2022 BPA forecast)

From: Leady Jr,William J (BPA) - PG-5 <wjleady@bpa.gov>
Sent: Friday, April 29, 2022 9:08 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Cooper,Suzanne B (BPA) - P-6 <sbcooper@bpa.gov>
Subject: RE: follow-up on E3

Eve,

Thank you. I agree, this seems to be the most appropriate comparisons, the specific cost the cost of power (not the FCRPS average) + LSRCP.

Bill Leady P.E.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, April 29, 2022 8:15 AM
To: Leady Jr,William J (BPA) - PG-5 <wjleady@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Cooper,Suzanne B (BPA) - P-6 <sbcooper@bpa.gov>
Subject: RE: follow-up on E3

Deliberative; FOIA-exempt
This was the information sent to E3 on the costs and used the same methodology of including F&W cost but used updated values from most recent SAMP from Gordon. I still think this is the appropriate assumption to use since we want to keep the assumptions matching the CRSO EIS methodology:

- The F&W cost in the CRSO EIS was $34,060,200 and spread evenly across the four plants results in a cost of generation:
FY2022 $/MWh

Plant	50-year Forecast with LSRCP
Lower Granite	$22.69
Little Goose	$15.71
Lower Monumental	$12.58
Ice Harbor	$15.84

Cost Calculation: The O&M budges used a flat 2% inflation rate. Capital numbers were based on modeled replacement needs influenced by asset risk so they varied year-to-year before levelizing. The capital replacement assumptions were inflated per asset using the 2021 BPA common planning assumptions for inflation (attached). Costs were levelized using BPA's nominal discount rate of 6.2% so the result is a levelized cost in real 2022 dollars.

From: Leady Jr,William J (BPA) - PG-5 <wjleady@bpa.gov>
Sent: Thursday, April 28, 2022 5:05 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Cooper,Suzanne B (BPA) - P-6 <sbcooper@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: RE: follow-up on E3

Suzanne, Birgit, Eve,

If E3 is trying to illustrate what the cost increase would be as a percentage of current cost I don't think the math is a simple as current costs (~$12MWh generating cost or ~$35MWh all in cost) + replacement costs. It is not complex math but you would have to estimate an new 'current cost'. Corporate overhead, RE, mitigation programs, etc. would still exist, likely at changed levels. Lower Snake Compensation would go away (presumably) . Lots of predicting the future in that math so I am not suggesting we ask them to do that. What we need them to do is to clearly define the "additional costs." I think they are close, if not there now.

Bill Leady P.E.
(acting) Vice President, Generation Asset Management | PG
BONNEVILLE POWER ADMINISTRATION
bpa.gov | Office 503-230-4270 | Cell (b)(6) [redacted]

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Thursday, April 28, 2022 4:48 PM
To: Cooper,Suzanne B (BPA) - P-6 <sbcooper@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Leady Jr,William J (BPA) - PG-5 <wjleady@bpa.gov>
Subject: RE: follow-up on E3

Suzanne, my guess is this is from the SAMP. Yes, we will follow up. That's such a tricky thing to figure out what numbers to use.

From: Cooper,Suzanne B (BPA) - P-6 <sbcooper@bpa.gov>
Sent: Thursday, April 28, 2022 4:46 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Leady Jr,William J (BPA) - PG-5 <wjleady@bpa.gov>
Subject: follow-up on E3

Verifying that you will be following up on the LSR dams generation costs and verifying the PF rate is 3.5 cents/kWh.
I recall seeing a table that shows the generation costs at each project – it may be helpful to locate that as it may reflect what Joel recalls as the generation cost for those dams being (ie, lower than $17/MWh).

From: Koehler,Birgit G (BPA) - PG-5
Sent: Monday, February 7, 2022 9:54 AM
To: Jack Moore
Subject: RE: potential project under the E3/BPA contract

Deliberative; FOIA-exempt

That works just fine. Thanks.

From: Jack Moore <jack@ethree.com>
Sent: Monday, February 7, 2022 9:53 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Arne Olson <arne@ethree.com>; Kushal Patel <kushal.patel@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Subject: [EXTERNAL] RE: potential project under the E3/BPA contract

Hi Birgit,

Thanks for checking in—we are having a short internal meeting in 10 minutes to confirm our proposal details and I'll send it over to you by 10:15. I hope that still give you enough time for a quick review. We can also discuss in real-time tomorrow any questions you may have.

Thanks!
Jack

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, February 7, 2022 9:47 AM
To: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Kushal Patel <kushal.patel@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Subject: RE: potential project under the E3/BPA contract

Deliberative; FOIA-exempt

Good morning all,

I am writing to check if you're ready to send us your thoughts on the study we discussed. We had planned to discuss with our leads internally at noon today so we can turn around our feedback to you by Tuesday's meeting.

Thanks,
Birgit

From: Jack Moore <jack@ethree.com>
Sent: Wednesday, February 2, 2022 11:29 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Arne Olson <arne@ethree.com>; Kushal Patel <kushal.patel@ethree.com>

Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Subject: [EXTERNAL] RE: potential project under the E3/BPA contract

That sounds good. Thank you Birgit.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, February 2, 2022 10:28 AM
To: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Kushal Patel <kushal.patel@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Subject: RE: potential project under the E3/BPA contract

Deliberative; FOIA-exempt

If it is easy for you to send out the invitation, that's fine with us. We haven't had trouble joining other web-meetings. We're happy to stay on past noon too.

You'll notice that I added a header upon the advice of our attorneys.

From: Jack Moore <jack@ethree.com>
Sent: Wednesday, February 2, 2022 9:59 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Arne Olson <arne@ethree.com>; Kushal Patel <kushal.patel@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Subject: [EXTERNAL] RE: potential project under the E3/BPA contract

Thanks Birgit—

It was great to talk with you. In your window, we are free from 11:30-12 (and Arne + I could stay to 12:15). Would you like to send out the invite so it works on BPA's system or should I?

We'll also aim to get material over to you to review by Friday afternoon or early Monday at the latest.

Thanks,
Jack

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Tuesday, February 1, 2022 3:38 PM
To: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Kushal Patel <kushal.patel@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Subject: RE: potential project under the E3/BPA contract

Hello Arne, Kushal, and Jack,

Thanks for the conversation today. We look forward to hearing your thoughts after you've had time to confer, and don't hesitate to be in touch by email if you have questions in the meantime.

As far as meeting next Tuesday, we got lucky on calendars at our end. Do you want to pick a time before calendars fill up? At the moment, we at BPA are free 10-1:30 and 2-4. How do your calendars look?

Cheers,
Birgit

From: Jack Moore <jack@ethree.com>
Sent: Tuesday, February 1, 2022 9:06 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Arne Olson <arne@ethree.com>; Kushal Patel <kushal.patel@ethree.com>
Subject: [EXTERNAL] RE: potential project under the E3/BPA contract

Thanks, Birgit. That sounds good—I look forward to talking this afternoon with you

---

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, January 31, 2022 4:56 PM
To: Jack Moore <jack@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Arne Olson <arne@ethree.com>; Kushal Patel <kushal.patel@ethree.com>
Subject: RE: potential project under the E3/BPA contract

Hello Jack,

Wonderful that you are interested in this study. Given that time is tight, let's talk tomorrow. (You'll get me out of a meeting that I'll be happy to miss.) I'll send a meeting invitation shortly to reserve the time.

And yes, we will work on the contracting paperwork right away. Eve did started on that and reached out to our contracting office already.

We'll talk tomorrow then,
Birgit

From: Jack Moore <jack@ethree.com>
Sent: Monday, January 31, 2022 4:21 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Arne Olson <arne@ethree.com>; Kushal Patel <kushal.patel@ethree.com>
Subject: [EXTERNAL] RE: potential project under the E3/BPA contract

Hi Birgit,

Thanks for reaching out to us. We'd definitely be interested discussing this more with you and coming up with an approach that is a good fit for what you need and in this timeline—which you are right, may affect how we should approach it.

Is there a good time for you to talk this week? Tomorrow 2-2:30 and Wed 11:30-12 both look open for us.

In parallel, to make the best use of the time until April, I think it's probably good to start the contracting process going so that we can begin efficiently and not need to wait. James, please let me know if you or Steve need anything from us to get things moving on that front.

Thanks!
Jack

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, January 31, 2022 11:01 AM
To: Jack Moore <jack@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: potential project under the E3/BPA contract

Good morning Mr. Moore,

Trevor Downen gave me your name as a contact for the IDIQ contract. We have another project that we hope you will be interested in.

We are looking for help with a study to identify one or more portfolios of resources that could potentially replace the full services the lower Snake River dams are able to supply. While BPA has the capability to do this study ourselves, we are looking for a third party to perform the study to minimize the appearance of bias in a BPA-led study. There is a tight turn-around in that we would like to have the information in April, and perhaps the timeline informs/constrains the scope.

You will find a short description of what we are looking for in the attachment. I'm happy to discuss further. When it comes to the nitty-gritty of adding this to the E3/BPA contract, I'll ask Eve James and Steve Bellcoff to work with our contracting office and with staff your organization as appropriate.

We certainly hope E3 is available and interested in performing this study! I look forward to hearing from you, and would be happy to discuss if you need more information before letting us know your interest.

Cheers,
Birgit

-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-
Birgit Koehler, Ph.D.
Deputy Vice President of Power Generation Asset Management
Bonneville Power Administration
(503) 230-4249
bgkoehler@bpa.gov

From:	Koehler,Birgit G (BPA) - PG-5
Sent:	Monday, July 11, 2022 10:08 PM
To:	Aaron Burdick; Arne Olson
Cc:	James,Eve A L (BPA) - PG-5
Subject:	RE: urgent, more swirl, maybe release this afternoon

You may have deliberately not included Scen 1b in Table 1 since it could have the same info as scen 1.

Will work on the Council invitations tomorrow. Public have to register on the council's web site, but the 4 of us should be invited as panelists

---

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Sent: Monday, July 11, 2022 10:04 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: RE: urgent, more swirl, maybe release this afternoon

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Sent: Monday, July 11, 2022 10:00 PM
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Ok, see public report attached with relevant updates made in the public deck reflected (corrected final NPV values, added scenario 1b w/ binding CES target, added range for scenario 2c).

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Sent: Tuesday, July 12, 2022 7:14 AM
To: Aaron Burdick; Arne Olson
Cc: James,Eve A L (BPA) - PG-5
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Aaron, it looks great.
And after thinking about it a little longer, not changing that table made sense.

Here's the link to our external website

- https://www.bpa.gov/energy-and-services/power/hydropower-impact

I sent the link to the Council staff this morning together with a request to make all 4 of us panelists for the presentation.

Thank you, thank you for the mad scramble yesterday!!!!

Now it is out, and no one can't take it back.

Birgit

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, July 12, 2022 7:03 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Arne Olson <arne@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
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I didn't add to that table since we didn't change those primary input variables. I expanded in the scenarios section what sensitivities we modeled. Let me know if changes are needed.

Aaron

Get Outlook for iOS

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, July 11, 2022 10:03:50 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>
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Release tonight would be an embargoed copy for DC at 6 pm Eastern time tonight.

Post public at 6 am tomorrow

From: Koehler,Birgit G (BPA) - PG-5
Sent: Monday, July 11, 2022 1:46 PM
To: Arne Olson <arne@ethree.com>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: urgent, more swirl, maybe release this afternoon

Hello Arne and Aaron,

I was just called onto a phone call if we can maybe release the PPT *and* report by 3 pm EASTERN time. I'll write more as we discuss internally.

Birgit

From:	Johnson,G Douglas (BPA) - DK-7
Sent:	Wednesday, July 6, 2022 10:42 AM
To:	Koehler,Birgit G (BPA) - PG-5; Leary,Jill C (BPA) - LN-7
Cc:	Baskerville,Sonya L (BPA) - AIN-WASH; Godwin,Mary E (BPA) - LN-7
Subject:	RE: questions from E3 for Council presentation
Attachments:	[EXTERNAL] Note from Hal

FYI for those of you who don't know, this came in this morning and I have yet to respond.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 10:38 AM
To: Leary,Jill C (BPA) - LN-7 <jcleary@bpa.gov>
Cc: Johnson,G Douglas (BPA) - DK-7 <gdjohnson@bpa.gov>; Baskerville,Sonya L (BPA) - AIN-WASH <slbaskerville@bpa.gov>; Godwin,Mary E (BPA) - LN-7 <megodwin@bpa.gov>
Subject: questions from E3 for Council presentation

Confidential and Privileged, Attorney-Client Communication, Do Not Release under FOIA

Jill and others,

Arne Olsen of E3 had 2 questions I want to share with you.

1- He would like to add two slides. I told him these seemed reasonable. Go ahead and add them, noting that I would let others know for awareness. Jill, if that will be a problem with DOE, we can pull back, but it seemed non-sensitive to me
    i. background about E3 in case the Council members aren't familiar
    ii. background on the NW RESOLVE model that was used in the study
2- Dan Catchpole of Clearing Up him asked for an advanced copy (that he would embargo) to help meet his Thursday deadline. I told him currently "no" but that I'd tell him if that changes

I didn't bother telling him about the swirl and the chance that don't have the full go-ahead yet

From: Koehler,Birgit G (BPA) - PG-5
Sent: Wednesday, July 6, 2022 10:29 AM
To: Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: Draft Exec Summary

Arne,
Your presentation meeting seems to be the only thing on the agenda. I registered already, and it gave me a meeting for Outlook for 90 minutes, starting at 8:30 PDT
F&W Committee Meeting and Council Meeting | Northwest Power and Conservation Council (nwcouncil.org)
(F&W committee meetings today, whole Council tomorrow)

You too should register.

Thursday, July 7

Council Meeting – 8:30am (PDT) / 9:30am (MDT)

General Webinar ATTENDEES should use this link to register. After registering, you will receiv email containing information about joining the webinar. (How to join a Webinar). Contact ITHe technical questions.

8:30am	Energy and Environmental Economics (E3) study **on Lower Snake River Dams P** **Replacement:** Arne Olsen, E3.

Adding those two slides makes sense to me. I will let others know, however, because you won't believe the scrutiny this has received. (I'll phrase it as an inform, not an ask for permission.)

I don't think we can give Dan Catchpole a copy today, but I'll check and will absolutely let you know if that changes.

Birgit

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, July 6, 2022 9:42 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Aaron Burdick <aaron.burdick@ethree.com>
Subject: [EXTERNAL] RE: Draft Exec Summary

Hi Birgit,

A few things. First, do you recall exactly when I'm supposed to go on and how much time I will have for the presentation?

Second, I'm thinking I want to add two slides to the deck for the Power Council presentation tomorrow, one with a bit of background about E3 in case the Council members aren't familiar with us, and a second with some background on the NW RESOLVE model that was used in the study. Does that make sense to you?

Third, Dan Catchpole of Clearing Up called and was hoping to get an advanced copy of the presentation to help with their writeup in advance of their Thursday deadline. They promise to embargo it until after the public presentation tomorrow. I think that makes sense unless you all disagree.

Any need to touch base this afternoon?

Thanks!

Arne

From: Hal Bernton

Sent: Wed Jul 06 08:27:20 2022

To: Johnson,G Douglas (BPA) - DK-7

Cc: Nick Turner

Subject: [EXTERNAL] Note from Hal

Importance: Normal

Do you expect the Snake River dam report this week?
I am ccing my colleague Nick Turner because I will be out of office on assignment for two weeks starting Friday, and if the report comes out, I want to make sure that you forward to Nick as well.
Best regards
Hal Bernton

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, August 1, 2022 5:08 PM
To: Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5
Cc: Arne Olson
Subject: [EXTERNAL] FW: Follow-Up Questions on LSRD Power Replacement Study
Attachments: Questions about LSRD removal study Assumptions.docx

FYI, we received some detailed questions on the study from NWPCC staff. We'll work to answer them and CC you on the response.

Aaron

From: Jennifer Light <JLight@NWCouncil.org>
Sent: Monday, August 1, 2022 2:28 PM
To: Arne Olson <arne@ethree.com>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: John Ollis <JOllis@NWCouncil.org>
Subject: Follow-Up Questions on LSRD Power Replacement Study

Hello Arne and Aaron,

Thank you for presenting your study at the July Council meeting. I think it was a great discussion. The fact that the Council members were able to ask so many good questions is a testament to the good presentation.

I am reaching out with a few follow up questions (see attached). My team had some questions about the analysis and assumptions that we were not able to fully answer through reading the report or listening to the presentation. As you can see, these get more into the weeds, as you might expect from the staff/analytical level. Our goal is to just make sure we understand the analysis, as we have been getting some questions from our members. I reached out to Bonneville to confirm that they were okay with us following up, and they asked that we just contact you directly. Hopefully you can take some time to respond.

Thank you in advance for your time, and please let me know if a call might be easier to talk through any of these.

Jennifer Light (she/her)
Interim Director of Power Planning
Office: 503-222-5161 | Direct: (b)(6) [redacted]
www.nwcouncil.org | LinkedIn
Northwest **Power** and
Conservation Council

1. Can you please provide more clarity on how you treated energy efficiency in this study? Our understanding is that you removed the expected energy efficiency from the load forecast. For the energy efficiency you subtracted from loads, did you only look at the energy efficiency that was cost-effective in the 2021 Plan? (pg 45). Or did you remove all of the energy efficiency in the Council (or other) supply curve? If the former, did you allow the model to consider energy efficiency that was not cost-effective under the 2021 Plan but was otherwise available in your supply curve?
2. Similar question for demand response. It appears from pg 45 that you looked at the demand response that was considered cost-effective in the plan, which I am assuming is the ~720 MW we identified in the resource program. What additional DR did you consider in the study?
3. Are the hourly load shapes used for the High Electrification case the same as in the baseline? Or do they change due to different sectoral usage patterns? (p. 17)
4. Is three years of sampling historical data enough to extrapolate hydro ramps? How is the 5% day to day shift of non-LSRD hydro energy shifting calculated? Does the PNUCC estimate of hydro capacity being 65% of nameplate apply to every dam individually or the NW system as a whole? Is there any assumed change in peaking capability of the non-LSRD hydropower after removal? From what years is the historical hydro dispatch data for the rest of the northwest fleet based? In general, do these shaping numbers change as the system and portfolio changes? (page 22-26)
5. When considering the ELCC of each resource type, the previous 2019 RA study seemed to use a larger NW footprint and portfolio when calculating ELCC. Since ELCC is generally sensitive to the portfolio makeup in which it is tested and unless we are mistaken this study seems to leverage the results from the previous study, how much do you suspect the different ELCC of new resources might be with the revised footprint for the NW used in this study? Did the removal of the LSR dams capability influence the ELCC calculations? Are there any intra-regional transmission limitations in the ELCC analysis? Is the ELCC analysis using historical hydro conditions from 1929 to 2008? Or a more limited set of hydro conditions? If reliability challenges shift to the summer ELCC of other resources might change other than storage, were any of these potential changes considered? (p. 24)
6. What is the data source or methodology to extract the deemed market emissions rate of 0.43 tons/MWh? (pg 30)
7. Can you provide some information as to why you used 2001 sustained peaking as a sample year (pg 33)? We understand that 2001 is a low hydro year, especially in the summer, but are wondering how this connects with the 15% planning reserve margin?
8. Can you provide more information why the model picked more wind in the no combustion case? We were seeing a different picture in our modeling of the amount of solar vs wind to replace peak needs, and are trying to understand your model better from that perspective.
9. Our understanding is that for outside the region you used policy targets and a planning reserve margin to develop the build trajectory. In this analysis, what kind of out of region natural gas additions do you assume (where? How much?).
10. In your high electrification scenario, did the potential of EE and DR increase from the baseline potential?
11. What is the underlying source or thought behind the Load following up and down assumptions of 3% of hourly load? Does that change with renewable buildout size? (P.55)

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Thursday, June 2, 2022 4:35 PM
To:	James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5
Cc:	Arne Olson
Subject:	[EXTERNAL] RE: BPA-E3
Attachments:	BPA_RESOLVE_PublicDeck_v3.pptx

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Ok, here is the updated deck in PPT form.

All the best,
Aaron

From: Aaron Burdick
Sent: Thursday, June 2, 2022 4:27 PM
To: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: BPA-E3

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I want to make sure we don't cross our wires on these cost metrics.

We are reporting:

- **Avg retail rate impact**: total RESOLVE RRQ increase divided by 2022 BPA Tier I load,
  - e.g. Case S2a: $860M in 2045 divided by 58,686 GWh/yr = 1.5 cents/kWh
- **Household cost impact**: retail rate impact * 1,000 kWh/mo * 12 mo/yr * 128% (electrification annual energy increase)
  - e.g. Case S2a: 1.5 cent/kWh * 1,280 kWh/mo * 12 mo/yr = $230/yr
- **Residential cost impact or total households impacted**:
  - This requires us to assume how much of the total RRQ impact is allocated to residential customers:
    - E.g. $860M * 40% = $344 million residential
    - $344 million divided by $230/yr/household = 1.5 million households
      - OR, if I don't adjust the electrification load increase and effectively stick with the 2022 Tier I rates, I get $180/yr. $344m / $180/yr/household → ~1.91 million households

So... shall we just say 2 million households? Or does BPA have specific data on residential customers we should use? For now I'll use 2 million unless I hear otherwise.

From: Arne Olson <arne@ethree.com>
Sent: Thursday, June 2, 2022 3:28 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: BPA-E3

I imagine only about 40% of the sales are residential, so the 4.9 million would be closer to 2 million, which is in the ballpark of what I would have expected. We can get more exact numbers from EIA Sales & Revenue if needed.

So $750 million per year divided by 2 million customers is about $375 per customer per year, or a total NPV of around $3000 per customer.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 3:20 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

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Ok, hopefully last clarifying question:

BPA on slide 3:
"Bullet 3: How many customers or households does this number represent? E.G. Public power costs increase by 9% or ~$125 per year, per household, for XX households (baseline scenario) [E3 was it households or customers? We want to quantify # of people affected. Please also reverse two sub-bullets to match order in Bullet 2. Deep carbon goes first]"

By "how many customers or households" **do you mean the number of customers or households of public power customers we assume will be impacted?** In other words, if we took the BPA's Tier 1 annual sales we assume (~58,686 GWh/yr per FY2022 BPA forecast) and our assumed 1,000 kWh per month per household, how many households would that be? Doing this we get 4.9 million households. Is this in line with BPA's expectation of Tier 1 customers? Of course, there are some distinctions between household electric use and C&I electric use (surely there are C&I Tier I loads as well as residential), making this calculation a bit imperfect...

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 2, 2022 2:44 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

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Sounds good to me Aaron

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 1:01 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

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Ok. Seems more appropriate in a footnote to me. How about I add this footnote to slide 17? "Replacement resource costs are calculated assuming project financing per E3's pro forma calculator, rather than assuming upfront congressional appropriation."

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Thursday, June 2, 2022 12:54 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

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...based on assuming that replace resource projects are financed rather than paid for upfront using $X billion appropriations of cash from congress
Yes, this is exactly what were meant. If you have a better way to phrase it than the current text, that's great.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 12:48 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Thanks. Follow up question below. We're working on pulling the 2C scenario "as much as" cost metrics. Hoping to complete that and send later today.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 2, 2022 12:32 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

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Thanks Aaron- how about replace that statement then with "E3 assumed transmission would be built as needed for renewable additions" to be clear of what transmission builds are in the study (please keep the suggested addition in italics about Congressional approval to breach the dams). We keep getting questions around Tx build outs.

Other comments below.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 12:25 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

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Re: slide 3, I also don't get this one: "E3 assumed the region is building the transmission needed even if the dams are not breached."

We assume transmission would be built as needed for renewable additions, etc. But we don't assume that any transmission needed for dam replacement would be built if the dams aren't getting replaced… Let me know if I am misunderstanding something.

Aaron

From: Aaron Burdick
Sent: Thursday, June 2, 2022 12:21 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

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A few specific responses and one question response needed to proceed:

- Slide 15: yes, this is H2 generation. Adjusted and added footnote to clarify.
- Slide 17: you suggested adding "if region funds through debt financing over 50 years rather than upfront appropriations from Congress". Our resource cost inputs are developed using E3's pro forma project financing model that is based primarily on PPA off-taker prices for new resource additions. The debt vs. equity ratios depend on the technology (E3 developed this dataset based on the NREL Annual Technology Baseline), but they all assume a blend. Financing lifetimes change depending on the technology.
  That makes sense, maybe it should read "if region funds through debt financing rather than upfront appropriations from Congress"

Do you mean that annual costs would be $XM per year based on assuming that replace resource projects are financed rather than paid for upfront using $X billion appropriations of cash from congress? Are you just trying to have us state that the costs assume project financing for replacement resources?

- Slide 17: "by 2045" vs "after 2045". I prefer "by" since it implies costs before 2045 as well. "After" to me implies the costs are only occurring after 2045. By works- I meant to put the added words after the text 2045
- Question re: slide 3 feedback:
  - BPA said:
    - Bullet 2: How much would it cost to replace the power benefits of the four Lower Snake River dams, in E3's study?
      - 2a: Given the trends towards aggressive carbon reduction policies, total costs would be $X.X billion in upfront capital costs, with ~XXX million per year for operational cost, absent breakthroughs in not-yet-commercialized emerging technologies. $46 billion total net present value (NPV) costs
        - QUESTION: when we just showing the S1 baseline, no range was needed. Seems like we either need to say "increase AS MUCH AS" or provide a range for the 3 deep decarb scenario we ran. Should I use "as much as" per the prior version's use for the third bullet on public power cost increases? Yes- that works
      - 2b: With today's carbon reduction policies, total costs would be $2.8 billion in upfront capital costs, with ~$110 million per year for operational cost. $7.5 billion total NPV costs

Thanks,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, June 1, 2022 8:45 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>

Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Good Morning-
For some reason I wasn't able to successfully save the PDF of your slide deck with my comments on the slides so I'm attaching a PPT with 2 slides that have some notes and suggestions for your consideration. We also started working on a handful of slides on BPA's perspective for either introduction or after your slides (I'm currently leaning on takeaways once you present the results). We are hoping to send materials to DOE by the end of the week to get their OK to set up a meeting with CEQ so a fast turn-around would be helpful. I'm attaching a rough draft of the slides we are currently working on (it's still a work-in-progress) so you can get an idea of what we are thinking.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, May 27, 2022 5:40 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

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One minor tweak made on slide 9. Please use this updated version.

All the best,
Aaron

From: Aaron Burdick
Sent: Friday, May 27, 2022 5:25 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

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Updated deck is attached.

We noted 700-900 aMW for now on slide 3, pending any further data/guidance on this (though we've still modeled 706 aMW in our RESOLVE cases).

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, May 27, 2022 3:59 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

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I was pulling some data and see that the 1,030 aMW number in the EIS is in reference to the No Action Alternative baseline. Most folks are out of the office by now for the holiday weekend so I'll make sure on Tuesday I get the correct LSN gen data. Some white book data I was looking at had the LSN gen ~940 aMW but I want to make sure it has the correct spill operation.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, May 27, 2022 11:32 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

We're nearing a second draft. Can we meet briefly after lunch to discuss how we've integrated the BPA feedback and confirm any open questions? Are you free at 2pm?

Aaron

From: Aaron Burdick
Sent: Thursday, May 26, 2022 8:32 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Thanks Eve. I'll work from this version as I make updates today and tomorrow. I'll follow up by end of day with any questions.

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, May 25, 2022 4:20 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT
Attached are some "notes" for you to consider in the presentation. You can copy and paste into your template slides for the suggestions you like- feel free to edit and reword as needed. We will find out on Thursday if the presentation materials are needed on Friday so hopefully we can keep making progress on this. We had hoped to use a single presentation for CEQ and the broader public but realized we need to go to a higher level and focus on some different points with CEQ. The attached presentation is focused on CEQ as an audience.

Thanks,

Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, May 25, 2022 11:59 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Johnson,G Douglas (BPA) - DK-7 <gdjohnson@bpa.gov>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Eve – thanks for the note on that. I wasn't quite following the logic of how those first couple slides fit into the flow, so will await your further thoughts.

Douglas – thanks for your feedback. I will work to incorporate as we update over the next couple days.

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, May 25, 2022 8:46 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Johnson,G Douglas (BPA) - DK-7 <gdjohnson@bpa.gov>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Hi Aaron-
I received from feedback that the "Bottom-Line Up Front" and Conclusion slides need some more work so we'll send another draft hopefully later this morning. The comments on the middle section of the deck should be fine for you to incorporate.

Thanks,
Eve

From: James,Eve A L (BPA) - PG-5
Sent: Tuesday, May 24, 2022 4:44 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Johnson,G Douglas (BPA) - DK-7 <gdjohnson@bpa.gov>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Hi Aaron-
Attached are some "notes" for you to consider in the presentation. You can copy and paste into your template slides for the suggestions you like- feel free to edit and reword as needed. I am also sending a copy to Doug in our communications staff to see if he has any additional thoughts or comments since he is very good at messaging most of our lower Snake River dam capability public reports.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, May 23, 2022 10:50 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Sure. See attached.

Aaron

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, May 23, 2022 6:45 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Good morning Aaron,
Could you send us a Power Point for us to make suggestions on?

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, May 20, 2022 3:46 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Eve and Birgit,

See attached for the draft public summary deck. We hope to receive your feedback on Monday afternoon and discuss a path forward to finalizing this document shortly. Assuming the messaging aligns with your expectations of what the summary should cover, we can draft the 1-pager summary next week to align with the final public deck.

All the best,
Aaron

From: Aaron Burdick
Sent: Wednesday, May 4, 2022 5:12 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Hi Eve,

This all seems doable. Would the 1-2 pager exec summary from our word report also suffice? If not, we'll likely need a bit of additional budget if we need to create a separate PPT doc. We can discuss further tomorrow.

Thanks,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, May 4, 2022 2:30 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Hi Aaron-
I took some notes at an internal meeting where we were discussing future sharing of study information at a higher level since at some point this will go to a layperson audience. I thought it might be a helpful reference to share- we referenced some of the graphics and slide numbers from the presentation you had on this email.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, April 27, 2022 5:18 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

An abridged summary version of the draft results is attached. Let me know if you have any suggested changes prior to the executive briefing tomorrow.

Thanks,
Aaron

-----Original Appointment-----
From: Cooper,Suzanne B (BPA) - P-6 <sbcooper@bpa.gov>
Sent: Tuesday, April 26, 2022 2:44 PM
To: Cooper,Suzanne B (BPA) - P-6; James,Eve A L (BPA) - PG-5; Cook,Joel D (BPA) - K-7; Leady Jr,William J (BPA) - PG-5; Armentrout,Scott G (BPA) - E-4
Cc: Aaron Burdick; Diffely,Robert J (BPA) - PGPL-5; Koehler,Birgit G (BPA) - PG-5 (bgkoehler@bpa.gov); Arne Olson
Subject: FW: BPA-E3
When: Thursday, April 28, 2022 3:30 PM-4:30 PM (UTC-08:00) Pacific Time (US & Canada).
Where: Webex

-----Original Appointment-----
From: Cooper,Suzanne B (BPA) - P-6 <sbcooper@bpa.gov>
Sent: Tuesday, April 26, 2022 2:31 PM
To: Cooper,Suzanne B (BPA) - P-6; Cooper,Suzanne B (BPA) - P-6; James,Eve A L (BPA) - PG-5; Cook,Joel D (BPA) - K-7; Leady Jr,William J (BPA) - PG-5; Armentrout,Scott G (BPA) - E-4
Subject: BPA-E3
When: Thursday, April 28, 2022 3:30 PM-4:30 PM (UTC-08:00) Pacific Time (US & Canada).
Where: Webex

You can forward this invitation to others.

Conference Room Services 1 is inviting you to a scheduled Webex meeting.

Thursday, April 28, 2022
3:30 PM | (UTC-07:00) Pacific Time (US & Canada) | 1 hr

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Meeting password: [redacted]

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Join by phone

+1-415-527-5035 US Toll

Global call-in numbers

Join from a video system or application

Dial 27627102796@mybpa.webex.com

Need help? Go to https://help.webex.com

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Friday, July 1, 2022 8:56 PM
To:	James,Eve A L (BPA) - PG-5; Arne Olson
Cc:	Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian
Subject:	[EXTERNAL] RE: Draft Exec Summary
Attachments:	E3 BPA LSR Dams_070122.pdf; E3 BPA LSR Dams_070122.pptx

Deliberative, FOIA exempt

And now the final PPT.

Aaron

From: Aaron Burdick
Sent: Friday, July 1, 2022 8:55 PM
To: 'James,Eve A L (BPA) - PG-5' <eajames@bpa.gov>; Arne Olson <arne@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Ran into some formatting issues when exporting to PDF. Had to switch to a different template, so there are a few formatting differences, but final version of the report is attached.

Final PPT slides coming in next email.

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, July 1, 2022 4:10 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

Great – thanks Aaron.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, July 1, 2022 4:02 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Arne Olson <arne@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: [EXTERNAL] RE: Draft Exec Summary

Deliberative, FOIA exempt

Thanks. I've included these edits.

Almost done but there are a few loose ends that will require some additional work. I'll plan to send later tonight once those are complete.

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, July 1, 2022 2:57 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Hi Aaron-
Attached is a draft with a few suggestions on page 49-50 in the transmission section for your consideration.

Thanks,
Eve

From: James,Eve A L (BPA) - PG-5
Sent: Thursday, June 30, 2022 5:35 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Hi Aaron-
Attached is a draft that has a few edits for your consideration. One general comment that Rob had was that there does not seem to be a discussion that directly addresses imports/exports between the regions- there may be questions around how that was treated when trying to compare between NWEC, EnergyGPS, etc...
I sent the report to our transmission staff to read through the transmission appendix material on page 49 – 50 and should have any edits/comments back from them by noon tomorrow.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, June 29, 2022 9:04 PM
To: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: [EXTERNAL] RE: Draft Exec Summary

Deliberative, FOIA exempt

And now the draft report, ready for BPA version control. Note there are a few placeholders still for some minor E3 updates.

Aaron

From: Aaron Burdick
Sent: Wednesday, June 29, 2022 9:03 PM
To: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>

Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Updated public summary deck attached w/ NPV values updated. We are now proposing to use the 3% NPV discount rate, which increases the NPV. This is better representative of the public power cost of capital and more closely aligns with the discount rates used in the Inslee/Murray report.

Report draft coming in the next email.

Aaron

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, June 29, 2022 5:47 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

Energy GPS study is out:

> If the LSRD are removed, an additional 14,900 MW of resources will be required. This is 23% of the Pacific Northwest's current generation capacity and enough to power 15 cities the size of Seattle.

https://www.linkedin.com/pulse/new-report-value-lower-snake-river-dams-effectively-/?trackingId=kLZaTd9mS%2F2IeThVJO4L0w%3D%3D

I think it would behoove us to put together a little comparison of the three studies.

Should be done with my edits on ours in the next hour.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, June 29, 2022 4:23 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Sounds good- thanks Aaron!

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, June 29, 2022 4:22 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] Re: Draft Exec Summary

Deliberative, FOIA exempt

Hi Eve,

The report version is the updated/corrected version. The 1b 2024 retirement case had too high an NPV previously. I'll send an updated public deck when I send the report over in a bit.

Aaron

Get [Outlook for iOS]

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, June 29, 2022 3:49:49 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt
Hi Aaron-
As I was going through the report and working on some internal talking points I noticed the NPV values in the draft report chart weren't matching the chart in the public presentation slide (see below). Can you let me know which table is correct? I can see rounding for 2b but for Scenario 1 2024 breach it isn't rounding error. If the slide deck needs updating could you send me a new version so I can make sure I have the correct materials to post?

Thanks,
Eve

Table 12. Total LSR Dams replacement costs[21]

	NPV Total Costs (Real 2022 $)	Annual Costs Increase (Real 2022 $)			Incremental Public Power Costs
	In the year of breaching (2032 or 2024)	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$7.4 billion	n/a	$434 million	$478 million	0.8 ¢/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$8.6 billion	$495 million	$466 million	$509 million	0.8 ¢/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$11.3 billion	n/a	$496 million	$860 million	1.5 ¢/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$6.7 billion	n/a	$415 million	$428 million	0.7 ¢/kWh [+8%]
Scenario 2c: Deep Decarb. (No New Combustion)	$46 billion	n/a	$1,953 million	$3,199 million	5.5 ¢/kWh [+65%]

	Total Costs (real 2022 $) Net Present Value in year of breaching
Scenario 1: 100% Clean Retail Sales	$7.5 billion
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$11 billion
Scenario 2a: Deep Decarb. (Baseline Technologies)	$11.5 billion
Scenario 2b: Deep Decarb. (Emerging Technologies)	$7 billion
Scenario 2c: Deep Decarb. *(No New Combustion)*	*$46 billion*

Deep decarbonization without emerging technologies drives impractically high costs

---

From: James,Eve A L (BPA) - PG-5
Sent: Wednesday, June 29, 2022 12:17 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt
Sounds good- I'll start reading and making notes to add to the version this afternoon.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, June 29, 2022 12:14 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: Draft Exec Summary

Deliberative, FOIA exempt

Eve,

Arne is still completing some edits, but I'm sending this "interim" draft version so you have the full report to start digging through. I'll send another version later today with all of Arne's edits, so suggest *E3 retains version control until later today when we share that version*, when it will transfer to BPA.

Note: Arne has made some changes to the exec summary, which I've keep tracked since you already reviewed that. I updated is response to your prior feedback (but did not track those changes).

All the best,
Aaron

From: Aaron Burdick
Sent: Tuesday, June 28, 2022 9:43 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Eve,

Status update: we're still working on a few remaining items in the draft and incorporating Arne's review. I'm hoping to send you the draft by mid-day tomorrow. Will either send of provide an update until then. I'm hoping we can get your review by end of day Thursday and update as needed on Friday before sharing the final version by Friday COB.

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Monday, June 27, 2022 3:36 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt
Hi Aaron-
Attached are some comments on the Executive Summary for your consideration.

Arne- I saw the Council's note on providing materials ahead of the July 7th meeting. Internally we were thinking that if we share the PPT this early we would need to be prepared to start fielding incoming questions and for the info to be shared with others. We're still working on some talking points for our communications staff and Account Executives. Also, just so you are aware there is a discussion with some of DC folks tomorrow so I was going to wait and email the Council staff tomorrow after that meeting if you don't mind. If you have concerns about waiting to share materials please let me know.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, June 24, 2022 3:12 PM

To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] Draft Exec Summary

Deliberative, FOIA exempt

Hi Eve,

I'm leaving for a weekend trip and OOO the rest of the afternoon. I'm providing the draft executive summary but the rest of the report draft will need to wait until Tuesday next week. Hopefully this provides enough to make sure we're aligned. I'm also copying the TOC for the draft report to make sure you're aware what we're working on.

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All the best,

Aaron Burdick, Associate Director
Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500 | San Francisco, CA 94104

818-807-6499 | aaron.burdick@ethree.com

Energy+Environmental Economics

BPA Lower Snake River Dams Power Replacement

Executive Summary

June 2022

Arne Olson, Sr. Partner
Aaron Burdick, Associate Director
Sierra Spencer, Sr. Consultant
Dr. Angineh Zohrabian, Consultant
Sam Kramer, Consultant
Jack Moore, Sr. Director

About this study

+ **BPA contracted with E3 to conduct an independent analysis of the electricity system value of the four lower Snake River (LSR) dams**
+ **E3 utilized our RESOLVE optimal capacity expansion model to identify least-cost portfolios of electricity resources needed to replace the electric energy and grid services provided by the dams through 2045**
+ **Replacement costs and emissions impacts are considered within the context of the Northwest region's aggressive, long-run decarbonization goals**

Key Study Questions:

- What **additional resources** would be needed to replace the power services provided by the LSR Dams through 2045?
- What is the **net cost to** BPA ratepayers?
- How do costs and resource needs change under **different types of clean energy futures**?
- How much does replacing the dams rely on **emerging, not-yet-commercialized technologies**?

27693337(01).pdf

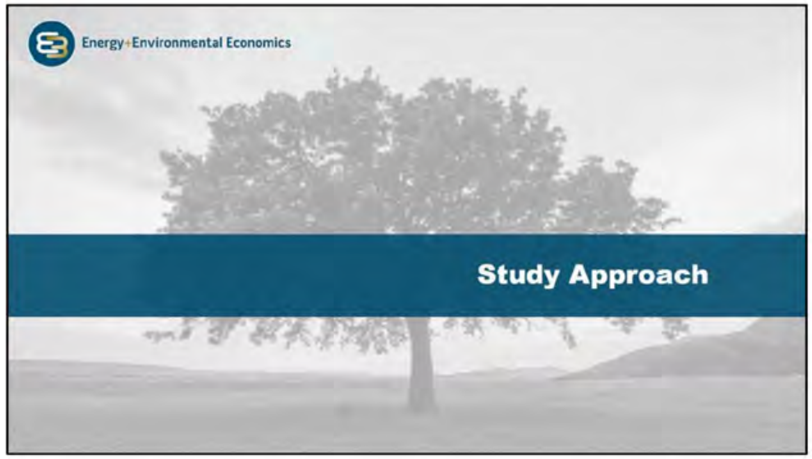
What would it take to replace the output of the four lower Snake River dams?

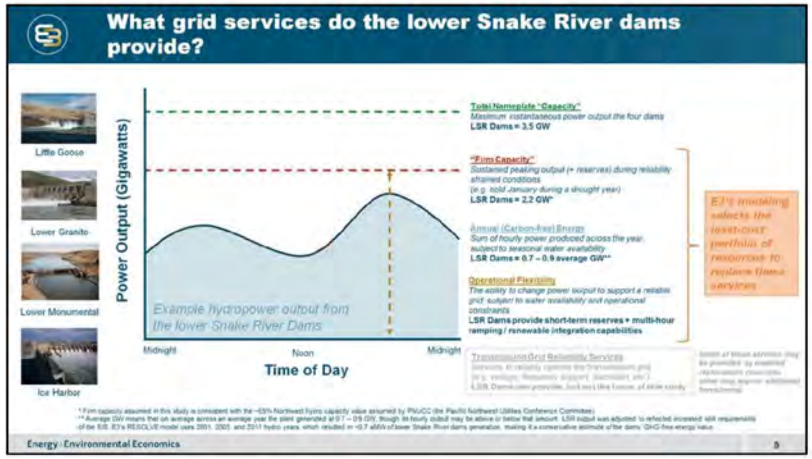
Key Study Conclusions

- **What energy services are lost if the dams are breached?**
  - 3,483 MW of nameplate capacity, including over 2,000 MW of firm peaking capability to avoid power shortages during extreme cold weather events
  - ~700-900[1] annual average MW of low-cost, zero-carbon energy (enough energy to support ~450,000 households or 1.7x the City of Portland) as well as operational flexibility services
- **How much would it cost to replace the power benefits of the four lower Snake River dams in E3's study?**
  - Given the trends towards aggressive carbon reductions policies, under a "deep decarbonization" scenario absent breakthroughs in not-yet-commercialized emerging technologies, total costs could be as much as $11 billion in upfront capital costs with up to $53 million per year for operational cost. Total net present value (NPV) costs could be as much as $46 billion.
  - With less load growth and less stringent long-term emissions reduction goals, total costs would be $2.8 billion in upfront capital costs with up to $110 million per year for operational cost. Total net present value (NPV) costs would be $7.5 billion.
- **What are the long-term rate impacts to ~2 million public power households in 2045?**
  - Public power costs could increase as much as 65% or $850 per year (deep decarbonization scenario absent emerging technology breakthroughs)
  - Public power costs increase by 9% or ~$125 per year (baseline scenario)
- **What resources are needed to replace the dams?**
  - A combination of energy efficiency, renewable generation (wind), and "clean firm" capacity additions (such as dual fuel natural gas + hydrogen plants, advanced nuclear, or gas with carbon capture and storage)
  - Battery storage cannot cost-effectively replace hydro capacity in the Northwest due to charging limitations during energy shortfall events
- **What is the timeline necessary to add the resources that would be required?**
  - E3 estimates that adding additional renewable energy and firm capacity additions would take approximately 5 years after congressional approval to breach the dams and possibly up to 10 years if additional new transmission was required. E3 assumed transmission would be built as needed for renewable additions.

Plant	Nameplate Capacity (MW)
Lower Granite	930
Little Goose	930
Lower Monumental	930
Ice Harbor	693

Total = 3,483 MW


Energy+Environmental Economics
Study Approach



27693337(01).pdf

What's new in this study compared to the CRSO EIS?

The study uses an optimization model to determine the least-cost replacement resources for the four lower Snake River dams subject to A) policy and B) reliability constraints

- **Least-cost optimization: includes updated resource pricing and new emerging technologies**
- **Policy: E3's modeling considers the effects of regional policies such as Washington's Clean Energy Transformation Act (CETA) and Oregon's 100% clean electricity standard**
  - Aggressive clean energy laws drive coal power plant retirements, price carbon emissions, and require long-term **carbon emissions reductions** by 2045
  - Study includes significant **electrification** that increases demand for electricity to support carbon-reduction in other sectors such as transportation, buildings, and industry, consistent with Washington's Energy Strategy
- **Reliability: E3's modeling captures the need for the Northwest system to meet peak load during extreme weather and low hydro conditions (known as "resource adequacy").**
  - Captures the abilities and limits of different technologies to serve load during reliability challenging conditions
    - E.g. during extended cold-weather periods with high load, low hydropower availability, and low wind and solar production
  - Resources with high energy production costs may be selected for reliability needs but then run sparsely only during extreme conditions (e.g. natural gas + hydrogen combustion turbines)
- **LSR operations: incorporates preferred alternative operations selected in the EIS**
  - Increases spill from the dams, lowering available annual energy and changing operational flexibility

Policy Landscape: Washington, Oregon, California

+ The study includes the impacts clean energy policies in the Pacific states

	RPS or Clean Energy Standard?	Coal Prohibition?	Cap-and-Trade?	New Natural Gas?	Economy-Wide Carbon Reduction?
WA	✔ Carbon neutral by 2030, 100% carbon free electricity by 2045	✔ Eliminate by 2025	✔ Cap-and-invest program established in 2021. SCC in utility planning	✔	✔ 95% GHG emission reduction below 1990 levels and achieve net zero emissions by 2050
OR	✔ 50% RPS by 2040, 100% GHG emission reduction by 2040 relative to 2010 levels	✔ Eliminate by 2030	✔ Climate Protection Plan adopted by DEQ in 2021 (power sector not included)	✖ HB 2021 bans expansion or construction of power plants that burn fossil fuels	✔ 90% GHG emission reduction from fossil fuel usage relative to 2022 baseline
CA	✔ 60% RPS by 2030, 100% clean energy by 2045	✔ Coal-fired electricity generation already phased out	✔	✖ CPUC IRP did not allow in recent procurement order	✔ 40% GHG emission reduction below 1990 levels by 2030 and 80% by 2050

Modeling approach involves a three-step process

1. ***With the lower Snake River dams*, optimize long-term resource needs and operations for the Pacific Northwest**
   - Produces necessary resource additions and total system costs and emissions

2. ***Remove the lower Snake River dam generating capacity, then re-optimize* long-term resource needs and operations for the Pacific Northwest**
   - Produces a second set of resource additions and total system costs and emissions
   - All scenarios breach the dams in 2032, except for one 2024 breaching sensitivity

3. ***Calculate additional resources and investment + operational costs* required to replace the dams**
   - Calculated as the difference between steps 1 and 2 above

Key Modeling Assumptions

Element	Study Approach	Impact on Dams Replacement Needs
Study Years	• 2025 through 2045, including fuel price forecasts and declining renewable + storage costs	Considers long-term needs
Clean Energy Policy Scenarios	• Aggressive OR+WA legislation reflected, including coal retirements + carbon pricing • Two electric emissions scenarios considered: 1. **100% clean retail sales** (~85% carbon reduction*) 2. **Zero-emissions** (100% carbon reduction)	Clean energy policy requires long-term replacement of LSR dams with GHG-free energy
Load Growth Scenarios	• Two load scenarios: 1. **Baseline** (per NWPCC 8th Power Plan) 2. **High electrification** load growth (to support economy-wide decarbonization) • Significant quantities of energy efficiency are embedded in all scenarios	Higher load scenarios increase the value of LSR dams energy + firm capacity
Reliability Needs	• Modeling ensures reliability needs during extreme conditions (e.g. high loads + low hydro) • Captures ability (and limits) of renewables, battery storage, and demand response to support system reliability	Reliability needs require replacement of LSR dams firm capacity contributions
Technologies Modeled, including "Emerging" Technologies	• Broad range of dam replacement technology options considered: • **Baseline technologies**: solar, wind, battery + pumped storage, energy efficiency, demand response, dual fuel natural gas + hydrogen combustion plants • **Sensitivities** include Emerging Technologies and Limited Technologies (No New Combustion) scenarios • Resource costs developed by E3 using NREL 2021 ATB, Lazard Cost of Storage v.7, NuScale Power (for small modular reactor costs)	Technology available for LSR dams replacement determines replacement cost
Distributed Energy Resource Options	• Energy efficiency, demand response, and customer solar embedded into modeling inputs • Additional energy efficiency and demand response can be selected	Demand resource can help replace LSR dams, though low-cost supply is limited

* A 100% clean retail sales target allows emissions for electric generation beyond that needed to serve "retail sales", i.e. losses during transmission to retail loads and exported energy

Scenarios

- **Scenario 1: 100% Clean Retail Sales**
  - Northwest resources produce enough clean energy to meet **100% of retail electricity sales** on an annual average basis
  - Some gas generation is retained for reliability, but carbon emissions are reduced **85% below 1990 levels**
  - **Business-as-usual** load growth
- **Scenario 2: Deep Decarbonization**
  - **Zero carbon emissions** by 2045
  - **High electrification** of buildings, transportation, and industry to reduce carbon emissions in other sectors
  - **Emerging technologies** become available to provide firm, carbon-free power

Emerging Technologies

Technology	S1 100% Clean	S2a Deep Decarb Baseline	S2b Deep Decarb Emerging Tech	S2c Deep Decarb No New Combustion
Mature technologies (solar, wind, battery + pumped storage, energy efficiency, demand response)	Available	Available	Available	Available
Hydrogen (existing natural gas retrofits)	Available	Available	Available	Available
Hydrogen (new dual fuel natural gas + hydrogen)	Available	Available	Available	Not available
Nuclear (small modular reactors)	Not available	Not available	Available	Not available
Natural Gas w/ Carbon Capture and Storage	Not available	Not available	Available	Not available
Offshore Wind (floating)	Not available	Not available	Available	Available

Available
Not available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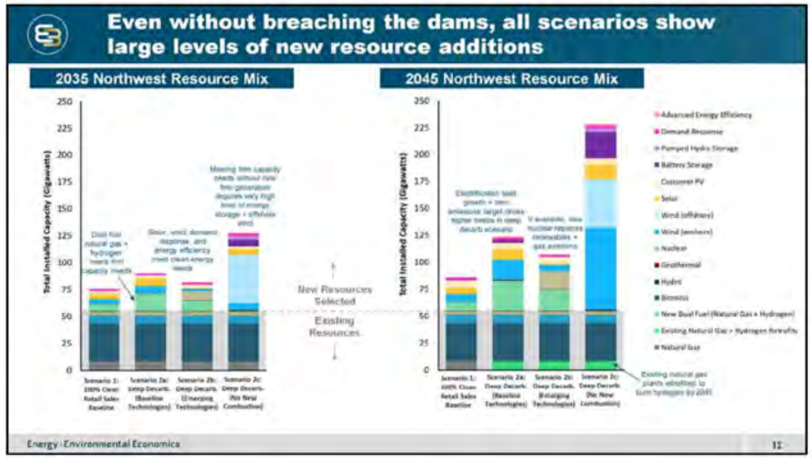
Northwest Resource Needs in Scenarios
With the Lower Snake River Dams


Even without breaching the dams, all scenarios show large levels of new resource additions
2035 Northwest Resource Mix
2045 Northwest Resource Mix
Total Installed Capacity (Gigawatts)
250
225
200
175
150
125
100
75
50
25
0
New Resources Selected
Existing Resources
Scenario 1: 100% Clean Retail Sales Baseline
Scenario 2a: Deep Decarb. (Baseline Technologies)
Scenario 2b: Deep Decarb. (Emerging Technologies)
Scenario 2c: Deep Decarb. (No New Combustion)
Advanced Energy Efficiency
Demand Response
Pumped Hydro Storage
Battery Storage
Customer PV
Solar
Wind (offshore)
Wind (onshore)
Nuclear
Geothermal
Hydro
Biomass
New Dual Fuel (Natural Gas + Hydrogen)
Existing Natural Gas + Hydrogen Retrofits
Natural Gas
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Replacing the Power from the Lower Snake River Dams

Detailed Replacement Costs + Resource Needs

- RESOLVE selects an optimal portfolio of replacement resources including additional advanced energy efficiency, wind, solar, green hydrogen, and/or advanced nuclear
- Firm capacity is mostly replaced with ~2 GW of dual fuel natural gas + hydrogen turbines
  - These turbines may initially burn natural gas when needed during reliability challenged periods, but would transition to hydrogen by 2045 to reach zero-emissions
- If advanced nuclear is available, it replaces renewables and some of the gas plants
- The "no new combustion" scenario requires very large (~12 GW) buildout of renewable energy to replace the dams' firm capacity contributions

Scenario	Replacement Resources Selected, Cumulative by 2045 (GW*)
Scenario 1: 100% Clean Retail Sales	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
Scenario 2a: Deep Decarb. (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW [illegible] + additional H2 generation*
Scenario 2b: Deep Decarb. (Emerging Technologies)	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR
Scenario 2c: Deep Decarb. (No New Combustion)	+ 10.6 GW wind + 1.4 GW solar

* 1 GW = 1,000 MW
** Replacing LSR dams GHG-free energy at least-cost leads RESOLVE to generate an additional 1.2 TWh of hydrogen generation during low renewable conditions (or 0.14 average GW)

Total costs for replacing the lower Snake River dams

+ **Costs are expected to fall on Bonneville Power Administration's public power customers**
  - Costs could **increase public power retail costs** by up to 65%
  - Costs could **raise annual residential electricity bills** by up to $850/year

	Total Costs (real 2022 $)	Annual Cost Increase (real 2022 $)			Incremental Public Power Costs [% increase vs. ~8.5 cents/kWh NW average retail rates]
	Net Present Value in year of breaching	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$7.5 billion	[illegible]	$434 million	$478 million	0.8 cents/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$11 billion	$495 million	$466 million	$509 million	0.8 cents/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$11.5 billion	[illegible]	$496 million	$860 million	1.5 cents/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$7 billion	[illegible]	$415 million	$428 million	0.7 cents/kWh [+8%]
Scenario 2c: Deep Decarb. *(No New Combustion)*	*$46 billion*	n/a	$1,853 million	$3,199 million	*5.5 cents/kWh [+65%]*

Cost differences driven primarily by 2045 carbon policy and availability of emerging technologies

Costs increase over time as loads grow and carbon policy becomes more stringent

NOTES:
- Cost increases account for replacement energy, capacity, and reserves as well as avoided LSR capital + expense, but do not include any costs for breaching the dams, which would be an additional cost.
- NPV and annual cost increase are shown for the Northwest Region as a whole, but the incremental costs are calculated relative to the BPA Tier I annual sales for public power customers.
- % increase versus average retail rates assumes ~8.5 cents/kWh retail rates (estimated from OR and WA average retail rates). This does not include additional rate increases driven by higher loads or clean energy needs that increase regional rates as shown in the earlier 2045 incremental cost chart.
- Annual residential customer cost impact assumes 1,280 kWh/month for average residential customers in Oregon and Washington (current ~1,000 kWh/month average + 28% from electrification load growth).

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Cost of generation for lower Snake River dams replacement resources (using common utility metric of $/MWh)

- The lower Snake River dams provide a low-cost source of GHG-free energy and firm capacity
- Even in a best-case scenario, replacement power would cost several times as much as the lower Snake River dams costs
- Compared to ~$13-17/MWh for the lower Snake River dams, replacement resources cost between $77/MWh to over $500/MWh, depending on the carbon-reduction policies and the availability of emerging technology

Incremental LSR Dam Replacement Resource Costs

Lower Snake River Dams All-in Generation Costs (2022 $/MWh)
$13/MWh w/o LSRCP*
$17/MWh w/ LSRCP*

Scenario	2045 Costs to replace LSR Generation** (real 2022 $/MWh)
S1: 100% Clean Retail Sales	$77/MWh
S1b: 100% Clean Retail Sales (2024 dam breaching)	$82/MWh
S2a: Deep Decarb	$139/MWh
S2b: Deep Decarb, w/ Emerging Tech	$69/MWh
S2a1: Deep Decarb, Limited Tech (no new combustion)	$517/MWh

* BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) facilities. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat 2917) to offset fish and wildlife losses caused by construction and operation of the four lower Snake River projects.

** Replacement $/MWh costs are calculated as CoreNW revenue requirement increase with LSR dams breached divided by the annual MWh of the LSR dams assumed in E3's modeling (~700 aMW). These costs includes replacement of the LSR dam energy, capacity, and reserve provision. A significant portion of the costs is capacity costs to replace the dams' RA capacity contributions.

Key Conclusions

1. **Replacing the four lower Snake River dams comes at a substantial cost**
   1. Require 2,300 – 12,000 MW of replacement resources
   2. An annual cost of $480 million – $3.2 billion by 2045*
   3. Total net present value cost of $7 – 46 billion from 2032-2065
   4. Increase in costs for public power customers of $110 – 850 per household per year (an 8 – 65% increase) by 2045
2. **The biggest cost drivers for replacement resources are the need to replace the lost firm capacity and the need to replace the lost zero-carbon energy**
3. **Replacement resources become more costly over time due to increasingly stringent clean energy standards and electrification-driven load growth**
4. **Emerging technologies such as hydrogen, advanced nuclear, and carbon capture can prevent the cost of replacement resources from increasing over time, but the pace of their commercialization is highly uncertain**

* Replacement resource costs are calculated assuming project financing per E3's pro forma calculator, rather than assuming upfront congressional appropriation

Additional Important Considerations

- **Breaching the LSR dams risks delaying the region's achievement of its clean energy goals**
  - The development, permitting, and construction of replacement resources and transmission takes time
  - Even without breaching the dams, the pace of clean energy growth needed to reach regional policy goals is ~2-4 times as large as the historical 2010-2020 average of 600 MW/yr
- **Studies indicate that the region faces a near-term deficit of firm capacity resources**
  - This deficit grows over time as coal resources are retired and electrification loads are added
  - Removing the firm capacity of the LSR dams accelerates the need for new firm capacity
- **Land use impacts**
  - Even with the LSR dams, the Baseline and Deep Decarbonization scenarios shows ~2-4x increase in NW land use for renewable energy; the "no new combustion" scenario would lead to ~11x increase in land use
  - Breaching of LSR dams increases pressure on sensitive lands
- **Transmission impacts**
  - LSR dam replacement resources would require significant new transmission investment to deliver energy from new resources to load centers

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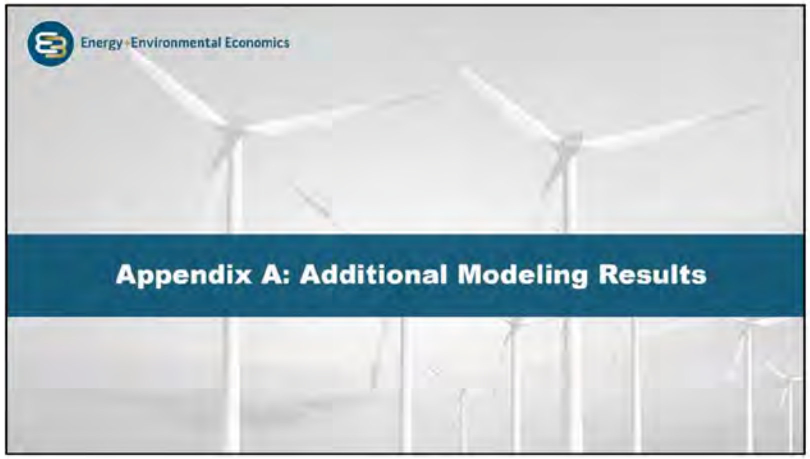
Thank you

Questions, please contact:

Arne Olson, arne@ethree.com

Aaron Burdick, aaron.burdick@ethree.com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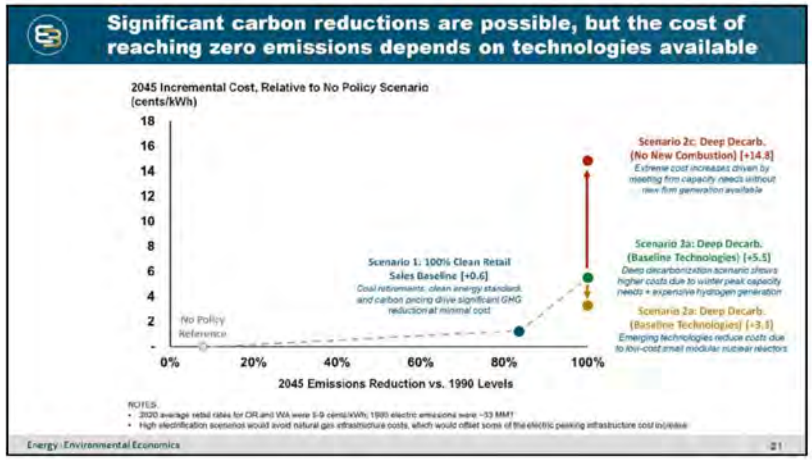
Appendix A: Additional Modeling Results


Significant carbon reductions are possible, but the cost of reaching zero emissions depends on technologies available
2045 Incremental Cost, Relative to No Policy Scenario (cents/kWh)
18
16
14
12
10
8
6
4
2
-
No Policy Reference
0%
20%
40%
60%
80%
100%
2045 Emissions Reduction vs. 1990 Levels
Scenario 1: 100% Clean Retail Sales Baseline [+0.6]
Coal retirements, clean energy standard, and carbon pricing drive significant GHG reduction at minimal cost
Scenario 2c: Deep Decarb. (No New Combustion) [+14.8]
Extreme cost increases driven by meeting firm capacity needs without new firm generation available
Scenario 2a: Deep Decarb. (Baseline Technologies) [+5.5]
Deep decarbonization scenario shows higher costs due to winter peak capacity needs + expensive hydrogen generation
Scenario 2a: Deep Decarb. (Baseline Technologies) [+3.3]
Emerging technologies reduce costs due to low-cost small modular nuclear reactors
NOTES:
2020 average retail rates for OR and WA were 5-9 cents/kWh; 1990 electric emissions were ~33 MMT
High electrification scenarios would avoid natural gas infrastructure costs, which would offset some of the electric peaking infrastructure cost increase
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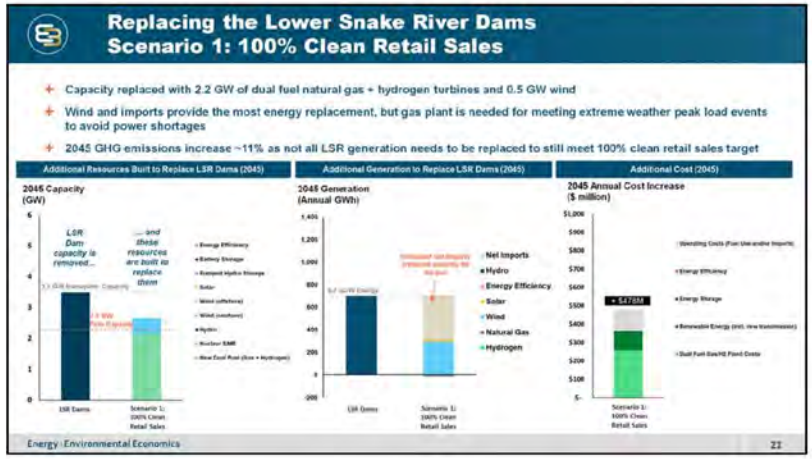

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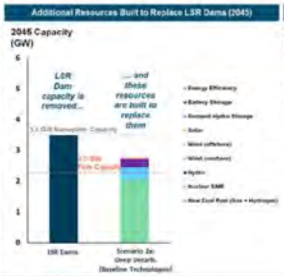
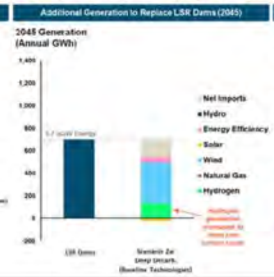
Replacing the Lower Snake River Dams
Scenario 2: Deep Decarbonization (Baseline Technologies)

- Scenario includes electric load increases for transportation and other sectors
- In 2045, hydrogen generation is a key replacement resource and is assumed to be available, though not commercially available today
- This scenario would cost $860 million dollars per year in 2045, driven by high hydrogen fuel costs (~$40/MMbtu)

Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)



Additional Cost (2045)

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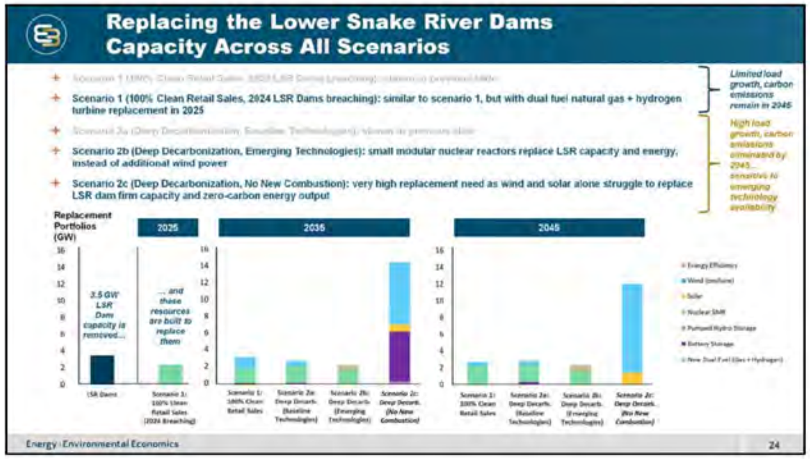

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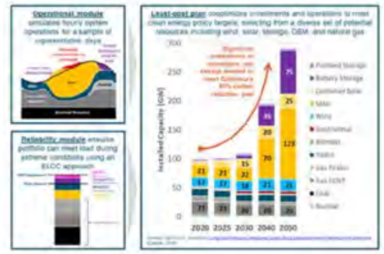
Appendix B: Additional Modeling Inputs

RESOLVE optimizes investments to meet clean energy targets reliably

RESOLVE is an optimal capacity expansion model specifically designed to identify least-cost plans to meet reliability needs and achieve compliance with regulatory and policy requirements

- **Linear optimization model explicitly tailored to study challenges to arise at high penetrations of variable renewables and energy storage**
- **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**



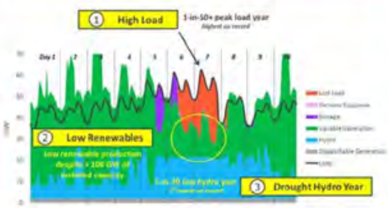
Load growth and carbon emissions in two clean energy scenarios modeled

Increases in Electricity Use and Declines in Carbon Emissions

Resource Adequacy Resource Options

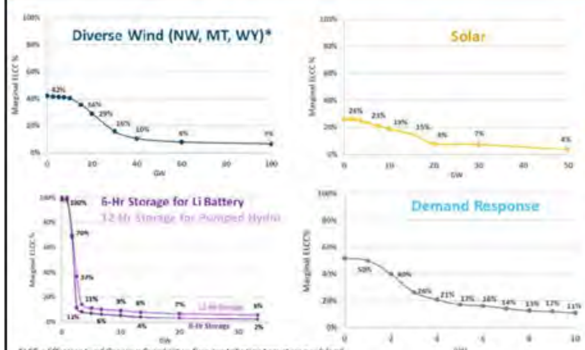
+ **RESOLVE resource adequacy constraint requires capacity to meet peak demand + a 15% planning reserve margin**
  - PRM constraint is "installed capacity" (ICAP) based for firm resources and uses ELCC for non-firm resources
+ **The nature of the Northwest reliability risk limits the ability of battery storage to provide reliable capacity contributions**
  - Storage and hydro show "antagonistic" interactions, which limit energy storage reliability value in "energy-limited" conditions where energy storage resources are unable to charge (with low hydro and renewable output) and run out of discharge (during extended energy shortfall events)

Key Drivers of Future Pacific Northwest Reliability Events



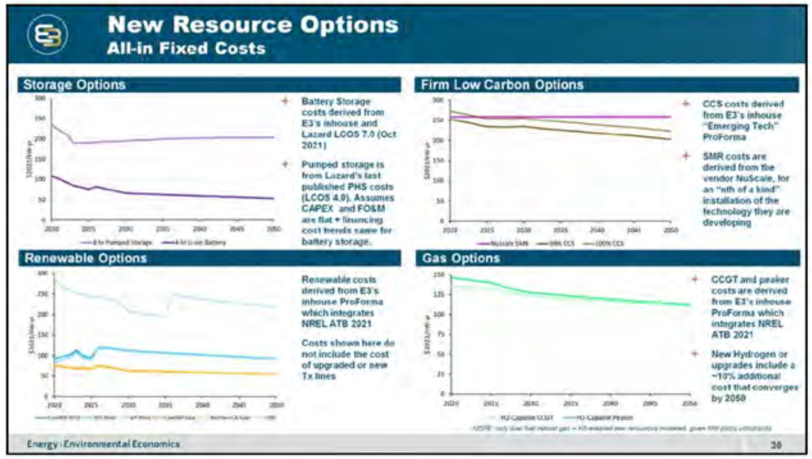
Resource	RA Capacity Contributions
Hydro	80%, based on sustained winter peaking capacity in critical water year conditions (per BPA/PNUCC). WRAP method is still evolving
Battery storage	Sharply declining ELCCs (due to hydro interaction effects)
Pumped storage	Sharply declining ELCCs (due to hydro interaction effects)
Solar	Declining ELCCs
Wind	Declining ELCCs
Demand Response	Declining ELCCs
Energy Efficiency	Limited potential vs. cost
Small Hydro	Limited potential
Geothermal	Limited potential
Natural gas to H2 retrofits	Clean firm, but not fully commercialized
New dual fuel natural gas + H2 plants	Clean firm, but not fully commercialized
New H2 only plants	Clean firm, but not fully commercialized
Gas w/ 90-100% carbon capture + storage	Clean firm, but not fully commercialized
Nuclear Small Modular Reactors	Clean firm, but not fully commercialized

Incorporating Declining Capacity Contributions of Renewables, Storage, and DR



ELCC = Effective Load Carrying Capability = firm contribution to system peak load

- A reliable electric system requires enough capacity to meet peak loads and contingencies
- This study incorporates information from E3's 2019 report *Resource Adequacy in the Northwest* about the effective capacity contribution of renewables, storage, and DR at various penetration levels



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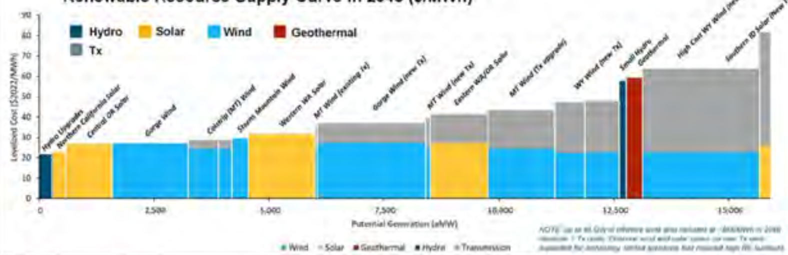
New Resource Options
Renewables

- The following supply curves integrate Tx costs that RESOLVE sees
- The "no new combustion" scenario required increases the supply of wind on new transmission (Northwest, MT+WY, and offshore) to enable a feasible solution



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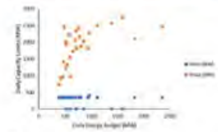
Hydro Operating Data

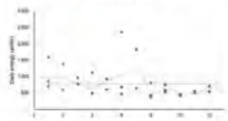
- Key RESOLVE inputs (for each representative RESOLVE day)
  - Max generation MW
  - Min generation MW
  - Daily MWh hydro budget
  - Ramp
- Hydro operating data is parameterized using representative conditions for 3 low/mid/high historical years (2001, 2005, 2011)
  - Lower Snake River and lower Columbia River dams were adjusted per BPA hydro modeling w/ latest fish spill constraints
- Hydro firm capacity contribution is assumed to be 65% of nameplate, per PNUCC methodology (based on BPA 10-hr sustaining peaking capacity)

LSR Hydro

Ramp Rates

Hydro Resource	1-hr	2-hr	3-hr	4-hr
LSR_Hydro	36%	43%	45%	48%

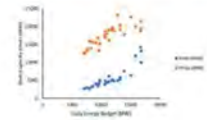


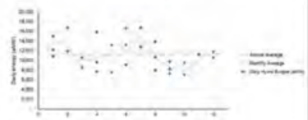


Non-LSR NW Hydro

Ramp Rates

Hydro Resource	1-hr	2-hr	3-hr	4-hr
CoreNW_Hydro	14%	23%	30%	34%





From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Friday, July 1, 2022 8:55 PM
To:	James,Eve A L (BPA) - PG-5; Arne Olson
Cc:	Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian
Subject:	[EXTERNAL] RE: Draft Exec Summary
Attachments:	E3 BPA LSR Dams Report_070122.docx; E3 BPA LSR Dams Report_070122.pdf

Deliberative, FOIA exempt

Ran into some formatting issues when exporting to PDF. Had to switch to a different template, so there are a few formatting differences, but final version of the report is attached.

Final PPT slides coming in next email.

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, July 1, 2022 4:10 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

Great – thanks Aaron.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, July 1, 2022 4:02 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Arne Olson <arne@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: [EXTERNAL] RE: Draft Exec Summary

Deliberative, FOIA exempt

Thanks. I've included these edits.

Almost done but there are a few loose ends that will require some additional work. I'll plan to send later tonight once those are complete.

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, July 1, 2022 2:57 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt
Hi Aaron-

Attached is a draft with a few suggestions on page 49-50 in the transmission section for your consideration.

Thanks,
Eve

From: James,Eve A L (BPA) - PG-5
Sent: Thursday, June 30, 2022 5:35 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Hi Aaron-
Attached is a draft that has a few edits for your consideration. One general comment that Rob had was that there does not seem to be a discussion that directly addresses imports/exports between the regions- there may be questions around how that was treated when trying to compare between NWEC, EnergyGPS, etc...
I sent the report to our transmission staff to read through the transmission appendix material on page 49 – 50 and should have any edits/comments back from them by noon tomorrow.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, June 29, 2022 9:04 PM
To: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: [EXTERNAL] RE: Draft Exec Summary

Deliberative, FOIA exempt

And now the draft report, ready for BPA version control. Note there are a few placeholders still for some minor E3 updates.

Aaron

From: Aaron Burdick
Sent: Wednesday, June 29, 2022 9:03 PM
To: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Updated public summary deck attached w/ NPV values updated. We are now proposing to use the 3% NPV discount rate, which increases the NPV. This is better representative of the public power cost of capital and more closely aligns with the discount rates used in the Inslee/Murray report.

Report draft coming in the next email.

Aaron

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, June 29, 2022 5:47 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

Energy GPS study is out:

If the LSRD are removed, an additional 14,900 MW of resources will be required. This is 23% of the Pacific Northwest's current generation capacity and enough to power 15 cities the size of Seattle.

https://www.linkedin.com/pulse/new-report-value-lower-snake-river-dams-effectively-/?trackingId=kLZaTd9mS%2F2IeThVJO4L0w%3D%3D

I think it would behoove us to put together a little comparison of the three studies.

Should be done with my edits on ours in the next hour.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, June 29, 2022 4:23 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Sounds good- thanks Aaron!

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, June 29, 2022 4:22 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] Re: Draft Exec Summary

Deliberative, FOIA exempt

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Get Outlook for iOS

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Sent: Wednesday, June 29, 2022 3:49:49 PM
To: Aaron Burdick <aaron.burdick@ethree.com>

Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
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All the best,

Aaron Burdick, Associate Director
Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500 | San Francisco, CA 94104

818-807-6499 | aaron.burdick@ethree.com

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Thursday, June 30, 2022 8:06 PM
To:	James,Eve A L (BPA) - PG-5; Arne Olson
Cc:	Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian
Subject:	[EXTERNAL] RE: Draft Exec Summary

Deliberative, FOIA exempt

Thanks Eve. We'll review and work on getting you an updated final version tomorrow. That will include the 50-year NPV and the battery storage ELCC sensitivity case we ran.

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 30, 2022 5:35 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

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Hi Aaron-
Attached is a draft that has a few edits for your consideration. One general comment that Rob had was that there does not seem to be a discussion that directly addresses imports/exports between the regions- there may be questions around how that was treated when trying to compare between NWEC, EnergyGPS, etc...
I sent the report to our transmission staff to read through the transmission appendix material on page 49 – 50 and should have any edits/comments back from them by noon tomorrow.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, June 29, 2022 9:04 PM
To: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
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Subject: [EXTERNAL] RE: Draft Exec Summary

Deliberative, FOIA exempt

And now the draft report, ready for BPA version control. Note there are a few placeholders still for some minor E3 updates.

Aaron

From: Aaron Burdick
Sent: Wednesday, June 29, 2022 9:03 PM
To: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>

Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
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Updated public summary deck attached w/ NPV values updated. We are now proposing to use the 3% NPV discount rate, which increases the NPV. This is better representative of the public power cost of capital and more closely aligns with the discount rates used in the Inslee/Murray report.

Report draft coming in the next email.

Aaron

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, June 29, 2022 5:47 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
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Energy GPS study is out:

> If the LSRD are removed, an additional 14,900 MW of resources will be required. This is 23% of the Pacific Northwest's current generation capacity and enough to power 15 cities the size of Seattle.

https://www.linkedin.com/pulse/new-report-value-lower-snake-river-dams-effectively-/?trackingId=kLZaTd9mS%2F2IeThVJO4L0w%3D%3D

I think it would behoove us to put together a little comparison of the three studies.

Should be done with my edits on ours in the next hour.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
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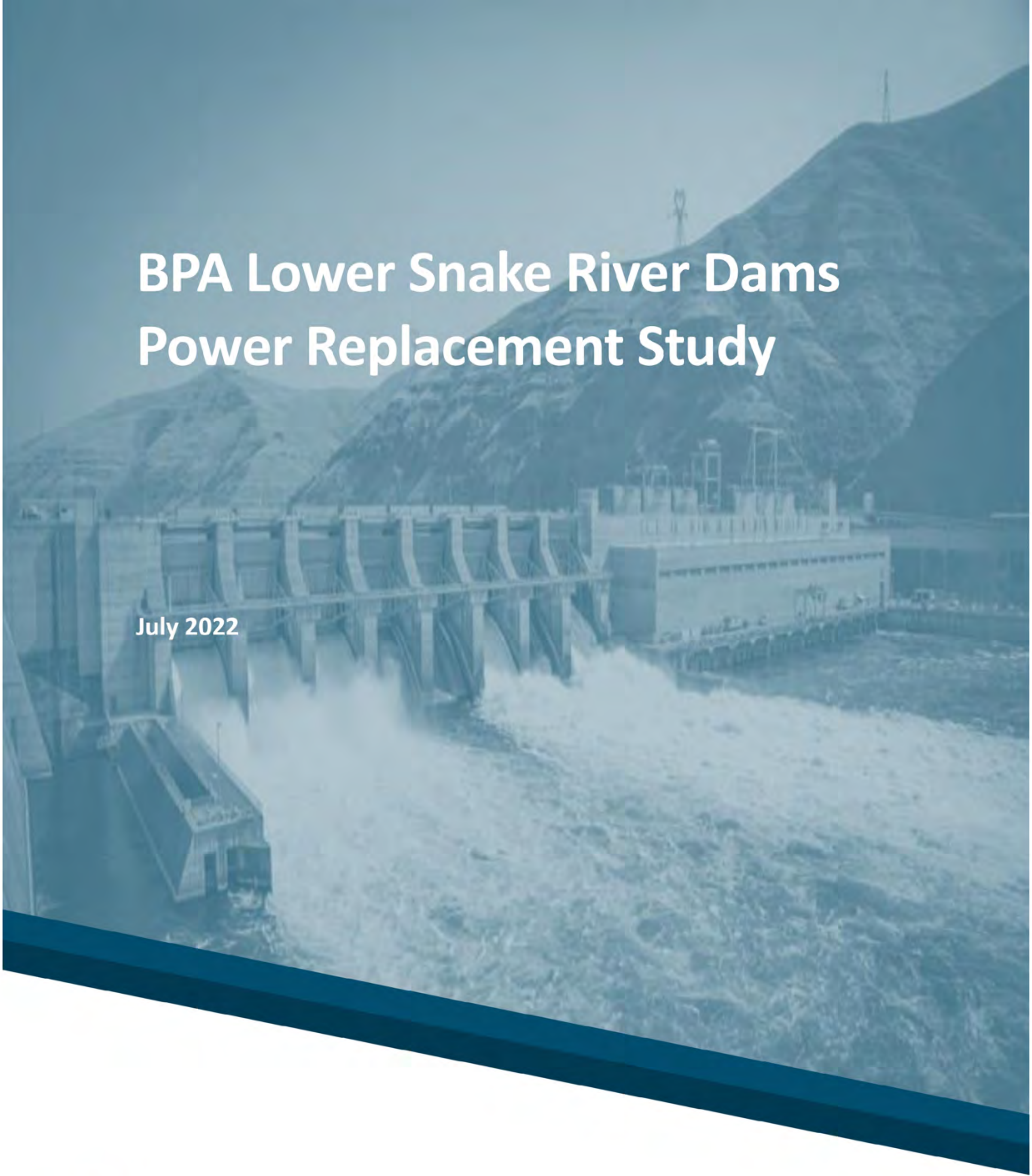
818-807-6499 | aaron.burdick@ethree.com

BPA Lower Snake River Dams Power Replacement Study

July 2022



Energy+Environmental Economics

BPA Lower Snake River Dams Power Replacement Study

July 2022

Energy and Environmental Economics, Inc. (E3)
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Sierra Spencer

Sam Kramer

Jack Moore

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Acronym Definitions

Acronym	Definition
BPA	Bonneville Power Administration
BTM Solar	Behind-the-meter Solar
CA	California
CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
CES	Clean Energy Standard
CRSO EIS	Columbia River System Operations Environmental Impact Statement
DR	Demand response
EE	Energy efficiency
EIA	Energy Information Administration
ELCC	Effective load carrying capability
HDV	Heavy-duty vehicles
H2	Hydrogen
LDV	Light-duty vehicles
LSR	Lower Snake River
NERC	North American Electric Reliability Corporation
NG	Natural Gas
NV	Nevada
NW	Northwest
PNUCC	Pacific Northwest Utilities Conference Committee
PRM	Planning Reserve Margin
RM	Rocky Mountains
RPS	Renewable Energy Standard
SMR	Small modular reactor
SW	Southwest
WECC	Western Electricity Coordinating Council

Executive Summary

E3 was contracted by the Bonneville Power Administration to conduct an independent study of the value of the lower Snake River dams ("LSR dams") to the Northwest power system. The dams provide approximately 3,500 megawatts ("MW") of total capacity[1] and approximately 2,300 MW of firm peaking capability[2] to support regional reliability. They also generate approximately 900 average MW of zero-carbon energy each year[3], provide essential grid services such as operating reserves and voltage support, and operational flexibility to support renewable integration. If the dams are breached, these power services will need to be replaced to ensure the Northwest power system can continue to provide reliable electricity service. Replacing the dams is complicated by the clean energy policies adopted either statutorily or voluntarily by jurisdictions and utilities throughout the region, which will necessitate a transformation of the power system over time toward non-emitting resources even as electricity demand grows substantially due to electrification of the transportation and building sectors.

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho, and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability. RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[4]. Using RESOLVE allows for a dynamic optimization that considers replacement resource needs in the context of long-term system load and policy drivers, not just the near-term resource mix

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[1] Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. The "total capacity" refers to the overload capacity, not the nameplate capacity. Historical peak generation was 3,431 MW.

[2] LSR dam firm capacity contributions are estimated using the PNUCC regional hydropower 65% capacity value, which was validated by looking at LSR Dam wintertime power and reserve provision during low hydro conditions. Additionally, E3 considered estimates on the impact of a lower firm capacity value in the results chapter.

[3] The data for the LSR dams was adjusted to reflect the Preferred Alternative operations defined in the Columbia River Systems Operation Environmental Impact Statement (CRSO EIS). E3's RESOLVE model uses 2001, 2005, and 2011 hydro years, which resulted in ~700 average MW of lower Snake River dams generation, making it a conservative estimate of the dams' GHG-free energy value.

[4] Pacific Northwest Low Carbon Scenario Analysis, December 2017, https://www.ethree.com/projects/study-policies-decarbonize-electric-sector-northwest-public-generating-pool-2017-present/; Pacific Northwest Zero-Emitting Resources Study, January 2020, https://www.ethree.com/e3-examines-role-of-nuclear-power-in-a-deeply-decarbonized-pacific-northwest/

and needs of the system today. The dams are assumed to be breached in 2032, except for one sensitivity that considered 2024 breaching.

This study's scenario design focuses on three key variables – clean energy policy, load growth, and emerging technology availability – that impact the cost to replace the dams. The scenarios and key assumptions are show in Table 1.

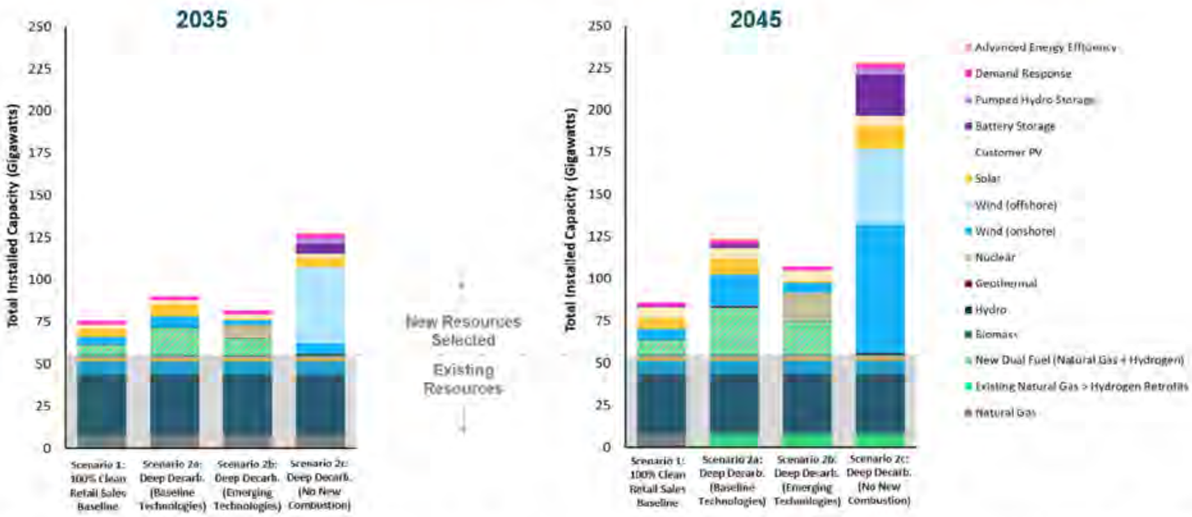
Table 1. Scenario Design

Scenario	Clean Energy Policy	Load Growth	Technology Availability
1 100% Clean Retail Sales[1]	100% retail sales (85% carbon reduction)	8th Power Plan Baseline	Baseline (incl. natural gas / hydrogen dual fuel plants)
2a Deep Decarbonization (Baseline Tech.)	100% carbon reduction	High Electrification	Baseline
2b Deep Decarbonization (Emerging Tech.)	100% carbon reduction	High Electrification	Baseline + offshore wind, gas w/ CCS, nuclear SMR
2c Deep Decarbonization (No New Combustion)	100% carbon reduction	High Electrification	Baseline (excluding natural gas / hydrogen dual fuel plants

Even with the dams in place, the region's clean energy goals and potential electrification load growth drive a significant need for new resources. In all scenarios, significant energy efficiency and customer solar is embedded into the load forecast, based on the NWPCC's 8th Power Plan. Additionally, 6 gigawatts ("GW" or 6,000 MW) of coal capacity is retired by 2030, while increasing carbon prices incent further clean energy resource additions. In Scenario 1, the regional power system is required to meet a goal of generating enough clean energy to provide 100% of retail electricity sales, on an average basis over a calendar year. This requires an additional 5 GW of solar and 5 GW of wind by 2045 to achieve the clean energy goal; 0.6 GW of battery storage, 2 GW of demand response, and 9 GW of dual fuel natural gas + hydrogen combustion plants are also added to meet the region's resource adequacy needs.

Though all scenarios require more "firm" resources – resources that can start when needed and operate for as long as needed – to meet peak loads, these resources are in higher demand in Scenario 2, in which all greenhouse gas emissions are eliminated from the regional power system by 2045. This scenario also assumes that electrification results in much higher electric loads, particularly in wintertime due to electrification of natural gas space heating in buildings. The baseline scenario (2a) selects additional wind, solar, and geothermal to meet clean energy needs as well as demand response, some battery storage, and 27 GW natural gas and hydrogen dual fuel combustion plants to meet reliability needs. An alternative "emerging technology" scenario selects 17 GW of advanced nuclear technology (small modular reactors or "SMRs") by 2045, in place of the firm capacity provided by natural gas generators while reducing the required quantities of wind, solar and batteries that are needed. The "no new combustion" scenario does not allow clean firm technologies such as hydrogen combustion turbines, gas generation with carbon capture and sequestration (CCS) or SMRs. As a result, it requires impractically high levels of additional onshore wind, offshore wind, and battery storage to meet firm capacity and carbon reduction needs, quadrupling the total installed MW of the Northwest grid by 2045.

Figure 1. Northwest Installed Capacity Mix in Scenarios with the Lower Snake River Dams



When the power services provided by the dams are removed from the regional power system, RESOLVE selects an optimal, i.e., least-cost portfolio of replacement resources that meets the Northwest's clean energy and system reliability needs. These replacement resources require a large investment and come at a substantial cost that increase over time as the region's clean energy goals become more stringent. In the latter years, the replacement costs are highly dependent on scenario-specific assumptions about the availability of emerging technologies. RESOLVE primarily replaces the carbon-free energy from the dams with additional wind power and the firm capacity with dual fuel natural gas and hydrogen combustion plants. Small amounts of additional energy efficiency and battery storage are also selected in some scenarios. By 2045, the dual fuel plants added burn additional hydrogen on low wind days to replace the carbon-free energy provided by the dams. Scenario 2b selects additional nuclear SMRs in lieu of some of the wind and gas resources. Scenario 2c disallows the new combustion plants, even those that would burn green hydrogen, and other emerging technologies, requiring a very large buildout of wind and solar power to replace both the firm capacity and the carbon-free energy of the dams.

The long-term emissions impact of removing the generation of the lower Snake River dams will depend on the implementation of the Oregon and Washington electric clean energy policies. Both a 100% clean retail sales and a zero-carbon emissions target require replacement of most or all of the LSR dams' GHG-free energy. However, without additional earlier carbon-free resource investments beyond those modeled in this study to meet clean energy policy trajectories, carbon emissions may increase initially when the dams are breached, before declining by 2045 as the carbon policy becomes more stringent.

Table 2. Summary of LSR Dams Replacement Resources and Cost Impacts (costs in the table below and throughout this report are shown in real 2022 dollars)

Scenario	Replacement Resources Selected, Cumulative by 2045 (GW)	NPV Replacement Costs[5]	Annual Replacement Costs[6]			Public Power Rate Impact[7]
			2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind	$11.8 Billion	-	$434 million/yr	$478 million/yr	0.8 ¢/kWh [+9%]
Scenario 1b: 100% Clean Retail Sales (2024 dam removal)	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind	$12.8 Billion	$495 million/yr	$466 million/yr	$509 million/yr	0.8 ¢/kWh [+9%]
Scenario 2a: Deep Decarbonization (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW advanced EE + 1.2 TWh H2-fueled generation	$19.0 Billion	-	$496 million/yr	$860 million/yr	1.5 ¢/kWh [+18%]
Scenario 2b: Deep Decarbonization (Emerging Technologies)	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR	$10.7 Billion	-	$415 million/yr	$428 million/yr	0.7 ¢/kWh [+8%]
Scenario 2c: Deep Decarbonization (No New Combustion)	+ 10.6 GW wind + 1.4 GW solar	$75.2 billion	-	$1,953 million/yr	$3,199 million/yr	5.5 ¢/kWh [+65%]

KEY FINDINGS:

+ ***Replacing the four lower Snake River dams while meeting clean energy goals and system reliability is possible but comes at a substantial cost***, even assuming emerging technologies are available:
    - Requires 2,300 – 2,700 MW of replacement resources
    - An annual cost of $415 million – $860 million by 2045

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[5] These NPV values are calculated assuming a 3% discount rate to represent the public power cost of capital, discounting 50-year of costs starting from the year of breaching (either 2032 or 2024).

[6] Replacement resource costs are calculated assuming project financing per E3's pro forma calculator, rather than assuming upfront congressional appropriation.

[7] This assumes that the annual replacement costs will be borne by BPA's Tier I public power customers. Percentage changes are shown relative to today's average OR + WA retail rate of ~8.5 ¢/kWh.

- Total net present value cost of $10.7-19.0 billion based on 3% discounting over a 50-year time horizon following the date of breaching
    - Increase in costs for public power customers of $100 – 230 per household per year (an 8 – 18% increase) by 2045
- The biggest cost drivers for replacement resources are the need to replace the lost ***firm capacity for regional resource adequacy*** and the need to replace the lost ***zero-carbon energy***
- Replacement becomes ***more costly over time*** due to increasingly stringent clean energy standards and electrification-driven load growth
- ***Emerging technologies*** such as hydrogen, advanced nuclear, and carbon capture ***can limit the cost of replacement resources*** to meet a zero emissions electric system, but the pace of their commercialization is highly uncertain
    - In economy-wide deep decarbonization scenarios, ***replacement without any emerging technologies requires very large renewable resource additions at a very high cost*** (12 GW of wind and solar at $75.2 billion NPV cost)

Background

E3 was contracted by the Bonneville Power Administration to conduct an independent study of the value of the lower Snake River dams ("LSR dams") to the Northwest power system. The dams provide approximately 3,500 megawatts ("MW") of total capacity[8] and approximately 2,300 MW of firm peaking capability[9] to support regional reliability. They also generate approximately 900 average MW of zero-carbon energy each year, provide essential grid services such as operating reserves and voltage support, and operational flexibility to support renewable integration. Figure 2 shows the power services that are the focus of this study and those that are out of scope.

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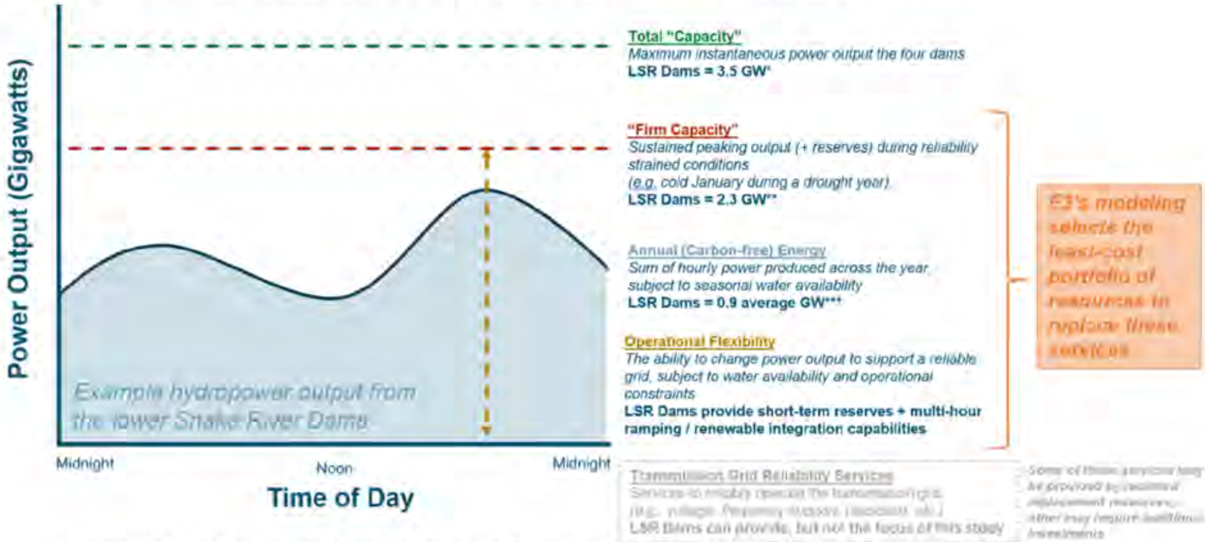
[8] Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. The "total capacity" refers to the overload capacity, not the nameplate capacity. Historical peak generation was 3,431 MW.

[9] LSR dam firm capacity contributions are estimated using the PNUCC regional hydropower 65% capacity value, which was validated by looking at LSR Dam wintertime power and reserve provision during low hydro conditions. Additionally, E3 considered estimates on the impact of a lower firm capacity value in the results chapter.

Figure 2. Power Services Considered for Replacement in this Study



* Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. Historical peak generation was 3,431 MW.

** Firm capacity assumed in this study is consistent with the ~65% Northwest hydro capacity value assumed by PNUCC (the Pacific Northwest Utilities Conference Committee).

*** Average GW means that on average across an average year the plant generated at 0.9 GW, though its hourly output may be above or below that amount. The data for the LSR dams was adjusted to reflect the Preferred Alternative operations defined in the Columbia River Systems Operation Environmental Impact Statement ("CRSO EIS"). E3's RESOLVE model uses 2001, 2005, and 2011 hydro years, which resulted in ~700 average MW of lower Snake River dams generation, making it a conservative estimate of the dams' GHG-free energy value.

If the dams are breached, these power services will need to be replaced to ensure the Northwest power system can continue to provide reliable electricity service. Replacing the dams is complicated by the clean energy policies adopted either statutorily or voluntarily by jurisdictions and utilities throughout the region, which will necessitate a transformation of the power system over time toward non-emitting resources even as electricity demand grows substantially due to electrification of the transportation and building sectors.

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability.

RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[10]. Using RESOLVE allows for a dynamic optimization that considers replacement resource needs in the context of long-term system load and policy drivers, not just the near-term resource mix and needs of the system today. The dams are assumed to be breached in 2032, except for one sensitivity that considered 2024 breaching.[11]

Key Study Questions:

- What **additional resources** would be needed to replace the power services provided by the LSR Dams through 2045?
- What is the **net cost to** BPA ratepayers?
- How do costs and resource needs change under **different types of clean energy futures**?
- How much does replacing the dams rely on **emerging, not-yet-commercialized technologies**?

This study builds off previous LSR dams replacement analysis by using a least-cost optimization-based modeling framework to replace the dams' power services. This optimization ensures that the region meets its aggressive clean energy policy goals, including both decarbonization of electricity as well as high electrification load growth consistent with economy-wide decarbonization goals set by Oregon and Washington.

The other key component of the optimization is maintaining resource adequacy for the region to ensure a reliable electricity supply to existing and any newly electrified loads. This is done using a planning reserve margin constraint and counting non-firm resources like solar, wind, battery storage, pumped hydro storage, and demand response at their effective load carrying capability ("ELCC"), based on E3's prior detailed loss of load probability modeling of the Northwest region.[12]

This modeling framework ensures that when the LSR dams are removed from the Northwest power system, a least-cost replacement mix of new investments and operational changes is found. Through the constraints of the optimization, this least-cost replacement mix meets the same clean energy policy and level of reliability as a system with the LSR dams still intact. This dynamic approach considers replacement resource needs in the context of the evolving long-term system load and policy drivers, not

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[10] Pacific Northwest Low Carbon Scenario Analysis, December 2017, https://www.ethree.com/projects/study-policies-decarbonize-electric-sector-northwest-public-generating-pool-2017-present/; Pacific Northwest Zero-Emitting Resources Study, January 2020, https://www.ethree.com/e3-examines-role-of-nuclear-power-in-a-deeply-decarbonized-pacific-northwest/

[11] The study examines LSRD breaching in 10 years (2032) and in 2 years (2024), based on with the approach used in the CRSO EIS.

[12] Resource Adequacy in the Pacific Northwest, March 2019, https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

just the near-term resource mix and needs of the system today. It recognizes that significant levels of new renewable energy and other resources are already needed to meet long-term regional needs, ensuring that the replacement resource mix selected is incremental to the long-term buildout, not just an interim solution before clean energy policies reach their apex in the 2040s.

Scenario Design

Regional Policy Landscape

To properly understand the resources needed to replace the power services of the lower Snake River dams, it is critical to consider the regional policy landscape of the Pacific Northwest. In the last few years, the states of Oregon and Washington have adopted some of the most aggressive clean energy policies in the nation. While the Pacific Northwest was already a leader in renewable energy production due to its abundant hydropower resource, these aggressive policies will require key changes to the region. First, coal power must be phased out in the Northwest during this decade and, at least in Washington, carbon will be priced via a market-based cap-and-trade mechanism[13]. Second, additional zero-carbon generation must be added to replace that coal power and to displace remaining emissions from natural gas resources whose firm capacity may still be needed by the region, but which will operate less over time as electric carbon emissions are reduced. Ultimately, to reach a zero-carbon system, those natural gas plants must retire, be converted to zero-carbon fuels (such as green hydrogen), or their emissions be offset in some other manner. Third, economy-wide carbon reduction goals will drive the transformation of the Northwest transportation, building, and industrial sectors, with the general expectation of significant electric load growth in annual energy and peak demand. Key policies in the Northwest and California are summarized in Table 3.

[13] For simplicity, this study assumes a uniform carbon price across the Core Northwest region beginning in 2023.

Table 3. Policy landscape in Washington, Oregon, and California

	RPS or Clean Energy Standard?	Coal Prohibition?	Cap-and-Trade?	New Gas?	Economy-Wide Carbon Reduction?
WA	✓ Carbon neutral by 2030, 100% carbon free electricity by 2045	✓ Eliminate by 2025	✓ Cap-and-invest program established in 2021, SCC in utility planning	✓	✓ 95% GHG emission reduction below 1990 levels and achieve net zero emissions by 2050
OR	✓ 50% RPS by 2040, 100% GHG emission reduction by 2040, relative to 2010 levels	✓ Eliminate by 2030	✓ Climate Protection Plan adopted by DEQ in 2021 (power sector not included)	× HB 2021 bans expansion or construction of power plants that burn fossil fuels	✓ 90% GHG emission reduction from fossil fuel usage relative to 2022 baseline
CA	✓ 60% RPS by 2030, 100% clean energy by 2045	✓ Coal-fired electricity generation already phased out	✓	× CPUC IRP did not allow in recent procurement order	✓ 40% GHG emission reduction below 1990 levels by 2030 and 80% by 2050

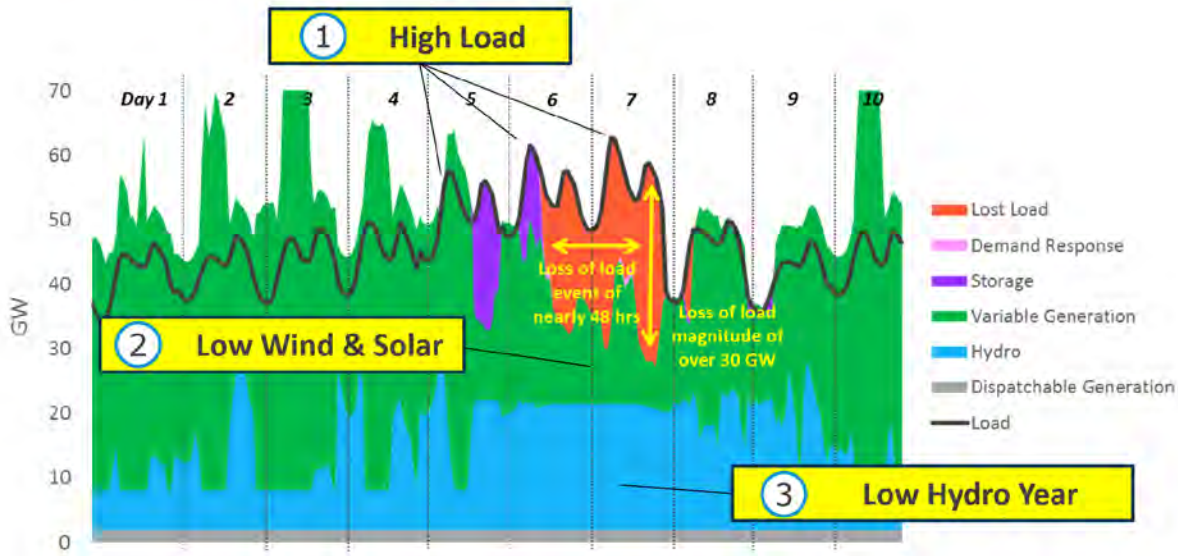
Maintaining Resource Adequacy in Low-carbon Grids

Like other regions pursuing aggressive climate policies, the Northwest faces a key decarbonization challenge: how to maintain a reliable electricity supply, while simultaneously increasing electric loads and retiring the firm, but emitting, capacity that currently supports regional reliability. In 2019, E3 used its RECAP loss of load probability model to study how decarbonizing the electricity supply impacts regional reliability.[14] This study found that clean energy resources such as solar, wind, batteries, and demand response can each provide a certain amount of reliable capacity and that combinations of them can provide even more by capturing "diversity benefits" (such as solar shifting the reliability risk into evening hours when wind output is higher). However, these resources also have limits to the amount of reliable capacity they can provide, and their contributions decline as more of them are added (the decline in capacity contributions of these resources is known as "saturation effects"). Figure 3 shows a graph from E3's 2019 study that illustrates the key drivers of reliability in a decarbonized grid: high load, low renewables, and low hydro conditions. Unlike a summer peaking *capacity constrained* system like the desert southwest, these conditions make it particularly challenging for battery storage to replace the Northwest's firm capacity resources, since batteries are unable to charge during *energy constrained* periods of low renewable energy and low hydro availability. The study concluded therefore that

[14] E3, 2019. *Resource Adequacy in the Pacific Northwest.* https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

additional firm generating capacity may be needed, even in scenarios that add significant amounts of non-firm solar, wind, batteries, and demand response. The resource adequacy modeling approach is described further in the section *Resource Adequacy Needs and Resource Contributions*.

Figure 3. Key Drivers of Pacific Northwest Reliability Events in a Decarbonized Grid



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Since the 2019 study, “emerging” technologies are increasingly seen as potentially viable options to reduce all of the carbon emissions in the Northwest. “Clean firm” resources like green hydrogen, gas with carbon capture and storage, and nuclear small modular reactors provide the firm capacity necessary to backup renewable resources and can provide the zero-carbon energy needed on low renewable days to operate a zero-carbon grid. While their costs and commercialization trajectories remain uncertain, this LSR dams replacement study considers various scenarios of their availability.

Table 4. Summary of Resource Adequacy Capacity Contributions of LSR Dam Replacement Resource Options

Replacement Resource Option	RA Capacity Contributions

Battery storage	Sharply declining ELCCs[15]
Pumped storage	Sharply declining ELCCs
Solar	Declining ELCCs
Wind	Declining ELCCs
Demand Response	Declining ELCCs
Energy Efficiency	Limited potential vs. cost
Small Hydro	Limited potential
Geothermal	Limited potential
Natural gas to H2 retrofits	Clean firm, but not fully commercialized
New dual fuel natural gas + H2 plants	Clean firm, but not fully commercialized
New H2 only plants	Clean firm, but not fully commercialized
Gas w/ 90-100% carbon capture + storage	Clean firm, but not fully commercialized
Nuclear Small Modular Reactors	Clean firm, but not fully commercialized

Scenarios Modeled

This study focuses on three key variables (clean energy policy, load growth, and emerging technology availability) that impact the cost to replace the dams.

Clean Energy Policy

Clean energy policy for the electric sector is modeled at either 100% clean retail sales or zero-carbon by 2045. A 100% clean retail sales policy requires serving 100% of electricity sold on an annual basis to be met by clean energy resources. This allows generation not used to serve retail sales (i.e., transmission and distribution losses) to be met by emitting resources. It also allows emitting generation or unspecified imports in one hour to be offset by exported generation in another hour of the year. In the baseline load scenario, reaching 100% clean retail sales by 2045 results in ~85% carbon reduction compared to 1990 levels. The zero-carbon scenario ensures that all electricity generated in the Northwest or imported from other regions emits no carbon emissions in every hour of the year.

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[15] E3 performed a sensitivity with battery ELCCs that do not decline so sharply. This sensitivity shows minor changes in the LSR dam replacement resources, but little to no change in the replacement costs.

Load Growth

With aggressive clean energy policies, load growth determines the amount of new zero-emitting resources that must be added to the Northwest power system. A baseline load growth scenario is modeled, based on the forecast in the NWPCC 8th Power Plan. A second high electrification scenario is developed based on the high electrification case in the Washington State Energy Strategy.[16] Based on E3's analysis of the electrification of transportation, buildings, and industry in that study, this scenario results in an additional annual energy demand increase of 28% by 2045 (above the baseline scenario) and an additional winter peak demand increase of 68%. The peak demand increase is high due to the electrification of space heating end uses, which requires replacing the significant quantities of energy provided by the natural gas system during extreme wintertime cold weather events with electricity.

Technology Availability

It is expected that the availability of emerging technologies may be critically important for replacing the LSR dam power services while reaching a deeply decarbonized grid. All scenarios include "mature technologies" such as solar, wind, battery storage, pumped hydro storage, demand response, energy efficiency, small hydro, and geothermal. Three scenarios of emerging technology availability are developed as follows:

A. **Baseline technologies**: mature technologies and dual fuel natural gas + hydrogen combustion plants
B. **Emerging technologies**: mature technologies, dual fuel natural gas + hydrogen combustion plants, small modular nuclear reactors, natural gas with carbon capture and storage, and floating offshore wind
C. **No new combustion (limited technologies)**: mature technologies and floating offshore wind

All scenarios assume that the existing natural gas capacity fleet can convert to green hydrogen, i.e., hydrogen produced using zero-carbon electricity. However, new firm resources are needed in all scenarios to replace retiring resources and meet growing electric loads.

Table 5 shows a summary of the four scenarios that are the focus of this study.

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[16] See Washington State's *2021 State Energy Strategy*, https://www.commerce.wa.gov/growing-the-economy/energy/2021-state-energy-strategy/

Table 5. Scenario Design

Scenario	Clean Energy Policy	Load Growth	Technology Availability
1 100% Clean Retail Sales[1]	100% retail sales (85% carbon reduction)	8th Power Plan Baseline	Baseline (incl. natural gas / hydrogen dual fuel plants)
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2c Deep Decarbonization (No New Combustion)	100% carbon reduction	High Electrification	Baseline (excluding natural gas / hydrogen dual fuel plants)

Modeling Approach

RESOLVE Model

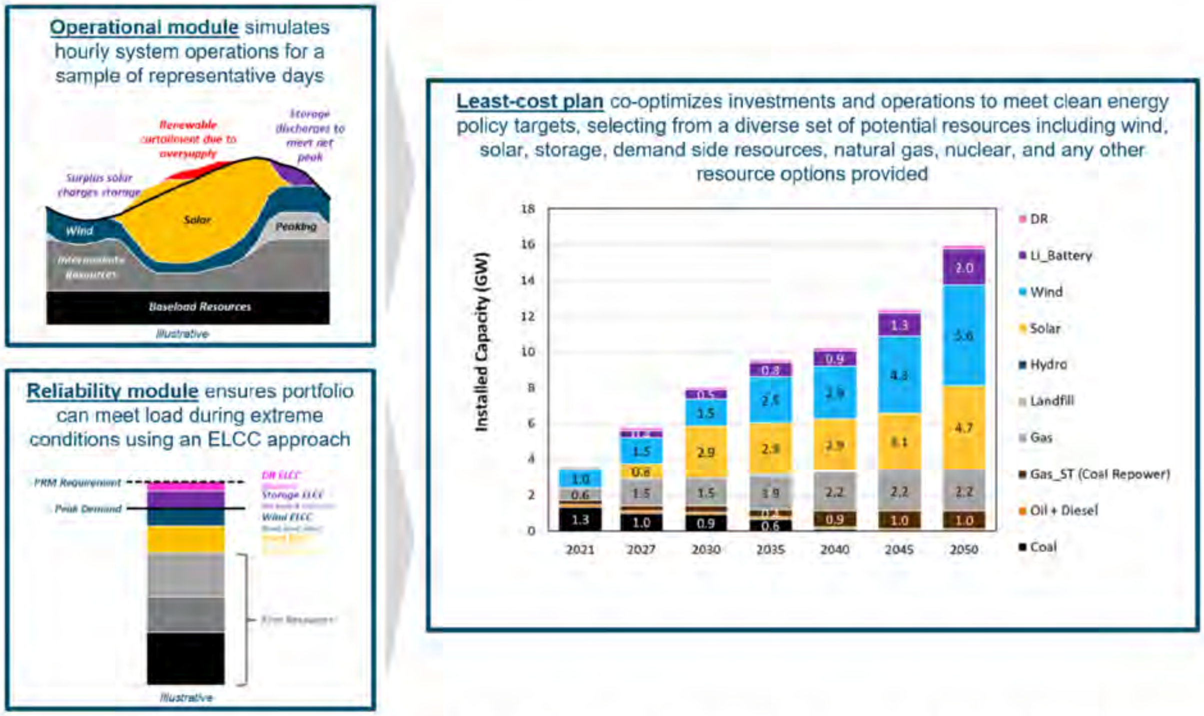
E3's Renewable Energy Solutions Model (RESOLVE) is used to perform a portfolio optimization of Northwest system's electric generating resource needs between 2025 and 2045. RESOLVE is an optimal capacity expansion and dispatch model that uses linear programming to identify optimal long-term generation and transmission investments in an electric system, subject to reliability, operational, and policy constraints. Designed specifically to address the capacity expansion questions for systems seeking to integrate large quantities of variable energy resources, RESOLVE layers capacity expansion logic on top of a production cost model to determine the least-cost investment plan, accounting for both the up-front capital costs of new resources and the variable costs to operate the grid reliably over time. In an environment in which most new investments in the electric system have fixed costs significantly larger than their variable operating costs, this type of model provides a strong foundation to identify potential investment benefits associated with alternative scenarios.

The three primary drivers of optimized resource portfolios include:

- **Reliability:** all portfolios ensure system meets resource adequacy requirements. In this case, the target reliability need is to meet 1-in-2 system peak plus additional 15% of planning reserve margin (PRM) requirement.
- **Clean Energy Standard ("CES") and/or carbon reduction targets:** all portfolios meet the clean energy standard and/or a carbon-reduction trajectory
- **Least cost**: the model's optimization develops a portfolio that minimizes costs

Figure 4 illustrates the use of RESOLVE's operational module, which tracks hourly system operations including cost and greenhouse gas emissions across a representative set of days, and RESOLVE's reliability module, that uses exogenously calculated input parameters to characterize system reliability of candidate portfolios using effective load carrying capability (ELCC) for solar and wind resources.

Figure 4. Schematic Representation of the RESOLVE Model Functionality



RESOLVE develops least-cost portfolios using key inputs and assumptions including loads, existing resources, new resource options, retirement or repowering resource options, resource costs, resource operating characteristics including resource adequacy contributions, a zonal transmission transfer topology, and new resource transmission costs.

Northwest RESOLVE Model

The Northwest RESOLVE model was developed in 2017 for E3's *Pacific Northwest Low Carbon Scenario Analysis* study.[17] It uses a zonal transmission topology to simulate flows among the various regions in the Western Interconnection. In this study, RESOLVE is designed to include six zones: the Core Northwest region and five external areas that represent the loads and resources of utilities throughout the rest of the Western Interconnection (see Figure 5). This study focuses on the Core Northwest region as the "Primary Zone"—the zone for which RESOLVE makes resource investment decisions. This zone covers Washington, Oregon, Northern Idaho and Western Montana. The remaining balancing authorities

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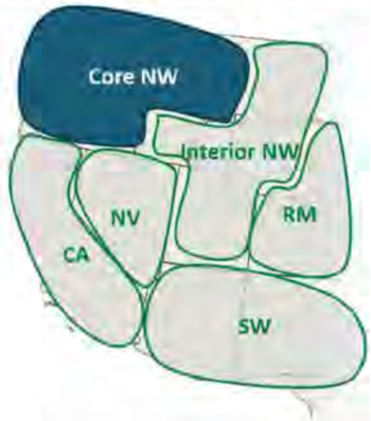
[17] Pacific Northwest Low Carbon Scenario Analysis - Achieving Least-Cost Carbon Emissions Reductions in the Electricity Sector, 2017. https://www.ethree.com/wp-content/uploads/2018/01/E3_PGP_GHGReductionStudy_2017-12-15_FINAL.pdf

outside of the Core Northwest are grouped into five additional zones: (1) Other Northwest, (2) California, (3) Southwest, (4) Nevada and (5) Rockies. For these zones, investments are not optimized; rather, the trajectory of new builds is established based on regional capacity needs to meet PRM targets, as well as renewable needs to comply with existing RPS and GHG policies in their respective regions, and held constant across all scenarios. E3's WECC-wide resource mix incorporates aggressive climate policy across the interconnection, as described in section *Baseline resources*.

Figure 5. RESOLVE Northwest zonal representation



The Northwest RESOLVE model simulates the operations of the WECC system for 41 independent days sampled from the historical meteorological record of the period 2007-2009. An optimization algorithm is used to select the 41 days and identify the weight for each day such that distributions of load, net load, wind, and solar generation match long-run distributions. Daily hydro conditions are sampled separately from dry (2001), average (2005), and wet (2011) hydro years to provide a complete distribution of potential hydro conditions. This allows RESOLVE to approximate annual operating costs and dynamics while limiting detailed operational simulations of grid operations to 41 days.

LSR Dams Modeling Approach

The LSR dams' capacity and operation are characterized with several input parameters that are presented in Section *Hydro parameters*. The approach taken in this analysis is to model LSR dams as an *in/out* resource to determine the dams' replacement costs and replacement portfolio. In other words, "in" scenarios include LSR dams in the existing resource portfolio of Core Northwest throughout the entire modeling period (i.e., 2025-2045); whereas "out" scenarios exclude LSR dams with preset

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retirement dates of 2032. An earlier retirement of LSR dams, 2024, is considered in a sensitivity case. The difference between the costs and resource portfolios for in and out cases reveals the value of LSR dams, as shown in Figure 6. Total NPV costs of resources replacing LSR dams are estimated in the year of breaching the dams.[18] NPV replacement costs are calculating using a 3% discount rate to represent the public power cost of capital.

Figure 6. Modeling Approach to Calculate the LSR Dams Replacement Resources and Costs

This modeling approach inherently considers the benefits of avoiding the LSR dams ongoing fixed and variable costs. The costs associated with breaching the LSR dams themselves are not included in this study. Other power services (i.e., transmission grid reliability services provided by the dams) are also not included but are summarized qualitatively in the Appendix.

Key Input Assumptions

Load forecast

Base load forecast is from NWPCC 2021 Plan and is adjusted to E3's boundary of Core Northwest which roughly represents 87.5% of load of the Northwest system in the NWPCC 2021 Plan. Additionally, a high electrification scenario is modeled which takes Washington's State Energy Strategy high electrification load, scaled up and benchmarked to the Core Northwest region. The baseline high electrification load trajectories are displayed in Figure 7. It is notable that in the high electrification scenario, electric energy demand grows by about 28% by 2045 across all sectors, most noticeably in the commercial building and

[18] I.e. when the dams are removed in 2032, future costs after 2032 are discounted to the year 2032 to calculate the NPV replacement costs.

transportation sectors, to meet net-zero emissions by 2050. In the commercial and residential space heating sectors, electrification indicates a switch to high electric resistance and heat pump adoption, which will significantly impact load profiles and ultimately peak load. Hourly loads are modeled in RESOLVE by scaling normalized hourly shapes with annual energy forecasts. The normalized shapes are adopted from E3's 2017 study *Pacific Northwest Low Carbon Scenario Analysis.*[19]

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[19] Pacific Northwest Low Carbon Scenario Analysis - Achieving Least-Cost Carbon Emissions Reductions in the Electricity Sector, 2017. https://www.ethree.com/wp-content/uploads/2018/01/E3_PGP_GHGReductionStudy_2017-12-15_FINAL.pdf

Figure 7. Annual energy load forecasts for Core Northwest

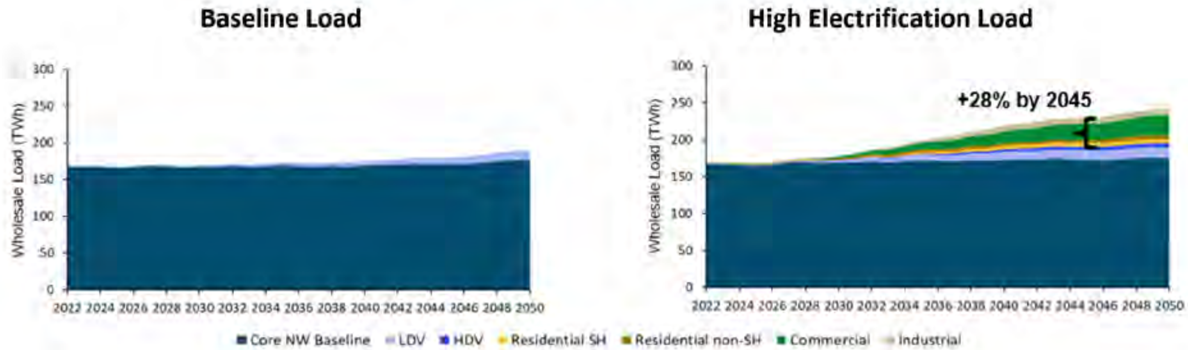
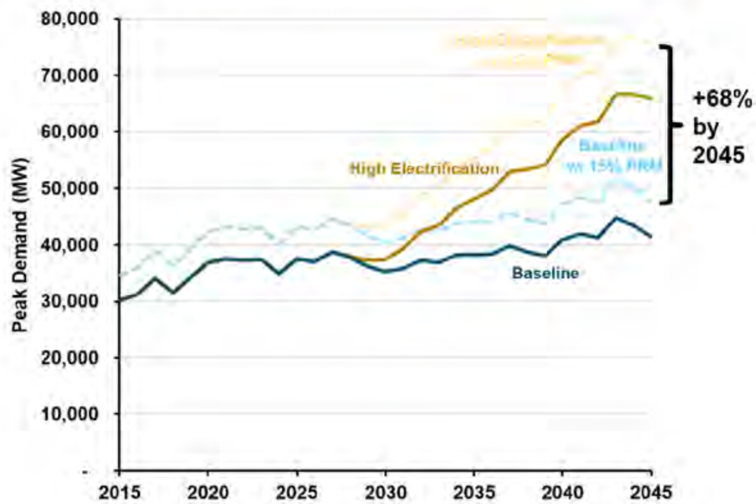


Figure 8 shows the peak demand impacts (including the 15% planning reserve margin) of the high electrification case relative to the baseline, showing a 68% increase by 2045. This high growth is driven by the winter peaking capacity required to replace the gas system peaking capacity to serve peak space heating needs.

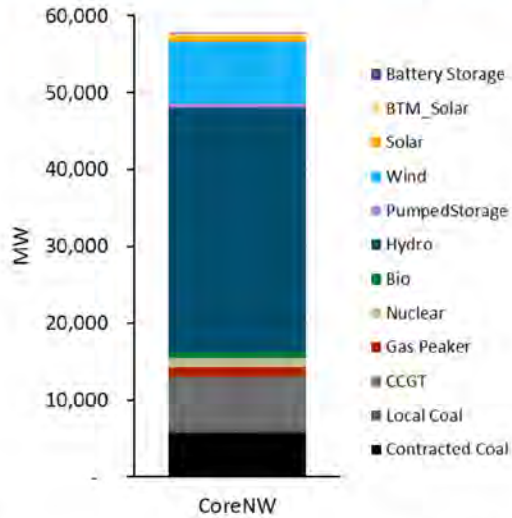
Figure 8. Peak demand forecasts for Core Northwest



Baseline resources

Baseline resources include the existing conventional resources such as natural gas and coal-fired technologies, existing nuclear capacity, hydro as well as pumped storage, battery storage, solar PV, BTM PV and onshore wind technologies. As shown in Figure 9, today's Northwest system has 58 GW capacity. The 1,185 MW nuclear capacity in the Northwest zone remains active throughout the modeling period while the 670 MW local coal capacity is retired by 2025 and the 5,700 MW contracted out of region coal capacity is retired by 2030. The WECC 2020 Anchor Data Set is used for Northwest's existing and planned resources. By 2045, about 5.8 GW additional customer PV is included as planned capacity to capture the growth in behind-the-meter generation forecasted in NWPCC 2021 Power Plan.

Figure 9. Northwest resource capacity in 2022



The investment decisions for external zones are pre-determined based on capacity expansion analysis completed by E3 that accounts for policy targets in each zone as summarized in Table 6. The new builds consist of significant increases in solar and battery capacity additions due to the more aggressive RPS targets, assumed electrification, and the decline of technology cost forecasts (see Figure 10). All future builds in these zones include mature technologies but as discussed in the next section, emerging technologies are made available for RESOLVE to optimize the future resource portfolios in the Northwest zone. There is significant solar and battery storage growth in California, the Southwest, and Nevada that generally lower the marginal value of solar energy produced across the WECC.

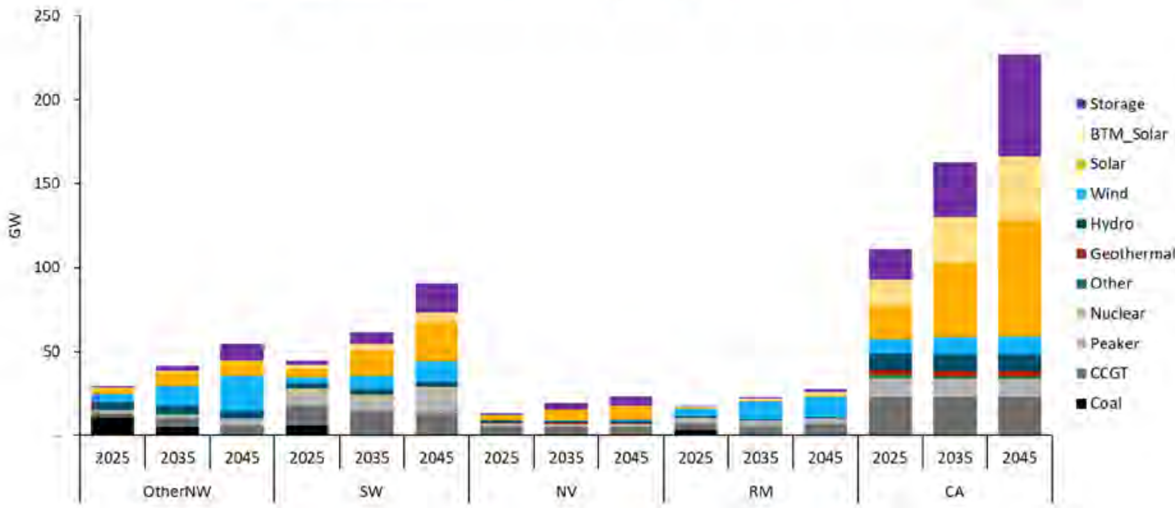
Table 6. Policy targets for builds in external zones

State	Requirement	Policy	2050 Renewable Target
AZ	40% by 2030; 60% by 2045	Transitions to CES[20]	70%
CA	60% by 2030; 100% by 2045	Transitions to CES	100%
CO	30% by 2020; 50% by 2030, 76% by 2050 (Xcel reaches 100% while other utilities stay at 50%)	Transitions to CES	75%
ID	90% by 2045 (ID Power's announced utility goals)	RPS	90%

[20] CES = "Clean Energy Standard", an annual based clean generation standard.

MT	87% by 2045 (state carbon reduction goal)	RPS	87%
NM	40% by 2025; 100% by 2045	Transitions to CES	100%
NV	50% by 2030; 100% by 2050	Transitions to CES	95%
UT	50% by 2030; 55% by 2045 (PacifiCorp's IRP)	RPS	55%
WY	50% by 2030, 55% by 2045 (PacifiCorp's IRP)	RPS	55%

Figure 10. Total installed capacity for external zones



Candidate resource options, potential, and cost

A wide range of technologies and resources are made available in RESOLVE, including mature and emerging technologies. The list of technologies made available in each modeled scenario is presented in Table 7. Some technologies such as solar and onshore wind are low-cost zero-carbon energy resources with limited resource potential and declining capacity values. Storage resources such as battery storage and pumped hydro support renewable integration but show limited capacity value given the large shares of hydro in the Northwest region. Demand response supports peak reduction but also faces declining ELCCs. Energy efficiency supports energy and peak reduction but increasingly competes against low-cost renewables. Geothermal is relatively high cost and has limited potential but provides highly valuable "clean firm" capacity.

Some emerging technologies are also made available in several scenarios to allow for firm zero-carbon technologies to be selected from. Hydrogen-capable generators such as dual fuel combustion turbines and combined cycles (i.e., capable of burning both natural gas and hydrogen) as well as retrofits of existing gas generators to burn hydrogen are modeled. These technologies provide low-cost capacity options with very high energy cost when burning expensive hydrogen fuel, therefore RESOLVE selects them for firm capacity needs but limits their hydrogen energy production. Natural gas with carbon capture and storage (CCS) technologies are moderately high cost in terms of both energy and capacity. Nuclear SMR provides moderately high capital cost but low operating cost for firm zero-carbon energy generation. This technology is made available to the model after 2035, to account for the time needed for technology development, licensing, and installation. Floating offshore wind is also modeled as an emerging technology which address onshore resource and land constraints, but is generally higher cost than onshore wind while providing a similar annual capacity factor to high quality Montana and Wyoming wind.

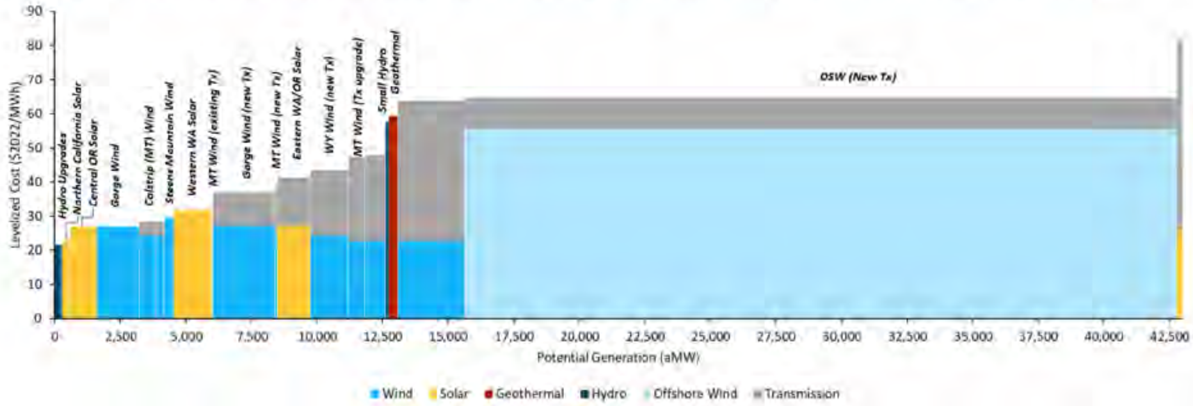
Table 7. Available technologies in each modeled scenario

Resource	A. Baseline	B. Emerging Tech	C. No New Combustion (Limited Tech)
Mature resources: solar, wind, battery storage, pumped storage, demand response, energy efficiency, small hydro, geothermal	✓	✓	✓
Natural gas to hydrogen retrofits	✓	✓	✓
Dual fuel natural gas + hydrogen plants	✓	✓	×
Natural gas with 90-100% carbon capture and storage	×	✓	×
Nuclear small modular reactors	×	✓	×
Floating offshore wind	×	✓	✓

There are physical limits to the quantity of renewable resources that can be developed in a given location; RESOLVE enforces limits on the maximum potential of each new resource that can be included in the portfolio. Moreover, some new resources will need extensive transmission upgrades which are accounted for in the renewable energy supply curve.[21] Figure 11 shows a "supply curve" for renewables in the year 2045, ordered by total generation plus transmission cost. While the quantity of solar and onshore wind energy is limited, offshore wind potential is effectively unlimited in the model although its cost remains high relative to land-based renewables through 2045. It should be noted that RESOLVE doesn't select resources based on their cost alone; it also considers the value these resources provide as part of a regional portfolio. More detail information on technology cost trajectories and data sources can be found in the Appendix.

[21] Note: certain solar resources (i.e., Western WA solar) might require transmission upgrades to bring the supply to load centers, which are not captured.

Figure 11. Renewable resource supply curve in 2045, including transmission cost adders



Clean energy policy targets

RESOLVE enforces a clean energy standard ("CES") requirement as a percentage of retail sales to ensure that the total quantity of energy procured from renewable resources meets the CES target in each year. The clean energy standard percentage is calculated as follows, and the target values are summarized in Table 2:

$$CES\ \% = \frac{Annual\ Renewable\ Energy\ or\ Zero\ Emitting\ Generation}{Annual\ CoreNW\ Retail\ Electric\ Sales}$$

Eligible renewable energy and zero-emitting resources include: solar, wind, geothermal, hydropower, nuclear, biomass, green hydrogen, and natural gas with carbon capture and storage.

Regarding GHG emissions, RESOLVE enforces a greenhouse gas constraint on the CoreNW region such that total annual emission generated in the zone must be less than or equal to the emissions cap. The greenhouse gas accounting for the Northwest zone follows the rules established by the California Air Resources Board. The CoreNW carbon emissions baseline is set as 33 MMT at the 1990 level. The total greenhouse gas emissions attributed to the Core Northwest region include:

- **In-region generation:** all greenhouse gas emissions emitted by fossil generators (coal and natural gas) within the region, based on the simulated fuel burned and fuel-specific CO_2 emissions intensity;
- **External resources owned/contracted by Core Northwest utilities:** greenhouse gas emissions emitted by resources located outside the Core Northwest but currently owned or contracted by utilities that serve load within the region, based on fuel burn and fuel-specific CO_2 emissions intensity; and
- **"Unspecified" imports to the Core Northwest:** assumed emissions associated with economic imports to the Core Northwest that are not attributed to a specific resource but represent unspecified flows of power into the region, based on a deemed emissions rate of 0.43 tons/MWh.

Table 8. Annual CES and carbon emissions targets modeled for CoreNW in RESOLVE

Resource	2025	2030	2035	2040	2045
Clean energy standard %	29%	49%	68%	88%	100%

(used in Scenarios 1 and 2[22])					
Carbon reduction emissions target (used only in Scenario 2)	22.7 MMT	17.0 MMT	11.3 MMT	5.7 MMT	0 MMT

Hydro parameters

RESOLVE characterizes the generation capability of the hydroelectric system by including three types of constraints from actual operational data: (1) daily energy budgets, which limit the amount of hydro generation in a day; (2) maximum and minimum hydro generation levels, which constrain the hourly hydro generation; and (3) multi-hour ramp rates, which limit the rate at which the output of the collective hydro system can change from one to four hours. Combined, these constraints limit the generation of the hydro fleet to reflect realistic seasonal limits on water availability, downstream flow requirements, and non-power factors that impact the operations of the hydro system.

In this analysis, hydro operating data are parameterized using conditions for three different hydrological years, i.e., 2001 for dry, 2005 for average and 2011 for wet conditions. For LSR dams, we use hourly generation data provided by BPA, which are adjusted for latest fish protection and spill constraints. For the remainder of the northwest hydro fleet, we rely on historical hydro dispatch data used to develop the TEPPC 2022 Common Case dataset. Using muti-year historical hydro operational data allows capturing the complete set of physical and institutional factors, such as cascading hydro, streamflow constraints, fish protection, navigation, irrigation, and flood control, that limit the amount of flexibility in the hydro system.

For each RESOLVE sampled day, the hydro daily energy budget is calculated as the average of daily electricity generated in the month of each sampled RESOLVE day in its corresponding matched hydro year.[23] The maximum and minimum hydro generation levels (P_{min} and P_{max}) are calculated as the absolute min and max of generation in the month of each sampled RESOLVE day in its corresponding matched year. Multi-hour ramp rates are estimated based on the 99th percentile of upward ramps observed across the three hydrological years of hourly data. In addition, for non-LSR Northwest hydro, the model allows 5% of the hydro energy in each day to be shifted to a different day within two months to capture additional flexibility for day-to-day hydro energy shift.

[22] While a clean energy standard is modeled in scenario 2, the mass-based carbon reduction target constraint is a more binding constraint, pushing the model beyond the minimum CES %'s shown here.

[23] LSR dams generate about 900 average MW of energy during an average hydro year. However, during the three years modeled in RESOLVE, the LSR dams produced only ~700 average MW generation for LSR dams. This means our estimate of the replacement cost of the dams is quite conservative relative to a longer-term expected average of ~900 MW.

Figure 12. RESOLVE Hydro inputs for LSR Dams and other Northwest hydro

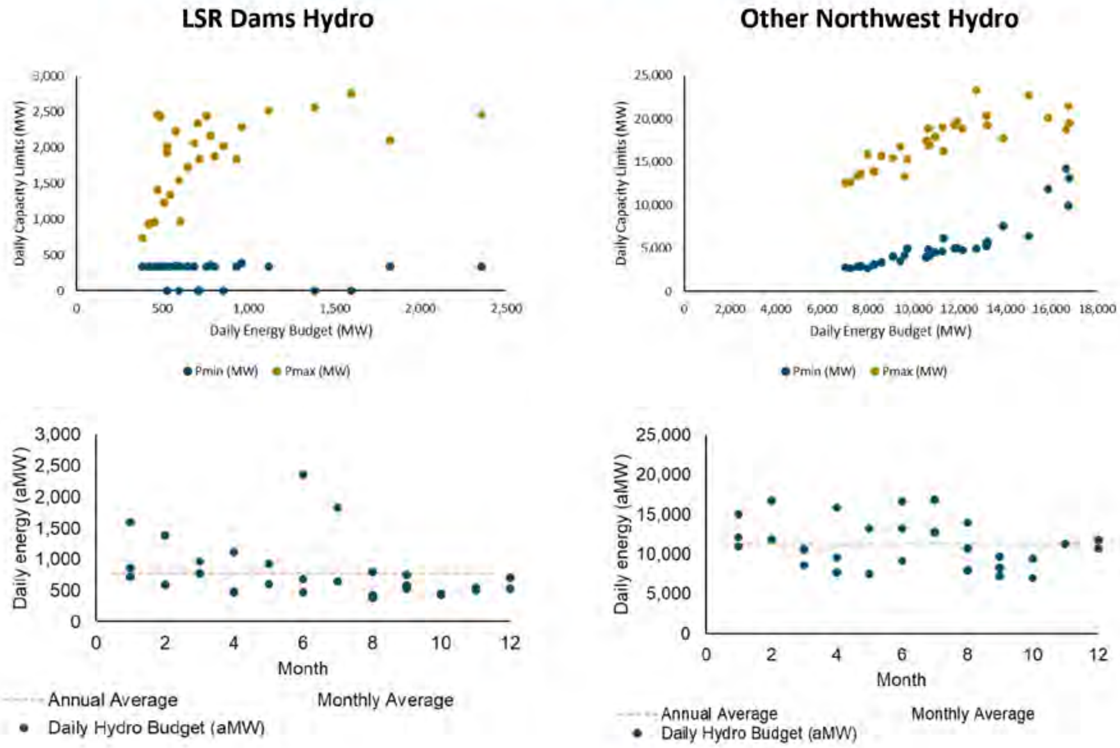


Table 9. Multi-hour ramping constraints applied to Northwest hydro

	One hour	Two hours	Three hours	Four hours
LSR Dams Hydro	36%	43%	45%	48%
Other Northwest Hydro	14%	23%	29%	32%

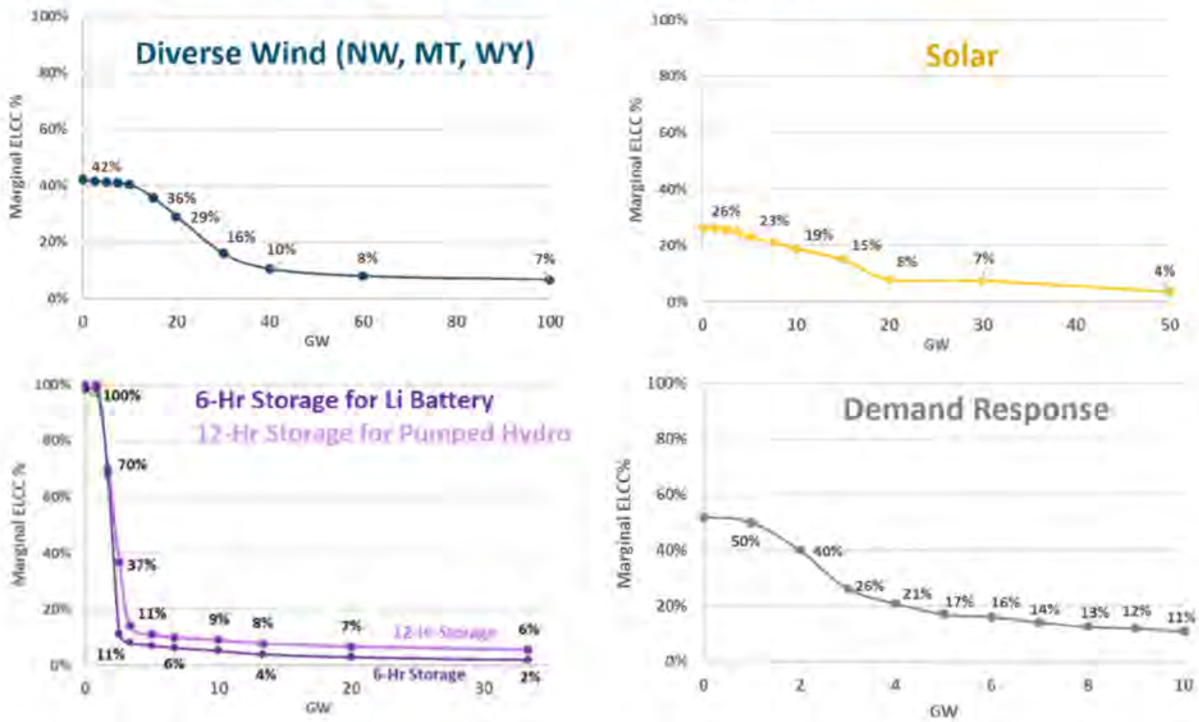
Resource Adequacy Needs and Resource Contributions

Hydro firm capacity contribution for both LSR dams and other Northwest hydro is assumed to be 65% of nameplate, per PNUCC methodology (based on 10-hr sustaining peaking capacity). This means that the LSR dams provide 2,284 MW of firm capacity that must be replaced if the dams are breached. This assumption was validated based on BPA modeled LSR dam performance data during the 2001 dry hydro year, as described in the section *Key Uncertainties for the Value of the Lower Snake River Dams*, which also describes estimates of the NPV impact of assuming a lower firm capacity value for the dams.

Resource adequacy needs are captured in RESOLVE by ensuring that all resource portfolios have enough capacity to meet the peak Core Northwest median peak demand plus a 15% planning reserve margin. Firm capacity resources are counted at their installed capacity. Hydro resources are counted at the 65% regional value used in PNUCC's 2021 resource adequacy analysis. Solar, wind, battery storage, pumped hydro storage, and demand response are counted at their effective load carrying capability ("ELCC") based on E3's RECAP modeling from its 2019 *Resource Adequacy in the Pacific Northwest* study.[24] Figure 13 shows the initial capacity values for these resources, as well as the declining marginal contributions as more of the resource is added. RESOLVE uses these data points to develop tranches of energy storage and demand response resources with declining marginal ELCCs for each tranche. Solar and wind ELCCs are input into RESOLVE using a 2-dimensional ELCC surface that captures the interactive benefits of adding various combinations of solar and wind together. Resources on the surface (such as different wind zones) are scaled in their ELCC based on their capacity factor relative to the base capacity factor assumed in the surface, and the entire surface is scaled as peak demand grows.

[24] Resource Adequacy in the Pacific Northwest, 2019. https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

Figure 13. Solar, Wind, Storage, and Demand Response Capacity Values



The capacity value for energy storage resources shown in Figure 13 are very different from those in other regions, such as California or the Desert Southwest, declining much more quickly as a function of penetration. There are two reasons for this. First, the Pacific Northwest is a winter peaking region in which loss-of-load events are primarily expected to occur during extreme cold weather events that occur under drought conditions in which the region faces an energy shortfall. These events, such as the one illustrated in Figure 3 above, result in multi-day periods in which there is insufficient energy available to charge storage resources, severely limiting their usefulness. This is unlike the Southwest, where the most stressful system conditions occur on hot summer days in which solar power is expected to be abundant and batteries can recharge on a diurnal cycle. Second, the Pacific Northwest already has a very substantial amount of reservoir storage which can shift energy production on a daily or even weekly basis. Thus, the Pacific Northwest is already much closer to the saturation point where additional diurnal energy shifting has limited value.

Nevertheless, recognizing that the capacity value of energy storage is still being researched, in the Northwest and elsewhere, we include a sensitivity case in which energy storage resources are assumed to have much higher ELCC values, similar to what is expected in the Southwest at comparable penetrations. This test case was used to assess whether a higher energy storage ELCC would change the replacement resources and replacement cost of the LSR dams. The results are presented in the section *Replacement Resources Firm Capacity Counting*.

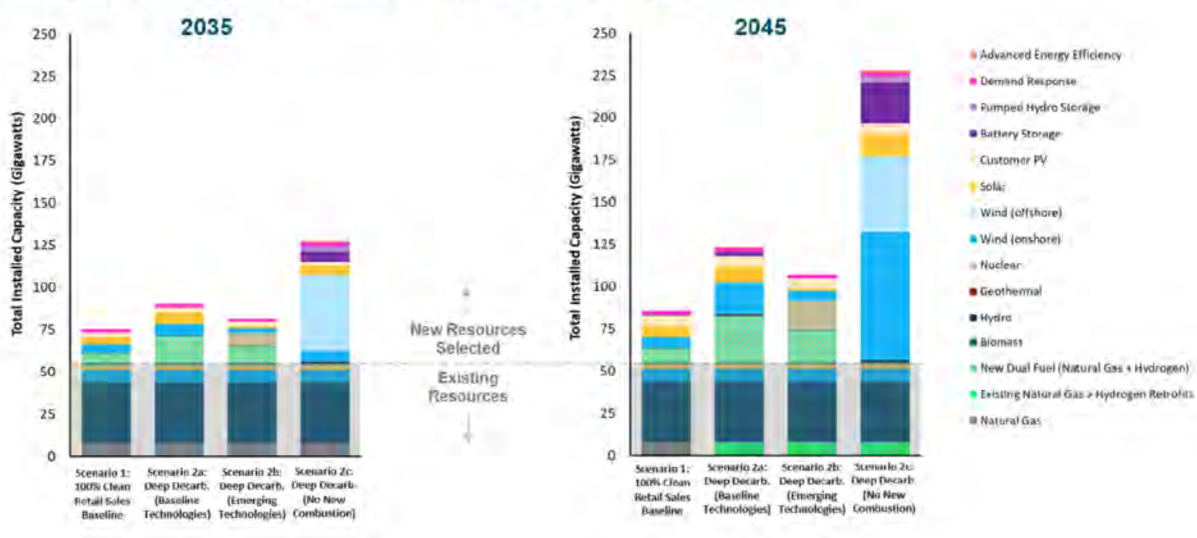
Results

RESOLVE model runs for the 2025-2045 period produce optimal resource portfolios of additions and retirements by resource type, as well as metrics of annual and hourly resource generation, carbon emissions, and total system costs. This section presents the RESOLVE modeling results, focused on the years of 2035 and 2045 to highlight the mid-term and long-term resource needs. Following that, the result of the RESOLVE runs with the LSR dams breached are presented, with the replacement resource and costs to replace the dams' power services.

Electricity Generation Portfolios With the Lower Snake River Dams Intact

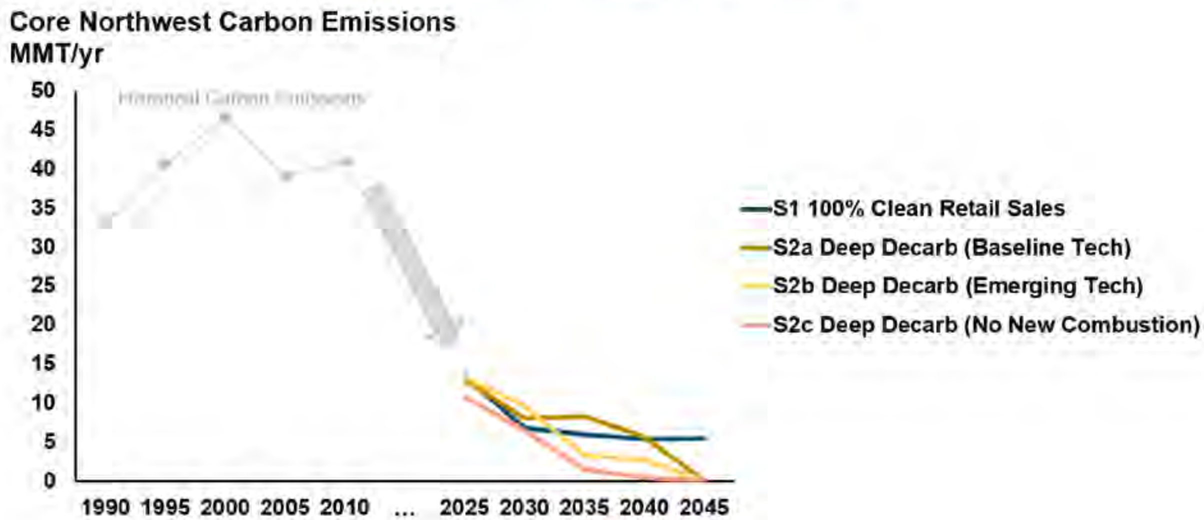
In the scenarios that do not assume breaching of the LSR dams, large amounts of utility-scale solar PV, onshore wind, offshore wind, hydrogen-capable combined cycle, and some amounts of energy efficiency and demand response are selected to meet the growing electricity demand, PRM, and emissions reductions. Electrification load growth along with zero emissions targets drive higher needs in deep decarbonization scenarios (i.e., S2a, S2b and S2c) compared to the reference scenario (S1) in both snapshot years of 2035 and 2045. In S2b, clean firm technologies such as SMR nuclear are selected in place of additional onshore wind, solar and dual-fuel CCGT selected in S2a. In the absence of clean firm technologies (no new combustion) in S2c, massive amounts of offshore wind (~45 GW) as well as more battery storage, pumped storage, demand response, and energy efficiency are selected as early as 2035 such that in this scenario, the new resource additions are almost five time the new builds in S1. These capacity additions increase even more substantially by 2045.

Figure 14. Large levels of new resource additions to meet the growing load, PRM needs and emissions reductions (assumes LSR Dams are NOT breached)



As shown in Figure 15 below, all four scenarios result in a sharp near-term decline in carbon emissions, driven by Washington and Oregon policies that drive coal retirement this decade. By 2045, Scenario 1, which requires 100% clean retail sales, shows an ~85% decline in carbon emissions relative to 1990 levels. Scenario 2 eliminates all carbon emissions by 2045.

Figure 15. Northwest Carbon Emissions

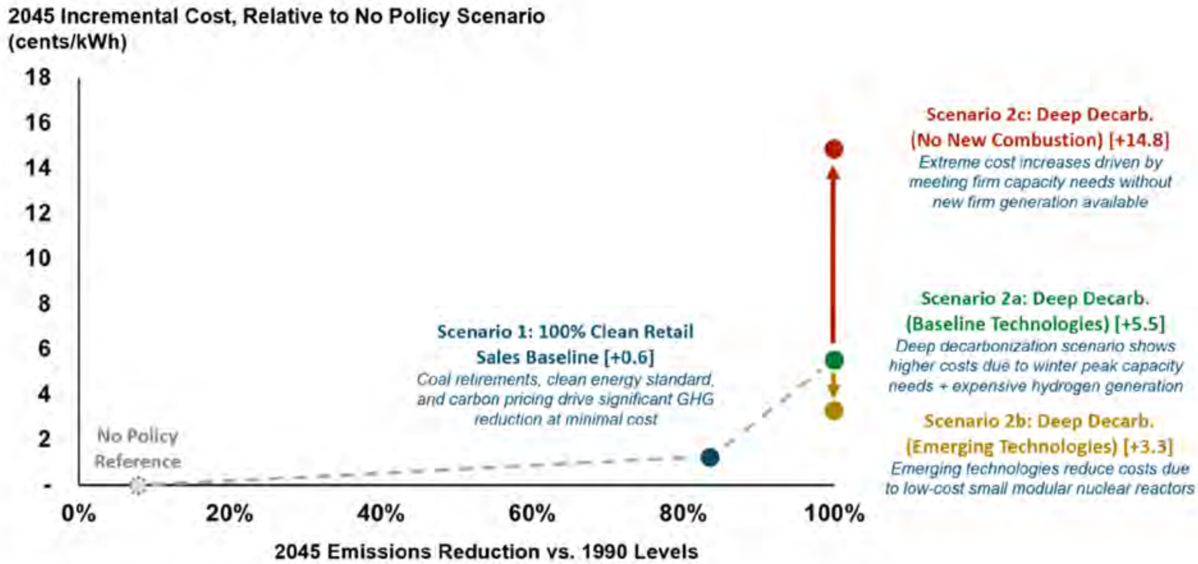


To put cost impacts in context, a "No Policy Reference" case uses the baseline load forecast and removes all electric clean energy policies, retaining the region's coal power with little emissions decline. The four clean energy futures modeled are compared against this Reference Case on A) their cost impacts, measured in incremental cents/kWh relative to the Reference, and B) their carbon emissions reductions, relative to 1990 levels. By 2045, as shown in Figure 16, with the region's aggressive carbon policies in place, emissions can be reduced by over 80% with a relatively small cost impact (+0.6 cents/kWh relative to the region's current average retail rate of 8-9 cents/kWh). Reaching a zero-carbon grid with increasing electric loads requires significantly more investment, increasing carbon reductions to 100% of 1990 levels, but also increasing costs by 3.3-14.8 cents/kWh. This range is highly dependent upon the availability of emerging technologies and their assumed costs. The low end assumes that low-cost small modular nuclear reactors become commercialized by 2035. The high end assumes no new combustion resources (such as green hydrogen)[25] or other emerging technologies are available[26],

[25] The authors recognize that hydrogen can be used to generate electricity by fuel cells instead of combustion turbines. That scenario would look similar to Scenario 2a, where the combustion plant additions are replaced with many GW of fuel cells for firm capacity needs.

showing that relying only on non-firm resource additions (renewable energy, demand side resources, and short- to medium-duration storage) leads to much higher costs.

Figure 16. Cost Impacts Compared to Emissions Reduction Impacts



NOTES:
- 2020 average retail rates for OR and WA were 8-9 cents/kWh; 1990 electric emissions were ~33 MMT
- High electrification scenarios would avoid natural gas infrastructure costs, which would offset some of the electric peaking infrastructure cost increase

LSR Dams Replacement

The resource replacement portfolios and costs of replacing the LSR dams are reported in this section, which is also focused on the midterm (2035) and long term (2045).

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[26] Floating offshore wind was allowed in the no new combustion case since it was required to allow a feasible solution without making any other firm capacity additions available in the model.

Capacity and energy replacement

In the midterm, given the expectations of load growth and coal capacity retirements resource adequacy needs are a primary driver of LSR dam replacement needs, with around 2 GW of additional firm dual fuel natural gas and hydrogen combustion plants selected to replace the LSR dams' capacity in Scenarios 1, 2a, and 2b (see Table 10). (Note that, these turbines may initially burn natural gas when needed during reliability challenged periods but would transition to hydrogen by 2045 to reach zero-emissions.) If advanced nuclear is available as assumed in Scenario 2b, it replaces renewables and some of the combustion resource builds. In addition to firm resources, some of the LSR capacity is replaced by renewables in Scenarios 1 and 2a, mostly by wind resources and some battery storage. In Scenario 2c, with no combustion or advanced nuclear available, a very large buildout of renewable capacity (in the order of 12 GW) is required to replace the capacity of LSR dams, due to resource availability and the fast decline in solar and wind ELCCs as early as 2035. Small amount of geothermal capacity is also part of the portfolio in 2035.

In the long term, the dam's carbon-free energy is replaced by a combination of wind power and another "clean firm" resource when available. Scenario 2a shows additional hydrogen generation, as well as small levels of energy efficiency and battery storage. In Scenario 2b, the LSR dams are entirely replaced by clean firm capacity of hydrogen combustion plants and nuclear SMRs, whereas in Scenario 2c, a large capacity of wind and solar is relied upon to replace both the carbon-free energy and firm capacity of the LSR dams. Overall, the magnitude of replacement portfolio capacities is close in both snapshot years (2035 and 2045) meaning that immediate capacity additions are necessary to replace LSR dams given the retirement year of 2032 while the capacity needs sustain throughout the modeling period. The early removal of LSR dams (i.e., by 2024) moves up the timing of the replacement portfolio to 2025 instead of 2035 in S1b, but the replacement portfolio remains similar.

Table 10. Optimal portfolios to replace the LSR dams

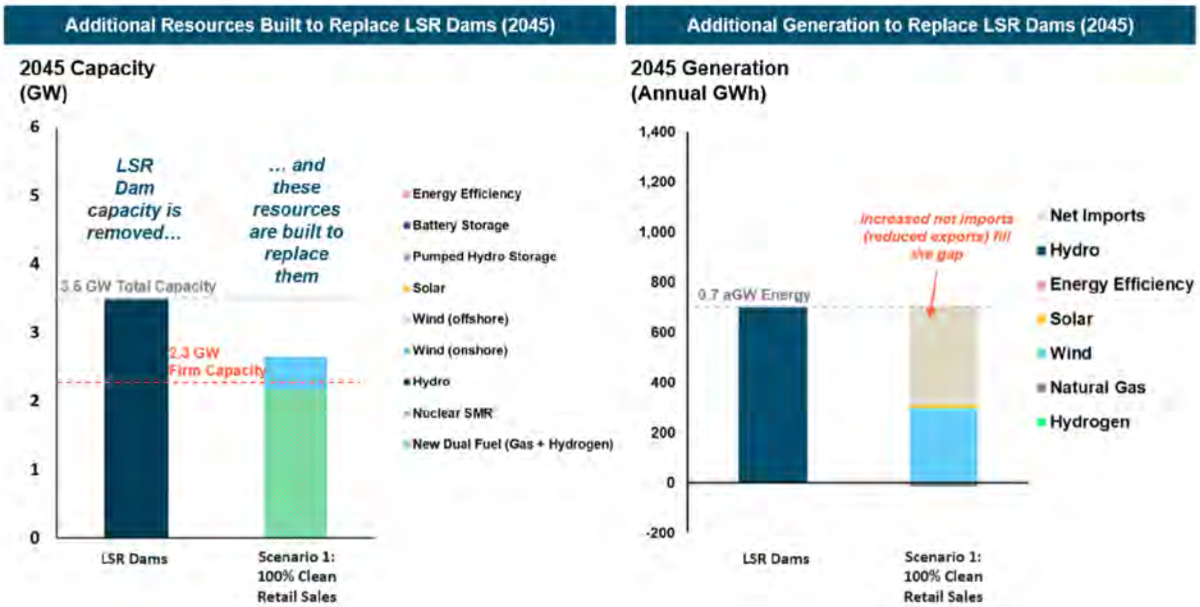
Scenario	Replacement Resources Selected, Cumulative by 2035[27] (GW)	Replacement Resources Selected, Cumulative by 2045 (GW)
Scenario 1: 100% Clean Retail Sales	+ 1.8 GW dual fuel NG/H2 CCGT - 0.5 GW solar + 1.3 GW wind	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind

[27] Replacement resources are calculated by comparing the "with LSR dams" RESOLVE portfolio to the "without LSR dams" RESOLVE portfolio. This means some resources may be built in 2035, such as 0.3 GW of geothermal in scenario 2c, that are not built when the dams are included. However, those resources may have already been selected in the "with LSR dams" case by 2045, hence do not show up as additional resource replacement needs in 2045. This explains the different resource changes between 2035 and 2045.

	+ 0.1 GW li-ion battery	
S1b: 100% Clean Retail Sales (2024 dam removal)	+ 1.8 GW dual fuel NG/H2 CCGT - 0.5 GW solar + 1.4 GW wind + 0.1 GW li-ion battery	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
Scenario 2a: Deep Decarbonization (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.6 GW wind + 0.1 GW li-ion battery	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW advanced EE + 1.2 TWh H2-fueled generation
Scenario 2b: Deep Decarbonization (Emerging Technologies)	+ 1.7 GW dual fuel NG/H2 CCGT + 0.6 GW nuclear SMR	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR
Scenario 2c: Deep Decarbonization (No New Combustion)	+ 9.1 GW offshore wind + 0.1 GW wind + 1.0 GW solar + 0.3 GW geothermal + 1.5 GW li-ion battery	+ 10.6 GW wind + 1.4 GW solar

Figure 17 through Figure 20 show details of the capacity replacement, energy replacement, and cost breakdown for Scenarios 1 and 2a. LSR dams energy in these scenarios is replaced with wind, net imports (i.e. reduced exports of hydropower outside the Core NW), and – in Scenario 2a – additional hydrogen generation, which is necessary in 2045 to meet the zero-carbon goal without the flexible LSR dam winter generation. The cost charts show that the dual fuel gas plants make up approximately half of the 2045 annual costs in Scenario 1 and approximately a quarter of the 2045 annual costs in Scenario 2a, which includes additional costs for energy efficiency and hydrogen generation.

Figure 17. Scenario 1: Capacity Replacement, Energy Replacement, and Costs[28]



[28] Regarding the "net imports" component of the energy replacement, this refers to either increased imports, decreased exports (generally of carbon-free energy), or a combination of both, such that RESOLVE does not need to build enough new generation to fully replace the LSR dams output. For instance, the region could export less hydropower to California and other neighbors to replace the LSR dams output without necessarily increasing Northwest carbon emissions in Scenario 1.

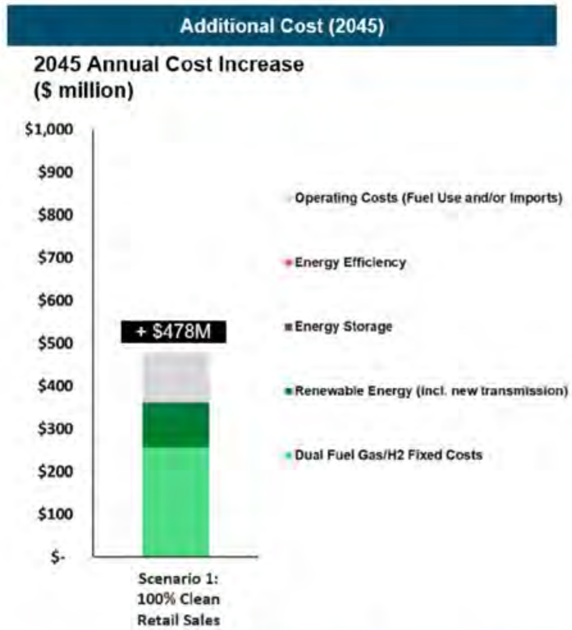
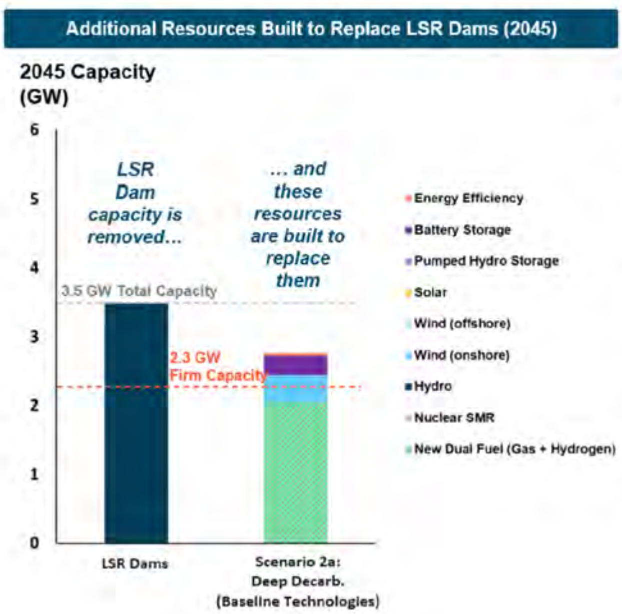
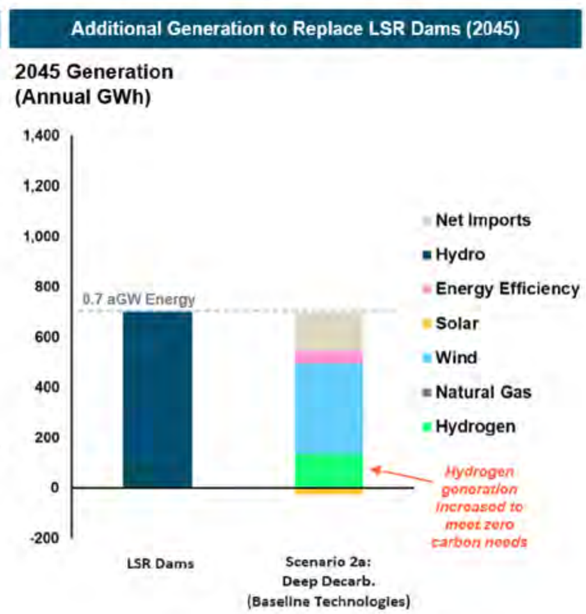


Figure 18. Scenario 2a Capacity Replacement, Energy Replacement, and Costs





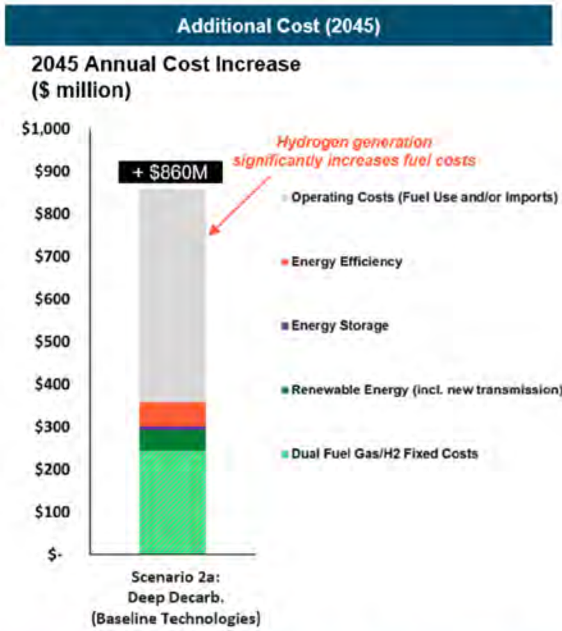
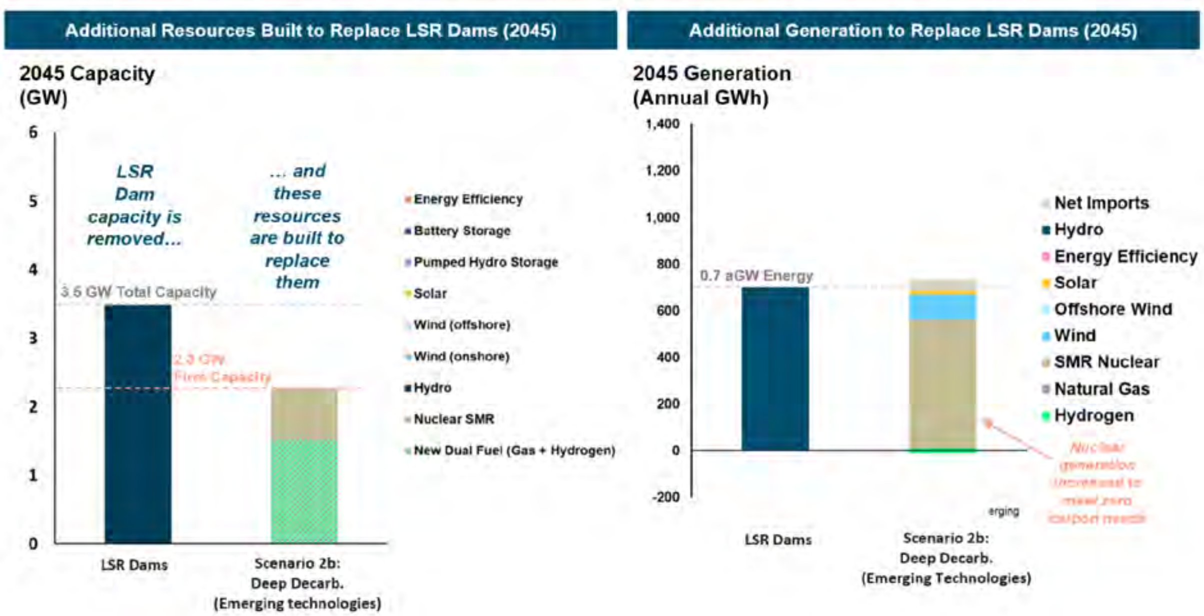


Figure 19. Scenario 2b Capacity Replacement, Energy Replacement, and Costs



Additional Cost (2045)

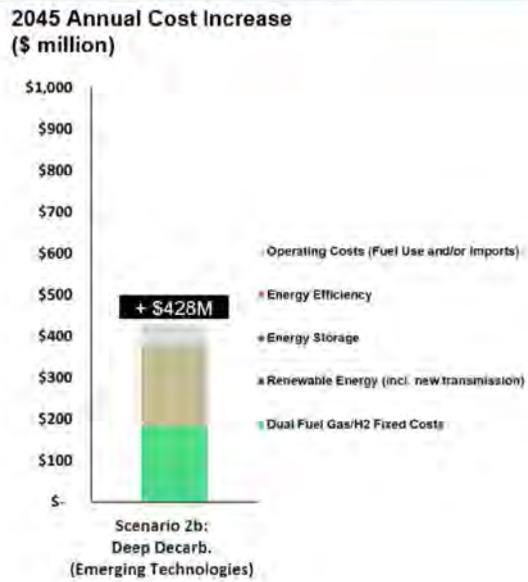
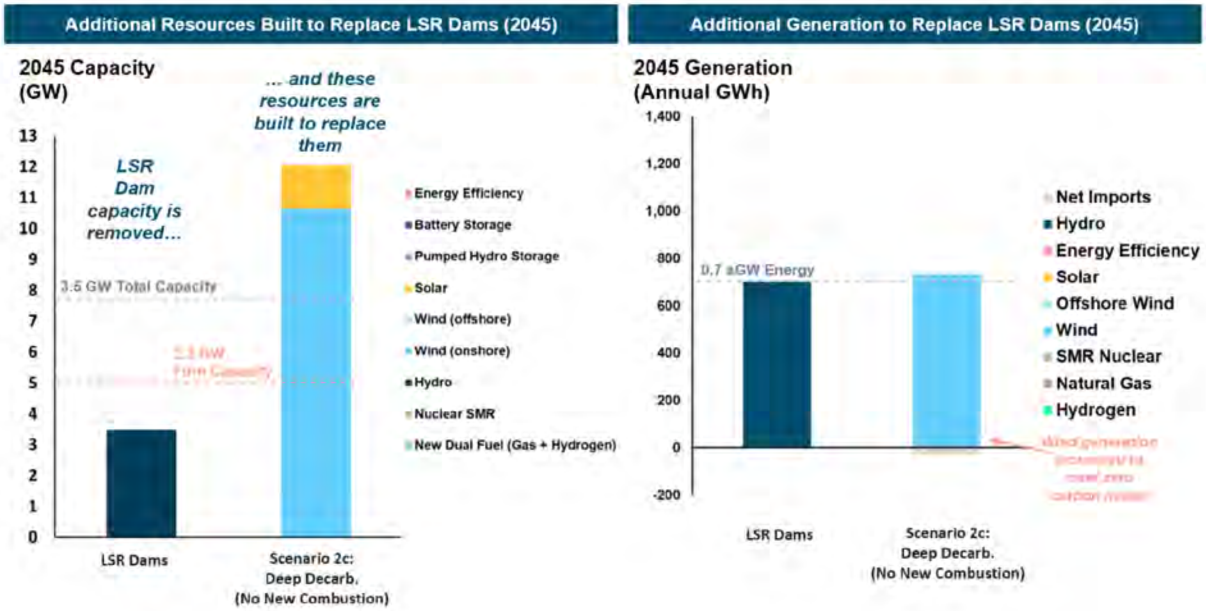


Figure 20. Scenario 2c Capacity Replacement, Energy Replacement, and Costs[29]



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[29] NOTE: the energy replacement does not show the total potential energy output of the wind built to replace the dams, because much of the potential energy output is curtailed due to oversupply of wind built for resource adequacy needs.

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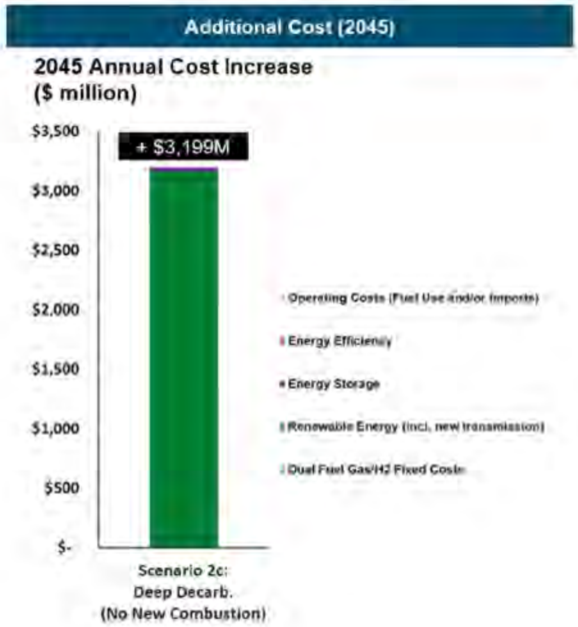

Replacement costs

The LSR dams provide a relatively low-cost source of GHG-free energy and firm capacity. Incremental costs for replacement resources are summarized in this section. All costs are shown in real 2022 dollars. Incremental costs to replace the power services of the LSR dams ranges from $69-139/MWh across most scenarios. Scenario 2c, however, shows a much higher replacement power cost of $517/MWh. These incremental costs are much higher than costs of maintaining the LSR dams (i.e., $13-17 per MWh[30]); they are calculated by taking the incremental fixed and variable investment costs for the no LSR RESOLVE runs and dividing them by the LSR annual generation being replaced. See the details in Table 11.

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[30] BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) facilities. The cost of generation at the lower Snake River dams is in the range of $13/MWh without LSRCP and $17/MWh with LSRCP. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat.2917) to offset fish and wildlife losses caused by construction and operation of the four lower Snake River projects.

Table 11. Incremental costs to replace LSR generation in 2045

Scenario	Incremental net costs in 2045[31], including avoided LSR dam costs (Real 2022 $/MWh)	Incremental gross costs in 2045[32], excluding $17/MWh avoided LSR dam costs (Real 2022 $/MWh)
Scenario 1: 100% Clean Retail Sales	$77/MWh	$94/MWh
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$82/MWh	$99/MWh
Scenario 2a: Deep Decarb. (Baseline Technologies)	$139/MWh	$156/MWh
Scenario 2b: Deep Decarb. (Emerging Technologies)	$69/MWh	$86/MWh
Scenario 2c: Deep Decarb. (No New Combustion)	$517/MWh	$534/MWh

The LSR dams' total replacement costs (in net present value) and annual replacement costs for 2025, 2035, and 2045 are shown in Table 12. NPV replacement costs are calculated based on discounting at a 3% discount rate, representative of the approximate public power cost of capital, over a 50-year time horizon following the date of breaching. Scenario 1 (100% clean retail sales) replacement costs are approximately $11.8 billion in net present value (NPV) in the year of breaching (in 2032); costs increase to $12.8 billion NPV if breached in 2024. Total replacement costs are similar in the economy-wide deep decarbonization scenario when emerging technology is available (scenario 2b), showing $10.7 billion NPV. Replacement costs are significantly higher in scenario 2c where no new combustion resources are allowed ($75.2 billion NPV). The economy-wide deep decarbonization (baseline technology scenario), 2a, shows more costly replacement ($19.0 billion NPV) than when nuclear SMRs are available, but lower costs than scenario 2c, due to the availability of hydrogen-enabled gas plants.

Annual costs increase by $415-860 million after LSR dams' removal in scenarios 1, 2a, and S2b. In Scenario 2c, the cost increase is in the order of $1.9-3.2 billion per year. Replacement costs generally increase over time due to increasingly stringent clean energy standards and electrification-driven load growth. The 2045 cost increases translate to 8-18% growth in BPA's public power customers costs in scenarios 1, 2a and 2b (assuming current retail rates are about 8.5 ₵/kWh based on OR and WA average

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[31] The generation replacement costs are calculated using the incremental RESOLVE's Core Northwest revenue requirement increase with LSR dams breached divided by the annual MWh of the LSR dams assuming 706 average MW generation.

[32] The generation replacement costs are calculated using the incremental RESOLVE's Core Northwest revenue requirement increase with LSR dams breached divided by the annual MWh of the LSR dams assuming 706 average MW generation.

retail rates). In these scenarios, public power households would see an increase in annual electricity costs of $100-230/yr in 2045. In Scenario 2c, rate impacts could be as high as 65%, which is equivalent to annual residential electricity bills raising by up to $850 per year.[33]

Note that these incremental cost increases include the ongoing LSR dams costs, such as operations and maintenance costs, avoided by breaching the dams, but do not include the costs of breaching. The rate impacts shown are only for the LSR dams' replacement, they do not include the additional rate increases driven by higher loads or clean energy needs (that are covered in the section *Electricity Generation Portfolios With the Lower Snake River Dams Intact* above), which apply even without removing generation from the LSR dams.

Table 12. Total LSR Dams replacement costs

	NPV Total Costs (Real 2022 $)[34]	Annual Costs Increase (Real 2022 $)			Incremental Public Power Costs[35]
	In the year of breaching (2032 or 2024)	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$11.8 billion	n/a	$434 million	$478 million	0.8 ₵/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$12.8 billion	$495 million	$466 million	$509 million	0.8 ₵/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$19.0 billion	n/a	$496 million	$860 million	1.5 ₵/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$10.7 billion	n/a	$415 million	$428 million	0.7 ₵/kWh [+8%]
Scenario 2c: Deep Decarb. (No New Combustion)	$75.2 billion	n/a	$1,953 million	$3,199 million	5.5 ₵/kWh [+65%]

[33] Annual residential customer cost impact assumes 1,000 kWh per month for average residential customers in Oregon and Washington in scenario 1 and 1,280 kWh per month for scenario 2, per the 28% retail sales increase due to electrification load growth.

[34] NPV replacement costs are based on discounting at a 3% discount rate, representative of the approximate public power cost of capital, over a 50-year time horizon following the date of breaching.

[35] Incremental public power costs are calculated assuming that all the replacement costs are paid by BPA Tier I customer, using the assumed 2022 Tier I annual sales of 58,686 GWh.

Carbon emissions impacts

LSR dams provide emissions-free generation for Northwest and depending on what these dams are replaced with, may impact the emissions associate with the electricity systems. The removal of LSR dams may potentially cause an increase in emissions over the near- or mid-term horizon. In Scenario 1, the 2024 LSR dam breaching scenario results in substantial increases to carbon emissions through 2030, in the range of 1-2.8 MMT/yr or 15-25% of the annual Northwest emissions. This scenario does not have a binding GHG constraint, and the region meets its clean energy goals in the near term without the dams. RESOLVE therefore does not replace all the LSR dam energy with clean resources.

Under 2032 breaching scenarios, small carbon emissions increases are observed in the mid-term (0.7 MMT/yr. or 8-10% of the region's carbon emissions in 2035). The economy-wide deep decarbonization cases all reach zero carbon emissions by 2045, so breaching the dams does not increase emissions in that year; RESOLVE instead builds the resources needed to replace all of the GHG-free energy.

Additional considerations

Depending on how the future of the electric grid evolves, there might be significant land-use associated with renewables expansion, more so if LSR dams are removed in conditions similar to Scenario 2c where significant capacity additions from solar and wind resources would be necessary.

In terms of costs, while this study considered the replacement costs of LSR dams from the electricity system perspective, there are other types of services that LSR dams provide that would need additional cost assessment. LSR dams are used for irrigation, recreation, navigation, and transportation. Breaching LSD dams could impact these services and therefore, should be considered alongside the electricity services replacement costs. Moreover, breaching the dams itself would be an additional cost. These factors are addressed in more detail in the report prepared by Senator Murray and Governor Inslee.[36]

Key Uncertainties for the Value of the Lower Snake River Dams

This study explicitly captures the following key drivers of the LSR dams power service replacement needs:

+ Replacing the **GHG-free energy**, **firm capacity**, **operating reserves**, and **operational flexibility** of the dams

[36] Lower Snake River Dams: Benefit Replacement Draft Report by U.S. Sen. Patty Murray, and Washington Gov. Jay Inslee, 2022. Lower Snake River Dams: Benefit Replacement Draft Report (senate.gov)

Uncertainty of the LSR dam value is considered under scenarios of:

+ **Clean energy policy**: replacement of carbon-free power becomes increasingly critical to reach a zero-emissions electricity grid
+ **Load growth**: replacement energy and capacity needs may change with increased electrification and peak higher winter space heating needs
+ **Technology availability**: replacement is more expensive with fewer emerging technology resource options
+ **Timing**: replacement was focused on breaching in 2032, but a 2024 sensitivity was also considered

Additional uncertainties regarding the value of the dams are:

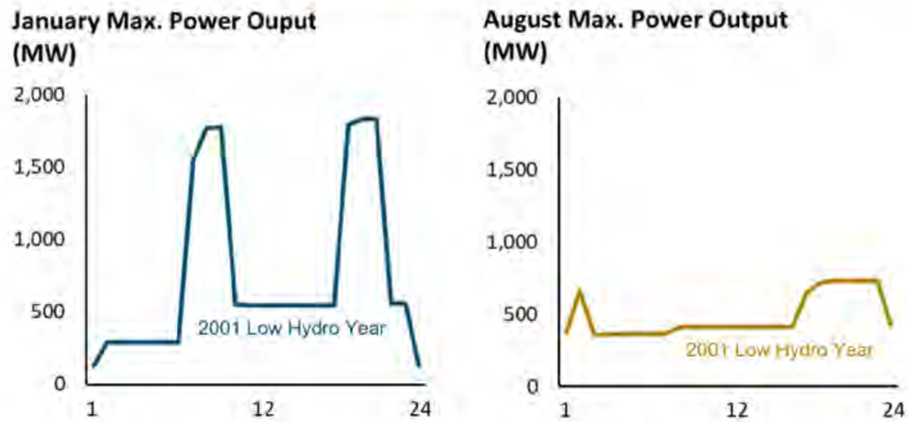
+ **LSR dams annual energy output**: E3's existing RESOLVE model data uses historical hydro years 2001, 2005, and 2011 as representative of the regional long-term average low/mid/high hydro year conditions. The data for the Columbia River System dams was adjusted to reflect the Preferred Alternative operations defined in the CRSO EIS. However, for the LSR dams, these selected historical hydro years resulted in a relatively low output of ~700 average MW, whereas the dams may generate ~900 average MW on average across the full historical range of hydro conditions. Therefore, E3's analysis likely underestimates the energy value of the dams and costs for replacing that extra GHG-free energy.
+ **LSR dams firm capacity counting**: as resource adequacy is found to be a key driver of future resource needs, the firm capacity contributions of the LSR dams is a key driver of their value. See below for further discussion of this uncertainty.
+ **Replacement resource capacity contributions**: if Northwest reliability challenges dramatically shift into the summer, this would also impact the capacity value of replacement resources. Directionally, this would likely increase the capacity value of energy storage, and change the relative value of solar and wind. It is expected that additional battery storage would be part of the regional capacity additions in lieu of dual fuel natural gas + hydrogen plants. See below for further discussion of this uncertainty.
+ **Replacement of transmission grid services:** this study does not focus on the transmission grid reliability services provided by the LSR dams. These services likely can be replaced by a combination of the new resources selected by RESOLVE and additional local transmission system investments. A qualitative summary of the transmission grid reliability services of the dams is summarized in the appendix of this report.

LSR Dams Firm Capacity Counting

Since resource adequacy is found to be a key driver of future resource needs, the firm capacity contribution of the LSR dams is a key driver of their value. E3 uses a regional hydro capacity value estimate for the LSR dams in this study, based on the PNUCC regional hydro capacity value assumption. More detailed follow-on ELCC studies could be done to confirm the LSR dams' capacity value, though proper and coordinated dispatch of the Northwest hydro fleet would be necessary to develop an accurate and fair value of the LSR dams within the context of the overall hydro fleet.

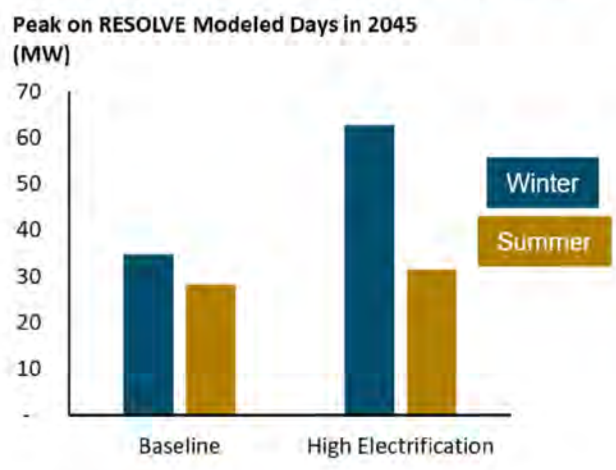
This study validated the assumed 2.28 GW of firm capacity from the LSR dams by considering BPA modeled LSR dams dispatch under 2001 dry hydro year conditions using the CRSO EIS spill constraint adjusted hourly modeling provided by BPA. Maximum January output (plus 100-250 MW of operating reserves) was 1.9-2.1 GW (~56-60% of total capacity), slightly less but close to the 65% regional hydro value the study assumes.

Figure 21. BPA-Modeled LSR Dam Output During the 2001 Low Hydro Year with CRSO EIS Preferred Alternative operations



The other capacity value uncertainty is whether the Northwest will remain winter reliability challenged or whether reliability events will shift to the summer due to climate impacts on load patterns and hydro output. If reliability challenges did shift to the summer, the LSR dam firm capacity contribution would be significantly lower than assumed. However, E3 believes it is reasonable to assume under high electrification scenarios that the region will remain winter challenged due to peak space heating needs, as shown in figure below.

Figure 22. Winter vs. Summer Peak Loads

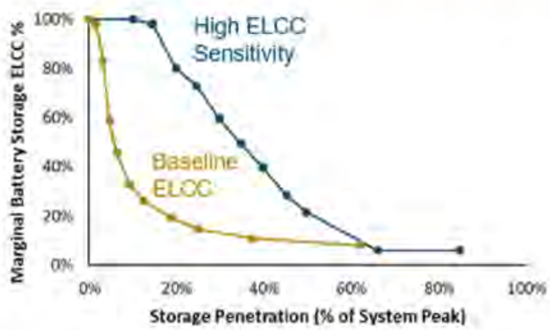


To address the capacity value uncertainty, a post-processing analysis was performed based on the replacement resources selected for firm capacity replacement. Based on this analysis performed on scenarios 1 and 2a, relative to the 2.28 GW assumption used in this study, it is estimated that a 1.5 GW firm capacity value (43%) for the dams would lower the NPV replacement costs by 9-20% and a 1.0 GW firm capacity value (29%) would lower the NPV replacement costs by 14-33%.

Replacement Resources Firm Capacity Counting

If Northwest reliability challenges dramatically shift into the summer, this would also impact the capacity value of replacement resources. One key input assumption this would change is the capacity value of battery storage additions, which were previously limited due to the Northwest wintertime energy-constrained reliability events causing charging sufficiency challenges for energy storage resources. To test whether higher energy storage ELCCs would impact the LSR dams replacement resources and replacement costs, a high storage ELCC sensitivity scenario was analyzed, per the ELCC inputs shown in Figure 23 below. This analysis was performed on scenarios 1 and 2a.

Figure 23. Inputs for High Battery Storage ELCC Sensitivity



In Scenario 1, with the LSR dams intact, higher battery ELCCs cause another 1.5 GW of batteries to be selected and 1.4 GW less dual fuel natural gas and hydrogen plants. In Scenario 2a, with the LSR dams intact, higher battery ELCCs cause another 2.4 GW of batteries and another 0.3 GW of wind to be selected, with 3.6 GW less dual fuel natural gas and hydrogen plants.

When the LSR dams are assumed to be breached, the differences in replacement resources are relatively small. In Scenario 1, an additional ~0.2 GW of battery storage, an additional 0.2 GW of wind, and 0.2 GW less dual fuel natural gas and hydrogen plants are selected to replace the dams. In Scenario 2a, an 0.3 GW less battery storage, 0.3 GW less wind, and an additional 0.1 GW of dual fuel natural gas and hydrogen plants are selected to replace the dams. This is because scenario 2a builds more wind and batteries in the base case already with the dams not breached, so the model prefers to select fewer of those resources for LSR dams replacement. Annual replacement costs in 2045 are 2% lower in scenario 1 and the same in scenario 2a. These results indicate that higher storage ELCCs would allow the region to build less dual fuel natural gas and hydrogen plants, but because energy storage ELCCs eventually saturate in either case, the replacement resources for the dam are not significantly changed and there is little impact on the replacement costs.

Conclusions and Key Findings

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho, and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability. RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[37]. Using RESOLVE allows for a dynamic optimization that considers replacement resource needs in the context of long-term system load and policy drivers, not just the near-term resource mix and needs of the system today. The dams are assumed to be breached in 2032, except for one sensitivity that considered 2024 breaching.

This study's scenario design focuses on three key variables – clean energy policy, load growth, and emerging technology availability – that impact the cost to replace the dams.

Even with the dams in place, the region's clean energy goals and potential electrification load growth drive a significant need for new resources. In all scenarios, significant energy efficiency and customer solar is embedded into the load forecast, based on the NWPCC's 8th Power Plan. Additionally, 6 gigawatts ("GW" or 6,000 MW) of coal capacity is retired by 2030, while increasing carbon prices incent further clean energy resource additions. In Scenario 1, the regional power system is required to meet a goal of generating enough clean energy to provide 100% of retail electricity sales, on an average basis over a calendar year. This requires an additional 5 GW of solar and 5 GW of wind by 2045 to achieve the clean energy goal; 0.6 GW of battery storage, 2 GW of demand response, and 9 GW of dual fuel natural gas + hydrogen combustion plants are also added to meet the region's resource adequacy needs.

Though all scenarios require more "firm" resources – resources that can generate when needed and operate for as long as needed – to meet peak loads, these resources are in higher demand in Scenario 2, in which all greenhouse gas emissions are eliminated from the regional power system by 2045. This scenario also assumes that electrification results in much higher electric loads, particularly in wintertime due to electrification of natural gas space heating in buildings. The baseline scenario (2a) selects additional wind, solar, and geothermal to meet clean energy needs as well as demand response, some

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[37] Pacific Northwest Low Carbon Scenario Analysis, December 2017, https://www.ethree.com/projects/study-policies-decarbonize-electric-sector-northwest-public-generating-pool-2017-present/; Pacific Northwest Zero-Emitting Resources Study, January 2020, https://www.ethree.com/e3-examines-role-of-nuclear-power-in-a-deeply-decarbonized-pacific-northwest/

battery storage, and 27 GW natural gas and hydrogen dual fuel combustion plants to meet reliability needs. An alternative "emerging technology" scenario selects 17 GW of advanced nuclear technology (small modular reactors or "SMRs") by 2045, in place of the firm capacity provided by natural gas generators while reducing the required quantities of wind, solar and batteries that are needed. The "no new combustion" scenario does not allow emerging clean firm technologies such as hydrogen combustion turbines, gas generation with carbon capture and sequestration (CCS) or SMRs. As a result, it requires impractically high levels of additional onshore wind, offshore wind, and battery storage to meet firm capacity and carbon reduction needs, quadrupling the total installed MW of the Northwest grid by 2045.

When the power services provided by the dams are removed from the regional power system, RESOLVE selects an optimal, i.e., least-cost portfolio of replacement resources that meets the Northwest's clean energy and system reliability needs. These replacement resources require a large investment and come at a substantial cost that increase over time as the region's clean energy goals become more stringent. In the latter years, the replacement costs are highly dependent on scenario-specific assumptions about the availability of emerging technologies. RESOLVE primarily replaces the carbon-free energy from the dams with additional wind power and the firm capacity with dual fuel natural gas and hydrogen combustion plants. Small amounts of additional energy efficiency and battery storage are also selected in some scenarios. By 2045, the dual fuel plants added burn additional hydrogen on low wind days to replace the carbon-free energy provided by the dams. Scenario 2b selects additional nuclear SMRs in lieu of some of the wind and gas resources. Scenario 2c disallows the new combustion plants, even those that would burn green hydrogen, and other emerging technologies, requiring a very large buildout of wind and solar power to replace both the firm capacity and the carbon-free energy of the dams.

The long-term emissions impact of removing the generation of the lower Snake River dams will depend on the implementation of the Oregon and Washington electric clean energy policies. Both a 100% clean retail sales and a zero-carbon emissions target require replacement of most or all of the LSR dams' GHG-free energy. However, without additional earlier carbon-free resource investments beyond those modeled in this study to meet clean energy policy trajectories, carbon emissions may increase initially when the dams are breached, before declining by 2045 as the carbon policy becomes more stringent.

KEY FINDINGS:

+ ***Replacing the four lower Snake River dams while meeting clean energy goals and system reliability is possible but comes at a substantial cost***, even assuming emerging technologies are available:
    - Requires 2,300 – 2,700 MW of replacement resources
    - An annual cost of $415 million – $860 million by 2045
    - Total net present value cost of $10.7-19 billion based on 3% discounting over a 50-year time horizon following the date of breaching
    - Increase in costs for public power customers of $100 – 230 per household per year (an 8 – 18% increase) by 2045
+ The biggest cost drivers for replacement resources are the need to replace the lost ***firm capacity for regional resource adequacy*** and the need to replace the lost ***zero-carbon energy***

- Replacement becomes ***more costly over time*** due to increasingly stringent clean energy standards and electrification-driven load growth
- ***Emerging technologies*** such as hydrogen, advanced nuclear, and carbon capture ***can limit the cost of replacement resources*** to meet a zero emissions electric system, but the pace of their commercialization is highly uncertain
    - In economy-wide deep decarbonization scenarios, ***replacement without any emerging technologies requires very large renewable resource additions at a very high cost*** (12 GW of wind and solar at $75 billion NPV cost)

Appendix

Additional Inputs Assumptions and Data Sources

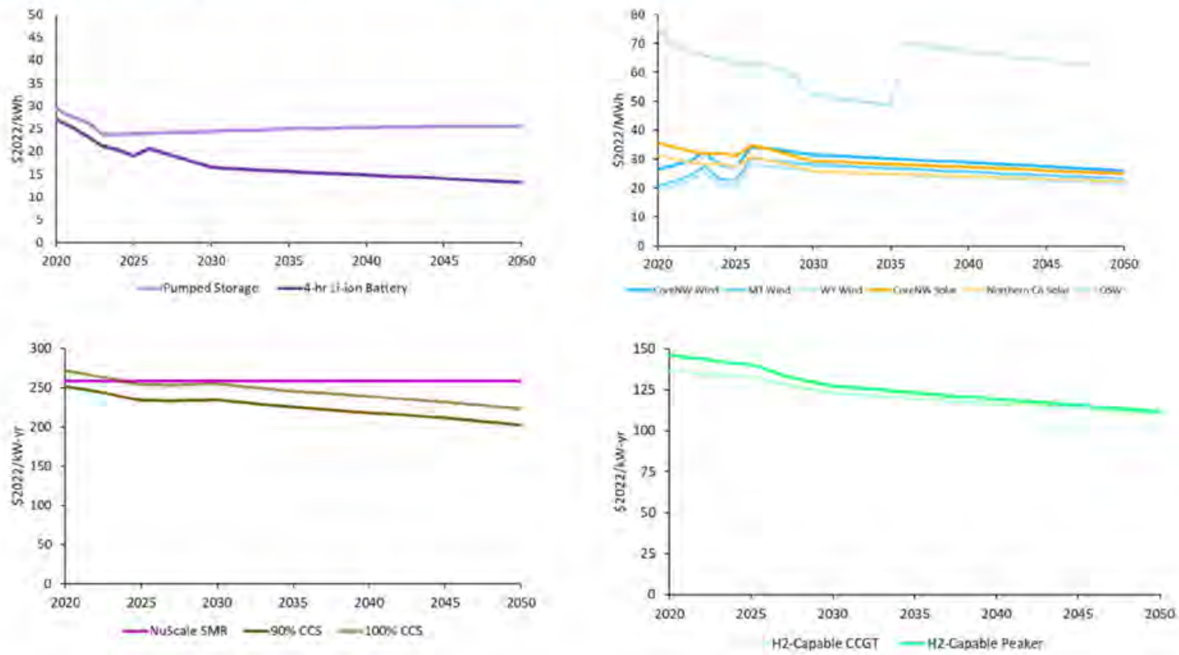
Candidate resource costs

The technology fixed costs trajectories for candidate resource options are shown in Figure 24 and use the following data sources:

+ Battery Storage: Costs derived from Lazard LCOS 7.0 and E3 modeling
+ Pumped Storage: Costs derived from Lazard's last published PHS costs (LCOS 4.0)
+ Renewables (solar, onshore, and offshore wind): Costs derived from E3's inhouse Pro Forma which integrates the NREL 2021 Annual Technology Baseline
+ Geothermal: Costs derived from E3's inhouse Pro Forma which integrates the NREL 2021 Annual Technology Baseline
+ Energy Efficiency and Demand Response: Costs supply curve adjusted for cost effective energy efficiency and DR potential from the 2021 Northwest Power Plan
+ Carbon Capture and Storage (CCS): Costs derived from E3's inhouse "Emerging Tech" Pro Forma using the NREL 2021 Annual Technology Baseline and Feron et al., 2019.[38]
+ Nuclear Small Modular Reactor (SMR): Costs are derived from the vendor NuScale, for an "nth of a kind" installation of the technology they are developing
+ Gas and Hydrogen-Capable Technologies: CCGT and peaker costs are derived from E3's inhouse ProForma which integrates NREL 2021 Annual Technology Baseline. New Hydrogen or natural gas to hydrogen upgrades include a ~10% additional cost that converges with standard CCGT and peaker costs by 2050

[38] Feron, P., Cousins, A., Jiang, K., Zhai, R., Thiruvenkatachari, R., & Burnard, K. (2019). Towards zero emissions from fossil fuel power stations. International Journal of Greenhouse Gas Control, 87, 188–202.

Figure 24. All-in fixed costs for candidate resource options[39]



Fuel prices

The fuel price forecasts used in this study are derived from a combination of market data and fundamentals-based modeling of natural gas supply and demand. Wholesale gas prices are pulled from forward contracts from NYMEX (Henry Hub) and Amerex and MI Forwards (all other hubs) for the next five years, after which the Henry Hub forecast trends towards EIA's AEO natural gas price by 2040. All other hubs forecast after the first five years are based on the average 5-year relationship between their near-term forward contracts and that of Henry Hub. Data sources used for fuel price forecasts used in modeling are as follows and the trajectories are presented in Figure 25:

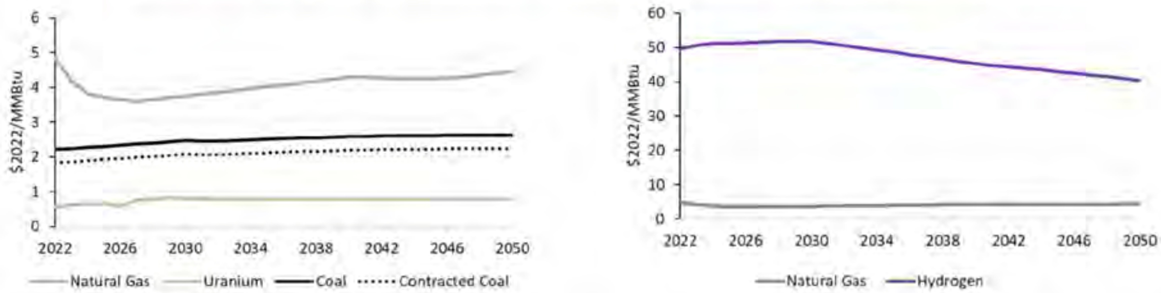
+ **Natural gas prices:** In near term, SNL NG price forecasts (i.e., for 2022-2026); and in long term, the EIA's AEO 2040 forecasts are used. Recent fuel cost increases due to market disruptions are excluded from the price trajectory.

---

[39] Storage costs are shown in $/kWh of energy storage. Renewable costs are shown in $/MWh. Clean firm resources (nuclear, CCS, hydrogen CCGT or peakers) are shown in $/kW-yr, since their $/MWh costs are a function of their runtime that RESOLVE would determine endogenously.

- **Coal prices:** EIA's AEO forecast are used
- **Uranium prices:** E3's in-house analysis
- **Hydrogen prices:** Conservative prices are used assuming no large-scale hydrogen economy, and thus electrolyzer capital costs and efficiencies are assumed to improve over time only slightly. Other assumptions include above ground hydrogen storage tanks and delivery via trucks from about 225 miles distance. Electrolyzers use dedicated off-grid Core NW wind power to produce hydrogen.

Figure 25. Fuel price forecasts for natural gas, coal, uranium, and hydrogen

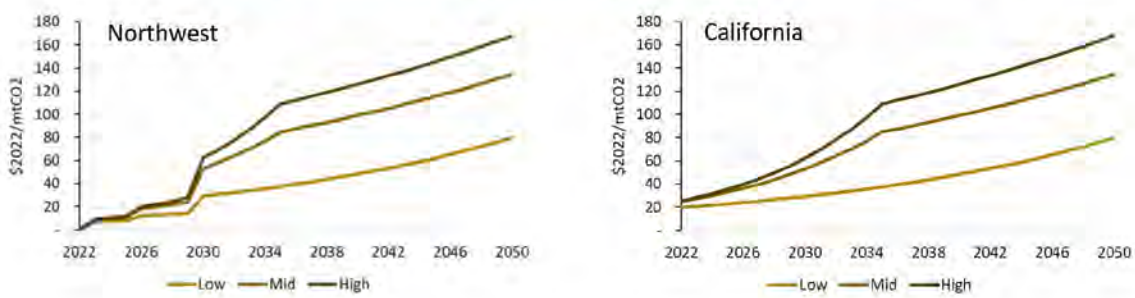


Annual average gas prices are further shaped according to a monthly profile to capture seasonal trends in the demand for natural gas and the consequent impact on pricing.

Carbon prices

For carbon pricing, it is assumed that Washington's cap-and-trade program starts in 2023 at around 50% of California carbon prices. For Oregon, it is assumed that a carbon price policy will be effective by 2026 for the electric sector. Prior to 2026, the Northwest carbon price is a load weighted share of carbon prices in WA and OR. Additionally, it is assumed that both states will converge to California's floor price by 2030. California's carbon prices are adopted from the Final 2021 IEPR GHG Allowance Price Projections (December 2021). Mid carbon prices presented in Figure 26 are used in modeled cases.

Figure 26. Carbon price forecasts for Northwest and California



Operating Reserves

It is assumed that all coal, gas, hydro, and storage resources within the Northwest zone can provide operating reserves. Additionally, RESOLVE allows renewable generation to contribute to meeting the needs for load following down; to allow for variable renewable generation curtailment to balance forecast error and sub-hourly variability. The following three types of operating reserve requirements are considered within the Core Northwest to ensure that in the event of a contingency, sufficient resources are available to respond and stabilize the electric grid:

+ **Spinning reserves:** Modeled as 3% of hourly load in agreement with WECC and NWPP operating standards
+ **Regulation up and down:** Modeled as 1% of hourly load
+ **Load following up and down:** Modeled as 3% of hourly load

Modeling of Imports and Exports

The Northwest RESOLVE model includes a zonal representation of the WECC. In modeling hourly dispatch during representative days, it considers the least-cost dispatch solution across the WECC, based on resource economics, resource operational limits, fuel and carbon prices, operating reserve requirements, and zonal transmission transfer limits. Imports to the CoreNW zone can occur from other neighboring zones; when they do a carbon adder is included for unspecified imports, while specified imports do not receive a carbon adder. Exports from the CoreNW zone may occur as deemed economic by RESOLVE, subject to other model constraints.

Minimum and maximum capacity limits are applied to the zonal representation of transmission between connected zones. These zonal transfer limits are shown in Table 13. Transmission hurdle rates as well as carbon hurdle rates (with regional carbon price adders) are applied to imports and exports.

Table 13. Transmission Capacity Limits between the CoreNW and other Zones

Transmission Constraint	Transmission from	Transmission to	Min Flow (MW)	Max Flow (MW)
CoreNW to OtherNW	CoreNW	OtherNW	-6,036	2,550
CoreNW to CA	CoreNW	CA	-6,820	5,433
CoreNW to SW	CoreNW	SW	0	0
CoreNW to NV	CoreNW	NV	-300	300
CoreNW to RM	CoreNW	RM	0	0

Contracted imports (such as imported coal and/or wind power) are included in the resource adequacy accounting captured in the planning reserve margin constraint. New remote resources include transmission cost adders to deliver them into the CoreNW zone. Additional unspecified imports are not assumed in RESOLVE's resource adequacy accounting.

Additional LSR Dam Power System Benefits (not modeled)

As described in this report, RESOLVE covers replacement of most power services provided by the LSR dams. However, RESOLVE does not model transmission grid operations (power flow, voltage and frequency, dynamic stability, etc.). Therefore, E3 notes that the LSR dams may provide the following additional essential reliability services to the transmission grid. In general, E3 expects that the replacement of these services can be achieved either through siting and operations of the incremental replacement capacity selected or by additional local transmission investments. The scale of these transmission investments requires more detailed study.

- **Reactive power and voltage control**: the LSR dams, like hydropower resources generally in the Northwest, provide significant reactive power capabilities that supports reliable power flow by optimally controlling voltage levels. Replacing this function likely requires siting additional resources with reactive power capabilities in a similar section of the transmission grid as the LSR dams.
- **Frequency response and inertia**: the LSR dams provide both primary and secondary frequency response capabilities. As synchronous generators they also provide system inertia that would be lost if the LSR dams are removed and as other synchronous generators retire. New efforts are underway to allow renewable generators or battery storage to provide "synthetic inertia" (or equivalent fast frequency response services), but this provision has not yet been proven to date at scale. The LSR dams are also highly tolerant of operating during high and low frequency events without sustaining blade damage.
- **Blackstart**: Large hydro resources have the capability to provide black start services when required, though not all hydro plants are chosen to provide this capability.
- **Participation in remedial action schemes**: Hydropower is a robust resource for participation in remedial action schemes because it can withstand being suddenly tripped off-line as part of a RAS action.
- **Short circuit and grounding contribution**: Synchronous generators (like hydropower) provide a large short circuit current that is important for the proper operation of protective relaying schemes.

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Wednesday, June 29, 2022 9:04 PM
To:	Arne Olson; James,Eve A L (BPA) - PG-5
Cc:	Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian
Subject:	[EXTERNAL] RE: Draft Exec Summary
Attachments:	BPA Final Report_Draft_v3.docx

Deliberative, FOIA exempt

And now the draft report, ready for BPA version control. Note there are a few placeholders still for some minor E3 updates.

Aaron

From: Aaron Burdick
Sent: Wednesday, June 29, 2022 9:03 PM
To: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Updated public summary deck attached w/ NPV values updated. We are now proposing to use the 3% NPV discount rate, which increases the NPV. This is better representative of the public power cost of capital and more closely aligns with the discount rates used in the Inslee/Murray report.

Report draft coming in the next email.

Aaron

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, June 29, 2022 5:47 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

Energy GPS study is out:

> If the LSRD are removed, an additional 14,900 MW of resources will be required. This is 23% of the Pacific Northwest's current generation capacity and enough to power 15 cities the size of Seattle.

https://www.linkedin.com/pulse/new-report-value-lower-snake-river-dams-effectively-/?trackingId=kLZaTd9mS%2F2IeThVJO4L0w%3D%3D

I think it would behoove us to put together a little comparison of the three studies.

Should be done with my edits on ours in the next hour.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, June 29, 2022 4:23 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Sounds good- thanks Aaron!

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, June 29, 2022 4:22 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] Re: Draft Exec Summary

Deliberative, FOIA exempt

Hi Eve,

The report version is the updated/corrected version. The 1b 2024 retirement case had too high an NPV previously. I'll send an updated public deck when I send the report over in a bit.

Aaron

Get Outlook for iOS

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, June 29, 2022 3:49:49 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Hi Aaron-
As I was going through the report and working on some internal talking points I noticed the NPV values in the draft report chart weren't matching the chart in the public presentation slide (see below). Can you let me know which table is correct? I can see rounding for 2b but for Scenario 1 2024 breach it isn't rounding error. If the slide deck needs updating could you send me a new version so I can make sure I have the correct materials to post?

Thanks,
Eve

Table 12. Total LSR Dams replacement costs[21]

	NPV Total Costs (Real 2022 $)	Annual Costs Increase (Real 2022 $)			Incremental Public Power Costs
	In the year of breaching (2032 or 2024)	**2025**	**2035**	**2045**	**2045**
Scenario 1: 100% Clean Retail Sales	$7.4 billion	n/a	$434 million	$478 million	0.8 ₵/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$8.6 billion	$495 million	$466 million	$509 million	0.8 ₵/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$11.3 billion	n/a	$496 million	$860 million	1.5 ₵/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$6.7 billion	n/a	$415 million	$428 million	0.7 ₵/kWh [+8%]
Scenario 2c: Deep Decarb. (No New Combustion)	$46 billion	n/a	$1,953 million	$3,199 million	5.5 ₵/kWh [+65%]

	Total Costs (real 2022 $) Net Present Value in year of breaching
Scenario 1: 100% Clean Retail Sales	$7.5 billion
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$11 billion
Scenario 2a: Deep Decarb. (Baseline Technologies)	$11.5 billion
Scenario 2b: Deep Decarb. (Emerging Technologies)	$7 billion
Scenario 2c: Deep Decarb. *(No New Combustion)*	*$46 billion*

Deep decarbonization without emerging technologies drives impractically high costs

From: James,Eve A L (BPA) - PG-5
Sent: Wednesday, June 29, 2022 12:17 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt
Sounds good- I'll start reading and making notes to add to the version this afternoon.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, June 29, 2022 12:14 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: Draft Exec Summary

Deliberative, FOIA exempt

Eve,

Arne is still completing some edits, but I'm sending this "interim" draft version so you have the full report to start digging through. I'll send another version later today with all of Arne's edits, so suggest *E3 retains version control until later today when we share that version*, when it will transfer to BPA.

Note: Arne has made some changes to the exec summary, which I've keep tracked since you already reviewed that. I updated is response to your prior feedback (but did not track those changes).

All the best,
Aaron

From: Aaron Burdick
Sent: Tuesday, June 28, 2022 9:43 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Eve,

Status update: we're still working on a few remaining items in the draft and incorporating Arne's review. I'm hoping to send you the draft by mid-day tomorrow. Will either send of provide an update until then. I'm hoping we can get your review by end of day Thursday and update as needed on Friday before sharing the final version by Friday COB.

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Monday, June 27, 2022 3:36 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt
Hi Aaron-
Attached are some comments on the Executive Summary for your consideration.

Arne- I saw the Council's note on providing materials ahead of the July 7th meeting. Internally we were thinking that if we share the PPT this early we would need to be prepared to start fielding incoming questions and for the info to be shared with others. We're still working on some talking points for our communications staff and Account Executives. Also, just so you are aware there is a discussion with some of DC folks tomorrow so I was going to wait and email the Council staff tomorrow after that meeting if you don't mind. If you have concerns about waiting to share materials please let me know.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, June 24, 2022 3:12 PM

To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] Draft Exec Summary

Deliberative, FOIA exempt

Hi Eve,

I'm leaving for a weekend trip and OOO the rest of the afternoon. I'm providing the draft executive summary but the rest of the report draft will need to wait until Tuesday next week. Hopefully this provides enough to make sure we're aligned. I'm also copying the TOC for the draft report to make sure you're aware what we're working on.

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All the best,

Aaron Burdick, Associate Director
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Energy+Environmental Economics

BPA Lower Snake River Dams Power Replacement Study

Executive Summary

July 2022

Arne Olson, Sr. Partner
Aaron Burdick, Associate Director
Dr. Angineh Zohrabian, Consultant
Sierra Spencer, Sr. Consultant
Sam Kramer, Consultant
Jack Moore, Sr. Director

About this study

+ **BPA contracted with E3 to conduct an independent analysis of the electricity system value of the four lower Snake River (LSR) dams**
+ **E3 utilized our RESOLVE optimal capacity expansion model to identify least-cost portfolios of electricity resources needed to replace the electric energy and grid services provided by the dams through 2045**
+ **Replacement costs are considered within the context of the Northwest region's aggressive, long-run decarbonization goals**

Key Study Questions:

- What **additional resources** would be needed to replace the power services provided by the LSR Dams through 2045?
- What is the **net cost to** BPA ratepayers?
- How do costs and resource needs change under **different types of clean energy futures**?
- How much does replacing the dams rely on **emerging, not-yet-commercialized technologies**?

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What would it take to replace the output of the four lower Snake River dams?

+ **What energy services are lost if the dams are breached?**
  - **3,483 MW of total capacity***, including approximately **2,300 MW of firm peaking** capability to avoid power shortages during extreme cold weather events
  - **~900** annual average MW of low-cost, zero-carbon energy** (enough energy to support ~450,000 households or 1.7x the City of Portland) as well as **operational flexibility** services
+ **How much would it cost to replace the power benefits of the four lower Snake River dams in E3's study with breaching in 2032?**
  - In E3's **baseline scenario**, total net present value (NPV)*** replacement costs would be **$11.8 billion**
  - In a **deep decarbonization scenario** with higher loads and zero emissions electricity by 2045, NPV costs range from **$10.7-19 billion** with at least one emerging technology
    - Reaching deep decarbonization **absent breakthroughs in not-yet-commercialized emerging technologies**, NPV costs could increase to **$75 billion**
+ **What are the long-term rate impacts to ~2 million public power households in 2045?**
  - Public power costs increase by **8-18% or ~$100-230 per year across most scenarios**
    - Costs increase by **65% or ~$850 per year** under deep decarbonization scenario **absent emerging technology breakthroughs**
+ **What resources are needed to replace the dams?**
  - A combination of **renewable generation** (wind), **"clean firm" resources** (such as dual fuel natural gas + hydrogen plants, advanced nuclear, or gas with carbon capture and storage), and **energy efficiency**
  - Battery storage cannot cost-effectively replace hydro capacity in the Northwest due to charging limitations during energy shortfall events
+ **What is the timeline necessary to add the resources that would be required?**
  - E3 estimates that adding additional renewable energy and firm capacity additions would take approximately 5-7 years after congressional approval to breach the dams and possibly up to 10-20 years if additional new large-scale transmission was required. E3 assumed transmission would be built as needed for renewable additions.

Plant	Total Capacity (MW)
Lower Granite	930
Little Goose	930
Lower Monumental	930
Ice Harbor	693

Total = 3,483 MW

* Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. Historical peak generation was 3,431 MW.
** E3's RESOLVE model uses 2001, 2005, and 2011 hydro years, which resulted in ~700 aMW of lower Snake River dams generation, making it a conservative estimate of the dams' GHG-free energy value
*** NPV calculated over a 50-year period following the date of breaching, using a 3% discount rate based on the approximate public power cost of capital.


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Study Approach

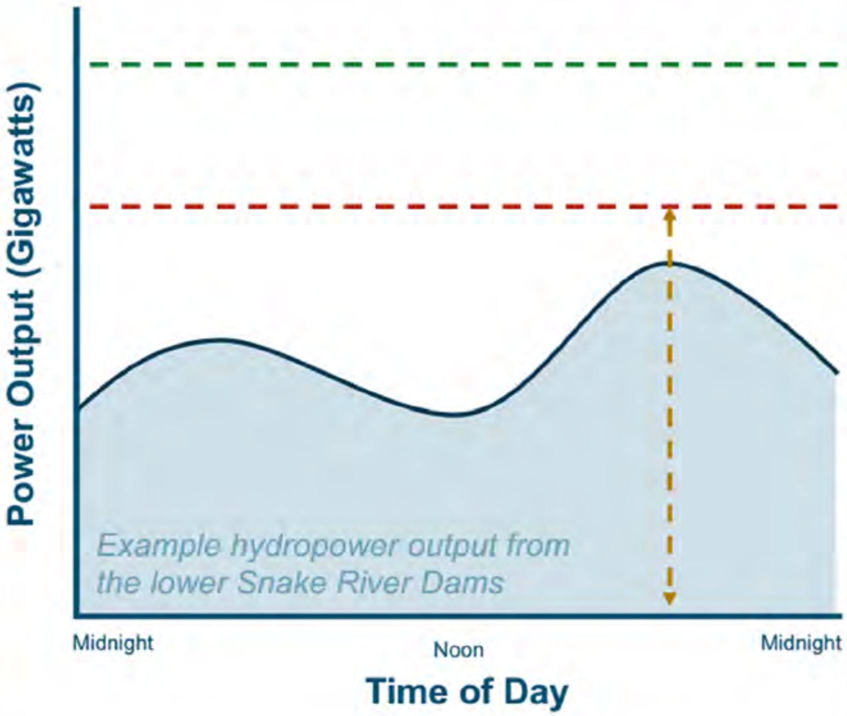
What grid services do the lower Snake River dams provide?


Little Goose


Lower Granite


Lower Monumental


Ice Harbor



<u>**Total "Capacity"**</u>
Maximum instantaneous power output the four dams
LSR Dams = 3.5 GW*

<u>**"Firm Capacity"**</u>
Sustained peaking output (+ reserves) during reliability strained conditions
(e.g. cold January during a drought year)
LSR Dams = 2.3 GW**

<u>Annual (Carbon-free) Energy</u>
Sum of hourly power produced across the year, subject to seasonal water availability
LSR Dams = 0.9 average GW***

<u>**Operational Flexibility**</u>
The ability to change power output to support a reliable grid, subject to water availability and operational constraints
LSR Dams provide short-term reserves + multi-hour ramping / renewable integration capabilities

E3's modeling selects the least-cost portfolio of resources to replace these services

<u>Transmission Grid Reliability Services</u>
Services to reliably operate the transmission grid
(e.g., voltage, frequency support, blackstart, etc.)
LSR Dams can provide, but not the focus of this study

Some of these services may be provided by modeled replacement resources, other may require additional investments

* Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. Historical peak generation was 3,431 MW.
** Firm capacity assumed in this study is consistent with the ~65% Northwest hydro capacity value assumed by PNUCC (the Pacific Northwest Utilities Conference Committee).
*** Average GW means that on average across an average year the plant generated at ~0.9 GW, though its hourly output may be above or below that amount. LSR output was adjusted to reflect increased spill requirements of the EIS. However, E3's RESOLVE model uses 2001, 2005, and 2011 hydro years, which resulted in ~0.7 aMW of lower Snake River dams generation, making it a conservative estimate of the dams' GHG-free energy value.

What's the focus in this study compared to the CRSO EIS?

The study uses an optimization model to determine the least-cost replacement resources for the four lower Snake River dams subject to A) policy and B) reliability constraints

+ **Least-cost optimization: includes updated resource pricing and new emerging technologies**
+ **Policy: E3's modeling considers the effects of regional policies such as Washington's Clean Energy Transformation Act (CETA) and Oregon's 100% clean electricity standard**
  - Aggressive clean energy laws drive coal power plant retirements, price carbon emissions, and require long-term **carbon emissions reductions** by 2045
  - Study includes significant **electrification** that increases demand for electricity to support carbon-reduction in other sectors such as transportation, buildings, and industry, consistent with Washington's Energy Strategy
+ **Reliability: E3's modeling captures the need for the Northwest system to meet peak load during extreme weather and low hydro conditions (known as "resource adequacy").**
  - Captures the abilities and limits of different technologies to serve load during reliability challenging conditions
    - E.g. during extended cold-weather periods with high load, low hydropower availability, and low wind and solar production
  - Resources with high energy production costs may be selected for reliability needs but then run sparsely only during extreme conditions (e.g. natural gas + hydrogen combustion turbines)
+ **LSR operations: incorporates preferred alternative operations selected in the EIS**
  - Increases spill from the dams, lowering available annual energy and changing operational flexibility

Policy landscape: Washington, Oregon, California

+ **The study includes the impacts from clean energy policies in the Pacific states**

	RPS or Clean Energy Standard?	Coal Prohibition?	Cap-and-Trade?	New Natural Gas?	Economy-Wide Carbon Reduction?
WA	✓ Carbon neutral by 2030, 100% carbon free electricity by 2045	✓ Eliminate by 2025	✓ Cap-and-invest program established in 2021, SCC in utility planning	✓	✓ 95% GHG emission reduction below 1990 levels and achieve net zero emissions by 2050
OR	✓ 50% RPS by 2040, 100% GHG emission reduction by 2040, relative to 2010 levels	✓ Eliminate by 2030	✓ Climate Protection Plan adopted by DEQ in 2021 (power sector not included)	✕ HB 2021 bans expansion or construction of power plants that burn fossil fuels	✓ 90% GHG emission reduction from fossil fuel usage relative to 2022 baseline
CA	✓ 60% RPS by 2030, 100% clean energy by 2045	✓ Coal-fired electricity generation already phased out	✓	✕ CPUC IRP did not allow in recent procurement order	✓ 40% GHG emission reduction below 1990 levels by 2030 and 80% by 2050

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Modeling approach involves a three-step process

1. ***With the lower Snake River dams*, optimize long-term resource needs and operations for the Pacific Northwest**
   - Produces necessary resource additions and total system costs and emissions

2. ***Remove the lower Snake River dam generating capacity, then re-optimize* long-term resource needs and operations for the Pacific Northwest**
   - Produces a second set of resource additions and total system costs and emissions
   - All scenarios breach the dams in 2032, except for one scenario in 2024

3. ***Calculate additional resources and investment + operational costs* required to replace the dams**
   - Calculated as the difference between steps 1 and 2 above

Key modeling assumptions

Element	Study Approach	Impact on Dams Replacement Needs
Study Years	• 2025 through 2045*, including fuel price forecasts and declining renewable + storage costs	Considers long-term needs
Clean Energy Policy Scenarios	• Aggressive OR+WA legislation reflected, including coal retirements + carbon pricing • Two electric emissions scenarios considered: 1. **100% clean retail sales** (~85% carbon reduction**) 2. **Zero-emissions** (100% carbon reduction)	Clean energy policy requires long-term **replacement of LSR dams with GHG-free energy**
Load Growth Scenarios	• Two load scenarios: 1. **Baseline** (per NWPCC 8th Power Plan) 2. **High electrification** load growth (to support economy-wide decarbonization) • Significant quantities of energy efficiency are embedded in all scenarios	Higher load scenarios **increase the value of LSR dams energy + firm capacity**
Reliability Needs	• Modeling ensures reliability needs during extreme conditions (e.g. high loads + low hydro) • Captures ability (and limits) of renewables, battery storage, and demand response to support system reliability	Reliability needs require **replacement of LSR dams firm capacity contributions**
Technologies Modeled, including "Emerging" Technologies	• Broad range of dam replacement technology options considered: • **Baseline technologies**: solar, wind, battery + pumped storage, energy efficiency, demand response, dual fuel natural gas + hydrogen combustion plants • **Sensitivities** include Emerging Technologies and Limited Technologies (No New Combustion) scenarios • Resource costs developed by E3 using NREL 2021 ATB, Lazard Cost of Storage v.7, NuScale Power (for small modular reactor costs)	**Technology available for LSR dams replacement** determines replacement cost
Distributed Energy Resource Options	• Energy efficiency, demand response, and customer solar embedded into modeling inputs • Additional energy efficiency and demand response can be selected	**Demand resource can help replace LSR dams**, though low-cost supply is limited

* 20-years of end effects are considered (2045-2065)

** A 100% clean retail sales target allows emissions for electric generation beyond that needed to serve "retail sales", i.e. losses during transmission to retail loads and exported energy

Scenarios

+ Scenario 1: 100% Clean Retail Sales

- Northwest resources produce enough clean energy to meet **100% of retail electricity sales** on an annual average basis
- Some gas generation is retained for reliability, but carbon emissions are reduced **85% below 1990 levels**
- **Business-as-usual** load growth

+ Scenario 2: Deep Decarbonization

- **Zero carbon emissions** by 2045
- **High electrification** of buildings, transportation, and industry to reduce carbon emissions in other sectors
- **Emerging technologies** become available to provide firm, carbon-free power

Emerging Technologies

Technology	S1 100% Clean	S2a Deep Decarb Baseline	S2b Deep Decarb Emerging Tech.	S2c Deep Decarb No New Combustion
Mature technologies (solar, wind, battery + pumped storage, energy efficiency, demand response)	Available	Available	Available	Available
Hydrogen (existing natural gas retrofits)	Available	Available	Available	Available
Hydrogen (new dual fuel natural gas + hydrogen)	Available	Available	Available	Not available
Nuclear (small modular reactors)	Not available	Not available	Available	Not available
Natural Gas w/ Carbon Capture and Storage	Not available	Not available	Available	Not available
Offshore Wind (floating)	Not available	Not available	Available	Available

Legend: Available / Not available

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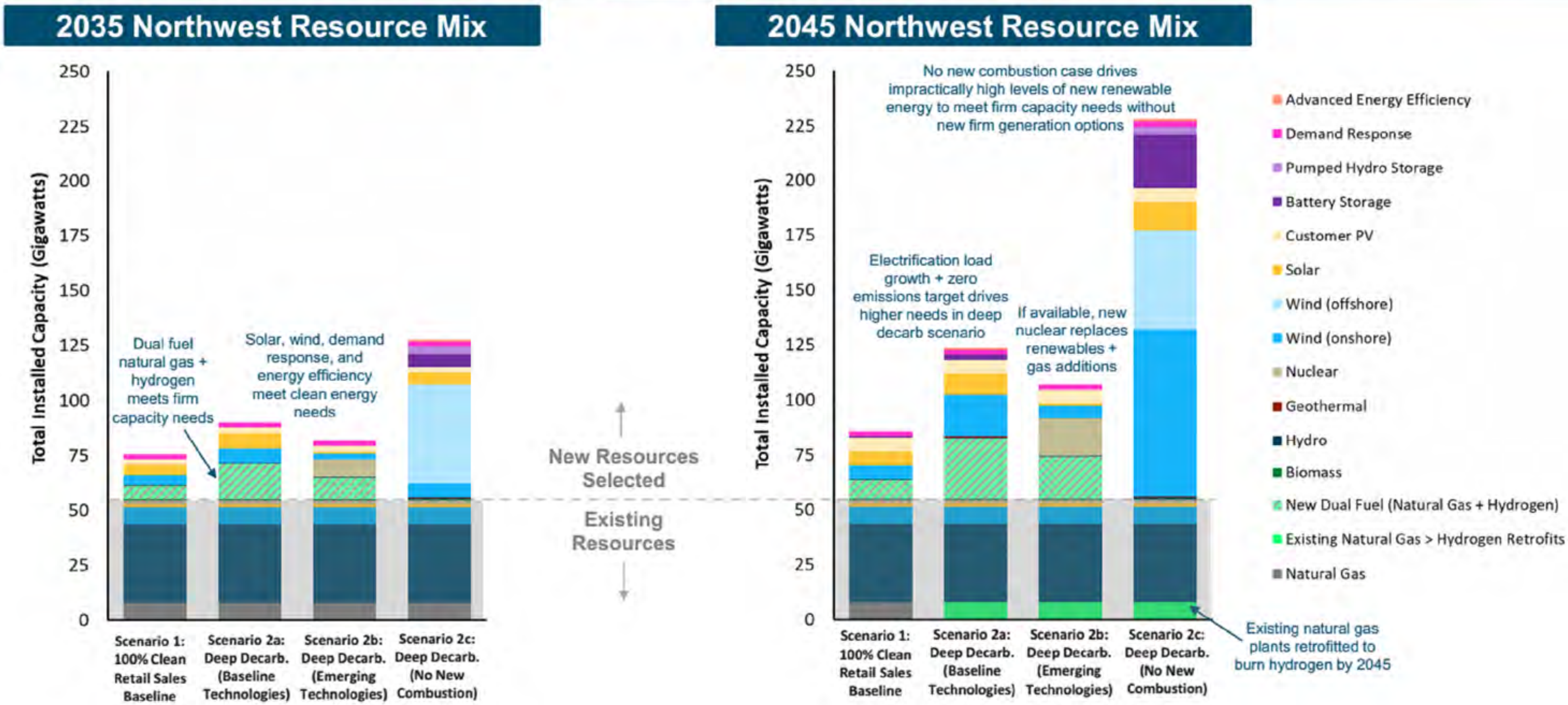
Northwest Resource Needs in Scenarios With the Lower Snake River Dams

Even without breaching the dams, all scenarios show large levels of new resource additions



27693383(01).pdf

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Replacing the Power from the Lower Snake River Dams

Replacement resources selected to replace the lower Snake River dams

- **RESOLVE selects an optimal portfolio of replacement resources including additional advanced energy efficiency, wind, solar, green hydrogen, and/or advanced nuclear**
- **Firm capacity is mostly replaced with ~2 GW of dual fuel natural gas + hydrogen turbines**
  - These turbines may initially burn natural gas when needed during reliability challenged periods, but would transition to hydrogen by 2045 to reach zero-emissions
- **If advanced nuclear is available, it replaces renewables and some of the gas plants**
- **The "no new combustion" scenario requires impractically large (~12 GW) buildout of renewable energy to replace the dams' firm capacity contributions and GHG-free energy**

Scenario	Replacement Resources Selected, Cumulative by 2045 (GW*)
Scenario 1: 100% Clean Retail Sales	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
Scenario 2a: Deep Decarb. (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW advanced energy efficiency + additional H2 generation**
Scenario 2b: Deep Decarb. (Emerging Technologies)	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR
Scenario 2c: Deep Decarb. *(No New Combustion)*	+ 10.6 GW wind + 1.4 GW solar

* 1 GW = 1,000 MW

** Replacing LSR dams GHG-free energy at least-cost leads RESOLVE to generate an additional 1.2 TWh of hydrogen generation during low renewable conditions (or 0.14 average GW).

Total costs for replacing the lower Snake River dams

+ Costs are expected to fall on Bonneville Power Administration's public power customers

- Costs could **increase public power retail costs** by 8-18%, or up to 65% absent emerging technologies
- Costs could **raise annual residential electricity bills** by up to $100-230/year, or up to $850/yr absent emerging technologies

	Total Costs (real 2022 $)	Annual Cost Increase (real 2022 $)			Incremental Public Power Costs [% increase vs. ~8.5 cents/kWh NW average retail rates]
	Net Present Value in year of breaching	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$11.8 billion	n/a	$434 million	$478 million	0.8 cents/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$12.8 billion	$495 million	$466 million	$509 million	0.8 cents/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$19.0 billion	n/a	$496 million	$860 million	1.5 cents/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$10.7 billion	n/a	$415 million	$428 million	0.7 cents/kWh [+8%]
Scenario 2c: Deep Decarb. *(No New Combustion)*	*$75.2 billion*	*n/a*	*$1,953 million*	*$3,199 million*	*5.5 cents/kWh [+65%]*

Deep decarbonization without emerging technologies drives impractically high costs

Cost differences driven primarily by 2045 carbon policy and availability of emerging technologies

Costs increase over time as loads grow and carbon policy becomes more stringent

- Cost increases account for replacement energy, capacity, and reserves as well as avoided LSR capital + expense, but do not include any costs for breaching the dams, which would be an additional cost.
- NPV and annual cost increase are shown for the Northwest Region as a whole, but the incremental costs are calculated relative to the BPA Tier I annual sales for public power customers. NPV calculated over a 50-year period following the date of breaching, using a 3% discount rate based on the public power cost of capital.
- % increase versus average retail rates assumes ~8.5 cents/kWh retail rates (estimated from OR and WA average retail rates). This does not include additional rate increases driven by higher loads or clean energy needs that increase regional rates as shown in the earlier 2045 incremental cost chart.
- Annual residential customer cost impact assumes 1,280 kWh/month for average residential customers in Oregon and Washington (current ~1,000 kWh/month average + 28% from electrification load growth).
- New federal tax credits for hydrogen plants/fuels or ITC/PTC extension for renewables would provide a cost reduction to public power customers from taxpayers

Cost of generation for lower Snake River dams replacement resources (using common utility metric of $/MWh)

- **The lower Snake River dams provide a low-cost source of GHG-free energy and firm capacity**
- **Even in a best-case scenario, replacement power would cost several times as much as the lower Snake River dams costs**
  - This is driven by both energy replacement as well as replacement of firm capacity and operational flexibility
- **Compared to ~$13-17/MWh for the lower Snake River dams, replacement resources cost between $77-139/MWh**
  - Replacement costs rise to over $500/MWh in a deep decarbonization scenario absent emerging technology

Incremental LSR Dam Replacement Resource Costs

Lower Snake River Dams All-in Generation Costs (2022 $/MWh)
$13/MWh w/o LSRCP*
$17/MWh w/ LSRCP*

Scenario	2045 Costs to replace LSR Generation** (real 2022 $/MWh)
S1: 100% Clean Retail Sales	$77/MWh
S1b: 100% Clean Retail Sales (2024 dam breaching)	$82/MWh
S2a: Deep Decarb	$139/MWh
S2b: Deep Decarb, w/ Emerging Tech	$69/MWh
S2c: Deep Decarb, Limited Tech (no new combustion)	$517/MWh

* BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) fish hatcheries and satellite facilities. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat.2917) to offset fish and wildlife losses caused by construction and operation of the four lower Snake River projects.

** Replacement $/MWh costs are calculated as CoreNW revenue requirement increase with LSR dams breached divided by the annual MWh of the LSR dams assumed in E3's modeling (~700 aMW). These costs includes replacement of the LSR dam energy, capacity, and reserve provision. A significant portion of the costs is capacity costs to replace the dams' RA capacity contributions.

Firm capacity value of the lower Snake River dams

+ **The firm capacity value is a significant driver of replacements costs**
+ **PNUCC 2021 estimate of NW hydro sustained peaking capacity was used for the lower Snake River dams' firm capacity value (65% or 2.3 GW)**
+ **E3 also analyzed modeled hourly LSR dam output during the 2001 low hydro year (using BPA data post EIS spill requirements)**
  - Suggests a winter firm capacity value of ~56-60%
+ **E3 predicts a continued concentration of risk in the winter in deep decarbonization scenarios with high space heating electrification**
  - However, in a system with higher summer reliability risk, the LSR firm capacity value would be lower
  - E3 estimates the impact of a lower firm capacity value for S1 and S2a scenarios to be:
    - 1.5 GW firm capacity value (43%) → ~9-20% lower NPV replacement cost
    - 1.0 GW firm capacity value (29%) → ~14-33% lower NPV replacement cost

* Includes 100-250 MW reserve provision on top of maximum power output

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Key conclusions

1. **Replacing the four lower Snake River dams comes at a substantial cost, even assuming emerging technologies are available**
   - Require 2,300 – 2,700 MW of replacement resources
   - An annual cost of $415 million – $860 million by 2045*
   - Total net present value replacement cost of $10.7 – 19.0 billion based on 3% discounting over a 50-year time horizon following the date of breaching
   - Increase in costs for public power customers of $100 – 230 per household per year (an 8 – 18% increase) by 2045
2. **The biggest cost drivers for replacement resources are the need to replace the lost firm capacity and the need to replace the lost zero-carbon energy**
3. **Replacement resources become more costly over time due to increasingly stringent clean energy standards and electrification-driven load growth**
4. **Emerging technologies such as hydrogen, advanced nuclear, and carbon capture can limit the cost of replacement resources to meet a zero emissions electric system, but the pace of their commercialization is highly uncertain**
   - Replacing the dams in deep decarbonization scenarios without any emerging technologies requires impractical levels of renewable additions at a very high cost ($75 billion NPV cost)

* Replacement resource costs are calculated assuming project financing per E3's pro forma calculator, rather than assuming upfront congressional appropriation

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Thank you

Questions, please contact:

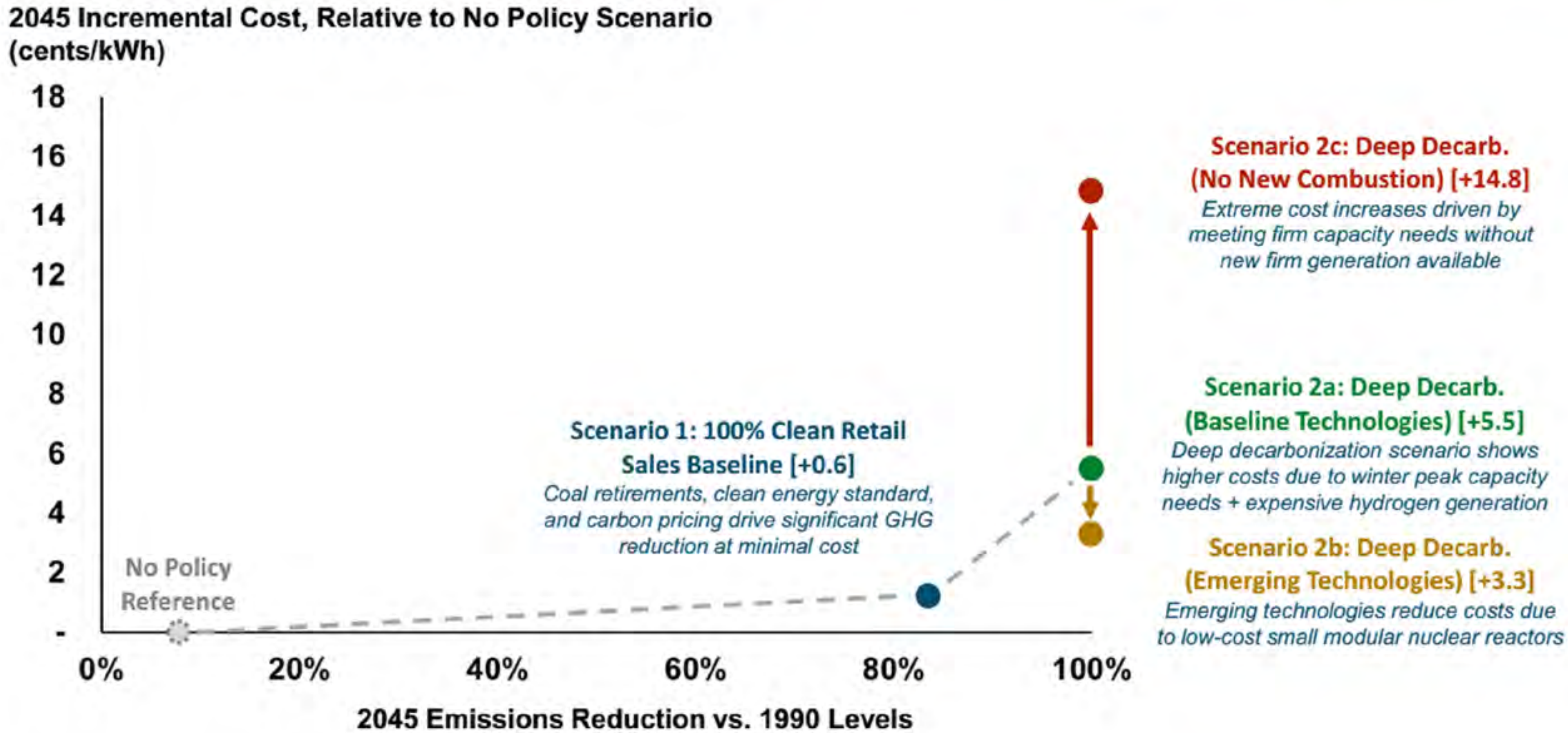
Arne Olson, arne@ethree.com

Aaron Burdick, aaron.burdick@ethree.com

Energy+Environmental Economics

Appendix A: Additional Modeling Results

Significant carbon reductions are possible, but the cost of reaching zero emissions depends on technologies available



NOTES:

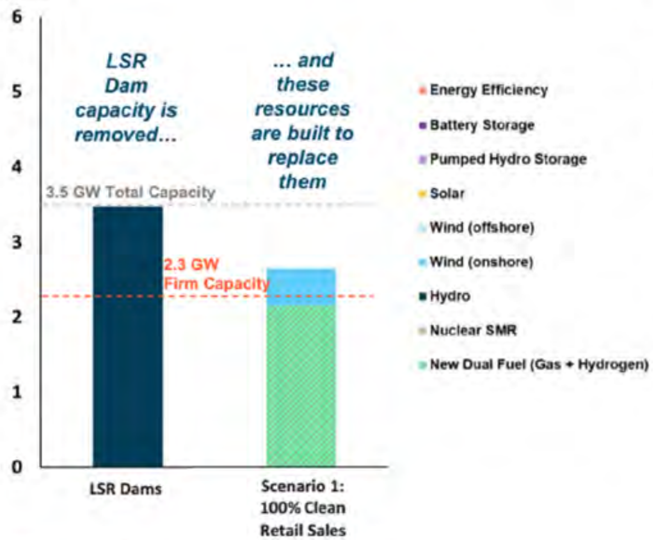
- 2020 average retail rates for OR and WA were 8-9 cents/kWh; 1990 electric emissions were ~33 MMT
- High electrification scenarios would avoid natural gas infrastructure costs, which would offset some of the electric peaking infrastructure cost increase

Replacing the Lower Snake River Dams
Scenario 1: 100% Clean Retail Sales

- Capacity replaced with 2.2 GW of dual fuel natural gas + hydrogen turbines and 0.5 GW wind
- Wind and imports provide the most energy replacement, but gas plant is needed for meeting extreme weather peak load events to avoid power shortages
- 2045 GHG emissions increase ~11% as not all LSR generation needs to be replaced to still meet 100% clean retail sales target

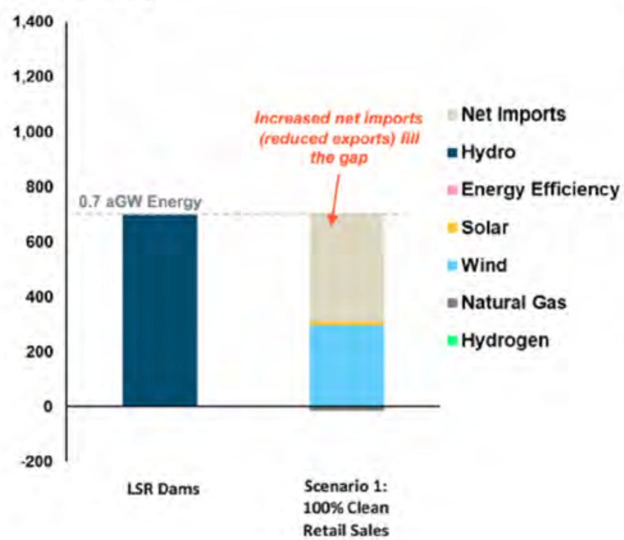
Additional Resources Built to Replace LSR Dams (2045)

2045 Capacity
(GW)



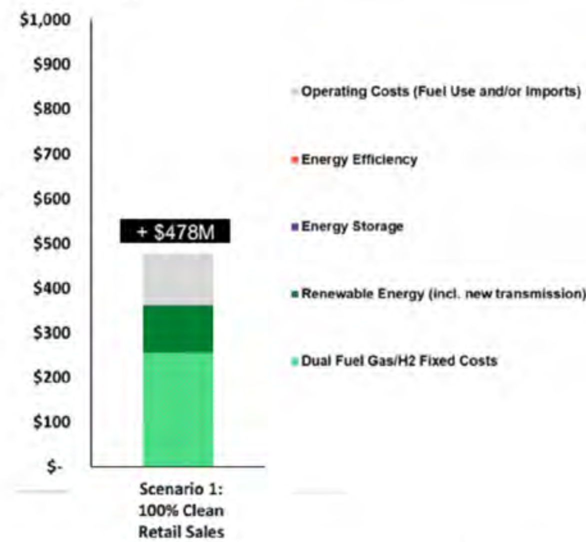
Additional Generation to Replace LSR Dams (2045)

2045 Generation
(Annual GWh)



Additional Cost (2045)

2045 Annual Cost Increase
($ million)



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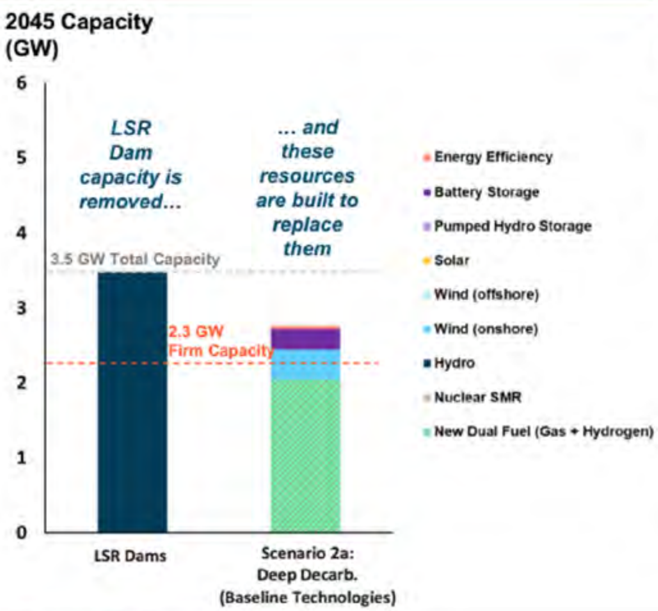
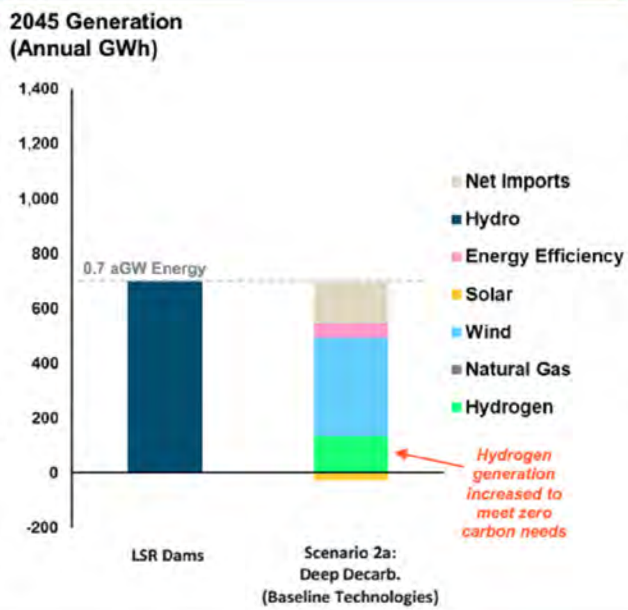
Replacing the Lower Snake River Dams
Scenario 2a: Deep Decarbonization (Baseline Technologies)

- Scenario includes electric load increases for transportation and other sectors
- In 2045, hydrogen generation is a key replacement resource and is assumed to be available, though not commercially available today
- This scenario would cost $860 million dollars per year in 2045, driven by high hydrogen fuel costs (~$40/MMbtu)

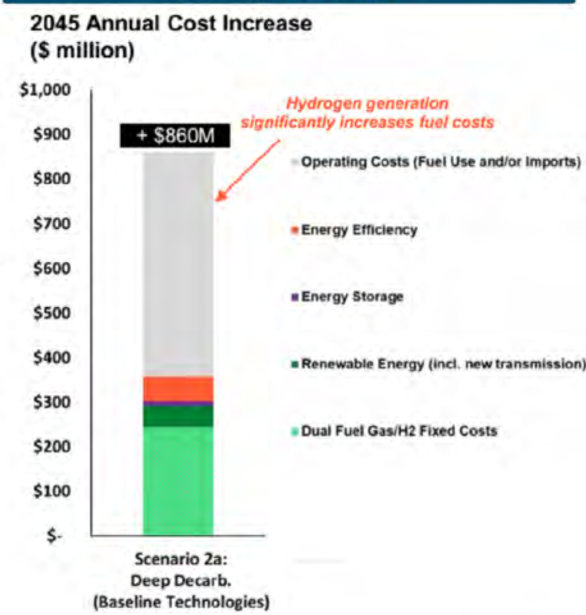
Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)



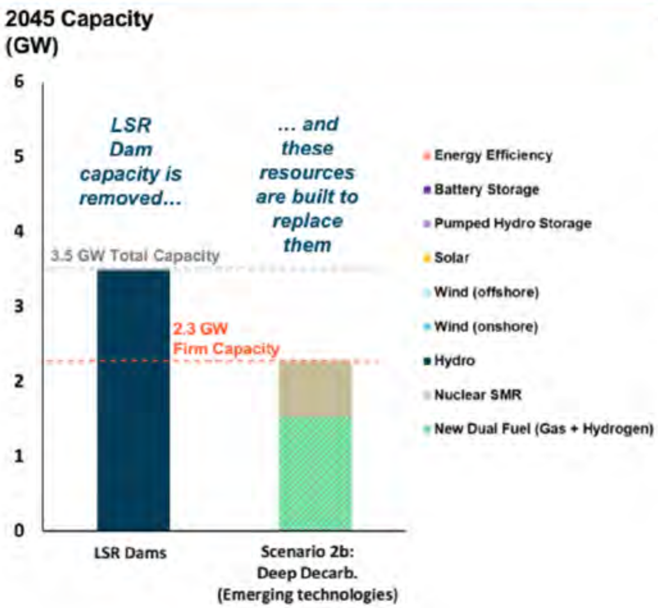
Additional Cost (2045)



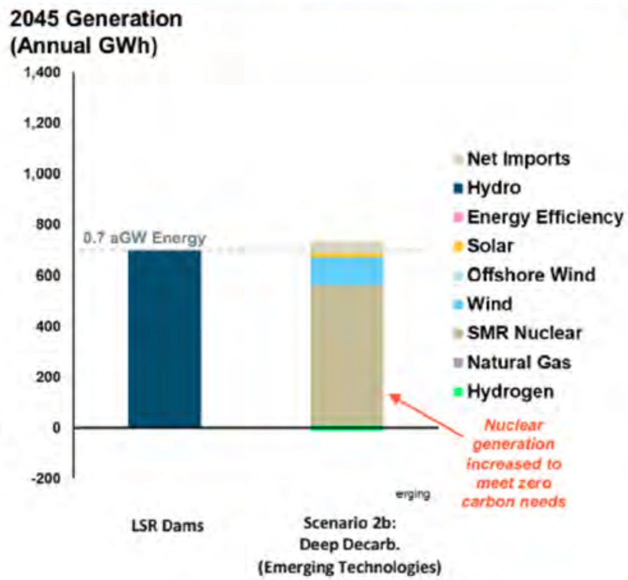
27693383(01).pdf

Replacing the Lower Snake River Dams
Scenario 2b: Deep Decarbonization (Emerging Technologies)

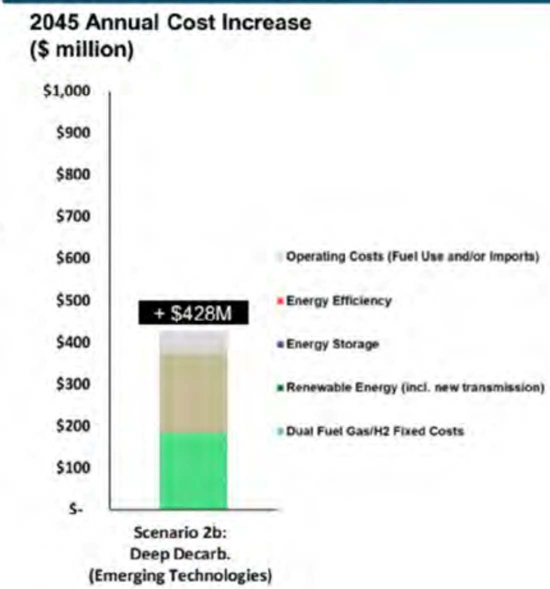
Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)



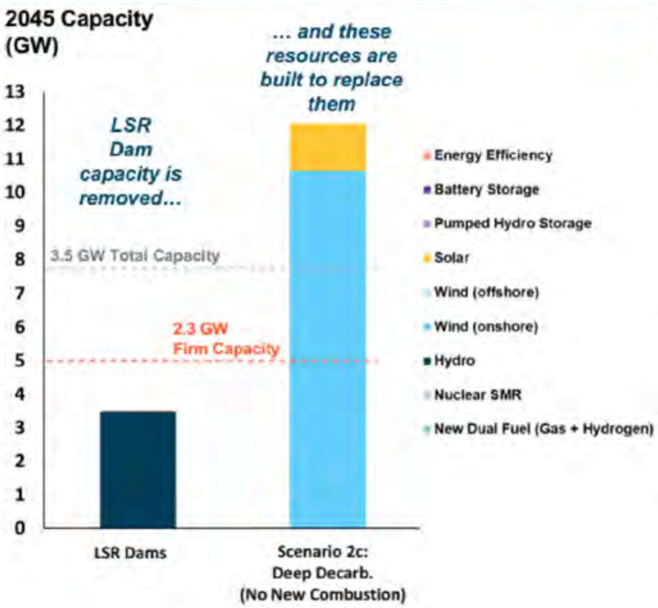
Additional Cost (2045)



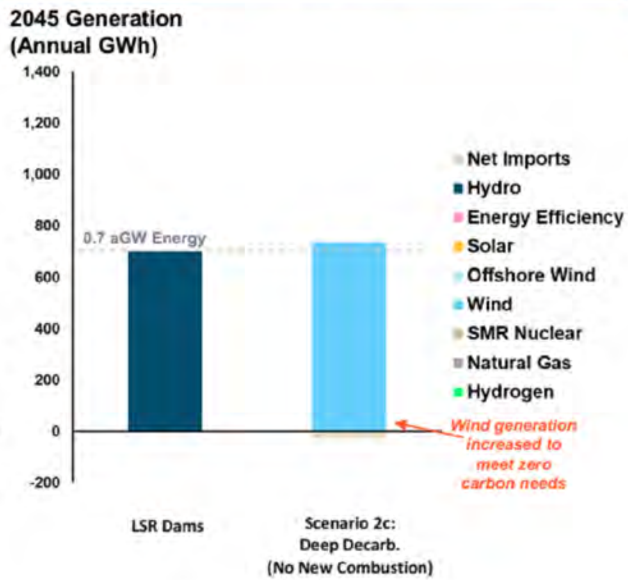
27693383(01).pdf

Replacing the Lower Snake River Dams
Scenario 2c: Deep Decarbonization (No New Combustion)

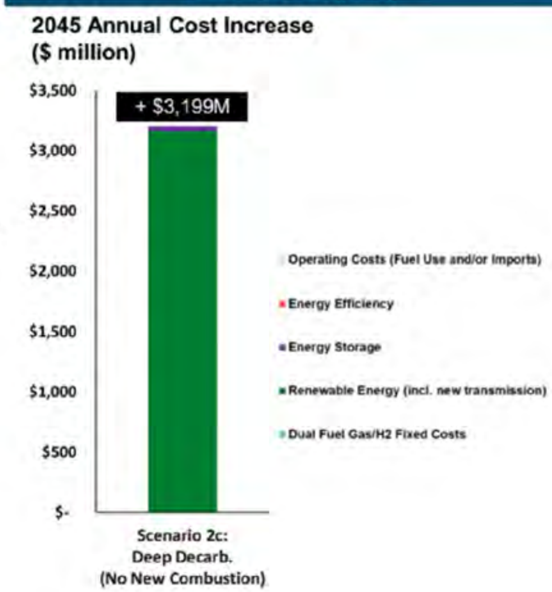
Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)



Additional Cost (2045)



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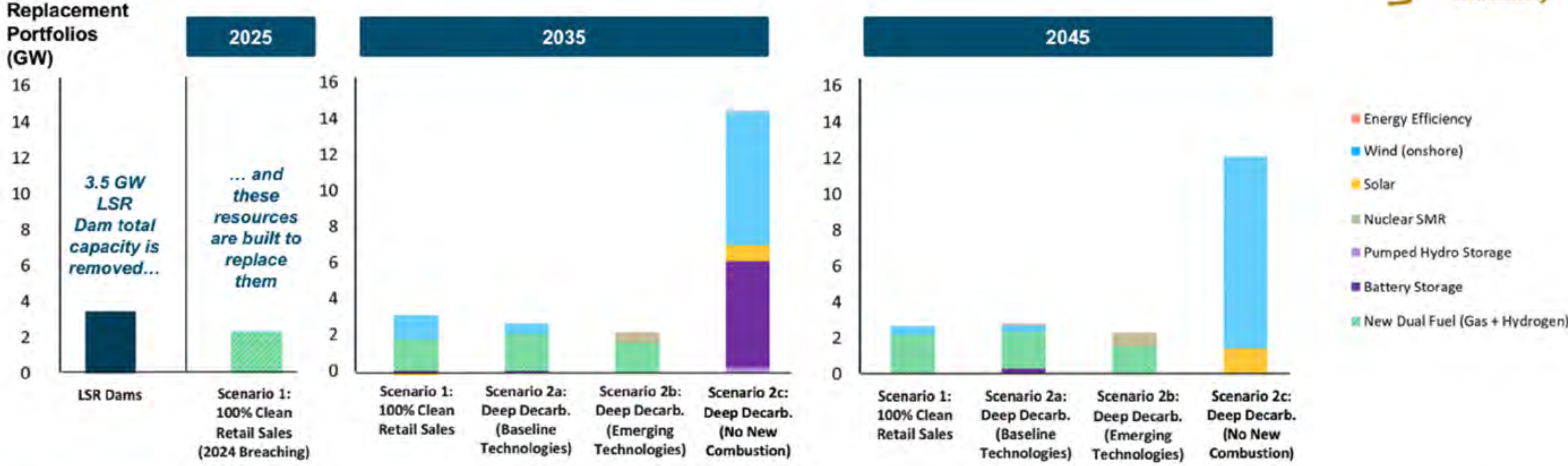
Replacing the Lower Snake River Dams Capacity Across All Scenarios

- Scenario 1 (100% Clean Retail Sales, 2032 LSR Dams breaching): shown in previous slide
- **Scenario 1 (100% Clean Retail Sales, 2024 LSR Dams breaching): similar to scenario 1, but with dual fuel natural gas + hydrogen turbine replacement in 2025**
- Scenario 2a (Deep Decarbonization, Baseline Technologies): shown in previous slide
- **Scenario 2b (Deep Decarbonization, Emerging Technologies): small modular nuclear reactors replace LSR capacity and energy, instead of additional wind power**
- **Scenario 2c (Deep Decarbonization, No New Combustion): very high replacement need as wind and solar alone struggle to replace LSR dam firm capacity and zero-carbon energy output**

Limited load growth, carbon emissions remain in 2045

High load growth, carbon emissions eliminated by 2045… sensitive to emerging technology availability



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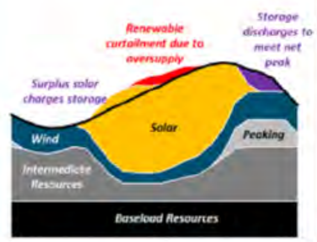
Appendix B: Additional Modeling Inputs

RESOLVE optimizes investments to meet clean energy targets reliably

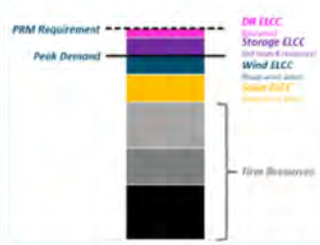
RESOLVE is an optimal capacity expansion model specifically designed to identify least-cost plans to meet reliability needs and achieve compliance with regulatory and policy requirements

- **Linear optimization model explicitly tailored to study challenges to arise at high penetrations of variable renewables and energy storage**
- **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**

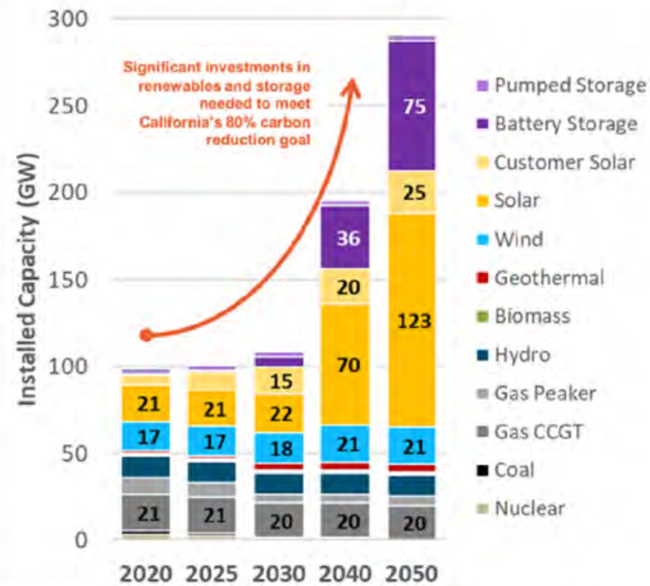
Operational module simulates hourly system operations for a sample of representative days



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



Least-cost plan cooptimizes 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

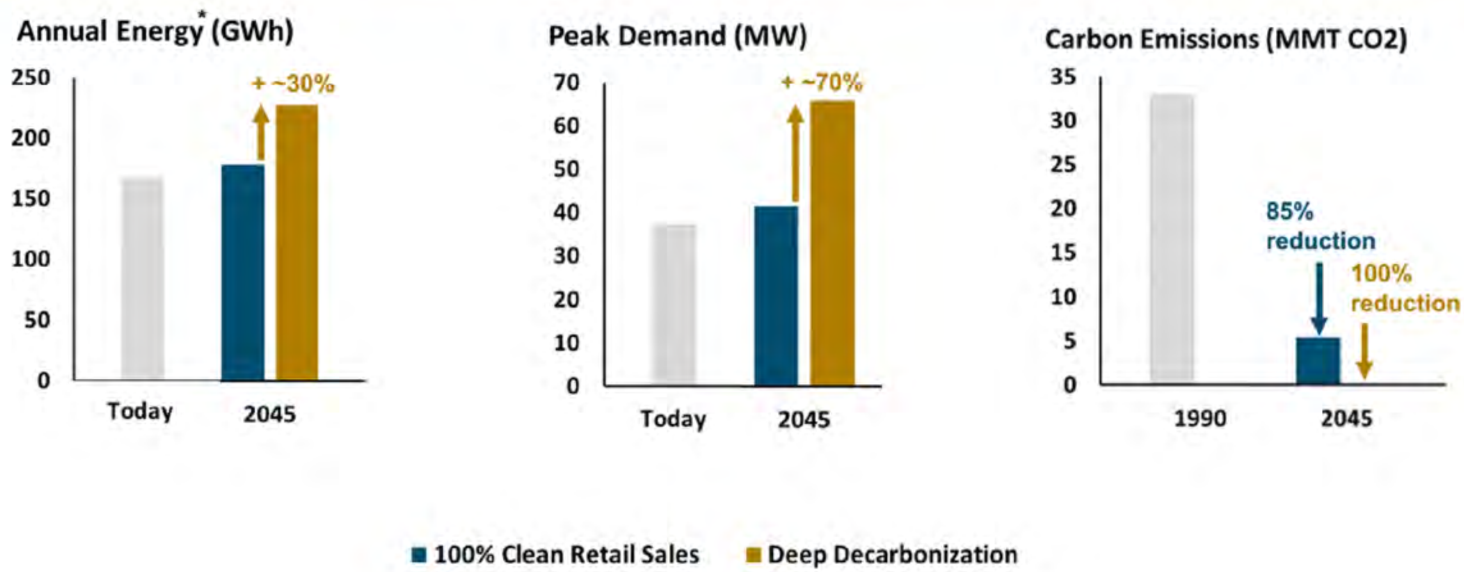


Example RESOLVE result from *Long-Run Resource Adequacy under Deep Decarbonization Pathways for California* (Calpine, 2019)

28

Load growth and carbon emissions in two clean energy scenarios modeled

Increases in Electricity Use and Declines in Carbon Emissions

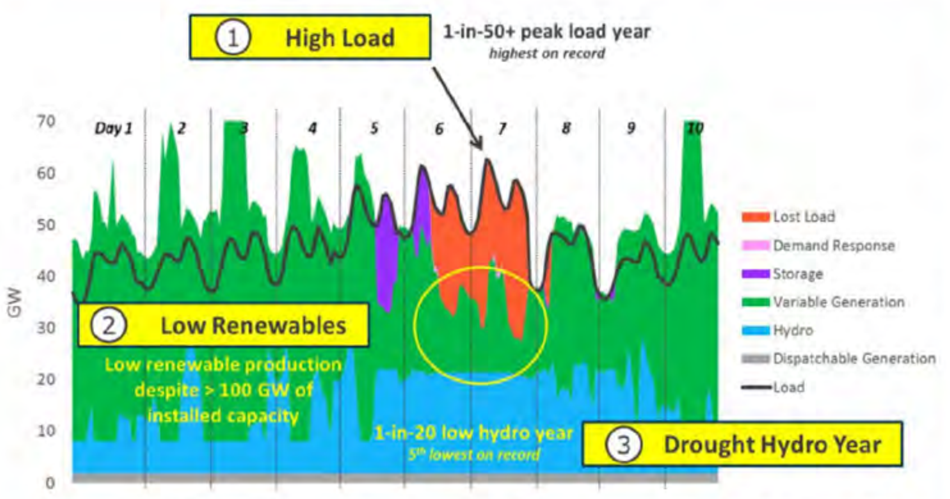


* Load based on 2021 NWPCC Power Plan, shown as retail sales (after assumed growth in customer PV and energy efficiency)

Resource Adequacy Resource Options

+ **RESOLVE resource adequacy constraint requires capacity to meet peak demand + a 15% planning reserve margin**
  - Planning reserve margin (PRM) constraint is "installed capacity" (ICAP) based for firm resources, peaking capacity for hydro, ELCC for other non-firm resources
+ **The nature of the Northwest reliability risk limits the ability of battery storage to provide reliable capacity contributions**
  - Storage and hydro show "antagonistic" interactions, which limit energy storage reliability value in "energy-limited" conditions where energy storage resources are unable to charge (with low hydro and renewable output) and run out of discharge (during extended energy shortfall events)

Key Drivers of Future Pacific Northwest Reliability Events



Sample week in 2050 in a 100% GHG reduction scenario, from E3, *Resource Adequacy in the Pacific Northwest*, 2019.

Resource	RA Capacity Contributions
Hydro	65%, based on sustained winter peaking capacity in critical water year conditions (per BPA/PNUCC)… WRAP method is still evolving
Battery storage	Sharply declining ELCCs*
Pumped storage	Sharply declining ELCCs*
Solar	Declining ELCCs
Wind	Declining ELCCs
Demand Response	Declining ELCCs
Energy Efficiency	Limited potential vs. cost
Small Hydro	Limited potential
Geothermal	Limited potential
Natural gas to H2 retrofits	Clean firm, but not fully commercialized
New dual fuel natural gas + H2 plants	Clean firm, but not fully commercialized
New H2 only plants	Clean firm, but not fully commercialized
Gas w/ 90-100% carbon capture + storage	Clean firm, but not fully commercialized
Nuclear Small Modular Reactors	Clean firm, but not fully commercialized

* E3 performed a sensitivity with battery ELCCs that do not decline so sharply. This sensitivity did change the LSR dam replacement resources and costs.

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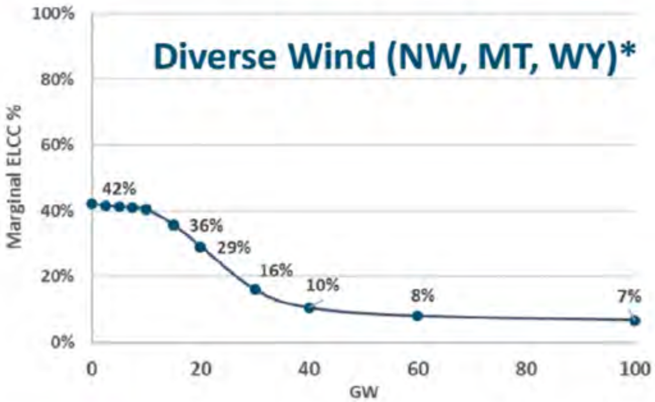
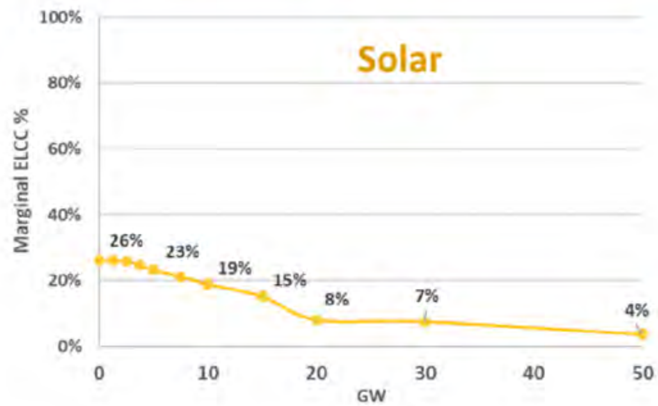
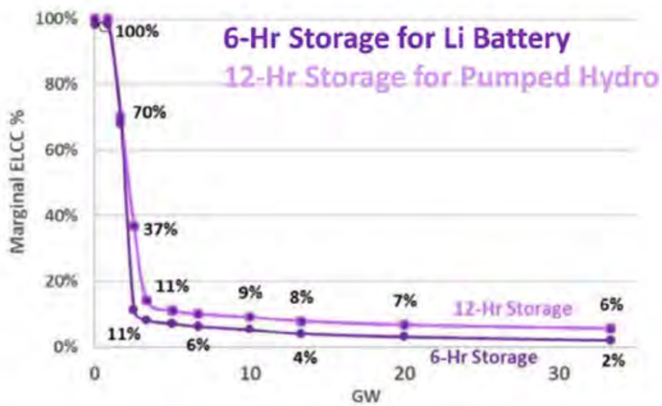
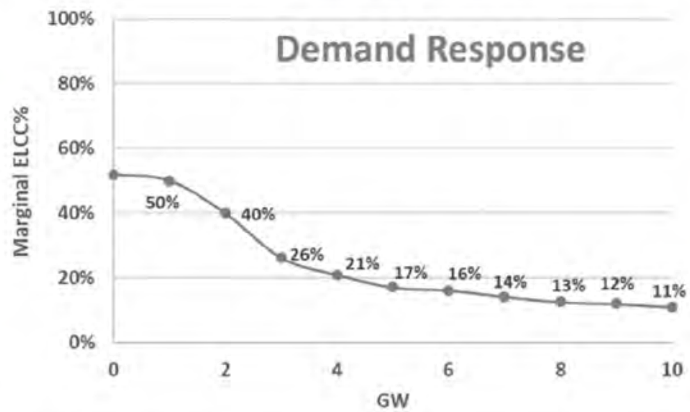
Incorporating Declining Capacity Contributions of Renewables, Storage, and DR









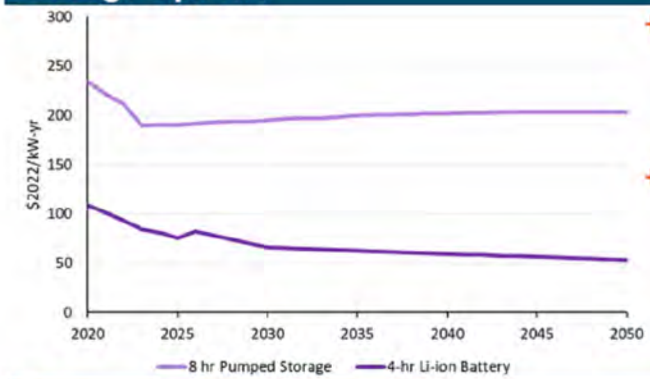
+ A reliable electric system requires enough capacity to meet peak loads and contingencies
+ This study incorporates information from E3's 2019 report *Resource Adequacy in the Northwest* about the effective capacity contribution of renewables, storage, and DR at various penetration levels

* The offshore wind sensitivity in this study assumed the same ELCC curve as modeled for diverse on-shore wind resources in the Resource Adequacy in the Northwest report.

ELCC = Effective Load Carrying Capability = firm contribution to system peak load

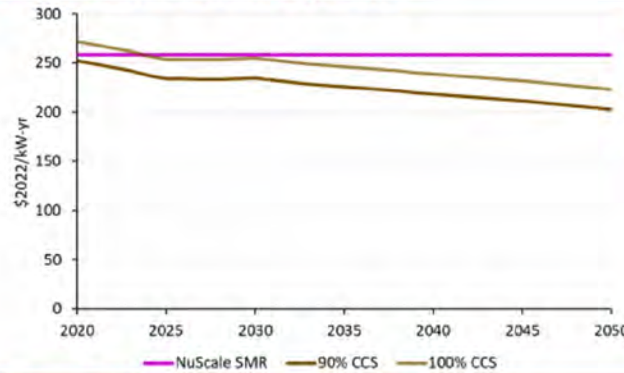
New Resource Options
All-in Fixed Costs

Storage Options



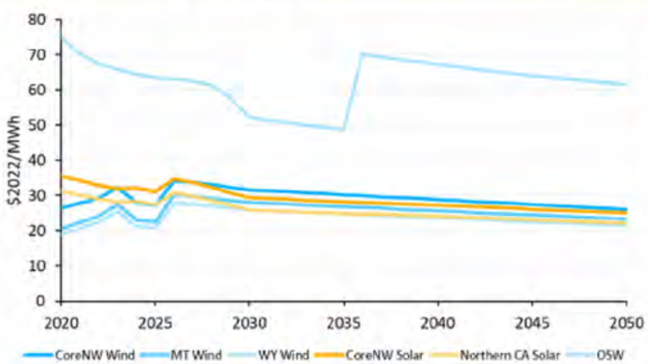
+ Battery Storage costs derived from E3's inhouse and Lazard LCOS 7.0 (Oct 2021)
+ Pumped storage is from Lazard's last published PHS costs (LCOS 4.0). Assumes CAPEX and FO&M are flat + financing cost trends same for battery storage.

Firm Low Carbon Options



+ CCS costs derived from E3's inhouse "Emerging Tech" ProForma
+ SMR costs are derived from the vendor NuScale, for an "nth of a kind" installation of the technology they are developing

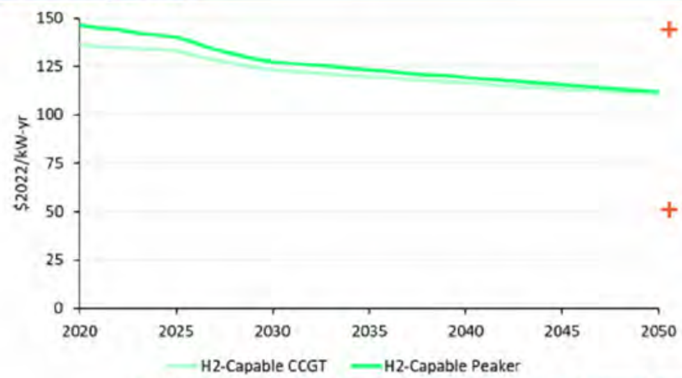
Renewable Options



Renewable costs derived from E3's in house Pro Forma which integrates NREL ATB 2021

Costs shown here do not include the cost of upgraded or new Transmission lines

Gas Options

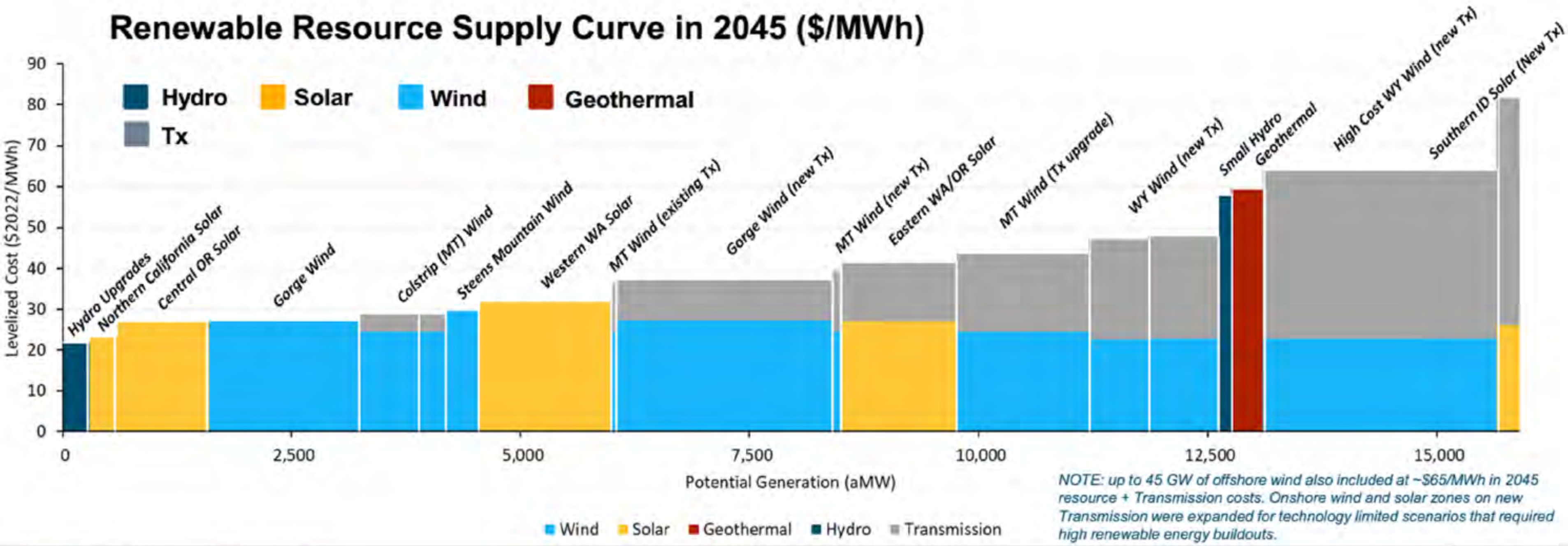


+ CCGT and peaker costs are derived from E3's inhouse ProForma which integrates NREL ATB 2021
+ New Hydrogen or upgrades include a ~10% additional cost that converges by 2050

NOTE: only dual fuel natural gas + H2-enabled new resources modeled, given NW policy constraints

New Resource Options
Renewables

+ The following supply curves integrate Transmission costs that RESOLVE sees
+ The "no new combustion" scenario required increases in the supply of wind on new transmission (Northwest, MT+WY, and offshore) to enable a feasible solution



NOTE: up to 45 GW of offshore wind also included at ~$65/MWh in 2045 resource + Transmission costs. Onshore wind and solar zones on new Transmission were expanded for technology limited scenarios that required high renewable energy buildouts.

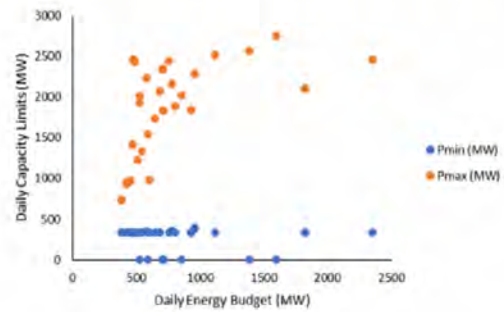
Hydro Operating Data

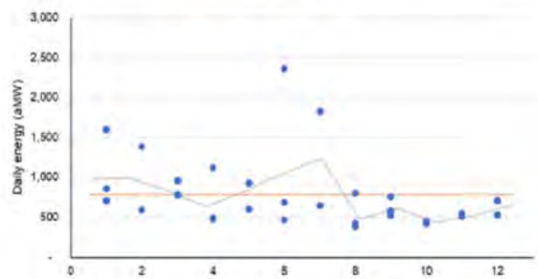
+ **Key RESOLVE inputs (for each representative RESOLVE day)**
  - Max generation MW
  - Min generation MW
  - Daily MWh hydro budget
  - Ramp
+ **Hydro operating data is parameterized using representative conditions for 3 low/mid/high historical years (2001, 2005, 2011)**
  - Lower Snake River and lower Columbia River dams were adjusted per BPA hydro modeling w/ latest fish spill constraints
+ **Hydro firm capacity contribution is assumed to be 65% of total MW, per PNUCC methodology (based on BPA 10-hr sustaining peaking capacity)**

LSR Hydro

Ramp Rates

Hydro Resource	1-hr	2-hr	3-hr	4-hr
LSR_Hydro	36%	43%	45%	48%

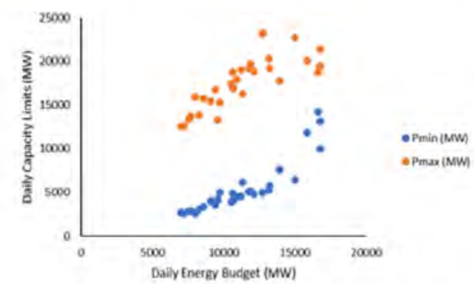


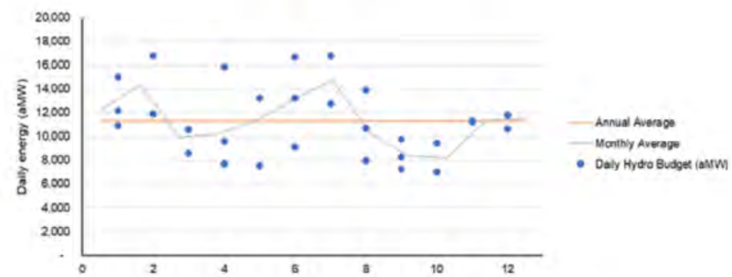


Non-LSR NW Hydro

Ramp Rates

Hydro Resource	1-hr	2-hr	3-hr	4-hr
CoreNW_Hydro	14%	23%	30%	34%





27693383(01).pdf

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Wednesday, June 29, 2022 9:03 PM
To:	Arne Olson; James,Eve A L (BPA) - PG-5
Cc:	Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian
Subject:	[EXTERNAL] RE: Draft Exec Summary
Attachments:	BPA_RESOLVE_PublicDeck_v6.pptx; E3_BPA_LowerSnakeRiverDams_draft_062922.pdf

Deliberative, FOIA exempt

Updated public summary deck attached w/ NPV values updated. We are now proposing to use the 3% NPV discount rate, which increases the NPV. This is better representative of the public power cost of capital and more closely aligns with the discount rates used in the Inslee/Murray report.

Report draft coming in the next email.

Aaron

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, June 29, 2022 5:47 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: Draft Exec Summary

Energy GPS study is out:

If the LSRD are removed, an additional 14,900 MW of resources will be required. This is 23% of the Pacific Northwest's current generation capacity and enough to power 15 cities the size of Seattle.

https://www.linkedin.com/pulse/new-report-value-lower-snake-river-dams-effectively-/?trackingId=kLZaTd9mS%2F2IeThVJO4L0w%3D%3D

I think it would behoove us to put together a little comparison of the three studies.

Should be done with my edits on ours in the next hour.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, June 29, 2022 4:23 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Sounds good- thanks Aaron!

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, June 29, 2022 4:22 PM

To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] Re: Draft Exec Summary

Deliberative, FOIA exempt

Hi Eve,

The report version is the updated/corrected version. The 1b 2024 retirement case had too high an NPV previously. I'll send an updated public deck when I send the report over in a bit.

Aaron

Get Outlook for iOS

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, June 29, 2022 3:49:49 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Hi Aaron-
As I was going through the report and working on some internal talking points I noticed the NPV values in the draft report chart weren't matching the chart in the public presentation slide (see below). Can you let me know which table is correct? I can see rounding for 2b but for Scenario 1 2024 breach it isn't rounding error. If the slide deck needs updating could you send me a new version so I can make sure I have the correct materials to post?

Thanks,
Eve

Table 12. Total LSR Dams replacement costs[21]

	NPV Total Costs (Real 2022 $)	Annual Costs Increase (Real 2022 $)			Incremental Public Power Costs
	In the year of breaching (2032 or 2024)	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$7.4 billion	n/a	$434 million	$478 million	0.8 ₵/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$8.6 billion	$495 million	$466 million	$509 million	0.8 ₵/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$11.3 billion	n/a	$496 million	$860 million	1.5 ₵/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$6.7 billion	n/a	$415 million	$428 million	0.7 ₵/kWh [+8%]
Scenario 2c: Deep Decarb. (No New Combustion)	$46 billion	n/a	$1,953 million	$3,199 million	5.5 ₵/kWh [+65%]

	Total Costs (real 2022 $)
	Net Present Value in year of breaching
Scenario 1: 100% Clean Retail Sales	$7.5 billion
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$11 billion
Scenario 2a: Deep Decarb. (Baseline Technologies)	$11.5 billion
Scenario 2b: Deep Decarb. (Emerging Technologies)	$7 billion
Scenario 2c: Deep Decarb. *(No New Combustion)*	*$46 billion*

Deep decarbonization without emerging technologies drives impractically high costs

---

From: James,Eve A L (BPA) - PG-5
Sent: Wednesday, June 29, 2022 12:17 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt
Sounds good- I'll start reading and making notes to add to the version this afternoon.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, June 29, 2022 12:14 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: Draft Exec Summary

Deliberative, FOIA exempt

Eve,

Arne is still completing some edits, but I'm sending this "interim" draft version so you have the full report to start digging through. I'll send another version later today with all of Arne's edits, so suggest *E3 retains version control until later today when we share that version*, when it will transfer to BPA.

Note: Arne has made some changes to the exec summary, which I've keep tracked since you already reviewed that. I updated is response to your prior feedback (but did not track those changes).

All the best,
Aaron

From: Aaron Burdick
Sent: Tuesday, June 28, 2022 9:43 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Eve,

Status update: we're still working on a few remaining items in the draft and incorporating Arne's review. I'm hoping to send you the draft by mid-day tomorrow. Will either send of provide an update until then. I'm hoping we can get your review by end of day Thursday and update as needed on Friday before sharing the final version by Friday COB.

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Monday, June 27, 2022 3:36 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt
Hi Aaron-
Attached are some comments on the Executive Summary for your consideration.

Arne- I saw the Council's note on providing materials ahead of the July 7th meeting. Internally we were thinking that if we share the PPT this early we would need to be prepared to start fielding incoming questions and for the info to be shared with others. We're still working on some talking points for our communications staff and Account Executives. Also, just so you are aware there is a discussion with some of DC folks tomorrow so I was going to wait and email the Council staff tomorrow after that meeting if you don't mind. If you have concerns about waiting to share materials please let me know.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, June 24, 2022 3:12 PM

To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] Draft Exec Summary

Deliberative, FOIA exempt

Hi Eve,

I'm leaving for a weekend trip and OOO the rest of the afternoon. I'm providing the draft executive summary but the rest of the report draft will need to wait until Tuesday next week. Hopefully this provides enough to make sure we're aligned. I'm also copying the TOC for the draft report to make sure you're aware what we're working on.

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All the best,

Aaron Burdick, Associate Director
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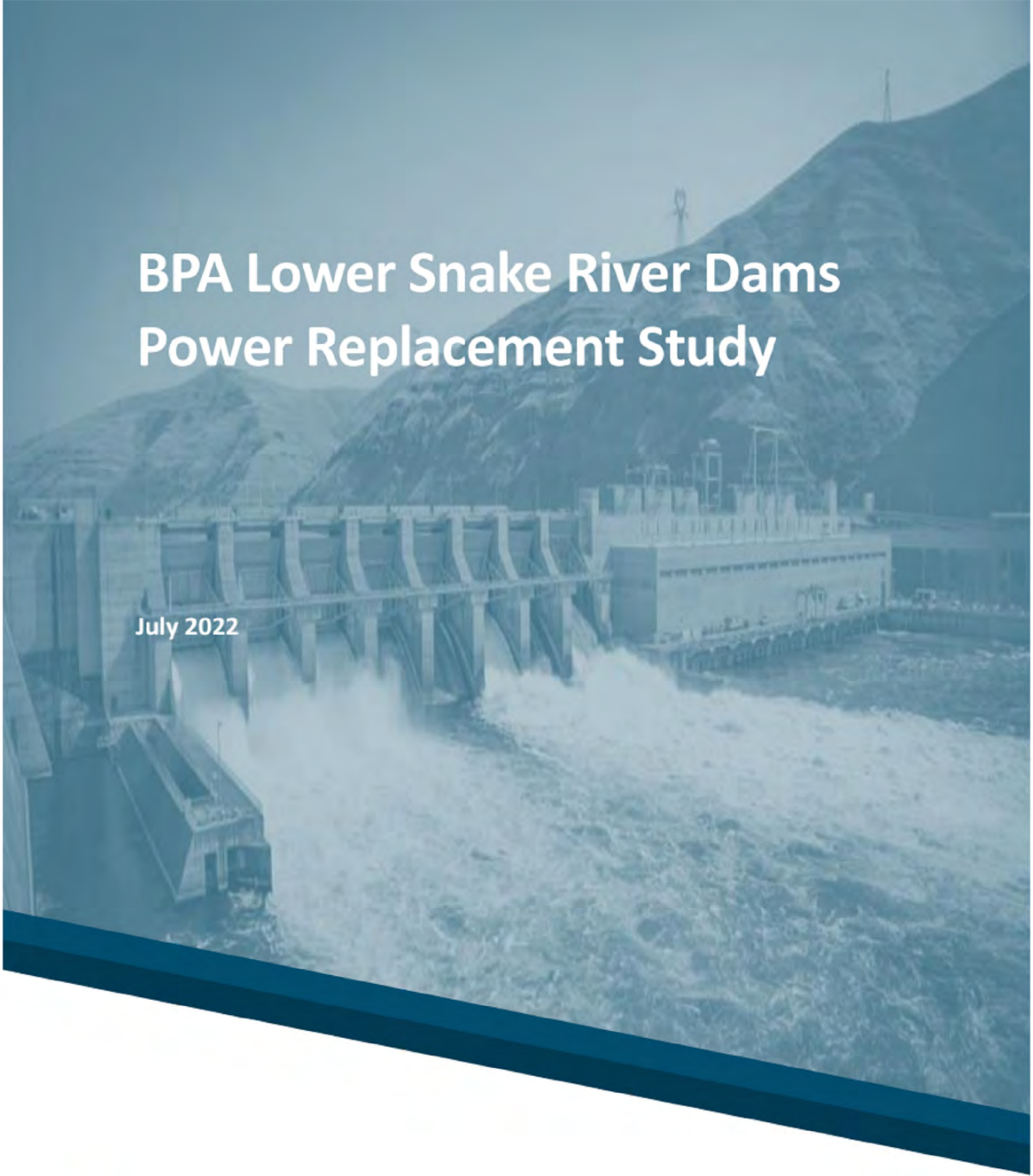

BPA Lower Snake River Dams Power Replacement Study

July 2022

Energy+Environmental Economics

BPA Lower Snake River Dams Power Replacement Study

July 2022

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27693389(01).pdf

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Acronym Definitions

Acronym	Definition
BPA	Bonneville Power Administration
BTM Solar	Behind-the-meter Solar
CA	California
CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
CES	Clean Energy Standard
CRSO EIS	Columbia River System Operations Environmental Impact Statement
DR	Demand response
EE	Energy efficiency
EIA	Energy Information Administration
ELCC	Effective load carrying capability
HDV	Heavy-duty vehicles
H2	Hydrogen
LDV	Light-duty vehicles
LSR	Lower Snake River
NERC	North American Electric Reliability Corporation
NG	Natural Gas
NV	Nevada
NW	Northwest
PNUCC	Pacific Northwest Utilities Conference Committee
PRM	Planning Reserve Margin
RM	Rocky Mountains
RPS	Renewable Energy Standard
SMR	Small modular reactor
SW	Southwest
WECC	Western Electricity Coordinating Council

Executive Summary

E3 was contracted by the Bonneville Power Administration to conduct an independent study of the value of the lower Snake River dams ("LSR dams") to the Northwest power system. The dams provide approximately 3,500 megawatts ("MW") of total capacity[1] and approximately 2,300 MW of firm peaking capability[2] to support regional reliability. They also generate approximately 900 average MW of zero-carbon energy each year[3], provide essential grid services such as operating reserves and voltage support, and operational flexibility to support renewable integration. If the dams are breached, these power services will need to be replaced to ensure the Northwest power system can continue to provide reliable electricity service. Replacing the dams is complicated by the clean energy policies adopted either statutorily or voluntarily by jurisdictions and utilities throughout the region, which will necessitate a transformation of the power system over time toward non-emitting resources even as electricity demand grows substantially due to electrification of the transportation and building sectors.

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho, and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability. RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[4]. Using RESOLVE allows for a dynamic optimization that considers replacement resource needs in the context of long-term system load and policy drivers, not just the near-term resource mix and needs of the system today. The dams are assumed to be breached in 2032, except for one sensitivity that considered 2024 breaching.

---

[1] Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. The "total capacity" refers to the overload capacity, not the nameplate capacity. Historical peak generation was 3,431 MW.

[2] LSR dam firm capacity contributions are estimated using the PNUCC regional hydropower 65% capacity value, which was validated by looking at LSR Dam wintertime power and reserve provision during low hydro conditions. Additionally, E3 considered estimates on the impact of a lower firm capacity value in the results chapter.

[3] The data for the LSR dams was adjusted to reflect the Preferred Alternative operations defined in the Columbia River Systems Operation Environmental Impact Statement (CRSO EIS). E3's RESOLVE model uses 2001, 2005, and 2011 hydro years, which resulted in ~700 average MW of lower Snake River dams generation, making it a conservative estimate of the dams' GHG-free energy value.

[4] Pacific Northwest Low Carbon Scenario Analysis, December 2017, https://www.ethree.com/projects/study-policies-decarbonize-electric-sector-northwest-public-generating-pool-2017-present/; Pacific Northwest Zero-Emitting Resources Study, January 2020, https://www.ethree.com/e3-examines-role-of-nuclear-power-in-a-deeply-decarbonized-pacific-northwest/

This study's scenario design focuses on three key variables – clean energy policy, load growth, and emerging technology availability – that impact the cost to replace the dams. The scenarios and key assumptions are show in Table 1.

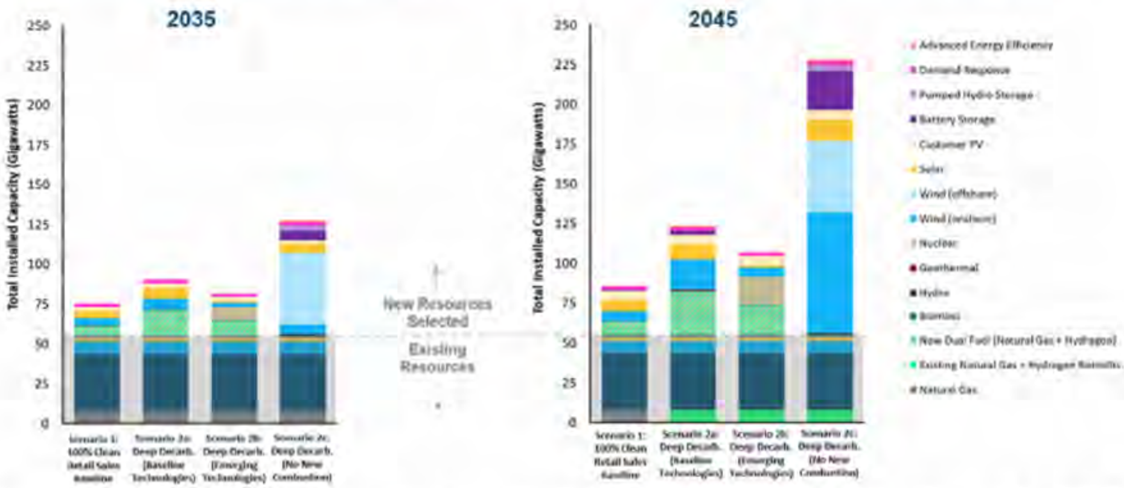
Table 1. Scenario Design

Scenario	Clean Energy Policy	Load Growth	Technology Availability
1 100% Clean Retail Sales[1]	100% retail sales (85% carbon reduction)	8th Power Plan Baseline	Baseline (incl. natural gas / hydrogen dual fuel plants)
2a Deep Decarbonization (Baseline Tech.)	100% carbon reduction	High Electrification	Baseline
2b Deep Decarbonization (Emerging Tech.)	100% carbon reduction	High Electrification	Baseline + offshore wind, gas w/ CCS, nuclear SMR
2c Deep Decarbonization (No New Combustion)	100% carbon reduction	High Electrification	Baseline (excluding natural gas / hydrogen dual fuel plants

Even with the dams in place, the region's clean energy goals and potential electrification load growth drive a significant need for new resources. In all scenarios, significant energy efficiency and customer solar is embedded into the load forecast, based on the NWPCC's 8th Power Plan. Additionally, 6 gigawatts ("GW" or 6,000 MW) of coal capacity is retired by 2030, while increasing carbon prices incent further clean energy resource additions. In Scenario 1, the regional power system is required to meet a goal of generating enough clean energy to provide 100% of retail electricity sales, on an average basis over a calendar year. This requires an additional 5 GW of solar and 5 GW of wind by 2045 to achieve the clean energy goal; 0.6 GW of battery storage, 2 GW of demand response, and 9 GW of dual fuel natural gas + hydrogen combustion plants are also added to meet the region's resource adequacy needs.

Though all scenarios require more "firm" resources – resources that can start when needed and operate for as long as needed – to meet peak loads, these resources are in higher demand in Scenario 2, in which all greenhouse gas emissions are eliminated from the regional power system by 2045. This scenario also assumes that electrification results in much higher electric loads, particularly in wintertime due to electrification of natural gas space heating in buildings. The baseline scenario (2a) selects additional wind, solar, and geothermal to meet clean energy needs as well as demand response, some battery storage, and 27 GW natural gas and hydrogen dual fuel combustion plants to meet reliability needs. An alternative "emerging technology" scenario selects 17 GW of advanced nuclear technology (small modular reactors or "SMRs") by 2045, in place of the firm capacity provided by natural gas generators while reducing the required quantities of wind, solar and batteries that are needed. The "no new combustion" scenario does not allow clean firm technologies such as hydrogen combustion turbines, gas generation with carbon capture and sequestration (CCS) or SMRs. As a result, it requires impractically high levels of additional onshore wind, offshore wind, and battery storage to meet firm capacity and carbon reduction needs, quadrupling the total installed MW of the Northwest grid by 2045.

Figure 1. Northwest Installed Capacity Mix in Scenarios with the Lower Snake River Dams



When the power services provided by the dams are removed from the regional power system, RESOLVE selects an optimal, i.e., least-cost portfolio of replacement resources that meets the Northwest's clean energy and system reliability needs. These replacement resources require a large investment and come at a substantial cost that increase over time as the region's clean energy goals become more stringent. In the latter years, the replacement costs are highly dependent on scenario-specific assumptions about the availability of emerging technologies. RESOLVE primarily replaces the carbon-free energy from the dams with additional wind power and the firm capacity with dual fuel natural gas and hydrogen combustion plants. Small amounts of additional energy efficiency and battery storage are also selected in some scenarios. By 2045, the dual fuel plants added burn additional hydrogen on low wind days to replace the carbon-free energy provided by the dams. Scenario 2b selects additional nuclear SMRs in lieu of some of the wind and gas resources. Scenario 2c disallows the new combustion plants, even those that would burn green hydrogen, and other emerging technologies, requiring a very large buildout of wind and solar power to replace both the firm capacity and the carbon-free energy of the dams.

The long-term emissions impact of removing the generation of the lower Snake River dams will depend on the implementation of the Oregon and Washington electric clean energy policies. Both a 100% clean retail sales and a zero-carbon emissions target require replacement of most or all of the LSR dams' GHG-free energy. However, without additional earlier carbon-free resource investments beyond those modeled in this study to meet clean energy policy trajectories, carbon emissions may increase initially when the dams are breached, before declining by 2045 as the carbon policy becomes more stringent.

Table 2. Summary of LSR Dams Replacement Resources and Cost Impacts (costs in the table below and throughout this report are shown in real 2022 dollars)

Scenario	Replacement Resources Selected, Cumulative by 2045 (GW)	NPV Replacement Costs[5]	Annual Replacement Costs[6]			Public Power Rate Impact[7]
			2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind	$11.8 Billion	-	$434 million/yr	$478 million/yr	0.8 ¢/kWh [+9%]
Scenario 1b: 100% Clean Retail Sales (2024 dam removal)	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind	$12.8 Billion	$495 million/yr	$466 million/yr	$509 million/yr	0.8 ¢/kWh [+9%]
Scenario 2a: Deep Decarbonization (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW [illegible] + 1.2 TWh H2-fueled generation	$19.0 Billion	-	$496 million/yr	$860 million/yr	1.5 ¢/kWh [+18%]
Scenario 2b: Deep Decarbonization (Emerging Technologies)	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR	$10.7 Billion	-	$415 million/yr	$428 million/yr	0.7 ¢/kWh [+8%]
Scenario 2c: Deep Decarbonization (No New Combustion)	+ 10.6 GW wind + 1.4 GW solar	$75.2 billion	-	$1,953 million/yr	$3,199 million/yr	5.5 ¢/kWh [+65%]

KEY FINDINGS:

- ***Replacing the four lower Snake River dams while meeting clean energy goals and system reliability is possible but comes at a substantial cost***, even assuming emerging technologies are available:
  - Requires 2,300 – 2,700 MW of replacement resources
  - An annual cost of $415 million – $860 million by 2045
  - Total net present value cost of $10.7-19.0 billion based on 3% discounting over a 50-year time horizon following the date of breaching
  - Increase in costs for public power customers of $100 – 230 per household per year (an 8 – 18% increase) by 2045
- The biggest cost drivers for replacement resources are the need to replace the lost ***firm capacity for regional resource adequacy*** and the need to replace the lost ***zero-carbon energy***
- Replacement becomes ***more costly over time*** due to increasingly stringent clean energy standards and electrification-driven load growth

[5] These NPV values are calculated assuming a 3% discount rate to represent the public power cost of capital, discounting 50-year of costs starting from the year of breaching (either 2032 or 2024).

[6] Replacement resource costs are calculated assuming project financing per E3's pro forma calculator, rather than assuming upfront congressional appropriation.

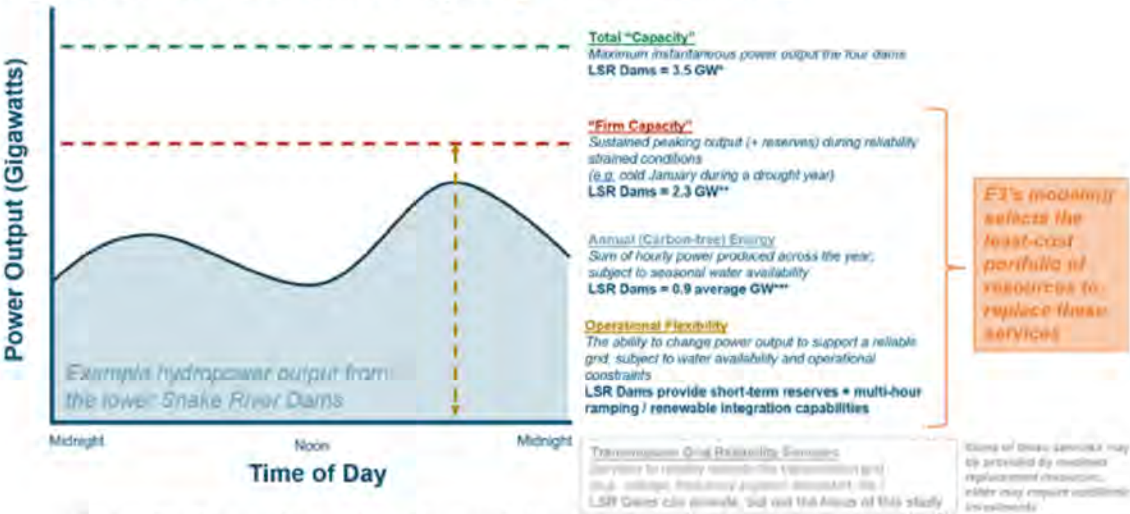
[7] This assumes that the annual replacement costs will be borne by BPA's Tier I public power customers. Percentage changes are shown relative to today's average OR + WA retail rate of ~8.5 ¢/kWh.

- ***Emerging technologies*** such as hydrogen, advanced nuclear, and carbon capture ***can limit the cost of replacement resources*** to meet a zero emissions electric system, but the pace of their commercialization is highly uncertain
    - In economy-wide deep decarbonization scenarios, ***replacement without any emerging technologies requires very large renewable resource additions at a very high cost*** (12 GW of wind and solar at $75.2 billion NPV cost)

Background

E3 was contracted by the Bonneville Power Administration to conduct an independent study of the value of the lower Snake River dams ("LSR dams") to the Northwest power system. The dams provide approximately 3,500 megawatts ("MW") of total capacity[8] and approximately 2,300 MW of firm peaking capability[9] to support regional reliability. They also generate approximately 900 average MW of zero-carbon energy each year, provide essential grid services such as operating reserves and voltage support, and operational flexibility to support renewable integration. Figure 2 shows the power services that are the focus of this study and those that are out of scope.

Figure 2. Power Services Considered for Replacement in this Study



* Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. Historical peak generation was 3,431 MW.

** Firm capacity assumed in this study is consistent with the ~65% Northwest hydro capacity value assumed by PNUCC (the Pacific Northwest Utilities Conference Committee).

*** Average GW means that on average across an average year the plant generated at 0.9 GW, though its hourly output may be above or below that amount. The data for the LSR dams was adjusted to reflect the Preferred Alternative operations defined in the Columbia River Systems Operation Environmental Impact Statement ("CRSO EIS"). E3's RESOLVE model uses 2001, 2005, and 2011 hydro years, which resulted in ~700 average MW of lower Snake River dams generation, making it a conservative estimate of the dams' GHG-free energy value.

If the dams are breached, these power services will need to be replaced to ensure the Northwest power system can continue to provide reliable electricity service. Replacing the dams is complicated by the clean energy policies adopted either statutorily or voluntarily by jurisdictions and utilities throughout the region,

[8] Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. The "total capacity" refers to the overload capacity, not the nameplate capacity. Historical peak generation was 3,431 MW.

[9] LSR dam firm capacity contributions are estimated using the PNUCC regional hydropower 65% capacity value, which was validated by looking at LSR Dam wintertime power and reserve provision during low hydro conditions. Additionally, E3 considered estimates on the impact of a lower firm capacity value in the results chapter.

which will necessitate a transformation of the power system over time toward non-emitting resources even as electricity demand grows substantially due to electrification of the transportation and building sectors.

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability. RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[10]. Using RESOLVE allows for a dynamic optimization that considers replacement resource needs in the context of long-term system load and policy drivers, not just the near-term resource mix and needs of the system today. The dams are assumed to be breached in 2032, except for one sensitivity that considered 2024 breaching.[11]

Key Study Questions:

+ What **additional resources** would be needed to replace the power services provided by the LSR Dams through 2045?
+ What is the **net cost to** BPA ratepayers?
+ How do costs and resource needs change under **different types of clean energy futures**?
+ How much does replacing the dams rely on **emerging, not-yet-commercialized technologies**?

This study builds off previous LSR dams replacement analysis by using a least-cost optimization-based modeling framework to replace the dams' power services. This optimization ensures that the region meets its aggressive clean energy policy goals, including both decarbonization of electricity as well as high electrification load growth consistent with economy-wide decarbonization goals set by Oregon and Washington.

The other key component of the optimization is maintaining resource adequacy for the region to ensure a reliable electricity supply to existing and any newly electrified loads. This is done using a planning reserve margin constraint and counting non-firm resources like solar, wind, battery storage, pumped hydro storage, and demand response at their effective load carrying capability ("ELCC"), based on E3's prior detailed loss of load probability modeling of the Northwest region.[12]

---

[10] Pacific Northwest Low Carbon Scenario Analysis, December 2017, https://www.ethree.com/projects/study-policies-decarbonize-electric-sector-northwest-public-generating-pool-2017-present/; Pacific Northwest Zero-Emitting Resources Study, January 2020, https://www.ethree.com/e3-examines-role-of-nuclear-power-in-a-deeply-decarbonized-pacific-northwest/

[11] The study examines LSRD breaching in 10 years (2032) and in 2 years (2024), based on with the approach used in the CRSO EIS.

[12] Resource Adequacy in the Pacific Northwest, March 2019, https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

This modeling framework ensures that when the LSR dams are removed from the Northwest power system, a least-cost replacement mix of new investments and operational changes is found. Through the constraints of the optimization, this least-cost replacement mix meets the same clean energy policy and level of reliability as a system with the LSR dams still intact. This dynamic approach considers replacement resource needs in the context of the evolving long-term system load and policy drivers, not just the near-term resource mix and needs of the system today. It recognizes that significant levels of new renewable energy and other resources are already needed to meet long-term regional needs, ensuring that the replacement resource mix selected is incremental to the long-term buildout, not just an interim solution before clean energy policies reach their apex in the 2040s.

Scenario Design

Regional Policy Landscape

To properly understand the resources needed to replace the power services of the lower Snake River dams, it is critical to consider the regional policy landscape of the Pacific Northwest. In the last few years, the states of Oregon and Washington have adopted some of the most aggressive clean energy policies in the nation. While the Pacific Northwest was already a leader in renewable energy production due to its abundant hydropower resource, these aggressive policies will require key changes to the region. First, coal power must be phased out in the Northwest during this decade and, at least in Washington, carbon will be priced via a market-based cap-and-trade mechanism[13]. Second, additional zero-carbon generation must be added to replace that coal power and to displace remaining emissions from natural gas resources whose firm capacity may still be needed by the region, but which will operate less over time as electric carbon emissions are reduced. Ultimately, to reach a zero-carbon system, those natural gas plants must retire, be converted to zero-carbon fuels (such as green hydrogen), or their emissions be offset in some other manner. Third, economy-wide carbon reduction goals will drive the transformation of the Northwest transportation, building, and industrial sectors, with the general expectation of significant electric load growth in annual energy and peak demand. Key policies in the Northwest and California are summarized in Table 3.

Table 3. Policy landscape in Washington, Oregon, and California

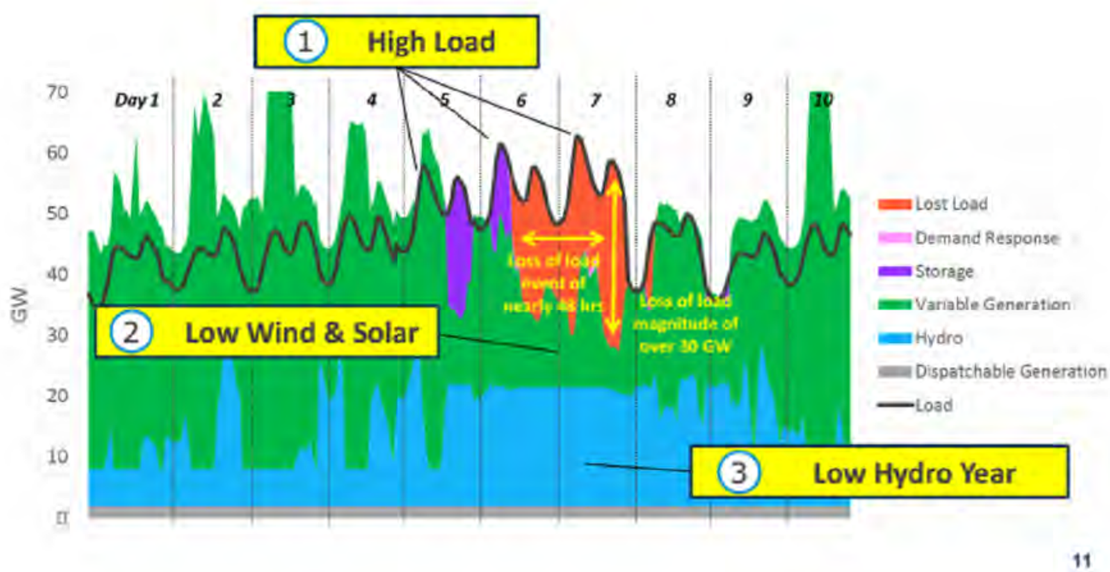
	RPS or Clean Energy Standard?	Coal Prohibition?	Cap-and-Trade?	New Gas?	Economy-Wide Carbon Reduction?
WA	✓ Carbon neutral by 2030, 100% carbon free electricity by 2045	✓ Eliminate by 2025	✓ Cap-and-invest program established in 2021, SCC in utility planning	✓	✓ 95% GHG emission reduction below 1990 levels and achieve net zero emissions by 2050
OR	✓ 50% RPS by 2040, 100% GHG emission reduction by 2040, relative to 2010 levels	✓ Eliminate by 2030	✓ Climate Protection Plan adopted by DEQ in 2021 (power sector not included)	× HB 2021 bans expansion or construction of power plants that burn fossil fuels	✓ 90% GHG emission reduction from fossil fuel usage relative to 2022 baseline
CA	✓ 60% RPS by 2030, 100% clean energy by 2045	✓ Coal-fired electricity generation already phased out	✓	× CPUC IRP did not allow in recent procurement order	✓ 40% GHG emission reduction below 1990 levels by 2030 and 80% by 2050

[13] For simplicity, this study assumes a uniform carbon price across the Core Northwest region beginning in 2023.

Maintaining Resource Adequacy in Low-carbon Grids

Like other regions pursuing aggressive climate policies, the Northwest faces a key decarbonization challenge: how to maintain a reliable electricity supply, while simultaneously increasing electric loads and retiring the firm, but emitting, capacity that currently supports regional reliability. In 2019, E3 used its RECAP loss of load probability model to study how decarbonizing the electricity supply impacts regional reliability. [14] This study found that clean energy resources such as solar, wind, batteries, and demand response can each provide a certain amount of reliable capacity and that combinations of them can provide even more by capturing "diversity benefits" (such as solar shifting the reliability risk into evening hours when wind output is higher). However, these resources also have limits to the amount of reliable capacity they can provide, and their contributions decline as more of them are added (the decline in capacity contributions of these resources is known as "saturation effects"). Figure 3 shows a graph from E3's 2019 study that illustrates the key drivers of reliability in a decarbonized grid: high load, low renewables, and low hydro conditions. Unlike a summer peaking *capacity constrained* system like the desert southwest, these conditions make it particularly challenging for battery storage to replace the Northwest's firm capacity resources, since batteries are unable to charge during *energy constrained* periods of low renewable energy and low hydro availability. The study concluded therefore that additional firm generating capacity may be needed, even in scenarios that add significant amounts of non-firm solar, wind, batteries, and demand response. The resource adequacy modeling approach is described further in the section *Resource Adequacy Needs and Resource Contributions.*

Figure 3. Key Drivers of Pacific Northwest Reliability Events in a Decarbonized Grid



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[14] E3, 2019. *Resource Adequacy in the Pacific Northwest.* https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

Since the 2019 study, "emerging" technologies are increasingly seen as potentially viable options to reduce all of the carbon emissions in the Northwest. "Clean firm" resources like green hydrogen, gas with carbon capture and storage, and nuclear small modular reactors provide the firm capacity necessary to backup renewable resources and can provide the zero-carbon energy needed on low renewable days to operate a zero-carbon grid. While their costs and commercialization trajectories remain uncertain, this LSR dams replacement study considers various scenarios of their availability.

Table 4. Summary of Resource Adequacy Capacity Contributions of LSR Dam Replacement Resource Options

Replacement Resource Option	RA Capacity Contributions
Battery storage	Sharply declining ELCCs[15]
Pumped storage	Sharply declining ELCCs
Solar	Declining ELCCs
Wind	Declining ELCCs
Demand Response	Declining ELCCs
Energy Efficiency	Limited potential vs. cost
Small Hydro	Limited potential
Geothermal	Limited potential
Natural gas to H2 retrofits	Clean firm, but not fully commercialized
New dual fuel natural gas + H2 plants	Clean firm, but not fully commercialized
New H2 only plants	Clean firm, but not fully commercialized
Gas w/ 90-100% carbon capture + storage	Clean firm, but not fully commercialized
Nuclear Small Modular Reactors	Clean firm, but not fully commercialized

Scenarios Modeled

This study focuses on three key variables (clean energy policy, load growth, and emerging technology availability) that impact the cost to replace the dams.

Clean Energy Policy

Clean energy policy for the electric sector is modeled at either 100% clean retail sales or zero-carbon by 2045. A 100% clean retail sales policy requires serving 100% of electricity sold on an annual basis to be met by clean energy resources. This allows generation not used to serve retail sales (i.e., transmission and distribution losses) to be met by emitting resources. It also allows emitting generation or unspecified

[15] E3 performed a sensitivity with battery ELCCs that do not decline so sharply. This sensitivity shows minor changes in the LSR dam replacement resources, but little to no change in the replacement costs.

imports in one hour to be offset by exported generation in another hour of the year. In the baseline load scenario, reaching 100% clean retail sales by 2045 results in ~85% carbon reduction compared to 1990 levels. The zero-carbon scenario ensures that all electricity generated in the Northwest or imported from other regions emits no carbon emissions in every hour of the year.

Load Growth

With aggressive clean energy policies, load growth determines the amount of new zero-emitting resources that must be added to the Northwest power system. A baseline load growth scenario is modeled, based on the forecast in the NWPCC 8th Power Plan. A second high electrification scenario is developed based on the high electrification case in the Washington State Energy Strategy.[16] Based on E3's analysis of the electrification of transportation, buildings, and industry in that study, this scenario results in an additional annual energy demand increase of 28% by 2045 (above the baseline scenario) and an additional winter peak demand increase of 68%. The peak demand increase is high due to the electrification of space heating end uses, which requires replacing the significant quantities of energy provided by the natural gas system during extreme wintertime cold weather events with electricity.

Technology Availability

It is expected that the availability of emerging technologies may be critically important for replacing the LSR dam power services while reaching a deeply decarbonized grid. All scenarios include "mature technologies" such as solar, wind, battery storage, pumped hydro storage, demand response, energy efficiency, small hydro, and geothermal. Three scenarios of emerging technology availability are developed as follows:

A. **Baseline technologies**: mature technologies and dual fuel natural gas + hydrogen combustion plants
B. **Emerging technologies**: mature technologies, dual fuel natural gas + hydrogen combustion plants, small modular nuclear reactors, natural gas with carbon capture and storage, and floating offshore wind
C. **No new combustion (limited technologies)**: mature technologies and floating offshore wind

All scenarios assume that the existing natural gas capacity fleet can convert to green hydrogen, i.e., hydrogen produced using zero-carbon electricity. However, new firm resources are needed in all scenarios to replace retiring resources and meet growing electric loads.

Table 5 shows a summary of the four scenarios that are the focus of this study.

[16] See Washington State's *2021 State Energy Strategy*, https://www.commerce.wa.gov/growing-the-economy/energy/2021-state-energy-strategy/

Table 5. Scenario Design

Scenario	Clean Energy Policy	Load Growth	Technology Availability
1 100% Clean Retail Sales[1]	100% retail sales (85% carbon reduction)	8th Power Plan Baseline	Baseline (incl. natural gas / hydrogen dual fuel plants)
2a Deep Decarbonization (Baseline Tech.)	100% carbon reduction	High Electrification	Baseline
2b Deep Decarbonization (Emerging Tech.)	100% carbon reduction	High Electrification	Baseline + offshore wind, gas w/ CCS, nuclear SMR
2c Deep Decarbonization (No New Combustion)	100% carbon reduction	High Electrification	Baseline (excluding natural gas / hydrogen dual fuel plants)

Modeling Approach

RESOLVE Model

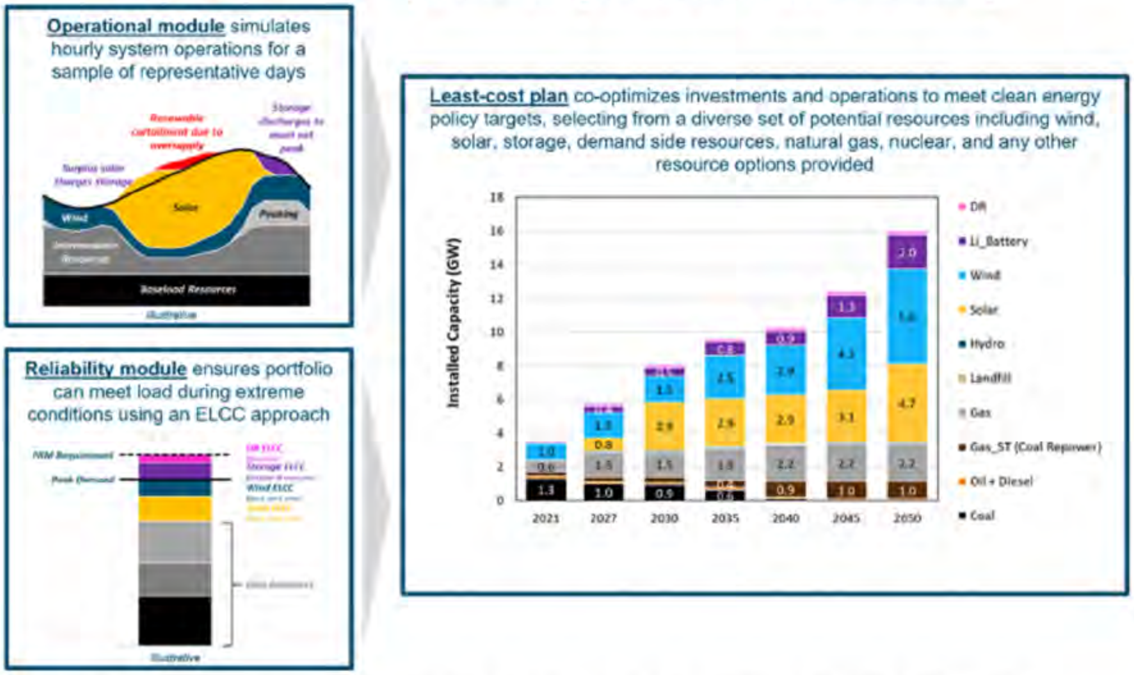
E3's Renewable Energy Solutions Model (RESOLVE) is used to perform a portfolio optimization of Northwest system's electric generating resource needs between 2025 and 2045. RESOLVE is an optimal capacity expansion and dispatch model that uses linear programming to identify optimal long-term generation and transmission investments in an electric system, subject to reliability, operational, and policy constraints. Designed specifically to address the capacity expansion questions for systems seeking to integrate large quantities of variable energy resources, RESOLVE layers capacity expansion logic on top of a production cost model to determine the least-cost investment plan, accounting for both the up-front capital costs of new resources and the variable costs to operate the grid reliably over time. In an environment in which most new investments in the electric system have fixed costs significantly larger than their variable operating costs, this type of model provides a strong foundation to identify potential investment benefits associated with alternative scenarios.

The three primary drivers of optimized resource portfolios include:

+ **Reliability:** all portfolios ensure system meets resource adequacy requirements. In this case, the target reliability need is to meet 1-in-2 system peak plus additional 15% of planning reserve margin (PRM) requirement.
+ **Clean Energy Standard ("CES") and/or carbon reduction targets:** all portfolios meet the clean energy standard and/or a carbon-reduction trajectory
+ **Least cost**: the model's optimization develops a portfolio that minimizes costs

Figure 4 illustrates the use of RESOLVE's operational module, which tracks hourly system operations including cost and greenhouse gas emissions across a representative set of days, and RESOLVE's reliability module, that uses exogenously calculated input parameters to characterize system reliability of candidate portfolios using effective load carrying capability (ELCC) for solar and wind resources.

Figure 4. Schematic Representation of the RESOLVE Model Functionality



RESOLVE develops least-cost portfolios using key inputs and assumptions including loads, existing resources, new resource options, retirement or repowering resource options, resource costs, resource operating characteristics including resource adequacy contributions, a zonal transmission transfer topology, and new resource transmission costs.

Northwest RESOLVE Model

The Northwest RESOLVE model was developed in 2017 for E3's *Pacific Northwest Low Carbon Scenario Analysis* study.[17] It uses a zonal transmission topology to simulate flows among the various regions in the Western Interconnection. In this study, RESOLVE is designed to include six zones: the Core Northwest region and five external areas that represent the loads and resources of utilities throughout the rest of the Western Interconnection (see Figure 5). This study focuses on the Core Northwest region as the "Primary Zone"—the zone for which RESOLVE makes resource investment decisions. This zone covers Washington, Oregon, Northern Idaho and Western Montana. The remaining balancing authorities outside of the Core Northwest are grouped into five additional zones: (1) Other Northwest, (2) California, (3) Southwest, (4) Nevada and (5) Rockies. For these zones, investments are not optimized; rather, the trajectory of new builds is established based on regional capacity needs to meet PRM targets, as well as renewable needs to comply with existing RPS and GHG policies in their respective regions, and held

[17] Pacific Northwest Low Carbon Scenario Analysis - Achieving Least-Cost Carbon Emissions Reductions in the Electricity Sector, 2017. https://www.ethree.com/wp-content/uploads/2018/01/E3_PGP_GHGReductionStudy_2017-12-15_FINAL.pdf

constant across all scenarios. E3's WECC-wide resource mix incorporates aggressive climate policy across the interconnection, as described in section *Baseline resources*.

Figure 5. RESOLVE Northwest zonal representation

The Northwest RESOLVE model simulates the operations of the WECC system for 41 independent days sampled from the historical meteorological record of the period 2007-2009. An optimization algorithm is used to select the 41 days and identify the weight for each day such that distributions of load, net load, wind, and solar generation match long-run distributions. Daily hydro conditions are sampled separately from dry (2001), average (2005), and wet (2011) hydro years to provide a complete distribution of potential hydro conditions. This allows RESOLVE to approximate annual operating costs and dynamics while limiting detailed operational simulations of grid operations to 41 days.

LSR Dams Modeling Approach

The LSR dams' capacity and operation are characterized with several input parameters that are presented in Section *Hydro parameters*. The approach taken in this analysis is to model LSR dams as an *in/out* resource to determine the dams' replacement costs and replacement portfolio. In other words, "in" scenarios include LSR dams in the existing resource portfolio of Core Northwest throughout the entire modeling period (i.e., 2025-2045); whereas "out" scenarios exclude LSR dams with preset retirement dates of 2032. An earlier retirement of LSR dams, 2024, is considered in a sensitivity case. The difference between the costs and resource portfolios for in and out cases reveals the value of LSR dams, as shown in Figure 6. Total NPV costs of resources replacing LSR dams are estimated in the year of breaching the dams.[18] NPV replacement costs are calculating using a 3% discount rate to represent the public power cost of capital.

[18] I.e. when the dams are removed in 2032, future costs after 2032 are discounted to the year 2032 to calculate the NPV replacement costs.

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Figure 6. Modeling Approach to Calculate the LSR Dams Replacement Resources and Costs

This modeling approach inherently considers the benefits of avoiding the LSR dams ongoing fixed and variable costs. The costs associated with breaching the LSR dams themselves are not included in this study. Other power services (i.e., transmission grid reliability services provided by the dams) are also not included but are summarized qualitatively in the Appendix.

Key Input Assumptions

Load forecast

Base load forecast is from NWPCC 2021 Plan and is adjusted to E3's boundary of Core Northwest which roughly represents 87.5% of load of the Northwest system in the NWPCC 2021 Plan. Additionally, a high electrification scenario is modeled which takes Washington's State Energy Strategy high electrification load, scaled up and benchmarked to the Core Northwest region. The baseline high electrification load trajectories are displayed in Figure 7. It is notable that in the high electrification scenario, electric energy demand grows by about 28% by 2045 across all sectors, most noticeably in the commercial building and transportation sectors, to meet net-zero emissions by 2050. In the commercial and residential space heating sectors, electrification indicates a switch to high electric resistance and heat pump adoption, which will significantly impact load profiles and ultimately peak load. Hourly loads are modeled in RESOLVE by scaling normalized hourly shapes with annual energy forecasts. The normalized shapes are adopted from E3's 2017 study *Pacific Northwest Low Carbon Scenario Analysis.*[19]

[19] Pacific Northwest Low Carbon Scenario Analysis - Achieving Least-Cost Carbon Emissions Reductions in the Electricity Sector, 2017. https://www.ethree.com/wp-content/uploads/2018/01/E3_PGP_GHGReductionStudy_2017-12-15_FINAL.pdf

Figure 7. Annual energy load forecasts for Core Northwest

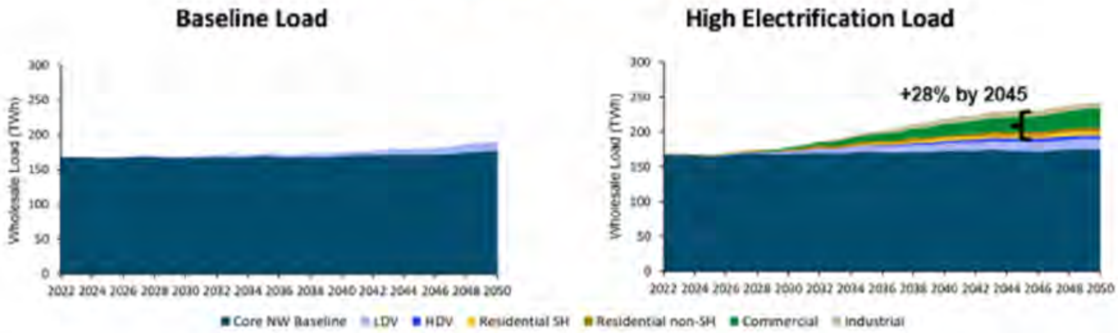
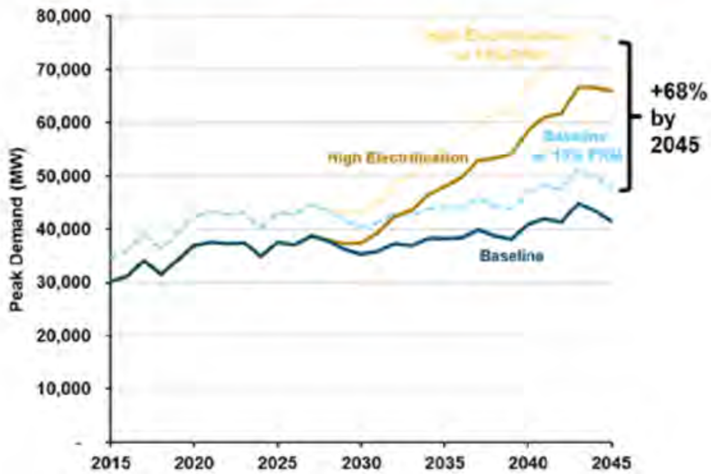


Figure 8 shows the peak demand impacts (including the 15% planning reserve margin) of the high electrification case relative to the baseline, showing a 68% increase by 2045. This high growth is driven by the winter peaking capacity required to replace the gas system peaking capacity to serve peak space heating needs.

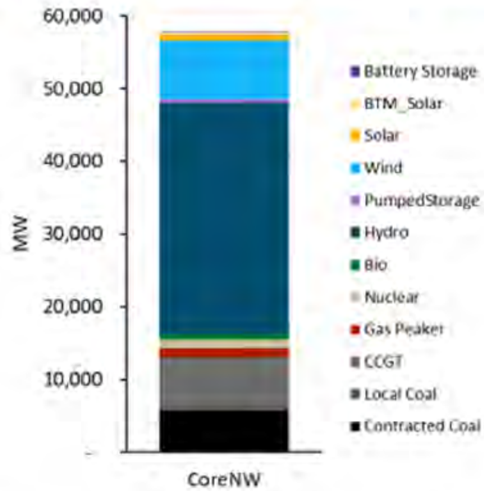
Figure 8. Peak demand forecasts for Core Northwest



Baseline resources

Baseline resources include the existing conventional resources such as natural gas and coal-fired technologies, existing nuclear capacity, hydro as well as pumped storage, battery storage, solar PV, BTM PV and onshore wind technologies. As shown in Figure 9, today's Northwest system has 58 GW capacity. The 1,185 MW nuclear capacity in the Northwest zone remains active throughout the modeling period while the 670 MW local coal capacity is retired by 2025 and the 5,700 MW contracted out of region coal capacity is retired by 2030. The WECC 2020 Anchor Data Set is used for Northwest's existing and planned resources. By 2045, about 5.8 GW additional customer PV is included as planned capacity to capture the growth in behind-the-meter generation forecasted in NWPCC 2021 Power Plan.

Figure 9. Northwest resource capacity in 2022



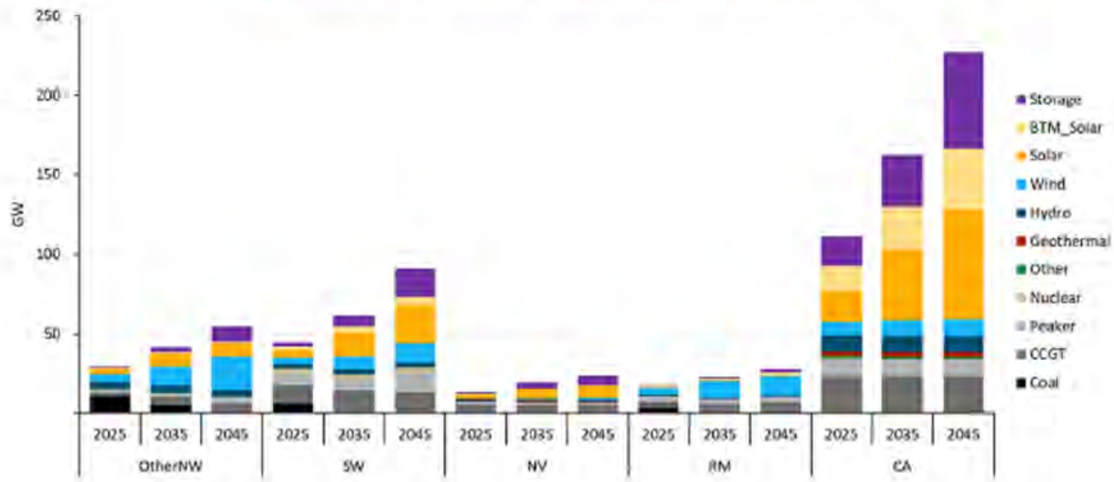
The investment decisions for external zones are pre-determined based on capacity expansion analysis completed by E3 that accounts for policy targets in each zone as summarized in Table 6. The new builds consist of significant increases in solar and battery capacity additions due to the more aggressive RPS targets, assumed electrification, and the decline of technology cost forecasts (see Figure 10). All future builds in these zones include mature technologies but as discussed in the next section, emerging technologies are made available for RESOLVE to optimize the future resource portfolios in the Northwest zone. There is significant solar and battery storage growth in California, the Southwest, and Nevada that generally lower the marginal value of solar energy produced across the WECC.

Table 6. Policy targets for builds in external zones

State	Requirement	Policy	2050 Renewable Target
AZ	40% by 2030; 60% by 2045	Transitions to CES[20]	70%
CA	60% by 2030; 100% by 2045	Transitions to CES	100%
CO	30% by 2020; 50% by 2030, 76% by 2050 (Xcel reaches 100% while other utilities stay at 50%)	Transitions to CES	75%
ID	90% by 2045 (ID Power's announced utility goals)	RPS	90%
MT	87% by 2045 (state carbon reduction goal)	RPS	87%
NM	40% by 2025; 100% by 2045	Transitions to CES	100%
NV	50% by 2030; 100% by 2050	Transitions to CES	95%
UT	50% by 2030; 55% by 2045 (PacifiCorp's IRP)	RPS	55%
WY	50% by 2030, 55% by 2045 (PacifiCorp's IRP)	RPS	55%

[20] CES = "Clean Energy Standard", an annual based clean generation standard.

Figure 10. Total installed capacity for external zones



Candidate resource options, potential, and cost

A wide range of technologies and resources are made available in RESOLVE, including mature and emerging technologies. The list of technologies made available in each modeled scenario is presented in Table 7. Some technologies such as solar and onshore wind are low-cost zero-carbon energy resources with limited resource potential and declining capacity values. Storage resources such as battery storage and pumped hydro support renewable integration but show limited capacity value given the large shares of hydro in the Northwest region. Demand response supports peak reduction but also faces declining ELCCs. Energy efficiency supports energy and peak reduction but increasingly competes against low-cost renewables. Geothermal is relatively high cost and has limited potential but provides highly valuable "clean firm" capacity.

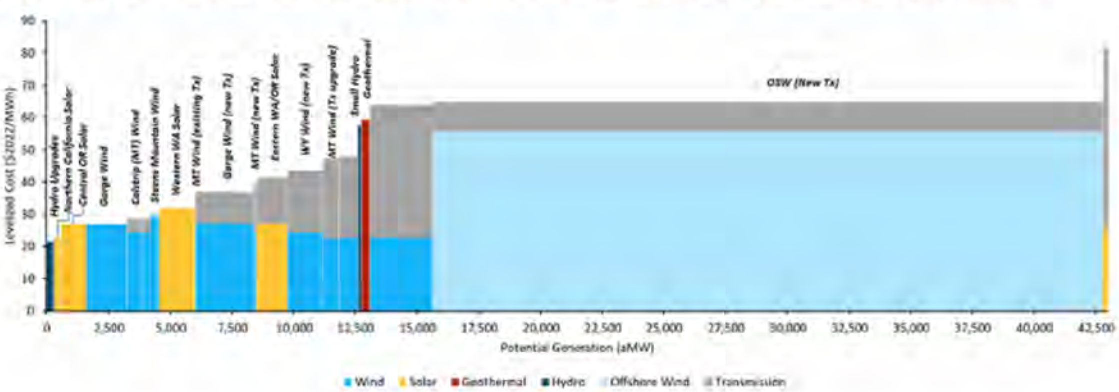
Some emerging technologies are also made available in several scenarios to allow for firm zero-carbon technologies to be selected from. Hydrogen-capable generators such as dual fuel combustion turbines and combined cycles (i.e., capable of burning both natural gas and hydrogen) as well as retrofits of existing gas generators to burn hydrogen are modeled. These technologies provide low-cost capacity options with very high energy cost when burning expensive hydrogen fuel, therefore RESOLVE selects them for firm capacity needs but limits their hydrogen energy production. Natural gas with carbon capture and storage (CCS) technologies are moderately high cost in terms of both energy and capacity. Nuclear SMR provides moderately high capital cost but low operating cost for firm zero-carbon energy generation. This technology is made available to the model after 2035, to account for the time needed for technology development, licensing, and installation. Floating offshore wind is also modeled as an emerging technology which address onshore resource and land constraints, but is generally higher cost than onshore wind while providing a similar annual capacity factor to high quality Montana and Wyoming wind.

Table 7. Available technologies in each modeled scenario

Resource	A. Baseline	B. Emerging Tech	C. No New Combustion (Limited Tech)
Mature resources: solar, wind, battery storage, pumped storage, demand response, energy efficiency, small hydro, geothermal	✓	✓	✓
Natural gas to hydrogen retrofits	✓	✓	✓
Dual fuel natural gas + hydrogen plants	✓	✓	×
Natural gas with 90-100% carbon capture and storage	×	✓	×
Nuclear small modular reactors	×	✓	×
Floating offshore wind	×	✓	✓

There are physical limits to the quantity of renewable resources that can be developed in a given location; RESOLVE enforces limits on the maximum potential of each new resource that can be included in the portfolio. Moreover, some new resources will need extensive transmission upgrades which are accounted for in the renewable energy supply curve.[21] Figure 11 shows a "supply curve" for renewables in the year 2045, ordered by total generation plus transmission cost. While the quantity of solar and onshore wind energy is limited, offshore wind potential is effectively unlimited in the model although its cost remains high relative to land-based renewables through 2045. It should be noted that RESOLVE doesn't select resources based on their cost alone; it also considers the value these resources provide as part of a regional portfolio. More detail information on technology cost trajectories and data sources can be found in the Appendix.

Figure 11. Renewable resource supply curve in 2045, including transmission cost adders



[21] Note: certain solar resources (i.e., Western WA solar) might require transmission upgrades to bring the supply to load centers, which are not captured.

Clean energy policy targets

RESOLVE enforces a clean energy standard ("CES") requirement as a percentage of retail sales to ensure that the total quantity of energy procured from renewable resources meets the CES target in each year. The clean energy standard percentage is calculated as follows, and the target values are summarized in Table 2:

$$CES\,\% = \frac{Annual\ Renewable\ Energy\ or\ Zero\ Emitting\ Generation}{Annual\ CoreNW\ Retail\ Electric\ Sales}$$

Eligible renewable energy and zero-emitting resources include: solar, wind, geothermal, hydropower, nuclear, biomass, green hydrogen, and natural gas with carbon capture and storage.

Regarding GHG emissions, RESOLVE enforces a greenhouse gas constraint on the CoreNW region such that total annual emission generated in the zone must be less than or equal to the emissions cap. The greenhouse gas accounting for the Northwest zone follows the rules established by the California Air Resources Board. The CoreNW carbon emissions baseline is set as 33 MMT at the 1990 level. The total greenhouse gas emissions attributed to the Core Northwest region include:

+ **In-region generation:** all greenhouse gas emissions emitted by fossil generators (coal and natural gas) within the region, based on the simulated fuel burned and fuel-specific CO_2 emissions intensity;
+ **External resources owned/contracted by Core Northwest utilities:** greenhouse gas emissions emitted by resources located outside the Core Northwest but currently owned or contracted by utilities that serve load within the region, based on fuel burn and fuel-specific CO_2 emissions intensity; and
+ **"Unspecified" imports to the Core Northwest:** assumed emissions associated with economic imports to the Core Northwest that are not attributed to a specific resource but represent unspecified flows of power into the region, based on a deemed emissions rate of 0.43 tons/MWh.

Table 8. Annual CES and carbon emissions targets modeled for CoreNW in RESOLVE

Resource	2025	2030	2035	2040	2045
Clean energy standard % (used in Scenarios 1 and 2[22])	29%	49%	68%	88%	100%
Carbon reduction emissions target (used only in Scenario 2)	22.7 MMT	17.0 MMT	11.3 MMT	5.7 MMT	0 MMT

Hydro parameters

RESOLVE characterizes the generation capability of the hydroelectric system by including three types of constraints from actual operational data: (1) daily energy budgets, which limit the amount of hydro generation in a day; (2) maximum and minimum hydro generation levels, which constrain the hourly hydro

[22] While a clean energy standard is modeled in scenario 2, the mass-based carbon reduction target constraint is a more binding constraint, pushing the model beyond the minimum CES %'s shown here.

generation; and (3) multi-hour ramp rates, which limit the rate at which the output of the collective hydro system can change from one to four hours. Combined, these constraints limit the generation of the hydro fleet to reflect realistic seasonal limits on water availability, downstream flow requirements, and non-power factors that impact the operations of the hydro system.

In this analysis, hydro operating data are parameterized using conditions for three different hydrological years, i.e., 2001 for dry, 2005 for average and 2011 for wet conditions. For LSR dams, we use hourly generation data provided by BPA, which are adjusted for latest fish protection and spill constraints. For the remainder of the northwest hydro fleet, we rely on historical hydro dispatch data used to develop the TEPPC 2022 Common Case dataset. Using muti-year historical hydro operational data allows capturing the complete set of physical and institutional factors, such as cascading hydro, streamflow constraints, fish protection, navigation, irrigation, and flood control, that limit the amount of flexibility in the hydro system.

For each RESOLVE sampled day, the hydro daily energy budget is calculated as the average of daily electricity generated in the month of each sampled RESOLVE day in its corresponding matched hydro year.[23] The maximum and minimum hydro generation levels (P_{min} and P_{max}) are calculated as the absolute min and max of generation in the month of each sampled RESOLVE day in its corresponding matched year. Multi-hour ramp rates are estimated based on the 99th percentile of upward ramps observed across the three hydrological years of hourly data. In addition, for non-LSR Northwest hydro, the model allows 5% of the hydro energy in each day to be shifted to a different day within two months to capture additional flexibility for day-to-day hydro energy shift.

[23] LSR dams generate about 900 average MW of energy during an average hydro year. However, during the three years modeled in RESOLVE, the LSR dams produced only ~700 average MW generation for LSR dams. This means our estimate of the replacement cost of the dams is quite conservative relative to a longer-term expected average of ~900 MW.

Figure 12. RESOLVE Hydro inputs for LSR Dams and other Northwest hydro

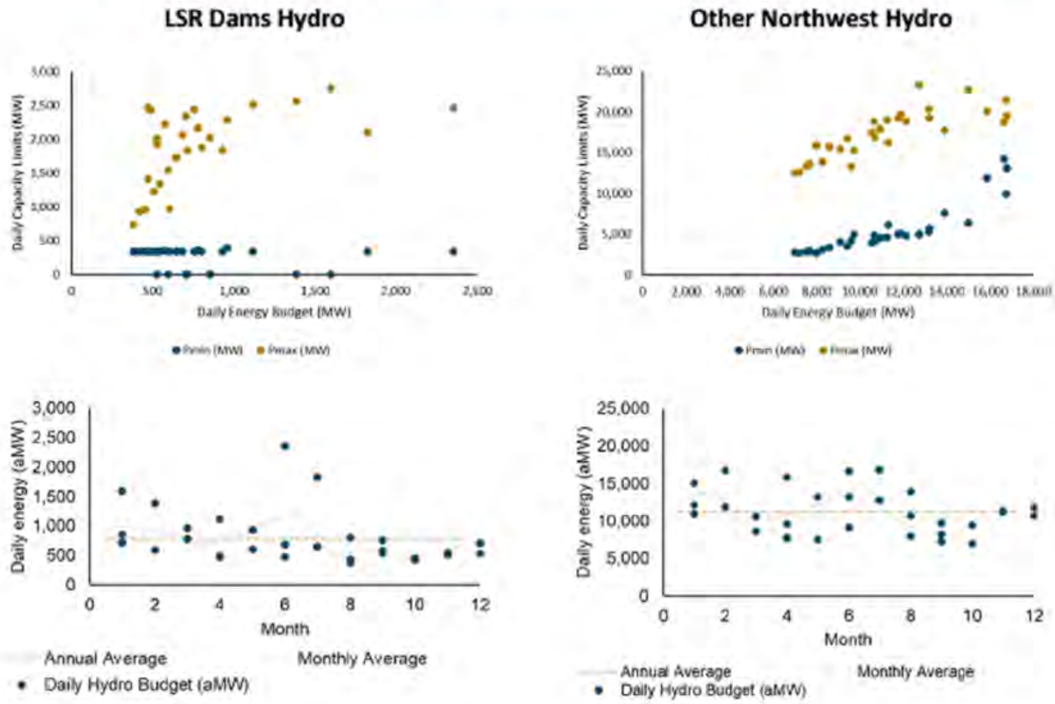


Table 9. Multi-hour ramping constraints applied to Northwest hydro

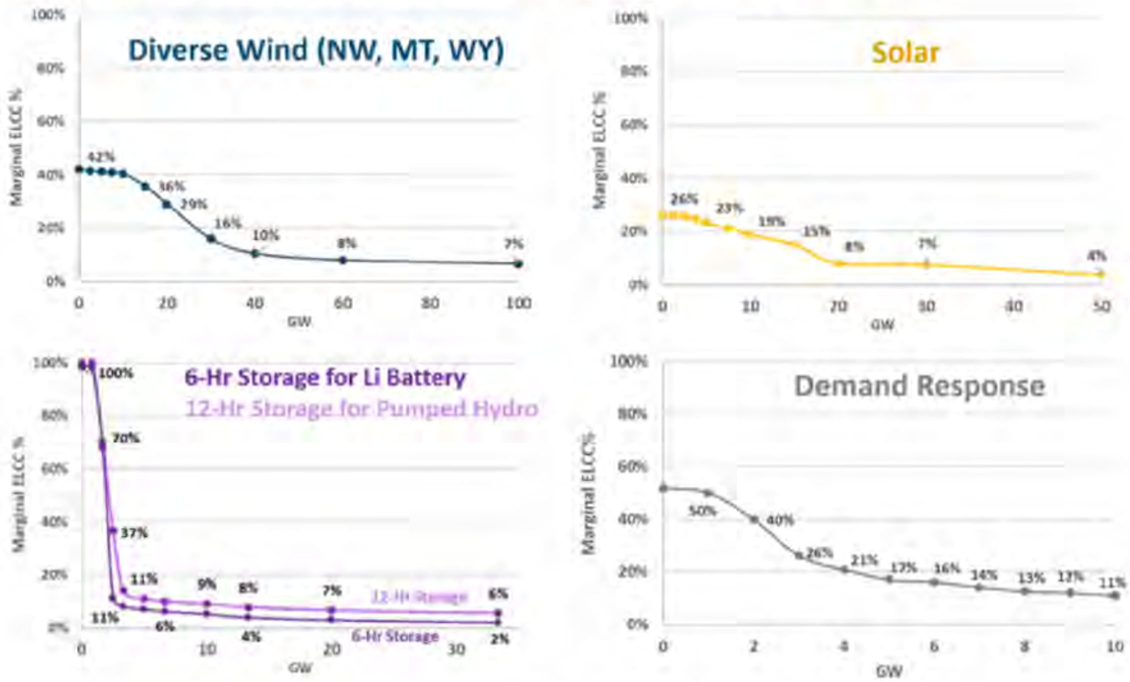
	One hour	Two hours	Three hours	Four hours
LSR Dams Hydro	36%	43%	45%	48%
Other Northwest Hydro	14%	23%	29%	32%

Resource Adequacy Needs and Resource Contributions

Hydro firm capacity contribution for both LSR dams and other Northwest hydro is assumed to be 65% of nameplate, per PNUCC methodology (based on 10-hr sustaining peaking capacity). This means that the LSR dams provide 2,284 MW of firm capacity that must be replaced if the dams are breached. This assumption was validated based on BPA modeled LSR dam performance data during the 2001 dry hydro year, as described in the section *Key Uncertainties for the Value of the Lower Snake River Dams*, which also describes estimates of the NPV impact of assuming a lower firm capacity value for the dams.

Resource adequacy needs are captured in RESOLVE by ensuring that all resource portfolios have enough capacity to meet the peak Core Northwest median peak demand plus a 15% planning reserve margin. Firm capacity resources are counted at their installed capacity. Hydro resources are counted at the 65% regional value used in PNUCC's 2021 resource adequacy analysis. Solar, wind, battery storage, pumped hydro storage, and demand response are counted at their effective load carrying capability ("ELCC") based on E3's RECAP modeling from its 2019 *Resource Adequacy in the Pacific Northwest* study.[24] Figure 13 shows the initial capacity values for these resources, as well as the declining marginal contributions as more of the resource is added. RESOLVE uses these data points to develop tranches of energy storage and demand response resources with declining marginal ELCCs for each tranche. Solar and wind ELCCs are input into RESOLVE using a 2-dimensional ELCC surface that captures the interactive benefits of adding various combinations of solar and wind together. Resources on the surface (such as different wind zones) are scaled in their ELCC based on their capacity factor relative to the base capacity factor assumed in the surface, and the entire surface is scaled as peak demand grows.

Figure 13. Solar, Wind, Storage, and Demand Response Capacity Values



The capacity value for energy storage resources shown in Figure 13 are very different from those in other regions, such as California or the Desert Southwest, declining much more quickly as a function of penetration. There are two reasons for this. First, the Pacific Northwest is a winter peaking region in which loss-of-load events are primarily expected to occur during extreme cold weather events that occur under drought conditions in which the region faces an energy shortfall. These events, such as the one illustrated in Figure 3 above, result in multi-day periods in which there is insufficient energy available to charge storage resources, severely limiting their usefulness. This is unlike the Southwest, where the most stressful system conditions occur on hot summer days in which solar power is expected to be abundant and batteries can recharge on a diurnal cycle. Second, the Pacific Northwest already has a very substantial amount of reservoir storage which can shift energy production on a daily or even weekly basis. Thus, the

[24] Resource Adequacy in the Pacific Northwest, 2019. https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

Pacific Northwest is already much closer to the saturation point where additional diurnal energy shifting has limited value.

Nevertheless, recognizing that the capacity value of energy storage is still being researched, in the Northwest and elsewhere, we include a sensitivity case in which energy storage resources are assumed to have much higher ELCC values, similar to what is expected in the Southwest at comparable penetrations. This test case was used to assess whether a higher energy storage ELCC would change the replacement resources and replacement cost of the LSR dams. The results are presented in the section *Replacement Resources Firm Capacity Counting*.

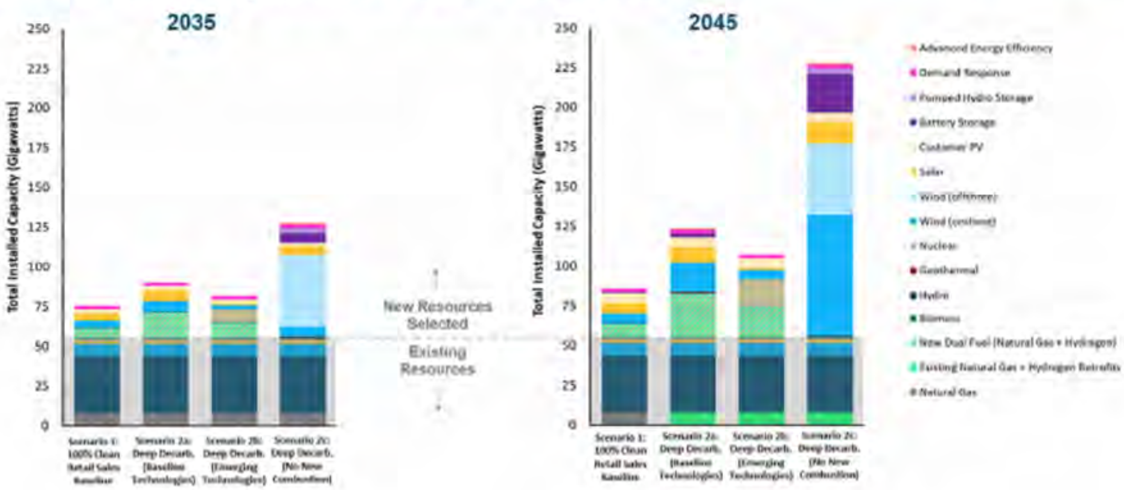
Results

RESOLVE model runs for the 2025-2045 period produce optimal resource portfolios of additions and retirements by resource type, as well as metrics of annual and hourly resource generation, carbon emissions, and total system costs. This section presents the RESOLVE modeling results, focused on the years of 2035 and 2045 to highlight the mid-term and long-term resource needs. Following that, the result of the RESOLVE runs with the LSR dams breached are presented, with the replacement resource and costs to replace the dams' power services.

Electricity Generation Portfolios With the Lower Snake River Dams Intact

In the scenarios that do not assume breaching of the LSR dams, large amounts of utility-scale solar PV, onshore wind, offshore wind, hydrogen-capable combined cycle, and some amounts of energy efficiency and demand response are selected to meet the growing electricity demand, PRM, and emissions reductions. Electrification load growth along with zero emissions targets drive higher needs in deep decarbonization scenarios (i.e., S2a, S2b and S2c) compared to the reference scenario (S1) in both snapshot years of 2035 and 2045. In S2b, clean firm technologies such as SMR nuclear are selected in place of additional onshore wind, solar and dual-fuel CCGT selected in S2a. In the absence of clean firm technologies (no new combustion) in S2c, massive amounts of offshore wind (~45 GW) as well as more battery storage, pumped storage, demand response, and energy efficiency are selected as early as 2035 such that in this scenario, the new resource additions are almost five time the new builds in S1. These capacity additions increase even more substantially by 2045.

Figure 14. Large levels of new resource additions to meet the growing load, PRM needs and emissions reductions (assumes LSR Dams are NOT breached)



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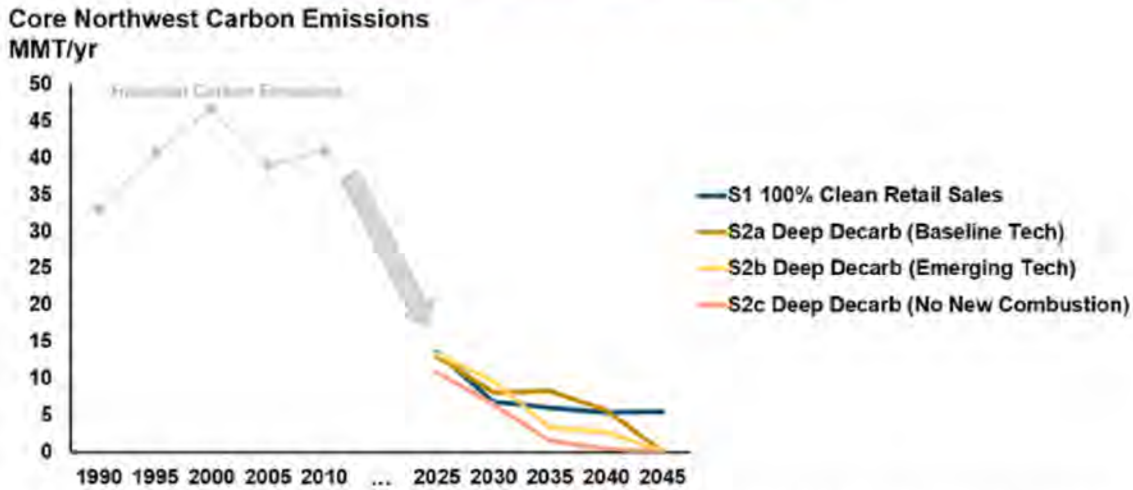
As shown in Figure 15 below, all four scenarios result in a sharp near-term decline in carbon emissions, driven by Washington and Oregon policies that drive coal retirement this decade. By 2045, Scenario 1, which requires 100% clean retail sales, shows an ~85% decline in carbon emissions relative to 1990 levels. Scenario 2 eliminates all carbon emissions by 2045.

Figure 15. Northwest Carbon Emissions



To put cost impacts in context, a "No Policy Reference" case uses the baseline load forecast and removes all electric clean energy policies, retaining the region's coal power with little emissions decline. The four clean energy futures modeled are compared against this Reference Case on A) their cost impacts, measured in incremental cents/kWh relative to the Reference, and B) their carbon emissions reductions, relative to 1990 levels. By 2045, as shown in Figure 16, with the region's aggressive carbon policies in place, emissions can be reduced by over 80% with a relatively small cost impact (+0.6 cents/kWh relative to the region's current average retail rate of 8-9 cents/kWh). Reaching a zero-carbon grid with increasing electric loads requires significantly more investment, increasing carbon reductions to 100% of 1990 levels, but also increasing costs by 3.3-14.8 cents/kWh. This range is highly dependent upon the availability of emerging technologies and their assumed costs. The low end assumes that low-cost small modular nuclear reactors become commercialized by 2035. The high end assumes no new combustion resources (such as green hydrogen)[25] or other emerging technologies are available[26], showing that relying only on non-firm resource additions (renewable energy, demand side resources, and short- to medium-duration storage) leads to much higher costs.

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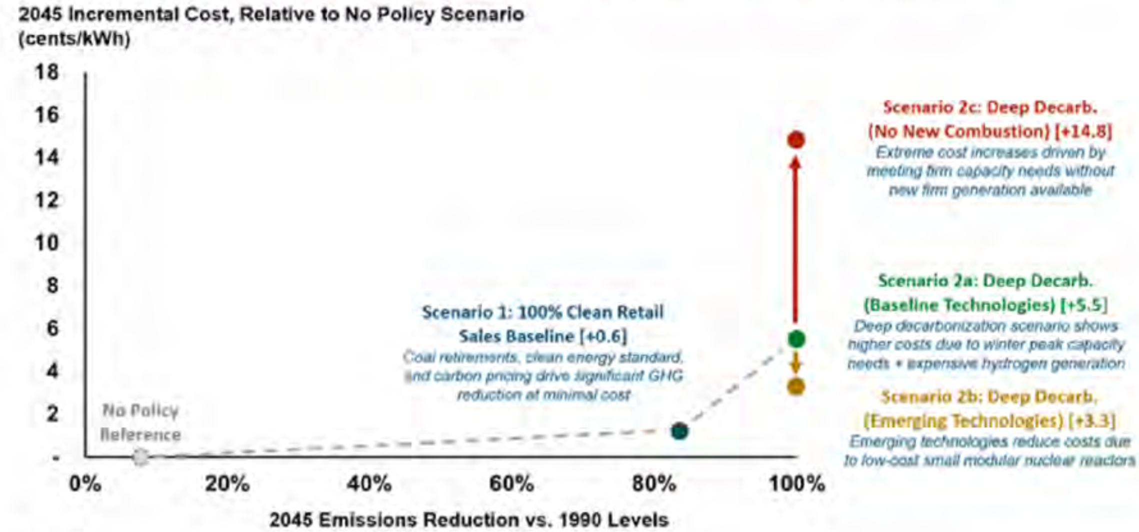
[25] The authors recognize that hydrogen can be used to generate electricity by fuel cells instead of combustion turbines. That scenario would look similar to Scenario 2a, where the combustion plant additions are replaced with many GW of fuel cells for firm capacity needs.

[26] Floating offshore wind was allowed in the no new combustion case since it was required to allow a feasible solution without making any other firm capacity additions available in the model.

Figure 16. Cost Impacts Compared to Emissions Reduction Impacts



NOTES:
- 2020 average retail rates for OR and WA were 8-9 cents/kWh; 1990 electric emissions were ~33 MMT
- High electrification scenarios would avoid natural gas infrastructure costs, which would offset some of the electric peaking infrastructure cost increase

LSR Dams Replacement

The resource replacement portfolios and costs of replacing the LSR dams are reported in this section, which is also focused on the midterm (2035) and long term (2045).

Capacity and energy replacement

In the midterm, given the expectations of load growth and coal capacity retirements resource adequacy needs are a primary driver of LSR dam replacement needs, with around 2 GW of additional firm dual fuel natural gas and hydrogen combustion plants selected to replace the LSR dams' capacity in Scenarios 1, 2a, and 2b (see Table 10). (Note that, these turbines may initially burn natural gas when needed during reliability challenged periods but would transition to hydrogen by 2045 to reach zero-emissions.) If advanced nuclear is available as assumed in Scenario 2b, it replaces renewables and some of the combustion resource builds. In addition to firm resources, some of the LSR capacity is replaced by renewables in Scenarios 1 and 2a, mostly by wind resources and some battery storage. In Scenario 2c, with no combustion or advanced nuclear available, a very large buildout of renewable capacity (in the order of 12 GW) is required to replace the capacity of LSR dams, due to resource availability and the fast decline in solar and wind ELCCs as early as 2035. Small amount of geothermal capacity is also part of the portfolio in 2035.

In the long term, the dam's carbon-free energy is replaced by a combination of wind power and another "clean firm" resource when available. Scenario 2a shows additional hydrogen generation, as well as small levels of energy efficiency and battery storage. In Scenario 2b, the LSR dams are entirely replaced by clean firm capacity of hydrogen combustion plants and nuclear SMRs, whereas in Scenario 2c, a large capacity of wind and solar is relied upon to replace both the carbon-free energy and firm capacity of the LSR dams. Overall, the magnitude of replacement portfolio capacities is close in both snapshot years (2035 and 2045) meaning that immediate capacity additions are necessary to replace LSR dams given the retirement year of 2032 while the capacity needs sustain throughout the modeling period. The early removal of LSR dams (i.e., by 2024) moves up the timing of the replacement portfolio to 2025 instead of 2035 in S1b, but the replacement portfolio remains similar.

Table 10. Optimal portfolios to replace the LSR dams

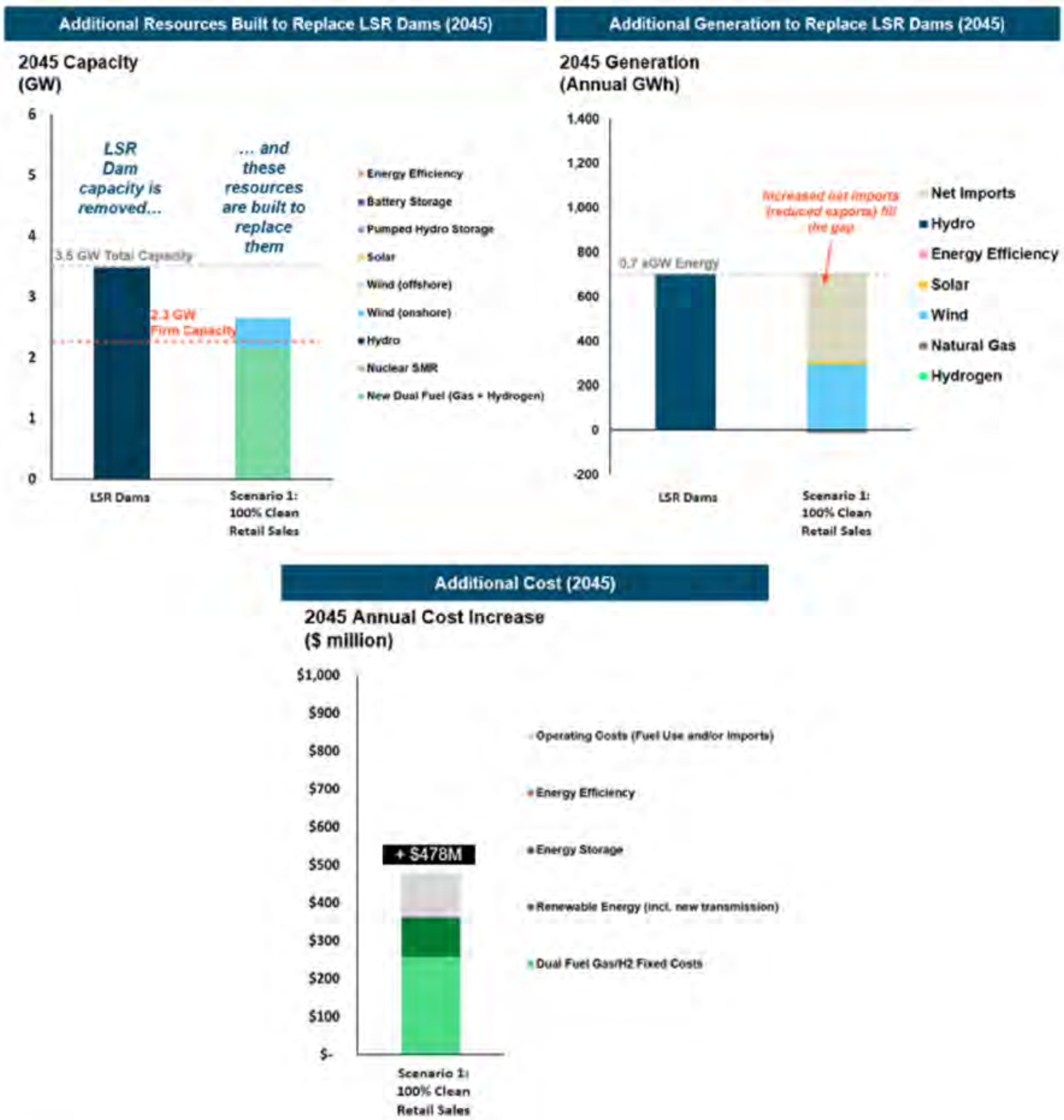
Scenario	Replacement Resources Selected, Cumulative by 2035[27] (GW)	Replacement Resources Selected, Cumulative by 2045 (GW)
Scenario 1: 100% Clean Retail Sales	+ 1.8 GW dual fuel NG/H2 CCGT - 0.5 GW solar + 1.3 GW wind + 0.1 GW li-ion battery	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
S1b: 100% Clean Retail Sales (2024 dam removal)	+ 1.8 GW dual fuel NG/H2 CCGT - 0.5 GW solar + 1.4 GW wind + 0.1 GW li-ion battery	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
Scenario 2a: Deep Decarbonization (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.6 GW wind + 0.1 GW li-ion battery	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW advanced EE + 1.2 TWh H2-fueled generation
Scenario 2b: Deep Decarbonization (Emerging Technologies)	+ 1.7 GW dual fuel NG/H2 CCGT + 0.6 GW nuclear SMR	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR
Scenario 2c: Deep Decarbonization (No New Combustion)	+ 9.1 GW [illegible] + 0.1 GW wind + 1.0 GW solar + 0.3 GW geothermal + 1.5 GW li-ion battery	+ 10.6 GW wind + 1.4 GW solar

Figure 17 through Figure 20 show details of the capacity replacement, energy replacement, and cost breakdown for Scenarios 1 and 2a. LSR dams energy in these scenarios is replaced with wind, net imports (i.e. reduced exports of hydropower outside the Core NW), and – in Scenario 2a – additional hydrogen generation, which is necessary in 2045 to meet the zero-carbon goal without the flexible LSR dam winter generation. The cost charts show that the dual fuel gas plants make up approximately half of the 2045

[27] Replacement resources are calculated by comparing the "with LSR dams" RESOLVE portfolio to the "without LSR dams" RESOLVE portfolio. This means some resources may be built in 2035, such as 0.3 GW of geothermal in scenario 2c, that are not built when the dams are included. However, those resources may have already been selected in the "with LSR dams" case by 2045, hence do not show up as additional resource replacement needs in 2045. This explains the different resource changes between 2035 and 2045.

annual costs in Scenario 1 and approximately a quarter of the 2045 annual costs in Scenario 2a, which includes additional costs for energy efficiency and hydrogen generation.

Figure 17. Scenario 1: Capacity Replacement, Energy Replacement, and Costs[28]



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[28] Regarding the "net imports" component of the energy replacement, this refers to either increased imports, decreased exports (generally of carbon-free energy), or a combination of both, such that RESOLVE does not need to build enough new generation to fully replace the LSR dams output. For instance, the region could export less hydropower to California and other neighbors to replace the LSR dams output without necessarily increasing Northwest carbon emissions in Scenario 1.

Figure 18. Scenario 2a Capacity Replacement, Energy Replacement, and Costs

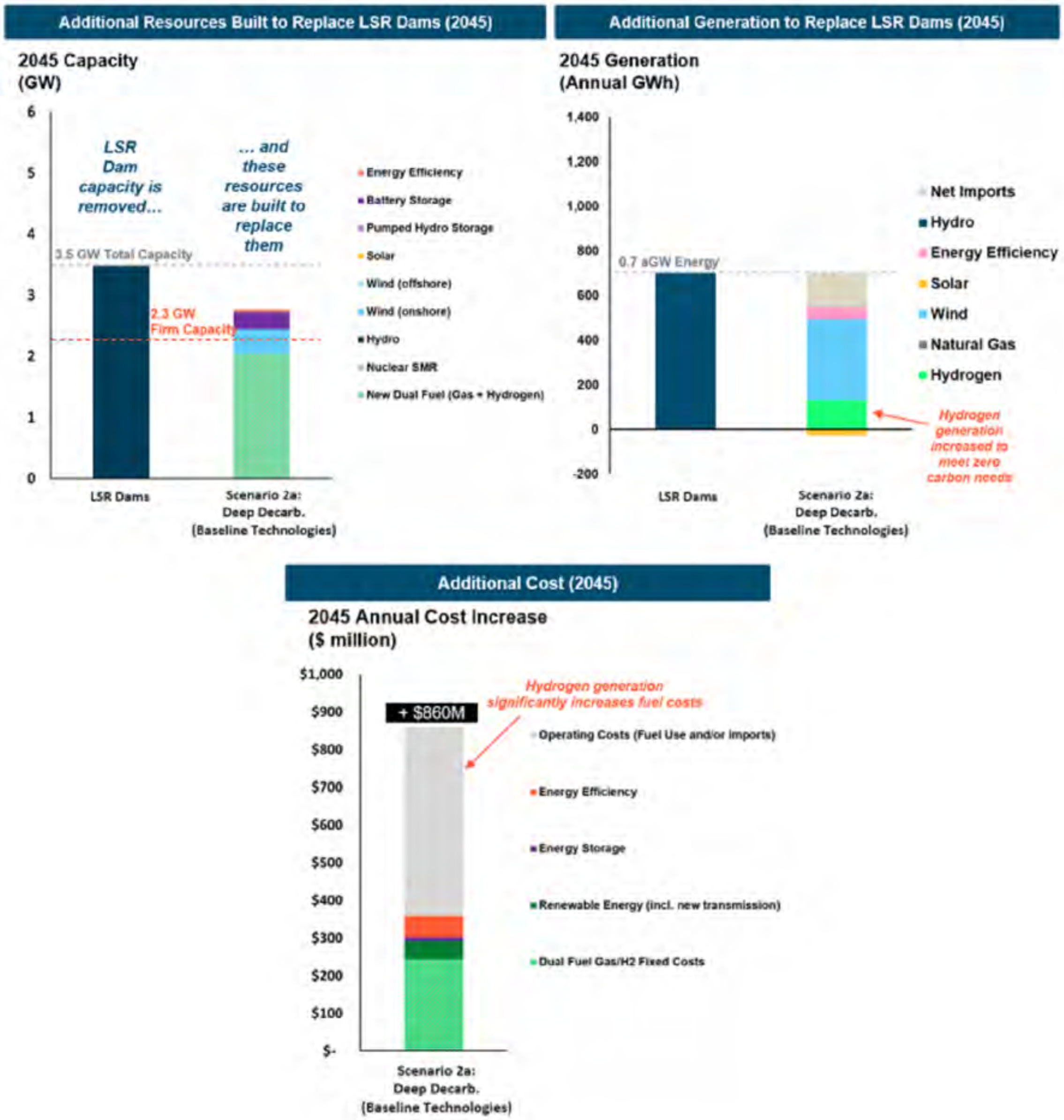

Figure 19. Scenario 2b Capacity Replacement, Energy Replacement, and Costs

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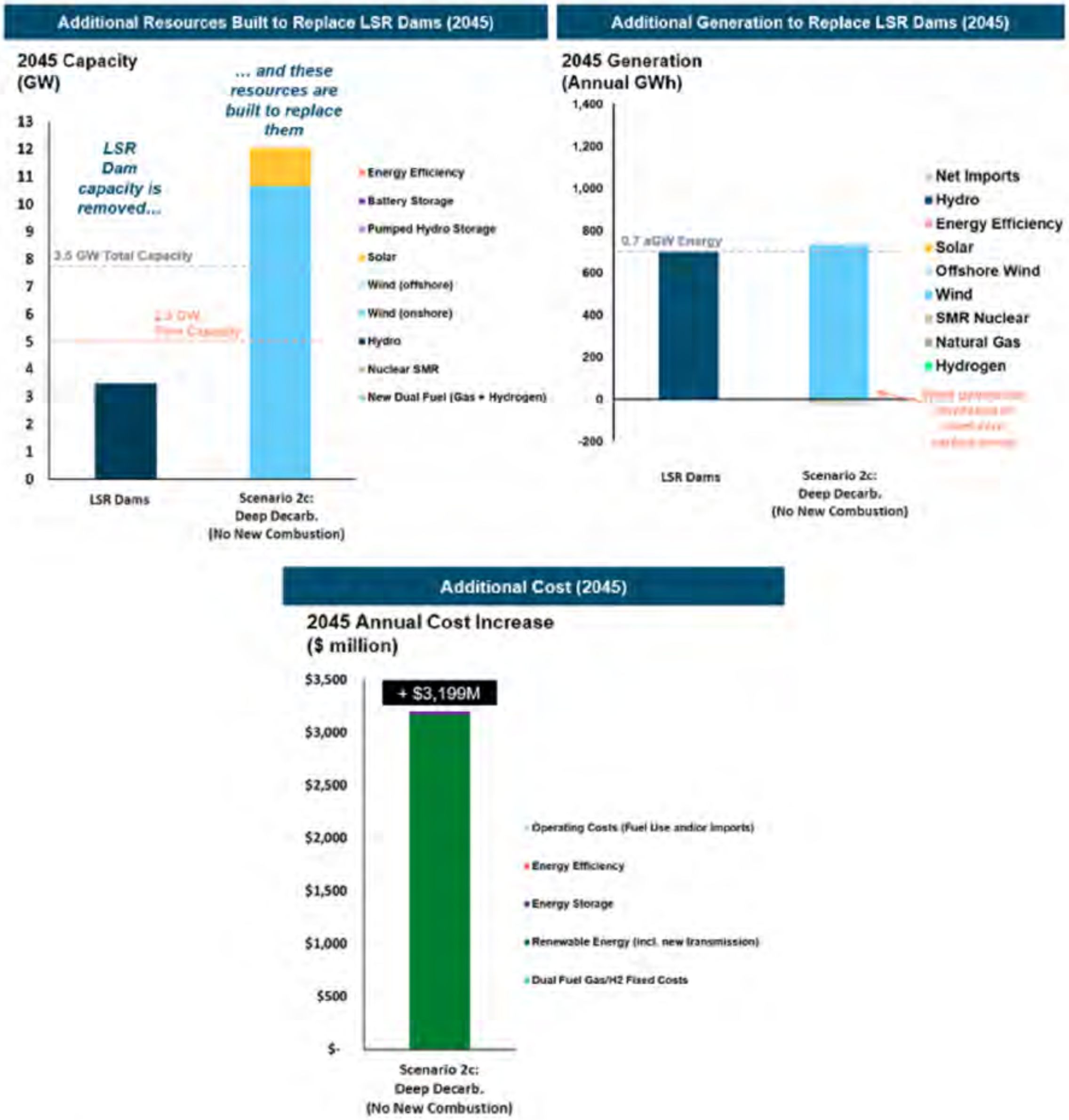
Figure 20. Scenario 2c Capacity Replacement, Energy Replacement, and Costs[29]



Replacement costs

The LSR dams provide a relatively low-cost source of GHG-free energy and firm capacity. Incremental costs for replacement resources are summarized in this section. All costs are shown in real 2022 dollars.

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[29] NOTE: the energy replacement does not show the total potential energy output of the wind built to replace the dams, because much of the potential energy output is curtailed due to oversupply of wind built for resource adequacy needs.

Incremental costs to replace the power services of the LSR dams ranges from $69-139/MWh across most scenarios. Scenario 2c, however, shows a much higher replacement power cost of $517/MWh. These incremental costs are much higher than costs of maintaining the LSR dams (i.e., $13-17 per MWh[30]); they are calculated by taking the incremental fixed and variable investment costs for the no LSR RESOLVE runs and dividing them by the LSR annual generation being replaced. See the details in Table 11.

Table 11. Incremental costs to replace LSR generation in 2045

Scenario	Incremental net costs in 2045[31], including avoided LSR dam costs (Real 2022 $/MWh)	Incremental gross costs in 2045[32], excluding $17/MWh avoided LSR dam costs (Real 2022 $/MWh)
Scenario 1: 100% Clean Retail Sales	$77/MWh	$94/MWh
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$82/MWh	$99/MWh
Scenario 2a: Deep Decarb. (Baseline Technologies)	$139/MWh	$156/MWh
Scenario 2b: Deep Decarb. (Emerging Technologies)	$69/MWh	$86/MWh
Scenario 2c: Deep Decarb. (No New Combustion)	$517/MWh	$534/MWh

The LSR dams' total replacement costs (in net present value) and annual replacement costs for 2025, 2035, and 2045 are shown in Table 12. NPV replacement costs are calculated based on discounting at a 3% discount rate, representative of the approximate public power cost of capital, over a 50-year time horizon following the date of breaching. Scenario 1 (100% clean retail sales) replacement costs are approximately $11.8 billion in net present value (NPV) in the year of breaching (in 2032); costs increase to $12.8 billion NPV if breached in 2024. Total replacement costs are similar in the economy-wide deep decarbonization scenario when emerging technology is available (scenario 2b), showing $10.7 billion NPV. Replacement costs are significantly higher in scenario 2c where no new combustion resources are allowed ($75.2 billion NPV). The economy-wide deep decarbonization (baseline technology scenario), 2a, shows more costly replacement ($19.0 billion NPV) than when nuclear SMRs are available, but lower costs than scenario 2c, due to the availability of hydrogen-enabled gas plants.

Annual costs increase by $415-860 million after LSR dams' removal in scenarios 1, 2a, and S2b. In Scenario 2c, the cost increase is in the order of $1.9-3.2 billion per year. Replacement costs generally increase over time due to increasingly stringent clean energy standards and electrification-driven load growth. The 2045

[30] BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) facilities. The cost of generation at the lower Snake River dams is in the range of $13/MWh without LSRCP and $17/MWh with LSRCP. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat.2917) to offset fish and wildlife losses caused by construction and operation of the four lower Snake River projects.

[31] The generation replacement costs are calculated using the incremental RESOLVE's Core Northwest revenue requirement increase with LSR dams breached divided by the annual MWh of the LSR dams assuming 706 average MW generation.

[32] The generation replacement costs are calculated using the incremental RESOLVE's Core Northwest revenue requirement increase with LSR dams breached divided by the annual MWh of the LSR dams assuming 706 average MW generation.

cost increases translate to 8-18% growth in BPA's public power customers costs in scenarios 1, 2a and 2b (assuming current retail rates are about 8.5 ₵/kWh based on OR and WA average retail rates). In these scenarios, public power households would see an increase in annual electricity costs of $100-230/yr in 2045. In Scenario 2c, rate impacts could be as high as 65%, which is equivalent to annual residential electricity bills raising by up to $850 per year.[33]

Note that these incremental cost increases include the ongoing LSR dams costs, such as operations and maintenance costs, avoided by breaching the dams, but do not include the costs of breaching. The rate impacts shown are only for the LSR dams' replacement, they do not include the additional rate increases driven by higher loads or clean energy needs (that are covered in the section *Electricity Generation Portfolios With the Lower Snake River Dams Intact* above), which apply even without removing generation from the LSR dams.

Table 12. Total LSR Dams replacement costs

	NPV Total Costs (Real 2022 $)[34]	Annual Costs Increase (Real 2022 $)			Incremental Public Power Costs[35]
	In the year of breaching (2032 or 2024)	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$11.8 billion	n/a	$434 million	$478 million	0.8 ₵/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$12.8 billion	$495 million	$466 million	$509 million	0.8 ₵/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$19.0 billion	n/a	$496 million	$860 million	1.5 ₵/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$10.7 billion	n/a	$415 million	$428 million	0.7 ₵/kWh [+8%]
Scenario 2c: Deep Decarb. (No New Combustion)	$75.2 billion	n/a	$1,953 million	$3,199 million	5.5 ₵/kWh [+65%]

[33] Annual residential customer cost impact assumes 1,000 kWh per month for average residential customers in Oregon and Washington in scenario 1 and 1,280 kWh per month for scenario 2, per the 28% retail sales increase due to electrification load growth.

[34] NPV replacement costs are based on discounting at a 3% discount rate, representative of the approximate public power cost of capital, over a 50-year time horizon following the date of breaching.

[35] Incremental public power costs are calculated assuming that all the replacement costs are paid by BPA Tier I customer, using the assumed 2022 Tier I annual sales of 58,686 GWh.

Carbon emissions impacts

LSR dams provide emissions-free generation for Northwest and depending on what these dams are replaced with, may impact the emissions associate with the electricity systems. The removal of LSR dams may potentially cause an increase in emissions over the near- or mid-term horizon. In Scenario 1, the 2024 LSR dam breaching scenario results in substantial increases to carbon emissions through 2030, in the range of 1-2.8 MMT/yr or 15-25% of the annual Northwest emissions. This scenario does not have a binding GHG constraint, and the region meets its clean energy goals in the near term without the dams. RESOLVE therefore does not replace all the LSR dam energy with clean resources.

Under 2032 breaching scenarios, small carbon emissions increases are observed in the mid-term (0.7 MMT/yr. or 8-10% of the region's carbon emissions in 2035). The economy-wide deep decarbonization cases all reach zero carbon emissions by 2045, so breaching the dams does not increase emissions in that year; RESOLVE instead builds the resources needed to replace all of the GHG-free energy.

Additional considerations

Depending on how the future of the electric grid evolves, there might be significant land-use associated with renewables expansion, more so if LSR dams are removed in conditions similar to Scenario 2c where significant capacity additions from solar and wind resources would be necessary.

In terms of costs, while this study considered the replacement costs of LSR dams from the electricity system perspective, there are other types of services that LSR dams provide that would need additional cost assessment. LSR dams are used for irrigation, recreation, navigation, and transportation. Breaching LSD dams could impact these services and therefore, should be considered alongside the electricity services replacement costs. Moreover, breaching the dams itself would be an additional cost. These factors are addressed in more detail in the report prepared by Senator Murray and Governor Inslee.[36]

Key Uncertainties for the Value of the Lower Snake River Dams

This study explicitly captures the following key drivers of the LSR dams power service replacement needs:

- Replacing the **GHG-free energy**, **firm capacity**, **operating reserves**, and **operational flexibility** of the dams

Uncertainty of the LSR dam value is considered under scenarios of:

- **Clean energy policy**: replacement of carbon-free power becomes increasingly critical to reach a zero-emissions electricity grid
- **Load growth**: replacement energy and capacity needs may change with increased electrification and peak higher winter space heating needs

[36] Lower Snake River Dams: Benefit Replacement Draft Report by U.S. Sen. Patty Murray, and Washington Gov. Jay Inslee, 2022. Lower Snake River Dams: Benefit Replacement Draft Report (senate.gov)

- **Technology availability**: replacement is more expensive with fewer emerging technology resource options
- **Timing**: replacement was focused on breaching in 2032, but a 2024 sensitivity was also considered

Additional uncertainties regarding the value of the dams are:

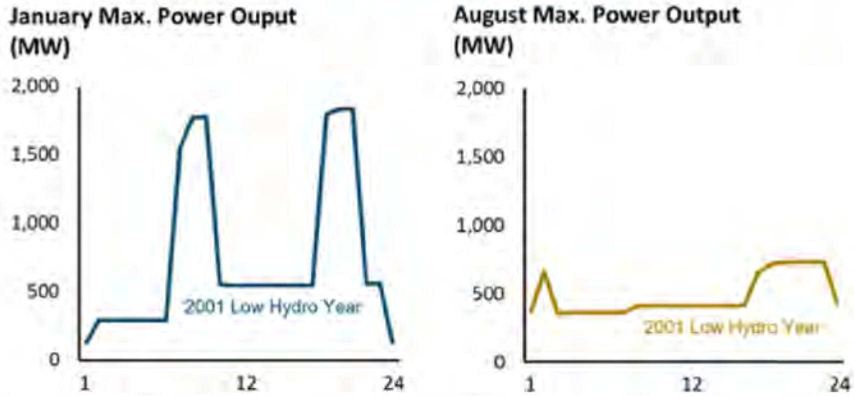
- **LSR dams annual energy output**: E3's existing RESOLVE model data uses historical hydro years 2001, 2005, and 2011 as representative of the regional long-term average low/mid/high hydro year conditions. The data for the Columbia River System dams was adjusted to reflect the Preferred Alternative operations defined in the CRSO EIS. However, for the LSR dams, these selected historical hydro years resulted in a relatively low output of ~700 average MW, whereas the dams may generate ~900 average MW on average across the full historical range of hydro conditions. Therefore, E3's analysis likely underestimates the energy value of the dams and costs for replacing that extra GHG-free energy.
- **LSR dams firm capacity counting**: as resource adequacy is found to be a key driver of future resource needs, the firm capacity contributions of the LSR dams is a key driver of their value. See below for further discussion of this uncertainty.
- **Replacement resource capacity contributions**: if Northwest reliability challenges dramatically shift into the summer, this would also impact the capacity value of replacement resources. Directionally, this would likely increase the capacity value of energy storage, and change the relative value of solar and wind. It is expected that additional battery storage would be part of the regional capacity additions in lieu of dual fuel natural gas + hydrogen plants. See below for further discussion of this uncertainty.
- **Replacement of transmission grid services:** this study does not focus on the transmission grid reliability services provided by the LSR dams. These services likely can be replaced by a combination of the new resources selected by RESOLVE and additional local transmission system investments. A qualitative summary of the transmission grid reliability services of the dams is summarized in the appendix of this report.

LSR Dams Firm Capacity Counting

Since resource adequacy is found to be a key driver of future resource needs, the firm capacity contribution of the LSR dams is a key driver of their value. E3 uses a regional hydro capacity value estimate for the LSR dams in this study, based on the PNUCC regional hydro capacity value assumption. More detailed follow-on ELCC studies could be done to confirm the LSR dams' capacity value, though proper and coordinated dispatch of the Northwest hydro fleet would be necessary to develop an accurate and fair value of the LSR dams within the context of the overall hydro fleet.

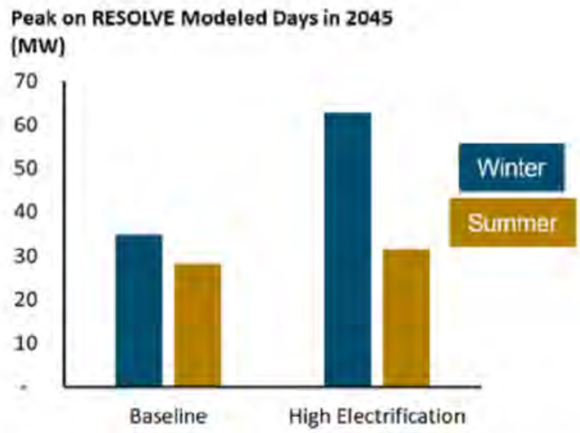
This study validated the assumed 2.28 GW of firm capacity from the LSR dams by considering BPA modeled LSR dams dispatch under 2001 dry hydro year conditions using the CRSO EIS spill constraint adjusted hourly modeling provided by BPA. Maximum January output (plus 100-250 MW of operating reserves) was 1.9-2.1 GW (~56-60% of total capacity), slightly less but close to the 65% regional hydro value the study assumes.

Figure 21. BPA-Modeled LSR Dam Output During the 2001 Low Hydro Year with CRSO EIS Preferred Alternative operations



The other capacity value uncertainty is whether the Northwest will remain winter reliability challenged or whether reliability events will shift to the summer due to climate impacts on load patterns and hydro output. If reliability challenges did shift to the summer, the LSR dam firm capacity contribution would be significantly lower than assumed. However, E3 believes it is reasonable to assume under high electrification scenarios that the region will remain winter challenged due to peak space heating needs, as shown in figure below.

Figure 22. Winter vs. Summer Peak Loads

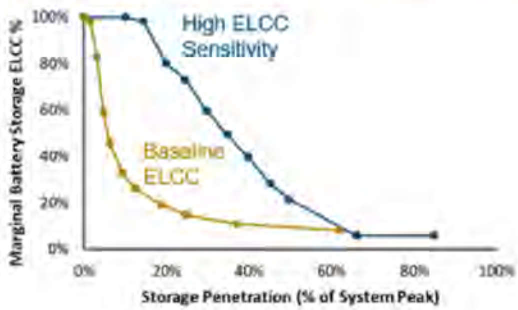


To address the capacity value uncertainty, a post-processing analysis was performed based on the replacement resources selected for firm capacity replacement. Based on this analysis performed on scenarios 1 and 2a, relative to the 2.28 GW assumption used in this study, it is estimated that a 1.5 GW firm capacity value (43%) for the dams would lower the NPV replacement costs by 9-20% and a 1.0 GW firm capacity value (29%) would lower the NPV replacement costs by 14-33%.

Replacement Resources Firm Capacity Counting

If Northwest reliability challenges dramatically shift into the summer, this would also impact the capacity value of replacement resources. One key input assumption this would change is the capacity value of battery storage additions, which were previously limited due to the Northwest wintertime energy-constrained reliability events causing charging sufficiency challenges for energy storage resources. To test whether higher energy storage ELCCs would impact the LSR dams replacement resources and replacement costs, a high storage ELCC sensitivity scenario was analyzed, per the ELCC inputs shown in Figure 23 below. This analysis was performed on scenarios 1 and 2a.

Figure 23. Inputs for High Battery Storage ELCC Sensitivity



In Scenario 1, with the LSR dams intact, higher battery ELCCs cause another 1.5 GW of batteries to be selected and 1.4 GW less dual fuel natural gas and hydrogen plants. In Scenario 2a, with the LSR dams intact, higher battery ELCCs cause another 2.4 GW of batteries and another 0.3 GW of wind to be selected, with 3.6 GW less dual fuel natural gas and hydrogen plants.

When the LSR dams are assumed to be breached, the differences in replacement resources are relatively small. In Scenario 1, an additional ~0.2 GW of battery storage, an additional 0.2 GW of wind, and 0.2 GW less dual fuel natural gas and hydrogen plants are selected to replace the dams. In Scenario 2a, an 0.3 GW less battery storage, 0.3 GW less wind, and an additional 0.1 GW of dual fuel natural gas and hydrogen plants are selected to replace the dams. This is because scenario 2a builds more wind and batteries in the base case already with the dams not breached, so the model prefers to select fewer of those resources for LSR dams replacement. Annual replacement costs in 2045 are 2% lower in scenario 1 and the same in scenario 2a. These results indicate that higher storage ELCCs would allow the region to build less dual fuel natural gas and hydrogen plants, but because energy storage ELCCs eventually saturate in either case, the replacement resources for the dam are not significantly changed and there is little impact on the replacement costs.

Conclusions and Key Findings

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho, and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability. RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[37]. Using RESOLVE allows for a dynamic optimization that considers replacement resource needs in the context of long-term system load and policy drivers, not just the near-term resource mix and needs of the system today. The dams are assumed to be breached in 2032, except for one sensitivity that considered 2024 breaching.

This study's scenario design focuses on three key variables – clean energy policy, load growth, and emerging technology availability – that impact the cost to replace the dams.

Even with the dams in place, the region's clean energy goals and potential electrification load growth drive a significant need for new resources. In all scenarios, significant energy efficiency and customer solar is embedded into the load forecast, based on the NWPCC's 8th Power Plan. Additionally, 6 gigawatts ("GW" or 6,000 MW) of coal capacity is retired by 2030, while increasing carbon prices incent further clean energy resource additions. In Scenario 1, the regional power system is required to meet a goal of generating enough clean energy to provide 100% of retail electricity sales, on an average basis over a calendar year. This requires an additional 5 GW of solar and 5 GW of wind by 2045 to achieve the clean energy goal; 0.6 GW of battery storage, 2 GW of demand response, and 9 GW of dual fuel natural gas + hydrogen combustion plants are also added to meet the region's resource adequacy needs.

Though all scenarios require more "firm" resources – resources that can generate when needed and operate for as long as needed – to meet peak loads, these resources are in higher demand in Scenario 2, in which all greenhouse gas emissions are eliminated from the regional power system by 2045. This scenario also assumes that electrification results in much higher electric loads, particularly in wintertime due to electrification of natural gas space heating in buildings. The baseline scenario (2a) selects additional wind, solar, and geothermal to meet clean energy needs as well as demand response, some battery storage, and 27 GW natural gas and hydrogen dual fuel combustion plants to meet reliability needs. An alternative "emerging technology" scenario selects 17 GW of advanced nuclear technology (small modular reactors or "SMRs") by 2045, in place of the firm capacity provided by natural gas generators while reducing the required quantities of wind, solar and batteries that are needed. The "no new combustion" scenario does not allow emerging clean firm technologies such as hydrogen combustion turbines, gas generation with carbon capture and sequestration (CCS) or SMRs. As a result, it requires

[37] Pacific Northwest Low Carbon Scenario Analysis, December 2017, https://www.ethree.com/projects/study-policies-decarbonize-electric-sector-northwest-public-generating-pool-2017-present/; Pacific Northwest Zero-Emitting Resources Study, January 2020, https://www.ethree.com/e3-examines-role-of-nuclear-power-in-a-deeply-decarbonized-pacific-northwest/

impractically high levels of additional onshore wind, offshore wind, and battery storage to meet firm capacity and carbon reduction needs, quadrupling the total installed MW of the Northwest grid by 2045.

When the power services provided by the dams are removed from the regional power system, RESOLVE selects an optimal, i.e., least-cost portfolio of replacement resources that meets the Northwest's clean energy and system reliability needs. These replacement resources require a large investment and come at a substantial cost that increase over time as the region's clean energy goals become more stringent. In the latter years, the replacement costs are highly dependent on scenario-specific assumptions about the availability of emerging technologies. RESOLVE primarily replaces the carbon-free energy from the dams with additional wind power and the firm capacity with dual fuel natural gas and hydrogen combustion plants. Small amounts of additional energy efficiency and battery storage are also selected in some scenarios. By 2045, the dual fuel plants added burn additional hydrogen on low wind days to replace the carbon-free energy provided by the dams. Scenario 2b selects additional nuclear SMRs in lieu of some of the wind and gas resources. Scenario 2c disallows the new combustion plants, even those that would burn green hydrogen, and other emerging technologies, requiring a very large buildout of wind and solar power to replace both the firm capacity and the carbon-free energy of the dams.

The long-term emissions impact of removing the generation of the lower Snake River dams will depend on the implementation of the Oregon and Washington electric clean energy policies. Both a 100% clean retail sales and a zero-carbon emissions target require replacement of most or all of the LSR dams' GHG-free energy. However, without additional earlier carbon-free resource investments beyond those modeled in this study to meet clean energy policy trajectories, carbon emissions may increase initially when the dams are breached, before declining by 2045 as the carbon policy becomes more stringent.

KEY FINDINGS:

- ***Replacing the four lower Snake River dams while meeting clean energy goals and system reliability is possible but comes at a substantial cost***, even assuming emerging technologies are available:
  - Requires 2,300 – 2,700 MW of replacement resources
  - An annual cost of $415 million – $860 million by 2045
  - Total net present value cost of $10.7-19 billion based on 3% discounting over a 50-year time horizon following the date of breaching
  - Increase in costs for public power customers of $100 – 230 per household per year (an 8 – 18% increase) by 2045
- The biggest cost drivers for replacement resources are the need to replace the lost ***firm capacity for regional resource adequacy*** and the need to replace the lost ***zero-carbon energy***
- Replacement becomes ***more costly over time*** due to increasingly stringent clean energy standards and electrification-driven load growth
- ***Emerging technologies*** such as hydrogen, advanced nuclear, and carbon capture ***can limit the cost of replacement resources*** to meet a zero emissions electric system, but the pace of their commercialization is highly uncertain
  - In economy-wide deep decarbonization scenarios, ***replacement without any emerging technologies requires very large renewable resource additions at a very high cost*** (12 GW of wind and solar at $75 billion NPV cost)

Appendix

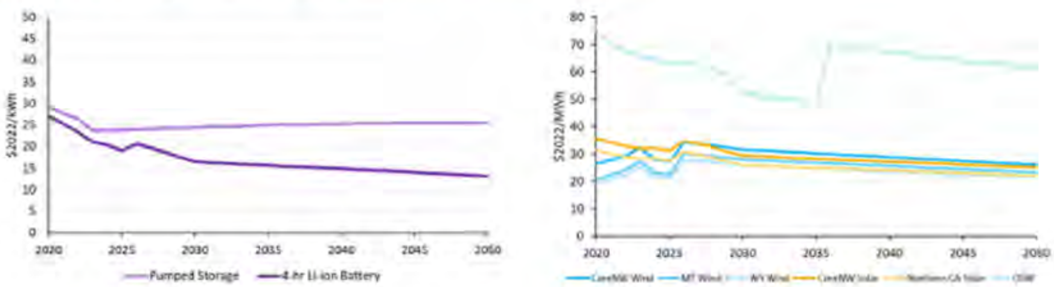
Additional Inputs Assumptions and Data Sources

Candidate resource costs

The technology fixed costs trajectories for candidate resource options are shown in Figure 24 and use the following data sources:

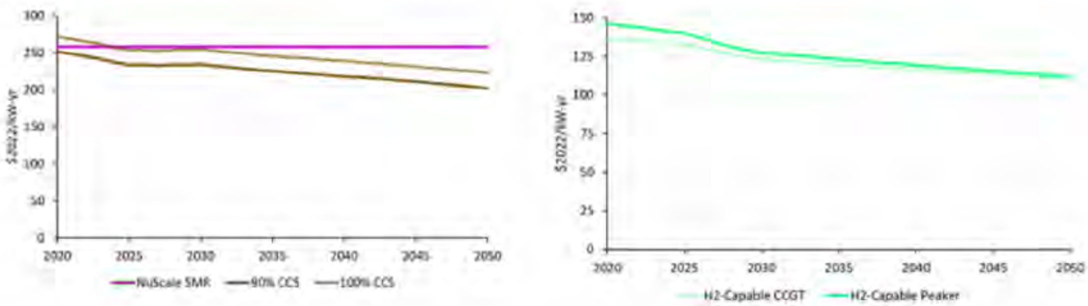
+ Battery Storage: Costs derived from Lazard LCOS 7.0 and E3 modeling
+ Pumped Storage: Costs derived from Lazard's last published PHS costs (LCOS 4.0)
+ Renewables (solar, onshore, and offshore wind): Costs derived from E3's inhouse Pro Forma which integrates the NREL 2021 Annual Technology Baseline
+ Geothermal: Costs derived from E3's inhouse Pro Forma which integrates the NREL 2021 Annual Technology Baseline
+ Energy Efficiency and Demand Response: Costs supply curve adjusted for cost effective energy efficiency and DR potential from the 2021 Northwest Power Plan
+ Carbon Capture and Storage (CCS): Costs derived from E3's inhouse "Emerging Tech" Pro Forma using the NREL 2021 Annual Technology Baseline and Feron et al., 2019.[38]
+ Nuclear Small Modular Reactor (SMR): Costs are derived from the vendor NuScale, for an "nth of a kind" installation of the technology they are developing
+ Gas and Hydrogen-Capable Technologies: CCGT and peaker costs are derived from E3's inhouse ProForma which integrates NREL 2021 Annual Technology Baseline. New Hydrogen or natural gas to hydrogen upgrades include a ~10% additional cost that converges with standard CCGT and peaker costs by 2050

Figure 24. All-in fixed costs for candidate resource options[39]



[38] Feron, P., Cousins, A., Jiang, K., Zhai, R., Thiruvenkatachari, R., & Burnard, K. (2019). Towards zero emissions from fossil fuel power stations. International Journal of Greenhouse Gas Control, 87, 188–202.

[39] Storage costs are shown in $/kWh of energy storage. Renewable costs are shown in $/MWh. Clean firm resources (nuclear, CCS, hydrogen CCGT or peakers) are shown in $/kW-yr, since their $/MWh costs are a function of their runtime that RESOLVE would determine endogenously.

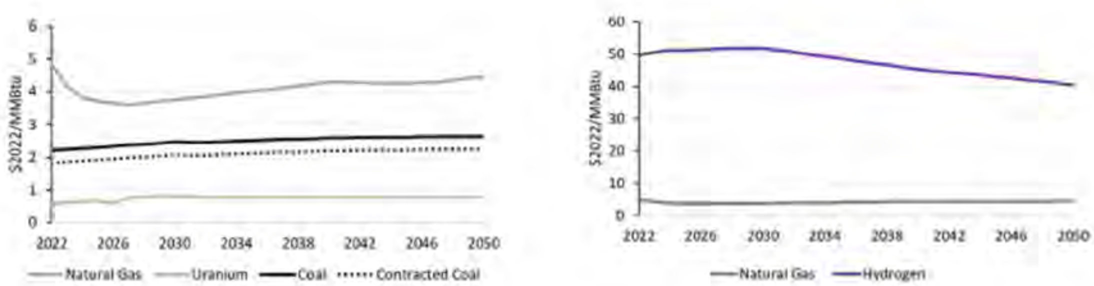


Fuel prices

The fuel price forecasts used in this study are derived from a combination of market data and fundamentals-based modeling of natural gas supply and demand. Wholesale gas prices are pulled from forward contracts from NYMEX (Henry Hub) and Amerex and MI Forwards (all other hubs) for the next five years, after which the Henry Hub forecast trends towards EIA's AEO natural gas price by 2040. All other hubs forecast after the first five years are based on the average 5-year relationship between their near-term forward contracts and that of Henry Hub. Data sources used for fuel price forecasts used in modeling are as follows and the trajectories are presented in Figure 25:

+ Natural gas prices: In near term, SNL NG price forecasts (i.e., for 2022-2026); and in long term, the EIA's AEO 2040 forecasts are used. Recent fuel cost increases due to market disruptions are excluded from the price trajectory.
+ Coal prices: EIA's AEO forecast are used
+ Uranium prices: E3's in-house analysis
+ Hydrogen prices: Conservative prices are used assuming no large-scale hydrogen economy, and thus electrolyzer capital costs and efficiencies are assumed to improve over time only slightly. Other assumptions include above ground hydrogen storage tanks and delivery via trucks from about 225 miles distance. Electrolyzers use dedicated off-grid Core NW wind power to produce hydrogen.

Figure 25. Fuel price forecasts for natural gas, coal, uranium, and hydrogen

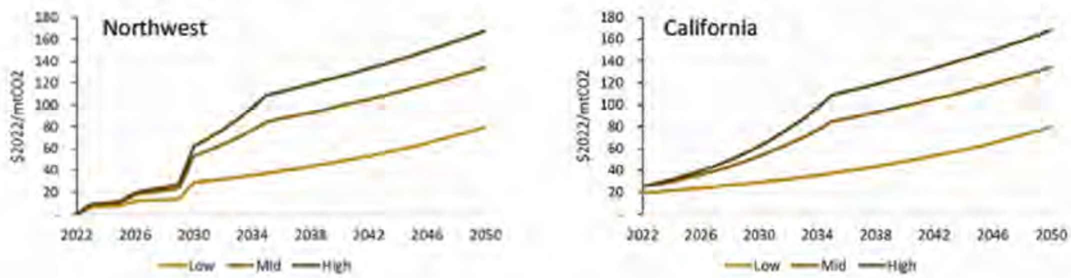


Annual average gas prices are further shaped according to a monthly profile to capture seasonal trends in the demand for natural gas and the consequent impact on pricing.

Carbon prices

For carbon pricing, it is assumed that Washington's cap-and-trade program starts in 2023 at around 50% of California carbon prices. For Oregon, it is assumed that a carbon price policy will be effective by 2026 for the electric sector. Prior to 2026, the Northwest carbon price is a load weighted share of carbon prices in WA and OR. Additionally, it is assumed that both states will converge to California's floor price by 2030. California's carbon prices are adopted from the Final 2021 IEPR GHG Allowance Price Projections (December 2021). Mid carbon prices presented in Figure 26 are used in modeled cases.

Figure 26. Carbon price forecasts for Northwest and California



Operating Reserves

It is assumed that all coal, gas, hydro, and storage resources within the Northwest zone can provide operating reserves. Additionally, RESOLVE allows renewable generation to contribute to meeting the needs for load following down; to allow for variable renewable generation curtailment to balance forecast error and sub-hourly variability. The following three types of operating reserve requirements are considered within the Core Northwest to ensure that in the event of a contingency, sufficient resources are available to respond and stabilize the electric grid:

- **Spinning reserves:** Modeled as 3% of hourly load in agreement with WECC and NWPP operating standards
- **Regulation up and down:** Modeled as 1% of hourly load
- **Load following up and down:** Modeled as 3% of hourly load

Modeling of Imports and Exports

The Northwest RESOLVE model includes a zonal representation of the WECC. In modeling hourly dispatch during representative days, it considers the least-cost dispatch solution across the WECC, based on resource economics, resource operational limits, fuel and carbon prices, operating reserve requirements, and zonal transmission transfer limits. Imports to the CoreNW zone can occur from other neighboring zones; when they do a carbon adder is included for unspecified imports, while specified imports do not receive a carbon adder. Exports from the CoreNW zone may occur as deemed economic by RESOLVE, subject to other model constraints.

Minimum and maximum capacity limits are applied to the zonal representation of transmission between connected zones. These zonal transfer limits are shown in Table 13. Transmission hurdle rates as well as carbon hurdle rates (with regional carbon price adders) are applied to imports and exports.

Table 13. Transmission Capacity Limits between the CoreNW and other Zones

Transmission Constraint	Transmission from	Transmission to	Min Flow (MW)	Max Flow (MW)
CoreNW to OtherNW	CoreNW	OtherNW	-6,036	2,550
CoreNW to CA	CoreNW	CA	-6,820	5,433
CoreNW to SW	CoreNW	SW	0	0
CoreNW to NV	CoreNW	NV	-300	300
CoreNW to RM	CoreNW	RM	0	0

Contracted imports (such as imported coal and/or wind power) are included in the resource adequacy accounting captured in the planning reserve margin constraint. New remote resources include transmission cost adders to deliver them into the CoreNW zone. Additional unspecified imports are not assumed in RESOLVE's resource adequacy accounting.

Additional LSR Dam Power System Benefits (not modeled)

As described in this report, RESOLVE covers replacement of most power services provided by the LSR dams. However, RESOLVE does not model transmission grid operations (power flow, voltage and frequency, dynamic stability, etc.). Therefore, E3 notes that the LSR dams may provide the following additional essential reliability services to the transmission grid. In general, E3 expects that the replacement of these services can be achieved either through siting and operations of the incremental replacement capacity selected or by additional local transmission investments. The scale of these transmission investments requires more detailed study.

- **Reactive power and voltage control**: the LSR dams, like hydropower resources generally in the Northwest, provide significant reactive power capabilities that supports reliable power flow by optimally controlling voltage levels. Replacing this function likely requires siting additional resources with reactive power capabilities in a similar section of the transmission grid as the LSR dams.
- **Frequency response and inertia**: the LSR dams provide both primary and secondary frequency response capabilities. As synchronous generators they also provide system inertia that would be lost if the LSR dams are removed and as other synchronous generators retire. New efforts are underway to allow renewable generators or battery storage to provide "synthetic inertia" (or equivalent fast frequency response services), but this provision has not yet been proven to date at scale. The LSR dams are also highly tolerant of operating during high and low frequency events without sustaining blade damage.
- **Blackstart**: Large hydro resources have the capability to provide black start services when required, though not all hydro plants are chosen to provide this capability.

- **Participation in remedial action schemes**: Hydropower is a robust resource for participation in remedial action schemes because it can withstand being suddenly tripped off-line as part of a RAS action.
- **Short circuit and grounding contribution**: Synchronous generators (like hydropower) provide a large short circuit current that is important for the proper operation of protective relaying schemes.

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BPA Lower Snake River Dams Power Replacement Study

Executive Summary

July 2022

Arne Olson, Sr. Partner
Aaron Burdick, Associate Director
Dr. Angineh Zohrabian, Consultant
Sierra Spencer, Sr. Consultant
Sam Kramer, Consultant
Jack Moore, Sr. Director

About this study

+ **BPA contracted with E3 to conduct an independent analysis of the electricity system value of the four lower Snake River (LSR) dams**
+ **E3 utilized our RESOLVE optimal capacity expansion model to identify least-cost portfolios of electricity resources needed to replace the electric energy and grid services provided by the dams through 2045**
+ **Replacement costs are considered within the context of the Northwest region's aggressive, long-run decarbonization goals**

Key Study Questions:

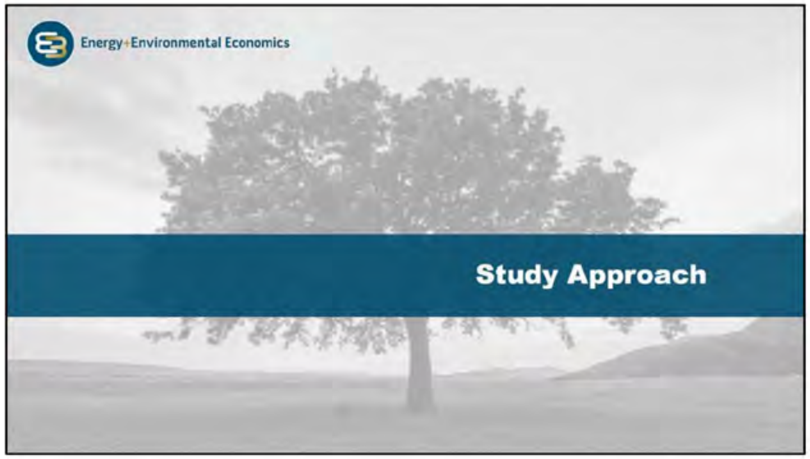
- What **additional resources** would be needed to replace the power services provided by the LSR Dams through 2045?
- What is the **net cost to** BPA ratepayers?
- How do costs and resource needs change under **different types of clean energy futures**?
- How much does replacing the dams rely on **emerging, not-yet-commercialized technologies**?

What would it take to replace the output of the four lower Snake River dams?

- **What energy services are lost if the dams are breached?**
  - **3,483 MW of total capacity***, including approximately **2,300 MW of firm peaking** capability to avoid power shortages during extreme cold weather events
  - **~900** annual average MW of low-cost, zero-carbon energy** (enough energy to support ~450,000 households or 1.7x the City of Portland) as well as **operational flexibility** services
- **How much would it cost to replace the power benefits of the four lower Snake River dams in E3's study with breaching in 2032?**
  - In E3's **baseline scenario**, total net present value (NPV)*** replacement costs would be **$11.8 billion**
  - In a **deep decarbonization scenario** with higher loads and zero emissions electricity by 2045, NPV costs range from **$10.7-19 billion** with at least one emerging technology
    - Reaching deep decarbonization **absent breakthroughs in not-yet-commercialized emerging technologies**, NPV costs could increase to **$75 billion**
- **What are the long-term rate impacts to ~2 million public power households in 2045?**
  - Public power costs increase by **8-18%** or **~$100-230 per year across most scenarios**
    - Costs increase by **68%** or **~$850 per year** under deep decarbonization scenario **absent emerging technology breakthroughs**
- **What resources are needed to replace the dams?**
  - A combination of **renewable generation** (wind), **"clean firm" resources** (such as dual fuel natural gas + hydrogen plants, advanced nuclear, or gas with carbon capture and storage), and **energy efficiency**
  - Battery storage cannot cost-effectively replace hydro capacity in the Northwest due to charging limitations during energy shortfall events
- **What is the timeline necessary to add the resources that would be required?**
  - E3 estimates that adding additional renewable energy and firm capacity additions would take approximately 5-7 years after congressional approval to breach the dams and possibly up to 10-20 years if additional new large-scale transmission was required. E3 assumed transmission would be built as needed for renewable additions.

Plant	Total Capacity (MW)
Lower Granite	930
Little Goose	930
Lower Monumental	930
Ice Harbor	693

Total = 3,483 MW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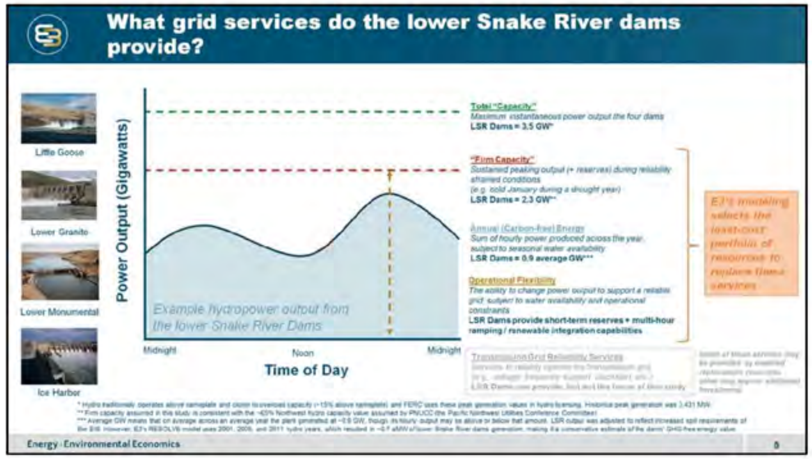
Study Approach



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What's the focus in this study compared to the CRSO EIS?

The study uses an optimization model to determine the least-cost replacement resources for the four lower Snake River dams subject to A) policy and B) reliability constraints

- **Least-cost optimization: includes updated resource pricing and new emerging technologies**
- **Policy: E3's modeling considers the effects of regional policies such as Washington's Clean Energy Transformation Act (CETA) and Oregon's 100% clean electricity standard**
  - Aggressive clean energy laws drive coal power plant retirements, price carbon emissions, and require long-term **carbon emissions reductions** by 2045
  - Study includes significant **electrification** that increases demand for electricity to support carbon-reduction in other sectors such as transportation, buildings, and industry, consistent with Washington's Energy Strategy
- **Reliability: E3's modeling captures the need for the Northwest system to meet peak load during extreme weather and low hydro conditions (known as "resource adequacy").**
  - Captures the abilities and limits of different technologies to serve load during reliability challenging conditions
    - E.g. during extended cold-weather periods with high load, low hydropower availability and low wind and solar production
  - Resources with high energy production costs may be selected for reliability needs but then run sparsely only during extreme conditions (e.g. natural gas + hydrogen combustion turbines)
- **LSR operations: incorporates preferred alternative operations selected in the EIS**
  - Increases spill from the dams, lowering available annual energy and changing operational flexibility

Policy landscape: Washington, Oregon, California

- The study includes the impacts from clean energy policies in the Pacific states

	RPS or Clean Energy Standard?	Coal Prohibition?	Cap-and-Trade?	New Natural Gas?	Economy-Wide Carbon Reduction?
WA	✔ Carbon neutral by 2030, 100% carbon free electricity by 2045	✔ Eliminate by 2025	✔ Cap-and-invest program established in 2021. SCC in utility planning	✔	✔ 95% GHG emission reduction below 1990 levels and achieve net zero emissions by 2050
OR	✔ 50% RPS by 2040, 100% GHG emission reduction by 2040 relative to 2010 levels	✔ Eliminate by 2030	✔ Climate Protection Plan adopted by DEQ in 2021 (power sector not included)	✖ HB 2021 bans expansion or construction of power plants that burn fossil fuels	✔ 90% GHG emission reduction from fossil fuel usage relative to 2022 baseline
CA	✔ 60% RPS by 2030, 100% clean energy by 2045	✔ Coal-fired electricity generation already phased out	✔	✖ CPUC IRP did not allow in recent procurement order	✔ 40% GHG emission reduction below 1990 levels by 2030 and 80% by 2050

Modeling approach involves a three-step process

1. ***With the lower Snake River dams***, **optimize long-term resource needs and operations for the Pacific Northwest**
   - Produces necessary resource additions and total system costs and emissions

2. ***Remove the lower Snake River dam generating capacity, then re-optimize*** **long-term resource needs and operations for the Pacific Northwest**
   - Produces a second set of resource additions and total system costs and emissions
   - All scenarios breach the dams in 2032, except for one scenario in 2024

3. ***Calculate additional resources and investment + operational costs*** **required to replace the dams**
   - Calculated as the difference between steps 1 and 2 above

Key modeling assumptions

Element	Study Approach	Impact on Dams Replacement Needs
Study Years	• 2025 through 2045*, including fuel price forecasts and declining renewable + storage costs	Considers long-term needs
Clean Energy Policy Scenarios	• Aggressive OR+WA legislation reflected, including coal retirements + carbon pricing • Two electric emissions scenarios considered: 1. **100% clean retail sales** (~85% carbon reduction**) 2. **Zero-emissions** (100% carbon reduction)	Clean energy policy requires long-term **replacement of LSR dams with GHG-free energy**
Load Growth Scenarios	• Two load scenarios: 1. **Baseline** (per NWPCC 8th Power Plan) 2. **High electrification** load growth (to support economy-wide decarbonization) • Significant quantities of energy efficiency are embedded in all scenarios	Higher load scenarios **increase the value of LSR dams energy + firm capacity**
Reliability Needs	• Modeling ensures reliability needs during extreme conditions (e.g. high loads + low hydro) • Captures ability (and limits) of renewables, battery storage, and demand response to support system reliability	Reliability needs require **replacement of LSR dams firm capacity contributions**
Technologies Modeled, including "Emerging" Technologies	• Broad range of dam replacement technology options considered: • **Baseline technologies**: solar, wind, battery + pumped storage, energy efficiency, demand response, dual fuel natural gas + hydrogen combustion plants • **Sensitivities** include Emerging Technologies and Limited Technologies (No New Combustion) scenarios • Resource costs developed by E3 using NREL 2021 ATB, Lazard Cost of Storage v7, NuScale Power (for small modular reactor costs)	**Technology available for LSR dams replacement** determines replacement cost
Distributed Energy Resource Options	• Energy efficiency, demand response, and customer solar embedded into modeling inputs • Additional energy efficiency and demand response can be selected	**Demand resource can help replace LSR dams**, though low-cost supply is limited

* 20-years of end effects are considered (2045-2065)
** A 100% clean retail sales target allows emissions for electric generation beyond that needed to serve "retail sales", i.e. losses during transmission to retail loads and exported energy

Scenarios

+ **Scenario 1: 100% Clean Retail Sales**
  - Northwest resources produce enough clean energy to meet **100% of retail electricity sales** on an annual average basis
  - Some gas generation is retained for reliability, but carbon emissions are reduced **85% below 1990 levels**
  - **Business-as-usual** load growth
+ **Scenario 2: Deep Decarbonization**
  - **Zero carbon emissions** by 2045
  - **High electrification** of buildings, transportation, and industry to reduce carbon emissions in other sectors
  - **Emerging technologies** become available to provide firm, carbon-free power

Emerging Technologies

Technology	S1 100% Clean	S2a Deep Decarb Baseline	S2b Deep Decarb Emerging Tech	S2c Deep Decarb No New Combustion
Mature technologies (solar, wind, battery + pumped storage, energy efficiency, demand response)	Available	Available	Available	Available
Hydrogen (existing natural gas retrofits)	Available	Available	Available	Available
Hydrogen (new dual fuel natural gas + hydrogen)	Available	Available	Available	Not available
Nuclear (small modular reactors)	Not available	Not available	Available	Not available
Natural Gas w/ Carbon Capture and Storage	Not available	Not available	Available	Not available
Offshore Wind (floating)	Not available	Not available	Available	Available

Available / Not available

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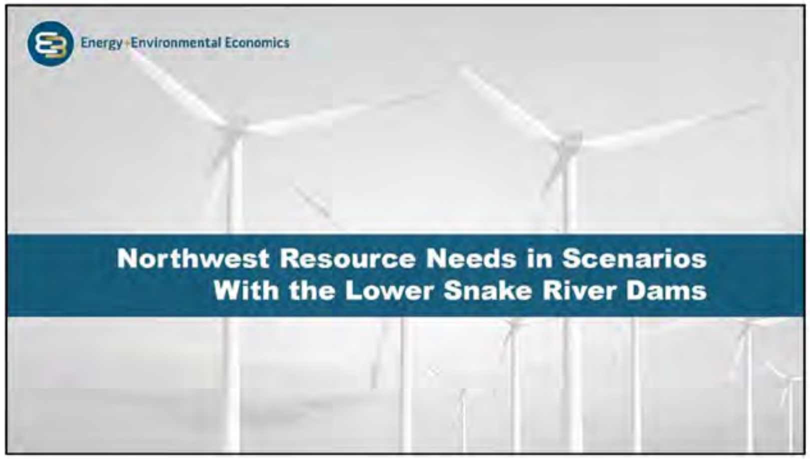
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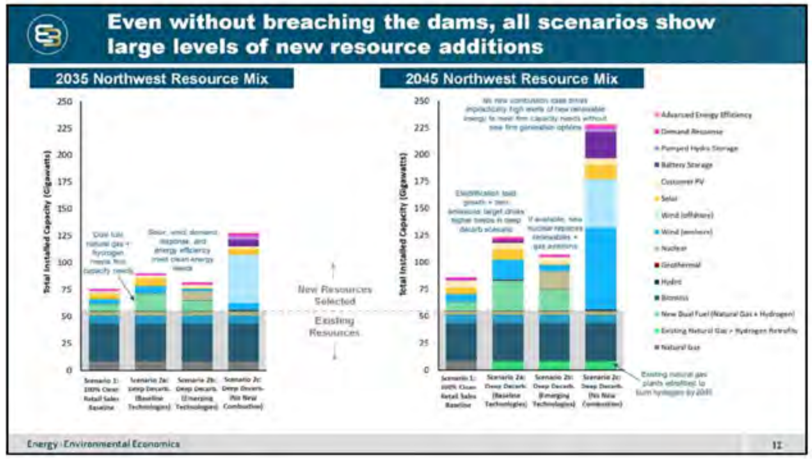
Northwest Resource Needs in Scenarios
With the Lower Snake River Dams


Even without breaching the dams, all scenarios show large levels of new resource additions
2035 Northwest Resource Mix
2045 Northwest Resource Mix
Total Installed Capacity (Gigawatts)
250
225
200
175
150
125
100
75
50
25
0
New Resources Selected
Existing Resources
Advanced Energy Efficiency
Demand Response
Pumped Hydro Storage
Battery Storage
Customer PV
Solar
Wind (offshore)
Wind (onshore)
Nuclear
Geothermal
Hydro
Biomass
New Dual Fuel (Natural Gas + Hydrogen)
Existing Natural Gas + Hydrogen Retrofits
Natural Gas
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12

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Replacing the Power from the Lower Snake River Dams

Replacement resources selected to replace the lower Snake River dams

- RESOLVE selects an optimal portfolio of replacement resources including additional advanced energy efficiency, wind, solar, green hydrogen, and/or advanced nuclear
- Firm capacity is mostly replaced with ~2 GW of dual fuel natural gas + hydrogen turbines
  - These turbines may initially burn natural gas when needed during reliability challenged periods, but would transition to hydrogen by 2045 to reach zero-emissions
- If advanced nuclear is available, it replaces renewables and some of the gas plants
- The "no new combustion" scenario requires impractically large (~12 GW) buildout of renewable energy to replace the dams' firm capacity contributions and GHG-free energy

Scenario	Replacement Resources Selected, Cumulative by 2045 (GW*)
Scenario 1: 100% Clean Retail Sales	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
Scenario 2a: Deep Decarb. (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW Advanced Energy Efficiency + additional H2 generation**
Scenario 2b: Deep Decarb. (Emerging Technologies)	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR
Scenario 2c: Deep Decarb. *(No New Combustion)*	+ 10.6 GW wind + 1.4 GW solar

* 1 GW = 1,000 MW
** Replacing LSR dams GHG-free energy at least cost leads RESOLVE to generate an additional 1.2 TWh of hydrogen generation during low renewable conditions (or 0.14 average GW)

Total costs for replacing the lower Snake River dams

+ **Costs are expected to fall on Bonneville Power Administration's public power customers**
  - Costs could **increase public power retail costs** by 8-18%, or up to 65% absent emerging technologies
  - Costs could **raise annual residential electricity bills** by up to $100-230/year, or up to $850/yr absent emerging technologies

	Total Costs (real 2022 $)	Annual Cost Increase (real 2022 $)			Incremental Public Power Costs [% increase vs. ~8.5 cents/kWh NW average retail rates]
	Net Present Value in year of breaching	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$11.8 billion	[illegible]	$434 million	$478 million	0.8 cents/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$12.8 billion	$485 million	$480 million	$589 million	0.8 cents/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$19.0 billion	[illegible]	$496 million	$960 million	1.5 cents/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$10.7 billion	[illegible]	$415 million	$428 million	0.7 cents/kWh [+8%]
Scenario 2c: Deep Decarb. *(No New Combustion)*	$75.2 billion	n/a	$1,953 million	$3,199 million	5.5 cents/kWh [+65%]

Deep decarbonization without emerging technologies drives impractically high costs

Cost differences driven primarily by 2045 carbon policy and availability of emerging technologies

Costs increase over time as loads grow and carbon policy becomes more stringent

- Cost increases account for replacement energy, capacity, and reserves as well as avoided LSR capital + expense, but do not include any costs for breaching the dams, which would be an additional cost.
- NPV and annual cost increase are shown for the Northwest Region as a whole, but the incremental costs are calculated relative to the BPA Tier I annual sales for public power customers. NPV calculated over a 50-year period following the date of breaching, using a 3% discount rate based on the public power cost of capital.
- % increase versus average retail rates assumes ~8.5 cents/kWh retail rates (estimated from OR and WA average retail rates). This does not include additional rate increases driven by higher loads or clean energy needs that increase regional rates as shown in the earlier 2045 incremental cost chart.
- Annual residential customer cost impact assumes 1,280 kWh/month for average residential customers in Oregon and Washington (current ~1,000 kWh/month average + 28% from electrification load growth).
- New federal tax credits for hydrogen plants/fuels or ITC/PTC extension for renewables would provide a cost reduction to public power customers from taxpayers

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Cost of generation for lower Snake River dams replacement resources (using common utility metric of $/MWh)

- **The lower Snake River dams provide a low-cost source of GHG-free energy and firm capacity**
- **Even in a best-case scenario, replacement power would cost several times as much as the lower Snake River dams costs**
  - This is driven by both energy replacement as well as replacement of firm capacity and operational flexibility
- **Compared to ~$13-17/MWh for the lower Snake River dams, replacement resources cost between $77-139/MWh**
  - Replacement costs rise to over $500/MWh in a deep decarbonization scenario absent emerging technology

Incremental LSR Dam Replacement Resource Costs

Lower Snake River Dams All-in Generation Costs (2022 $/MWh)
$13/MWh w/o LSRCP*
$17/MWh w/ LSRCP*

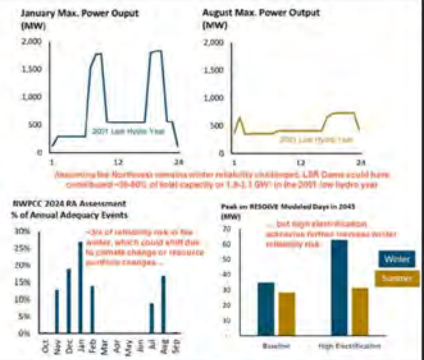
Scenario	2045 Costs to replace LSR Generation** (real 2022 $/MWh)
S1: 100% Clean Retail Sales	$77/MWh
S1b: 100% Clean Retail Sales (2024 dam breaching)	$82/MWh
S2a: Deep Decarb	$139/MWh
S2b: Deep Decarb, w/ Emerging Tech	$69/MWh
S2c: Deep Decarb, Limited Tech (no new combustion)	$517/MWh

* BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) fish hatcheries and satellite facilities. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat 2917) to offset fish and wildlife losses caused by construction and operation of the four lower Snake River projects.

** Replacement $/MWh costs are calculated as CoreNW revenue requirement increase with LSR dams breached divided by the annual MWh of the LSR dams assumed in E3's modeling (~700 aMW). These costs includes replacement of the LSR dam energy, capacity, and reserve provision. A significant portion of the costs is capacity costs to replace the dams' RA capacity contributions.

Firm capacity value of the lower Snake River dams

- **The firm capacity value is a significant driver of replacements costs**
- **PNUCC 2021 estimate of NW hydro sustained peaking capacity was used for the lower Snake River dams' firm capacity value (65% or 2.3 GW)**
- **E3 also analyzed modeled hourly LSR dam output during the 2001 low hydro year (using BPA data post EIS spill requirements)**
  - Suggests a winter firm capacity value of ~56-60%
- **E3 predicts a continued concentration of risk in the winter in deep decarbonization scenarios with high space heating electrification**
  - However, in a system with higher summer reliability risk, the LSR firm capacity value would be lower
  - E3 estimates the impact of a lower firm capacity value for S1 and S2a scenarios to be:
    - 1.5 GW firm capacity value (43%) → ~9-20% lower NPV replacement cost
    - 1.0 GW firm capacity value (29%) → ~14-33% lower NPV replacement cost



Key conclusions

1. **Replacing the four lower Snake River dams comes at a substantial cost, even assuming emerging technologies are available**
   - Require 2,300 – 2,700 MW of replacement resources
   - An annual cost of $415 million – $860 million by 2045*
   - Total net present value replacement cost of $10.7 – 19.0 billion based on 3% discounting over a 50-year time horizon following the date of breaching
   - Increase in costs for public power customers of $100 – 230 per household per year (an 8 – 18% increase) by 2045
2. **The biggest cost drivers for replacement resources are the need to replace the lost firm capacity and the need to replace the lost zero-carbon energy**
3. **Replacement resources become more costly over time due to increasingly stringent clean energy standards and electrification-driven load growth**
4. **Emerging technologies such as hydrogen, advanced nuclear, and carbon capture can limit the cost of replacement resources to meet a zero emissions electric system, but the pace of their commercialization is highly uncertain**
   - Replacing the dams in deep decarbonization scenarios without any emerging technologies requires impractical levels of renewable additions at a very high cost ($75 billion NPV cost)

* Replacement resource costs are calculated assuming project financing per E3's pro forma calculator, rather than assuming upfront congressional appropriation

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Thank you

Questions, please contact:

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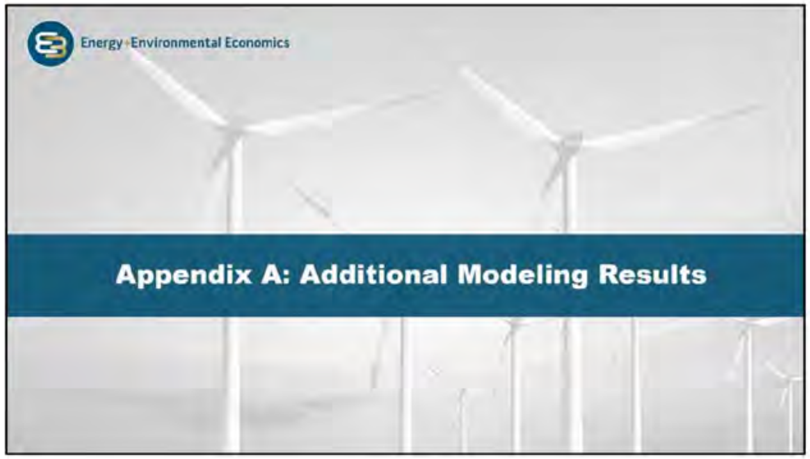
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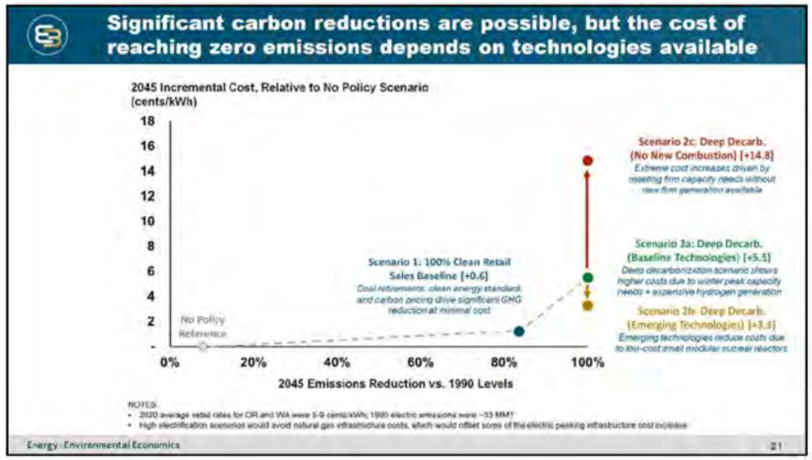
Appendix A: Additional Modeling Results


Significant carbon reductions are possible, but the cost of reaching zero emissions depends on technologies available
2045 Incremental Cost, Relative to No Policy Scenario (cents/kWh)
18
16
14
12
10
8
6
4
2
-
No Policy Reference
Scenario 1: 100% Clean Retail Sales Baseline [+0.6]
Coal retirements, clean energy standard, and carbon pricing drive significant GHG reduction at minimal cost
Scenario 2c: Deep Decarb. (No New Combustion) [+14.8]
Extreme cost increases driven by meeting firm capacity needs without new firm generation available
Scenario 2a: Deep Decarb. (Baseline Technologies) [+5.5]
Deep decarbonization scenario shows higher costs due to winter peak capacity needs + expensive hydrogen generation
Scenario 2b: Deep Decarb. (Emerging Technologies) [+3.3]
Emerging technologies reduce costs due to low-cost small modular nuclear reactors
0%
20%
40%
60%
80%
100%
2045 Emissions Reduction vs. 1990 Levels
NOTES:
• 2020 average retail rates for OR and WA were 5-9 cents/kWh; 1990 electric emissions were ~33 MMT
• High electrification scenarios would avoid natural gas infrastructure costs, which would offset some of the electric peaking infrastructure cost increase
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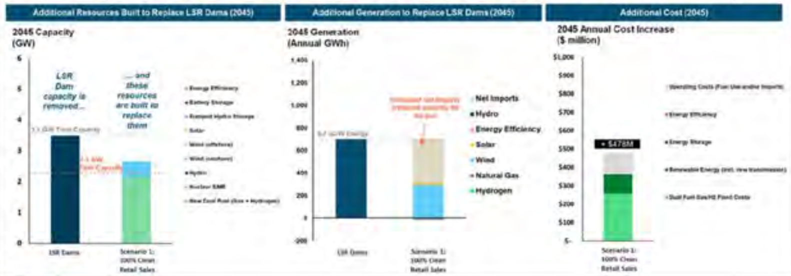
Replacing the Lower Snake River Dams
Scenario 1: 100% Clean Retail Sales

- Capacity replaced with 2.2 GW of dual fuel natural gas + hydrogen turbines and 0.5 GW wind
- Wind and imports provide the most energy replacement, but gas plant is needed for meeting extreme weather peak load events to avoid power shortages
- 2045 GHG emissions increase ~11% as not all LSR generation needs to be replaced to still meet 100% clean retail sales target

Additional Resources Built to Replace LSR Dams (2045)	Additional Generation to Replace LSR Dams (2045)	Additional Cost (2045)



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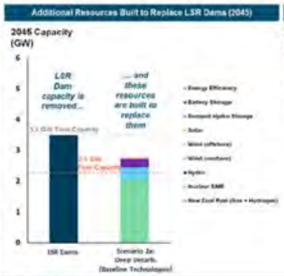
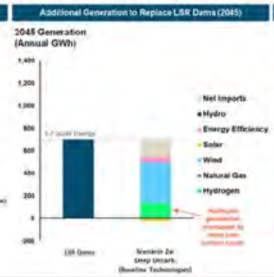
Replacing the Lower Snake River Dams
Scenario 2a: Deep Decarbonization (Baseline Technologies)

- Scenario includes electric load increases for transportation and other sectors
- In 2045, hydrogen generation is a key replacement resource and is assumed to be available, though not commercially available today
- This scenario would cost $860 million dollars per year in 2045, driven by high hydrogen fuel costs (~$40/MMbtu)

Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)



Additional Cost (2045)

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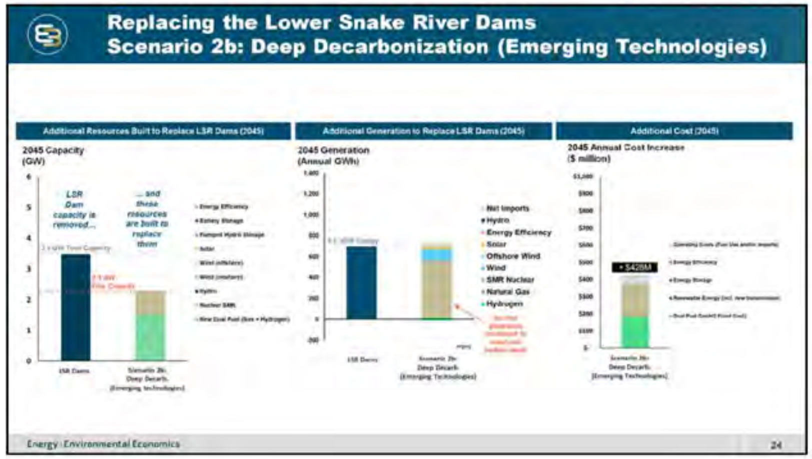
Replacing the Lower Snake River Dams
Scenario 2b: Deep Decarbonization (Emerging Technologies)
Additional Resources Built to Replace LSR Dams (2045)
2045 Capacity (GW)
LSR Dam capacity is removed...
... and these resources are built to replace them
LSR Dams
Scenario 2b: Deep Decarb. (Emerging technologies)
Additional Generation to Replace LSR Dams (2045)
2045 Generation (Annual GWh)
Net Imports
Hydro
Energy Efficiency
Solar
Offshore Wind
Wind
SMR Nuclear
Natural Gas
Hydrogen
LSR Dams
Scenario 2b: Deep Decarb. (Emerging Technologies)
Additional Cost (2045)
2045 Annual Cost Increase ($ million)
+ $428M
Scenario 2b: Deep Decarb. (Emerging Technologies)
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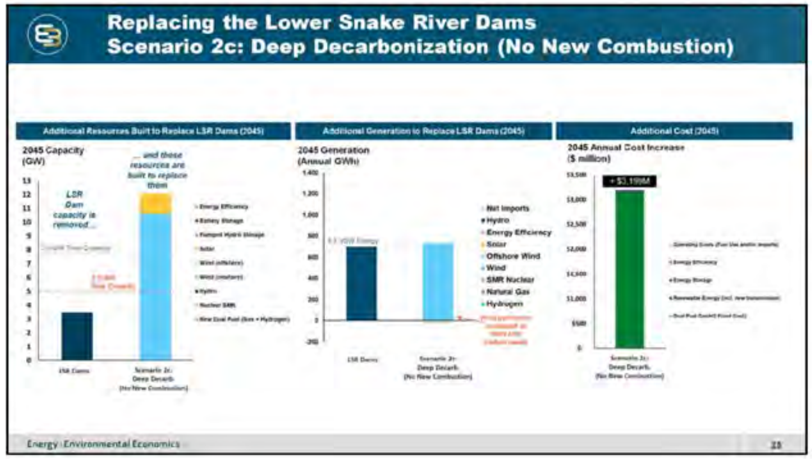

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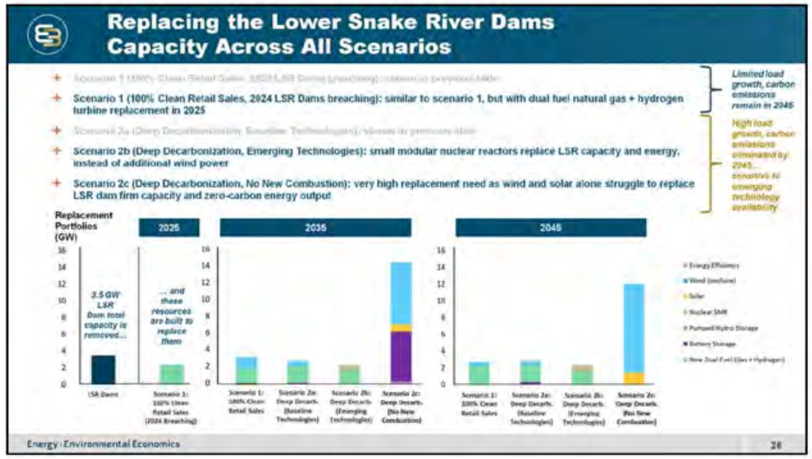

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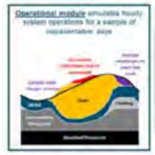
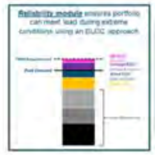
Appendix B: Additional Modeling Inputs

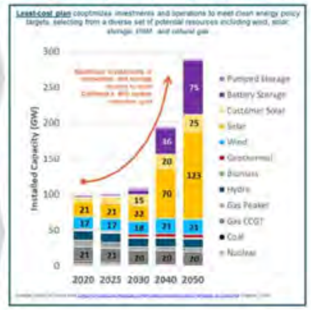
RESOLVE optimizes investments to meet clean energy targets reliably

RESOLVE is an optimal capacity expansion model specifically designed to identify least-cost plans to meet reliability needs and achieve compliance with regulatory and policy requirements

- **Linear optimization model explicitly tailored to study challenges to arise at high penetrations of variable renewables and energy storage**
- **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**







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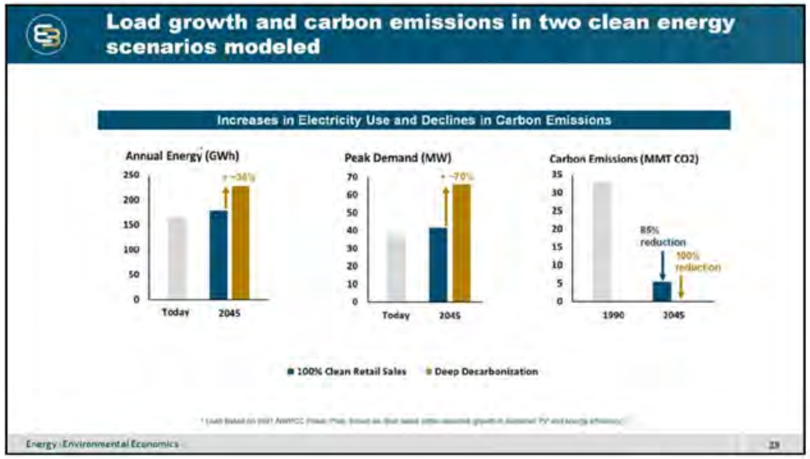

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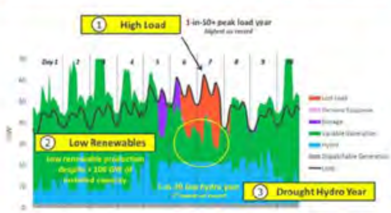
Resource Adequacy Resource Options

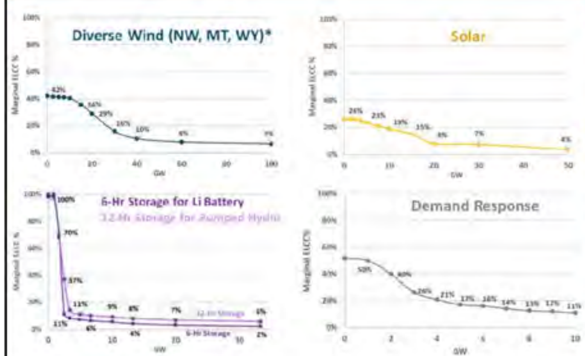
- RESOLVE resource adequacy constraint requires capacity to meet peak demand + a 15% planning reserve margin
  - Planning reserve margin (PRM) constraint is "installed capacity" (ICAP) based for firm resources, peaking capacity for hydro, ELCC for other non-firm resources
- The nature of the Northwest reliability risk limits the ability of battery storage to provide reliable capacity contributions
  - Storage and hydro show "antagonistic" interactions, which limit energy storage reliability value in "energy-limited" conditions where energy storage resources are unable to charge (with low hydro and renewable output) and run out of discharge (during extended energy shortfall events)

Key Drivers of Future Pacific Northwest Reliability Events



Resource	RA Capacity Contributions
Hydro	85%, based on sustained winter peaking capacity in critical water year conditions (per BPA/PNUCC). WRAP method is still evolving
Battery storage	Sharply declining ELCCs*
Pumped storage	Sharply declining ELCCs
Solar	Declining ELCCs
Wind	Declining ELCCs
Demand Response	Declining ELCCs
Energy Efficiency	Limited potential vs. cost
Small Hydro	Limited potential
Geothermal	Limited potential
Natural gas to H2 retrofits	Clean firm, but not fully commercialized
New dual fuel natural gas + H2 plants	Clean firm, but not fully commercialized
New H2 only plants	Clean firm, but not fully commercialized
Gas w/ 90-100% carbon capture + storage	Clean firm, but not fully commercialized
Nuclear Small Modular Reactors	Clean firm, but not fully commercialized

Incorporating Declining Capacity Contributions of Renewables, Storage, and DR



- A reliable electric system requires enough capacity to meet peak loads and contingencies
- This study incorporates information from E3's 2019 report *Resource Adequacy in the Northwest* about the effective capacity contribution of renewables, storage, and DR at various penetration levels

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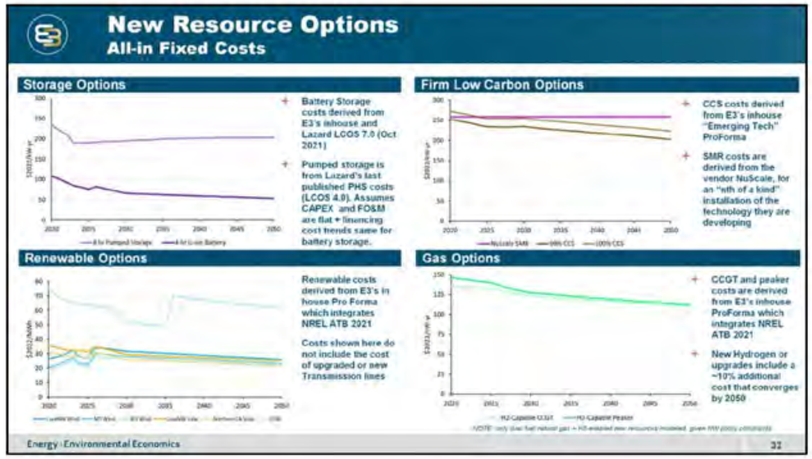
ELCC = Effective Load Carrying Capability = firm contribution to system peak load


New Resource Options
All-in Fixed Costs
Storage Options
Battery Storage costs derived from E3's inhouse and Lazard LCOS 7.0 (Oct 2021)
Pumped storage is from Lazard's last published PHS costs (LCOS 4.0). Assumes CAPEX and FO&M are flat + financing cost trends same for battery storage.
Firm Low Carbon Options
CCS costs derived from E3's inhouse "Emerging Tech" ProForma
SMR costs are derived from the vendor NuScale, for an "nth of a kind" installation of the technology they are developing
Renewable Options
Renewable costs derived from E3's in house Pro Forma which integrates NREL ATB 2021
Costs shown here do not include the cost of upgraded or new Transmission lines
Gas Options
CCGT and peaker costs are derived from E3's inhouse ProForma which integrates NREL ATB 2021
New Hydrogen or upgrades include a ~10% additional cost that converges by 2050
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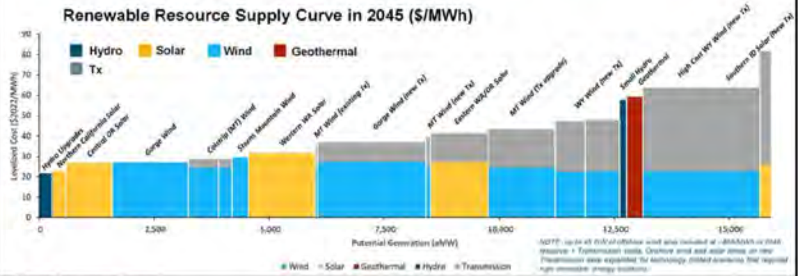
New Resource Options
Renewables

- The following supply curves integrate Transmission costs that RESOLVE sees
- The "no new combustion" scenario required increases in the supply of wind on new transmission (Northwest, MT+WY, and offshore) to enable a feasible solution



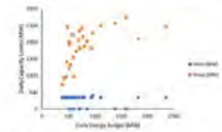
Hydro Operating Data

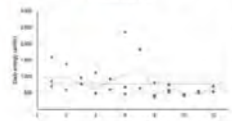
- Key RESOLVE inputs (for each representative RESOLVE day)
  - Max generation MW
  - Min generation MW
  - Daily MWh hydro budget
  - Ramp
- Hydro operating data is parameterized using representative conditions for 3 low/mid/high historical years (2001, 2005, 2011)
  - Lower Snake River and lower Columbia River dams were adjusted per BPA hydro modeling w/ latest fish spill constraints
- Hydro firm capacity contribution is assumed to be 65% of total MW, per PNUCC methodology (based on BPA 10-hr sustaining peaking capacity)

LSR Hydro

Ramp Rates

Hydro Resource	1-hr	2-hr	3-hr	4-hr
LSR_Hydro	36%	43%	45%	48%

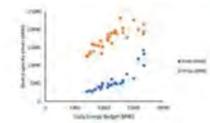


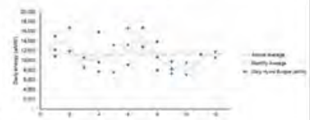


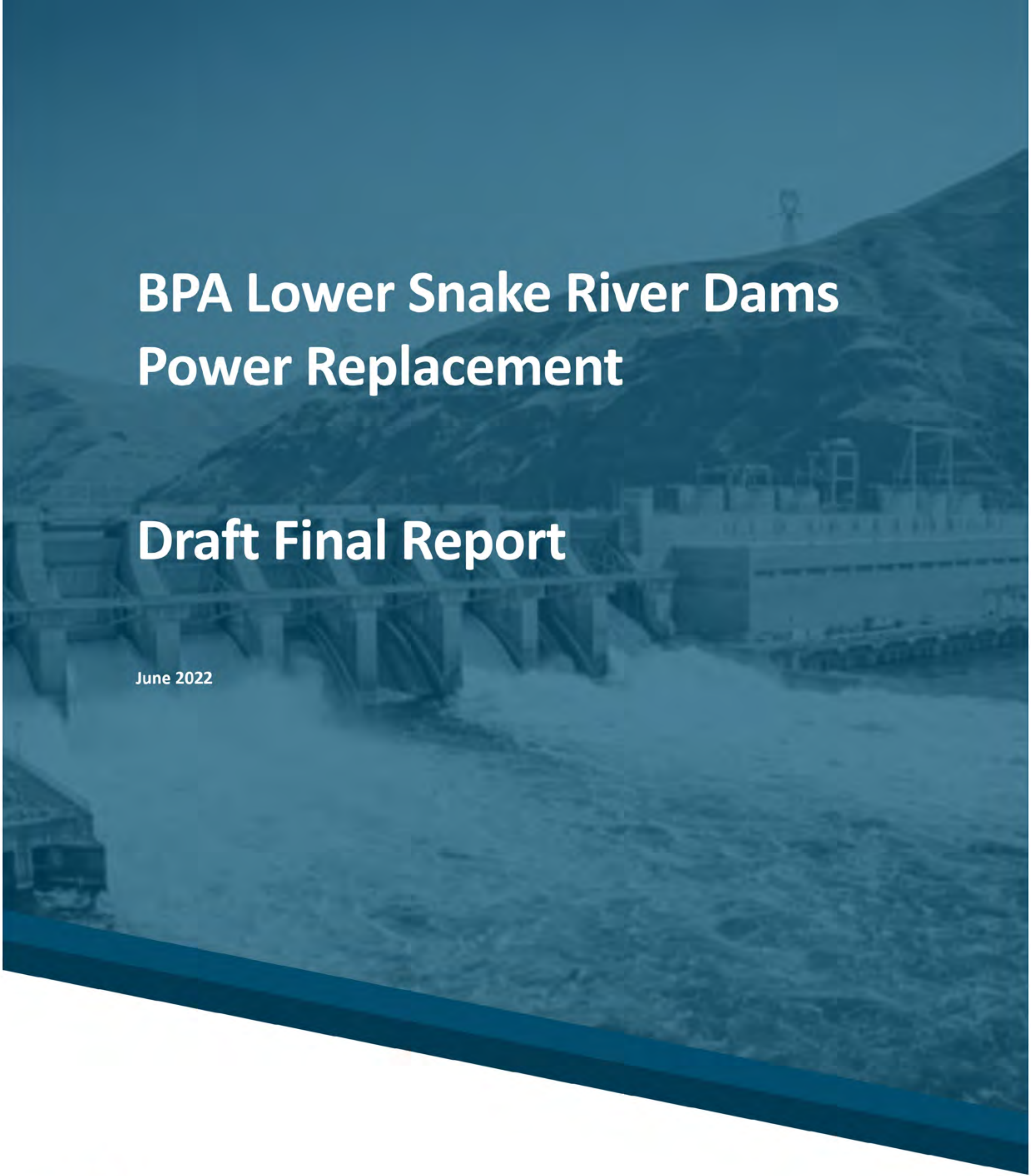
Non-LSR NW Hydro

Ramp Rates

Hydro Resource	1-hr	2-hr	3-hr	4-hr
CoreNW_Hydro	14%	23%	30%	34%







BPA Lower Snake River Dams Power Replacement

Draft Final Report

June 2022

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BPA Lower Snake River Dams Power Replacement

Draft Final Report

June 2022

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Acronym and Abbreviation Definitions

Acronym	Definition
LSR	Lower Snake River
NW	Northwest
CA	California
NV	Nevada
SW	Southwest
RM	Rocky Mountains
WECC	Western Electricity Coordinating Council
ELCC	Effective load carrying capability
DR	Demand response
PRM	Planning Reserve Margin
BPA	Bonneville Power Administration
PNUCC	Pacific Northwest Utilities Conference Committee
CES	Clean Energy Standard
NERC	North American Electric Reliability Corporation
CCS	Carbon capture and storage
SMR	Small modular reactor
CCGT	Combined cycle gas turbine
EE	Energy efficiency

Executive Summary

E3 was contracted by the Bonneville Power Administration to conduct an independent study of the value of the lower Snake River dams ("LSR dams") to the Northwest power system. The dams provide approximately 3,500 megawatts ("MW") of total capacity[1] and over 2,200 MW of firm peaking capability[2] to support regional reliability. They also generate approximately 900 average MW of zero-carbon energy each year, provide essential grid services such as operating reserves and voltage support, and operational flexibility to support renewable integration. If the dams are breached, these power services will need to be replaced to ensure the Northwest power system can continue to provide reliable electricity service. Replacing the dams is complicated by the clean energy policies adopted either statutorily or voluntarily by jurisdictions and utilities throughout the region, which will necessitate a transformation of the power system over time toward non-emitting resources even as electricity demand grows substantially due to electrification of the transportation and building sectors.

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability. RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[3]. Using RESOLVE allows for a dynamic optimization that considers replacement resource needs in the context of long-term system load and policy drivers, not just the near-term resource mix and needs of the system today. The dams are assumed to be breached in 2032, except for one sensitivity that considered 2024 breaching.

---

[1] Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. The "total capacity" refers to the overload capacity, not the nameplate capacity. Historical peak generation was 3,431 MW.

[2] LSR dam firm capacity contributions were estimated using the PNUCC regional hydropower 65% capacity value, which was validated by looking at LSR Dam wintertime power and reserve provision during low hydro conditions. Additionally, E3 considered estimates on the impact of a lower firm capacity value in section 4.3.

[3] Pacific Northwest Low Carbon Scenario Analysis, December 2017, https://www.ethree.com/projects/study-policies-decarbonize-electric-sector-northwest-public-generating-pool-2017-present/; Pacific Northwest Zero-Emitting Resources Study, January 2020, https://www.ethree.com/e3-examines-role-of-nuclear-power-in-a-deeply-decarbonized-pacific-northwest/

This study's scenario design focuses on three key variables – clean energy policy, load growth, and emerging technology availability – that impact the cost to replace the dams. The scenarios and key assumptions are show in Table 1.

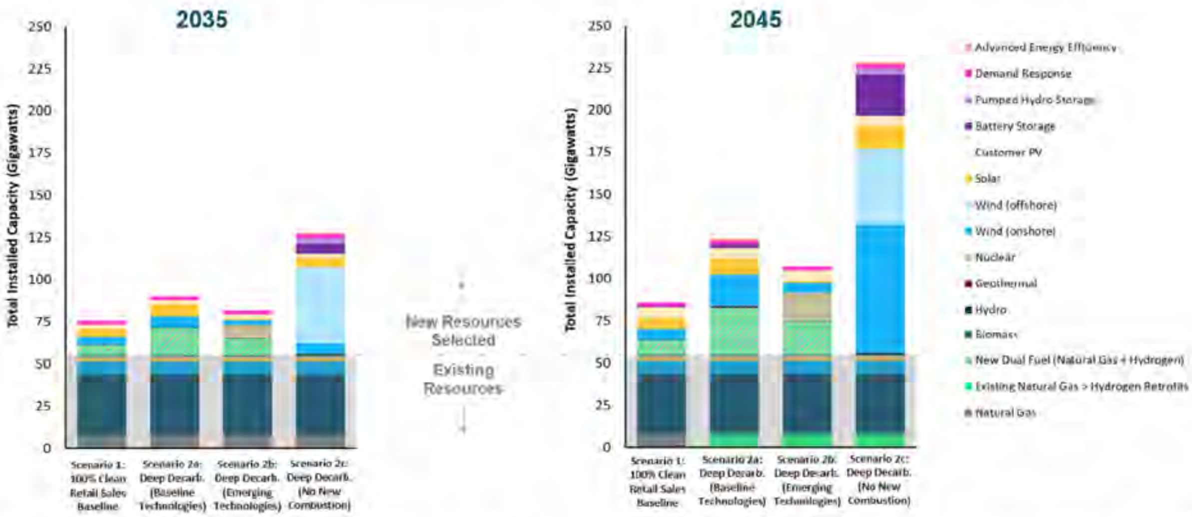
Table 1. Scenario Design

Scenario	Clean Energy Policy	Load Growth	Technology Availability
1 100% Clean Retail Sales[1]	100% retail sales (85% carbon reduction)	8th Power Plan Baseline	Baseline (incl. natural gas / hydrogen dual fuel plants)
2a Deep Decarbonization (Baseline Tech.)	100% carbon reduction	High Electrification	Baseline
2b Deep Decarbonization (Emerging Tech.)	100% carbon reduction	High Electrification	Baseline + offshore wind, gas w/ CCS, nuclear SMR
2c Deep Decarbonization (No New Combustion)	100% carbon reduction	High Electrification	Baseline (excluding natural gas / hydrogen dual fuel plants

Even with the dams in place, the region's clean energy goals and potential electrification load growth drive a significant need for new resources. In all scenarios, significant energy efficiency and customer solar is embedded into the load forecast, based on the NWPCC's 8th Power Plan. Additionally, 6 gigawatts ("GW" or 6,000 MW) of coal capacity is retired by 2030, while increasing carbon prices incent further clean energy resource additions. In Scenario 1, the regional power system is required to meet a goal of generating enough clean energy to provide 100% of retail electricity sales, on an average basis over a calendar year. This requires an additional 5 GW of solar and 5 GW of wind by 2045 to achieve the clean energy goal; 0.6 GW of battery storage, 2 GW of demand response, and 9 GW of dual fuel natural gas + hydrogen combustion plants are also added to meet the region's resource adequacy needs.

Though all scenarios require more "firm" resources – resources that can start when needed and operate for as long as needed – to meet peak loads, these resources are in higher demand in Scenario 2, in which all greenhouse gas emissions are eliminated from the regional power system by 2045. This scenario also assumes that electrification results in much higher electric loads, particularly in wintertime due to electrification of natural gas space heating in buildings. The baseline scenario (2a) selects additional wind, solar, and geothermal to meet clean energy needs as well as demand response, some battery storage, and 27 GW natural gas and hydrogen dual fuel combustion plants to meet reliability needs. An alternative "emerging technology" scenario selects 17 GW of advanced nuclear technology (small modular reactors or "SMRs") by 2045, in place of the firm capacity provided by natural gas generators while reducing the required quantities of wind, solar and batteries that are needed. The "no new combustion" scenario does not allow clean firm technologies such as hydrogen combustion turbines, gas generation with carbon capture and sequestration (CCS) or SMRs. As a result, it requires impractically high levels of additional onshore wind, offshore wind, and battery storage to meet firm capacity and carbon reduction needs, quadrupling the total installed MW of the Northwest grid by 2045.

Figure 1. Northwest Installed Capacity Mix in Scenarios with the Lower Snake River Dams



When the power services provided by the dams are removed from the regional power system, RESOLVE selects an optimal, i.e., least-cost portfolio of replacement resources that meets the Northwest's clean energy and system reliability needs. These replacement resources require a large investment and come at a substantial cost that increase over time as the region's clean energy goals become more stringent. In the latter years, the replacement costs are highly dependent on scenario-specific assumptions about the availability of emerging technologies. RESOLVE primarily replaces the carbon-free energy from the dams with additional wind power and the firm capacity with dual fuel natural gas and hydrogen combustion plants. Small amounts of additional energy efficiency and battery storage are also selected in some scenarios. By 2045, the dual fuel plants added burn additional hydrogen on low wind days to replace the carbon-free energy provided by the dams. Scenario 2b selects additional nuclear SMRs in lieu of some of the wind and gas resources. Scenario 2c disallows the new combustion plants, even those that would burn green hydrogen, and other emerging technologies, requiring a very large buildout of wind and solar power to replace both the firm capacity and the carbon-free energy of the dams.

The long-term emissions impact of removing the generation of the lower Snake River dams will depend on the implementation of the Oregon and Washington electric clean energy policies. Both a 100% clean retail sales and a zero-carbon emissions target require replacement of most or all of the LSR dams' GHG-free energy. However, without additional earlier carbon-free resource investments beyond those modeled in this study to meet clean energy policy trajectories, carbon emissions may increase initially when the dams are breached, before declining by 2045 as the carbon policy becomes more stringent.

Table 2. Summary of LSR Dams Replacement Resources and Cost Impacts (costs in the table below and throughout this report are shown in real 2022 dollars)

Scenario	Replacement Resources Selected, Cumulative by 2045 (GW)	NPV Replacement Costs[4]	Annual Replacement Costs[5]			Public Power Rate Impact[6]
			2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind	$9.7 Billion	-	$434 million/yr	$478 million/yr	0.8 ¢/kWh [+9%]
Scenario 1b: 100% Clean Retail Sales (2024 dam removal)	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind	$11.7 Billion	$495 million/yr	$466 million/yr	$509 million/yr	0.8 ¢/kWh [+9%]
Scenario 2a: Deep Decarbonization (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW advanced EE + 1.2 TWh H2-fueled generation	$15.1 Billion	-	$496 million/yr	$860 million/yr	1.5 ¢/kWh [+18%]
Scenario 2b: Deep Decarbonization (Emerging Technologies)	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR	$8.7 Billion	-	$415 million/yr	$428 million/yr	0.7 ¢/kWh [+8%]
Scenario 2c: Deep Decarbonization (No New Combustion)	+ 10.6 GW wind + 1.4 GW solar	$61 billion	-	$1,953 million/yr	$3,199 million/yr	5.5 ¢/kWh [+65%]

KEY FINDINGS:

+ ***Replacing the four lower Snake River dams while meeting clean energy goals and system reliability is possible but comes at a substantial cost***, even assuming emerging technologies are available:
    - Requires 2,300 – 2,700 MW of replacement resources
    - An annual cost of $415 million – $860 million by 2045
    - Total net present value cost of $8.7-15.1 billion from 2032-2065

---

[4] These NPV values are calculated assuming a 3% discount rate to represent the public power cost of capital, discounting costs between the year of breaching (either 2032 or 2024) and 2065.

[5] Replacement resource costs are calculated assuming project financing per E3's pro forma calculator, rather than assuming upfront congressional appropriation.

[6] This assumes that the annual replacement costs will be borne by BPA's Tier I public power customers. Percentage changes are shown relative to today's average OR + WA retail rate of ~8.5 ¢/kWh.

- Increase in costs for public power customers of $100 – 230 per household per year (an 8 – 18% increase) by 2045

+ The biggest cost drivers for replacement resources are the need to replace the lost ***firm capacity for regional resource adequacy*** and the need to replace the lost ***zero-carbon energy***
+ Replacement becomes ***more costly over time*** due to increasingly stringent clean energy standards and electrification-driven load growth
+ ***Emerging technologies*** such as hydrogen, advanced nuclear, and carbon capture ***can limit the cost of replacement resources*** to meet a zero emissions electric system, but the pace of their commercialization is highly uncertain
    - In deep decarbonization scenarios, ***replacement without any emerging technologies requires very large renewable resource additions at a very high cost*** (12 GW of wind and solar at $61 billion NPV cost)

1 Background

E3 was contracted by the Bonneville Power Administration to conduct an independent study of the value of the lower Snake River dams ("LSR dams") to the Northwest power system. The dams provide approximately 3,500 megawatts ("MW") of total capacity[7] and over 2,200 MW of firm peaking capability[8] to support regional reliability. They also generate approximately 900 average MW of zero-carbon energy each year, provide essential grid services such as operating reserves and voltage support, and operational flexibility to support renewable integration. Figure 2 shows the power services that are the focus of this study and those that are out of scope.

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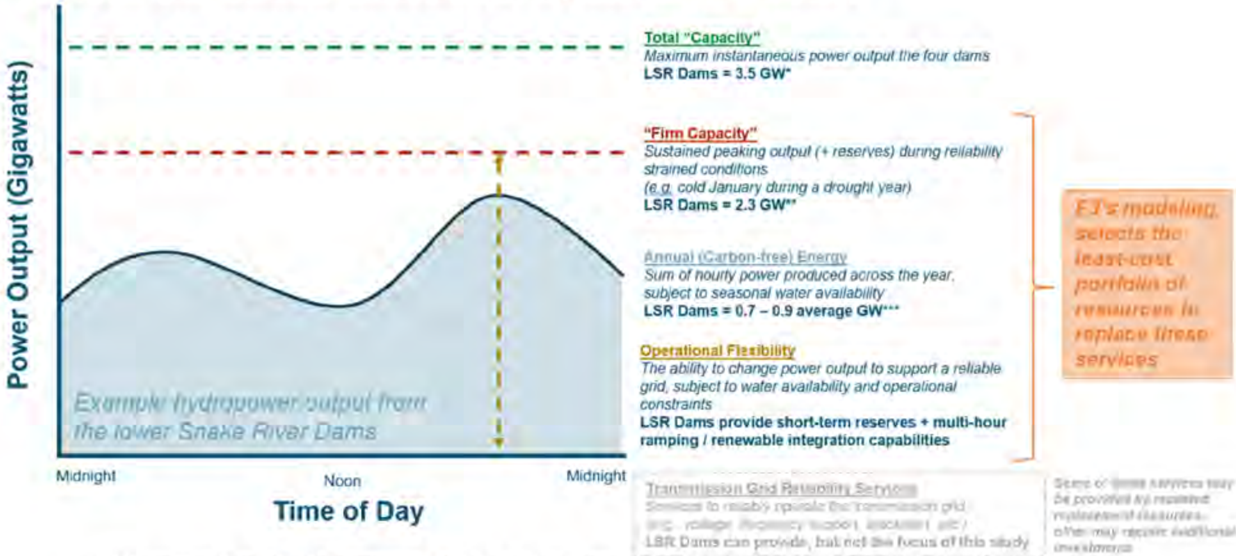
[7] Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. The "total capacity" refers to the overload capacity, not the nameplate capacity. Historical peak generation was 3,431 MW.

[8] LSR dam firm capacity contributions were estimated using the PNUCC regional hydropower 65% capacity value, which was validated by looking at LSR Dam wintertime power and reserve provision during low hydro conditions. Additionally, E3 considered estimates on the impact of a lower firm capacity value in section 4.3.

Figure 2. Power Services Considered for Replacement in this Study



* Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. Historical peak generation was 3,431 MW.

** Firm capacity assumed in this study is consistent with the ~65% Northwest hydro capacity value assumed by PNUCC (the Pacific Northwest Utilities Conference Committee).

*** Average GW means that on average across an average year the plant generated at 0.7 – 0.9 GW, though its hourly output may be above or below that amount. LSR output was adjusted to reflect increased spill requirements of the EIS. E3's RESOLVE model uses 2001, 2005, and 2011 hydro years, which resulted in ~0.7 aGW of lower Snake River dams generation, making it a conservative estimate of the dams' GHG-free energy value.

If the dams are breached, these power services will need to be replaced to ensure the Northwest power system can continue to provide reliable electricity service. Replacing the dams is complicated by the clean energy policies adopted either statutorily or voluntarily by jurisdictions and utilities throughout the region, which will necessitate a transformation of the power system over time toward non-emitting resources even as electricity demand grows substantially due to electrification of the transportation and building sectors.

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability.

RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[9]. Using RESOLVE allows for a dynamic optimization that considers replacement resource needs in the context of long-term system load and policy drivers, not just the near-term resource mix and needs of the system today. The dams are assumed to be breached in 2032, except for one sensitivity that considered 2024 breaching.

Key Study Questions:

- What **additional resources** would be needed to replace the power services provided by the LSR Dams through 2045?
- What is the **net cost to** BPA ratepayers?
- How do costs and resource needs change under **different types of clean energy futures**?
- How much does replacing the dams rely on **emerging, not-yet-commercialized technologies**?

This study builds off previous LSR dams replacement analysis by using a least-cost optimization-based modeling framework to replace the dams' power services. This optimization ensures that the region meets its aggressive clean energy policy goals, including both decarbonization of electricity as well as high electrification load growth consistent with economywide decarbonization goals set by Oregon and Washington.

The other key component of the optimization is maintaining resource adequacy for the region to ensure a reliable electricity supply to existing and any newly electrified loads. This is done using a planning reserve margin constraint and counting non-firm resources like solar, wind, battery storage, pumped hydro storage, and demand response at their effective load carrying capability ("ELCC"), based on E3's prior detailed loss of load probability modeling of the Northwest region.[10]

This modeling framework ensures that when the LSR dams are removed from the Northwest power system, a least-cost replacement mix of new investments and operational changes is found. Through the constraints of the optimization, this least-cost replacement mix meets the same clean energy policy and level of reliability as a system with the LSR dams still intact. This dynamic approach considers replacement resource needs in the context of the evolving long-term system load and policy drivers, not just the near-term resource mix and needs of the system today. It recognizes that significant levels of

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[9] Pacific Northwest Low Carbon Scenario Analysis, December 2017, https://www.ethree.com/projects/study-policies-decarbonize-electric-sector-northwest-public-generating-pool-2017-present/; Pacific Northwest Zero-Emitting Resources Study, January 2020, https://www.ethree.com/e3-examines-role-of-nuclear-power-in-a-deeply-decarbonized-pacific-northwest/

[10] Resource Adequacy in the Pacific Northwest, March 2019, https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

new renewable energy and other resources are already needed to meet long-term regional needs, ensuring that the replacement resource mix selected is incremental to the long-term buildout, not just an interim solution before clean energy policies reach their apex in the 2040s.

2 Scenario Design

2.1 Regional Policy Landscape

To properly understand the resources needed to replace the power services of the lower Snake River dams, it is critical to consider the regional policy landscape of the Pacific Northwest. In the last few years, the states of Oregon and Washington have adopted some of the most aggressive clean energy policies in the nation. While the Pacific Northwest was already a leader in renewable energy production due to its abundant hydropower resource, these aggressive policies will require key changes to the region. First, coal power must be phased out in the Northwest during this decade and, at least in Washington, carbon will be priced via a market-based cap-and-trade mechanism[11]. Second, additional zero-carbon generation must be added to replace that coal power and to displace remaining emissions from natural gas resources whose firm capacity may still be needed by the region, but which will operate less over time as electric carbon emissions are reduced. Ultimately, to reach a zero-carbon system, those natural gas plants must retire, be converted to zero-carbon fuels (such as green hydrogen), or their emissions be offset in some other manner. Third, economywide carbon reduction goals will drive the transformation of the Northwest transportation, building, and industrial sectors, with the general expectation of significant electric load growth in annual energy and peak demand. Key policies in the Northwest and California are summarized in Table 3.

[1111] For simplicity, this study assumes a uniform carbon price across the Core Northwest region beginning in XXX.

Table 3. Policy landscape in Washington, Oregon, and California

	RPS or Clean Energy Standard?	Coal Prohibition?	Cap-and-Trade?	New Gas?	Economy-Wide Carbon Reduction?
WA	✓ Carbon neutral by 2030, 100% carbon free electricity by 2045	✓ Eliminate by 2025	✓ Cap-and-invest program established in 2021, SCC in utility planning	✓	✓ 95% GHG emission reduction below 1990 levels and achieve net zero emissions by 2050
OR	✓ 50% RPS by 2040, 100% GHG emission reduction by 2040, relative to 2010 levels	✓ Eliminate by 2030	✓ Climate Protection Plan adopted by DEQ in 2021 (power sector not included)	× HB 2021 bans expansion or construction of power plants that burn fossil fuels	✓ 90% GHG emission reduction from fossil fuel usage relative to 2022 baseline
CA	✓ 60% RPS by 2030, 100% clean energy by 2045	✓ Coal-fired electricity generation already phased out	✓	× CPUC IRP did not allow in recent procurement order	✓ 40% GHG emission reduction below 1990 levels by 2030 and 80% by 2050

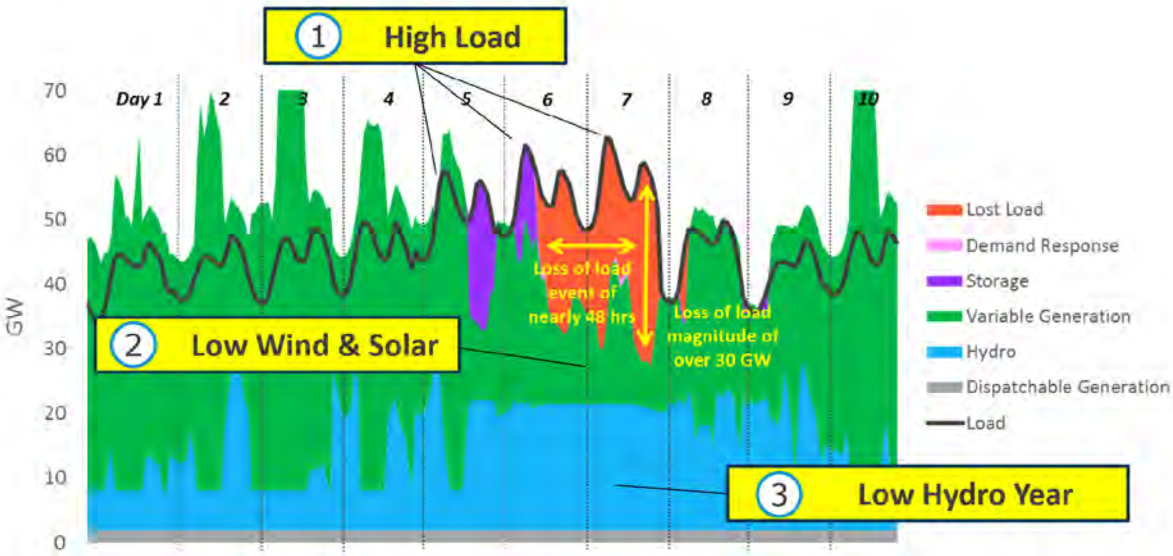
2.2 Maintaining Resource Adequacy in Low-carbon Grids

Like other regions pursuing aggressive climate policies, the Northwest faces a key decarbonization challenge: how to maintain a reliable electricity supply, while simultaneously increasing electric loads and retiring the firm, but emitting, capacity that currently supports regional reliability. In 2019, E3 used its RECAP loss of load probability model to study how decarbonizing the electricity supply impacts regional reliability.[12] This study found that clean energy resources such as solar, wind, batteries, and demand response can each provide a certain amount of reliable capacity and that combinations of them can provide even more by capturing "diversity benefits" (such as solar shifting the reliability risk into evening hours when wind output is higher). However, these resources also have limits to the amount of reliable capacity they can provide, and their contributions decline as more of them are added (the decline in capacity contributions of these resources is known as "saturation effects"). Figure 3 shows a graph from E3's 2019 study that illustrates the key drivers of reliability in a decarbonized grid: high load, low renewables, and low hydro conditions. Unlike a summer peaking *capacity constrained* system like the desert southwest, these conditions make it particularly challenging for battery storage to replace the Northwest's firm capacity resources, since batteries are unable to charge during *energy constrained* periods of low renewable energy and low hydro availability. The study concluded therefore that

[12] E3, 2019. *Resource Adequacy in the Pacific Northwest.* https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

additional firm generating capacity may be needed, even in scenarios that add significant amount of non-firm solar, wind, batteries, and demand response. The resource adequacy constraints in RESOLVE and the capacity value of LSR dam replacement resource options are described in section 3.4.6.

Figure 3. Key Drivers of Pacific Northwest Reliability Events in a Decarbonized Grid



[11]

Since the 2019 study, "emerging" technologies are increasingly seen as potentially viable option to reduce all of the carbon emissions in the Northwest. "Clean firm" resources like green hydrogen, gas with carbon capture and storage, and nuclear small modular reactors provide the firm capacity necessary to backup renewable resources and can provide the zero-carbon energy needed on low renewable days to operate a zero-carbon grid. While their costs and commercialization trajectories remain uncertain, this LSR dams replacement study considers various scenarios of their availability.

Table 4. Summary of Resource Adequacy Capacity Contributions of LSR Dam Replacement Resource Options

Replacement Resource Option	RA Capacity Contributions
Battery storage	Sharply declining ELCCs
Pumped storage	Sharply declining ELCCs
Solar	Declining ELCCs
Wind	Declining ELCCs
Demand Response	Declining ELCCs
Energy Efficiency	Limited potential vs. cost
Small Hydro	Limited potential

Geothermal	Limited potential
Natural gas to H2 retrofits	Clean firm, but not fully commercialized
New dual fuel natural gas + H2 plants	Clean firm, but not fully commercialized
New H2 only plants	Clean firm, but not fully commercialized
Gas w/ 90-100% carbon capture + storage	Clean firm, but not fully commercialized
Nuclear Small Modular Reactors	Clean firm, but not fully commercialized

2.3 Scenarios Modeled

This study focuses on three key variables (clean energy policy, load growth, and emerging technology availability) that impact the cost to replace the dams.

Clean Energy Policy

Clean energy policy for the electric sector is modeled at either 100% clean retail sales or zero-carbon by 2045. A 100% clean retail sales policy requires serving 100% of electricity sold on an annual basis to be met by clean energy resources. This allows generation not used to serve retail sales (i.e., transmission and distribution losses) to be met by emitting resources. It also allows emitting generation or unspecified imports in one hour to be offset by exported generation in another hour of the year. In the baseline load scenario, reaching 100% clean retail sales by 2045 results in ~85% carbon reduction compared to 1990 levels. The zero-carbon scenario ensures that all electricity generated in the Northwest or imported from other regions emits no carbon emissions in every hour of the year.

Load Growth

With aggressive clean energy policies, load growth determines the amount of new zero-emitting resources that must be added to the Northwest power system. A baseline load growth scenario is modeled, based on the forecast in the NWPCC 8th Power Plan. A second high electrification scenario is developed based on the high electrification case in the Washington State Energy Strategy.[13] Based on E3's analysis of the electrification of transportation, buildings, and industry in that study, this scenario results in an additional annual energy demand increase of 28% by 2045 (above the baseline scenario) and an additional winter peak demand increase of 68%. The peak demand increase is high due to the

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[13] See Washington State's *2021 State Energy Strategy*, https://www.commerce.wa.gov/growing-the-economy/energy/2021-state-energy-strategy/

electrification of space heating end uses, which requires replacing the significant quantities of energy provided by the natural gas system during extreme wintertime cold weather events with electricity.

Technology Availability

It is expected that the availability of emerging technologies may be critically important for replacing the LSR dam power services while reaching a deeply decarbonized grid. All scenarios include "mature technologies" such as solar, wind, battery storage, pumped hydro storage, demand response, energy efficiency, small hydro, and geothermal. Three scenarios of emerging technology availability are developed as follows:

1. **Baseline technologies**: mature technologies and dual fuel natural gas + hydrogen combustion plants
2. **Emerging technologies**: mature technologies, dual fuel natural gas + hydrogen combustion plants, small modular nuclear reactors, natural gas with carbon capture and storage, and floating offshore wind
3. **No new combustion**: mature technologies and floating offshore wind

All scenarios assume that the existing natural gas capacity fleet can convert to green hydrogen, i.e., hydrogen produced using zero-carbon electricity. However, new firm resources are needed in all scenarios to replace retiring resources and meet growing electric loads.

Table 5 shows a summary of the four scenarios that were the focus of this study.

Table 5. Scenario Design

Scenario	Clean Energy Policy	Load Growth	Technology Availability
1 100% Clean Retail Sales[1]	100% retail sales (85% carbon reduction)	8th Power Plan Baseline	Baseline (incl. natural gas / hydrogen dual fuel plants)
2a Deep Decarbonization (Baseline Tech.)	100% carbon reduction	High Electrification	Baseline
2b Deep Decarbonization (Emerging Tech.)	100% carbon reduction	High Electrification	Baseline + offshore wind, gas w/ CCS, nuclear SMR
2c Deep Decarbonization (No New Combustion)	100% carbon reduction	High Electrification	Baseline (excluding natural gas / hydrogen dual fuel plants)

3 Modeling Approach

3.1 RESOLVE Model

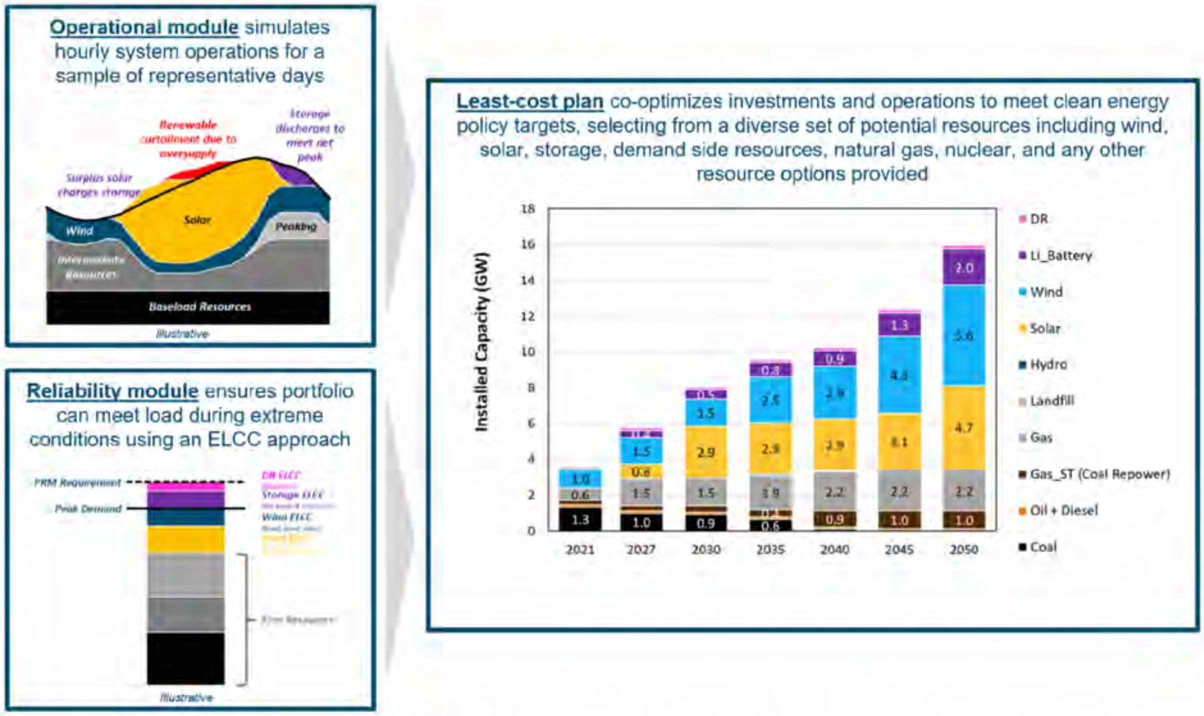
E3's Renewable Energy Solutions Model (RESOLVE) is used to perform a portfolio optimization of Northwest system's electric generating resource needs between 2025 and 2045. RESOLVE is an optimal capacity expansion and dispatch model that uses linear programming to identify optimal long-term generation and transmission investments in an electric system, subject to reliability, operational, and policy constraints. Designed specifically to address the capacity expansion questions for systems seeking to integrate large quantities of variable energy resources, RESOLVE layers capacity expansion logic on top of a production cost model to determine the least-cost investment plan, accounting for both the up-front capital costs of new resources and the variable costs to operate the grid reliably over time. In an environment in which most new investments in the electric system have fixed costs significantly larger than their variable operating costs, this type of model provides a strong foundation to identify potential investment benefits associated with alternative scenarios.

The three primary drivers of optimized resource portfolios include:

+ **Reliability:** all portfolios ensure system meets resource adequacy requirements. In this case, the target reliability need is to meet 1-in-2 system peak plus additional 15% of planning reserve margin (PRM) requirement.
+ **Clean Energy Standard ("CES") and/or carbon reduction targets:** all portfolios meet the clean energy standard and/or a carbon-reduction trajectory
+ **Least cost**: the model's optimization develops a portfolio that minimizes costs

Figure 4 illustrates the use of RESOLVE's operational module, which tracks hourly system operations including cost and greenhouse gas emissions across a representative set of days, and RESOLVE's reliability module, that uses exogenously calculated input parameters to characterize system reliability of candidate portfolios using effective load carrying capability (ELCC) for solar and wind resources.

Figure 4. Schematic Representation of the RESOLVE Model Functionality



RESOLVE develops least-cost portfolios using key inputs and assumptions including loads, existing resources, new resource options, retirement or repowering resource options, resource costs, resource operating characteristics including resource adequacy contributions, a zonal transmission transfer topology, and new resource transmission costs.

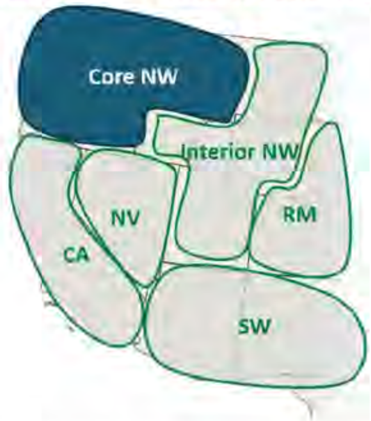
3.2 Northwest RESOLVE Model

The Northwest RESOLVE model was developed in 2017 for E3's *Pacific Northwest Low Carbon Scenario Analysis* study.[14] It uses a zonal transmission topology to simulate flows among the various regions in the Western Interconnection. In this study, RESOLVE is designed to include six zones: the Core Northwest region and five external areas that represent the loads and resources of utilities throughout the rest of the Western Interconnection (see Figure 5). This study focuses on the Core Northwest region as the "Primary Zone"—the zone for which RESOLVE makes resource investment decisions. This zone covers Washington, Oregon, Northern Idaho and Western Montana. The remaining balancing authorities

[14] Pacific Northwest Low Carbon Scenario Analysis - Achieving Least-Cost Carbon Emissions Reductions in the Electricity Sector, 2017. https://www.ethree.com/wp-content/uploads/2018/01/E3_PGP_GHGReductionStudy_2017-12-15_FINAL.pdf

outside of the Core Northwest are grouped into five additional zones: (1) Other Northwest, (2) California, (3) Southwest, (4) Nevada and (5) Rockies. For these zones, investments are not optimized; rather, the trajectory of new builds is established based on regional capacity needs to meet PRM targets, as well as renewable needs to comply with existing RPS and GHG policies in their respective regions, and held constant across all scenarios. E3's WECC-wide resource mix incorporates aggressive climate policy across the interconnection, as described in section 3.4.2.

Figure 5. RESOLVE Northwest zonal representation

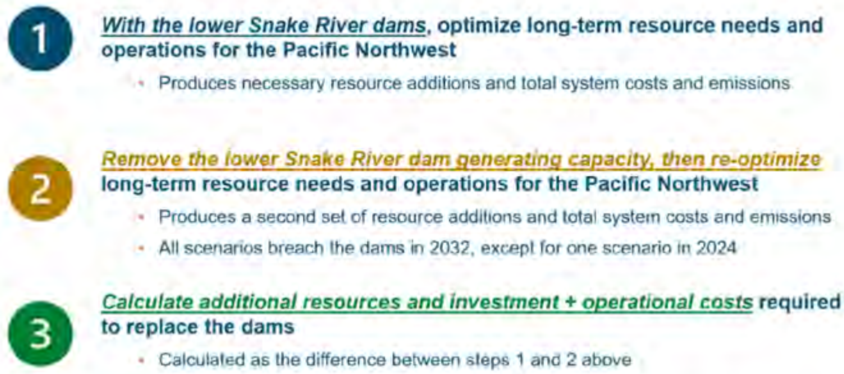


The Northwest RESOLVE model simulates the operations of the WECC system for 41 independent days sampled from the historical meteorological record of the period 2007-2009. An optimization algorithm is used to select the 41 days and identify the weight for each day such that distributions of load, net load, wind, and solar generation match long-run distributions. Daily hydro conditions are sampled separately from dry (2001), average (2005), and wet (2011) hydro years to provide a complete distribution of potential hydro conditions. This allows RESOLVE to approximate annual operating costs and dynamics while limiting detailed operational simulations of grid operations to 41 days.

3.3 LSR Dams Modeling Approach

The LSR dams' capacity and operation are characterized with several input parameters that are presented in Section 3.4.5. The approach taken in this analysis is to model LSR dams as an *in/out* resource to determine the dams' replacement costs and replacement portfolio. In other words, "in" scenarios include LSR dams in the existing resource portfolio of Core Northwest throughout the entire modeling period (i.e., 2025-2045); whereas "out" scenarios exclude LSR dams with preset retirement dates of 2032. An earlier retirement of LSR dams, 2024, is considered in a sensitivity case. The difference between the costs and resource portfolios for in and out cases reveals the value of LSR dams, as shown in Figure 6. Total NPV costs of resources replacing LSR dams are estimated in the year of breaching the dams.[15] NPV replacement costs are calculating using a 3% discount rate to represent the public power cost of capital.

Figure 6. Modeling Approach to Calculate the LSR Dams Replacement Resources and Costs



This modeling approach inherently considers the benefits of avoiding the LSR dams ongoing fixed and variable costs. The costs associated with breaching the LSR dams themselves are not included in this study. Other power services (i.e., transmission grid reliability services provided by the dams) are also not included but are summarized qualitatively in the Appendix.

3.4 Key Input Assumptions

3.4.1 Load forecast

Base load forecast is from NWPCC 2021 Plan and is adjusted to E3's boundary of Core Northwest which roughly represents 87.5% of load of the Northwest system in the NWPCC 2021 Plan. Additionally, a high Electrification scenario is modeled which takes Washington's State Energy Strategy high electrification load, scaled up and benchmarked to the Core Northwest region. The baseline high electrification load trajectories are displayed in Figure 7. It is notable that in the high electrification scenario, electric energy demand grows by about 28% by 2045 across all sectors, most noticeably in the commercial building and

[15] I.e. when the dams are removed in 2032, future costs after 2032 are discounted to the year 2032 to calculate the NPV replacement costs.

transportation sectors, to meet net-zero emissions by 2050. In the commercial and residential space heating sectors, electrification indicates a switch to high electric resistance and heat pump adoption, which will significantly impact load profiles and ultimately peak load. Hourly loads are modeled in RESOLVE by scaling normalized hourly shapes with annual energy forecasts. The normalized shapes are adopted from E3's 2017 study *Pacific Northwest Low Carbon Scenario Analysis.*[16]

Figure 7. Annual energy load forecasts for Core Northwest

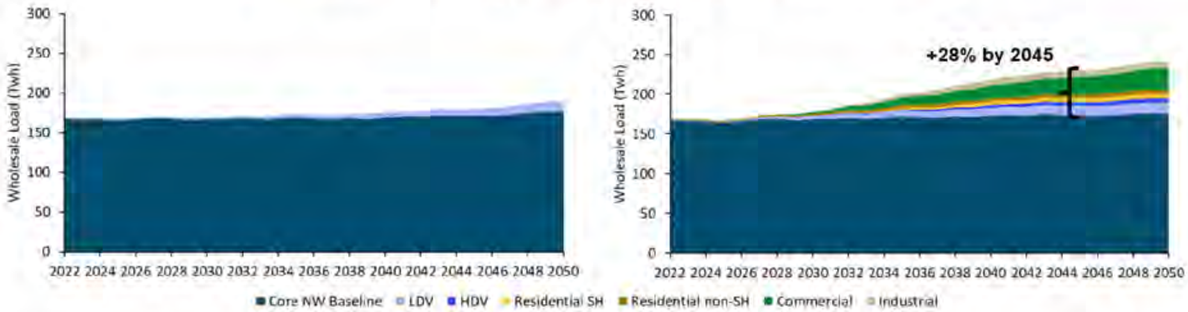
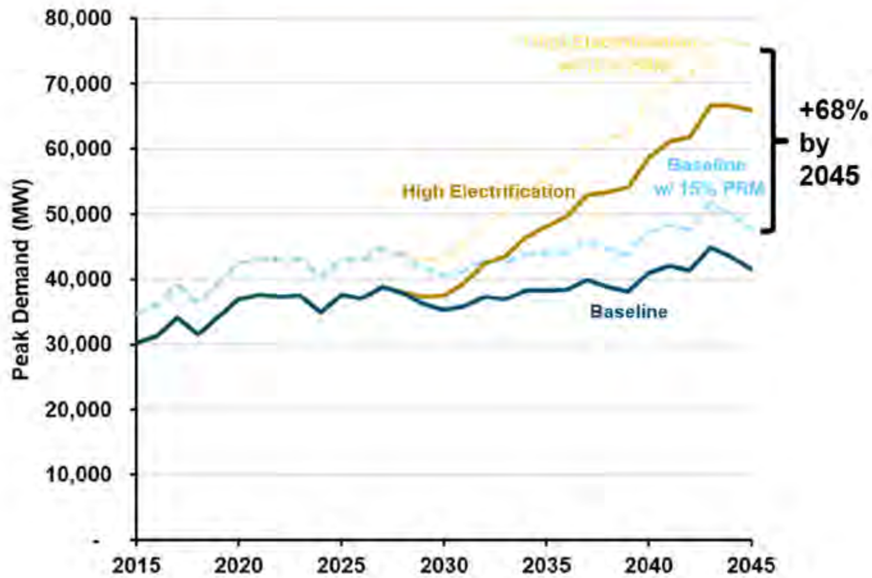


Figure 8 shows the peak demand impacts (including the 15% planning reserve margin) of the high electrification case relative to the baseline, showing a 68% increase by 2045. This high growth is driven by the winter peaking capacity required to replace the gas system peaking capacity to serve peak space heating needs.

[16] Pacific Northwest Low Carbon Scenario Analysis - Achieving Least-Cost Carbon Emissions Reductions in the Electricity Sector, 2017. https://www.ethree.com/wp-content/uploads/2018/01/E3_PGP_GHGReductionStudy_2017-12-15_FINAL.pdf

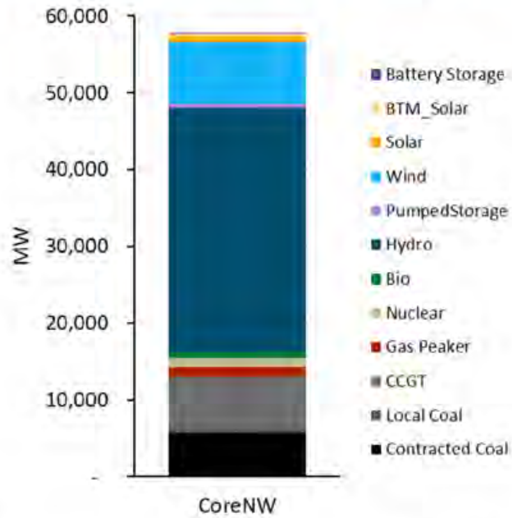
Figure 8. Peak demand forecasts for Core Northwest



3.4.2 Baseline resources

Baseline resources include the existing conventional resources such as natural gas and coal-fired technologies, nuclear, hydro as well as pumped storage, battery storage, solar PV, BTM PV and onshore wind technologies. As shown in Figure 9, today's Northwest system has 58 GW capacity. The 1,185 MW nuclear capacity in the Northwest zone remains active throughout the modeling period while the 670 MW local coal capacity is retired by 2025 and the 5,700 MW contracted out of region coal capacity is retired by 2030. The WECC 2020 Anchor Data Set is used for Northwest's existing and planned resources. By 2045, about 5.8 GW additional customer PV is included as planned capacity to capture the growth in behind-the-meter generation forecasted in NWPCC 2021 Power Plan.

Figure 9. Northwest resource capacity in 2022

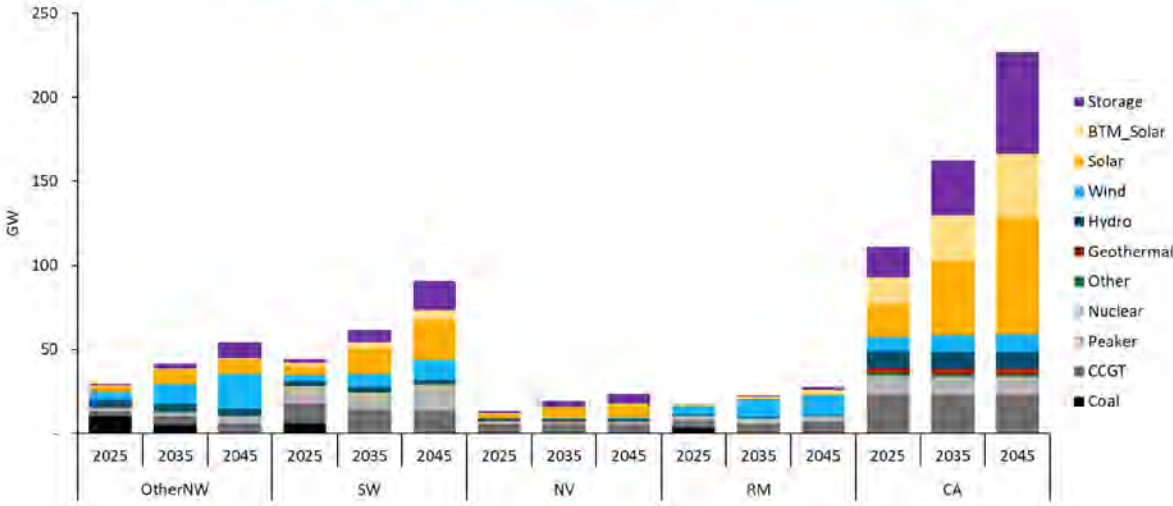


The investment decisions for external zones are pre-determined based on capacity expansion analysis completed by E3 that accounts for policy targets in each zone as summarized in Table 6. The new builds consist of significant increases in solar and battery capacity additions due to the more aggressive RPS targets, assumed electrification, and the decline of technology cost forecasts (see Figure 10). All future builds in these zones include mature technologies but as discussed in the next section, emerging technologies are made available for RESOLVE to optimize the future resource portfolios in the Northwest zone. There is significant solar and battery storage growth in California, the Southwest, and Nevada that generally lower the marginal value of solar energy produced across the WECC.

Table 6. Policy targets for builds in external zones

State	Requirement	Policy	2050 Renewable Target
AZ	40% by 2030; 60% by 2045	Transitions to CES	70%
CA	60% by 2030; 100% by 2045	Transitions to CES	100%
CO	30% by 2020; 50% by 2030, 76% by 2050 (Xcel reaches 100% while other utilities stay at 50%)	Transitions to CES	75%
ID	90% by 2045 (ID Power's announced utility goals)	RPS	90%
MT	87% by 2045 (state carbon reduction goal)	RPS	87%
NM	40% by 2025; 100% by 2045	Transitions to CES	100%
NV	50% by 2030; 100% by 2050	Transitions to CES	95%
UT	50% by 2030; 55% by 2045 (PacifiCorp's IRP)	RPS	55%
WY	50% by 2030, 55% by 2045 (PacifiCorp's IRP)	RPS	55%

Figure 10. Total installed capacity for external zones



3.4.3 *Candidate resource options, potential, and cost*

A wide range of technologies and resources are made available in RESOLVE, including mature and emerging technologies. The list of technologies made available in each modeled scenario is presented in Table 7. Some technologies such as solar and onshore wind are low cost zero-carbon energy resources with limited resource potential and declining capacity values. Storage resources such as battery storage and pumped hydro support renewable integration but show limited capacity value given the large shares of hydro in the Northwest region. Demand response supports peak reduction but also faces declining ELCCs. Energy efficiency supports energy and peak reduction but increasingly competes against low-cost renewables. Geothermal is relatively high cost and has limited potential but provides highly valuable "clean firm" capacity.

Some emerging technologies are also made available in several scenarios to allow for firm zero-carbon technologies to be selected from. Hydrogen-capable generators such as dual fuel combustion turbines and combined cycles (i.e., capable of burning both natural gas and hydrogen) as well as retrofits of existing gas generators to burn hydrogen are modeled. These technologies provide low-cost capacity options with very high energy cost when burning expensive hydrogen fuel, therefore RESOLVE selects them for firm capacity needs but limits their hydrogen energy production. Natural gas with carbon capture and storage (CCS) technologies are moderately high cost in terms of both energy and capacity. Nuclear SMR provides moderately high capital cost but low operating cost for firm zero-carbon energy generation. This technology is made available to the model after 2035, to account for the time needed for technology development, licensing, and installation. Floating offshore wind is also modeled as an emerging technology which address onshore resource and land constraints, but is generally higher cost than onshore wind while providing a similar annual capacity factor to high quality Montana and Wyoming wind.

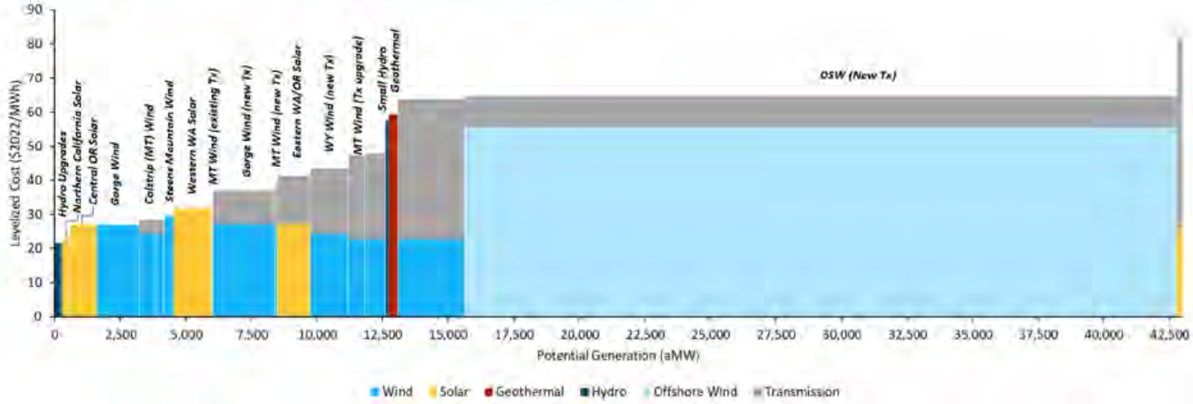
Table 7. Available technologies in each modeled scenario

Resource	Baseline	Emerging Tech	Limited Tech (No New Combustion)
Mature resources: solar, wind, battery storage, pumped storage, demand response, energy efficiency, small hydro, geothermal	✓	✓	✓
Natural gas to hydrogen retrofits	✓	✓	✓
Dual fuel natural gas + hydrogen plants	✓	✓	×
Natural gas with 90-100% carbon capture and storage	×	✓	×
Nuclear small modular reactors	×	✓	×
Floating offshore wind	×	✓	×

There are physical limits to the quantity of renewable resources that can be developed in a given location; RESOLVE enforces limits on the maximum potential of each new resource that can be included in the portfolio. Moreover, some new resources will need extensive transmission upgrades which are accounted for in the renewable energy supply curve.[17] Figure 11 shows a "supply curve" for renewables in the year 2045, ordered by total generation plus transmission cost. While the quantity of solar and onshore wind energy is limited, offshore wind potential is effectively unlimited in the model although its cost remains high relative to land-based renewables through 2045. It should be noted that RESOLVE doesn't select resources based on their cost alone; it also considers the value these resources provide as part of a regional portfolio. More detail information on technology cost trajectories and data sources can be found in the Appendix.

[17] Note: certain solar resources (i.e., Western WA solar) might require transmission upgrades to bring the supply to load centers, which are not captured.

Figure 11. Renewable resource supply curve in 2045



3.4.4 Clean energy policy targets

RESOLVE enforces a clean energy standard ("CES") requirement as a percentage of retail sales to ensure that the total quantity of energy procured from renewable resources meets the CES target in each year. The clean energy standard percentage is calculated as follows, and the target values are summarized in Table 2:

$$CES\ \% = \frac{Annual\ Renewable\ Energy\ or\ Zero\ Emitting\ Generation}{Annual\ CoreNW\ Retail\ Electric\ Sales}$$

Eligible renewable energy and zero-emitting resources include: solar, wind, geothermal, hydropower, nuclear, biomass, green hydrogen, and natural gas with carbon capture and storage.

Regarding GHG emissions, RESOLVE enforces a greenhouse gas constraint on the CoreNW region such that total annual emission generated in the zone must be less than or equal to the emissions cap. The greenhouse gas accounting for the Northwest zone follows the rules established by the California Air Resources Board. The CoreNW carbon emissions baseline is set as 33 MMT at the 1990 level. The total greenhouse gas emissions attributed to the Core Northwest region include:

+ **In-region generation:** all greenhouse gas emissions emitted by fossil generators (coal and natural gas) within the region, based on the simulated fuel burned and fuel-specific CO_2 emissions intensity;
+ **External resources owned/contracted by Core Northwest utilities:** greenhouse gas emissions emitted by resources located outside the Core Northwest but currently owned or contracted by utilities that serve load within the region, based on fuel burn and fuel-specific CO_2 emissions intensity; and
+ **"Unspecified" imports to the Core Northwest:** assumed emissions associated with economic imports to the Core Northwest that are not attributed to a specific resource but represent unspecified flows of power into the region, based on a deemed emissions rate of 0.43 tons/MWh.

Table 8. Annual CES and carbon emissions targets modeled for CoreNW in RESOLVE

Resource	2025	2030	2035	2040	2045
Clean energy standard %	29%	49%	68%	88%	100%

(used in Scenarios 1 and 2[18])					
Carbon reduction emissions target (used only in Scenario 2)	22.7 MMT	17.0 MMT	11.3 MMT	5.7 MMT	0 MMT

3.4.5 *Hydro parameters*

RESOLVE characterizes the generation capability of the hydroelectric system by including three types of constraints from actual operational data: (1) daily energy budgets, which limit the amount of hydro generation in a day; (2) maximum and minimum hydro generation levels, which constrain the hourly hydro generation; and (3) multi-hour ramp rates, which limit the rate at which the output of the collective hydro system can change from one to four hours. Combined, these constraints limit the generation of the hydro fleet to reflect realistic seasonal limits on water availability, downstream flow requirements, and non-power factors that impact the operations of the hydro system.

In this analysis, hydro operating data are parameterized using conditions for three different hydrological years, i.e., 2001 for dry, 2005 for average and 2011 for wet conditions. For LSR dams, we use hourly generation data provided by BPA which were adjusted for latest fish protection and spill constraints. For the remainder of the northwest hydro fleet, we rely on historical hydro dispatch data used to develop the TEPPC 2022 Common Case dataset. Using muti-year historical hydro operational data allows to capture the complete set of physical and institutional factors, such as cascading hydro, streamflow constraints, fish protection, navigation, irrigation, and flood control, that limit the amount of flexibility in the hydro system.

For each RESOLVE sampled day, the hydro daily energy budget is calculated as the average of daily electricity generated in the month of each sampled RESOLVE day in its corresponding matched hydro year.[19] The maximum and minimum hydro generation levels (P_{min} and P_{max} in Figure 12) are calculated as the absolute min and max of generation in the month of each sampled RESOLVE day in its corresponding matched year. Multi-hour ramp rates are estimated based on the 99th percentile of upward ramps observed across the three hydrological years of hourly data. In addition, for non-LSR Northwest hydro, the model allows 5% of the hydro energy in each day to be shifted to a different day within two months

[18] While a clean energy standard is modeled in scenario 2, the mass-based carbon reduction target constraint is a more binding constraint, pushing the model beyond the minimum CES %'s shown here.

[19] LSR dams generate about 900 average MW of energy during an average hydro year. However, during the three years modeled in RESOLVE, the LSR dams produced only ~700 average MW generation for LSR dams. This means our estimate of the replacement cost of the dams is quite conservative relative to a longer-term expected average of ~900 MW.

to capture additional flexibility for day-to-day hydro energy shift. These inputs are presented in Figure 12 and Table 9.

Figure 12. RESOLVE Hydro inputs for LSR Dams and other Northwest hydro

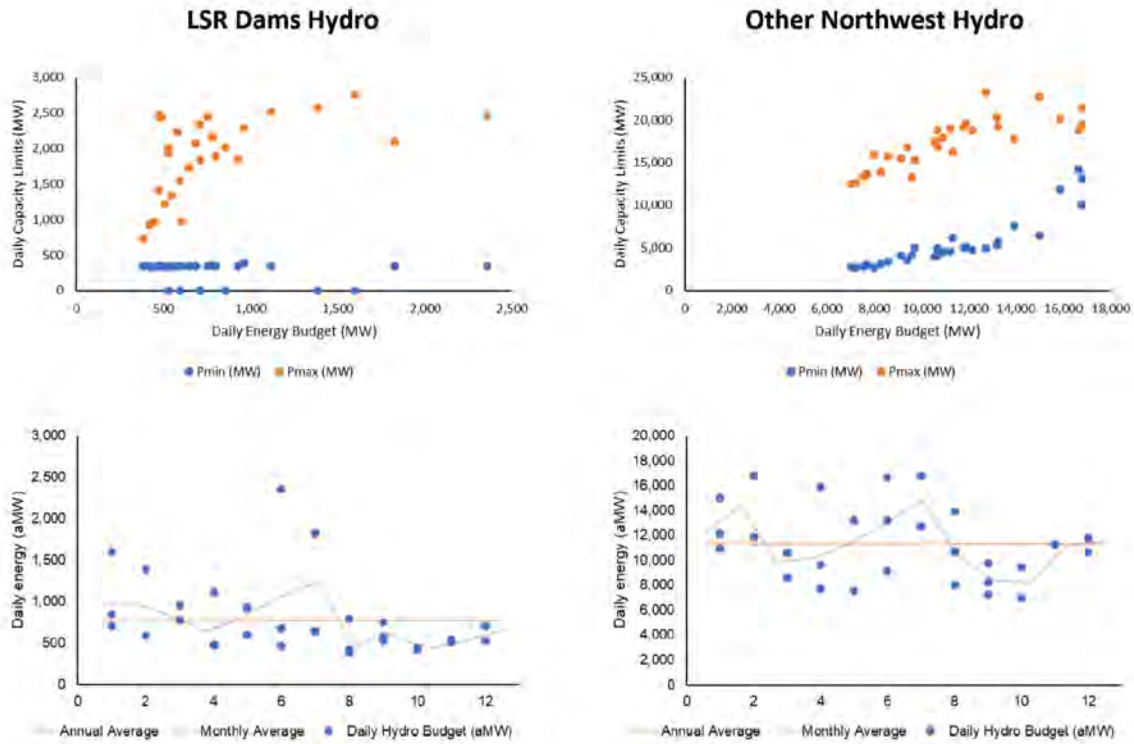


Table 9. Multi-hour ramping constraints applied to Northwest hydro

	One hour	Two hours	Three hours	Four hours
LSR Dams Hydro	36%	43%	45%	48%
Other Northwest Hydro	14%	23%	29%	32%

3.4.6 Resource Adequacy Needs and Resource Contributions

Hydro firm capacity contribution for both LSR dams and other Northwest hydro is assumed to be 65% of nameplate, per PNUCC methodology (based on 10-hr sustaining peaking capacity). This means that the LSR dams provide 2,284 MW MW of firm capacity that must be replaced if the dams are breached. This assumption was validated based on BPA modeled LSR dam performance data during the 2001 dry hydro year, as described in section 4.3, which also describes estimates of the NPV impact of assuming a lower firm capacity value for the dams.

Resource adequacy needs are captured in RESOLVE by ensuring that all resource portfolios have enough capacity to meet the peak Core Northwest median peak demand plus a 15% planning reserve margin. Firm capacity resources are counted at their installed capacity. Hydro resources are counted at the 65% regional value used in PNUCC's 2021 resource adequacy analysis. Solar, wind, battery storage, pumped hydro storage, and demand response are counted at their effective load carrying capability ("ELCC") based on E3's RECAP modeling from its 2019 *Resource Adequacy in the Pacific Northwest* study.[20] Figure 13 shows the initial capacity values for these resources, as well as the declining marginal contributions as more of the resource is added. RESOLVE uses these data points to develop tranches of energy storage and demand response resources with declining marginal ELCCs for each tranche. Solar and wind ELCCs are input into RESOLVE using a 2-dimensional ELCC surface that captures the interactive benefits of adding various combinations of solar and wind together. Resources on the surface (such as different wind zones) are scaled in their ELCC based on their capacity factor relative to the base capacity factor assumed in the surface, and the entire surface is scaled as peak demand grows.

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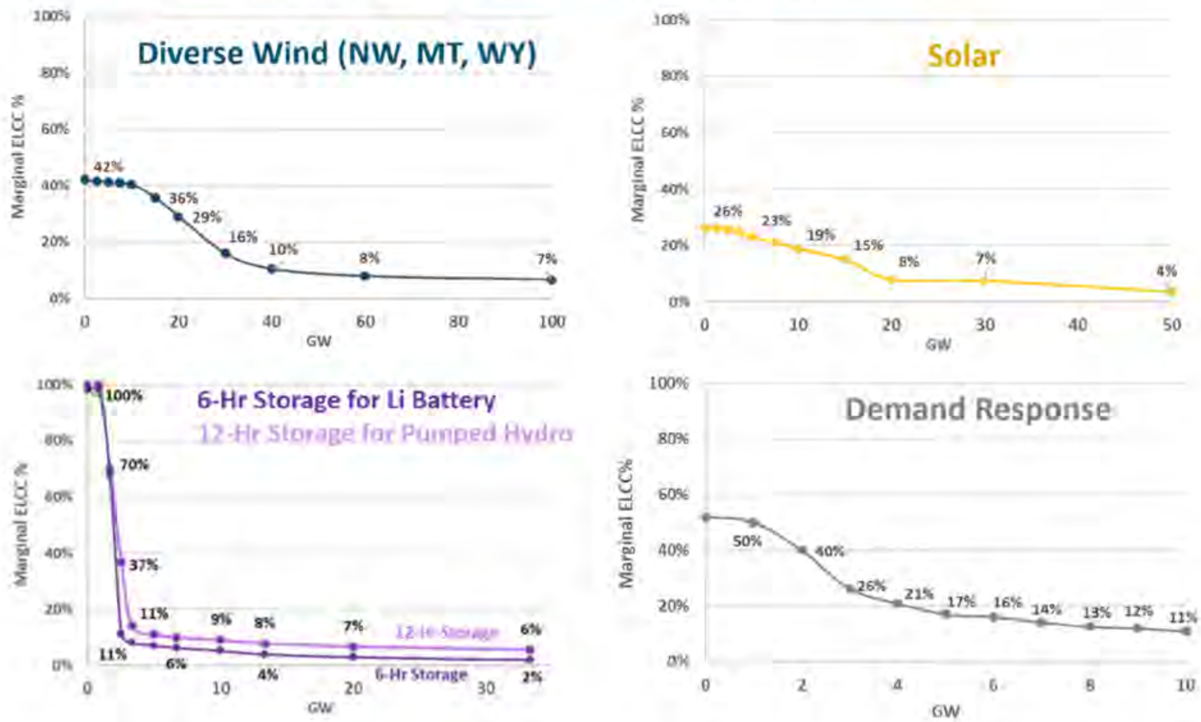
[20] Resource Adequacy in the Pacific Northwest, 2019. https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

Figure 13. Solar, Wind, Storage, and Demand Response Capacity Values



The capacity value for energy storage resources shown in Figure 13 are very different from those in other regions, such as California or the Desert Southwest, declining much more quickly as a function of penetration. There are two reasons for this. First, the Pacific Northwest is a winter peaking region in which loss-of-load events are primarily expected to occur during extreme cold weather events that occur under drought conditions in which the region faces an energy shortfall. These events, such as the one illustrated in Figure 3 above, result in multi-day periods in which there is insufficient energy available to charge storage resources, severely limiting their usefulness. This is unlike the Southwest, where the most stressful system conditions occur on hot summer days in which solar power is expected to be abundant and batteries can recharge on a diurnal cycle. Second, the Pacific Northwest already has a very substantial amount of reservoir storage which can shift energy production on a daily or even weekly basis. Thus, the Pacific Northwest is already much closer to the saturation point where additional diurnal energy shifting has limited value.

Nevertheless, recognizing that the capacity value of energy storage is still being researched, in the Northwest and elsewhere, we include a sensitivity case in which energy storage resources are assumed to have much higher ELCC values, similar to what is expected in the Southwest at comparable penetrations.

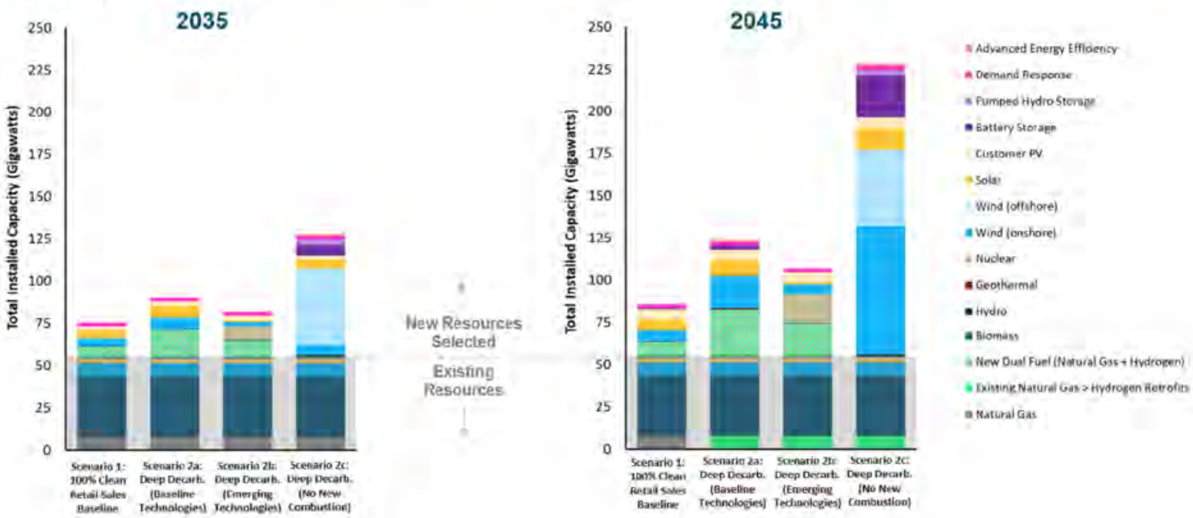
4 Results

RESOLVE model runs for the 2025-2045 period produce optimal resource portfolios of additions and retirements by resource type, as well as metrics of annual and hourly resource generation, carbon emissions, and total system costs. This section presents the RESOLVE modeling results, focused on the years of 2035 and 2045 to highlight the mid-term and long-term resource needs. Following that, the result of the RESOLVE runs with the LSR dams breached are presented, with the replacement resource and costs to replace the dams' power services.

4.1 Baseline Electricity Generation Portfolios

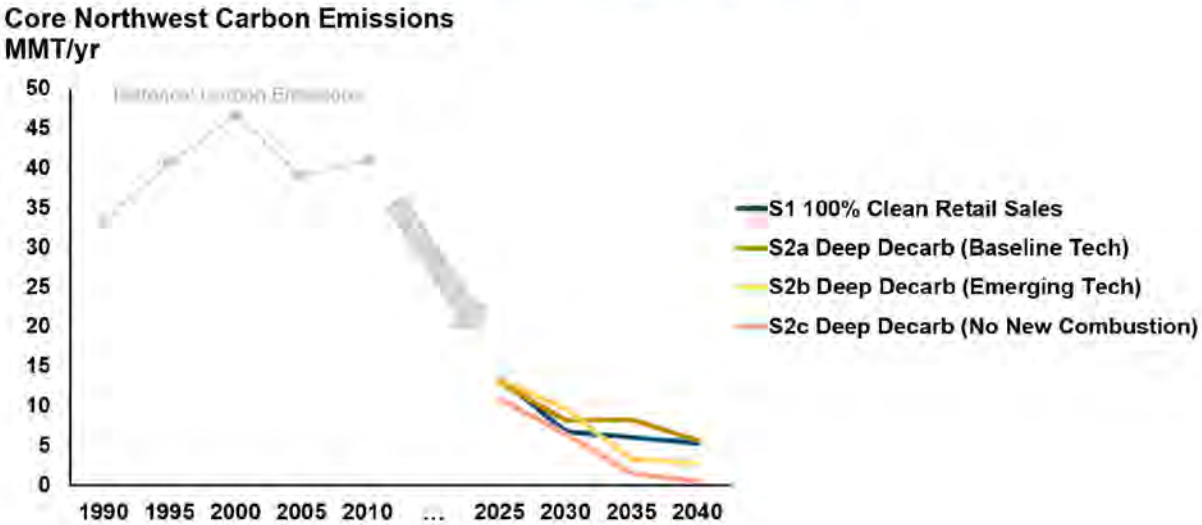
In the baseline scenarios, large amounts of utility-scale solar PV, onshore wind, offshore wind, hydrogen-capable combined cycle, and some amounts of energy efficiency and demand response are selected to meet the growing electricity demand, PRM and emissions reductions. Electrification load growth along with zero emissions target drives higher needs in deep decarbonization scenarios (i.e., S2a, S2b and S2c) compared to the reference scenario (S1) in both snapshot years of 2035 and 2045. In S2b, clean firm technologies such as SMR nuclear are selected in place of additional onshore wind, solar and dual-fuel CCGT selected in S2a. In the absence of clean firm technologies (no new combustion) in S2c, massive amounts of offshore wind (~45 GW) as well as more battery storage, pumped storage, demand response, and energy efficiency were selected as early as 2035 such that in this scenario, the new resource additions are almost five time the new builds in S1. These capacity additions increase even more substantially by 2045.

Figure 14. Large levels of new resource additions to meet the growing load, PRM needs and emissions reductions



As shown in Figure 15 below, all four scenarios result in a sharp near-term decline in carbon emissions, driven by Washington and Oregon policies that drive coal retirement this decade. By 2045, Scenario 1, which requires 100% clean retail sales, shows an ~85% decline in carbon emissions relative to 1990 levels. Scenario 2 eliminates all carbon emissions by 2045.

Figure 15. Northwest Carbon Emissions

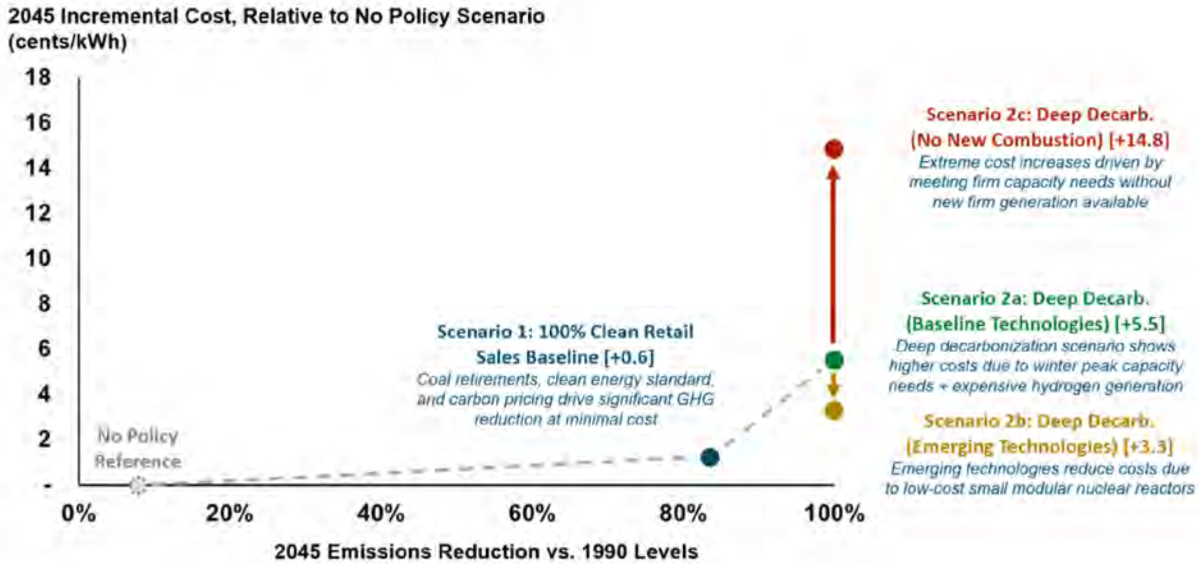


To put cost impacts in context, a "No Policy Reference" case uses the baseline load forecast and removes all electric clean energy policies, retaining the region's coal power with little emissions decline. The four clean energy futures modeled are compared against this Reference Case on A) their cost impacts, measured in incremental cents/kWh relative to the Reference, and B) their carbon emissions reductions, relative to 1990 levels. By 2045, as shown in Figure 16, with the region's aggressive carbon policies in place, emissions can be reduced by over 80% with a relatively small cost impact (+0.6 cents/kWh relative to the region's current average retail rate of 8-9 cents/kWh). Reaching a zero-carbon grid with increasing electric loads requires significantly more investment, increasing carbon reductions to 100% of 1990 levels, but also increasing costs by 3.3-14.8 cents/kWh. This range is highly dependent upon the availability of emerging technologies and their assumed costs. The low end assumes that low-cost small modular nuclear reactors become commercialized by 2035. The high end assumes no new combustion resources (such as green hydrogen)[21] or other emerging technologies are available, showing

[21] The authors recognize that hydrogen can be used to generate electricity by fuel cells instead of combustion turbines. That scenario would look similar to Scenario 2a, where the combustion plant additions are replaced with many GW of fuel cells for firm capacity needs.

that relying only on non-firm resource additions (renewable energy, demand side resources, and short- to medium-duration storage) leads to much higher costs.

Figure 16. Cost Impacts Compared to Emissions Reduction Impacts



NOTES:
- 2020 average retail rates for OR and WA were 8-9 cents/kWh; 1990 electric emissions were ~33 MMT
- High electrification scenarios would avoid natural gas infrastructure costs, which would offset some of the electric peaking infrastructure cost increase

4.2 LSR Dams Replacement

The resource replacement portfolios and costs of replacing the LSR dams are reported in this section, which is also focused on the midterm (2035) and long term (2045).

4.2.1 Capacity and energy replacement

In the midterm, given the expectations of load growth and coal capacity retirements resource adequacy needs are a primary driver of LSR dam replacement needs, with around 2 GW of additional firm dual fuel natural gas and hydrogen combustion plants selected to replace the LSR dams' capacity in Scenarios 1, 2a, and 2b (see Table 10). (Note that, these turbines may initially burn natural gas when needed during reliability challenged periods but would transition to hydrogen by 2045 to reach zero-emissions.) If advanced nuclear is available as assumed in Scenario 2b, it replaces renewables and some of the combustion resource builds. In addition to firm resources, some of the LSR capacity is replaced by renewables in Scenarios 1 and 2a, mostly by wind resources and some battery storage. In Scenario 2c, with no combustion or advanced nuclear available, a very large buildout of renewable capacity (in the order of 12 GW) is required to replace the capacity of LSR dams, due to resource availability and the fast decline in solar and wind ELCCs as early as 2035. Small amount of geothermal capacity is also part of the portfolio in 2035.

In the long term, the dam's carbon-free energy is replaced by a combination of wind power and another "clean firm" resource when available. Scenario 2a shows additional hydrogen generation, as well as small levels of energy efficiency and battery storage. In Scenario 2b, the LSR dams are entirely replaced by clean firm capacity of hydrogen combustion plants and nuclear SMRs, whereas in Scenario 2c, a large capacity of wind and solar is relied upon to replace both the carbon-free energy and firm capacity of the LSR dams. Overall, the magnitude of replacement portfolio capacities is close in both snapshot years (2035 and 2045) meaning that immediate capacity additions are necessary to replace LSR dams given the retirement year of 2032 while the capacity needs sustain throughout the modeling period. The early removal of LSR dams (i.e., by 2024) moves up the timing of the replacement portfolio to 2025 instead of 2035 in S1b, but the replacement portfolio remains similar.

Table 10. Optimal portfolios to replace the LSR dams

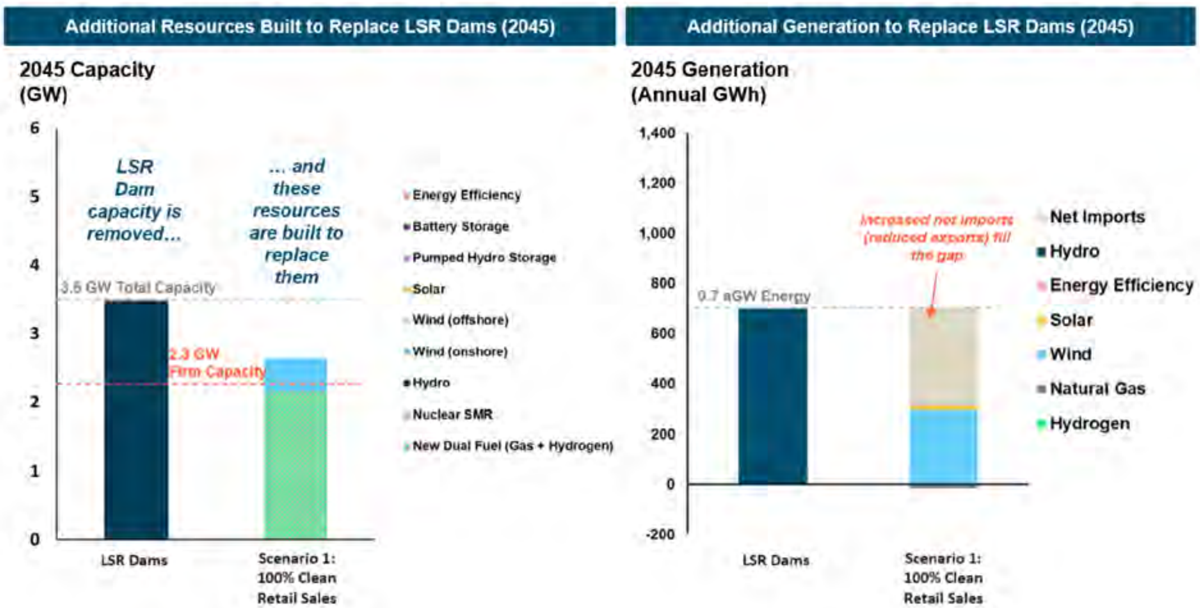
Scenario	Replacement Resources Selected, Cumulative by 2035[22] (GW)	Replacement Resources Selected, Cumulative by 2045 (GW)
Scenario 1: 100% Clean Retail Sales	+ 1.8 GW dual fuel NG/H2 CCGT - 0.5 GW solar + 1.3 GW wind + 0.1 GW li-ion battery	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
S1b: 100% Clean Retail Sales (2024 dam removal)	+ 1.8 GW dual fuel NG/H2 CCGT - 0.5 GW solar + 1.4 GW wind + 0.1 GW li-ion battery	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
Scenario 2a: Deep Decarbonization (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.6 GW wind + 0.1 GW li-ion battery	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW advanced EE + 1.2 TWh H2-fueled generation
Scenario 2b: Deep Decarbonization (Emerging Technologies)	+ 1.7 GW dual fuel NG/H2 CCGT + 0.6 GW nuclear SMR	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR
Scenario 2c: Deep Decarbonization	+ 9.1 GW offshore wind + 0.1 GW wind	+ 10.6 GW wind + 1.4 GW solar

[22] Replacement resources are calculated by comparing the "with LSR dams" RESOLVE portfolio to the "without LSR dams" RESOLVE portfolio. This means some resources may be built in 2035, such as 0.3 GW of geothermal in scenario 2c, that were not built when the dams were included. However, those resources may have already been selected in the "with LSR dams" case by 2045, hence do not show up as additional resource replacement needs in 2045. This explains the different resource changes between 2035 and 2045.

(No New Combustion)	+ 1.0 GW solar + 0.3 GW geothermal + 1.5 GW li-ion battery	

Figure 17 and Figure 18 show details of the capacity replacement, energy replacement, and cost breakdown for Scenarios 1 and 2a. LSR dams energy in these scenarios is replaced with wind, net imports (i.e. reduced exports of hydropower outside the Core NW), and – in Scenario 2a – additional hydrogen generation, which is necessary in 2045 to meet the zero-carbon goal without the flexible LSR dam winter generation. The cost charts show that the dual fuel gas plants make up approximately half of the 2045 annual costs in Scenario 1 and approximately a quarter of the 2045 annual costs in Scenario 2a, which includes additional costs for energy efficiency and hydrogen generation.

Figure 17. Scenario 1 Capacity Replacement, Energy Replacement, and Costs[23]



[23] Regarding the "net imports" component of the energy replacement, this refers to either increased imports, decreased exports (generally of carbon-free energy), or a combination of both, such that RESOLVE does not need to build enough new generation to fully replace the LSR dams output. For instance, the region could export less hydropower to California and other neighbors to replace the LSR dams output without necessarily increasing carbon emissions.

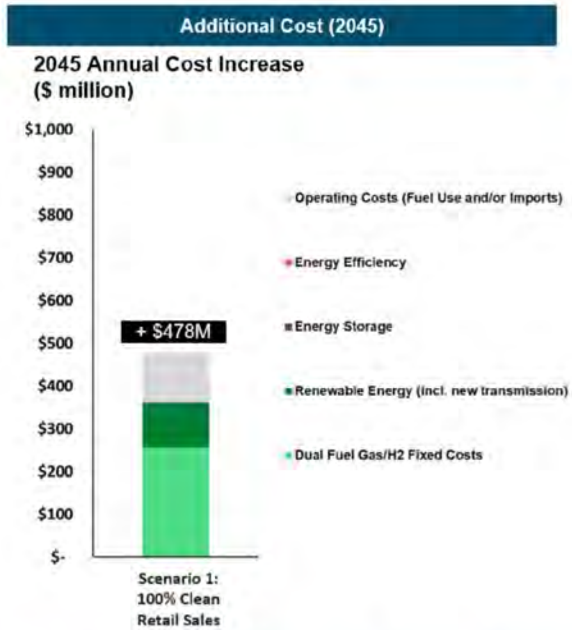
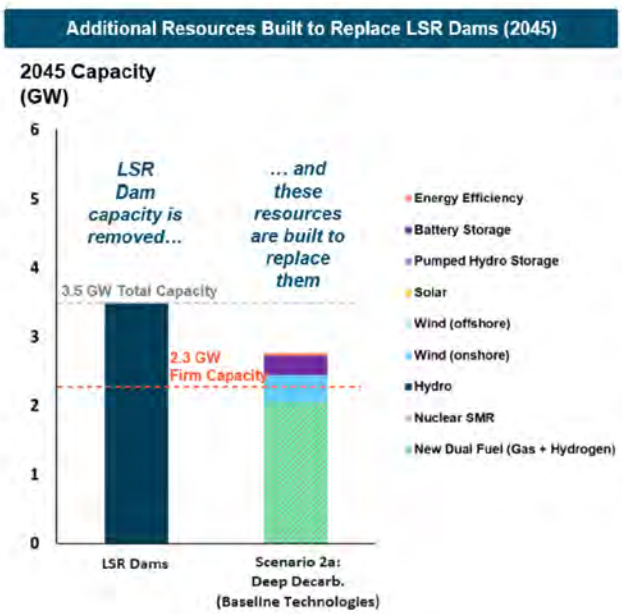
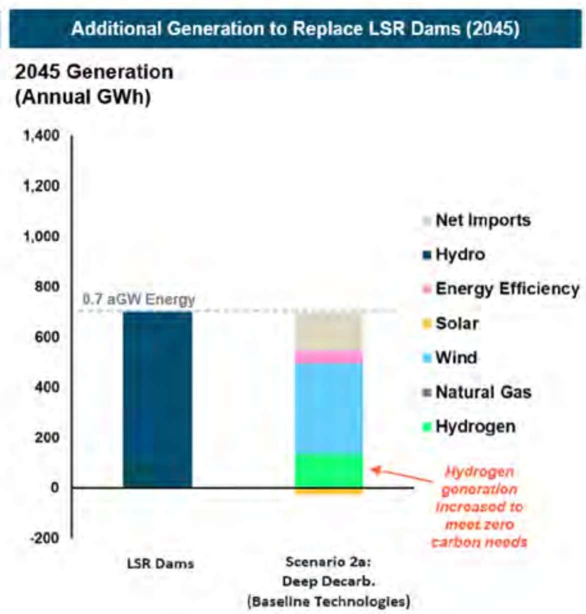
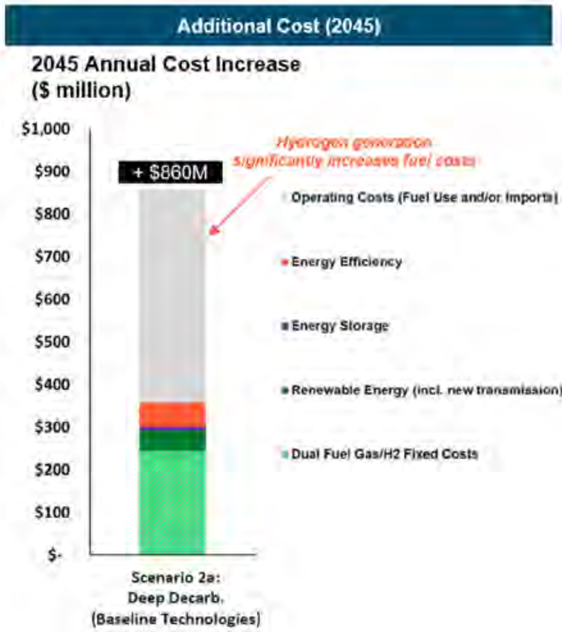


Figure 18. Scenario 2a Capacity Replacement, Energy Replacement, and Costs







4.2.2 Replacement costs

The LSR dams provide a relatively low-cost source of GHG-free energy and firm capacity. Incremental costs for replacement resources are summarized in this section. All costs are shown in real 2022 dollars. Incremental costs to replace the power services of the LSR dams ranges from $69-139/MWh across most scenarios. Scenario 2c, however, shows a much lower replacement power cost of $517/MWh. These incremental costs are much higher than costs of maintaining the LSR dams (i.e., $13-17 per MWh[24]); they are calculated by taking the incremental fixed and variable investment costs for the no LSR RESOLVE runs and dividing them by the LSR annual generation being replaced. See the details in Table 11.

[24] BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) facilities which is in the range of $13/MWh without LSRCP and $17/MWh with LSRC. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat.2917) to offset fish and wildlife losses caused by construction and operation of the four lower Snake River projects.

Table 11. Incremental costs to replace LSR generation in 2045

Scenario	Incremental net costs in 2045[25], including avoided LSR dam costs (Real 2022 $/MWh)	Incremental gross costs in 2045[26], excluding $17/MWh avoided LSR dam costs (Real 2022 $/MWh)
Scenario 1: 100% Clean Retail Sales	$77/MWh	$94/MWh
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$82/MWh	$99/MWh
Scenario 2a: Deep Decarb. (Baseline Technologies)	$139/MWh	$156/MWh
Scenario 2b: Deep Decarb. (Emerging Technologies)	$69/MWh	$86/MWh
Scenario 2c: Deep Decarb. (No New Combustion)	$517/MWh	$534/MWh

The LSR dams' total replacement costs (in net present value) and annual replacement costs for 2025, 2035, and 2045 are shown in Table 12. NPV replacement costs are calculated discounted to the year of breaching (e.g. 2032 or 2022) based on costs modeled in RESOLVE 2025-2045 (plus 20 years added to account for end effects). Scenario 1 (100% clean retail sales) replacement costs are approximately $9.7 billion in net present value (NPV) in the year of breaching (in 2032); costs increase to $11.7 billion NPV if breached in 2024. Total replacement costs are similar in the Deep Decarbonization scenario when emerging technology is available (scenario 2b), showing $8.7 billion NPV. Replacement costs are significantly higher in scenario 2c where no new combustion resources are allowed ($61 billion NPV). The Deep Decarbonization (baseline technology scenario), 2a, shows more costly replacement ($11.3 billion NPV) than when nuclear SMRs are available, but lower costs than scenario 2c, due to the availability of hydrogen-enabled gas plants.

Annual costs increase by $415-860 million after LSR dams' removal in scenarios 1, 2a, and S2b. In Scenario 2c, the cost increase is in the order of $1.9-3.2 billion per year. Replacement costs generally increase over time due to increasingly stringent clean energy standards and electrification-driven load growth. The 2045 cost increases translate to 8-18% growth in BPA's public power customers costs in scenarios 1, 2a and 2b (assuming current retail rates are about 8.5 ¢/kWh based on OR and WA average

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[25] The generation replacement costs are calculated using the incremental RESOLVE's Core Northwest revenue requirement increase with LSR dams breached divided by the annual MWh of the LSR dams assuming 706 average MW generation.

[26] The generation replacement costs are calculated using the incremental RESOLVE's Core Northwest revenue requirement increase with LSR dams breached divided by the annual MWh of the LSR dams assuming 706 average MW generation.

retail rates). In these scenarios, public power households would see an increase in annual electricity costs of $100-230/yr in 2045. In Scenario 2c, rate impacts could be as high as 65%, which is equivalent to annual residential electricity bills raising by up to $850 per year.[27]

Note that these incremental cost increases include the ongoing LSR dams costs avoided by breaching the dams, but do not include the costs of breaching. The rate impacts show are only for the LSR dams replacement, they do not include the additional rate increases driven by higher loads or clean energy needs (that are covered in section 4.1 above).

Table 12. Total LSR Dams replacement costs

	NPV Total Costs (Real 2022 $)[28]	Annual Costs Increase (Real 2022 $)			Incremental Public Power Costs[29]
	In the year of breaching (2032 or 2024)	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$9.7 billion	n/a	$434 million	$478 million	0.8 ₵/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$11.7 billion	$495 million	$466 million	$509 million	0.8 ₵/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$15.1 billion	n/a	$496 million	$860 million	1.5 ₵/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$8.7 billion	n/a	$415 million	$428 million	0.7 ₵/kWh [+8%]

[27] Annual residential customer cost impact assumes 1,000 kWh per month for average residential customers in Oregon and Washington in scenario 1 and 1,280 kWh per month for scenario 2, per the 28% retail sales increase due to electrification load growth.

[28] NPV replacement costs are shown discounted to the year of breaching, using a 3% discount rate to represent the public power cost of capital.

[29] Incremental public power costs are calculated assuming that all the replacement costs are paid by BPA Tier I customer, using the assumed 2022 Tier I annual sales of 58,686 GWh.

Scenario 2c: Deep Decarb. (No New Combustion)	$61 billion	n/a	$1,953 million	$3,199 million	5.5 ¢/kWh [+65%]

4.2.3 *Carbon emissions impacts*

LSR dams provide emissions-free generation for Northwest and depending on what these dams are replaced with, may impact the emissions associate with the electricity systems. The removal of LSR dams may potentially cause an increase in emissions over the near- or mid-term horizon. In Scenario 1, the 2024 LSR dam breaching scenario results in substantial increases to carbon emissions through 2030, in the range of 1-2.8 MMT/yr or 15-25% of the annual Northwest emissions. This scenario does not have a binding GHG constraint, and the region meets its clean energy goals in the near term without the dams. RESOLVE therefore does not replace all the LSR dam energy with clean resources.

Under 2032 breaching scenarios, small carbon emissions increases are observed in the mid-term (0.7 MMT/yr. or 8-10% of the region's carbon emissions in 2035). The deep decarbonization cases all reach zero carbon emissions by 2045, so breaching the dams does not increase emissions in that year; RESOLVE instead builds the resources needed to replace all of the GHG-free energy.

4.2.4 *Additional considerations*

Depending on how the future of the electric grid evolves, there might be significant land-use associated with renewables expansion, more so if LSR dams are removed in conditions similar to Scenario 2c where significant capacity additions from solar and wind resources would be necessary.

In terms of costs, while this study considered the replacement costs of LSR dams from the electricity system perspective, there are other types of services that LSR dams provide that would need additional cost assessment. LSR dams are used for irrigation, recreation, navigation, and transportation. Breaching LSD dams could impact these services and therefore, should be considered alongside the electricity services replacement costs. Moreover, breaching the dams itself would be an additional cost. These factors are addressed in more detail in the report prepared by Senator Murray and Governor Inslee.[30]

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[30] Lower Snake River Dams: Benefit Replacement Draft Report by U.S. Sen. Patty Murray, and Washington Gov. Jay Inslee, 2022. Lower Snake River Dams: Benefit Replacement Draft Report (senate.gov)

4.3 Key Uncertainties for the Value of the Lower Snake River Dams

This study explicitly captures the following key drivers of the LSR dams power service replacement needs:

- Replacing the **GHG-free energy**, **firm capacity**, **operating reserves**, and **operational flexibility** of the dams

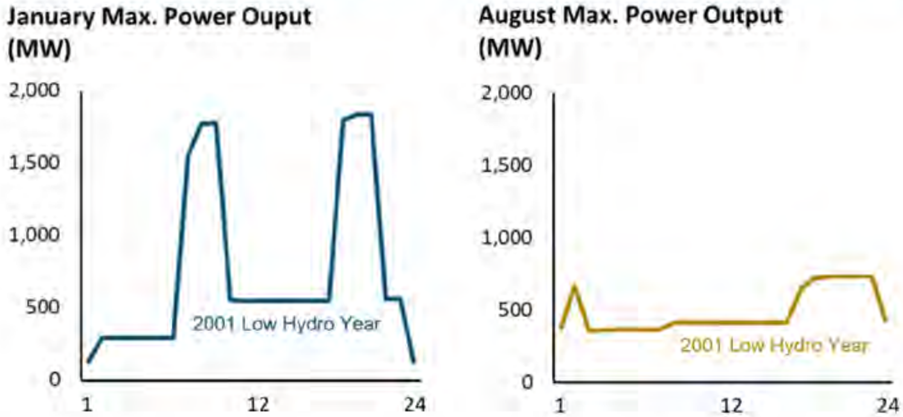
Uncertainty of the LSR dam value is considered under:

- **Clean energy policy**: replacement of carbon-free power becomes increasingly critical to reach a zero-emissions electricity grid
- **Load growth**: replacement energy and capacity needs may change with increased electrification and peak higher winter space heating needs
- **Technology availability**: replacement is more expensive with fewer emerging technology resource options
- **Timing**: replacement was focused on breaching in 2032, but a 2024 sensitivity was also considered

Additional uncertainties regarding the value of the dams are as follows:

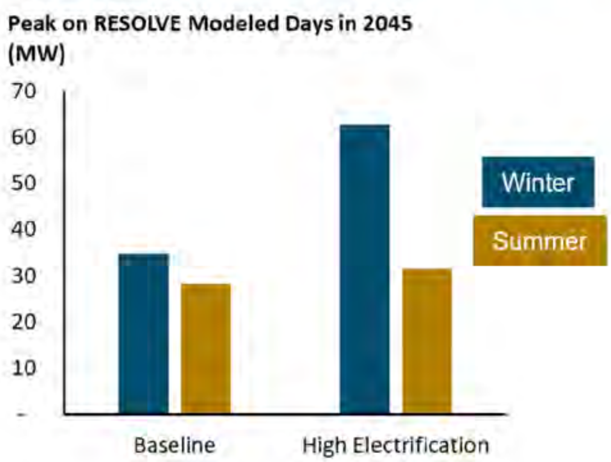
- **Annual energy output**: E3's existing RESOLVE model data uses historical hydro years 2001, 2005, and 2011 as representative of the long-term average low/mid/high hydro year conditions. However, for the LSR dams, this leads to a relatively low output of ~700 average MW, whereas the dams may generate ~900 average MW on average across a range of hydro conditions – according to BPA data post EIS spill constraints. Therefore, E3's analysis likely underestimates the energy value of the dams and costs for replacing that extra GHG-free energy.
- **Firm capacity counting**: as resource adequacy is found to be a key driver of future resource needs, the firm capacity contributions of the LSR dams is a key driver of their value.
  - E3 uses a regional hydro capacity value estimate for the LSR dams in this study. More detailed follow-on ELCC studies could be done to confirm the LSR dams' capacity value, though proper and coordinated dispatch of the Northwest hydro fleet would be necessary to develop an accurate and fair value of the LSR dams within the context of the overall hydro fleet.
  - This study validated the assumed 2.28 GW of firm capacity from the dams by considering BPA modeled LSR dams dispatch under 2001 conditions using the EIS spill constraint adjusted model. Maximum January output (plus 100-250 MW of operating reserves) was 1.9-2.1 GW (~56-60% of total capacity), slightly less but close to the 65% regional hydro value the study assumes.

Figure 19. BPA-Modeled LSR Dam Output During the 2001 Low Hydro Year



- o The other capacity value uncertainty is whether the Northwest will remain winter reliability challenged or whether reliability events will shift to the summer due to climate impacts on load patterns and hydro output. If reliability challenges did shift to the summer, the LSR dam firm capacity contribution would be significantly lower than assumed. However, E3 believes it is reasonable to assume under high electrification scenarios that the region will remain winter challenged due to peak space heating needs, as shown in figure below.

Figure 20. Winter vs. Summer Peak Loads



- o To address the capacity value uncertainty, E3 estimates that a 1.5 GW firm capacity value (43%) for the dams would lower the NPV replacement costs by 9-20% and a 1.0 GW firm capacity value (29%) would lower the NPV replacement costs by 14-33%.

+ **Replacement resource capacity contributions**: if Northwest reliability challenges dramatically shift into the summer, this would also impact the capacity value of replacement resources. Directionally, this would likely lower the value of wind and increase the value of solar and energy storage. It is expected that additional solar and storage would be part of the regional capacity additions in lieu of wind and dual fuel natural gas + hydrogen plants. However, it is unclear whether the marginal capacity LSR dams replacement resources would change since the region would likely saturate solar and battery storage capacity value in cases with the dams not breached, even if it took longer for the capacity value of those resources to saturate. E3 MAY ADD FURTHER NOTES HERE.

+ **Replacement of transmission grid services:** this study does not focus on the transmission grid reliability services provided by the LSR dams. These services likely can be replaced by a combination of the new resources selected by RESOLVE and additional local transmission system investments. A qualitative summary of the transmission grid reliability services of the dams is summarized in the appendix of this report.

5 Conclusions and Key Findings

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability. RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[31]. Using RESOLVE allows for a dynamic optimization that considers replacement resource needs in the context of long-term system load and policy drivers, not just the near-term resource mix and needs of the system today. The dams are assumed to be breached in 2032, except for one sensitivity that considered 2024 breaching. This study's scenario design focuses on three key variables – clean energy policy, load growth, and emerging technology availability – that impact the cost to replace the dams.

Even with the dams in place, the region's clean energy goals and potential electrification load growth drive a significant need for new resources. In all scenarios, significant energy efficiency and customer solar is embedded into the load forecast, based on the NWPCC's 8[th] Power Plan. Additionally, 6 gigawatts ("GW" or 6,000 MW) of coal capacity is retired by 2030, while increasing carbon prices incent further clean energy resource additions. In Scenario 1, the regional power system is required to meet a goal of generating enough clean energy to provide 100% of retail electricity sales, on an average basis over a calendar year. This requires an additional 5 GW of solar and 5 GW of wind by 2045 to achieve the clean energy goal; 0.6 GW of battery storage, 2 GW of demand response, and 9 GW of dual fuel natural gas + hydrogen combustion plants are also added to meet the region's resource adequacy needs.

Though all scenarios require more "firm" resources – resources that can start when needed and operate for as long as needed – to meet peak loads, these resources are in higher demand in Scenario 2, in which all greenhouse gas emissions are eliminated from the regional power system by 2045. This scenario also assumes that electrification results in much higher electric loads, particularly in wintertime due to electrification of natural gas space heating in buildings. The baseline scenario (2a) selects additional wind, solar, and geothermal to meet clean energy needs as well as demand response, some battery

[31] Pacific Northwest Low Carbon Scenario Analysis, December 2017, https://www.ethree.com/projects/study-policies-decarbonize-electric-sector-northwest-public-generating-pool-2017-present/; Pacific Northwest Zero-Emitting Resources Study, January 2020, https://www.ethree.com/e3-examines-role-of-nuclear-power-in-a-deeply-decarbonized-pacific-northwest/

storage, and 27 GW natural gas and hydrogen dual fuel combustion plants to meet reliability needs. An alternative "emerging technology" scenario selects 17 GW of advanced nuclear technology (small modular reactors or "SMRs") by 2045, in place of the firm capacity provided by natural gas generators while reducing the required quantities of wind, solar and batteries that are needed. The "no new combustion" scenario does not allow clean firm technologies such as hydrogen combustion turbines, gas generation with carbon capture and sequestration (CCS) or SMRs. As a result, it requires impractically high levels of additional onshore wind, offshore wind, and battery storage to meet firm capacity and carbon reduction needs, quadrupling the total installed MW of the Northwest grid by 2045.

When the power services provided by the dams are removed from the regional power system, RESOLVE selects an optimal, i.e., least-cost portfolio of replacement resources that meets the Northwest's clean energy and system reliability needs. These replacement resources require a large investment and come at a substantial cost that increase over time as the region's clean energy goals become more stringent. In the latter years, the replacement costs are highly dependent on scenario-specific assumptions about the availability of emerging technologies. RESOLVE primarily replaces the carbon-free energy from the dams with additional wind power and the firm capacity with dual fuel natural gas and hydrogen combustion plants. Small amounts of additional energy efficiency and battery storage are also selected in some scenarios. By 2045, the dual fuel plants added burn additional hydrogen on low wind days to replace the carbon-free energy provided by the dams. Scenario 2b selects additional nuclear SMRs in lieu of some of the wind and gas resources. Scenario 2c disallows the new combustion plants, even those that would burn green hydrogen, and other emerging technologies, requiring a very large buildout of wind and solar power to replace both the firm capacity and the carbon-free energy of the dams.

The long-term emissions impact of removing the generation of the lower Snake River dams will depend on the implementation of the Oregon and Washington electric clean energy policies. Both a 100% clean retail sales and a zero-carbon emissions target require replacement of most or all of the LSR dams' GHG-free energy. However, without additional earlier carbon-free resource investments beyond those modeled in this study to meet clean energy policy trajectories, carbon emissions may increase initially when the dams are breached, before declining by 2045 as the carbon policy becomes more stringent.

KEY FINDINGS:

+ ***Replacing the four lower Snake River dams while meeting clean energy goals and system reliability is possible but comes at a substantial cost***, even assuming emerging technologies are available:
    - Requires 2,300 – 2,700 MW of replacement resources
    - An annual cost of $415 million – $860 million by 2045
    - Total net present value cost of $8.7-15.1 billion from 2032-2065
    - Increase in costs for public power customers of $100 – 230 per household per year (an 8 – 18% increase) by 2045
+ The biggest cost drivers for replacement resources are the need to replace the lost ***firm capacity for regional resource adequacy*** and the need to replace the lost ***zero-carbon energy***
+ Replacement becomes ***more costly over time*** due to increasingly stringent clean energy standards and electrification-driven load growth

- ***Emerging technologies*** such as hydrogen, advanced nuclear, and carbon capture ***can limit the cost of replacement resources*** to meet a zero emissions electric system, but the pace of their commercialization is highly uncertain
  - In deep decarbonization scenarios, ***replacement without any emerging technologies requires very large renewable resource additions at a very high cost*** (12 GW of wind and solar at $61 billion NPV cost)

6 Appendix

6.1 Additional Inputs Assumptions and Data Sources

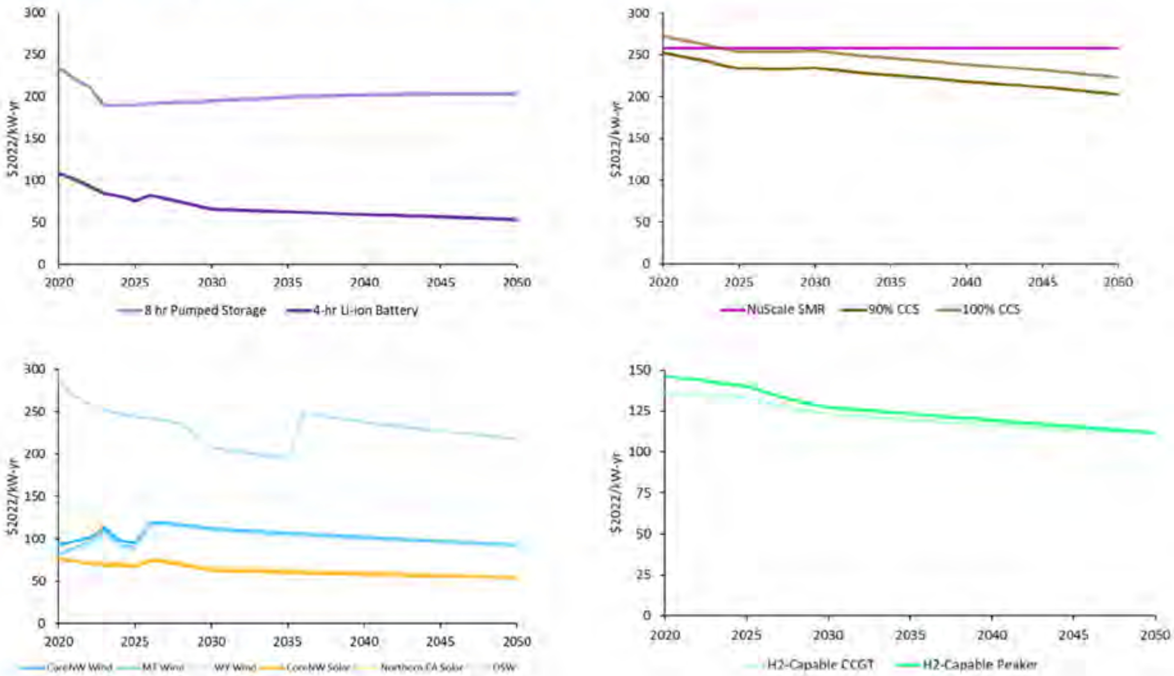
6.1.1 Candidate resource costs

The technology fixed costs trajectories for candidate resource options are shown in **Error! Reference ource not found.** and use the following data sources:

- **Battery Storage:** Costs derived from Lazard LCOS 7.0 and E3 modeling
- **Pumped Storage:** Costs derived from Lazard's last published PHS costs (LCOS 4.0)
- **Renewables (solar, onshore, and offshore wind):** Costs derived from E3's inhouse Pro Forma which integrates the NREL 2021 Annual Technology Baseline
- **Geothermal:** Costs derived from E3's inhouse Pro Forma which integrates the NREL 2021 Annual Technology Baseline
- **Energy Efficiency and Demand Response:** Costs supply curve adjusted for cost effective energy efficiency and DR potential from the 2021 Northwest Power Plan
- **Carbon Capture and Storage (CCS):** Costs derived from E3's inhouse "Emerging Tech" Pro Forma using the NREL 2021 Annual Technology Baseline and Feron et al., 2019.[32]
- **Nuclear Small Modular Reactor (SMR):** Costs are derived from the vendor NuScale, for an "nth of a kind" installation of the technology they are developing
- **Gas and Hydrogen-Capable Technologies:** CCGT and peaker costs are derived from E3's inhouse ProForma which integrates NREL 2021 Annual Technology Baseline. New Hydrogen or natural gas to hydrogen upgrades include a ~10% additional cost that converges with standard CCGT and peaker costs by 2050

[32] Feron, P., Cousins, A., Jiang, K., Zhai, R., Thiruvenkatachari, R., & Burnard, K. (2019). Towards zero emissions from fossil fuel power stations. *International Journal of Greenhouse Gas Control*, 87, 188–202.

Figure 21. All-in fixed costs for candidate resource options



6.1.2 Fuel prices

The fuel price forecasts used in this study are derived from a combination of market data and fundamentals-based modeling of natural gas supply and demand. Wholesale gas prices are pulled from forward contracts from NYMEX (Henry Hub) and Amerex and MI Forwards (all other hubs) for the next five years, after which the Henry Hub forecast trends towards EIA's AEO natural gas price by 2040. All other hubs forecast after the first five years are based on the average 5-year relationship between their near-term forward contracts and that of Henry Hub. Data sources used for fuel price forecasts used in modeling are as follows and the trajectories are presented in Figure 22:

+ **Natural gas prices:** In near term, SNL NG price forecasts (i.e., for 2022-2026); and in long term, the EIA's AEO 2040 forecasts are used. Recent fuel cost increases due to market disruptions are excluded from the price trajectory.
+ **Coal prices:** EIA's AEO forecast are used
+ **Uranium prices:** E3's in-house analysis
+ **Hydrogen prices:** Conservative prices are used assuming no large-scale hydrogen economy, and thus electrolyzer capital costs and efficiencies were assumed to improve over time only slightly. Other assumptions include above ground hydrogen storage tanks and delivery via trucks from about 225 miles distance. Electrolyzers use dedicated off-grid Core NW wind power to produce hydrogen.

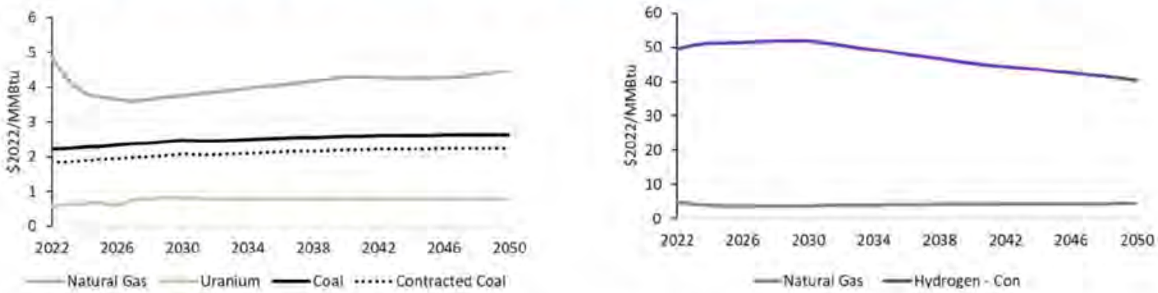


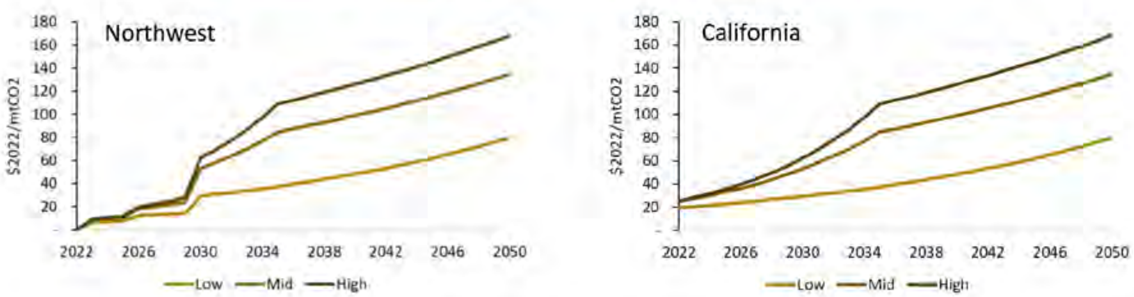
Figure 22. Fuel price forecasts for natural gas, coal, uranium, and hydrogen

Annual average gas prices are further shaped according to a monthly profile to capture seasonal trends in the demand for natural gas and the consequent impact on pricing.

6.1.3 Carbon prices

For carbon pricing, it is assumed that Washington's cap-and-trade program starts in 2023 at around 50% of California carbon prices. For Oregon, it is assumed that a carbon price policy will be effective by 2026 for the electric sector. Prior to 2026, the Northwest carbon price is a load weighted share of carbon prices in WA and OR. Additionally, it is assumed that both states will converge to California's floor price by 2030. California's carbon prices are adopted from the Final 2021 IEPR GHG Allowance Price Projections (December 2021). Mid carbon prices presented in Figure 23 are used in modeled cases.

Figure 23. Carbon price forecasts for Northwest and California



6.1.4 Operating Reserves

It is assumed that all coal, gas, hydro, and storage resources within the Northwest zone can provide operating reserves. Additionally, RESOLVE allows renewable generation to contribute to meeting the needs for load following down; to allow for variable renewable generation curtailment to balance forecast error and sub-hourly variability. The following three types of operating reserve requirements are considered within the Core Northwest to ensure that in the event of a contingency, sufficient resources are available to respond and stabilize the electric grid:

+ **Spinning reserves:** Modeled as 3% of hourly load in agreement with WECC and NWPP operating standards

+ **Regulation up and down:** Modeled as 1% of hourly load

+ **Load following up and down:** Modeled as 3% of hourly load

6.2 Additional LSR Dam Power System Benefits (not modeled)

As described in this report, RESOLVE covers replacement of most power services provided by the LSR dams. However, RESOLVE does not model transmission grid operations (power flow, voltage and frequency, dynamic stability, etc.). Therefore, E3 notes that the LSR dams may provide the following additional essential reliability services to the transmission grid. In general, E3 expects that the replacement of these services can be achieved either through siting and operations of the incremental replacement capacity selected or by additionally (relatively small) local transmission investments.

- **Reactive power and voltage control**: the LSR dams, like hydropower resources generally in the Northwest, provide significant reactive power capabilities that supports reliable power flow by optimally controlling voltage levels. Replacing this function likely requires siting additional resources with reactive power capabilities in a similar section of the transmission grid as the LSR dams. The LSR dams are also highly tolerant of operating during high and low frequency events without sustaining blade damage.
- **Frequency response and inertia**: the LSR dams provide both primary and secondary frequency response capabilities. As synchronous generators they also provide system inertia that is lost as other synchronous generators retire. New efforts are underway to allow renewable generators or battery storage to provide "synthetic inertia" (or equivalent fast frequency response services), but this provision has not yet been proven to date at scale.
- **Blackstart**: Large hydro resources have the capability to provide black start services when required, though not all hydro plants are chosen to provide this capability. Small (low-head) hydro typically cannot black start on their own; however, the Idaho National Laboratory has experimented with enhancing this capability through retrofitting small hydro systems with ultracapacitors.
- **Participation in remedial action schemes**: Hydropower is a robust resource for participation in remedial action schemes because it can withstand being suddenly tripped off-line as part of a RAS action.
- **Short circuit and grounding contribution**: Synchronous generators (like hydropower) provides a large short circuit current that can be sustained; exact contribution depends on the hydro generator type.

Energy+Environmental Economics

BPA Lower Snake River Dams Power Replacement

Executive Summary

June 2022

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Aaron Burdick, Associate Director
Sierra Spencer, Sr. Consultant
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Sam Kramer, Consultant
Jack Moore, Sr. Director

About this study

- BPA contracted with E3 to conduct an independent analysis of the electricity system value of the four lower Snake River (LSR) dams
- E3 utilized our RESOLVE optimal capacity expansion model to identify least-cost portfolios of electricity resources needed to replace the electric energy and grid services provided by the dams through 2045
- Replacement costs are considered within the context of the Northwest region's aggressive, long-run decarbonization goals

Key Study Questions:

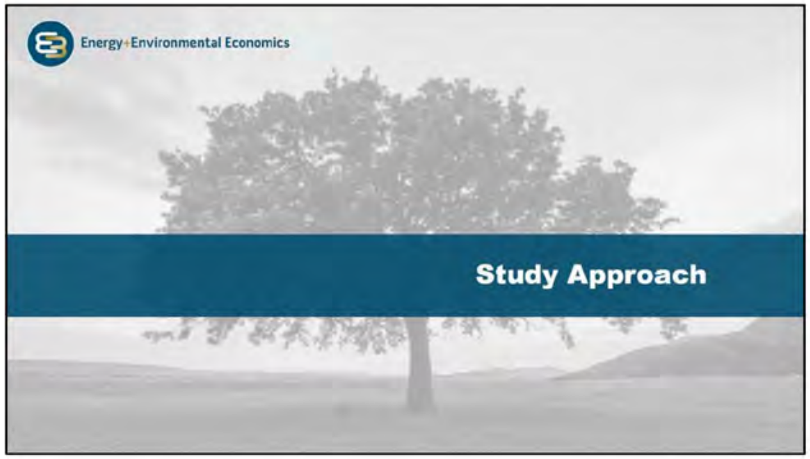
- What **additional resources** would be needed to replace the power services provided by the LSR Dams through 2045?
- What is the **net cost to** BPA ratepayers?
- How do costs and resource needs change under **different types of clean energy futures**?
- How much does replacing the dams rely on **emerging, not-yet-commercialized technologies**?

What would it take to replace the output of the four lower Snake River dams?

- **What energy services are lost if the dams are breached?**
  - **3,483 MW of total capacity***, including over **2,000 MW of firm peaking** capability to avoid power shortages during extreme cold weather events
  - **~700-800** annual average MW of low-cost, zero-carbon energy** (enough energy to support ~450,000 households or 1.7x the City of Portland) as well as **operational flexibility** services
- **How much would it cost to replace the power benefits of the four lower Snake River dams in E3's study with breaching in 2032?**
  - In E3's **baseline scenario**, total net present value (NPV)*** replacement costs would be **$9.7 billion**
  - In a **deep decarbonization scenario** with higher loads and zero emissions electricity by 2045, NPV costs range from **$8.7-15.1 billion** with at least one emerging technology
    - Reaching deep decarbonization **absent breakthroughs in not-yet-commercialized emerging technologies**, NPV costs could increase to **$61 billion**
- **What are the long-term rate impacts to ~2 million public power households in 2045?**
  - Public power costs increase by **8-18% or ~$100-230 per year across most scenarios**
    - Costs increase by **68% or ~$850 per year** under deep decarbonization scenario **absent emerging technology breakthroughs**
- **What resources are needed to replace the dams?**
  - A combination of **renewable generation** (wind), **"clean firm" resources** (such as dual fuel natural gas + hydrogen plants, advanced nuclear, or gas with carbon capture and storage), and **energy efficiency**
  - Battery storage cannot cost-effectively replace hydro capacity in the Northwest due to charging limitations during energy shortfall events
- **What is the timeline necessary to add the resources that would be required?**
  - E3 estimates that adding additional renewable energy and firm capacity additions would take approximately 5-7 years after congressional approval to breach the dams and possibly up to 10-20 years if additional new large-scale transmission was required. E3 assumed transmission would be built as needed for renewable additions.

Plant	Total Capacity (MW)
Lower Granite	930
Little Goose	930
Lower Monumental	930
Ice Harbor	693

Total = 3,483 MW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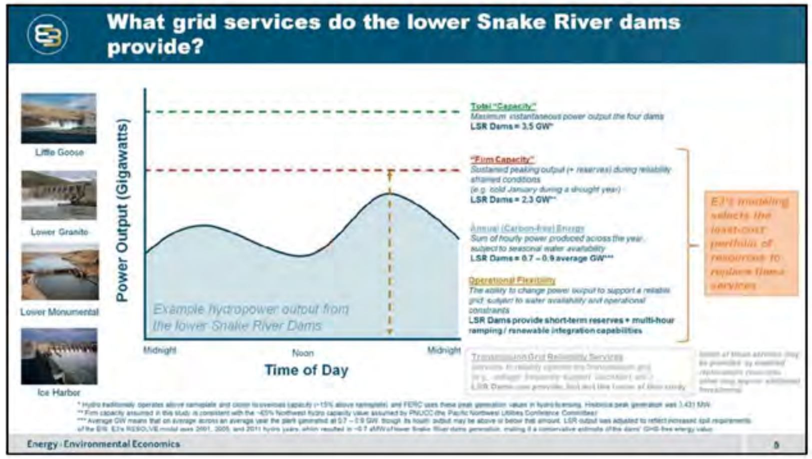
Study Approach



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What's the focus in this study compared to the CRSO EIS?

The study uses an optimization model to determine the least-cost replacement resources for the four lower Snake River dams subject to A) policy and B) reliability constraints

- **Least-cost optimization: includes updated resource pricing and new emerging technologies**
- **Policy: E3's modeling considers the effects of regional policies such as Washington's Clean Energy Transformation Act (CETA) and Oregon's 100% clean electricity standard**
  - Aggressive clean energy laws drive coal power plant retirements, price carbon emissions, and require long-term **carbon emissions reductions** by 2045
  - Study includes significant **electrification** that increases demand for electricity to support carbon-reduction in other sectors such as transportation, buildings, and industry, consistent with Washington's Energy Strategy
- **Reliability: E3's modeling captures the need for the Northwest system to meet peak load during extreme weather and low hydro conditions (known as "resource adequacy").**
  - Captures the abilities and limits of different technologies to serve load during reliability challenging conditions
    - E.g. during extended cold-weather periods with high load, low hydropower availability, and low wind and solar production
  - Resources with high energy production costs may be selected for reliability needs but then run sparsely only during extreme conditions (e.g. natural gas + hydrogen combustion turbines)
- **LSR operations: incorporates preferred alternative operations selected in the EIS**
  - Increases spill from the dams, lowering available annual energy and changing operational flexibility

Policy landscape: Washington, Oregon, California

- The study includes the impacts from clean energy policies in the Pacific states

	RPS or Clean Energy Standard?	Coal Prohibition?	Cap-and-Trade?	New Natural Gas?	Economy-Wide Carbon Reduction?
WA	✔ Carbon neutral by 2030, 100% carbon free electricity by 2045	✔ Eliminate by 2025	✔ Cap-and-invest program established in 2021. SCC in utility planning	✔	✔ 95% GHG emission reduction below 1990 levels and achieve net zero emissions by 2050
OR	✔ 50% RPS by 2040, 100% GHG emission reduction by 2040 relative to 2010 levels	✔ Eliminate by 2030	✔ Climate Protection Plan adopted by DEQ in 2021 (power sector not included)	✖ HB 2021 bans expansion or construction of power plants that burn fossil fuels	✔ 90% GHG emission reduction from fossil fuel usage relative to 2022 baseline
CA	✔ 60% RPS by 2030, 100% clean energy by 2045	✔ Coal-fired electricity generation already phased out	✔	✖ CPUC IRP did not allow in recent procurement order	✔ 40% GHG emission reduction below 1990 levels by 2030 and 80% by 2050

Modeling approach involves a three-step process

1. ***With the lower Snake River dams***, **optimize long-term resource needs and operations for the Pacific Northwest**
   - Produces necessary resource additions and total system costs and emissions

2. ***Remove the lower Snake River dam generating capacity, then re-optimize*** **long-term resource needs and operations for the Pacific Northwest**
   - Produces a second set of resource additions and total system costs and emissions
   - All scenarios breach the dams in 2032, except for one scenario in 2024

3. ***Calculate additional resources and investment + operational costs*** **required to replace the dams**
   - Calculated as the difference between steps 1 and 2 above

Key modeling assumptions

Element	Study Approach	Impact on Dams Replacement Needs
Study Years	• 2025 through 2045*, including fuel price forecasts and declining renewable + storage costs	Considers long-term needs
Clean Energy Policy Scenarios	• Aggressive OR+WA legislation reflected, including coal retirements + carbon pricing • Two electric emissions scenarios considered: 1. **100% clean retail sales** (~85% carbon reduction**) 2. **Zero-emissions** (100% carbon reduction)	Clean energy policy requires long-term replacement of LSR dams with GHG-free energy
Load Growth Scenarios	• Two load scenarios: 1. **Baseline** (per NWPCC 8th Power Plan) 2. **High electrification** load growth (to support economy-wide decarbonization) • Significant quantities of energy efficiency are embedded in all scenarios	Higher load scenarios increase the value of LSR dams energy + firm capacity
Reliability Needs	• Modeling ensures reliability needs during extreme conditions (e.g. high loads + low hydro) • Captures ability (and limits) of renewables, battery storage, and demand response to support system reliability	Reliability needs require replacement of LSR dams firm capacity contributions
Technologies Modeled, including "Emerging" Technologies	• Broad range of dam replacement technology options considered: • **Baseline technologies**: solar, wind, battery + pumped storage, energy efficiency, demand response, dual fuel natural gas + hydrogen combustion plants • **Sensitivities** include Emerging Technologies and Limited Technologies (No New Combustion) scenarios • Resource costs developed by E3 using NREL 2021 ATB, Lazard Cost of Storage v.7, NuScale Power (for small modular reactor costs)	Technology available for LSR dams replacement determines replacement cost
Distributed Energy Resource Options	• Energy efficiency, demand response, and customer solar embedded into modeling inputs • Additional energy efficiency and demand response can be selected	Demand resource can help replace LSR dams, though low-cost supply is limited

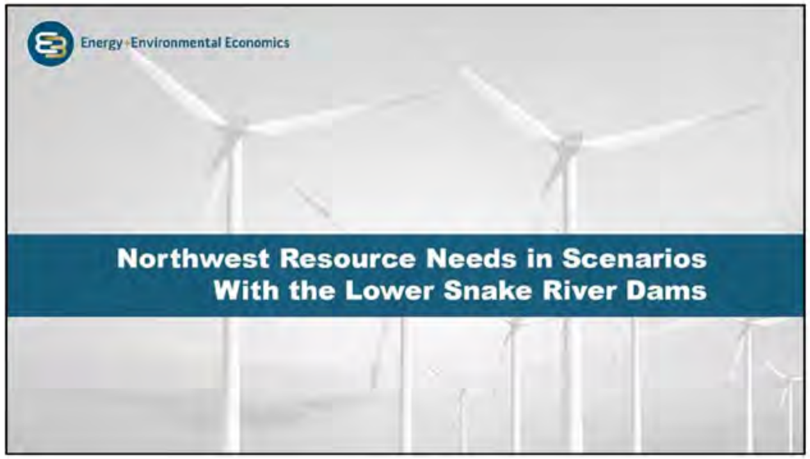
Scenarios

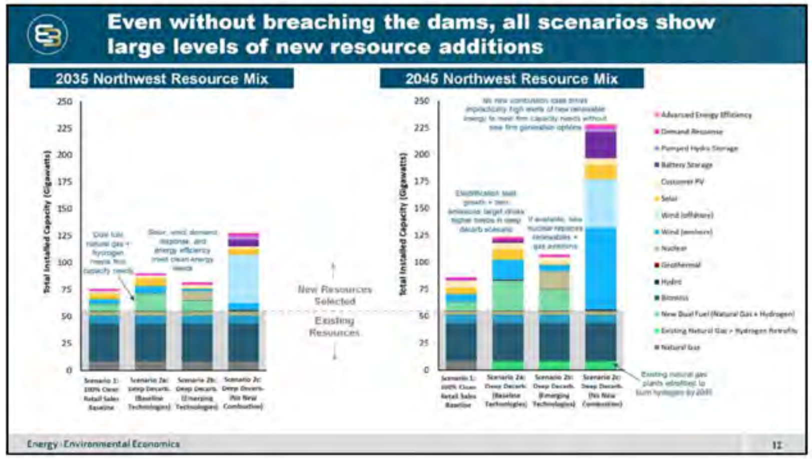
+ **Scenario 1: 100% Clean Retail Sales**
  - Northwest resources produce enough clean energy to meet **100% of retail electricity sales** on an annual average basis
  - Some gas generation is retained for reliability, but carbon emissions are reduced **85% below 1990 levels**
  - **Business-as-usual** load growth
+ **Scenario 2: Deep Decarbonization**
  - **Zero carbon emissions** by 2045
  - **High electrification** of buildings, transportation, and industry to reduce carbon emissions in other sectors
  - **Emerging technologies** become available to provide firm, carbon-free power

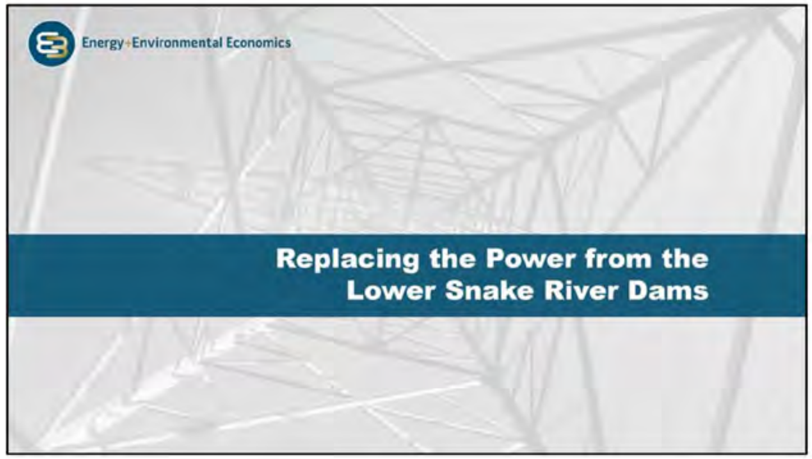
Emerging Technologies

Technology	S1 100% Clean	S2a Deep Decarb Baseline	S2b Deep Decarb Emerging Tech	S2c Deep Decarb No New Combustion
Mature technologies (solar, wind, battery + pumped storage, energy efficiency, demand response)				
Hydrogen (existing natural gas retrofits)				
Hydrogen (new dual fuel (natural gas + hydrogen))				
Nuclear (small modular reactors)				
Natural Gas w/ Carbon Capture and Storage				
Offshore Wind (floating)				

Available
Not available


Energy+Environmental Economics
Northwest Resource Needs in Scenarios
With the Lower Snake River Dams


Even without breaching the dams, all scenarios show large levels of new resource additions
2035 Northwest Resource Mix
2045 Northwest Resource Mix
Total Installed Capacity (Gigawatts)
250
225
200
175
150
125
100
75
50
25
0
New Resources Selected
Existing Resources
Advanced Energy Efficiency
Demand Response
Pumped Hydro Storage
Battery Storage
Customer PV
Solar
Wind (offshore)
Wind (onshore)
Nuclear
Geothermal
Hydro
Biomass
New Dual Fuel (Natural Gas + Hydrogen)
Existing Natural Gas + Hydrogen Retrofits
Natural Gas
Energy+Environmental Economics
12


Energy+Environmental Economics
Replacing the Power from the
Lower Snake River Dams

Replacement resources selected to replace the lower Snake River dams

- RESOLVE selects an optimal portfolio of replacement resources including additional advanced energy efficiency, wind, solar, green hydrogen, and/or advanced nuclear
- Firm capacity is mostly replaced with ~2 GW of dual fuel natural gas + hydrogen turbines
  - These turbines may initially burn natural gas when needed during reliability challenged periods, but would transition to hydrogen by 2045 to reach zero-emissions
- If advanced nuclear is available, it replaces renewables and some of the gas plants
- The "no new combustion" scenario requires impractically large (~12 GW) buildout of renewable energy to replace the dams' firm capacity contributions and GHG-free energy

Scenario	Replacement Resources Selected, Cumulative by 2045 (GW*)
Scenario 1: 100% Clean Retail Sales	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
Scenario 2a: Deep Decarb. (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW advanced energy efficiency + additional H2 generation**
Scenario 2b: Deep Decarb. (Emerging Technologies)	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR
Scenario 2c: Deep Decarb. *(No New Combustion)*	+ 10.6 GW wind + 1.4 GW solar

* 1 GW = 1,000 MW
** Replacing LSR dams GHG-free energy at least-cost leads RESOLVE to generate an additional 1.2 TWh of hydrogen generation during low renewable conditions (or 0.14 average GW)

Total costs for replacing the lower Snake River dams

+ Costs are expected to fall on Bonneville Power Administration's public power customers

- Costs could **increase public power retail costs** by 8-18%, or up to 65% absent emerging technologies
- Costs could **raise annual residential electricity bills** by up to $100-230/year, or up to $850/yr absent emerging technologies

	Total Costs (real 2022 $)	Annual Cost Increase (real 2022 $)			Incremental Public Power Costs [% increase vs. ~8.5 cents/kWh NW average retail rates]
	Net Present Value in year of breaching	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$9.7 billion	[illegible]	$434 million	$478 million	0.8 cents/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$11.7 billion	$485 million	$460 million	$589 million	0.8 cents/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$15.1 billion	[illegible]	$496 million	$860 million	1.5 cents/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$8.7 billion	[illegible]	$415 million	$428 million	0.7 cents/kWh [+8%]
Scenario 2c: Deep Decarb. (No New Combustion)	*$81 billion*	n/a	*$1,853 million*	*$3,199 million*	*5.5 cents/kWh [+65%]*

Deep decarbonization without emerging technologies drives impractically high costs

Cost differences driven primarily by 2045 carbon policy and availability of emerging technologies

Costs increase over time as loads grow and carbon policy becomes more stringent

- Cost increases account for replacement energy, capacity, and reserves as well as avoided LSR capital + expense, but do not include any costs for breaching the dams, which would be an additional cost.
- NPV and annual cost increase are shown for the Northwest Region as a whole, but the incremental costs are calculated relative to the BPA Tier I annual sales for public power customers. NPV calculations use a 3% discount rate per public power cost of capital.
- % increase versus average retail rates assumes ~8.5 cents/kWh retail rates (estimated from OR and WA average retail rates). This does not include additional rate increases driven by higher loads or clean energy needs that increase regional rates as shown in the earlier 2045 incremental cost chart.
- Annual residential customer cost impact assumes 1,280 kWh/month for average residential customers in Oregon and Washington (current ~1,000 kWh/month average + 28% from electrification load growth).
- New federal tax credits for hydrogen plants/fuels or ITC/PTC extension for renewables would provide a cost reduction to public power customers from taxpayers.

Cost of generation for lower Snake River dams replacement resources (using common utility metric of $/MWh)

+ **The lower Snake River dams provide a low-cost source of GHG-free energy and firm capacity**
+ **Even in a best-case scenario, replacement power would cost several times as much as the lower Snake River dams costs**
  - This is driven by both energy replacement as well as replacement of firm capacity and operational flexibility
+ **Compared to ~$13-17/MWh for the lower Snake River dams, replacement resources cost between $77-139/MWh**
  - Replacement costs rise to over $500/MWh in a deep decarbonization scenario absent emerging technology

Incremental LSR Dam Replacement Resource Costs

Lower Snake River Dams All-in Generation Costs (2022 $/MWh)
$13/MWh w/o LSRCP*
$17/MWh w/ LSRCP*

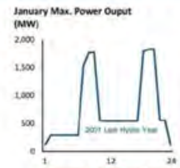
Scenario	2045 Costs to replace LSR Generation** (real 2022 $/MWh)
S1: 100% Clean Retail Sales	$77/MWh
S1b: 100% Clean Retail Sales (2024 dam breaching)	$82/MWh
S2a: Deep Decarb	$139/MWh
S2b: Deep Decarb, w/ Emerging Tech	$89/MWh
S2c: Deep Decarb, Limited Tech (no new combustion)	$517/MWh

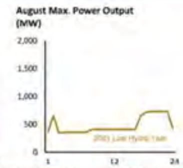
* BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) fish hatcheries and satellite facilities. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat 2917) to offset fish and wildlife losses caused by construction and operation of the four lower Snake River projects.

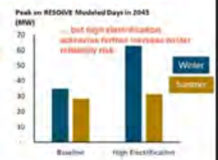
** Replacement $/MWh costs are calculated as CoreNW revenue requirement increase with LSR dams breached divided by the annual MWh of the LSR dams assumed in E3's modeling (~700 aMW). These costs includes replacement of the LSR dam energy, capacity, and reserve provision. A significant portion of the costs is capacity costs to replace the dams' RA capacity contributions.

Firm capacity value of the lower Snake River dams

- The firm capacity value is a significant driver of replacements costs
- PNUCC 2021 estimate of NW hydro sustained peaking capacity was used for the lower Snake River dams' firm capacity value (65% or 2.3 GW)
- E3 also analyzed modeled hourly LSR dam output during the 2001 low hydro year (using BPA data post EIS spill requirements)
  - Suggests a winter firm capacity value of ~56-60%
- E3 predicts a continued concentration of risk in the winter in deep decarbonization scenarios with high space heating electrification
  - However, in a system with higher summer reliability risk, the LSR firm capacity value would be lower
  - E3 estimates the impact of a lower firm capacity value for S1 and S2a scenarios to be:
    - 1.5 GW firm capacity value (43%) → ~9-20% lower NPV replacement cost
    - 1.0 GW firm capacity value (29%) → ~14-33% lower NPV replacement cost







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Key conclusions

1. **Replacing the four lower Snake River dams comes at a substantial cost, even assuming emerging technologies are available**
   - Require 2,300 – 2,700 MW of replacement resources
   - An annual cost of $415 million – $860 million by 2045*
   - Total net present value replacement cost of $8.7 – 15.1 billion from 2032-2065
   - Increase in costs for public power customers of $100 – 230 per household per year (an 8 – 18% increase) by 2045
2. **The biggest cost drivers for replacement resources are the need to replace the lost firm capacity and the need to replace the lost zero-carbon energy**
3. **Replacement resources become more costly over time due to increasingly stringent clean energy standards and electrification-driven load growth**
4. **Emerging technologies such as hydrogen, advanced nuclear, and carbon capture can limit the cost of replacement resources to meet a zero emissions electric system, but the pace of their commercialization is highly uncertain**
   - Replacing the dams in deep decarbonization scenarios without any emerging technologies requires impractical levels of renewable additions at a very high cost ($61 billion NPV cost)

* Replacement resource costs are calculated assuming project financing per E3's pro forma calculator, rather than assuming upfront congressional appropriation

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Thank you

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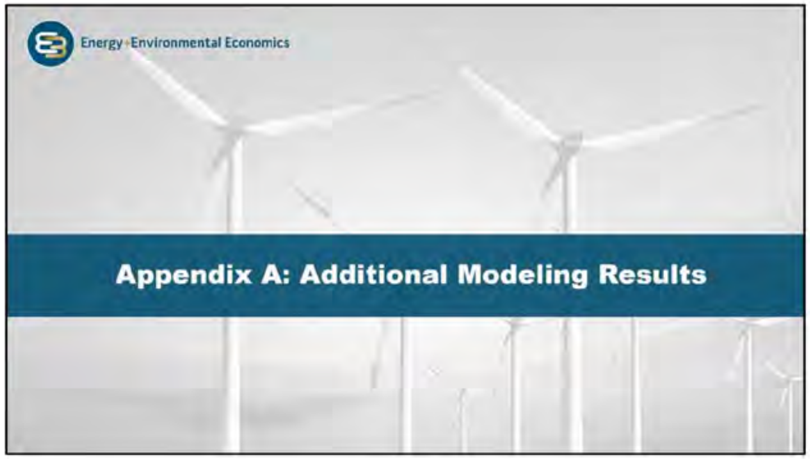
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Appendix A: Additional Modeling Results