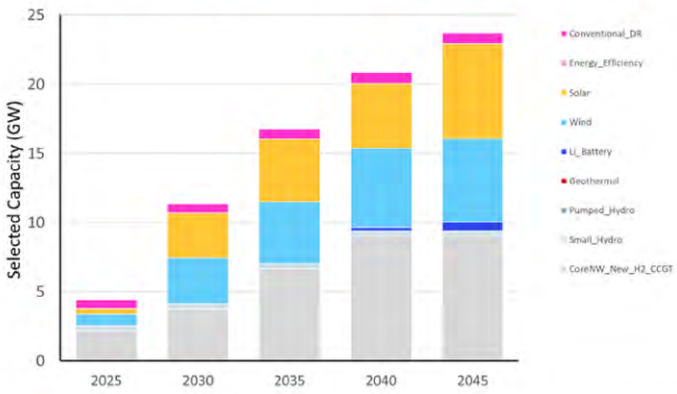
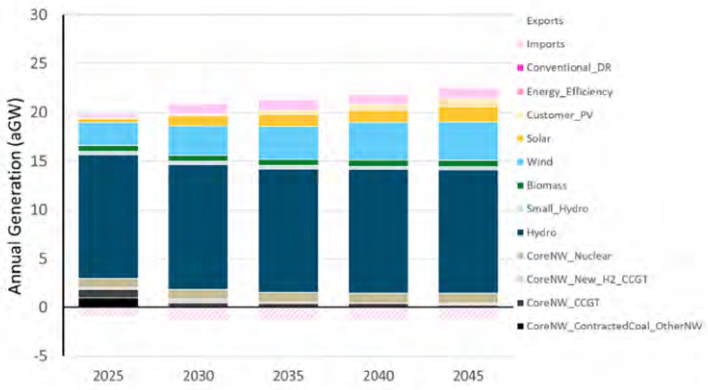
S1: Baseline – 100% Clean Retail Sales

With Carbon Price

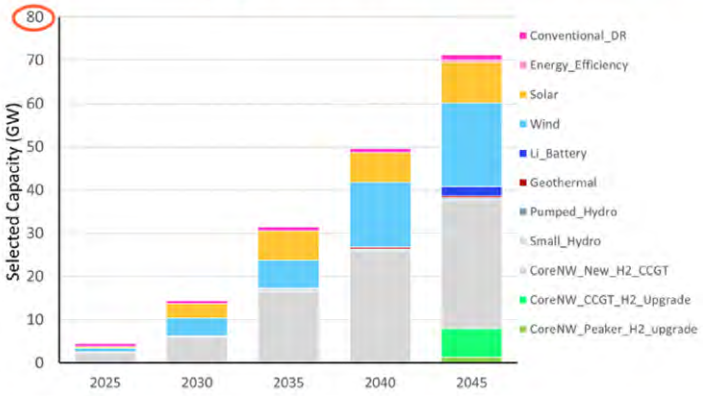
+ **With a 100% Clean Retail Sales requirement by 2045, forced coal retirements, and a carbon price, resource adequacy is the most binding constraint, followed by CES**
  - New build of dual fuel plants (gas + H_2) needed to provide reliability; these plants burn gas first, then H2 in 2045
  - Region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

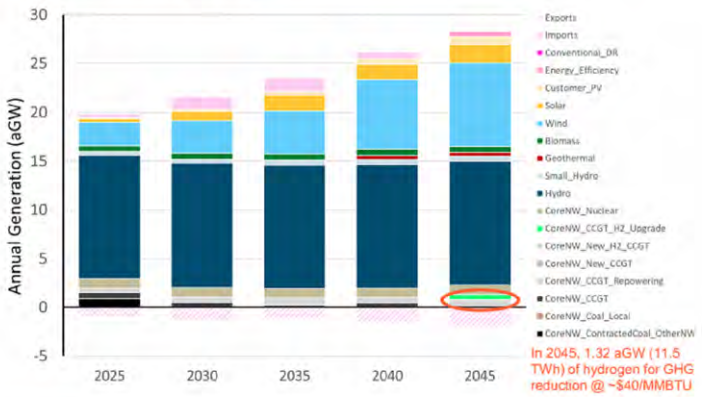




S2: Deep Decarbonization

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



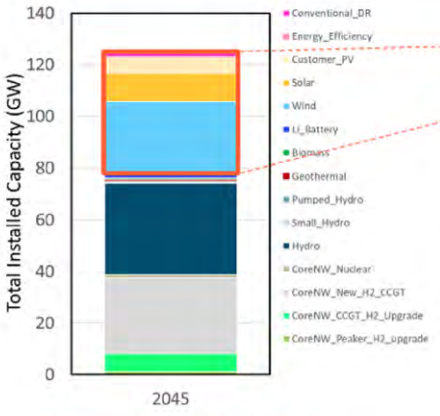


S2: Deep Decarbonization – Resource Adequacy Needs

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

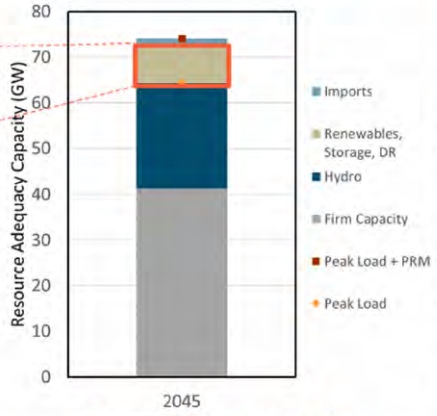
2045 Deep Decarbonization Scenario Results

Installed Nameplate Capacity (GW)



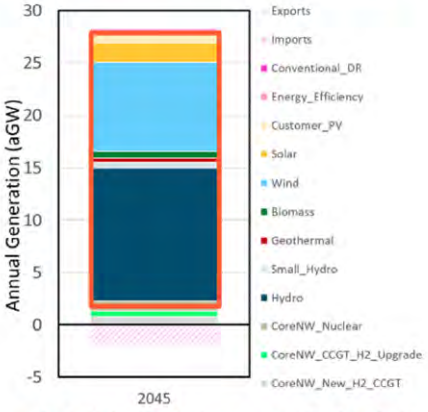
Renewables, storage, and DR provide significant installed MW…

Resource Adequacy Capacity (GW)



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

Annual Generation (TWh)

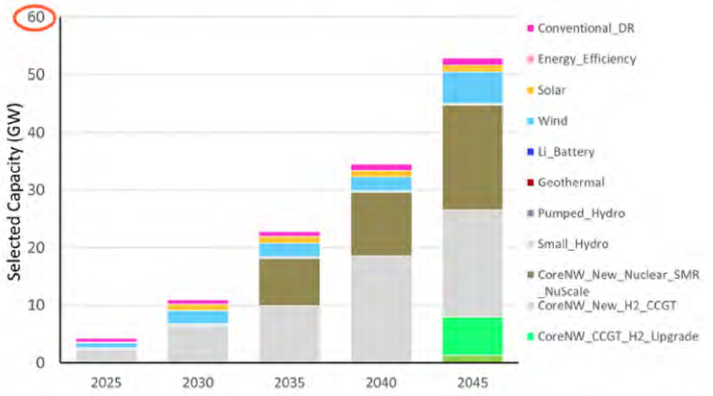


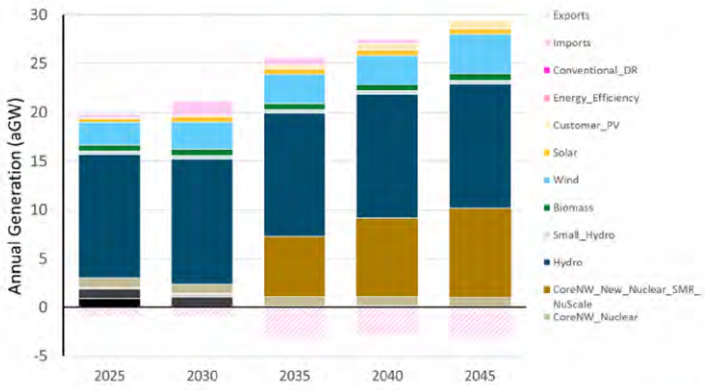
…due to high costs, hydrogen generation is limited to low hydro, low renewable periods; renewables + hydro + nuclear provide 95% of annual energy

S2b: Deep Decarbonization – Emerging Technology

+ With nuclear SMR available, renewable energy build is minimized

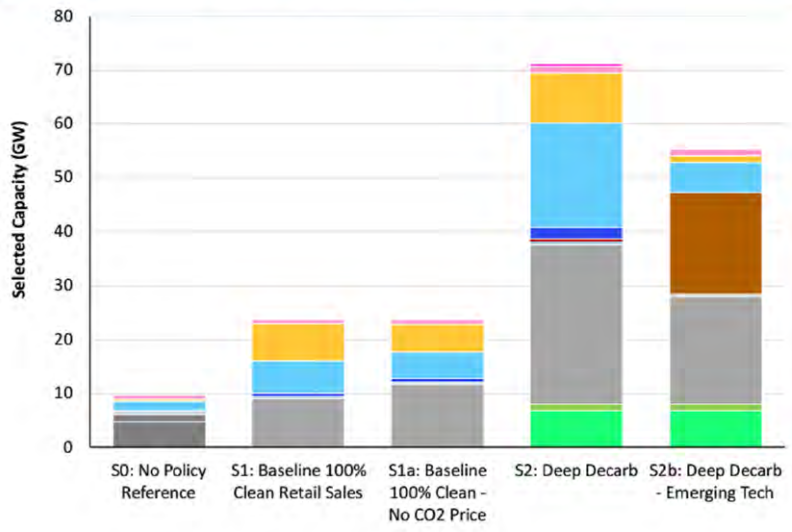
- Lower build of new resources (~50 GW in 2045 vs. ~70 GW in the S2 Deep Decarb case)
- Large buildout of nuclear SMR and new + retrofitted hydrogen plants provide RA capacity needs
- Nuclear SMR provides zero-carbon energy for Northwest and results in increased exports to other regions
  - No expensive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



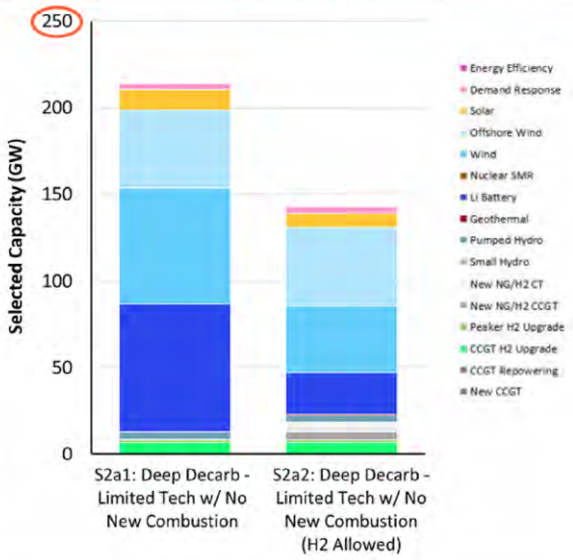


Comparison of 2045 Cumulative Selected Capacity

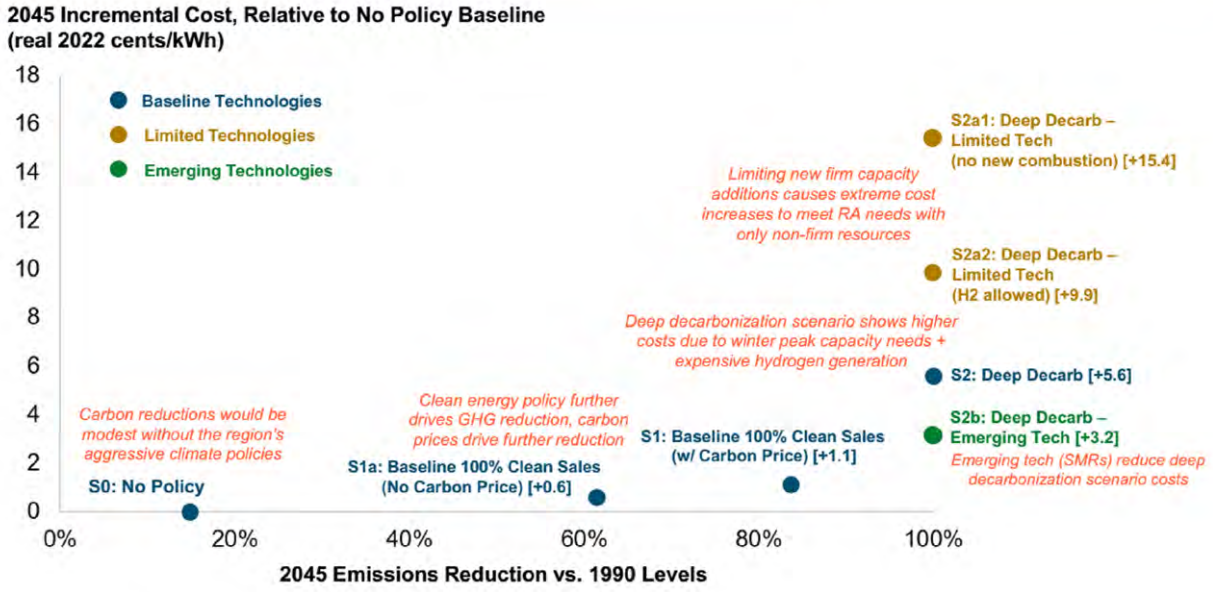
Baseline and Emerging Technology Scenarios



Limited Technology Scenarios



Decarbonization Scenarios Cost Impacts



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

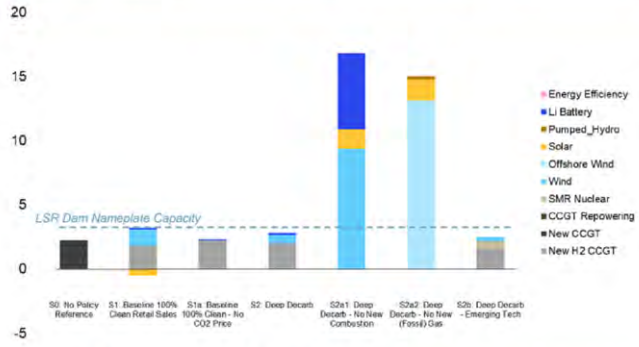
Summary of No LSR Dam RESOLVE Analysis

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

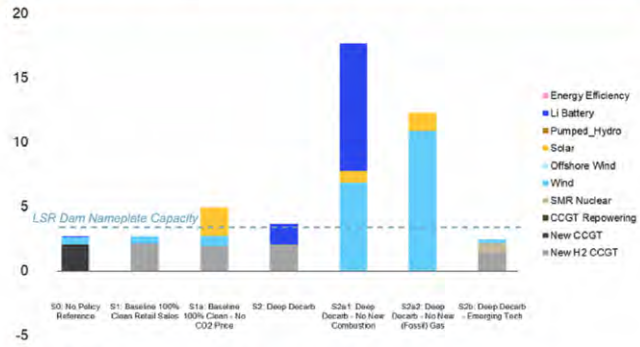
Cost increases account for replacement energy, capacity, and reserves as well as avoided LSR capital + expense, but do not include any costs for breaching the dams, which would be an additional cost.

Replacement Resource Needs

LSR Dam Replacement Portfolio in 2035 (GW)



LSR Dam 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

Replacement Resource Costs

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

Incremental LSR Dam Replacement Resource Costs

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

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

* Replacement $/MWh costs are calculated as CoreNW revenue requirement increase with LSR dams removed divided by the annual MWh of the LSR dams. These costs includes replacement of the LSR dam energy, capacity, and reserve provision. A significant portion of the costs is capacity costs to replace the dams' RA capacity contributions.
** Incremental BPA customers costs calculated as the incremental annual revenue requirement divided by BPA's Tier 1 annual sales (~58,686 GWh/yr per FY2022 BPA forecast)

Next steps

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