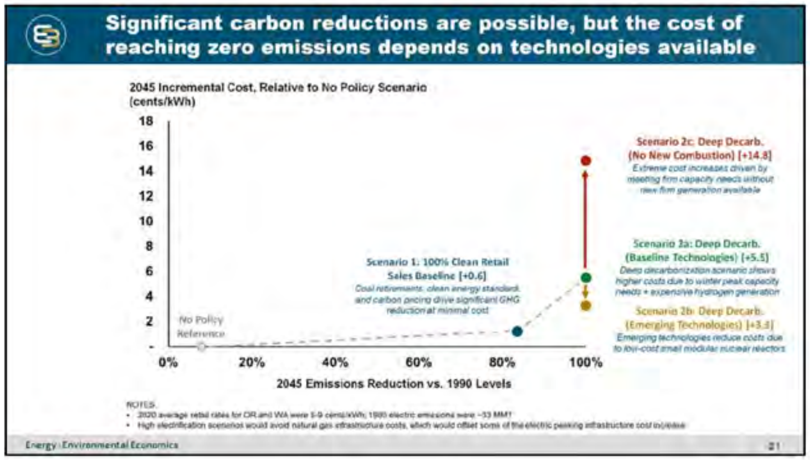
Significant carbon reductions are possible, but the cost of reaching zero emissions depends on technologies available



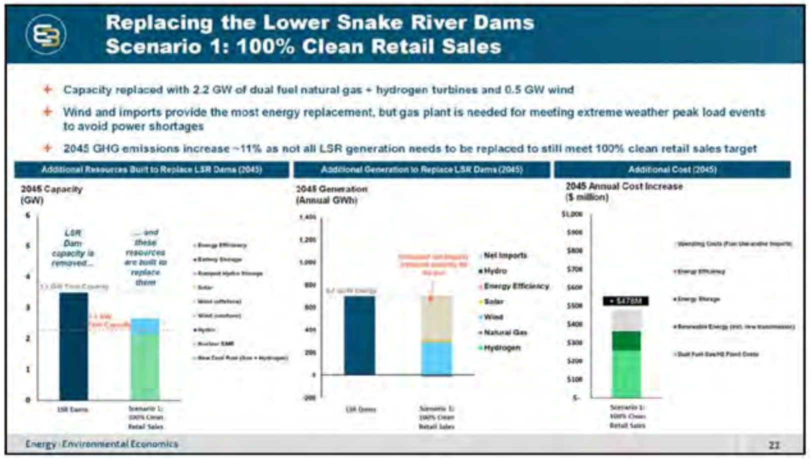
Scenario 1: 100% Clean Retail Sales Baseline [+0.6]
Coal retirements, clean energy standard, and carbon pricing drive significant GHG reduction at minimal cost

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

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



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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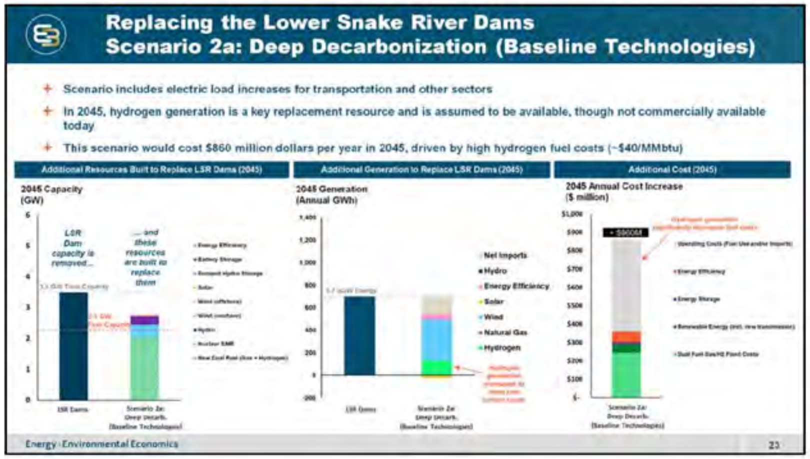


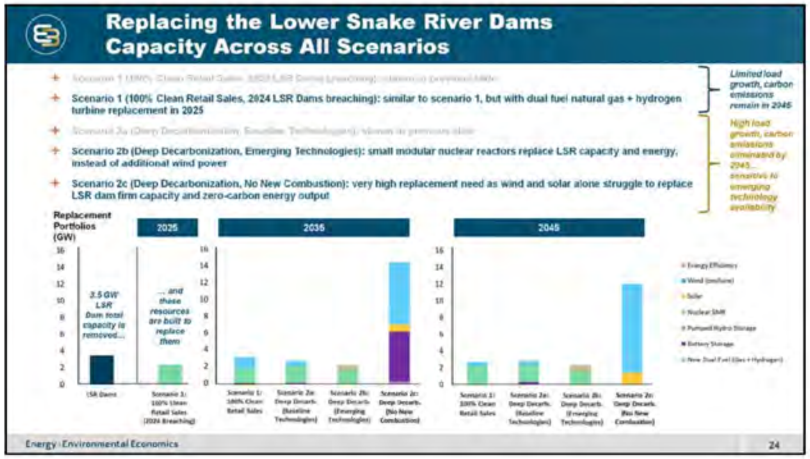
Replacing the Lower Snake River Dams
Scenario 2a: Deep Decarbonization (Baseline Technologies)

- 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)



Replacing the Lower Snake River Dams Capacity Across All Scenarios

- Scenario 1 (100% Clean Retail Sales, [illegible] 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

3.5 GW LSR Dam total capacity is removed...

... and these resources are built to replace them

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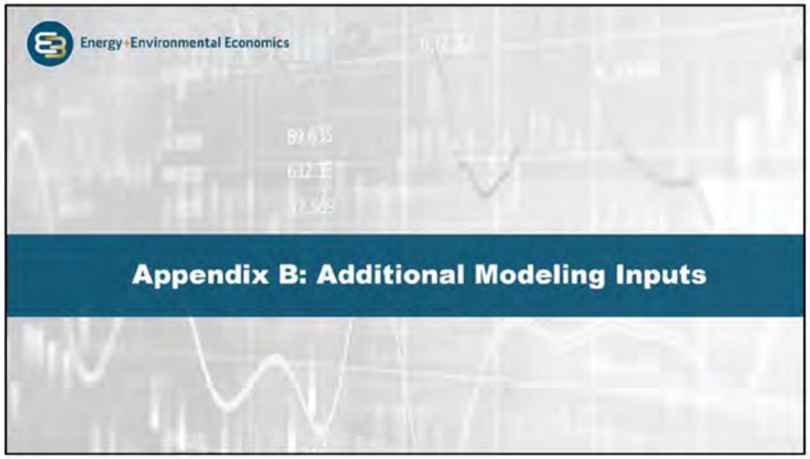

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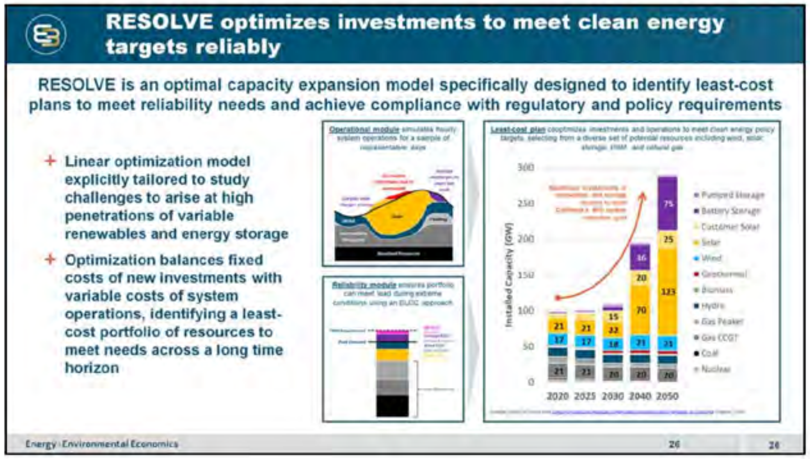
Appendix B: Additional Modeling Inputs



RESOLVE optimizes investments to meet clean energy targets reliably

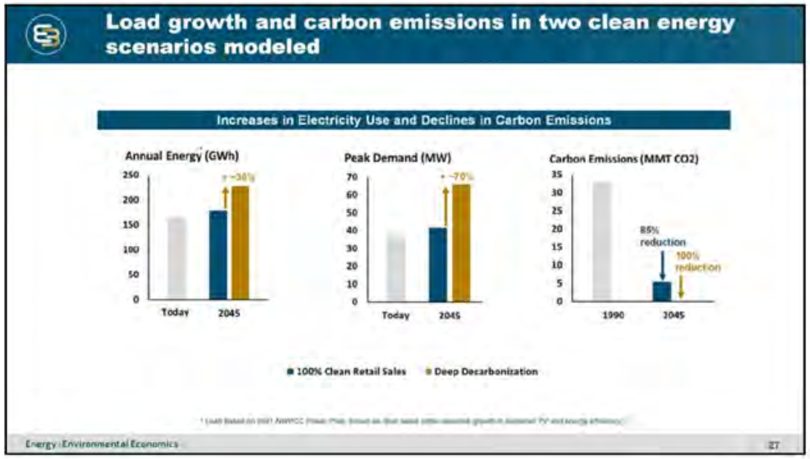
RESOLVE is an optimal capacity expansion model specifically designed to identify least-cost plans to meet reliability needs and achieve compliance with regulatory and policy requirements

- 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

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

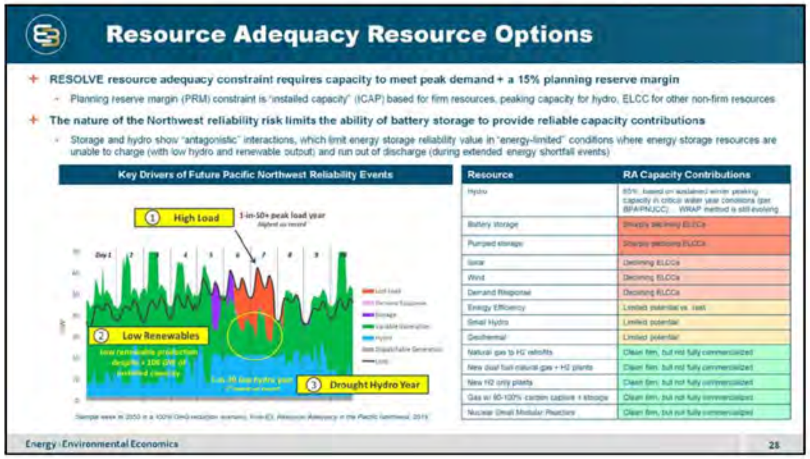
Reliability module ensures portfolio can meet load during extreme conditions using an ELCC approach

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



Load growth and carbon emissions in two clean energy scenarios modeled

Increases in Electricity Use and Declines in Carbon Emissions



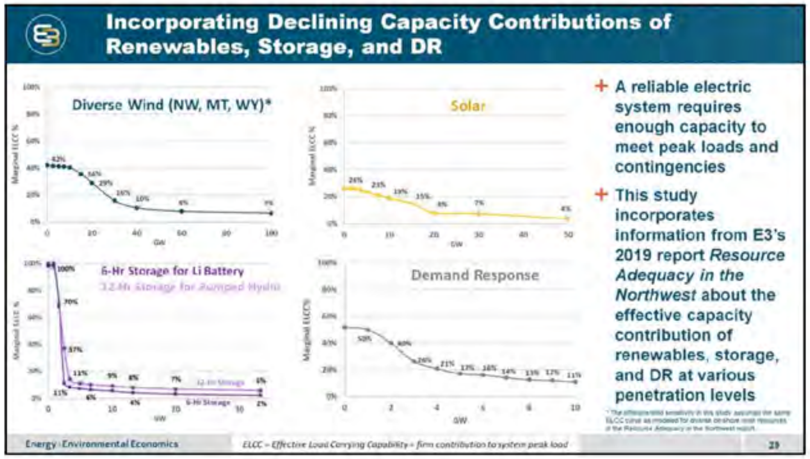
Resource Adequacy Resource Options

- **RESOLVE resource adequacy constraint requires capacity to meet peak demand + a 15% planning reserve margin**
  - 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

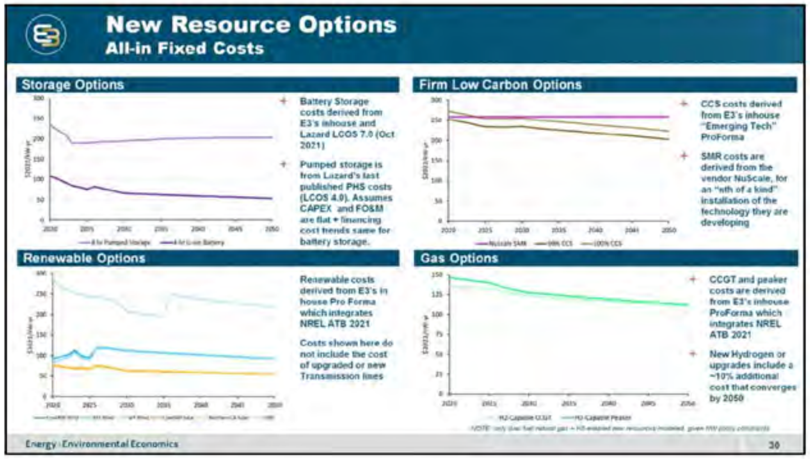
Resource	RA Capacity Contributions
Hydro	85%, based on sustained winter peaking capacity in critical water year conditions (per BPA/PNUCC). WRAP method is still evolving
Battery storage	Sharply declining ELCCs
Pumped storage	Sharply declining ELCCs
Solar	Declining ELCCs
Wind	Declining ELCCs
Demand Response	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

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

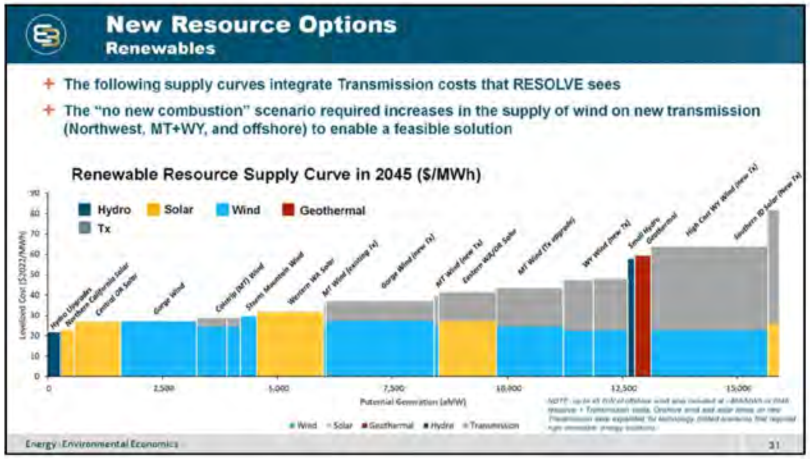
Renewable costs derived from E3's in house Pro Forma which integrates NREL ATB 2021

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 [illegible] 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

Renewable Resource Supply Curve in 2045 ($/MWh)

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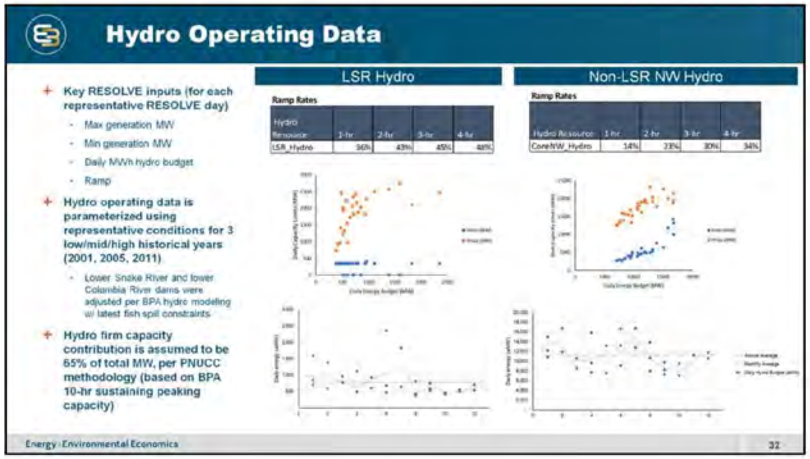

Hydro Operating Data

- 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 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%

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BPA Lower Snake River Dams Power Replacement

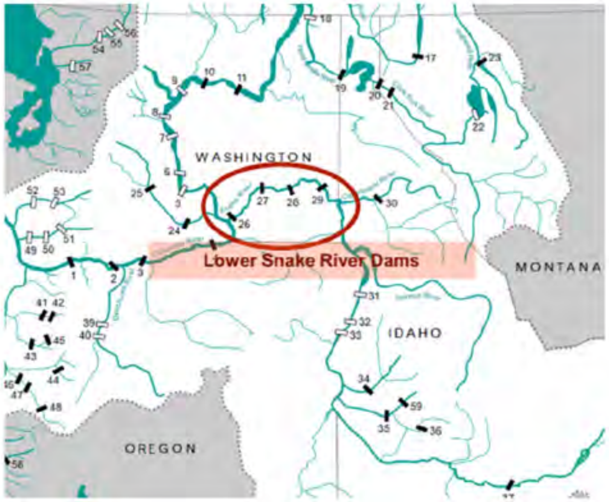
Executive Summary

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 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
  - **~700-900** 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 **$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 **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

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* 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 using a 5% discount rate representative of independent power producer owned/financed replacement resources sold through PPAs

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Study Approach

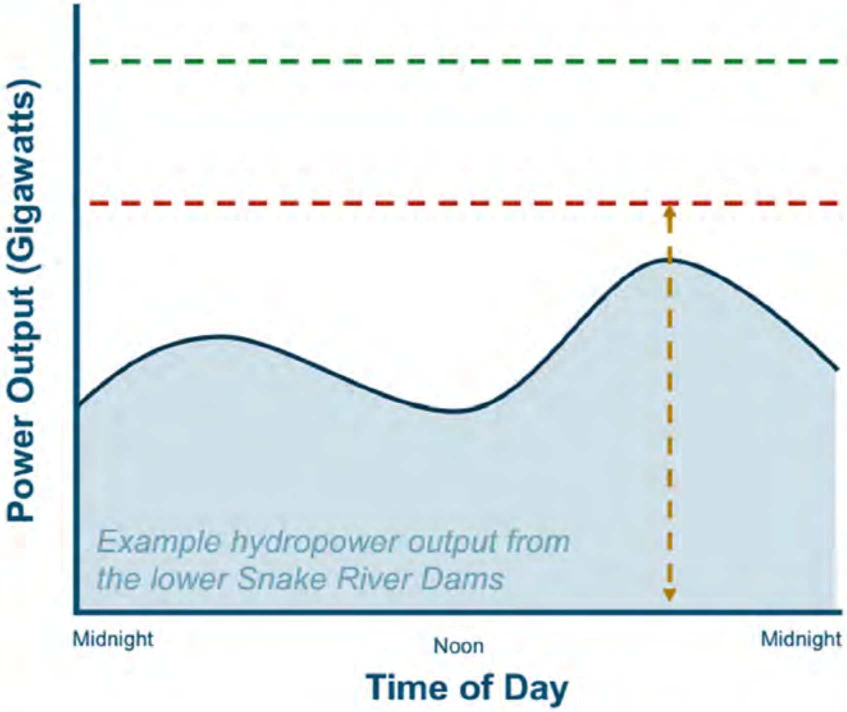
What grid services do the lower Snake River dams provide?

Little Goose

Lower Granite

Lower Monumental

Ice Harbor



Total "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 = 2.3 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
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

Transmission Grid Reliability Services
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

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* 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 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

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)	🟩	🟩	🟩	🟩
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

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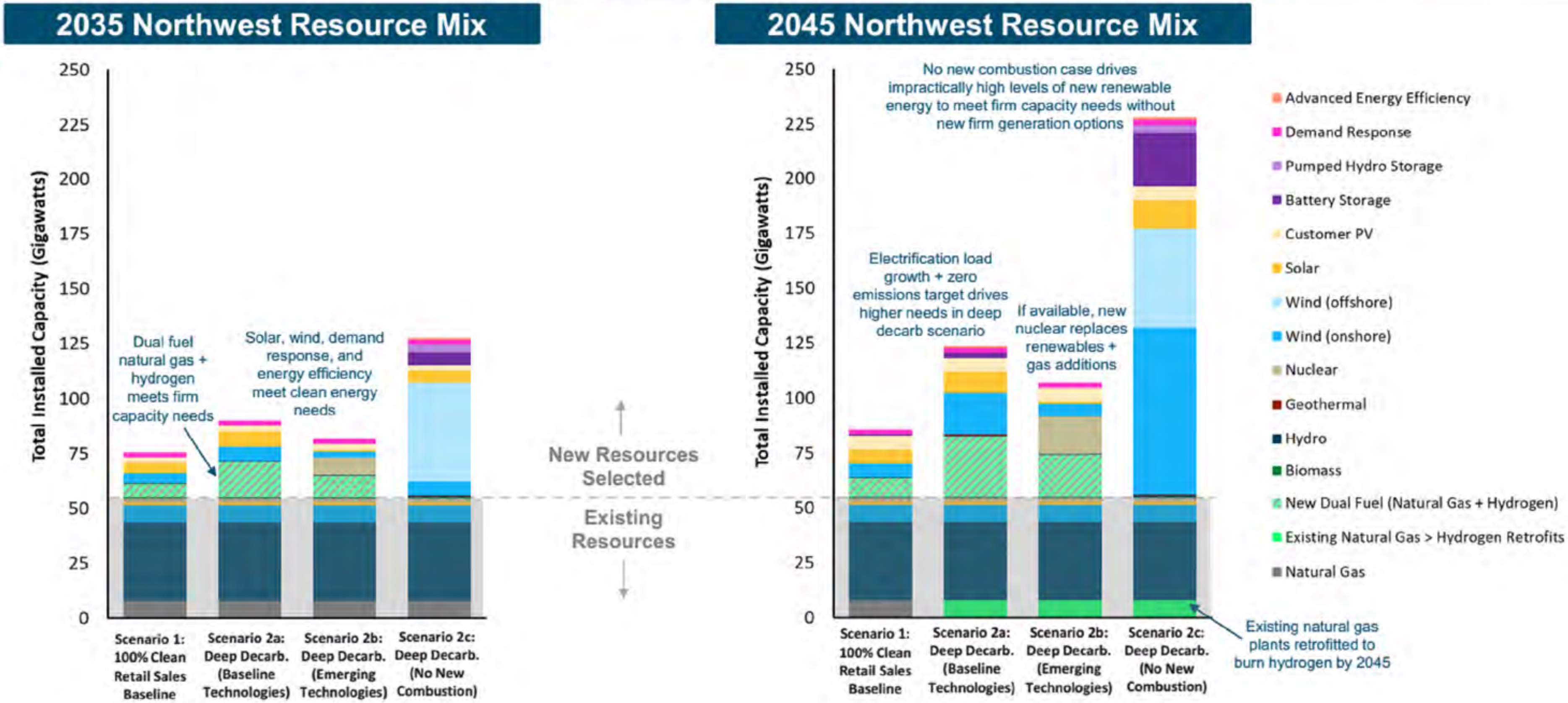
Northwest Resource Needs in Scenarios With the Lower Snake River Dams

Even without breaching the dams, all scenarios show large levels of new resource additions



Dual fuel natural gas + hydrogen meets firm capacity needs

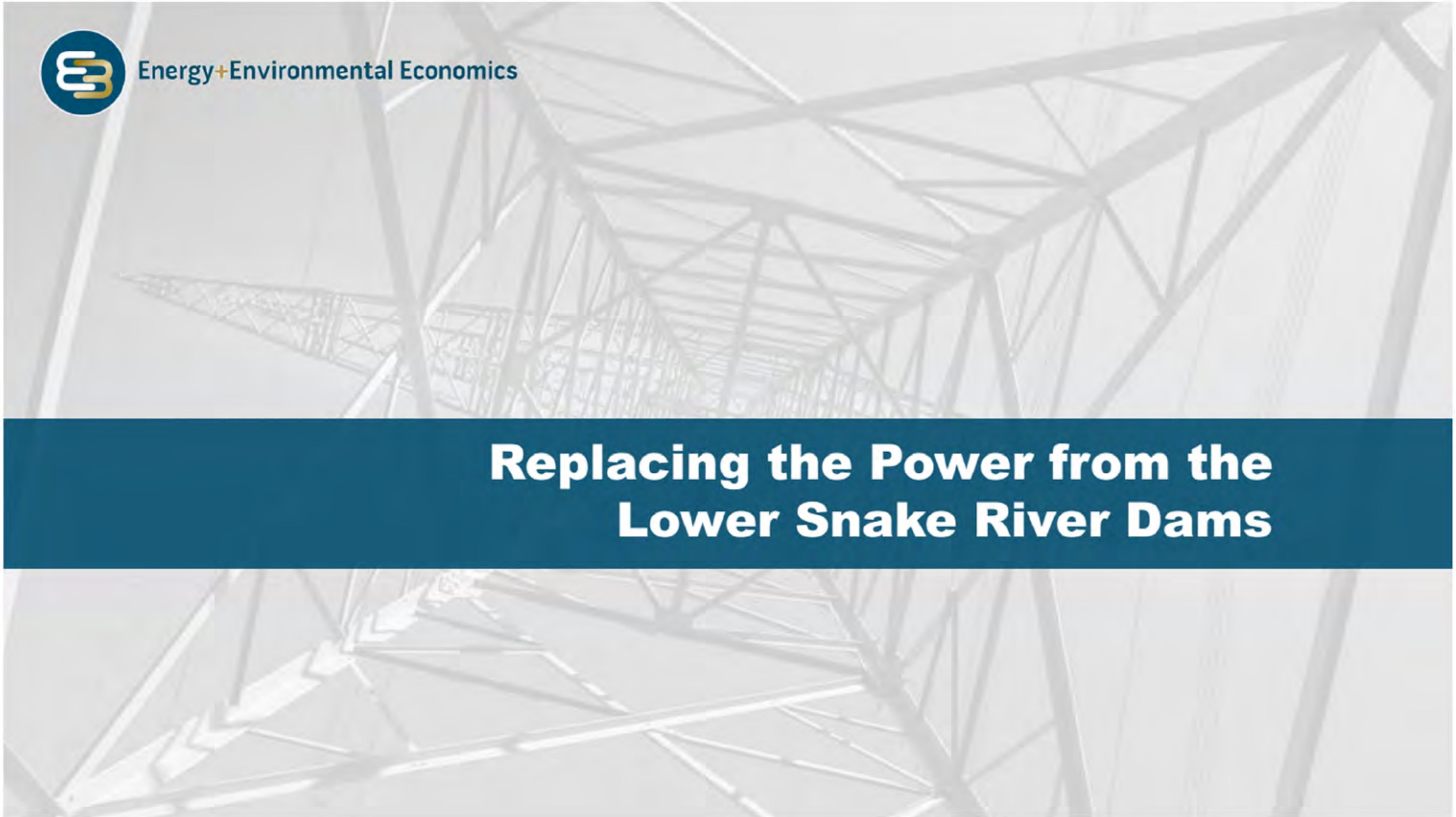
Solar, wind, demand response, and energy efficiency meet clean energy needs

No new combustion case drives impractically high levels of new renewable energy to meet firm capacity needs without new firm generation options

Electrification load growth + zero emissions target drives higher needs in deep decarb scenario

If available, new nuclear replaces renewables + gas additions

Existing natural gas plants retrofitted to burn hydrogen by 2045



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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	$9.7 billion	n/a	$434 million	$478 million	0.8 cents/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$11.7 billion	$495 million	$466 million	$509 million	0.8 cents/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$15.1 billion	n/a	$496 million	$860 million	1.5 cents/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$8.7 billion	n/a	$415 million	$428 million	0.7 cents/kWh [+8%]
Scenario 2c: Deep Decarb. *(No New Combustion)*	*$61 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 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*

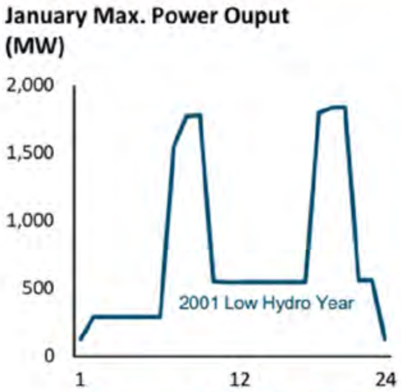
Scenario	2045 Costs to replace LSR Generation** (real 2022 $/MWh)
S1: 100% Clean Retail Sales	$77/MWh
S1b: 100% Clean Retail Sales (2024 dam breaching)	$82/MWh
S2a: Deep Decarb	$139/MWh
S2b: Deep Decarb, w/ Emerging Tech	$69/MWh
S2c: Deep Decarb, Limited Tech (no new combustion)	$517/MWh

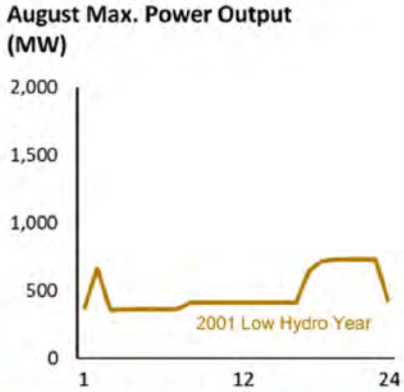
* BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) fish hatcheries and satellite facilities. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat.2917) to offset fish and wildlife losses caused by construction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

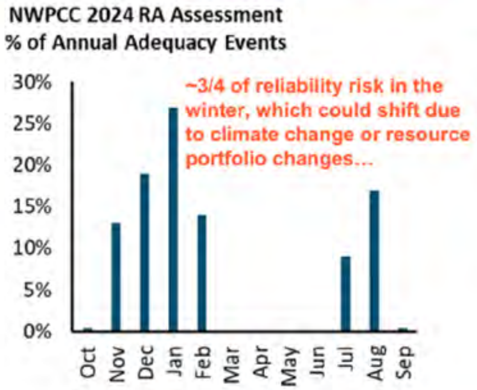
Firm capacity value of the lower Snake River dams

- **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

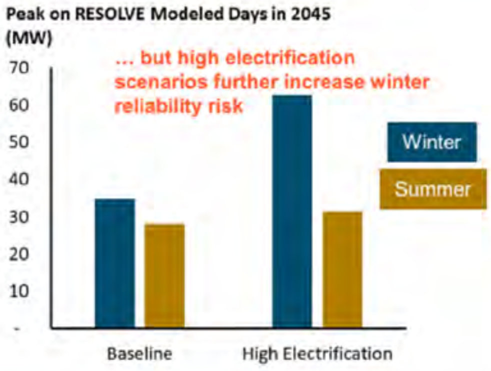

January Max. Power Ouput (MW)


August Max. Power Output (MW)

Assuming the Northwest remains winter reliability challenged, LSR Dams could have contributed ~56-60% of total capacity or 1.9-2.1 GW* in the 2001 low hydro year


NWPCC 2024 RA Assessment
% of Annual Adequacy Events

~3/4 of reliability risk in the winter, which could shift due to climate change or resource portfolio changes…


Peak on RESOLVE Modeled Days in 2045 (MW)

… but high electrification scenarios further increase winter reliability risk

* Includes 100-250 MW reserve provision on top of maximum power output

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

Energy+Environmental Economics

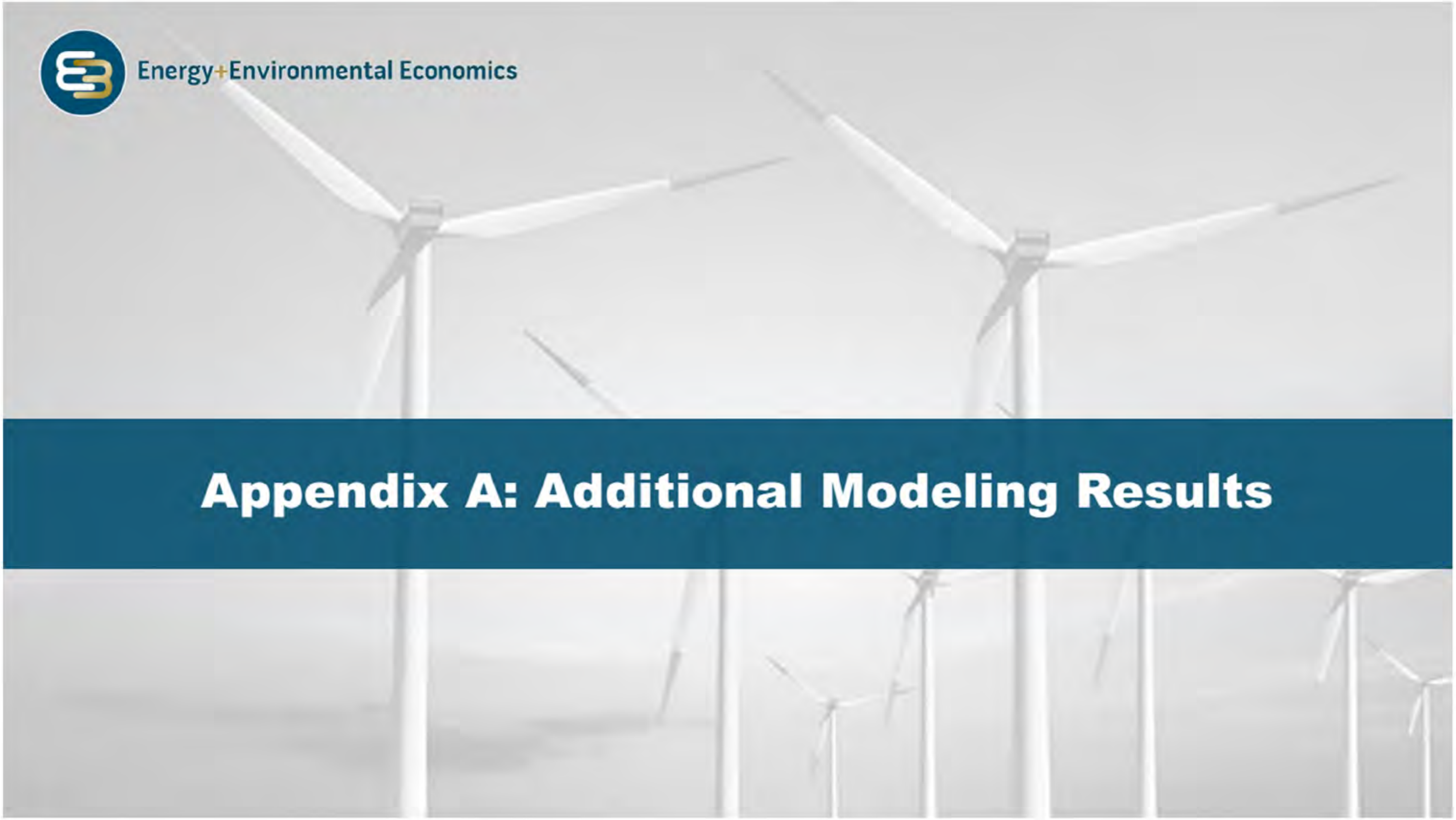
Thank you

Questions, please contact:

Arne Olson, arne@ethree.com

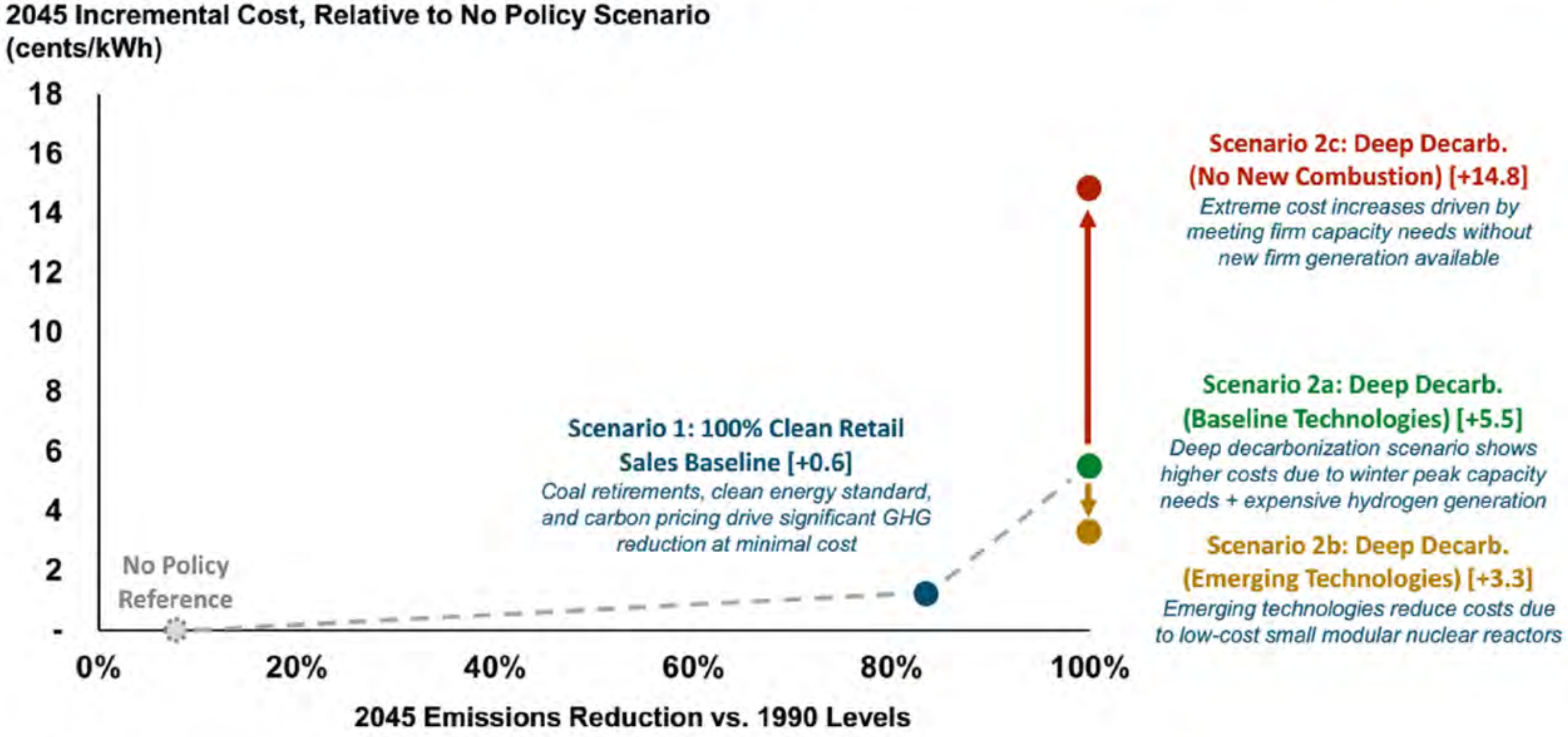
Aaron Burdick, aaron.burdick@ethree.com

Energy+Environmental Economics



Appendix A: Additional Modeling Results

Significant carbon reductions are possible, but the cost of reaching zero emissions depends on technologies available



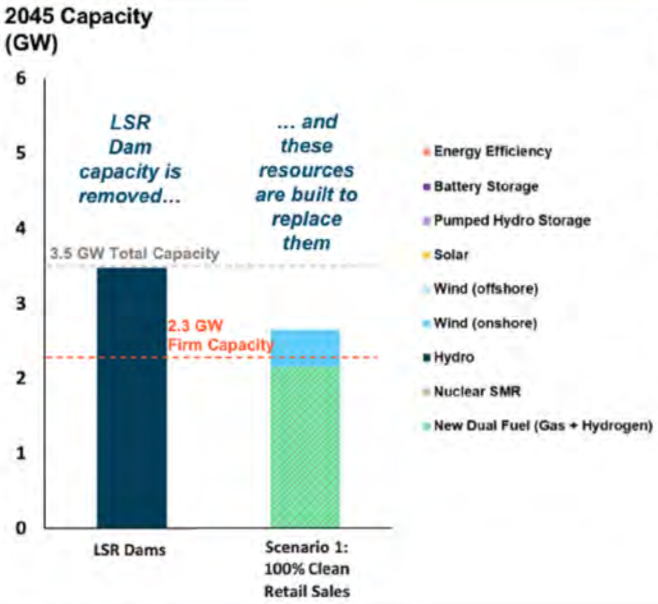
NOTES:

- 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

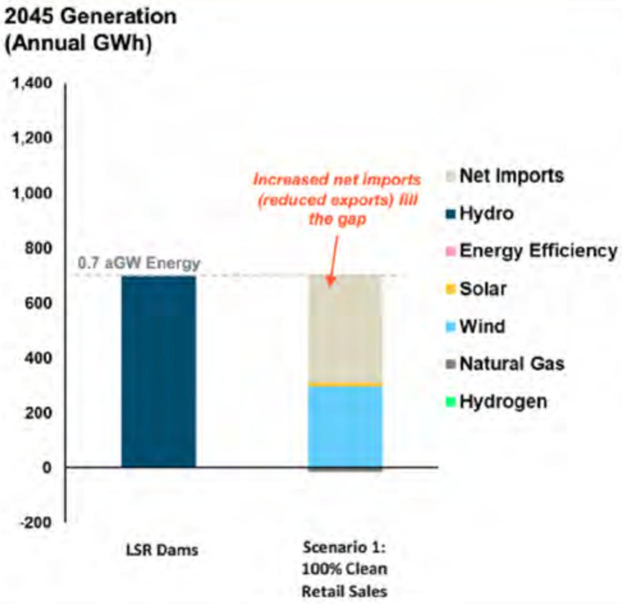
Replacing the Lower Snake River Dams
Scenario 1: 100% Clean Retail Sales

- 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

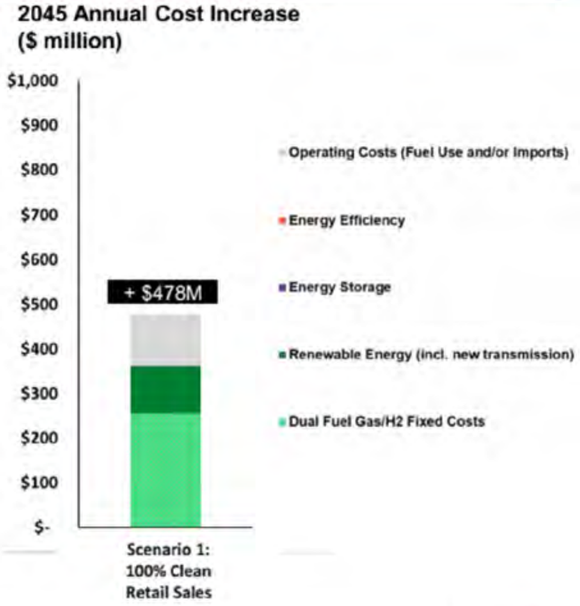
Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)



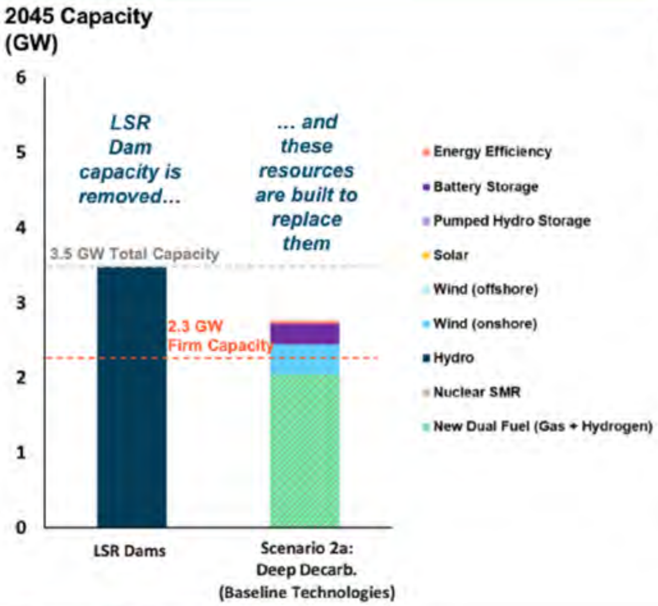
Additional Cost (2045)



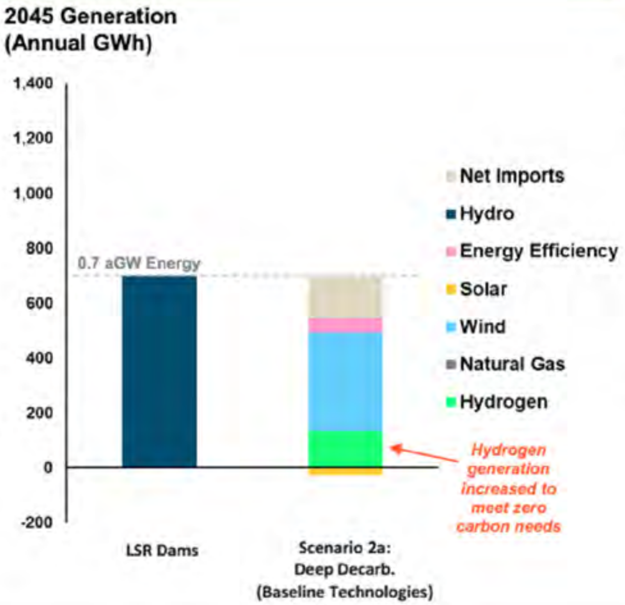
Replacing the Lower Snake River Dams
Scenario 2a: Deep Decarbonization (Baseline Technologies)

- 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)

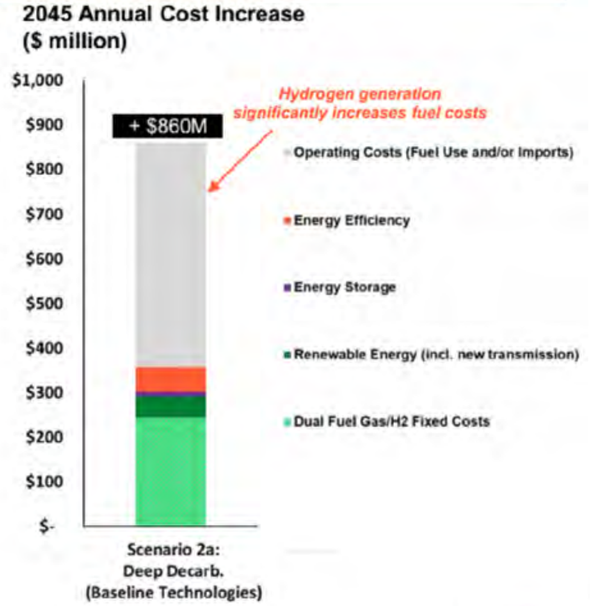
Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)



Additional Cost (2045)

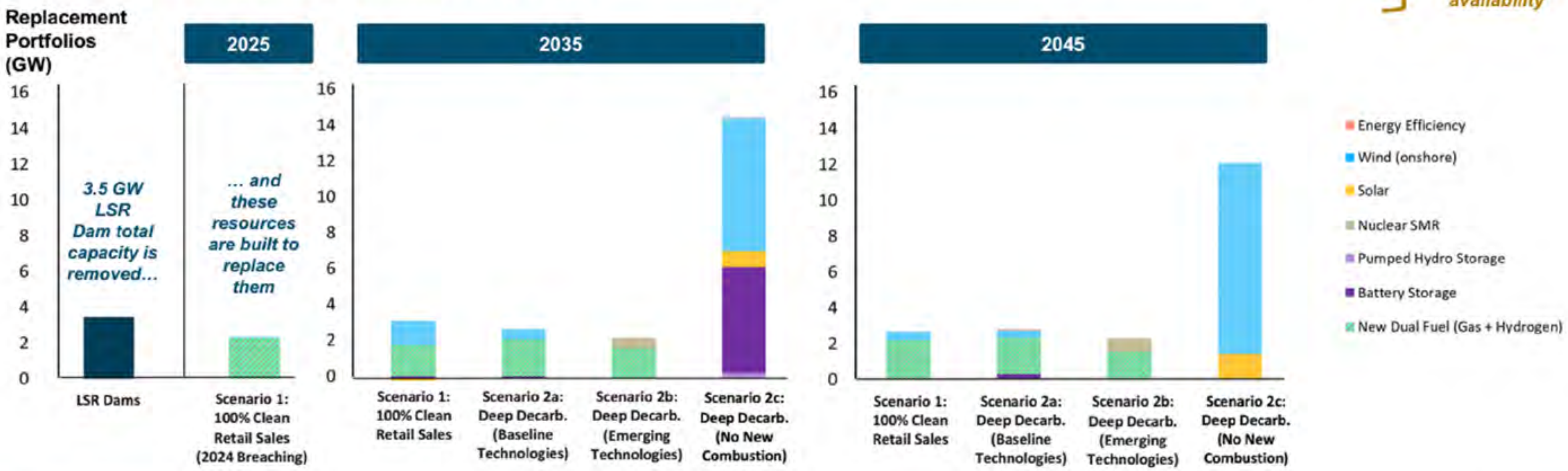


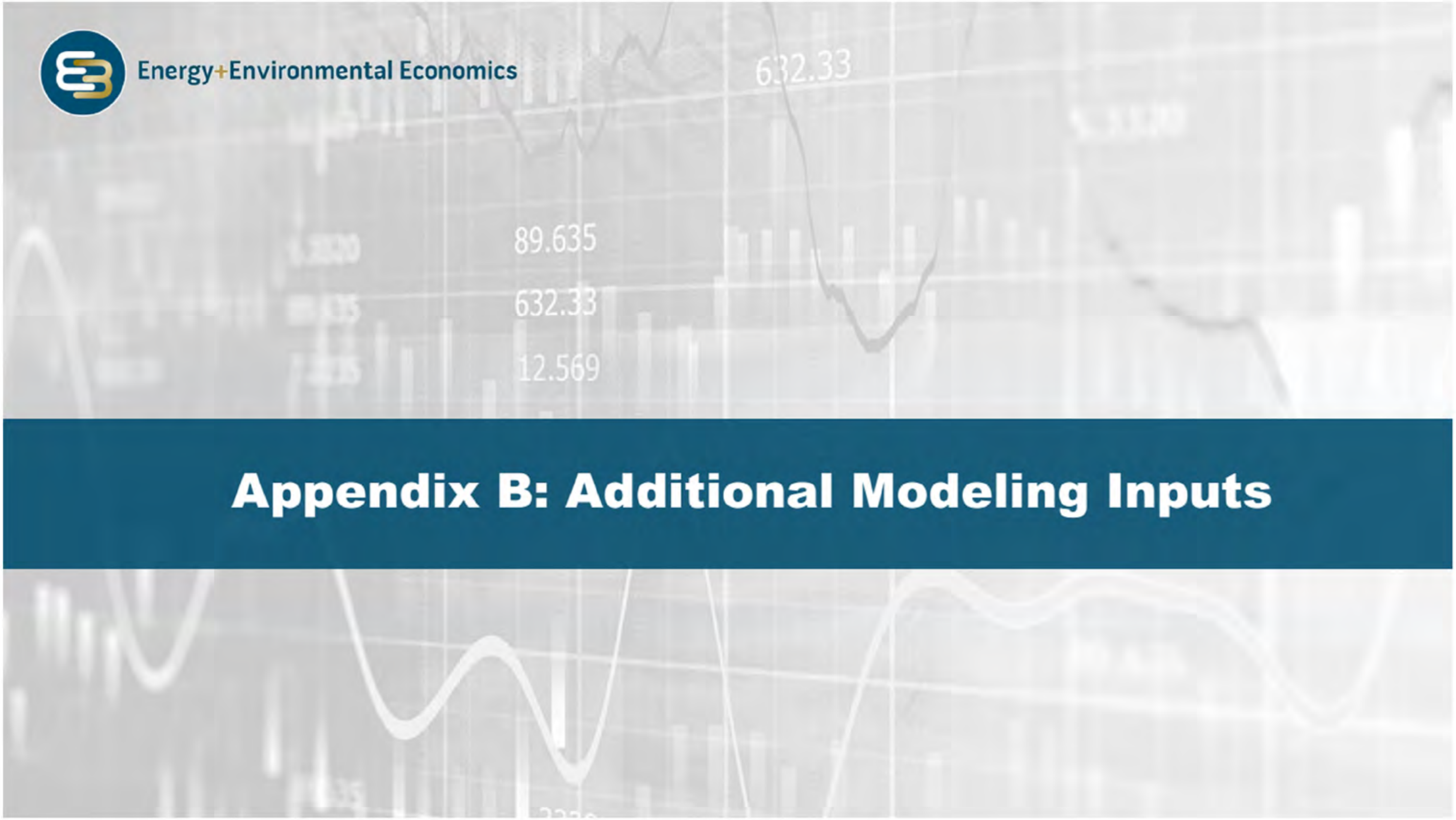
Replacing the Lower Snake River Dams Capacity Across All Scenarios

- 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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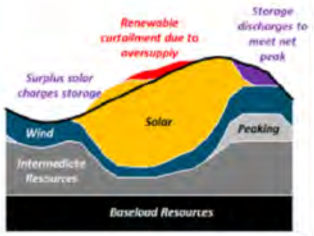
Appendix B: Additional Modeling Inputs

RESOLVE optimizes investments to meet clean energy targets reliably

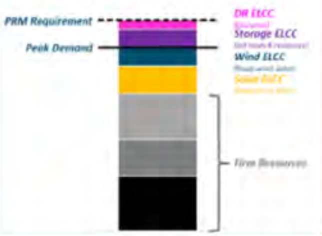
RESOLVE is an optimal capacity expansion model specifically designed to identify least-cost plans to meet reliability needs and achieve compliance with regulatory and policy requirements

- **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**

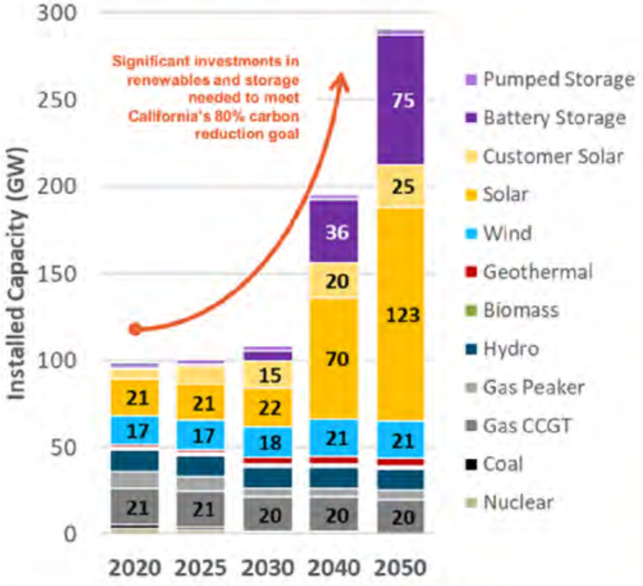
Operational module simulates hourly system operations for a sample of representative days



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



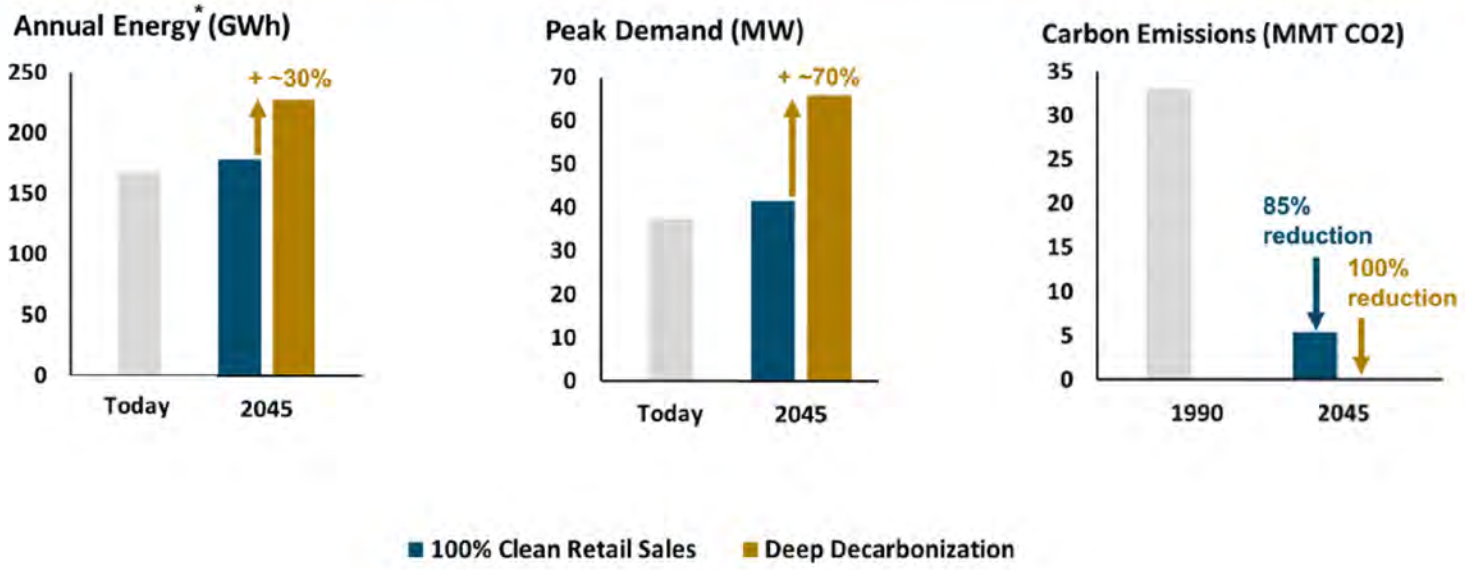
Least-cost plan cooptimizes investments and operations to meet clean energy policy targets, selecting from a diverse set of potential resources including wind, solar, storage, DSM, and natural gas



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

Load growth and carbon emissions in two clean energy scenarios modeled

Increases in Electricity Use and Declines in Carbon Emissions

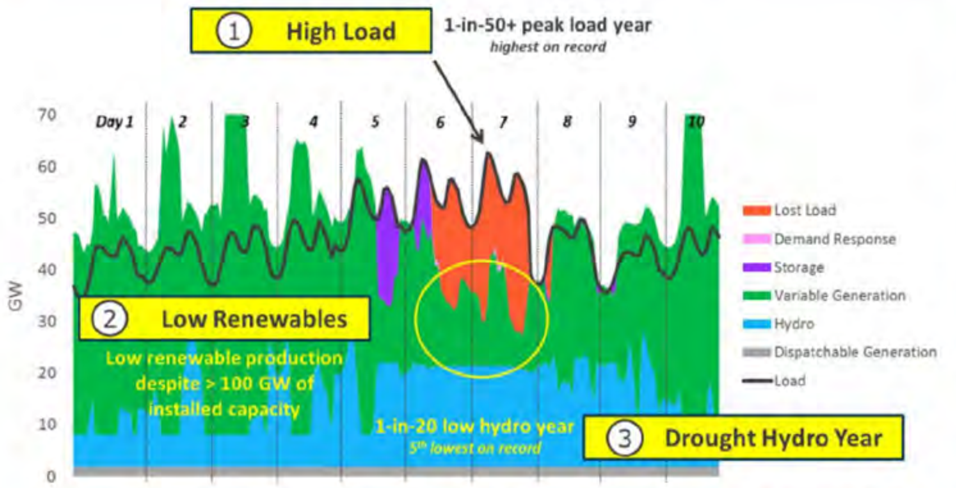


* Load based on 2021 NWPCC Power Plan, shown as retail sales (after assumed growth in customer PV and energy efficiency)

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)

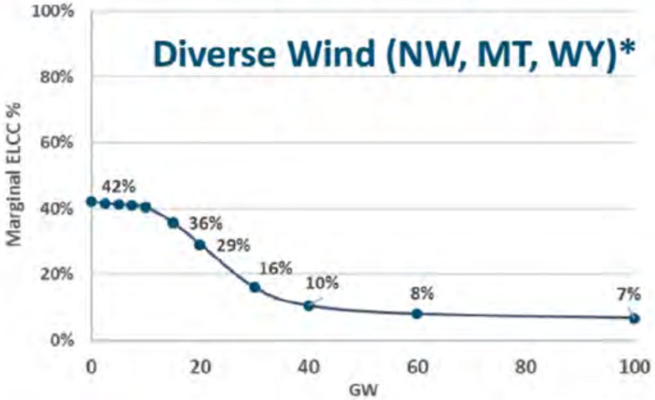
Key Drivers of Future Pacific Northwest Reliability Events

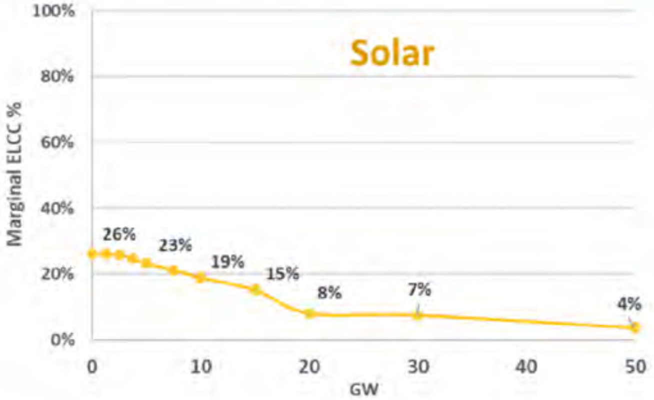


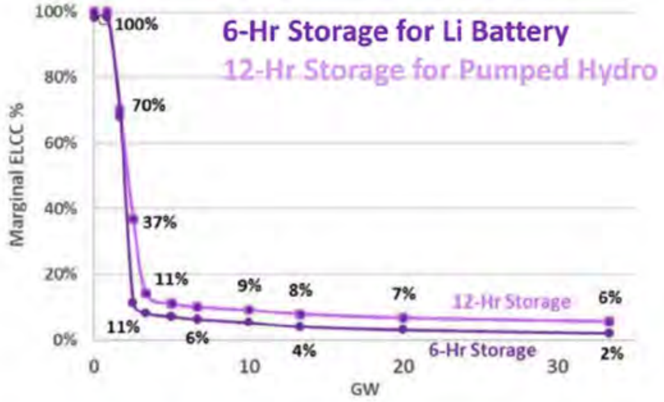
Sample week in 2050 in a 100% GHG reduction scenario, from E3, *Resource Adequacy in the Pacific Northwest*, 2019.

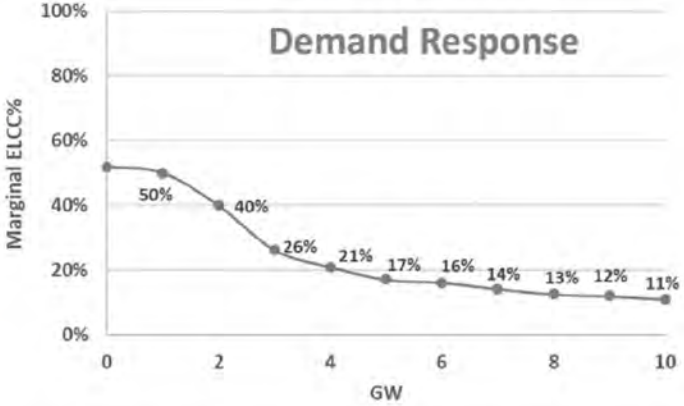
Resource	RA Capacity Contributions
Hydro	65%, based on sustained winter peaking capacity in critical water year conditions (per BPA/PNUCC)... WRAP method is still evolving
Battery storage	Sharply declining ELCCs
Pumped storage	Sharply declining ELCCs
Solar	Declining ELCCs
Wind	Declining ELCCs
Demand 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

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

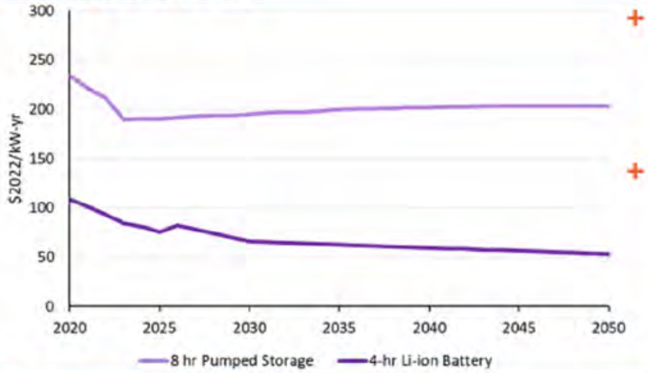
* The offshore wind sensitivity in this study assumed the same ELCC curve as modeled for diverse on-shore wind resources in the Resource Adequacy in the Northwest report.

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

New Resource Options

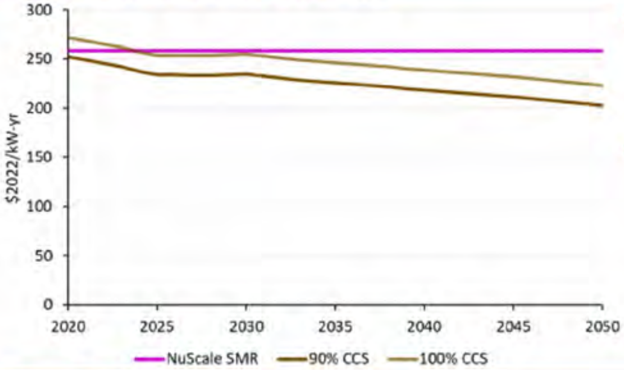
All-in Fixed Costs

Storage Options



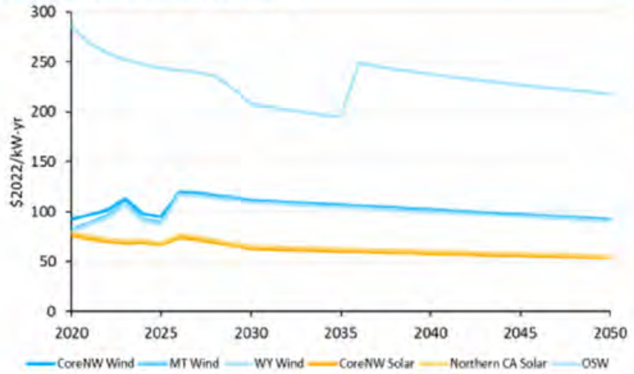
- Battery Storage costs derived from E3's inhouse and Lazard LCOS 7.0 (Oct 2021)
- Pumped storage is from Lazard's last published PHS costs (LCOS 4.0). Assumes CAPEX and FO&M are flat + financing cost trends same for battery storage.

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

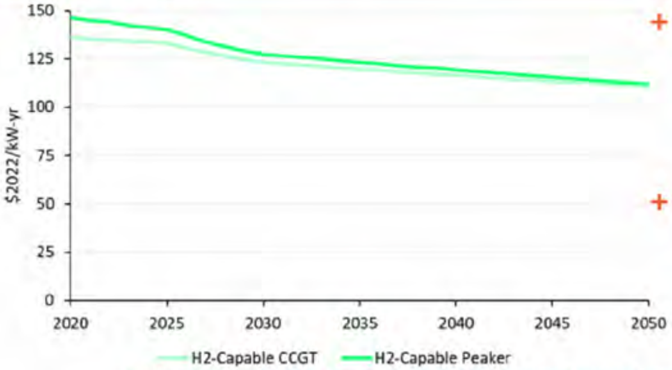
Renewable Options



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



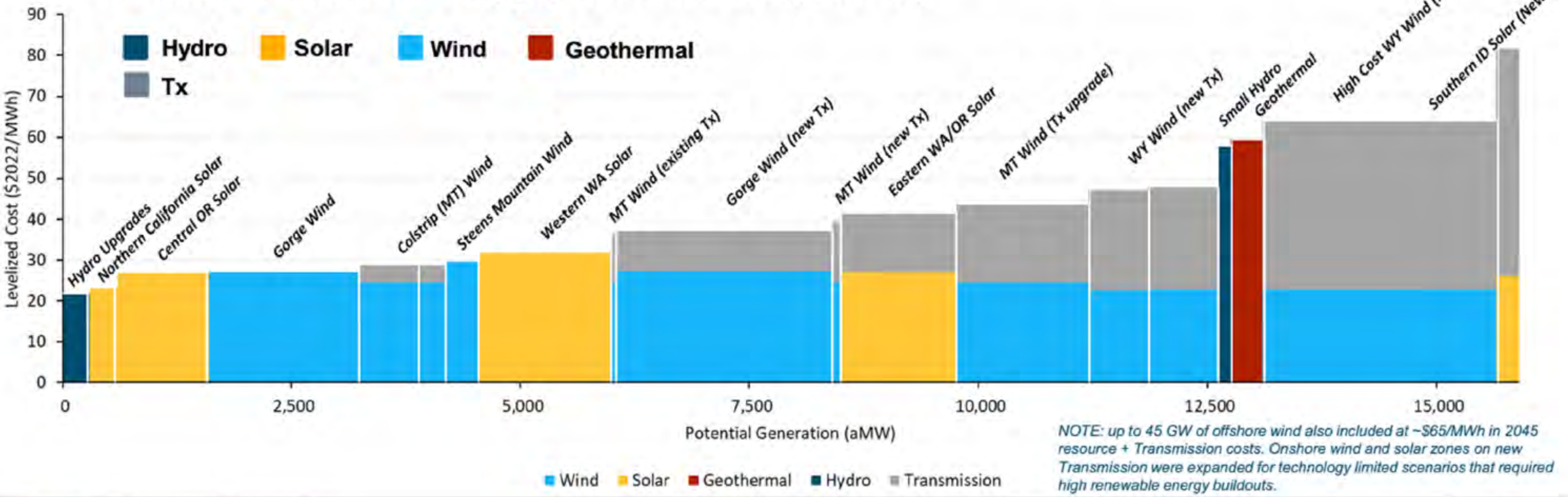
- CCGT and peaker costs are derived from E3's inhouse ProForma which integrates NREL ATB 2021
- New Hydrogen or upgrades include a ~10% additional cost that converges by 2050

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

Renewable Resource Supply Curve in 2045 ($/MWh)



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.

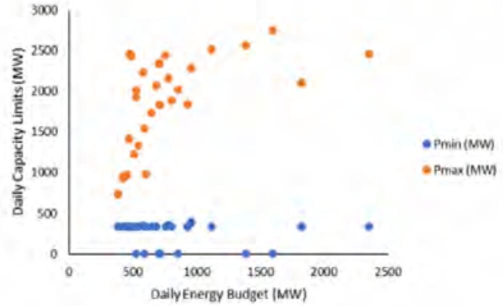
Hydro Operating Data

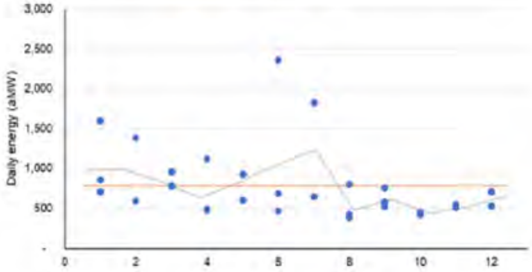
- **Key RESOLVE inputs (for each representative RESOLVE day)**
  - Max generation MW
  - Min generation MW
  - Daily MWh hydro budget
  - Ramp
- **Hydro operating data is parameterized using representative conditions for 3 low/mid/high historical years (2001, 2005, 2011)**
  - Lower Snake River and lower 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%

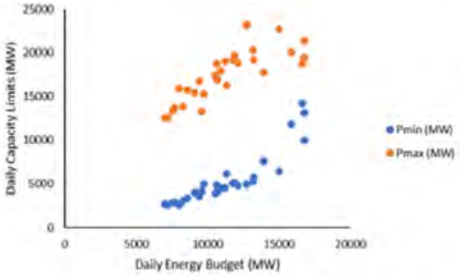


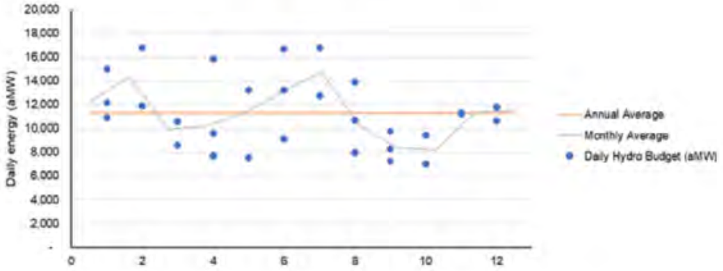


Non-LSR NW Hydro

Ramp Rates

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





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From: Arne Olson <arne@ethree.com>
Sent: Wednesday, July 6, 2022 3:14 PM
To: Koehler,Birgit G (BPA) - PG-5
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

It happens. Pretty easy for me just to decline to comment about anything internal to BPA/DOE/the administration.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 3:04 PM
To: Arne Olson <arne@ethree.com>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Deliberative, FOIA exempt

Arne,
Sorry I didn't reply yet. I didn't quite know what to say. Dan also reached out to our Communications staff, so we can let them reply (or not). I'm sorry that you are caught in the middle of this.

Birgit

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, July 6, 2022 2:21 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Birgit,

Dan Catchpole called again. I told him I couldn't answer any questions until after the Council meeting tomorrow. Two things to flag for you:]

1. He is not aware of any press briefing, and he would like to ask me some questions on the record. I assume that will be OK but told him I needed to run that by you.
2. His spidey sense is tingling (my words) about the way DOE is handling this. He plans to ask me whether there were any internal briefings at DOE, etc. and what the reaction was. I assume that I should punt any discussion of the internal briefings over to BPA or DOE? He may have some pointed questions for you.

Thanks,

Arne

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 10:52 AM
To: Arne Olson <arne@ethree.com>
Subject: FW: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Deliberative, FOIA exempt

Arne,
Would you send me your revised slide set when ready?

And please don't send to Chad until you hear back from me. Sorry for the extra hurdles.

Birgit

From: Chad Madron <CMadron@NWCouncil.org>
Sent: Wednesday, July 6, 2022 10:10 AM
To: Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>; Arne Olsen (arne@ethree.com) <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Jennifer Light <JLight@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Good morning Arne and BPA folks,

Just a reminder that it is our preference for you to send slides shown tomorrow morning to me ahead of time - then I use our computer to present them, but give you "keyboard and mouse control" so you can advance them using your equipment. This makes it so you don't have to worry about presenting from your machine. If you are very comfortable presenting from your computer directly we can accommodate that, we just find we have more consistent results if we do it the other way as different folks have differing levels of comfort with different webinar technologies.

Thanks!
Chad
(b)(6)

From: Chad Madron
Sent: Monday, June 27, 2022 10:48 AM
To: Ryan J (BPA) - PGPR-5 Egerdahl - BPA (rjegerdahl@bpa.gov) <rjegerdahl@bpa.gov>; Arne Olsen (arne@ethree.com) <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Jennifer Light - Northwest Power and Conservation Council (JLight@NWCouncil.org) <JLight@NWCouncil.org>; Kendra Coles (kcoles@nwcouncil.org) <kcoles@nwcouncil.org>
Subject: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Ryan, Eve, and Arne,

I am working with Jenn on pulling together a memo and any other background material we can for Members ahead of the July 7 presentation on BPA's Snake River Dams study that is at 8:30am Pacific.

Can you confirm who from BPA and E3 will officially be presenting/speaking? Arne, I know you are giving the main presentation. Is there a report exec summary or any slides we could include with the memo to help them prepare? We will be sending them the prep memo THIS Wed by the middle of the day. Any info you can help us provide to help them be prepared is appreciated.

For July 7 – I will make sure you three all have calendar invites and panelist email/invites for the webinar.

Arne – speakers generally appear on camera, but it is not required. Our preference is for you to send me your slides and then I use our computer to present them, but give you "keyboard and mouse control" so you can advance them using your equipment. This makes it so you don't have to worry about presenting from your machine. If you are very

comfortable presenting from your screen directly we can accommodate that, we just find we have more consistent results if we do it the other way as different folks have differing levels of comfort with different webinar technologies.

You should all get the GoToWebinar emails today! Those will have your UNIQUE entry links for the webinar. You will get the emails again 1 day and 1 hour before the meeting as reminders.

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, July 6, 2022 10:55 AM
To: Koehler,Birgit G (BPA) - PG-5
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.
Attachments: E3 BPA LSR Dams 2022-07-06.pptx

Here is the new version. I added Slide #2 and Slide #9.

Understood on sharing the deck.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 10:52 AM
To: Arne Olson <arne@ethree.com>
Subject: FW: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Deliberative, FOIA exempt

Arne,
Would you send me your revised slide set when ready?

And please don't send to Chad until you hear back from me. Sorry for the extra hurdles.

Birgit

From: Chad Madron <CMadron@NWCouncil.org>
Sent: Wednesday, July 6, 2022 10:10 AM
To: Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>; Arne Olsen (arne@ethree.com) <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Jennifer Light <JLight@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Good morning Arne and BPA folks,

Just a reminder that it is our preference for you to send slides shown tomorrow morning to me ahead of time - then I use our computer to present them, but give you "keyboard and mouse control" so you can advance them using your equipment. This makes it so you don't have to worry about presenting from your machine. If you are very comfortable presenting from your computer directly we can accommodate that, we just find we have more consistent results if we do it the other way as different folks have differing levels of comfort with different webinar technologies.

Thanks!
Chad
(b)(6)

From: Chad Madron
Sent: Monday, June 27, 2022 10:48 AM
To: Ryan J (BPA) - PGPR-5 Egerdahl - BPA (rjegerdahl@bpa.gov) <rjegerdahl@bpa.gov>; Arne Olsen (arne@ethree.com)

<arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Jennifer Light - Northwest Power and Conservation Council (JLight@NWCouncil.org) <JLight@NWCouncil.org>; Kendra Coles (kcoles@nwcouncil.org) <kcoles@nwcouncil.org>
Subject: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Ryan, Eve, and Arne,

I am working with Jenn on pulling together a memo and any other background material we can for Members ahead of the July 7 presentation on BPA's Snake River Dams study that is at 8:30am Pacific.

Can you confirm who from BPA and E3 will officially be presenting/speaking? Arne, I know you are giving the main presentation. Is there a report exec summary or any slides we could include with the memo to help them prepare? We will be sending them the prep memo THIS Wed by the middle of the day. Any info you can help us provide to help them be prepared is appreciated.

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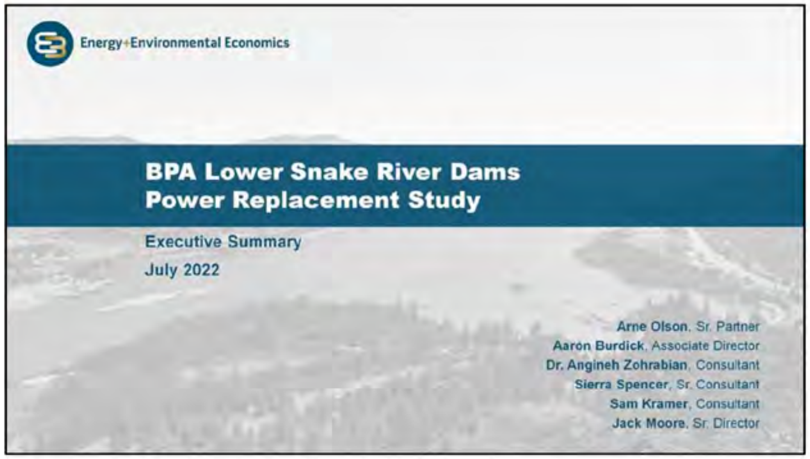


Energy+Environmental Economics

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

Who is E3?

Thought Leadership, Fact Based, Trusted.

100+ full-time consultants | 30 years of deep expertise | Engineering, Economics, Mathematics, Public Policy…

San Francisco

New York

Boston

Calgary

E3 Clients

300+ projects per year across our diverse client base

Recent Examples of E3 Projects

Buy-side diligence support on several successful investments in electric utilities (~$10B in total)

Acquisition support for investment in a residential demand response company (~$100M)

Supporting investment in several stand-alone storage platforms and individual assets across North America (10+ GW | ~$1B)

Acquisition support for several portfolios and individual gas-fired and renewable generation assets (20+ GW | ~$2B)

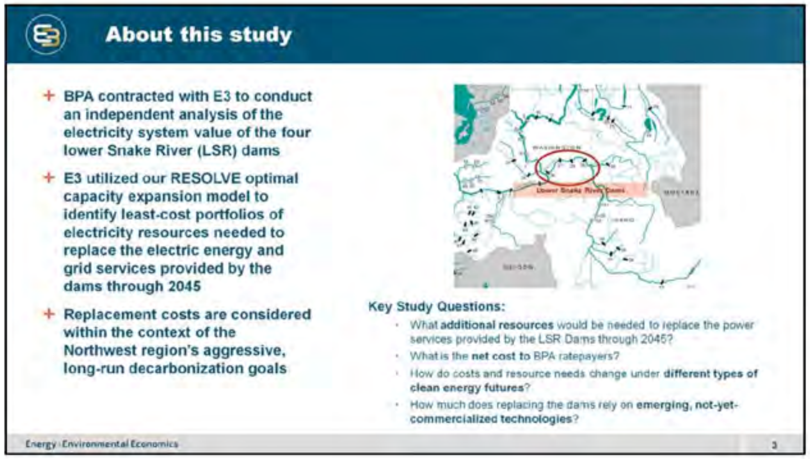
United Nations Deep Decarbonization Pathways Project

California: 100% clean energy planning and carbon market design for California agencies

Net Zero New England study with Energy Futures Initiative

New York: NYSERDA 100% clean energy planning

Pacific Northwest: 100% renewables and resource adequacy studies for multiple utilities

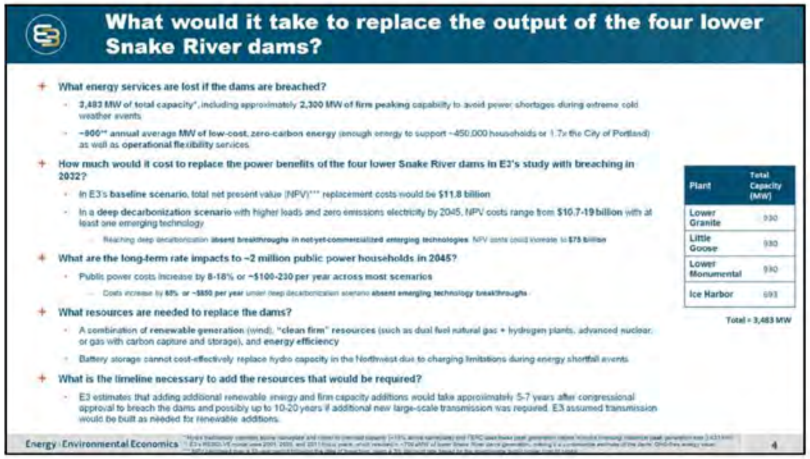


About this study

- **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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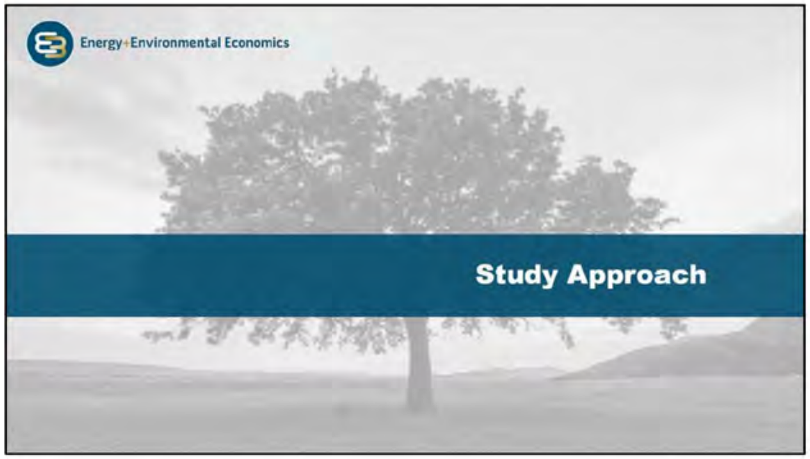

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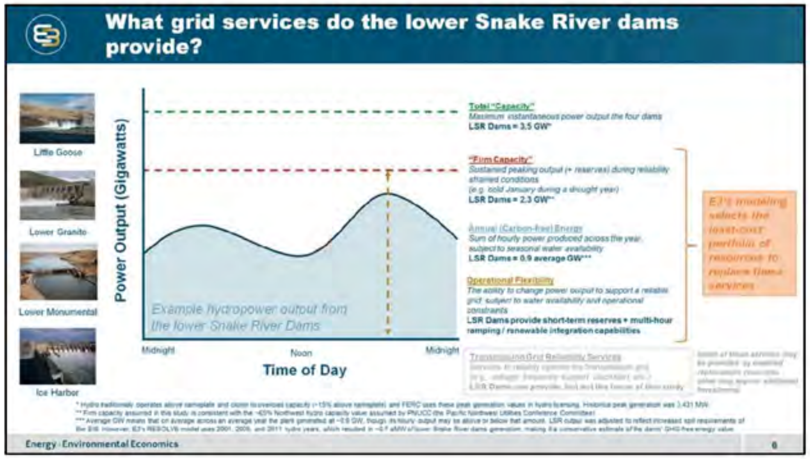
Study Approach



What grid services do the lower Snake River dams provide?

Total "Capacity"
Maximum instantaneous power output the four dams
LSR Dams = 3.5 GW*

"Firm Capacity"
Sustained peaking output (+ reserves) during reliability stressed conditions
(e.g. cold January during a drought year)
LSR Dams = 2.3 GW**

Annual (Carbon-free) Energy
Sum of hourly power produced across the year, subject to seasonal water availability
LSR Dams = 0.9 average GW***

Operational Flexibility
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

Transmission/Grid Reliability Services
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

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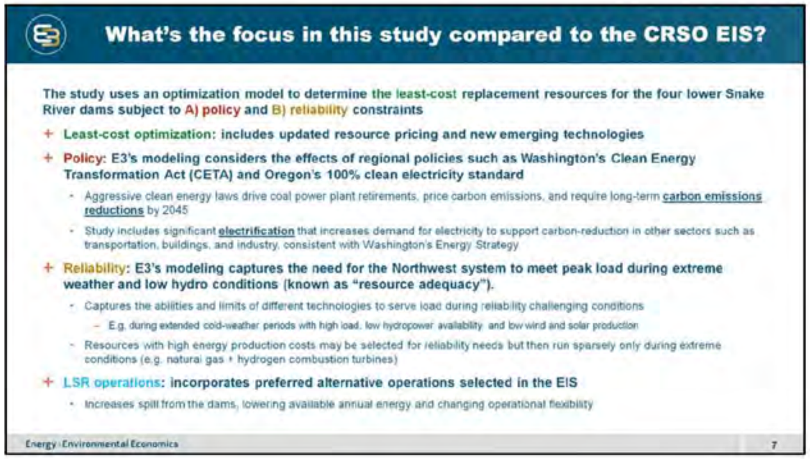

What's the focus in this study compared to the CRSO EIS?

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

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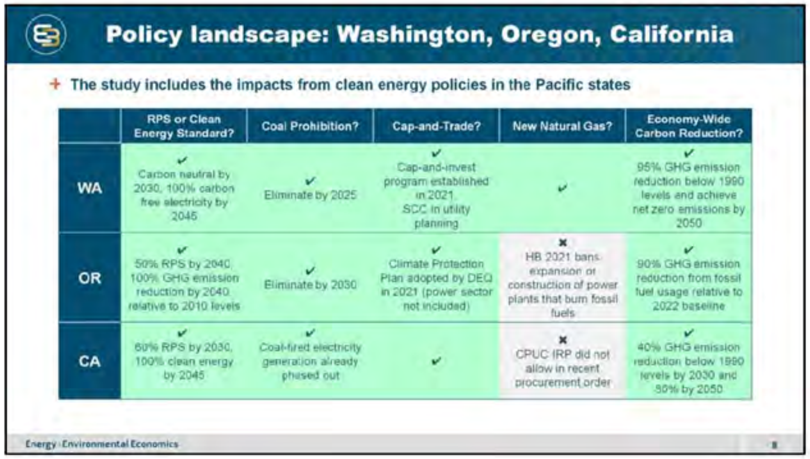
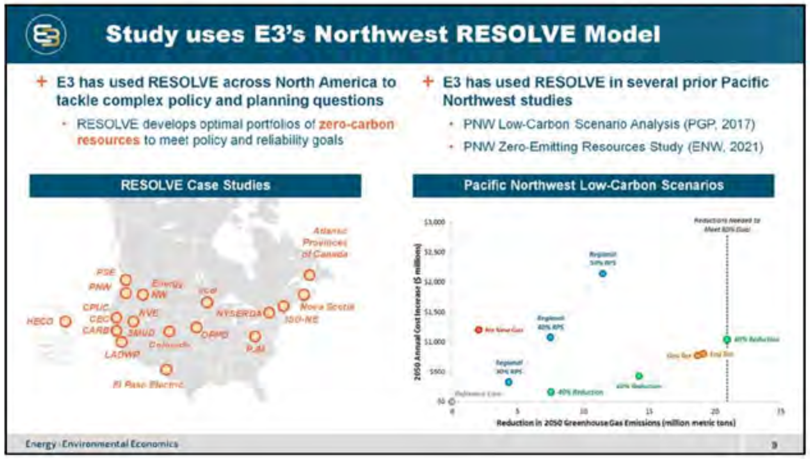


Policy landscape: Washington, Oregon, California

- 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

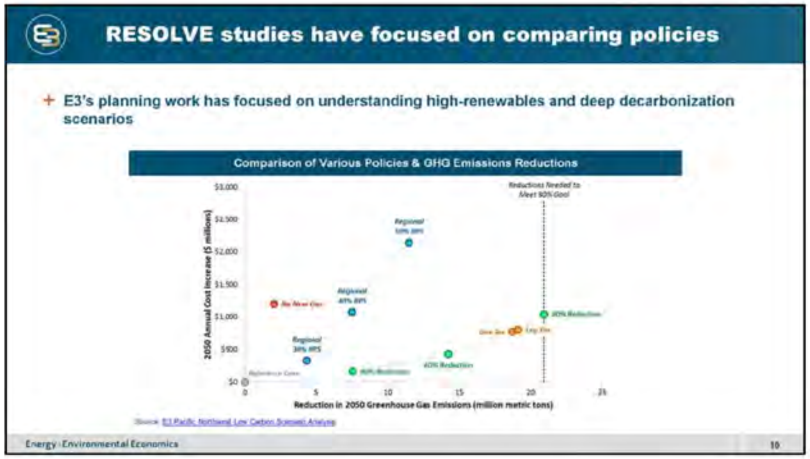


Study uses E3's Northwest RESOLVE Model

- **E3 has used RESOLVE across North America to tackle complex policy and planning questions**
  - RESOLVE develops optimal portfolios of **zero-carbon resources** to meet policy and reliability goals
- **E3 has used RESOLVE in several prior Pacific Northwest studies**
  - PNW Low-Carbon Scenario Analysis (PGP, 2017)
  - PNW Zero-Emitting Resources Study (ENW, 2021)

RESOLVE Case Studies

Pacific Northwest Low-Carbon Scenarios



RESOLVE studies have focused on comparing policies

- E3's planning work has focused on understanding high-renewables and deep decarbonization scenarios

Comparison of Various Policies & GHG Emissions Reductions

Source: E3 Pacific Northwest Low Carbon Scenario Analysis

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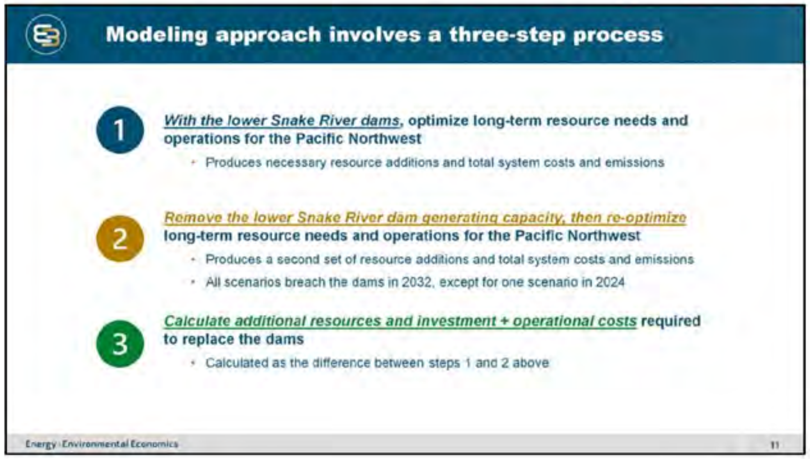
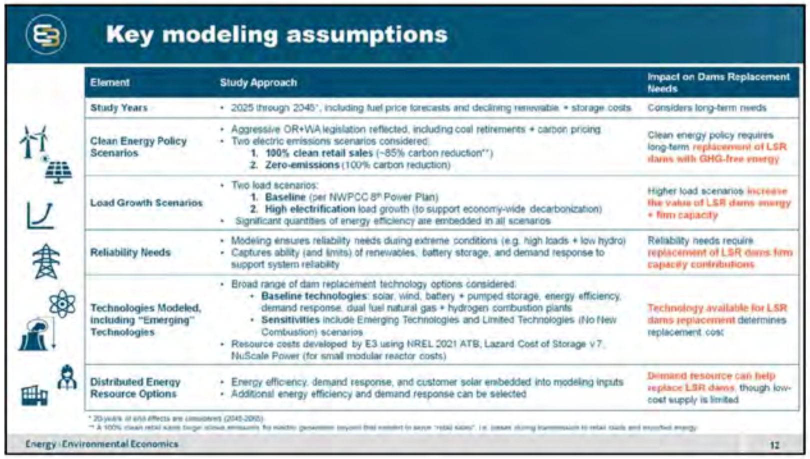


Modeling approach involves a three-step process

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 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

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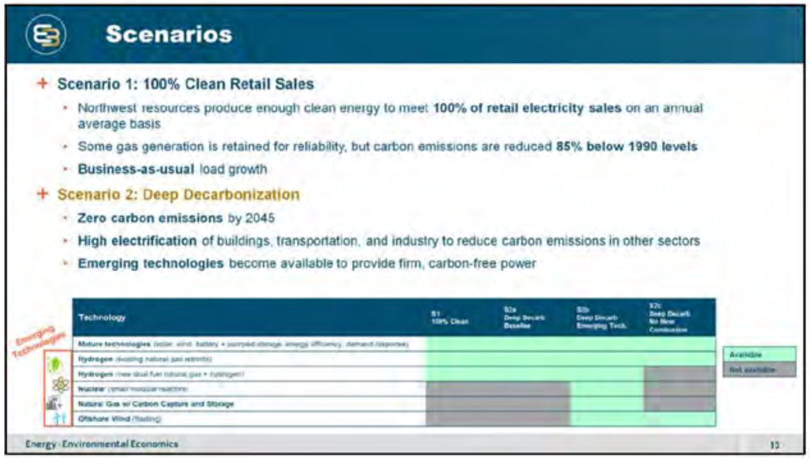

Scenarios

- **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

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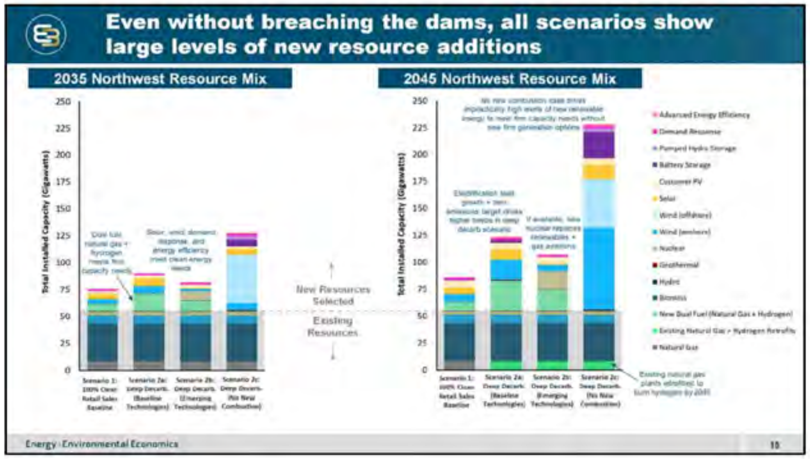
Northwest Resource Needs in Scenarios With the Lower Snake River Dams



Even without breaching the dams, all scenarios show large levels of new resource additions

2035 Northwest Resource Mix

Dual fuel natural gas + hydrogen meets firm capacity needs

Solar, wind, demand response, and energy efficiency meet clean energy needs

New Resources Selected

Existing Resources

2045 Northwest Resource Mix

No new combustion case drives impractically high levels of new renewable energy to meet firm capacity needs without new firm generation options

Electrification load growth + zero emissions target drives higher builds in deep decarb scenario

If available, new nuclear replaces renewables + gas additions

Existing natural gas plants retrofitted to burn hydrogen by 2045

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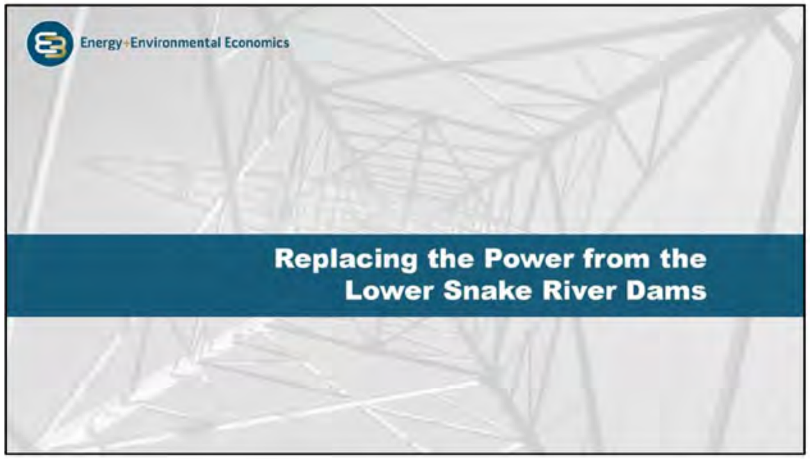

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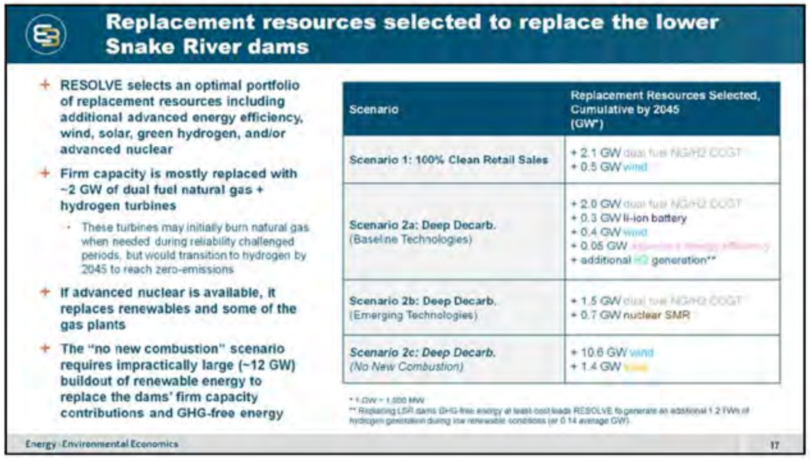
Replacing the Power from the Lower Snake River Dams



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)

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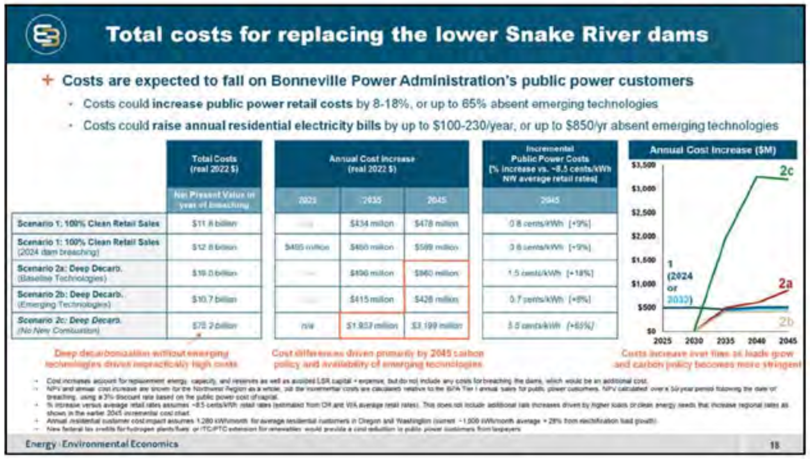


Total costs for replacing the lower Snake River dams

- **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

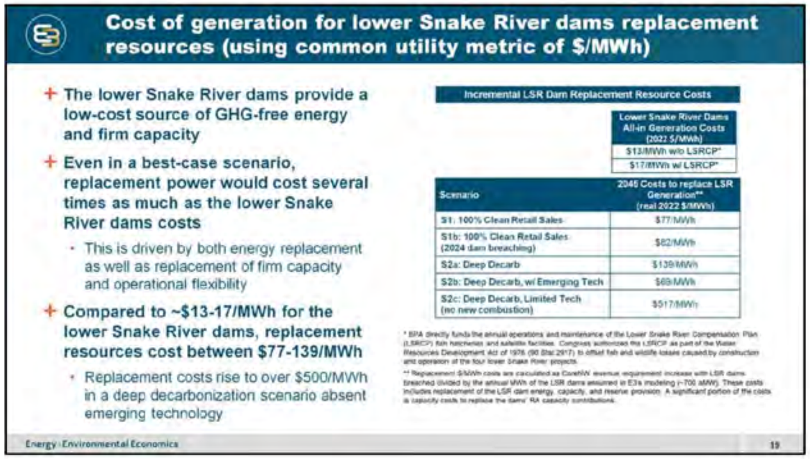
	Total Costs (real 2022 $)	Annual Cost Increase (real 2022 $)			Incremental Public Power Costs [% increase vs. ~8.5 cents/kWh NW average retail rates]
	Net Present Value in year of breaching	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$11.8 billion	[illegible]	$434 million	$478 million	0.8 cents/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$12.8 billion	$495 million	$460 million	$589 million	0.8 cents/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$19.0 billion	[illegible]	$496 million	$860 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 1 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

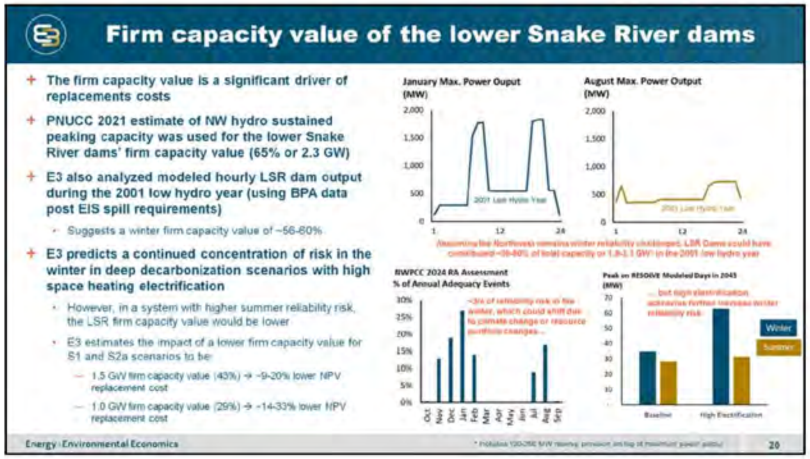
Incremental LSR Dam Replacement Resource Costs

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

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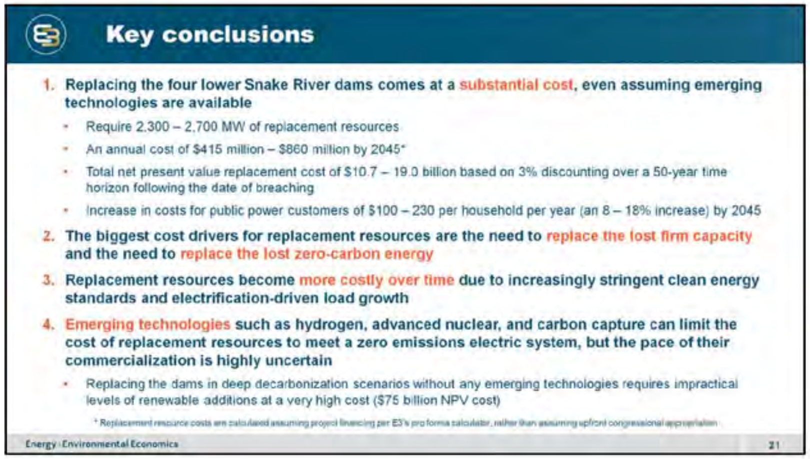

Key conclusions

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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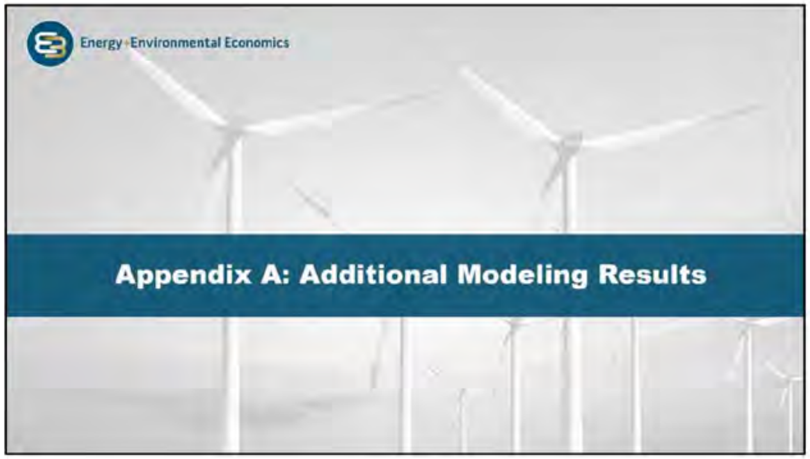
Thank you

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



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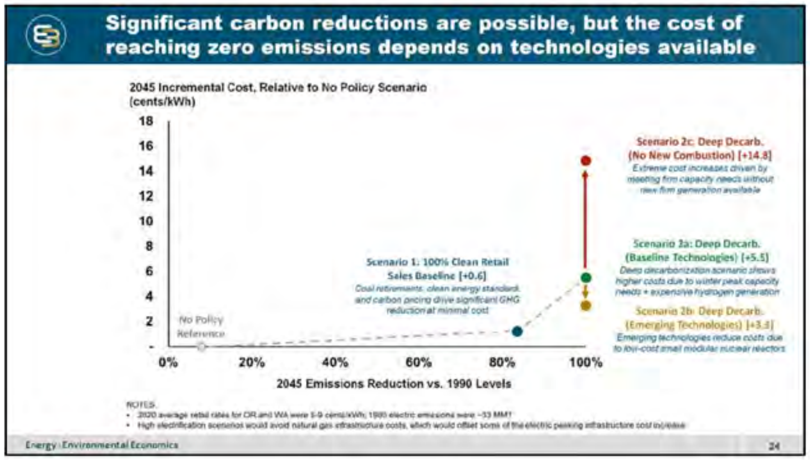
Appendix A: Additional Modeling Results



Significant carbon reductions are possible, but the cost of reaching zero emissions depends on technologies available

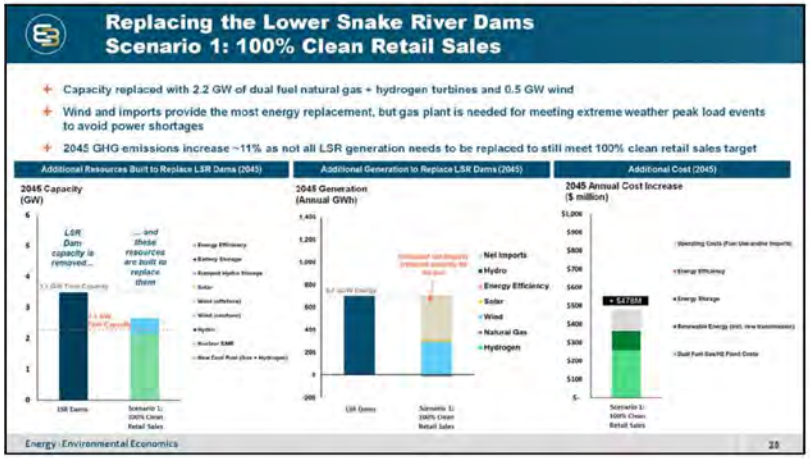
Scenario 1: 100% Clean Retail Sales Baseline [+0.6]
Coal retirements, clean energy standard, and carbon pricing drive significant GHG reduction at minimal cost

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

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



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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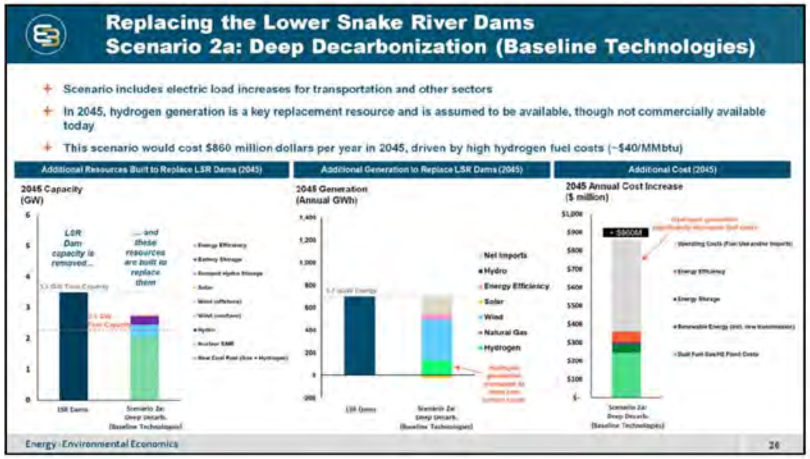
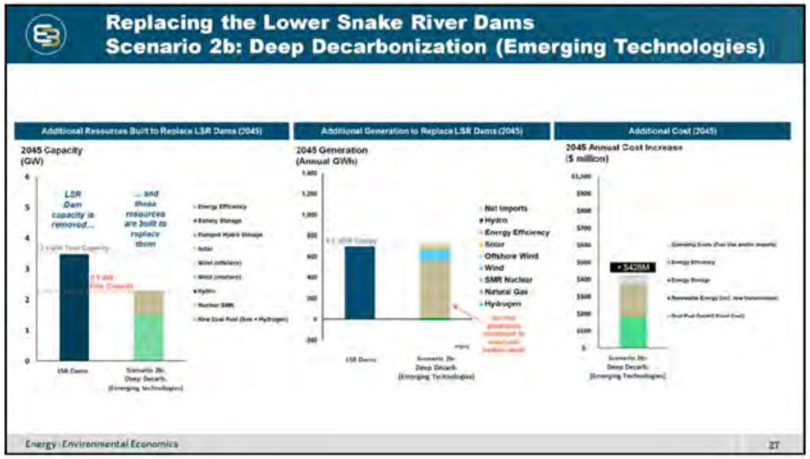


Replacing the Lower Snake River Dams
Scenario 2a: Deep Decarbonization (Baseline Technologies)

- 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)



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

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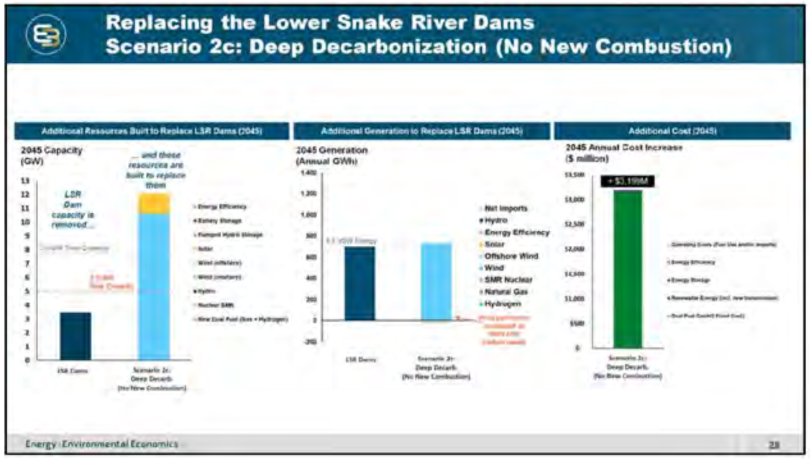
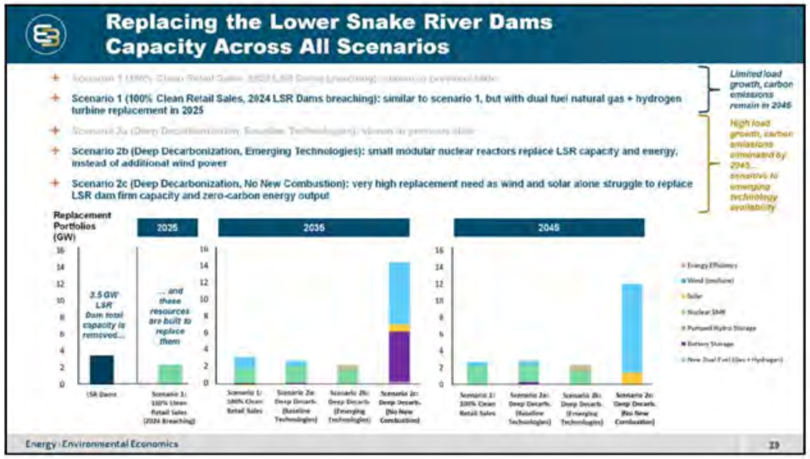


Replacing the Lower Snake River Dams
Scenario 2c: Deep Decarbonization (No New Combustion)

Additional Resources Built to Replace LSR Dams (2045)

Additional Generation to Replace LSR Dams (2045)

Additional Cost (2045)



Replacing the Lower Snake River Dams Capacity Across All Scenarios

- Scenario 1 (100% Clean Retail Sales, 2023 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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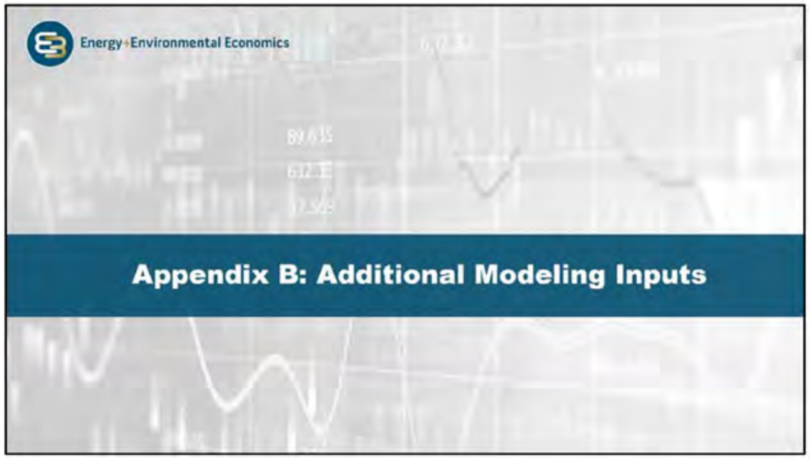

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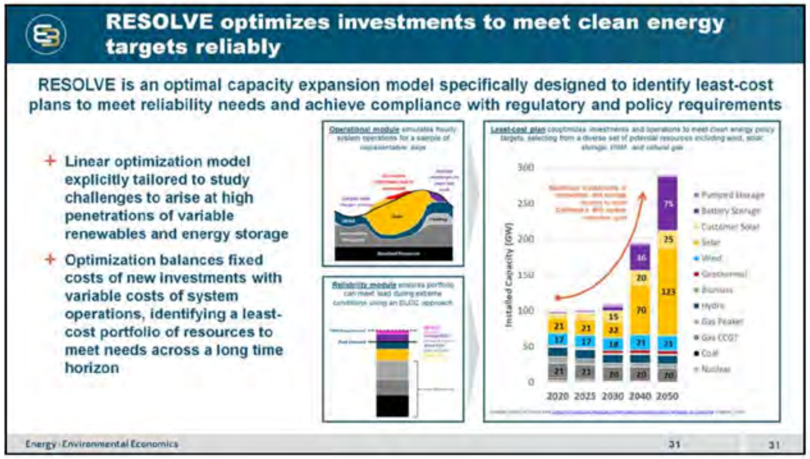
Appendix B: Additional Modeling Inputs



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, and natural gas

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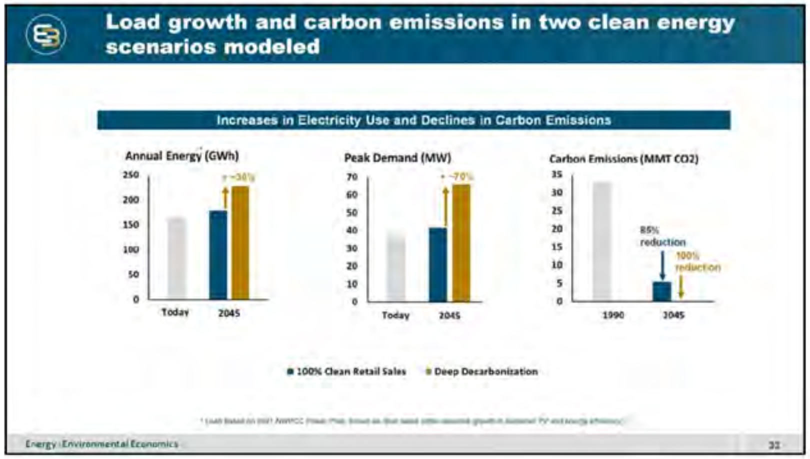

Load growth and carbon emissions in two clean energy scenarios modeled

Increases in Electricity Use and Declines in Carbon Emissions

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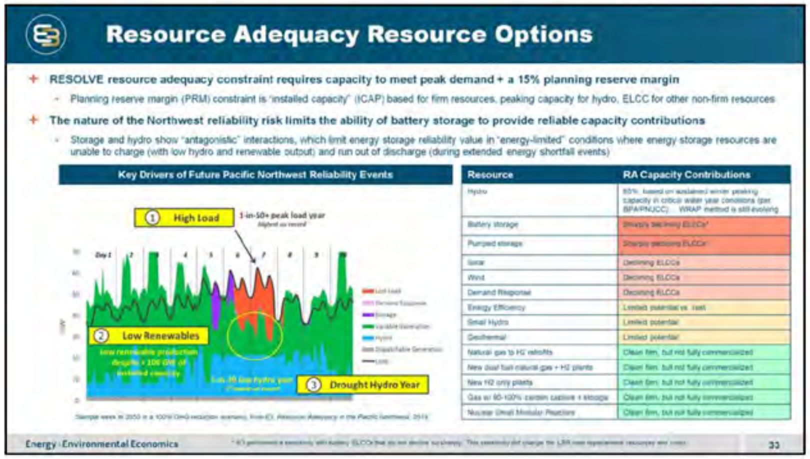
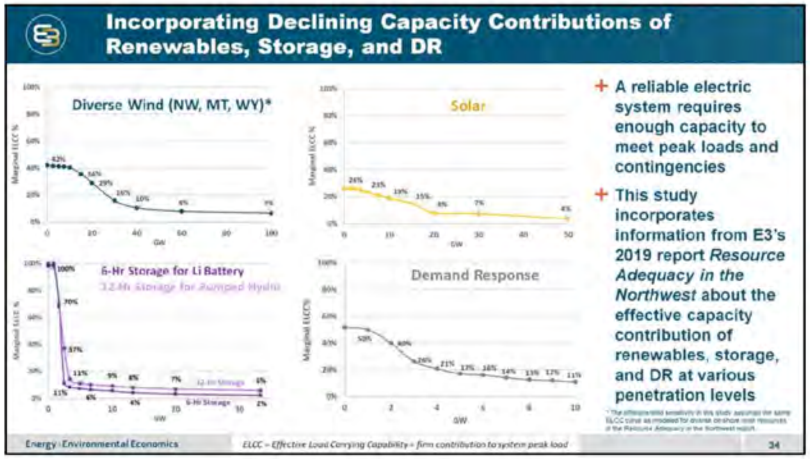


Resource Adequacy Resource Options

- 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

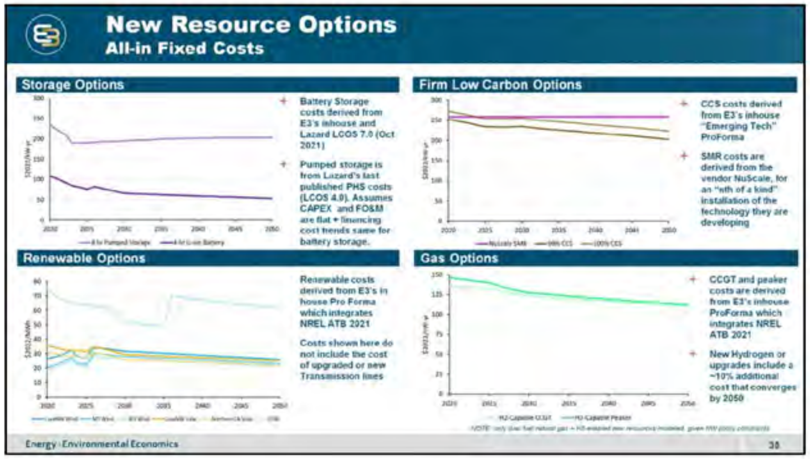
Resource	RA Capacity Contributions
Hydro	85%, based on sustained winter peaking capacity in critical water year conditions (per BPA/PNUCC). WRAP method is still evolving
Battery storage	Sharply declining ELCCs*
Pumped storage	Sharply declining ELCCs*
Solar	Declining ELCCs
Wind	Declining ELCCs
Demand 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

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

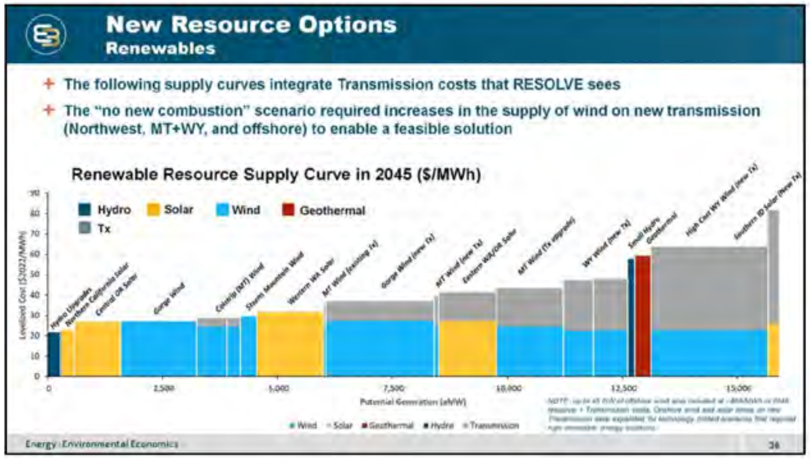
Renewable Options

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



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

Renewable Resource Supply Curve in 2045 ($/MWh)

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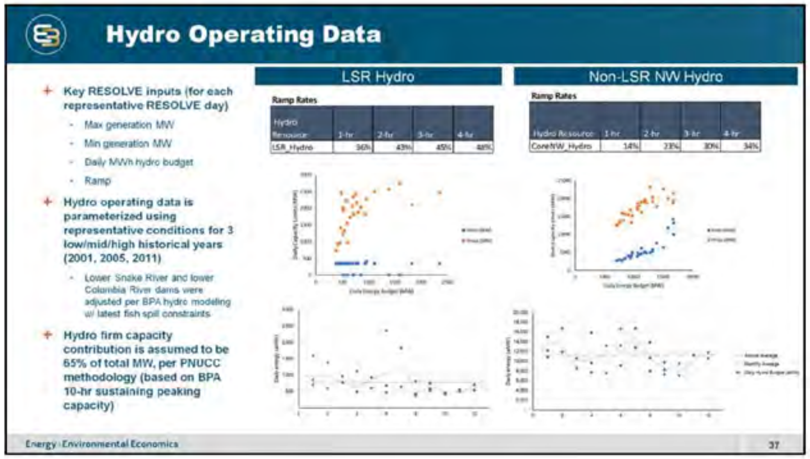

Hydro Operating Data

- 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 Colombia 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%

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From: Arne Olson <arne@ethree.com>
Sent: Tuesday, July 12, 2022 5:14 PM
To: Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5
Cc: Aaron Burdick
Subject: [EXTERNAL] Re: Anything you want to debreif about?

Thanks! I'm fine waiting until the reviews come in. We should probably touch base briefly before the Thursday meeting in any event.

Sent from my Verizon, Samsung Galaxy smartphone
Get Outlook for Android

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Tuesday, July 12, 2022 5:04:08 PM
To: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: Anything you want to debreif about?

First off, really well done. Huge thanks.

I got one comment from Liz Klumpp on internal IM:

Birgit, If you see this. I'm not sure NPCC members get that the E3 LSR analysis is INCREMENTAL above the 2045 study with the LSRs. KC asking about EE means he's not getting it. The extra EE is in the base case for reaching 2045 goals w the dams still operating. Thanks.

If you'd like, we can hop on a call. But I don't have anything else particular. Would you like to talk? Else the next 2-3 days will show how people interpreted this information

---

From: Arne Olson <arne@ethree.com>
Sent: Tuesday, July 12, 2022 5:01 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] Anything you want to debreif about?

Arne Olson, Senior Partner
Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500 | San Francisco, CA 94104
415-391-5100, ext. 307 |(b)(6) (mobile) | arne@ethree.com
he/him/his

From:	James,Eve A L (BPA) - PG-5
Sent:	Thursday, June 9, 2022 2:17 PM
To:	Koehler,Birgit G (BPA) - PG-5; Zelinsky,Benjamin D (BPA) - E-4; Pruder Scruggs,Kathryn M (BPA) - E-4
Subject:	BPA E3 results takeaways slides
Attachments:	2022-06-08_BPAperspective_E3study_PublicDeck.pptx

Deliberative, FOIA exempt

Attached is an updated slide deck of the BPA perspective on the E3 study results incorporating DOE feedback. Let me know if you have additional comments/edits. There is one slide that is duplicated- one version showing Seattle, and one showing map of LSN reservoirs- let me know which one looks better.

Thanks,
Eve

From: Pruder Scruggs,Kathryn M (BPA) - E-4
Sent: Tuesday, May 31, 2022 2:36 PM
To: James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5
Subject: BPA bottom line perspective from the E3 study.pptx
Attachments: BPA bottom line perspective from the E3 study.pptx

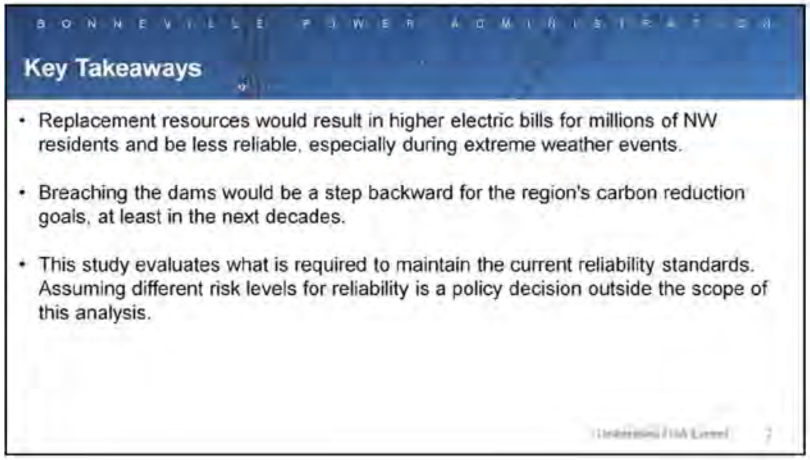
Deliberative, FOIA Exempt

Here's a start on the slides – just something on paper for us to noodle on.

BONNEVILLE POWER ADMINISTRATION

Key Takeaways

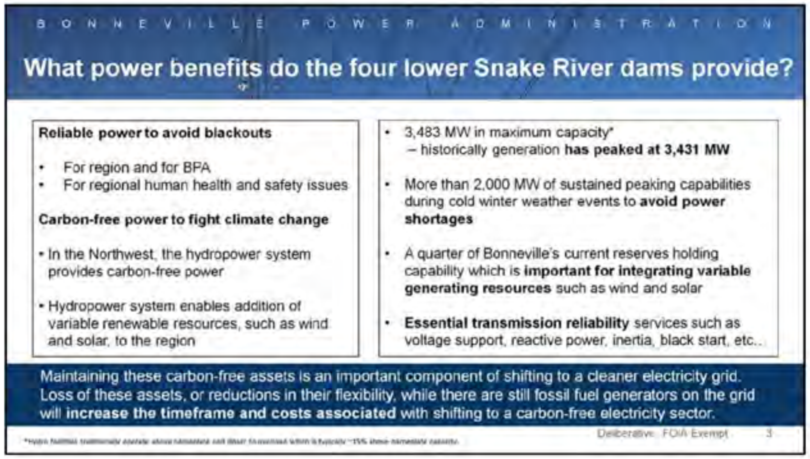
Bonneville perspective on E3 study



BONNEVILLE POWER ADMINISTRATION

Key Takeaways

- Replacement resources would result in higher electric bills for millions of NW residents and be less reliable, especially during extreme weather events.
- Breaching the dams would be a step backward for the region's carbon reduction goals, at least in the next decades.
- This study evaluates what is required to maintain the current reliability standards. Assuming different risk levels for reliability is a policy decision outside the scope of this analysis.



BONNEVILLE POWER ADMINISTRATION

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

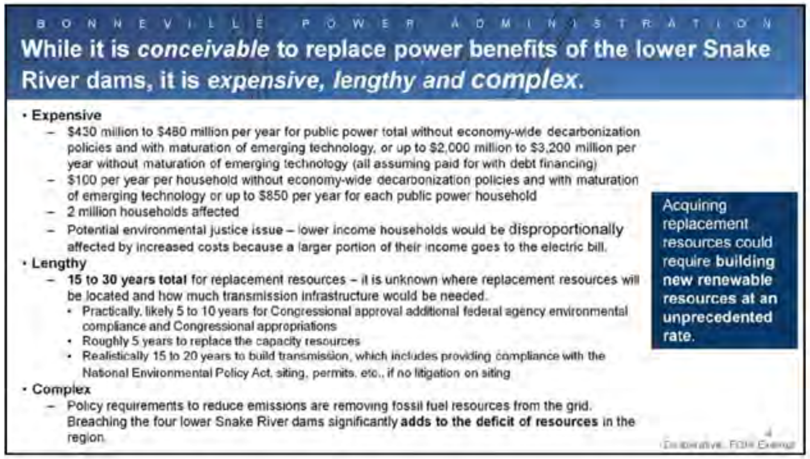
- 3,483 MW in maximum capacity*
  - historically generation **has peaked at 3,431 MW**

- 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..

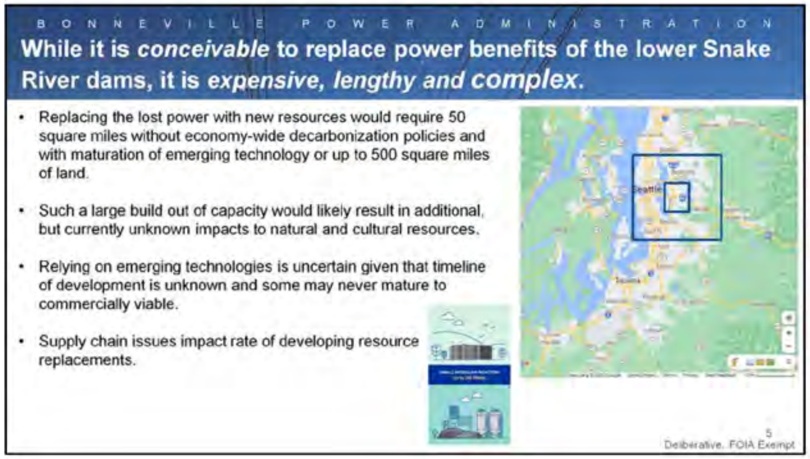
Maintaining these carbon-free assets is an important component of shifting to a cleaner electricity grid. Loss of these assets, or reductions in their flexibility, while there are still fossil fuel generators on the grid will **increase the timeframe and costs associated** with shifting to a carbon-free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



While it is *conceivable* to replace power benefits of the lower Snake River dams, it is *expensive, lengthy and complex*.

- **Expensive**
  - $430 million to $480 million per year for public power total without economy-wide decarbonization policies and with maturation of emerging technology, or up to $2,000 million to $3,200 million per year without maturation of emerging technology (all assuming paid for with debt financing)
  - $100 per year per household without economy-wide decarbonization policies and with maturation of emerging technology or up to $850 per year for each public power household
  - 2 million households affected
  - Potential environmental justice issue – lower income households would be disproportionally affected by increased costs because a larger portion of their income goes to the electric bill.
- **Lengthy**
  - **15 to 30 years total** for replacement resources – it is unknown where replacement resources will be located and how much transmission infrastructure would be needed.
    - Practically, likely 5 to 10 years for Congressional approval additional federal agency environmental compliance and Congressional appropriations
    - Roughly 5 years to replace the capacity resources
    - Realistically 15 to 20 years to build transmission, which includes providing compliance with the National Environmental Policy Act, siting, permits, etc., if no litigation on siting
- **Complex**
  - 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.**



While it is *conceivable* to replace power benefits of the lower Snake River dams, it is *expensive, lengthy and complex.*

- Replacing the lost power with new resources would require 50 square miles without economy-wide decarbonization policies and with maturation of emerging technology or up to 500 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.
- Relying on emerging technologies is uncertain given that timeline of development is unknown and some may never mature to commercially viable.
- Supply chain issues impact rate of developing resource replacements.

While it is *conceivable* to replace power benefits of the lower Snake River dams, it is *expensive, lengthy and complex.*

- Replacing the lost power with new resources would require 50 square miles without economy-wide decarbonization policies and with maturation of emerging technology or up to 500 square miles of land.
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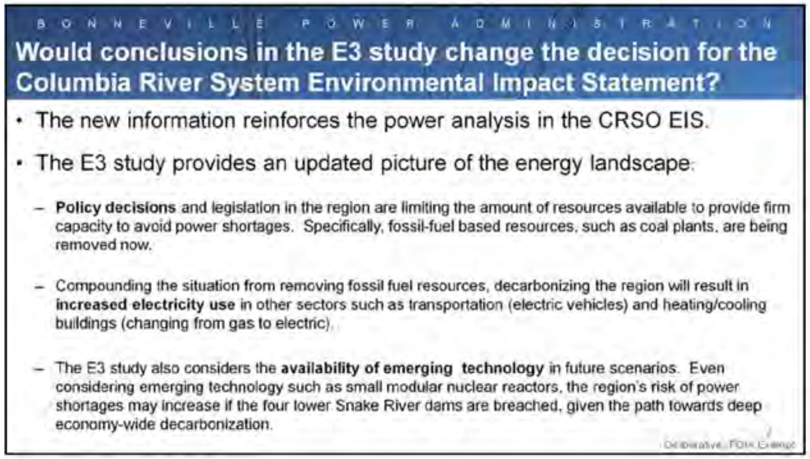
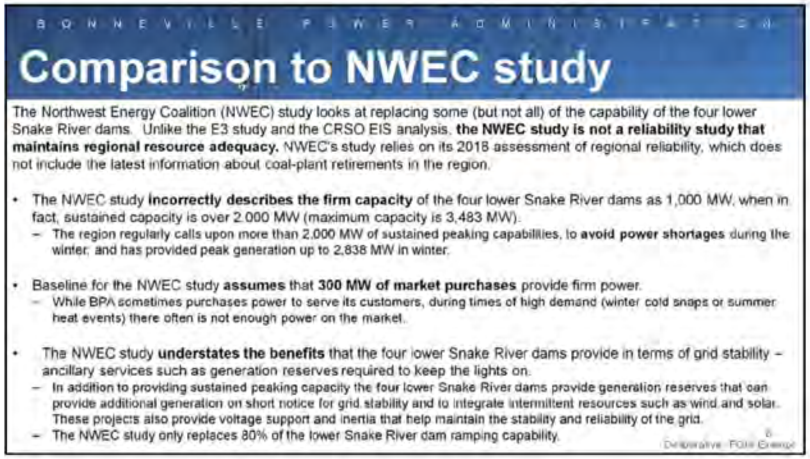


Would conclusions in the E3 study change the decision for the Columbia River System Environmental Impact Statement?

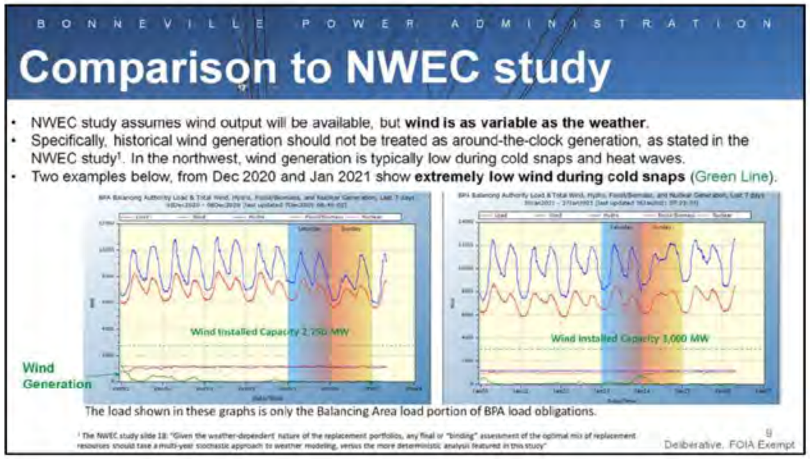
- The new information reinforces the power analysis in the CRSO EIS.
- The E3 study provides an updated picture of the energy landscape.
  - **Policy decisions** and legislation in the region are limiting the amount of resources available to provide firm capacity to avoid power shortages. Specifically, 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 economy-wide decarbonization.



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 study and the CRSO EIS analysis, **the NWEC study is not a reliability study that maintains regional resource adequacy.** NWEC's study relies on its 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 firm capacity** of the four lower Snake River dams as 1,000 MW, when in fact, sustained capacity is over 2,000 MW (maximum capacity is 3,483 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.
- 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 four 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.



BONNEVILLE POWER ADMINISTRATION

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 generation, as stated in the NWEC study[1]. In the northwest, wind generation is typically low during cold snaps and heat waves.
- Two examples below, from Dec 2020 and Jan 2021 show **extremely low wind during cold snaps** (Green Line).

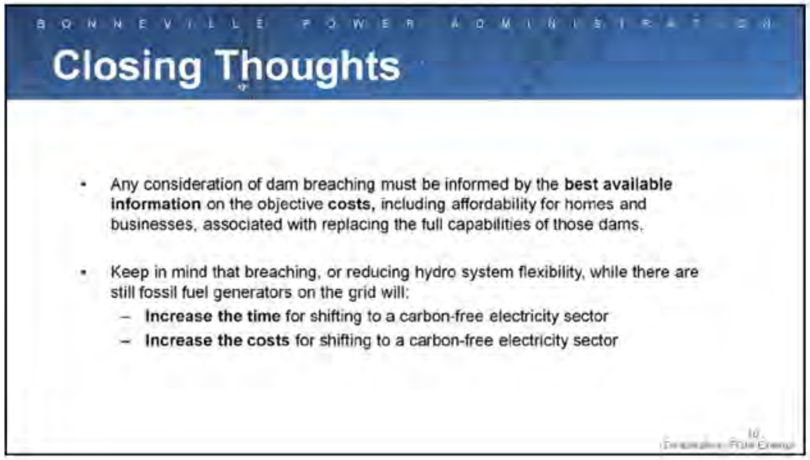
The load shown in these graphs is only the Balancing Area load portion of BPA load obligations.

---

[1] The NWEC study slide 18: "Given the weather-dependent nature of the replacement portfolios, any final or "binding" assessment of the optimal mix of replacement resources should take a multi-year stochastic approach to weather modeling, versus the more deterministic analysis featured in this study"

9

Deliberative, FOIA Exempt



Closing Thoughts

- Any consideration of dam breaching must be informed by the **best available information** on the objective **costs,** including affordability for homes and businesses, associated with replacing the full capabilities of those dams.
- Keep in mind that breaching, or reducing hydro system 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

---

From: Koehler,Birgit G (BPA) - PG-5
Sent: Tuesday, July 5, 2022 9:51 AM
To: Leary,Jill C (BPA) - LN-7
Subject: FW: Draft Exec Summary
Attachments: E3 BPA LSR Dams_070122.pdf

PDF of the final presentation

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, July 1, 2022 8:56 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

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.

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From: Arne Olson <arne@ethree.com>
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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.

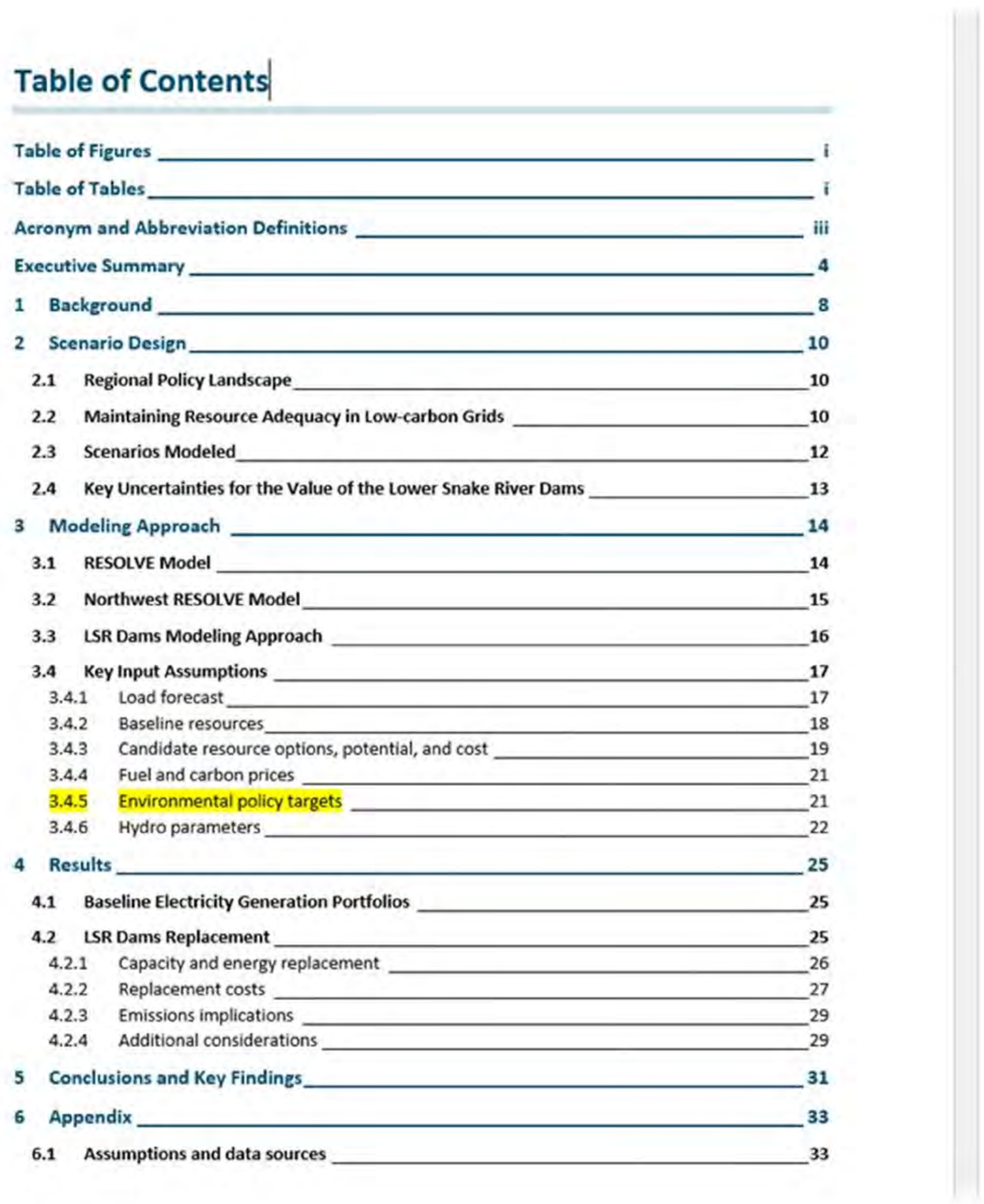


Table of Contents

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:	James,Eve A L (BPA) - PG-5
Sent:	Thursday, June 30, 2022 2:22 PM
To:	Harris,Marcus A (BPA) - F-2; Mandell,Zach R (BPA) - FA-2
Cc:	Koehler,Birgit G (BPA) - PG-5
Subject:	FW: Draft Exec Summary

Deliberative, FOIA exempt

Hi Marcus and Zach- I was referred to you as potentially having worked on the Net Present Value calculations in the CRSO EIS and I want to make sure the information we send back to E3 on calculating the NPV on their lower Snake River dam power replacement study (see below):

From: Ashby,Gordon S (BPA) - PGA-6 <gsashby@bpa.gov>
Sent: Thursday, June 30, 2022 1:44 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Stiffler,Peter B (BPA) - KSL-4 <pbstiffler@bpa.gov>; Lennox,Alexander (BPA) - FTR-2 <alennox@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

We typically used a 50-year NPV analysis for hydro projects. I don't think that there is a comparable number in the EIS. The Corps presented the differences in scenarios in terms of average annual costs. I can't remember there being NPVs anywhere that compared the expected future value of generation and project costs with and without the LSRDs. Birgit and I put together a question response that put some additional perspective around net benefits, but those were again on an average annual basis using the information the Corps put together. For context, I believe the Corps' average annual calculations were also done on 50 years of data. That's how much I provided for Capital and O&M anyway.

Gordon

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 30, 2022 1:33 PM
To: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Stiffler,Peter B (BPA) - KSL-4 <pbstiffler@bpa.gov>; Ashby,Gordon S (BPA) - PGA-6 <gsashby@bpa.gov>; Lennox,Alexander (BPA) - FTR-2 <alennox@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: FW: Draft Exec Summary

Deliberative, FOIA exempt

Hello-
Let me know what your thoughts are on this- does one method work better for comparing to the CRSO EIS analysis? I'm not sure who all worked on this type of NPV analysis for the CRSO EIS or who might have helpful thoughts on how to respond to E3 since this is out of my realm of expertise.

Thanks,
Eve

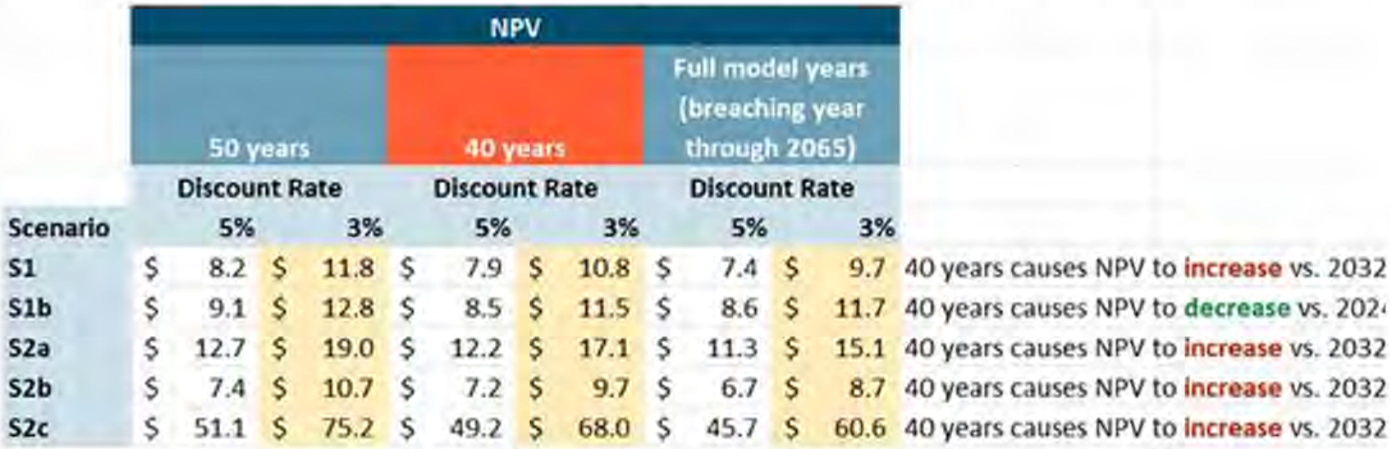
From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 30, 2022 1:16 PM

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

Ok, hopefully the last question before we finalize the NPV values. We were previously using the year of breaching to the end of the RESOLVE modeling horizon (2045 + 20 years of end effects, ie 2065). We calculated NPVs instead using 40 years or 50 years, e.g. 40 years would be 2024-2064 or 2032-2072 (we extend the 2045 RESOLVE modeled year out as far as needed to do this). The results are below. I'll note that the Inslee/Murray report uses a 50-year timeline for its NPV calculation.

Can you review the table below and advise thoughts on using 40 years vs. 50 years for the NPV calculation? We think either of those is better than the current approach, that ends up using a different number of years for the 2024 breaching case, driving an artificial difference between S1 an S2b. All values below are 2022$ billion.



	NPV						
	50 years		40 years		Full model years (breaching year through 2065)		
	Discount Rate		Discount Rate		Discount Rate		
Scenario	5%	3%	5%	3%	5%	3%	
S1	$ 8.2	$ 11.8	$ 7.9	$ 10.8	$ 7.4	$ 9.7	40 years causes NPV to increase vs. 2032
S1b	$ 9.1	$ 12.8	$ 8.5	$ 11.5	$ 8.6	$ 11.7	40 years causes NPV to decrease vs. 202
S2a	$ 12.7	$ 19.0	$ 12.2	$ 17.1	$ 11.3	$ 15.1	40 years causes NPV to increase vs. 2032
S2b	$ 7.4	$ 10.7	$ 7.2	$ 9.7	$ 6.7	$ 8.7	40 years causes NPV to increase vs. 2032
S2c	$ 51.1	$ 75.2	$ 49.2	$ 68.0	$ 45.7	$ 60.6	40 years causes NPV to increase vs. 2032

I should also note that the Energy GPS study seems to use no discounting at all (just a 2% inflation adjustment), which could lend itself to critique of over-inflation of the NPV values. Something to be aware of when comparing the numbers.

Note: the other thing we plan to add to the report is a sensitivity using higher storage ELCCs (that are more aligned with the latest GENESYS runs showing higher summer vs. winter risk). That sensitivity showed that more storage gets built to displace gas additions, but it shows basically no change in the replacement resources and costs for the LSR dams. This basically shows that you could add some short duration storage to push the risk back into the winter (since we did not lower the LSR dam contributions assuming the risk stays in the summer long term). We saturate battery storage either way (i.e. either at 2 GW or 10 GW) and need alternative resources to cost effectively replace the dams capacity. It's a fairly rough sensitivity (we only adjusted storage ELCCs), but directionally provides some good validation that storage can't replace the dams in context of the broader regional needs... We're working to add – **let us know if you have any thoughts on this**.

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 30, 2022 6:58 AM
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

Thanks Aaron- I was following up on a highlighted section in the report about the public power cost of capital and this is in closer alignment with what the 2022 WACC for BPA uses in planning which is 2.81%. Using 3% will be much closer to what we use and closer to how other reports are calculating the discount rates and our assumptions.

From: Aaron Burdick <aaron.burdick@ethree.com>
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: [EXTERNAL] RE: Draft Exec Summary

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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.

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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.

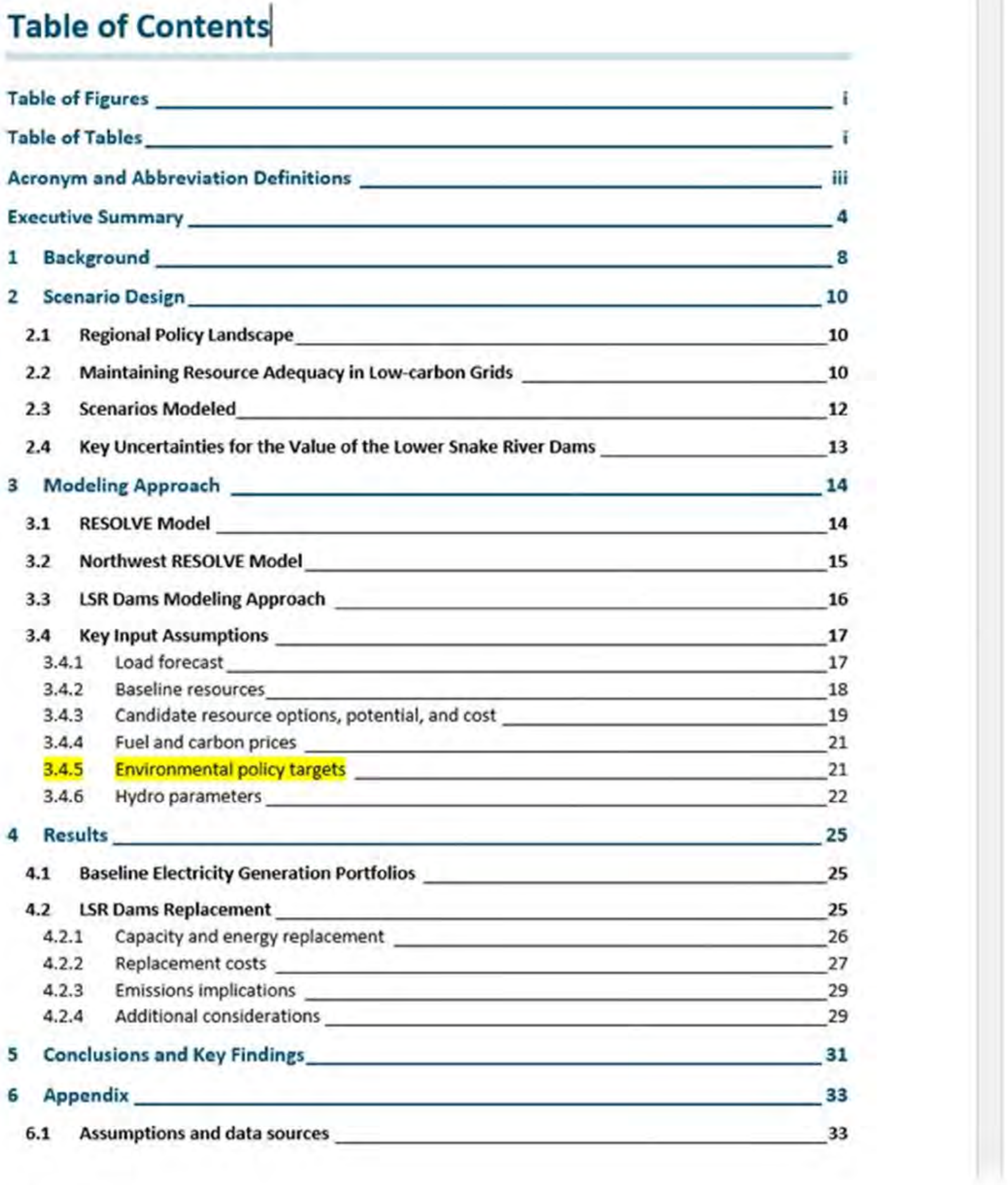

Table of Contents

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: Koehler,Birgit G (BPA) - PG-5
Sent: Wednesday, July 6, 2022 3:05 PM
To: Leary,Jill C (BPA) - LN-7
Cc: Johnson,G Douglas (BPA) - DK-7; Habibi,Maryam A (BPA) - DKP-7; Scruggs,Joel L (BPA) - DK-7; Baskerville,Sonya L (BPA) - AIN-WASH
Subject: FW: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Confidential and Privileged, Attorney-Client Communication, Do Not Release under FOIA

FYI, I replied without explanation to Arne on his request from Clearing Up

---

From: Koehler,Birgit G (BPA) - PG-5
Sent: Wednesday, July 6, 2022 3:04 PM
To: 'Arne Olson' <arne@ethree.com>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Deliberative, FOIA exempt

Arne,
Sorry I didn't reply yet. I didn't quite know what to say. Dan also reached out to our Communications staff, so we can let them reply (or not). I'm sorry that you are caught in the middle of this.

Birgit

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, July 6, 2022 2:21 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Birgit,

Dan Catchpole called again. I told him I couldn't answer any questions until after the Council meeting tomorrow. Two things to flag for you:]

1. He is not aware of any press briefing, and he would like to ask me some questions on the record. I assume that will be OK but told him I needed to run that by you.
2. His spidey sense is tingling (my words) about the way DOE is handling this. He plans to ask me whether there were any internal briefings at DOE, etc. and what the reaction was. I assume that I should punt any discussion of the internal briefings over to BPA or DOE? He may have some pointed questions for you.

Thanks,

Arne

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 10:52 AM
To: Arne Olson <arne@ethree.com>
Subject: FW: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Deliberative, FOIA exempt

Arne,
Would you send me your revised slide set when ready?

And please don't send to Chad until you hear back from me. Sorry for the extra hurdles.

Birgit

From: Chad Madron <CMadron@NWCouncil.org>
Sent: Wednesday, July 6, 2022 10:10 AM
To: Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>; Arne Olsen (arne@ethree.com) <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Jennifer Light <JLight@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Good morning Arne and BPA folks,

Just a reminder that it is our preference for you to send slides shown tomorrow morning to me ahead of time - then I use our computer to present them, but give you "keyboard and mouse control" so you can advance them using your equipment. This makes it so you don't have to worry about presenting from your machine. If you are very comfortable presenting from your computer directly we can accommodate that, we just find we have more consistent results if we do it the other way as different folks have differing levels of comfort with different webinar technologies.

Thanks!
Chad
(b)(6)

From: Chad Madron
Sent: Monday, June 27, 2022 10:48 AM
To: Ryan J (BPA) - PGPR-5 Egerdahl - BPA (rjegerdahl@bpa.gov) <rjegerdahl@bpa.gov>; Arne Olsen (arne@ethree.com) <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Jennifer Light - Northwest Power and Conservation Council (JLight@NWCouncil.org) <JLight@NWCouncil.org>; Kendra Coles (kcoles@nwcouncil.org) <kcoles@nwcouncil.org>
Subject: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Ryan, Eve, and Arne,

I am working with Jenn on pulling together a memo and any other background material we can for Members ahead of the July 7 presentation on BPA's Snake River Dams study that is at 8:30am Pacific.

Can you confirm who from BPA and E3 will officially be presenting/speaking? Arne, I know you are giving the main presentation. Is there a report exec summary or any slides we could include with the memo to help them prepare? We will be sending them the prep memo THIS Wed by the middle of the day. Any info you can help us provide to help them be prepared is appreciated.

For July 7 – I will make sure you three all have calendar invites and panelist email/invites for the webinar.

Arne – speakers generally appear on camera, but it is not required. Our preference is for you to send me your slides and then I use our computer to present them, but give you “keyboard and mouse control” so you can advance them using your equipment. This makes it so you don’t have to worry about presenting from your machine. If you are very comfortable presenting from your screen directly we can accommodate that, we just find we have more consistent results if we do it the other way as different folks have differing levels of comfort with different webinar technologies.

You should all get the GoToWebinar emails today! Those will have your UNIQUE entry links for the webinar. You will get the emails again 1 day and 1 hour before the meeting as reminders.

From: Baskerville,Sonya L (BPA) - AIN-WASH
Sent: Wednesday, July 6, 2022 2:32 PM
To: Koehler,Birgit G (BPA) - PG-5; Leary,Jill C (BPA) - LN-7
Cc: Johnson,G Douglas (BPA) - DK-7; James,Eve A L (BPA) - PG-5; Godwin,Mary E (BPA) - LN-7
Subject: FW: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Definitely punt the very astute spidey senser to DOE and let them deal with this mess.

Sonya Baskerville
BPA National Relations
(b)(6)

On Jul 6, 2022 4:22 PM, "Koehler,Birgit G (BPA) - PG-5" <bgkoehler@bpa.gov> wrote:

Confidential and Privileged, Attorney-Client Communication, Do Not Release under FOIA

Any guidance for my reply?

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, July 6, 2022 2:21 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Birgit,

Dan Catchpole called again. I told him I couldn't answer any questions until after the Council meeting tomorrow. Two things to flag for you:]

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Deliberative, FOIA exempt

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You should all get the GoToWebinar emails today! Those will have your UNIQUE entry links for the webinar. You will get the emails again 1 day and 1 hour before the meeting as reminders.

From: Koehler,Birgit G (BPA) - PG-5
Sent: Monday, July 25, 2022 9:49 AM
To: Arne Olson; Baskerville,Sonya L (BPA) - AIN-WASH; James,Eve A L (BPA) - PG-5
Cc: Aaron Burdick
Subject: RE: Congressional staff briefing

Let me pile on my thanks as well. The questions we did get made it clear that they were thinking about what you were saying. And they had looked at the report. I think it went quite well. (We'd have needed more time if we wanted a longer discussion.)

Cheers,
Birgit

From: Arne Olson <arne@ethree.com>
Sent: Monday, July 25, 2022 9:39 AM
To: Baskerville,Sonya L (BPA) - AIN-WASH <slbaskerville@bpa.gov>; 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] RE: Congressional staff briefing

Glad it went well. They didn't say much but hopefully they got the info they needed.

From: Baskerville,Sonya L (BPA) - AIN-WASH <slbaskerville@bpa.gov>
Sent: Monday, July 25, 2022 9:03 AM
To: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: Re: Congressional staff briefing

Thanks! This was great. Even generated questions! Sometimes they can be totally quiet.

Sonya Baskerville
BPA National Relations
(b)(6) m

From: James,Eve A L (BPA) - PG-5
Sent: Friday, July 1, 2022 2:57 PM
To: Aaron Burdick; Arne Olson
Cc: Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian
Subject: RE: Draft Exec Summary
Attachments: BPA Final Report_Draft_v3-eaj-txpage49-50.docx

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**
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Deep decarbonization without emerging technologies drives impractically high costs

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All the best,
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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.

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From: Aaron Burdick <aaron.burdick@ethree.com>
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Subject: [EXTERNAL] Draft Exec Summary

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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.

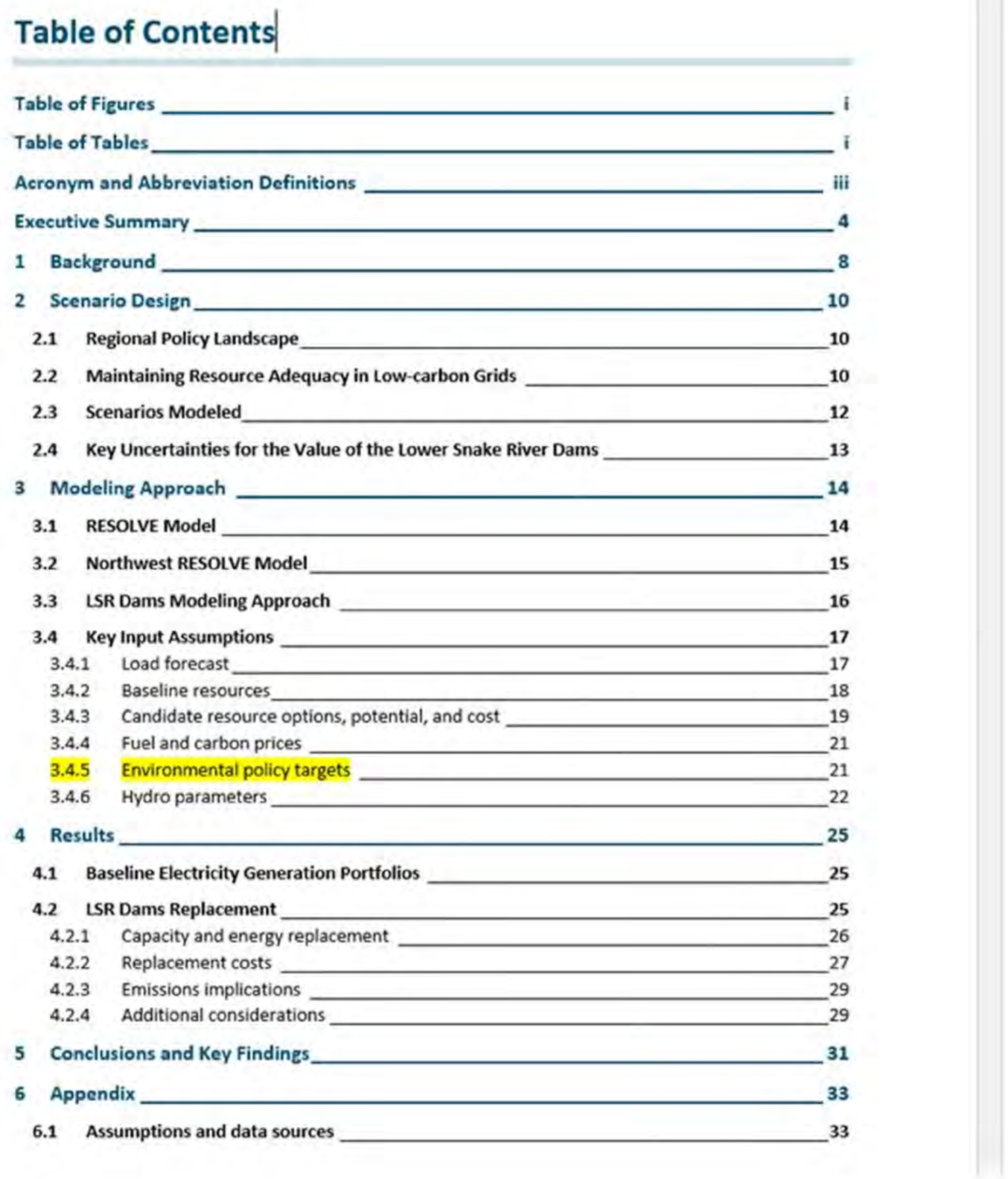

Table of Contents

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

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Sent: Thursday, June 30, 2022 5:35 PM
To: Aaron Burdick; Arne Olson
Cc: Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian
Subject: RE: Draft Exec Summary
Attachments: BPA Final Report_Draft_v3-eaj.docx

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>
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And now the draft report, ready for BPA version control. Note there are a few placeholders still for some minor E3 updates.

Aaron

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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.

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Should be done with my edits on ours in the next hour.

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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

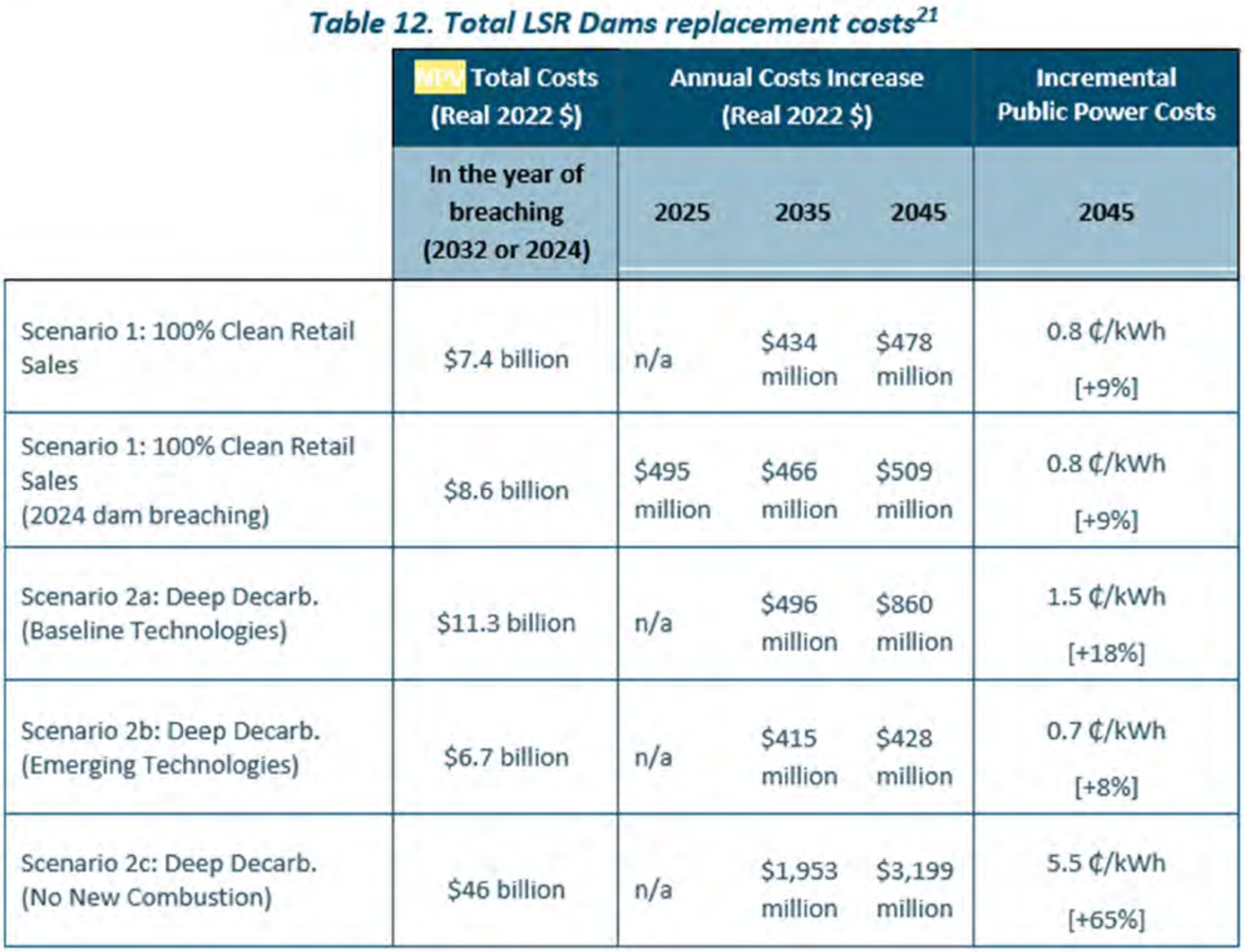

Table 12. Total LSR Dams replacement costs[21]

	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%]
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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 $)
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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

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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>
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

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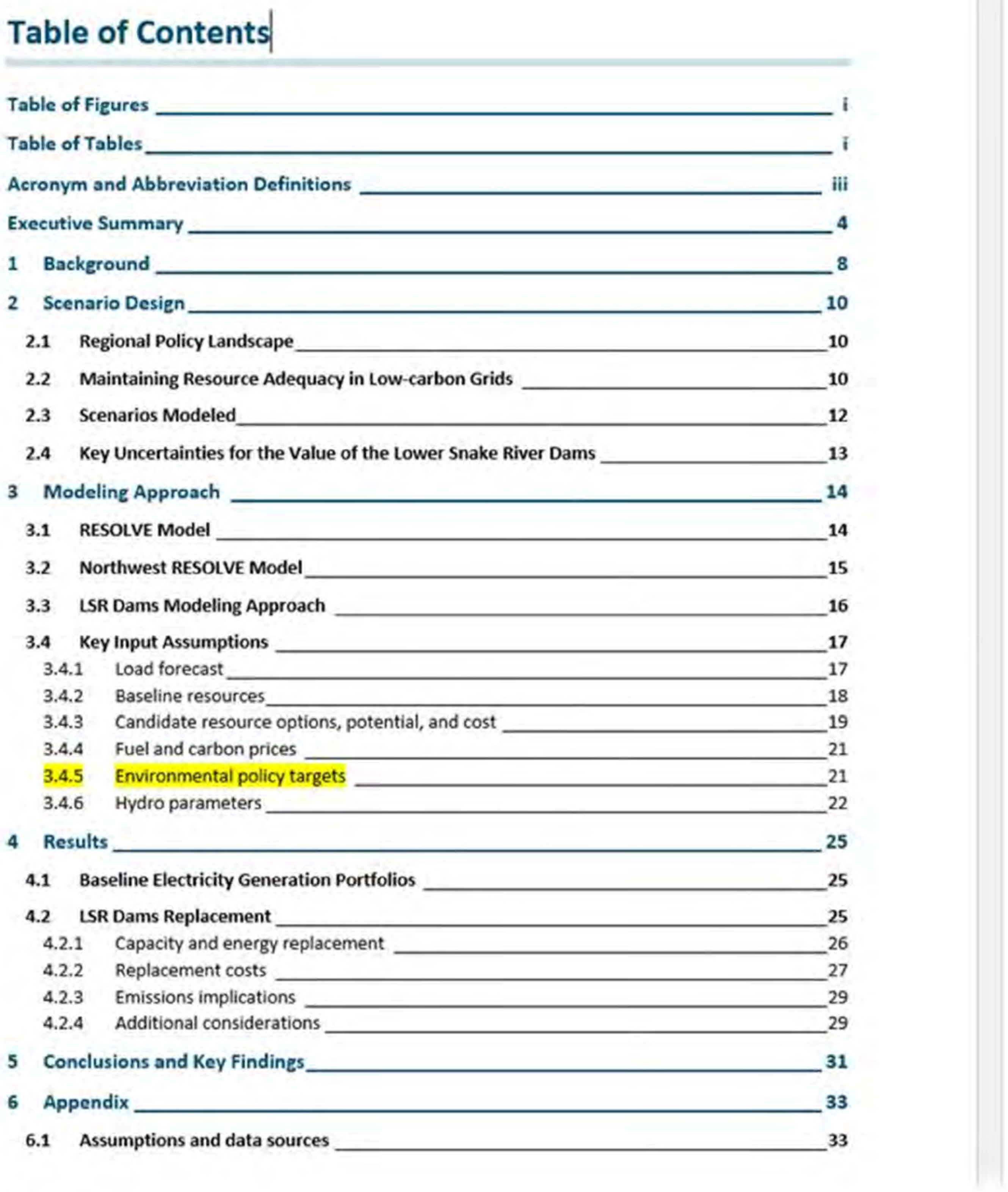

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All the best,

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: Stiffler,Peter B (BPA) - KSL-4
Sent: Thursday, June 30, 2022 2:23 PM
To: Ashby,Gordon S (BPA) - PGA-6; James,Eve A L (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5; Lennox,Alexander (BPA) - FTR-2
Cc: Koehler,Birgit G (BPA) - PG-5
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

50 years seems most consistent with other analysis. Ultimately, it should be tied to the useful life of the LSR dams. If storage assets have 10 year useful, and LSR dams are expected to last 50 years, then full modelling would include 5 tranches of battery additions.

It sounds like E3 is using production cost modelling to make resource build decisions, so they would then be accounting for this.

From: Ashby,Gordon S (BPA) - PGA-6 <gsashby@bpa.gov>
Sent: Thursday, June 30, 2022 1:44 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Stiffler,Peter B (BPA) - KSL-4 <pbstiffler@bpa.gov>; Lennox,Alexander (BPA) - FTR-2 <alennox@bpa.gov>
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Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

We typically used a 50-year NPV analysis for hydro projects. I don't think that there is a comparable number in the EIS. The Corps presented the differences in scenarios in terms of average annual costs. I can't remember there being NPVs anywhere that compared the expected future value of generation and project costs with and without the LSRDs. Birgit and I put together a question response that put some additional perspective around net benefits, but those were again on an average annual basis using the information the Corps put together. For context, I believe the Corps' average annual calculations were also done on 50 years of data. That's how much I provided for Capital and O&M anyway.

Gordon

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Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: FW: Draft Exec Summary

Deliberative, FOIA exempt

Hello-
Let me know what your thoughts are on this- does one method work better for comparing to the CRSO EIS analysis? I'm not sure who all worked on this type of NPV analysis for the CRSO EIS or who might have helpful thoughts on how to respond to E3 since this is out of my realm of expertise.

Thanks,

Eve

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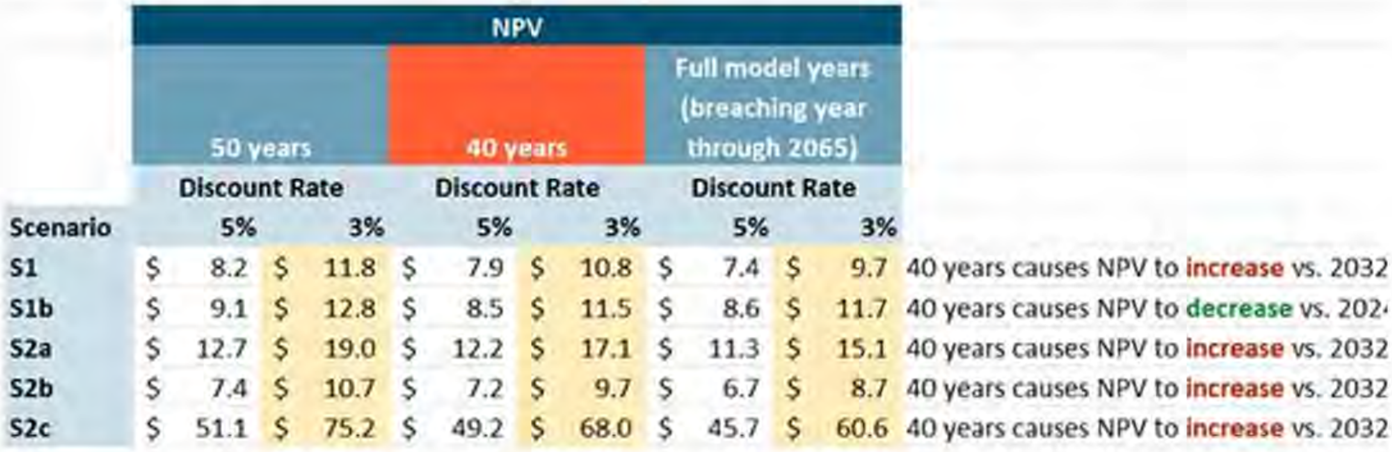
Sent: Thursday, June 30, 2022 1:16 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Arne Olson <arne@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: [EXTERNAL] RE: Draft Exec Summary

Deliberative, FOIA exempt

Ok, hopefully the last question before we finalize the NPV values. We were previously using the year of breaching to the end of the RESOLVE modeling horizon (2045 + 20 years of end effects, ie 2065). We calculated NPVs instead using 40 years or 50 years, e.g. 40 years would be 2024-2064 or 2032-2072 (we extend the 2045 RESOLVE modeled year out as far as needed to do this). The results are below. I'll note that the Inslee/Murray report uses a 50-year timeline for its NPV calculation.

Can you review the table below and advise thoughts on using 40 years vs. 50 years for the NPV calculation? We think either of those is better than the current approach, that ends up using a different number of years for the 2024 breaching case, driving an artificial difference between S1 an S2b. All values below are 2022$ billion.



	NPV						
	50 years		40 years		Full model years (breaching year through 2065)		
	Discount Rate		Discount Rate		Discount Rate		
Scenario	**5%**	**3%**	**5%**	**3%**	**5%**	**3%**	
S1	$ 8.2	$ 11.8	$ 7.9	$ 10.8	$ 7.4	$ 9.7	40 years causes NPV to increase vs. 2032
S1b	$ 9.1	$ 12.8	$ 8.5	$ 11.5	$ 8.6	$ 11.7	40 years causes NPV to decrease vs. 202
S2a	$ 12.7	$ 19.0	$ 12.2	$ 17.1	$ 11.3	$ 15.1	40 years causes NPV to increase vs. 2032
S2b	$ 7.4	$ 10.7	$ 7.2	$ 9.7	$ 6.7	$ 8.7	40 years causes NPV to increase vs. 2032
S2c	$ 51.1	$ 75.2	$ 49.2	$ 68.0	$ 45.7	$ 60.6	40 years causes NPV to increase vs. 2032

I should also note that the Energy GPS study seems to use no discounting at all (just a 2% inflation adjustment), which could lend itself to critique of over-inflation of the NPV values. Something to be aware of when comparing the numbers.

Note: the other thing we plan to add to the report is a sensitivity using higher storage ELCCs (that are more aligned with the latest GENESYS runs showing higher summer vs. winter risk). That sensitivity showed that more storage gets built to displace gas additions, but it shows basically no change in the replacement resources and costs for the LSR dams. This basically shows that you could add some short duration storage to push the risk back into the winter (since we did not lower the LSR dam contributions assuming the risk stays in the summer long term). We saturate battery storage either way (i.e. either at 2 GW or 10 GW) and need alternative resources to cost effectively replace the dams capacity. It's a fairly rough sensitivity (we only adjusted storage ELCCs), but directionally provides some good validation that storage can't replace the dams in context of the broader regional needs... We're working to add – **let us know if you have any thoughts on this**.

All the best,
Aaron

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Deliberative, FOIA exempt

Thanks Aaron- I was following up on a highlighted section in the report about the public power cost of capital and this is in closer alignment with what the 2022 WACC for BPA uses in planning which is 2.81%. Using 3% will be much closer to what we use and closer to how other reports are calculating the discount rates and our assumptions.

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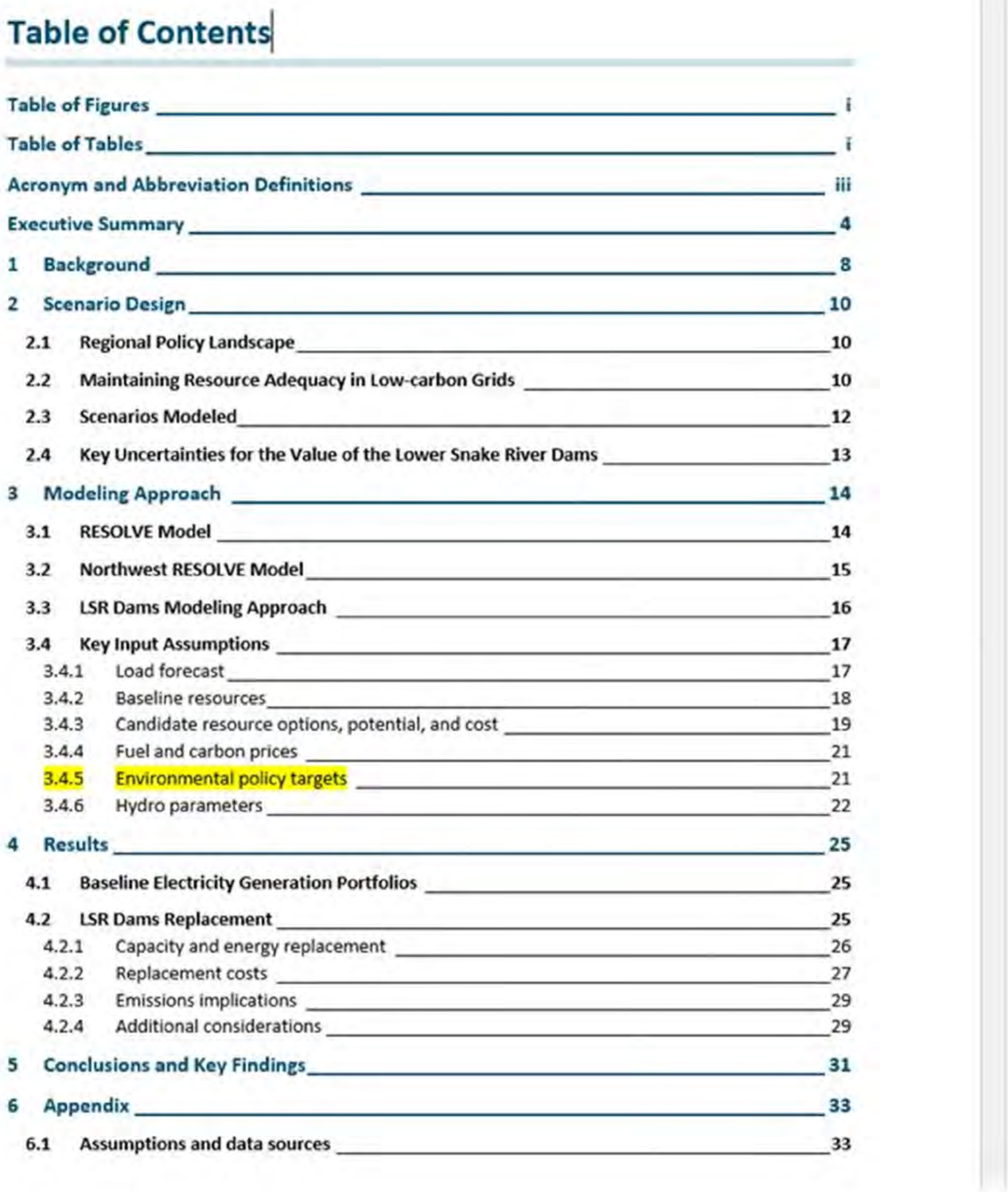

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All the best,

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: Lennox,Alexander (BPA) - FTR-2
Sent: Thursday, June 30, 2022 1:38 PM
To: James,Eve A L (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5; Stiffler,Peter B (BPA) - KSL-4; Ashby,Gordon S (BPA) - PGA-6
Cc: Koehler,Birgit G (BPA) - PG-5
Subject: RE: Draft Exec Summary

This is outside of my expertise as well. I'll let the economists opine.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 30, 2022 1:33 PM
To: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Stiffler,Peter B (BPA) - KSL-4 <pbstiffler@bpa.gov>; Ashby,Gordon S (BPA) - PGA-6 <gsashby@bpa.gov>; Lennox,Alexander (BPA) - FTR-2 <alennox@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: FW: Draft Exec Summary

Deliberative, FOIA exempt

Hello-
Let me know what your thoughts are on this- does one method work better for comparing to the CRSO EIS analysis? I'm not sure who all worked on this type of NPV analysis for the CRSO EIS or who might have helpful thoughts on how to respond to E3 since this is out of my realm of expertise.

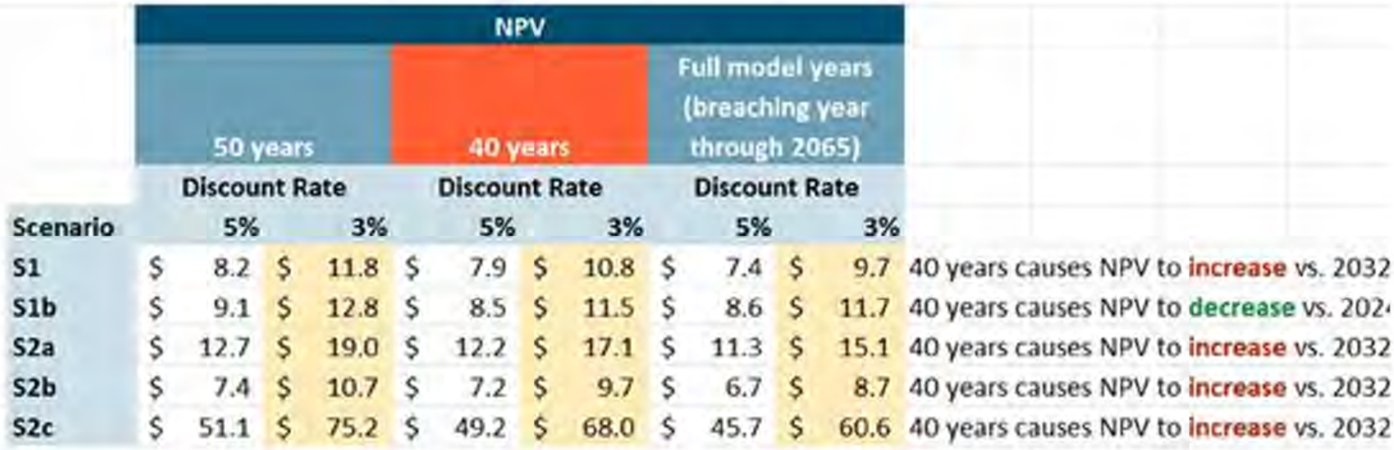
Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 30, 2022 1:16 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

Ok, hopefully the last question before we finalize the NPV values. We were previously using the year of breaching to the end of the RESOLVE modeling horizon (2045 + 20 years of end effects, ie 2065). We calculated NPVs instead using 40 years or 50 years, e.g. 40 years would be 2024-2064 or 2032-2072 (we extend the 2045 RESOLVE modeled year out as far as needed to do this). The results are below. I'll note that the Inslee/Murray report uses a 50-year timeline for its NPV calculation.

Can you review the table below and advise thoughts on using 40 years vs. 50 years for the NPV calculation? We think either of those is better than the current approach, that ends up using a different number of years for the 2024 breaching case, driving an artificial difference between S1 an S2b. All values below are 2022$ billion.



	NPV						
	50 years		40 years		Full model years (breaching year through 2065)		
	Discount Rate		Discount Rate		Discount Rate		
Scenario	5%	3%	5%	3%	5%	3%	
S1	$ 8.2	$ 11.8	$ 7.9	$ 10.8	$ 7.4	$ 9.7	40 years causes NPV to increase vs. 2032
S1b	$ 9.1	$ 12.8	$ 8.5	$ 11.5	$ 8.6	$ 11.7	40 years causes NPV to decrease vs. 202
S2a	$ 12.7	$ 19.0	$ 12.2	$ 17.1	$ 11.3	$ 15.1	40 years causes NPV to increase vs. 2032
S2b	$ 7.4	$ 10.7	$ 7.2	$ 9.7	$ 6.7	$ 8.7	40 years causes NPV to increase vs. 2032
S2c	$ 51.1	$ 75.2	$ 49.2	$ 68.0	$ 45.7	$ 60.6	40 years causes NPV to increase vs. 2032

I should also note that the Energy GPS study seems to use no discounting at all (just a 2% inflation adjustment), which could lend itself to critique of over-inflation of the NPV values. Something to be aware of when comparing the numbers.

Note: the other thing we plan to add to the report is a sensitivity using higher storage ELCCs (that are more aligned with the latest GENESYS runs showing higher summer vs. winter risk). That sensitivity showed that more storage gets built to displace gas additions, but it shows basically no change in the replacement resources and costs for the LSR dams. This basically shows that you could add some short duration storage to push the risk back into the winter (since we did not lower the LSR dam contributions assuming the risk stays in the summer long term). We saturate battery storage either way (i.e. either at 2 GW or 10 GW) and need alternative resources to cost effectively replace the dams capacity. It's a fairly rough sensitivity (we only adjusted storage ELCCs), but directionally provides some good validation that storage can't replace the dams in context of the broader regional needs… We're working to add – **let us know if you have any thoughts on this**.

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 30, 2022 6:58 AM
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

Thanks Aaron- I was following up on a highlighted section in the report about the public power cost of capital and this is in closer alignment with what the 2022 WACC for BPA uses in planning which is 2.81%. Using 3% will be much closer to what we use and closer to how other reports are calculating the discount rates and our assumptions.

From: Aaron Burdick <aaron.burdick@ethree.com>
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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Sounds good- thanks Aaron!

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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>
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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

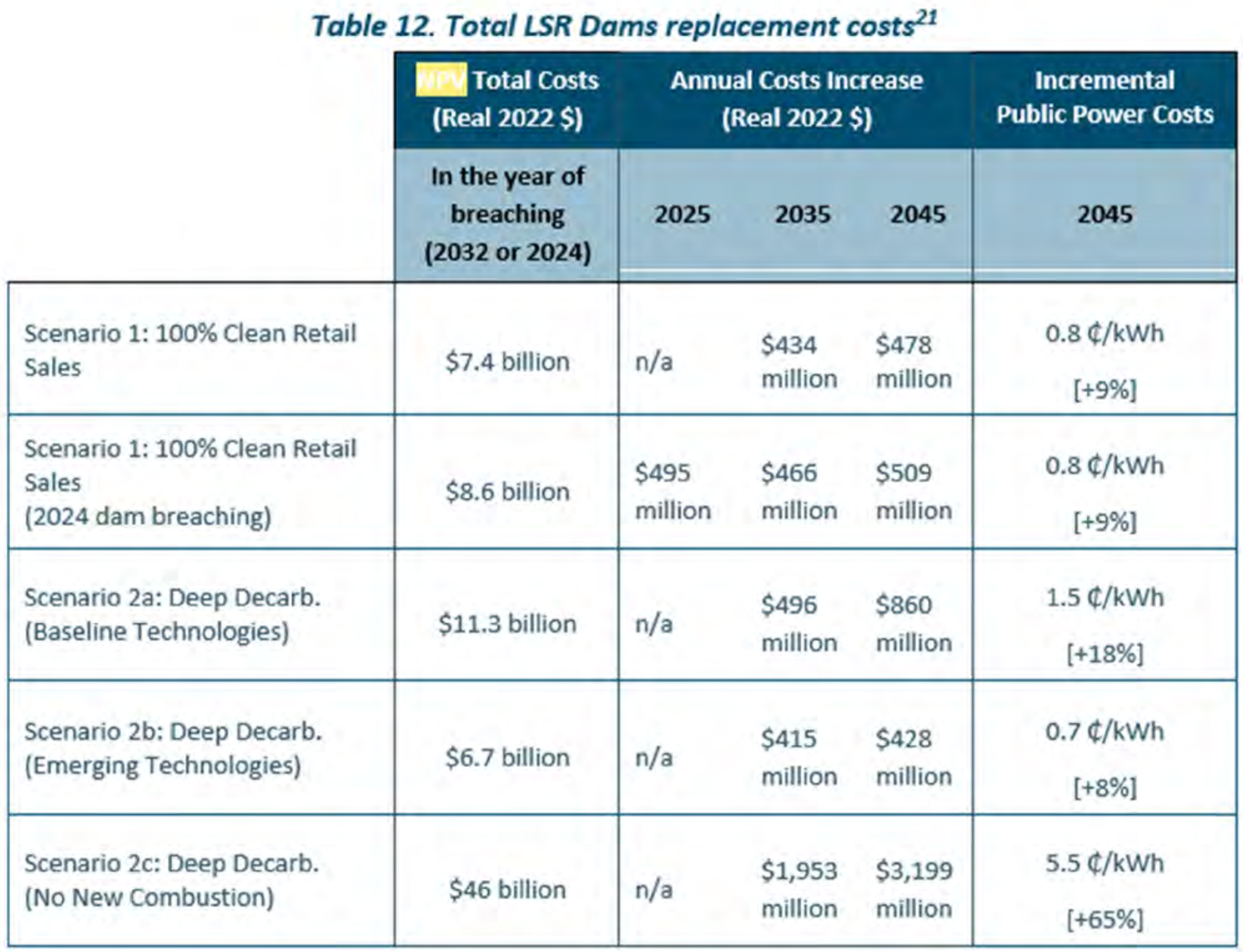

Table 12. Total LSR Dams replacement costs[21]

	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

---

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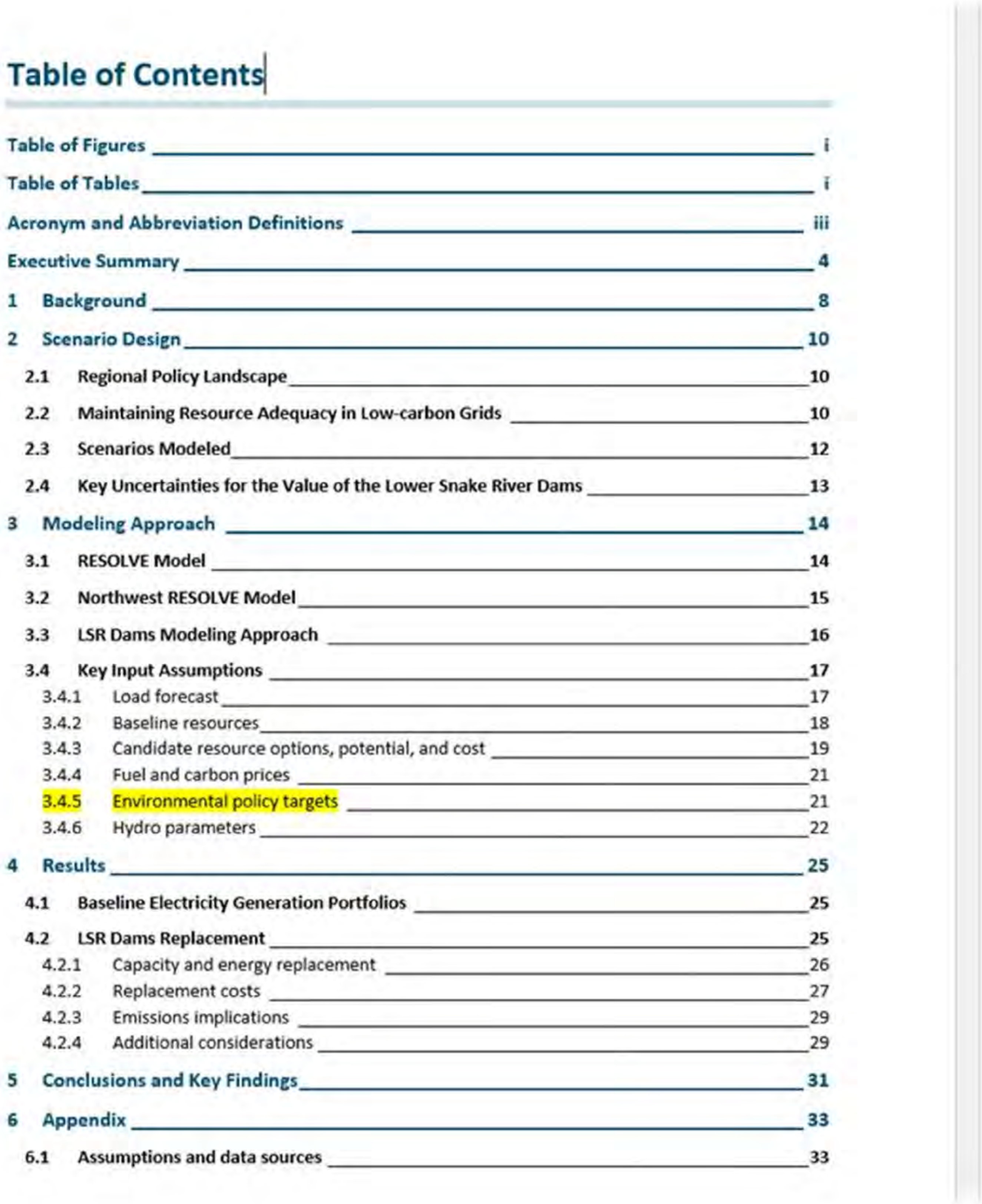

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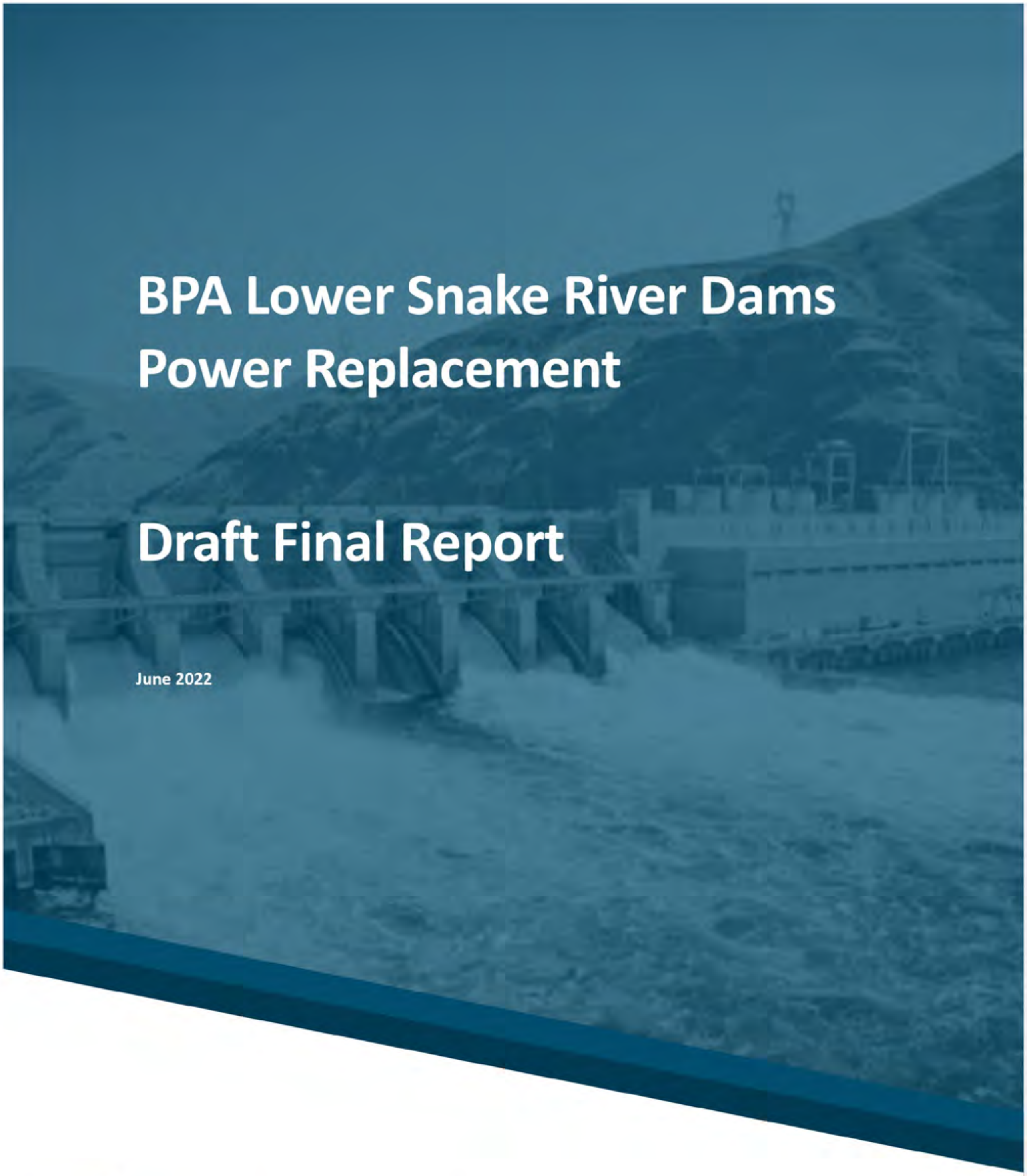
Aaron Burdick, Associate Director
Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500 | San Francisco, CA 94104

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



BPA Lower Snake River Dams Power Replacement

Draft Final Report

June 2022

Energy+Environmental Economics

BPA Lower Snake River Dams Power Replacement

Draft Final Report

June 2022

Energy and Environmental Economics, Inc. (E3)
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San Francisco, CA 94104

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Project Team:

Arne Olson

Aaron Burdick

Sierra Spencer

Dr. Angineh Zohrabian

Sam Kramer

Jack Moore

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Table of Tables

Acronym and Abbreviation Definitions

Comment [AZ1]: Reminder to put in the alphabetical order in the end

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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
NG	Natural Gas
H2 (maybe others from the table listing replacement resources for the LSN?)	Hydrogen
LDV, HDV	From Figure 7
CES and RPS	
BTM Solar	

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.

Comment [EAJ2]: Should this be 2,300 to match the firm capacity # in the graphic- or maybe the graphic needs to be updated?

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/

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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.

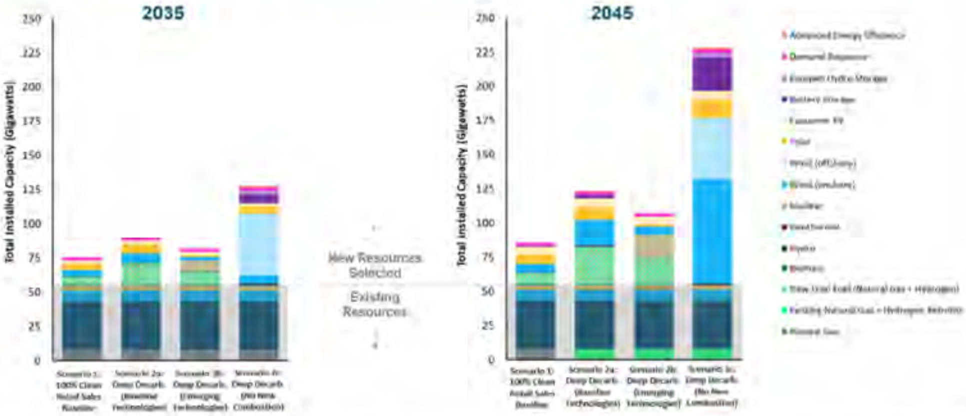
Table 1. Scenario Design

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)	[illegible]	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 [illegible] + 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%]

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Comment [AB3]: Note to BPA: we re-examined these and there were some generally small changes to the values (including removing previous rounding). Exception is the 2024 breaching. The prior NPV was too high and this updated value is correct.

We also propose to use the 3% discount rate that better represents the public power cost of capital.

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

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[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.

Comment [EAJ4]: Same as above- either 2,300 or graphic change. These values should match

Field Code Changed

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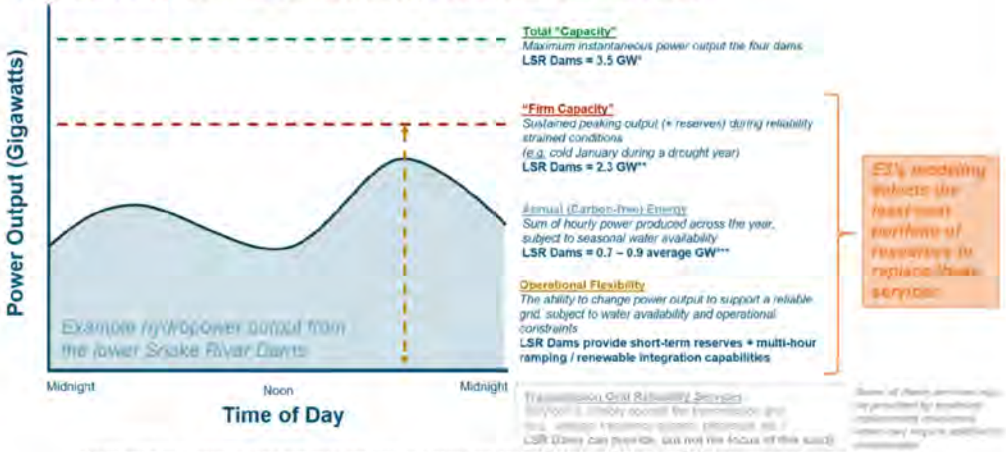
[7] Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. The "total capacity" refers to the overload capacity, not the nameplate capacity. Historical peak generation was 3,431 MW.

[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.

Comment [EAJ5]: Should be consistent with the language change in the Executive summary

Comment [EAJ6]: Doesn't match 900 value in paragraph text above

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.

Comment [EAJ7]: Not sure if you want to put in a footnote I grabbed from the peer review document "The study examines LSRD breaching in 10 years (2032) and in 2 years (2024), consistent with the approach used in the CRSO EIS" – it seems like that questions gets asked a lot when the 2024 date is mentioned.

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.

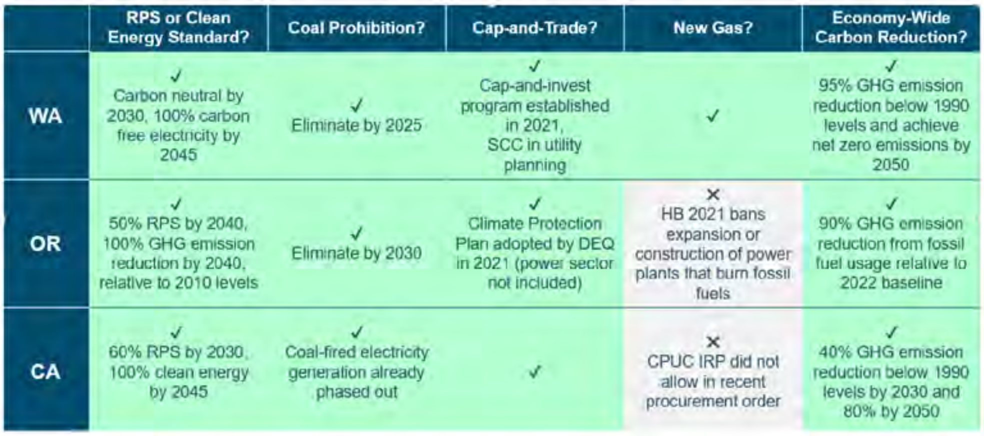
2 Scenario Design

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

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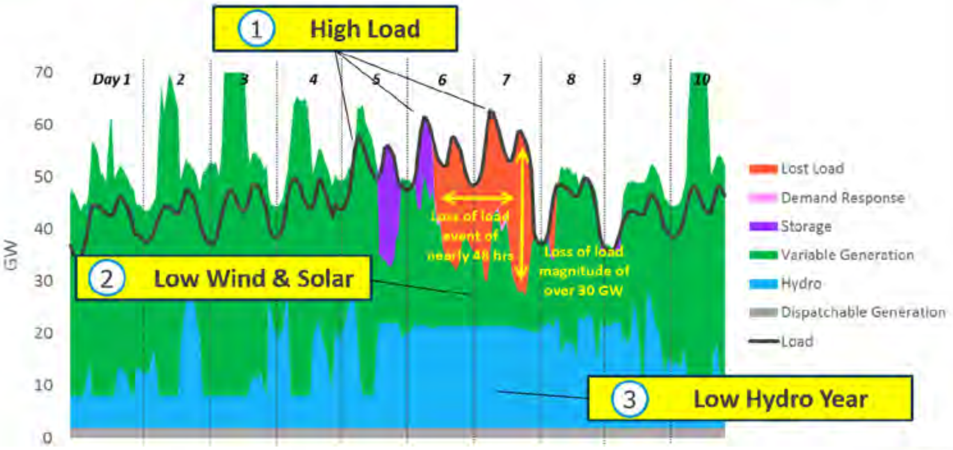
[12] E3, 2019. *Resource Adequacy in the Pacific Northwest.* https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

additional firm generating capacity may be needed, even in scenarios that add significant amounts 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 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
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

Comment [EAJ8]: Consider labeling a, b, c rather than 1,2,3 to match with the scenario names

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.

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Table 5~~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)

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3 Modeling Approach

3.1 RESOLVE Model

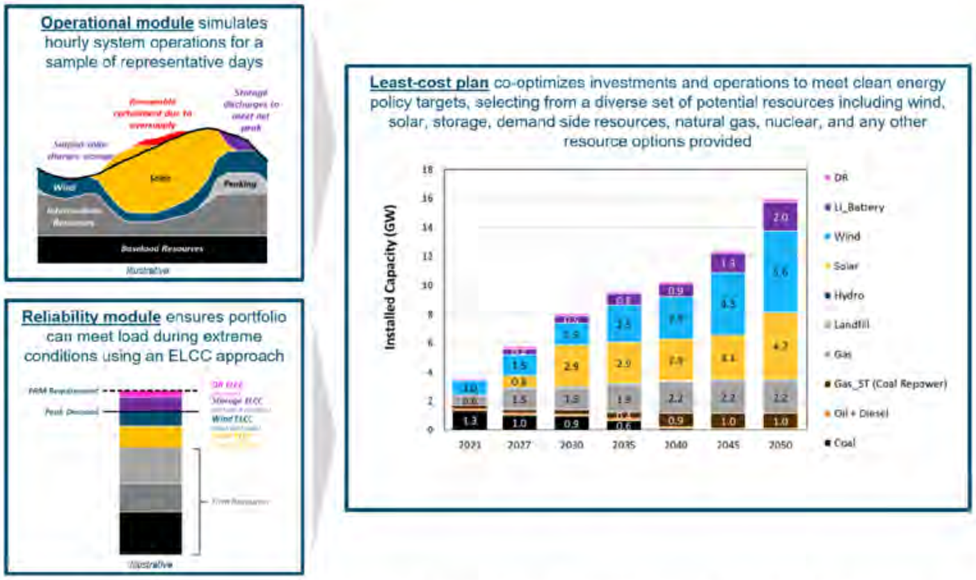
E3's Renewable Energy Solutions Model (RESOLVE) is used to perform a portfolio optimization of Northwest system's electric generating resource needs between 2025 and 2045. RESOLVE is an optimal capacity expansion and dispatch model that uses linear programming to identify optimal long-term generation 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



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

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

Least-cost plan co-optimizes investments and operations to meet clean energy policy targets, selecting from a diverse set of potential resources including wind, solar, storage, demand side resources, natural gas, nuclear, and any other resource options provided

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

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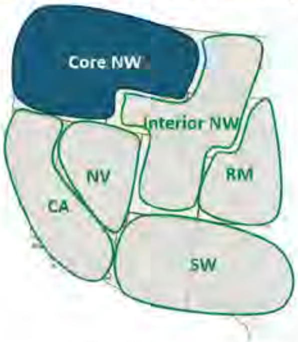
[14] Pacific Northwest Low Carbon Scenario Analysis - Achieving Least-Cost Carbon Emissions Reductions in the Electricity Sector, 2017. https://www.ethree.com/wp-content/uploads/2018/01/E3_PGP_GHGReductionStudy_2017-12-15_FINAL.pdf

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

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

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

Comment [EAJ9]: To really make it easy for the reader, consider adding "baseline" and "high electrification" above the left and right graphs in Figure 7. Also need to adjust the bracket so it doesn't include the light blue LDV which is also present in the baseline case- I think the bracket should just be dark blue through tan industrial?

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[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

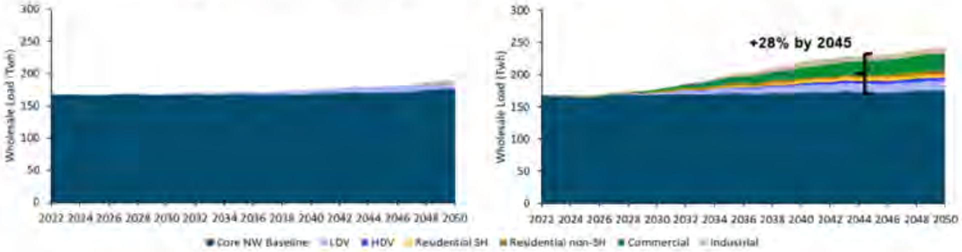

Figure 8 shows the peak demand impacts (including the 15% planning reserve margin) of the high electrification case relative to the baseline, showing a 68% increase by 2045. This high growth is driven by the winter peaking capacity required to replace the gas system peaking capacity to serve peak space heating needs.

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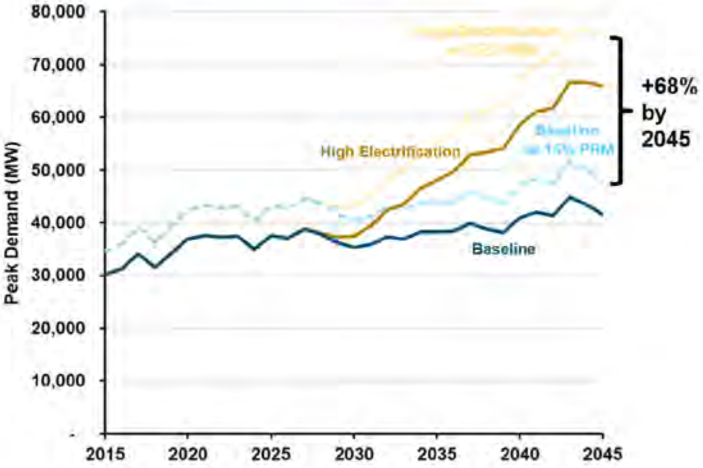
[16] Pacific Northwest Low Carbon Scenario Analysis - Achieving Least-Cost Carbon Emissions Reductions in the Electricity Sector, 2017. https://www.ethree.com/wp-content/uploads/2018/01/E3_PGP_GHGReductionStudy_2017-12-15_FINAL.pdf

Figure 8. Peak demand forecasts for Core Northwest

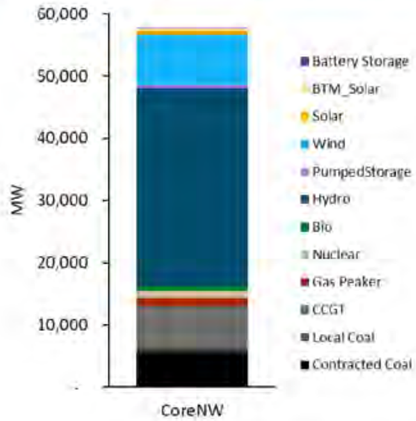


3.4.2 *Baseline resources*

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.

Comment [EAJ10]: Consider clarifying that this is no SMR, not sure if there is a term for conventional nuclear

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%

Comment [EAJ11]: Consider defining CES somewhere around here, either in the table caption or creatively including it in a sentence in the prior paragraph.

Otherwise it is not defined until 3.4.4. (acronyms are not what I am focusing on in the review, but I happen to struggle with remembering what CES stands for)

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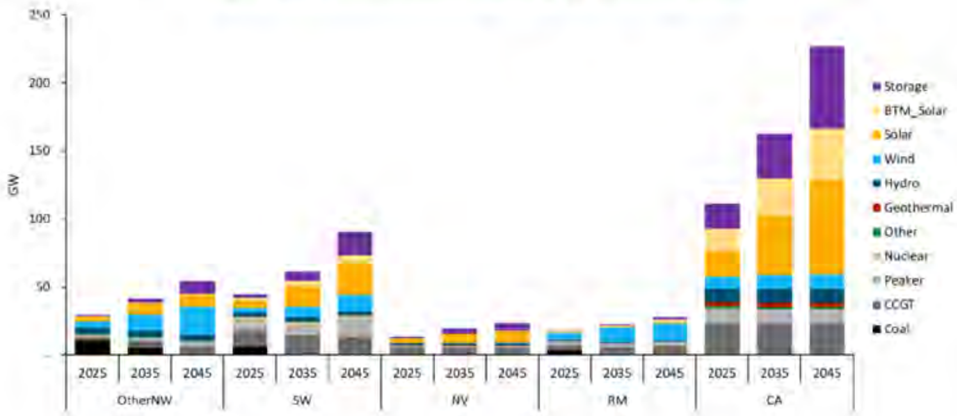
Figure 10. Total installed capacity for external zones



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	×	✓	×

Comment [EAJ12]: It seems that you are mostly using "no new combustion" as the primary name for 2c. So maybe put "limited tech" in parentheses or use "limited tech" in place of "no new combustion" throughout the report.

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.

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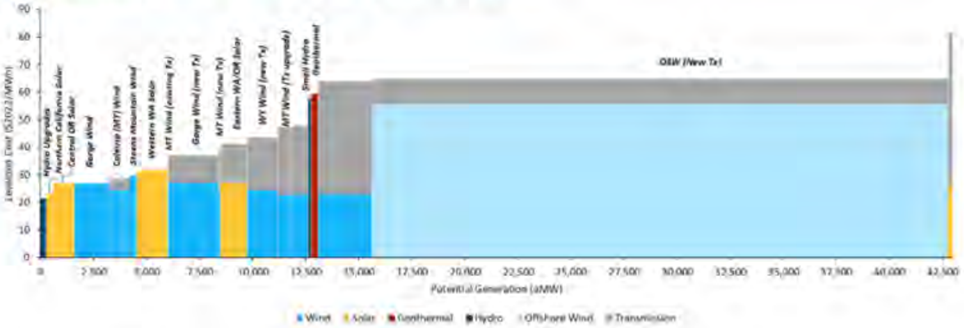
[17] Note: certain solar resources (i.e., Western WA solar) might require transmission upgrades to bring the supply to load centers, which are not captured.

Figure 11. Renewable resource supply curve in 2045

Comment [EAJ13]: For this figure, Transmission isn't a resource. Is it a limitation on the resource?



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%

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(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~~ capturinge 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

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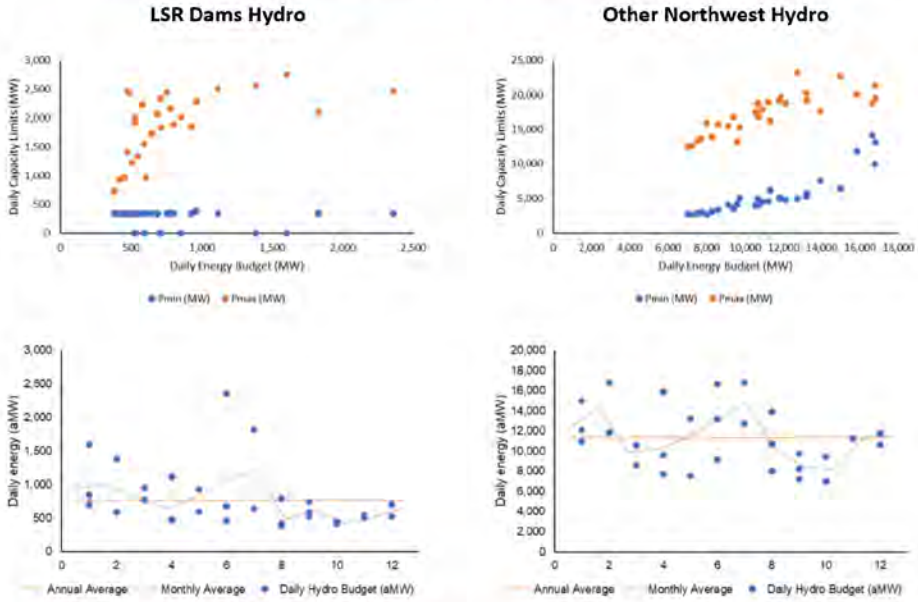
[18] While a clean energy standard is modeled in scenario 2, the mass-based carbon reduction target constraint is a more binding constraint, pushing the model beyond the minimum CES %'s shown here.

[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



LSR Dams Hydro

Other Northwest Hydro

Comment [AZ14]: Could spend some time to make these plots visually better.

Comment [AB15]: Not worth much time, but can you just increase the font size. These (and some other small font graphs) are a bit hard to read.

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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%

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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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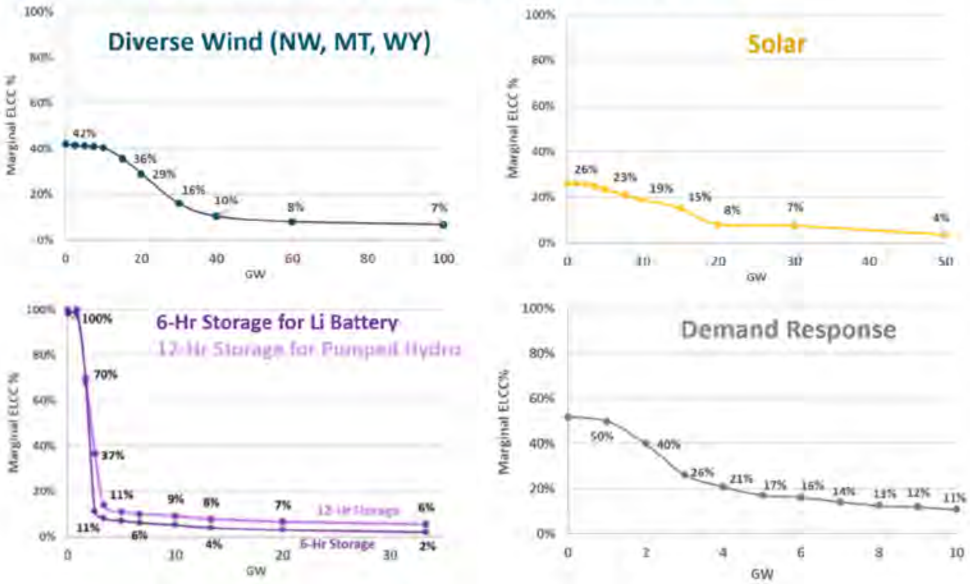
[20] Resource Adequacy in the Pacific Northwest, 2019. https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

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.

Comment [AB16]: E3 is still reviewing this case and deciding whether to include or not.

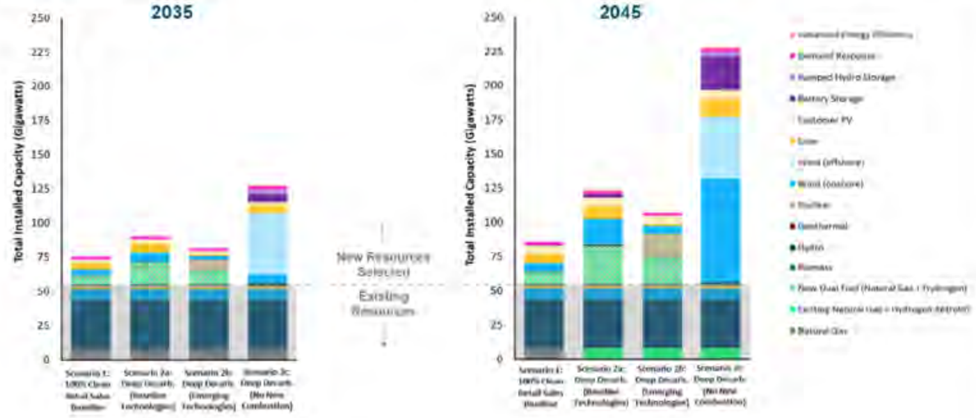
4 Results

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 targets 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



Comment [EAJ17]: Consider reminding the reader that you are talking about the case that includes LSN generation first, both in the text and the figure caption

Comment [EAJ18]: Use "are" throughout or "were" throughout

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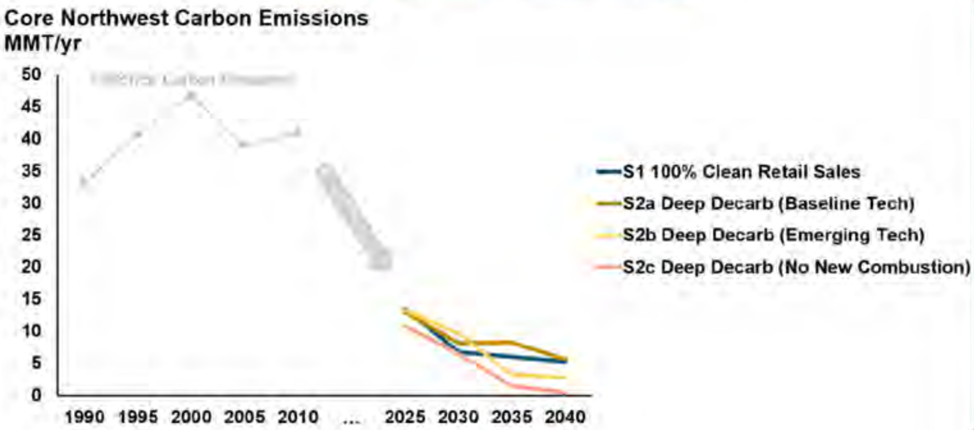
As shown in Figure 15 below, all four scenarios result in a sharp near-term decline in carbon emissions, driven by Washington and Oregon policies that drive coal retirement this decade. By 2045, Scenario 1, which requires 100% clean retail sales, shows an ~85% decline in carbon emissions relative to 1990 levels. Scenario 2 eliminates all carbon emissions by 2045.

Figure 15. Northwest Carbon Emissions



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Comment [AO19]: Don't we have 2015 or 2020 emissions?

Comment [20]: We had 2013 from the pgp study. Would take some work to update those calculations to get other years.

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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

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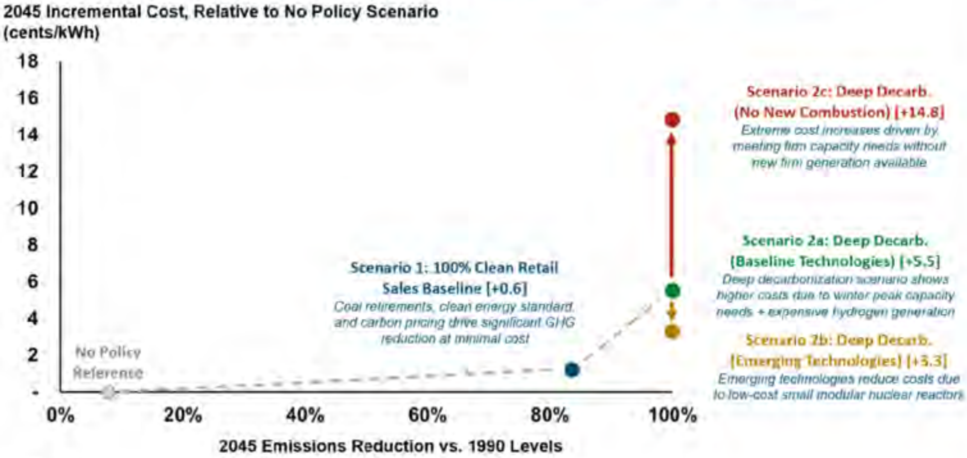
[21] The authors recognize that hydrogen can be used to generate electricity by fuel cells instead of combustion turbines. That scenario would look similar to Scenario 2a, where the combustion plant additions are replaced with many GW of fuel cells for firm capacity needs.

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 [illegible] + 0.1 GW wind	+ 10.6 GW wind + 1.4 GW solar

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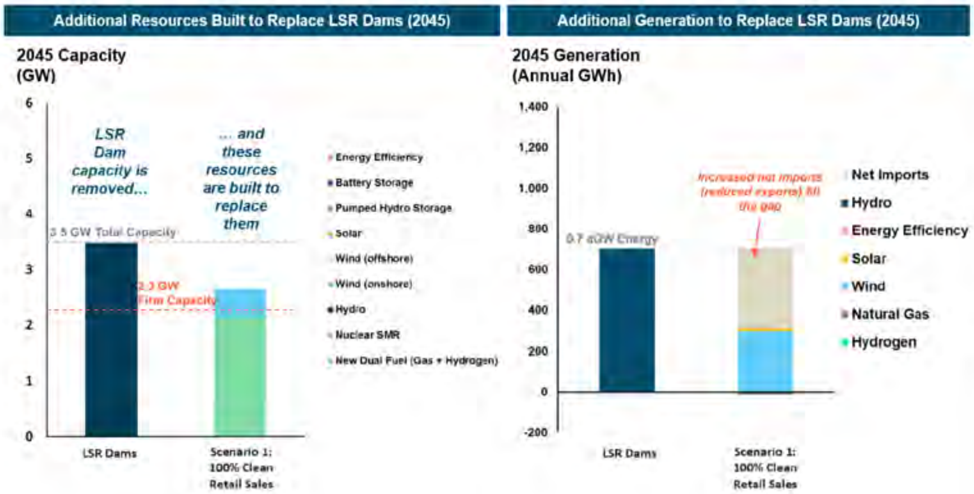
[22] Replacement resources are calculated by comparing the "with LSR dams" RESOLVE portfolio to the "without LSR dams" RESOLVE portfolio. This means some resources may be built in 2035, such as 0.3 GW of geothermal in scenario 2c, that were not built when the dams were included. However, those resources 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.

Comment [EAJ21]: Suggest adding "Scenario 1" to the footnote out of paranoia that someone would simply quote the footnote and take it out of context.

Figure 17. Scenario 1 Capacity Replacement, Energy Replacement, and Costs[23]



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[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 in Scenario 1.

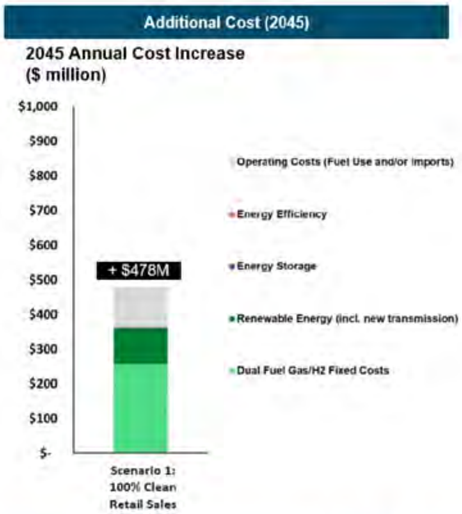
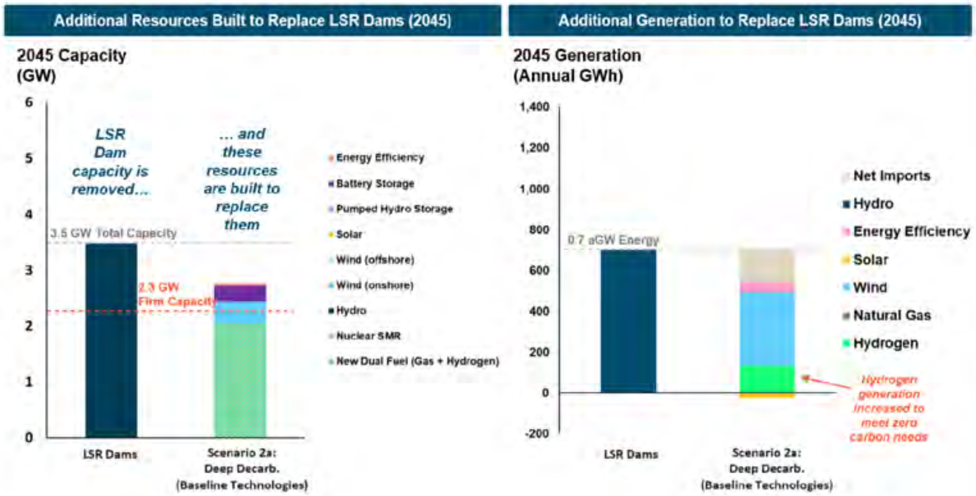
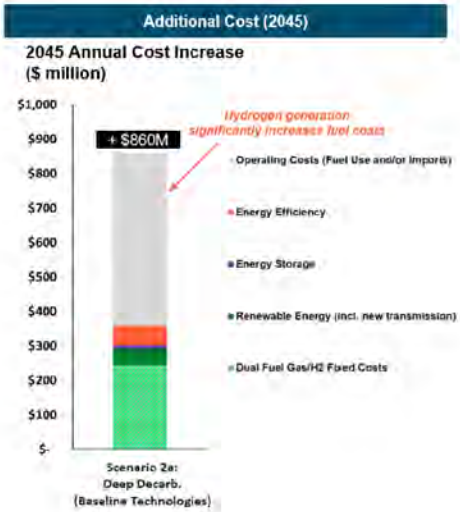


Figure 18. Scenario 2a Capacity Replacement, Energy Replacement, and Costs

Comment [EAJ22]: Should 2b and 2c info be included as well?





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.

Comment [EAJ23]: I think you mean "HIGHER" here?

Comment [EAJ24]: Suggested language revision in the footnote

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[24] 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 ~~which~~ 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[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

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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 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 section 4.1 above) which apply even without removing generation from the LSR dams.

Comment [EAJ25]: Maybe add "such as operations and maintenance costs"?

Table 12. Total LSR Dams replacement costs

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	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]

---

[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:

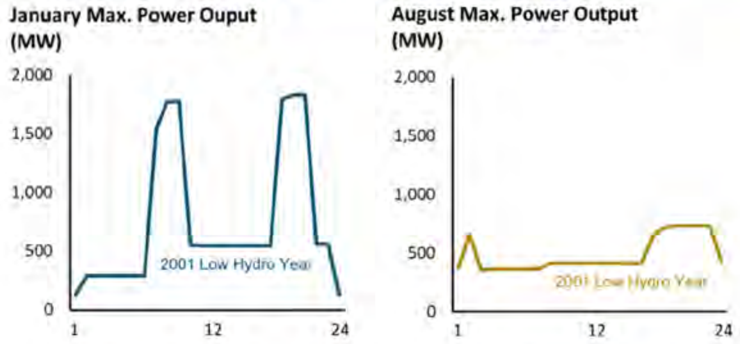
- **Annual energy output**: E3's existing RESOLVE model data uses historical hydro years 2001, 2005, and 2011 as representative of the regional long-term average low/mid/high hydro year conditions. The data for the Columbia River System dams was adjusted to reflect the Preferred Alternative operations defined in the CRSO EIS. However, for the LSR dams, these selected historical hydro years resulted in ~~this leads to~~ a relatively low output of ~700 average MW, whereas the dams may generate ~900 average MW on average across the full historicala 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 CRSO 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.

Comment [EAJ26]: If this acronym hasn't been used then "Columbia River System Operations Environmental Impact Statement"

Comment [AB27]: Eve/BPA to review and confirm

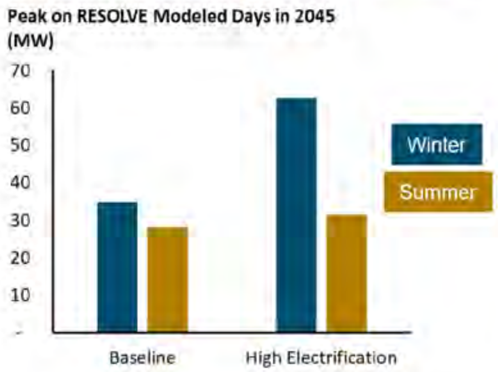
Figure 19. BPA-Modeled LSR Dam Output During the 2001 Low Hydro Year with CRSO EIS Preferred Alternative operations

Comment [EAJ28]: Might be worth adding if someone looks at chart without reading the detail in the text



- 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



- 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.

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Comment [AB29]: @Angineh Zohrabian to update if we have more info

5 Conclusions and Key Findings

Comment [AB30]: NOTE: copy of exec summary text. Update if/when exec summary text is updated.

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 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.

Comment [EAJ31]: Consider "generate" here and in similar sentence earlier. (My brain first went to black-start or to other reasons for having start-up issues, not so much what the text is intending of just plain dispatchability.

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

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[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 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.

Comment [EAJ32]: Consider adding "emerging" as a bit of an explanation for why they are not considered. (I know it is explained elsewhere, but many people will only read this section.)

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*

Comment [AB33]: @Anginéh Zohrabian - what about EE, DR, geothermal? Anything to say about those? Geo from ATB? EE/DR from NWPCC?

Comment [AZ34]: Added geothermal. We didn't do much with the cost adjustments for EE/DR so they were from before. We adjusted the capacity based on 2021 Power plan.

The technology fixed costs trajectories for candidate resource options are shown in **Error! Reference source 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

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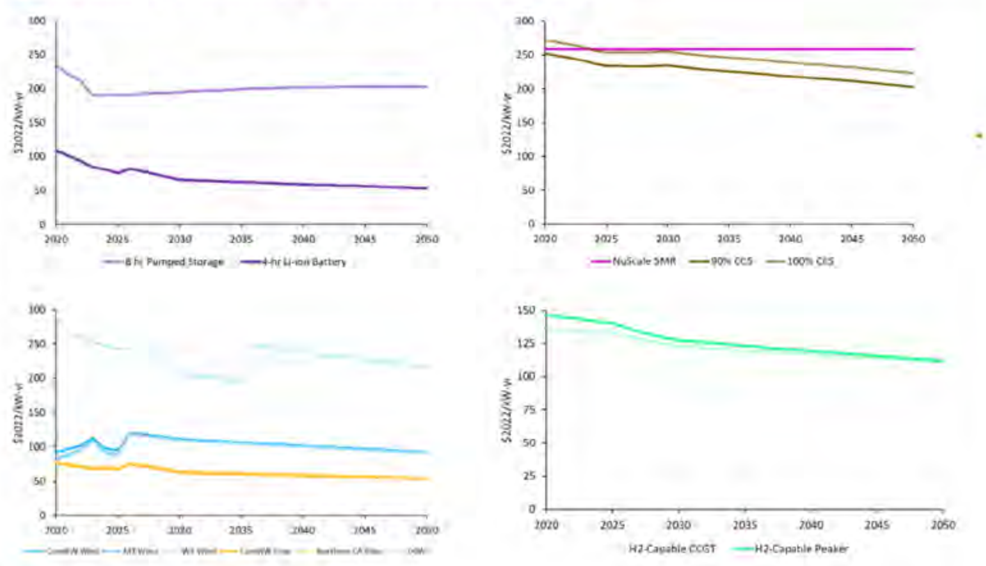
[32] Feron, P., Cousins, A., Jiang, K., Zhai, R., Thiruvenkatachari, R., & Burnard, K. (2019). Towards zero emissions from fossil fuel power stations. *International Journal of Greenhouse Gas Control*, 87, 188–202.

Figure 21. All-in fixed costs for candidate resource options



Comment [AO35]: Can we change to $/MWh please?

Comment [AO36]: ($/kWh for storage)

Comment [AB37]: @Angineh Zohrabian to update

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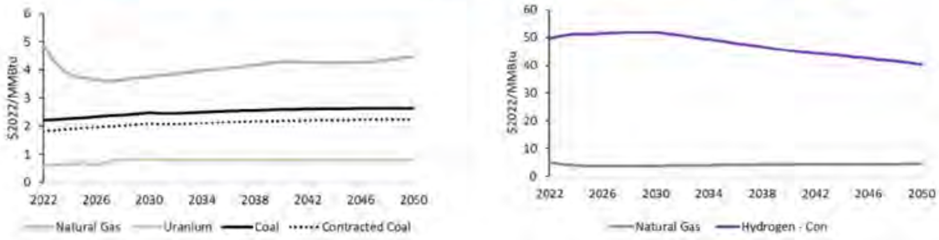
6.1.2 Fuel prices

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.

Comment [EAJ38]: Is this in acronym list? Also EIA

Figure 22. Fuel price forecasts for natural gas, coal, uranium, and hydrogen



Comment [EAJ39]: In legend what does Hydrogen-Con mean?

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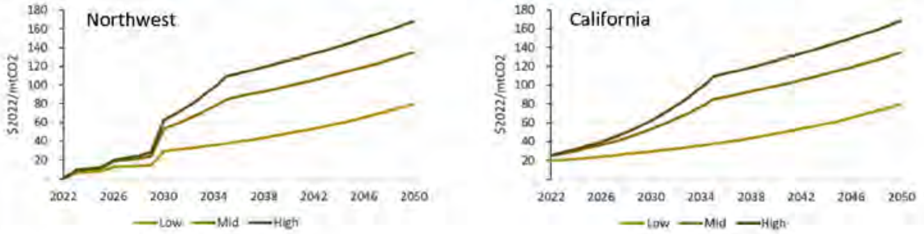
Annual average gas prices are further shaped according to a monthly profile to capture seasonal trends in the demand for natural gas and the consequent impact on pricing.

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.

Comment [AZ40]: Add citation

Figure 23. Carbon price forecasts for Northwest and California



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6.1.4 Operating Reserves

Comment [JA41]: Has Bart McManus had a chance to review this?

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 would be ~~is~~ 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. 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 is important for the proper operation of protective relaying schemes~~can be sustained; exact contribution depends on the hydro generator type~~.

Comment [AB42]: Q for BPA - NWEC did some transmission analysis in their 2018 study. Is it appropriate to reference that work? Or should we keep it generic?

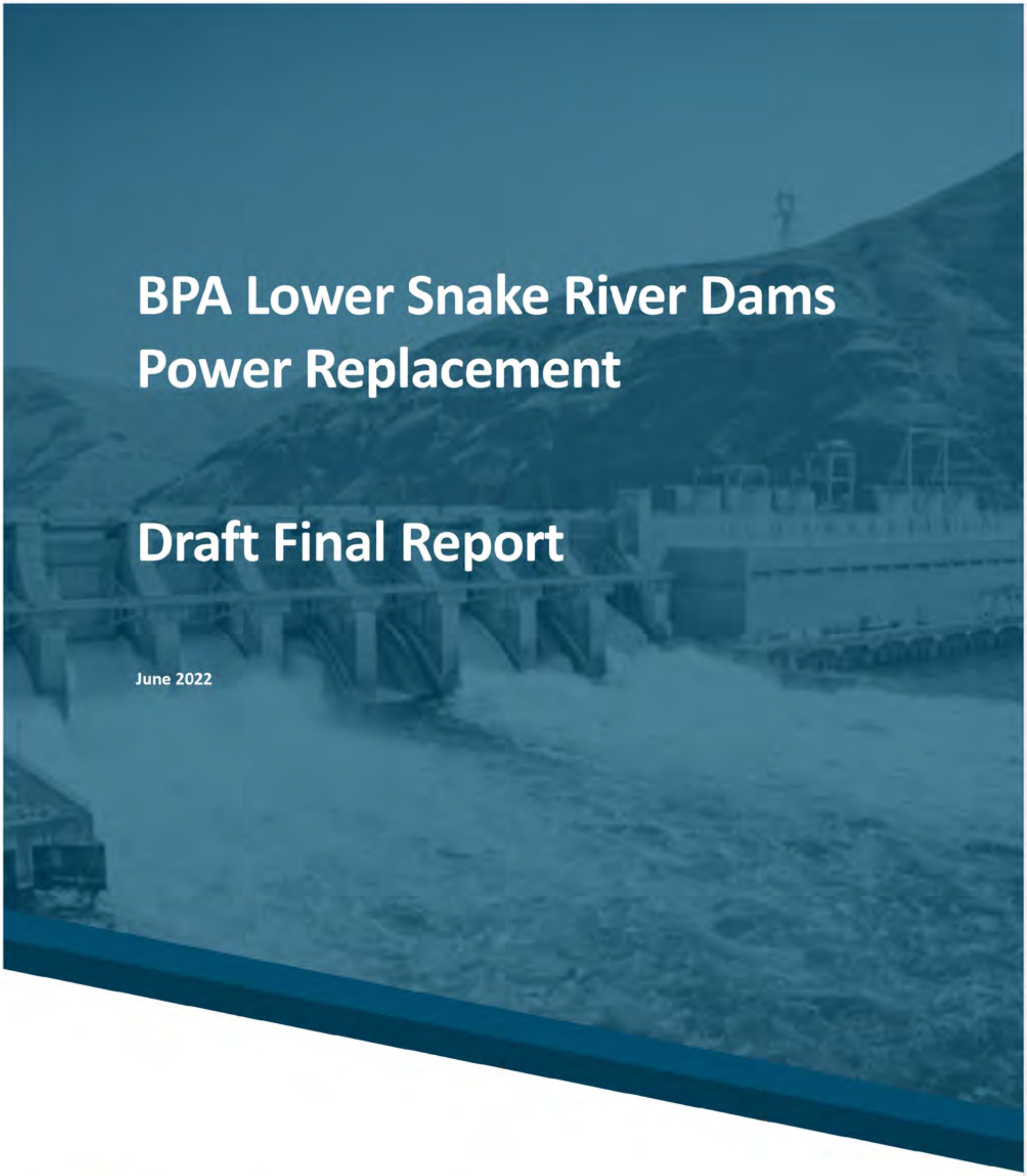
Comment [AB43]: Also, note that I incorporated BPA Tx team's feedback here, but would welcome their review of this appendix before we publish.

Comment [EAJ44]: Maybe instead say "comparatively small" since they are still big costs, just not as big as the RESOLVE modeled costs.

Comment [JA45]: I think the term "relatively small" should be removed. I don't think we fully know what all the costs will be in order to fully replace on these various services.

Comment [JA46]: I am not sure that this statement is technically correct. It is also unclear as to what they consider "small hydro" to be. Our Lower Columbia projects are considered low head, but they are certainly not small.

Comment [AB47]: BPA - we propose deleting this appendix placeholder section that was here on the Regional Capacity Needs. There already is a ton of info out there on near-term capacity needs, the report is quite long already, and we don't have much extra budget to draft a comprehensive appendix here. Please confirm you're ok dropping it or your thoughts.



BPA Lower Snake River Dams Power Replacement

Draft Final Report

June 2022

Energy+Environmental Economics

BPA Lower Snake River Dams Power Replacement

Draft Final Report

June 2022

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Acronym and Abbreviation Definitions

Comment [AZ1]: Reminder to put in the alphabetical order in the end

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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
NG	Natural Gas
H2 (maybe others from the table listing replacement resources for the LSN?)	Hydrogen
LDV, HDV	From Figure 7
CES and RPS	
BTM Solar	
CRSO EIS	Columbia River System Operations Environmental Impact Statement

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.

Comment [EAJ2]: Should this be 2,300 to match the firm capacity # in the graphic- or maybe the graphic needs to be updated?

Comment [EAJ3]: Consider adding a footnote "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)". I know it is described in further in the text but some may only read the Executive Summary.

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.

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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 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/

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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.

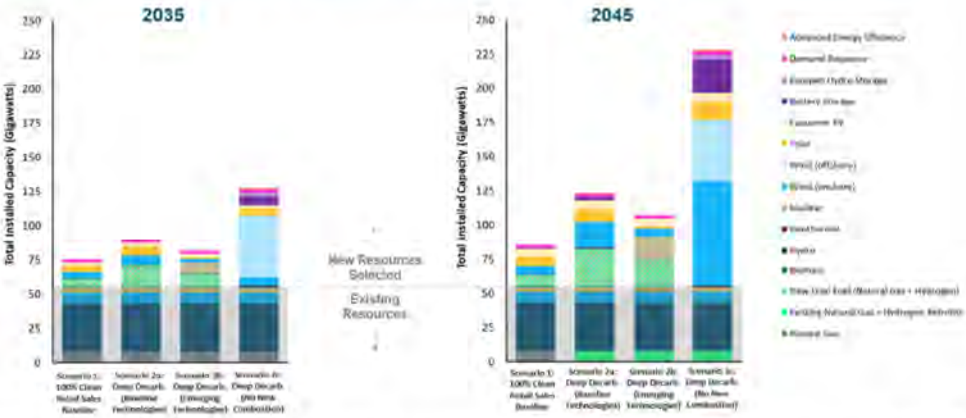
Table 1. Scenario Design

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)		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 pumped [illegible] + 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%]

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Comment [AB4]: Note to BPA: we re-examined these and there were some generally small changes to the values (including removing previous rounding). Exception is the 2024 breaching. The prior NPV was too high and this updated value is correct.

We also propose to use the 3% discount rate that better represents the public power cost of capital.

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

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[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 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 $61 billion NPV cost)

Comment [EAJ5]: Consider adding this term- DOE peer review seemed confused with deep decarbonization term since 100% retail sales also results in decarbonization with coal and NG retiring

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.

Comment [EAJ6]: Same as above- either 2,300 or graphic change. These values should match

Field Code Changed

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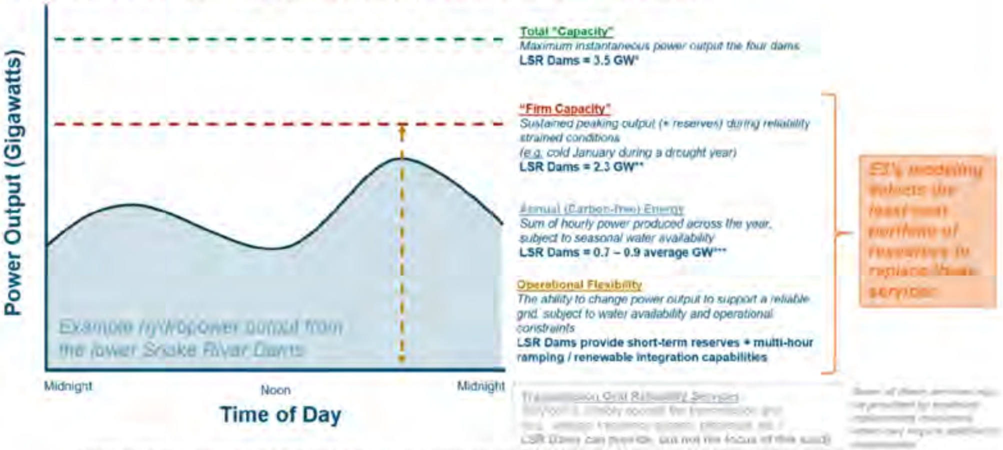
[7] Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. The "total capacity" refers to the overload capacity, not the nameplate capacity. Historical peak generation was 3,431 MW.

[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.

Comment [EAJ7]: Should be consistent with the language change in the Executive summary

Comment [EAJ8]: Doesn't match 900 value in paragraph text above

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.

Comment [EAJ9]: Not sure if you want to put in a footnote I grabbed from the peer review document "The study examines LSRD breaching in 10 years (2032) and in 2 years (2024), consistent with the approach used in the CRSO EIS" – it seems like that questions gets asked a lot when the 2024 date is mentioned.

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.[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.

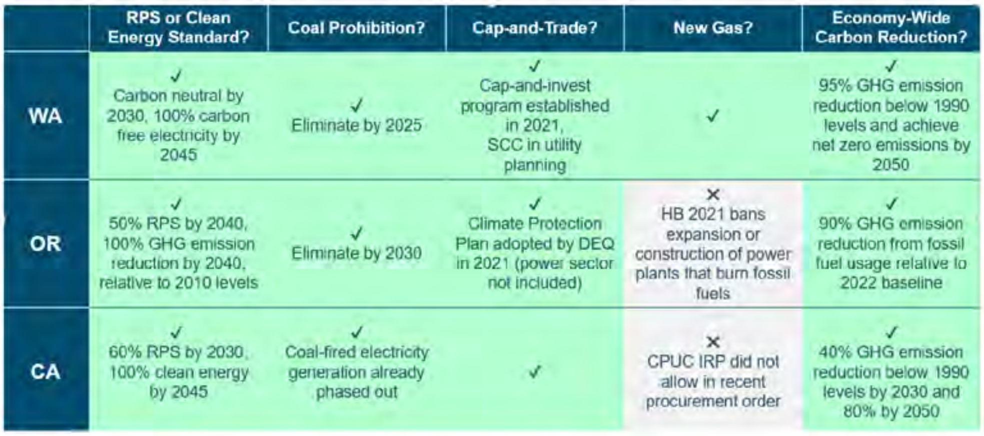
2 Scenario Design

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, 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.

[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

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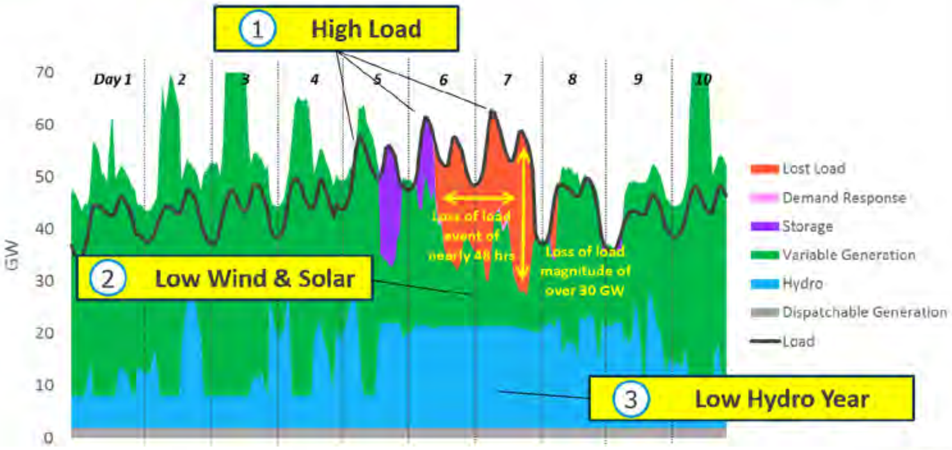
[12] E3, 2019. *Resource Adequacy in the Pacific Northwest.* https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

additional firm generating capacity may be needed, even in scenarios that add significant amounts 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 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
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

Comment [EAJ10]: Consider labeling a, b, c rather than 1,2,3 to match with the scenario names

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.

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Table 5~~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)

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3 Modeling Approach

3.1 RESOLVE Model

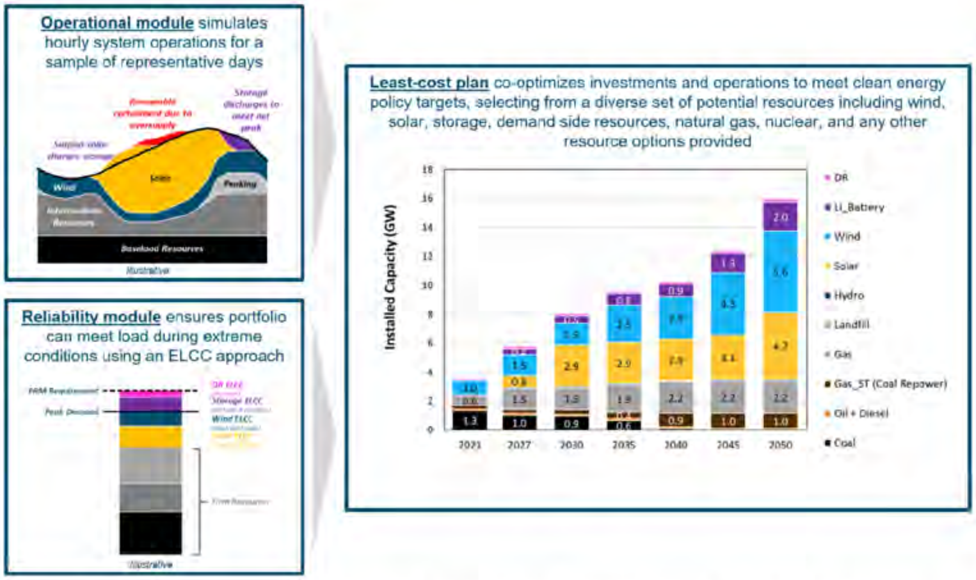
E3's Renewable Energy Solutions Model (RESOLVE) is used to perform a portfolio optimization of Northwest system's electric generating resource needs between 2025 and 2045. RESOLVE is an optimal capacity expansion and dispatch model that uses linear programming to identify optimal long-term generation 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



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

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

Least-cost plan co-optimizes investments and operations to meet clean energy policy targets, selecting from a diverse set of potential resources including wind, solar, storage, demand side resources, natural gas, nuclear, and any other resource options provided

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

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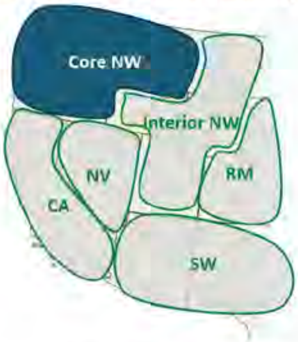
[14] Pacific Northwest Low Carbon Scenario Analysis - Achieving Least-Cost Carbon Emissions Reductions in the Electricity Sector, 2017. https://www.ethree.com/wp-content/uploads/2018/01/E3_PGP_GHGReductionStudy_2017-12-15_FINAL.pdf

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

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

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~~ 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

Comment [EAJ11]: To really make it easy for the reader, consider adding "baseline" and "high electrification" above the left and right graphs in Figure 7. Also need to adjust the bracket so it doesn't include the light blue LDV which is also present in the baseline case- I think the bracket should just be dark blue through tan industrial?

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[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.

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.*[16]

Figure 7. Annual energy load forecasts for Core Northwest

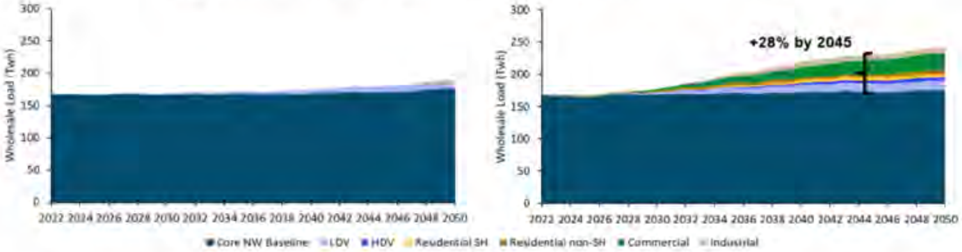

Figure 8 shows the peak demand impacts (including the 15% planning reserve margin) of the high electrification case relative to the baseline, showing a 68% increase by 2045. This high growth is driven by the winter peaking capacity required to replace the gas system peaking capacity to serve peak space heating needs.

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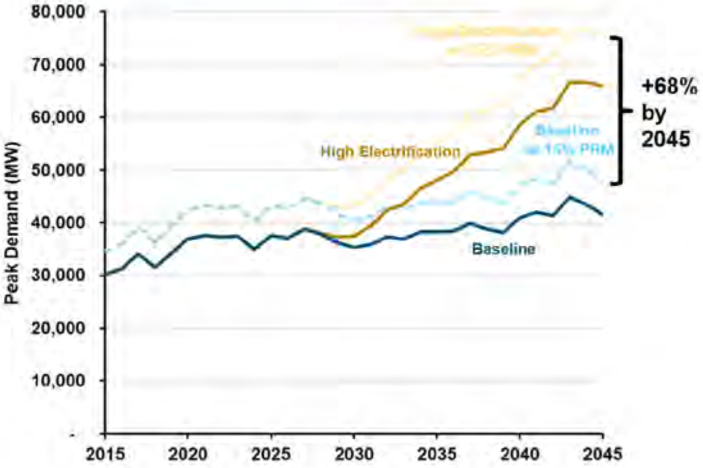
[16] Pacific Northwest Low Carbon Scenario Analysis - Achieving Least-Cost Carbon Emissions Reductions in the Electricity Sector, 2017. https://www.ethree.com/wp-content/uploads/2018/01/E3_PGP_GHGReductionStudy_2017-12-15_FINAL.pdf

Figure 8. Peak demand forecasts for Core Northwest

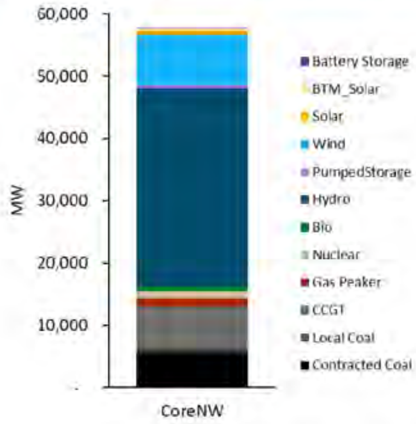


3.4.2 Baseline resources

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.

Comment [EAJ12]: Consider clarifying that this is no SMR, not sure if there is a term for conventional nuclear

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%

Comment [EAJ13]: Consider defining CES somewhere around here, either in the table caption or creatively including it in a sentence in the prior paragraph.

Otherwise it is not defined until 3.4.4. (acronyms are not what I am focusing on in the review, but I happen to struggle with remembering what CES stands for)

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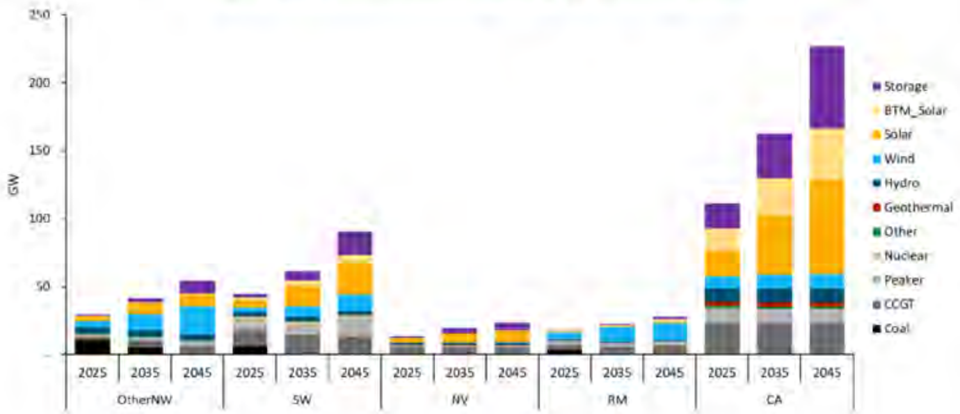
Figure 10. Total installed capacity for external zones



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	×	✓	×

Comment [EAJ14]: It seems that you are mostly using "no new combustion" as the primary name for 2c. So maybe put "limited tech" in parentheses or use "limited tech" in place of "no new combustion" throughout the report.

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.

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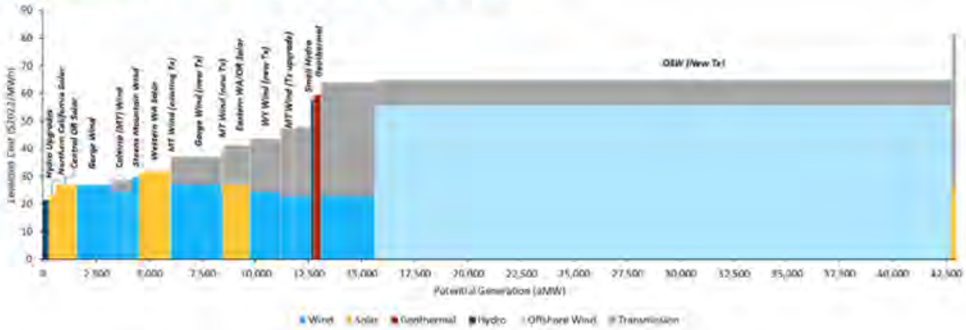
[17] Note: certain solar resources (i.e., Western WA solar) might require transmission upgrades to bring the supply to load centers, which are not captured.

Figure 11. Renewable resource supply curve in 2045

Comment [EAJ15]: For this figure, Transmission isn't a resource. Is it a limitation on the resource?



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%

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(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~~ capturing~~e~~ 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

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[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

Comment [AZ16]: Could spend some time to make these plots visually better.

Comment [AB17]: Not worth much time, but can you just increase the font size. These (and some other small font graphs) are a bit hard to read.

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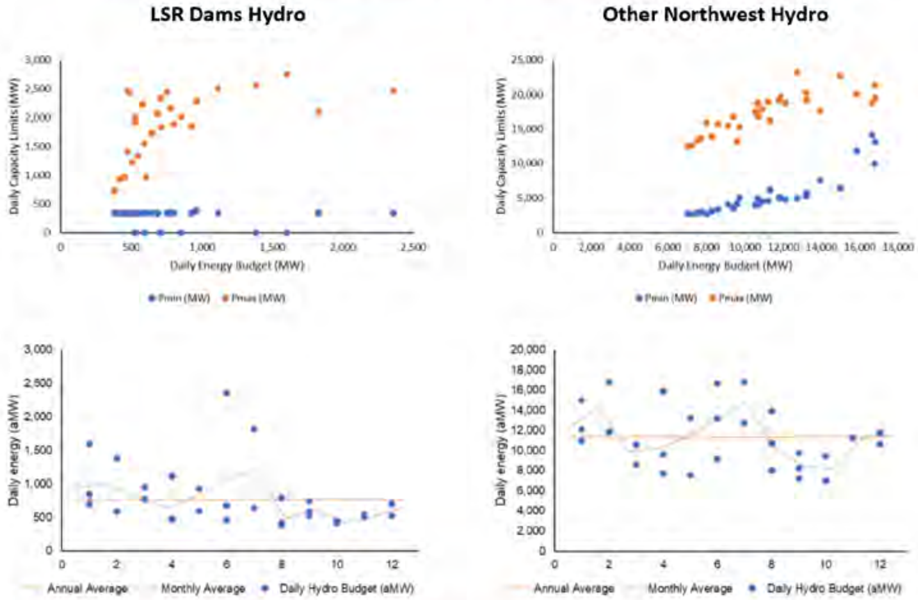
LSR Dams Hydro

Other Northwest Hydro

Table 9. Multi-hour ramping constraints applied to Northwest hydro

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	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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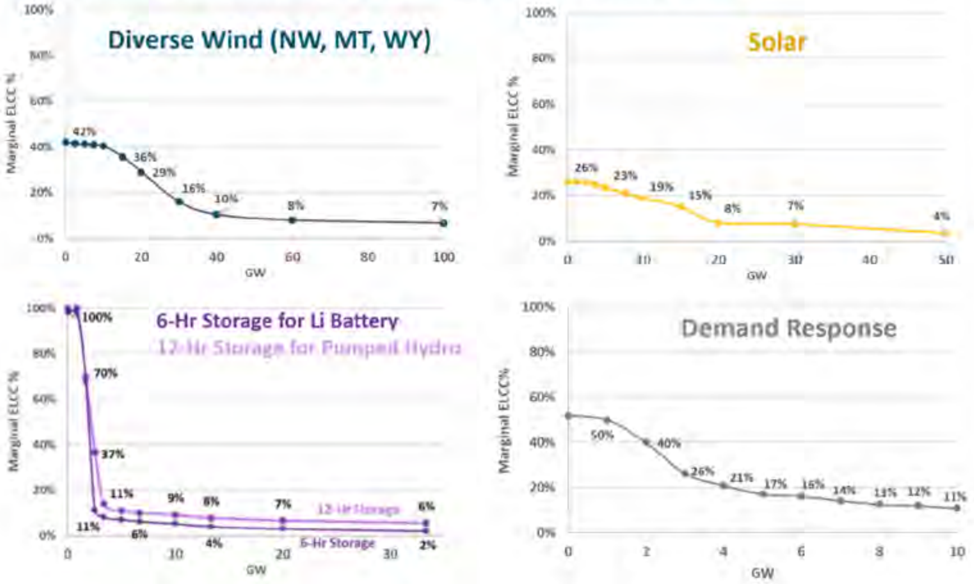
[20] Resource Adequacy in the Pacific Northwest, 2019. https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

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.

Comment [AB18]: E3 is still reviewing this case and deciding whether to include or not.

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 targets 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.

Comment [EAJ19]: Consider reminding the reader that you are talking about the case that includes LSN generation first, both in the text and the figure caption

Comment [EAJ20]: Use "are" throughout or "were" throughout

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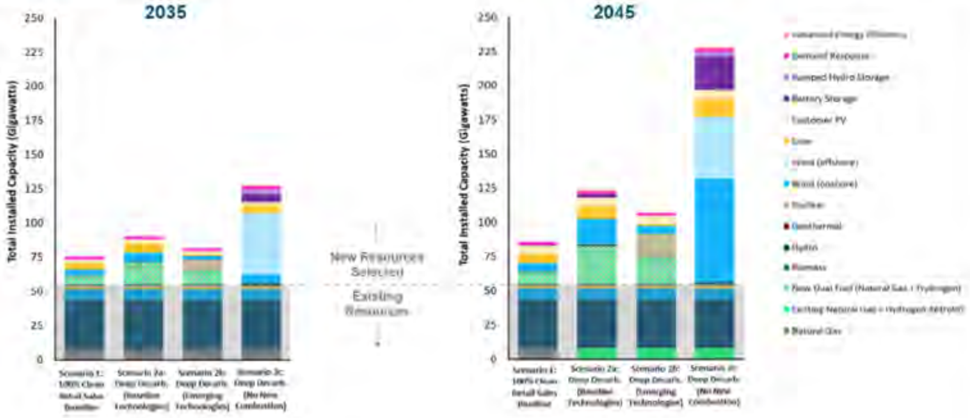
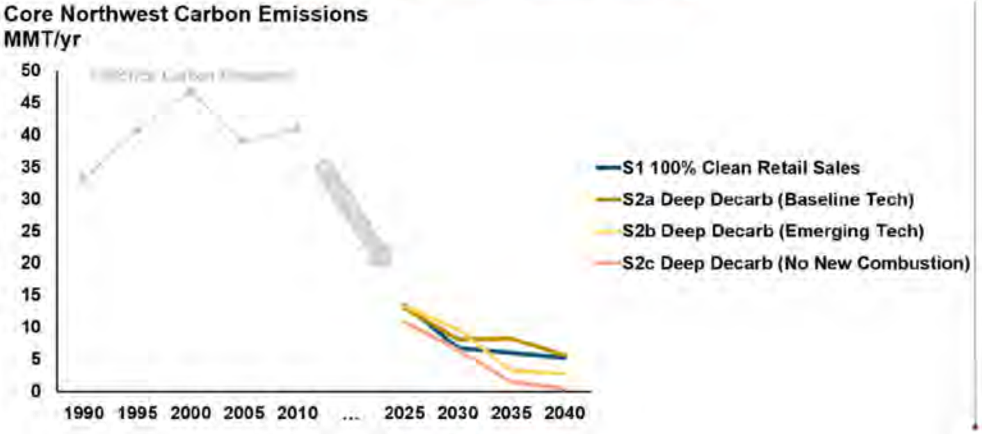
Figure 14. Large levels of new resource additions to meet the growing load, PRM needs and emissions reductions



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



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Comment [AO21]: Don't we have 2015 or 2020 emissions?

Comment [22]: We had 2013 from the pgp study. Would take some work to update those calculations to get other years.

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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

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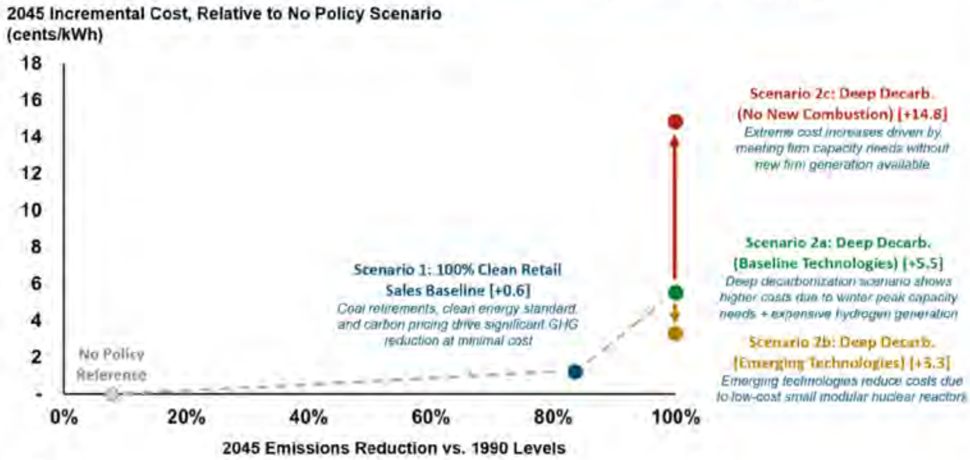
[21] The authors recognize that hydrogen can be used to generate electricity by fuel cells instead of combustion turbines. That scenario would look similar to Scenario 2a, where the combustion plant additions are replaced with many GW of fuel cells for firm capacity needs.

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 [illegible] + 0.1 GW wind	+ 10.6 GW wind + 1.4 GW solar

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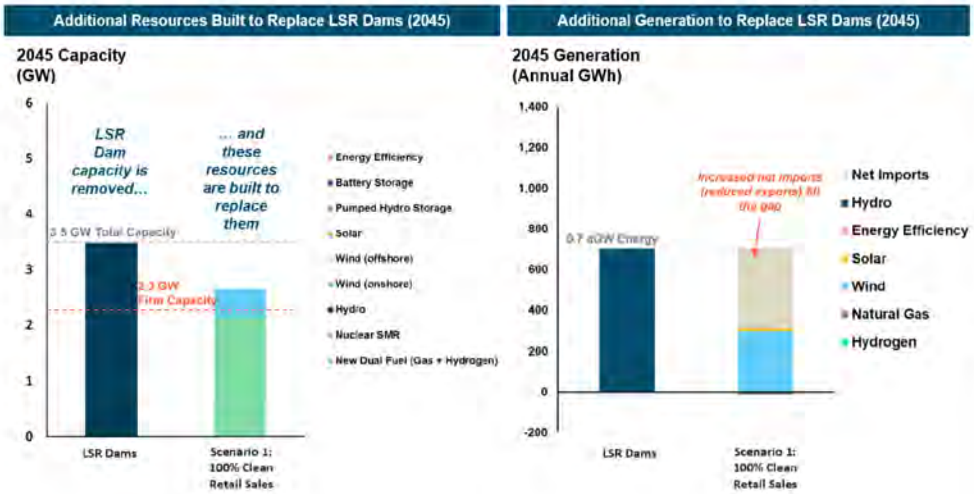
[22] Replacement resources are calculated by comparing the "with LSR dams" RESOLVE portfolio to the "without LSR dams" RESOLVE portfolio. This means some resources may be built in 2035, such as 0.3 GW of geothermal in scenario 2c, that were not built when the dams were included. However, those resources 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]



Comment [EAJ23]: Suggest adding "Scenario 1" to the footnote out of paranoia that someone would simply quote the footnote and take it out of context.

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[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 in Scenario 1.

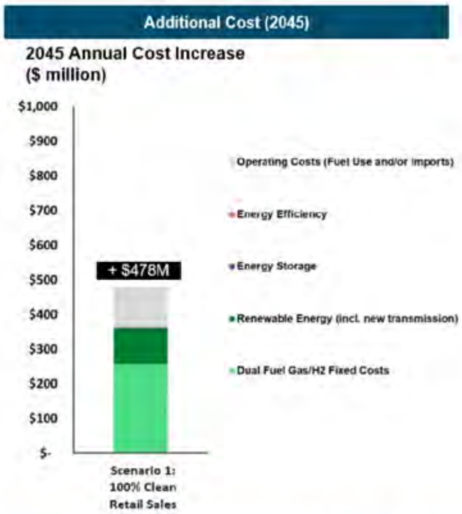
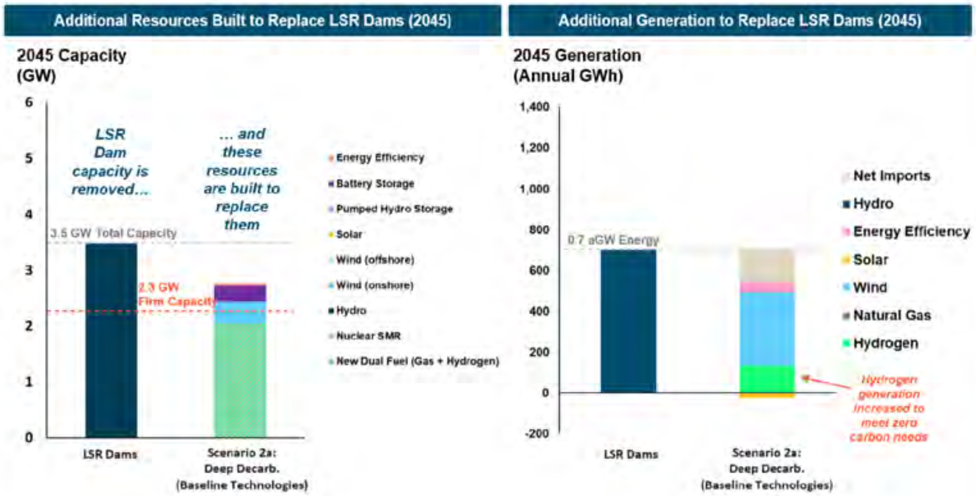
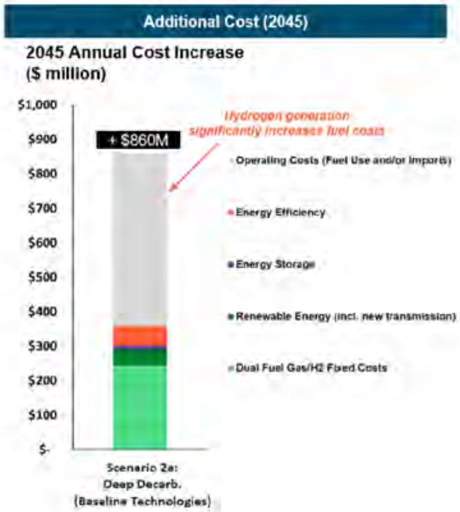


Figure 18. Scenario 2a Capacity Replacement, Energy Replacement, and Costs

Comment [EAJ24]: Should 2b and 2c info be included as well?





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.

Comment [EAJ25]: I think you mean "HIGHER" here?

Comment [EAJ26]: Suggested language revision in the footnote

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[24] 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 ~~which~~ 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[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

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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 economy-wide 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 economy-wide 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

---

[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 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 section 4.1 above) which apply even without removing generation from the LSR dams.

Comment [EAJ27]: Maybe add "such as operations and maintenance costs"?

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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 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.

Comment [EAJ28]: Throughout the document sometimes this is capitalized and sometimes not

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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:

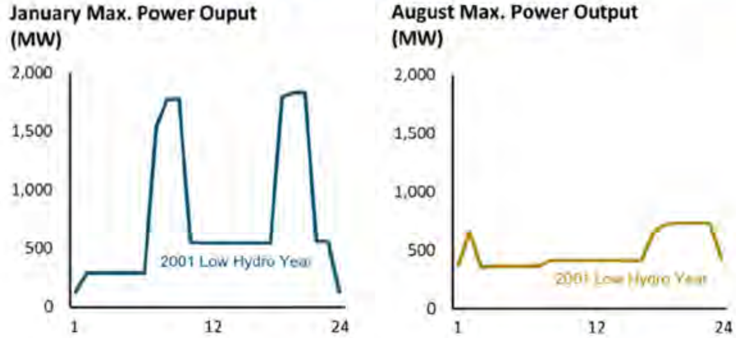
- **Annual energy output**: E3's existing RESOLVE model data uses historical hydro years 2001, 2005, and 2011 as representative of the regional long-term average low/mid/high hydro year conditions. The data for the Columbia River System dams was adjusted to reflect the Preferred Alternative operations defined in the CRSO EIS. However, for the LSR dams, these selected historical hydro years resulted in ~~this leads to~~ a relatively low output of ~700 average MW, whereas the dams may generate ~900 average MW on average across the full historicala 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 CRSO 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.

Comment [EAJ29]: If this acronym hasn't been used then "Columbia River System Operations Environmental Impact Statement"

Comment [AB30]: Eve/BPA to review and confirm

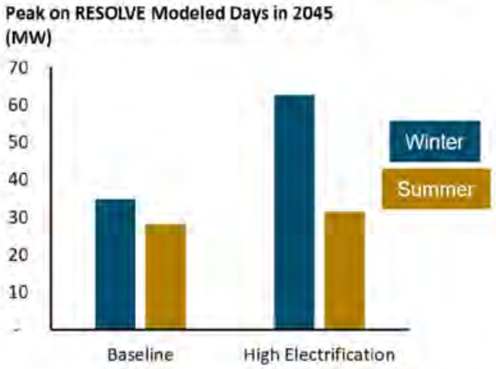
Figure 19. BPA-Modeled LSR Dam Output During the 2001 Low Hydro Year with CRSO EIS Preferred Alternative operations

Comment [EAJ31]: Might be worth adding if someone looks at chart without reading the detail in the text



- 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



- 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.

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Comment [AB32]: @Angineh Zohrabian to update if we have more info

+ **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

Comment [AB33]: NOTE: copy of exec summary text. Update if/when exec summary text is updated.

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 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.

Comment [EAJ34]: Consider "generate" here and in similar sentence earlier. (My brain first went to black-start or to other reasons for having start-up issues, not so much what the text is intending of just plain dispatchability.

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

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[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 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.

Comment [EAJ35]: Consider adding "emerging" as a bit of an explanation for why they are not considered. (I know it is explained elsewhere, but many people will only read this section.)

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 source not found.**~~Error! Reference source 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

Comment [AB36]: @Angineh Zohrabian - what about EE, DR, geothermal? Anything to say about those? Geo from ATB? EE/DR from NWPCC?

Comment [AZ37]: Added geothermal. We didn't do much with the cost adjustments for EE/DR so they were from before. We adjusted the capacity based on 2021 Power plan.

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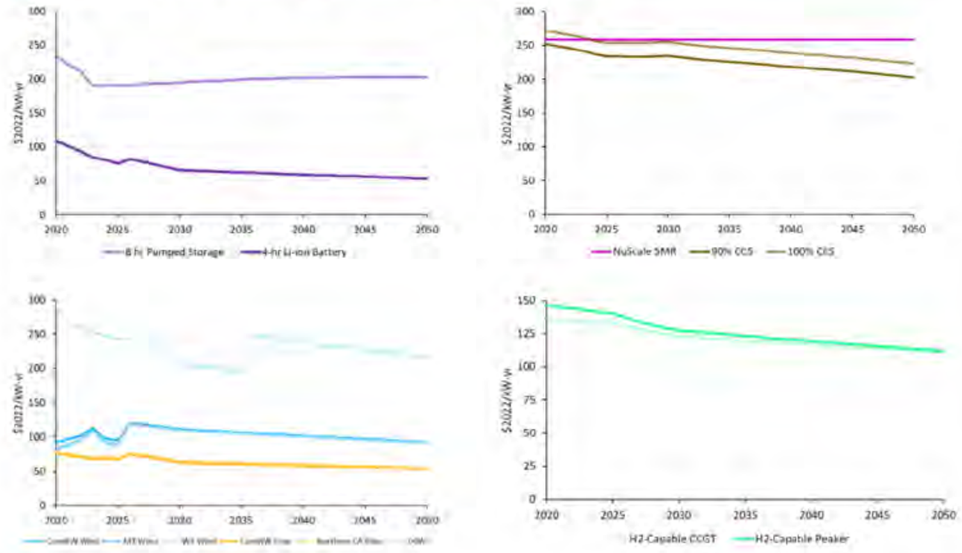
[32] Feron, P., Cousins, A., Jiang, K., Zhai, R., Thiruvenkatachari, R., & Burnard, K. (2019). Towards zero emissions from fossil fuel power stations. *International Journal of Greenhouse Gas Control*, 87, 188–202.

Figure 21. All-in fixed costs for candidate resource options



Comment [AO38]: Can we change to $/MWh please?

Comment [AO39]: ($/kWh for storage)

Comment [AB40]: @Angineh Zohrabian to update

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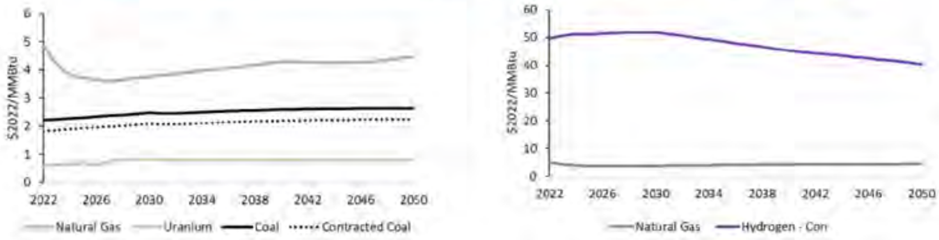
6.1.2 Fuel prices

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.

Comment [EAJ41]: Is this in acronym list? Also EIA

Figure 22. Fuel price forecasts for natural gas, coal, uranium, and hydrogen



Comment [EAJ42]: In legend what does Hydrogen-Con mean?

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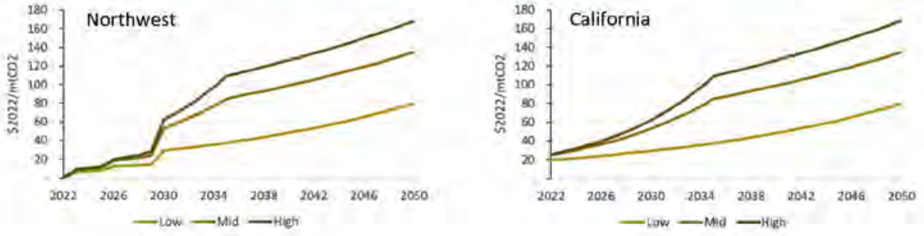
Annual average gas prices are further shaped according to a monthly profile to capture seasonal trends in the demand for natural gas and the consequent impact on pricing.

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.

Comment [AZ43]: Add citation

Figure 23. Carbon price forecasts for Northwest and California



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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.

Comment [AB44]: Q for BPA - NWEC did some transmission analysis in their 2018 study. Is it appropriate to reference that work? Or should we keep it generic?

Comment [AB45]: Also, note that I incorporated BPA Tx team's feedback here, but would welcome their review of this appendix before we publish.

Comment [EAJ46]: Maybe instead say "comparatively small" since they are still big costs, just not as big as the RESOLVE modeled costs.

Comment [AB47]: BPA - we propose deleting this appendix placeholder section that was here on the Regional Capacity Needs. There already is a ton of info out there on near-term capacity needs, the report is quite long already, and we don't have much extra budget to draft a comprehensive appendix here. Please confirm you're ok dropping it or your thoughts.

From: Anasis,John G (TFE)(BPA) - TOOP-DITT-2
Sent: Friday, July 1, 2022 2:52 PM
To: James,Eve A L (BPA) - PG-5
Cc: Koehler,Birgit G (BPA) - PG-5
Subject: RE: E3 report- transmission section
Attachments: BPA Final E3 Report_Draft_v3-eaj-jga.docx

Importance: High

Eve,

My sincerest apologies for being late with my comments. I did have a few on the last couple pages that you asked me to review. I did not have a chance to look at any other parts of the report.

Please let me know if you have any questions. Thank you and have a great weekend!

John

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 30, 2022 5:01 PM
To: Anasis,John G (TFE)(BPA) - TOOP-DITT-2 <jganasis@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: E3 report- transmission section

Great- thanks John!

From: Anasis,John G (TFE)(BPA) - TOOP-DITT-2 <jganasis@bpa.gov>
Sent: Thursday, June 30, 2022 5:01 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: E3 report- transmission section

Eve,

I don't have too many meetings tomorrow morning, so I should be able to get you some feedback by your noon deadline.

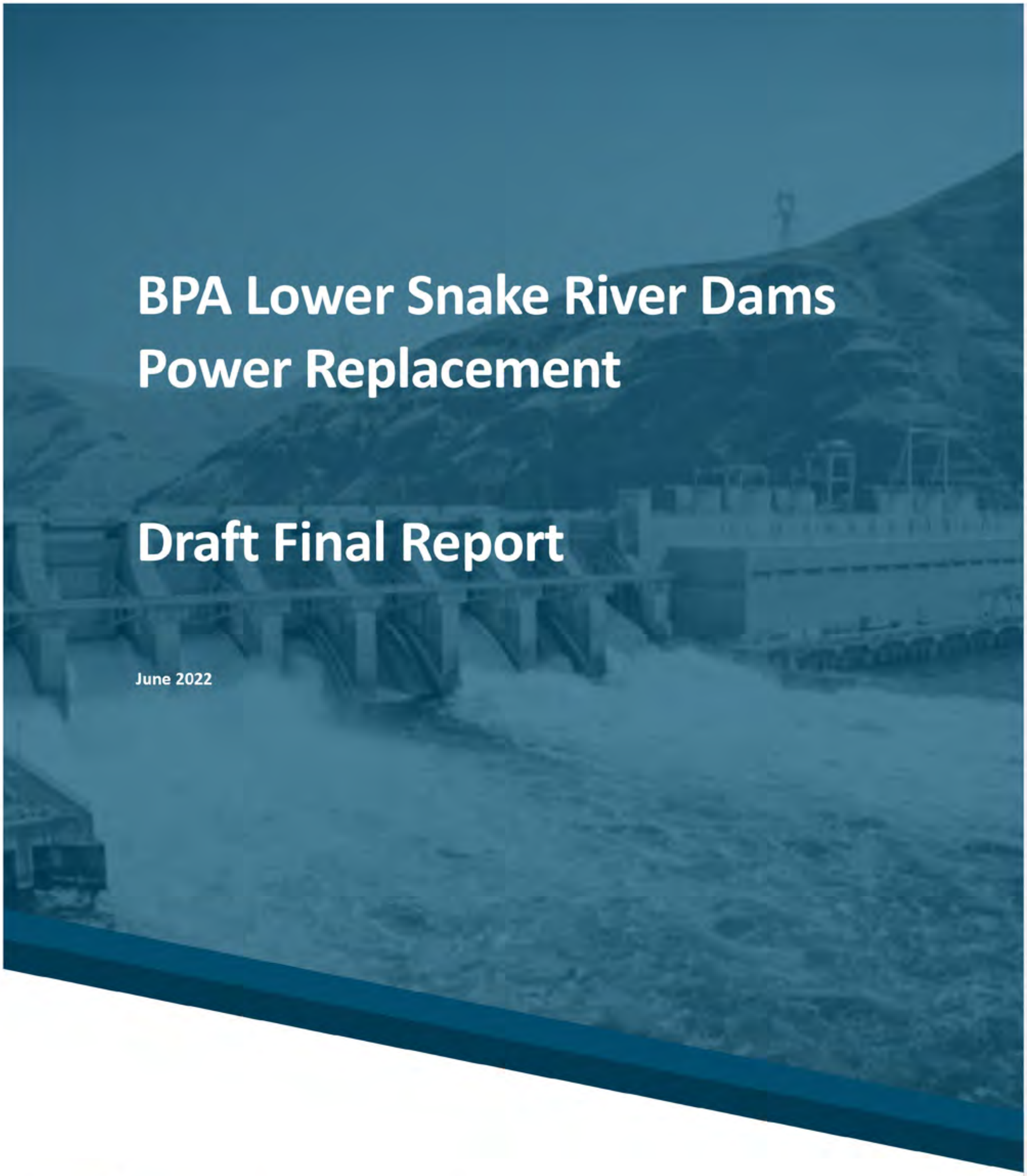
John

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 30, 2022 4:47 PM
To: Anasis,John G (TFE)(BPA) - TOOP-DITT-2 <jganasis@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: E3 report- transmission section

Deliberative, FOIA exempt
Hi John-

Attached is a draft of the E3 report- this is a close hold document for now as we are still coordinating a release plan. E3 incorporated some earlier feedback from transmission but I was hoping you could read through the qualitatively grid services section one more time for any red flag edits/comments (page 49 – 50). We are trying to keep a light touch since it is and independent study but they don’t have the Tx expertise so happy to incorporate feedback. I know if is Friday before a holiday and early out day but if you could get it back to me by noon I would appreciate it!

Thanks,
Eve



BPA Lower Snake River Dams Power Replacement

Draft Final Report

June 2022

Energy+Environmental Economics

BPA Lower Snake River Dams Power Replacement

Draft Final Report

June 2022

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Aaron Burdick

Sierra Spencer

Dr. Angineh Zohrabian

Sam Kramer

Jack Moore

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Acronym and Abbreviation Definitions

Comment [AZ1]: Reminder to put in the alphabetical order in the end

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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
NG	Natural Gas
H2 (maybe others from the table listing replacement resources for the LSN?)	Hydrogen
LDV, HDV	From Figure 7
CES and RPS	
BTM Solar	

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.

Comment [EAJ2]: Should this be 2,300 to match the firm capacity # in the graphic- or maybe the graphic needs to be updated?

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.

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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 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/

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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.

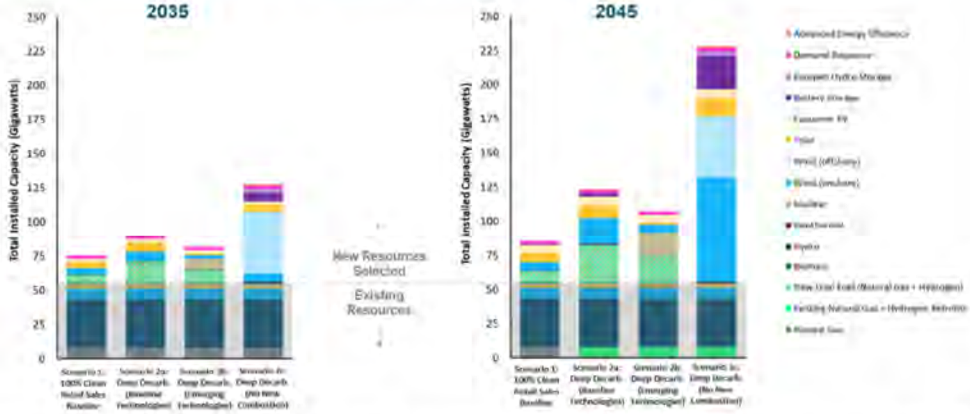
Table 1. Scenario Design

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)	[illegible]	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 [illegible] + 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%]

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Comment [AB3]: Note to BPA: we re-examined these and there were some generally small changes to the values (including removing previous rounding). Exception is the 2024 breaching. The prior NPV was too high and this updated value is correct.

We also propose to use the 3% discount rate that better represents the public power cost of capital.

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

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[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.

Comment [EAJ4]: Same as above- either 2,300 or graphic change. These values should match

Field Code Changed

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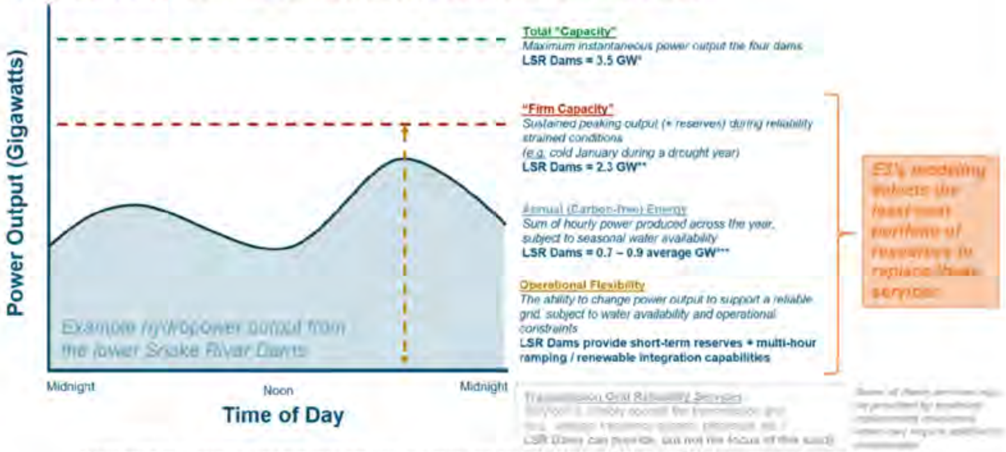
[7] Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. The "total capacity" refers to the overload capacity, not the nameplate capacity. Historical peak generation was 3,431 MW.

[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.

Comment [EAJ5]: Should be consistent with the language change in the Executive summary

Comment [EAJ6]: Doesn't match 900 value in paragraph text above

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.

Comment [EAJ7]: Not sure if you want to put in a footnote I grabbed from the peer review document "The study examines LSRD breaching in 10 years (2032) and in 2 years (2024), consistent with the approach used in the CRSO EIS" – it seems like that questions gets asked a lot when the 2024 date is mentioned.

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

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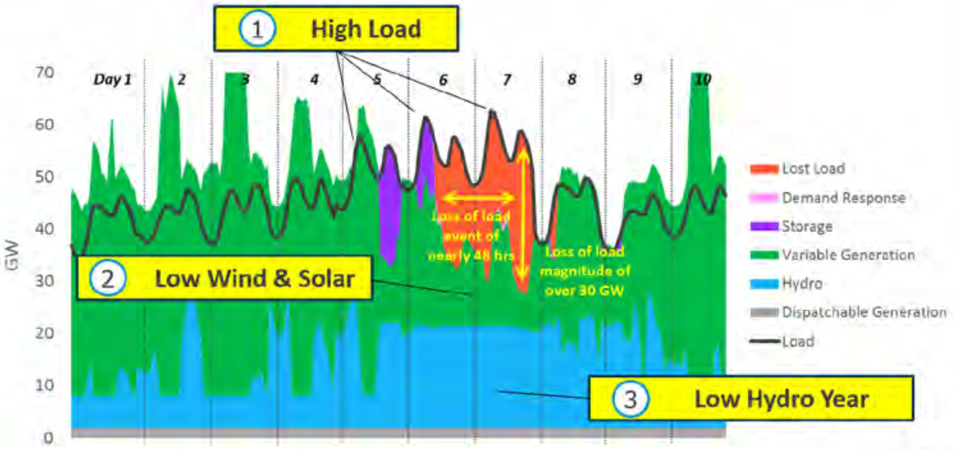
[12] E3, 2019. *Resource Adequacy in the Pacific Northwest.* https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

additional firm generating capacity may be needed, even in scenarios that add significant amounts 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 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
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

Comment [EAJ8]: Consider labeling a, b, c rather than 1,2,3 to match with the scenario names

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.

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Table 5~~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)

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3 Modeling Approach

3.1 RESOLVE Model

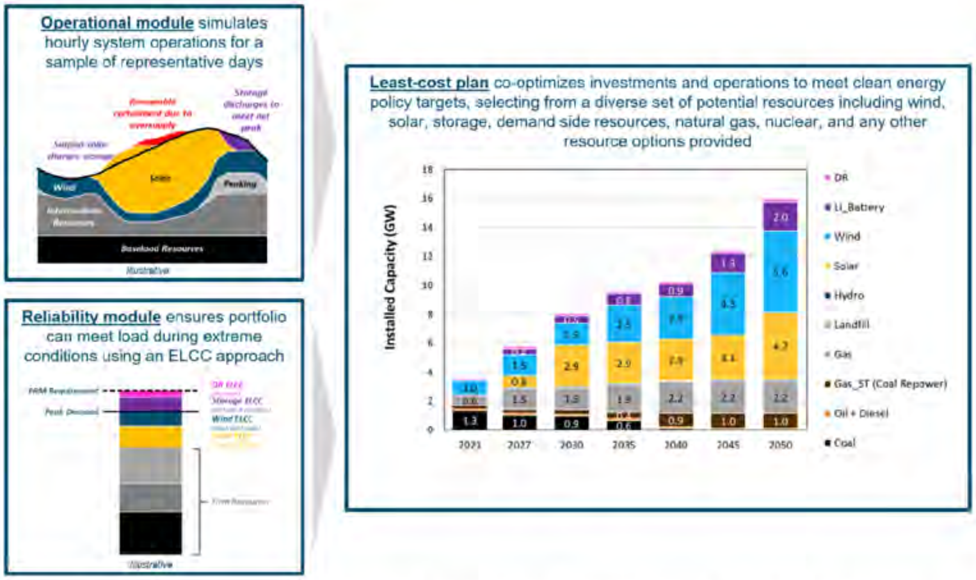
E3's Renewable Energy Solutions Model (RESOLVE) is used to perform a portfolio optimization of Northwest system's electric generating resource needs between 2025 and 2045. RESOLVE is an optimal capacity expansion and dispatch model that uses linear programming to identify optimal long-term generation 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

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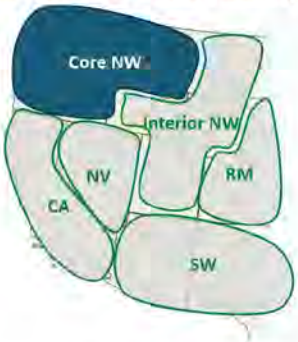
[14] Pacific Northwest Low Carbon Scenario Analysis - Achieving Least-Cost Carbon Emissions Reductions in the Electricity Sector, 2017. https://www.ethree.com/wp-content/uploads/2018/01/E3_PGP_GHGReductionStudy_2017-12-15_FINAL.pdf

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

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

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

Calculate additional resources and investment + operational costs **required to replace the dams**

- Calculated as the difference between steps 1 and 2 above

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

Comment [EAJ9]: To really make it easy for the reader, consider adding "baseline" and "high electrification" above the left and right graphs in Figure 7. Also need to adjust the bracket so it doesn't include the light blue LDV which is also present in the baseline case- I think the bracket should just be dark blue through tan industrial?

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[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

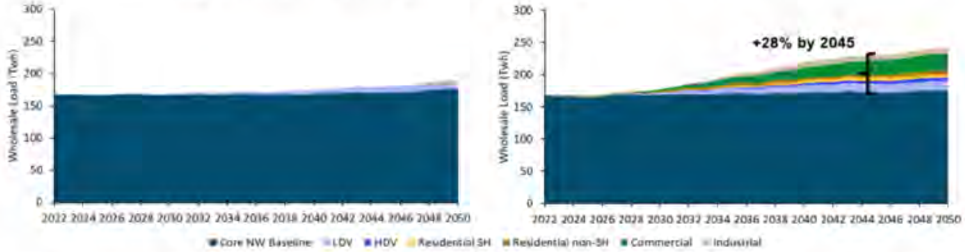

Figure 8 shows the peak demand impacts (including the 15% planning reserve margin) of the high electrification case relative to the baseline, showing a 68% increase by 2045. This high growth is driven by the winter peaking capacity required to replace the gas system peaking capacity to serve peak space heating needs.

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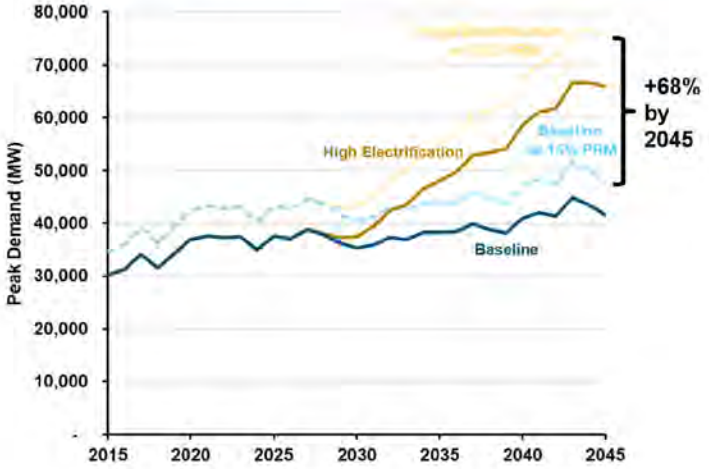
[16] Pacific Northwest Low Carbon Scenario Analysis - Achieving Least-Cost Carbon Emissions Reductions in the Electricity Sector, 2017. https://www.ethree.com/wp-content/uploads/2018/01/E3_PGP_GHGReductionStudy_2017-12-15_FINAL.pdf

Figure 8. Peak demand forecasts for Core Northwest

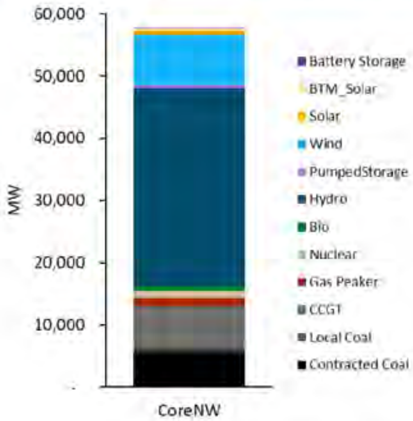


3.4.2 Baseline resources

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.

Comment [EAJ10]: Consider clarifying that this is no SMR, not sure if there is a term for conventional nuclear

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%

Comment [EAJ11]: Consider defining CES somewhere around here, either in the table caption or creatively including it in a sentence in the prior paragraph.

Otherwise it is not defined until 3.4.4. (acronyms are not what I am focusing on in the review, but I happen to struggle with remembering what CES stands for)

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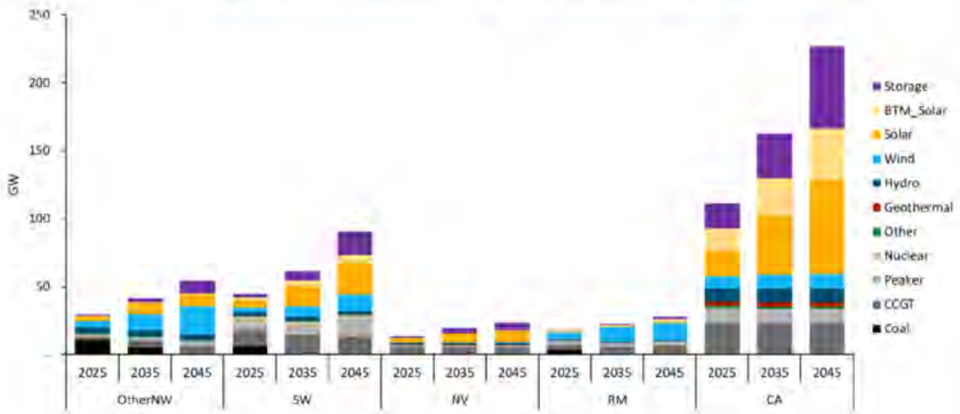
Figure 10. Total installed capacity for external zones



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	✗	✓	✗

Comment [EAJ12]: It seems that you are mostly using "no new combustion" as the primary name for 2c. So maybe put "limited tech" in parentheses or use "limited tech" in place of "no new combustion" throughout the report.

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.

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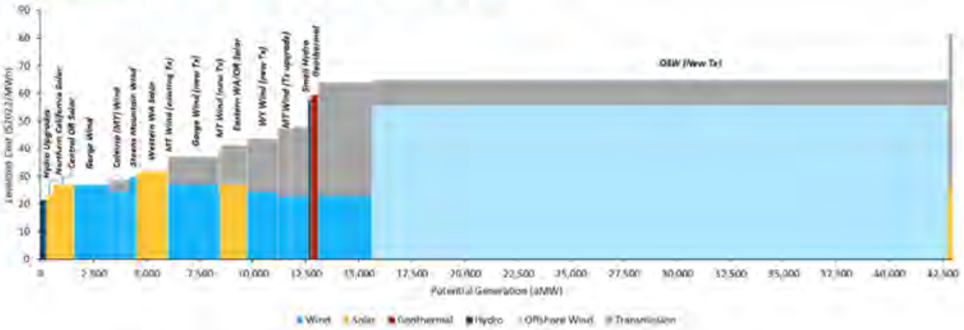
[17] Note: certain solar resources (i.e., Western WA solar) might require transmission upgrades to bring the supply to load centers, which are not captured.

Figure 11. Renewable resource supply curve in 2045

Comment [EAJ13]: For this figure, Transmission isn't a resource. Is it a limitation on the resource?



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%

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(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~~ capturinge 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

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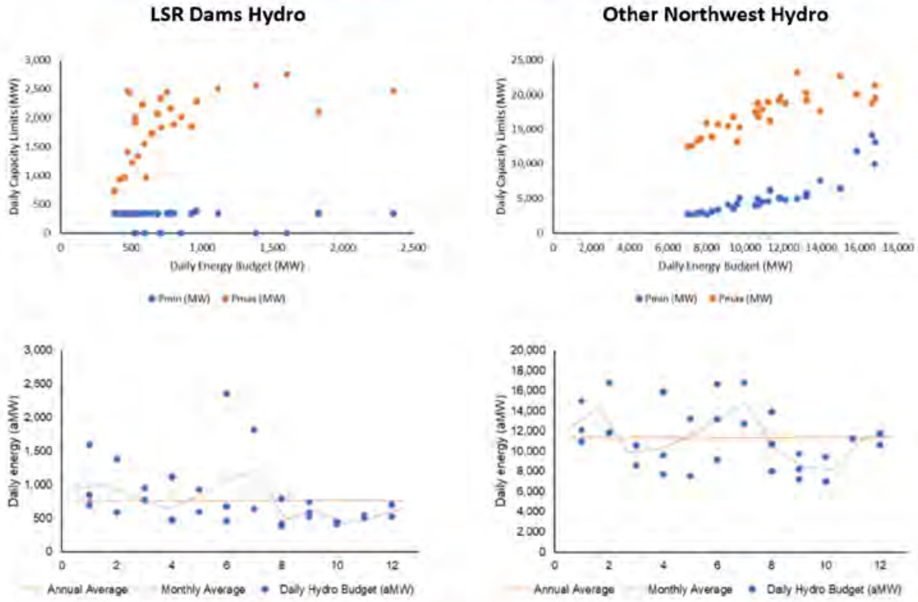
[18] While a clean energy standard is modeled in scenario 2, the mass-based carbon reduction target constraint is a more binding constraint, pushing the model beyond the minimum CES %'s shown here.

[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



Comment [AZ14]: Could spend some time to make these plots visually better.

Comment [AB15]: Not worth much time, but can you just increase the font size. These (and some other small font graphs) are a bit hard to read.

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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%

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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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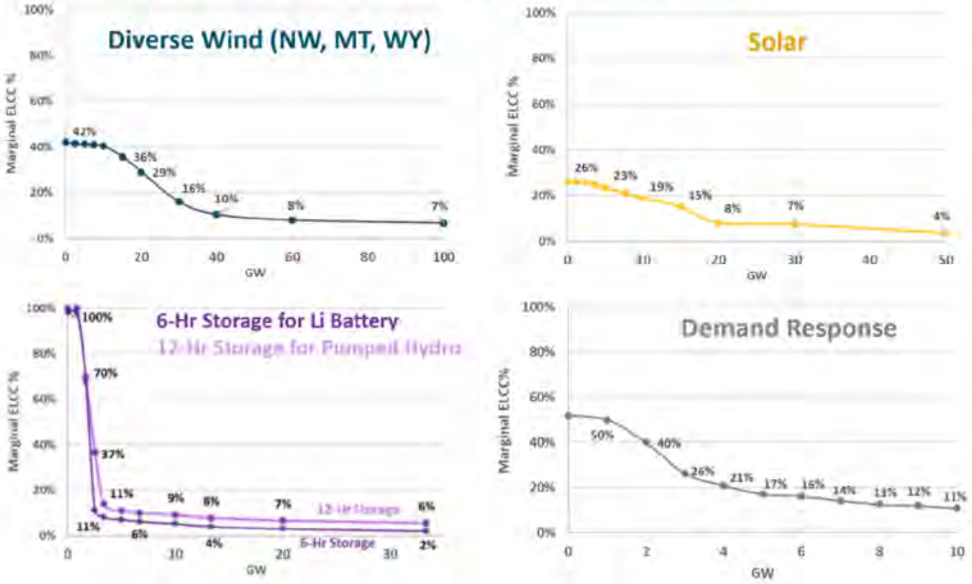
[20] Resource Adequacy in the Pacific Northwest, 2019. https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

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.

Comment [AB16]: E3 is still reviewing this case and deciding whether to include or not.

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 targets 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.

Comment [EAJ17]: Consider reminding the reader that you are talking about the case that includes LSN generation first, both in the text and the figure caption

Comment [EAJ18]: Use "are" throughout or "were" throughout

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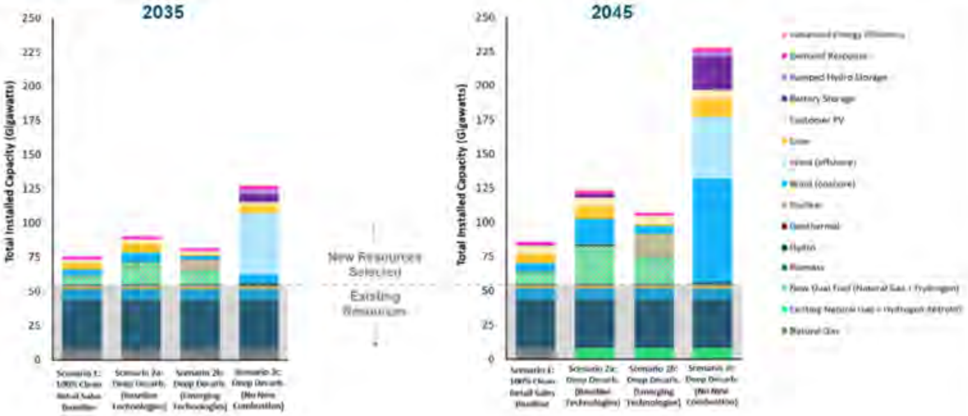
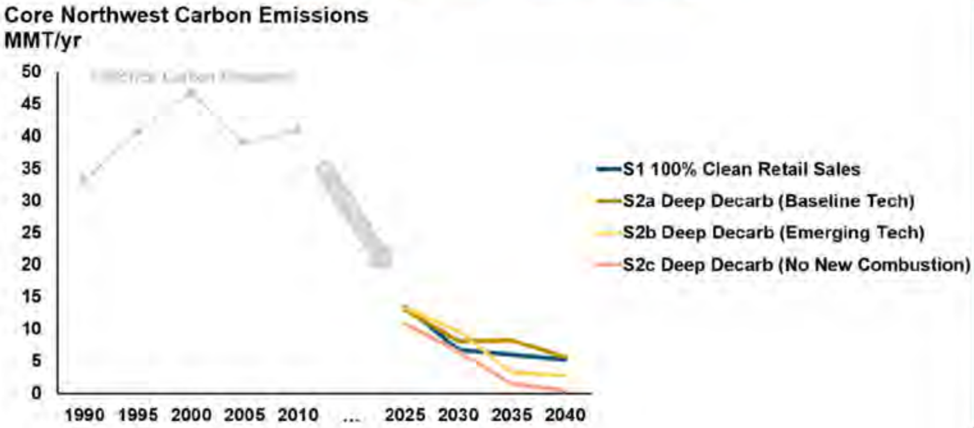
Figure 14. Large levels of new resource additions to meet the growing load, PRM needs and emissions reductions



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



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Comment [AO19]: Don't we have 2015 or 2020 emissions?

Comment [20]: We had 2013 from the pgp study. Would take some work to update those calculations to get other years.

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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

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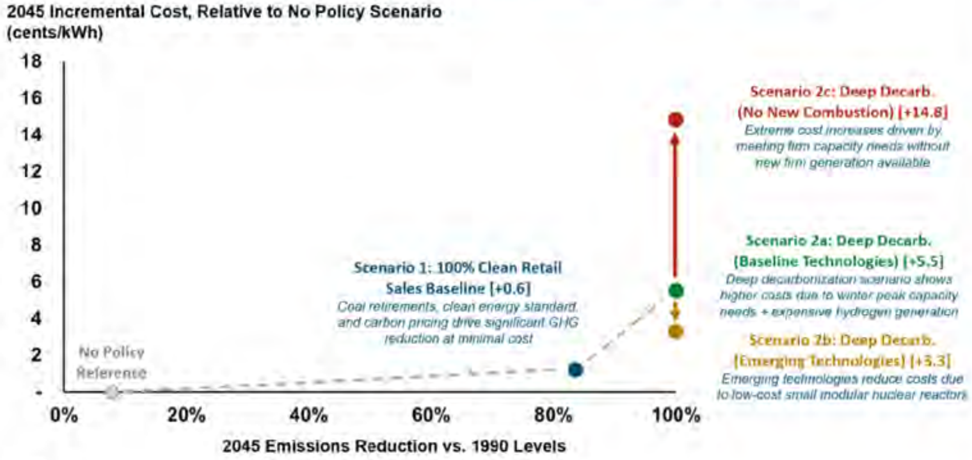
[21] The authors recognize that hydrogen can be used to generate electricity by fuel cells instead of combustion turbines. That scenario would look similar to Scenario 2a, where the combustion plant additions are replaced with many GW of fuel cells for firm capacity needs.

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 [illegible] + 0.1 GW wind	+ 10.6 GW wind + 1.4 GW solar

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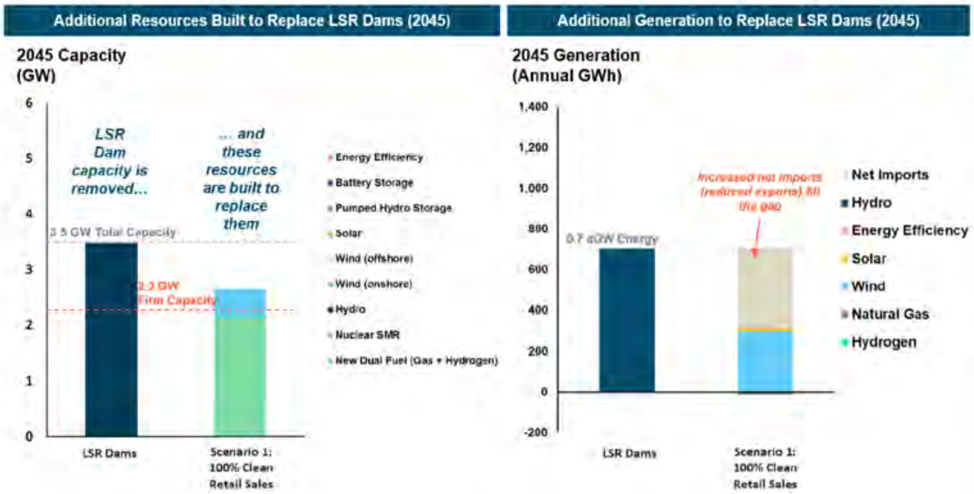
[22] Replacement resources are calculated by comparing the "with LSR dams" RESOLVE portfolio to the "without LSR dams" RESOLVE portfolio. This means some resources may be built in 2035, such as 0.3 GW of geothermal in scenario 2c, that were not built when the dams were included. However, those resources 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]

Comment [EAJ21]: Suggest adding "Scenario 1" to the footnote out of paranoia that someone would simply quote the footnote and take it out of context.



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[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 in Scenario 1.

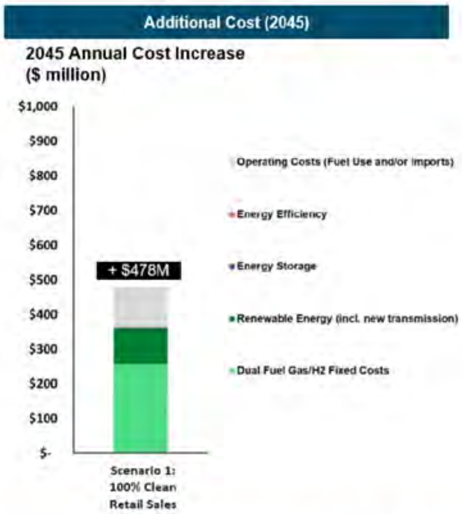
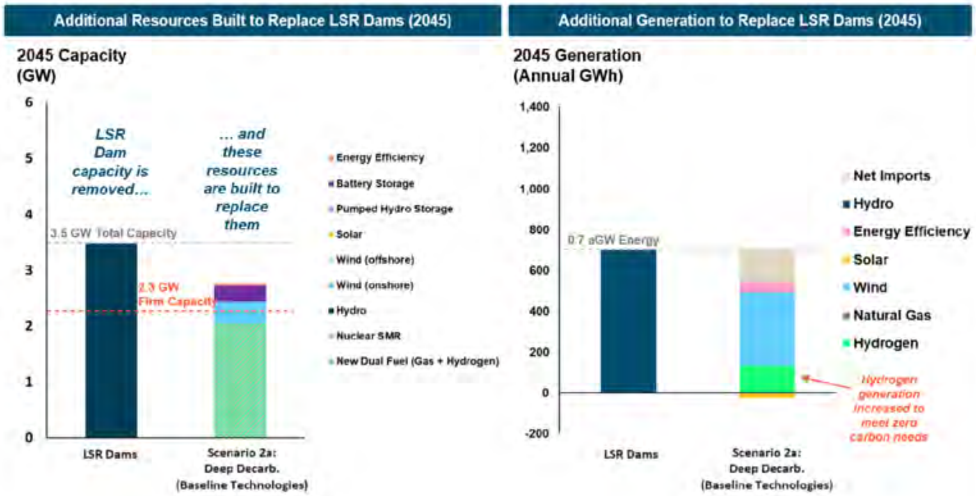


Figure 18. Scenario 2a Capacity Replacement, Energy Replacement, and Costs

Comment [EAJ22]: Should 2b and 2c info be included as well?



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.

Comment [EAJ23]: I think you mean "HIGHER" here?

Comment [EAJ24]: Suggested language revision in the footnote

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[24] 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 ~~which~~ 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[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

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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 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 section 4.1 above) which apply even without removing generation from the LSR dams.

Comment [EAJ25]: Maybe add "such as operations and maintenance costs"?

Table 12. Total LSR Dams replacement costs

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	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%]

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[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:

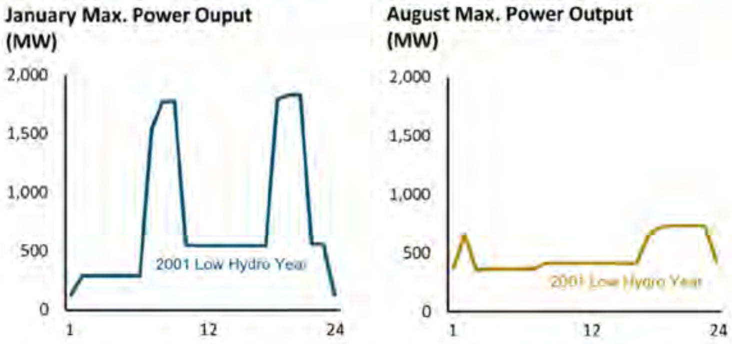
- **Annual energy output**: E3's existing RESOLVE model data uses historical hydro years 2001, 2005, and 2011 as representative of the regional long-term average low/mid/high hydro year conditions. The data for the Columbia River System dams was adjusted to reflect the Preferred Alternative operations defined in the CRSO EIS. However, for the LSR dams, these selected historical hydro years resulted in ~~this leads to~~ a relatively low output of ~700 average MW, whereas the dams may generate ~900 average MW on average across the full historicala 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 CRSO 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.

Comment [EAJ26]: If this acronym hasn't been used then "Columbia River System Operations Environmental Impact Statement"

Comment [AB27]: Eve/BPA to review and confirm

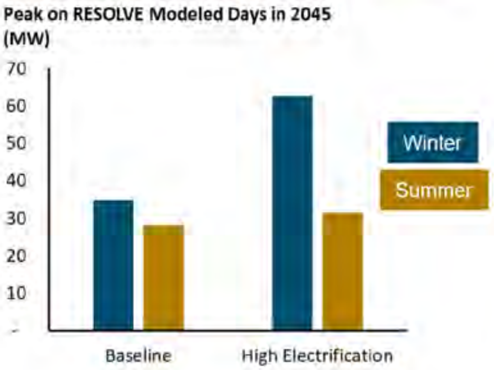
Figure 19. BPA-Modeled LSR Dam Output During the 2001 Low Hydro Year with CRSO EIS Preferred Alternative operations

Comment [EAJ28]: Might be worth adding if someone looks at chart without reading the detail in the text



- 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.

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Comment [AB29]: @Angineh Zohrabian to update if we have more info

5 Conclusions and Key Findings

Comment [AB30]: NOTE: copy of exec summary text. Update if/when exec summary text is updated.

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 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

Comment [EAJ31]: Consider "generate" here and in similar sentence earlier. (My brain first went to black-start or to other reasons for having start-up issues, not so much what the text is intending of just plain dispatchability.

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[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 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.

Comment [EAJ32]: Consider adding "emerging" as a bit of an explanation for why they are not considered. (I know it is explained elsewhere, but many people will only read this section.)

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

Comment [AB33]: @Angineh Zohrabian - what about EE, DR, geothermal? Anything to say about those? Geo from ATB? EE/DR from NWPCC?

Comment [AZ34]: Added geothermal. We didn't do much with the cost adjustments for EE/DR so they were from before. We adjusted the capacity based on 2021 Power plan.

The technology fixed costs trajectories for candidate resource options are shown in **Error! Reference source 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

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[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

Comment [AO35]: Can we change to $/MWh please?

Comment [AO36]: ($/kWh for storage)

Comment [AB37]: @Angineh Zohrabian to update

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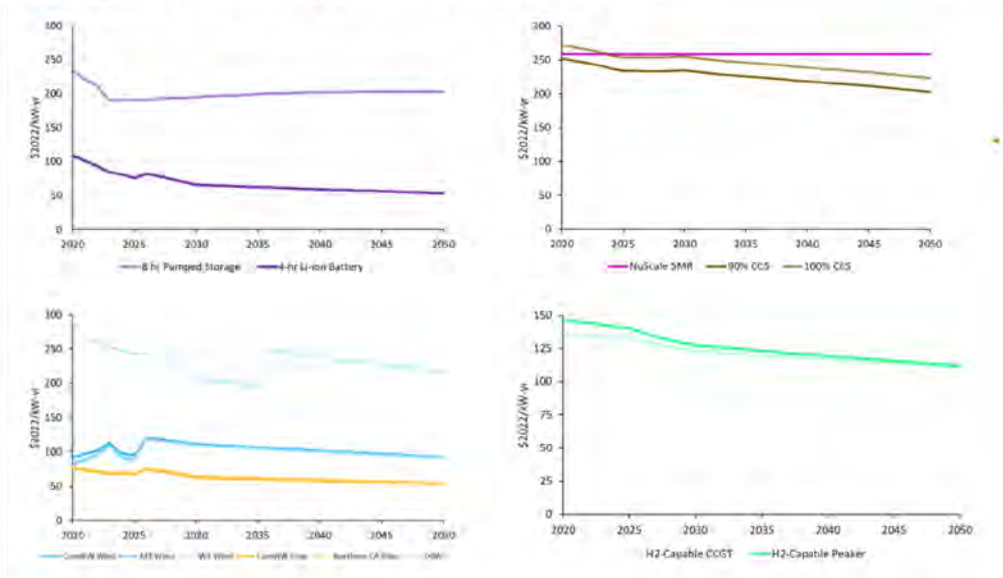


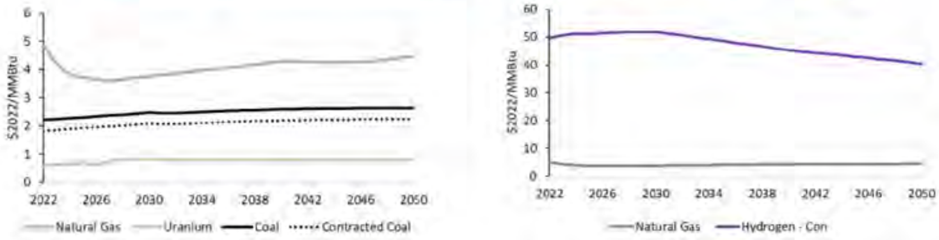
6.1.2 Fuel prices

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.

Comment [EAJ38]: Is this in acronym list? Also EIA

Figure 22. Fuel price forecasts for natural gas, coal, uranium, and hydrogen



Comment [EAJ39]: In legend what does Hydrogen-Con mean?

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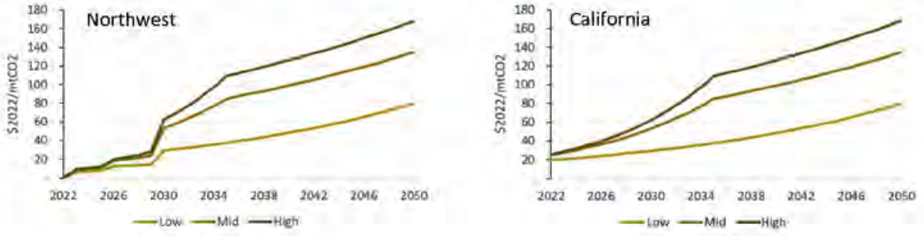
Annual average gas prices are further shaped according to a monthly profile to capture seasonal trends in the demand for natural gas and the consequent impact on pricing.

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.

Comment [AZ40]: Add citation

Figure 23. Carbon price forecasts for Northwest and California



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6.1.4 Operating Reserves

Comment [JA41]: Has Bart McManus had a chance to review this?

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 would be ~~is~~ 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. 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 is important for the proper operation of protective relaying schemes~~can be sustained; exact contribution depends on the hydro generator type~~.

Comment [AB42]: Q for BPA - NWEC did some transmission analysis in their 2018 study. Is it appropriate to reference that work? Or should we keep it generic?

Comment [AB43]: Also, note that I incorporated BPA Tx team's feedback here, but would welcome their review of this appendix before we publish.

Comment [EAJ44]: Maybe instead say "comparatively small" since they are still big costs, just not as big as the RESOLVE modeled costs.

Comment [JA45]: I think the term "relatively small" should be removed. I don't think we fully know what all the costs will be in order to fully replace on these various services.

Comment [JA46]: See if Dan Goodrich would like to comment on this item since he is our lead for system restoration.

Comment [JA47]: I am not sure that this statement is technically correct. It is also unclear as to what they consider "small hydro' to be. Our Lower Columbia projects are considered low head, but they are certainly not small.

Comment [AB48]: BPA - we propose deleting this appendix placeholder section that was here on the Regional Capacity Needs. There already is a ton of info out there on near-term capacity needs, the report is quite long already, and we don't have much extra budget to draft a comprehensive appendix here. Please confirm you're ok dropping it or your thoughts.

Comment [JA49]: It would be good to get some input from Caitlin Martin and Andrew Christensen on this item.

From: Koehler,Birgit G (BPA) - PG-5
Sent: Monday, June 27, 2022 2:42 PM
To: James,Eve A L (BPA) - PG-5
Subject: RE: Executive Summary
Attachments: E3_ExecSummaryDraft_062422-eaj, bgk.docx

Categories: CRSO

Deliberative, FOIA exempt

Hi Eve,
I tried to follow your example of "light touch." When I suggested rewording, it was more for clarity than content, I hope. And I have a suggestion for rewording one of the comments.

Birgit

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Monday, June 27, 2022 1:54 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: Executive Summary

Deliberative, FOIA exempt
Hi Birgit-
Attached is a commented version of the E3 Executive Summary. Let me know if you have any additional comments. I got your red-flag edit incorporated. I'm taking the light touch perspective and assuming the reader will have some level of energy expertise rather than general public. If you think I need to adjust any of that in my commenting on the report let me know.

Thanks,
Eve

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 are ~3,500 megawatts (MW) of total capacity[1] and provide over 2,200 MW of firm peaking capabilities to support regional reliability. They also provide 700-900 average MW of zero-carbon energy, as well as operating reserves and operational flexibility to support renewable integration. If the dams are breached, many – if not all – of these power services will need to be replaced to ensure the Northwest meets its clean energy policy targets and maintains sufficient levels of electric reliability. This study used 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. The dams are assumed to be breached in 2032, except for one sensitivity that considered 2024 breaching.

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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.

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

This study focuses on three key variables (clean energy policy, load growth, and emerging technology availability) that impact the cost to replace the dams. RESOLVE considered optimal investment and operations for each scenario to achieve the Northwest's long-term clean energy policy goals at least-cost, while ensuring resource adequacy.

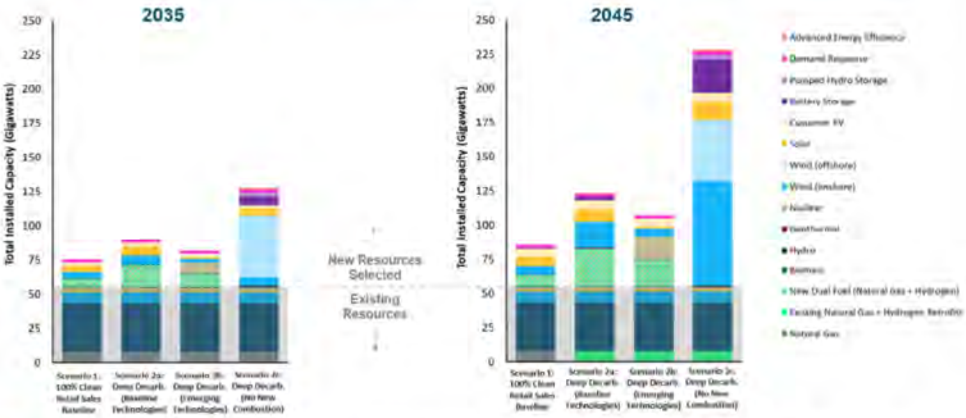
Even with the dams not breached, the region's clean energy goals and potential electrification load growth drive a significant need for new resources. In all scenarios, significant energy efficiency and customer solar is embedded into the load forecast, based on the NWPCC's 8th Power Plan. Additionally, 6 gigawatts (GW or 6,000 MW) coal capacity is retired by 2030, while increasing carbon prices incent further clean energy resource additions. In scenario 1, by 2045 an additional 5 GW of solar and 5 GW of wind are selected to meet clean energy needs; 0.6 GW of battery storage, 2 GW of demand response, and 9 GW of dual fuel natural gas + hydrogen combustion plants are added to meet resource adequacy needs. Though all scenarios require more firm capacity resources to meet higher winter peak demand, the types of resources selected in scenario 2 ~~is~~ are a function of technology availability. The baseline scenario (S2a) 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. The emerging technology scenario selects 17 GW of nuclear small modular reactors (SMRs) by 2045 to displace solar, wind, batteries, and gas plants. The no new combustion scenario requires potentially impractically high levels of additional onshore wind, offshore wind, and battery storage to meet firm capacity and carbon reduction needs relying only on new non-firm resource additions, quadrupling the total installed MW of the Northwest grid by 2045.

Comment [EAJ1]: Might want to describe why there is higher winter peak demand (e.g. is this the heat pump peaks?)

Birgit adds: one of the points that contrasts this study from others is that you found winter to be "the hardest period" to cover. So putting more emphasis on that might be worthwhile.

Comment [KG(-P2]: Consider using "in lieu of selecting" since we aren't turning off existing wind, solar specifically (not counting potential over-build that doesn't run all the time)

Figure 1. Northwest Installed Capacity Mix in Scenarios with the Lower Snake River Dams



~~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. These costs increase over time as the region's clean energy goals become more stringent, with 2045 replacement costs highly dependent on the availability of emerging technologies. RESOLVE primarily replaced 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. To meet zero-carbon electricity by 2045, the dual fuel plants added burning additional hydrogen on low wind days to replace the carbon-free energy provided by the dams. Scenario 2b displaces some of the wind and gas with nuclear SMRs. 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.

Comment [EAJ3]: Red flag edit- please make sure to keep language neutral since decision to breach or not has not been made.

Comment [KG(-P4]: Do you mind if I modify your comment? I don't think they were meaning to be non-neutral.

"Red Flag edit: using the word "when" is correct for your modeling, but it could be perceived by the reader as if it is only a matter of time until the dams will be removed (for real, not just in the model).

Comment [KG(-P5]: E3: consider revising to "If the generation from the dams is removed...."
We have been very careful to distinguish between breaching the dams (which takes out the earthen embankments but does not remove the whole structures.

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Comment [KG(-P6]: See comment above that "displaces" could be construed incorrectly as turning off wind/solar rather than "being selected in lieu of". Consider rewording.

The long-term emissions impact 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 at least a portion 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 if the dams are breached in 2032, before declining by 2045 as the carbon policy becomes more stringent.

Comment [EAJ7]: Do you mean the long-term emissions impact of **replacing** the power capabilities of the LSRDs?

Table 2. Summary of LSR Dams Replacement Resources and Cost Impacts

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Scenario	Replacement Resources Selected, Cumulative by 2045 (GW)	NPV Replacement Costs[2]	Annual Replacement Costs[3]			Public Power Rate Impact[4]
			2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind	$7.5 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 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	$11.5 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	$7 billion	-	$415 million/yr	$428 million/yr	0.7 ₵/kWh [+8%]
Scenario 2c: Deep Decarbonization (No New	+ 10.6 GW wind + 1.4 GW solar	$46 billion	-	$1,953 million/yr	$3,199 million/yr	5.5 ₵/kWh [+65%]

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[2] These NPV values are calculated assuming a 5% real discount rate. If a lower 3% discount rate was used instead, the NPV replacement costs would be higher.

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

[4] 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.

Combustion)						

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 $7 – 11.5 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 impractical levels of renewable additions at a very high cost*** (12 GW of wind and solar at $46 billion NPV cost)

From: Habibi,Maryam A (BPA) - DKP-7
Sent: Wednesday, July 6, 2022 3:29 PM
To: Koehler,Birgit G (BPA) - PG-5; Leary,Jill C (BPA) - LN-7
Cc: Johnson,G Douglas (BPA) - DK-7; Scruggs,Joel L (BPA) - DK-7; Baskerville,Sonya L (BPA) - AIN-WASH
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

If we can provide responses to Dan's questions to Arne or Doug, I can take care of that this afternoon while Doug is out.

Maryam Habibi
Manager | Media Relations, Policy Communications and Writing
BONNEVILLE POWER ADMINISTRATION
P 503-230-4413 | C (b)(6)

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 3:05 PM
To: Leary,Jill C (BPA) - LN-7 <jcleary@bpa.gov>
Cc: Johnson,G Douglas (BPA) - DK-7 <gdjohnson@bpa.gov>; Habibi,Maryam A (BPA) - DKP-7 <maasgharian@bpa.gov>; Scruggs,Joel L (BPA) - DK-7 <jlscruggs@bpa.gov>; Baskerville,Sonya L (BPA) - AIN-WASH <slbaskerville@bpa.gov>
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FYI, I replied without explanation to Arne on his request from Clearing Up

---

From: Koehler,Birgit G (BPA) - PG-5
Sent: Wednesday, July 6, 2022 3:04 PM
To: 'Arne Olson' <arne@ethree.com>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Deliberative, FOIA exempt

Arne,
Sorry I didn't reply yet. I didn't quite know what to say. Dan also reached out to our Communications staff, so we can let them reply (or not). I'm sorry that you are caught in the middle of this.

Birgit

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, July 6, 2022 2:21 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Birgit,

Dan Catchpole called again. I told him I couldn't answer any questions until after the Council meeting tomorrow. Two things to flag for you:]

1. He is not aware of any press briefing, and he would like to ask me some questions on the record. I assume that will be OK but told him I needed to run that by you.
2. His spidey sense is tingling (my words) about the way DOE is handling this. He plans to ask me whether there were any internal briefings at DOE, etc. and what the reaction was. I assume that I should punt any discussion of the internal briefings over to BPA or DOE? He may have some pointed questions for you.

Thanks,

Arne

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 10:52 AM
To: Arne Olson <arne@ethree.com>
Subject: FW: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

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Arne,
Would you send me your revised slide set when ready?

And please don't send to Chad until you hear back from me. Sorry for the extra hurdles.

Birgit

From: Chad Madron <CMadron@NWCouncil.org>
Sent: Wednesday, July 6, 2022 10:10 AM
To: Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>; Arne Olsen (arne@ethree.com) <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Jennifer Light <JLight@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Good morning Arne and BPA folks,

Just a reminder that it is our preference for you to send slides shown tomorrow morning to me ahead of time - then I use our computer to present them, but give you "keyboard and mouse control" so you can advance them using your equipment. This makes it so you don't have to worry about presenting from your machine. If you are very comfortable presenting from your computer directly we can accommodate that, we just find we have more consistent results if we do it the other way as different folks have differing levels of comfort with different webinar technologies.

Thanks!
Chad
(b)(6)

From: Chad Madron
Sent: Monday, June 27, 2022 10:48 AM
To: Ryan J (BPA) - PGPR-5 Egerdahl - BPA (rjegerdahl@bpa.gov) <rjegerdahl@bpa.gov>; Arne Olsen (arne@ethree.com) <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Jennifer Light - Northwest Power and Conservation Council (JLight@NWCouncil.org) <JLight@NWCouncil.org>;

Kendra Coles (kcoles@nwcouncil.org) <kcoles@nwcouncil.org>
Subject: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Ryan, Eve, and Arne,

I am working with Jenn on pulling together a memo and any other background material we can for Members ahead of the July 7 presentation on BPA's Snake River Dams study that is at 8:30am Pacific.

Can you confirm who from BPA and E3 will officially be presenting/speaking? Arne, I know you are giving the main presentation. Is there a report exec summary or any slides we could include with the memo to help them prepare? We will be sending them the prep memo THIS Wed by the middle of the day. Any info you can help us provide to help them be prepared is appreciated.

For July 7 – I will make sure you three all have calendar invites and panelist email/invites for the webinar.

Arne – speakers generally appear on camera, but it is not required. Our preference is for you to send me your slides and then I use our computer to present them, but give you "keyboard and mouse control" so you can advance them using your equipment. This makes it so you don't have to worry about presenting from your machine. If you are very comfortable presenting from your screen directly we can accommodate that, we just find we have more consistent results if we do it the other way as different folks have differing levels of comfort with different webinar technologies.

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From: Johnson,G Douglas (BPA) - DK-7
Sent: Wednesday, July 6, 2022 2:40 PM
To: Leary,Jill C (BPA) - LN-7; Koehler,Birgit G (BPA) - PG-5
Cc: Godwin,Mary E (BPA) - LN-7; James,Eve A L (BPA) - PG-5; Baskerville,Sonya L (BPA) - AIN-WASH
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Copy. Thanks for the info.

From: Leary,Jill C (BPA) - LN-7 <jcleary@bpa.gov>
Sent: Wednesday, July 6, 2022 2:40 PM
To: Johnson,G Douglas (BPA) - DK-7 <gdjohnson@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
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Still TBD – will report out once I have an answer.

From: Johnson,G Douglas (BPA) - DK-7 <gdjohnson@bpa.gov>
Sent: Wednesday, July 6, 2022 2:33 PM
To: Leary,Jill C (BPA) - LN-7 <jcleary@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
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Does that no green light include the presentation tomorrow? Or is that set in stone?

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At this point yes…John H. and I are still working the issue with DOE, but we do not have a greenlight on anything yet.

From: Johnson,G Douglas (BPA) - DK-7 <gdjohnson@bpa.gov>
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To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Leary,Jill C (BPA) - LN-7 <jcleary@bpa.gov>
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I am assuming any semblance of a media advisory is off the table. Correct?

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Any guidance for my reply?

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Subject:	RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

I will be out of the office around 3 p.m. If we happen to get changes to the talking points, an approved media advisory and/or any other materials we can share with external parties, please provide them to Joel Scruggs and Maryam Habibi, who are copied on this email. Thanks.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
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Sent: Wednesday, July 6, 2022 10:10 AM
To: Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>; Arne Olsen (arne@ethree.com) <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Jennifer Light <JLight@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Good morning Arne and BPA folks,

Just a reminder that it is our preference for you to send slides shown tomorrow morning to me ahead of time - then I use our computer to present them, but give you "keyboard and mouse control" so you can advance them using your equipment. This makes it so you don't have to worry about presenting from your machine. If you are very comfortable presenting from your computer directly we can accommodate that, we just find we have more consistent results if we do it the other way as different folks have differing levels of comfort with different webinar technologies.

Thanks!
Chad
(b)(6)

From: Chad Madron
Sent: Monday, June 27, 2022 10:48 AM
To: Ryan J (BPA) - PGPR-5 Egerdahl - BPA (rjegerdahl@bpa.gov) <rjegerdahl@bpa.gov>; Arne Olsen (arne@ethree.com) <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Jennifer Light - Northwest Power and Conservation Council (JLight@NWCouncil.org) <JLight@NWCouncil.org>; Kendra Coles (kcoles@nwcouncil.org) <kcoles@nwcouncil.org>
Subject: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Ryan, Eve, and Arne,

I am working with Jenn on pulling together a memo and any other background material we can for Members ahead of the July 7 presentation on BPA's Snake River Dams study that is at 8:30am Pacific.

Can you confirm who from BPA and E3 will officially be presenting/speaking? Arne, I know you are giving the main presentation. Is there a report exec summary or any slides we could include with the memo to help them prepare? We will be sending them the prep memo THIS Wed by the middle of the day. Any info you can help us provide to help them be prepared is appreciated.

For July 7 – I will make sure you three all have calendar invites and panelist email/invites for the webinar.

Arne – speakers generally appear on camera, but it is not required. Our preference is for you to send me your slides and then I use our computer to present them, but give you "keyboard and mouse control" so you can advance them using your equipment. This makes it so you don't have to worry about presenting from your machine. If you are very comfortable presenting from your screen directly we can accommodate that, we just find we have more consistent results if we do it the other way as different folks have differing levels of comfort with different webinar technologies.

You should all get the GoToWebinar emails today! Those will have your UNIQUE entry links for the webinar. You will get the emails again 1 day and 1 hour before the meeting as reminders.

From: Johnson,G Douglas (BPA) - DK-7
Sent: Wednesday, July 6, 2022 2:26 PM
To: Koehler,Birgit G (BPA) - PG-5; Leary,Jill C (BPA) - LN-7
Cc: Godwin,Mary E (BPA) - LN-7; James,Eve A L (BPA) - PG-5; Baskerville,Sonya L (BPA) - AIN-WASH
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

I am assuming any semblance of a media advisory is off the table. Correct?

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 2:22 PM
To: Leary,Jill C (BPA) - LN-7 <jcleary@bpa.gov>
Cc: Godwin,Mary E (BPA) - LN-7 <megodwin@bpa.gov>; Johnson,G Douglas (BPA) - DK-7 <gdjohnson@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Baskerville,Sonya L (BPA) - AIN-WASH <slbaskerville@bpa.gov>
Subject: FW: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Confidential and Privileged, Attorney-Client Communication, Do Not Release under FOIA

Any guidance for my reply?

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, July 6, 2022 2:21 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Birgit,

Dan Catchpole called again. I told him I couldn't answer any questions until after the Council meeting tomorrow. Two things to flag for you:]

1. He is not aware of any press briefing, and he would like to ask me some questions on the record. I assume that will be OK but told him I needed to run that by you.
2. His spidey sense is tingling (my words) about the way DOE is handling this. He plans to ask me whether there were any internal briefings at DOE, etc. and what the reaction was. I assume that I should punt any discussion of the internal briefings over to BPA or DOE? He may have some pointed questions for you.

Thanks,

Arne

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 10:52 AM
To: Arne Olson <arne@ethree.com>
Subject: FW: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Deliberative, FOIA exempt

Arne,
Would you send me your revised slide set when ready?

And please don't send to Chad until you hear back from me. Sorry for the extra hurdles.

Birgit

From: Chad Madron <CMadron@NWCouncil.org>
Sent: Wednesday, July 6, 2022 10:10 AM
To: Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>; Arne Olsen (arne@ethree.com) <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Jennifer Light <JLight@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Good morning Arne and BPA folks,

Just a reminder that it is our preference for you to send slides shown tomorrow morning to me ahead of time - then I use our computer to present them, but give you "keyboard and mouse control" so you can advance them using your equipment. This makes it so you don't have to worry about presenting from your machine. If you are very comfortable presenting from your computer directly we can accommodate that, we just find we have more consistent results if we do it the other way as different folks have differing levels of comfort with different webinar technologies.

Thanks!
Chad
(b)(6)

From: Chad Madron
Sent: Monday, June 27, 2022 10:48 AM
To: Ryan J (BPA) - PGPR-5 Egerdahl - BPA (rjegerdahl@bpa.gov) <rjegerdahl@bpa.gov>; Arne Olsen (arne@ethree.com) <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Jennifer Light - Northwest Power and Conservation Council (JLight@NWCouncil.org) <JLight@NWCouncil.org>; Kendra Coles (kcoles@nwcouncil.org) <kcoles@nwcouncil.org>
Subject: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Ryan, Eve, and Arne,

I am working with Jenn on pulling together a memo and any other background material we can for Members ahead of the July 7 presentation on BPA's Snake River Dams study that is at 8:30am Pacific.

Can you confirm who from BPA and E3 will officially be presenting/speaking? Arne, I know you are giving the main presentation. Is there a report exec summary or any slides we could include with the memo to help them prepare? We will be sending them the prep memo THIS Wed by the middle of the day. Any info you can help us provide to help them be prepared is appreciated.

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Subject:	RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Interesting. I just got off the phone with Dan. I have asked him to send me his questions via email so I can share them with this group. You'll have them when I have them. He has also asked for an embargoed copy of the presentation.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 2:22 PM
To: Leary,Jill C (BPA) - LN-7 <jcleary@bpa.gov>
Cc: Godwin,Mary E (BPA) - LN-7 <megodwin@bpa.gov>; Johnson,G Douglas (BPA) - DK-7 <gdjohnson@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Baskerville,Sonya L (BPA) - AIN-WASH <slbaskerville@bpa.gov>
Subject: FW: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

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Any guidance for my reply?

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, July 6, 2022 2:21 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

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To: Arne Olson <arne@ethree.com>
Subject: FW: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

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Arne,
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And please don't send to Chad until you hear back from me. Sorry for the extra hurdles.

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Cc: Jennifer Light <JLight@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

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Thanks!
Chad
(b)(6)

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Cc: Jennifer Light - Northwest Power and Conservation Council (JLight@NWCouncil.org) <JLight@NWCouncil.org>; Kendra Coles (kcoles@nwcouncil.org) <kcoles@nwcouncil.org>
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Hi Ryan, Eve, and Arne,

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From: Koehler,Birgit G (BPA) - PG-5
Sent: Tuesday, July 12, 2022 9:57 AM
To: Kendra Coles; Chad Madron; Jennifer Light
Cc: James,Eve A L (BPA) - PG-5; John Shurts
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Thank you Kendra and team!

From: Kendra Coles <kcoles@nwcouncil.org>
Sent: Tuesday, July 12, 2022 9:56 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Chad Madron <CMadron@NWCouncil.org>; Jennifer Light <JLight@NWCouncil.org>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; John Shurts <jshurts@nwcouncil.org>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Birgit,

The following are panelists: Arne, Aaron, Eve and yourself. You will be receiving an email from Meeting Organizer with your **unique login**. Please let us know if you do not receive this email.

Thanks,
Kendra

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Tuesday, July 12, 2022 6:18 AM
To: Chad Madron <CMadron@NWCouncil.org>; Jennifer Light <JLight@NWCouncil.org>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Kendra Coles <kcoles@nwcouncil.org>; John Shurts <jshurts@nwcouncil.org>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Good morning Chad and Jennifer,

Here at last is the long-awaited link to the page with the E3 study

- https://www.bpa.gov/energy-and-services/power/hydropower-impact

Would you make all of us panelists for the presentation today please?
Arne Olson arne@ethree.com
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

We expect Arne and Aaron to do 99% of the talking, but Eve and I would answer a question if it were directed at BPA.

Thanks for coordinating all of this ☺

Birgit

From: Koehler,Birgit G (BPA) - PG-5
Sent: Monday, July 11, 2022 3:22 PM
To: Chad Madron <CMadron@NWCouncil.org>; Jennifer Light <JLight@NWCouncil.org>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Kendra Coles <kcoles@nwcouncil.org>; jshurts@nwcouncil.org
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hello Chad and Jennifer,

We are ready to post the E3 analysis tomorrow morning at 6 am. I will send you a link to the E3 analysis as soon as we have it ready.

Our administrator, John Hairston, will call Council leadership to inform them that we are releasing it.

Birgit

From: Koehler,Birgit G (BPA) - PG-5
Sent: Thursday, July 7, 2022 9:41 AM
To: Chad Madron <CMadron@NWCouncil.org>; Jennifer Light <JLight@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; John Shurts <jshurts@nwcouncil.org>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Great. Thanks.

From: Chad Madron <CMadron@NWCouncil.org>
Sent: Thursday, July 7, 2022 9:39 AM
To: Jennifer Light <JLight@NWCouncil.org>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Kendra Coles <kcoles@nwcouncil.org>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; John Shurts <jshurts@nwcouncil.org>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

This has been updated online
https://www.nwcouncil.org/meeting/council-meeting-july-12-2022/

Arne will receive a new panelist email soon – as I'm assuming he is presenting via webinar.

From: Jennifer Light <JLight@NWCouncil.org>
Sent: Thursday, July 7, 2022 9:33 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Chad Madron <CMadron@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; John Shurts <jshurts@nwcouncil.org>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Thanks for confirming.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Thursday, July 7, 2022 9:11 AM
To: Jennifer Light <JLight@NWCouncil.org>; Chad Madron <CMadron@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; John Shurts <jshurts@nwcouncil.org>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Good morning Jennifer,

Arne told me that he is available from 1-5 that day (and 8-11 am). If 3:30-5 is the only good time that works from your end, then that's what we should do.

Thanks again and thanks again and again for the scramble.

Cheers,
Birgit

From: Jennifer Light <JLight@NWCouncil.org>
Sent: Thursday, July 7, 2022 8:44 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Chad Madron <CMadron@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; John Shurts <jshurts@nwcouncil.org>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Birgit,

It looks like we can move a couple things around to accommodate the E3 presentation at 3:30-5:00. I realize that is late in the day, but that is the only time we could work. Does this work for Arne? We want to confirm before updating our online agenda.

Thanks
Jennifer

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 7:25 PM
To: Chad Madron <CMadron@NWCouncil.org>; Jennifer Light <JLight@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Cc: Division Directors <DivisionDirectors@NWCouncil.org>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; John Shurts <jshurts@nwcouncil.org>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Thanks Chad. Speedy work.

I'm calling it a day. (It's been a long one!)
We can connect again tomorrow.

Have a good evening.

Cheers,
Birgit

From: Chad Madron <CMadron@NWCouncil.org>
Sent: Wednesday, July 6, 2022 7:04 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Jennifer Light <JLight@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Cc: Division Directors <DivisionDirectors@NWCouncil.org>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; John Shurts <jshurts@nwcouncil.org>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Birgit, we have updated our website.
https://www.nwcouncil.org/meeting/fw-and-council-meeting-july-6-2022/

For now it says this item is tentatively scheduled for July 12 – however John Hairston had indicated to Guy in conversation that he expected that date to be acceptable. Please let us know as soon as you can that we can remove the word tentative!

We will work to adjust the schedule that is posted there now tomorrow morning to work Arne in sometime after 1:30pm. My assumption is he would present via webinar, but if he is available to come to Spokane that would be great!

Chad

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 6:50 PM
To: Chad Madron <CMadron@NWCouncil.org>; Jennifer Light <JLight@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; John Shurts <jshurts@nwcouncil.org>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hello Chad,
As luck would have it, I already received a reply from E3. Arne is available Tuesday afternoon.

For your awareness, we cannot fully guarantee on our end that we will have the go-ahead for next week, but I sure do hope so!

Birgit

From: Chad Madron <CMadron@NWCouncil.org>
Sent: Wednesday, July 6, 2022 6:41 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Jennifer Light <JLight@NWCouncil.org>; Kendra Coles <kcoles@nwcouncil.org>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; John Shurts <jshurts@nwcouncil.org>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Would E3 be available Tue afternoon in particular? If we adjust agenda that is likely where they will land.

We are working on notice and such now. If we can confirm their availability for next week tonight or early tomorrow that'd be especially helpful!

Sent via the Samsung Galaxy S21 Ultra 5G, an AT&T 5G smartphone

-------- Original message --------
From: "Koehler,Birgit G (BPA) - PG-5" <bgkoehler@bpa.gov>
Date: 7/6/22 6:27 PM (GMT-08:00)
To: Jennifer Light <JLight@NWCouncil.org>, Chad Madron <CMadron@NWCouncil.org>
Cc: "James,Eve A L (BPA) - PG-5" <eajames@bpa.gov>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hello again,

I'm afraid I just received confirmation that the presentation is indeed being delayed a week. Guy Normal has been informed, and I think Mike Edmonds too, or at least he knows that this was likely.

I'm checking with E3 on their availability for next week in hopes that we have the go-ahead to proceed—and that it works from your end too.

Again, sorry for the last minute change in plans.
Birgit

From: Jennifer Light <JLight@NWCouncil.org>
Sent: Wednesday, July 6, 2022 5:11 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Chad Madron <CMadron@NWCouncil.org>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Thanks for the note Birgit. We will stay tuned. We are discussing options for next week to try to make it work if needed.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 4:46 PM
To: Jennifer Light <JLight@NWCouncil.org>; Chad Madron <CMadron@NWCouncil.org>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Jennifer and Chad,

I have some news for you, not the presentation you have been waiting for.

The E3 presentation to the Council tomorrow will **likely** be canceled. The current plan is to delay one week, potentially to the full Council meeting, but this still needs to be confirmed and coordinated. The Council Chair has already been contacted and is aware.

Should it turn out that we are delaying the presentation, is there availability on the agenda for July 12 or 13th? I'll also need to check with Arne Olson at E3 if he is available. For now, I've just given him the same alert that we are likely but not yet confirmed about delaying.

Sorry about all the swirl,
Birgit

From: Jennifer Light <JLight@NWCouncil.org>
Sent: Wednesday, July 6, 2022 3:27 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Chad Madron <CMadron@NWCouncil.org>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Fantastic. Thanks for confirming.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 3:27 PM
To: Jennifer Light <JLight@NWCouncil.org>; Chad Madron <CMadron@NWCouncil.org>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hello Jennifer,

Yes, that's the current plan. There is still some coordination on our side, but unless you hear from me, please introduce Arne and pass it off to him. We engaged them to do an independent study, and so are happy to let them present independently.

Cheers,
Birgit

From: Jennifer Light <JLight@NWCouncil.org>
Sent: Wednesday, July 6, 2022 3:24 PM
To: Chad Madron <CMadron@NWCouncil.org>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Birgit,

One more quick question. I just want to confirm the plan for the morning. My understanding is that it is Bonneville's preference that I just introduce Arne for the topic and him just diving right in, rather than first handing it off to someone at Bonneville to introduce him. I just want to make sure that I pass it to the right person.

Thanks!
Jennifer

From: Chad Madron <CMadron@NWCouncil.org>
Sent: Wednesday, July 6, 2022 2:39 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Jennifer Light <JLight@NWCouncil.org>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Cool, no worries! I just hadn't heard from him at all so I was worried he was perhaps not seeing my traffic. I appreciate you confirming. Even slides by 8am is ok if that is what needs to happen!

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 2:34 PM
To: Chad Madron <CMadron@NWCouncil.org>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Chad,

Sorry for the delay. Yes, the slides are still being reviewed. I will do my utmost to make sure you get them in plenty of time for the meeting.

Birgit

From: Chad Madron <CMadron@NWCouncil.org>
Sent: Wednesday, July 6, 2022 2:32 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] FW: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Birgit,

I haven't heard at all from Arne. Are you all still in edit mode on slides and such?

From: Chad Madron
Sent: Wednesday, July 6, 2022 10:10 AM
To: Ryan J (BPA) - PGPR-5 Egerdahl - BPA (rjegerdahl@bpa.gov) <rjegerdahl@bpa.gov>; Arne Olsen (arne@ethree.com) <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; bgkoehler@bpa.gov
Cc: Jennifer Light - Northwest Power and Conservation Council (JLight@NWCouncil.org) <JLight@NWCouncil.org>; Kendra Coles (kcoles@nwcouncil.org) <kcoles@nwcouncil.org>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Good morning Arne and BPA folks,

Just a reminder that it is our preference for you to send slides shown tomorrow morning to me ahead of time - then I use our computer to present them, but give you "keyboard and mouse control" so you can advance them using your equipment. This makes it so you don't have to worry about presenting from your machine. If you are very comfortable presenting from your computer directly we can accommodate that, we just find we have more consistent results if we do it the other way as different folks have differing levels of comfort with different webinar technologies.

Thanks!
Chad
(b)(6)

From: Chad Madron
Sent: Monday, June 27, 2022 10:48 AM
To: Ryan J (BPA) - PGPR-5 Egerdahl - BPA (rjegerdahl@bpa.gov) <rjegerdahl@bpa.gov>; Arne Olsen (arne@ethree.com) <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Jennifer Light - Northwest Power and Conservation Council (JLight@NWCouncil.org) <JLight@NWCouncil.org>;

Kendra Coles (kcoles@nwcouncil.org) <kcoles@nwcouncil.org>
Subject: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Hi Ryan, Eve, and Arne,

I am working with Jenn on pulling together a memo and any other background material we can for Members ahead of the July 7 presentation on BPA's Snake River Dams study that is at 8:30am Pacific.

Can you confirm who from BPA and E3 will officially be presenting/speaking? Arne, I know you are giving the main presentation. Is there a report exec summary or any slides we could include with the memo to help them prepare? We will be sending them the prep memo THIS Wed by the middle of the day. Any info you can help us provide to help them be prepared is appreciated.

For July 7 – I will make sure you three all have calendar invites and panelist email/invites for the webinar.

Arne – speakers generally appear on camera, but it is not required. Our preference is for you to send me your slides and then I use our computer to present them, but give you "keyboard and mouse control" so you can advance them using your equipment. This makes it so you don't have to worry about presenting from your machine. If you are very comfortable presenting from your screen directly we can accommodate that, we just find we have more consistent results if we do it the other way as different folks have differing levels of comfort with different webinar technologies.

You should all get the GoToWebinar emails today! Those will have your UNIQUE entry links for the webinar. You will get the emails again 1 day and 1 hour before the meeting as reminders.

From: James,Eve A L (BPA) - PG-5
Sent: Tuesday, June 7, 2022 10:38 AM
To: Arne Olson; Aaron Burdick
Cc: Koehler,Birgit G (BPA) - PG-5
Subject: RE: Scheduling meeting with CEQ/DOE

Great- thanks. I'll keep you updated as the timeline gets narrowed down.

From: Arne Olson <arne@ethree.com>
Sent: Tuesday, June 7, 2022 10:35 AM
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>
Subject: [EXTERNAL] RE: Scheduling meeting with CEQ/DOE

I'm still working out my schedule for the 14th and 15th but should have some windows. I'm available on the 16th from 8-9 AM and 12:30 – 3:00 and anytime on Friday the 17th except 2-3 PM PDT.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, June 7, 2022 10:31 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: Scheduling meeting with CEQ/DOE

Deliberative, FOIA exempt

I just got some more information on the timeline it sounds like there is a Deputy Secretary meeting June 23 with a prep meeting scheduled June 21 – the E3 results will need to be presented to DOE/CEQ prior to that meeting. Are you available to present without Arne for any time blocks before June 21?

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, June 7, 2022 10:15 AM
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>
Subject: [EXTERNAL] RE: Scheduling meeting with CEQ/DOE

Deliberative, FOIA exempt

Arne is traveling a bit so let's go with times that do work (all shown in PST). In general, next week is pretty tight… (@Arne Olson – please add if there are any windows in your 6/14-15 travel that might work.)

- Fri 6/10 – 10-11am, 12-1:30pm
- Tue 6/21 – 8:30-9:30am
- Wed 6/22 – 11-2pm
- Thurs 6/23 – 8-9am, 1-3pm
- Fri 6/24 – 8-11am, 12-2pm

Though we're on track to wrap up before then, note that I'm out the first week and the last week of July.

All the best,

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, June 7, 2022 7:02 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: Scheduling meeting with CEQ/DOE

Deliberative, FOIA exempt

Good Morning-

BPA staff are coordinating times with DOE and CEQ for a presentation on the study results. Could you send me a list of available times you have in the next week or two (or times that don't work – whichever is easier).

Thanks,
Eve

From: James,Eve A L (BPA) - PG-5
Sent: Wednesday, June 8, 2022 11:12 AM
To: Aaron Burdick; Arne Olson
Cc: Koehler,Birgit G (BPA) - PG-5
Subject: RE: Scheduling meeting with CEQ/DOE

Okay- yesterday I replied that June 16th at 8 AM is the strong preference and that June 15th at 8 AM may be possible. The expectation is that E3 will present the public deck and then BPA will present a few slides on our perspective on the study results. We are expecting DOE to provide their review of the slide deck materials today so I'll send that along once we receive them.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, June 7, 2022 4:57 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>
Subject: [EXTERNAL] Re: Scheduling meeting with CEQ/DOE

Confirming 16th at 8am works for me. Once you get scheduled let us know what to expect. I presume we'll just walk through our public deck.

Get Outlook for iOS

From: Arne Olson <arne@ethree.com>
Sent: Tuesday, June 7, 2022 4:09:21 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>
Subject: RE: Scheduling meeting with CEQ/DOE

I will be in transit on the 15th, could possible make it work but the 16th is safer.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, June 7, 2022 3:05 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: Scheduling meeting with CEQ/DOE

Deliberative, FOIA exempt

Hello,
CEQ responded and has very limited availability next week for the E3 study presentation.

The options are all at 8am Pacific either June 15, 16 or 17. Looks like only 6/16 at 8 AM works for you. Does June 15th work as well or only June 16th?

Thanks,

Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, June 7, 2022 10:40 AM
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>
Subject: [EXTERNAL] RE: Scheduling meeting with CEQ/DOE

Deliberative, FOIA exempt

Of Arne's times, I could do 6/16 8-9. 6/16 could work for me 12:30-2:30 if needed. I'm unavailable on 6/17.

Aaron

From: Arne Olson <arne@ethree.com>
Sent: Tuesday, June 7, 2022 10:35 AM
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>
Subject: RE: Scheduling meeting with CEQ/DOE

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Sent: Tuesday, June 7, 2022 10:31 AM
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Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: Scheduling meeting with CEQ/DOE

Deliberative, FOIA exempt

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From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, June 7, 2022 10:15 AM
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>
Subject: [EXTERNAL] RE: Scheduling meeting with CEQ/DOE

Deliberative, FOIA exempt

Arne is traveling a bit so let's go with times that do work (all shown in PST). In general, next week is pretty tight... (@Arne Olson – please add if there are any windows in your 6/14-15 travel that might work.)

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- Tue 6/21 – 8:30-9:30am
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- Thurs 6/23 – 8-9am, 1-3pm
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Though we're on track to wrap up before then, note that I'm out the first week and the last week of July.

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, June 7, 2022 7:02 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: Scheduling meeting with CEQ/DOE

Deliberative, FOIA exempt

Good Morning-
BPA staff are coordinating times with DOE and CEQ for a presentation on the study results. Could you send me a list of available times you have in the next week or two (or times that don't work – whichever is easier).

Thanks,
Eve

From: Anasis,John G (TFE)(BPA) - TOOP-DITT-2
Sent: Wednesday, June 1, 2022 2:23 PM
To: James,Eve A L (BPA) - PG-5
Cc: Koehler,Birgit G (BPA) - PG-5; Pruder Scruggs,Kathryn M (BPA) - E-4; McManus,Bart (BPA) - TOOC-DITT-2
Subject: RE: Transmission considerations for LSN replacement study
Attachments: BPA_RESOLVE_PublicSummary_052722.pdf; BPA bottom line perspective from the E3 study kps 6 1_JGA comment.pptx

DELIBERATIVE FOIA EXEMPT

Eve,

Thank you for your note. I added a sentence to slide 6 in the attached version of the PowerPoint to flag voltage support and inertia as a couple other important things we get from the Lower Snake projects. That is shown in red. Slide 6 was the only place where I saw any transmission related references, so please let me know if I missed something. I did not see any transmission items on slide 4.

As far as what additional information may be needed, that depends on who the intended audience is for this PowerPoint presentation. If it is for the general public, policy-makers, or the fisheries community, then I think this is about the right level of detail. If the target audience is more technically oriented, such as regional utility folks, then they may want some additional detail. Please let me know if we need to look at this further based on who will be seeing the final version.

I have copied Bart on this e-mail so that he can comment on the statements on reserves if he sees fit.

Let me know if this meets your needs or if I can be of any other help. Thank you again!

John

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, June 1, 2022 8:25 AM
To: Anasis,John G (TFE)(BPA) - TOOP-DITT-2 <jganasis@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Pruder Scruggs,Kathryn M (BPA) - E-4 <kpruder@bpa.gov>
Subject: Transmission considerations for LSN replacement study

DELIBERATIVE FOIA EXEMPT

Hi John-

We are putting together a few slides together with BPA's perspective on the LSN replacement study work. Execs would like a transmission considerations slide. We want to make sure to keep the information in the presentation consistent with the EIS as much as we can. Birgit, Katie, and I are working on some messaging and were hoping for some feedback from TX on slide 4 and we can add an additional slide or Tx info on other slides if needed. If we should be bugging someone else over in Transmission for this information please let us know. The PDF is a rough draft version of the E3 study results that we will be putting our slides with.

Thanks,
Eve

Energy+Environmental Economics

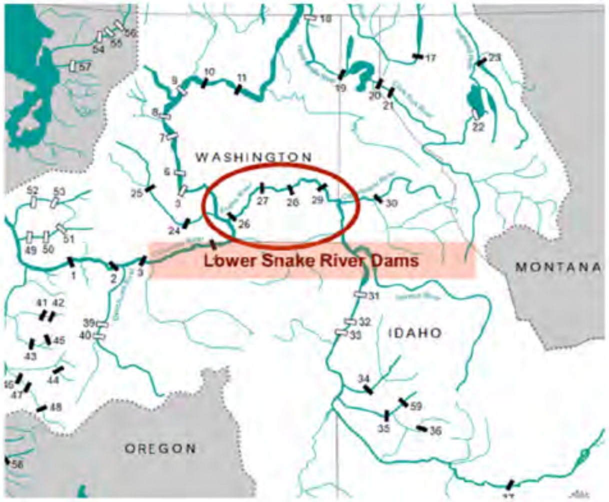
BPA Lower Snake River Dams Replacement Executive Summary

May 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 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 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 annual average MW of low-cost, zero-carbon energy as well as operational flexibility services

+ How much would it cost to replace the benefits of the four Lower Snake River dams, in E3's baseline scenario?

- $2.8 billion in upfront capital costs, with ~$110 million per year in annual operational cost per year after that
- $7.5 billion total NPV costs
- Absent breakthroughs in not-yet-commercialized emerging technologies, total costs (NPV) could quadruple with aggressive carbon reduction policies that drive the Northwest grid to zero-emissions

+ What are the long-term rate impacts to public power customers in 2045?

- Public power costs increase by 9% or ~$125 per year (baseline scenario)
- Public power costs could increase as much as 65% or $850 per year (deep decarbonization scenario absent emerging technology breakthroughs)

+ 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 and possibly up to 10 years if additional new transmission was required

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

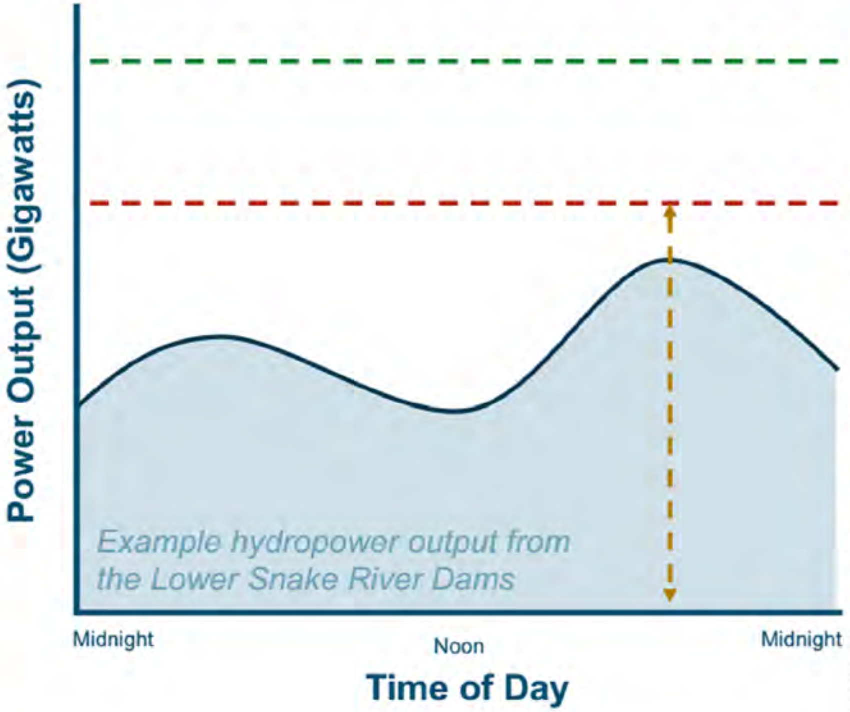
What grid services do the Lower Snake River Dams provide?

Little Goose

Lower Granite

Lower Monumental

Ice Harbor



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 average GW**

Operational Flexibility
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

Transmission Grid Reliability Services
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

* 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 the year the plant generated at 0.7 GW, though its hourly output may be above or below that amount. LSR output was adjusted to reflected increased spill requirements of the EIS.

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)	🟩	🟩	🟩	🟩
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

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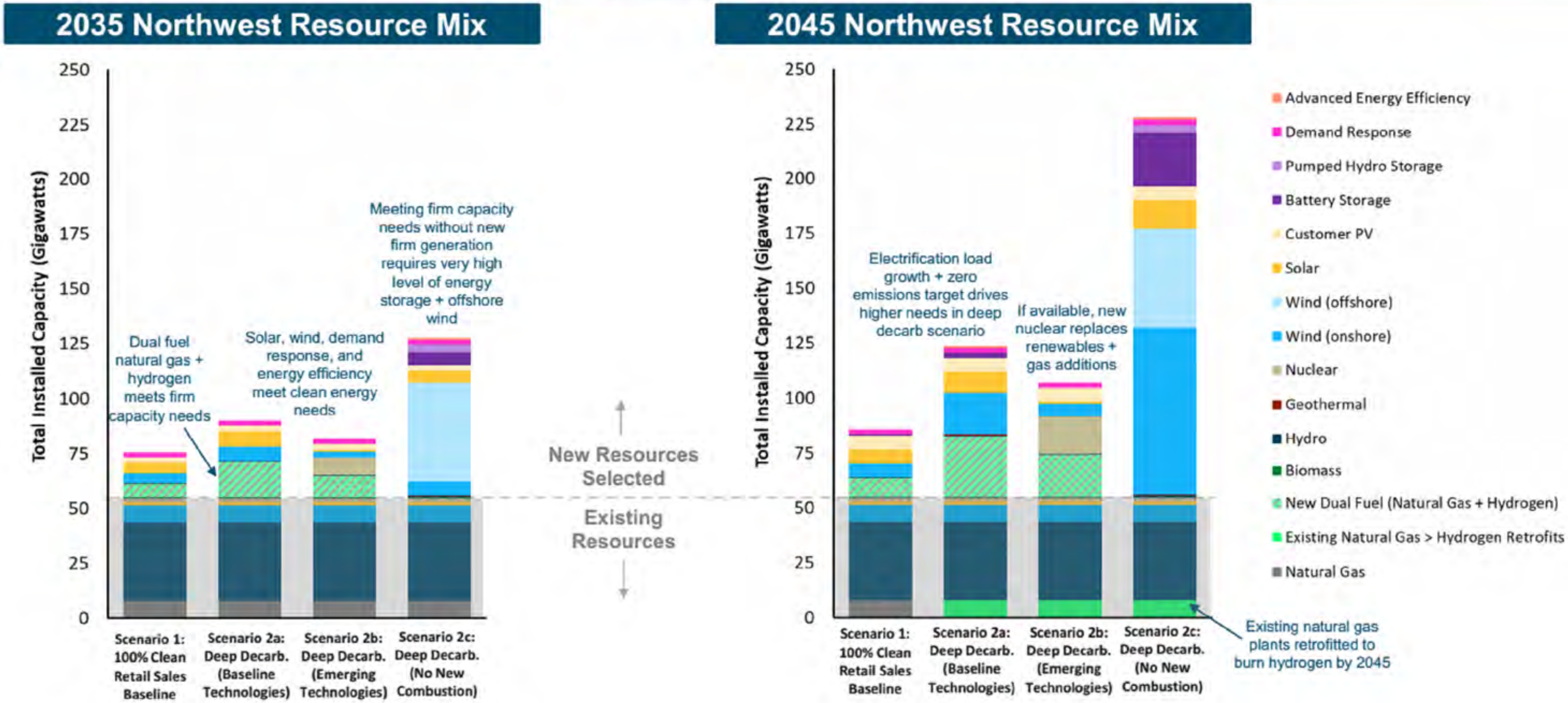
Northwest Resource Needs in Scenarios With the Lower Snake River Dams

Even without breaching the dams, all scenarios show large levels of new resource additions



2035 Northwest Resource Mix

2045 Northwest Resource Mix

Dual fuel natural gas + hydrogen meets firm capacity needs

Solar, wind, demand response, and energy efficiency meet clean energy needs

Meeting firm capacity needs without new firm generation requires very high level of energy storage + offshore wind

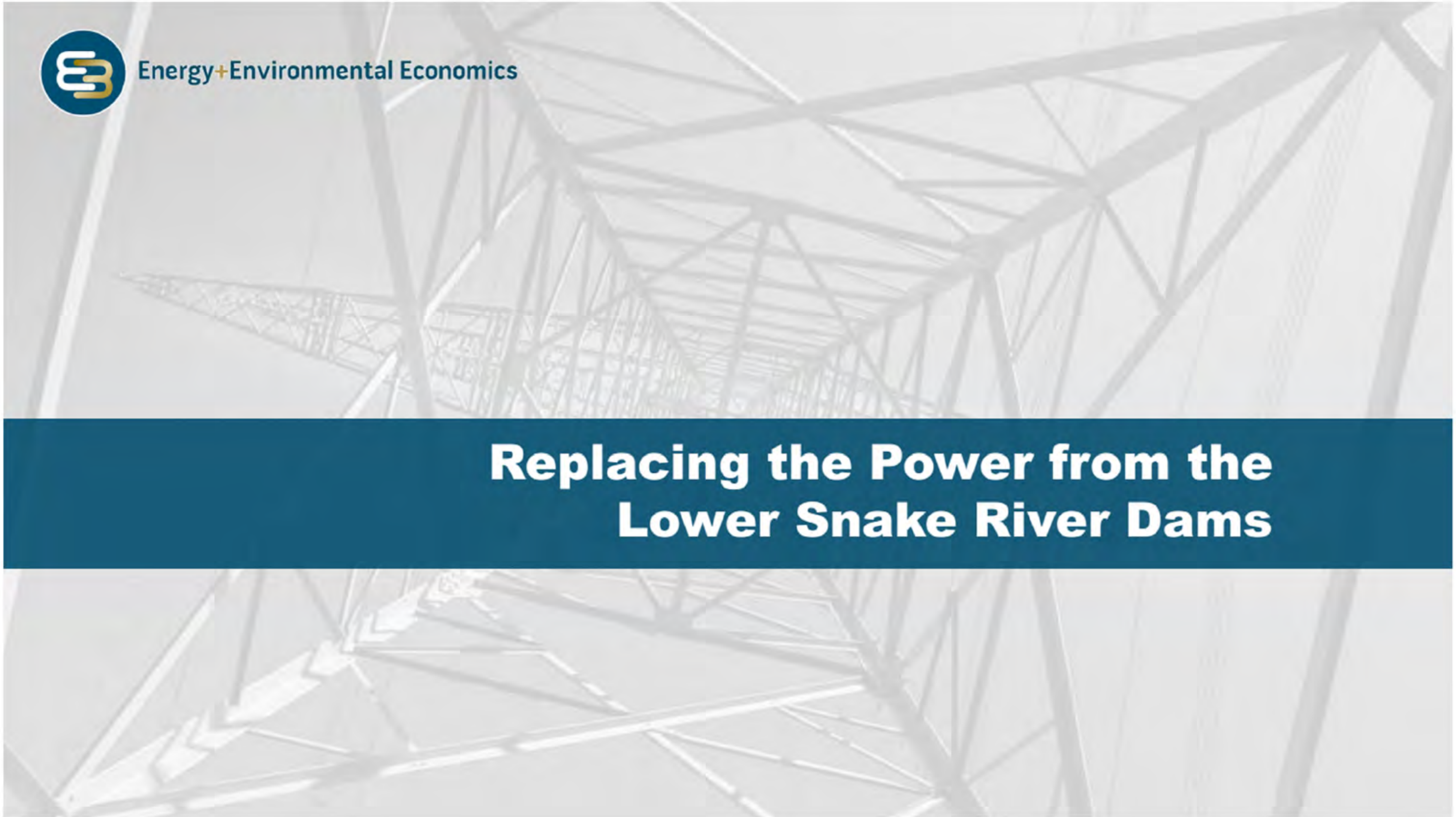
New Resources Selected

Existing Resources

Electrification load growth + zero emissions target drives higher needs in deep decarb scenario

If available, new nuclear replaces renewables + gas additions

Existing natural gas plants retrofitted to burn hydrogen by 2045



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 advanced energy efficiency + 1.2 TWh 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

Total costs for replacing the Lower Snake River Dams

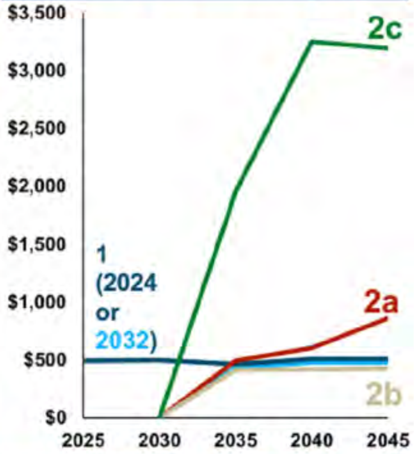
+ Costs are expected to fall on Bonneville Power Administration's public power customers

- 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 rates]
	Net Present Value in year of breaching	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$7.5 billion	n/a	$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	n/a	$496 million	$860 million	1.5 cents/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$7 billion	n/a	$415 million	$428 million	0.7 cents/kWh [+8%]
Scenario 2c: Deep Decarb. *(No New Combustion)*	*$46 billion*	*n/a*	*$1,953 million*	*$3,199 million*	*5.5 cents/kWh [+65%]*

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

Annual Cost Increase ($M)



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 rates assumes OR + WA average retail rates are ~8.5 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 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. 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 0.7 – 5.5 cents/kWh 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**

Additional 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

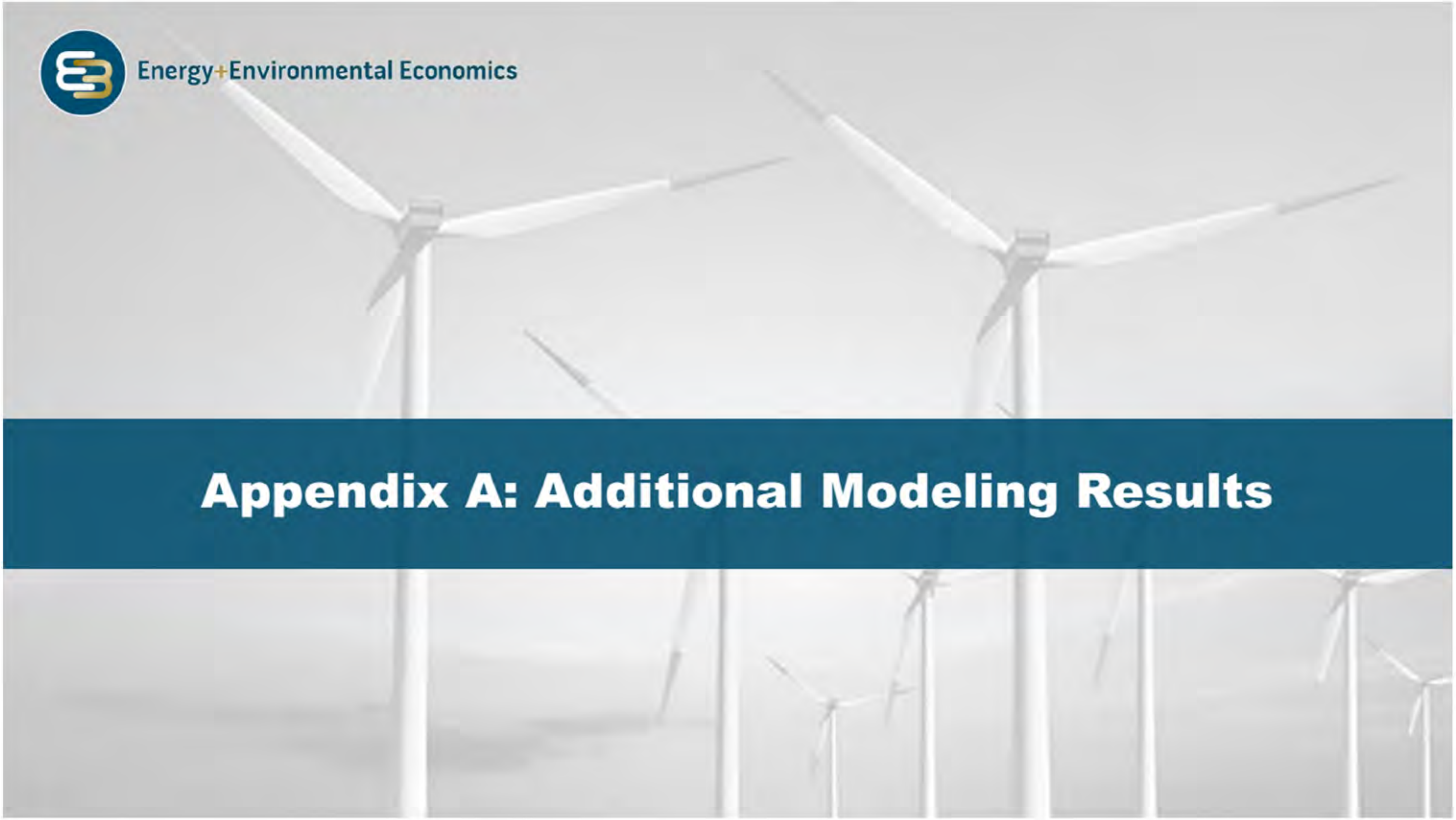
Energy+Environmental Economics

Thank you

Questions, please contact:

Arne Olson, arne@ethree.com

Aaron Burdick, aaron.burdick@ethree.com



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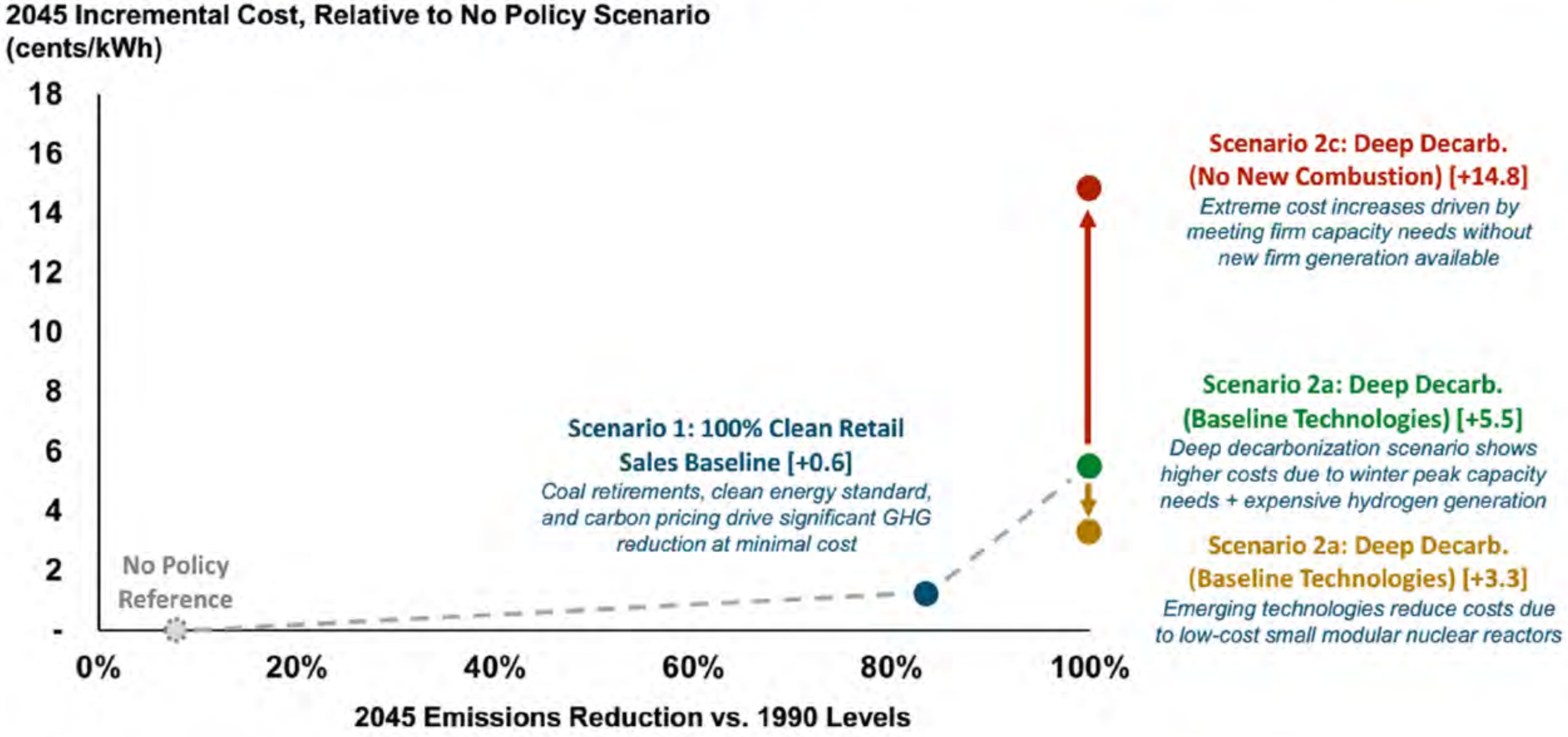
Appendix A: Additional Modeling Results

Significant carbon reductions are possible, but the cost of reaching zero emissions depends on technologies available



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

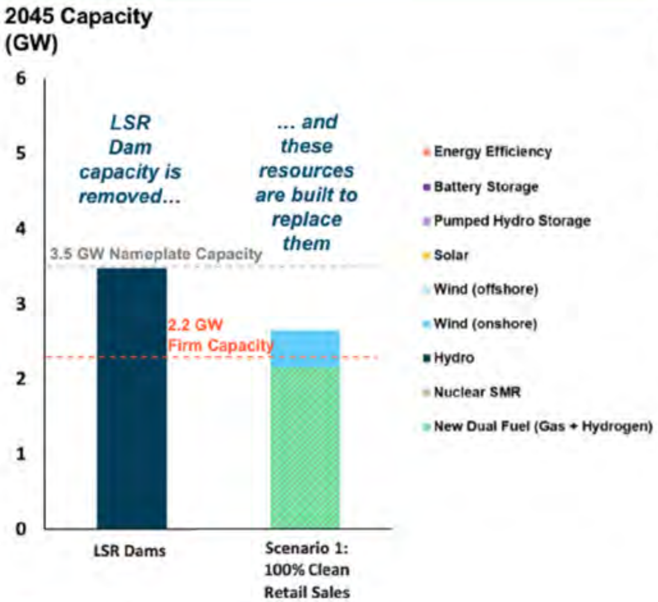
Scenario 2a: Deep Decarb. (Baseline Technologies) [+3.3]
Emerging technologies reduce costs due to low-cost small modular nuclear reactors

NOTES:
- 2020 average retail rates for OR and WA were 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

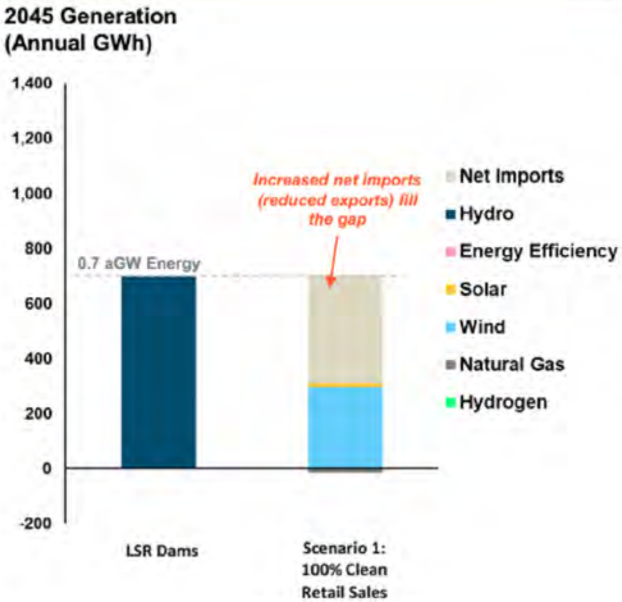
Replacing the Lower Snake River Dams
Scenario 1: 100% Clean Retail Sales

- 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

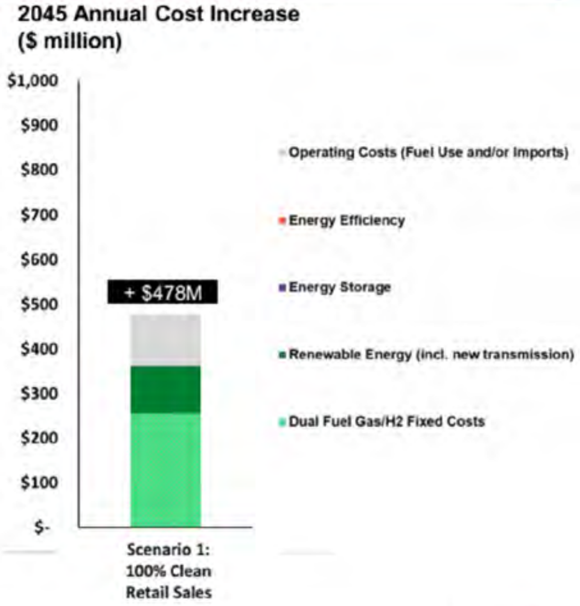
Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)



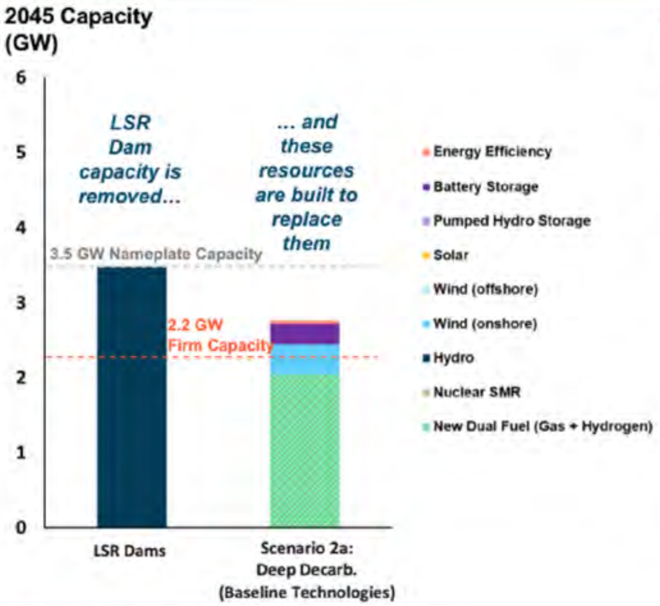
Additional Cost (2045)



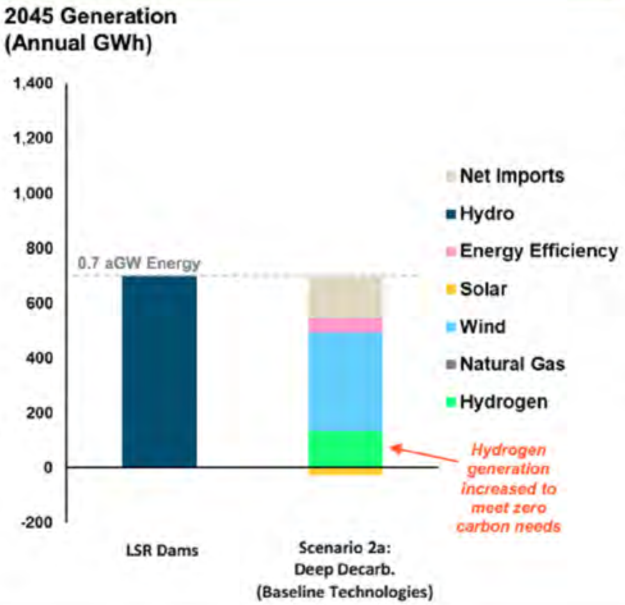
Replacing the Lower Snake River Dams
Scenario 2: Deep Decarbonization (Baseline Technologies)

- 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)

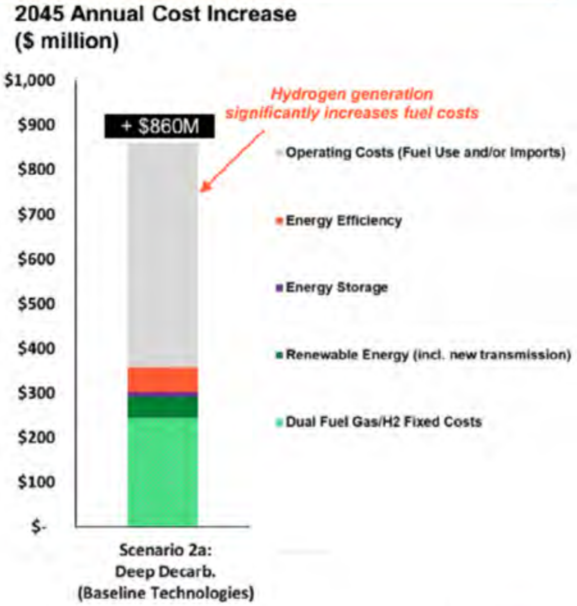
Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)



Additional Cost (2045)

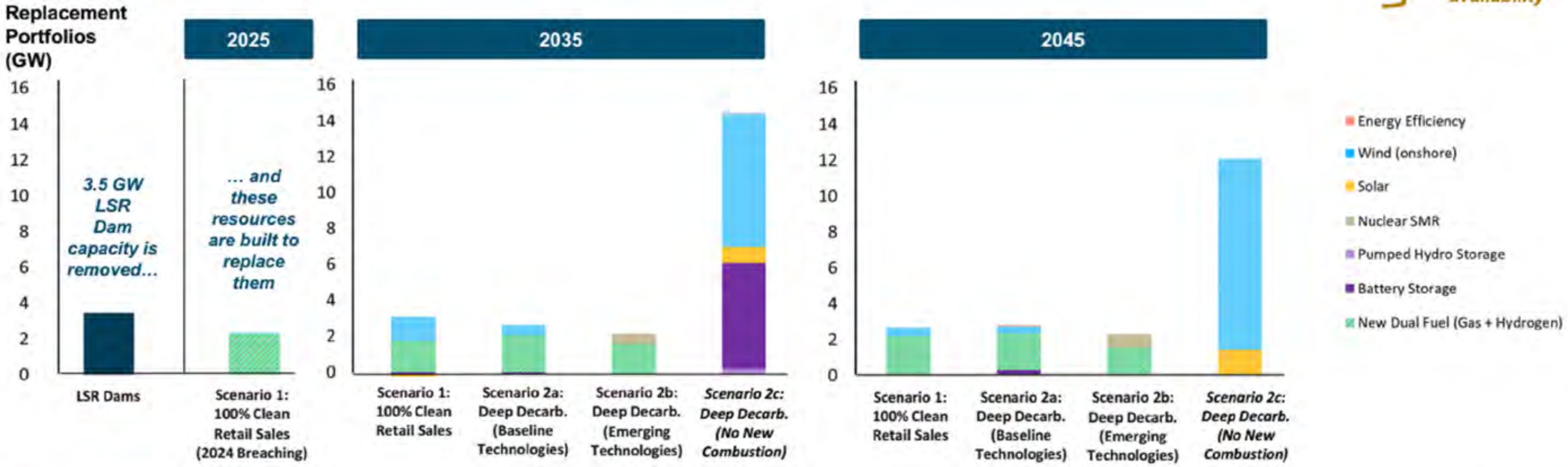


Replacing the Lower Snake River Dams Capacity Across All Scenarios

- 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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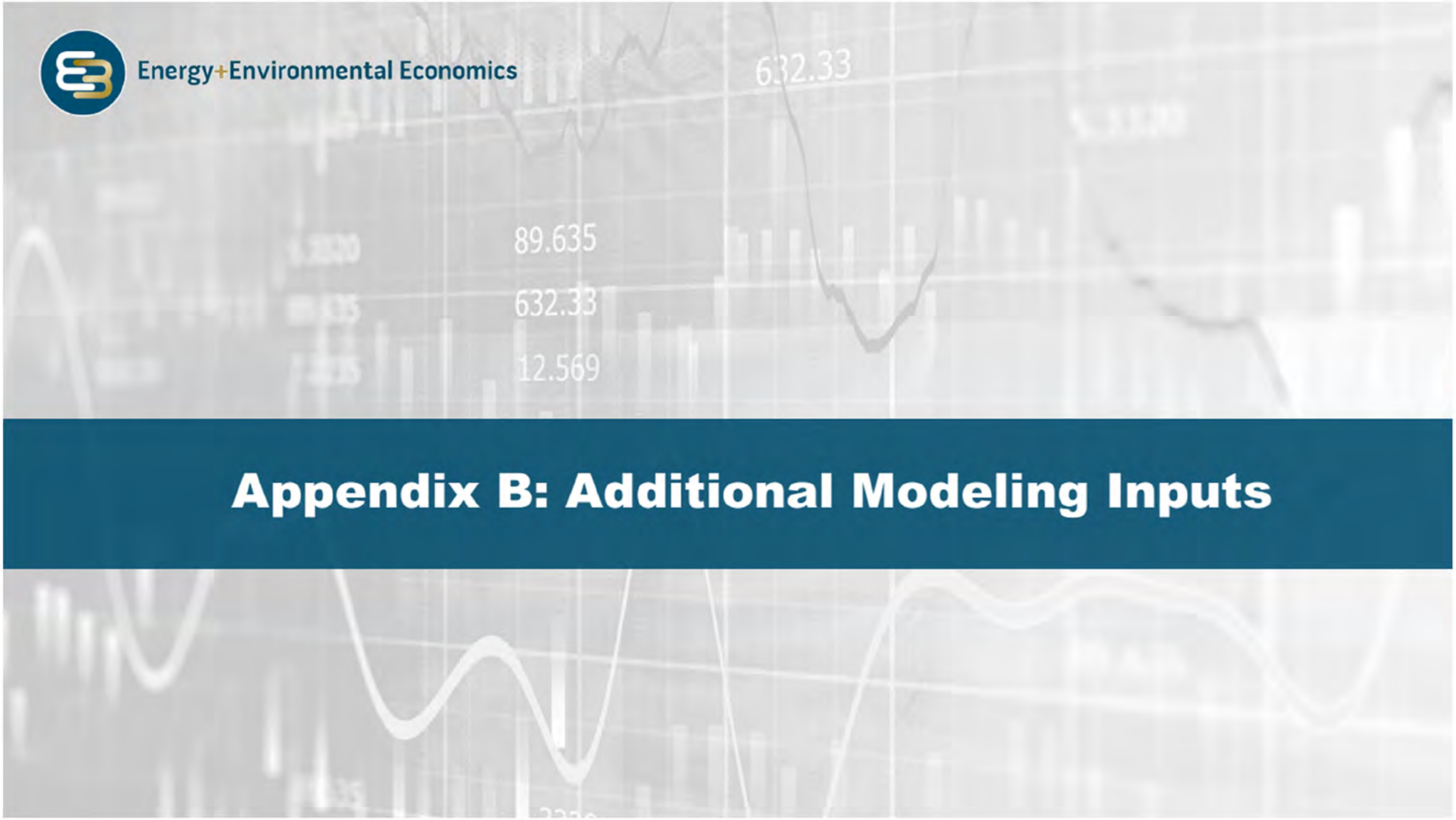


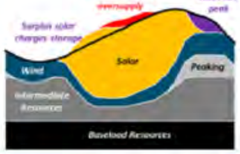
Appendix B: Additional Modeling Inputs

RESOLVE optimizes investments to meet clean energy targets reliably

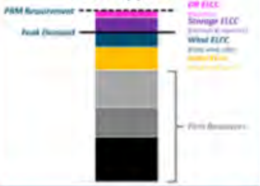
RESOLVE is an optimal capacity expansion model specifically designed to identify least-cost plans to meet reliability needs and achieve compliance with regulatory and policy requirements

- **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**

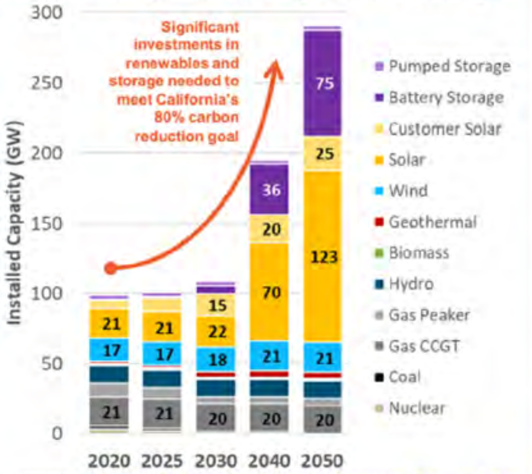
Operational module simulates hourly system operations for a sample of representative days



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



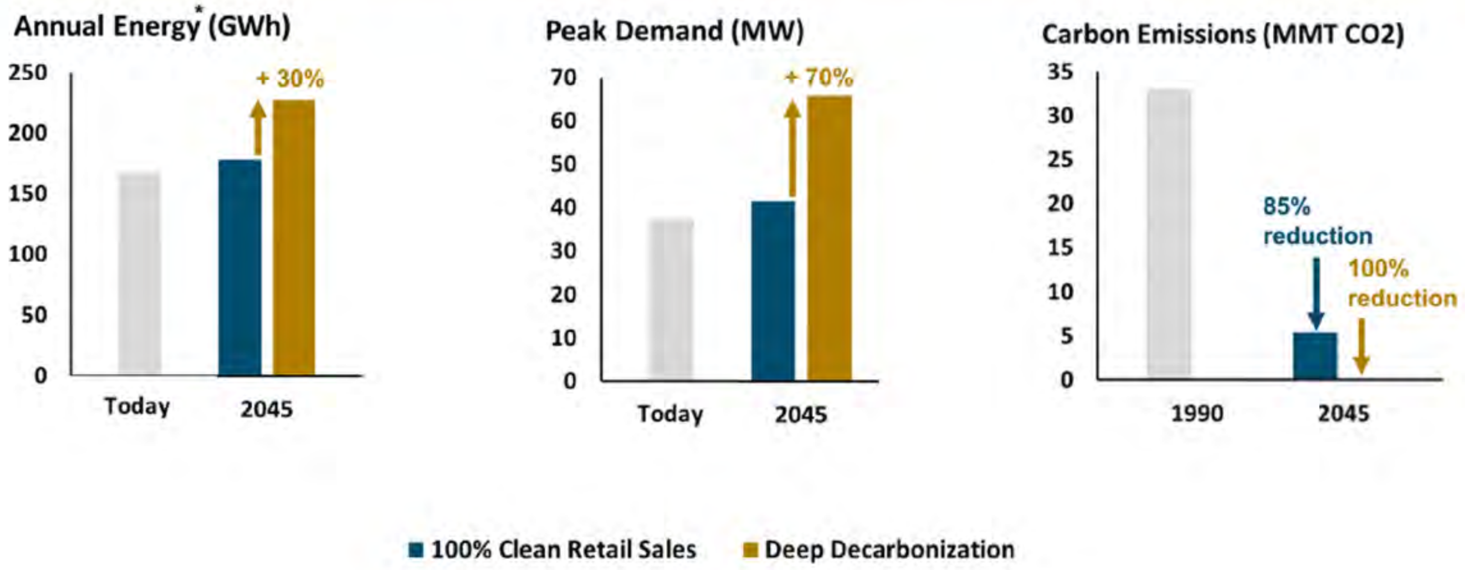
Least-cost plan cooptimizes investments and operations to meet clean energy policy targets, selecting from a diverse set of potential resources including wind, solar, storage, DSM, and natural gas



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

Load growth and carbon emissions in two clean energy scenarios modeled

Increases in Electricity Use and Declines in Carbon Emissions

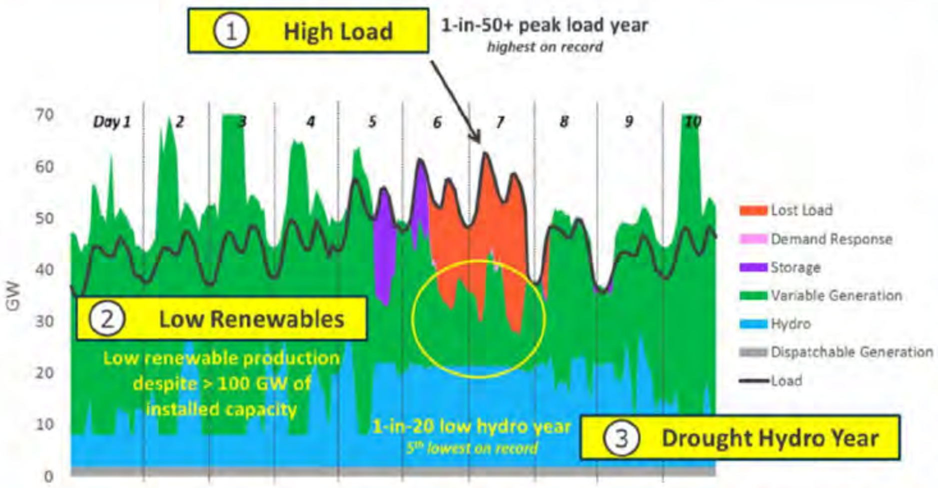


* Load based on 2021 NWPCC Power Plan, shown as retail sales (after assumed growth in customer PV and energy efficiency)

Resource Adequacy Resource Options

- **RESOLVE resource adequacy constraint requires capacity to meet peak demand + a 15% planning reserve margin**
  - 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)

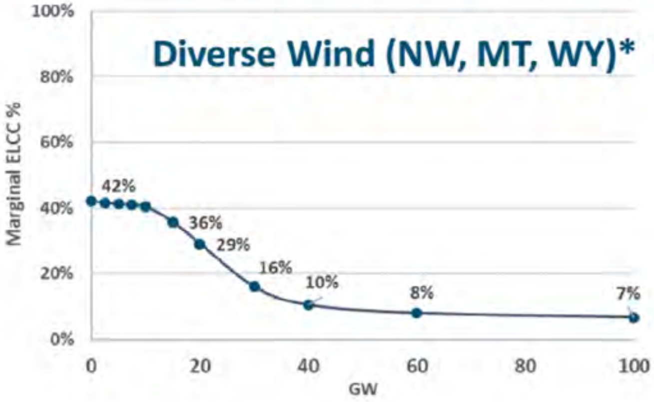
Key Drivers of Future Pacific Northwest Reliability Events

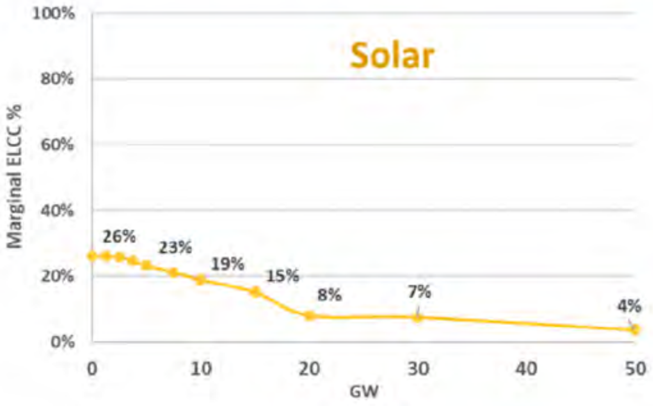


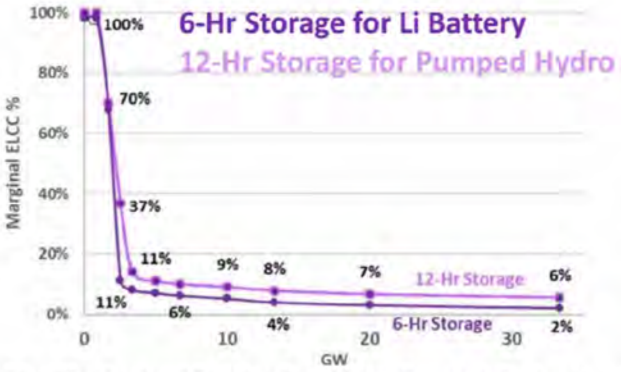
Sample week in 2050 in a 100% GHG reduction scenario, from E3, *Resource Adequacy in the Pacific Northwest*, 2019.

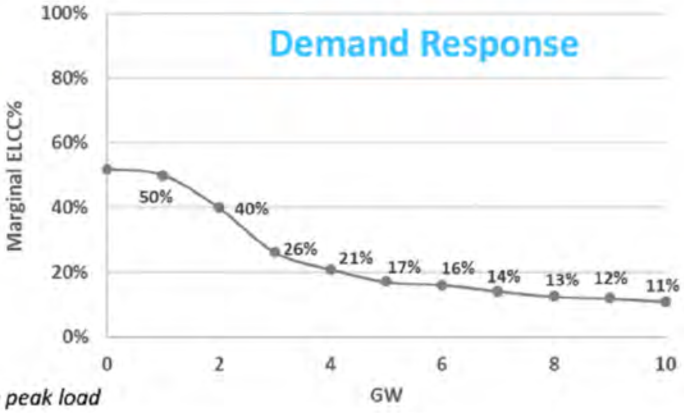
Resource	RA Capacity Contributions
Hydro	65%, based on sustained winter peaking capacity in critical water year conditions (per BPA/PNUCC)... WRAP method is still evolving
Battery storage	Sharply declining ELCCs (due to hydro interactive effects)
Pumped storage	Sharply declining ELCCs (due to hydro interactive 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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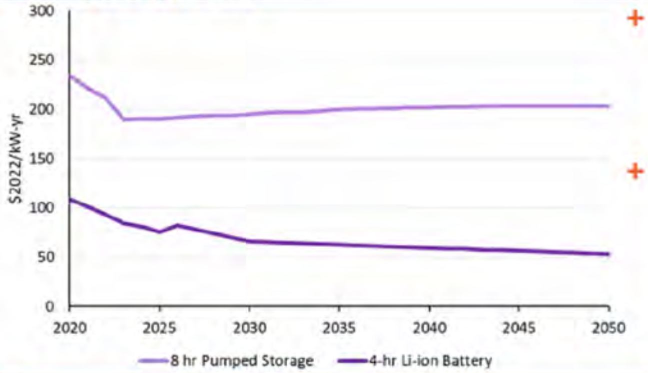
* The offshore wind sensitivity in this study assumed the same ELCC curve as modeled for diverse on-shore wind resources in the Resource Adequacy in the Northwest report.

New Resource Options

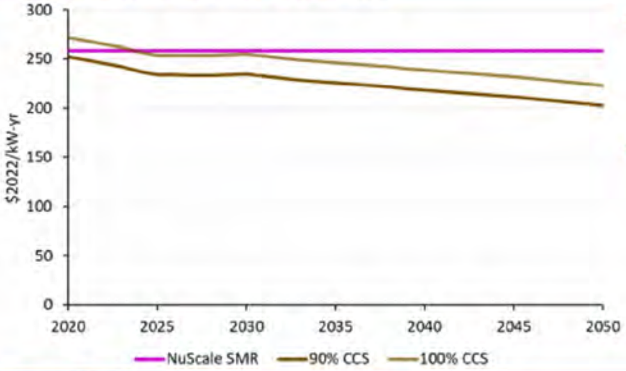
All-in Fixed Costs

Storage Options



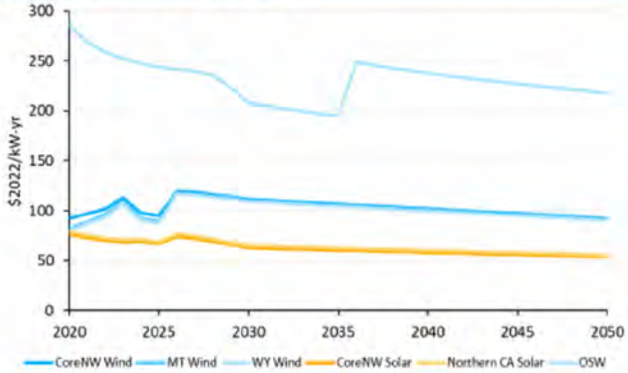
- Battery Storage costs derived from E3's inhouse and Lazard LCOS 7.0 (Oct 2021)
- Pumped storage is from Lazard's last published PHS costs (LCOS 4.0). Assumes CAPEX and FO&M are flat + financing cost trends same for battery storage.

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

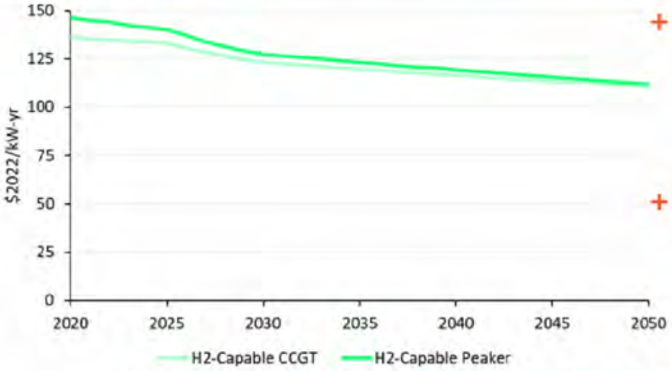
Renewable Options



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



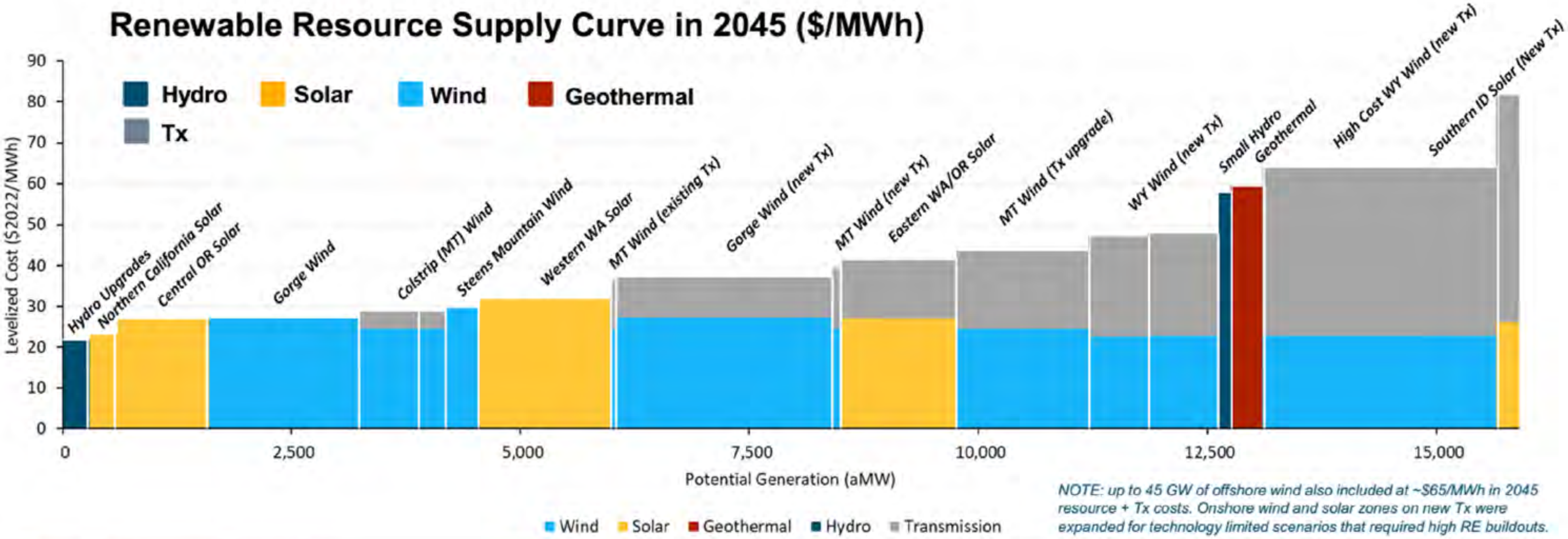
NOTE: only dual fuel natural gas + H2-enabled new resources modeled, given NW policy constraints

- 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

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)



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.

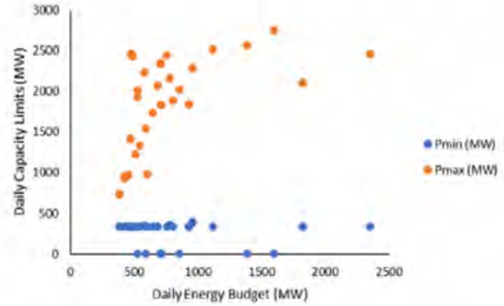
Hydro Operating Data

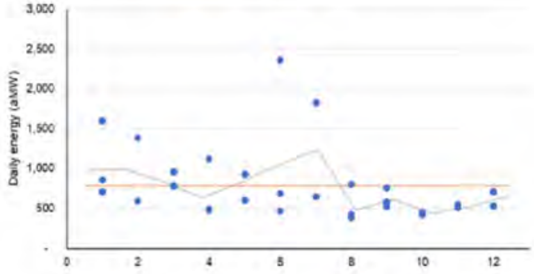
- **Key RESOLVE inputs (for each representative RESOLVE day)**
  - Max generation MW
  - Min generation MW
  - Daily MWh hydro budget
  - Ramp
- **Hydro operating data is parameterized using representative conditions for 3 low/mid/high historical years (2001, 2005, 2011)**
  - Lower Snake River and Lower 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%

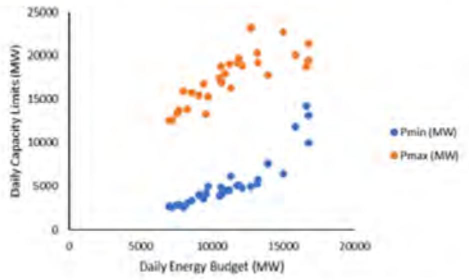


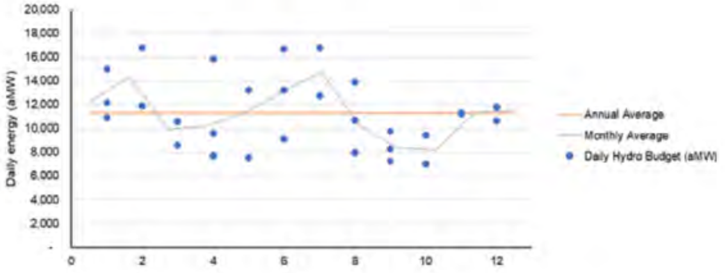


Non-LSR NW Hydro

Ramp Rates

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





From: Johnson,G Douglas (BPA) - DK-7
Sent: Tuesday, July 5, 2022 12:38 PM
To: Koehler,Birgit G (BPA) - PG-5; Goodwin,Summer G (BPA) - DKS-7
Subject: RE: calendaring E3/BPA

1 p.m. is fine. I must have crossed my ET/PT wires. Just means some larger media outlets will publish preliminary online stories before the media availability.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Tuesday, July 5, 2022 12:34 PM
To: Johnson,G Douglas (BPA) - DK-7 <gdjohnson@bpa.gov>; Goodwin,Summer G (BPA) - DKS-7 <sggoodwin@bpa.gov>
Subject: FW: calendaring E3/BPA

He didn't specify PDT, but the time for the Council meeting is PDT, so that has to be it.

Aaron hasn't responded, but Arne is the Principal, so we can go with this.

From: Arne Olson <arne@ethree.com>
Sent: Tuesday, July 5, 2022 12:31 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Subject: [EXTERNAL] RE: calendaring E3/BPA

Hi Birgit,

Here is my schedule for this week:

7/6
- Available any time except 7-8 AM and 4-5 PM

7/7
- 8:30 – 10:00, Power Council Presentation
- 10:00 – 1:00, not available
- 1:00 – 2:00, holding for press availability
- 2;00 – 3:00, not available
- 3:00 – 5:00 available

7/8
- 8:00 – 9:00 available
- 9:00 – 10:00 not available
- 10:30 – 1:00, holding for Congressional staff briefings
- 1:00 – 5:00 available

Arne

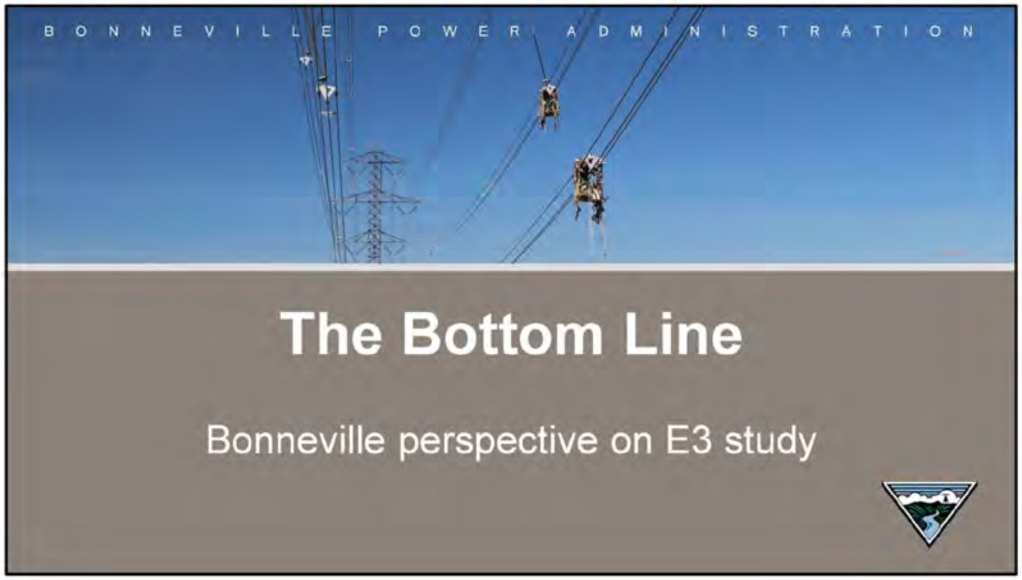
From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Tuesday, July 5, 2022 12:13 PM

To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>
Subject: calendaring E3/BPA

Good morning Arne and Aaron,

I'm starting a new email thread with a subject line that will make it easier to track. I know Eve had your schedules well in hand, but I am having trouble putting my fingers on the details as they are in email threads with various subjects. I found a message saying you were mostly available July 6 and 7, but not from 10-1; the message wasn't clear whether 10-1 applied to the 6th or the 7th. Would you mind confirming your availablilty on the 7th and the 8th in case I get asked to help schedule anything else?

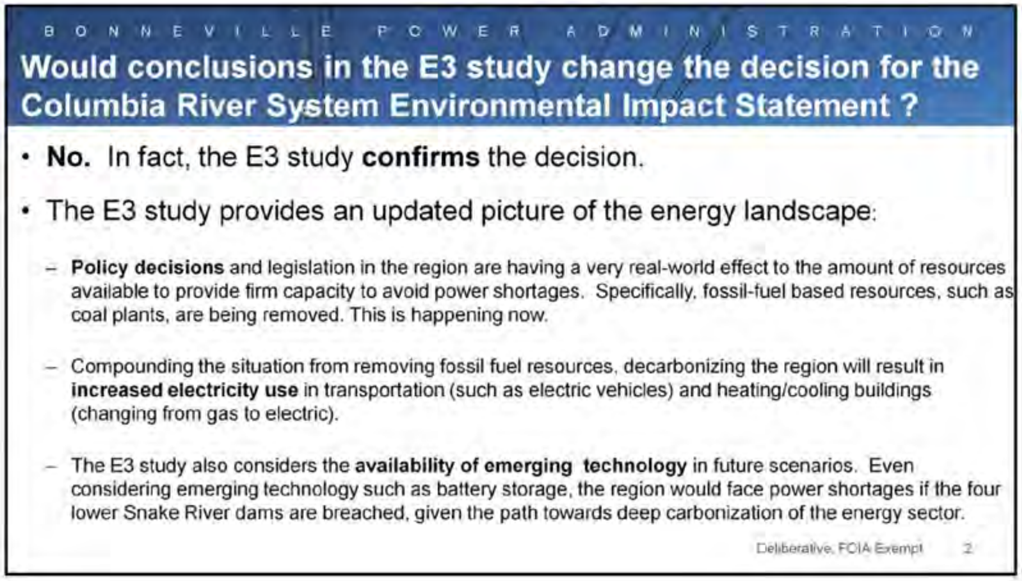
Thanks,
Birgit



BONNEVILLE POWER ADMINISTRATION

The Bottom Line

Bonneville perspective on E3 study

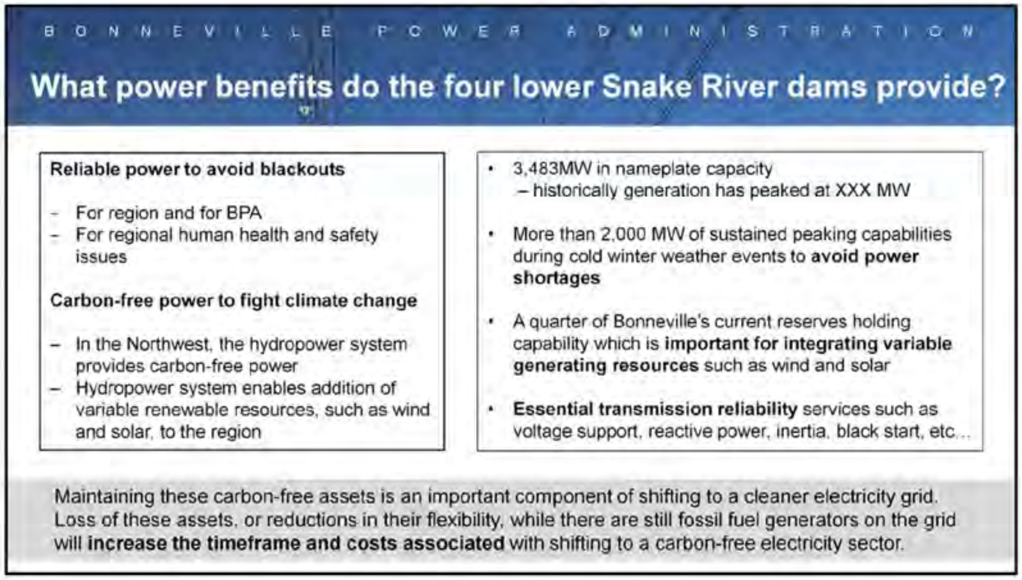


BONNEVILLE POWER ADMINISTRATION

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.

Deliberative, FOIA Exempt 2



BONNEVILLE POWER ADMINISTRATION

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

Reliable power to avoid blackouts

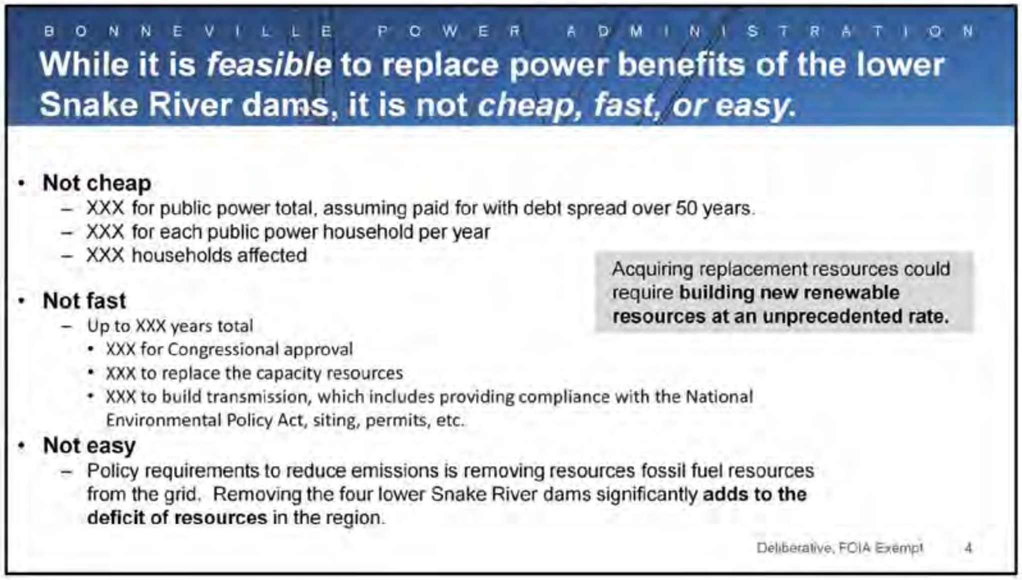
- For region and for BPA
- For regional human health and safety issues

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…

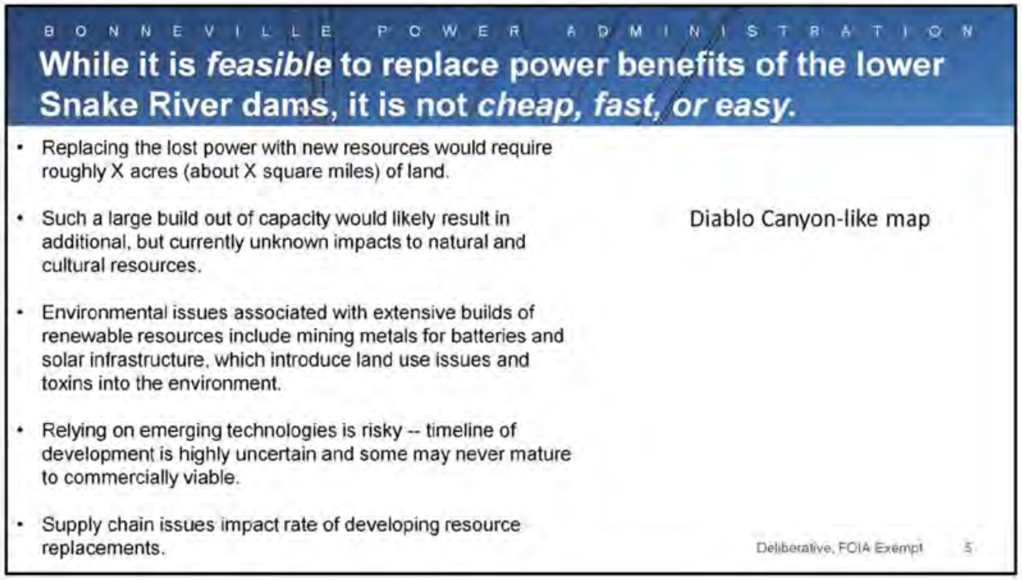
Maintaining these carbon-free assets is an important component of shifting to a cleaner electricity grid. Loss of these assets, or reductions in their flexibility, while there are still fossil fuel generators on the grid will **increase the timeframe and costs associated** with shifting to a carbon-free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



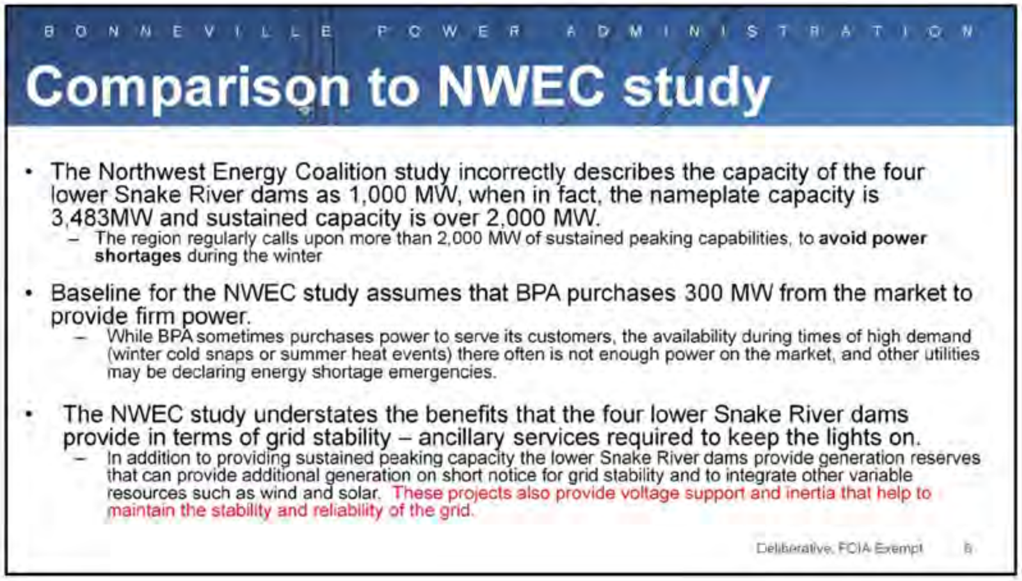
BONNEVILLE POWER ADMINISTRATION

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

Deliberative, FOIA Exempt 5



BONNEVILLE POWER ADMINISTRATION

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. These projects also provide voltage support and inertia that help to maintain the stability and reliability of the grid.

Deliberative, FOIA Exempt 6

From:	Koehler,Birgit G (BPA) - PG-5
Sent:	Friday, July 8, 2022 2:25 PM
To:	Arne Olson
Cc:	James,Eve A L (BPA) - PG-5; Aaron Burdick
Subject:	RE: latest update, and calendaring

This would be in addition to the Council presentation. I think it would be for DOE and maybe also CEQ. I'm pretty sure you presented to them before, but maybe they want another overview and/or time for questions. I hope to get more specifics next week.

From: Arne Olson <arne@ethree.com>
Sent: Friday, July 8, 2022 2:23 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Subject: [EXTERNAL] RE: latest update, and calendaring

Does this mean no Power Council presentation on Tuesday?

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Friday, July 8, 2022 12:49 PM
To: Arne Olson <arne@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: latest update, and calendaring

Hello for the umpteenth time,

Arne,

We would like to schedule a meeting for Thursday, July 14, from 2-3 pm ET. (If my brain is working correctly, that's 11 am PDT.) as of a couple of days ago, that looks free on your calendar, so I hope that's still the case.

Meeting is called "Department and Agency E3 Meeting."

Thanks,
Birgit

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, July 6, 2022 6:45 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Subject: [EXTERNAL] RE: latest update, and calendaring

Thanks Birgit.

Here is my availability for next week:

Tuesday, 7/12
- 8-11 AM
- 1-5 PM

Wednesday, 7/13
- Anytime

Thursday, 7/14
- After 10 AM

Friday, 7/15
- 8-10 AM

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 6:23 PM
To: Arne Olson <arne@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: latest update, and calendaring

DELIBERATIVE FOIA EXEMPT

Hello Arne,
Well, here I am one more time with an email. I'm afraid I just received confirmation that we are indeed delaying the presentation.

In hopes that we can reschedule for next week's Council meeting, I'm hoping that you would be free. Would you mind giving me your availability for Tuesday and Wed July 12 and 13 (for the Council). I have not heard what the plans are for Congressional or media, but I would guess that we would try to set that up similar to what was planned today. So if it isn't too much of an ask, would you also share your availability for Thursday and possibly Friday, just in case?

Aaron and Eve might not have missed all the fun afterall.

Birgit

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, July 6, 2022 4:54 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Subject: [EXTERNAL] RE: latest update

OK, understood. I'll wait to hear.

Thanks,

Arne

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 4:38 PM
To: Arne Olson <arne@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: latest update

DELIBERATIVE FOIA EXEMPT

Because of a need for additional coordination with DC-level executives

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From: Arne Olson <arne@ethree.com>
Sent: Wednesday, July 6, 2022 4:35 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Subject: [EXTERNAL] RE: latest update

Huh. Is this from DOE or from the Council?

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, July 6, 2022 4:34 PM
To: Arne Olson <arne@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: latest update

Hello Arne,

Here is the latest information I have.

"The E3 presentation to the Council tomorrow will **likely** be canceled. The current plan is to delay one week, potentially to the full Council meeting, but this still needs to be confirmed and coordinated."

Once I hear that a decision is finalized, I'll send you another email plus let the Council staff know. The Council Chair has already been contacted. On the Council website, I see that the next Council meeting is July 12 and 13th.

(Clearing Up will be an interesting read this weekend.)

Birgit

From: Koehler,Birgit G (BPA) - PG-5
Sent: Monday, July 11, 2022 11:52 AM
To: Aaron Burdick; Arne Olson
Cc: James,Eve A L (BPA) - PG-5
Subject: RE: not presenting at Monday's Deputies Committee meeting

12:30 works well for me. Eve is still out today

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, July 11, 2022 11:50 AM
To: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: [EXTERNAL] RE: not presenting at Monday's Deputies Committee meeting

DELIBERATIVE FOIA EXEMPT

Can we touch base briefly today at 12:30pm or 4:30pm today?

Aaron

From: Arne Olson <arne@ethree.com>
Sent: Friday, July 8, 2022 11:37 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: RE: not presenting at Monday's Deputies Committee meeting

Thanks for the heads-up. FWIW, I did not have this meeting on my calendar, but happy to meet whenever needed.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Friday, July 8, 2022 11:05 AM
To: Arne Olson <arne@ethree.com>
Cc: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: not presenting at Monday's Deputies Committee meeting

DELIBERATIVE FOIA EXEMPT

Hello again Arne,

I just got a note saying that you are off the hook, not on the agenda to present at Monday morning's Deputies Meeting. DOE apologizes for the short notice. I don't know if it was even on your radar, as I had only seen a passing reference to this meeting and couldn't find it on anyone's calendar at BPA.

Cheers,
Birgit

From: Koehler,Birgit G (BPA) - PG-5
Sent: Wednesday, May 25, 2022 4:14 PM
To: James,Eve A L (BPA) - PG-5; Pruder Scruggs,Kathryn M (BPA) - E-4
Subject: lay-person ppt
Attachments: LayPersonPPT 5 25 mid-afternoon.pptx

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, May 25, 2022 12:02 PM
To: Pruder Scruggs,Kathryn M (BPA) - E-4 <kpruder@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: LayPersonPPT 5 25noon.pptx

From: James,Eve A L (BPA) - PG-5
Sent: Wednesday, June 8, 2022 3:02 PM
To: Koehler,Birgit G (BPA) - PG-5
Subject: updated decks
Attachments: 2022-06-06_BPA_RESOLVE_PublicDeck_v3.pptx; 2022-06-07_BPAperspective_E3study_PublicDeck.pptx

Confidential FOIA-exempt

Updated decks

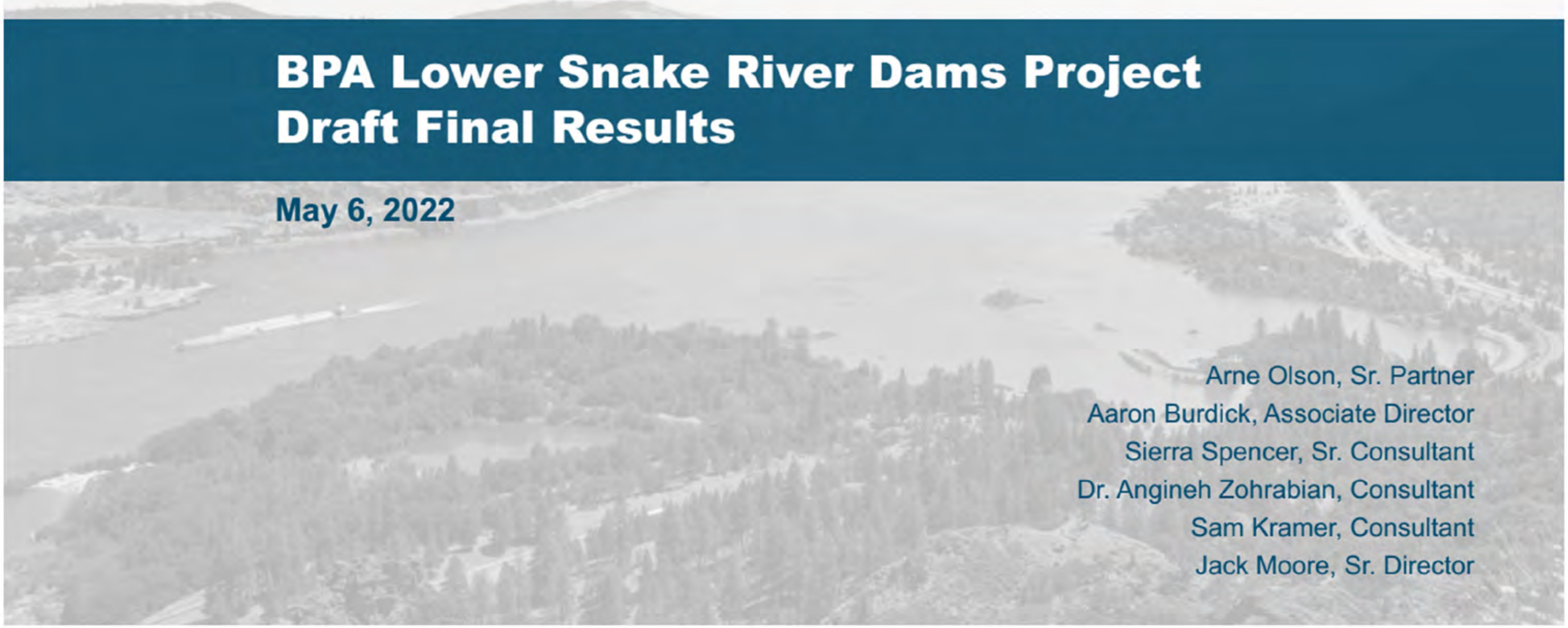
From: Koehler,Birgit G (BPA) - PG-5
Sent: Tuesday, July 12, 2022 6:26 AM
To: Hairston,John L (BPA) - A-7; Armentrout,Scott G (BPA) - E-4; Zelinsky,Benjamin D (BPA) - E-4; Baskerville,Sonya L (BPA) - AIN-WASH; Leary,Jill C (BPA) - LN-7; Godwin,Mary E (BPA) - LN-7
Cc: James,Eve A L (BPA) - PG-5; Scruggs,Joel L (BPA) - DK-7
Subject: The E3 study is posted on BPA.gov
Attachments: E3 BPA LSR Dams_071122.pdf; E3 BPA LSR Dams Report_071122.pdf

- https://www.bpa.gov/energy-and-services/power/hydropower-impact

Thanks to E3 working past 10 last night and then Ryan Zimmerman for getting up at 5:30 am
The Council staff, Chad and Jennifer, have a copy of the link so they can include that in their materials now.

Today we will see what happens with the DC press release.

Energy+Environmental Economics



BPA Lower Snake River Dams Project Draft Final Results

May 6, 2022

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

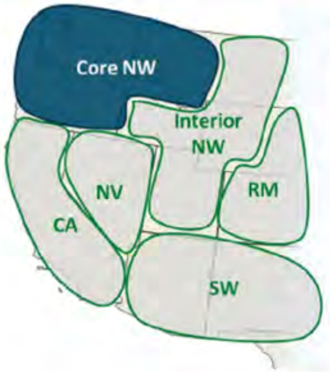
Contents

Energy+Environmental Economics

Project Background

About This Study

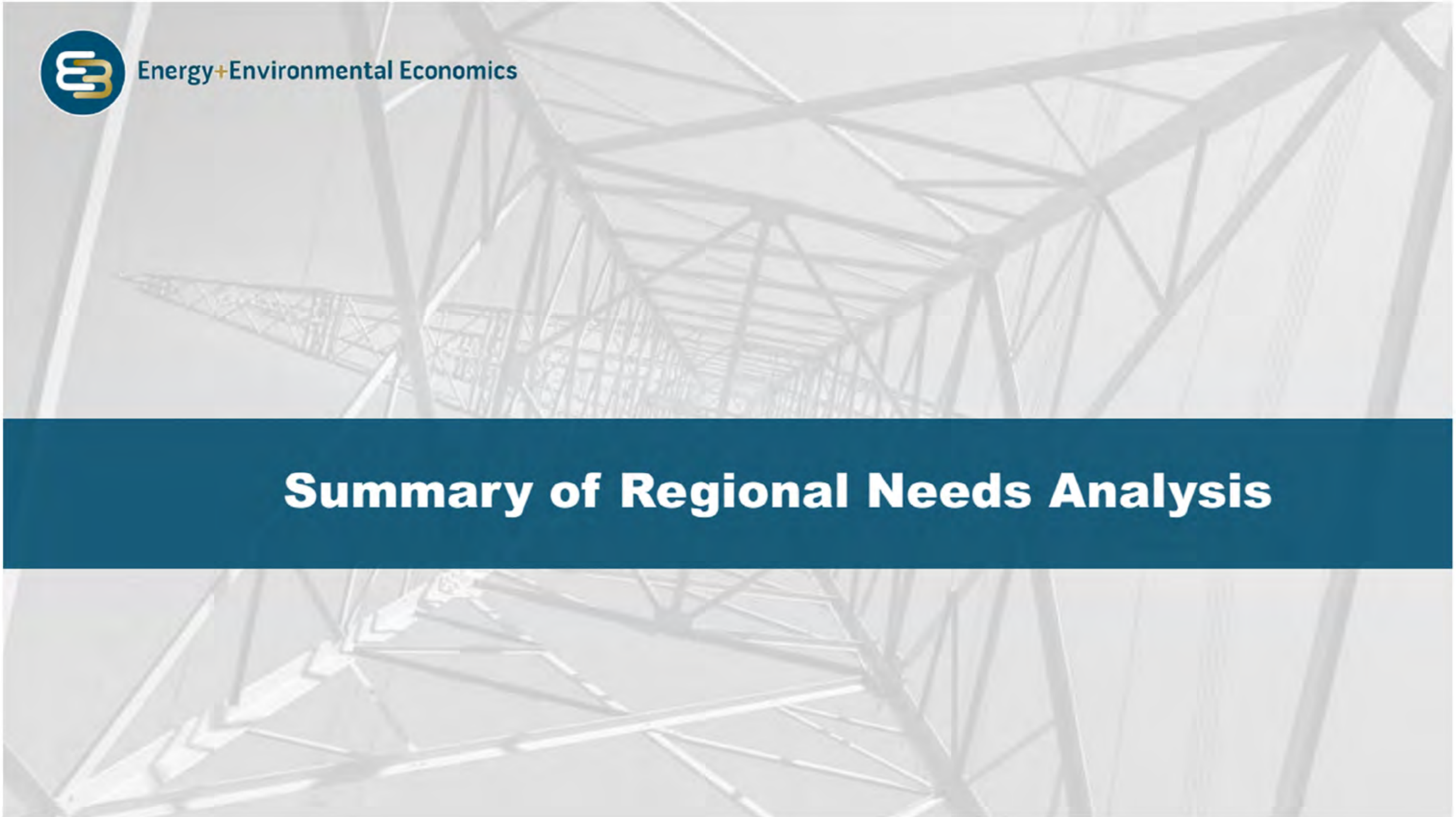
- **BPA contracted with E3 to provide independent analysis about the value of the lower snake river dams to the Northwest energy system, including the cost and resource needs for replacement**
  - This study takes a regional view of electricity supplies and uses E3's RESOLVE model to optimize the portfolio of resources serving loads in the "Core NW" region
- **Lower Snake River (LSR) Dams are ~10% of Northwest hydro capacity and provide reliability, GHG-free energy, and high flexibility**
- **This study captures:**
  - Latest aggressive OR + WA clean energy policies
  - High electrification load growth scenarios
  - Resource adequacy replacement (including capacity saturation curves for clean energy replacement options)
  - Emerging technology options (hydrogen, carbon capture + storage, small modular nuclear reactors)
  - High embedded EE, DR, and customer PV with additional EE+DR as a selectable resource



Plant	Nameplate Capacity (MW)*	50-year Forecasted Costs** (real 2022 $/MWh)
Lower Granite	930	$22.69
Little Goose	930	$15.71
Lower Monumental	930	$12.58
Ice Harbor	693	$15.84
	Total = 3,483	**Avg = $17/MWh**

** Nameplate capacities from BPA White book*

*** Costs provided by BPA based on the CRSO EIS, including sustaining capex, O&M, and fish + wildlife related costs.*



Energy+Environmental Economics

Summary of Regional Needs Analysis

Executive Summary
E3 View of California, Oregon, and Washington Regional Needs

+ State policy is moving aggressively toward a decarbonized power sector in California, Oregon, and Washington

- California has an established national leadership position in the pursuit of decarbonization
- Oregon and Washington have accelerated the adoption of aggressive decarbonization legislation since 2019
- Across all three states, decarbonization is creating a current and deepening need for capacity, especially if that capacity is clean and firm

+ Generation in the region may take advantage of wholesale market opportunities in California, or reliability-driven need in the Pacific Northwest (PNW), or possibly both

- Energy storage deployment has accelerated rapidly in California as storage assets pursue lucrative but shallow Ancillary Services value; while this market is saturating quickly, energy arbitrage value is likely to persist as solar capacity continues to grow
- In the PNW, retirement of firm fossil fuel capacity and volatility in hydropower generation is coinciding with the implementation of the Western Resource Adequacy Program (WRAP) for compensating reliability providers through deeper regional coordination

+ While California's capacity deficit is on course to be addressed by the end of the decade through rapid deployment of energy storage and other resources, the Pacific Northwest continues to face a capacity deficit whether viewed from the top down (regional level) or bottom up (via utility IRPs)

- Given average rate of capacity additions in the PNW over the past decade (~1GW/year since 2010), there is significant execution risk associated with utility IRP resource plans

+ The Pacific Northwest market is in the midst of an evolution that is likely to lead to increasing regionalization of power markets, with significant uncertainty around the timing and depth of these changes

- In the context of decarbonization policies culminating in goals for 2040 (Oregon) and 2045 (Washington), the region will likely need to explore multiple potential pathways to achieve climate, cost, and reliability targets as utilities navigate the energy transition

Policy Landscape: Washington, Oregon, California

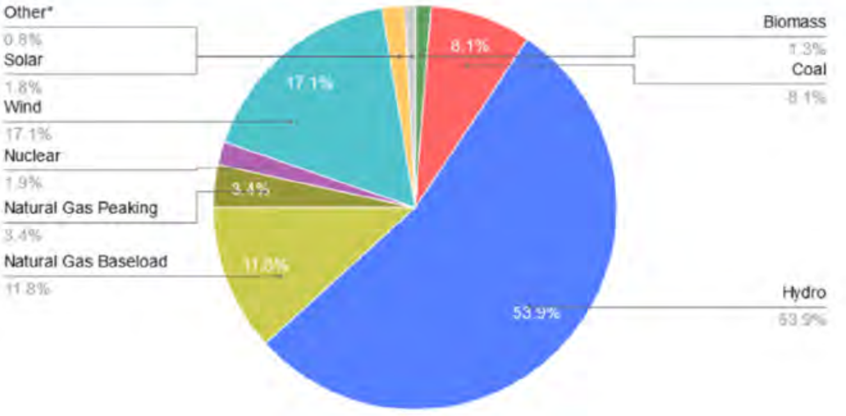
	RPS or Clean Energy Standard?	Coal Prohibition?	Cap-and-Trade?	New Gas?	Economy-Wide Carbon Reduction?
WA	✓ Carbon neutral by 2030, 100% carbon free electricity by 2045	✓ Eliminate by 2025	✓ Cap-and-invest program established in 2021, SCC in utility planning	✓	✓ 95% GHG emission reduction below 1990 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

CONFIDENTIAL DRAFT

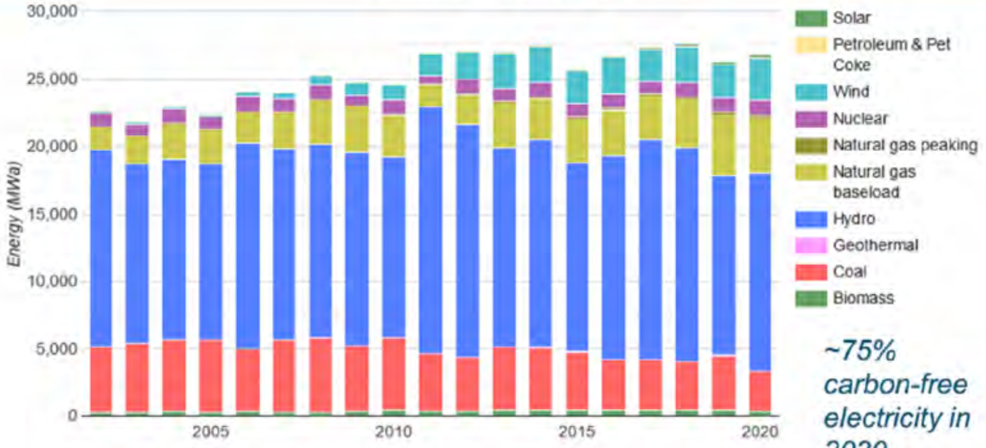
Northwest Installed Capacity and Historical Energy Production

+ **Hydropower dominates historical generation, followed by coal and natural gas**
  - Wind has grown but remains a small share of generation
  - Solar has only very recently started to grow in its share of generation

Installed Capacity (~64 GW total)



Annual Energy



~75% carbon-free electricity in 2020

Source: NWPCC https://www.nwcouncil.org/energy/energy-topics/power-supply/

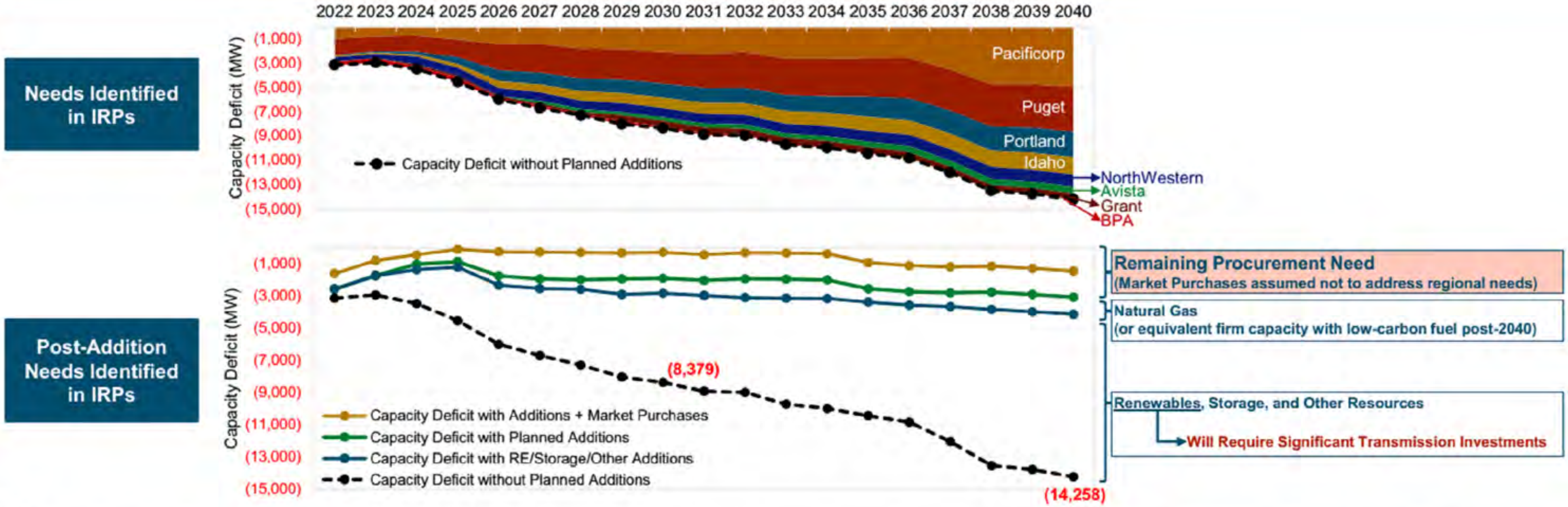
CONFIDENTIAL DRAFT

PNW Near- to Mid-Term Capacity Need

Bottom-Up Capacity Need vs. Planned Additions

- **Through their IRPs, individual utilities have identified their capacity needs over a 20-year time horizon**
  - IRP planned additions do not adequately address full capacity need, leaving ~3,000 MW of additional need by 2040
- **Utility IRP expectations of firm capacity in the form of market purchases pose reliability risks due to regional resource adequacy trends**

Summary of Utility IRP-based Capacity Needs



Remaining Procurement Need
(Market Purchases assumed not to address regional needs)

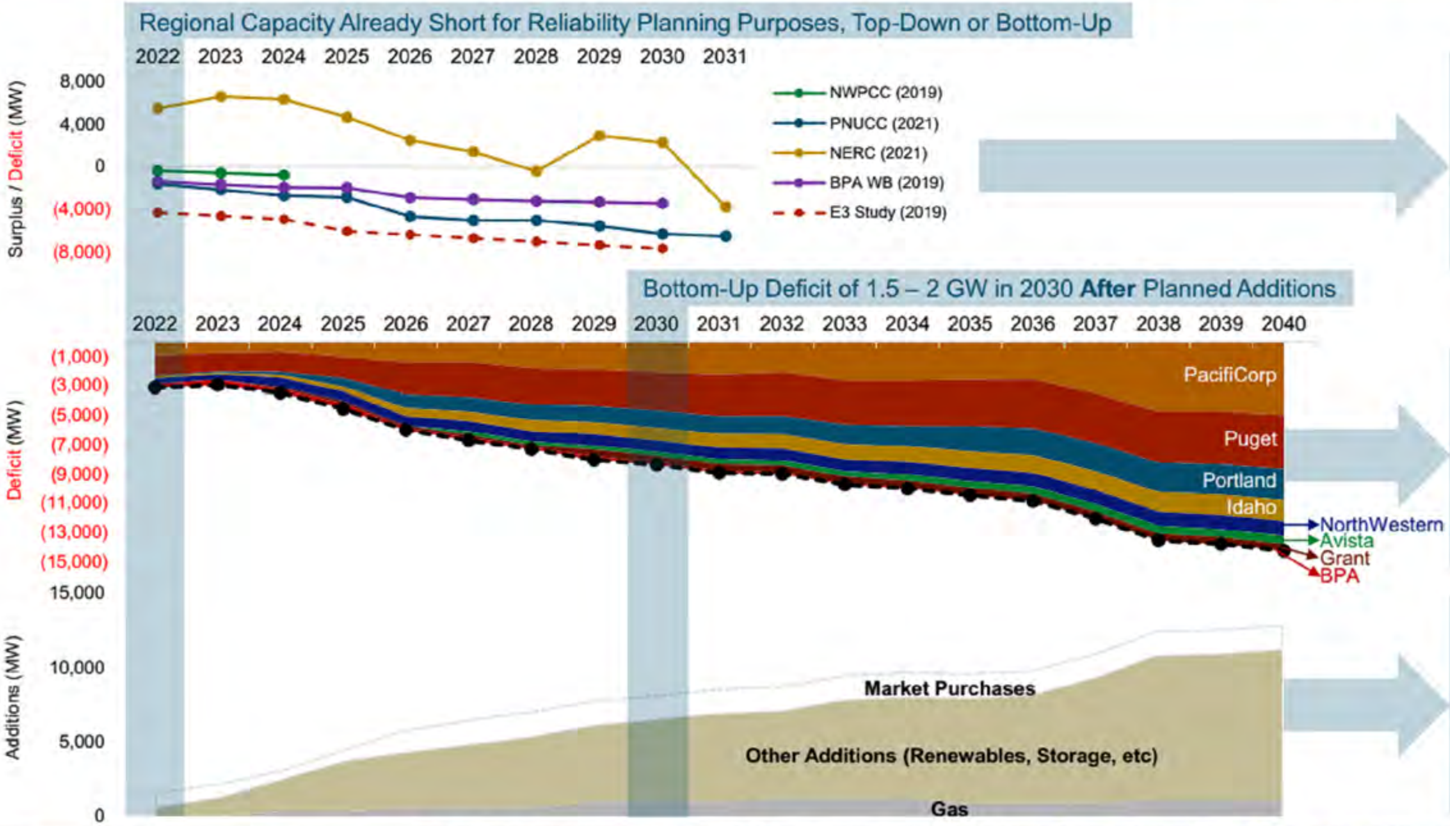
Natural Gas
(or equivalent firm capacity with low-carbon fuel post-2040)

Renewables, Storage, and Other Resources
→ **Will Require Significant Transmission Investments**

Note:
- Most utilities reported deficits, additions, and existing resources in effective/perfect capacity but some, such as BPA and PGE, reported nameplate capacity. E3 adjusted nameplate capacity based on its 2019 study Resource Adequacy in the Pacific Northwest.
- E3 also considered Chelan, Seattle City Light, and Douglas but they do not report a shortage in capacity.

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



Regional Capacity Already Short for Reliability Planning Purposes, Top-Down or Bottom-Up

Bottom-Up Deficit of 1.5 – 2 GW in 2030 **After** Planned Additions

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

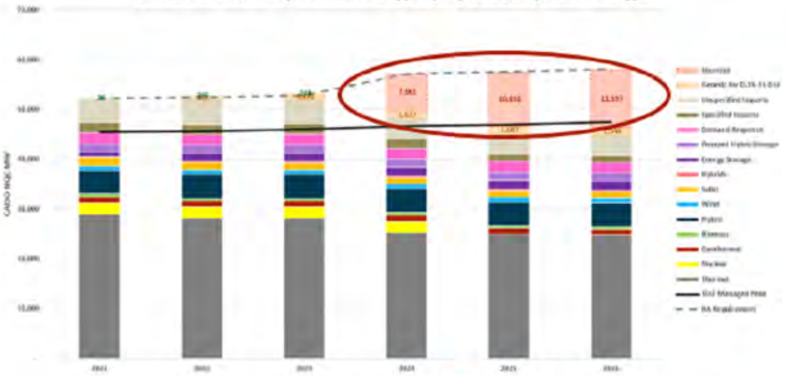
IRP Planned Additions

~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**



CAISO RA Stack by Resource Type (High Need (2020 IEPR))

CPUC Mid-Term Reliability Procurement Order

Type of Resource	2023	2024	2025	2026	Total
Generic reliability additions[1]	2,000	6,000	1,500	-	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) A subset must be 2,500 MW zero-emissions generation, gen paired w/ storage, or DR resources for Diablo Canyon replacement, online by 2025.

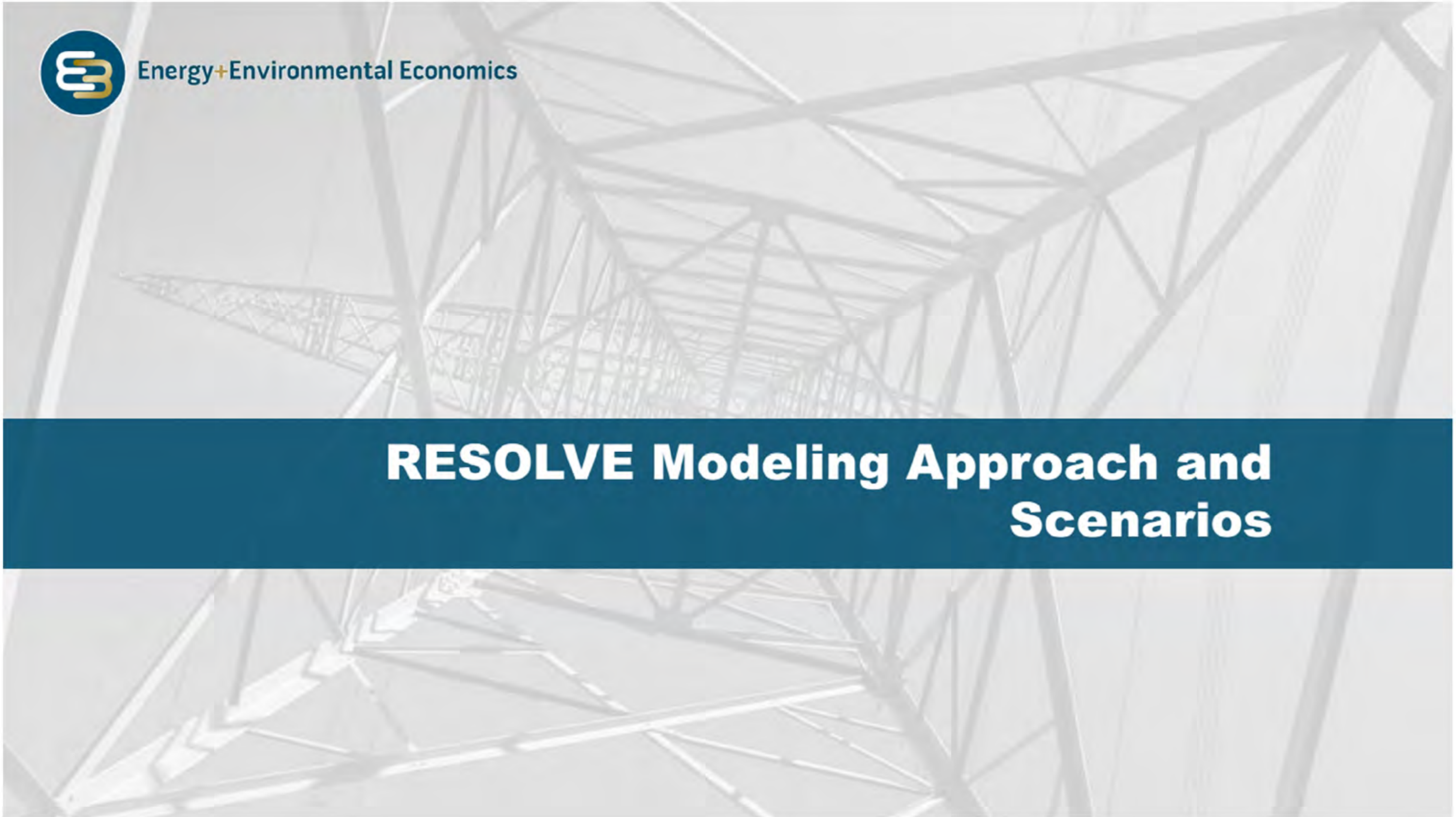
(2) LSEs may request an extension by Feb 1, 2023 up to 2028 for the LLT resources.

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

Role of Hydropower to Meet Regional Needs

- **Hydropower resources provide unique system benefits to support system needs in California and the Northwest**

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
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



Energy+Environmental Economics

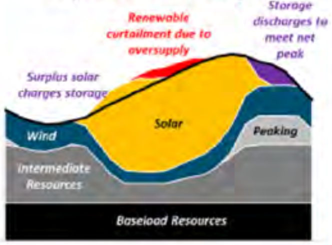
RESOLVE Modeling Approach and Scenarios

RESOLVE: Optimal Capacity Expansion Under Aggressive Clean Energy Goals

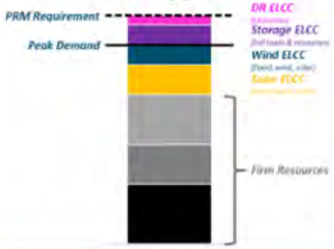
- RESOLVE is a linear optimization model explicitly tailored to the study of electricity systems with high renewable & clean energy policy goals

- 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

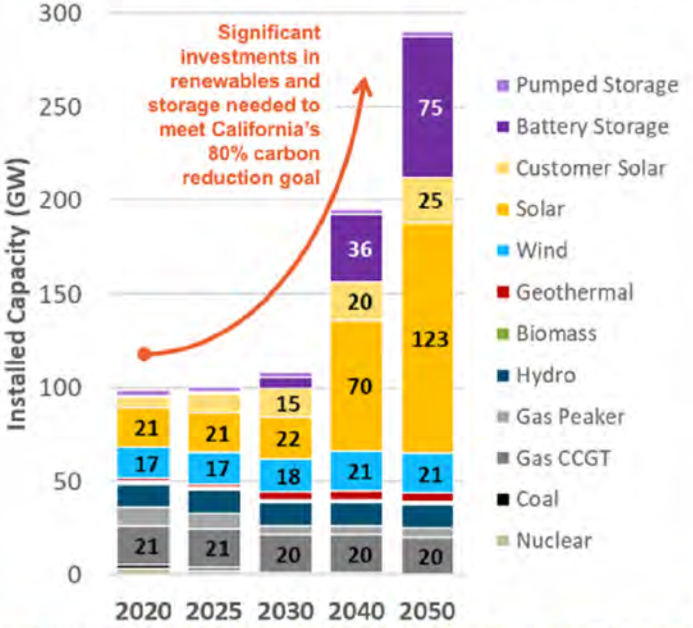
Operational module simulates hourly system operations for a sample of representative days



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)

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

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

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	LSR Dams 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 – Limited Tech (no new combustion)	High Electrification	0 MMT by 2045	Limited Tech (no new combustion)	2032
2a2	Deep Decarb – Limited Tech (no new gas, limited H2)	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

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Technology Availability

Technology Scenarios

	Baseline	Emerging Tech	Limited Tech* (No New Gas, Limited H2)	Limited Tech* (No New Combustion)
Solar	🟩	🟩	🟩	🟩
Wind	🟩	🟩	🟩	🟩
Battery Storage	🟩	🟩	🟩	🟩
Pumped Storage	🟩	🟩	🟩	🟩
Demand Response	🟩	🟩	🟩	🟩
Energy Efficiency	🟩	🟩	🟩	🟩
Small Hydro	🟩	🟩	🟩	🟩
Geothermal	🟩	🟩	🟩	🟩
Offshore Wind (floating)	⬜	🟩	🟩	🟩
Natural Gas to H2 Retrofits	🟩	🟩	🟩	🟩
New Dual Fuel Natural Gas + H2 Plants	🟩	🟩	⬜	⬜
New H2 Only Plants	⬜	⬜	🟩	⬜
Gas w/ 90-100% Carbon Capture + Storage	⬜	🟩	⬜	⬜
Nuclear Small Modular Reactors	⬜	🟩	⬜	⬜

⬜ **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.

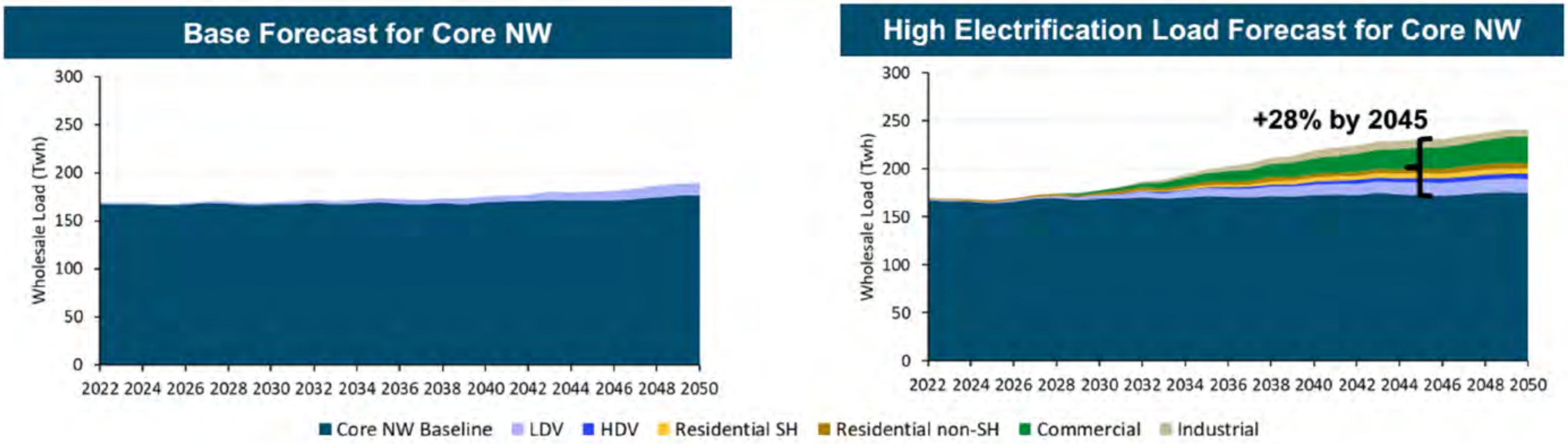
+ Mature Technologies

- 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)… hydrogen assumed to be via dedicated off-grid production
- 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

Electrification Load Growth (Annual GWh)



Base Forecast for Core NW

High Electrification Load Forecast for Core NW

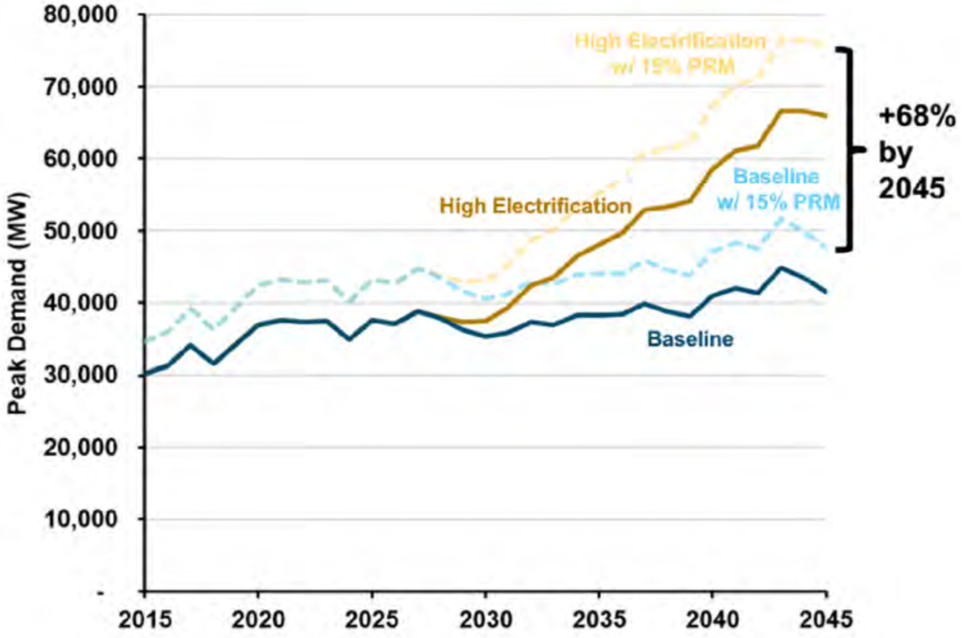
- **Base load forecast is from NWPCC 2021 Plan benchmarked to E3's boundary of Core NW**
  - Includes EE+DR in the Power Plan + incremental selectable EE+DR
  - For incremental EE, the 8th Power Plan recommends* ~6 TWh by 2027 and ~19 TWh by 2041

** Power Plan EE converted from aMW to TWh and scaled down to the CoreNW region (87.5% of the NWPCC total loads)*

- **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

Electrification Load Growth (Peak Demand)

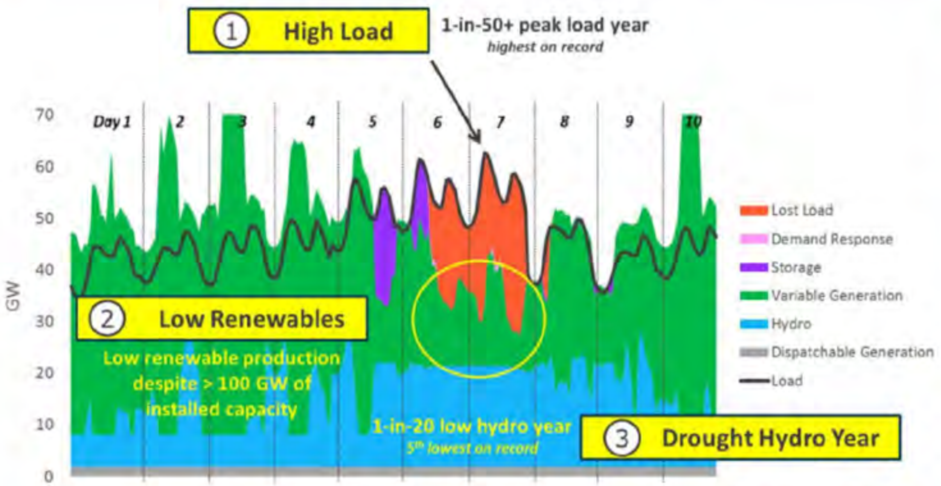
- **Peak demands increase higher than annual energy due to the winter "peak heat" challenge**
  - Heat pump efficiency declines as temperatures decrease
- **Peak electric demand growth is consistent with replacing peak NW gas needs with electric peaking capacity**
- **Peak demands could be lower with:**
  - 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)
  - Decarbonized gas/electric hybrids heat pumps



Resource Adequacy Resource Options

- **RESOLVE resource adequacy constraint requires capacity to meet peak demand + a 16% planning reserve margin**
  - PRM constraint is "installed capacity" (ICAP) based for firm resources and uses ELCC for non-firm resources
- **Northwest reliability risk is driven by a combination of high loads, low renewables, and low hydro output**
  - 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 (due to hydro interactive effects)
Pumped storage	Sharply declining ELCCs (due to hydro interactive 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

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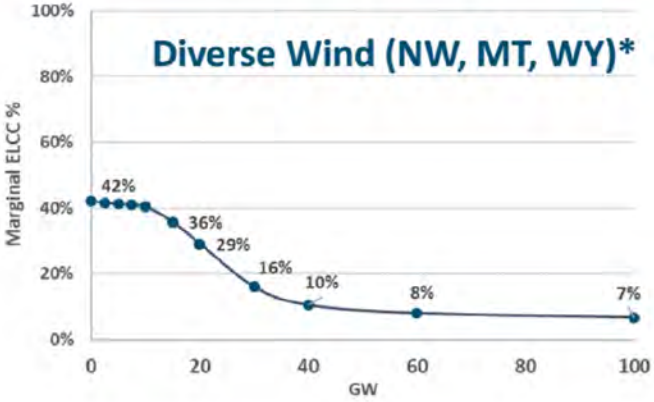
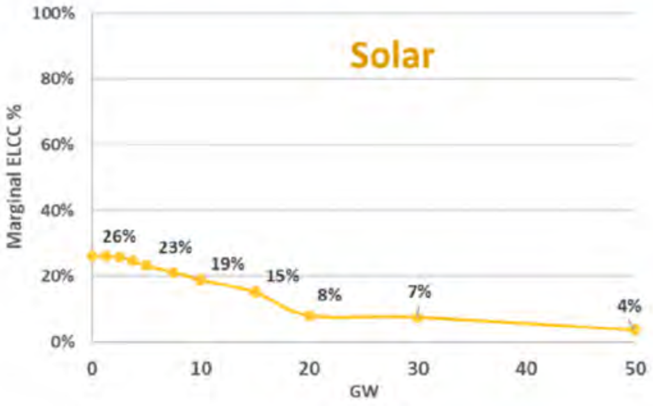
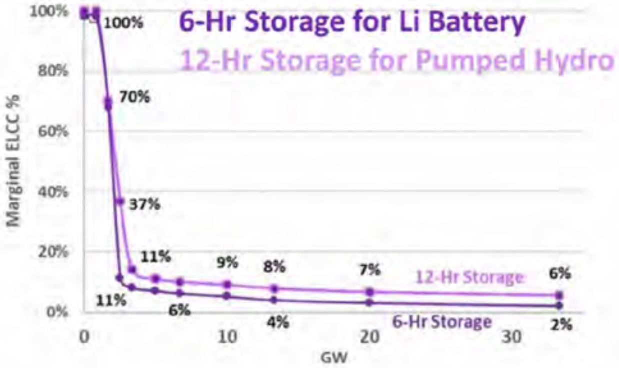
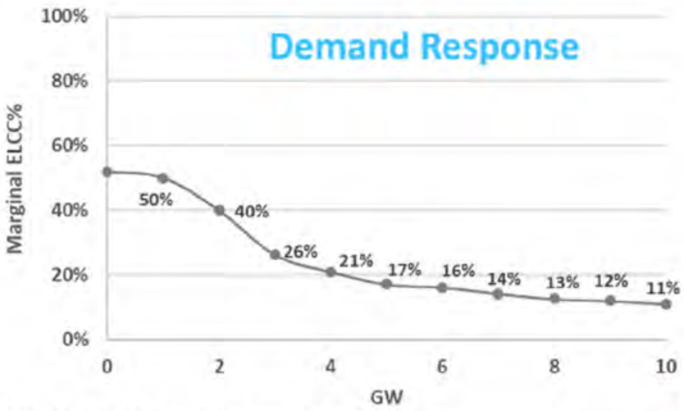
Incorporating Declining Capacity Contributions of Renewables, Storage, and DR









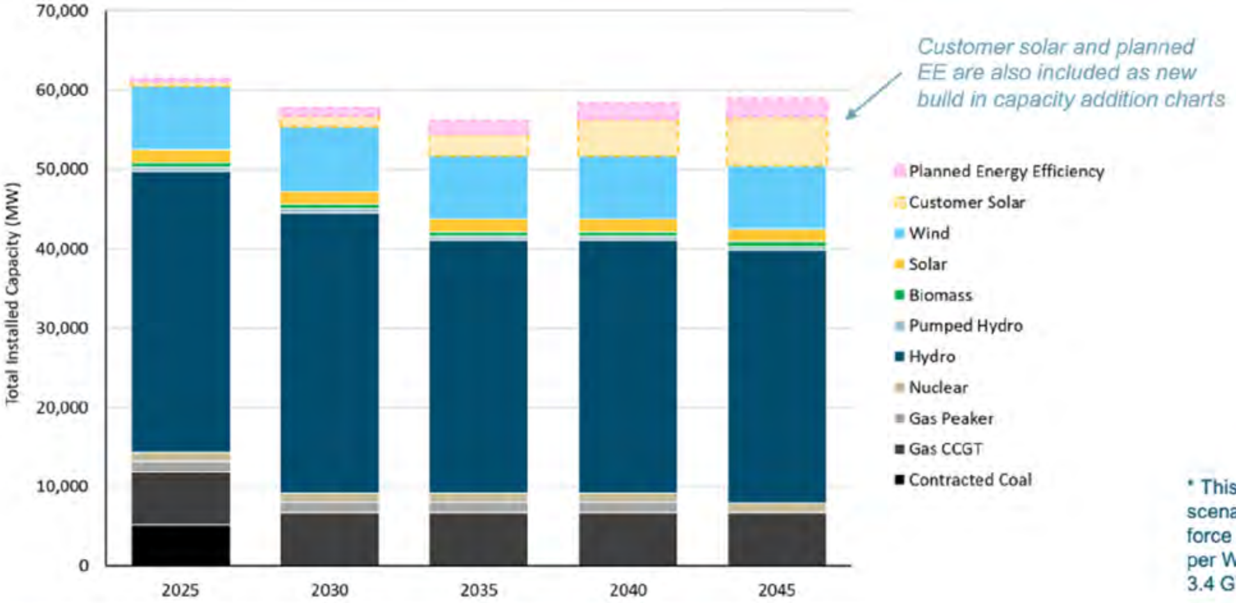
- A reliable electric system requires enough capacity to meet peak loads and contingencies
- This study incorporates information from E3's 2019 report *Resource Adequacy in the Northwest* about the effective capacity contribution of renewables, storage and DR at various penetration levels

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

* 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.

Baseline Resources

- **Baseline resources are the same across most* scenarios**
  - Baseline includes limited amount of near-term planned additions and planned/mandated coal retirements per OR/WA law
  - Baseline also includes assumed customer PV and energy efficiency per the NWPCC 8th Power Plan
  - Result slides show capacity additions on top of this baseline, in addition to the planned customer PV and EE additions



Customer solar and planned EE are also included as new build in capacity addition charts

* 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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RESOLVE Results

Summary of RESOLVE Results (with LSR Dams)

+ **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

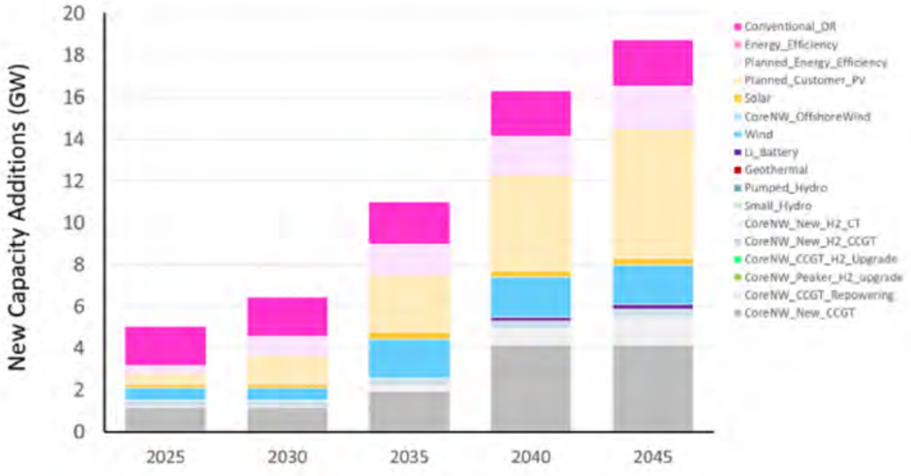
Energy+Environmental Economics

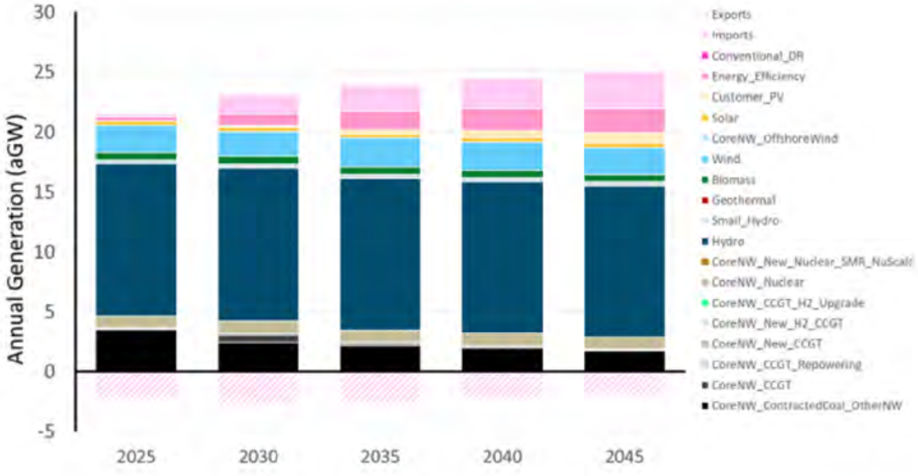
Scenarios with the Lower Snake River Dams

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… the Northwest is a net exporter until 2040
- Energy efficiency and customer PV grow per NWPCC 8th Power Plan

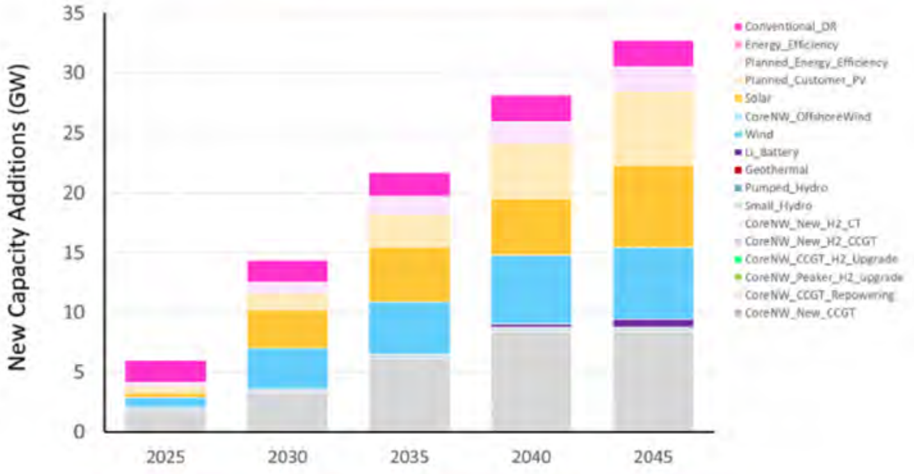


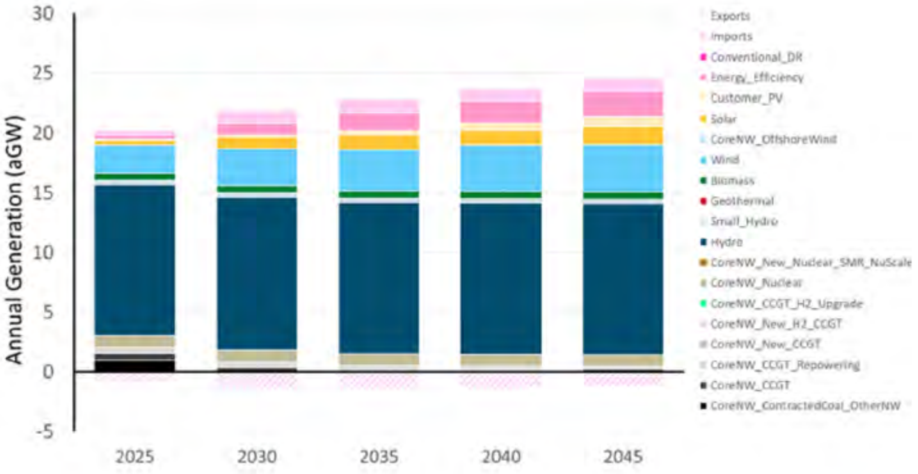


S1: Baseline – 100% Clean Retail Sales

With Carbon Price

- **With a 100% Clean Retail Sales requirement by 2045, forced coal retirements, and a carbon price, resource adequacy remains the key binding constraint**
  - Region reaches near-100% clean retail sales by 2025 then exceeds 100% as carbon prices drives more solar + wind
    - However, GHG emissions still remain in 2045 per retail sales policy interpretation (i.e., for line losses + exported clean energy)
  - New build of dual fuel plants (gas + H_2) added for reliability needs (these plants can burn gas until emissions constraints become binding, and then can switch to using H_2)



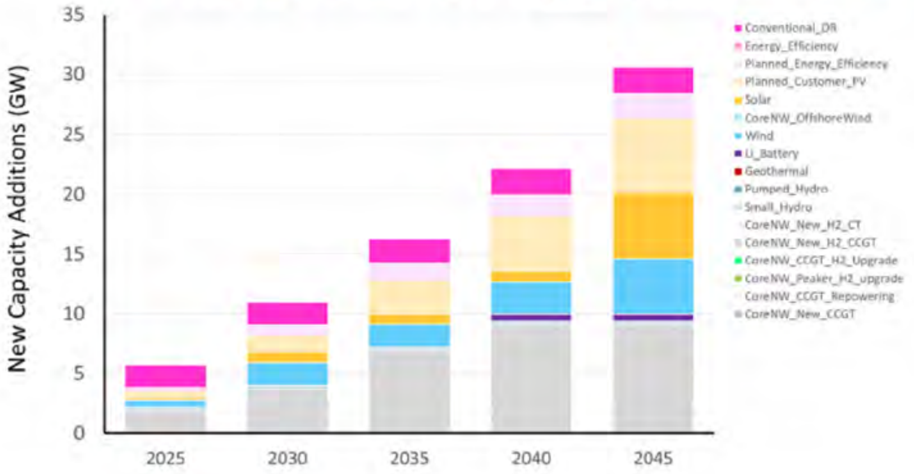


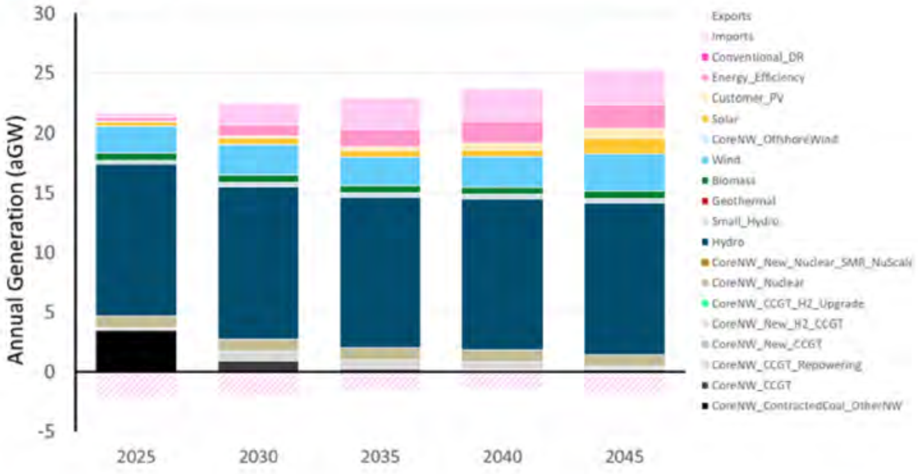
Near-term buildout is subject to renewable supply chain dynamics

S1a: Baseline – 100% Clean Retail Sales

Without Carbon Price

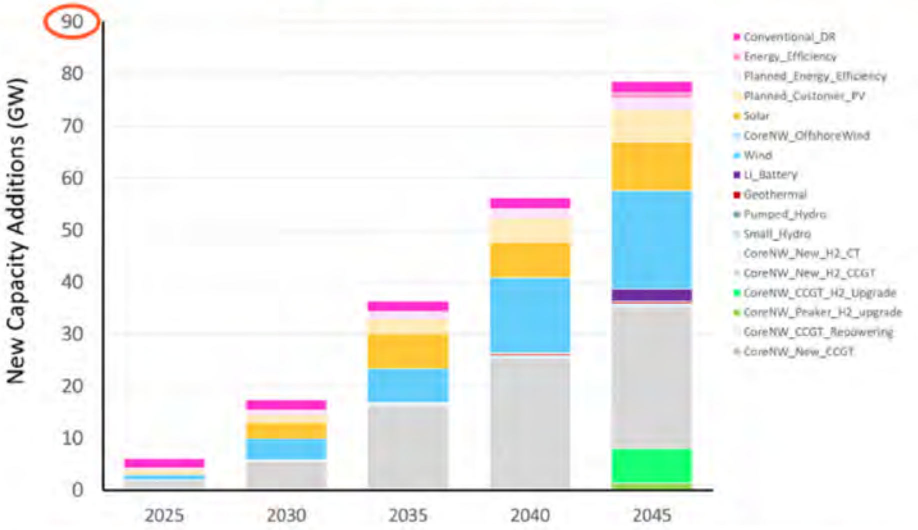
- **With a 100% Clean Retail Sales requirement by 2045 and forced coal retirements, both resource adequacy and the 100% clean target drive resource needs**
  - With no carbon price, there is less solar + wind added across the planning horizon, and the 100% clean target binds in 2045
  - New build of dual fuel plants (gas + H_2) added for reliability needs (these plants can burn gas until emissions constraints become binding, and then can switch to using H_2)
  - Core NW is net exporter prior to 2035, and a net importer afterwards

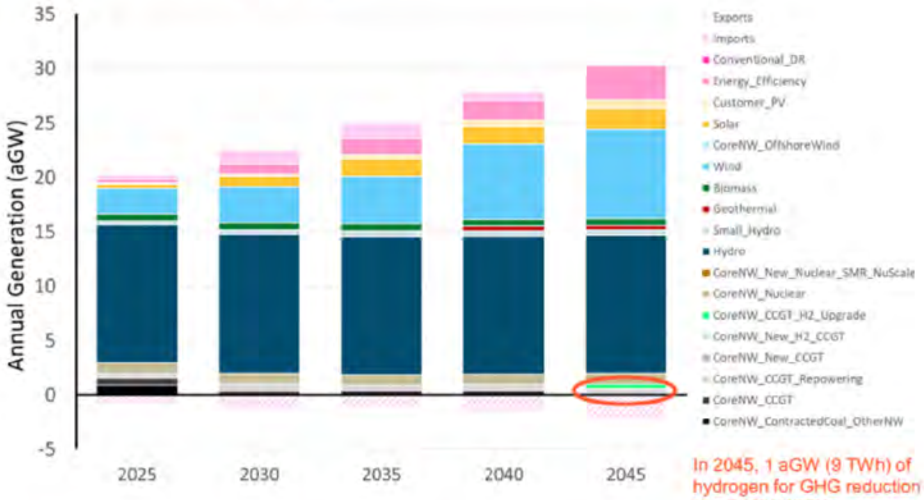




S2: Deep Decarbonization

- **With higher energy + peak loads and a 0 MMT GHG target by 2045, both resource adequacy and GHG reduction drive incremental resource needs**
  - Much higher build of new resources (e.g., ~75 GW in 2045 vs. ~23 GW in 100% clean baseline scenario)
  - Existing gas plants are forced to stop burning gas in 2045 and are retrofitted to combust H_2
  - Additionally, new dual fuel (H_2 + gas) plants are still selected, with fuel switching to entirely H_2 in these plants by 2045
    - Hydrogen combustion required to meet zero emissions on low renewables/low hydro days





In 2045, 1 aGW (9 TWh) of hydrogen for GHG reduction @ ~$40/MMBTU

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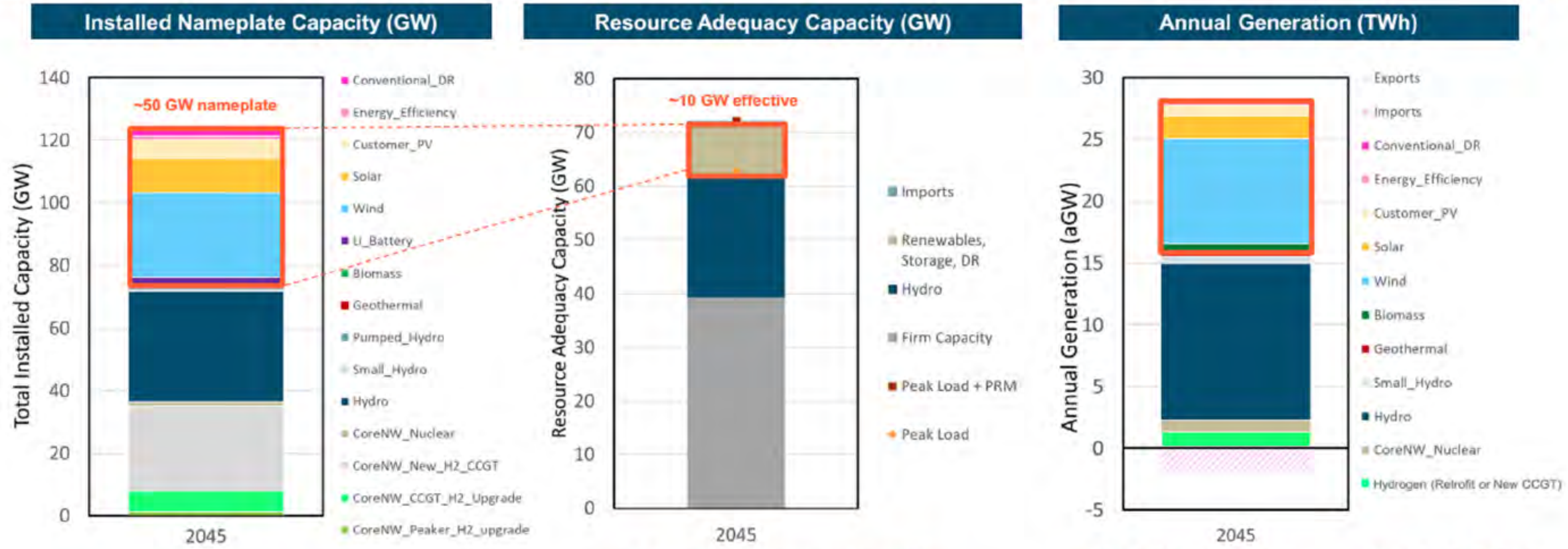
S2: Deep Decarbonization – Resource Adequacy Needs

"Non-firm" 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)

Resource Adequacy Capacity (GW)

Annual Generation (TWh)

Renewables, storage, and DR provide significant installed MW…

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

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

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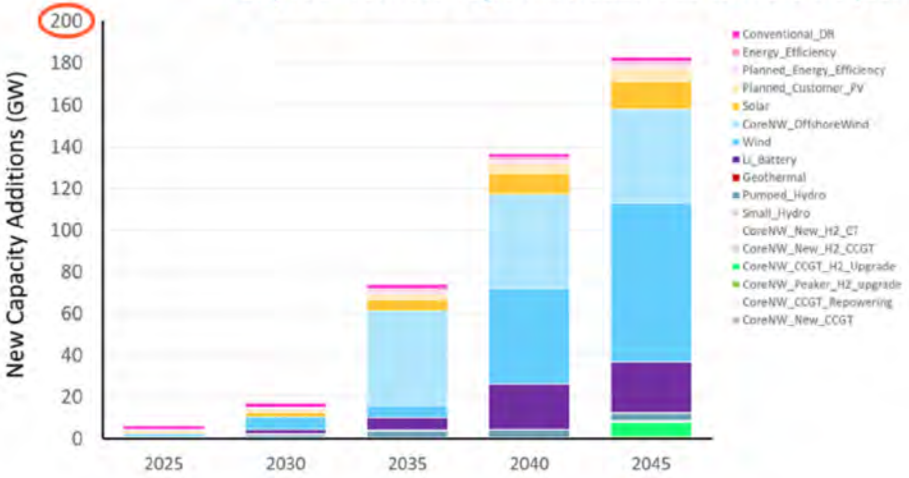
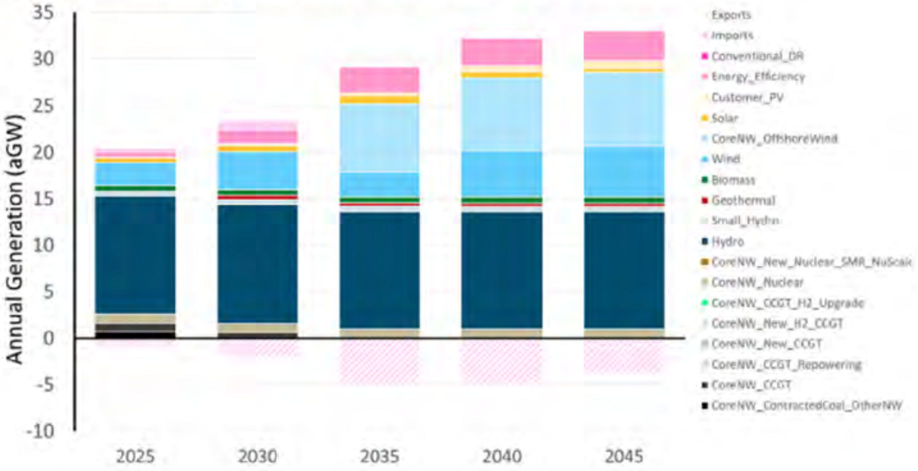
* These results are shown after energy efficiency load reductions

S2a1: Deep Decarbonization – Limited Tech (No New Combustion)

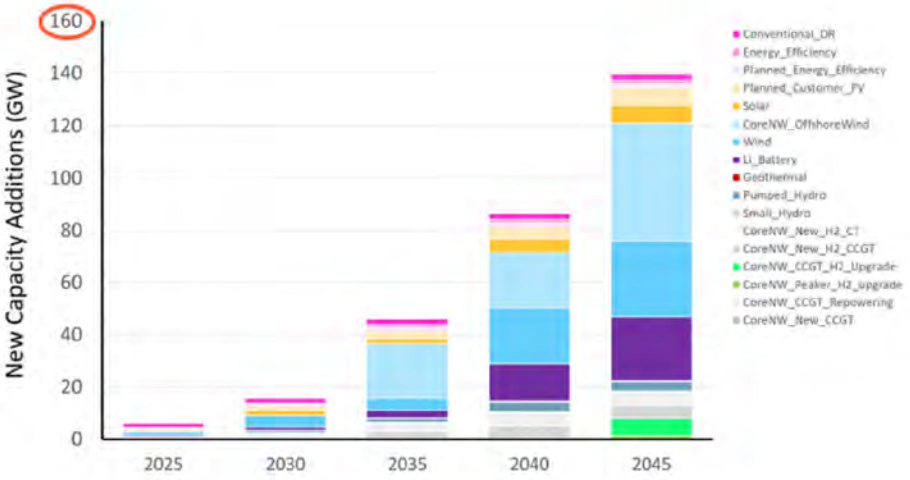
- **Without new natural gas or H2 combustion turbines to meet growing resource adequacy needs, a large overbuild of onshore wind, offshore wind, and battery storage are selected**
  - Even higher build of new resources (~180 GW in 2045 vs. ~75 GW in the S2 Deep Decarb case)
  - Existing gas plants are 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

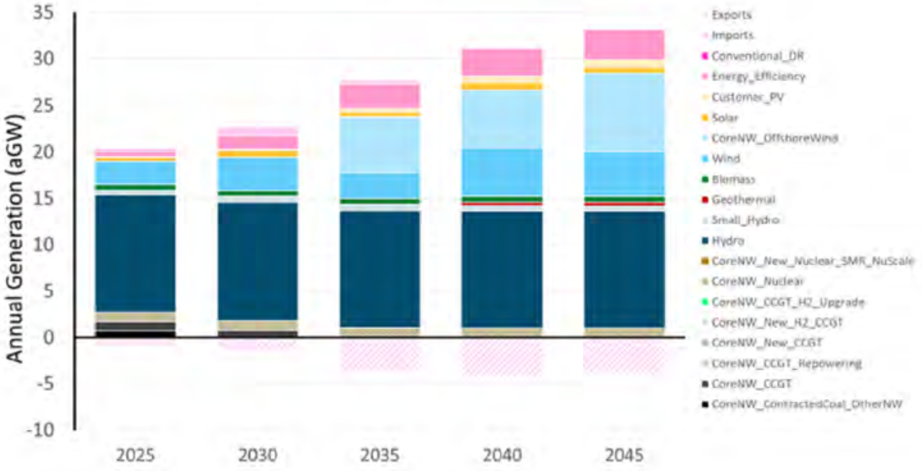




S2a2: Deep Decarbonization – Limited Tech w/ No New Gas (Limited H_2 Allowed)

- **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**
  - Still very high build of new resources (~140 GW in 2045 vs. ~75 GW in the S2 Deep Decarb case)
  - Allowing 10 GW of new H_2 in 2045 helps bring down new resource build from ~180 GW (in S2a1) to ~140 GW

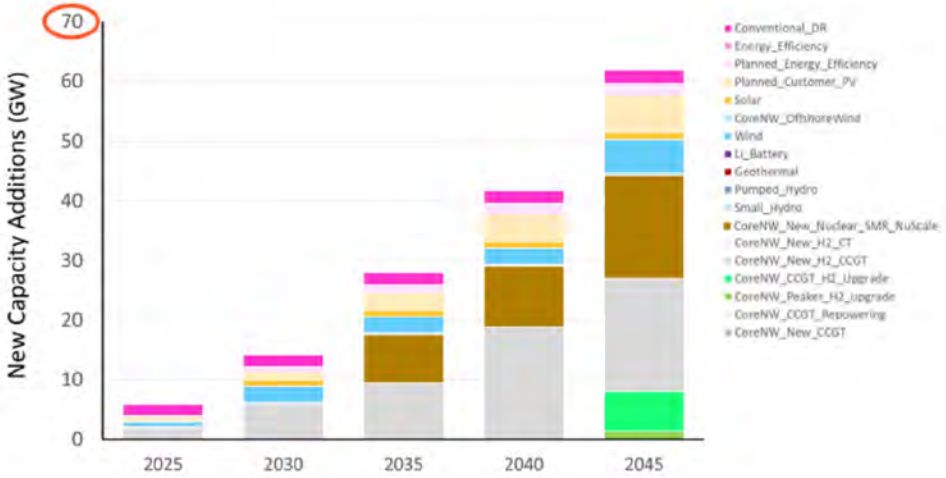


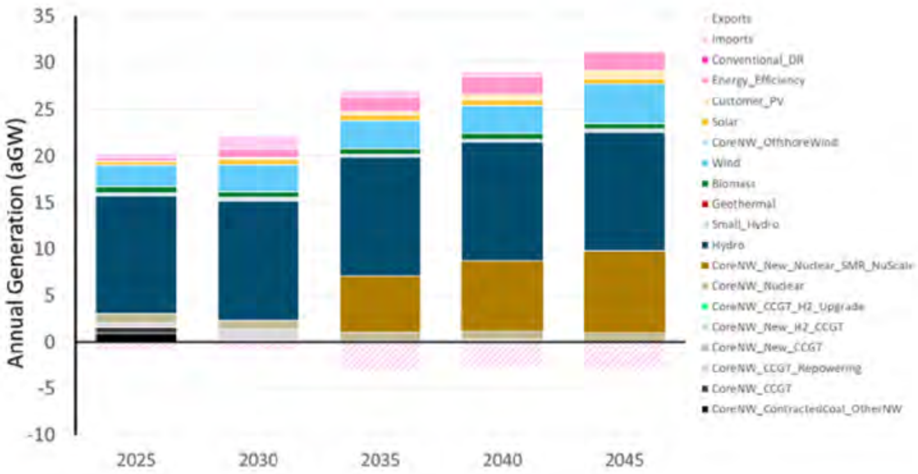


S2b: Deep Decarbonization – Emerging Technology

+ With nuclear SMR available, renewable energy build is minimized

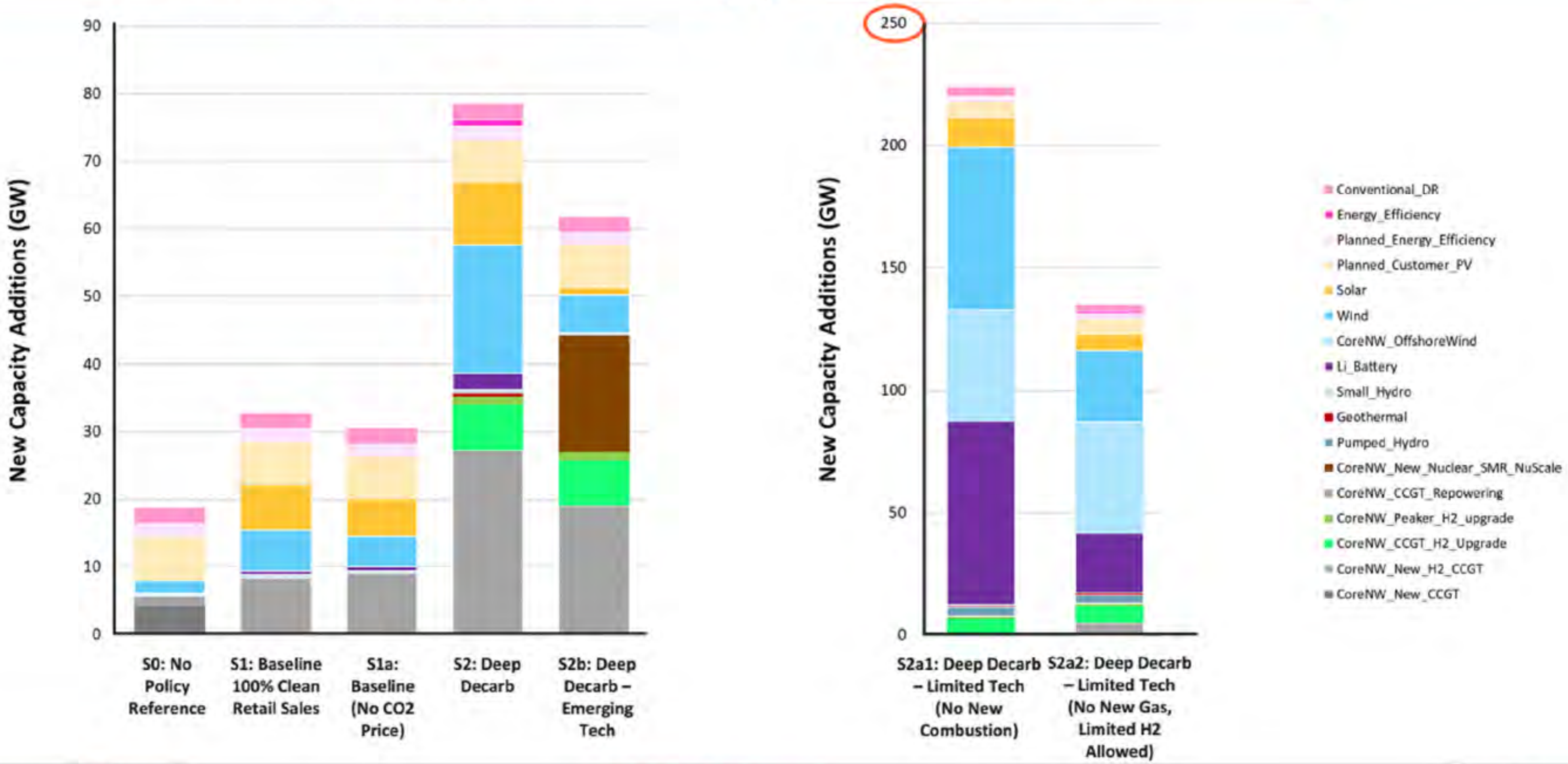
- Lower build of new resources (~60 GW in 2045 vs. ~75 GW in the S2 Deep Decarb case)
- Large buildout of nuclear SMR and new + retrofitted hydrogen plants provide RA capacity needs
- Nuclear SMR provides zero-carbon energy for Northwest and results in increased exports to other regions
  - No expensive hydrogen generation is required to meet zero emissions goal on modeled RESOLVE days





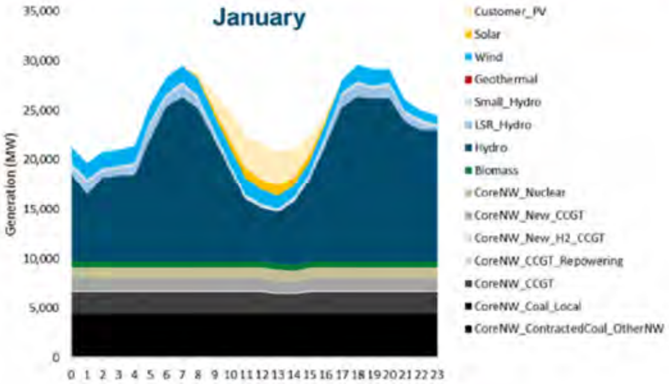
Comparison of 2045 Cumulative Selected Capacity

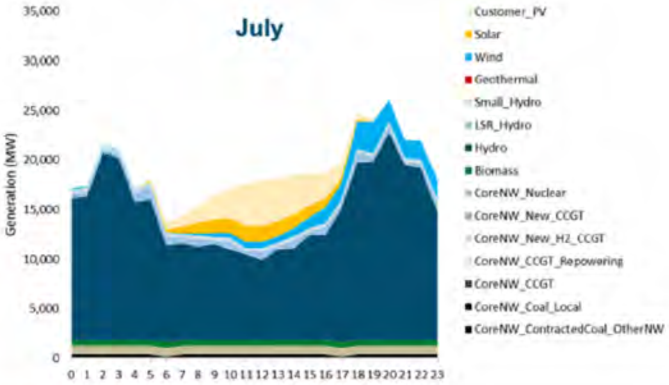
Baseline and Emerging Technology Scenarios | **Limited Technology Scenarios**



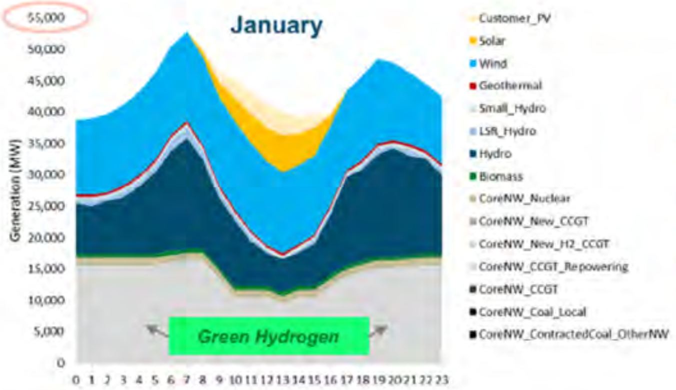
Resource Dispatch in 2045

S0: No Policy Reference

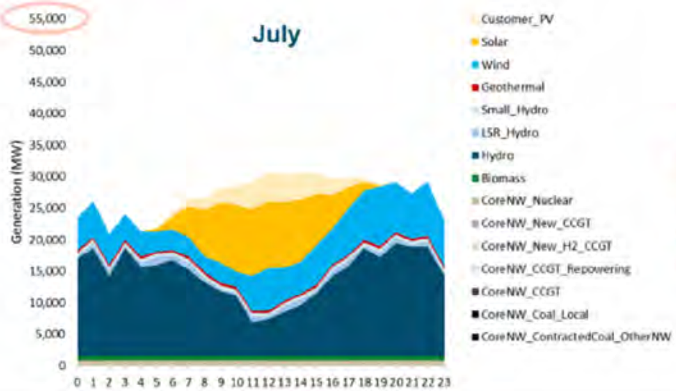




S2: Deep Decarbonization

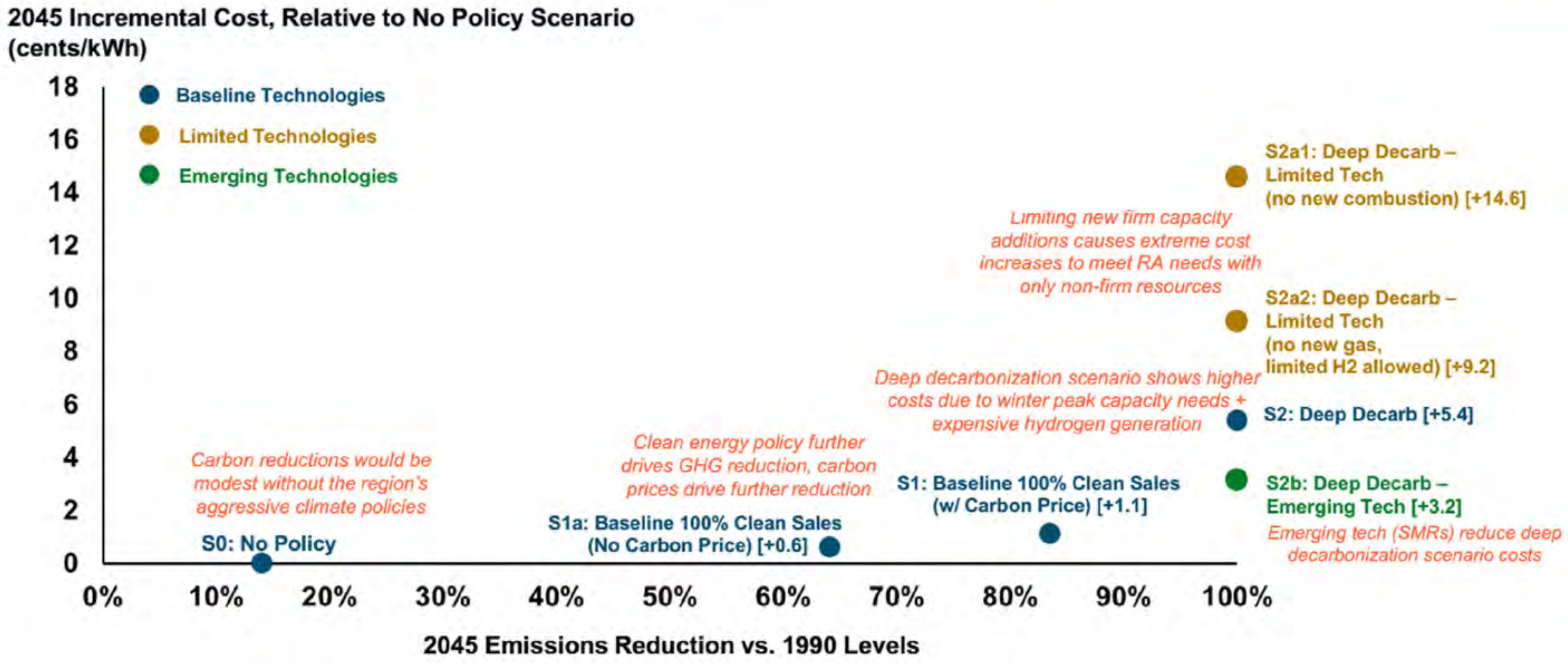


Electrification drives higher winter loads, coal + gas replaced w/ hydrogen generation



Northwest operates at ~100% renewables during many days of the year

Decarbonization Scenarios Cost Impacts



Carbon reductions would be modest without the region's aggressive climate policies

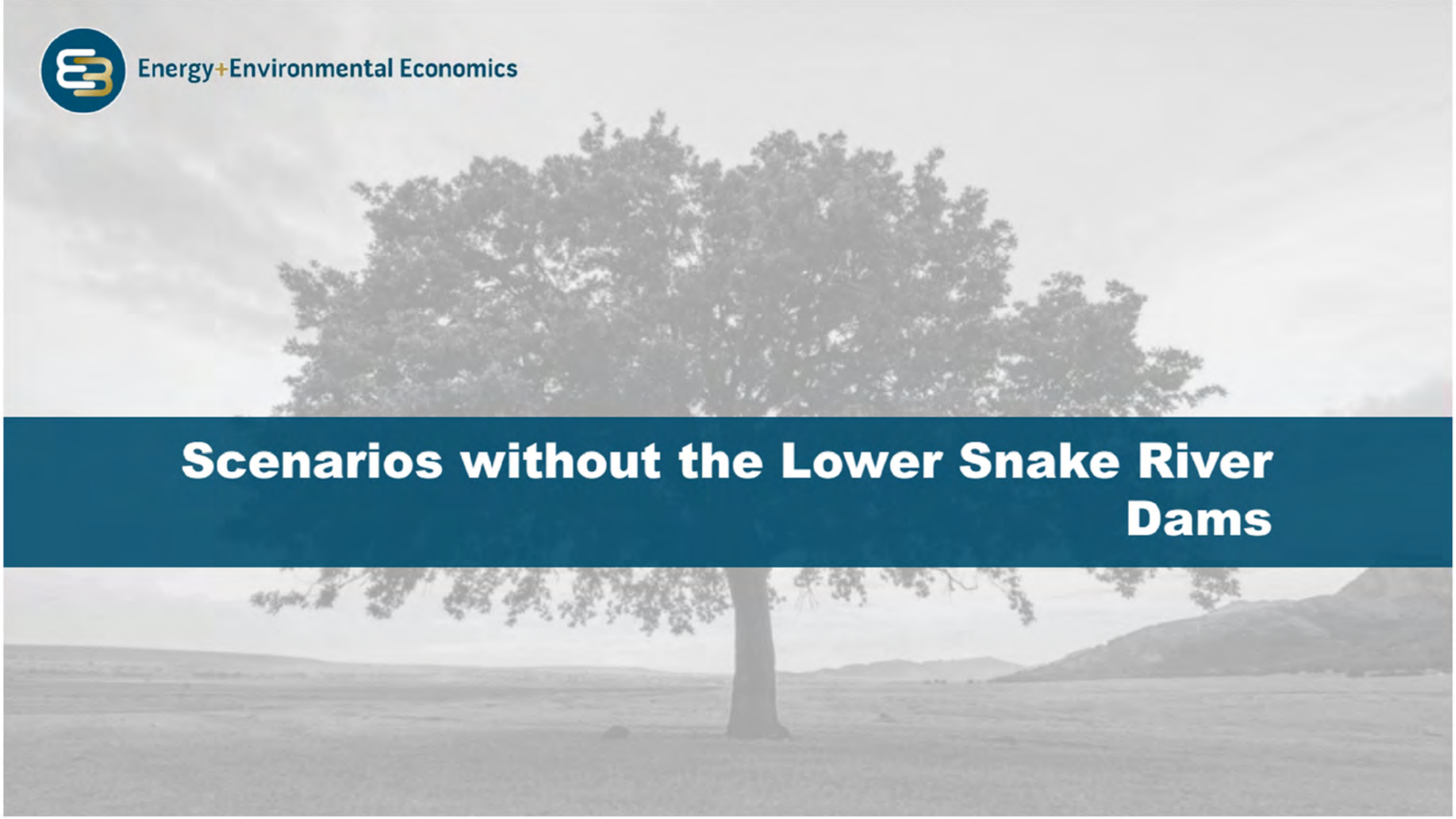
Clean energy policy further drives GHG reduction, carbon prices drive further reduction

Deep decarbonization scenario shows higher costs due to winter peak capacity needs + expensive hydrogen generation

Limiting new firm capacity additions causes extreme cost increases to meet RA needs with only non-firm resources

Emerging tech (SMRs) reduce deep decarbonization scenario costs

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



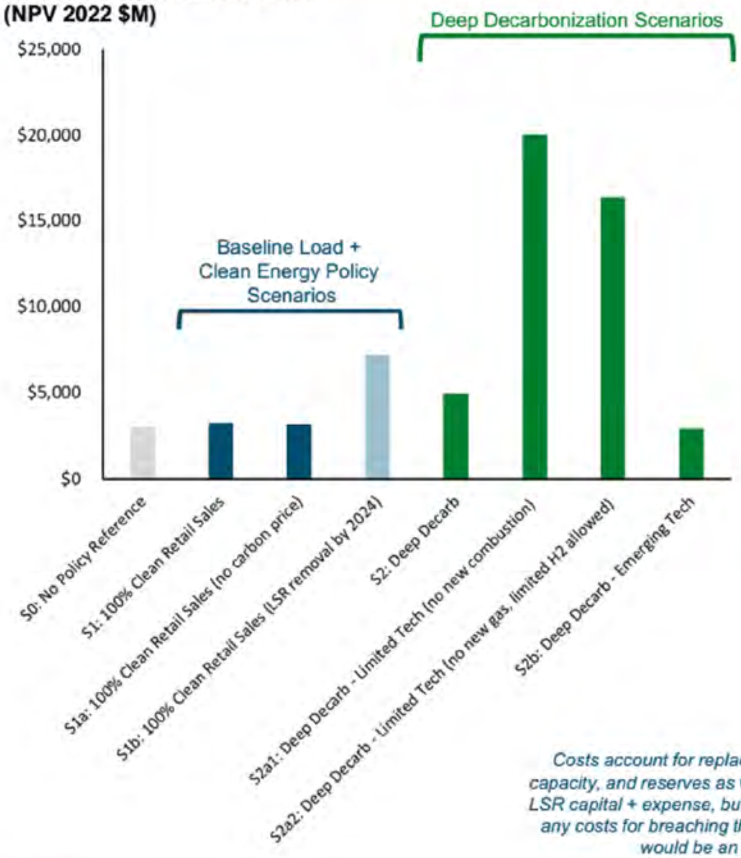
Energy+Environmental Economics

Scenarios without the Lower Snake River Dams

Summary of Replacement Costs of Lower Snake River Dams

- **Replacement costs of the Lower Snake River Dams range from ~$3 to $7 billion (NPV)**
- **No policy reference and 100% CES scenarios show similar costs, driven primarily by RA replacement needs**
- **Deep decarbonization scenarios show higher replacement costs to replace the GHG-free energy output of the dams**
- **Replacement costs range greatly depending on whether emerging technologies are available for replacement (particularly, hydrogen turbines or nuclear SMR)**
  - Limited technology scenarios lead to higher replacement costs ~$16 to ~$20 billion (NPV)

LSR Dam Replacement Costs (NPV 2022 $M)



Costs 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.

Detailed Replacement Costs + Resource Needs

Annual Replacement Cost

Total NPV Replacement Cost

		2035		2045		
	NPV Increase* ($M)	Cost Increase* ($M)	Resource Needs (GW)	Cost Increase ($M)	Resource Needs (GW)	Notes
S0: No Policy Reference	**$2,988**	$453	+ 2.3 GW NG CCGT	$413	+ 2.1 GW NG CCGT + 0.5 GW wind	Replacement costs driven by RA needs and energy redispatch
S1: 100% Clean Retail Sales	**$3,267**	$434	+ 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)	**$3,149**	$445	+ 2.2 GW NG/H2 CCGT + 0.1 GW li-ion battery	$473	+ 1.8 GW NG/H2 CCGT + 1.3 GW solar + 1.2 GW wind	CES binds, increasing 2045 solar + wind replacement, but increased costs offset by lower avoided carbon cost
S1b: 100% Clean Retail Sales (2024 dam removal)	**$7,193**	$466	+ 1.8 GW NG/H2 CCGT + 1.4 GW wind + 0.1 GW li-ion battery - 0.5 GW solar	$509	+ 2.1 GW NG/H2 CCGT + 0.5 GW wind	Earlier removal requires earlier investment in replacement resources, driving a higher NPV replacement cost
S2: Deep Decarb	**$4,957**	$496	+ 2 GW NG/H2 CCGT + 0.6 GW wind + 0.1 GW li-ion battery	$860	+ 2.0 GW NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW energy efficiency + 1.2 TWh H2 generation	Replacement costs increases due to 2045 GHG-free energy replacement w/ expensive H2 generation
S2a1: Deep Decarb, Limited Tech (no new combustion)	**$19,990**	$1,953	+ 7.5 GW wind + 0.9 GW solar + 0.01 GW energy efficiency + 0.3 GW pumped hydro + 6 GW li-ion battery	$3,199	+ 10.6 GW wind + 1.4 GW solar	Meeting high electrification RA needs without firm capacity available drives extremely high replacement cost
S2a2: Deep Decarb, Limited Tech (no new gas, limited H2 allowed)	**$16,398**	$1,624	+ 9.1 GW offshore wind + 0.1 GW wind + 1.0 GW solar + 0.3 GW geothermal + 1.5 GW li-ion battery	$2,737	+ 10.6 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	**$2,958**	$415	+ 1.7 GW NG/H2 CCGT + 0.6 GW nuclear SMR	$428	+ 1.5 GW NG/H2 CCGT + 0.7 GW nuclear SMR	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 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 ~$65-140/MWh
- **BPA customer costs would increase by ~0.7-1.5 cents/kWh**
  - An increase of ~20-40% compared to current estimated BPA generation rate of 3.5 cents/kWh
- **Limited technology scenarios drive extreme replacement costs of to LSR dam resource adequacy capacity value**

Incremental LSR Dam Replacement Resource Costs

Lower Snake River Dams All-in Generation Costs (2022 $/MWh)	Current BPA Tier I Rate (cent/kWh)
$13/MWh w/o LSRCP*	3.5 cent/kWh
$17/MWh w/ LSRCP*	

Scenario	2045 Costs to replace LSR Generation** (real 2022 $/MWh)	2045 Incremental BPA Customer Costs*** (real 2022 cents/kWh)
S0: No Policy Reference	$67/MWh	+ 0.7 cents/kwh
S1: 100% Clean Retail Sales	$77/MWh	+ 0.8 cents/kwh
S1a: 100% Clean Retail Sales (no carbon price)	$76/MWh	+ 0.8 cents/kwh
S1b: 100% Clean Retail Sales (2024 dam removal)	$82/MWh	+ 0.9 cents/kwh
S2: Deep Decarb	$139/MWh	+ 1.5 cents/kwh
S2b: Deep Decarb, w/ Emerging Tech	$69/MWh	+ 0.7 cents/kwh
S2a1: Deep Decarb, Limited Tech (no new combustion)	$517/MWh	+ 5.5 cents/kwh
S2a2: Deep Decarb, Limited Tech (no new gas, H2 allowed)	$443/MWh	+ 4.7 cents/kwh

Outlier cases

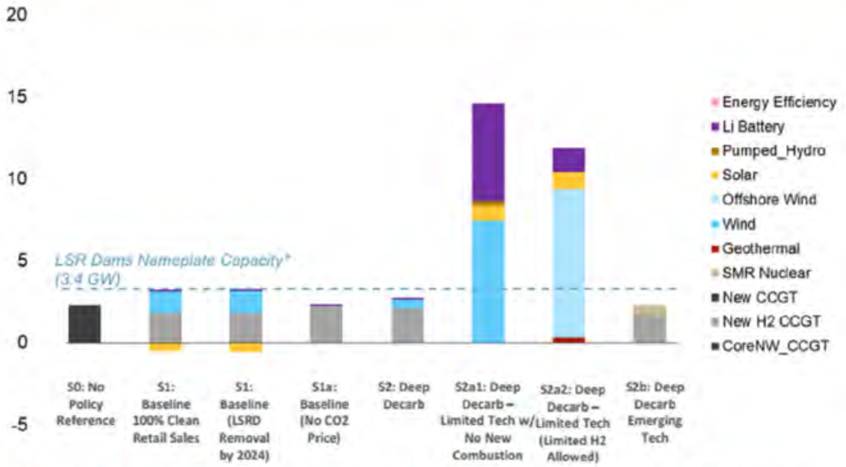
* BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) facilities. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat.2917) to offset fish and wildlife losses caused by construction and operation of the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

** Replacement $/MWh costs are calculated as CoreNW revenue requirement increase with LSR dams 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.

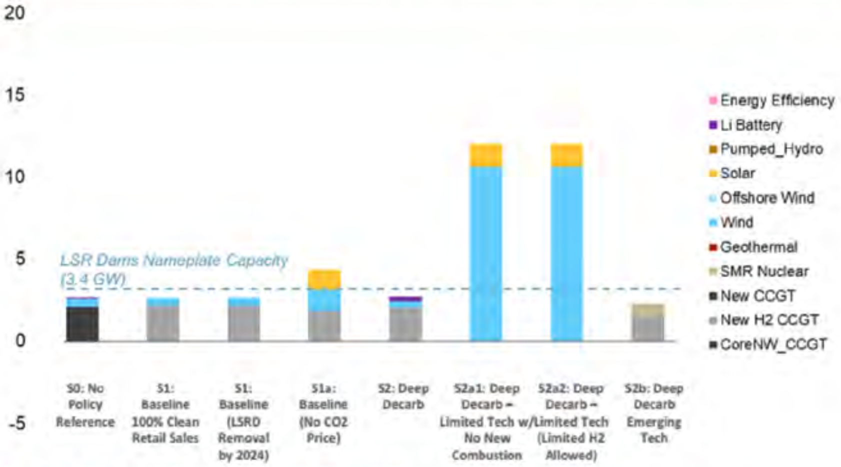
*** Incremental BPA customers costs calculated as the incremental annual revenue requirement divided by BPA's Tier 1 annual sales (~58,686 GWh/yr per FY2022 BPA forecast)

Additional Capacity Builds for Dams Replacement

LSR Dams Replacement Portfolio in 2035 (GW)



LSR Dams Replacement Portfolio in 2045 (GW)



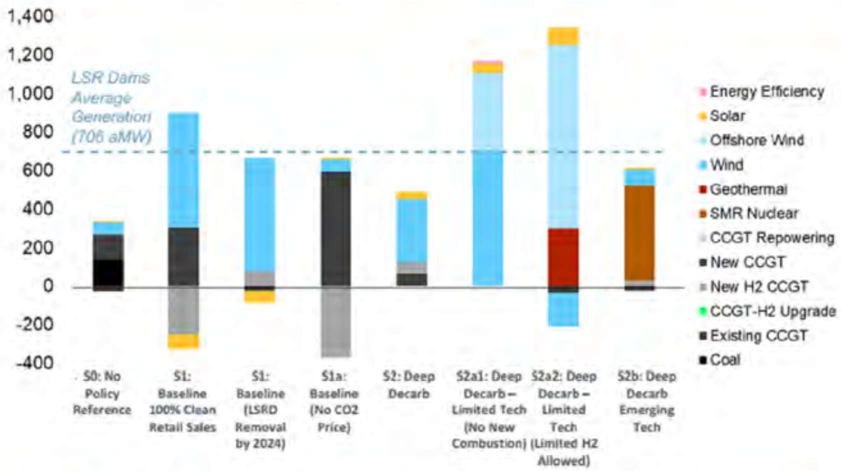
+ **2035 replacement is driven by resource adequacy needs**
  - Firm gas, H2, or nuclear provide replacement RA capacity
  - Scenarios without firm capacity require RA to be replaced by very large amounts of wind, solar, and batteries

+ **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

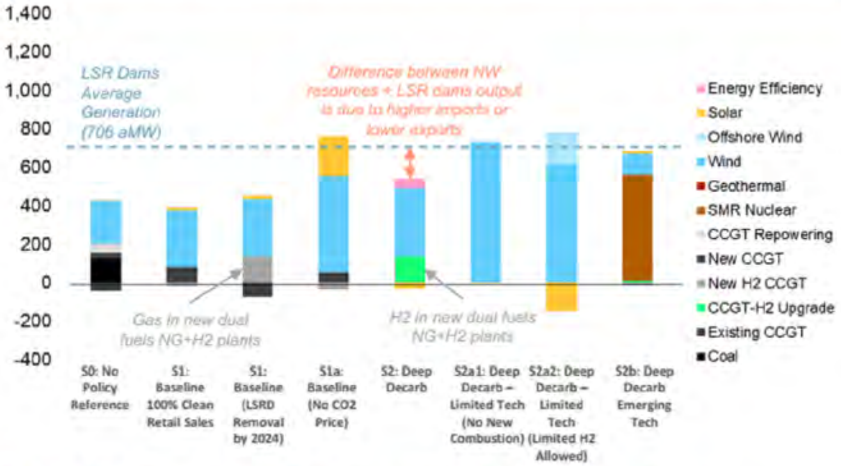
* NOTE: LSR Dam resource adequacy (firm) capacity is ~2.2 GW

Additional Energy Generation for Dams Replacement

LSR Dams Replacement Generation in 2035 (aMW)



LSR Dams Replacement Generation in 2045 (aMW)

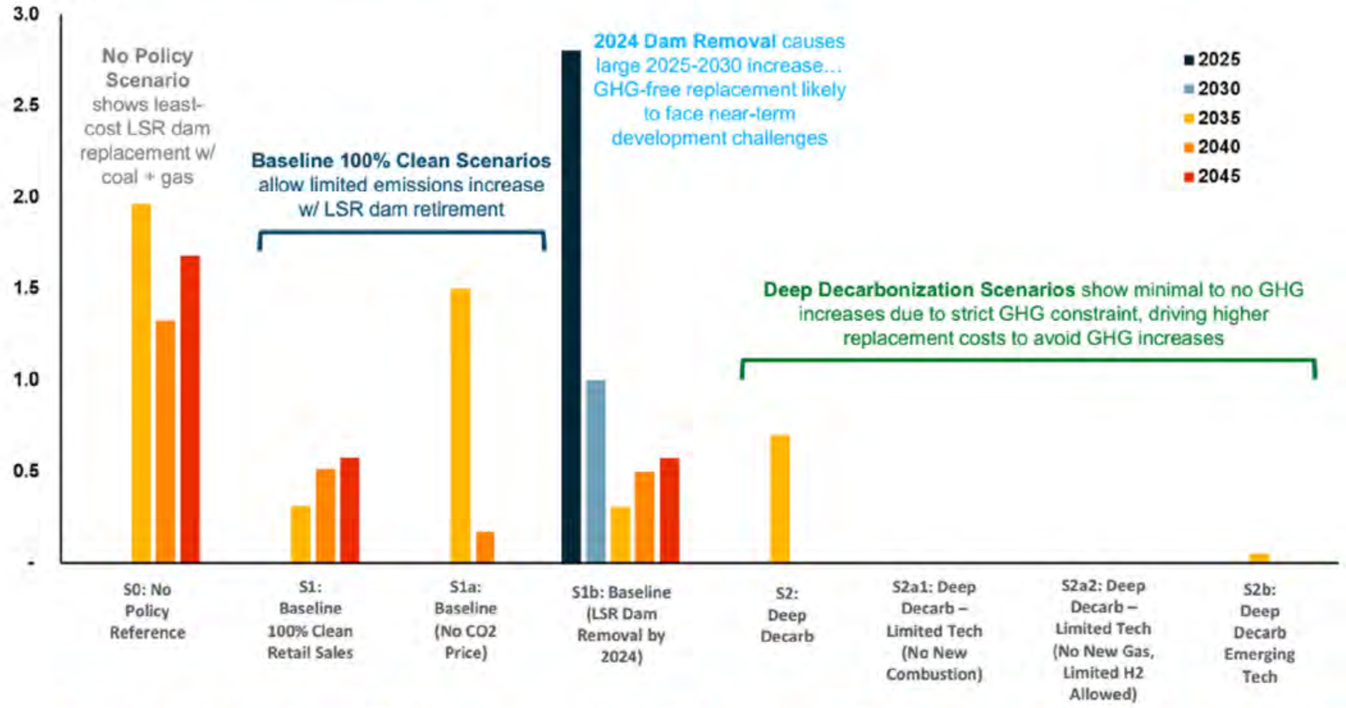


- **In 2035, LSRD generation is replaced by a mix of gas generation, renewable resources, and net imports**
  - Imports tend to increase and exports to decrease
  - In deep decarbonization scenarios, replacement generation is supplied from wind, solar, geothermal, or nuclear SMR

- **2045 energy replacement is driven by clean energy needs**
  - In most scenarios, LSR dams replaced primarily with wind and lower net exports
  - Some generation may be replaced by thermal generation (natural gas in scenarios that allow it or hydrogen in scenarios that do not) or imports

Carbon Emissions Impacts of LSR Dams Removal

Northwest GHG Increases w/ LSR Dams Removal (MMT CO_2/yr)



No Policy Scenario shows least-cost LSR dam replacement w/ coal + gas

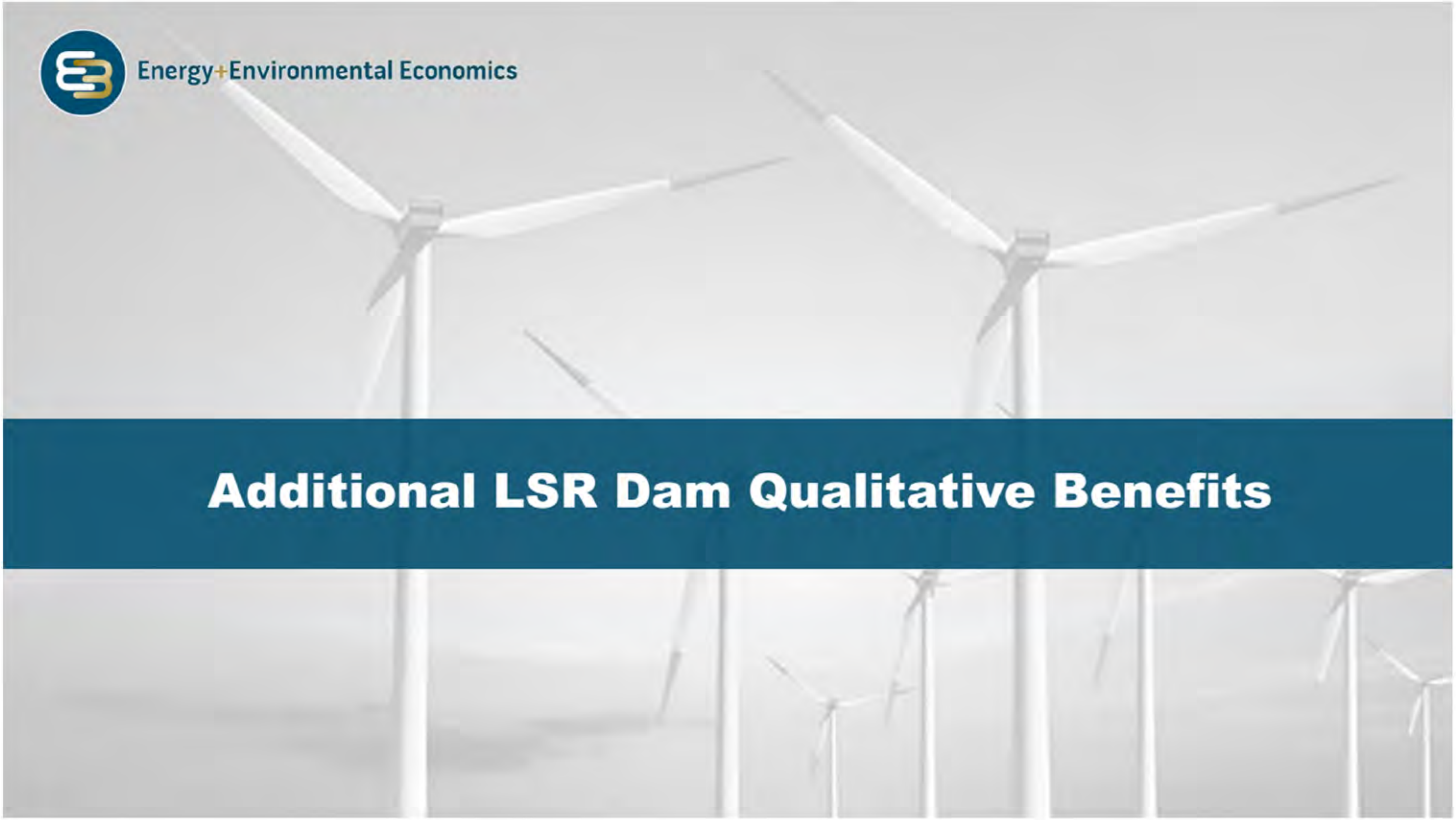
Baseline 100% Clean Scenarios allow limited emissions increase w/ LSR dam retirement

2024 Dam Removal causes large 2025-2030 increase… GHG-free replacement likely to face near-term development challenges

Deep Decarbonization Scenarios show minimal to no GHG increases due to strict GHG constraint, driving higher replacement costs to avoid GHG increases

Under current policy, LSR dams removal will likely increase GHG emissions in the near- to mid-term, with ultimate long-term impacts dependent upon 2045 policy and future carbon prices

Note: 1990 emissions were ~33 MMT, 2035 deep decarb scenario emissions constraint is 8 MMT



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Additional LSR Dam Qualitative Benefits

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	☒

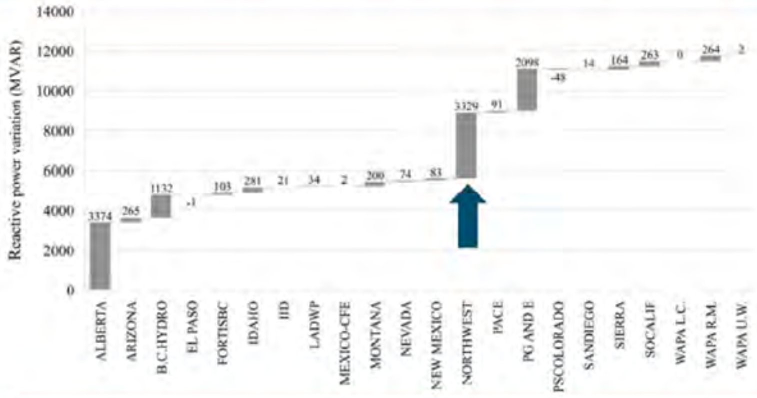
NOTE: RESOLVE also includes new transmission costs for replacement renewable resources (as needed).

- **Hydroelectric generation produces additional benefits not directly captured in E3's RESOLVE model**
- **Most ancillary benefits can be provided by any turbine-based generation resource… and some "synthetically" by inverter-based batteries, wind, or solar**
- **Replacement costs for these essential reliability services (ERS) were not calculated**
  - However, the replacement capacity selected can likely provide many of these services…
  - … additional investments for remaining ERS needs is likely small relative to the generation and transmission investments modeled in RESOLVE

Hydro is a Key Regional Source of Reactive Power

- **Hydropower operates with more headroom than conventional turbine-based resources**
  - The additional headroom relative to conventional resources can be used to provide dynamic reactive power support in the event of grid disturbances such as voltage drops
- **PNW hydropower provides >30% of reactive power in the WECC**
  - The PNW is one of the largest contributors of reactive power to the Western Interconnection
  - Hydropower is the largest contributing resource, contributing more than 30% of reactive power within some service areas
  - As conventional sources are moved offline, the buffer provided by hydropower will become more important system-wide
  - Inverter-based renewables provide limited reactive power in the current system
- **Hydro continues to be a key source of reactive power benefits even in low-flow years**

The PNW Supplies WECC with Reactive Power …



… and Hydro is the Key Contributing Resource

Source: Pacific Northwest National Laboratory. (2021). "Hydropower's Contributions to Grid Resilience." https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-30554.pdf

Voltage Ride-Through and Frequency Response

- **Hydro generators are uniquely tolerant of high and low frequency events (PNNL 2021)**
  - Hydro turbines can continue to operate during high- and low-frequency events without sustaining blade damage – and are required to do so
- **Conventional thermal turbines trip offline outside a narrow frequency range to avoid permanent damage to turbine blades (PNNL 2021)**
  - Turbines in conventional power plants spin at a higher speed than hydro turbines and are highly sensitive to deviations in speed resulting from frequency fluctuations
  - Damage to turbine blades becomes increasingly likely after just minutes of **cumulative lifetime operation** outside the safe range

Interconnection	High Frequency Duration Setting		Low Frequency Duration Setting	
	Instantaneous Trip	Time at >= 60.6 Hz	Instantaneous Trip	Time at <= 59.4 Hz
Quebec (Hydro only)	**>66.0 Hz**	**660 seconds**	**<55.5 Hz**	**660 seconds**
Western	>=61.7 Hz	180 seconds	<57.5 Hz	180 seconds
ERCOT	>=61.8 Hz	540 seconds	<59.4 Hz	540 seconds

Source: NERC. (2018). "Standard PRC-024-2 — Generator Frequency and Voltage Protective Relay Settings". https://www.nerc.com/pa/Stand/Reliability%20Standards/PRC-024-2.pdf

Inertia Buffers the Grid Against Instability

- **NREL: "Inertia is derived from hundreds or thousands of generators that are synchronized, meaning they are all rotating in lock step at the same frequency"**
  - Inertia buffers grid systems against variability in frequency and allows systems to recover more quickly in the event of major frequency fluctuations
  - Hydropower provides inertia through its rotating turbines, without the emissions associated with conventional generation
- **As the Pacific Northwest and other regions in the WECC pursue low-carbon electric systems, there may be many operating hours when conventional generating facilities that historically provided inertia are not online**
  - Inertia capability in the overall grid system will decrease, which increases the need for fast-acting reserves such as hydropower
- **Inverter-based generation cannot inherently provide inertia, but may still be able to provide fast frequency response via grid forming inverters**
  - NREL researchers point out other design solutions, such as power electronics that increase the responsiveness of renewable generation, can be tapped to preserve system reliability in a low-inertia system

Source: NREL. (2020). Inertia and the Power Grid: A Guide Without the Spin. https://www.nrel.gov/docs/fy20osti/73856.pdf

Additional Grid Resilience Benefits

+ Black start capability

- Large hydro is historically a major provider of black start services when required
- 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 (PNNL 2021)

+ Participation in Remedial Action Schemes

- Hydropower typically operates well below nameplate capacity and therefore has significant headroom to support immediate provision of real or reactive power to maintain bulk grid stability during cascading or extreme events as part of Remedial Action Scheme.

+ Short-Circuit and Grounding Contribution

- Synchronous hydropower provides a large short circuit current that can be sustained; exact contribution depends on the hydro generator type

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Thank You

Questions, please contact:

Aaron Burdick, aaron.burdick@ethree.com

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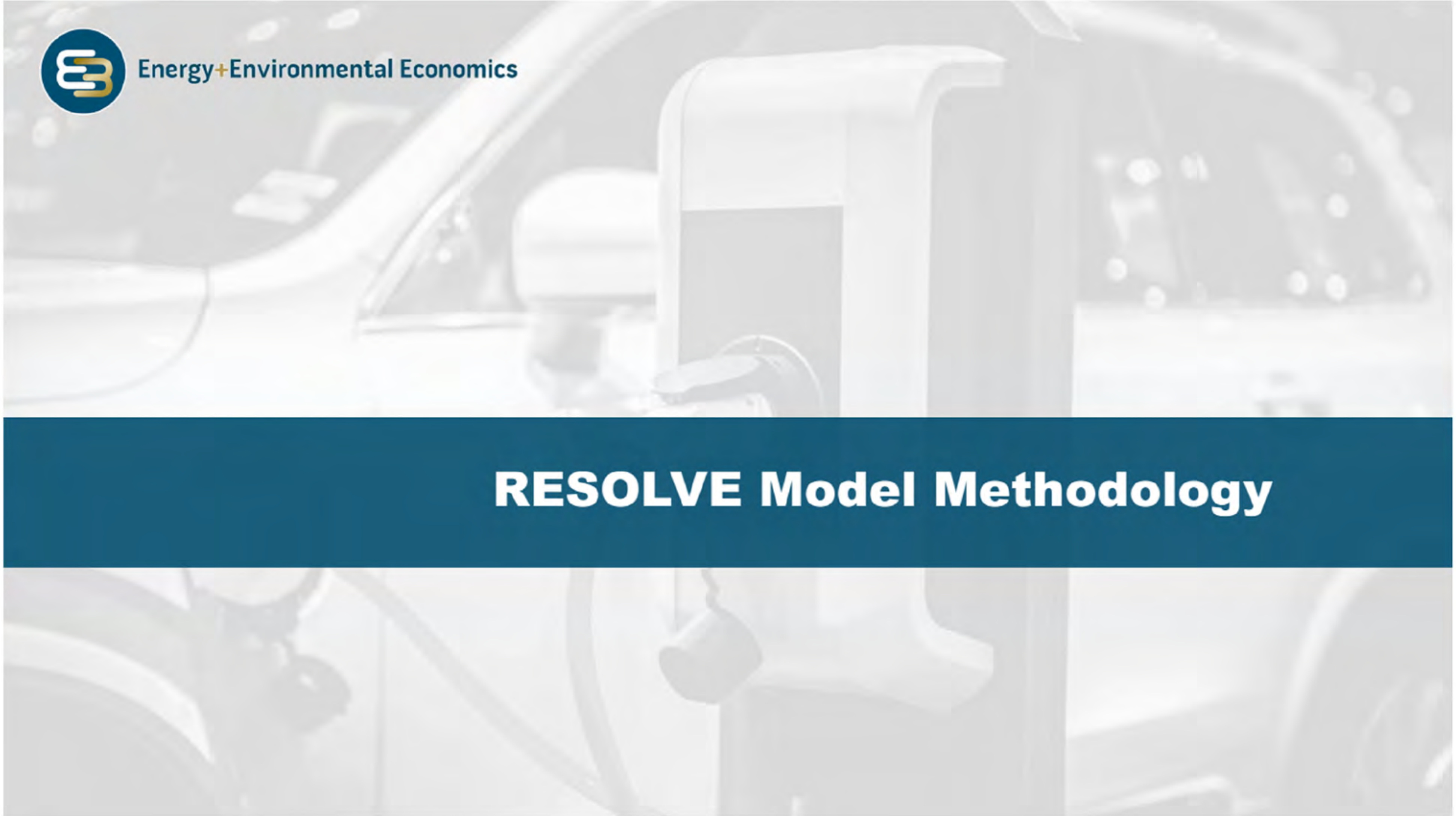
Appendix



Energy+Environmental Economics

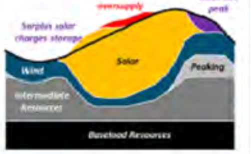
RESOLVE Model Methodology

RESOLVE optimizes investments to meet clean energy targets reliably

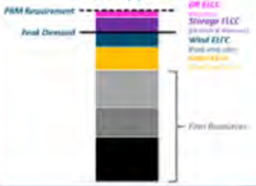
RESOLVE is an optimal capacity expansion model specifically designed to identify least-cost plans to meet reliability needs and achieve compliance with regulatory and policy requirements

- **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**

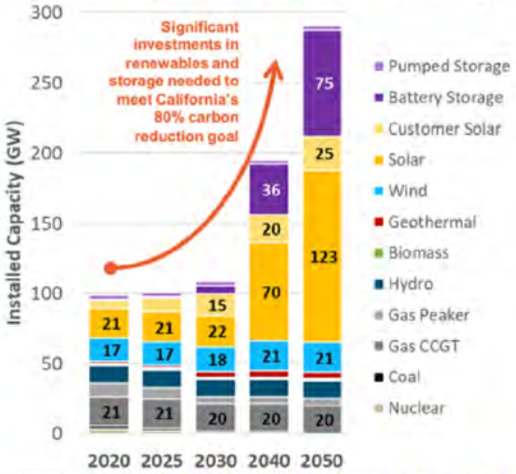
Operational module simulates hourly system operations for a sample of representative days



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

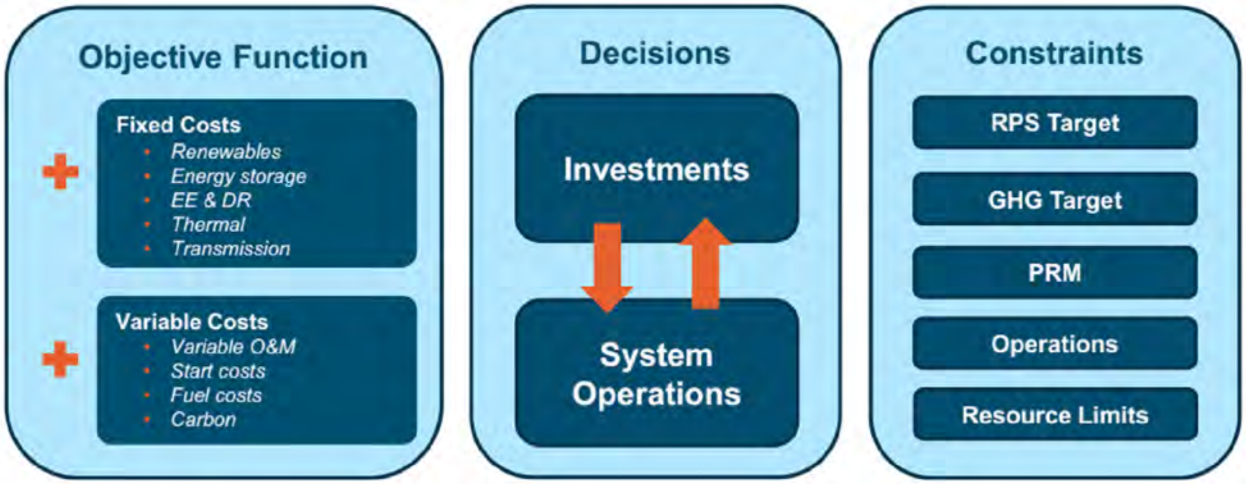


Significant investments in renewables and storage needed to meet California's 80% carbon reduction goal

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

Investment and Operational Decisions in RESOLVE

- **RESOLVE co-optimizes investments and operations to minimize total NPV of electric system cost**
  - Investments and operations optimized in a single stage
  - Single-stage optimization directly captures linkages between investment decisions and system operations



Objective Function

+ **Fixed Costs**
  - *Renewables*
  - *Energy storage*
  - *EE & DR*
  - *Thermal*
  - *Transmission*

+ **Variable Costs**
  - *Variable O&M*
  - *Start costs*
  - *Fuel costs*
  - *Carbon*

Decisions

Investments

System Operations

Constraints

RPS Target

GHG Target

PRM

Operations

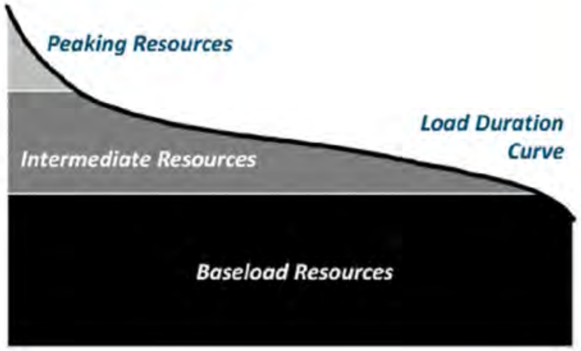
Resource Limits

Evolving Considerations in Planning

System Operations

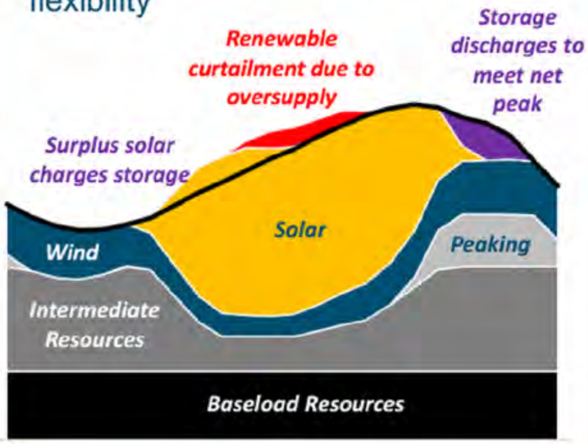
Traditional Planning Paradigm

- Heuristic approaches provide a reasonable means of evaluating resource needs and investment options
- Tradeoff between capital-intensive resources with low operating costs and low capital resources with high operating costs



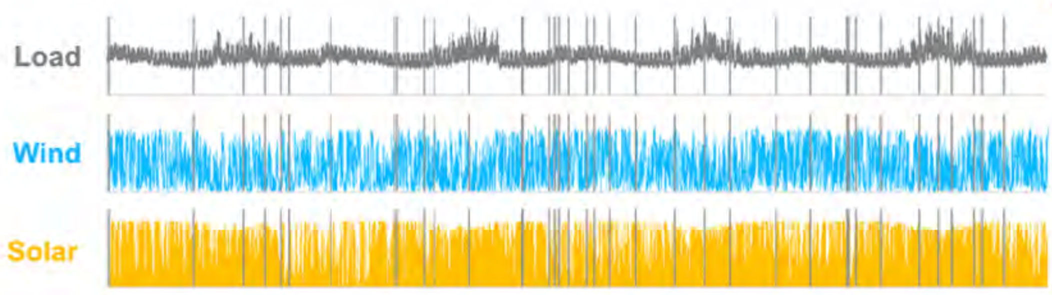
New Planning Paradigm

- Understanding system dispatch at hourly & subhourly timescales becomes necessary to evaluate investments
- Chronological simulation needed to capture constraints on operational flexibility



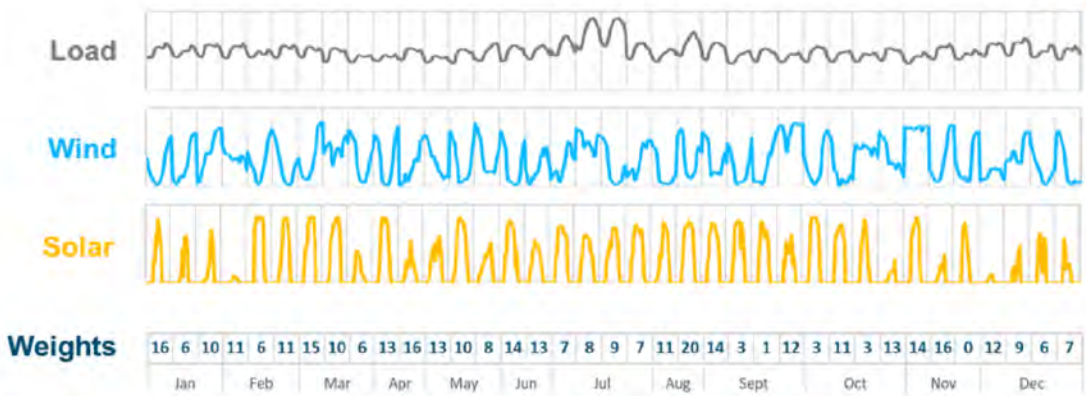
Downsampling historical data sets to a subset of representative days

***Illustrative**, not specific to this project*



3-4 years
of time-synchronous hourly load & renewable profiles

Day selection algorithm selects optimized subsample of days & corresponding weights to match key characteristics observed in long-term record



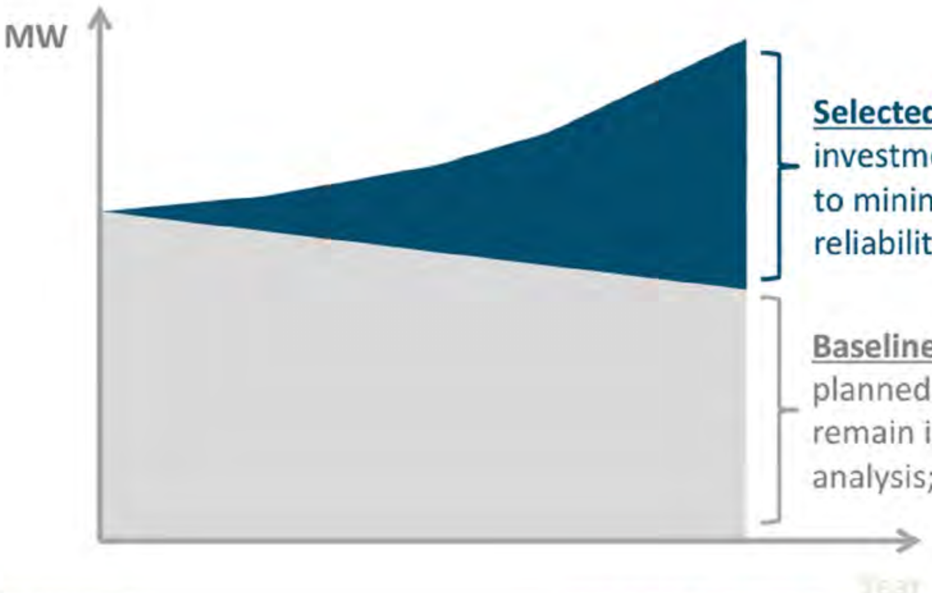
35-40 days
selected as "representative" and modeled in RESOLVE's operational simulation

Weights sum to represent
365 days

NOTE: hydro availability also captured across multiple hydro years

Planned vs. Selected Resources

- **RESOLVE is designed to optimize incremental investments added to an existing electric system**
  - Embedded costs of existing infrastructure are treated as sunk costs
  - Fixed costs of new investments included in objective function



Selected Resources: new resource investments optimized by RESOLVE to minimize cost while meeting reliability and policy goals

Baseline Resources: existing and planned resources assumed to remain in service throughout analysis; costs assumed to be sunk

RESOLVE selects portfolios that balance a wide range of resource options

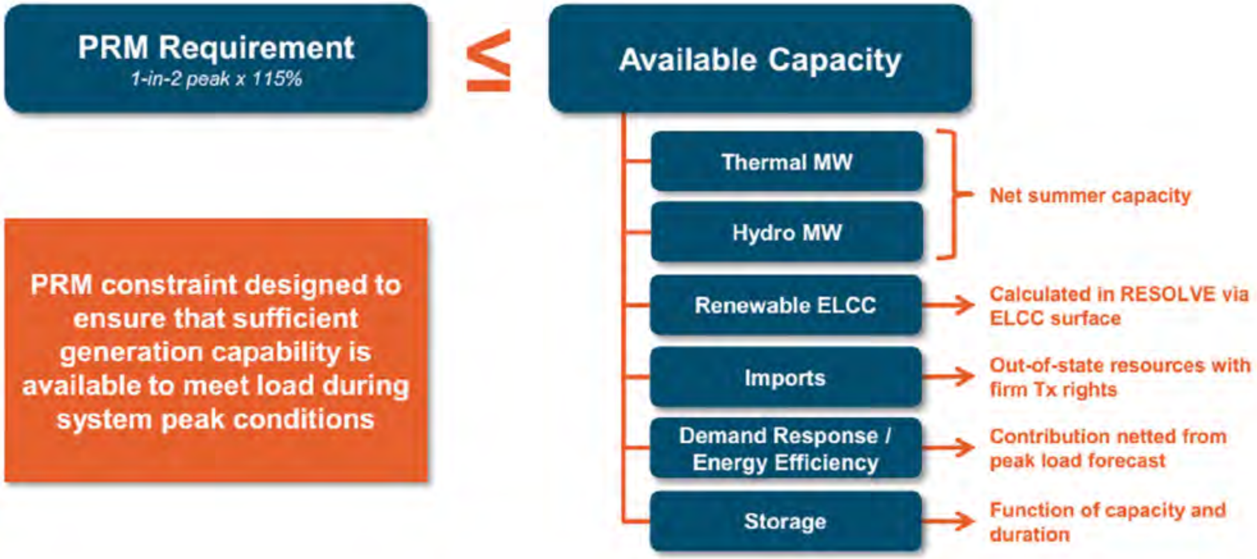
- Options for new resources considered in RESOLVE span a broad range of technologies
- Each resource is characterized by:
  - **Cost:** all **fixed** (capital, interconnection, fixed O&M, financing, taxes) and **operating costs** (fuel, carbon, variable O&M) for each resource
  - **Potential:** technical or other limits on developable potential
  - **Performance:** operating characteristics, including operating constraints, hourly profiles, capacity contributions

Resource Type	Examples of Available Options
Natural Gas Generation	• Simple cycle combustion turbines (CTs) • Combined cycle gas turbines (CCGTs) • Reciprocating engines • *CCGTs with CCS*
Renewable Generation	• Biomass • Geothermal • Hydro upgrades • Solar PV • Wind (onshore & offshore)
Energy Storage	• Battery storage (>1 hr) • Pumped storage (>12 hr)
Customer Technologies	• Energy efficiency • Demand response
Additional Resource Options	• *Nuclear small modular reactors (SMRs)* • *H2 combustion turbines (or NG+H2 dual-fuel)*

Options listed in italics are emerging technologies and are not always included in studies

Resource adequacy needs maintained with a planning reserve margin

- In each year, RESOLVE imposes a planning reserve margin constraint on the total generation fleet
- Contribution of each resource to PRM requirement depends on its attributes



PRM Requirement
1-in-2 peak x 115%

≤

Available Capacity

- **Thermal MW**
- **Hydro MW**
- **Renewable ELCC**
- **Imports**
- **Demand Response / Energy Efficiency**
- **Storage**

Thermal MW, Hydro MW: Net summer capacity

Renewable ELCC → Calculated in RESOLVE via ELCC surface

Imports → Out-of-state resources with firm Tx rights

Demand Response / Energy Efficiency → Contribution netted from peak load forecast

Storage → Function of capacity and duration

PRM constraint designed to ensure that sufficient generation capability is available to meet load during system peak conditions

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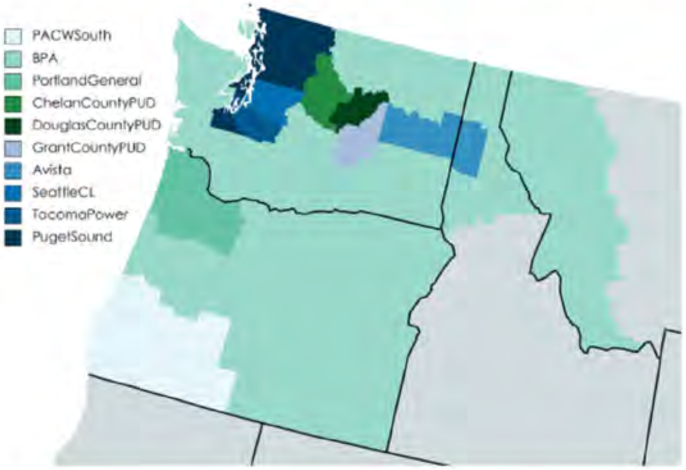
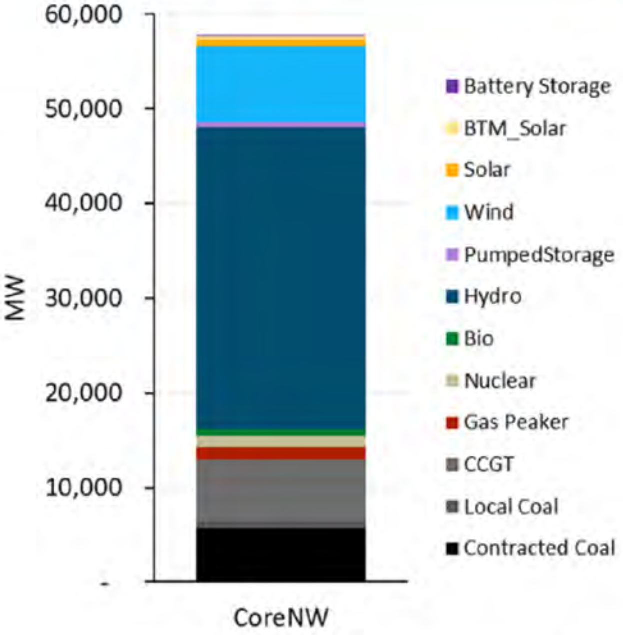
RESOLVE Inputs

Core NW

- **This study takes a regional view of electricity supplies and uses E3's RESOLVE model to optimize the portfolio of resources serving loads in the "Core NW" region**
- **Core NW includes Washington, Oregon, as well as the BPA and Avista serving regions of Idaho and Montana**
- **Existing and expected builds come from the WECC 2020 Anchor dataset and the NWPCC 2021 Power Plan**

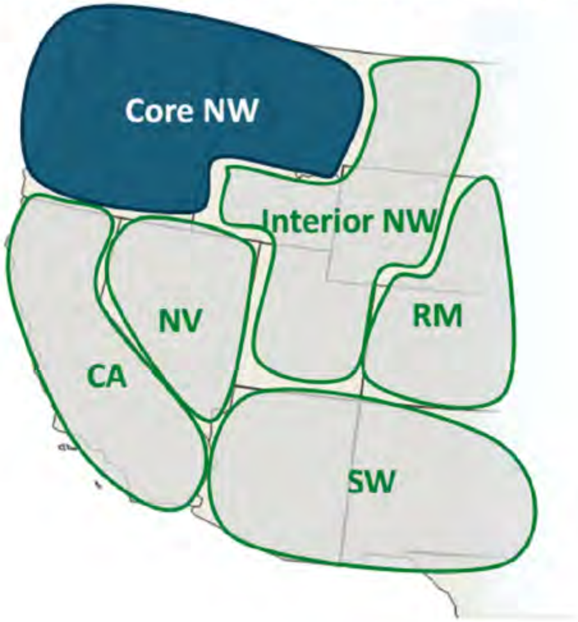


Core NW 2022 Capacity



External Zone - Approach

- RESOLVE makes investment decisions for the Core NW zone while simulating the dispatch decisions for all zones modeled including the main Core NW zone and external zones.
- The investment decisions for external zones are pre-determined based on the results of another WECC-wide capacity expansion model developed by E3. Policy targets assumed for each state is listed below



Policy Targets for the Pre-determined External Zones Builds

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%

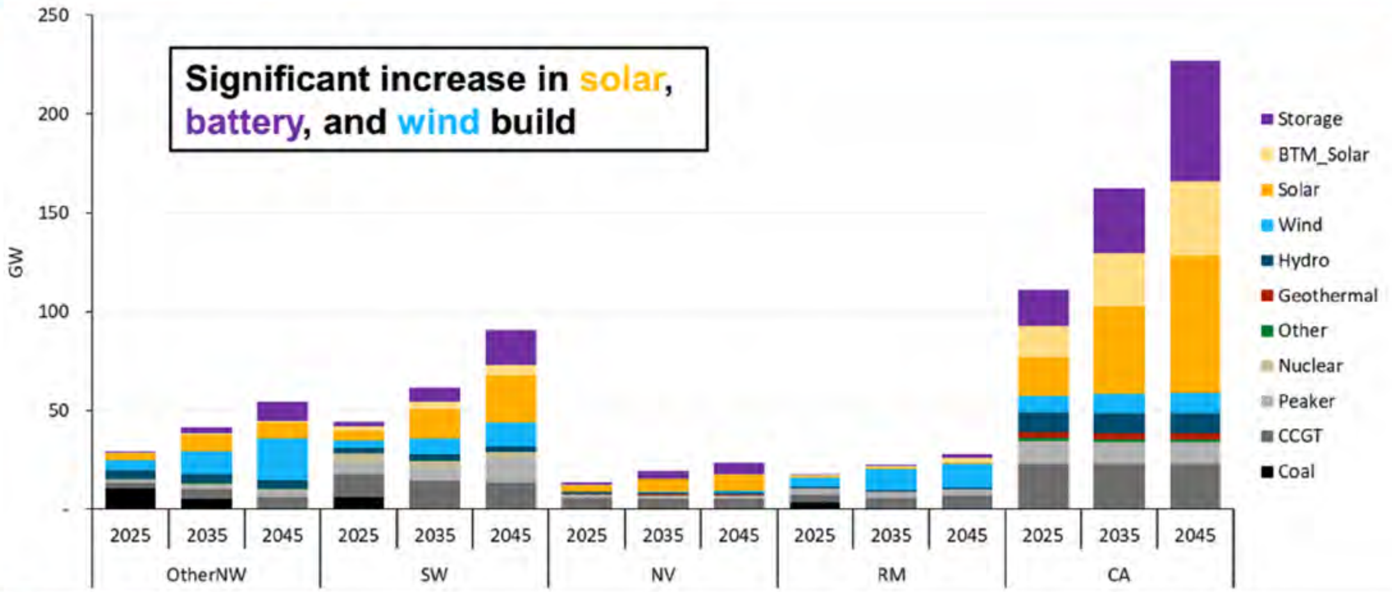
Notes:

- Individual LSE targets implemented for Public Service Co of Colorado, LADWP, Nevada Power Co, and APS
- Post-2030 targets include hydro and nuclear carbon-free generation
- Some regions reflect targets that are strongly expected to come to fruition

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

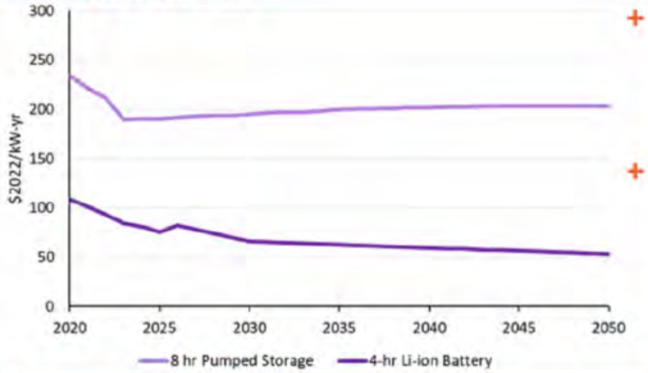
Total Installed Capacity for External Zones



New Resource Options

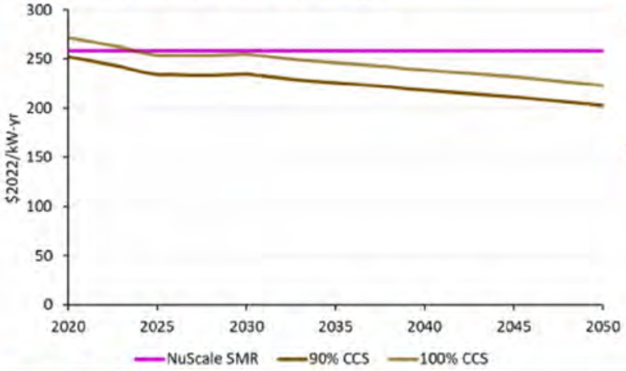
All-in Fixed Costs

Storage Options



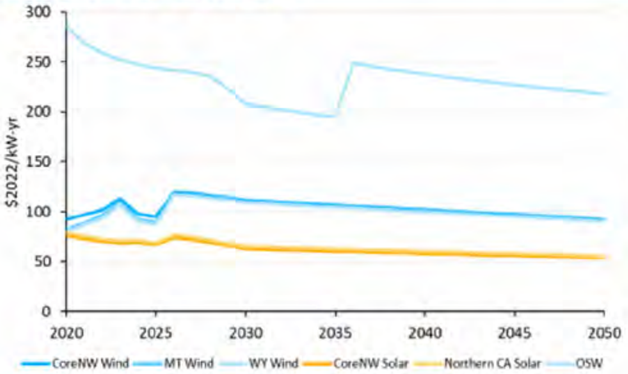
- Battery Storage costs derived from E3's inhouse and Lazard LCOS 7.0 (Oct 2021)
- Pumped storage is from Lazard's last published PHS costs (LCOS 4.0). Assumes CAPEX and FO&M are flat + financing cost trends same for battery storage.

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

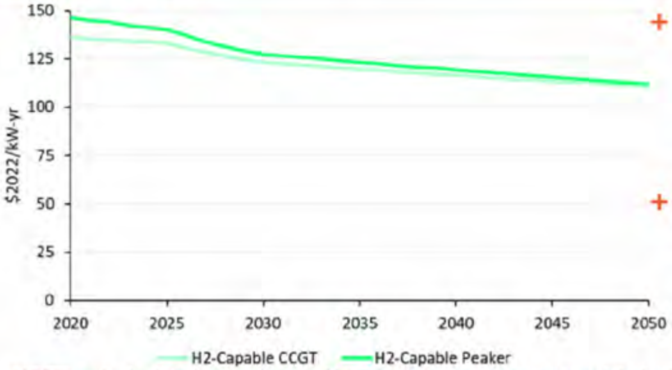
Renewable Options



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

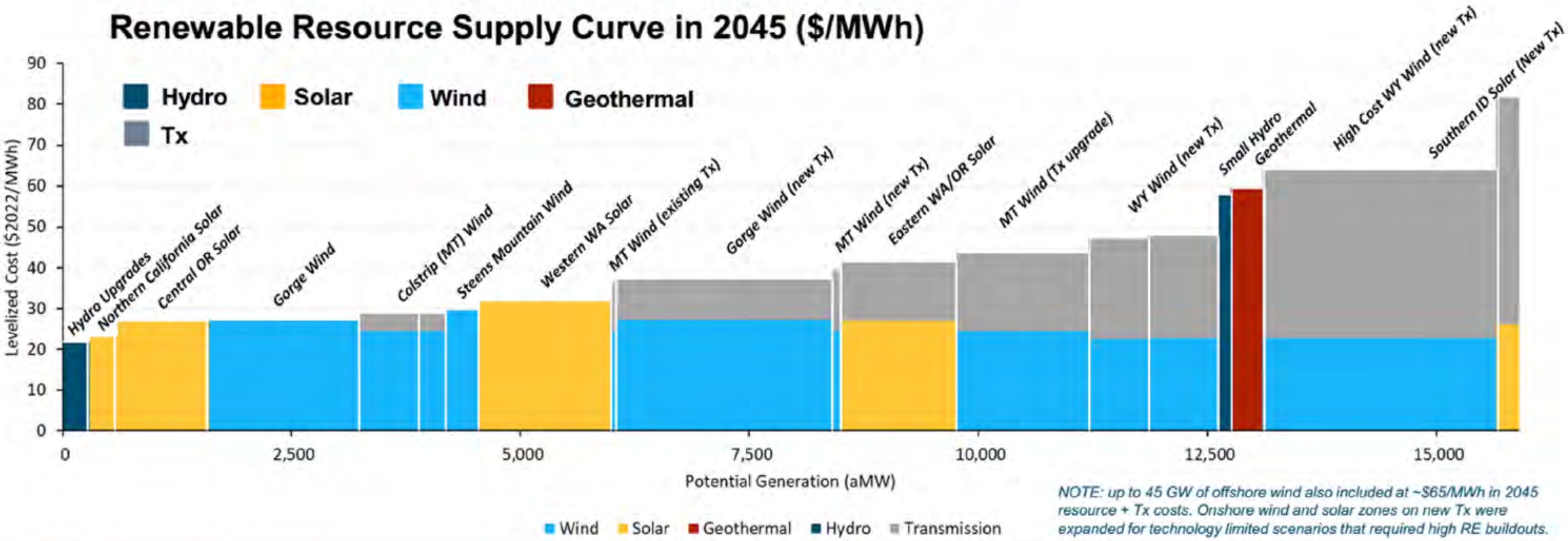


- CCGT and peaker costs are derived from E3's inhouse ProForma which integrates NREL ATB 2021
- New Hydrogen or upgrades include a ~10% additional cost that converges by 2050

NOTE: only dual fuel natural gas + H2-enabled new resources modeled, given NW policy constraints

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.

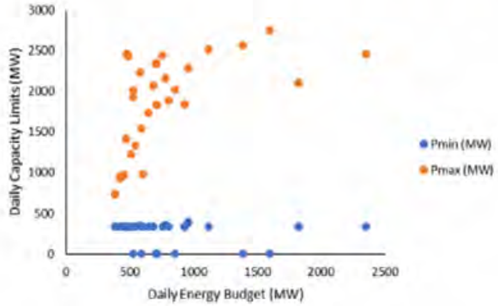
Hydro Operating Data

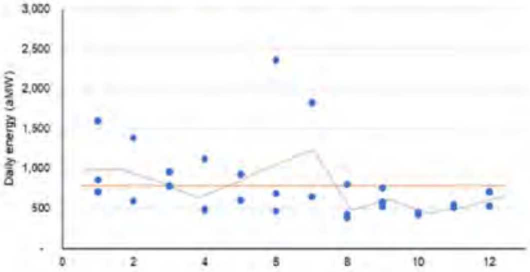
- **Key RESOLVE inputs (for each representative RESOLVE day)**
  - Max generation MW
  - Min generation MW
  - Daily MWh hydro budget
  - Ramp
- **Hydro operating data is parameterized using representative conditions for 3 low/mid/high historical years (2001, 2005, 2011)**
  - Lower Snake River and Lower 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%

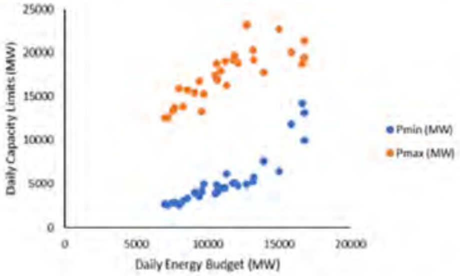


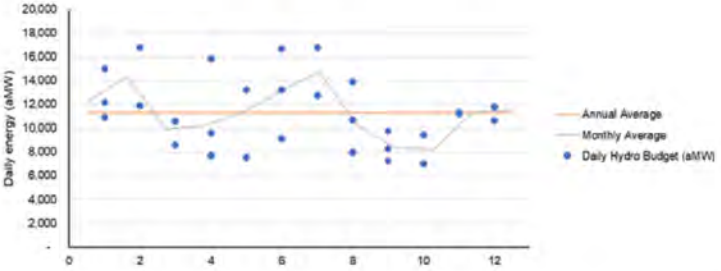


Non-LSR NW Hydro

Ramp Rates

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

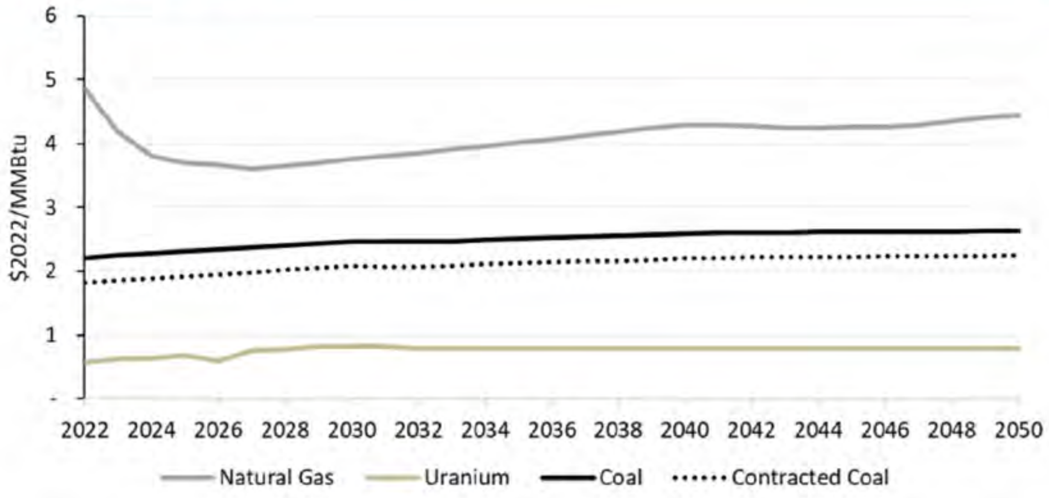




Fuel Prices

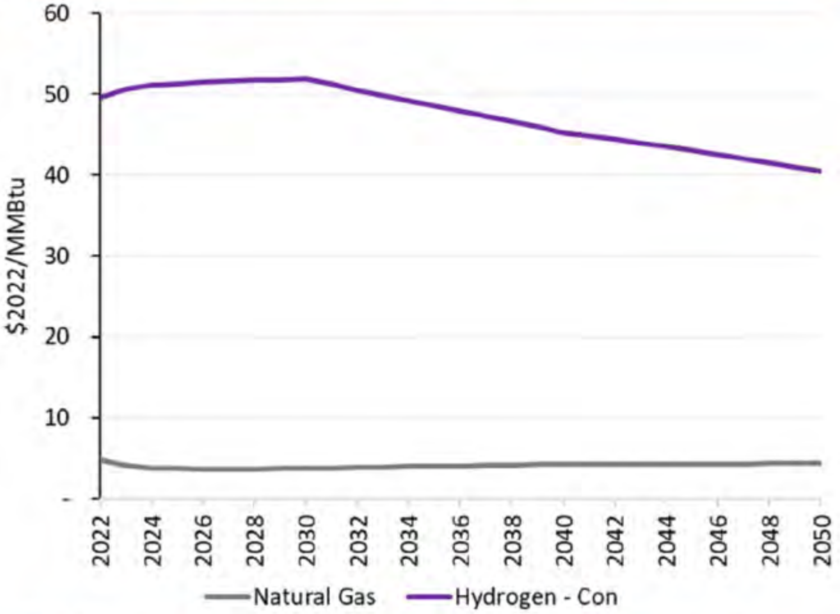
- E3 base gas prices are derived using a combination of SNL forwards in the near term (2022-2026) and then trending it to the EIA's AEO fundamentals-based 2040 forecast for the longer term
- Coal prices are from EIA's AEO forecast
- Uranium prices are from E3's in-house work with regional players

Thermal Fuel Prices



Fuel Prices - Hydrogen

Hydrogen price forecast (2020$/MMBtu)*

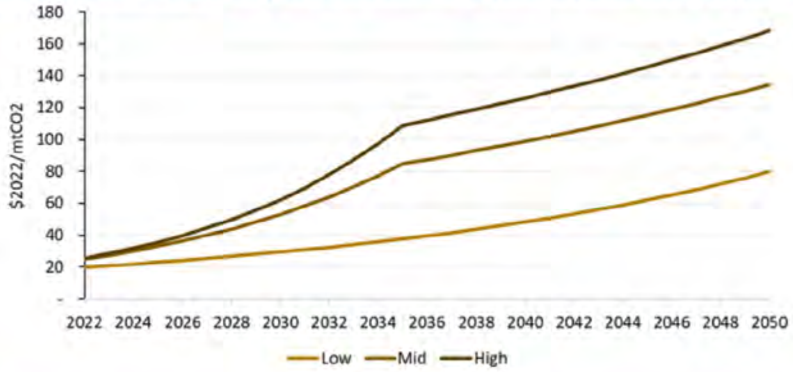


*Note the optimistic fuel price in the near term is not currently viable. It is shown for illustrative purposes under the assumption underground storage and dedicated pipelines are actively in use today.

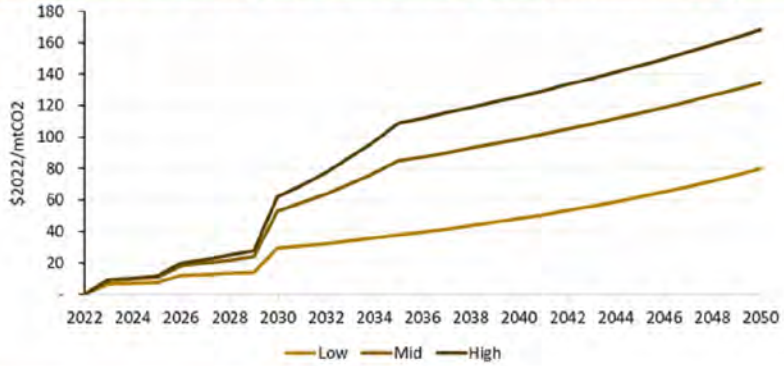
- **The conservative hydrogen price is used as the basis for all scenarios. It assumes:**
  - There is not a massive H_2 economy and thus electrolyzer capital costs and efficiencies have only slightly decreased
  - H_2 is stored in above ground tanks and delivered via trucks.
- **Conservative assumes dedicated off-grid Core NW wind power are used to produce H_2**
  - Renewable levelized fixed costs are derived from NREL's ATB.
  - Capacity factors from E3 analysis
- **Fuel price trajectories assume ~225 mile trip to deliver hydrogen**
- **RESOLVE modeling assumes unlimited supply of H_2 as a drop in fuel to existing (w/ upgrades) or new gas plants**

Carbon Price

California carbon price forecast (2022$/mton CO_2)



CoreNW carbon price forecast (2022$/mton CO_2)



- **California's carbon price is from the Final 2021 IEPR GHG Allowance Price Projections (12/21)**
- **CoreNW assumes**
  - Washington's cap-and-trade program set to implement in 2023 will sell at roughly 50% of California
  - That Oregon will follow close behind with and a carbon price will be implemented by 2026
  - Until 2026 the resulting carbon price is a load weighted share
  - Both states will converge to California's floor price by 2030
- **"Mid" forecast will be the default assumption for both regions**

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

Land Use Impacts

- Summary of direct and indirect land use impacts

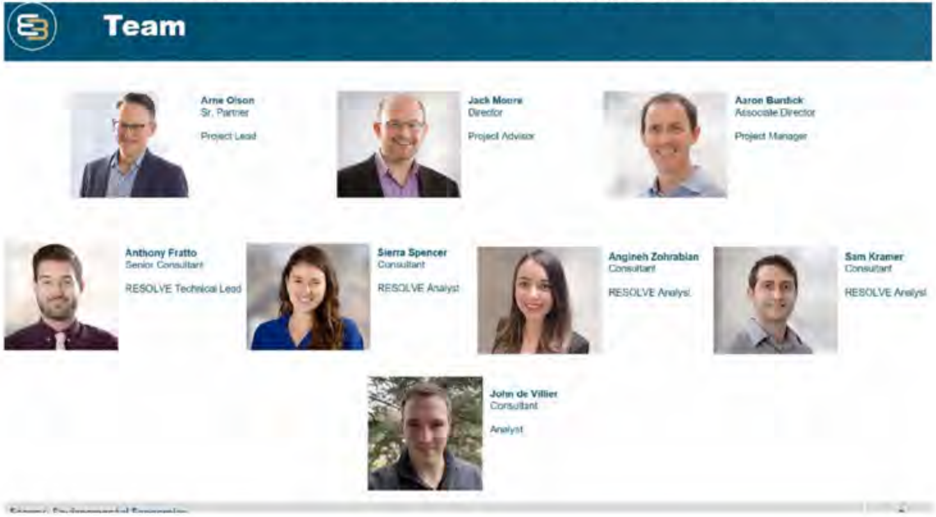
E3 will update for the final version of this report

Climate Change Impacts

- We haven’t done any new work here, so will simply summarize our reliance on the power plan load impacts and no adjustments to hydro availability.

E3 will update for the final version of this report

Angineh Zohrabian, Aaron Burdick (Project Manager), Jack Moore, Arne, Sierra



Team

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Sr. Partner
Project Lead

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Project Advisor

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Project Manager

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RESOLVE Technical Lead

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Sam Kramer
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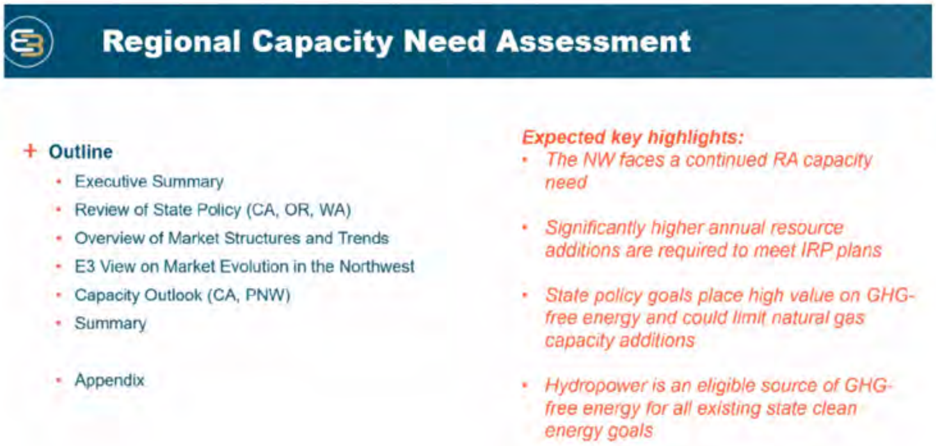
RESOLVE Analyst

John de Villier
Consultant
Analyst

	Week of													
	28-Feb	7-Mar	14-Mar	21-Mar	28-Mar	4-Apr	11-Apr	18-Apr	25-Apr	2-May	9-May	16-May	23-May	30-May
Task 1 Capacity Need Assessment														
Update Regional Capacity Needs + CA/WA/OR Policy	🟦	🟦	🟦											
Incorporate Hydro-Specific Considerations			🟦	🟦	🟦									
PPT Report					🟨	🟨								
Task 2 RESOLVE Analysis														
Input updates	🟦	🟦												
Functionality updates to model 4 LSR dams		🟦	🟦											
Scenario Design		🟦	🟦											
RESOLVE Runs				🟦	🟦									
Document Draft Results in PPT Report					🟨	🟨								
Additional RESOLVE Runs (as needed)						🟦	🟦	🟦						
Task 3 Qualitative Analysis														
E3 develop draft non-modeled benefits PPT			🟦	🟦	🟦									
BPA Review + Feedback					🟨	🟨								
Task 4 Written Report														
Draft Final Word Report (15-25 pages)								🟦	🟦	🟦	🟨			
Final Word Report												🟦	🟨	

Tasks 1-3 are preferred by April 1 but could be by April 15
Task 4 is due by June 1



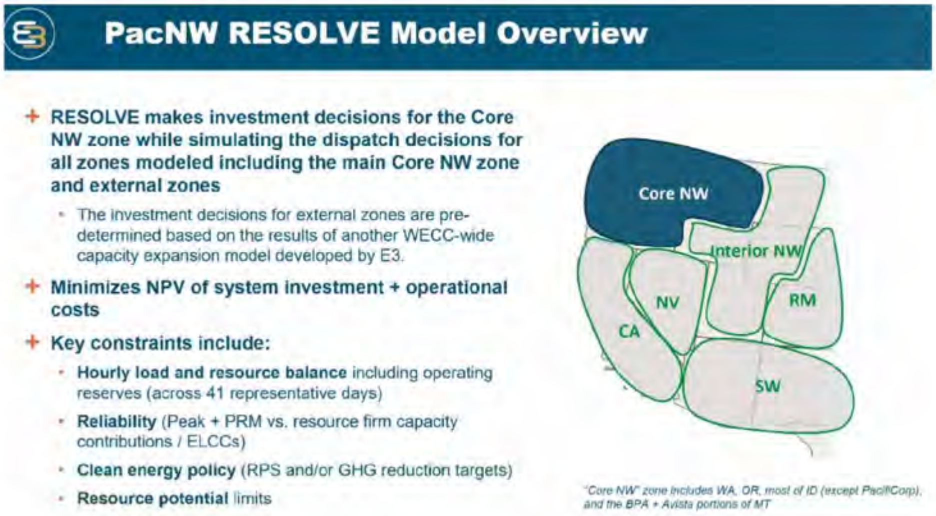
Regional Capacity Need Assessment

+ **Outline**
  - Executive Summary
  - Review of State Policy (CA, OR, WA)
  - Overview of Market Structures and Trends
  - E3 View on Market Evolution in the Northwest
  - Capacity Outlook (CA, PNW)
  - Summary
  - Appendix

Expected key highlights:
- *The NW faces a continued RA capacity need*
- *Significantly higher annual resource additions are required to meet IRP plans*
- *State policy goals place high value on GHG-free energy and could limit natural gas capacity additions*
- *Hydropower is an eligible source of GHG-free energy for all existing state clean energy goals*

Arne points out that Resolver will not replace less than the full capacity of the LSN since the region is already deficit

Rob asks about CC. They would start with their standard loads. If time left, could add load



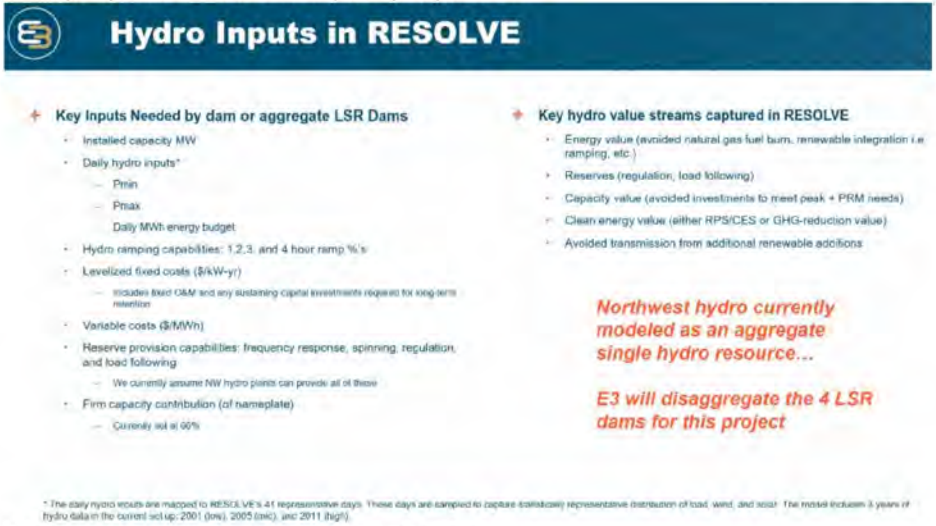
PacNW RESOLVE Model Overview

- **RESOLVE makes investment decisions for the Core NW zone while simulating the dispatch decisions for all zones modeled including the main Core NW zone and external zones**
  - The investment decisions for external zones are pre-determined based on the results of another WECC-wide capacity expansion model developed by E3.
- **Minimizes NPV of system investment + operational costs**
- **Key constraints include:**
  - **Hourly load and resource balance** including operating reserves (across 41 representative days)
  - **Reliability** (Peak + PRM vs. resource firm capacity contributions / ELCCs)
  - **Clean energy policy** (RPS and/or GHG reduction targets)
  - **Resource potential** limits

"Core NW" zone includes WA, OR, most of ID (except PacifiCorp), and the BPA + Avista portions of MT

Solar/wind capacity at ELCC (declining as more are added)

Resolve does operations and capacity expansion. It can look at multiple water years, but only limited to a few days. (Could be done in Aurora too, but think Resolve is as good and well built). Some stakeholders will criticize fidelity.
It models sample days, but draws from multiple years, e.g. hot/cold days, wet days. Not 8760 hours of multiple years. Better for capacity expansion.



Hydro Inputs in RESOLVE

- **Key Inputs Needed by dam or aggregate LSR Dams**
  - Installed capacity MW
  - Daily hydro inputs*
    - Pmin
    - Pmax
    - Daily MWh energy budget
  - Hydro ramping capabilities: 1,2,3, and 4 hour ramp %'s
  - Levelized fixed costs ($/kW-yr)
    - Includes fixed O&M and any sustaining capital investments required for long-term retention
  - Variable costs ($/MWh)
  - Reserve provision capabilities: frequency response, spinning, regulation, and load following
    - We currently assume NW hydro plants can provide all of these
  - Firm capacity contribution (of nameplate)
    - Currently set at 66%
- **Key hydro value streams captured in RESOLVE**
  - Energy value (avoided natural gas fuel burn, renewable integration i.e ramping, etc.)
  - Reserves (regulation, load following)
  - Capacity value (avoided investments to meet peak + PRM needs)
  - Clean energy value (either RPS/CES or GHG-reduction value)
  - Avoided transmission from additional renewable additions

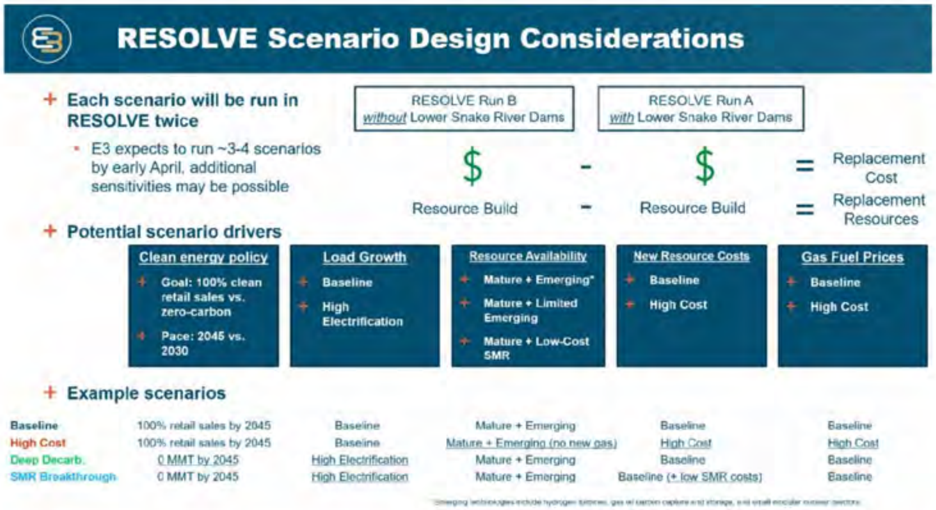
Northwest hydro currently modeled as an aggregate single hydro resource…

E3 will disaggregate the 4 LSR dams for this project

* The daily hydro inputs are mapped to RESOLVE's 41 representative days. These days are sampled to capture statistically representative distribution of load, wind, and solar. The model includes 3 years of hydro data in the current set up: 2001 (low), 2005 (mid), and 2011 (high).

Pmin - minimum power output (min gen)

Will look at capacity expansion with and wo the dams
Frim capacity contribution of nameplate of 66% is for peak events in lower hydro conditions. May be applied more for the whole region hydrosystem.



RESOLVE Scenario Design Considerations

- **Each scenario will be run in RESOLVE twice**
  - E3 expects to run ~3-4 scenarios by early April, additional sensitivities may be possible

RESOLVE Run B *without* Lower Snake River Dams		RESOLVE Run A *with* Lower Snake River Dams		
$	-	$	=	Replacement Cost
Resource Build	-	Resource Build	=	Replacement Resources

- **Potential scenario drivers**

Clean energy policy
- Goal: 100% clean retail sales vs. zero-carbon
- Pace: 2045 vs. 2030

Load Growth
- Baseline
- High Electrification

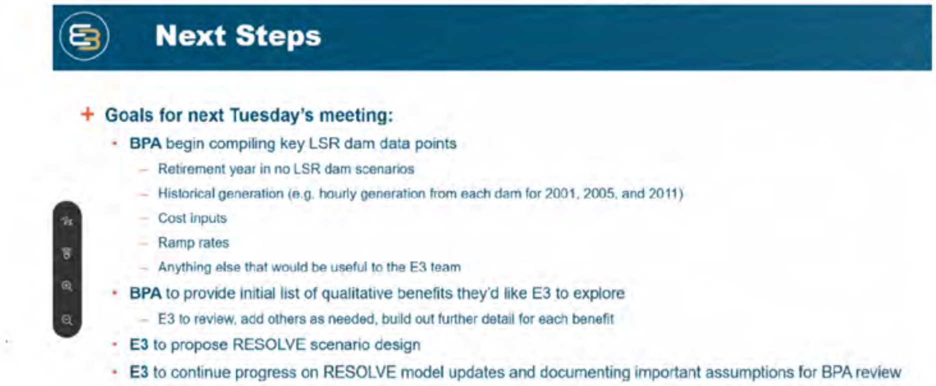
Resource Availability
- Mature + Emerging*
- Mature + Limited Emerging
- Mature + Low-Cost SMR

New Resource Costs
- Baseline
- High Cost

Gas Fuel Prices
- Baseline
- High Cost

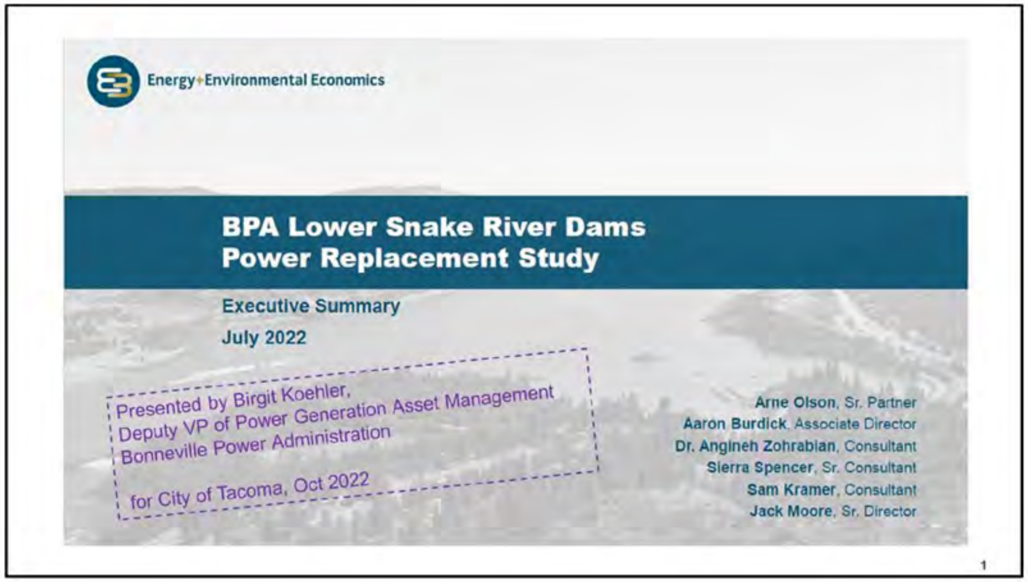
- **Example scenarios**

Baseline	100% retail sales by 2045	Baseline	Mature + Emerging	Baseline	Baseline
High Cost	100% retail sales by 2045	Baseline	Mature + Emerging (no new gas)	High Cost	High Cost
Deep Decarb.	0 MMT by 2045	High Electrification	Mature + Emerging	Baseline	Baseline
SMR Breakthrough	0 MMT by 2045	High Electrification	Mature + Emerging	Baseline (+ low SMR costs)	Baseline



Next Steps

- **Goals for next Tuesday's meeting:**
  - **BPA** begin compiling key LSR dam data points
    - Retirement year in no LSR dam scenarios
    - Historical generation (e.g. hourly generation from each dam for 2001, 2005, and 2011)
    - Cost inputs
    - Ramp rates
    - Anything else that would be useful to the E3 team
  - **BPA** to provide initial list of qualitative benefits they'd like E3 to explore
    - E3 to review, add others as needed, build out further detail for each benefit
  - **E3** to propose RESOLVE scenario design
  - **E3** to continue progress on RESOLVE model updates and documenting important assumptions for BPA review



Energy+Environmental Economics

BPA Lower Snake River Dams Power Replacement Study

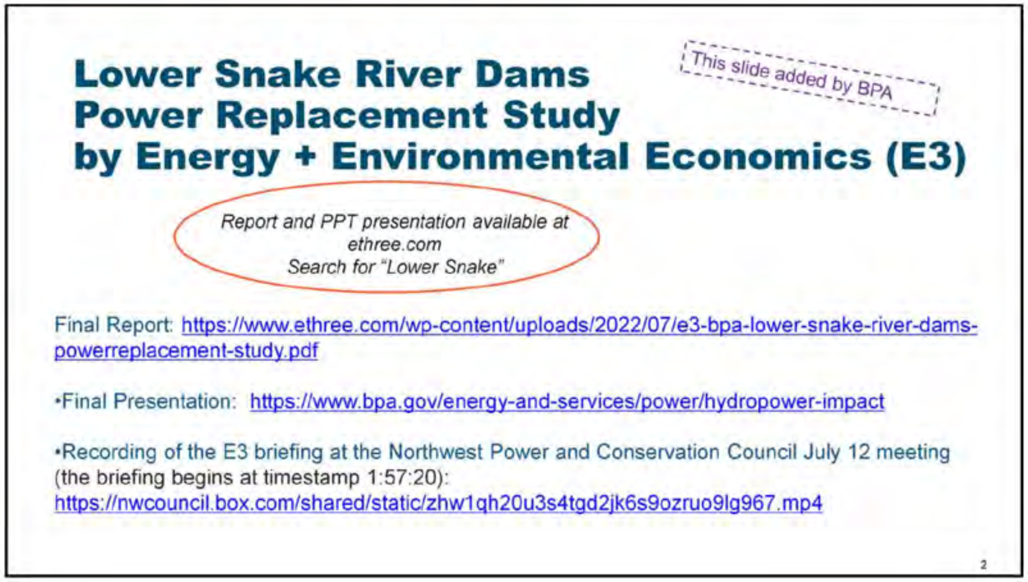
Executive Summary

July 2022

Presented by Birgit Koehler,
Deputy VP of Power Generation Asset Management
Bonneville Power Administration

for City of Tacoma, Oct 2022

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



This slide added by BPA

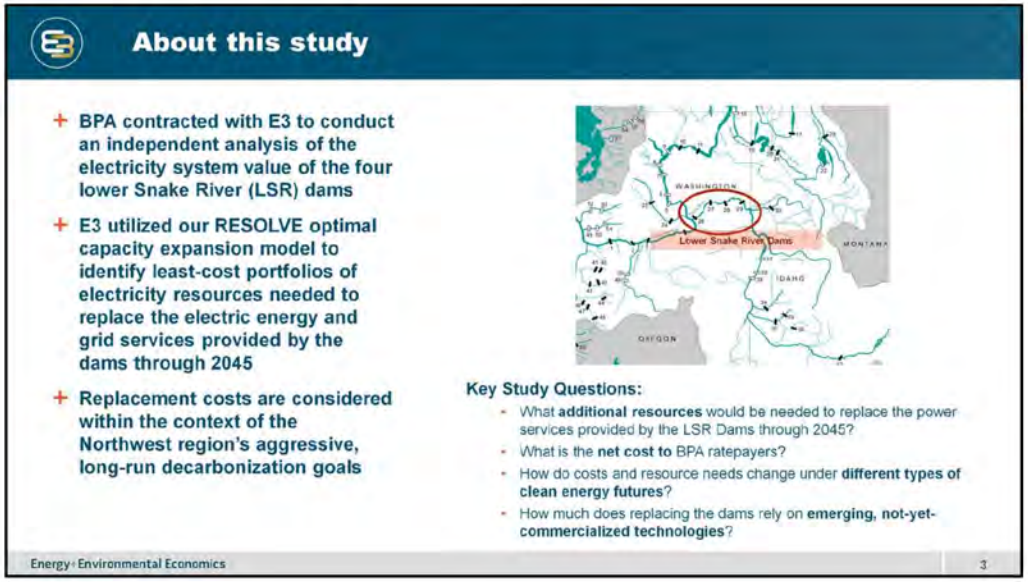
Lower Snake River Dams Power Replacement Study by Energy + Environmental Economics (E3)

Report and PPT presentation available at
ethree.com
Search for "Lower Snake"

Final Report: https://www.ethree.com/wp-content/uploads/2022/07/e3-bpa-lower-snake-river-dams-powerreplacement-study.pdf

•Final Presentation: https://www.bpa.gov/energy-and-services/power/hydropower-impact

•Recording of the E3 briefing at the Northwest Power and Conservation Council July 12 meeting (the briefing begins at timestamp 1:57:20):
https://nwcouncil.box.com/shared/static/zhw1qh20u3s4tgd2jk6s9ozruo9lg967.mp4

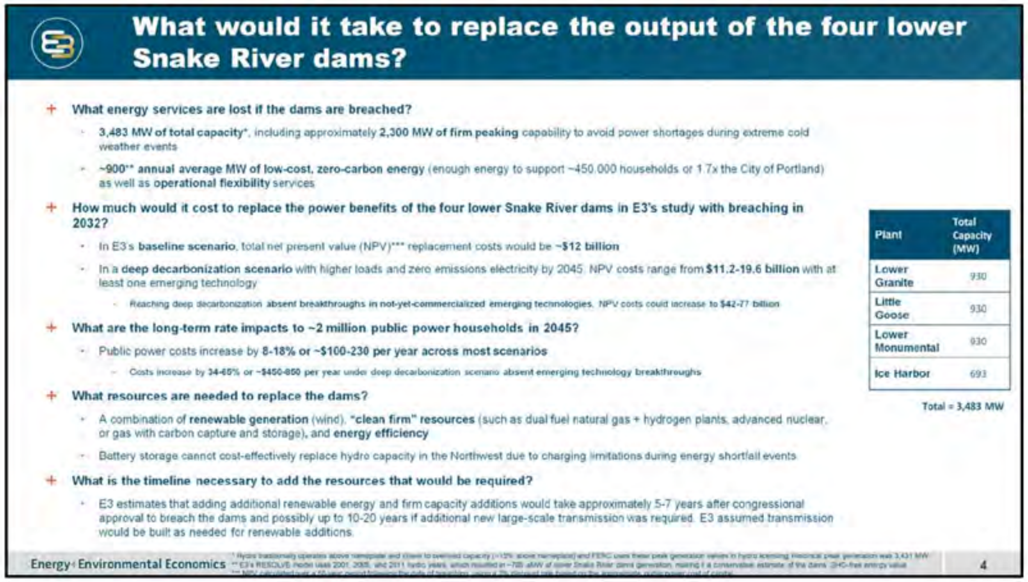


About this study

- 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**?

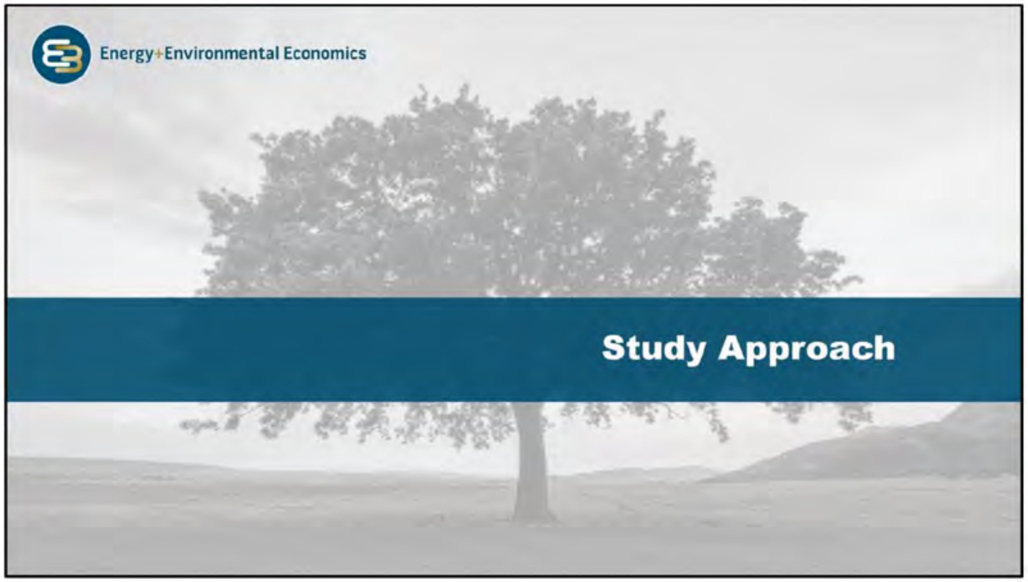


What would it take to replace the output of the four lower Snake River dams?

- **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 **~$12 billion**
  - In a **deep decarbonization scenario** with higher loads and zero emissions electricity by 2045, NPV costs range from **$11.2-19.6 billion** with at least one emerging technology
    - Reaching deep decarbonization **absent breakthroughs in not-yet-commercialized emerging technologies**, NPV costs could increase to **$42-77 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 **34-65% or ~$450-850 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.

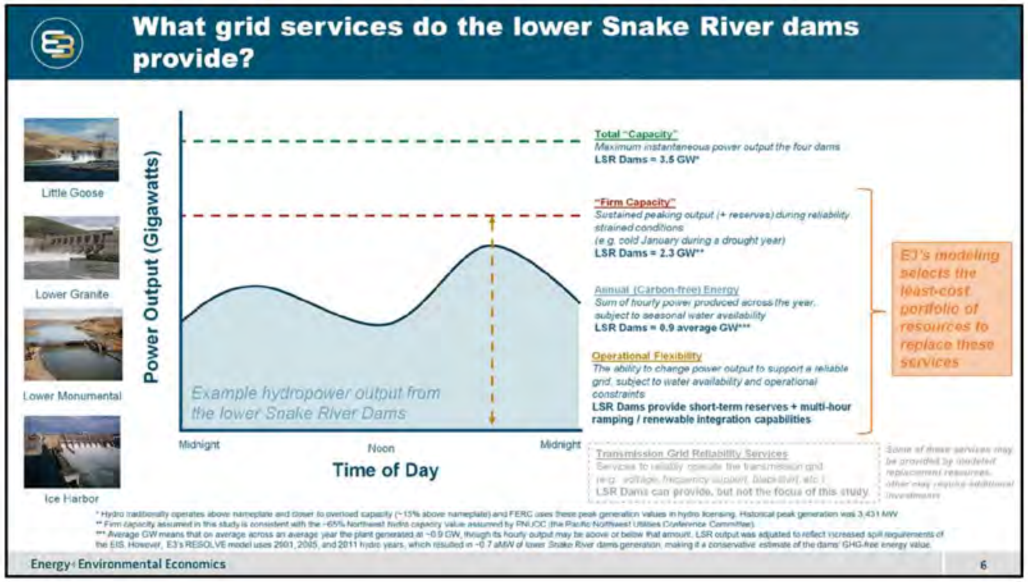
Plant	Total Capacity (MW)
Lower Granite	930
Little Goose	930
Lower Monumental	930
Ice Harbor	693

Total = 3,483 MW



Energy+Environmental Economics

Study Approach



What grid services do the lower Snake River dams provide?

Total "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 = 2.3 GW**

Annual (Carbon-free) Energy
Sum of hourly power produced across the year, subject to seasonal water availability
LSR Dams = 0.9 average GW***

Operational Flexibility
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

Transmission Grid Reliability Services
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

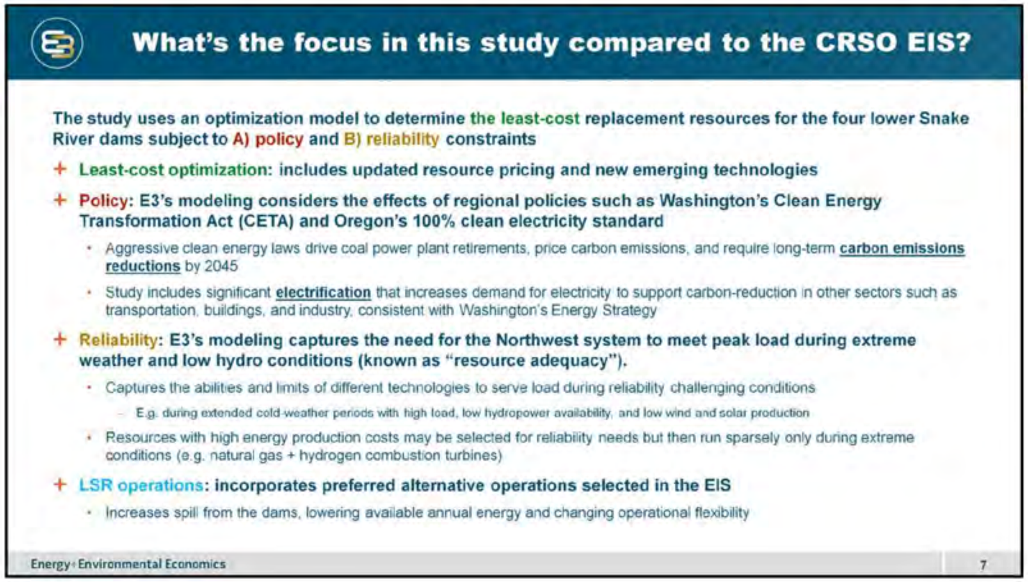
* Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. Historical peak generation was 3,431 MW

** 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.

Energy+Environmental Economics

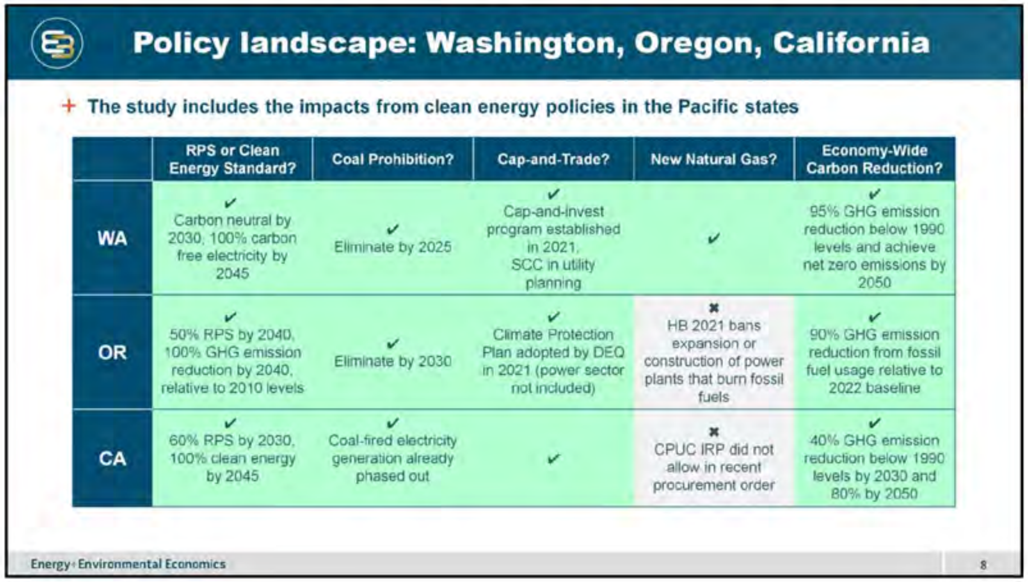
6



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

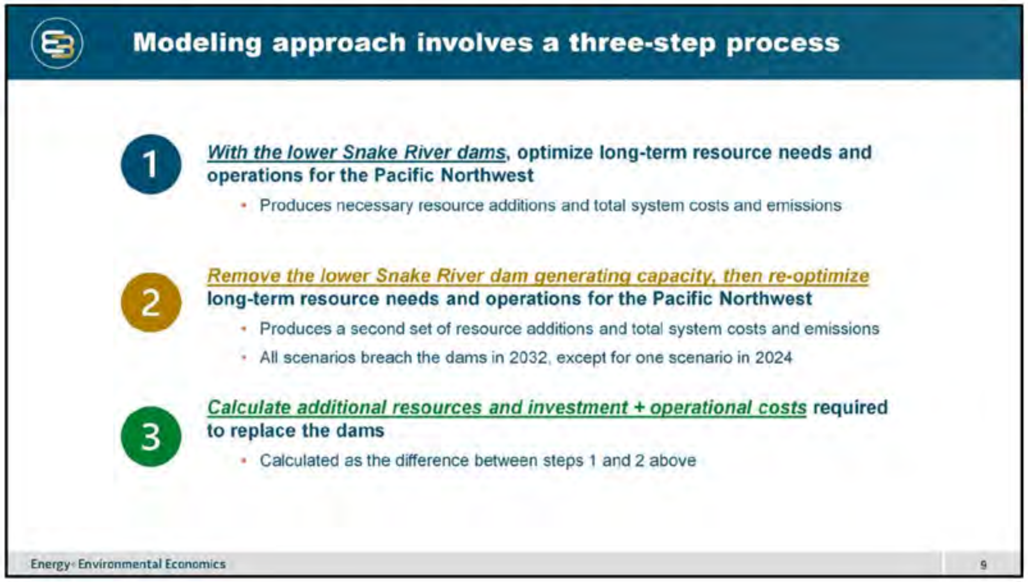
- **Least-cost optimization: includes updated resource pricing and new emerging technologies**
- **Policy: E3's modeling considers the effects of regional policies such as Washington's Clean Energy Transformation Act (CETA) and Oregon's 100% clean electricity standard**
  - Aggressive clean energy laws 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



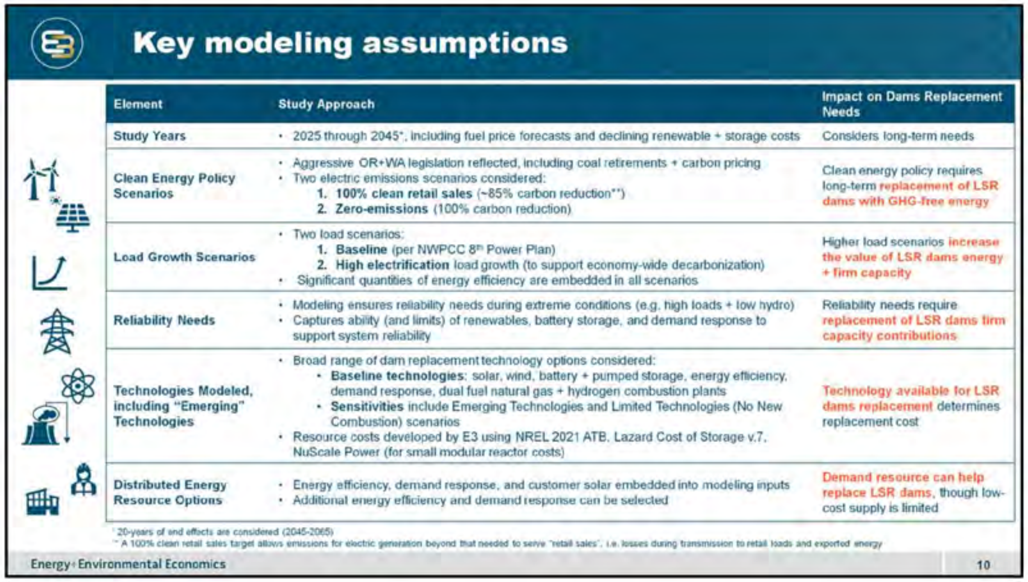
Modeling approach involves a three-step process

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

Energy+Environmental Economics

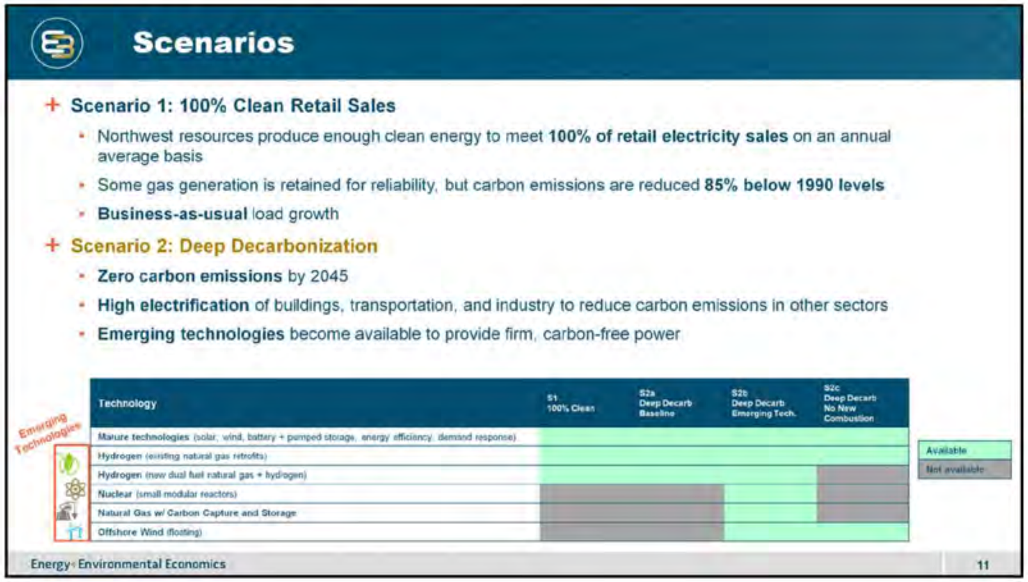


Key modeling assumptions

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)	🟩	🟩	🟩	🟩
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

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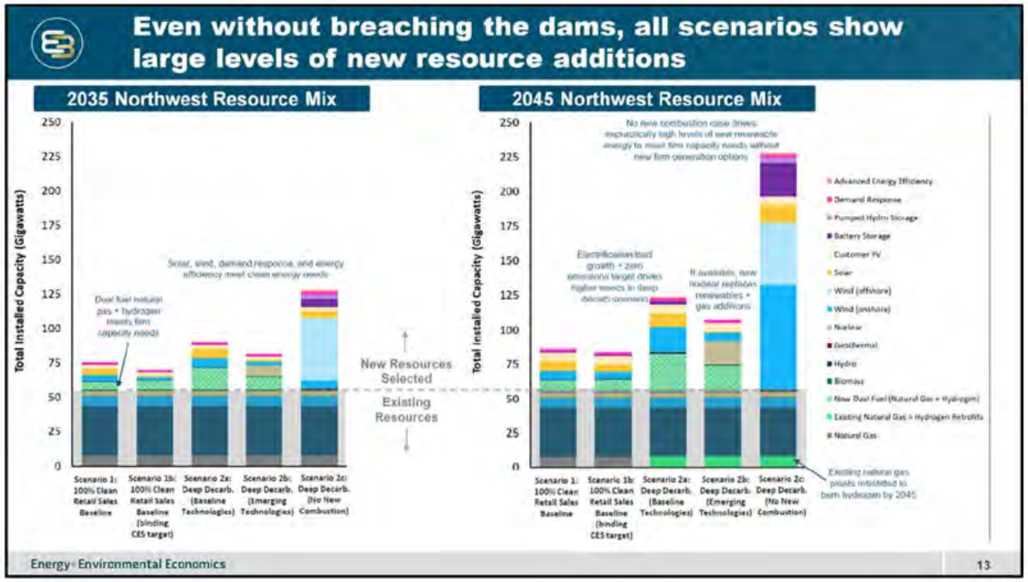
Northwest Resource Needs in Scenarios With the Lower Snake River Dams



Even without breaching the dams, all scenarios show large levels of new resource additions

2035 Northwest Resource Mix

Dual fuel natural gas + hydrogen meets firm capacity needs

Solar, wind, demand response, and energy efficiency meet clean energy needs

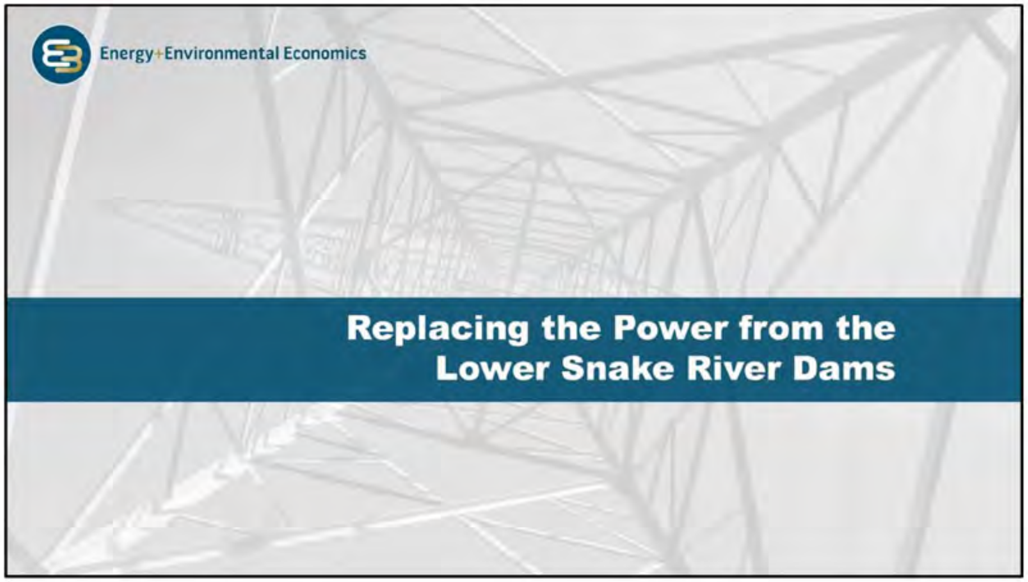
2045 Northwest Resource Mix

No new combustion case drives impractically high levels of new renewable energy to meet firm capacity needs without new firm generation options

Electrification load growth + zero emissions target drives higher needs in deep decarb scenarios

If available, new nuclear replaces renewables + gas additions

Existing natural gas plants retrofitted to burn hydrogen by 2045



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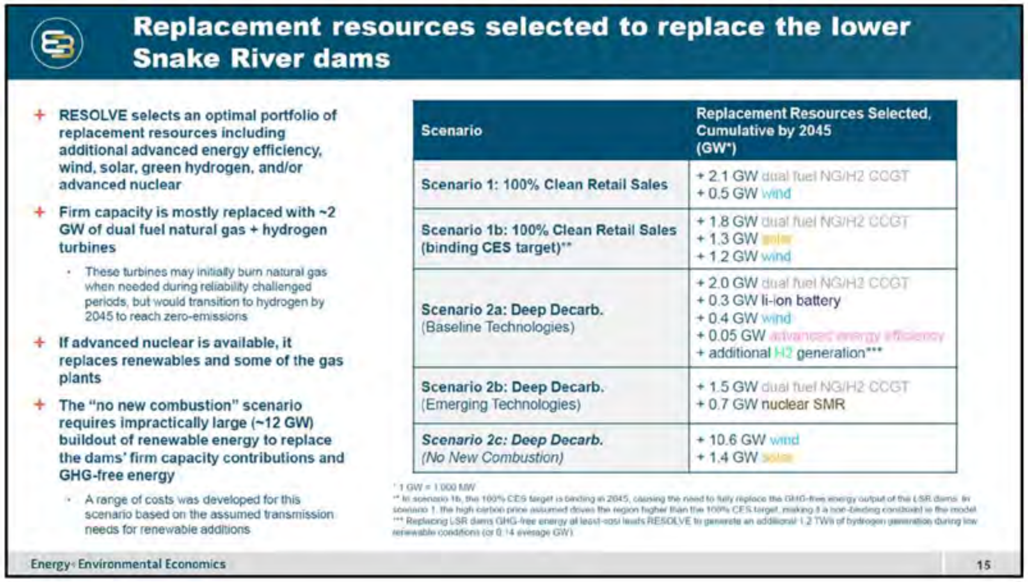
Replacing the Power from the Lower Snake River Dams



Replacement resources selected to replace the lower Snake River dams

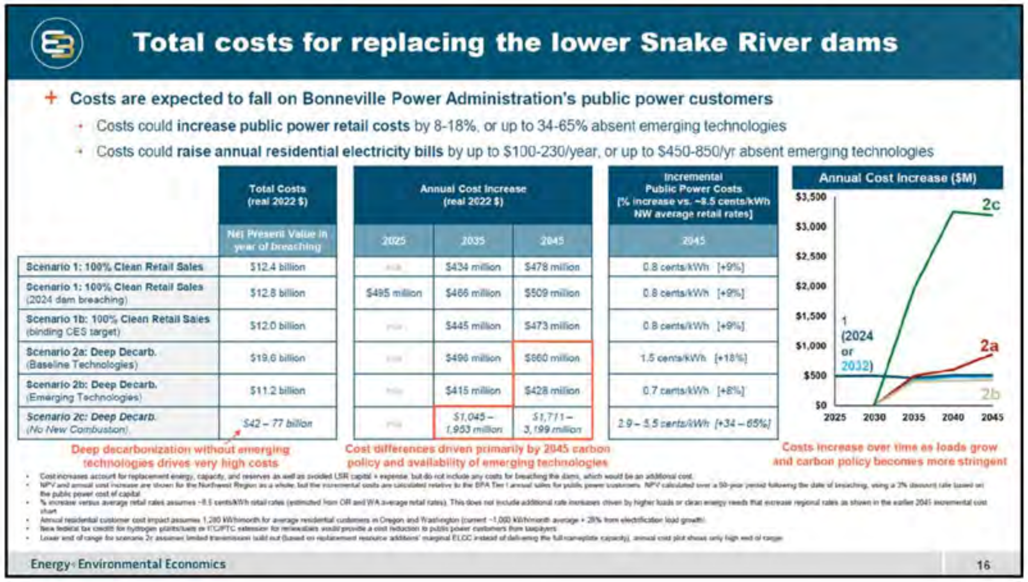
- **RESOLVE selects an optimal portfolio of replacement resources including additional advanced energy efficiency, wind, solar, green hydrogen, and/or advanced nuclear**
- **Firm capacity is mostly replaced with ~2 GW of dual fuel natural gas + hydrogen turbines**
  - These turbines may initially burn 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**
  - A range of costs was developed for this scenario based on the assumed transmission needs for renewable additions

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 1b: 100% Clean Retail Sales (binding CES target)**	+ 1.8 GW dual fuel NG/H2 CCGT + 1.3 GW solar + 1.2 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

** In scenario 1b, the 100% CES target is binding in 2045, causing the need to fully replace the GHG-free energy output of the LSR dams. In scenario 1, the high carbon price assumed drives the region higher than the 100% CES target, making it a non-binding constraint in the model

*** 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 34-65% absent emerging technologies
  - Costs could **raise annual residential electricity bills** by up to $100-230/year, or up to $450-850/yr absent emerging technologies

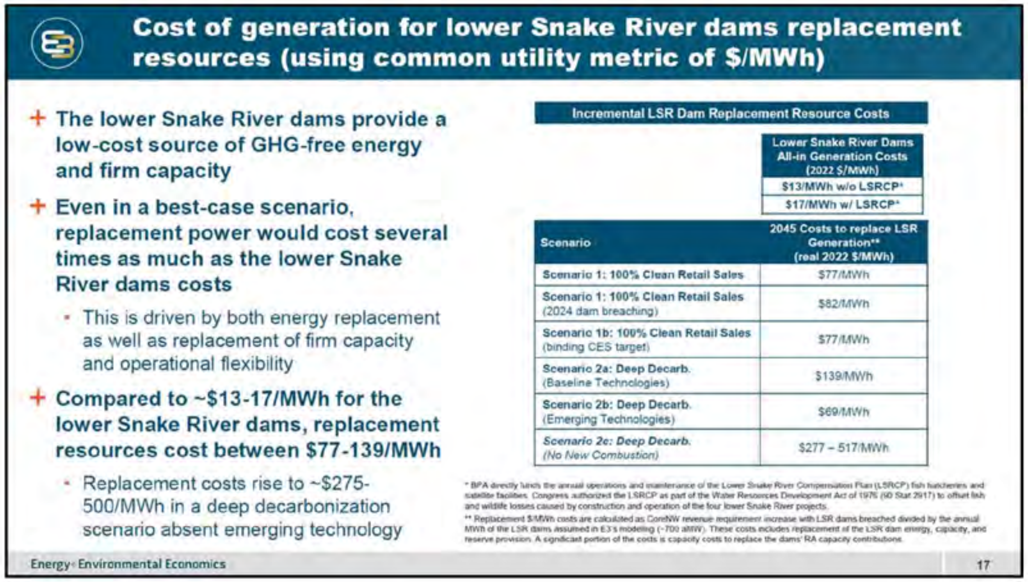
	Total Costs (real 2022 $)	Annual Cost Increase (real 2022 $)			Incremental Public Power Costs [% increase vs. ~8.5 cents/kWh NW average retail rates]
	Net Present Value in year of breaching	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$12.4 billion	n/a	$434 million	$478 million	0.8 cents/kWh [+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 1b: 100% Clean Retail Sales (binding CES target)	$12.0 billion	n/a	$445 million	$473 million	0.8 cents/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$19.6 billion	n/a	$496 million	$860 million	1.5 cents/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$11.2 billion	n/a	$415 million	$428 million	0.7 cents/kWh [+8%]
Scenario 2c: Deep Decarb. *(No New Combustion)*	*$42 – 77 billion*	n/a	*$1,045 – 1,953 million*	*$1,711 – 3,199 million*	*2.9 – 5.5 cents/kWh [+34 – 65%]*

Deep decarbonization without emerging technologies drives very 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
- Lower end of range for scenario 2c assumes limited transmission build out (based on replacement resource additions' marginal ELCC instead of delivering the full nameplate capacity); annual cost plot shows only high end of range



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 ~$275-500/MWh in a deep decarbonization scenario absent emerging technology

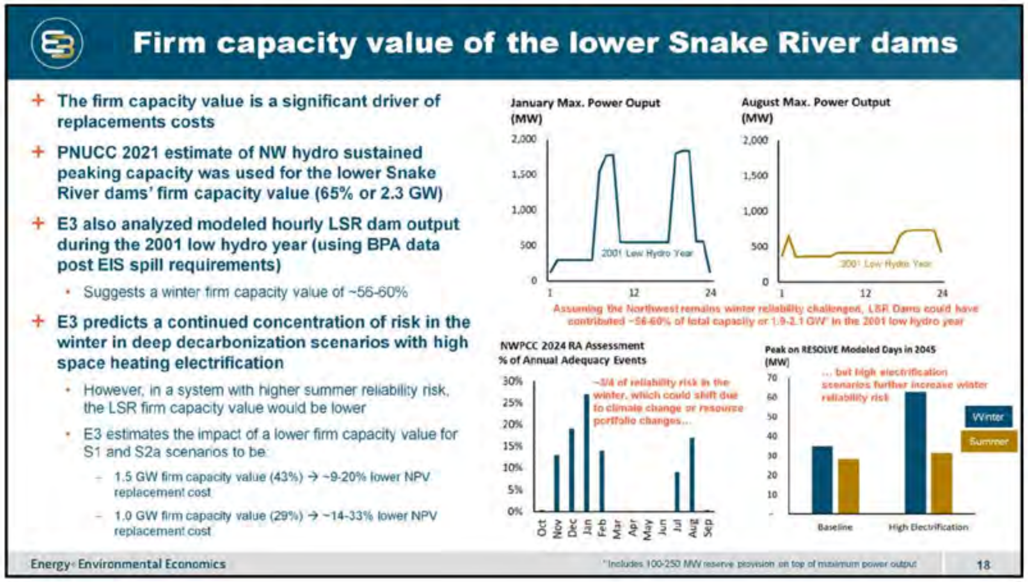
Incremental LSR Dam Replacement Resource Costs

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)
Scenario 1: 100% Clean Retail Sales	$77/MWh
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$82/MWh
Scenario 1b: 100% Clean Retail Sales (binding CES target)	$77/MWh
Scenario 2a: Deep Decarb. (Baseline Technologies)	$139/MWh
Scenario 2b: Deep Decarb. (Emerging Technologies)	$69/MWh
Scenario 2c: Deep Decarb. *(No New Combustion)*	$277 – 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

Assuming the Northwest remains winter reliability challenged, LSR Dams could have contributed ~56-60% of total capacity or 1.9-2.1 GW* in the 2001 low hydro year

~3/4 of reliability risk in the winter, which could shift due to climate change or resource portfolio changes…

… but high electrification scenarios further increase winter reliability risk

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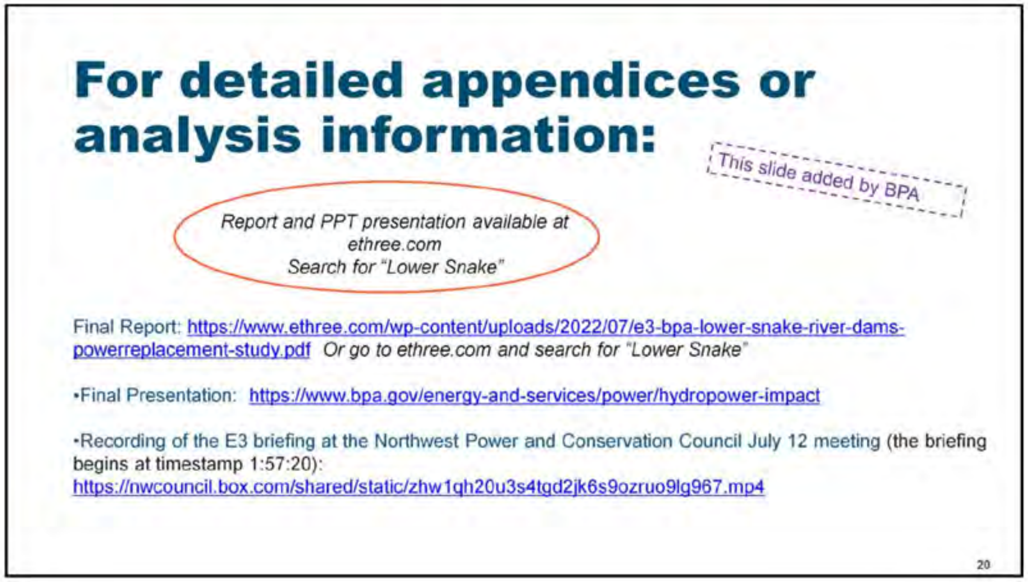
*Includes 100-250 MW reserve provision on top of maximum power output

Key conclusions

1. **Replacing the four lower Snake River dams comes at a substantial cost, even assuming emerging technologies are available**
   - Require 2,300 – 4,300 MW of replacement resources
   - An annual cost of $415 million – $860 million by 2045*
   - Total net present value replacement cost of $11.2 – 19.6 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 ($42-77 billion NPV cost)

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



For detailed appendices or analysis information:

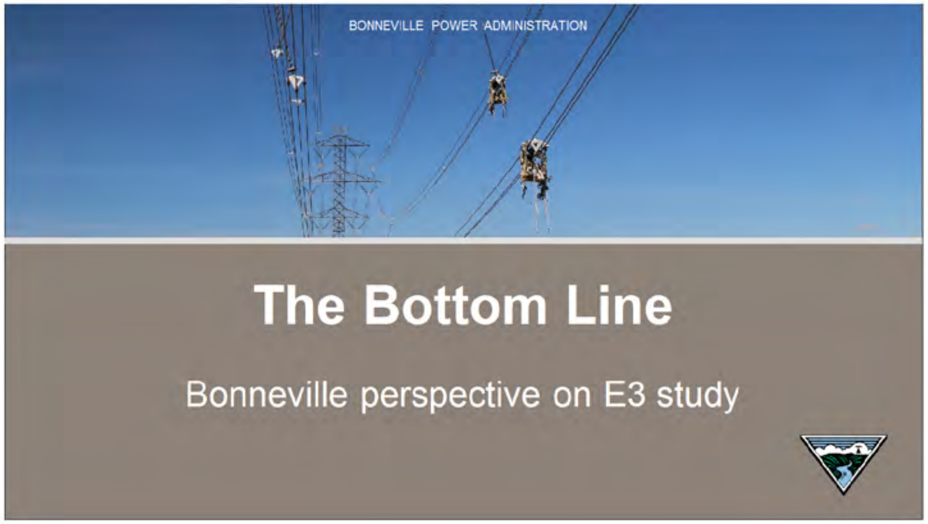
This slide added by BPA

Report and PPT presentation available at
ethree.com
Search for "Lower Snake"

Final Report: https://www.ethree.com/wp-content/uploads/2022/07/e3-bpa-lower-snake-river-dams-powerreplacement-study.pdf *Or go to ethree.com and search for "Lower Snake"*

- Final Presentation: https://www.bpa.gov/energy-and-services/power/hydropower-impact

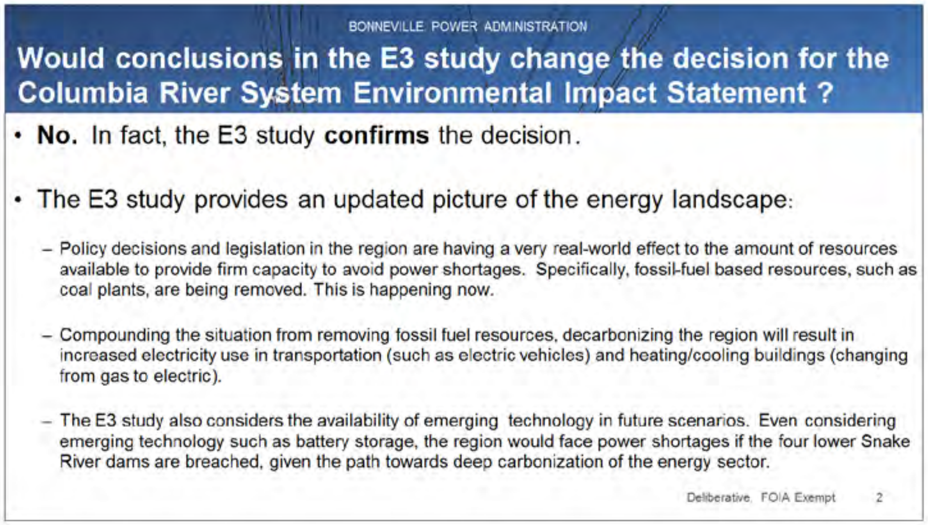
- Recording of the E3 briefing at the Northwest Power and Conservation Council July 12 meeting (the briefing begins at timestamp 1:57:20): https://nwcouncil.box.com/shared/static/zhw1qh20u3s4tgd2jk6s9ozruo9lg967.mp4



BONNEVILLE POWER ADMINISTRATION

The Bottom Line

Bonneville perspective on E3 study



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

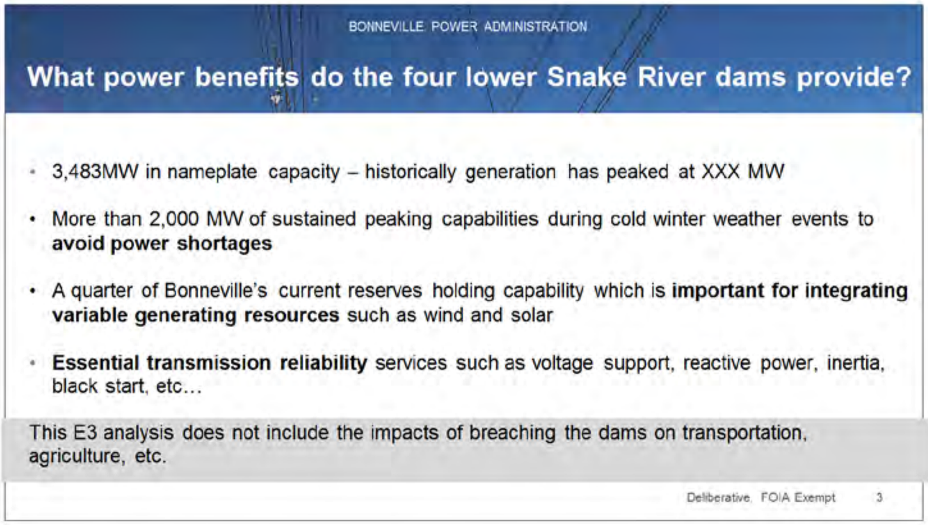
- **No.** In fact, the E3 study **confirms** the decision.

- 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.



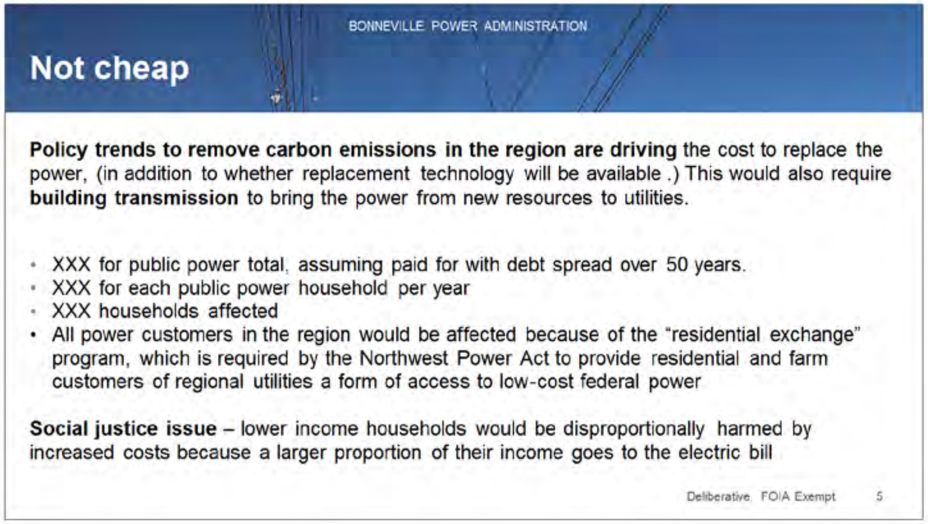
BONNEVILLE POWER ADMINISTRATION

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

- 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…

This E3 analysis does not include the impacts of breaching the dams on transportation, agriculture, etc.

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



Not cheap

Policy trends to remove carbon emissions in the region are driving the cost to replace the power, (in addition to whether replacement technology will be available .) This would also require **building transmission** to bring the power from new resources to utilities.

- 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
- All power customers in the region would be affected because of the "residential exchange" program, which is required by the Northwest Power Act to provide residential and farm customers of regional utilities a form of access to low-cost federal power

Social justice issue – lower income households would be disproportionally harmed by increased costs because a larger proportion of their income goes to the electric bill

Not fast

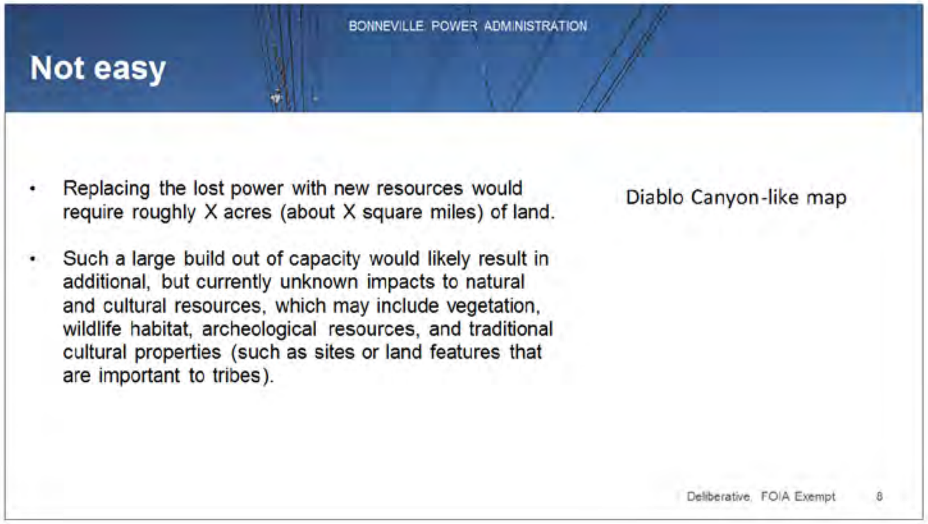
- Up to XXX years total
  - XXX for Congressional approval
  - XXX to replace the capacity resources
  - XXX to build transmission, which includes providing compliance with the National Environmental Policy Act, siting, permits, etc.

Placeholder for Congressional logo/seal

Not easy

- Policy requirements to reduce emissions is removing resources fossil fuel resources from the grid. Consequently, with retiring coal and gas plants, the region is ***already*** facing resource adequacy issues.
- 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.**

Placeholder for graphic showing coal retirements



BONNEVILLE POWER ADMINISTRATION

Not 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, which may include vegetation, wildlife habitat, archeological resources, and traditional cultural properties (such as sites or land features that are important to tribes).

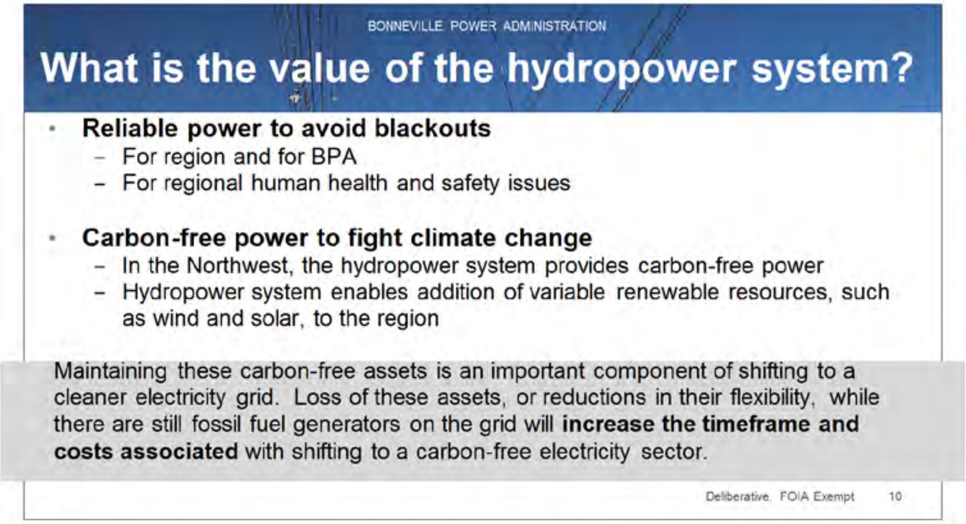
Diablo Canyon-like map

Not easy

- 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
  - 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.

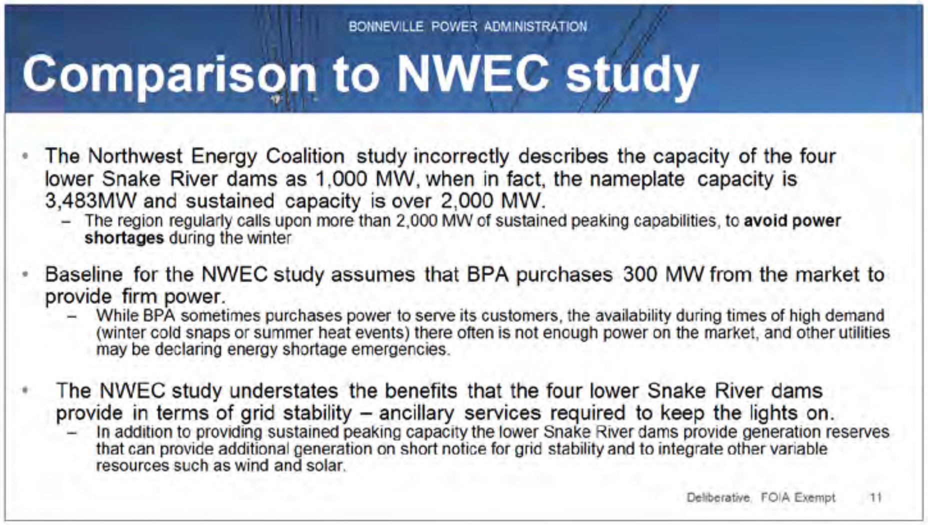


What is the value of the hydropower system?

- **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

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.



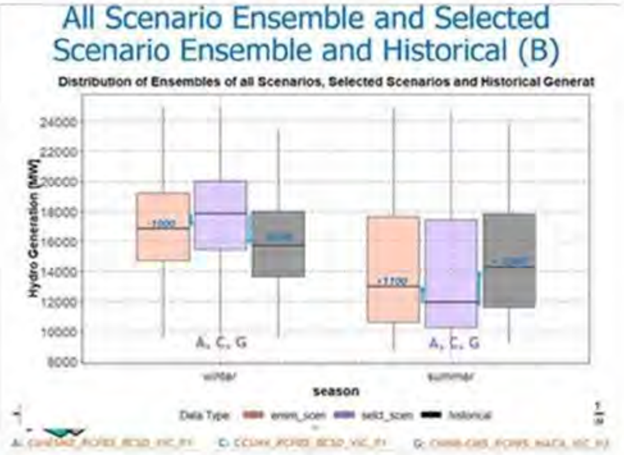
Comparison to NWEC study

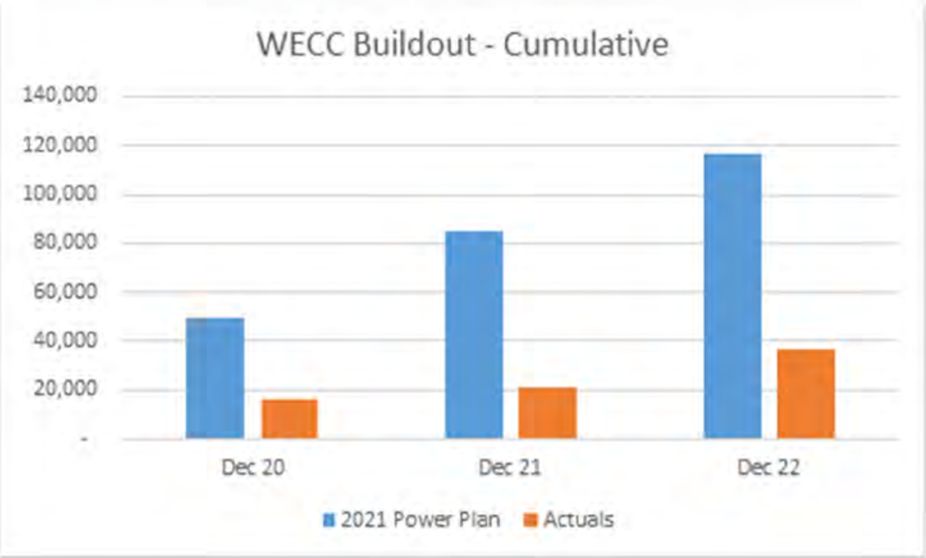
- The Northwest Energy Coalition study incorrectly describes the capacity of the four lower Snake River dams as 1,000 MW, when in fact, the nameplate capacity is 3,483MW and sustained capacity is over 2,000 MW.
  - The region regularly calls upon more than 2,000 MW of sustained peaking capabilities, 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: Diffely,Robert J (BPA) - PGPL-5
Sent: Friday, July 1, 2022 1:37 PM
To: Aaron Burdick; James,Eve A L (BPA) - PG-5; Arne Olson
Cc: Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

I share your concerns about how they were set up. The three climate change scenarios that they picked (purple) don't underlie the distribution of RMJOC19(orange) (+1,000 aMW in winter and -1,000 aMW lower summer generation (first graph below)). They are also using 4.8 MAF (18% more) of storage than what is in Hysdim and unrealistic peaking operations. The second chart below is the renewable buildout in the plan and how they compare with actuals (this effects imports and power prices). But, I will leave it to your professional judgement (and independence).





From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, July 1, 2022 1:25 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>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Subject: [EXTERNAL] RE: Draft Exec Summary

Deliberative, FOIA exempt

The new Genesys run is the (not so new anymore) runs they did last year that showed lower regional risk and shifted risk to the summer under climate change and new regional import/export scenarios. We (and many others) have some reservations about how these were set up, but we are aware of utilities in the region using them for their own reliability analyses (and these analyses may show higher storage ELCCs than we saw in our winter challenged RECAP analysis, hence the benefits of showing this sensitivity).

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 30, 2022 3:01 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>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Hi Aaron-

We typically use a 50-year NPV analysis for hydro projects and seems most consistent with other analysis. Ultimately, it should be tied to the useful life of the LSR dams which extends beyond the study timeframe. Just curious on the new Genesys run you refer to- is that from the Energy GPS study or the Council?

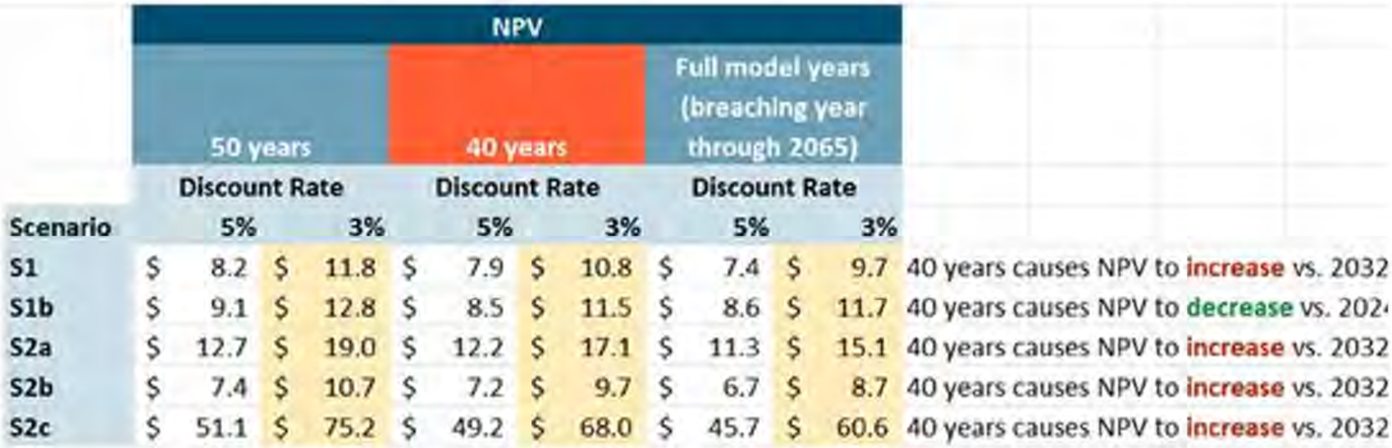
I also think if you have time to add the storage ELCC sensitivity that might help address some of the feedback from the DOE review.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 30, 2022 1:16 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

Ok, hopefully the last question before we finalize the NPV values. We were previously using the year of breaching to the end of the RESOLVE modeling horizon (2045 + 20 years of end effects, ie 2065). We calculated NPVs instead using 40 years or 50 years, e.g. 40 years would be 2024-2064 or 2032-2072 (we extend the 2045 RESOLVE modeled year out as far as needed to do this). The results are below. I'll note that the Inslee/Murray report uses a 50-year timeline for its NPV calculation.

Can you review the table below and advise thoughts on using 40 years vs. 50 years for the NPV calculation? We think either of those is better than the current approach, that ends up using a different number of years for the 2024 breaching case, driving an artificial difference between S1 an S2b. All values below are 2022$ billion.



	NPV						
	50 years		40 years		Full model years (breaching year through 2065)		
	Discount Rate		Discount Rate		Discount Rate		
Scenario	5%	3%	5%	3%	5%	3%	
S1	$ 8.2	$ 11.8	$ 7.9	$ 10.8	$ 7.4	$ 9.7	40 years causes NPV to increase vs. 2032
S1b	$ 9.1	$ 12.8	$ 8.5	$ 11.5	$ 8.6	$ 11.7	40 years causes NPV to decrease vs. 202
S2a	$ 12.7	$ 19.0	$ 12.2	$ 17.1	$ 11.3	$ 15.1	40 years causes NPV to increase vs. 2032
S2b	$ 7.4	$ 10.7	$ 7.2	$ 9.7	$ 6.7	$ 8.7	40 years causes NPV to increase vs. 2032
S2c	$ 51.1	$ 75.2	$ 49.2	$ 68.0	$ 45.7	$ 60.6	40 years causes NPV to increase vs. 2032

I should also note that the Energy GPS study seems to use no discounting at all (just a 2% inflation adjustment), which could lend itself to critique of over-inflation of the NPV values. Something to be aware of when comparing the numbers.

Note: the other thing we plan to add to the report is a sensitivity using higher storage ELCCs (that are more aligned with the latest GENESYS runs showing higher summer vs. winter risk). That sensitivity showed that more storage gets built to displace gas additions, but it shows basically no change in the replacement resources and costs for the LSR dams. This basically shows that you could add some short duration storage to push the risk back into the winter (since we did not lower the LSR dam contributions assuming the risk stays in the summer long term). We saturate battery storage either way (i.e. either at 2 GW or 10 GW) and need alternative resources to cost effectively replace the dams capacity. It's a fairly rough sensitivity (we only adjusted storage ELCCs), but directionally provides some good validation that storage can't replace the dams in context of the broader regional needs… We're working to add – **let us know if you have any thoughts on this**.

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 30, 2022 6:58 AM
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

Thanks Aaron- I was following up on a highlighted section in the report about the public power cost of capital and this is in closer alignment with what the 2022 WACC for BPA uses in planning which is 2.81%. Using 3% will be much closer to what we use and closer to how other reports are calculating the discount rates and our assumptions.

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

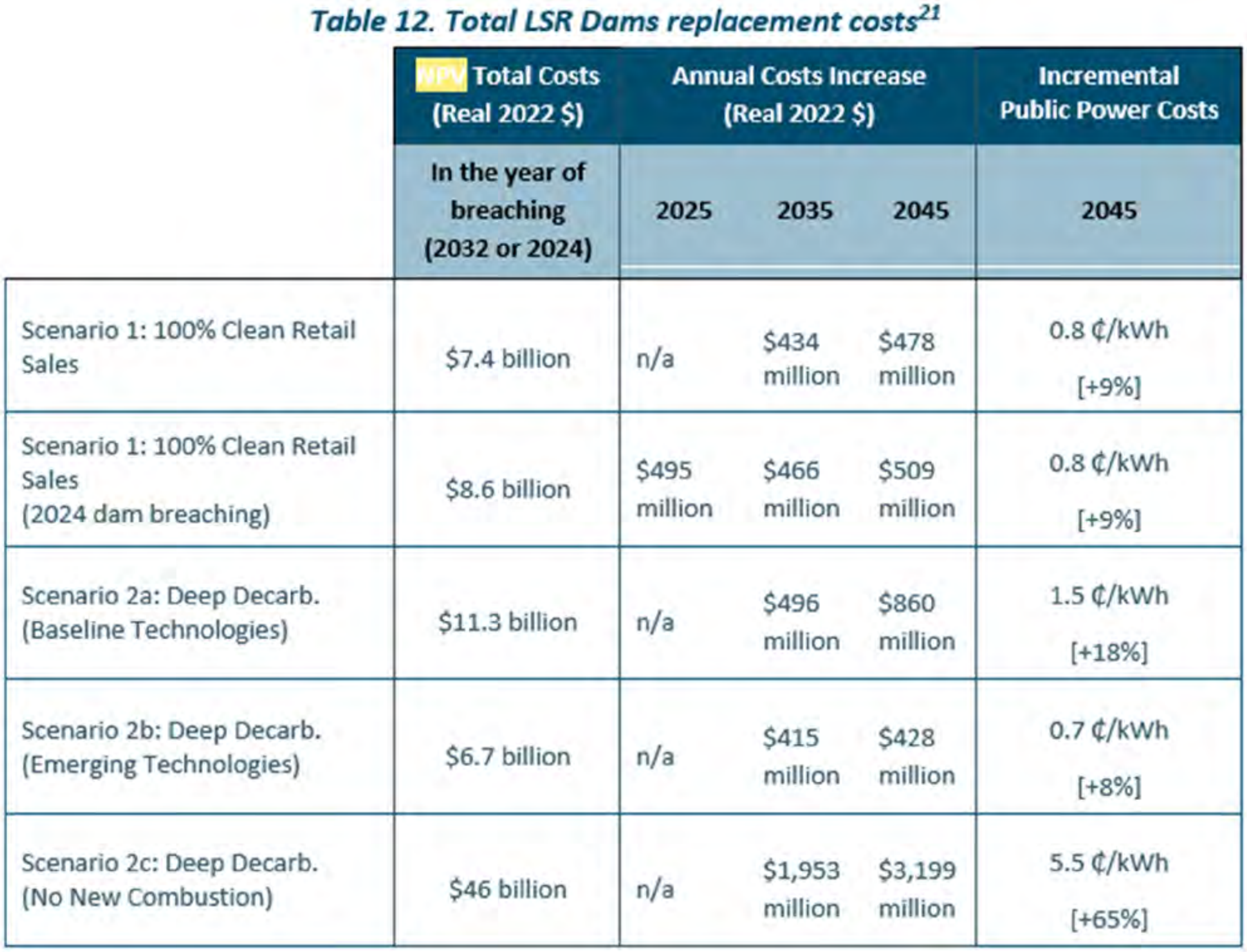


Table 12. Total LSR Dams replacement costs[21]

	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.

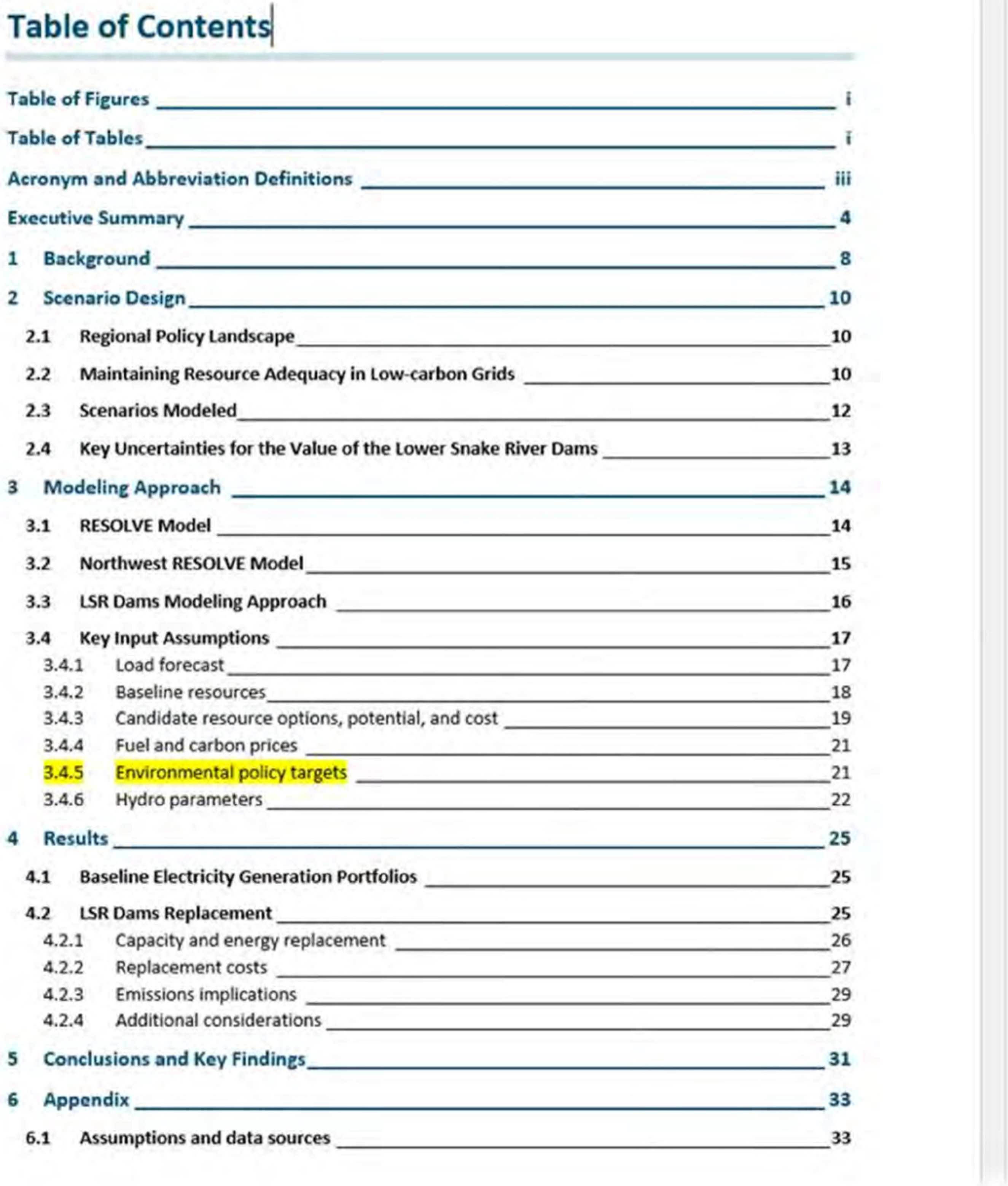


Table of Contents

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: Friday, May 27, 2022 5:25 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_PublicSummary_052722.pdf

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

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

Join meeting

More ways to join:

Join from the meeting link

https://mybpa.webex.com/mybpa/j.php?MTID=m90c20a2372398102deac9a0e3860f270

Join by meeting number

Meeting number (access code): (b)(6)

Meeting password: 5UKeHJ2kK@2

Tap to join from a mobile device (attendees only)

+1-415-527-5035,(b)(6) ## US Toll

Join by phone

+1-415-527-5035 US Toll

Global call-in numbers

Join from a video system or application

Dial (b)(6) @mybpa.webex.com

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

From: Arne Olson <arne@ethree.com>
Sent: Monday, July 25, 2022 6:38 PM
To: Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5
Cc: Aaron Burdick
Subject: [EXTERNAL] FW: Clearing Up, Issue 2065
Attachments: CUp2065.pdf

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.

-----Original Message-----
From: NewsData <newsdata@newsdata.com>
Sent: Friday, July 22, 2022 4:26 PM
To: Subscriptions <subscriptions@ethree.com>
Subject: Clearing Up, Issue 2065

You can access this week's issue of Clearing Up on the Web or as a PDF...or both!

For the online version of Clearing Up, go to:

https://www.newsdata.com/clearing_up/

As a subscriber you have full access to digital content allowed by your subscription, once you've completed a simple registration process. Please visit https://www.newsdata.com/tutorial-create-a-login/video_bbd2af52-d02c-11e9-adfe-3fc4ba234b3c.html for information on how to register.

The Clearing Up website also features archives of past issues and links to other NewsData news and information services.

Attached to this email is the latest Clearing Up in Adobe Acrobat file format. The issue number is indicated in the subject line of this email.

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From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, July 11, 2022 5:13 PM
To: Koehler,Birgit G (BPA) - PG-5; Arne Olson
Cc: James,Eve A L (BPA) - PG-5
Subject: [EXTERNAL] RE: urgent, more swirl, maybe release this afternoon
Attachments: E3 BPA LSR Dams_071122.pdf; E3 BPA LSR Dams_071122.pptx

Final deck is attached in PPT and PDF. Note that we made another small change to the NPV calculations that had a minor impact (corrected an interpolation error) to raise the NPVs slightly across the cases. These will be the final values.

Thanks,
Aaron

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, July 11, 2022 4:25 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

We have a little time.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, July 11, 2022 4:24 PM
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>
Subject: [EXTERNAL] RE: urgent, more swirl, maybe release this afternoon

Working on a few more edits on the PPT, should send something shortly. Final report will have to come later tonight.

From: Aaron Burdick
Sent: Monday, July 11, 2022 3:31 PM
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>
Subject: RE: urgent, more swirl, maybe release this afternoon

Confirmed. Working on the final PPT now, shooting for 4pm. Report may take a little longer into the evening. Will send when it's completed.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, July 11, 2022 3:19 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

So, for final versions

Report

- your late edits to scenario 1 and 2c
- without second paragraph about irrigation, navigation, etc under "Other consideration" on p 37 (might be an earlier page in Word than in PDF)
- no watermark

PPt

- your late edits to scenario 1 (and 2c)
- no watermark

To be released at 6 am Pacific time. I don't know my hard deadline for this, but 4 pm would certainly work

---

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, July 11, 2022 2:56 PM
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>
Subject: [EXTERNAL] RE: urgent, more swirl, maybe release this afternoon

Sending embargoed PDF now. 2c cost range added (now $40-75B). We will make the other update (adding scenario 1B) by 4pm and resend. So, this version should not get released, but the 4pm version will be the one to release.

Aaron

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, July 11, 2022 2:07 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: RE: urgent, more swirl, maybe release this afternoon

OK, here's the story:
A Salmon "Science" paper is going to a Congressional staff briefing at 6 pm EASTERN i.e. less than an hour, and DOE&BPA want the E3 study to be there too. Both will be discussed without BPA or E3 present. So we want the document info there at least.

Plan.
Keep paper as is except
P. 37 delete paragraph
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]

Need a PDF with watermark "Embargoed until 6:00 am on July 12, 2022"
Need another copy (can follow) without the embargo

PPT, I have the latest copy that we would have presented last week, but for best version control, feel free to send me a new copy
Also need one PDF with "embargoed…" And one without

From: Koehler,Birgit G (BPA) - PG-5
Sent: Monday, July 11, 2022 1:52 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: RE: urgent, more swirl, maybe release this afternoon

This is looking likely. Can you reply that you have received my email?

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

40th ANNIVERSARY NEWSDATA

CLEARING UP

Energy and Utility News
for the Pacific
Northwest and
Western Canada

NewsData LLC, Seattle & San Francisco: July 22, 2022 • No. 2065

The Week In Summary

[1] Studies Find Wide Range of Transmission Costs for Offshore Oregon Wind

A trio of studies finds a wide range of costs could be associated with integrating southern Oregon offshore wind generation into BPA's transmission system. A study by the National Renewable Energy Laboratory says BPA's system could take on 2.6 GW of offshore wind without upgrades, while Bonneville says 2 GW will cost $905 million and a recent consultant's study puts the price tag at between $2 billion and $3 billion. ***At [10], the debate over the costs of developing onshore versus offshore wind begins.***

[2] Federal Judge Tells Talen to Produce Plan to Close or Operate Colstrip

A federal bankruptcy judge has told Talen Energy Supply that it needs to come up with a plan for the future of the Colstrip coal-fired power plant in Montana. The judge also said the four Pacific Northwest co-owners wanting a reasonable option for exiting by 2025 cannot be held captive while Talen grapples with its debt. ***At [12], Talen must submit the plan by Aug. 11.***

[3] NOAA Scientist Says Habitat is Key in Lower Snake River Dam Breaching Debate

With all the talk about removing dams, NOAA Fisheries scientist Lisa Crozier worries that habitat restoration isn't getting the attention it needs. In a recent webinar, she outlined the reasons that restoring tributary and estuary habitat is a critical piece of salmon and steelhead recovery in the Snake River, especially in light of climate change. ***At [13], could restoration benefits offer faster and more measurable results too?***

[4] Energy Regulators Highlight Importance of Interregional Transmission

Federal energy regulators are focusing on building new interregional electric transmission infrastructure even though previous efforts have fallen short, while states seek a new planning process that increases reliability as energy shortages grow more and more likely. Those were themes at a July 20 joint federal-state task force meeting. ***At [15], clear interregional need, but hard to get there.***

[5] Idaho Power's Study Points to Slashing Net-Metering Payments

A study filed by Idaho Power represents a major step forward in the utility's years-long effort to reduce the payments it makes to customers for excess energy from on-site generation. It also sidesteps the issue of paying for the generation's environmental attributes, saying Idaho Power is under no state mandate to do so and can't monetize the attributes in any event. ***The study doesn't make recommendations, but presents alternative valuation methodologies that would slash export credit rates in half, at [11].***

Inside

Energy alphabet soup got you confused?
Click here for a list of acronyms we use.

Opinion & Perspectives

Price Report

Hot Weather Ignites Regional Prices
Details on Page 4.

Energy Jobs Portal

Go to www.EnergyJobsPortal.com for the latest in regional energy career opportunities.

[6] Murray-Inslee Report Comments Differ on Dams' Value

The debate over removing the four lower Snake River dams continued in comments to a draft report prepared for Sen. Patty Murray (D-Wash.) and Washington Gov. Jay Inslee. Some said the report didn't capture what's at stake if the dams are removed, while others pointed to what's at stake if they're not. ***At [14], Clearing Up offers a quick review.***

[7] POTOMAC: Biden Signs Exec Actions After Manchin Sinks Climate Agenda

Sen. Joe Manchin (D-W.V.) came in for a round of scorn after he scuttled climate and energy provisions last week proposed for a filibuster-exempt budget bill. Meanwhile, President Joe Biden moved forward with executive actions that chipped away at the loss, with a promise for more, perhaps including declaring a "climate emergency." ***At [16], U.S. Postal Service beefs up proposed electric vehicle purchase after criticism of plans.***

Briefs

[8] Conservation Groups Ask Regulators to Overturn Rosebud Mine Expansion

Environmental advocates want the Montana Board of Environmental Review to reverse the state-approved expansion of the Rosebud coal mine, which is the sole fuel supplier for the adjacent Colstrip power plant.

In the past year, the advocacy groups, represented by Earthjustice, have successfully blocked two other expansions in state and federal courts.

The Montana Environmental Information Center and the Sierra Club argue in their June 27 appeal that the Montana Department of Environmental Quality didn't thoroughly consider the expansion's potential effect on water quality and didn't require an adequate buffer for affected streams.

They also contend that the MDEQ should have considered how climate change likely will affect the area's hydrology.

In May, the department approved expanding the Rosebud mine by just over 9,000 acres. The expansion gives the mine's owner, Westmoreland Rosebud Mining, access to an estimated additional 62 million tons of coal and was the third expansion approved by the state in recent years.

State regulators must determine that expanded mining, along with previous and current activity, will not significantly harm water quality in affected areas. The state's analysis was too narrow and failed to consider current and past mining, the groups say in their appeal, which was filed June 27.

In the past year, MEIC, Sierra Club and other conservation groups have won two challenges to other Rosebud expansions by arguing that regulators failed to adequately consider the effects on water quality.

In one of these rulings, in October, a state district judge reversed MDEQ's approval of a 300-acre expansion and ordered the agency to review the application again *[DV 19-34]*. The mine owner and state agencies have challenged the decision before the state Supreme Court *[DA 22-0064]*.

In the other decision, in November, a federal magistrate ruled that federal regulators had illegally approved a roughly 6,500-acre expansion of the mine *[CV 19-130]*. ***[Dan Catchpole]***

[8.1] Western Markets Exploratory Group Nearly Doubles in Size

The Western Markets Exploratory Group has grown to 25 members serving 16 million customers, after 11 utilities joined the group, WMEG announced July 21 in a statement.

The group is evaluating a staged approach to organized regional market structures that can benefit customers and help participants meet carbon emission-reduction goals.

That pathway could be "up to and including operating as a regional transmission organization," it said.

Six of the new members are from the Northwest—BPA, Avista, NorthWestern Energy, Tacoma Power, and Chelan and Grant county PUDs.

The other five are Arizona Electric Power Cooperative, Balancing Authority of Northern California, El Paso Electric, Tri-State Generation and Transmission Association, and Western Area Power Administration.

They join the 14 existing members: Xcel Energy-Colorado, Black Hills Energy, Platte River Power Authority, Arizona Public Service, Tucson Electric Power, Salt River Project, Idaho Power, NV Energy, PacifiCorp, Portland General Electric, Puget Sound Energy, Public Service Company of New Mexico, Seattle City Light, and the Los Angeles Department of Water and Power.

In March, the group hired Kirkland, Wash.-based Utilicast, an energy consulting company, to help it evaluate expanding market services in the West, including day-ahead energy sales, transmission system expansion, and power supply and grid solutions, the group said in a news release at the time.

At least seven entities, including BPA and Avista, were contacted in May about joining WMEG (CU No. 2057 [9]).

Utilicast is expected to complete a road map by the end of summer, Idaho Power COO Adam Richins told Clearing Up in June. WMEG is "really just focused on the road map" right now and currently has no firm timelines or explicit goals beyond that, he added.

However, in its July 21 press release, the group said, "WMEG expects these work products will be available towards the end of 2022." ***[D. C.]***

[8.2] Avista Wildfire Prevention Measures Could Extend Some Outage Times

Avista on July 20 announced temporary changes to Washington and Idaho power-line operations in response to dry summer conditions and increasing wildfire danger in the region. The changes will help decrease the potential for sparking a wildfire when reenergizing a power line, the utility said.

During the current dry weather conditions, Avista's line personnel will physically patrol an outage area before a line is placed back into service, rather than allowing the action to occur automatically, as is typical in other circumstances.

While this can take more time to restore service, it decreases the potential fire danger, the company said, noting that it had employed this "dry-land mode" for over 20 years. This action was enhanced in 2020 by pairing it with fire-weather monitoring, which allows system operators and field managers to make more informed decisions to reduce fire risk.

The enhanced practice is part of the utility's 10-year wildfire resiliency plan, which also includes improving defense strategies such as "hardening" power lines and removing dead trees near lines. ***[R. A.]***

[8.3] Brief Mentions: News Roundup

NOAA Fisheries announced its recommendation to fund 19 programs totaling $95 million to help salmon and steelhead, awarded through the Pacific Coastal Salmon Recovery Fund. The recommendation includes $61 million to continue current programs and $34 million for new projects in California, Oregon, Washington, Idaho and Alaska using Infrastructure Investment and Jobs Act funding. Numerous state and tribal projects are proposed throughout the Northwest, including studies to reintroduce salmon above Chief Joseph and Grand Coulee dams, habitat projects compatible with the Columbia Basin Collaborative, and habitat restoration in the Klamath River.

A federal judge on July 7 granted a request by the Confederated Tribes of the Grand Ronde Community of Oregon to intervene in a lawsuit in U.S. District Court for the District of Oregon *[22-533]* filed by Portland General Electric seeking to acquire land at the base of Willamette Falls by eminent domain (CU No. 2058 [7.1]). Answering the complaint on July 14, the tribe denies that PGE is required by FERC to "own all lands," claiming instead only lands needed for construction, maintenance and operation of the project are required. The tribe also states that PGE did not identify the property as necessary to the project during relicensing.

The City Council in Bend, Ore., has proposed mandating the inclusion of a home energy score in the property listing of any single-family home put up for sale, citing estimates that residential energy use makes up 29 percent of the city's greenhouse gas emissions. The score—based on federal methodology and analytic tools—aims to quantify a structure's energy efficiency. The proposed ordinance requires the assessment be performed by a state-licensed home energy assessor. Milwaukie, Ore., a Portland suburb, began requiring home energy scores in 2020.

Jefferson County PUD, BPA and Pacific Seafood have reduced the company's lighting demand by 75 percent at its shellfish hatchery in the Quilcene, Wash. The hatchery is one of the biggest in the world and can produce more than 50 billion oyster larvae per year using high-powered grow lights in hoop houses. The PUD helped replace 241 1-kW halide bulbs with 250-watt LEDs using Energy Efficiency Incentive funding from BPA. The upgrade is expected to save more than 1 million kWh per year, Bonneville says. ***[C. U.]***

[8.4] CORRECTION: NEEA Spent $6.5 Million on Research, Analysis, Evaluation

A recent item (CU No. 2063 [5.2]) underreported what the Northwest Energy Efficiency Alliance spent on research, analysis and evaluation in 2021. It spent $6.5 million. We regret the error. ***[C. U.]***

Opinion & Perspectives

Bearing Down

[9] Renewable NW Responds to LSRD Power Replacement Study

SUMMARY: Sashwat Roy, technology and policy manager at Renewable Northwest, argues that the recent Energy and Environmental Economics study commissioned by BPA on replacing generation from lower Snake River dams relied on a modeling tool that didn't fully capture the value of existing renewables and battery storage, nor did it account for the impact of climate change on hydro generation and load.

BPA's study of optimal capacity expansion scenarios with and without the lower Snake River dams indicates a disregard for existing renewable and storage capacity resources vital to ensuring resource adequacy in the region, according to Renewable Northwest's analysis.

The Energy and Environmental Economics study portrays an alternate reality where only "firm or dispatchable" resources like natural gas-fired power plants and small modular nuclear reactors are able to replace the capacity provided by the LSRD. Hybrid and stand-alone storage projects (including long-duration storage resources) in conjunction with distributed energy resources and demand response mechanisms will be important complementary resources to BPA's hydro fleet in providing the necessary capacity and flexibility to the Pacific Northwest electric grid.

The modeling tool used, RESOLVE, does not account for the full value of hybrid and stand-alone storage resources. Rather than make decisions based on a one-year model, the RESOLVE model simulates the operations of WECC's system for 41 independent days sampled from the historical meteorological record from 2007-2009.

It is risky to assume that this abbreviated time series accurately captures the full intrayear variability of renewable resources and storage as well as that of the hydro system. Studies comparing different generation types typically rely on production-cost models that can run sequentially for 8,760 hours and can fully dispatch

Continued on page 5

Price Report

Hot Weather Ignites Regional Prices

Continuing high temperatures across the Western U.S. coupled with system constraints sent energy prices higher for another week.

Above-normal temperatures across California and the Desert Southwest drove up prices yet again, according to the U.S. Energy Information Administration. As an example, it said the daily high temperature in Phoenix stayed around 110 F for all but one day in its Wednesday-to-Wednesday report week.

Regional natural gas hubs gained between 77 cents and more than $2 in July 14 to July 21 trading. Seven hubs gained more than a dollar. Sumas natural gas' price rocketed from the lowest price in the region at $4.72/MMBtu, gaining $2.70 to end at $7.42/MMBtu. The hub price has been subject to variations based on recent increases in Canadian production and upstream flow capacity, the EIA noted.

A total of four hubs traded above $8/MMBtu. PG&E CityGate natural gas posted the highest regional price—$8.90/MMBtu. Alberta gas proved the exception, dropping 38 cents to $5.18/MMBtu by July 21.

Natural gas consumed for electric generation in California climbed week over week by 25 percent, or 0.5 Bcf per day, the EIA said. Total natural gas use in the Pacific Northwest, however, was "effectively flat" due to normal temperatures.

The EIA noted in its weekly report that Westcoast pipeline operator Enbridge posted a critical notice July 18 stating that it was curtailing pipeline flows at Station 4B South in inland British Columbia. This has reduced the amount of natural gas being conveyed to the U.S. border.

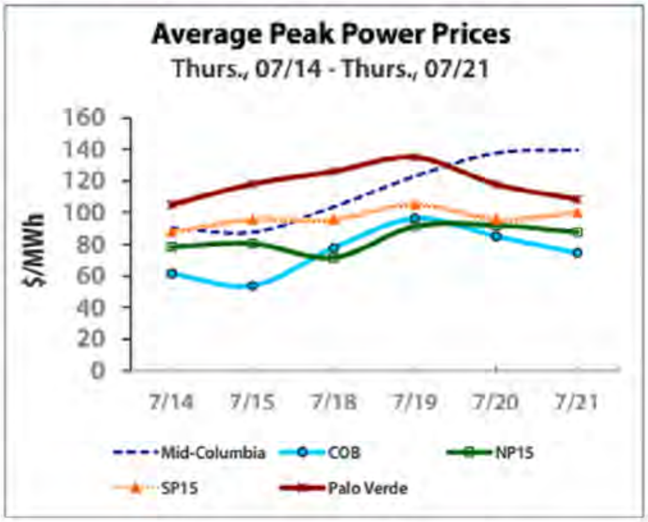
Southern California Gas on July 19 issued a curtailment watch for the SoCalGas and San Diego Gas & Electric service territories. The following day, the utility said the notice—which potentially affects customers in Riverside, Imperial and San Diego counties—remains in effect until further notice.

Low scheduled natural gas volumes in SoCalGas' Southern System precipitated the notice. Noncore customers could be required to either reduce or cease their natural gas use. In California, electric generators and industrial users are considered noncore natural gas customers.

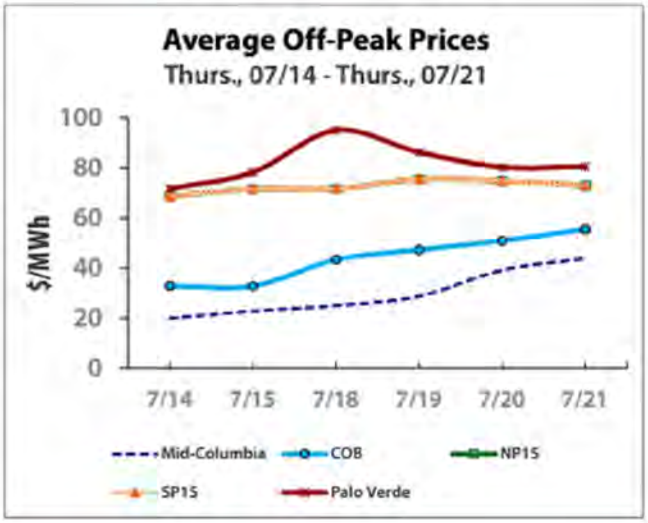
Western daytime power prices followed natural gas higher, up between $3.25 and $49.25/MWh. Mid-Columbia peak power posted the greatest increase, gaining 55 percent or $49.25 week over week to arrive at $139.60/MWh, which was also the highest daytime spot power price. South of Path 15 and Palo Verde also ended above $100/MWh.

Off-peak power values rose by between $4.10 and $24 in trading. Mid-C nighttime power added the most value, up $24 to $43.85/MWh.

California ISO demand peaked at 41,279 MW July 18. Total renewables on the CAISO grid reached 16,933 MW July 20, meeting almost 42 percent of demand. Generation from thermal sources peaked at 23,898 MW July 19, meeting 58 percent of the day's demand. ***[Linda Dailey Paulson]***



Average Peak Power Prices
Thurs., 07/14 - Thurs., 07/21



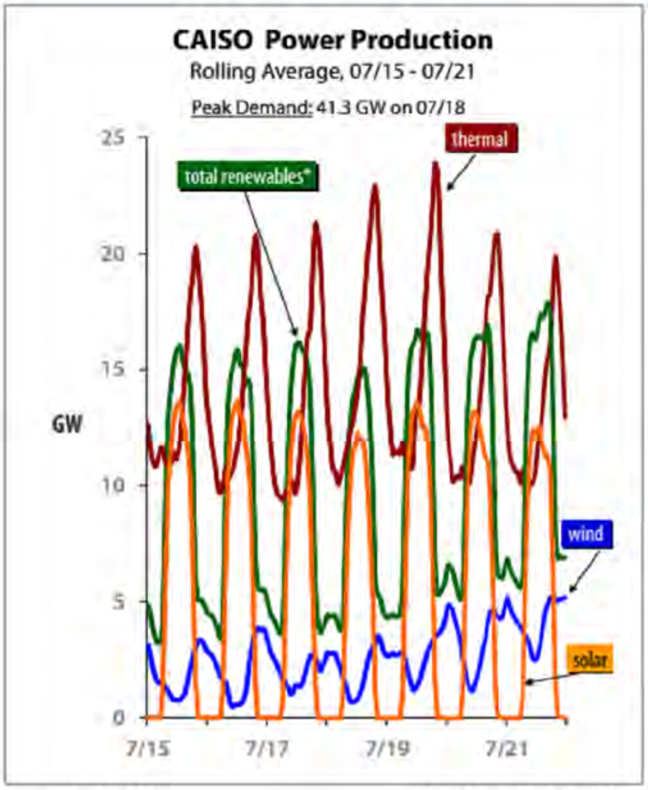
Average Off-Peak Prices
Thurs., 07/14 - Thurs., 07/21

Average Natural Gas Prices ($/MMBtu)

	Thurs. 07/14	Tues. 07/19	Thurs. 07/21
Henry Hub	6.86	7.39	7.95
Sumas	4.72	6.99	7.42
Alberta	5.56	4.86	5.18
Malin	6.50	7.40	8.00
Opal/Kern	6.57	7.30	7.71
Stanfield	5.78	7.21	7.73
PG&E CityGate	7.78	8.44	8.90
SoCal Border	7.79	8.53	8.63
SoCal CityGate	8.01	8.95	8.78
EP-Permian	6.38	6.99	7.55
EP-San Juan	6.63	7.34	7.63

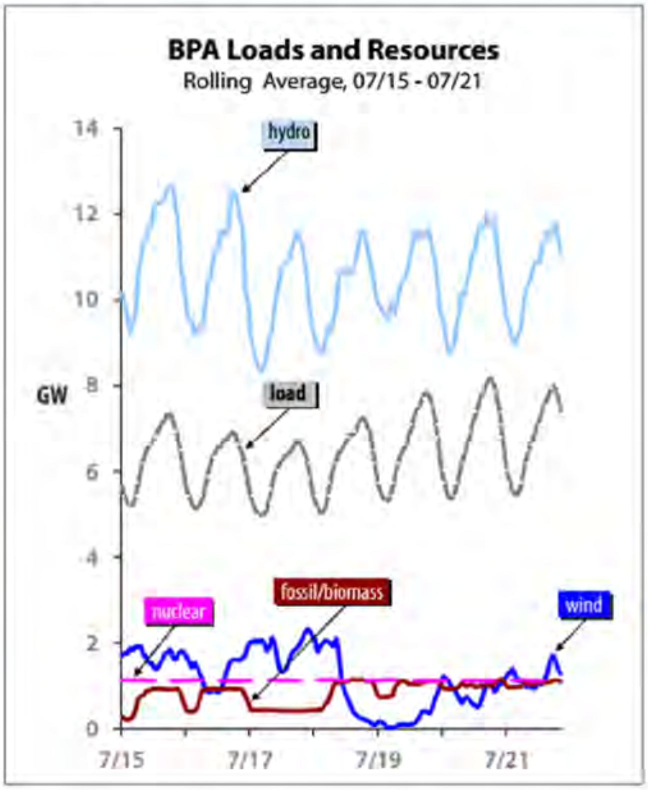
Power/gas prices courtesy of *Enerfax*

Power Gauge


CAISO Power Production

Rolling Average, 07/15 - 07/21

Peak Demand: 41.3 GW on 07/18


BPA Loads and Resources

Rolling Average, 07/15 - 07/21

Sources: CAISO and BPA

* includes small hydro (<30 MW)

Continued from page 3

resources across hours, days and weeks to understand the system and resource interactions, and dispatch. Instead, RESOLVE selects resources based primarily on their capital costs and capacity accreditation value to fill the need.

RESOLVE replaces the energy from the dams with additional wind power and "firm capacity" with natural gas and hydrogen combustion plants. Small amounts of energy efficiency and battery storage are also selected in some scenarios. The report mentions that "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."

This highlights the limitations of relying on a capacity expansion model without a full-year production-cost model because storage resources can provide both flexibility and capacity benefits and act as a complement to hydro resources.

The report does not mention hybrid solar/wind plus battery storage resources at all. Although battery storage resources can be selected individually by the RESOLVE or RECAP model, the model cannot co-optimize its dispatch with solar or wind generation. The cost-effectiveness of hybrid resources in the region is shown in recent integrated resource plans from PacifiCorp, Portland General Electric and Idaho Power, where hybrid resources—especially solar paired with four-hour battery storage–have over 80 percent effective load carrying capability (ELCC) value.

Idaho Power's recent portfolio modeling in its 2021 IRP shows that ELCC values of hybrids and four-hour stand-alone storage exceed 85 percent with eight-hour battery storage assigned a 97 percent ELCC value. It is implausible that a capacity expansion model would not select solar plus storage or even long-duration stand-alone storage resources like pumped hydro in the region unless the model does not fully realize their value. If the model cannot endogenously co-optimize, it leads to overbuilding and over-curtailment in the resource portfolio.

E3's modeling does not account for the impact of climate change-adjusted hydro and load in the changing demand pattern of the region. According to the recent 2021 Secure Water Act Study by the Bureau of Reclamation, increasing temperatures, earlier runoff and lower summer flows may reduce hydropower flexibility in the Pacific Northwest.

This is particularly impactful for the summer peak hours. E3 states that "[t]he biggest cost drivers for replacement resources are the need to replace the lost firm capacity for regional resource adequacy" especially during multiday events in the winter. The climate data suggests that the Pacific Northwest is increasingly moving toward more high-demand hours in the summer than winter due to lesser hydro availability in summer primarily due to higher temperatures. This was also the conclusion of the Northwest Power and Conservation Council's 2021 regional plan. It is surprising that E3 does not consider downscaled climate data that BPA has worked on to undertake this regional analysis and instead relies on outdated historical data for future projections.

The region is moving toward clean, non-emitting capacity resources to meet capacity needs and state-policy targets. Investor-owned utilities like PacifiCorp, PGE, and Idaho Power will procure more than 3 GW of solar, wind, hybrid and energy storage resources over the next few years because of their zero variable costs, increasingly lower capital expenditures, and operational characteristics that include flexibility and dispatchability.

The E3 study selects extremely speculative near-term resources, dual-fuel natural gas and small modular reactors, to replace the LSRD. The Oregon PUC recently acknowledged PacifiCorp's 2021 IRP only to the extent that nuclear is not included in the preferred portfolio, which indicates the financial risk in such investments (CU No. 2049 [10]).

While hydrogen-fired combustion turbines may be cost-effective in the future, there is not enough supply or infrastructure in the region to satisfy that need in the near term.

Additionally, the study does not consider the electrolyzer load that would be added to the system and how it would interact with the generation portfolio in the Pacific Northwest. Investing in natural gas-fired generation plants in the present with a hope that eventually they would be converted to burn hydrogen is a risky investment strategy.

The effect of the Western Resource Adequacy Program is not captured in the E3 study. E3 states that "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 percent planning reserve margin."

Once WRAP is up and running, the load and resource diversity in the region will lead to a more efficient resource buildout and allocation going forward, lowering planning reserve margins for individual utilities. It is unclear why E3 uses data that is inconsistent with WRAP's assumptions for reduced PRM.

To meet regional decarbonization goals and mandates irrespective of whether the lower Snake River dams are breached or not, load-serving entities will need to procure clean and non-emitting capacity resources like solar or wind, paired with battery storage and longer duration batteries and pumped-hydro resources.

Investor-owned utilities in the region have already started on this energy transition. It is unhelpful to the region to continue to rely on speculative markets and outdated modeling assumptions which exclude existing capacity resources. The tools and analysis used to determine how to move forward on new procurements and generator replacements need to consider resources which are commercially available and consistent with our region's procurement mandates and decarbonization goals.

Steve Wright wrote in last week's column that the region is taking a risk by waiting for a "mystery resource" to rescue us from our resource adequacy issues.

In fact, there is also an argument that there is no mystery resource at all but a portfolio of resources, each having their own values, that would be able to solve these challenges.

Perhaps the mystery resource is staring us right in the face and we just need to look differently at the resources we currently have at our disposal. ***[Sashwat Roy]***

Editor's Note: The second part of Steve Wright's two-part guest column on resource adequacy, originally scheduled to run in this issue, is postponed and will be published soon. Check out the first part in CU No. 2064.

Supply & Demand

[10] Studies See Wide Range of Transmission Costs for Offshore Oregon Wind • *from [1]*

Oregon's coastal waters may be the "Saudi Arabia of offshore wind," but those electrons will still have to connect to American infrastructure.

A trio of studies outlines the challenges and estimates a wide range of costs of integrating offshore wind along the southern coast of Oregon in two areas identified by the U.S Bureau of Ocean Energy Management off Coos Bay and Brookings.

Earlier studies have indicated that the combined area could hold up to 3 GW of wind generated from floating wind turbines. A study by the National Renewable Energy Laboratory concluded that 2.6 GW of wind could be developed before BPA would have to upgrade its transmission network in the area.

But an upcoming BPA transmission cluster study shows that connecting that much offshore wind to Bonneville's system on the southern coast would cost $905 million, and a recent consultant's study puts the price tag at upwards of $3 billion.

While NREL estimated wind integration amounts at all five BPA substations along the Oregon coast, BPA concentrated on two substations near Coos Bay, because potential wind production in that area is much greater than areas further north.

BPA's study shows that roughly 1 GW of offshore wind could be integrated for about $50 million to $60 million, primarily involving upgrading transformers, breakers and related equipment at existing substations.

Costs jump quickly above 1 GW of wind.

At 1.5 GW, BPA says it would likely cost $750 million for upgrades. At 2 and 3 GW, costs climb to $905 million and upgrades would likely not be ready until 2033.

But Randy Hardy, principal at Hardy Energy Consulting and former BPA administrator, says the agency's numbers are too optimistic.

"At about the 1.5 GW level of integration, BPA needs to bypass its relatively weak 115/230 kV Oregon coastal transmission system and instead build 260 miles of 500 kV line, along with two new and two expanded 500 kV substations."

This would be needed in order to wheel that level of Oregon offshore wind from the coast, over the Oregon

Coast Range and then to Eugene and Roseburg where it would interconnect with Bonneville's 500 kV system that runs along the Interstate 5 corridor, Hardy said in a study he shared with Clearing Up.

The costs, schedule and environmental challenges involved with building that kind of transmission over environmentally sensitive areas are "hard to overstate," he said.

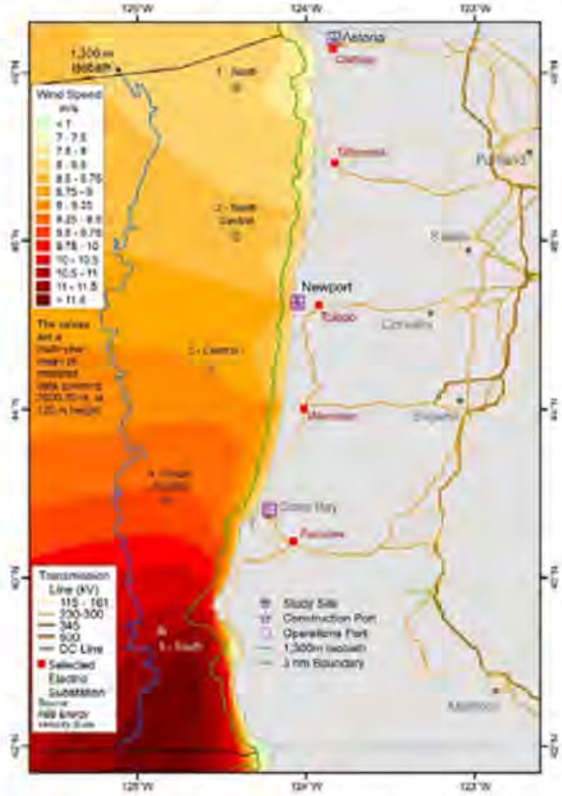
"Most of the 260 miles of 500 kV transmission line construction would probably be on new or existing, but expanded, rights of way," Hardy said. "It would no doubt require a programmatic EIS which would likely identify ESA related bird issues and related environmental challenges. In my view, the cost of this effort would probably range from $2 [billion]-$3 billion (rather than BPA's initial $905 million estimate) with an energization date of post 2035 or longer."

BPA's 2022 cluster study is expected to be released in the coming weeks. Hardy was given early access to the study for his report. Clearing Up confirmed the accuracy of the costs with Bonneville.

Hardy said the cost of building new transmission for offshore wind is far more expensive than integrating larger amounts of wind and solar from east of the Cascade Range and the Intermountain West.

The costs of integrating 1 GW of wind—either land-based (from BPA's 2021 cluster study) or offshore—are roughly similar, about $50 million-$60 million, Hardy says.

However, BPA can probably integrate 3 GW of land-based wind or solar for roughly $500 million, whereas BPA's estimated cost for integrating 3 GW of Oregon offshore wind is projected at $905 million, he added.



Map of Oregon trans-coastal transmission lines.

Source: National Renewable Energy Laboratory

Policymakers and developers have been eyeing offshore wind as a key resource in helping meet the region's clean-energy goals. The Biden administration has set a goal of having 30 GW deployed in U.S. coastal waters by 2030.

Mark Thompson, an Oregon PUC commissioner, described southern Oregon and Northern California waters as being "the Saudi Arabia of offshore wind," during a panel discussion at a Law Seminars International conference in April.

He went on to say there were lots of "interesting questions" around the new resource, such as transmission costs, how much transmission is needed to get those resources to load, who will pay for it and who is in charge of planning that transmission.

With capacity factors ranging from 48 to 60 percent, offshore wind could serve between 84 to 88 percent and 90 to 93 percent of the hourly coastal load in the Mid Offshore and High Offshore scenarios, respectively, according to the NREL study.

But it may not help ease east-west transmission congestion on BPA's system or necessarily relieve the region of having to build new transmission across the Cascades.

"Across all scenarios we found a robust relationship of approximately 500-550 MW decrease in hourly flow along cross Cascade transmission for every 1,000 MW of hourly offshore wind generation," the NREL study concluded. "However, we also found there was not a strong relationship between the highest cross-Cascade transmission flow hours and high offshore wind generation, limiting the extent to which offshore wind can be considered a non-wires alternative to cross Cascade transmission."

NREL says the levelized cost of energy for offshore wind in 2032 could be $63/MWh, down from $123/MWh today. The LCOE for onshore wind is currently between $40/MWh to $45/MWh.

Hardy believes the region should focus on acquiring as much land-based wind as possible, and resolving the cross-Cascade transmission issues that prevent more renewables from being imported into Portland and Seattle areas.

"Offshore wind probably won't be available until 2035, or maybe post 2040," he said. "Our problem is between now and 2030, that's when Puget Sound Energy and Portland General Electric need to be at 80 percent clean. I just think offshore is irrelevant in the time frame when we need it most." ***[Steve Ernst]***

[11] Idaho Power Study Points to Slashing Net-Metering Export Rates • *from [5]*

Idaho Power says its net-metering rate design is antiquated and forces traditional customers to pick up a greater share of fixed costs due to the rapid growth of customer-owned generation capacity on its system.

However, the utility said in a study filed June 30 with the Idaho PUC, restoring some balance between non-net-metering and net-metering customers is possible.

The study looks at how customer-owned generation is compensated and how net energy usage is tallied *[IPC-E-22-22]*.

The study does not recommend any regulatory actions, but Idaho Power says it hopes to use it as springboard for tweaking the program. It has unsuccessfully tried to cut its export credit rate—what it pays customers with on-site generation for their excess energy—most recently in 2020 (CU No. 1934 [11]).

While the utility currently pays retail energy rates, the study lays out several methodologies for calculating the export credit rate, "each of which differ materially from current retail energy rates, suggesting consideration of modifications is warranted," the company says.

Idaho Power has the technical capability to go from measuring net energy use on a monthly basis to hourly intervals, which would improve the accuracy of cost assignment and compensation for on-site generation customers, it says.

The report also presents considerations for transitioning to a revised net-metering rate.

The current export credit rate is between 8 and 10 cents/kWh depending on the customer class. The study's alternative methods cut the rate to less than 4 cents/kWh.

Supporters of the current rate slammed the study in a Sierra Club press release.

"A neutral third-party should review the results of the valuation study of customer generated power to ensure that fair and equitable rates are assigned to all avoided cost opportunities for Idaho Power as well as ensure the environmental and health benefits of distributed clean energy are included in the study," said Chair Mike Engle of Portneuf Resource Council, a grassroots organization based in Bannock County.

Emma Sperry of the Idaho Conservation League said such a reduction would effectively make on-site solar financially unviable for many homeowners and business owners.

None of the methodologies include public health, economic and environmental benefits, such as rooftop solar's avoided cost of carbon emissions, noted the Sierra Club and Idaho Conservation League.

"By not including any of these critical metrics in its study, its proposed export credit rates are far lower than they should be, and it disregards the very real and measurable contributions of solar owners in our communities in reducing pollution and creating green jobs," said Lisa Young, director of Sierra Club's Idaho chapter.

The study touched on this issue, saying that since the state doesn't have a renewables portfolio standard, and the utility "is not subject to a Carbon Tax and cannot monetize those emission reductions," there are no environmental costs that on-site generation avoids.

In addition, the study notes, while it "may be logistically possible for Idaho Power to aggregate and certify RECs from customer-generators," there are many hurdles to doing so.

Customer-owned generation on the utility's system has shot up in recent years. Its net-metering program began in 1983 with a single customer.

In 2017, it had nearly 2,000 customers with combined nameplate capacity of just over 15 MW. It currently has 11,600 customers with 111 MW of generating nameplate capacity, Idaho Power spokesman Jordan Rodriguez told Clearing Up.

In 2021, those customers produced 17 million kWh of excess energy, according to Idaho Power's filings; almost all of that energy came from on-site solar generation.

Although most of the systems are owned by residential customers, the program's 242 irrigation customers play an outsized role. While only making up 2 percent of Idaho Power's active and pending net-metering customers, they have about 20 percent of the nameplate capacity.

With so much capacity, "the existing retail rate net metering compensation structure oversimplifies the arrangement, treating the exchange as one-for-one when the reality of the transaction for on-site generation customers is not so straightforward," the company says in its application.

Like most electric utilities, Idaho Power uses volumetric rates to recoup the bulk of its fixed costs of serving customers. More than 90 percent of the fixed costs for serving residential and small general service customers is collected via energy rate charges. For irrigation customers, it is 70 percent. It is 60 percent for commercial customers and just under 40 percent for industrial customers, the company said in a filing.

Idaho Power incurs the same fixed costs for net-metering customers as it does for regular customers, but it is only charging them for their monthly net energy use—consumption minus what they export back to Idaho Power.

"The result of this misalignment is that net metering customers are being charged rates that do not appropriately reflect the benefits and costs of interconnecting customer-owned on-site generation to Idaho Power's system and this, in turn, has resulted in a situation susceptible to inequitable cost shifts between customers who choose to install on-site generation and those who do not," the company says in its application.

Whether the company will push to reduce its reliance on volumetric rates "is not something we would speculate on at this point," Idaho Power's Rodriguez said in an email. ***[Dan Catchpole]***

Courts & Commissions

[12] Federal Judge Tells Talen to Show Plan to Close or Operate Colstrip • *from [2]*

Talen Energy Supply has until Aug. 11 to file a plan for the future of the Colstrip coal-fired power plant in Montana, a federal bankruptcy court told Talen Energy.

The plan must include options for either closing the plant by 2025 or keeping it running.

The plants five utility owners—Avista, Portland General Electric, Puget Sound Energy, PacifiCorp and NorthWestern Energy—need clarity to plan for their future energy needs and cannot be held captive while Talen crawls out from a mountain of debt, U.S. Bankruptcy Judge Marvin Isgur said during a July 12 hearing in a Houston courtroom *[22-90054]*.

"I am not going to have folks in Montana or in Seattle without reliable power in accordance with applicable law," he said. "I'm not going to let the bankruptcy case have that effect."

In early May, the company filed for Chapter 11 protection for it and more than 70 of its affiliates—including Colstrip co-owner and operator Talen Montana—in the U.S. Bankruptcy Court for the Southern District of Texas *[22-90054]*.

The company, a subsidiary of holding company Talen Energy Corp., needs to slash $4.5 billion in debt, according to its filings.

At the July 12 hearing, Isgur extended a freeze on a pair of lawsuits filed by the co-owners last year, which underscores the unraveling of the Colstrip ownership group. The four Pacific Northwest owners—PSE, PGE, Avista and PacifiCorp—and NorthWestern had asked to lift the stay and allow the litigation to proceed.

In May 2021, the four Pacific Northwest owners sued in federal court to overturn two Montana laws meant to make it harder for them to exit Colstrip *[CV-00047-SPW-KLD]*.

In late 2021, NorthWestern filed a lawsuit in Montana state district court to compel arbitration to settle whether a unanimous vote among the owners is necessary to close units 3 and 4. If only a majority vote is required, then the four Pacific Northwest owners, who own 70 percent of the plant, could force its closure.

Isgur said the stay will remain in place so long as Talen Energy files a "reasonable proposal" for the plant's future by Aug. 11.

"I'm just shooting a shot over the debtor's bow," he said. "This better be a reasonable proposal because if it's not, then I'll just turn everything loose and let somebody else make that decision that is able to do so. I strongly encourage the debtors to come up with reasonable alternatives."

Talen's attorney, Jessica Liu, assured him the company would do that. "We are going to make a proposal—putting aside whether they like it or not—that will put an end to their interests in Colstrip."

She then indicated that Talen might consider buying out its co-owners.

"They want to get rid of all of their ownership. Will you take over all of the ownership and take over all of their operating expenses?" Isgur asked.

"I'd have to speak to the client on whether or not we'd be willing to take over all of their ownership interest," Liu said, "but Talen Montana has expressed interest in taking over their ownership interest, as well as Northwestern, I would say. And so, I think there is an opportunity for a conversation to be had."

Talen did not reply to request for comment on this possibility.

Washington lawmakers who backed the state's Clean Energy Transformation Act and its 2025 deadline for exiting coal-fired resources have said the law's goal is to reduce emissions in absolute terms. In 2020, the Legislature updated the state's greenhouse gas emissions limits, explicitly stating the caps must be met without shifting emissions to other areas.

PGE, PSE and Avista told Clearing Up that they are exploring options for exiting the plant as required by Washington and Oregon decarbonization laws.

NorthWestern's attorney, Joseph Acosta, told Isgur that Colstrip's future cannot hang in the balance, undecided, for long.

"We can live with the fact that Colstrip shuts down, but we have to know how we're going to replace Colstrip," he said during the hearing.

NorthWestern and Talen previously have both said they want to operate the plant for as long as possible.

The fight over the plant's future has played out in the co-owners' negotiations over Colstrip's annual operating budgets. The four Pacific Northwest owners do not want to pay for maintenance and other work needed to operate the plant past 2025, and in fact, Oregon and Washington regulators have directed utilities not to make investments that would prolong the life of the plant.

The Colstrip operating budgets typically are approved by Sept. 1, but the current one was not approved until January due to the chasm between the two sides.

Sept. 1 is fast approaching again and the budgets have significant consequences for NWE's budget, Acosta said.

"We're not talking about a budget of $10 million, we're not talking about a budget of $20 million," he said. "We're talking about a budget that last year was $130 million." ***[Dan Catchpole]***

Check Out 'Voices From Behind the Meter' Online

Clearing Up publishes energy-related "letters to the editor" on its website, and we invite/encourage readers to share their thoughts in this regional dialogue. Please see these submission guidelines. We look forward to hearing from you!

Environment

Fish

[13] In LSRD Breaching Debate, NOAA Scientist Spotlights Habitat • *from [3]*

The focus on breaching lower Snake River dams to recover healthy and harvestable salmon runs has at least one NOAA research scientist concerned that other essential findings are being missed.

"The No. 1 threat is large-scale estuary and habitat impacts," Lisa Crozier, research scientist at NOAA's Northwest Fisheries Science Center, told Clearing Up. "That should not be minimized. If all we're focused on is the political will to remove the dams, I think expectations are going to be very high for what the benefits are going to be. My concern is that we will ignore the rest of that report. Those actions are critical."

Like removing the dams, other actions identified in NOAA's report would also impact many people and require major investments, she noted.

Crozier said salmon are likely to benefit both from removing the dams and from restoring their spawning,

Salmon fry. *Photo: Ruth Hartnup/Flickr*

rearing and estuary habitat. But in her assessment, there's more uncertainty surrounding the benefits of removing dams. Conversely, the potential benefits of habitat restoration could be easily measured with some simple scientific studies, she said.

The draft report—released by NOAA Fisheries July 12—outlined several actions considered essential for achieving healthy and harvestable fish populations in the Columbia Basin in the face of the climate crisis (CU No. 2064 [14]).

Other measures in the report considered essential included fish passage into blocked areas; improved passage at lower Columbia River dams; improvements to water quality and quantity; management of predators; tributary and estuarine habitat restoration; and hatchery and harvest reform.

During an hour-long presentation on a University of Idaho webinar on July 19 about the threat of climate change to Snake River salmon and steelhead, Crozier focused on habitat restoration.

Her talk, "Climate Change & Salmon in the Snake River Basin," identified four key messages.

The most important point, she said, is that projected impacts of climate change are a critical threat to Pacific Northwest salmon. "They are going to encounter conditions that they've never encountered before," she said.

But salmon respond to these changing conditions with changes in their abundance, behavior, physiology and life history. "Salmon are not passive," she said. They are adaptive, and very responsive to changes, which makes them resilient, she noted.

Growth and survival in the ocean may decline very rapidly, Crozier said. That's especially true for spring-summer Chinook.

Finally, restoring and protecting spawning, rearing and estuary habitat is absolutely essential for preserving populations, she said.

In a 2019 assessment of 33 Pacific salmon and steelhead runs, Crozier and other scientists found Snake River sockeye and Snake River spring-summer Chinook are among the most at-risk stocks from the impacts of climate change (CU No. 1914 [13]).

Some of the factors that contribute to their vulnerability include a longer period of time spent in freshwater, and more dependency on near-shore or estuary rearing, she said. They were also in locations experiencing some of the greatest temperature ranges and areas more vulnerable to flooding.

"We are already experiencing unprecedented warming, and that will continue during this century," Crozier said.

She said air temperatures in Idaho have already increased by almost 2 F since the beginning of the 20th century, and are projected to increase by 5 F by the middle or end of this century, and that could rise as high as 10 F if carbon emissions are not reduced soon.

Salmon will experience a host of changes as temperatures rise, including earlier snowmelt and runoff, lower summer flows at higher elevations, and a loss of spawning and rearing habitat, she noted.

"In Idaho, we may see peak snowpack a month or six weeks earlier than historically," she said. Marine heat waves will also occur more frequently.

Crozier said the low Snake River parr-to-smolt survival rate of just 16 percent is one area where management actions could help increase returns. She said the low survival at that life-cycle stage is likely related to overwintering in the lower Salmon River. She said scientists don't currently know where salmon go to overwinter in order to pinpoint where habitat work could be done.

"We could answer that question relatively quickly compared to the dam removal issue," she said, noting that similar work is already being done in the upper Columbia River, where low productivity is also a problem.

With climate change, she noted, "It's going to be absolutely imperative to increase the carrying capacity and productivity in freshwater." Key strategies for improving habitat include protecting cold-water flows and cold-water refuge, increasing flows in tributaries, protecting off-channel habitats, reconnecting rivers and streams with floodplains, protecting vegetated stream corridors and upland forests, and restoring stream corridors with the greatest potential to lower water temperatures.

In addition to habitat restoration, Crozier said, investment in marine research will also be important, so that scientists can analyze what actions are most effective at improving survival in the ocean—which is most at risk under a changing climate.

Healthy and harvestable salmon populations are not likely to result from habitat restoration alone, Crozier noted. "But is it essential? I think so," she said.

She said one of the potential benefits from breaching the dams is cooler water temperatures. EPA's study on total maximum daily loads for the Columbia Basin found temperature at the dam locations, if removed, would be reduced by 0.5 F at Lower Granite Dam and by 0.7 F at Ice Harbor Dam.

But the other benefits are harder to quantify, Crozier said. Improved smolt-to-adult returns from models assume delayed or latent mortality. That's the impact dams have on later life-cycle stages of salmon, after the journey downstream. The effect has been documented, but it's not well understood, she said.

She said three methods of trying to quantify delayed mortality include comparing the survival of fish that migrate in the river with fish that are transported; comparing marine survival of fish that went through turbines or bypass facilities with fish that traveled over spillways; and comparing the marine survival of fish from different rivers that migrate through a different number of dams. Each of these methods is problematic, she said.

"The problem with latent mortality is, it's one of those fundamental uncertainties that cannot be answered without removing the dams," Crozier said, and added, "There are things we could do a lot more quickly." ***[K.C. Mehaffey]***

[14] Commenters Seek Changes in Murray-Inslee Draft Report • *from [6]*

Northwest hydropower advocates contend that the real value of the lower Snake River dams (LSRD) in the context of a rapidly decarbonizing grid was not adequately captured in a draft study of whether the dams could be replaced.

Those who support removing them say much attention has been paid to the $12 billion to $27 billion replacement price tag instead of the real potential that Snake River salmon will go extinct if the dams aren't breached.

Comments on the study—titled "Lower Snake River Dams: Benefit Replacement Draft Report"—prepared for Sen. Patty Murray (D-Wash.) and Washington Gov. Jay Inslee, were due July 11 (CU No. 2059 [10]). Clearing Up reviewed letters from some of the most active players in the breaching debate. A final report is expected this summer, with the comments contributing to recommendations for Columbia Basin salmon recovery from Inslee and Murray.

In reviewing the letters Clearing Up found a major theme from both sides of the issue is that the draft report doesn't do a good enough job capturing what's at stake if the dams are removed or what's at stake if they're not.

Several of the comments could be categorized under broad topics related to their requests for changes in the final report:

Strengthen Language on Value of Salmon to Tribes

Save Our Wild Salmon wrote that the report acknowledges the central role that salmon play in tribal cultures. "But we are concerned that it doesn't fully convey the way in which Tribes perceive the extinction of salmon as a genuinely existential issue. We encourage you to ensure that the final report clearly communicates to nonNative [sic] readers the incalculable cost of salmon extinction especially for the People of the Salmon," stated the comment from Save Our Wild Salmon and 45 other conservation and fishing groups, including NW Energy Coalition, National Wildlife Federation, Earthjustice, Northwest Sportfishing Industry Association, Columbia Riverkeeper and National Resources Defense Council.

Include Recovery Uncertainty From Removing Dams

The report details multiple studies predicting long-term benefits for Snake River salmon if the dams are breached. As NW Energy Coalition commented, "The science is clear that keeping the dams will lead to salmon extinction and breaching them will not. Dam breaching is the key to restoring wild salmon and steelhead abundance, alongside other necessary measures."

NWEC's comment was also signed by the Idaho Conservation League, Earthjustice, Save Our Wild Salmon, Sierra Club Salmon Campaign, Natural Resources Defense Council and Idaho Rivers United.

But public power advocates say the science is not so clear, and the report should reflect the uncertainty and the broader context. "The Draft fails to question the likely effectiveness of dam breaching for salmon recovery in light of coastwide declines in Chinook salmon stocks," Northwest RiverPartners wrote.

"While hydropower is one factor, other factors such as harvest, habitat and hatchery conditions—also known as 'The All-H' approach to salmon recovery—must be addressed," Public Power Council commented.

BPA further commented that two metrics used to gauge current status and trends—smolt-to-adult returns and quasi-extinction thresholds—risk overestimating hydro-system impacts and ignore the larger effect of ocean conditions. "Although the dams are a contributing factor in diminishing salmon returns, the factors involved in these declines are much more varied and complex," the agency wrote.

Calculate the Monetary Value of a Free-Flowing River

Save Our Wild Salmon lamented that media coverage and regional discussion of the report have highlighted the $10 billion to $27 billion cost of replacing the dams. While doubting those figures, the groups noted that the report does not offer a comparable 50-year estimate of costs—and of the benefits that would not be realized—if the dams remain. Their comment states that annual operating and capital costs of $134 million to $151 million; annual fish mitigation costs of $54 million to $159 million; costs of additional fish measures; and major capital expenses like turbine replacement should be added up for comparison.

In addition, the final report should calculate benefits of a free-flowing river, including the monetary value of increased tribal, recreational and commercial fishing, it said.

NWEC agreed, stating a major shortcoming of the report is its lack of a 50-year cost and risk comparison between keeping the dams in place and replacing them with clean-energy resources.

"Without this information, decision-makers and the public are left with an incomplete picture of clean energy net benefits, including increased protection for salmon and other fish and wildlife, and improvements to the value and performance of the Northwest power system," its comment stated.

Reassess the Value of the Dams as an Energy Resource

Public power advocates agreed that the report far underestimated the value of the dams as part of the larger hydropower system, and their potential and value as a firm energy source to help the region transition away from fossil fuels.

The LSRD are "unambiguously a source of tremendous power supply for the region," PPC wrote, adding, "The flexible capacity that the LSRDs provide will only increase in demand and value as state and federal legislation, policies and economic or societal factors drive the further retirement of fossil-fueled base load resources and replace them with intermittent renewable generation."

RiverPartners added, "The Draft fundamentally misunderstands the requirements of maintaining a

The Snake River where it passes between Lewiston, Idaho and Clarkston, Wash. *Photo: Jeremy Segrott/Flickr*

reliable, low-cost electric grid in the context of the region's clean energy laws."

Some of the concern involves a lack of adequate analysis in the report regarding how replacement energy sources will produce power under extreme, peak conditions, such as prolonged cold snaps and heat waves. BPA noted extreme conditions can coincide with calm weather or dark winter days. In addition, current utility-scale batteries have only four hours of sustained capacity and require power to regenerate.

"Bonneville has relied heavily upon the LSRD when these conditions have occurred in the past to maintain regional reliability. There is substantial uncertainty that the proposed replacement portfolio of resources could perform to the same level of reliability and the Draft Report should make this uncertainty clear," the agency commented.

BPA noted that the report's conclusion that it's feasible to replace the hydropower generation within the $12 billion to $27 billion cost relies on several critical assumptions—emerging technology will be available at a commercial scale; transmission infrastructure will be built; replacement resources that may only be needed during extreme weather events will be built; and winter demand for electricity to heat buildings will not increase significantly under new policies for decarbonization.

PPC warned, "Removal may be the tipping point, nudging the Northwest system into acute scarcity." It asked findings from several studies be included in the final report, including the irreplaceable role the dams play in avoiding or reducing the magnitude and duration of blackouts; the risks of extreme electricity prices; and the difficulty in meeting clean-energy goals if they're removed.

NWEC countered that the report confirms that the LSRD energy resources can be replaced with careful planning and adequate funding. It says that replacement resources will add value to the grid by addressing seasonal limitations of the dams, especially in the late summer when Snake River flows drop. Their comment predicts that the dams will become less valuable as more renewable resources are developed and become available. "The final report should note that interest in development of clean energy generation in the Northwest is high and growing, and that LSRD energy replacement would represent only a small fraction of the total planned, 'shovel-ready' clean energy resources being driven by market conditions," their comment stated.

NWEC also pointed to four reasons that LSRD value will be reduced in the future, including higher costs of generation; the need for transmission and distribution upgrades with or without dam removal; the long-term costs of continued operations; and modifications needed to meet water-quality standards.

Public power advocates also asked for a thorough examination of energy-related carbon dioxide emissions in the final report, noting that the Columbia River System Operations EIS concluded that a portfolio of wind, solar and batteries would increase the region's carbon footprint by 1.3 million metric tons per year, as existing fossil-fuel plants are heavily relied upon for grid reliability.

"Rescue efforts for salmon must start with decarbonizing our energy grid and the rest of our economy," RiverPartners commented, and added, "The loss of the LSRD most certainly will delay the completion for a zero-carbon grid by years and will add millions of tons of emissions into the atmosphere." ***[K.C. Mehaffey]***

Clearing It Up

[15] Regulators Stress Importance of Interregional Transmission • *from [4]*

Federal energy regulators are focusing on building new interregional electric transmission infrastructure, realizing that previous efforts have fallen short, while states are looking to a new planning process to increase reliability as energy shortages in the majority of the U.S. grow more and more likely.

FERC Chairman Richard Glick said July 20 that much progress has been made recently as states and the federal government increase coordination on the issue of transmission buildout. He acknowledged that Order No. 1000, the agency's rule on transmission development issued in 2011, was "well-intentioned," but "there actually hasn't been any interregional transmission built as a result of this process."

Glick made his comments at the fourth meeting of the Joint Federal-State Task Force on Electric Transmission, held in San Diego in conjunction with the National Association of Regulatory Utility Commissioners' Summer Policy Summit.

He noted that there were hundreds of deaths in Texas due to grid outages during Winter Storm Uri in February 2021 caused by the paucity of interconnection to other regions.

In contrast, he said, the Southwest Power Pool and Midcontinent ISO also lost significant generation resources during the extreme cold-weather event, but didn't have widespread outages.

"The reason is because they were connected to these other regions of the country, including PJM, and were able to wheel in a lot of power—of course it wasn't as cold in PJM at the time—and the results were remarkably different," Glick said. "This is just one example. There are a lot of benefits to regional transmission."

The task force's third meeting was held in May, also in San Diego, where state regulators expressed some hesitancy about increased federal control over transmission siting (CU No. 2054 [11]).

The discussion at the current meeting was generally less skeptical, although regulators from areas without organized energy markets pushed back slightly on the concept of requiring regional capacity transfer capabilities floated by FERC member Allison Clements.

FERC has two notices of proposed rulemaking in play at the moment to deal with transmission and bringing new resources on line. One is the NOPR on transmission planning and cost allocation, issued in April *[RM21-17]*, and the other is a NOPR on improvements to generator interconnection procedures and agreements issued in June *[RM22-14]*.

"We have come a long way since our first meeting, when the [allocation NOPR] was just a baby, although a very big baby, at that," Kansas Corporation Commission member Andrew French said at the task force meeting.

French noted that the Kansas commission, the Southwest Power Pool Regional State Committee and many others have asked FERC to focus on interregional transmission, although there are already robust efforts underway in regional transmission organizations and independent system operators to address long-term planning and interconnection issues.

"There is an overwhelming and continuing body of evidence that materially expanding import and export capacity among the regions will produce immense economic, reliability and public policy benefits," French said. He added that additional transmission capacity will help solve long-term planning and generator-interconnection issues.

On interregional planning and cost allocation, French said, "From my perspective, it is the one area where a federal entity is uniquely suited to move us past parochial interests, inconsistent planning methodologies and the pricing challenges that thwart the free movement of clean, affordable and reliable power to the customers that want it."

Gladys Brown Dutrieuille of the Pennsylvania PUC said her state is one of the top exporters of electricity in terms of megawatt-hours in the PJM Interconnection and across the country. Growth of renewable energy will cause changes in system congestion and energy flows, she said.

For that reason, building interregional transmission "where prudent and needed" will alleviate some of the uncertainty around renewables integration, Dutrieuille said. State regulators need to be mindful and plan the transmission system to be reliable and resilient as well as cost-effective, she said, adding that understanding transfer capacity between regions is an important issue.

But there is a barrier in terms of understanding what transfer capacity exists, which should be studied under various scenarios including the impact of unplanned events like wildfires, she said. The next step would be studying what type of interregional capacity is needed.

"Looking at transfer capacity is an important issue and an opportunity for us," Dutrieuille said, adding that there is a lack of visibility as to what transfer capacity exists. There is a need for two studies, she said—one looking at the present and one at the future.

Jason Stanek, chairman of the Maryland PSC, noted that FERC has been working on transmission reform for many years, such as in its Order No. 890 issued in 2007, which was meant to reduce barriers to entry in developing new transmission.

"Literally these many years later, we are still addressing the root causes that have prevented us from building new transmission," Stanek said. He said that less than 10 percent of transmission in the U.S. has been built since 2013.

"We have to do more to connect the interconnects, to connect the RTOs," Stanek said.

California PUC member Cliff Rechtschaffen agreed with Glick and other state commissioners about the need for new interregional transmission, saying the most important benefit is accessing low-cost renewable energy and delivering it to load centers. This can yield very large cost savings as well as emission reductions, Rechtschaffen said.

California is building transmission that crosses regions to access renewables, but they are not interregional projects in the sense that they are funded solely by California ratepayers, he said, adding that there are lots of reliability and resiliency benefits to interregional transmission. This is increasingly important as a hedge against climate, economic and weather volatility, Rechtschaffen said.

"Every day of the summer we certainly realize how important that is," he said. But a significant challenge is that grid operators in different regions go about evaluating the benefits of transmission in different ways, which makes it difficult to come up with fair cost allocation for new facilities.

In the West, other than the California ISO, planners do not consider resource development beyond those that are already under development, Rechtschaffen said.

"That asymmetry makes it harder to come up with [an] agreed-upon planning and cost-allocation framework," Rechtschaffen said. The success of interregional planning will also depend on the effectiveness of planning within individual regions, he added. ***[Jason Fordney]***

[16] POTOMAC: Biden Signs Exec Actions After Manchin Sinks Climate Agenda • *from [7]*

Democrats and renewable-energy groups roundly criticized Sen. Joe Manchin's (D-W.V.) scuttling of climate and energy provisions proposed for a filibuster-exempt budget bill, prompting President Joe Biden to embark on a course of executive actions meant to recoup a small part of what was blocked.

Manchin announced July 15 that he would halt negotiations on energy- and climate-related tax and spending provisions in the Democrats' reconciliation package (CU No. 2064 [20]).

The announcement followed concerns Manchin raised July 13 about the impact of additional federal spending on inflation.

"No matter what spending aspirations some in Congress may have, it is clear to anyone who visits a grocery store or a gas station that we cannot add more fuel to this inflation fire," Manchin said.

Senate Majority Leader Charles Schumer (D-N.Y.) and Manchin had been negotiating a slimmed-down reconciliation bill with less spending than the House-passed, $1.75 trillion Build Back Better bill that stalled last year when Manchin announced his opposition. The House legislation includes $550 billion in energy- and climate-related tax and spending measures.

Sen. Raúl Grijalva (D-Ariz.), chair of the Senate Natural Resources Committee, had strong words for Manchin's action.

"Like most Americans right now, I am sickened that the changing whims of one man could put the very near future of our country, our planet, and our health and safety on the brink," he said, adding, "As we watch the most existential crisis of our time worsen before our eyes, the Republicans' entire platform has been to obstruct, spew faux outrage, and recite the talking points of the very industries that are killing us."

The Oregon Solar + Storage Industries Association said July 19 in a statement that it was "extremely disappointed" by Manchin's actions and that it would work with the Solar Energy Industries Association to continue "fighting for a strong and extended" investment tax credit.

SEIA President Abigail Ross Hopper said the solar industry is here to stay and "already a critical piece of our nation's economy and energy mix."

"I know our industry will keep growing despite shortsighted policy decisions like this," Hopper said.

At the time Manchin announced he was ending negotiations, President Joe Biden was attending a summit in Saudi Arabia to bolster U.S. strategic relationships in the Middle East.

Asked by reporters during a summit break on July 15 for a message to Americans "looking for relief" on climate and energy issues, Biden said, "I am not going away. I'm going to use every power I have as president to continue to fulfill my pledge to move toward dealing with global warming."

He also said, "So let me be clear: If the Senate will not move to tackle the climate crisis and strengthen our domestic clean-energy industry, I will take strong executive action to meet this moment."

Biden Pushes Ahead With Climate, Energy Initiatives

Making good on his vow to do an end run around the torpedoed climate and energy provisions in a Senate budget bill, Biden on July 20 announced executive orders supporting offshore wind energy programs and helping communities adapt to extreme heat, the first in a series of climate change-related actions he is expected to take.

With a closed coal-fired power plant in Somerset, Mass., as a backdrop and temperatures in the mid-90s, he announced actions that include $2.3 billion in resilience and infrastructure funding through the Federal Emergency Management Agency to help communities deal with record-setting temperatures.

Biden said he also will direct the Department of Health and Human Services to issue guidance to help communities access $385 million in federal funding to buy efficient air-conditioning equipment, set up community cooling centers in schools and reduce other energy costs.

The administration also said it had identified 700,000 acres for possible offshore wind energy development in the Gulf of Mexico, and that Biden would direct the Interior Department to move ahead with offshore wind development in areas off the Atlantic coast where President Donald Trump banned oil and gas development.

The success of this effort could hinge on reversing a 10-year ban on offshore energy development in the southern Atlantic Ocean signed by Trump in the fall of 2020, although the ban didn't mention wind development.

Biden is expected to announce additional executive actions in the coming weeks as he faces pressure to fulfill his pledge to cut U.S. greenhouse gas emissions in half relative to 2005 levels by 2030, but it isn't clear whether these will include declaring a "climate emergency," which would allow federal resources to be used without Senate approval.

The White House said it has not ruled out this action, but wants to proceed carefully. National Climate Advisor Gina McCarthy told reporters, "I think the considerations are just that the president wants to make sure that we're doing this right, that we're laying it out, and that we have the time we need to get this work done. That's all."

Some have questioned whether an emergency declaration could accomplish much, particularly in the wake of the Supreme Court's recent ruling restricting federal regulation of carbon emissions.

Report: Economy, Fossil Fuel Prices Drop GHG Emissions

In its eighth annual Taking Stock report on U.S. carbon emissions, the Rhodium Group said the country is on track to reduce greenhouse gas emissions 24 to 35 percent below 2005 levels by 2030, "absent any additional policy action."

While this falls significantly short of the U.S.'s Paris Agreement pledge to reduce GHG emissions by 50 to 52 percent, it represents a "rosier outlook for emissions reductions" compared to the firm's 2021 findings, which estimated a 17 to 30 percent reduction.

However, the report notes, the change is largely due to a slower economy and higher fossil fuel prices, and not to large policy changes.

Even by 2035, the report says, GHG emissions remain "stubbornly high" at 26 to 41 percent below 2005 levels.

"Now, more than ever, it's important for policymakers to focus on maximizing the impacts of policy," the report says, warning that "the clock is ticking" on achieving the 2030 climate goals and on reducing emissions "to avert the worst impacts of climate change."

DOE Announces New Solar Funding

The White House and the Department of Energy on July 14 announced $56 million in funding—including $10 million from Biden's bipartisan infrastructure law—to bolster solar manufacturing and recycling innovations.

The initiative is aimed at improving manufacturing and strengthening the domestic solar supply chain, Energy Secretary Jennifer Granholm said in a statement.

Among the efforts supported are expanding production of domestically sourced thin-film modules and supporting newer technologies like perovskite solar cells.

The supported areas and their funding levels are $29 million to support projects that increase the reuse and recycling of solar technologies, and $27 million for commercializing new technologies that can expand private investment in U.S. solar manufacturing.

This second area includes boosting domestic manufacturing of thin-film photovoltaics made from cadmium telluride, the second-most-common PV technology on the market behind silicon, DOE said.

Other new solar funding includes $18 million for seven proposed national laboratory projects designed to tackle commercialization challenges faced by DOE-funded solar technologies, and $8 million to seven small companies to underwrite research and development in concentrating solar-thermal power, power electronics and solar-powered water technologies.

Biden Secures Energy, Climate Deals at Mideast Summit

Biden on July 15 reached agreement on several energy issues during a summit in Saudi Arabia to bolster U.S. strategic relationships in the Middle East.

Jeddah Security and Development Summit participants included the Gulf Cooperation Council and the Republic of Egypt, the Republic of Iraq and the Kingdom of Jordan, collectively known as the GCC+3. The GCC comprises Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates.

Among the agreements reached during the daylong meeting was an investment of $3 billion by the GCC in projects that align with the G7's Partnership for Global Infrastructure and Investment. These projects would bolster global energy security through investments in climate-resilient infrastructure, transformational energy technologies and the development of clean-energy supply chains.

The summit also advanced Iraq's energy integration with the GCC and Jordan through an agreement to link Iraq's electricity grid to the grids in the GCC.

Biden also welcomed the recent announcement by OPEC+ to increase oil supply during July and August, and said he anticipates additional supply increases over the coming months, depending on market conditions and analysis.

He also reaffirmed the U.S. commitment to preserving the free flow of commerce through strategic international waterways like the Bab el-Mandeb and the Strait of Hormuz, through which 40 percent of the world's energy passes every day, via multiple joint naval task forces, in partnership with longstanding U.S. partners integrated through U.S. Central Command.

In addition, Saudi Arabia signed a bilateral Partnership Framework for Advancing Clean Energy, which outlines new Saudi investments to accelerate an energy transition to help decarbonize infrastructure. The framework focuses particularly on solar, green hydrogen, nuclear, and other clean-energy initiatives.

USPS Boosts Its Electric Mail Truck Order

The U.S. Postal Service on July 20 significantly increased its commitment to replace its delivery fleet with more electric vehicles, upping it from 10,000 to at least 25,000.

The increase follows fierce criticism from lawmakers and environmental groups after the agency announced in March that it would spend nearly $3 billion on an initial order for 50,000 new mail trucks, only 20 percent of them all-electric battery EVs (BEVs).

That announcement followed the release in February of a record of decision to acquire up to 165,000 next-generation delivery vehicles powered by various means, with a commitment for at least 10 percent BEVs. Postmaster General Louis DeJoy defended the plan, saying the USPS couldn't afford faster electrification of its delivery fleet (CU No. 2042 [14]).

Since then, 16 states, four environmental groups and the United Auto Workers union sued to block the plan, and the Biden administration and many lawmakers asked the agency to reconsider.

In a statement issued July 20, the USPS characterized the adjustments to its plan as "refinements" based on improvements in the agency's financial outlook and availability of technology.

USPS also said it will purchase another 34,500 vehicles from other manufacturers, "including as many BEVs as are commercially available."

Of the total 84,500 vehicles to be purchased, at least 40 percent of them would be electric, the agency said.

"The Postal Service reiterates its commitment to the fiscally responsible roll-out of electric-powered vehicles for America's largest and oldest federal fleet," its statement says. "New NGDV are expected to start servicing postal routes in late 2023." ***[Rick Adair]***

One of the next-generation delivery vans being made for the U.S. Postal Service. ***Source: USPS***

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BPA Lower Snake River Dams Power Replacement Study

Executive Summary

July 2022

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Who is E3?

Thought Leadership, Fact Based, Trusted.

100+ full-time consultants | 30 years of deep expertise | Engineering, Economics, Mathematics, Public Policy…


San Francisco


New York


Boston


Calgary

E3 Clients

300+ projects per year across our diverse client base

- Investors, Developers & Asset Owners
- Utilities & System Operators
- Public and Non-Profit Sector

Recent Examples of E3 Projects

Buy-side diligence support on several successful investments in electric utilities (~$10B in total)

Acquisition support for investment in a residential demand response company (~$100M)

Supporting investment in several stand-alone storage platforms and individual assets across North America (10+ GW | ~$1B)

Acquisition support for several portfolios and individual gas-fired and renewable generation assets (20+ GW | ~$2B)

United Nations Deep Decarbonization Pathways Project

California: 100% clean energy planning and carbon market design for California agencies

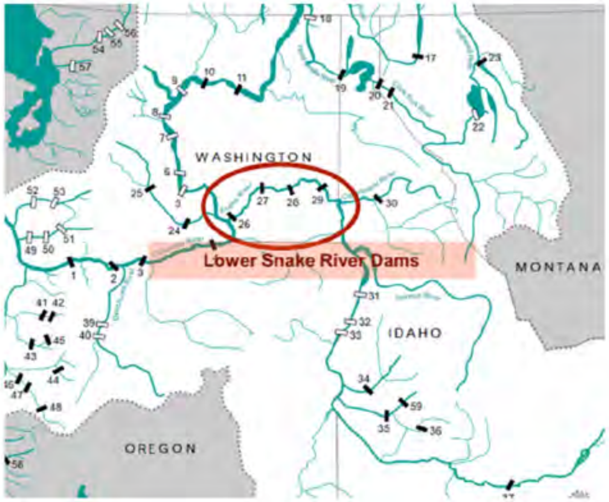
Net Zero New England study with Energy Futures Initiative

New York: NYSERDA 100% clean energy planning

Pacific Northwest: 100% renewables and resource adequacy studies for multiple utilities

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 **~$12 billion**
  - In a **deep decarbonization scenario** with higher loads and zero emissions electricity by 2045, NPV costs range from **$11.2-19.6 billion** with at least one emerging technology
    - Reaching deep decarbonization **absent breakthroughs in not-yet-commercialized emerging technologies**, NPV costs could increase to **$42-77 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 **34-65% or ~$450-850 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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* 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

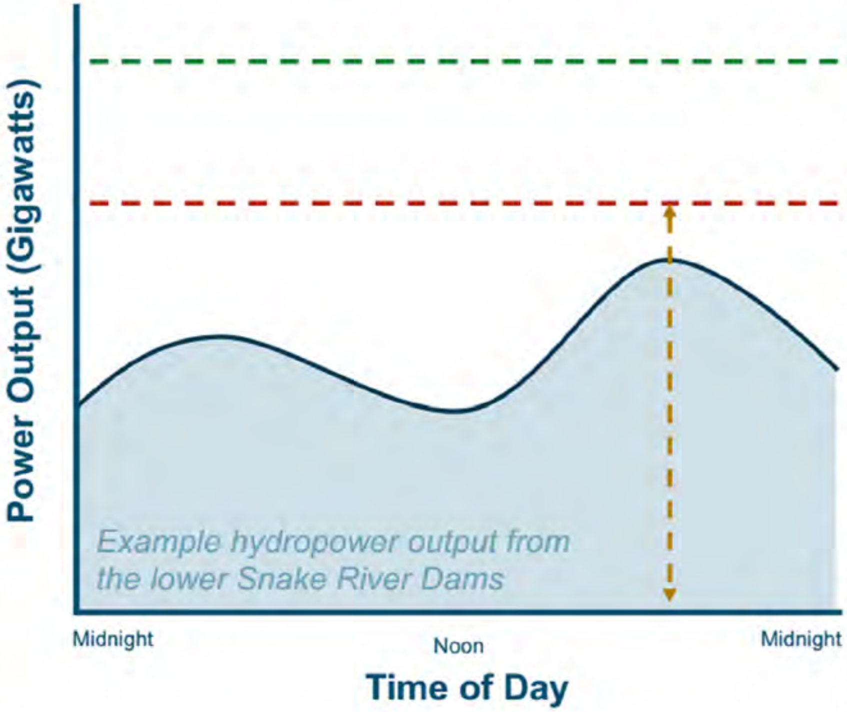
What grid services do the lower Snake River dams provide?


Little Goose


Lower Granite


Lower Monumental


Ice Harbor



Total "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 = 2.3 GW**

Annual (Carbon-free) Energy
Sum of hourly power produced across the year, subject to seasonal water availability
LSR Dams = 0.9 average GW***

Operational Flexibility
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

Transmission Grid Reliability Services
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

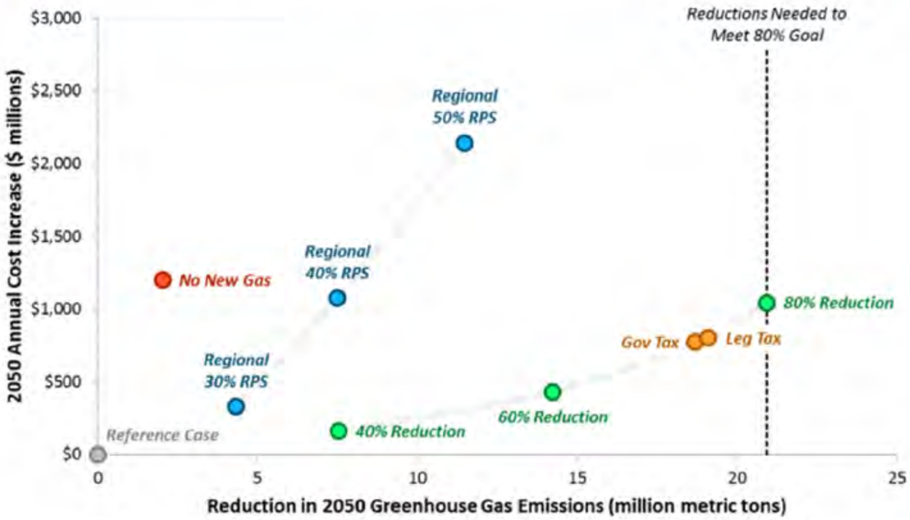
Study uses E3's Northwest RESOLVE Model

- **E3 has used RESOLVE across North America to tackle complex policy and planning questions**
  - RESOLVE develops optimal portfolios of **zero-carbon resources** to meet policy and reliability goals

- **E3 has used RESOLVE in several prior Pacific Northwest studies**
  - PNW Low-Carbon Scenario Analysis (PGP, 2017)
  - PNW Zero-Emitting Resources Study (ENW, 2021)

RESOLVE Case Studies

Pacific Northwest Low-Carbon Scenarios



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** (~65-85% 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 also considered in RESOLVE (2045-2065) and LSR Dam replacement costs were calculated based on 50-years (e.g. 2032-2082)

** The carbon price assumed drives the region to >100% CES by 2045, so a scenario without a carbon price was modeled to understand the LSR dam replacement impacts of a binding CES target.

*** 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)	🟩	🟩	🟩	🟩
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

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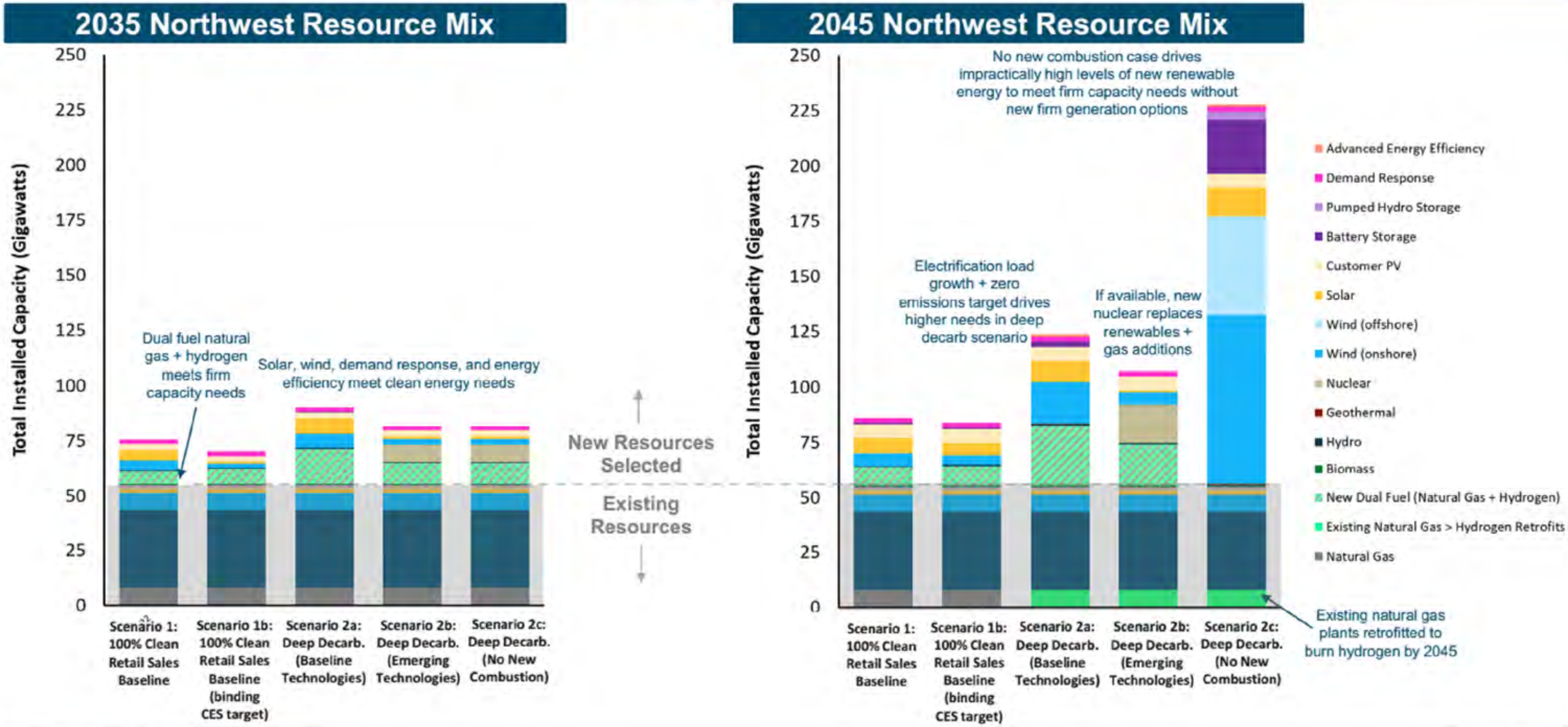
Northwest Resource Needs in Scenarios With the Lower Snake River Dams

Even without breaching the dams, all scenarios show large levels of new resource additions



2035 Northwest Resource Mix

2045 Northwest Resource Mix

Dual fuel natural gas + hydrogen meets firm capacity needs

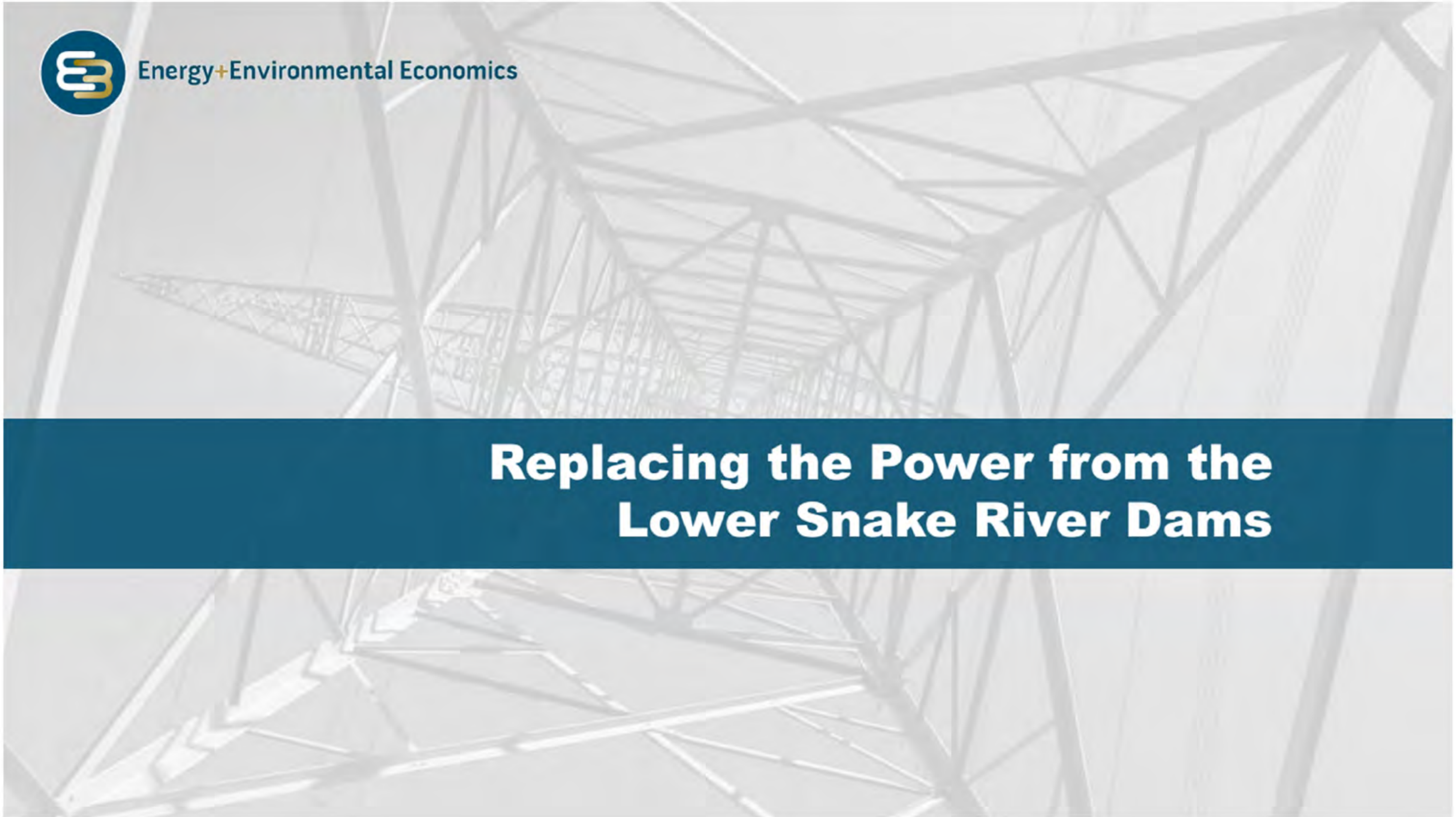
Solar, wind, demand response, and energy efficiency meet clean energy needs

Electrification load growth + zero emissions target drives higher needs in deep decarb scenario

If available, new nuclear replaces renewables + gas additions

No new combustion case drives impractically high levels of new renewable energy to meet firm capacity needs without new firm generation options

Existing natural gas plants retrofitted to burn hydrogen by 2045



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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**
  - A range of costs was developed for this scenario based on the assumed transmission needs for renewable additions

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 1b: 100% Clean Retail Sales (binding CES target)**	+ 1.8 GW dual fuel NG/H2 CCGT + 1.3 GW solar + 1.2 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

** In scenario 1b, the 100% CES target is binding in 2045, causing the need to fully replace the GHG-free energy output of the LSR dams. In scenario 1, the high carbon price assumed drives the region higher than the 100% CES target, making it a non-binding constraint in the model.

*** 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 34-65% absent emerging technologies
- Costs could **raise annual residential electricity bills** by up to $100-230/year, or up to $450-850/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	$12.4 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 1b: 100% Clean Retail Sales (binding CES target)	$12.0 billion	n/a	$445 million	$473 million	0.8 cents/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$19.6 billion	n/a	$496 million	$860 million	1.5 cents/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$11.2 billion	n/a	$415 million	$428 million	0.7 cents/kWh [+8%]
Scenario 2c: Deep Decarb. *(No New Combustion)*	*$42 – 77 billion*	n/a	*$1,045 – 1,953 million*	*$1,711 – 3,199 million*	*2.9 – 5.5 cents/kWh [+34 – 65%]*

Deep decarbonization without emerging technologies drives very 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
- Lower end of range for scenario 2c assumes limited transmission build out (based on replacement resource additions' marginal ELCC instead of delivering the full nameplate capacity), annual cost plot shows only high end of range

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 ~$275-500/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)
Scenario 1: 100% Clean Retail Sales	$77/MWh
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$82/MWh
Scenario 1b: 100% Clean Retail Sales (binding CES target)	$77/MWh
Scenario 2a: Deep Decarb. (Baseline Technologies)	$139/MWh
Scenario 2b: Deep Decarb. (Emerging Technologies)	$69/MWh
Scenario 2c: Deep Decarb. *(No New Combustion)*	$277 – 517/MWh

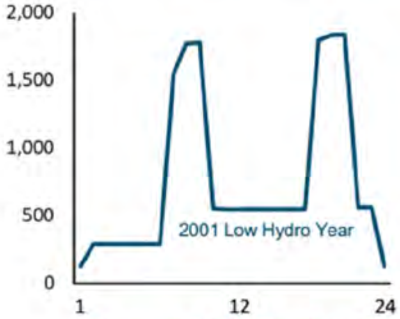
* BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) fish hatcheries and satellite facilities. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat.2917) to offset fish and wildlife losses caused by construction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

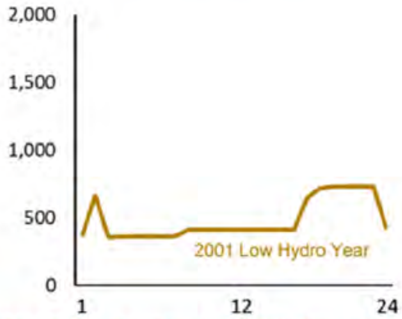
Firm capacity value of the lower Snake River dams

- **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

January Max. Power Ouput (MW)

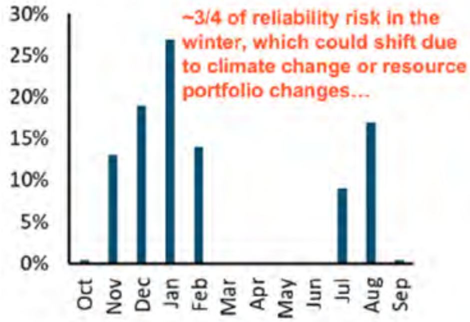


August Max. Power Output (MW)



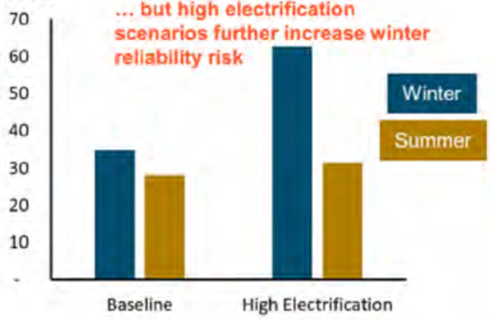
Assuming the Northwest remains winter reliability challenged, LSR Dams could have contributed ~56-60% of total capacity or 1.9-2.1 GW* in the 2001 low hydro year

NWPCC 2024 RA Assessment % of Annual Adequacy Events



~3/4 of reliability risk in the winter, which could shift due to climate change or resource portfolio changes...

Peak on RESOLVE Modeled Days in 2045 (MW)



... but high electrification scenarios further increase winter reliability risk

* Includes 100-250 MW reserve provision on top of maximum power output

Key conclusions

1. **Replacing the four lower Snake River dams comes at a substantial cost, even assuming emerging technologies are available**
   - Require 2,300 – 4,300 MW of replacement resources
   - An annual cost of $415 million – $860 million by 2045*
   - Total net present value replacement cost of $11.2 – 19.6 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 ($42-77 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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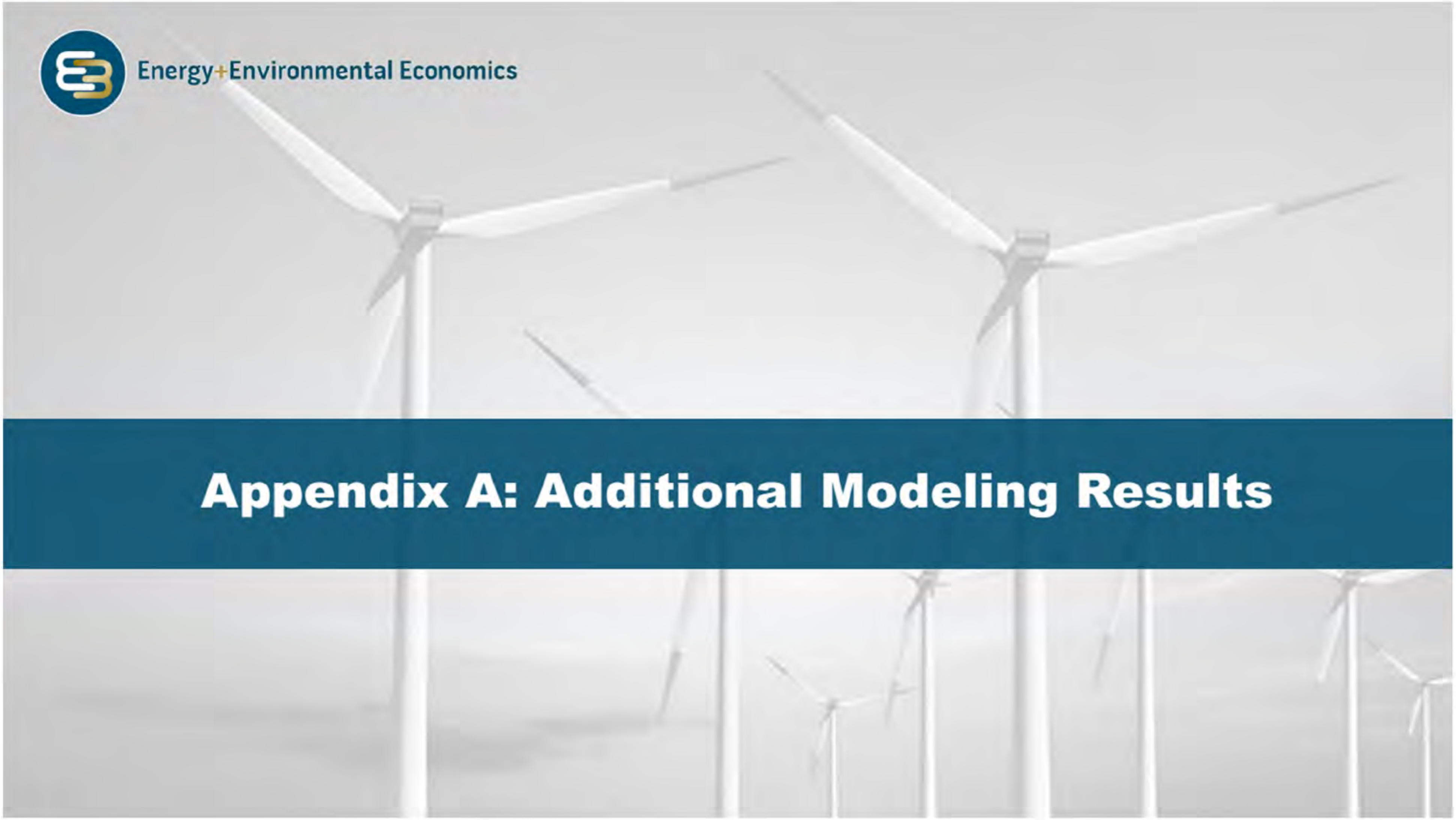

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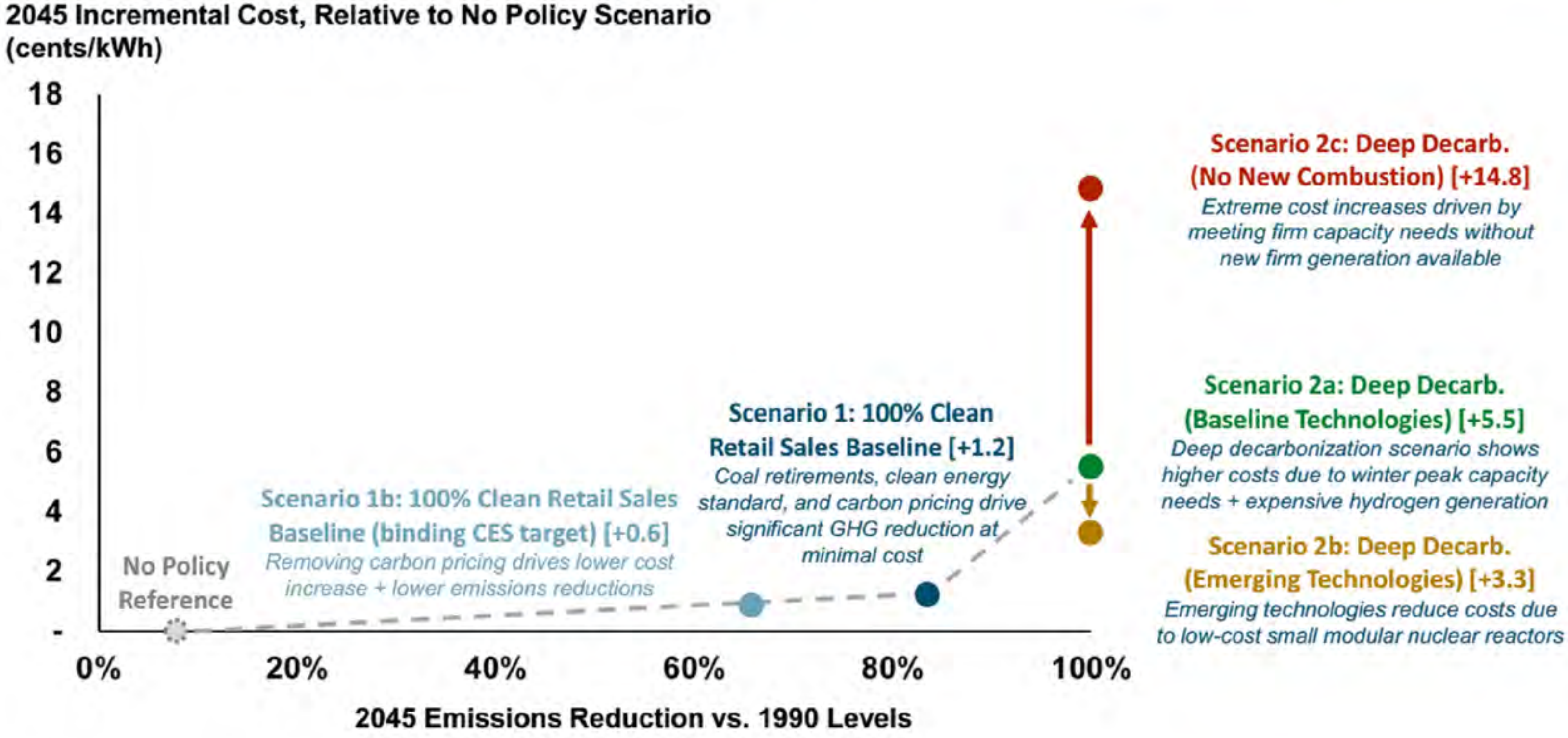
Appendix A: Additional Modeling Results

Significant carbon reductions are possible, but the cost of reaching zero emissions depends on technologies available



No Policy Reference

Scenario 1b: 100% Clean Retail Sales Baseline (binding CES target) [+0.6]
Removing carbon pricing drives lower cost increase + lower emissions reductions

Scenario 1: 100% Clean Retail Sales Baseline [+1.2]
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

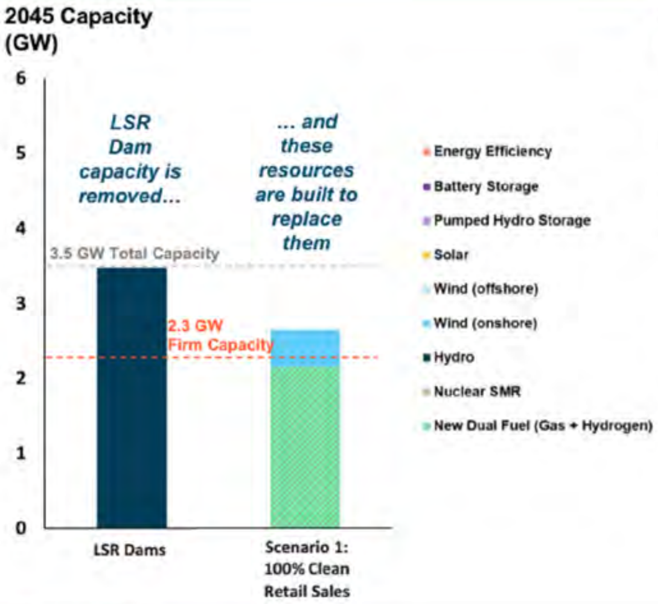
Scenario 2b: Deep Decarb. (Emerging Technologies) [+3.3]
Emerging technologies reduce costs due to low-cost small modular nuclear reactors

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

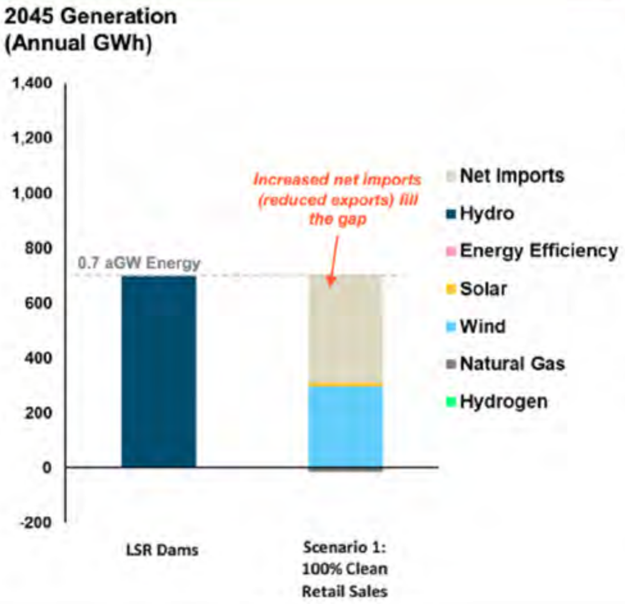
Replacing the Lower Snake River Dams
Scenario 1: 100% Clean Retail Sales

- 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

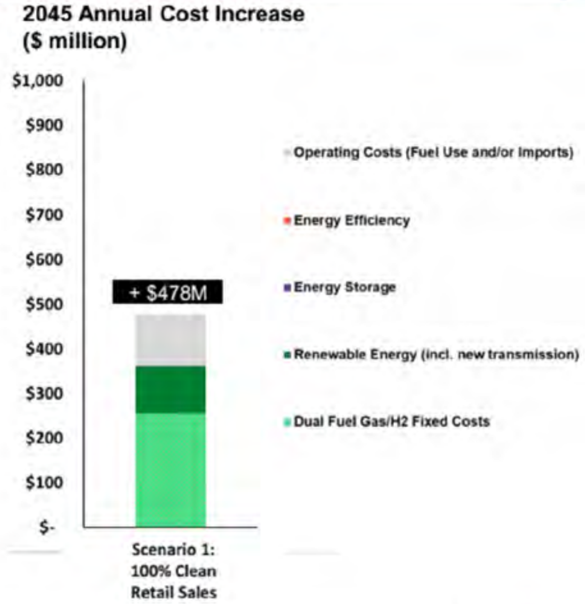
Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)



Additional Cost (2045)

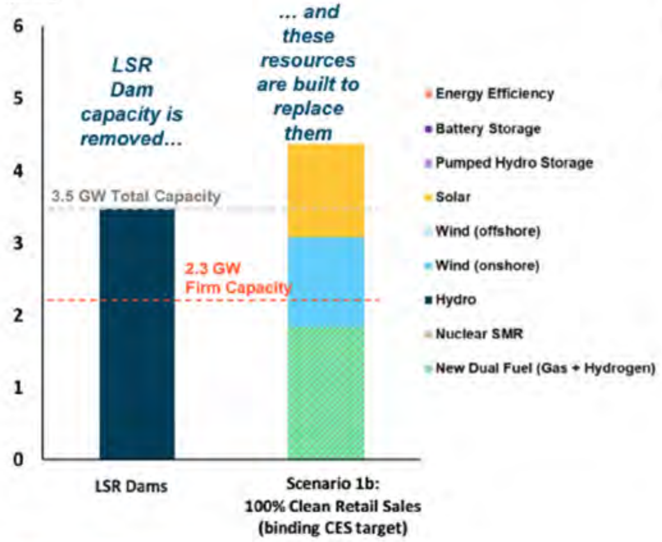


Replacing the Lower Snake River Dams
Scenario 1b: 100% Clean Retail Sales (binding CES target)

- **Capacity replaced with 1.8 GW of dual fuel natural gas + hydrogen turbines, 1.3 GW solar, and 1.2 GW wind**
- **Wind and solar provide the energy replacement, but gas plant is needed for meeting extreme weather peak load events to avoid power shortages**

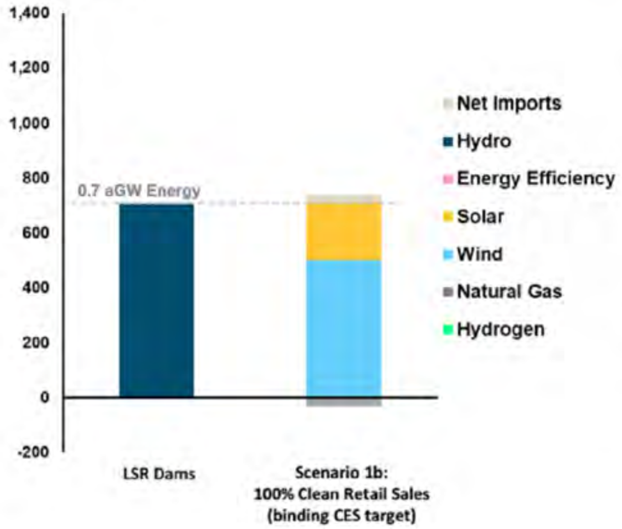
Additional Resources Built to Replace LSR Dams (2045)

2045 Capacity (GW)



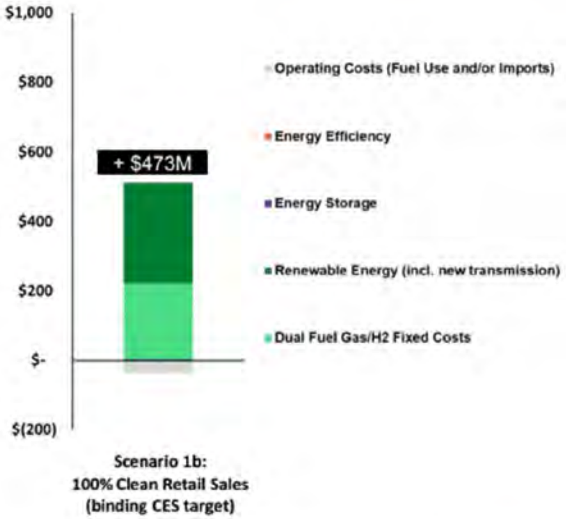
Additional Generation to Replace LSR Dams (2045)

2045 Generation (Annual GWh)



Additional Cost (2045)

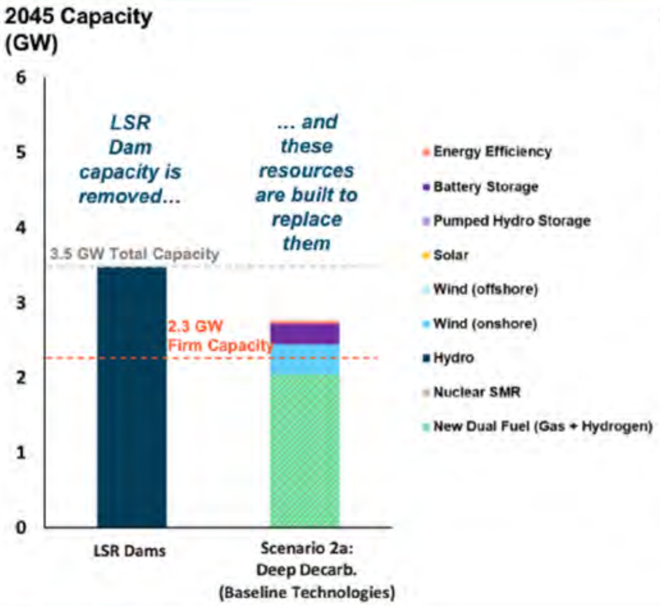
2045 Annual Cost Increase ($ million)



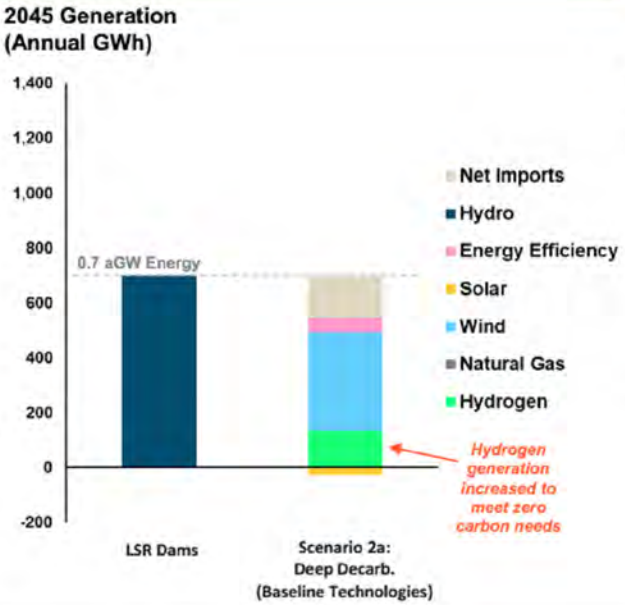
Replacing the Lower Snake River Dams
Scenario 2a: Deep Decarbonization (Baseline Technologies)

- 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)

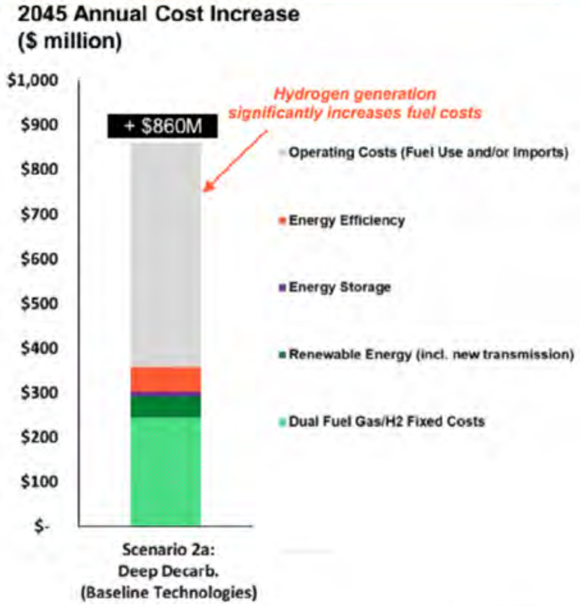
Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)

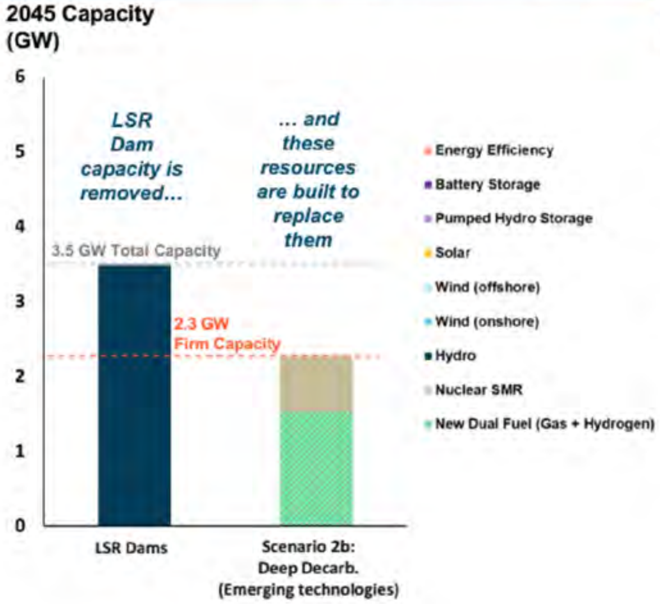


Additional Cost (2045)

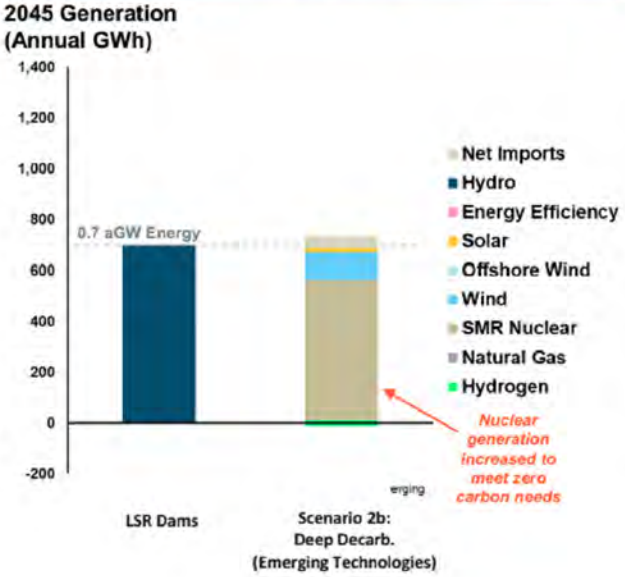


Replacing the Lower Snake River Dams
Scenario 2b: Deep Decarbonization (Emerging Technologies)

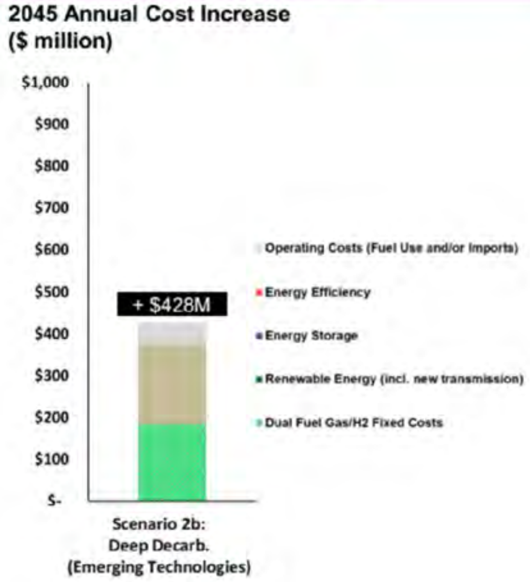
Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)

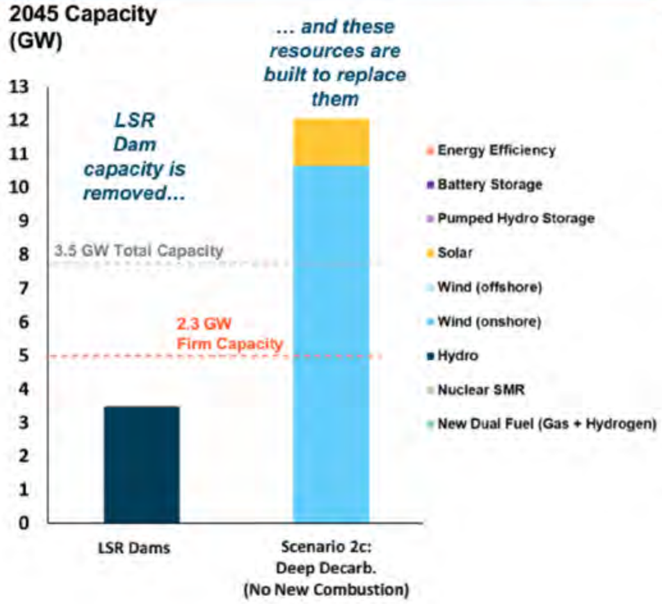


Additional Cost (2045)

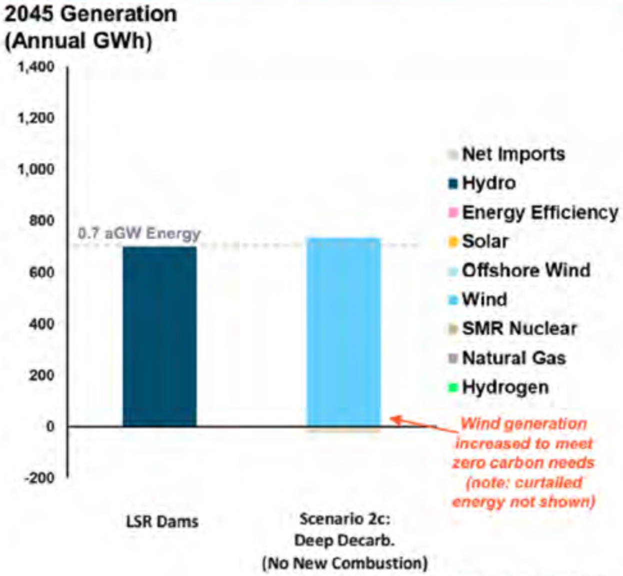


Replacing the Lower Snake River Dams
Scenario 2c: Deep Decarbonization (No New Combustion)

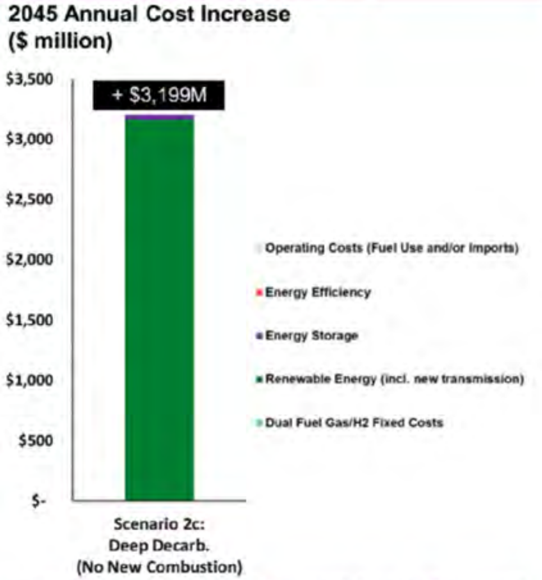
Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)



Additional Cost (2045)



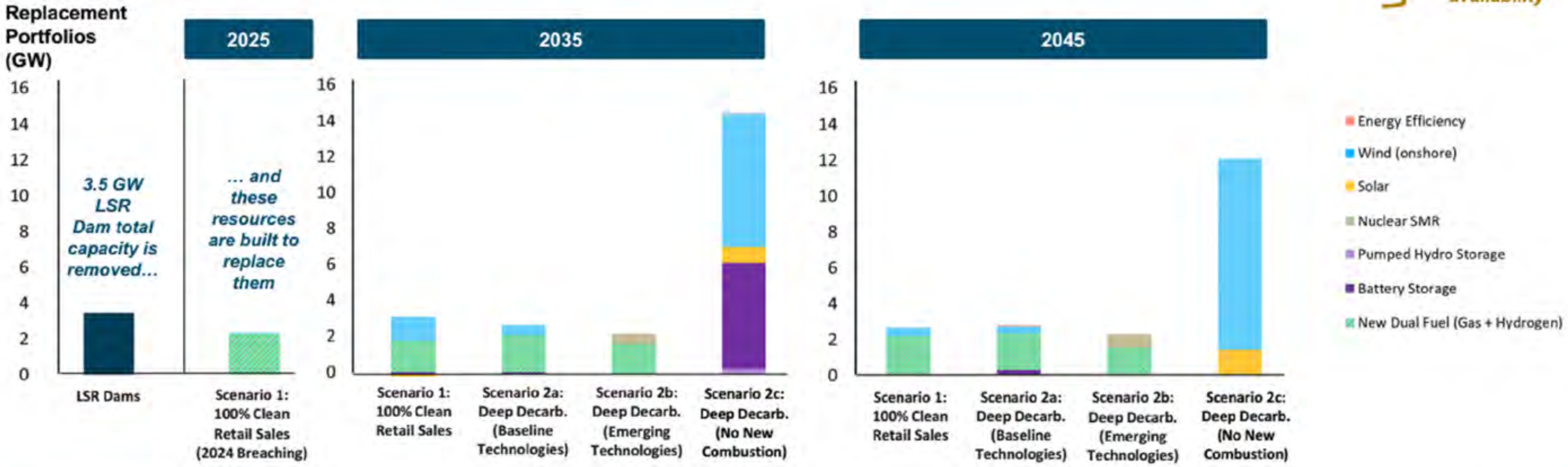
- Note: in the cost summary, a range of costs was developed for this scenario based on the assumed transmission needs for renewable additions
- High end assumes 100% of nameplate, low end assumes 25% of nameplate (approx. marginal ELCC of renewable additions)
- Low end represents a higher ratio of renewable capacity to transmission capacity, recognizing that much of the additional energy added by 2045 would be curtailed due to over-supply

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



3.5 GW LSR Dam total capacity is removed…

… and these resources are built to replace them

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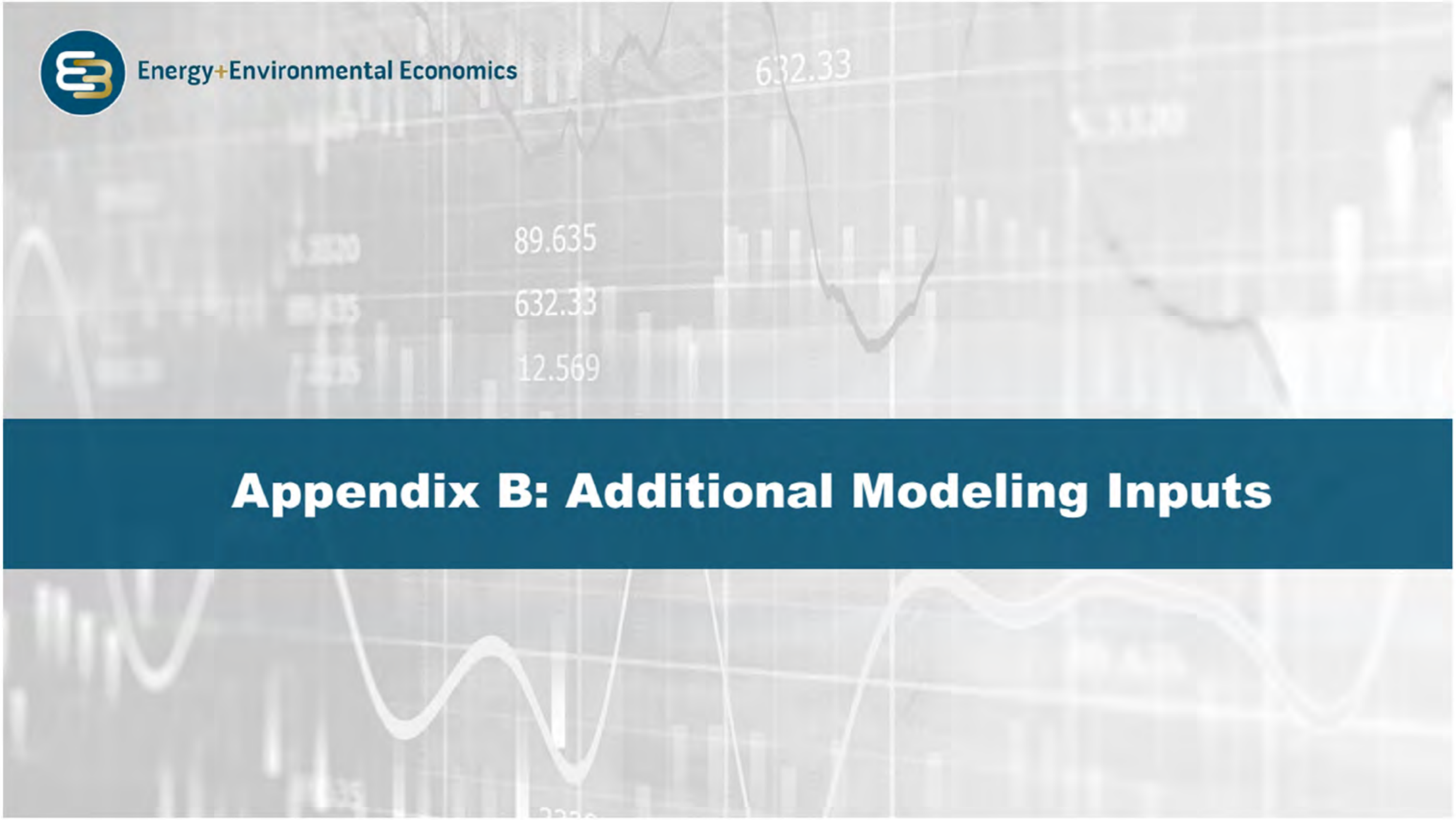


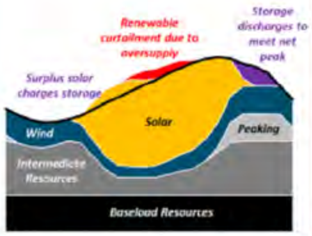
Appendix B: Additional Modeling Inputs

RESOLVE optimizes investments to meet clean energy targets reliably

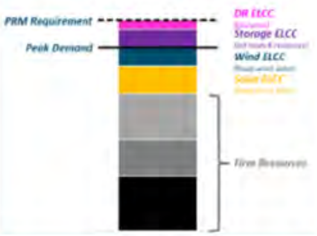
RESOLVE is an optimal capacity expansion model specifically designed to identify least-cost plans to meet reliability needs and achieve compliance with regulatory and policy requirements

- 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

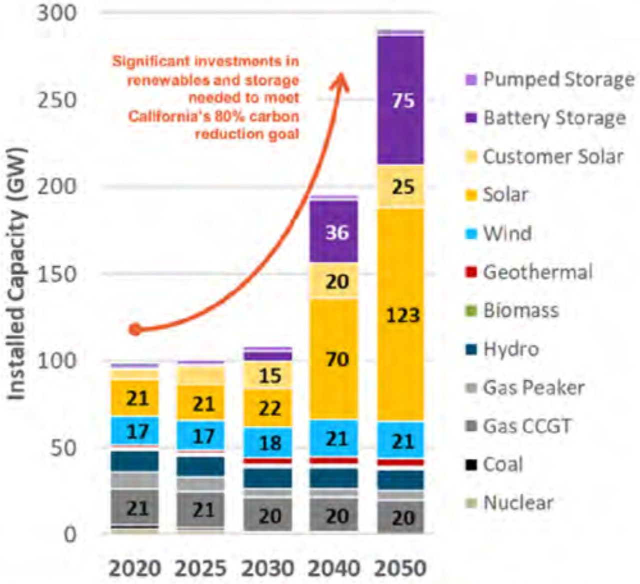
Operational module simulates hourly system operations for a sample of representative days



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



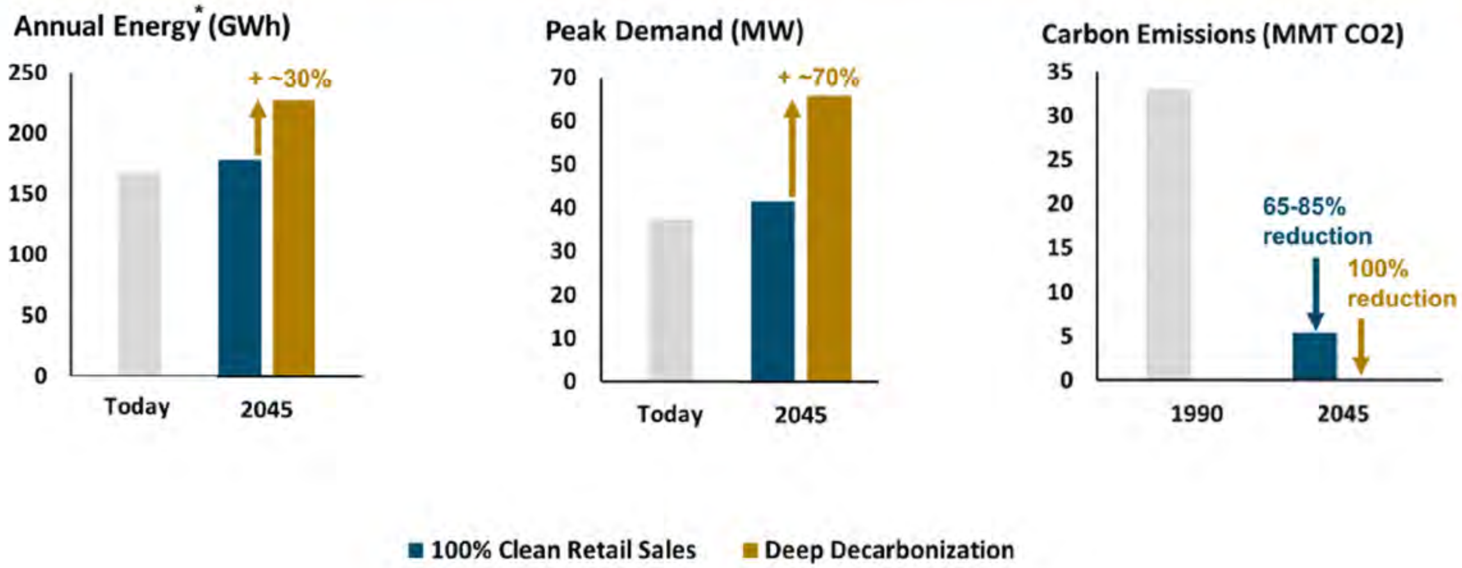
Least-cost plan cooptimizes investments and operations to meet clean energy policy targets, selecting from a diverse set of potential resources including wind, solar, storage, DSM, and natural gas



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

Load growth and carbon emissions in two clean energy scenarios modeled

Increases in Electricity Use and Declines in Carbon Emissions

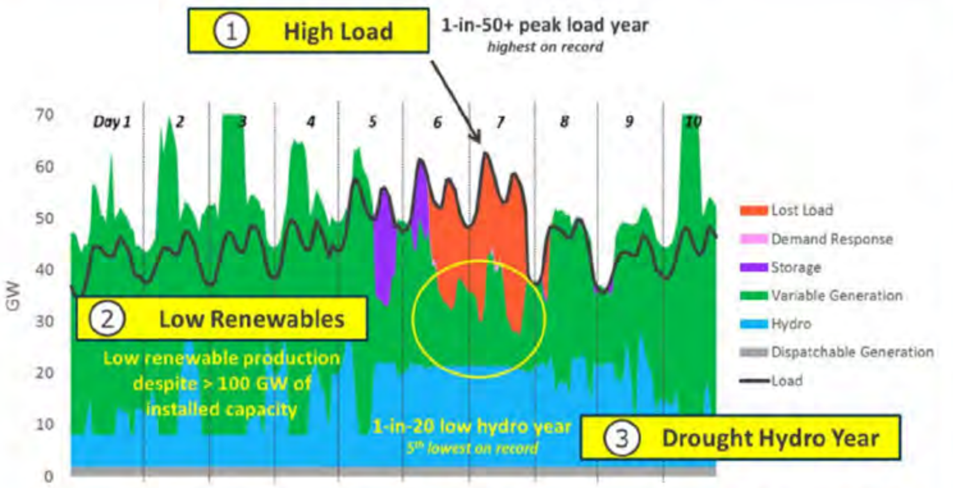


* Load based on 2021 NWPCC Power Plan, shown as retail sales (after assumed growth in customer PV and energy efficiency)

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

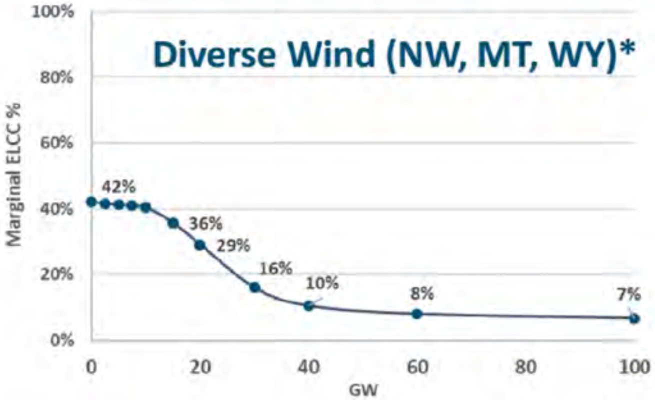


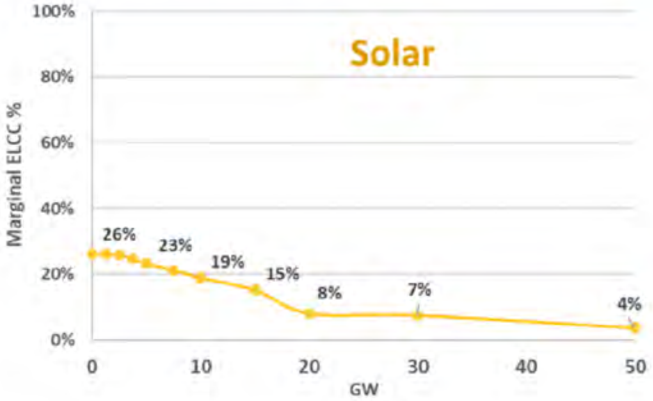
Sample week in 2050 in a 100% GHG reduction scenario, from E3, *Resource Adequacy in the Pacific Northwest*, 2019.

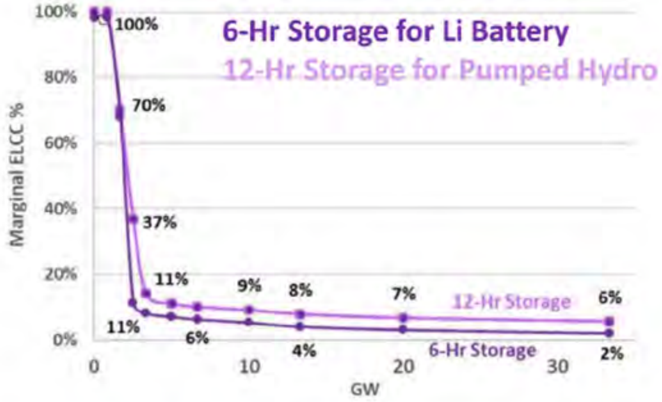
Resource	RA Capacity Contributions
Hydro	65%, based on sustained winter peaking capacity in critical water year conditions (per BPA/PNUCC)… WRAP method is still evolving
Battery storage	Sharply declining ELCCs*
Pumped storage	Sharply declining ELCCs*
Solar	Declining ELCCs
Wind	Declining ELCCs
Demand 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

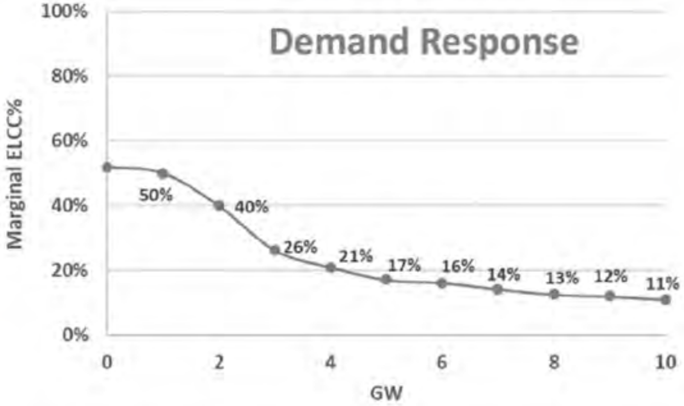
* E3 performed a sensitivity with battery ELCCs that do not decline so sharply. This sensitivity did change the LSR dam replacement resources and costs.

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**

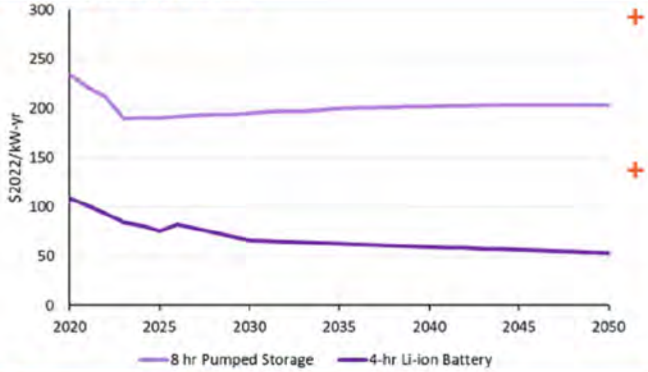
* The offshore wind sensitivity in this study assumed the same ELCC curve as modeled for diverse on-shore wind resources in the Resource Adequacy in the Northwest report.

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

New Resource Options

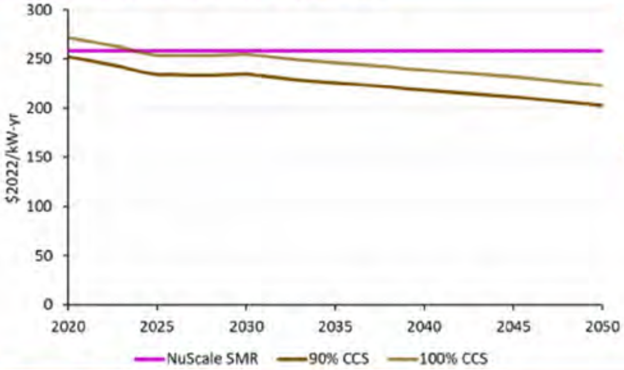
All-in Fixed Costs

Storage Options



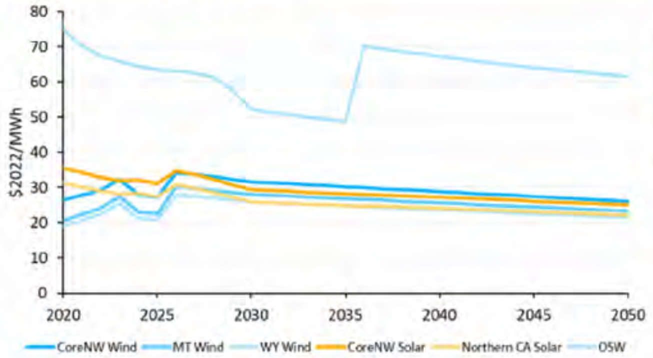
- Battery Storage costs derived from E3's inhouse and Lazard LCOS 7.0 (Oct 2021)
- Pumped storage is from Lazard's last published PHS costs (LCOS 4.0). Assumes CAPEX and FO&M are flat + financing cost trends same for battery storage.

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

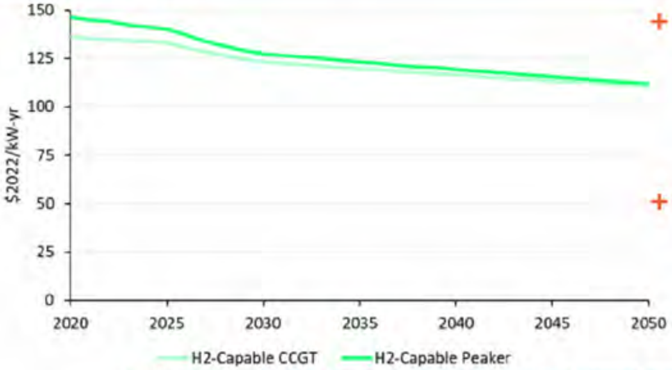
Renewable Options



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

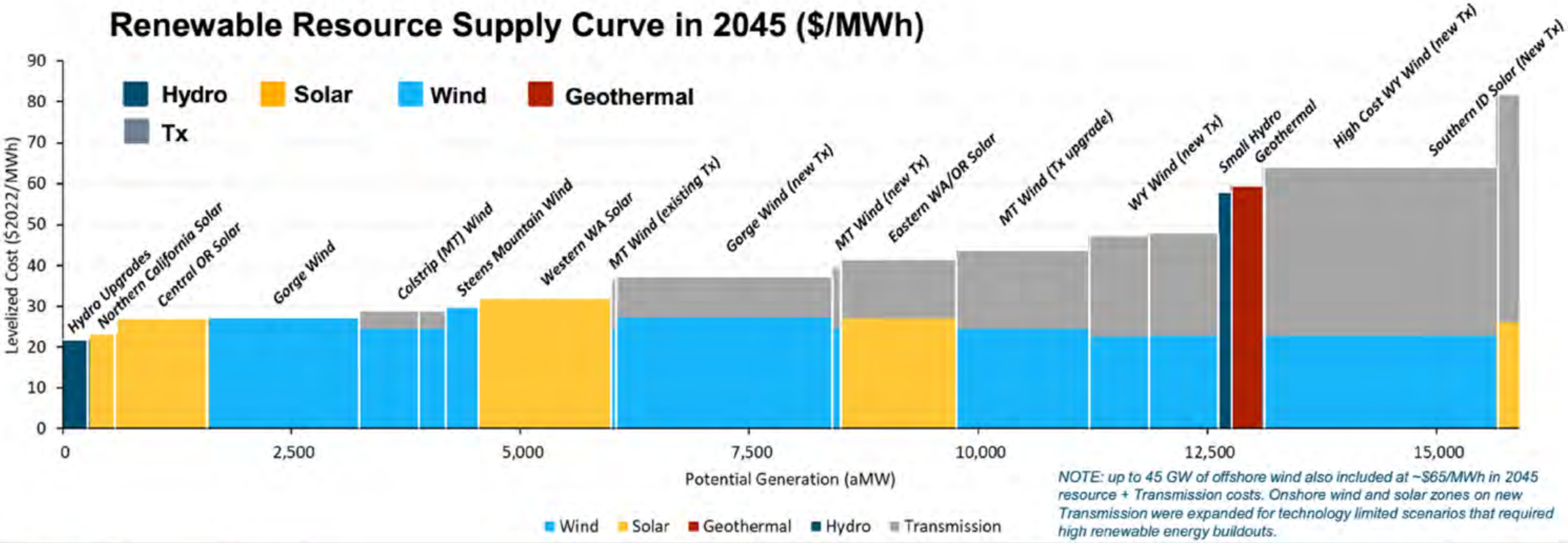


- CCGT and peaker costs are derived from E3's inhouse ProForma which integrates NREL ATB 2021
- New Hydrogen or upgrades include a ~10% additional cost that converges by 2050

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



Renewable Resource Supply Curve in 2045 ($/MWh)

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.

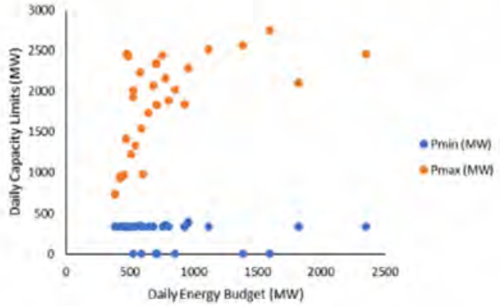
Hydro Operating Data

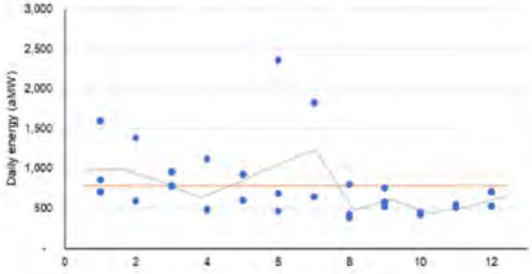
- **Key RESOLVE inputs (for each representative RESOLVE day)**
  - Max generation MW
  - Min generation MW
  - Daily MWh hydro budget
  - Ramp
- **Hydro operating data is parameterized using representative conditions for 3 low/mid/high historical years (2001, 2005, 2011)**
  - Lower Snake River and lower 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%

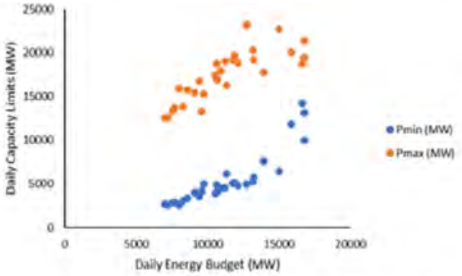


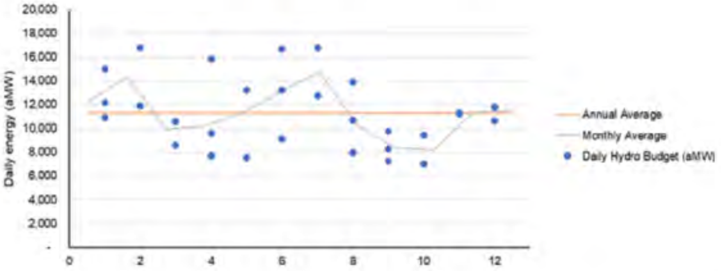


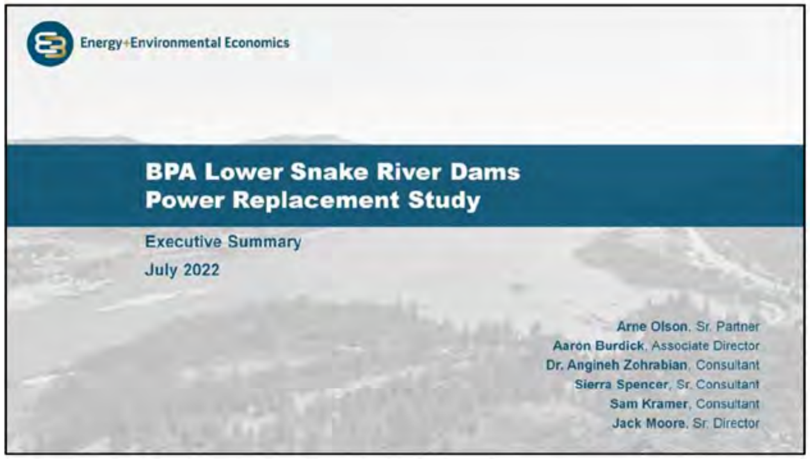
Non-LSR NW Hydro

Ramp Rates

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







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

Who is E3?

Thought Leadership, Fact Based, Trusted.

100+ full-time consultants | 30 years of deep expertise | Engineering, Economics, Mathematics, Public Policy…

San Francisco

New York

Boston

Calgary

E3 Clients

300+ projects per year across our diverse client base

Recent Examples of E3 Projects

Buy-side diligence support on several successful investments in electric utilities (~$10B in total)

Acquisition support for investment in a residential demand response company (~$100M)

Supporting investment in several stand-alone storage platforms and individual assets across North America (10+ GW | ~$1B)

Acquisition support for several portfolios and individual gas-fired and renewable generation assets (20+ GW | ~$2B)

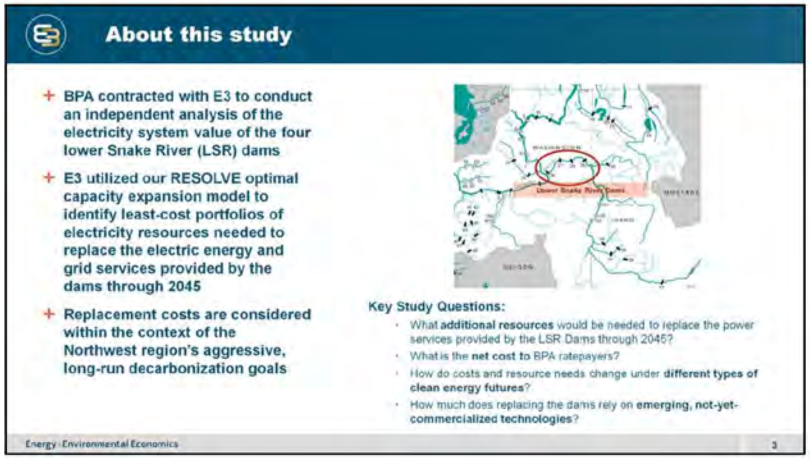
United Nations Deep Decarbonization Pathways Project

California: 100% clean energy planning and carbon market design for California agencies

Net Zero New England study with Energy Futures Initiative

New York: NYSERDA 100% clean energy planning

Pacific Northwest: 100% renewables and resource adequacy studies for multiple utilities

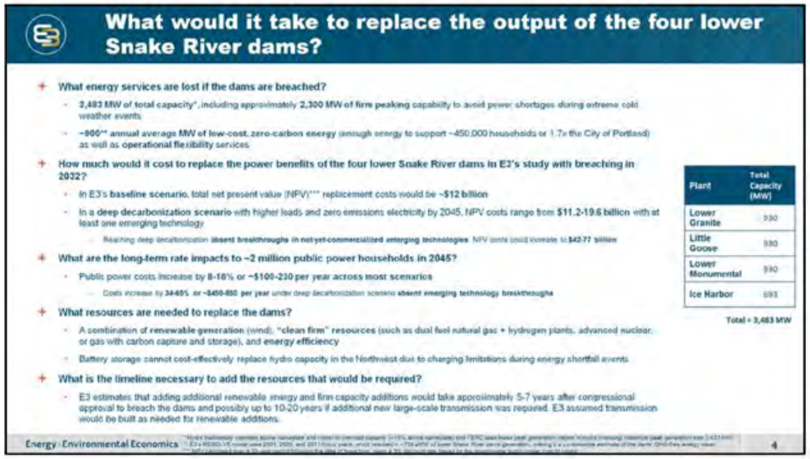


About this study

- **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**?

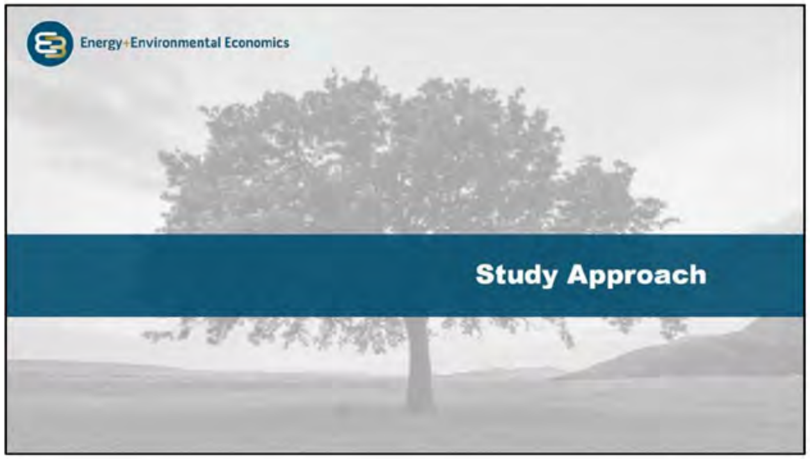


What would it take to replace the output of the four lower Snake River dams?

- **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 **~$12 billion**
  - In a **deep decarbonization scenario** with higher loads and zero emissions electricity by 2045, NPV costs range from **$11.2-19.6 billion** with at least one emerging technology
    - Reaching deep decarbonization **absent breakthroughs in not-yet-commercialized emerging technologies**, NPV costs could increase to **$42-77 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 **34-65% or ~$450-850 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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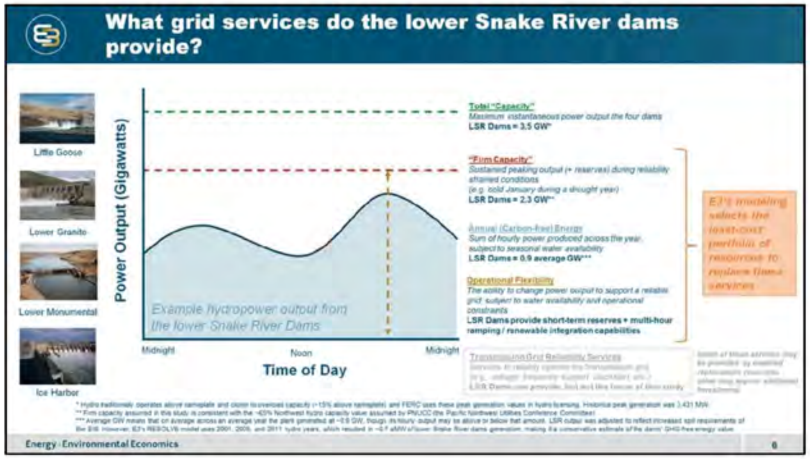
Study Approach



What grid services do the lower Snake River dams provide?

Total "Capacity"
Maximum instantaneous power output the four dams
LSR Dams = 3.5 GW*

"Firm Capacity"
Sustained peaking output (+ reserves) during reliability stressed conditions
(e.g. cold January during a drought year)
LSR Dams = 2.3 GW**

Annual (Carbon-free) Energy
Sum of hourly power produced across the year, subject to seasonal water availability
LSR Dams = 0.9 average GW***

Operational Flexibility
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

Transmission/Grid Reliability Services
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 selected 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

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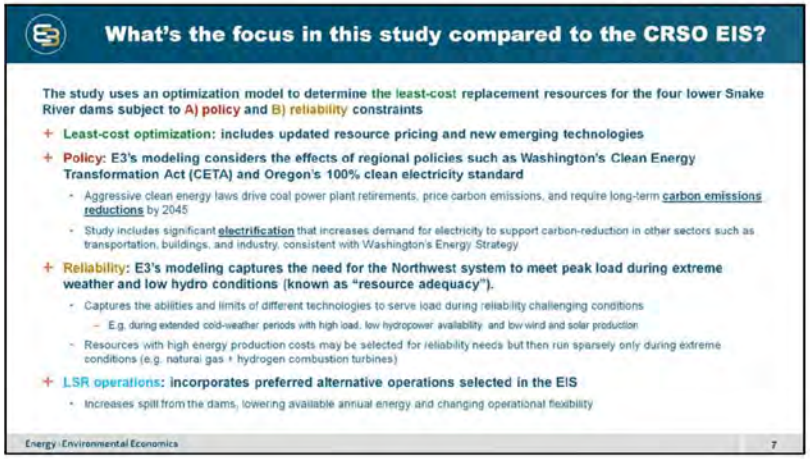
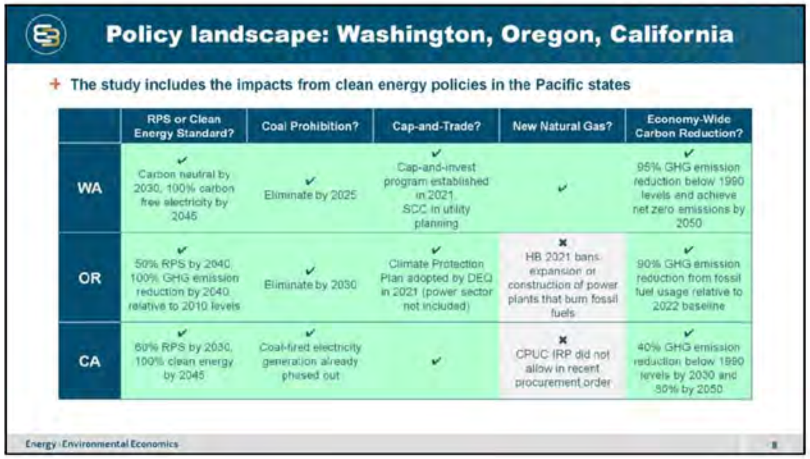


What's the focus in this study compared to the CRSO EIS?

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

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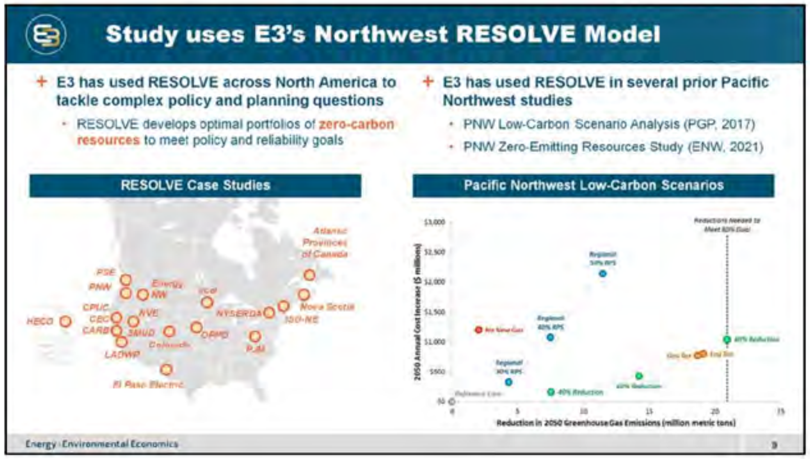
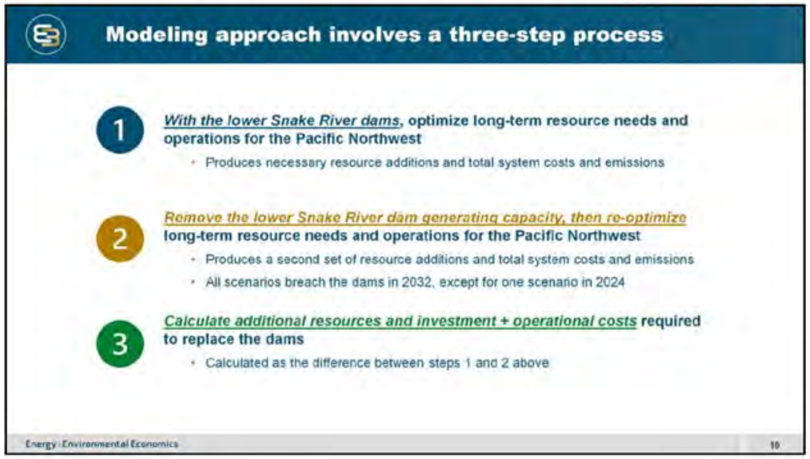


Study uses E3's Northwest RESOLVE Model

- E3 has used RESOLVE across North America to tackle complex policy and planning questions
  - RESOLVE develops optimal portfolios of **zero-carbon resources** to meet policy and reliability goals
- E3 has used RESOLVE in several prior Pacific Northwest studies
  - PNW Low-Carbon Scenario Analysis (PGP, 2017)
  - PNW Zero-Emitting Resources Study (ENW, 2021)

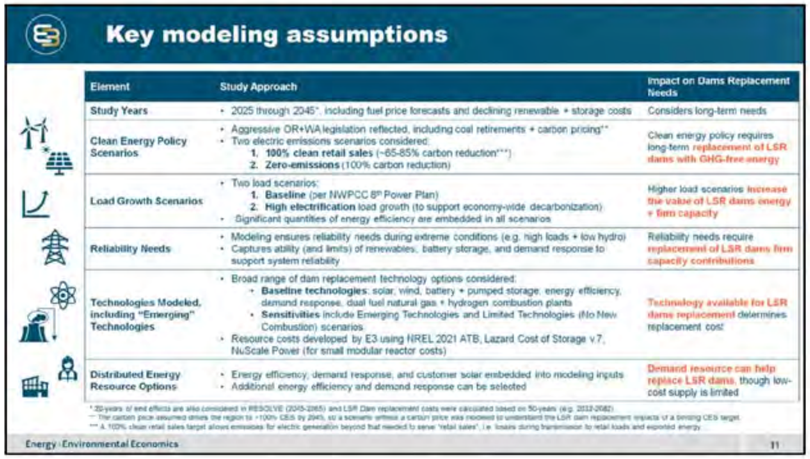
RESOLVE Case Studies

Pacific Northwest Low-Carbon Scenarios



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** (~65-85% 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 also considered in RESOLVE (2045-2065) and LSR Dam replacement costs were calculated based on 50-years (e.g. 2032-2082)

** The carbon price assumed drives the region to ~100% CES by 2045, so a scenario without a carbon price was modeled to understand the LSR dam replacement impacts of a binding CES target

*** 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

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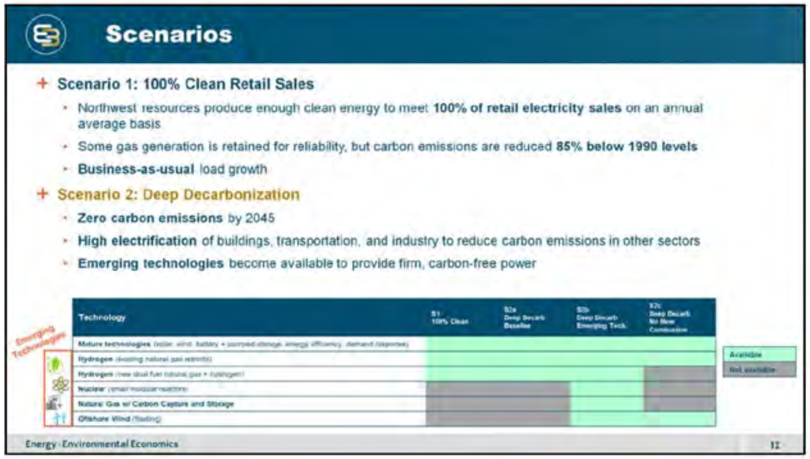

Scenarios

- **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

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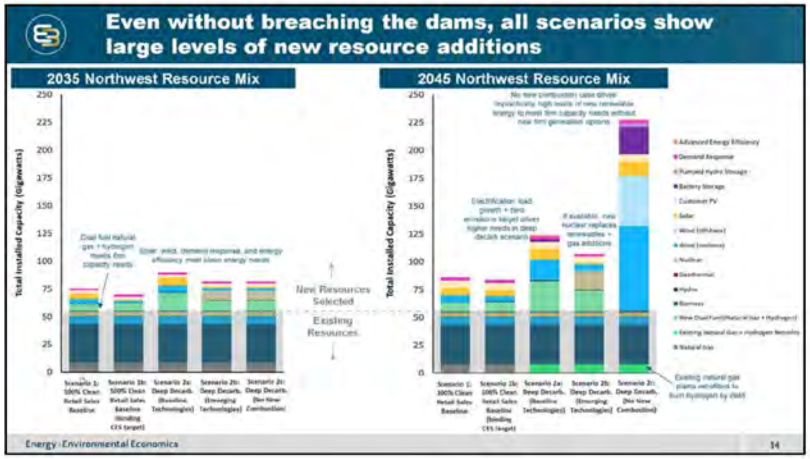
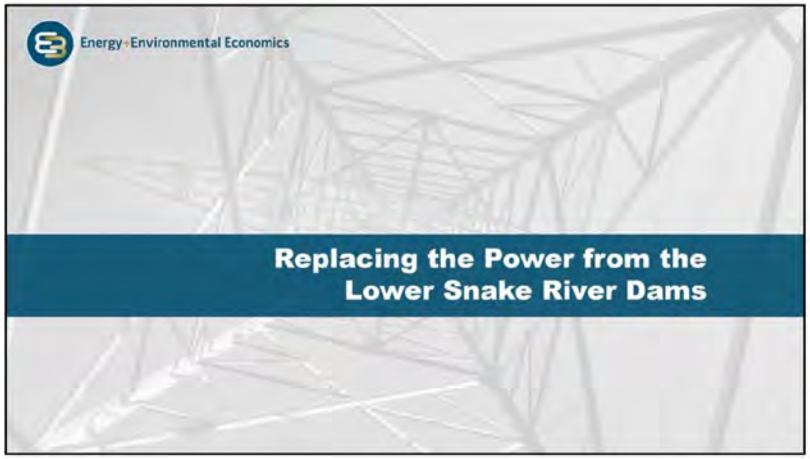
Northwest Resource Needs in Scenarios With the Lower Snake River Dams





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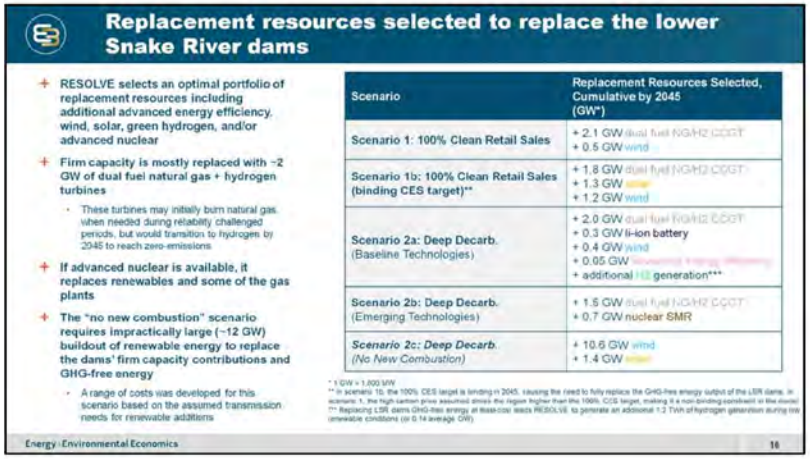
Replacing the Power from the Lower Snake River Dams



Replacement resources selected to replace the lower Snake River dams

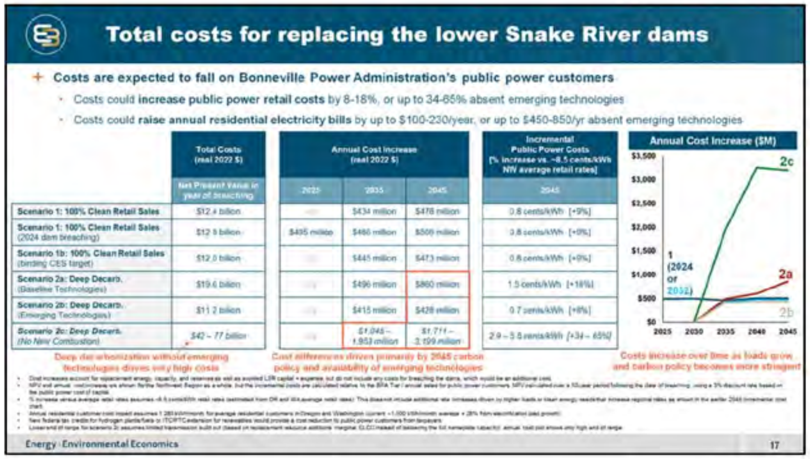
- RESOLVE selects an optimal portfolio of replacement resources including additional advanced energy efficiency, wind, solar, green hydrogen, and/or advanced nuclear
- Firm capacity is mostly replaced with ~2 GW of dual fuel natural gas + hydrogen turbines
  - These turbines may initially burn natural 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
  - A range of costs was developed for this scenario based on the assumed transmission needs for renewable additions

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 1b: 100% Clean Retail Sales (binding CES target)**	+ 1.8 GW dual fuel NG/H2 CCGT + 1.3 GW solar + 1.2 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

** In scenario 1b, the 100% CES target is binding in 2045, causing the need to fully replace the GHG-free energy output of the LSR dams. In scenario 1, the high carbon price assumed drives the region higher than the 100% CES target, making it a non-binding constraint in the model

*** 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 34-65% absent emerging technologies
  - Costs could **raise annual residential electricity bills** by up to $100-230/year, or up to $450-850/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	$12.4 billion	–	$434 million	$478 million	0.8 cents/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$12.9 billion	$495 million	$466 million	$509 million	0.8 cents/kWh [+9%]
Scenario 1b: 100% Clean Retail Sales (binding CES target)	$12.0 billion	–	$445 million	$473 million	0.8 cents/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$19.6 billion	n/a	$496 million	$860 million	1.5 cents/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$11.2 billion	n/a	$415 million	$428 million	0.7 cents/kWh [+8%]
Scenario 2c: Deep Decarb. *(No New Combustion)*	*$42 – 77 billion*	n/a	*$1,045 – 1,953 million*	*$1,711 – 3,199 million*	*2.9 – 5.5 cents/kWh [+34 – 65%]*

Deep decarbonization without emerging technologies drives very high costs

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

Annual Cost Increase ($M)

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

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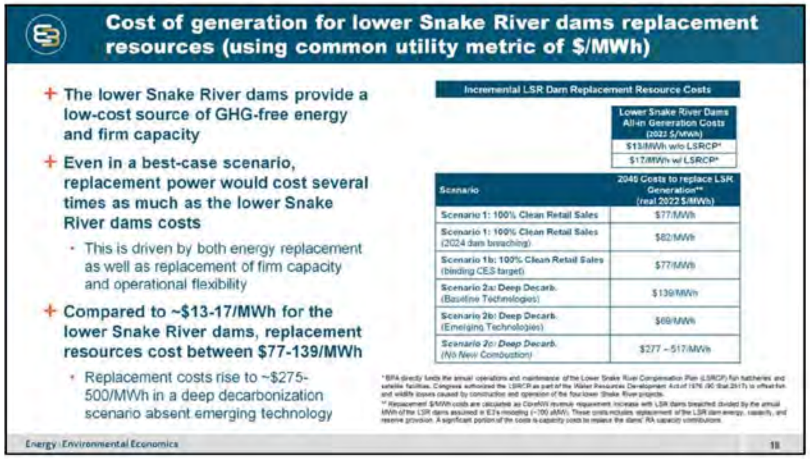


Cost of generation for lower Snake River dams replacement resources (using common utility metric of $/MWh)

- 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 ~$275-500/MWh in a deep decarbonization scenario absent emerging technology

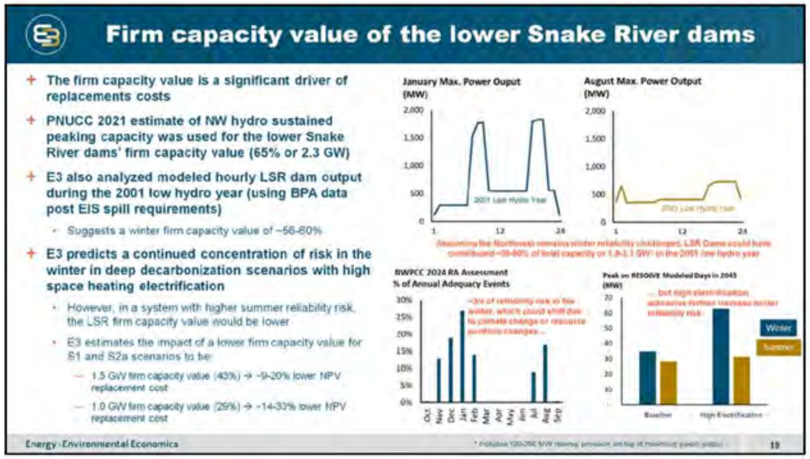
Incremental LSR Dam Replacement Resource Costs

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)
Scenario 1: 100% Clean Retail Sales	$77/MWh
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$82/MWh
Scenario 1b: 100% Clean Retail Sales (binding CES target)	$77/MWh
Scenario 2a: Deep Decarb. (Baseline Technologies)	$139/MWh
Scenario 2b: Deep Decarb. (Emerging Technologies)	$69/MWh
Scenario 2c: Deep Decarb. *(No New Combustion)*	$277 – 517/MWh

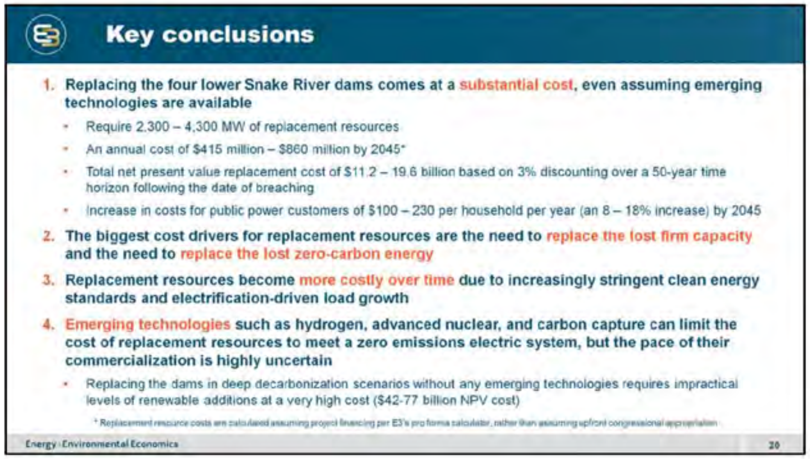
*BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) fish hatcheries and satellite facilities. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat.2917) to offset fish and wildlife losses caused by construction 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 – 4,300 MW of replacement resources
   - An annual cost of $415 million – $860 million by 2045*
   - Total net present value replacement cost of $11.2 – 19.6 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 ($42-77 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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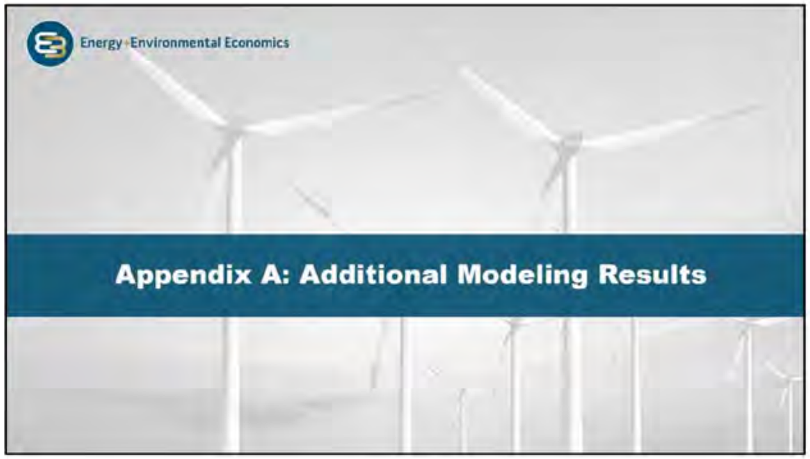
Thank you

Questions, please contact:

Arne Olson, arne@ethree.com

Aaron Burdick, aaron.burdick@ethree.com



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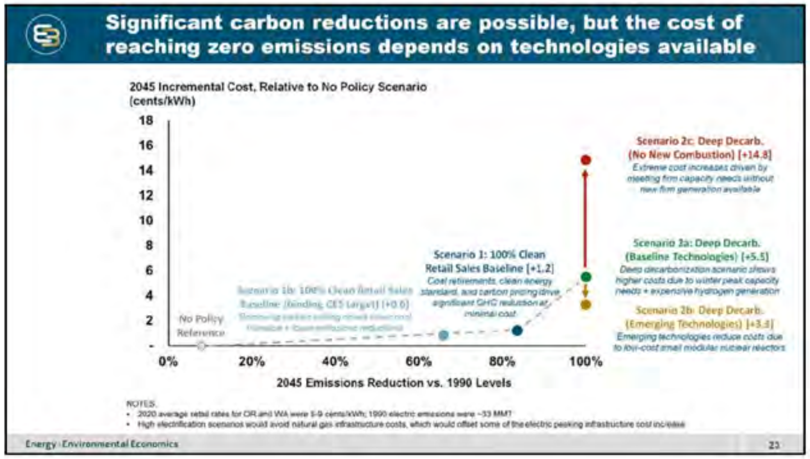
Appendix A: Additional Modeling Results



Significant carbon reductions are possible, but the cost of reaching zero emissions depends on technologies available

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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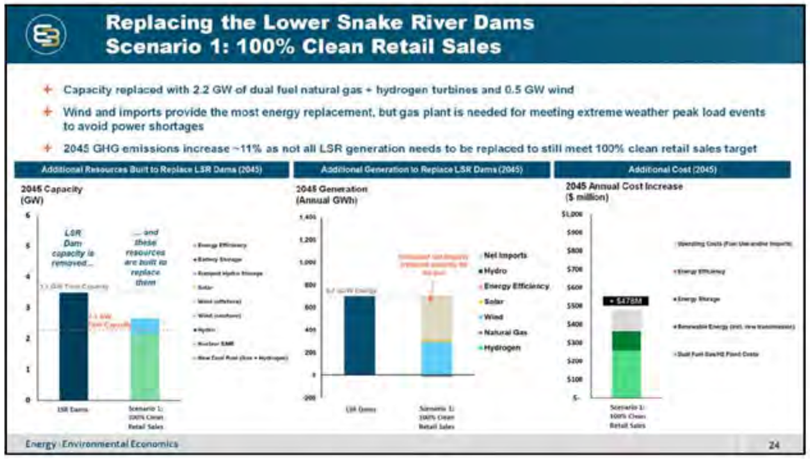
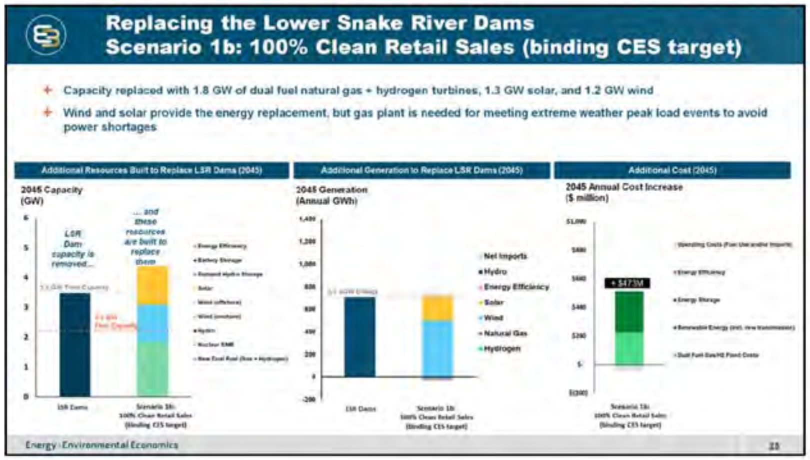


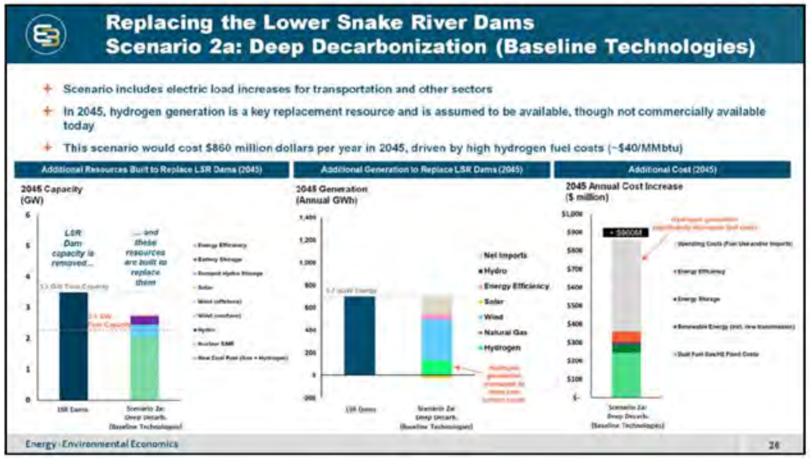
Replacing the Lower Snake River Dams
Scenario 1: 100% Clean Retail Sales

- 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



Replacing the Lower Snake River Dams
Scenario 1b: 100% Clean Retail Sales (binding CES target)

- Capacity replaced with 1.8 GW of dual fuel natural gas + hydrogen turbines, 1.3 GW solar, and 1.2 GW wind
- Wind and solar provide the energy replacement, but gas plant is needed for meeting extreme weather peak load events to avoid power shortages



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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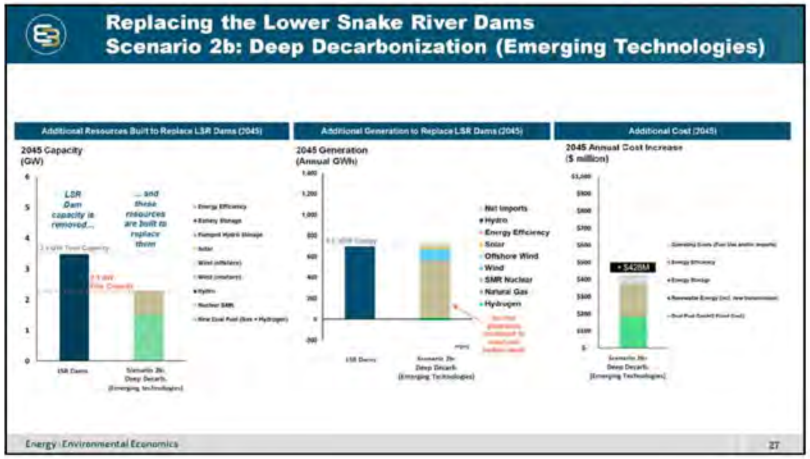

Replacing the Lower Snake River Dams
Scenario 2b: Deep Decarbonization (Emerging Technologies)

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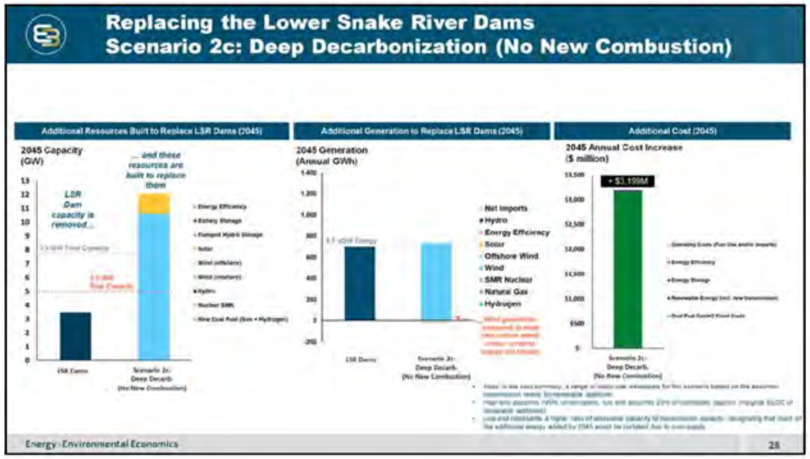

Replacing the Lower Snake River Dams
Scenario 2c: Deep Decarbonization (No New Combustion)

Additional Resources Built to Replace LSR Dams (2045)

Additional Generation to Replace LSR Dams (2045)

Additional Cost (2045)

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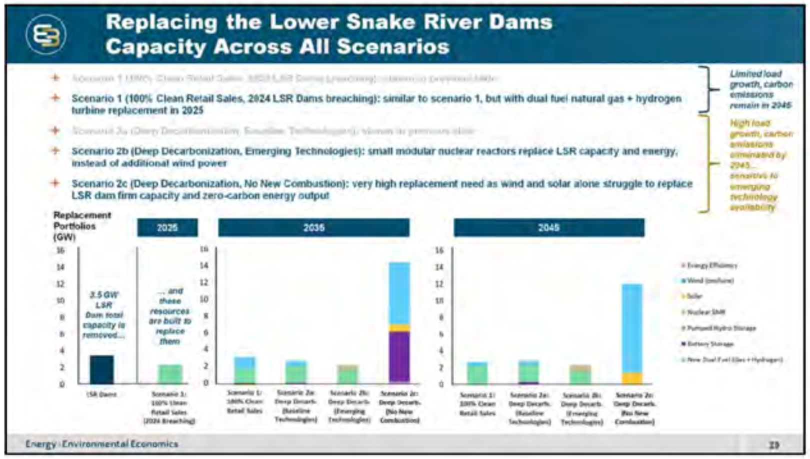

Replacing the Lower Snake River Dams Capacity Across All Scenarios

- 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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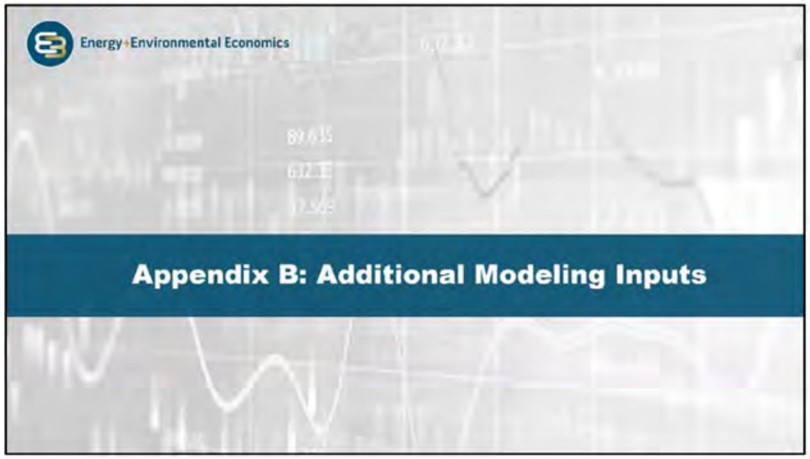

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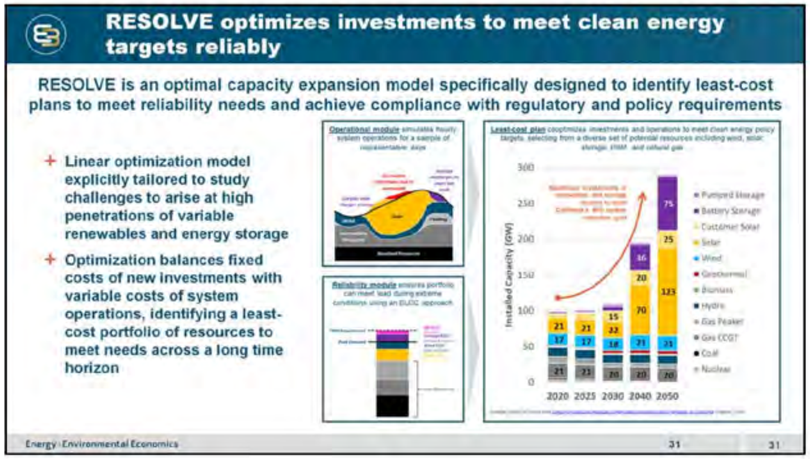
Appendix B: Additional Modeling Inputs



RESOLVE optimizes investments to meet clean energy targets reliably

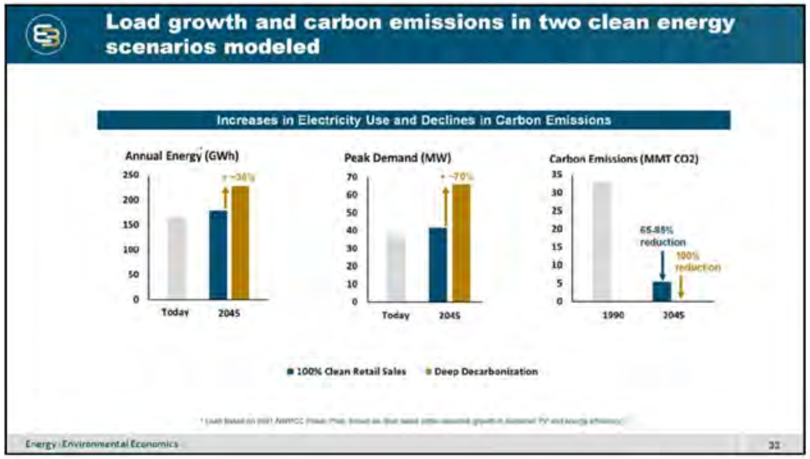
RESOLVE is an optimal capacity expansion model specifically designed to identify least-cost plans to meet reliability needs and achieve compliance with regulatory and policy requirements

- 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

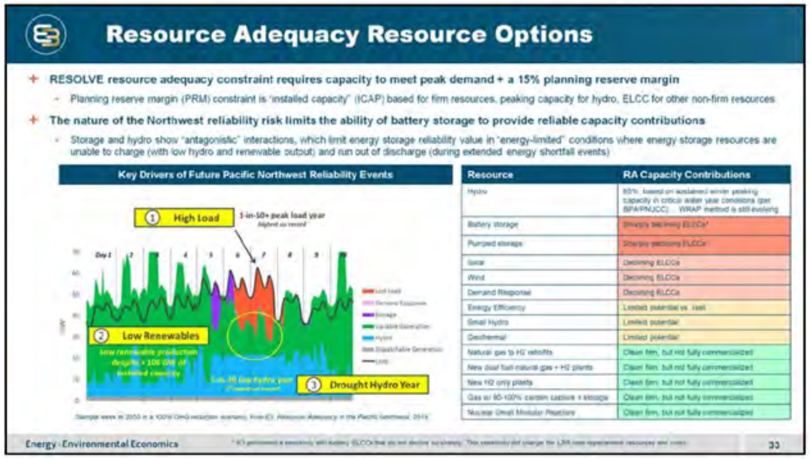
Reliability module ensures portfolio can meet load during extreme conditions using an ELCC approach

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



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
  - 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	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

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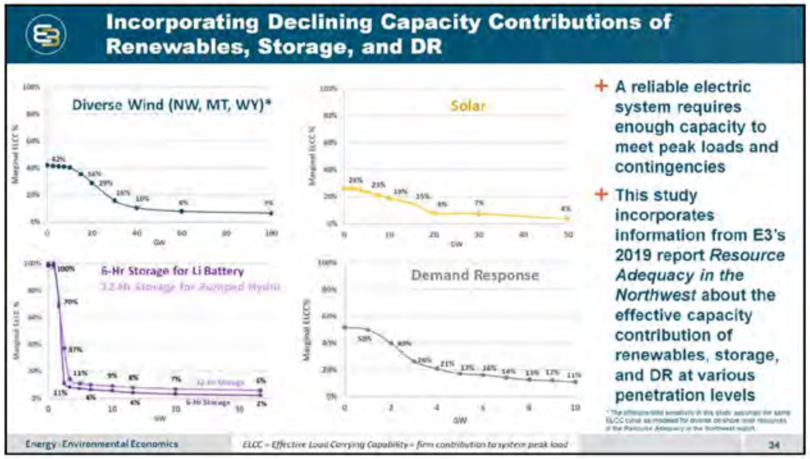
* E3 performed a sensitivity with battery ELCCs that do not decline so sharply. This sensitivity did change the LSR new replacement resources and costs.



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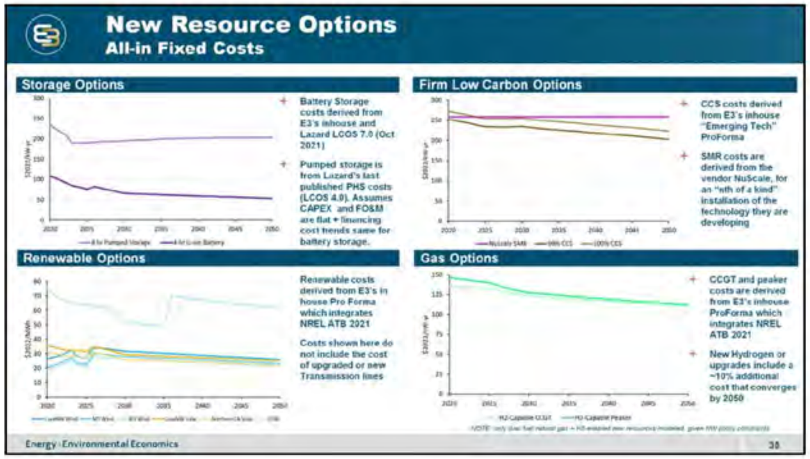
ELCC = Effective Load Carrying Capability = firm contribution to system peak load



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

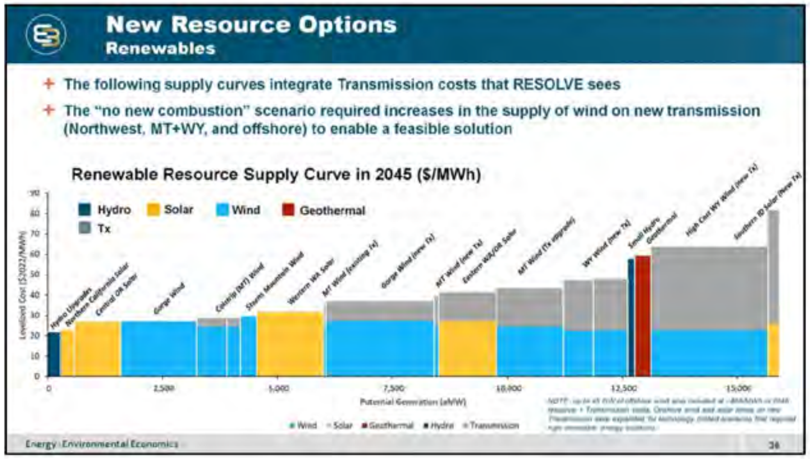
Renewable Options

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

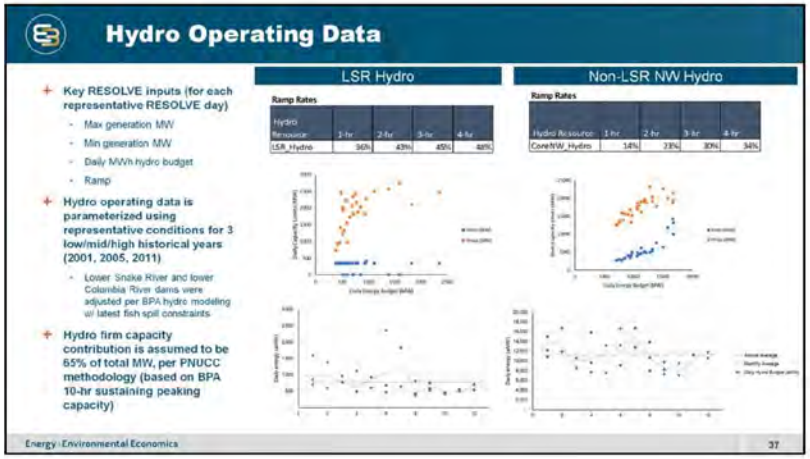


New Resource Options

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

Renewable Resource Supply Curve in 2045 ($/MWh)



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%

From:	Arne Olson <arne@ethree.com>
Sent:	Tuesday, July 5, 2022 5:18 PM
To:	Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian; James,Eve A L (BPA) - PG-5
Subject:	[EXTERNAL] RE: Draft Exec Summary

I'm not on vacation this week. Aaron is the one who is missing the big rollout due to his vacation schedule. ☹

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Tuesday, July 5, 2022 5:16 PM
To: Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: RE: Draft Exec Summary

Got it, thanks.

(I hope you're not trying to be on vacation and have to do this, but I know that's life.)

From: Arne Olson <arne@ethree.com>
Sent: Tuesday, July 5, 2022 5:13 PM
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>
Subject: [EXTERNAL] RE: Draft Exec Summary

Birgit, our data on the cost of retaining the 4 LSR dams all came from BPA. So we have whatever is included in the $17/MWh plus the reduced production based on the most recent biological opinion.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Tuesday, July 5, 2022 4:59 PM
To: Angineh Zohrabian <angineh.zohrabian@ethree.com>; Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Angineh,

One clarification question. The Lower Snake River Comp Plan is not an operation, but actually money that BPA spends elsewhere. (I don't remember specifics, but it might be on fish hatcheries or on restoring streams higher up in the river basin.) Your email indicates that you are including operations, but not the costs aside from operations.

Thanks

From: Koehler,Birgit G (BPA) - PG-5
Sent: Tuesday, July 5, 2022 4:56 PM
To: Angineh Zohrabian <angineh.zohrabian@ethree.com>; Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Arne Olson <arne@ethree.com>
Subject: RE: Draft Exec Summary

Thank you Angineh!

From: Angineh Zohrabian <angineh.zohrabian@ethree.com>
Sent: Tuesday, July 5, 2022 3:26 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: Draft Exec Summary

Hi Birgit,

Since Aaron is out today, I will try to answer your question. Your intuition is right. We modeled the costs of LSRD operations including the costs for fish protection and spill operations in all cases with LSR Dams in. And if LSR dams were out, their operational costs were zero. Therefore, the total cost increases in that table include the cost savings associate with LSR dams operations.

Please let me know if you have other questions.

Best,
Angineh

Angineh Zohrabian, Ph.D., Consultant
Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500 | San Francisco, CA 94104
415-391-5100 | angineh.zohrabian@ethree.com

From: Koehler,Birgit G (BPA) - PG-5
Sent: Tuesday, July 5, 2022 10:23 AM
To: Aaron Burdick; James,Eve A L (BPA) - PG-5; Arne Olson
Cc: Angineh Zohrabian
Subject: RE: Draft Exec Summary

Deliberative, FOIA exempt

Good morning team,

Big **THANKS** for all the hard work, including plenty of scramble toward the end of last week.

No surprise, there is a lot of interest in the final presentation from BPA and DOE. In fact, I've already been peppered with questions this morning. Here is one I'd like to pass to you:

Do you costs of replacing the LSN generation such as in this table from the PPT include the cost savings from not doing mitigation for fish in the LSN? Particularly, Eve might have sent you information on the Lower Snake River Comp Plan. I know you have the $/MWh for LSN w/wo LSRCP for the table on slide 16, but I don't know if you include that or any other fish mitigation cost in your total cost of replacement, in the $millions/year on slide 15.

	Total Costs (real 2022 $)	Annual Cost Increase (real 2022 $)			[% inc NW
	Net Present Value in year of breaching	2025	2035	2045	
1: 100% Clean Retail Sales	$11.8 billion	n/a	$434 million	$478 million	0
1: 100% Clean Retail Sales breaching)	$12.8 billion	$495 million	$466 million	$509 million	0
2a: Deep Decarb. Technologies)	$19.0 billion	n/a	$496 million	$860 million	1.
2b: Deep Decarb. Technologies)	$10.7 billion	n/a	$415 million	$428 million	0
2c: Deep Decarb. ombustion)	*$75.2 billion*	*n/a*	*$1,953 million*	*$3,199 million*	5.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, July 1, 2022 8:56 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

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.

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Sent: Wednesday, June 29, 2022 5:47 PM
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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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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>
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Deliberative, FOIA exempt

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Get Outlook for iOS

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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.

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Deliberative, FOIA exempt
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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.

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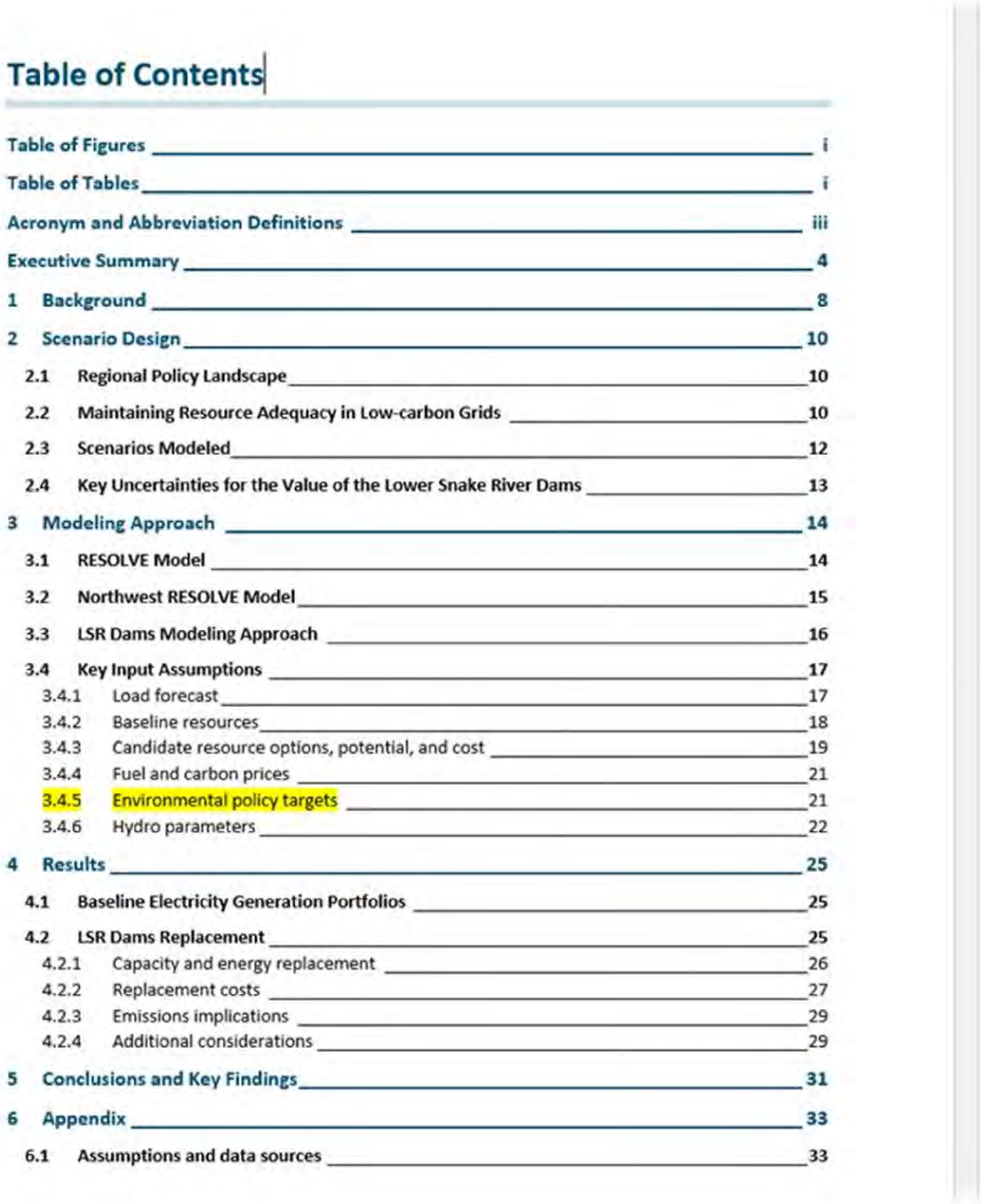
Hi Eve,

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

From: James,Eve A L (BPA) - PG-5
Sent: Friday, July 1, 2022 9:20 PM
To: Aaron Burdick; Arne Olson
Cc: Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian
Subject: [EXTERNAL] RE: Draft Exec Summary

Thanks Aaron- I am off to the (b)(6) but Birgit will be available for any questions next week.

On Jul 1, 2022 8:57 PM, Aaron Burdick <aaron.burdick@ethree.com> wrote:
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>
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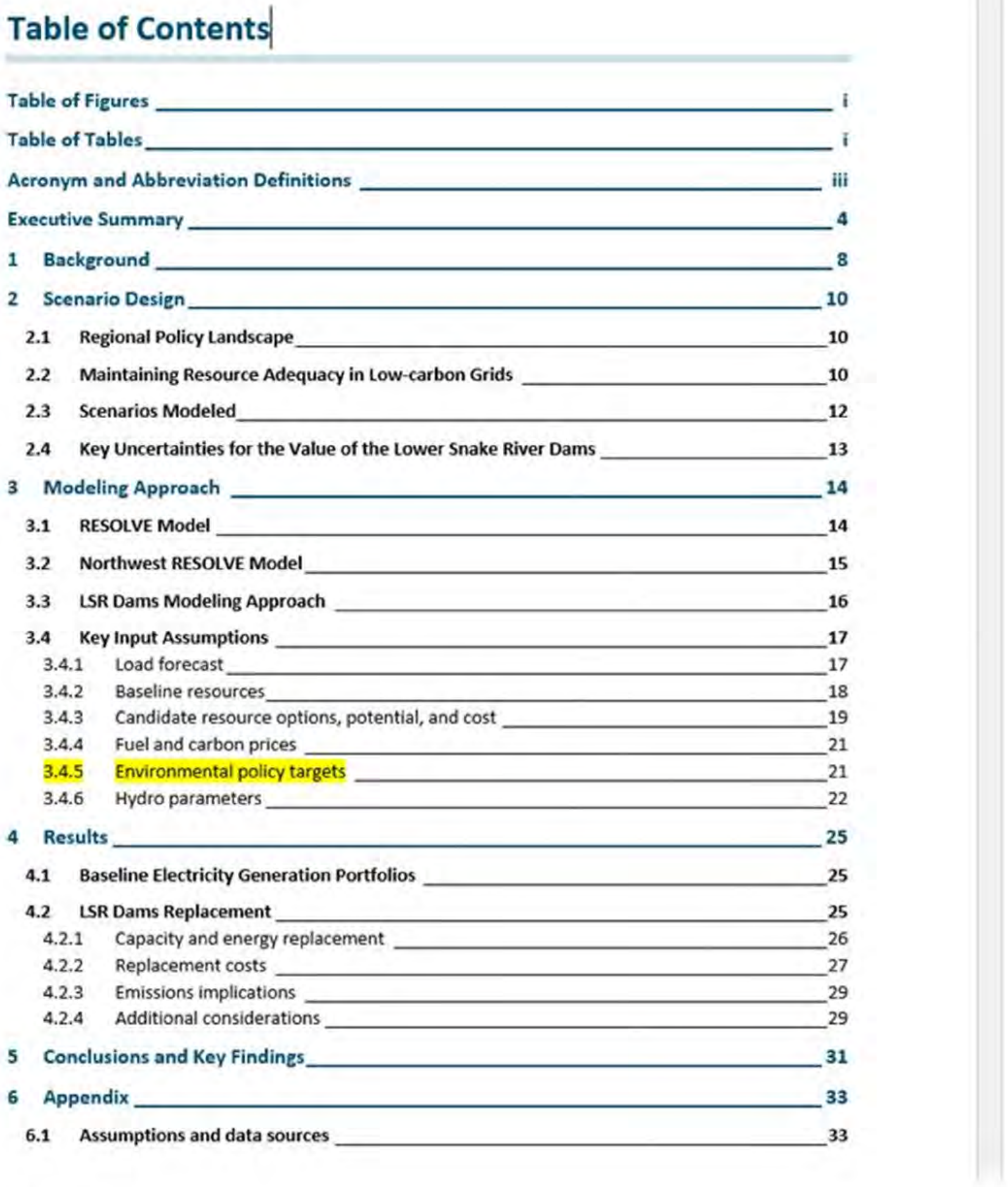

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44 Montgomery Street, Suite 1500 | San Francisco, CA 94104

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

From: Koehler,Birgit G (BPA) - PG-5
Sent: Thursday, August 4, 2022 8:33 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

And that capitalization isn't necessarily worth fixing. So all is good

From: Arne Olson <arne@ethree.com>
Sent: Thursday, August 4, 2022 8:32 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] RE: E3 Response to Renewables Northwest Critique of 4 LSRD study

Thanks Birgit, I think the real deadline is today so I will make a quick update to the capitalization and send over. I had already noted in the parenthetical that Energy Strategies didn't replace all the firm capacity so I think we are covered there.

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Thursday, August 4, 2022 8:27 AM
To: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: E3 Response to Renewables Northwest Critique of 4 LSRD study

Never mind. I see that I was too late. Completely my fault, but your reply looks great.

From: Koehler,Birgit G (BPA) - PG-5
Sent: Thursday, August 4, 2022 8:25 AM
To: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: E3 Response to Renewables Northwest Critique of 4 LSRD study

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
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)

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
Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500 | San Francisco, CA 94104
415-391-5100, ext. 307 | (b)(6) (mobile) | arne@ethree.com
he/him/his

ACORD®

CERTIFICATE OF LIABILITY INSURANCE

DATE(MM/DD/YYYY)
11/03/2021

THIS CERTIFICATE IS ISSUED AS A MATTER OF INFORMATION ONLY AND CONFERS NO RIGHTS UPON THE CERTIFICATE HOLDER. THIS CERTIFICATE DOES NOT AFFIRMATIVELY OR NEGATIVELY AMEND, EXTEND OR ALTER THE COVERAGE AFFORDED BY THE POLICIES BELOW. THIS CERTIFICATE OF INSURANCE DOES NOT CONSTITUTE A CONTRACT BETWEEN THE ISSUING INSURER(S), AUTHORIZED REPRESENTATIVE OR PRODUCER, AND THE CERTIFICATE HOLDER.

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Holder Identifier :

PRODUCER
Aon Risk Insurance Services West, Inc.
Los Angeles CA Office
707 Wilshire Boulevard
Suite 2600
Los Angeles CA 90017-0460 USA

CONTACT NAME:
PHONE (A/C. No. Ext): (866) 283-7122
FAX (A/C. No.): (800) 363-0105
E-MAIL ADDRESS:

INSURED
Energy and Environmental Economics, Inc.
(E3)
2401 East Katella Avenue, Suite 300
Anaheim CA 92806 USA

	INSURER(S) AFFORDING COVERAGE	NAIC #
INSURER A:	Travelers Property Cas Co of America	25674
INSURER B:	The Travelers Indemnity Co of CT	25682
INSURER C:	Lexington Insurance Company	19437
INSURER D:		
INSURER E:		
INSURER F:		

COVERAGES **CERTIFICATE NUMBER:** 570090178244 **REVISION NUMBER:**

THIS IS TO CERTIFY THAT THE POLICIES OF INSURANCE LISTED BELOW HAVE BEEN ISSUED TO THE INSURED NAMED ABOVE FOR THE POLICY PERIOD INDICATED. NOTWITHSTANDING ANY REQUIREMENT, TERM OR CONDITION OF ANY CONTRACT OR OTHER DOCUMENT WITH RESPECT TO WHICH THIS CERTIFICATE MAY BE ISSUED OR MAY PERTAIN, THE INSURANCE AFFORDED BY THE POLICIES DESCRIBED HEREIN IS SUBJECT TO ALL THE TERMS, EXCLUSIONS AND CONDITIONS OF SUCH POLICIES. LIMITS SHOWN MAY HAVE BEEN REDUCED BY PAID CLAIMS. **Limits shown are as requested**

INSR LTR	TYPE OF INSURANCE	ADDL INSD	SUBR WVD	POLICY NUMBER	POLICY EFF (MM/DD/YYYY)	POLICY EXP (MM/DD/YYYY)	LIMITS	
A	☒ COMMERCIAL GENERAL LIABILITY ☐ CLAIMS-MADE ☒ OCCUR ☐ ☐ GEN'L AGGREGATE LIMIT APPLIES PER: ☒ POLICY ☐ PRO-JECT ☐ LOC ☐ OTHER:			P6307J366586TIL21	11/09/2021	11/09/2022	EACH OCCURRENCE DAMAGE TO RENTED PREMISES (Ea occurrence) MED EXP (Any one person) PERSONAL & ADV INJURY GENERAL AGGREGATE PRODUCTS - COMP/OP AGG	$1,000,000 $1,000,000 $15,000 $1,000,000 $2,000,000 $2,000,000
B	AUTOMOBILE LIABILITY ☒ ANY AUTO ☐ OWNED AUTOS ONLY ☐ SCHEDULED AUTOS ☐ HIRED AUTOS ONLY ☐ NON-OWNED AUTOS ONLY ☐ ☐			810-7N676545-21-43-G	11/09/2021	11/09/2022	COMBINED SINGLE LIMIT (Ea accident) BODILY INJURY (Per person) BODILY INJURY (Per accident) PROPERTY DAMAGE (Per accident)	$1,000,000
A	☒ UMBRELLA LIAB ☒ OCCUR ☐ EXCESS LIAB ☐ CLAIMS-MADE DED ☐ RETENTION			CUP9056X9762143	11/09/2021	11/09/2022	EACH OCCURRENCE AGGREGATE	$1,000,000 $1,000,000
A	WORKERS COMPENSATION AND EMPLOYERS' LIABILITY Y / N ANY PROPRIETOR / PARTNER / EXECUTIVE OFFICER/MEMBER EXCLUDED? N (Mandatory in NH) If yes, describe under DESCRIPTION OF OPERATIONS below	N / A		UB0L6636782143G	11/09/2021	11/09/2022	☒ PER STATUTE ☐ OTH-ER E.L. EACH ACCIDENT E.L. DISEASE-EA EMPLOYEE E.L. DISEASE-POLICY LIMIT	 $1,000,000 $1,000,000 $1,000,000
C	Archit&Eng Prof			028174912 SIR applies per policy terms & conditions	11/09/2021	11/09/2022	Aggregate Per Claim	$2,000,000 $1,000,000

Certificate No : 570090178244

DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES (ACORD 101, Additional Remarks Schedule, may be attached if more space is required)

RE: RFP No. 4792.
Bonneville Power Administration and its agents, officers, directors and employees are included as Additional Insured in accordance with the policy provisions of the General Liability and Automobile Liability policies. General Liability policy evidenced herein is Primary and Non-Contributory to other insurance available to an Additional Insured, but only in accordance with the policy's provisions. A Waiver of Subrogation is granted in favor of Bonneville Power Administration in accordance with the policy provisions of the General Liability, Automobile Liability, Professional Liability and Workers' Compensation policies.

CERTIFICATE HOLDER

Bonneville Power Administration
905 NE 11th Avenue
Portland OR OR 97232 USA

CANCELLATION

SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, NOTICE WILL BE DELIVERED IN ACCORDANCE WITH THE POLICY PROVISIONS.

AUTHORIZED REPRESENTATIVE

Aon Risk Insurance Services West, Inc.

ACORD 25 (2016/03)

From: James,Eve A L (BPA) - PG-5
Sent: Thursday, June 16, 2022 11:03 AM
To: Peterson,Melissa J (BPA) - NSSF-4400-2
Cc: Bellcoff,Steve (BPA) - PGPR-5
Subject: RE: BPA-22-C-89829 Add Task

Okay- does it make sense to expand task 4 to include these additional meetings or does it need a new task since this line item is a NTE construct?

From: Peterson,Melissa J (BPA) - NSSF-4400-2 <mjpeterson@bpa.gov>
Sent: Wednesday, June 15, 2022 2:49 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Subject: RE: BPA-22-C-89829 Add Task

Eve,

Sounds good. Yes, I concur – let's capture as much as possible in this modification's NTE Line Item to reduce the need of future modifications.

You may contact me with any questions at 360-619-6088 or mjpeterson@bpa.gov.

Melissa J. Peterson
Team Lead | Contracting Officer (NSSF) | Corporate & Infrastructure | Facilities | Technology Team
Special Emphasis Program Manager – Veterans Employment Program
Secretary: Military Veterans Resource Group (MVRG)
BONNEVILLE POWER ADMINISTRATION | U.S. DOE
bpa.gov | P 360.619.6088| C (b)(6) [redacted] | E mjpeterson@bpa.gov

INTEGRITY | KINDNESS | ENTHUSIASM | CONSISTENCY | FUN

"Every man has his secret sorrows which the world knows not; and often times we call a man cold when he is only sad." – Henry Wadsworth Longfellow

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From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, June 15, 2022 2:47 PM
To: Peterson,Melissa J (BPA) - NSSF-4400-2 <mjpeterson@bpa.gov>
Cc: Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Subject: RE: BPA-22-C-89829 Add Task

Thanks Melissa- I will work on filling this out. The presentation we originally added will take place tomorrow. There is a lot of regional interest in the study so currently I know of requests for 2 additional meetings, one for Congressional representatives and one for the Public Power Council. Because the timing of scheduling these is unknown (and Congress takes a summer break at some point) we might need to extend the contract date to late fall. I will ask around with some of our Public Relations staff on potential timing. If we do a line item NTE maybe we should add a budget for up to 3 or 4 meetings so we don't have to do additional modifications? I will ask some Executives if they think there will be more than the 2 meetings requested.

From: Peterson,Melissa J (BPA) - NSSF-4400-2 <mjpeterson@bpa.gov>
Sent: Wednesday, June 15, 2022 2:39 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Subject: RE: BPA-22-C-89829 Add Task

Hi Eva,

I am agreeable to move forward with adding an additional line item as an NTE; however, I do have a few clarification questions.

1. Is the presentation the same presentation identified in Line Item 0005 – Task 4; Public Presentation & Summary or is it a different study presentation?
2. This contract is set to expire 7/30/2022; if we add this new task; how will we know when this contract has accomplished its mission?
    a. Do you have a period of performance end-date in mind?
3. Attached is the Statement of Work, please add your additional task requirements and highlight those additions;
4. Provide a budgetary estimate to include level of effort of what Bonneville anticipates this task will require in order to be accomplished.

Labor Category	Rate	Hour	Extended
Senior Partner	(b)(4) [redacted]		
Director	[redacted]		
Associate Director	[redacted]		
Senior Consultant	[redacted]		

Please complete the attached CCR Checklist, and create the CCR once you have your period of performance end date, and not-to-exceed amount identified.

You may contact me with any questions at 360-619-6088 or mjpeterson@bpa.gov.

Melissa J. Peterson
Team Lead | Contracting Officer (NSSF) | Corporate & Infrastructure | Facilities | Technology Team
Special Emphasis Program Manager – Veterans Employment Program
Secretary: Military Veterans Resource Group (MVRG)
BONNEVILLE POWER ADMINISTRATION | U.S. DOE
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INTEGRITY | KINDNESS | ENTHUSIASM | CONSISTENCY | FUN

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From: Peterson,Melissa J (BPA) - NSSF-4400-2
Sent: Tuesday, June 14, 2022 9:22 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Subject: RE: BPA-22-C-89829-M-001 FE

Eve,

This is something we will need to discuss, as this contract was setup as a FFP, and not Time and Materials. Changing the structure of the contract isn't possible. Let me review the terms & scope and I'll setup a meeting to discuss how we can move forward.

You may contact me with any questions at 360-619-6088 or mjpeterson@bpa.gov.

Melissa J. Peterson
Team Lead | Contracting Officer (NSSF) | Corporate & Infrastructure | Facilities | Technology Team
Special Emphasis Program Manager – Veterans Employment Program
Secretary: Military Veterans Resource Group (MVRG)
BONNEVILLE POWER ADMINISTRATION | U.S. DOE
bpa.gov | P 360.619.6088| C (b)(6) E mjpeterson@bpa.gov

INTEGRITY | KINDNESS | ENTHUSIASM | CONSISTENCY | FUN

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From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, June 14, 2022 8:54 AM
To: Peterson,Melissa J (BPA) - NSSF-4400-2 <mjpeterson@bpa.gov>
Cc: Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Subject: RE: BPA-22-C-89829-M-001 FE

Good Morning-
Due to the interest in this study we are trying to work with scheduling a meeting for E3 to present study results to the Power Council. It is unclear when the meeting will fit into schedules this summer and if the materials will need to be updated. Also, due to the extreme interest in the study there may be more requests for meetings. Contracting-wise is it possible to put in a "not to exceed" budget or something a little more flexible since the exact request isn't known? Just looking for what types of options might be available for this need.

Thanks,
Eve

From: Peterson,Melissa J (BPA) - NSSF-4400-2 <mjpeterson@bpa.gov>
Sent: Tuesday, May 24, 2022 7:29 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Subject: BPA-22-C-89829-M-001 FE

Good morning,

Attached is a copy of the fully executed modification for your records.

You may contact me with any questions at 360-619-6088 or mjpeterson@bpa.gov.

Melissa J. Peterson
Team Lead | Contracting Officer (NSSF) | Corporate & Infrastructure | Facilities
Special Emphasis Program Manager – Veterans Employment Program

Secretary: Military Veterans Resource Group (MVRG)
BONNEVILLE POWER ADMINISTRATION | U.S. DOE
bpa.gov | P 360.619.6088| C (b)(6) | E mjpeterson@bpa.gov

INTEGRITY | KINDNESS | ENTHUSIASM | CONSISTENCY | FUN

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From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, May 23, 2022 11:36 AM
To: Peterson,Melissa J (BPA) - NSSF-4400-2 <mjpeterson@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Subject: [EXTERNAL] RE: BPA-22-C-89829-M-001 (needs signature)

E3 signed copy attached.

Thanks!
Aaron

From: Peterson,Melissa J (BPA) - NSSF-4400-2 <mjpeterson@bpa.gov>
Sent: Wednesday, May 18, 2022 7:39 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Subject: BPA-22-C-89829-M-001 (needs signature)

Good morning Aaron,

Please review, sign and return the attached modification to my attention at mjpeterson@bpa.gov at your earliest convenience.

You may contact me with any questions at 360-619-6088 or mjpeterson@bpa.gov.

Melissa J. Peterson
Team Lead | Contracting Officer (NSSF) | Corporate & Infrastructure | Facilities
Special Emphasis Program Manager – Veterans Employment Program
Secretary: Military Veterans Resource Group (MVRG)
BONNEVILLE POWER ADMINISTRATION | U.S. DOE
bpa.gov | P 360.619.6088| C (b)(6) E mjpeterson@bpa.gov

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