Department of Energy

Bonneville Power Administration
P.O. Box 3621
Portland, Oregon 97208-3621

FREEDOM OF INFORMATION ACT/PRIVACY PROGRAM

October 29, 2024

In reply refer to: FOIA #BPA-2023-00855-F

Andrew Missel
Advocates for the West
3701 SE Milwaukie Ave., Ste. B
Portland, OR 97202
Email: amissel@advocateswest.org

Dear Mr. Missel,

This communication is the Bonneville Power Administration's (BPA) third partial response to your request for records, submitted to the agency under the Freedom of Information Act, 5 U.S.C. § 552 (FOIA). Your request was received on April 20, 2023, and formally acknowledged on May 11, 2023. A first partial release of records was provided to you on July 31, 2024, and a second partial release was provided to you on September 16, 2024.

Request

"…the records described below concerning the relationship between the Bonneville Power Administration ("BPA") and Energy and Environmental Economics, Inc. ("E3")—specifically, records pertaining to the Lower Snake River Dams Replacement Study ("LSRD Study") commissioned by BPA and prepared by E3 that was released in July 2022:

1. All contracts, statements of work, and similar documents between BPA and E3 that were prepared or executed in connection with the LSRD Study;
2. All communications between BPA and E3 that relate in any way to the LSRD Study, including any communications concerning the LSRD Study's release, press stories about the LSRD Study, etc.;
3. All records that document, memorialize, or refer to any meetings, conversations, or other communications between BPA and E3 concerning the LSRD Study; and
4. All internal BPA memos, emails, etc. that refer to the LSRD Study."

Any reference to an entity—such as "BPA" or "E3"—includes all employees and agents of that entity as well as the entity itself and any division thereof. Requesters seek records from any time up until the time of search."

Clarifications

Following email exchanges with the agency's FOIA Public Liaison between June 22, 2023 and June 28, 2023, you amended the scope of your FOIA request to, "…limit the search … to include only those communications that have someone from E3 on one end…" and "…re-scope the request to seek only ‘all emails from [DATE] to the date of search that include anyone from E3 in any address field (e.g., to, from, cc),’ where [DATE] is either January 1, 2019 or some later date that, according to knowledgeable BPA personnel, marks the start of BPA's efforts to commission the LSRD Study. Of course, I would like any attachments to responsive emails as well.” This was in addition to the records BPA had already collected.

Third Partial Response

To both accommodate the review of the large volume of responsive records and to provide the records expediently within the limitations of available agency resources, BPA is releasing responsive records to you in installments, as permitted by the FOIA.

A third partial release of responsive records accompanies this communication. The third partial comprises 1,999 pages of responsive records and three Excel workbooks, with redactions applied under the following:

- One exemption applied under 5 U.S.C. § 552(b)(4).
- 184 exemptions applied under 5 U.S.C. § 552(b)(6).

A more detailed explanation of the applied exemptions follows.

Explanation of Exemptions

The FOIA generally requires the release of all agency records upon request. However, the FOIA permits or requires withholding certain limited information that falls under one or more of nine statutory exemptions (5 U.S.C. §§ 552(b)(1-9)).

<u>Exemption 4</u>

Exemption 4 protects “trade secrets and commercial or financial information obtained from a person [that is] privileged or confidential.” (5 U.S.C. § 552(b)(4)). Information is considered commercial or financial in nature if it relates to business or trade. This exemption is intended to protect the interests of both the agency and third-party submitters of information. Prior to publicly releasing agency records, BPA was required by Exemption 4 to solicit objections to the public release of any third party’s confidential commercial information contained in the responsive records set. BPA provided Energy and Environmental Economics, Inc. (“E3”) with an opportunity to formally object to the public release of their information contained in BPA records. E3 submitted a small number of objections to BPA, consisting of hourly rates for individuals working on the project. BPA accepted those objections, based on guidance available from the U.S. Department of Justice. The FOIA does not permit discretionary release of information otherwise protected by Exemption 4.

<u>Exemption 6</u>

Exemption 6 serves to protect Personally Identifiable Information (PII) contained in agency records when no overriding public interest in the information exists. BPA does not find an overriding public interest in a release of the information redacted under Exemption 6—

specifically, Webex meeting passcodes, signatures, cell phone numbers, personal information about availability, and comments sent from a private citizen to E3. This information sheds no light on the executive functions of the agency and BPA finds no overriding public interest in its release. BPA cannot waive these redactions, as the protections afforded by Exemption 6 belong to individuals and not to the agency.

Certification
Pursuant to 10 C.F.R. § 1004.7(b)(2), I am the individual responsible for the partial release and exemption determinations described above.

Next Partial Release Target Date
BPA continues to review and process the remaining responsive records collected in response to your request. The remaining records include internal records and those containing information belonging to the Council on Environmental Quality and the Department of Energy. We are consulting with those agencies to determine if they have objections to the release of their information. To accommodate this review, the agency estimates a final records release date of December 31, 2024.

We appreciate your patience as the agency works towards completing your request. If you have any questions about the content of this communication, please contact FOIA Program Lead Jason Taylor at jetaylor@bpa.gov or 503-230-3537. You may also contact FOIA Public Liaison James King at jjking@bpa.gov or 503-230-7621.

Sincerely,

Candice D. Palen
Freedom of Information/Privacy Act Officer

Responsive agency records accompany this communication.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, June 24, 2022 3:12 PM
To: James,Eve A L (BPA) - PG-5
Cc: Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian; Arne Olson
Subject: [EXTERNAL] Draft Exec Summary
Attachments: E3_ExecSummaryDraft_062422.docx

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:	Arne Olson <arne@ethree.com>
Sent:	Monday, August 1, 2022 10:27 PM
To:	Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5
Cc:	Aaron Burdick
Subject:	[EXTERNAL] Draft response to Renewable Northwest op ed
Attachments:	E3 Renewables-NW Response 2022-08-01.docx

DELIBERATIVE FOIA EXEMPT

Hi Birgit and Eve,

Please find a draft response to the Renewable Northwest op-ed attached. Aaron has not yet had a chance to review so the final version may look a bit different from this, but I thought it might be helpful to get it to you at this stage to see if you have any substantive feedback. Please let me know. We are trying to get this to Mark O by EOD Wednesday.

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) [redacted] mobile) | arne@ethree.com
he/him/his

Energy+Environmental Economics
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Response to Renewable Northwest Op-Ed

August 1

Renewable Northwest published an op-ed in the July 22, 2022 edition of Clearing Up criticizing E3's Lower Snake River Dams Power Replacement Study, prepared on behalf of the Bonneville Power Administration. The op-ed is critical of E3's modeling for "not fully capturing the value of existing renewables and battery storage" and not accounting for the impact of climate change on hydro and load. Unfortunately, the op-ed is simplistic and belies a fundamental lack of understanding of the dynamics of deeply-decarbonized and highly-renewable power systems, particularly when in service of an economy-wide carbon reduction goal.

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

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

– is necessary to achieve carbon emissions reductions beyond approximately 80% due to the limitations of variable renewables and short-duration storage.[1]

E3's study assumes that hydrogen-capable combustion turbines are available to fill this role in most scenarios. Other options are advanced nuclear, fossil generation with carbon capture, and long-duration energy storage. These emerging technologies dramatically reduce the cost of achieving deep decarbonization – and the cost of replacing existing clean firm resources such as the Lower Snake River dams – relative to scenarios without them. E3's study not only fully captures the value of wind, solar and storage, but optimistically assumes that additional resources are available to complement them, resources that are not commercially available today.

The electricity sector's twin tasks of serving load reliably while reducing carbon emissions are intensified when considering electricity's role in achieving economy-wide decarbonization. Extensive electrification of transportation and building sector loads, called for in every economy-wide pathways study including Washington's 2021 State Energy Strategy[2], will significantly increase peak electricity demands, particularly during winter cold spells during which natural gas currently supplies over two-thirds of heating demand.

While a warming climate, diminishing snowpack and deteriorating load-resource balance will almost certainly lead to summertime reliability challenges in the Northwest over the next decade, meeting wintertime heating demands will be the largest reliability issue in the long run, even for southern systems such as California[3] and Texas[4]. Maintaining resource adequacy in the Pacific Northwest will requiring fully replacing the Four Lower Snake dams' wintertime

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

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

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

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

peaking capabilities. The op-ed disappointingly does not mention electrification or appear to consider its impact on regional electric loads.

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

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

- The op-ed suggests that a full-year production simulation model would be better able to capture the complementary nature of wind, solar, batteries and hydro. In fact, RESOLVE's internal production simulation algorithms are fully capable of capturing these operational dynamics. In fact, RESOLVE likely *over-optimizes* the dispatch of storage and renewable resources relative to hybrid resources with operational constraints caused by reliance on a single inverter or interconnection limit. Neither RESOLVE nor production simulation models accurately capture the ability of various resources to provide resource adequacy. That's why RESOLVE uses results from a Loss-of-Load Probability model, in this case E3's RECAP model which was used in our 2019 Study *Resource Adequacy in the Pacific Northwest*[5], to characterize the resource adequacy contribution of various resources.

- E3's study is criticized for not selecting hybrid solar and storage resources, which have a very high ELCC values for Idaho Power's system, to replace the dams. However, Idaho Power's and other IRP-related assessments of renewable ELCC values are focused on *the value of those resources today and in the near future*. Because there is very little solar and battery storage in the Pacific Northwest today, these resources have relatively high capacity value on strongly summer-peaking systems like Idaho Power. However, it is well understood that as more variable and duration-limited

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

resources are added to a power system, their marginal capacity value declines[6]. Because E3's study is optimizing the replacement resources on a system with zero or near zero carbon emissions, the baseline system includes tens of thousands of MW of new solar and wind resources. The marginal capacity contribution from adding *even more* wind and solar is very small, hence the model finds it more cost-effective to add hydrogen-capable combustion turbines which are very effective at providing capacity even though their dispatch costs are high.

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

+ The op-ed's criticism of E3's reliance on historical weather data to characterize the resource adequacy contribution of the dams is fair. As discussed above, this study relies on the results of E3's 2019 study of resource adequacy in the region to provide input parameters. Utilization of projected climate-altered weather and hydro conditions would likely have shown more reliability challenges in the summertime when the dams' peaking capability is reduced. To evaluate this possibility, E3 did include a sensitivity case with the peaking capability reduced from 2.3 GW to 1.0 GW. The replacement costs were estimated to be 14-33% lower than in the base scenarios. More importantly, this line of criticism ignores the fact that electrification of heating load is likely to drive wintertime peak electric loads up by 50% or even more. Serving load reliably during extreme cold weather events is expected to be the single biggest challenge for decarbonized energy systems around the world, a challenge against which wind, solar and batteries are largely ineffective.

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

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 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.

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.

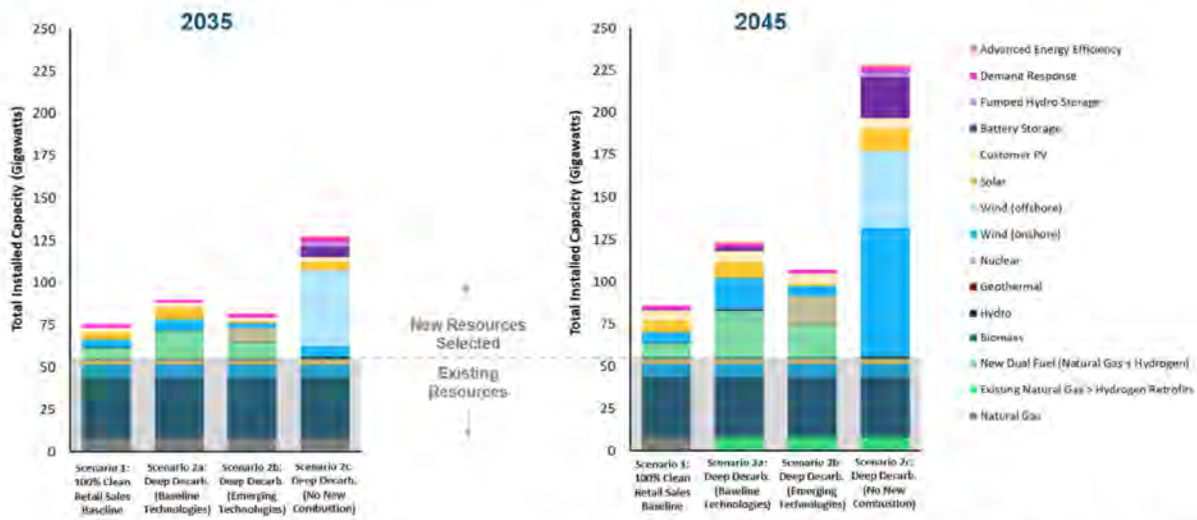
Table 1. Scenario Design

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

[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.

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 GW 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 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 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.

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



When 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 burn 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.

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.

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

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 advanced EE + 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%]

[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.

Scenario 2c: Deep Decarbonization (No New Combustion)	+ 10.6 GW wind + 1.4 GW solar	$46 billion	–	$1,953 million/yr	$3,199 million/yr	5.5 ¢/kWh [+65%]

KEY FINDINGS:

- ***Replacing the four lower Snake River dams while meeting clean energy goals and system reliability is possible but comes at a substantial cost***, even assuming emerging technologies are available:
  - Requires 2,300 – 2,700 MW of replacement resources
  - An annual cost of $415 million – $860 million by 2045
  - Total net present value cost of $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:	James,Eve A L (BPA) - PG-5
Sent:	Wednesday, July 13, 2022 9:34 AM
To:	Aaron Burdick; Arne Olson
Subject:	[EXTERNAL] RE: [EXTERNAL] RE: Briefing scheduling

Great- I'll let them know and get back to you on timing.

On Jul 13, 2022 9:31 AM, Aaron Burdick <aaron.burdick@ethree.com> wrote:
I can be free anytime between 9am-2pm PST on Monday.
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, July 13, 2022 9:24 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: Briefing scheduling
Ok thanks Arne. Aaron are you available?
On Jul 13, 2022 9:21 AM, Arne Olson <arne@ethree.com> wrote:
I'm tied up all day Monday at a client site.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, July 13, 2022 9:19 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>
Subject: Briefing scheduling
Hi Aaron and Arne-
There is a scheduling conflict with the briefing tomorrow. Would any time Monday between 9 AM and 2 PM work for rescheduling the 30 - 45 min briefing?

From:	Arne Olson <arne@ethree.com>
Sent:	Thursday, June 2, 2022 6:09 PM
To:	Aaron Burdick; James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5
Subject:	[EXTERNAL] RE: BPA-E3

But I think you can just assume a uniform 1.5 cent/kWh increase in power costs across all classes. That's probably a better way to get to the total household bill impacts.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 4:27 PM
To: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

I want to make sure we don't cross our wires on these cost metrics.

We are reporting:

- **Avg retail rate impact**: total RESOLVE RRQ increase divided by 2022 BPA Tier I load,
    - e.g. Case S2a: $860M in 2045 divided by 58,686 GWh/yr = 1.5 cents/kWh
- **Household cost impact**: retail rate impact * 1,000 kWh/mo * 12 mo/yr * 128% (electrification annual energy increase)
    - e.g. Case S2a: 1.5 cent/kWh * 1,280 kWh/mo * 12 mo/yr = $230/yr
- **Residential cost impact or total households impacted**:
    - This requires us to assume how much of the total RRQ impact is allocated to residential customers:
        - E.g. $860M * 40% = $344 million residential
        - $344 million divided by $230/yr/household = 1.5 million households
            - OR, if I don't adjust the electrification load increase and effectively stick with the 2022 Tier I rates, I get $180/yr. $344m / $180/yr/household → ~1.91 million households

So... shall we just say 2 million households? Or does BPA have specific data on residential customers we should use? For now I'll use 2 million unless I hear otherwise.

From: Arne Olson <arne@ethree.com>
Sent: Thursday, June 2, 2022 3:28 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: BPA-E3

I imagine only about 40% of the sales are residential, so the 4.9 million would be closer to 2 million, which is in the ballpark of what I would have expected. We can get more exact numbers from EIA Sales & Revenue if needed.

So $750 million per year divided by 2 million customers is about $375 per customer per year, or a total NPV of around $3000 per customer.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 3:20 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Ok, hopefully last clarifying question:

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

By "how many customers or households" **do you mean the number of customers or households of public power customers we assume will be impacted?** In other words, if we took the BPA's Tier 1 annual sales we assume (~58,686 GWh/yr per FY2022 BPA forecast) and our assumed 1,000 kWh per month per household, how many households would that be? Doing this we get 4.9 million households. Is this in line with BPA's expectation of Tier 1 customers? Of course, there are some distinctions between household electric use and C&I electric use (surely there are C&I Tier I loads as well as residential), making this calculation a bit imperfect...

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 2, 2022 2:44 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Sounds good to me Aaron

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

DELIBERATIVE FOIA EXEMPT

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

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

DELIBERATIVE FOIA EXEMPT

...based on assuming that replace resource projects are financed rather than paid for upfront using $X billion appropriations of cash from congress

Yes, this is exactly what were meant. If you have a better way to phrase it than the current text, that's great.

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

DELIBERATIVE FOIA EXEMPT

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

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 2, 2022 12:32 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
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Thanks Aaron- how about replace that statement then with "E3 assumed transmission would be built as needed for renewable additions" to be clear of what transmission builds are in the study (please keep the suggested addition in italics about Congressional approval to breach the dams). We keep getting questions around Tx build outs.

Other comments below.

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

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

Aaron

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Sent: Thursday, June 2, 2022 12:21 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
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A few specific responses and one question response needed to proceed:

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

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

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

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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

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Aaron

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Thanks,
Aaron

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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;

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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) [redacted]
Meeting password: 5UKeHJ2kK@2

Tap to join from a mobile device (attendees only)

+1-415-527-5035,,(b)(6) [redacted]## US Toll

Join by phone

+1-415-527-5035 US Toll

Global call-in numbers

Join from a video system or application

Dial [redacted] mybpa.webex.com

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

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Sent:	Thursday, June 2, 2022 11:55 AM
To:	James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5
Cc:	Arne Olson
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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

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

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Cc: Aaron Burdick; Diffely,Robert J (BPA) - PGPL-5; Koehler,Birgit G (BPA) - PG-5 (bgkoehler@bpa.gov); Arne Olson
Subject: FW: BPA-E3
When: Thursday, April 28, 2022 3:30 PM-4:30 PM (UTC-08:00) Pacific Time (US & Canada).
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From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Friday, May 27, 2022 4:38 PM
To:	James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5
Cc:	Arne Olson
Subject:	[EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Thanks Eve. As mentioned, the pre-spill adjusted data showed 865 aMW in our RESOLVE years modeled (2001, 2005, 2011), but only 706 aMW after the EIS spill. We'd want to verify the post-EIS preferred alternative expected annual average energy (what to compare to the 706 aMW derived from the BPA data for those 3 years). As Arne mentioned, this may be due to calibrating our NW hydro data for the entire region vs. the annual average of the LSR dams themselves. If anything, this makes our study a bit more conservative...

PDF of the deck is coming shortly.

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>
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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

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

DELIBERATIVE FOIA EXEMPT

Eve and Birgit,

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All the best,
Aaron

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Sent: Wednesday, May 4, 2022 5:12 PM
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Cc: Arne Olson <arne@ethree.com>
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Hi Eve,

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To:	Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5
Cc:	Arne Olson
Subject:	[EXTERNAL] RE: BPA-E3
Attachments:	BPA_Public Deck_DRAFT_052022.pptx

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

DELIBERATIVE FOIA EXEMPT

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

All the best,
Aaron

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

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

Please remember to say what CES stands for.

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

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

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Energy+Environmental Economics

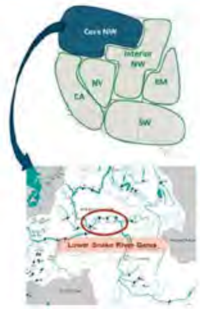
BPA Lower Snake River Dams Project
Draft Final Results

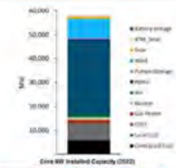
May, 2022

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

E3 conducted an independent analysis of LSR Dam replacement in the context of Pacific Northwest resource needs

- **Lower Snake River (LSR) Dams are ~10% of Northwest hydro capacity and provide GHG-free energy, firm capacity, operational flexibility, and grid services**
- **E3 was contracted by BPA to conduct 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 electricity planning model to optimize electricity resource needs for the Northwest through 2045**
  - RESOLVE optimally determines the least-cost LSR Dams replacement resources, subject to reliability + policy constraints





Plant	Nameplate Capacity (MW)	All-in Cost (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 MW	Avg = $17/MWh

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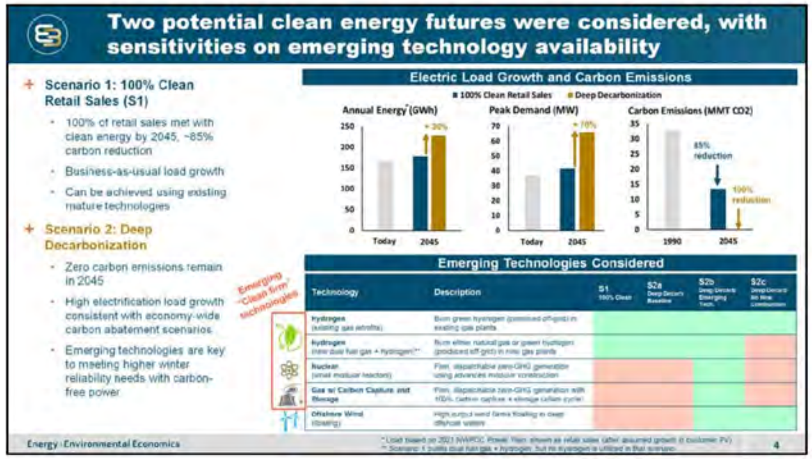
This study considers key elements necessary to capture near- and long-term replacement needs of the LSR Dams

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

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



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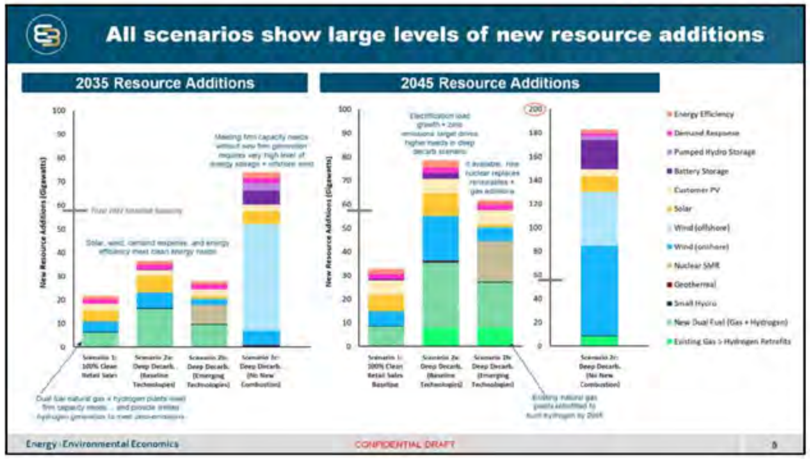

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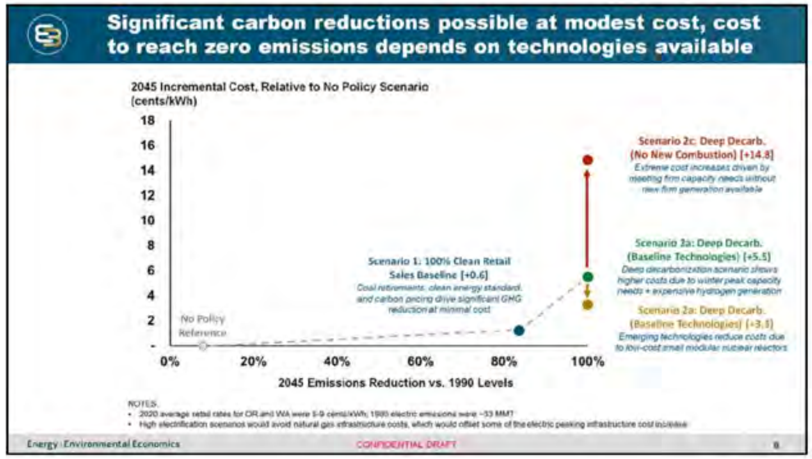
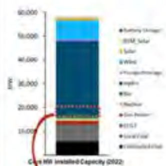

Significant carbon reductions possible at modest cost, cost to reach zero emissions depends on technologies available
2045 Incremental Cost, Relative to No Policy Scenario (cents/kWh)
18
16
14
12
10
8
6
4
2
-
No Policy Reference
Scenario 1: 100% Clean Retail Sales Baseline [+0.6]
Coal retirements, clean energy standard, and carbon pricing drive significant GHG reduction at minimal cost
Scenario 2c: Deep Decarb. (No New Combustion) [+14.8]
Extreme cost increases driven by meeting firm capacity needs without new firm generation available
Scenario 3a: 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
0%
20%
40%
60%
80%
100%
2045 Emissions Reduction vs. 1990 Levels
NOTES:
Energy Environmental Economics
CONFIDENTIAL DRAFT

If the Lower Snake River Dams are removed, the services they provide would need to be replaced

+ RESOLVE determines replacement needs and cost by optimizing regional needs with the dams and then again without the dams



LSR Dams are removed in 2032

(a sensitivity considered 2024 removal)

Electric Grid Benefit	Captured in E3's RESOLVE Modeling?
GHG-free Energy Output (MWh) GHG-free energy displaces the costs and carbon emissions of NW coal + gas generation or imported power	☑
Reliable Capacity (MW) Firm capacity contributions towards resource adequacy	☑
Flexibility and Operating Reserves (MW) Sub-hourly ancillary service provision and renewable integration benefits	☑
Essential Reliability Services Services support reliably operating the transmission grid (voltage, reactive power, inertia, blackstart, etc.)	☒

NOTE: RESOLVE also includes new transmission costs for renewable replacement resources

E3's RESOLVE modeling captures most expected system benefits provided by the LSR dams

E3's Replacement Needs Methodology

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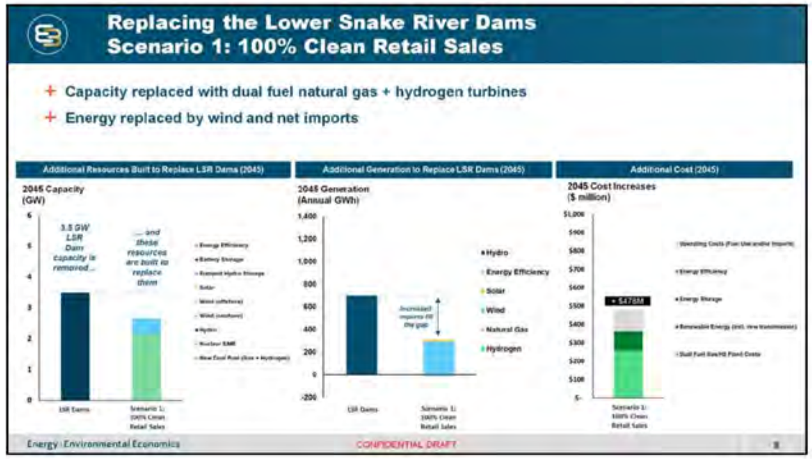

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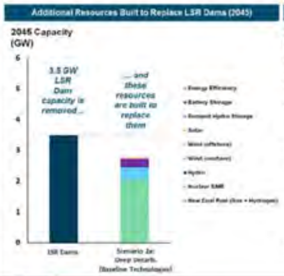
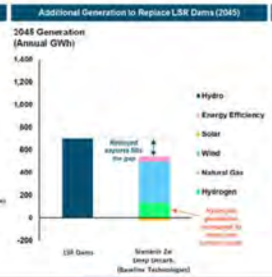
Replacing the Lower Snake River Dams
Scenario 2: Deep Decarbonization (Baseline Technologies)

+ Capacity replaced with dual fuel natural gas + hydrogen turbines, energy efficiency, and energy storage
+ Energy replaced by wind, reduced exports, energy efficiency, and increased hydrogen generation

Additional Resources Built to Replace LSR Dams (2045)



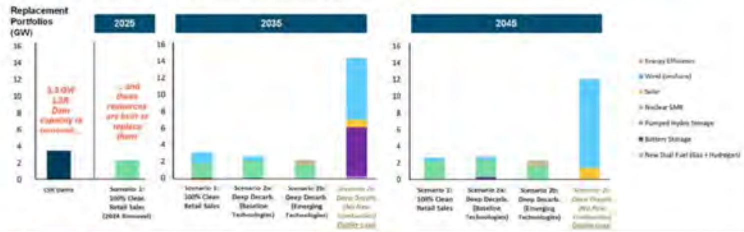
Additional Generation to Replace LSR Dams (2045)



Additional Cost (2045)

Replacing the Lower Snake River Dams
Capacity Replacement Across All Scenarios

- **Capacity replacement for additional scenarios and years is shown below:**
  - **Scenario 1 (100% Clean Retail Sales, 2024 LSR Dam removal)**: similar to scenario 1, but with dual fuel natural gas + hydrogen turbine replacement in 2025
  - **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



Replacing the Lower Snake River Dams is costly and could increase public power costs by 8-65%

+ **Replacing the GHG-free energy, capacity, and operational benefits of the dams requires investment in new resources at increased total system costs**
  - Cost differences between scenarios driven by 2045 GHG-free energy replacement and the availability of "clean firm" emerging technologies
+ **Costs are expected to fall on Bonneville Power Administration's public power customers, raising residential electricity costs by ~$100 – 850 per year**

	Total Costs	Annual Cost Increase			Incremental Public Power Costs [% increase vs. ~8.5 cents/kWh NW average rates]
	2022 Net Present Value	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$3.3 billion	—	$434 million	$478 million	0.8 cents/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam removal)	$7.2 billion	$495 million	$490 million	$509 million	0.8 cents/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$5.0 billion	—	$490 million	$800 million	1.5 cents/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$3.0 billion	—	$415 million	$428 million	0.7 cents/kWh [+8%]
Scenario 3: Deep Decarb. (No New Combustion)	$20.0 billion	n/a	[illegible]	[illegible]	[illegible]

NOTES:
- Cost increases account for replacement energy, capacity, and reserves as well as avoided LSR capital + expense, but do not include any costs for breaching the dams, which would be an additional cost.
- NPV and annual cost increase are shown for the Northwest Region as a whole, but the incremental costs are calculated relative to the BPA Tier I annual sales for public power customers.
- % increase versus average rates assumes OR + WA average retail rates are ~8.5 cents/kWh. This does not include additional rate increases driven by higher loads of 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).

Key Conclusions

- **Replacement of the Lower Snake River Dams is driven by its 1) firm reliable capacity provision, and 2) GHG-free energy output**
- **In the long-run, in a zero-emissions Pacific Northwest with growing electrification loads, replacement resources and costs depend on technology availability**
  - If new firm capacity is not available to replace the dams, replacement requires potentially unrealistic levels of renewable build (at high cost, transmission need impact, and land use impact)
  - Building new dispatchable combustion resources that are capable of eventually burning carbon-free green hydrogen is one way to meet both reliability and clean energy replacement needs
    - These resources would be coupled with increased renewable energy and eventually increased green hydrogen generation to ensure zero-carbon replacement of the dams by 2045
  - Alternatively, small modular nuclear reactors or new gas plants with carbon capture and storage could provide the need for "clean firm" power to replace the dams, though these technologies are not commercially available today
    - Additional emerging technologies like multi-day batteries or other ultra-long-duration storage resources could also play a role
- **Replacing the dams comes at a substantial cost for new resource replacement that would have a meaningful impact on the rates of Bonneville Power Administration's public power customers**

Energy+Environmental Economics

Thank You

Questions, please contact:

Arne Olson, arne@ethree.com

Aaron Burdick, aaron.burdick@ethree.com

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Tuesday, April 19, 2022 10:45 AM
To:	Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5; Angineh Zohrabian; Sierra Spencer
Subject:	[EXTERNAL] RE: BPA-E3 Check-In

Proposed agenda for today:

- Discuss draft deliverables shared on Fri
    - General BPA feedback and/or timing for feedback
    - Cost metrics for no LSR cases
    - GHG impacts of no LSR cases
    - Confirm any additional sensitivity cases to run
- DOJ requests for information

-----Original Appointment-----
From: Aaron Burdick
Sent: Wednesday, March 2, 2022 4:53 PM
To: Aaron Burdick; Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; rjdiffely@bpa.gov; Angineh Zohrabian; Sierra Spencer
Subject: BPA-E3 Check-In
When: Tuesday, April 19, 2022 11:00 AM-12:00 PM (UTC-08:00) Pacific Time (US & Canada).
Where: https://ethree.webex.com/ethree/j.php?MTID=m228a4e26c5b763d73adb84c525782f42

Updating series from 30 mins to 1 hr.

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

-.-

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From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Wednesday, April 6, 2022 9:31 AM
To:	Diffely,Robert J (BPA) - PGPL-5; James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5
Cc:	Arne Olson; Jack Moore; Angineh Zohrabian; Sierra Spencer
Subject:	[EXTERNAL] RE: BPA-E3 Check-In

HI Rob,

We embed the cost-effective EE and DR that's within the Power Plan load forecast. We also make some additional DR available (~3.5 GW per the power plan potential) and some EE as well. The DR is getting selected in many cases and the EE is generally not selected. Note we include a declining ELCC curve for DR per our NW RECAP study.

All the best,
Aaron

From: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Sent: Wednesday, April 6, 2022 7:28 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

One thing that I forgot to mention yesterday on the power point is how conservation is embedded in the model. The power point stated that the Power Plan load forecast was used. Does the demand forecast selected include 8th Power Plan cost-effective conservation?

Also, will the supply options include conservation identified in the 8th Plan, but not deemed cost effective?

Rob

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, April 4, 2022 9:50 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

DELIBERATIVE FOIA EXEMPT

Hi BPA team,

A few project updates:

- **Task 1 Capacity Needs + Task 3 Qualitative Benefits**: we're nearing completion on a draft of these materials for your review. I expect to share our PPT draft decks within the next week for your review.
- **Task 2 RESOLVE Analysis**: we have been running RESOLVE cases to validate our initial results for scenarios 1, 2, 2a, and 2b. We are now targeting the end of the week for the model runs so can use next week's Tuesday check in to discuss the results.

Suggested agenda for Tue 4/5 meeting:

1. **DOE meeting on Thursday**: confirmation of schedule, E3 attendance, any material prep, etc.
2. **EnergyGPS study**: EnergyGPS reached out to us about their study on the lower snake dams for Northwest River Partners. They've asked for a brief chat with us to understand the basics of our approach (study years, data sources, etc.), recognizing that our analyses will be independent.
3. **No LSR dam scenario costs (breaching cost)**: we received costs from you on the cost of continued operation. We have not yet discussed the costs for breaching the dams and whether to include these. Are there solid estimates or ranges for these through the EIS work? Should we be including these in the economic analysis of continued operations vs. breaching the dams? (Note: we can do this endogenously in RESOLVE or as a post-process to the NPV comparison of the in/out cases.)
4. **Overview of RESOLVE inputs**: while you await results, I figured we can provide an overview of the updated PacNW RESOLVE model inputs we have developed for this project (loads, resources, external zones resources / policies, resource costs, etc.).

Any other topics you'd like to cover?

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
Sent: Tuesday, March 29, 2022 10:45 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Jack Moore <Jack@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

DELIBERATIVE FOIA EXEMPT

Hi Eve,

Below is the updated scenario matrix. The four primary scenarios did not change (1, 2, 2a, 2b), but I updated sensitivities to reflect the feedback from Birgit and Rob last week. Tentative sensitivities are now on the baseline scenario, considering earlier retirement or removal of fish constraints. However, we agreed to finalize what sensitivities will be run after we have the results of the 4 primary scenarios next week.

Let me know if you have any questions.

Each scenario will be run twice: with and without the lower snake river dams

Scenario	Scenario Name	Loads	Clean Energy Policy
1	Baseline - 100% clean retail sales	Baseline	100% retail sales by 2040-45
2	Deep Decarb	High Electrification	0 MMT by 2045
2a	Deep Decarb - limited tech	High Electrification	0 MMT by 2045
2b	Deep Decarb - emerging tech	High Electrification	0 MMT by 2045
1a	Baseline - earlier LSR removal	High Electrification	0 MMT by 2045
1b	Baseline - no fish constraints	High Electrification	0 MMT by 2045
0	No policy reference	Baseline	No policy

Runs w/o LSR dams will be labeled "1_noLSR", etc.

Technology Scenarios:
Mature + H2: solar, wind, bat
Mature + emerging: adds gas
Mature + no new gas: exclud

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 <eajames@bpa.gov>
Sent: Tuesday, March 29, 2022 10:25 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Hi Aaron-
I'm okay with cancelling the check-in if you could provide a copy of the updated scenarios after the meeting last week. I want to make sure I'm clear on where the 4 primary scenarios landed.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, March 29, 2022 10:16 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

I don't have any agenda topics for today so I'd like to propose that we cancel this check-in, unless BPA has specific items to discuss.

Providing a general update on progress below:

- Per last week's discussion + email exchanges, we are moving forward with the hydro operating parameters and capacity value that Angineh and I shared via email
- We are initiating RESOLVE runs now and are targeting to have draft results for the 4 primary scenarios by next week
- We are concurrently working on Task 1 (Regional Capacity Needs and Role of Hydropower) and Task 3 (Documenting value streams not captured in RESOLVE) and expect to share draft deliverables for these tasks next week as well

Let me know if you would like to meet today, otherwise I'll send a cancellation.

All the best,
Aaron

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To: Aaron Burdick; Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; rjdiffely@bpa.gov; Angineh Zohrabian; Sierra Spencer
Subject: BPA-E3 Check-In
When: Tuesday, March 29, 2022 11:00 AM-12:00 PM (UTC-08:00) Pacific Time (US & Canada).
Where: https://ethree.webex.com/ethree/j.php?MTID=m228a4e26c5b763d73adb84c525782f42

Updating series from 30 mins to 1 hr.

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

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To:	Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5
Cc:	Arne Olson; Jack Moore; Angineh Zohrabian; Sierra Spencer
Subject:	[EXTERNAL] RE: BPA-E3 Check-In

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Let me know if you would like to meet today, otherwise I'll send a cancellation.

All the best,
Aaron

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From: Aaron Burdick
Sent: Wednesday, March 2, 2022 4:53 PM
To: Aaron Burdick; Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; rjdiffely@bpa.gov; Angineh Zohrabian; Sierra Spencer
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From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Thursday, March 10, 2022 3:22 PM
To:	Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5
Cc:	Arne Olson; Jack Moore; Angineh Zohrabian; Sierra Spencer
Subject:	[EXTERNAL] RE: BPA-E3 Check-In
Attachments:	BPA Value of Lower Snake River Dams_030922.pdf

Deliberative; FOIA-exempt

Nice to meet everyone yesterday. I've attached E3's slides.

As a follow up to the data needs question, we have confirmed that we have hourly historical generation by hydro plant so can use that to develop a disaggregation of the NW hydro resource from the lower snake river dam resource in RESOLVE. However, we still need a few data points:

1. **Cost data** on the lower snake river dams
    a. This includes $/MWh variable O&M and $/kw-yr fixed costs. The fixed costs would include fixed O&M and sustaining capex. We use levelized costs in RESOLVE, but feel free to provide in whatever format is available.
2. **Year to assume retirement** in the no LSR dam scenarios
3. **Max. continuous 1/2/3/4 hour output / ramp rates / any other critical operational limitations**
    a. We have a way of estimating some of this via historical data, but feel free to advise if there are specific constraints you can share for these dams.

All the best,
Aaron

-----Original Appointment-----
From: Aaron Burdick
Sent: Wednesday, March 2, 2022 12:15 PM
To: Aaron Burdick; Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; rjdiffely@bpa.gov; Angineh Zohrabian; Sierra Spencer
Subject: BPA-E3 Check-In
When: Wednesday, March 9, 2022 4:00 PM-4:30 PM (UTC-08:00) Pacific Time (US & Canada).
Where: https://ethree.webex.com/ethree/j.php?MTID=m97e494b356576770da19622bd6b15564

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

-~-

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From:	Angineh Zohrabian <angineh.zohrabian@ethree.com>
Sent:	Friday, March 25, 2022 1:47 PM
To:	James,Eve A L (BPA) - PG-5; Aaron Burdick; Riley,Erin A (BPA) - PGPR-5
Cc:	Koehler,Birgit G (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5; Egerdahl,Ryan J (BPA) - PGPR-5; Sierra Spencer; Arne Olson; Jack Moore
Subject:	[EXTERNAL] RE: BPA-E3 Check-In - 3-22 action items
Attachments:	Draft_LSR_CoreNW_Hydro_Characteristics_Updated_for_New_Spill_Operations.xlsx

Hi All,

Please find attached the updated characteristics and RESOLVE inputs for LSR and Core NW hydro. From BPA's provided hydro generation data, we combined Jan-Sep from trace2001 and Oct-Dec from trace2002 to get to 2001 calendar year (similarly for 2005 and 2011). The logic was that a fiscal year is named by the year that ends in September. However, the dates in the data were confusing (for example, Jan 1, 2024 is trace2001 whereas Dec 31, 2023 is trace2002). Please let us know if we should treat this differently.
We also included the values calculated based on WECC historical generation data for comparison, and in case of future use in the sensitivity run.

Thank you. Feel free to reach out with any questions.
- Angineh

Sent from Mail for Windows

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, March 25, 2022 11:17:02 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>
Cc: Angineh Zohrabian <angineh.zohrabian@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>; Sierra Spencer <sierra.spencer@ethree.com>; Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>
Subject: RE: BPA-E3 Check-In - 3-22 action items
Deliberative; FOIA-exempt
Hi Aaron-
Sounds good about updating with the information provided by Erin for the scenarios. I will send an updated "no spill" constraint sensitivity data set since the historical data for 2011 and 2005 have higher summer spill amounts than the current spill program and have spill during the spring as well.
Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, March 25, 2022 11:10 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>
Cc: Angineh Zohrabian <angineh.zohrabian@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>; Sierra Spencer <sierra.spencer@ethree.com>; Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In - 3-22 action items
Deliberative; FOIA-exempt
Hi Eve,

Angineh has used replaced our historical hydro hourly output for the plants provided by Erin. This means our min/max gen and daily MWh budgets will be updated accordingly, to align with the latest spill requirements. This is the baseline set of hydro assumptions we plan to start modeling in RESOLVE. Angineh or I will share an updated summary document shortly.
If we decide later to model a "no updated spill constraint" sensitivity as Birgit suggested, would switching back to our historical data suffice to capture that difference in max gen and daily MWh?
All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, March 25, 2022 8:13 AM
To: Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>
Subject: RE: BPA-E3 Check-In - 3-22 action items
Deliberative; FOIA-exempt
Thanks for sending this along while I was out of the office Erin.
Aaron let me know if this covers what you need- I am available today except for 1 – 2 PM if you need to call and talk through anything.
Thanks,
Eve

From: Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>
Sent: Wednesday, March 23, 2022 8:11 AM
To: aaron.burdick@ethree.com
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>
Subject: BPA-E3 Check-In - 3-22 action items
Deliberative; FOIA-exempt
Hi Aaron,
I've attached some hourly modeled output for the CYs you requested that I have on the shelf. See if that will suit your needs to create your pmin/ pmax curves.
These data are initialized from a monthly model, that monthly model has split Aprils & August, the second halves begin on the 16th. The incremental flows are interpolated from the monthly flows, so there is a smoothed component relative to actuals. You will notice that the diurnal pattern has a monthly change, this is part of that modeling: the shape of coulee is modeled after actual shaping in recent operations, and the daily peak power shaping is based on maximizing value during peak loads/ prices. The model is not provided with prices, it is provided hours during which to peak. There is some shaping to load in our forebay requests, but inherently the underlying logic assumes unlimited purchases and sales. There is a breakout in the data of the reserves that the projects are holding.
This model reflects the spill in the 2020 EIS: 125% flex spill.
Data notes: The model was run on the FY, as indicated by the "trace" column. For CY I provided the Oct-Dec of the following FY trace. I did not correct the date to be continuous because:
This model simulation, generation is peaking during these dates in the datetime column:

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

Depending on your analysis you might want to include or exclude these. For the weather events, we draft coulee 3 days fairly aggressively, then target coulee to be back on track over the next week. In particular, you might want to exclude July 3-5 as I think this operation might be violating July4 holiday targets.
I can also re-run to exclude this logic.
Data dictionary:

"*.Power" = hourly generation in MW
"*.GN_Max_HK_ModelCap" = one hour capacity.
"*.Rsrv_DEC_Sim" = Dec reserves held at that project, or total if * is BPA
"*.Rsrv_INC_Sim" = Inc reserves held by that project, or total is * is BPA
Please let me know if you need data based on actuals instead.
The attached data are only for the purpose of the contracted work. Thank you.
Best,
Erin

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

Deliberative; FOIA-exempt

Action items from today's check in:

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

Many thanks,

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

Erin Riley
Operations Research Analyst
PGPR- Long Term Power Planning
Bonneville Power Administration
503-230-3717

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Tuesday, April 19, 2022 10:42 AM
To:	Jack Moore; Diffely,Robert J (BPA) - PGPL-5; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5
Cc:	Arne Olson; Angineh Zohrabian; Sierra Spencer; Bellcoff,Steve (BPA) - PGPR-5
Subject:	[EXTERNAL] RE: BPA-E3 Draft Deliverables: Tasks 1, 2, and 3 - Rob's comments

Rob – thanks for your comments! Some further responses below.

From: Jack Moore <jack@ethree.com>
Sent: Monday, April 18, 2022 10:28 PM
To: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>; 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>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>; Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Subject: RE: BPA-E3 Draft Deliverables: Tasks 1, 2, and 3 - Rob's comments

Thanks Robert on your first question – the first 3 rows in the table are for specific sub-types of resources that need to be procured (long-duration, firm zero-emitting, etc). the remaining amounts (2000 MW in 2023, 6000 in 2024, 1000 in 2025 can come from "generic RA" resource that don't have to meet one of those narrower definitions. These generic RA resources will primarily 4-hour batteries most likely.

From: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Sent: Monday, April 18, 2022 3:35 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; 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>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>; Jack Moore <jack@ethree.com>; Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Subject: RE: BPA-E3 Draft Deliverables: Tasks 1, 2, and 3 - Rob's comments

Struggling with this chart (page 48 out of the CPUC procurement decision and on E3 slide). Discussion on E3 slide about the 11.5 GW capacity requirement by 2026. What resources are missing from this table to get to 11.5 GW? Jack captured it, but it is confusing so I'll update this chart to avoid that confusion.

CPUC Mid-Term Reliability Procurement Order

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

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

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

- Slide 19 need for 'explanation' of storage resources limited value in PNW hydro system We'll work to include a slide / figure to explain this.
- Slide 19 both on-shore and offshore wind in section of mature technology – should offshore (floating) be in emerging? Good catch. Updated this.
- Slide 20 (below) is additional EE added (above the 8th Power Plan) to the demand forecast or is it a potential resource in Resolve Modeling? Both. We include cost-effective EE in the load forecast and then allow RESOLVE to select up to 0.5 GW additional EE.

Includes EE+DR in the Power Plan + incremental selectable EE+DR

- Page 38 is the 1st page stating real dollars ($2022) – should this be noted earlier in the presentation? Added a note to the NPV in/out slide explaining all costs are in real 2022 $.
- Should there be a note in this power point about climate change impacts to loads and hydro (or state that climate change was not incorporated) We haven't done any new work here, so will need to determine what climate impacts if any were in the power plan load forecast and summarize that. Can note we're not adjusting hydro.
- Should there be any discussion on incremental GHG emissions with Snake and no/Snake? We've pulled this and can discuss today on how to include.
- High level slide on land use (i.e. acres / square miles)? We can use some high level heuristics to estimate these… will further show how challenging the tech limited cases would be.
-

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, April 15, 2022 9:56 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>; Jack Moore <jack@ethree.com>; Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Subject: [EXTERNAL] BPA-E3 Draft Deliverables: Tasks 1, 2, and 3

BPA team,

Please see attached:

- **Regional Capacity Needs and Role of Hydropower (Task 1)**
  - Larger deck containing our view of the regional policies, market dynamics, and capacity needs.
- **RESOLVE Results + Qualitative Benefits (Tasks 2 and 3)**
  - Expanded deck of what we reviewed Tuesday and Thursday this week, including the "limited technology" S2a cases, that result in very high resource needs and extremely high LSR dam replacement costs, driven by resource adequacy costs without any new firm capacity available.
  - Note, we have revised the LSR dam replacement cost metrics (see slide 38). We are seeking BPA's input on the use of these metrics and the data put into them (e.g. our 3.5 cent/kWh estimate of BPA's current generation rate).

Per our contract, these are draft deliverables and we welcome feedback to refine these and incorporate into the final deliverables by June 1.

All the best,

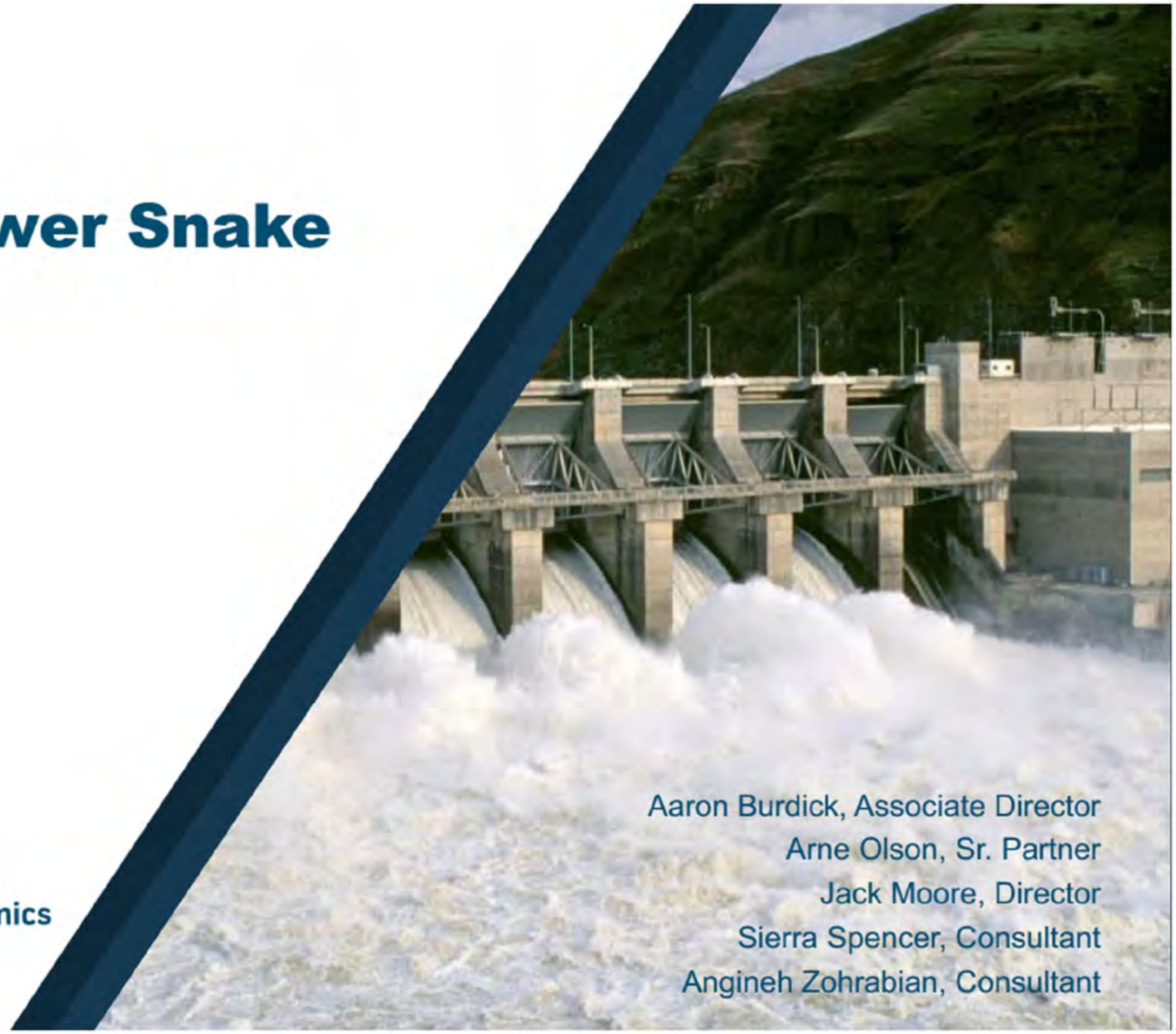
Aaron Burdick, Associate Director
Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500 | San Francisco, CA 94104
818-807-6499 | aaron.burdick@ethree.com

BPA Value of Lower Snake River Dams

Kickoff Meeting

March 9, 2022

Energy+Environmental Economics



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

March 9 Meeting Agenda

+ **Introductions**
+ **Project Timeline**
+ **Regional Capacity Needs**
  - Outline + Expected Highlights
+ **RESOLVE Modeling**
  - Overview
  - Hydro inputs
  - Scenarios
+ **Next steps**

Team

Arne Olson
Sr. Partner

Project Lead

Jack Moore
Director

Project Advisor

Aaron Burdick
Associate Director

Project Manager

Anthony Fratto
Senior Consultant

RESOLVE Technical Lead

Sierra Spencer
Consultant

RESOLVE Analyst

Angineh Zohrabian
Consultant

RESOLVE Analyst

Sam Kramer
Consultant

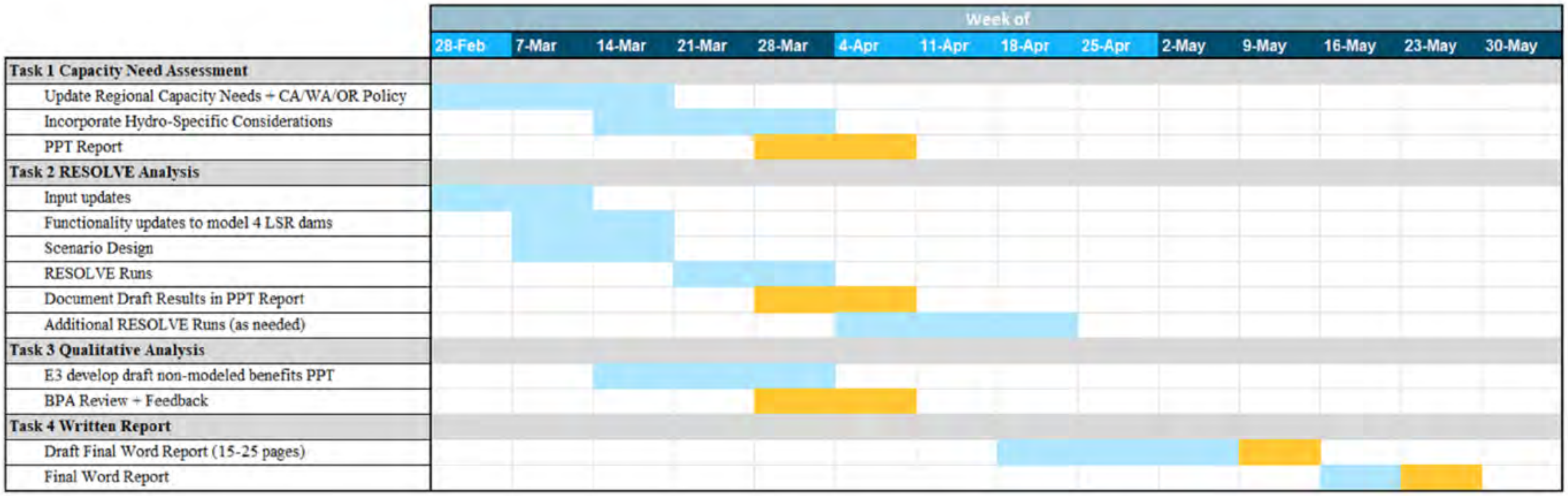
RESOLVE Analyst

John de Villier
Consultant

Analyst

Deliberative; FOIA-exempt

Project Timeline



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

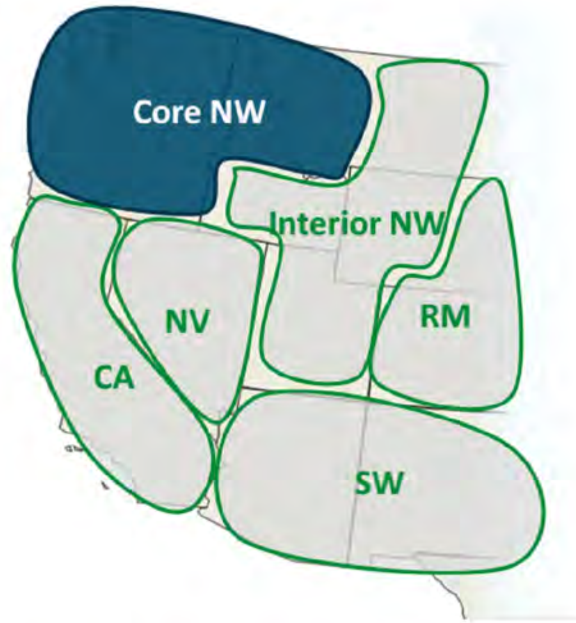
Expected key highlights:

- *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*

Deliberative; FOIA-exempt

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, and the BPA + Avista portions of ID and MT

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).

27680246(01).pdf

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	Load Growth	Resource Availability	New Resource Costs	Gas Fuel Prices
+ Goal: 100% clean retail sales vs. zero-carbon + Pace: 2045 vs. 2030	+ Baseline + High Electrification	+ Mature + Emerging* + Mature + Limited Emerging + Mature + Low-Cost SMR	+ Baseline + High Cost	+ 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

* Emerging technologies include hydrogen turbines, gas w/ carbon capture and storage, and small modular nuclear reactors

Deliberative; FOIA-exempt

Next Steps

+ **Goals for next Tuesday's meeting:**
  - **BPA** to share the following LSR dam assumptions:
    - Retirement year in no LSR dam scenarios
    - Cost inputs
    - Ramp rates
    - Anything else deemed useful to the E3 team
  - **E3** to disaggregate NW hydro and LSR dam resources in RESOLVE
  - **E3** to review initial list of qualitative benefits and recommend other benefits as needed
    - Build off the list in the scope of work
    - **BPA** to advise any other transmission related benefits not in that list
  - **E3** to propose RESOLVE scenario design
  - **E3** to continue progress on RESOLVE model updates and documenting key assumptions for BPA review

Appendix

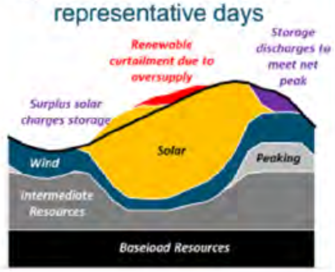
Energy+Environmental Economics

RESOLVE: Optimal Capacity Expansion Under Aggressive Clean Energy Goals

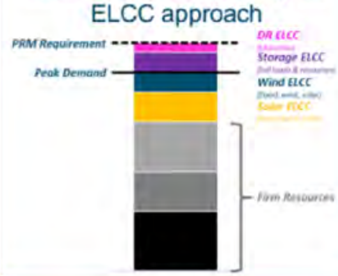
+ **RESOLVE is a linear optimization model explicitly tailored to the study of electricity systems with high renewable & clean energy policy goals**

+ **Optimization balances fixed costs of new investments with variable costs of system operations, identifying a least-cost portfolio of resources to meet needs across a long time horizon**

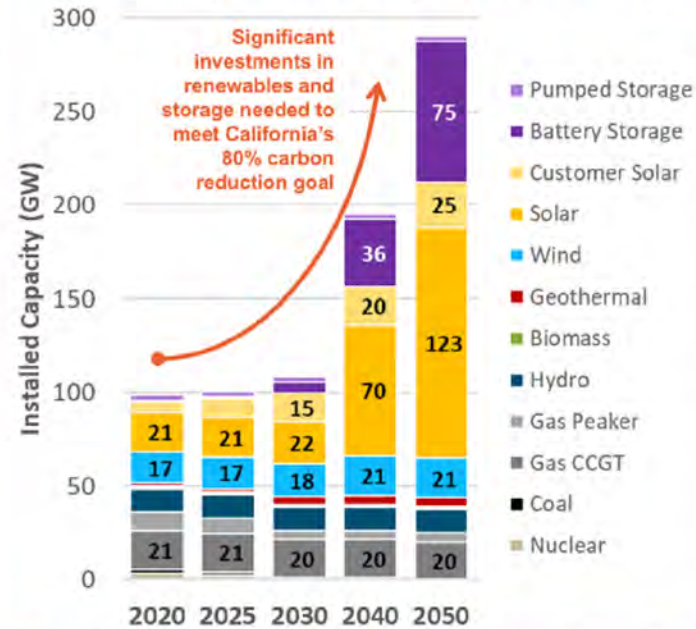
Operational module simulates hourly system operations for a sample of representative days



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



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



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

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RESOLVE Co-optimizes Investment and Operational Decisions

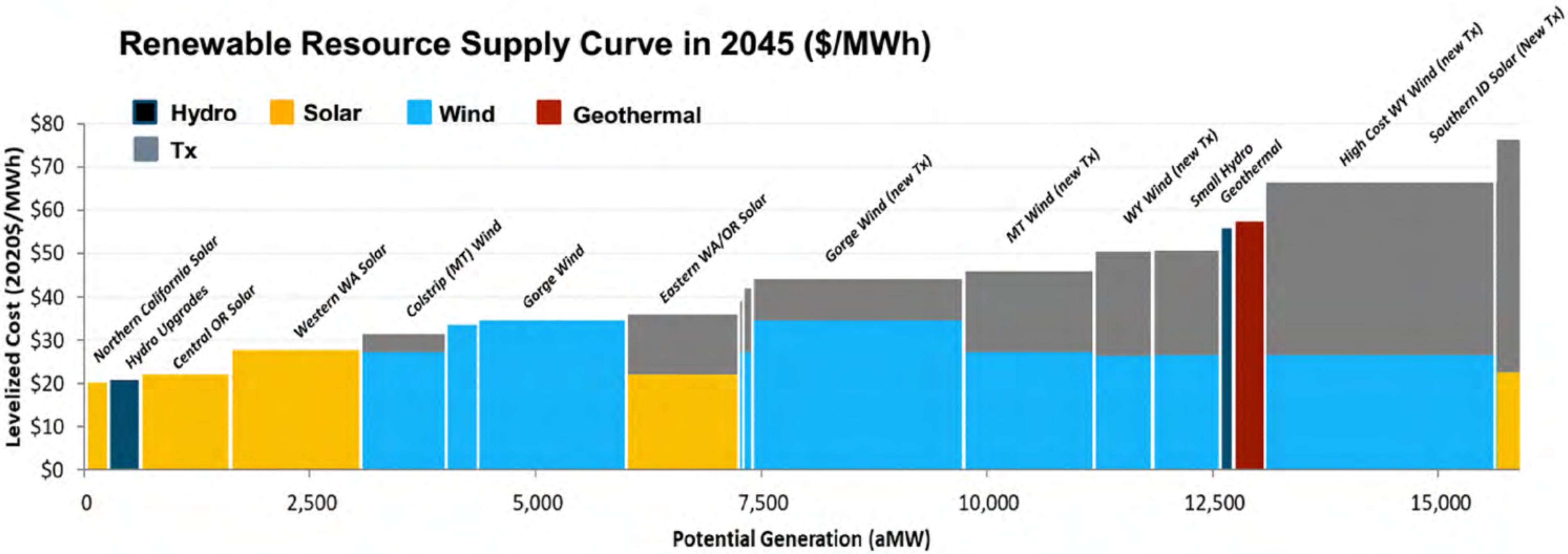
+ **RESOLVE allows portfolio optimization across a long-time horizon (20-30 years)**
  - Investments made in multiple periods
+ **Operational detail directly informs investment decisions to economically address primary drivers of renewable integration challenges**
+ **Fixed costs capture capital, financing,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

RESOLVE Objective Function

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

New Resource Options
Renewables

+ Resource costs



Note: these costs are in the process of being updated for the BPA Lower Snake River Dam analysis

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Thursday, June 2, 2022 4:43 PM
To:	James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5
Cc:	Arne Olson
Subject:	[EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

I also wanted to provide an update that we're getting tight on our budget after all the iteration on the public deck. We have about $15k left for drafting the word report, assuming no other tasks on the public materials, which is a bit tight vs. the $25k we originally had planned.

From: Aaron Burdick
Sent: Thursday, June 2, 2022 4:35 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

Ok, here is the updated deck in PPT form.

All the best,
Aaron

From: Aaron Burdick
Sent: Thursday, June 2, 2022 4:27 PM
To: Arne Olson <arne@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

I want to make sure we don't cross our wires on these cost metrics.

We are reporting:

- **Avg retail rate impact**: total RESOLVE RRQ increase divided by 2022 BPA Tier I load,
  - e.g. Case S2a: $860M in 2045 divided by 58,686 GWh/yr = 1.5 cents/kWh
- **Household cost impact**: retail rate impact * 1,000 kWh/mo * 12 mo/yr * 128% (electrification annual energy increase)
  - e.g. Case S2a: 1.5 cent/kWh * 1,280 kWh/mo * 12 mo/yr = $230/yr
- **Residential cost impact or total households impacted**:
  - This requires us to assume how much of the total RRQ impact is allocated to residential customers:
    - E.g. $860M * 40% = $344 million residential
    - $344 million divided by $230/yr/household = 1.5 million households
      - OR, if I don't adjust the electrification load increase and effectively stick with the 2022 Tier I rates, I get $180/yr. $344m / $180/yr/household → ~1.91 million households

So... shall we just say 2 million households? Or does BPA have specific data on residential customers we should use? For now I'll use 2 million unless I hear otherwise.

From: Arne Olson <arne@ethree.com>
Sent: Thursday, June 2, 2022 3:28 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: BPA-E3

I imagine only about 40% of the sales are residential, so the 4.9 million would be closer to 2 million, which is in the ballpark of what I would have expected. We can get more exact numbers from EIA Sales & Revenue if needed.

So $750 million per year divided by 2 million customers is about $375 per customer per year, or a total NPV of around $3000 per customer.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 3:20 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Ok, hopefully last clarifying question:

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

By "how many customers or households" **do you mean the number of customers or households of public power customers we assume will be impacted?** In other words, if we took the BPA's Tier 1 annual sales we assume (~58,686 GWh/yr per FY2022 BPA forecast) and our assumed 1,000 kWh per month per household, how many households would that be? Doing this we get 4.9 million households. Is this in line with BPA's expectation of Tier 1 customers? Of course, there are some distinctions between household electric use and C&I electric use (surely there are C&I Tier I loads as well as residential), making this calculation a bit imperfect...

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 2, 2022 2:44 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Sounds good to me Aaron

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 1:01 PM

To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

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

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

DELIBERATIVE FOIA EXEMPT

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

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

DELIBERATIVE FOIA EXEMPT

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

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

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

Other comments below.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 12:25 PM

To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

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

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

Aaron

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

DELIBERATIVE FOIA EXEMPT

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

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

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

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

- 2b: With today's carbon reduction policies, total costs would be $2.8 billion in upfront capital costs, with ~$110 million per year for operational cost. $7.5 billion total NPV costs

Thanks,
Aaron

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

DELIBERATIVE FOIA EXEMPT

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

Thanks,
Eve

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

DELIBERATIVE FOIA EXEMPT

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

All the best,
Aaron

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

DELIBERATIVE FOIA EXEMPT

Updated deck is attached.

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

Aaron

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

DELIBERATIVE FOIA EXEMPT

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

Thanks,
Eve

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

DELIBERATIVE FOIA EXEMPT

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

Aaron

From: Aaron Burdick
Sent: Thursday, May 26, 2022 8:32 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

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

All the best,
Aaron

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

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

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

Thanks,
Eve

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

DELIBERATIVE FOIA EXEMPT

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

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

Aaron

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

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) [redacted]

Meeting password: 5UKeHJ2kK@2

Tap to join from a mobile device (attendees only)

+1-415-527-5035,[redacted]## US Toll

Join by phone

+1-415-527-5035 US Toll

Global call-in numbers

Join from a video system or application

Dial [redacted]@mybpa.webex.com

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

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 30, 2022 2:28 PM
To: Arne Olson; James,Eve A L (BPA) - PG-5
Subject: [EXTERNAL] RE: CEQ meeting

Deliberative, FOIA exempt

I'm also free anytime on the 11th.

Aaron

From: Arne Olson <arne@ethree.com>
Sent: Thursday, June 30, 2022 2:24 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: CEQ meeting

I'm free any time on the 11th.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 30, 2022 2:20 PM
To: Arne Olson <arne@ethree.com>; Aaron Burdick <aaron.burdick@ethree.com>
Subject: CEQ meeting
Importance: High

Deliberative, FOIA exempt

Hi Aaron and Arne-
There is a question for another potential meeting with CEQ for presenting E3 study. I don't know if that would be just Q&A or what exactly they want. They were thinking during a regularly scheduled meeting would be a good time which is July 11 6 AM – 8 AM PDT (9 – 11 AM EDT). Let me know if that works with your schedules otherwise we can find another time if it is needed.

They would like feedback ASAP on your availability. I am working on the email from Aaron about the NPV and coordinating with some of our finance/fed hydro staff and will get back to you on that soon.

Thanks,
Eve

From: Arne Olson <arne@ethree.com>
Sent: Tuesday, July 26, 2022 10:01 AM
To: Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5
Cc: Aaron Burdick
Subject: [EXTERNAL] RE: Clearing Up, Issue 2065

Thanks Birgit, I'll check with Aaron on the budget but in the meantime will move ahead with drafting the response.

-----Original Message-----
From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Tuesday, July 26, 2022 9:58 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: Clearing Up, Issue 2065

That all sounds fine to me.
Eve wasn't sure of how much budget you had left, but beyond that, I would say to proceed.

-----Original Message-----
From: Arne Olson <arne@ethree.com>
Sent: Tuesday, July 26, 2022 9:56 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: Clearing Up, Issue 2065

Thanks Birgit. I just mean that BPA would need to approve of us writing the response. And since it will take a few hours of labor, to allow us to bill those to the contract. Definitely the final document would be an E3 work product subject to E3's editorial control, although we would want BPA to review it to make sure it keeps to a narrow technical track and doesn't stray into areas of policy that were outside of the study scope.

If this all makes sense to you, please reply with an authorization to proceed and I will get the ball rolling on our side.

Thanks!

Arne

-----Original Message-----
From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Tuesday, July 26, 2022 8:33 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: Clearing Up, Issue 2065

Good morning Arne,

We do agree that a response would be appropriate.

What do you mean by us "sponsoring"? We would certainly like it to be your independent response.

Thanks,
Birgit

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

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

-----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

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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, August 1, 2022 1:11 PM
To: James,Eve A L (BPA) - PG-5
Subject: [EXTERNAL] RE: Confirming final project deliverables for each task

Catching up on emails now that I'm back online. Thanks for the clarification below Eve. Looks like the invoices for Tasks 4 and 5 already got sent while I was out.

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, July 26, 2022 10:39 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: Confirming final project deliverables for each task

Hi Aaron-
Sorry my email has been crazy as I've been periodically out of the office. I think Tasks 1 – 5 can be closed out. The report and slide deck appendix slides cover the materials we need. I think you submitted an invoice for 1 – 3 so go ahead and submit one for 4 and 5 and I will work with contracting on the approval process. Keeping Task 6 open is good as items keep winging in (such as the response to the Clearing Up article etc.).

Thanks,
Eve

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

Hi Eve,

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

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

Happy to chat briefly if you like.

Thanks!

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

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, June 29, 2022 3:57 PM
To: James,Eve A L (BPA) - PG-5; Aaron Burdick; Koehler,Birgit G (BPA) - PG-5
Subject: [EXTERNAL] RE: Congressional staff briefing

Yes, that works and makes sense.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, June 29, 2022 3:22 PM
To: Arne Olson <arne@ethree.com>; Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: Congressional staff briefing

Deliberative, FOIA exempt

Thanks Arne- can we slot an hour on July 7th for a joint hour-long press availability- maybe 1:00 PDT? Basically our communications would set up a conference line where any press outlet could call and ask questions about the report or presentation from the Council meeting. We would defer to you for any of the analytical questions and then BPA would cover any questions related to CRSO EIS, future consequences on FCRPS, etc..

From: Arne Olson <arne@ethree.com>
Sent: Wednesday, June 29, 2022 1:35 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] RE: Congressional staff briefing

Apologies, I now have a conflict until 4 PM EDT on the 7th. Could probably skip the last hour of the seminar I'm participating in and be available at 3 PM EDT if necessary. I've blocked off the hour on the 8th.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, June 29, 2022 1:16 PM
To: Arne Olson <arne@ethree.com>; Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: Congressional staff briefing

Deliberative, FOIA exempt

Hi Arne-
Murray's office would like an E3 results briefing July 8 at 3:00 PM Eastern time (12:00 Pacific). There is also a broader NW Congressional briefing that may be scheduled with staff still working around the availability you mentioned below for July 7 after 2 PM EDT and July 8 outside of the Murray time of 3 – 4 since they wanted a separate briefing. Let me know if your availability has changed at all.

Thanks,
Eve

From: Arne Olson <arne@ethree.com>
Sent: Thursday, June 23, 2022 2:11 PM

To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] RE: Congressional staff briefing

I'm tied up until 2 PM EDT on July 7 but am available any time on July 8.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 23, 2022 2:07 PM
To: Arne Olson <arne@ethree.com>; Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: Congressional staff briefing

Deliberative, FOIA exempt

Hi Arne-
I just heard from our DC relations staff that Congressional staff would prefer their own briefing of the E3 results. Would you be available later on July 7 (outside of your 10 – 1 PM conflict) or the next day to present? Let me know your availability and we'll work on scheduling a virtual presentation.

Thanks,
Eve

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Wednesday, April 20, 2022 4:19 PM
To:	James,Eve A L (BPA) - PG-5; Angineh Zohrabian; Riley,Erin A (BPA) - PGPR-5
Cc:	Koehler,Birgit G (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5; Egerdahl,Ryan J (BPA) - PGPR-5; Sierra Spencer; Arne Olson; Jack Moore
Subject:	[EXTERNAL] RE: Data for E3

Deliberative; FOIA Exempt

Thanks Eve for confirming this is the dataset we would use if we can get to that case.

Aaron

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

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

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

Deliberative; FOIA Exempt

Hi Eve,

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

Otherwise the run parameters are the same as before.

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

Wednesday, December 6, 2023	Friday, December 8, 2023
Wednesday, January 3, 2024	Friday, January 5, 2024
Wednesday, February 7, 2024	Friday, February 9, 2024

Wednesday, July 3, 2024	Friday, July 5, 2024
Wednesday, August 21, 2024	Friday, August 23, 2024

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

Erin Riley
Operations Research Analyst
PGPR- Long Term Power Planning
Bonneville Power Administration
503-230-3717

From: Arne Olson <arne@ethree.com>
Sent: Friday, July 1, 2022 3:55 PM
To: James,Eve A L (BPA) - PG-5
Cc: Baskerville,Sonya L (BPA) - AIN-WASH; Aaron Burdick; Kohne,Kyle R (BPA) - TPM-OPP-3
Subject: [EXTERNAL] RE: July 8 meetings

Got it. Thank you. I have blocked off the time on my calendar.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, July 1, 2022 3:48 PM
To: Arne Olson <arne@ethree.com>
Cc: Baskerville,Sonya L (BPA) - AIN-WASH <slbaskerville@bpa.gov>; Kohne,Kyle R (BPA) - TPM-OPP-3 <krkohne@bpa.gov>
Subject: July 8 meetings

Hi Arne-
There will be 2 Congressional staff meetings on July 8 for the E3 study results presentation. 1:30 – 2:30 PM EDT for all NW Congressional delegation, and 3:00 PM EDT for Sen Murray's staff. Sonya will send you and Birgit the WebEx information once that gets set up.

Thanks,
Eve

From: Arne Olson <arne@ethree.com>
Sent: Thursday, May 19, 2022 12:11 PM
To: James,Eve A L (BPA) - PG-5; Aaron Burdick
Cc: Koehler,Birgit G (BPA) - PG-5
Subject: [EXTERNAL] RE: Peer review

Eve, my perspective is that these represent criticisms we are likely to receive from regional stakeholders once the study is rolled out. I didn't see anything that pointed out a flaw per se, but it did seem like a few additional sensitivity cases might be useful to provide some information about the potential magnitude of some of the major uncertainties.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, May 19, 2022 11:58 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: Peer review

DELIBERATIVE FOIA EXEMPT

Hi Aaron-
Just to level set for the Monday meeting- do you think the DOE comments point out flaws with the study that need to be fixed or are just focused on different interests and would fall in a "nice to have" category? For example, they mentioned an interim date for LSR replacement - we would not want to have additional analysis of a different year since it wouldn't be consistent with the CRSO EIS analysis. However, regarding the comments about ELCC assumptions I can't tell if those are important to address or just note the source or logic behind the assumption and would be interesting to study variations?

Thanks,
Eve

From: James,Eve A L (BPA) - PG-5
Sent: Thursday, May 19, 2022 11:14 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: Peer review

DELIBERATIVE FOIA EXEMPT

Yes- I will be available for an hour during that time window. I do prefer earlier if that works for you [redacted] (b)(6) (b)(6)

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, May 19, 2022 11:02 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] RE: Peer review

DELIBERATIVE FOIA EXEMPT

Thanks for sharing Eve. Lots of smart and useful feedback here, as we expected. We should have a discussion about how to proceed, given that addressing some of these would require significant new analysis beyond remaining budget/scope/timeline. One option is to release the current work as a draft and consider refinement for a final report, though we can discuss other options as well.

I plan to send out draft public deck by tomorrow morning after incorporating forthcoming feedback from Arne.

Are you available Mon for an hour between 2-5pm to discuss the draft public deck and how to incorporate the peer review?

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, May 19, 2022 9:30 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: Peer review

DELIBERATIVE FOIA EXEMPT

Good Morning-
Attached is the peer review comments from DOE/National Labs staff. I had added some comments in as starting language where I had guesses to answers but please edit/revise/or delete as needed since most of the answers should be coming from your shop. This review was based off the E3_BPA_LowerSnakeRiverDams_draft_050622.pdf for the comments that reference to specific slide numbers. Let me know if you have any preference for next steps- I could set up meetings with technical staff if needed or we could address in the document and email responses.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, May 6, 2022 4:02 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] RE: Peer review

DELIBERATIVE FOIA EXEMPT

Thanks Eve. We flew through things but it was a sharp group that followed along very well. Was a nice touch that Ryan unknowingly set up the exact cost metrics we developed.

Here is a slightly updated version of the deck sent earlier this week. This should generally be comprehensive enough for the DOE/Labs peer review. We've included many of the inputs and methodologies (in the deck as well as the appendix). Sharing model files is possible, but would require significant time for them and us to orient them to the data and model structure. This deck includes resource cost graphs and LSR/hydro capacity counting metrics. I suggest we start with this document and we're happy to follow up with any other materials needed.

Note I adjusted the qualitative impacts summary slide (46) per our discussion the other day.

I wish you a great weekend as well!

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, May 6, 2022 2:51 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: Peer review

DELIBERATIVE FOIA EXEMPT

Hi Aaron-
Thanks for the great presentation with the DOE staff today- I thought it went really well. As follow-up on the peer review topic, if you could send materials to me then I will coordinate with Jill to get them to Emily at DOE to distribute to staff who are planning to review. Of course the technical PPT is the minimum, but Ryan already shared it would be helpful to have access to some of the underlying data and model descriptions for RESOLVE. He specifically mentioned the assumed cost of replacement resources (solar, gas, etcc) and the assumed ELCC of the LSR dams and that sort of information. Let me know if there are any issues with getting that type of information put together. We can touch base on that next week. I forwarded the budget estimate you sent for the additional lay person/policy level materials to contracting so hopefully the modification will get completed next week as well.

Have a great weekend!
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, May 4, 2022 11:38 AM
To: James,Eve A L (BPA) - PG-5
Subject: [EXTERNAL] RE: Scheduling E3+BPA check in this week

Deliberative; FOIA Exempt

Thanks Eve. I'll include these updates.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, May 4, 2022 11:34 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: Scheduling E3+BPA check in this week

Deliberative; FOIA Exempt
I realize I forgot to explain the blue edit- that description will need to read current BPA Tier I rate instead of Generation rate.

From: James,Eve A L (BPA) - PG-5
Sent: Wednesday, May 4, 2022 9:55 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: Scheduling E3+BPA check in this week

Deliberative; FOIA Exempt
Hi Aaron-
Thanks for sending out the meeting for tomorrow. Since you are expecting to have the updated RESOLVE power point later today I wanted to send you a note on some edits that would be helpful to Slide 20. After our Exec meeting there was some questions around the information on that slide so thought it might help clarify a few things:

Incremental LSR Dam Replacement Resource Costs

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

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

‹placement $/MWh costs are calculated as CoreNW revenue requirement increase with LSR dams removed divided by the annual
h of the LSR dams. These costs includes replacement of the LSR dam energy, capacity, and reserve provision. A significant portion
ie costs is capacity costs to replace the dams' RA capacity contributions.
ıcremental BPA customers costs calculated as the incremental annual revenue requirement divided by BPA's Tier 1 annual sales
3,888 GWh/yr per FY2022 BPA forecast)

And since my mouse edits are messy the red edits would look:

LSR Dam all-in Generation costs (2022 $/MWh)
$13/MWh without LSRCP *
$17/MWh with LSRCP

* add footnote about LSRCP

Bonneville 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.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, May 3, 2022 10:34 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] Scheduling E3+BPA check in this week

Deliberative; FOIA Exempt

Hi Eve,

We have all our final cases now run, but are still working to package the final results. No major changes so not much to discuss. (The only big new finding is the early LSR removal case in 2024, which increases the replacement costs to ~$7B

NPV vs. $3.3B NPV in the baseline S1 case on which we ran it.) One thing however we should briefly discuss is whether we want to show all cases or remove some – I can note our recommendation when I send over the updated slides.

Do you have availability any of these times for a check in this week? I think we can primarily focus on the peer review email that Eve sent. We are certainly open to it and think a short discussion to align on the objectives/scope would be useful.

- Wed 12-1 or 3-4
- Thurs 11-12 or 2:30-4

We should have the updated RESOLVE PPT package done by end of day Wednesday, but, again, since there aren't really substantive changes in the results, I don't think we need to walk through them. So that needn't constrain when we meet.

Thanks,

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

From:	Arne Olson <arne@ethree.com>
Sent:	Thursday, August 4, 2022 2:56 PM
To:	Koehler,Birgit G (BPA) - PG-5; Aaron Burdick
Cc:	James,Eve A L (BPA) - PG-5
Subject:	[EXTERNAL] RE: did you see the Council summary of your study?

Pretty good summary!

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Thursday, August 4, 2022 1:58 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: did you see the Council summary of your study?

You probably saw this already, but just in case...

Lower Snake River Dams Replacement Power Study by E3 (nwcouncil.org)

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Monday, July 11, 2022 10:00 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 Report_071122.docx

Ok, see public report attached with relevant updates made in the public deck reflected (corrected final NPV values, added scenario 1b w/ binding CES target, added range for scenario 2c).

Will send PDF for report next.

Aaron

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, July 11, 2022 5:17 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

I was just about to hit send on this when Aaron's email arrived with the ppt....

Here's BPA's plan regarding timing.

I'll take a quick look when I get the documents then send them to our communications staff. One person will be up at 5:30 am to set up a 6 am post on BPA's web site. (We recently switched or set up a new system for something posting automatically, but since it is new and this one's important, they didn't want to risk it.) So, while I don't want you to have to work all night, I also don't want you racing so fast that you don't have time to be careful. Send them to me when you're ready.

- ----------

Not urgent for tonight, but to keep you in the loop:
BPA communications decided not to set up a formal session with the media now that reports will have the report and not just the ppt tomorrow. You should feel free to respond to the media on any questions related to your analysis and conclusions. We expect BPA will get inquiries about the process on this strange roll-out. If you do get many requests and want to set up a media briefing, I could ask our folks to help facilitate that if you'd like.

BPA will offer briefings to Congressionals, probably one general session and one for Senator Murray's office as per last week's plan. If there are significant changes to your availability since last Wed please let us know, maybe even extend into next week.

From: Koehler,Birgit G (BPA) - PG-5
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

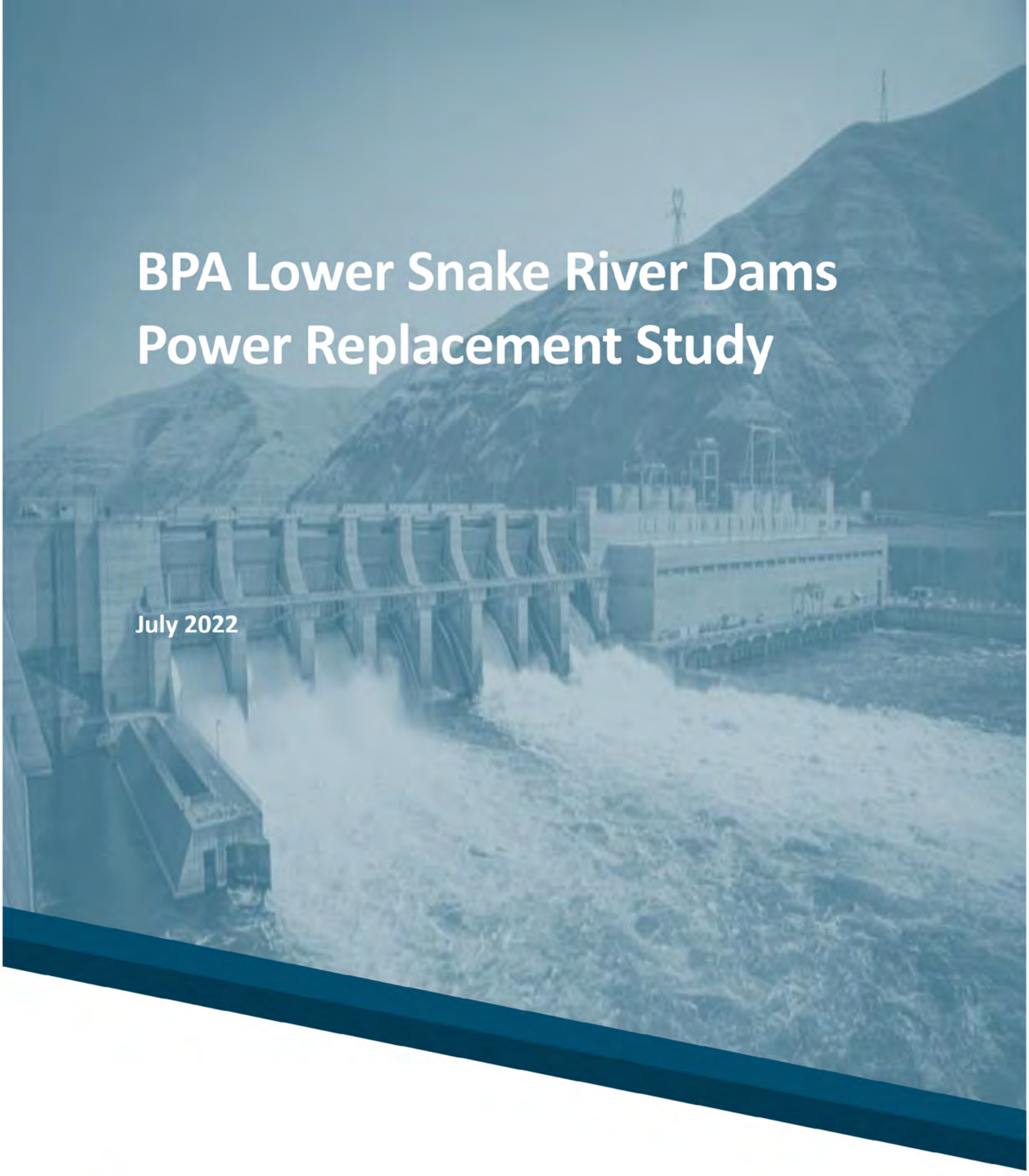
Hello Arne and Aaron,

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

BPA Lower Snake River Dams Power Replacement Study

July 2022



Energy+Environmental Economics

BPA Lower Snake River Dams Power Replacement Study

July 2022

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Acronym Definitions

Acronym	Definition
BPA	Bonneville Power Administration
BTM Solar	Behind-the-meter Solar
CA	California
CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
CES	Clean Energy Standard
CRSO EIS	Columbia River System Operations Environmental Impact Statement
DR	Demand response
EE	Energy efficiency
EIA	Energy Information Administration
ELCC	Effective load carrying capability
HDV	Heavy-duty vehicles
H2	Hydrogen
LDV	Light-duty vehicles
LSR	Lower Snake River
NERC	North American Electric Reliability Corporation
NG	Natural Gas
NV	Nevada
NW	Northwest
PNUCC	Pacific Northwest Utilities Conference Committee
PRM	Planning Reserve Margin
RM	Rocky Mountains
RPS	Renewable Energy Standard
SMR	Small modular reactor
SW	Southwest
WECC	Western Electricity Coordinating Council

Executive Summary

E3 was contracted by the Bonneville Power Administration to conduct an independent study of the value of the lower Snake River dams ("LSR dams") to the Northwest power system. The dams provide approximately 3,500 megawatts ("MW") of total capacity[1] and approximately 2,300 MW of firm peaking capability[2] to support regional reliability. They also generate approximately 900 average MW of zero-carbon energy each year[3], provide essential grid services such as operating reserves and voltage support, and operational flexibility to support renewable integration. If the dams are breached, these power services will need to be replaced to ensure the Northwest power system can continue to provide reliable electricity service. Replacing the dams is complicated by the clean energy policies adopted either statutorily or voluntarily by jurisdictions and utilities throughout the region, which will necessitate a transformation of the power system over time toward non-emitting resources even as electricity demand grows substantially due to electrification of the transportation and building sectors.

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho, and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability. RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[4]. Using RESOLVE allows for a dynamic optimization that considers replacement resource needs in the context of long-term system load and policy drivers, not just the near-term resource mix

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

[2] LSR dam firm capacity contributions are estimated using the PNUCC regional hydropower 65% capacity value, which was validated by looking at LSR Dam wintertime power and reserve provision during low hydro conditions. Additionally, E3 considered estimates on the impact of a lower firm capacity value in the results chapter.

[3] The data for the LSR dams was adjusted to reflect the Preferred Alternative operations defined in the Columbia River Systems Operation Environmental Impact Statement (CRSO EIS). E3's RESOLVE model uses 2001, 2005, and 2011 hydro years, which resulted in ~700 average MW of lower Snake River dams generation, making it a conservative estimate of the dams' GHG-free energy value.

[4] Pacific Northwest Low Carbon Scenario Analysis, December 2017, https://www.ethree.com/projects/study-policies-decarbonize-electric-sector-northwest-public-generating-pool-2017-present/; Pacific Northwest Zero-Emitting Resources Study, January 2020, https://www.ethree.com/e3-examines-role-of-nuclear-power-in-a-deeply-decarbonized-pacific-northwest/

and needs of the system today. The dams are assumed to be breached in 2032, except for one sensitivity that considered 2024 breaching.

This study's scenario design focuses on three key variables – clean energy policy, load growth, and emerging technology availability – that impact the cost to replace the dams. The scenarios and key assumptions are show in Table 1.

Table 1. Scenario Design

Scenario	Clean Energy Policy	Load Growth	Technology Availability
1 100% Clean Retail Sales	100% retail sales (65-85% 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

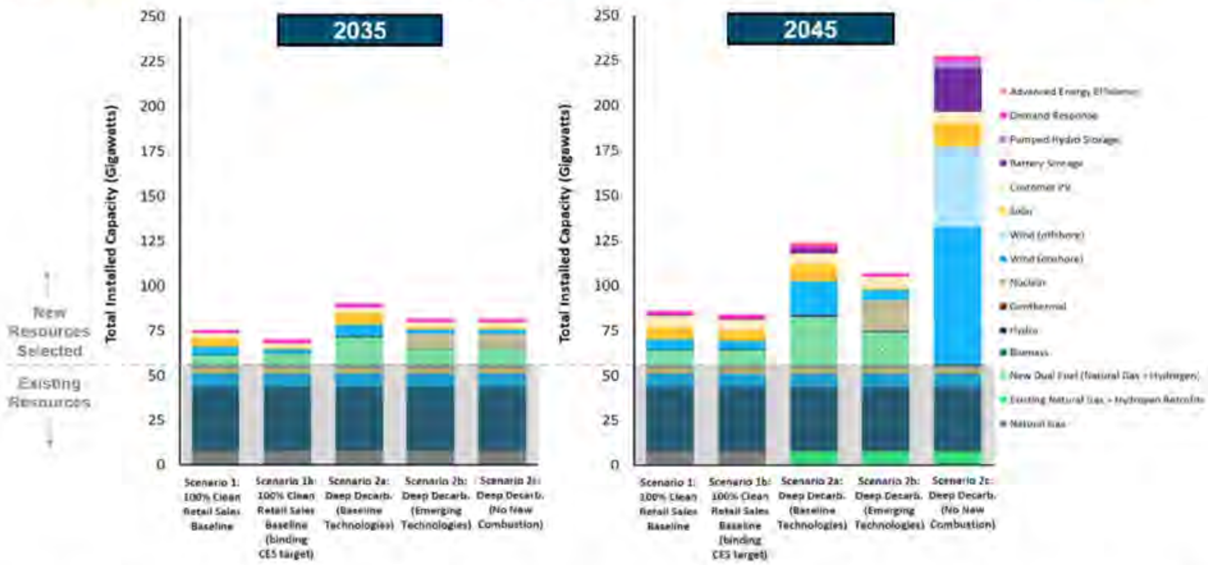
Even with the dams in place, the region's clean energy goals and potential electrification load growth drive a significant need for new resources. In all scenarios, significant energy efficiency and customer solar is embedded into the load forecast, based on the NWPCC's 8th Power Plan. Additionally, 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 5.5-7 GW of solar and 4.6-6 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.[5]

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

[5] E3 ran two versions of scenario 1. 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. 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. The values shown here represent the range of additions across both scenarios.

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 and solar power and the firm capacity with dual fuel natural gas and hydrogen combustion plants. Small amounts of additional energy efficiency and battery storage are also selected in some scenarios. By 2045, the dual fuel plants added burn additional hydrogen on low wind days to replace the carbon-free energy provided by the dams. Scenario 2b selects additional nuclear SMRs in lieu of some of the wind and gas resources. Scenario 2c disallows the new combustion plants, even those that would burn green hydrogen, and other emerging technologies, requiring a very large buildout of wind and solar power to replace both the firm capacity and the carbon-free energy of the dams.

The long-term emissions impact of removing the generation of the lower Snake River dams will depend on the implementation of the Oregon and Washington electric clean energy policies. Both a 100% clean retail sales and a zero-carbon emissions target require replacement of most or all of the LSR dams' GHG-free energy. However, without additional earlier carbon-free resource investments beyond those modeled in this study to meet clean energy policy trajectories, carbon emissions may increase initially when the dams are breached, before declining by 2045 as the carbon policy becomes more stringent.

Table 2. Summary of LSR Dams Replacement Resources and Cost Impacts (costs in the table below and throughout this report are shown in real 2022 dollars)

Scenario	Replacement Resources Selected, Cumulative by 2045 (GW)	NPV Replacement Costs[6]	Annual Replacement Costs[7]			Public Power Rate Impact[8]
			2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind	$12.4 Billion	-	$434 million/yr	$478 million/yr	0.8 ¢/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam removal)	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind	$12.8 Billion	$495 million/yr	$466 million/yr	$509 million/yr	0.8 ¢/kWh [+9%]
Scenario 1b: 100% Clean Retail Sales (binding CES target)	+ 1.8 GW dual fuel NG/H2 CCGT + 1.3 GW solar + 1.2 GW wind	$12.0 Billion	-	$445 million/yr	$473 million/yr	0.8 ¢/kWh [+9%]
Scenario 2a: Deep Decarbonization (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW advanced EE + 1.2 TWh H2-fueled generation	$19.6 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	$11.2 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	$42 – 77 billion[9]	-	$ 1,045 – 1,953 million/yr	$1,711 – 3,199 million/yr	2.9 – 5.5 ¢/kWh [+ 34 – 65%]

KEY FINDINGS:

[6] These NPV values are calculated assuming a 3% discount rate to represent the public power cost of capital, discounting 50-year of costs starting from the year of breaching (either 2032 or 2024).

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

[8] 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.

[9] 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 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 – 4,300 MW of replacement resources
    - An annual cost of $415 million – $860 million by 2045
    - Total net present value 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
+ 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 $42 – 77 billion NPV cost)

Background

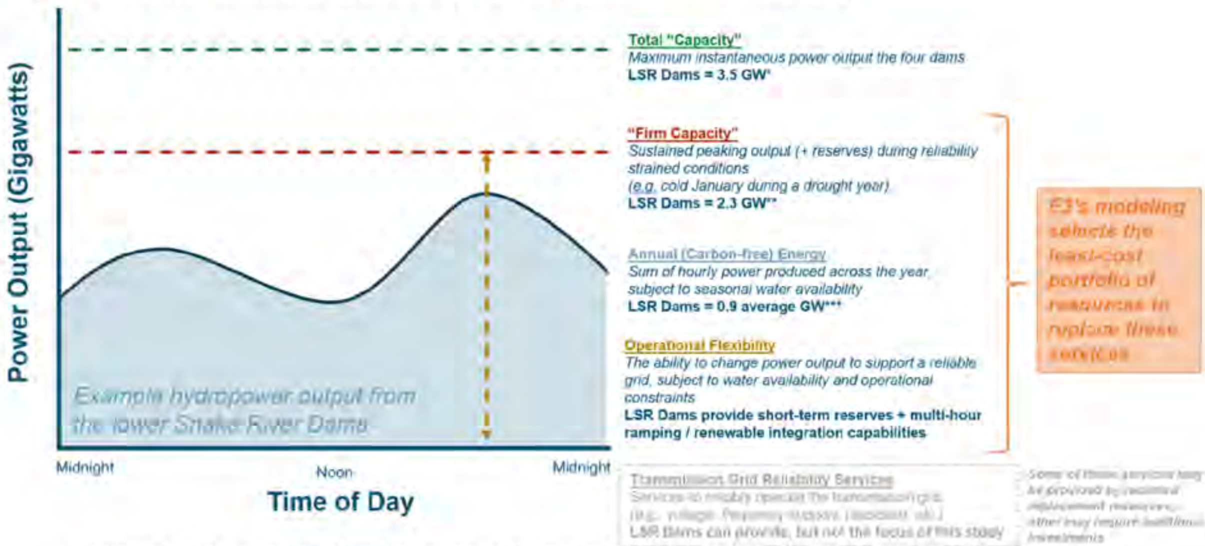
E3 was contracted by the Bonneville Power Administration to conduct an independent study of the value of the lower Snake River dams ("LSR dams") to the Northwest power system. The dams provide approximately 3,500 megawatts ("MW") of total capacity[10] and approximately 2,300 MW of firm peaking capability[11] 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.

---

[10] 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.

[11] LSR dam firm capacity contributions are estimated using the PNUCC regional hydropower 65% capacity value, which was validated by looking at LSR Dam wintertime power and reserve provision during low hydro conditions. Additionally, E3 considered estimates on the impact of a lower firm capacity value in the results chapter.

Figure 2. Power Services Considered for Replacement in this Study



* Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. Historical peak generation was 3,431 MW.

** Firm capacity assumed in this study is consistent with the ~65% Northwest hydro capacity value assumed by PNUCC (the Pacific Northwest Utilities Conference Committee).

*** Average GW means that on average across an average year the plant generated at 0.9 GW, though its hourly output may be above or below that amount. The data for the LSR dams was adjusted to reflect the Preferred Alternative operations defined in the Columbia River Systems Operation Environmental Impact Statement ("CRSO EIS"). E3's RESOLVE model uses 2001, 2005, and 2011 hydro years, which resulted in ~700 average MW of lower Snake River dams generation, making it a conservative estimate of the dams' GHG-free energy value.

If the dams are breached, these power services will need to be replaced to ensure the Northwest power system can continue to provide reliable electricity service. Replacing the dams is complicated by the clean energy policies adopted either statutorily or voluntarily by jurisdictions and utilities throughout the region, which will necessitate a transformation of the power system over time toward non-emitting resources even as electricity demand grows substantially due to electrification of the transportation and building sectors.

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability.

RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[12]. 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.[13]

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.[14]

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

[12] 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/

[13] The study examines LSRD breaching in 10 years (2032) and in 2 years (2024), based on with the approach used in the CRSO EIS.

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

just the near-term resource mix and needs of the system today. It recognizes that significant levels of new renewable energy and other resources are already needed to meet long-term regional needs, ensuring that the replacement resource mix selected is incremental to the long-term buildout, not just an interim solution before clean energy policies reach their apex in the 2040s.

Scenario Design

Regional Policy Landscape

To properly understand the resources needed to replace the power services of the lower Snake River dams, it is critical to consider the regional policy landscape of the Pacific Northwest. In the last few years, the states of Oregon and Washington have adopted some of the most aggressive clean energy policies in the nation. While the Pacific Northwest was already a leader in renewable energy production due to its abundant hydropower resource, these aggressive policies will require key changes to the region. First, coal power must be phased out in the Northwest during this decade and, at least in Washington, carbon will be priced via a market-based cap-and-trade mechanism[15]. 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.

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[15] For simplicity, this study assumes a uniform carbon price across the Core Northwest region beginning in 2023.

Table 3. Policy landscape in Washington, Oregon, and California

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

Maintaining Resource Adequacy in Low-carbon Grids

Like other regions pursuing aggressive climate policies, the Northwest faces a key decarbonization challenge: how to maintain a reliable electricity supply, while simultaneously increasing electric loads and retiring the firm, but emitting, capacity that currently supports regional reliability. In 2019, E3 used its RECAP loss of load probability model to study how decarbonizing the electricity supply impacts regional reliability.[16] 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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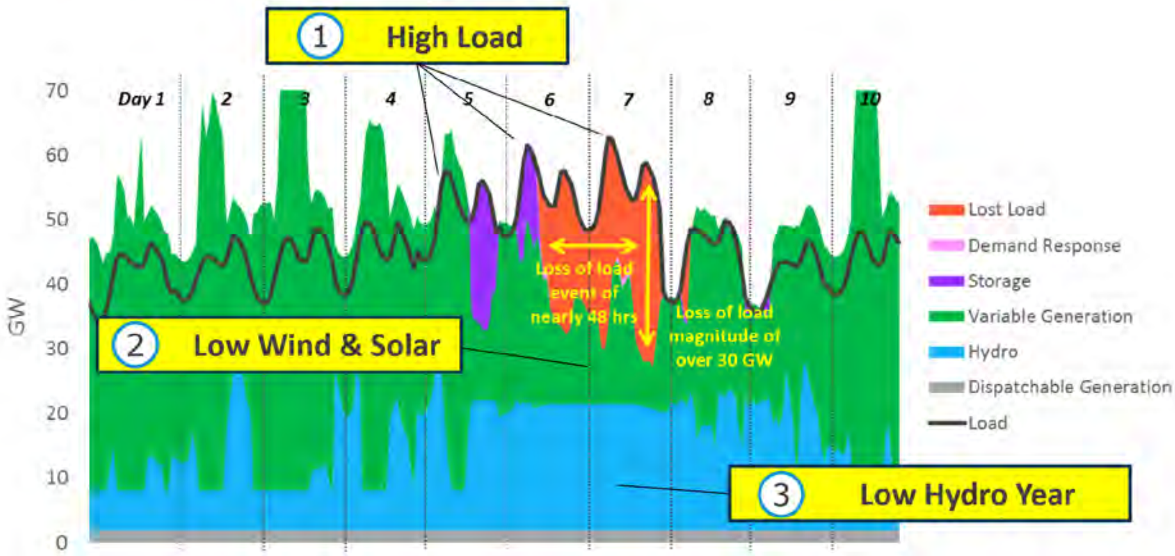
[16] E3, 2019. *Resource Adequacy in the Pacific Northwest.* https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

additional firm generating capacity may be needed, even in scenarios that add significant amounts of non-firm solar, wind, batteries, and demand response. The resource adequacy modeling approach is described further in the section *Resource Adequacy Needs and Resource Contributions*.

Figure 3. Key Drivers of Pacific Northwest Reliability Events in a Decarbonized Grid



[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[17]
Pumped storage	Sharply declining ELCCs
Solar	Declining ELCCs
Wind	Declining ELCCs
Demand Response	Declining ELCCs
Energy Efficiency	Limited potential vs. cost
Small Hydro	Limited potential
Geothermal	Limited potential
Natural gas to H2 retrofits	Clean firm, but not fully commercialized
New dual fuel natural gas + H2 plants	Clean firm, but not fully commercialized
New H2 only plants	Clean firm, but not fully commercialized
Gas w/ 90-100% carbon capture + storage	Clean firm, but not fully commercialized
Nuclear Small Modular Reactors	Clean firm, but not fully commercialized

Scenarios Modeled

This study focuses on three key variables (clean energy policy, load growth, and emerging technology availability) that impact the cost to replace the dams.

Clean Energy Policy

Clean energy policy for the electric sector is modeled at either 100% clean retail sales or zero-carbon by 2045. A 100% clean retail sales policy requires serving 100% of electricity sold on an annual basis to be met by clean energy resources. This allows generation not used to serve retail sales (i.e., transmission and distribution losses) to be met by emitting resources. It also allows emitting generation or unspecified imports in one hour to be offset by exported generation in another hour of the year. In the baseline load scenario, reaching 100% clean retail sales by 2045 results in ~65-85% 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.

[17] E3 performed a sensitivity with battery ELCCs that do not decline so sharply. This sensitivity shows minor changes in the LSR dam replacement resources, but little to no change in the replacement costs.

Load Growth

With aggressive clean energy policies, load growth determines the amount of new zero-emitting resources that must be added to the Northwest power system. A baseline load growth scenario is modeled, based on the forecast in the NWPCC 8th Power Plan. A second high electrification scenario is developed based on the high electrification case in the Washington State Energy Strategy.[18] Based on E3's analysis of the electrification of transportation, buildings, and industry in that study, this scenario results in an additional annual energy demand increase of 28% by 2045 (above the baseline scenario) and an additional winter peak demand increase of 68%. The peak demand increase is high due to the electrification of space heating end uses, which requires replacing the significant quantities of energy provided by the natural gas system during extreme wintertime cold weather events with electricity.

Technology Availability

It is expected that the availability of emerging technologies may be critically important for replacing the LSR dam power services while reaching a deeply decarbonized grid. All scenarios include "mature technologies" such as solar, wind, battery storage, pumped hydro storage, demand response, energy efficiency, small hydro, and geothermal. Three scenarios of emerging technology availability are developed as follows:

A. **Baseline technologies**: mature technologies and dual fuel natural gas + hydrogen combustion plants
B. **Emerging technologies**: mature technologies, dual fuel natural gas + hydrogen combustion plants, small modular nuclear reactors, natural gas with carbon capture and storage, and floating offshore wind
C. **No new combustion (limited technologies)**: mature technologies and floating offshore wind

All scenarios assume that the existing natural gas capacity fleet can convert to green hydrogen, i.e., hydrogen produced using zero-carbon electricity. However, new firm resources are needed in all scenarios to replace retiring resources and meet growing electric loads.

Table 5 shows a summary of the four scenarios that are the primary focus of this study.

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[18] See Washington State's *2021 State Energy Strategy*, https://www.commerce.wa.gov/growing-the-economy/energy/2021-state-energy-strategy/

Table 5. Scenario Design

Scenario	Clean Energy Policy	Load Growth	Technology Availability
1 100% Clean Retail Sales	100% retail sales (65-85% carbon reduction)	8^{th} 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)

The following additional sensitivities were considered:

- **Scenario 1: 100% Clean Retail Sales (2024 dam removal)**: same as scenario 1, but with 2024 LSR Dams breaching instead of 2032.
- **Scenario 1b 100% Clean Retail Sales (Binding CES Target)**: E3 ran two versions of scenario 1. 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. In scenario 1b, no carbon price was assumed and the 100% CES target is binding in 2045, causing the need to fully replace the GHG-free energy output of the LSR dams.
- **High Storage ELCC Sensitivity**: sensitivities were run on both Scenarios 1 and 2a to test whether a higher Northwest storage ELCC would change the marginal resources and replacement costs for the LSR dams.

Modeling Approach

RESOLVE Model

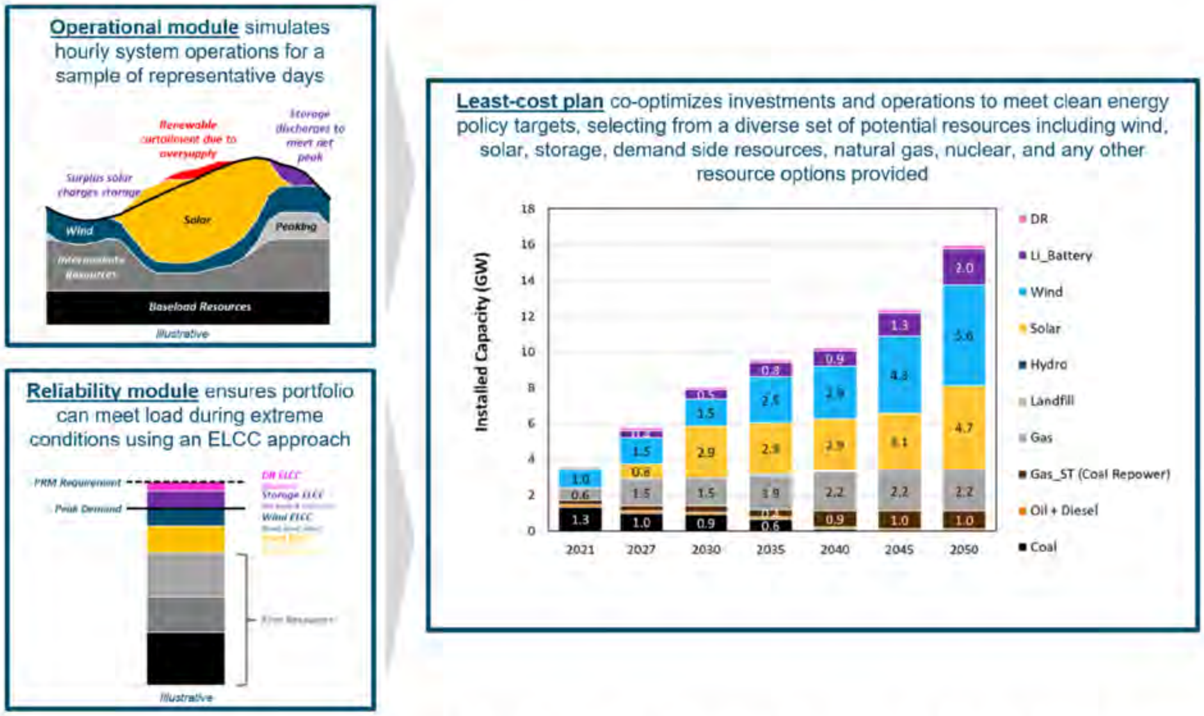
E3's Renewable Energy Solutions Model (RESOLVE) is used to perform a portfolio optimization of Northwest system's electric generating resource needs between 2025 and 2045. RESOLVE is an optimal capacity expansion and dispatch model that uses linear programming to identify optimal long-term generation and transmission investments in an electric system, subject to reliability, operational, and policy constraints. Designed specifically to address the capacity expansion questions for systems seeking to integrate large quantities of variable energy resources, RESOLVE layers capacity expansion logic on top of a production cost model to determine the least-cost investment plan, accounting for both the up-front capital costs of new resources and the variable costs to operate the grid reliably over time. In an environment in which most new investments in the electric system have fixed costs significantly larger than their variable operating costs, this type of model provides a strong foundation to identify potential investment benefits associated with alternative scenarios.

The three primary drivers of optimized resource portfolios include:

+ **Reliability:** all portfolios ensure system meets resource adequacy requirements. In this case, the target reliability need is to meet 1-in-2 system peak plus additional 15% of planning reserve margin (PRM) requirement.
+ **Clean Energy Standard ("CES") and/or carbon reduction targets:** all portfolios meet the clean energy standard and/or a carbon-reduction trajectory
+ **Least cost**: the model's optimization develops a portfolio that minimizes costs

Figure 4 illustrates the use of RESOLVE's operational module, which tracks hourly system operations including cost and greenhouse gas emissions across a representative set of days, and RESOLVE's reliability module, that uses exogenously calculated input parameters to characterize system reliability of candidate portfolios using effective load carrying capability (ELCC) for solar and wind resources.

Figure 4. Schematic Representation of the RESOLVE Model Functionality



RESOLVE develops least-cost portfolios using key inputs and assumptions including loads, existing resources, new resource options, retirement or repowering resource options, resource costs, resource operating characteristics including resource adequacy contributions, a zonal transmission transfer topology, and new resource transmission costs.

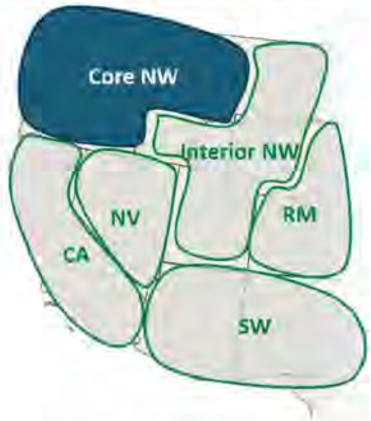
Northwest RESOLVE Model

The Northwest RESOLVE model was developed in 2017 for E3's *Pacific Northwest Low Carbon Scenario Analysis* study.[19] 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

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

outside of the Core Northwest are grouped into five additional zones: (1) Other Northwest, (2) California, (3) Southwest, (4) Nevada and (5) Rockies. For these zones, investments are not optimized; rather, the trajectory of new builds is established based on regional capacity needs to meet PRM targets, as well as renewable needs to comply with existing RPS and GHG policies in their respective regions, and held constant across all scenarios. E3's WECC-wide resource mix incorporates aggressive climate policy across the interconnection, as described in section *Baseline resources*.

Figure 5. RESOLVE Northwest zonal representation



The Northwest RESOLVE model simulates the operations of the WECC system for 41 independent days sampled from the historical meteorological record of the period 2007-2009. An optimization algorithm is used to select the 41 days and identify the weight for each day such that distributions of load, net load, wind, and solar generation match long-run distributions. Daily hydro conditions are sampled separately from dry (2001), average (2005), and wet (2011) hydro years to provide a complete distribution of potential hydro conditions. This allows RESOLVE to approximate annual operating costs and dynamics while limiting detailed operational simulations of grid operations to 41 days.

LSR Dams Modeling Approach

The LSR dams' capacity and operation are characterized with several input parameters that are presented in Section *Hydro parameters*. The approach taken in this analysis is to model LSR dams as an *in/out* resource to determine the dams' replacement costs and replacement portfolio. In other words, "in" scenarios include LSR dams in the existing resource portfolio of Core Northwest throughout the entire modeling period (i.e., 2025-2045); whereas "out" scenarios exclude LSR dams with preset 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.[20] NPV replacement costs are calculating using a 3% discount rate to represent the public power cost of capital.

Figure 6. Modeling Approach to Calculate the LSR Dams Replacement Resources and Costs

This modeling approach inherently considers the benefits of avoiding the LSR dams ongoing fixed and variable costs. The costs associated with breaching the LSR dams themselves are not included in this study. Other power services (i.e., transmission grid reliability services provided by the dams) are also not included but are summarized qualitatively in the Appendix.

Key Input Assumptions

Load forecast

Base load forecast is from NWPCC 2021 Plan and is adjusted to E3's boundary of Core Northwest which roughly represents 87.5% of load of the Northwest system in the NWPCC 2021 Plan. Additionally, a high electrification scenario is modeled which takes Washington's State Energy Strategy high electrification load, scaled up and benchmarked to the Core Northwest region. The baseline high electrification load trajectories are displayed in Figure 7. It is notable that in the high electrification scenario, electric energy demand grows by about 28% by 2045 across all sectors, most noticeably in the commercial building and

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[20] 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.*[21]

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

Figure 7. Annual energy load forecasts for Core Northwest

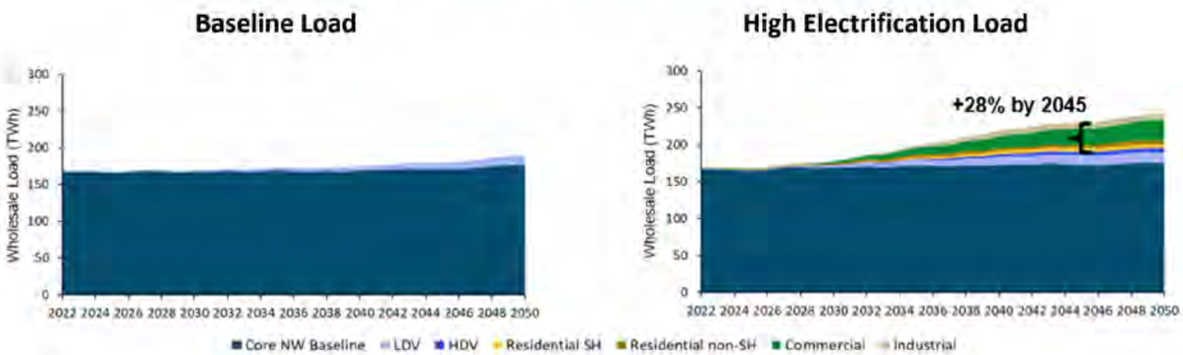
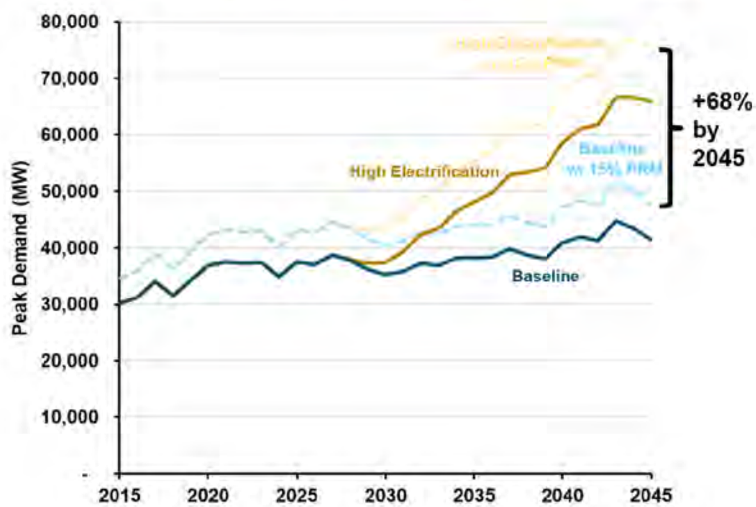


Figure 8 shows the peak demand impacts (including the 15% planning reserve margin) of the high electrification case relative to the baseline, showing a 68% increase by 2045. This high growth is driven by the winter peaking capacity required to replace the gas system peaking capacity to serve peak space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

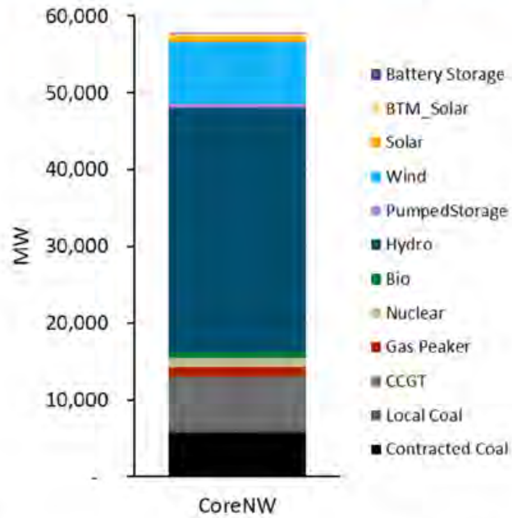
Figure 8. Peak demand forecasts for Core Northwest



Baseline resources

Baseline resources include the existing conventional resources such as natural gas and coal-fired technologies, existing nuclear capacity, hydro as well as pumped storage, battery storage, solar PV, BTM PV and onshore wind technologies. As shown in Figure 9, today's Northwest system has 58 GW capacity. The 1,185 MW nuclear capacity in the Northwest zone remains active throughout the modeling period while the 670 MW local coal capacity is retired by 2025 and the 5,700 MW contracted out of region coal capacity is retired by 2030. The WECC 2020 Anchor Data Set is used for Northwest's existing and planned resources. By 2045, about 5.8 GW additional customer PV is included as planned capacity to capture the growth in behind-the-meter generation forecasted in NWPCC 2021 Power Plan.

Figure 9. Northwest resource capacity in 2022



The investment decisions for external zones are pre-determined based on capacity expansion analysis completed by E3 that accounts for policy targets in each zone as summarized in Table 6. The new builds consist of significant increases in solar and battery capacity additions due to the more aggressive RPS targets, assumed electrification, and the decline of technology cost forecasts (see Figure 10). All future builds in these zones include mature technologies but as discussed in the next section, emerging technologies are made available for RESOLVE to optimize the future resource portfolios in the Northwest zone. There is significant solar and battery storage growth in California, the Southwest, and Nevada that generally lower the marginal value of solar energy produced across the WECC.

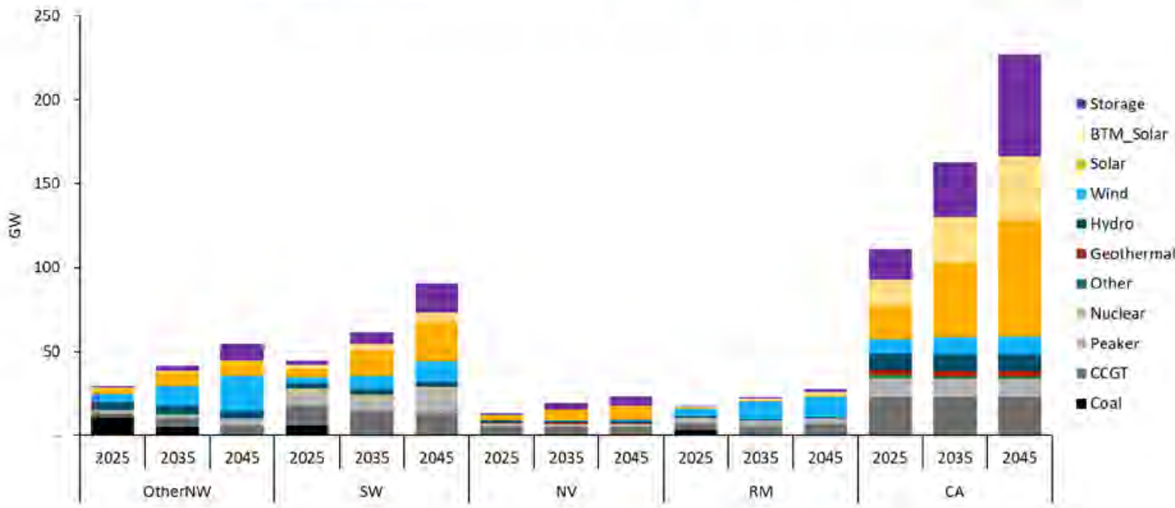
Table 6. Policy targets for builds in external zones

State	Requirement	Policy	2050 Renewable Target
AZ	40% by 2030; 60% by 2045	Transitions to CES[22]	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%

[22] CES = "Clean Energy Standard", an annual based clean generation standard.

MT	87% by 2045 (state carbon reduction goal)	RPS	87%
NM	40% by 2025; 100% by 2045	Transitions to CES	100%
NV	50% by 2030; 100% by 2050	Transitions to CES	95%
UT	50% by 2030; 55% by 2045 (PacifiCorp's IRP)	RPS	55%
WY	50% by 2030, 55% by 2045 (PacifiCorp's IRP)	RPS	55%

Figure 10. Total installed capacity for external zones



Candidate resource options, potential, and cost

A wide range of technologies and resources are made available in RESOLVE, including mature and emerging technologies. The list of technologies made available in each modeled scenario is presented in Table 7. Some technologies such as solar and onshore wind are low-cost zero-carbon energy resources with limited resource potential and declining capacity values. Storage resources such as battery storage and pumped hydro support renewable integration but show limited capacity value given the large shares of hydro in the Northwest region. Demand response supports peak reduction but also faces declining ELCCs. Energy efficiency supports energy and peak reduction but increasingly competes against low-cost renewables. Geothermal is relatively high cost and has limited potential but provides highly valuable "clean firm" capacity.

Some emerging technologies are also made available in several scenarios to allow for firm zero-carbon technologies to be selected from. Hydrogen-capable generators such as dual fuel combustion turbines and combined cycles (i.e., capable of burning both natural gas and hydrogen) as well as retrofits of existing gas generators to burn hydrogen are modeled. These technologies provide low-cost capacity options with very high energy cost when burning expensive hydrogen fuel, therefore RESOLVE selects them for firm capacity needs but limits their hydrogen energy production. Natural gas with carbon capture and storage (CCS) technologies are moderately high cost in terms of both energy and capacity. Nuclear SMR provides moderately high capital cost but low operating cost for firm zero-carbon energy generation. This technology is made available to the model after 2035, to account for the time needed for technology development, licensing, and installation. Floating offshore wind is also modeled as an emerging technology which address onshore resource and land constraints but is generally higher cost than onshore wind while providing a similar annual capacity factor to high quality Montana and Wyoming wind.

Table 7. Available technologies in each modeled scenario

Resource	A. Baseline	B. Emerging Tech	C. No New Combustion (Limited Tech)
Mature resources: solar, wind, battery storage, pumped storage, demand response, energy efficiency, small hydro, geothermal	✓	✓	✓
Natural gas to hydrogen retrofits	✓	✓	✓
Dual fuel natural gas + hydrogen plants	✓	✓	×
Natural gas with 90-100% carbon capture and storage	×	✓	×
Nuclear small modular reactors	×	✓	×
Floating offshore wind	×	✓	✓

There are physical limits to the quantity of renewable resources that can be developed in each 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.[23] 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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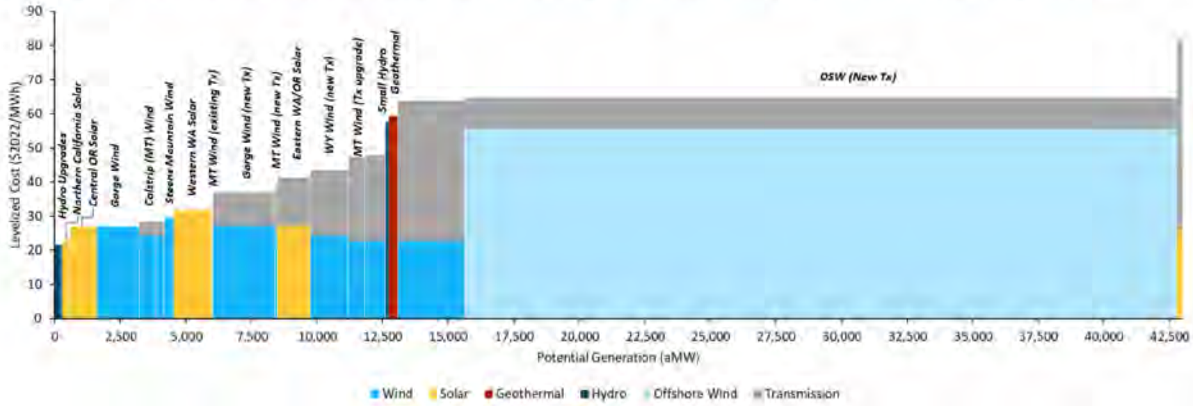
[23] Note: certain solar resources (i.e., Western WA solar) might require transmission upgrades to bring the supply to load centers, which are not captured.

Figure 11. Renewable resource supply curve in 2045, including transmission cost adders



Clean energy policy targets

RESOLVE enforces a clean energy standard ("CES") requirement as a percentage of retail sales to ensure that the total quantity of energy procured from renewable resources meets the CES target in each year. The clean energy standard percentage is calculated as follows, and the target values are summarized in Table 2:

$$CES\ \% = \frac{Annual\ Renewable\ Energy\ or\ Zero\ Emitting\ Generation}{Annual\ CoreNW\ Retail\ Electric\ Sales}$$

Eligible renewable energy and zero-emitting resources include: solar, wind, geothermal, hydropower, nuclear, biomass, green hydrogen, and natural gas with carbon capture and storage.

Regarding GHG emissions, RESOLVE enforces a greenhouse gas constraint on the CoreNW region such that total annual emission generated in the zone must be less than or equal to the emissions cap. The greenhouse gas accounting for the Northwest zone follows the rules established by the California Air Resources Board. The CoreNW carbon emissions baseline is set as 33 MMT at the 1990 level. The total greenhouse gas emissions attributed to the Core Northwest region include:

+ **In-region generation:** all greenhouse gas emissions emitted by fossil generators (coal and natural gas) within the region, based on the simulated fuel burned and fuel-specific CO_2 emissions intensity;
+ **External resources owned/contracted by Core Northwest utilities:** greenhouse gas emissions emitted by resources located outside the Core Northwest but currently owned or contracted by utilities that serve load within the region, based on fuel burn and fuel-specific CO_2 emissions intensity; and
+ **"Unspecified" imports to the Core Northwest:** assumed emissions associated with economic imports to the Core Northwest that are not attributed to a specific resource but represent unspecified flows of power into the region, based on a deemed emissions rate of 0.43 tons/MWh.

Table 8. Annual CES and carbon emissions targets modeled for CoreNW in RESOLVE

Resource	2025	2030	2035	2040	2045
Clean energy standard %	29%	49%	68%	88%	100%

(used in Scenarios 1 and 2[24])					
Carbon reduction emissions target (used only in Scenario 2)	22.7 MMT	17.0 MMT	11.3 MMT	5.7 MMT	0 MMT

Hydro parameters

RESOLVE characterizes the generation capability of the hydroelectric system by including three types of constraints from actual operational data: (1) daily energy budgets, which limit the amount of hydro generation in a day; (2) maximum and minimum hydro generation levels, which constrain the hourly hydro generation; and (3) multi-hour ramp rates, which limit the rate at which the output of the collective hydro system can change from one to four hours. Combined, these constraints limit the generation of the hydro fleet to reflect realistic seasonal limits on water availability, downstream flow requirements, and non-power factors that impact the operations of the hydro system.

In this analysis, hydro operating data are parameterized using conditions for three different hydrological years, i.e., 2001 for dry, 2005 for average and 2011 for wet conditions. For LSR dams, we use hourly generation data provided by BPA, which are adjusted for latest fish protection and spill constraints. For the remainder of the northwest hydro fleet, we rely on historical hydro dispatch data used to develop the TEPPC 2022 Common Case dataset. Using muti-year historical hydro operational data allows capturing the complete set of physical and institutional factors, such as cascading hydro, streamflow constraints, fish protection, navigation, irrigation, and flood control, that limit the amount of flexibility in the hydro system.

For each RESOLVE sampled day, the hydro daily energy budget is calculated as the average of daily electricity generated in the month of each sampled RESOLVE day in its corresponding matched hydro year.[25] The maximum and minimum hydro generation levels (P_{min} and P_{max}) are calculated as the absolute min and max of generation in the month of each sampled RESOLVE day in its corresponding matched year. Multi-hour ramp rates are estimated based on the 99th percentile of upward ramps observed across the three hydrological years of hourly data. In addition, for non-LSR Northwest hydro, the model allows 5% of the hydro energy in each day to be shifted to a different day within two months to capture additional flexibility for day-to-day hydro energy shift.

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[24] 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.

[25] LSR dams generate about 900 average MW of energy during an average hydro year. However, during the three years modeled in RESOLVE, the LSR dams produced only ~700 average MW generation for LSR dams. This means our estimate of the replacement cost of the dams is quite conservative relative to a longer-term expected average of ~900 MW.

Figure 12. RESOLVE Hydro inputs for LSR Dams and other Northwest hydro

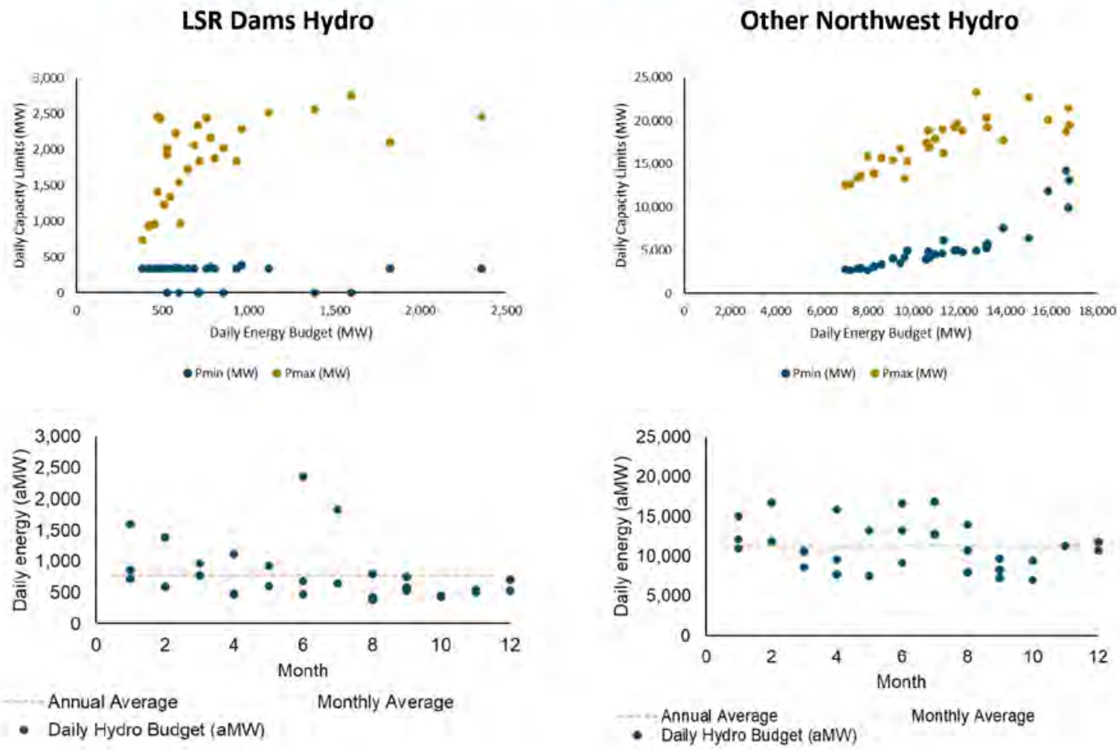

Table 9. Multi-hour ramping constraints applied to Northwest hydro

	One hour	Two hours	Three hours	Four hours
LSR Dams Hydro	36%	43%	45%	48%
Other Northwest Hydro	14%	23%	29%	32%

Resource Adequacy Needs and Resource Contributions

Hydro firm capacity contribution for both LSR dams and other Northwest hydro is assumed to be 65% of nameplate, per PNUCC methodology (based on 10-hr sustaining peaking capacity). This means that the LSR dams provide 2,284 MW of firm capacity that must be replaced if the dams are breached. This assumption was validated based on BPA modeled LSR dam performance data during the 2001 dry hydro year, as described in the section *Key Uncertainties for the Value of the Lower Snake River Dams*, which also describes estimates of the NPV impact of assuming a lower firm capacity value for the dams.

Resource adequacy needs are captured in RESOLVE by ensuring that all resource portfolios have enough capacity to meet the peak Core Northwest median peak demand plus a 15% planning reserve margin. Firm capacity resources are counted at their installed capacity. Hydro resources are counted at the 65% regional value used in PNUCC's 2021 resource adequacy analysis. Solar, wind, battery storage, pumped hydro storage, and demand response are counted at their effective load carrying capability ("ELCC") based on E3's RECAP modeling from its 2019 *Resource Adequacy in the Pacific Northwest* study.[26] 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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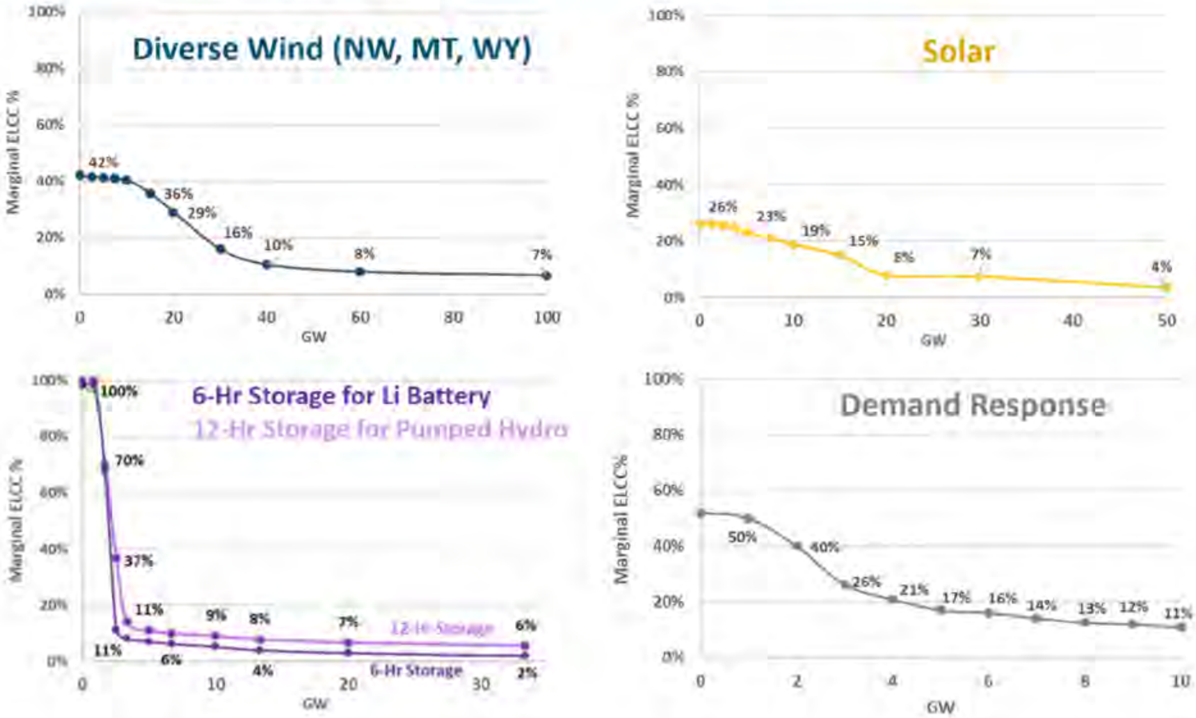
[26] Resource Adequacy in the Pacific Northwest, 2019. https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

Figure 13. Solar, Wind, Storage, and Demand Response Capacity Values



The capacity value for energy storage resources shown in Figure 13 are very different from those in other regions, such as California or the Desert Southwest, declining much more quickly as a function of penetration. There are two reasons for this. First, the Pacific Northwest is a winter peaking region in which loss-of-load events are primarily expected to occur during extreme cold weather events that occur under drought conditions in which the region faces an energy shortfall. These events, such as the one illustrated in Figure 3 above, result in multi-day periods in which there is insufficient energy available to charge storage resources, severely limiting their usefulness. This is unlike the Southwest, where the most stressful system conditions occur on hot summer days in which solar power is expected to be abundant and batteries can recharge on a diurnal cycle. Second, the Pacific Northwest already has a very substantial amount of reservoir storage which can shift energy production on a daily or even weekly basis. Thus, the Pacific Northwest is already much closer to the saturation point where additional diurnal energy shifting has limited value.

Nevertheless, recognizing that the capacity value of energy storage is still being researched, in the Northwest and elsewhere, we include a sensitivity case in which energy storage resources are assumed to have much higher ELCC values, similar to what is expected in the Southwest at comparable penetrations. This test case was used to assess whether a higher energy storage ELCC would change the replacement resources and replacement cost of the LSR dams. The results are presented in the section *Replacement Resources Firm Capacity Counting*.

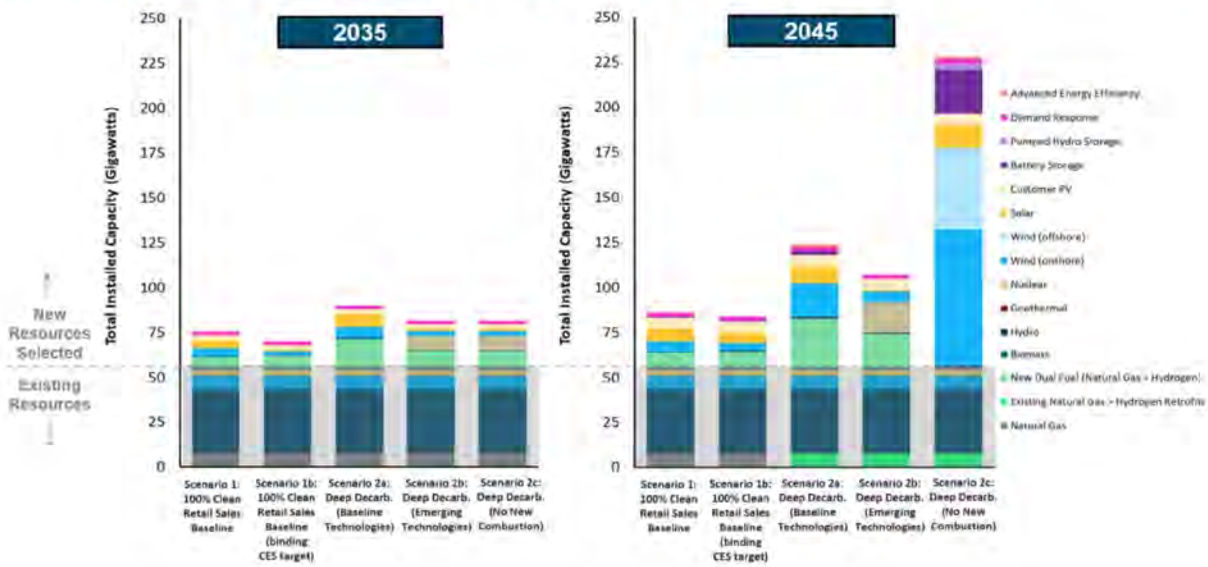
Results

RESOLVE model runs for the 2025-2045 period produce optimal resource portfolios of additions and retirements by resource type, as well as metrics of annual and hourly resource generation, carbon emissions, and total system costs. This section presents the RESOLVE modeling results, focused on the years of 2035 and 2045 to highlight the mid-term and long-term resource needs. Following that, the result of the RESOLVE runs with the LSR dams breached are presented, with the replacement resource and costs to replace the dams' power services.

Electricity Generation Portfolios with the Lower Snake River Dams Intact

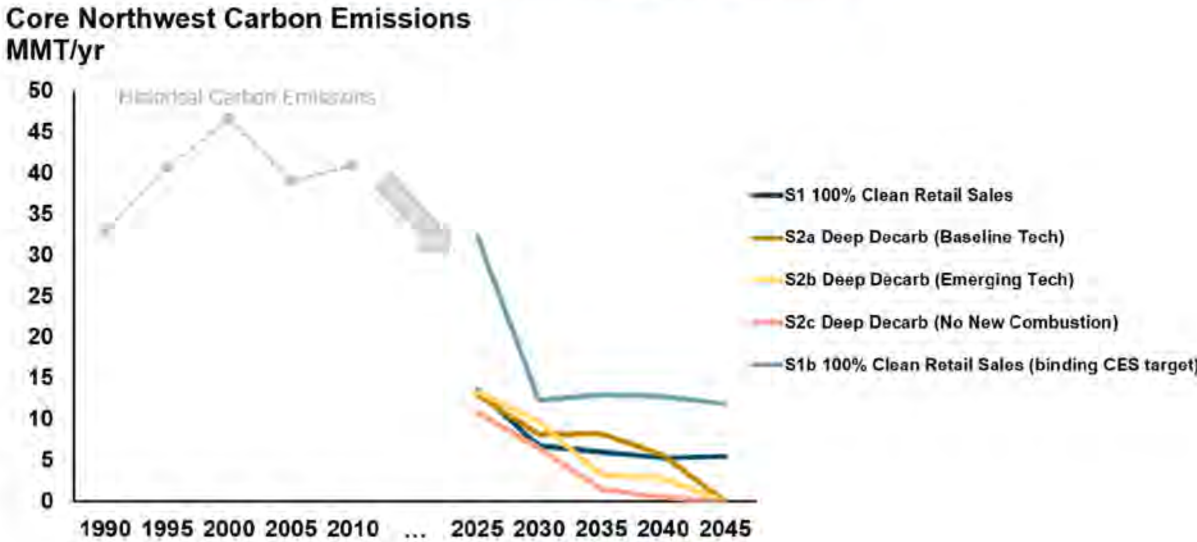
In the scenarios that do not assume breaching of the LSR dams, large amounts of utility-scale solar PV, onshore wind, offshore wind, hydrogen-capable combined cycle, and some amounts of energy efficiency and demand response are selected to meet the growing electricity demand, PRM, and emissions reductions. Electrification load growth along with zero emissions targets drive higher needs in deep decarbonization scenarios (i.e., S2a, S2b and S2c) compared to the reference scenario (S1) in both snapshot years of 2035 and 2045. In S2b, clean firm technologies such as SMR nuclear are selected in place of additional onshore wind, solar and dual-fuel CCGT selected in S2a. In the absence of clean firm technologies (no new combustion) in S2c, massive amounts of offshore wind (~45 GW) as well as more battery storage, pumped storage, demand response, and energy efficiency are selected as early as 2035 such that in this scenario, the new resource additions are almost five time the new builds in S1. These capacity additions increase even more substantially by 2045.

Figure 14. Large levels of new resource additions to meet the growing load, PRM needs and emissions reductions (assumes LSR Dams are NOT breached)



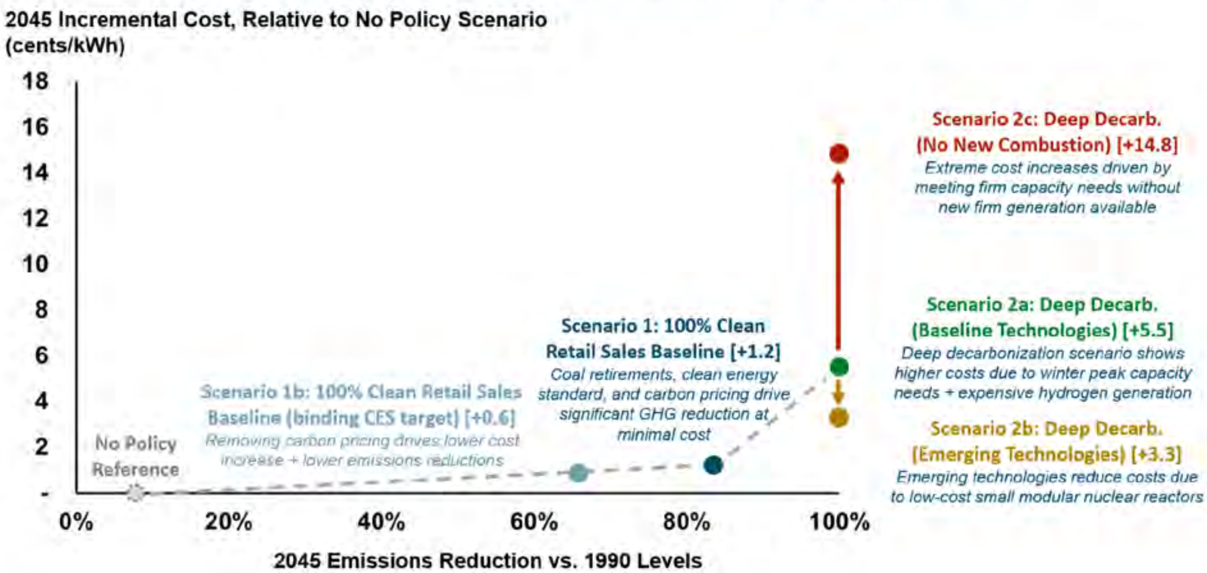
As shown in Figure 15 below, all four scenarios result in a sharp near-term decline in carbon emissions, driven by Washington and Oregon policies that drive coal retirement this decade. By 2045, Scenario 1, which requires 100% clean retail sales, shows an ~85% decline in carbon emissions relative to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

Figure 15. Northwest Carbon Emissions



To put cost impacts in context, a "No Policy Reference" case uses the baseline load forecast and removes all electric clean energy policies, retaining the region's coal power with little emissions decline. The four clean energy futures modeled are compared against this Reference Case on A) their cost impacts, measured in incremental cents/kWh relative to the Reference, and B) their carbon emissions reductions, relative to 1990 levels. By 2045, as shown in Figure 16, with the region's aggressive carbon policies in place, emissions can be reduced by over 80% with a relatively small cost impact (+1.2 cents/kWh relative to the region's current average retail rate of 8-9 cents/kWh). Without a carbon price (scenario 1b), emissions are reduced ~65% with a cost impact of 0.6 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)[27] or other emerging technologies are available[28], showing that relying only on non-firm resource additions (renewable energy, demand side resources, and short- to medium-duration storage) leads to much higher costs.

Figure 16. Cost Impacts Compared to Emissions Reduction Impacts



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

LSR Dams Replacement

The resource replacement portfolios and costs of replacing the LSR dams are reported in this section.

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

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[27] 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.

[28] Floating offshore wind was allowed in the no new combustion case since it was required to allow a feasible solution without making any other firm capacity additions available in the model.

natural gas and hydrogen combustion plants selected to replace the LSR dams' capacity in Scenarios 1, 1b, 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, solar, and a small amount of 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 S1 with 2024 removal, but the replacement portfolio remains similar.

Table 10. Optimal portfolios to replace the LSR dams

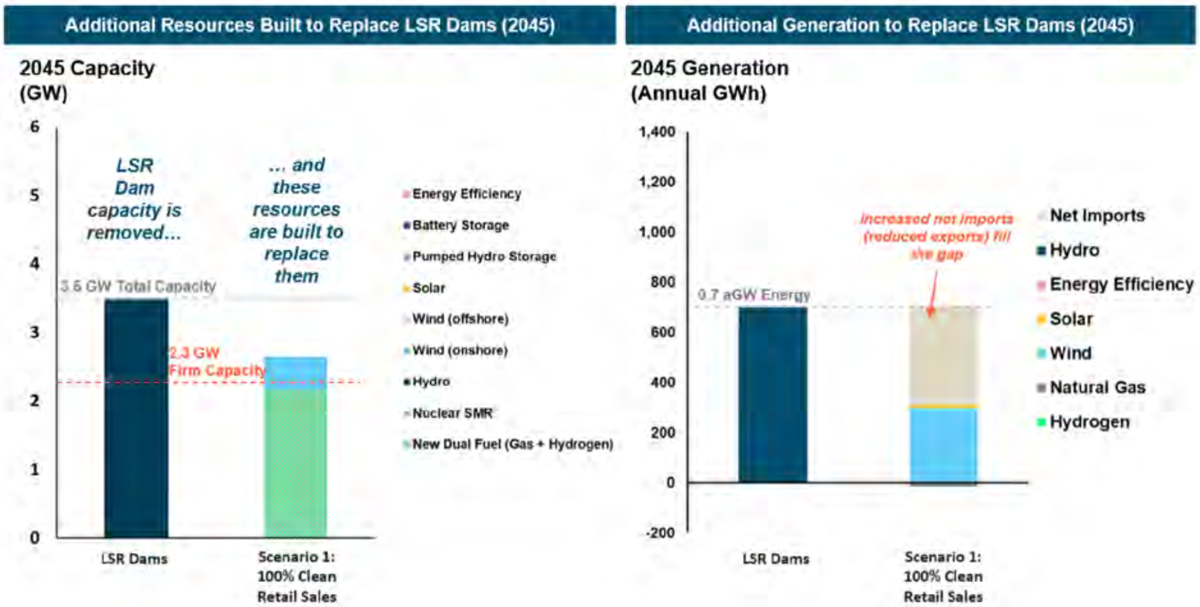
Scenario	Replacement Resources Selected, Cumulative by 2035[29] (GW)	Replacement Resources Selected, Cumulative by 2045 (GW)
Scenario 1: 100% Clean Retail Sales	+ 1.8 GW dual fuel NG/H2 CCGT - 0.5 GW solar + 1.3 GW wind + 0.1 GW li-ion battery	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
Scenario 1: 100% Clean Retail Sales (2024 dam removal)	+ 1.8 GW dual fuel NG/H2 CCGT - 0.5 GW solar + 1.4 GW wind	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind

[29] Replacement resources are calculated by comparing the "with LSR dams" RESOLVE portfolio to the "without LSR dams" RESOLVE portfolio. This means some resources may be built in 2035, such as 0.3 GW of geothermal in scenario 2c, that are not built when the dams are included. However, those resources may have already been selected in the "with LSR dams" case by 2045, hence do not show up as additional resource replacement needs in 2045. This explains the different resource changes between 2035 and 2045.

	+ 0.1 GW li-ion battery	
Scenario 1b: 100% Clean Retail Sales (binding CES target)	+ 2.2 GW dual fuel NG/H2 CCGT + 0.1 GW li-ion battery	+ 1.8 GW dual fuel NG/H2 CCGT + 1.3 GW solar + 1.2 GW wind
Scenario 2a: Deep Decarbonization (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.6 GW wind + 0.1 GW li-ion battery	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW advanced EE + 1.2 TWh H2-fueled generation
Scenario 2b: Deep Decarbonization (Emerging Technologies)	+ 1.7 GW dual fuel NG/H2 CCGT + 0.6 GW nuclear SMR	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR
Scenario 2c: Deep Decarbonization (No New Combustion)	+ 9.1 GW [illegible] + 0.1 GW wind + 1.0 GW solar + 0.3 GW geothermal + 1.5 GW li-ion battery	+ 10.6 GW wind + 1.4 GW solar

Figure 17 through Figure 21 show details of the capacity replacement, energy replacement, and cost breakdown for Scenarios 1, 1b, 2a, 2b, and 2c. LSR dams energy in these scenarios is replaced with wind, solar, 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[30]



[30] Regarding the "net imports" component of the energy replacement, this refers to either increased imports, decreased exports (generally of carbon-free energy), or a combination of both, such that RESOLVE does not need to build enough new generation to fully replace the LSR dams output. For instance, the region could export less hydropower to California and other neighbors to replace the LSR dams output without necessarily increasing Northwest carbon emissions in Scenario 1.

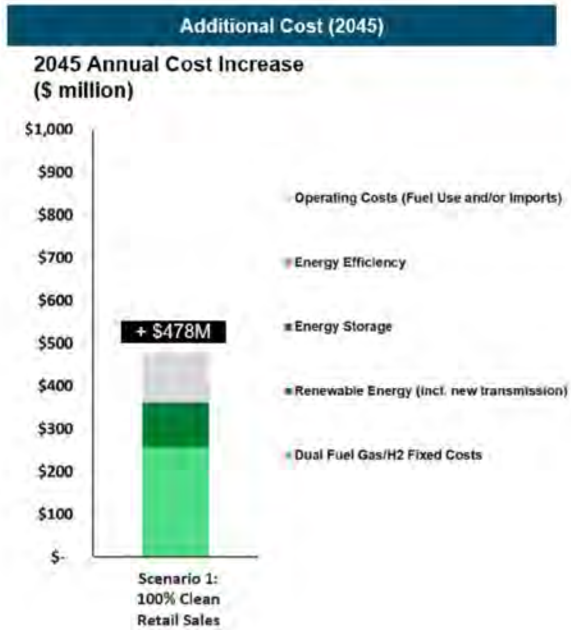

Additional Cost (2045)
2045 Annual Cost Increase
($ million)
$1,000
$900
$800
$700
$600
$500
$400
$300
$200
$100
$-
+ $478M
Scenario 1:
100% Clean
Retail Sales
Operating Costs (Fuel Use and/or Imports)
Energy Efficiency
Energy Storage
Renewable Energy (incl. new transmission)
Dual Fuel Gas/H2 Fixed Costs

Figure 18. Scenario 1b Capacity Replacement, Energy Replacement, and Costs

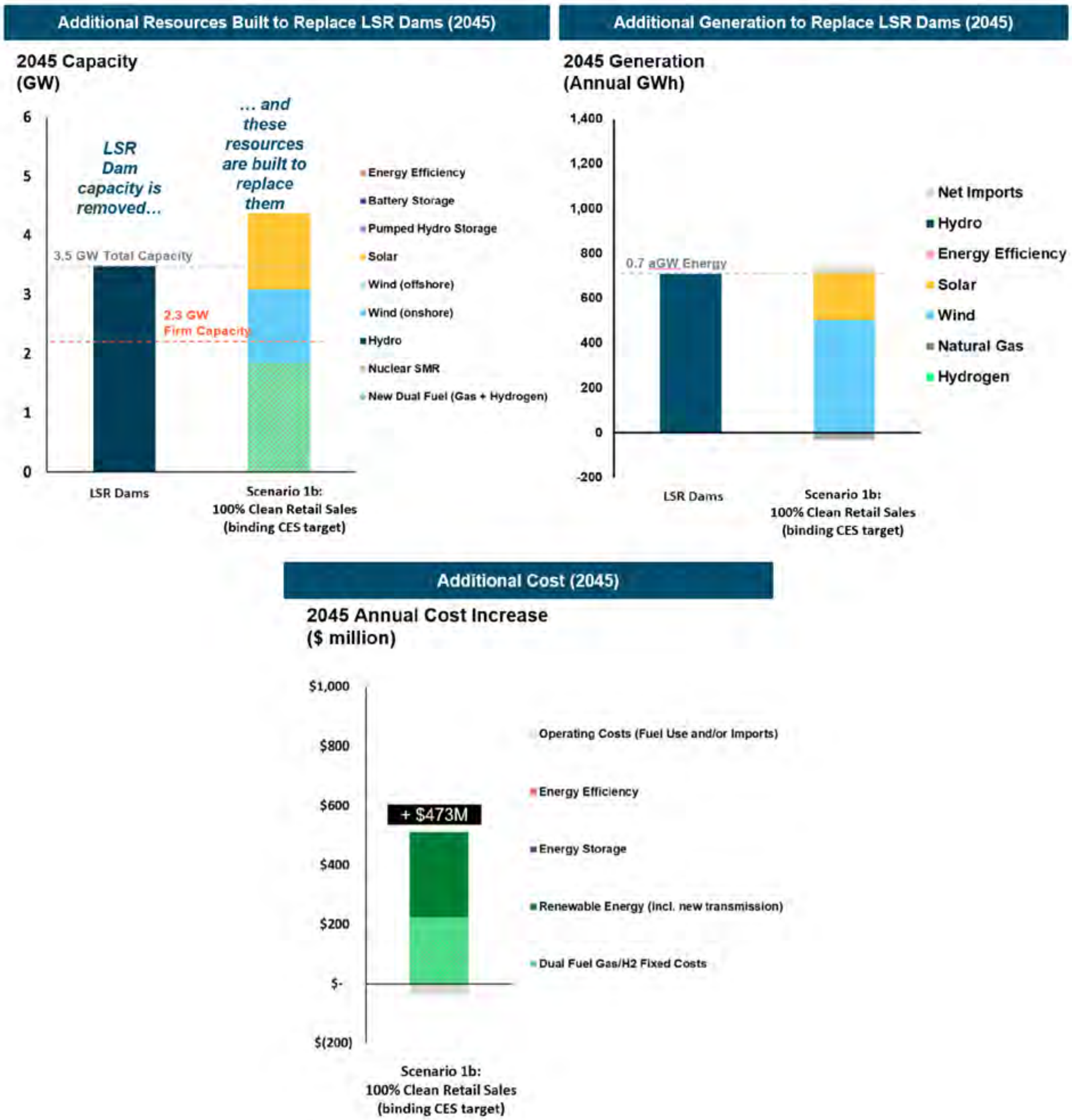


Figure 19. Scenario 2a Capacity Replacement, Energy Replacement, and Costs

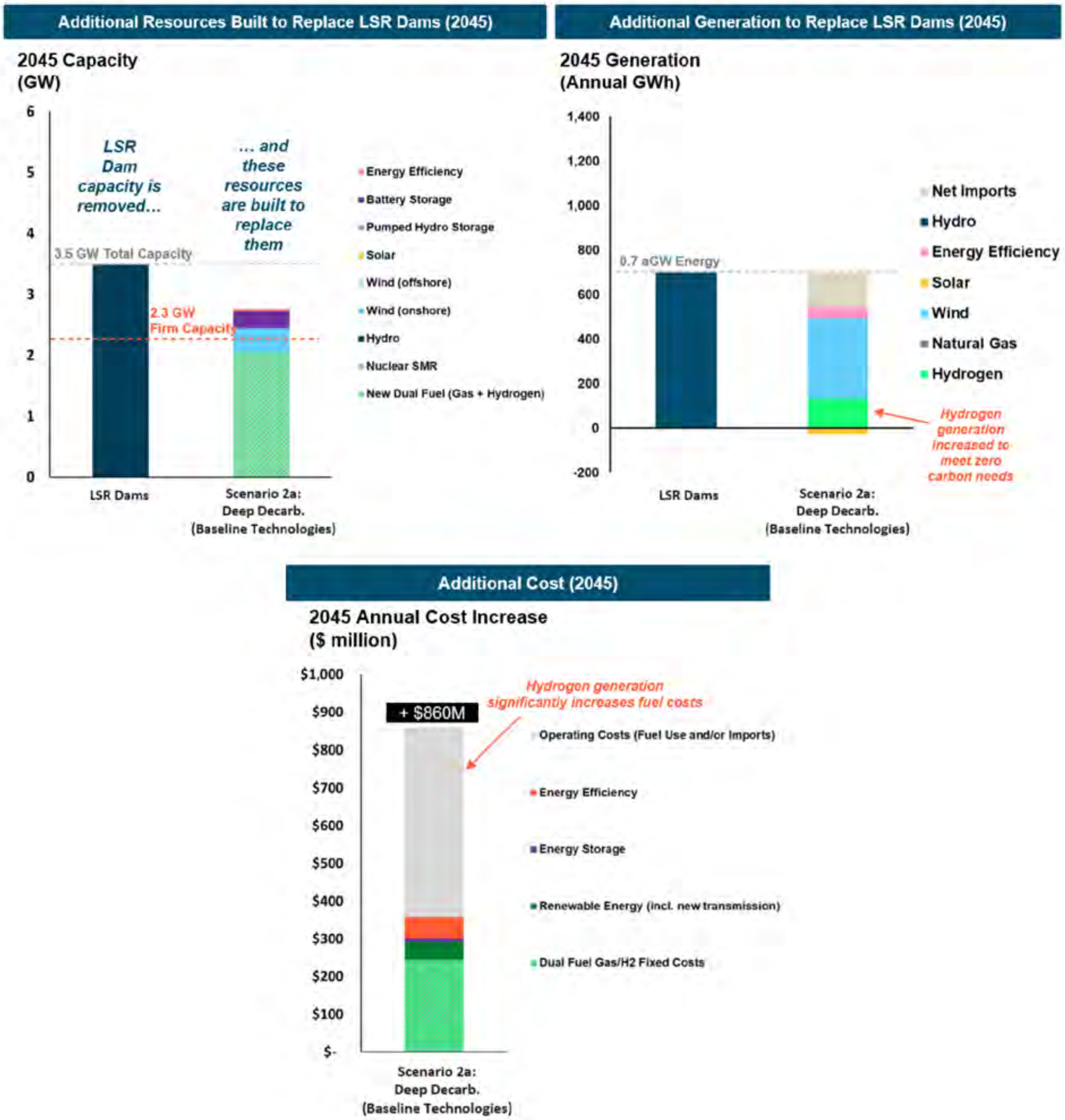
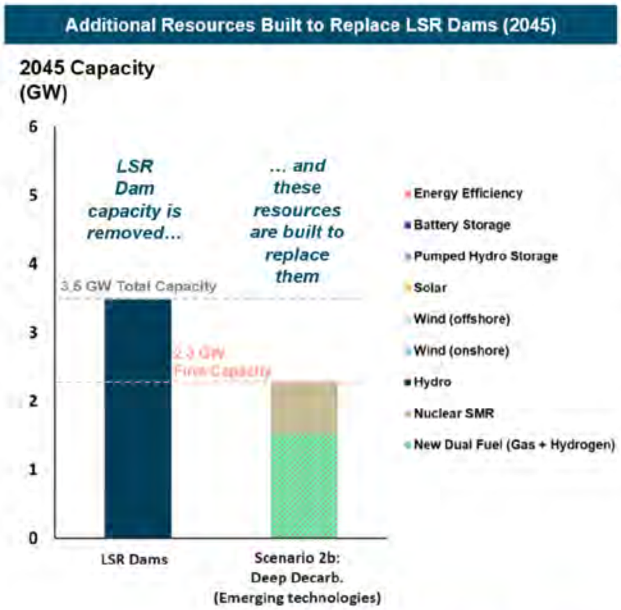
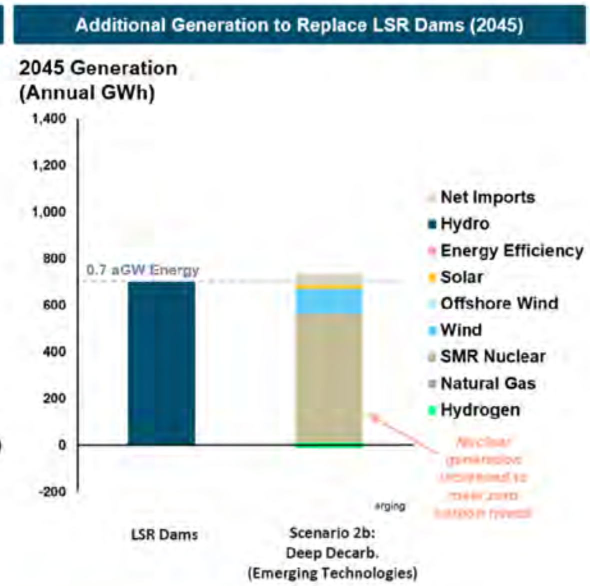


Figure 20. Scenario 2b Capacity Replacement, Energy Replacement, and Costs





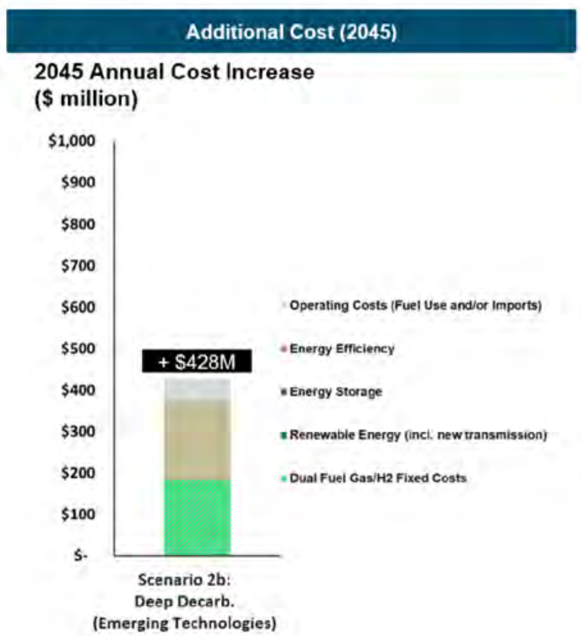
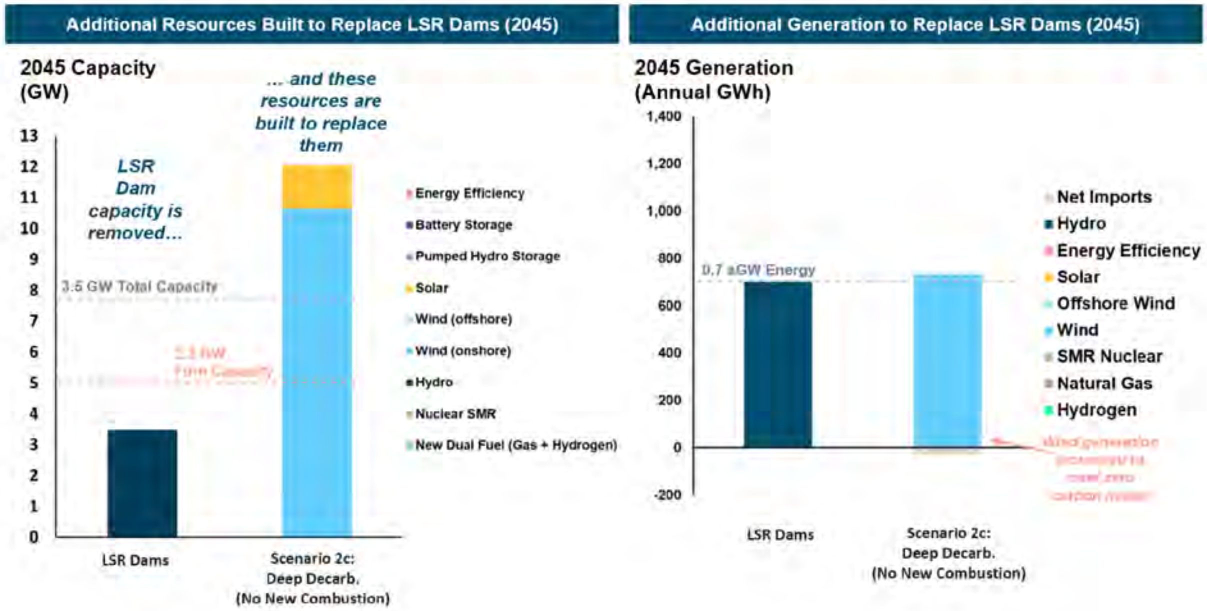


Figure 21. Scenario 2c Capacity Replacement, Energy Replacement, and Costs[31]



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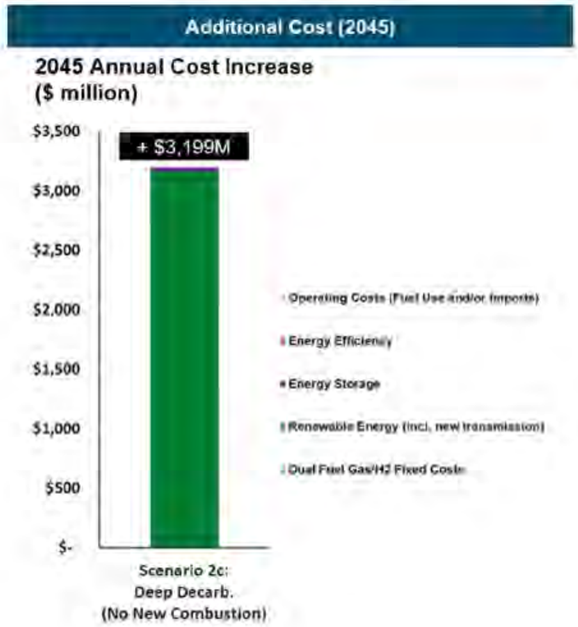
[31] NOTE: the energy replacement does not show the total potential energy output of the wind built to replace the dams, because much of the potential energy output is curtailed due to oversupply of wind built for resource adequacy needs.



Replacement costs

The LSR dams provide a relatively low-cost source of GHG-free energy and firm capacity. Incremental costs for replacement resources are summarized in this section. All costs are shown in real 2022 dollars. Incremental costs to replace the power services of the LSR dams ranges from \$69-139/MWh across most scenarios. Scenario 2c, however, shows a much higher replacement power cost of \$277-517/MWh. These incremental costs are much higher than costs of maintaining the LSR dams (i.e., \$13-17 per MWh[32]); they are calculated by taking the incremental fixed and variable investment costs for the no LSR RESOLVE runs and dividing them by the LSR annual generation being replaced. See the details in Table 11.

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[32] BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) facilities. The cost of generation at the lower Snake River dams is in the range of \$13/MWh without LSRCP and \$17/MWh with LSRCP. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat.2917) to offset fish and wildlife losses caused by construction and operation of the four lower Snake River projects.

Table 11. Incremental costs to replace LSR generation in 2045

Scenario	Incremental net costs in 2045[33], including avoided LSR dam costs (Real 2022 $/MWh)	Incremental gross costs in 2045[34], 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 1b: 100% Clean Retail Sales (binding CES target)	$77/MWh	$94/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)	$277-517/MWh	$294-534/MWh

The LSR dams' total replacement costs (in net present value) and annual replacement costs for 2025, 2035, and 2045 are shown in Table 12. NPV replacement costs are calculated based on discounting at a 3% discount rate, representative of the approximate public power cost of capital, over a 50-year time horizon following the date of breaching. Scenario 1 (100% clean retail sales) replacement costs are approximately $12-12.4 billion in net present value (NPV) in the year of breaching (in 2032); costs increase to $12.8 billion NPV if breached in 2024. Total replacement costs are similar in the economy-wide deep decarbonization scenario when emerging technology is available (scenario 2b), showing $11.2 billion NPV. Replacement costs are significantly higher in scenario 2c where no new combustion resources are allowed ($42-77 billion NPV). The economy-wide deep decarbonization (baseline technology scenario), 2a, shows more costly replacement ($19.6 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

[33] 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.

[34] 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.

growth. The 2045 cost increases translate to 8-18% growth in BPA's public power customers costs in scenarios 1, 1b, 2a and 2b (assuming current retail rates are about 8.5 ₵/kWh based on OR and WA average retail rates). In these scenarios, public power households would see an increase in annual electricity costs of $100-230/yr in 2045. In Scenario 2c, rate impacts could be as high as 34-65%, which is equivalent to annual residential electricity bills raising by up to $450-850 per year.[35] Note that these incremental cost increases include the ongoing LSR dams costs, such as operations and maintenance costs, avoided by breaching the dams, but do not include the costs of breaching. The rate impacts shown are only for the LSR dams' replacement, they do not include the additional rate increases driven by higher loads or clean energy needs (that are covered in the section *Electricity Generation Portfolios with the Lower Snake River Dams Intact* above), which apply even without removing generation from the LSR dams.

Table 12. Total LSR Dams replacement costs

	NPV Total Costs (Real 2022 $)[36]	Annual Costs Increase (Real 2022 $)			Incremental Public Power Costs[37]
	In the year of breaching (2032 or 2024)	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$12.4 billion	n/a	$434 million	$478 million	0.8 ₵/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$12.8 billion	$495 million	$466 million	$509 million	0.8 ₵/kWh [+9%]
Scenario 1b: 100% Clean Retail Sales (binding CES target)	$12.0 billion	n/a	$445 million/yr	$473 million/yr	0.8 ₵/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$19.6 billion	n/a	$496 million	$860 million	1.5 ₵/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$11.2 billion	n/a	$415 million	$428 million	0.7 ₵/kWh [+8%]

35 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.

36 NPV replacement costs are based on discounting at a 3% discount rate, representative of the approximate public power cost of capital, over a 50-year time horizon following the date of breaching.

37 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)	$42 – 77 billion[38]	-	$ 1,045 – 1,953 million/yr	$1,711 – 3,199 million/yr	2.9 – 5.5 ₵/kWh [+ 34 – 65%]

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, carbon emissions increases are observed in the mid-term (0.7-1.5 MMT/yr. or ~10% of the region's carbon emissions in 2035). Scenario 1b, when the CES target binds in 2045, shows to GHG increases in 2045, since the GHG-free energy of the LSR dams is replaced by solar and wind power. 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 to meet the zero-carbon constraint.

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.

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

[38] 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.

Uncertainty of the LSR dam value is considered under scenarios of:

- **Clean energy policy**: replacement of carbon-free power becomes increasingly critical to reach a zero-emissions electricity grid
- **Load growth**: replacement energy and capacity needs may change with increased electrification and peak higher winter space heating needs
- **Technology availability**: replacement is more expensive with fewer emerging technology resource options
- **Timing**: replacement was focused on breaching in 2032, but a 2024 sensitivity was also considered
- **Carbon pricing**: a sensitivity scenario was considered for scenario 1 that considered no carbon pricing, which causes the 100% CES target to bind

Additional uncertainties regarding the value of the dams are:

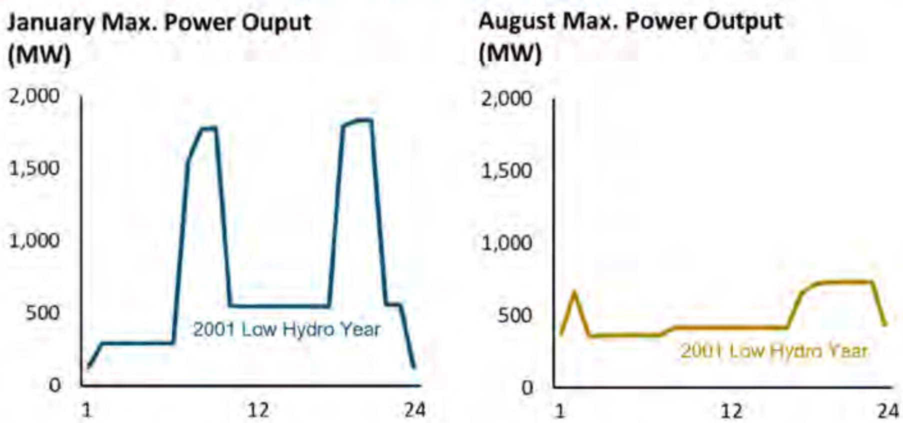
- **LSR dams annual energy output**: E3's existing RESOLVE model data uses historical hydro years 2001, 2005, and 2011 as representative of the regional long-term average low/mid/high hydro year conditions. The data for the Columbia River System dams was adjusted to reflect the Preferred Alternative operations defined in the CRSO EIS. However, for the LSR dams, these selected historical hydro years resulted in a relatively low output of ~700 average MW, whereas the dams may generate ~900 average MW on average across the full historical range of hydro conditions. Therefore, E3's analysis likely underestimates the energy value of the dams and costs for replacing that extra GHG-free energy.
- **LSR dams firm capacity counting**: as resource adequacy is found to be a key driver of future resource needs, the firm capacity contributions of the LSR dams is a key driver of their value. See below for further discussion of this uncertainty.
- **Replacement resource capacity contributions**: if Northwest reliability challenges dramatically shift into the summer, this would also impact the capacity value of replacement resources. Directionally, this would likely increase the capacity value of energy storage, and change the relative value of solar and wind. It is expected that additional battery storage would be part of the regional capacity additions in lieu of dual fuel natural gas + hydrogen plants. See below for further discussion of this uncertainty.
- **Replacement of transmission grid services:** this study does not focus on the transmission grid reliability services provided by the LSR dams. These services likely can be replaced by a combination of the new resources selected by RESOLVE and additional local transmission system investments. A qualitative summary of the transmission grid reliability services of the dams is summarized in the appendix of this report.

LSR Dams Firm Capacity Counting

Since resource adequacy is found to be a key driver of future resource needs, the firm capacity contribution of the LSR dams is a key driver of their value. E3 uses a regional hydro capacity value estimate for the LSR dams in this study, based on the PNUCC regional hydro capacity value assumption. More detailed follow-on ELCC studies could be done to confirm the LSR dams' capacity value, though proper and coordinated dispatch of the Northwest hydro fleet would be necessary to develop an accurate and fair value of the LSR dams within the context of the overall hydro fleet.

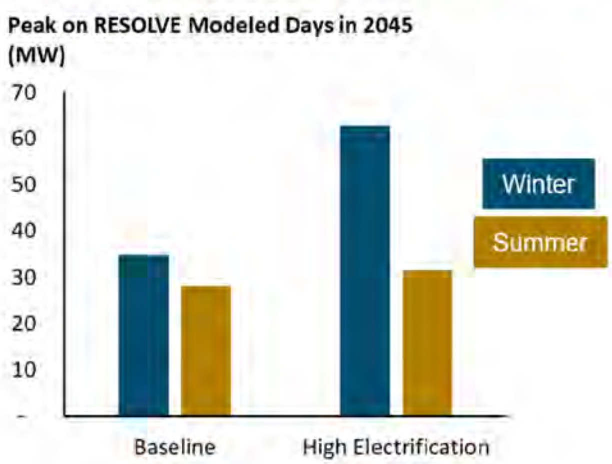
This study validated the assumed 2.28 GW of firm capacity from the LSR dams by considering BPA modeled LSR dams dispatch under 2001 dry hydro year conditions using the CRSO EIS spill constraint adjusted hourly modeling provided by BPA. Maximum January output (plus 100-250 MW of operating reserves) was 1.9-2.1 GW (~56-60% of total capacity), slightly less but close to the 65% regional hydro value the study assumes.

Figure 22. BPA-Modeled LSR Dam Output During the 2001 Low Hydro Year with CRSO EIS Preferred Alternative operations



The other capacity value uncertainty is whether the Northwest will remain winter reliability challenged or whether reliability events will shift to the summer due to climate impacts on load patterns and hydro output. If reliability challenges did shift to the summer, the LSR dam firm capacity contribution would be significantly lower than assumed. However, E3 believes it is reasonable to assume under high electrification scenarios that the region will remain winter challenged due to peak space heating needs, as shown in figure below.

Figure 23. Winter vs. Summer Peak Loads

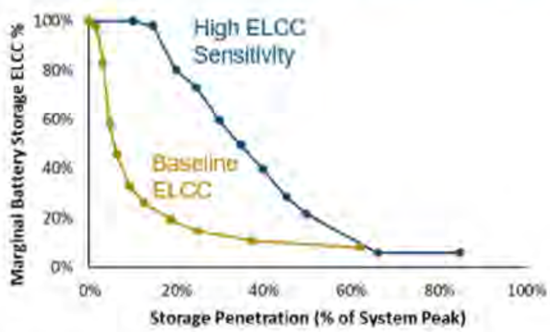


To address the capacity value uncertainty, a post-processing analysis was performed based on the replacement resources selected for firm capacity replacement. Based on this analysis performed on scenarios 1 and 2a, relative to the 2.28 GW assumption used in this study, it is estimated that a 1.5 GW firm capacity value (43%) for the dams would lower the NPV replacement costs by 9-20% and a 1.0 GW firm capacity value (29%) would lower the NPV replacement costs by 14-33%.

Replacement Resources Firm Capacity Counting

If Northwest reliability challenges dramatically shift into the summer, this would also impact the capacity value of replacement resources. One key input assumption this would change is the capacity value of battery storage additions, which were previously limited due to the Northwest wintertime energy-constrained reliability events causing charging sufficiency challenges for energy storage resources. To test whether higher energy storage ELCCs would impact the LSR dams replacement resources and replacement costs, a high storage ELCC sensitivity scenario was analyzed, per the ELCC inputs shown in Figure 24 below. This analysis was performed on scenarios 1 and 2a.

Figure 24. Inputs for High Battery Storage ELCC Sensitivity



In Scenario 1, with the LSR dams intact, higher battery ELCCs cause another 1.5 GW of batteries to be selected and 1.4 GW less dual fuel natural gas and hydrogen plants. In Scenario 2a, with the LSR dams intact, higher battery ELCCs cause another 2.4 GW of batteries and another 0.3 GW of wind to be selected, with 3.6 GW less dual fuel natural gas and hydrogen plants.

When the LSR dams are assumed to be breached, the differences in replacement resources are relatively small. In Scenario 1, an additional ~0.2 GW of battery storage, an additional 0.2 GW of wind, and 0.2 GW less dual fuel natural gas and hydrogen plants are selected to replace the dams. In Scenario 2a, an 0.3 GW less battery storage, 0.3 GW less wind, and an additional 0.1 GW of dual fuel natural gas and hydrogen plants are selected to replace the dams. This is because scenario 2a builds more wind and batteries in the base case already with the dams not breached, so the model prefers to select fewer of those resources for LSR dams replacement. Annual replacement costs in 2045 are 2% lower in scenario 1 and the same in scenario 2a. These results indicate that higher storage ELCCs would allow the region to build less dual fuel natural gas and hydrogen plants, but because energy storage ELCCs eventually saturate in either case, the replacement resources for the dam are not significantly changed and there is little impact on the replacement costs.

Conclusions and Key Findings

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho, and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability. RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[39]. 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 5.5-7 GW of solar and 4.6-6 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.[40]

Though all scenarios require more "firm" resources – resources that can generate when needed and operate for as long as needed – to meet peak loads, these resources are in higher demand in Scenario 2,

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[39] 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/

[40] E3 ran two versions of scenario 1. 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. 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. The values shown here represent the range of additions across both scenarios.

in which all greenhouse gas emissions are eliminated from the regional power system by 2045. This scenario also assumes that electrification results in much higher electric loads, particularly in wintertime due to electrification of natural gas space heating in buildings. The baseline scenario (2a) selects additional wind, solar, and geothermal to meet clean energy needs as well as demand response, some battery storage, and 27 GW natural gas and hydrogen dual fuel combustion plants to meet reliability needs. An alternative "emerging technology" scenario selects 17 GW of advanced nuclear technology (small modular reactors or "SMRs") by 2045, in place of the firm capacity provided by natural gas generators while reducing the required quantities of wind, solar and batteries that are needed. The "no new combustion" scenario does not allow emerging clean firm technologies such as hydrogen combustion turbines, gas generation with carbon capture and sequestration (CCS) or SMRs. As a result, it requires impractically high levels of additional onshore wind, offshore wind, and battery storage to meet firm capacity and carbon reduction needs, quadrupling the total installed MW of the Northwest grid by 2045.

When the power services provided by the dams are removed from the regional power system, RESOLVE selects an optimal, i.e., least-cost portfolio of replacement resources that meets the Northwest's clean energy and system reliability needs. These replacement resources require a large investment and come at a substantial cost that increase over time as the region's clean energy goals become more stringent. In the latter years, the replacement costs are highly dependent on scenario-specific assumptions about the availability of emerging technologies. RESOLVE primarily replaces the carbon-free energy from the dams with additional wind and solar 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 – 4,300 MW of replacement resources
  - An annual cost of $415 million – $860 million by 2045
  - Total net present value 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

+ 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 \$42-77 billion NPV cost)

Appendix

Additional Inputs Assumptions and Data Sources

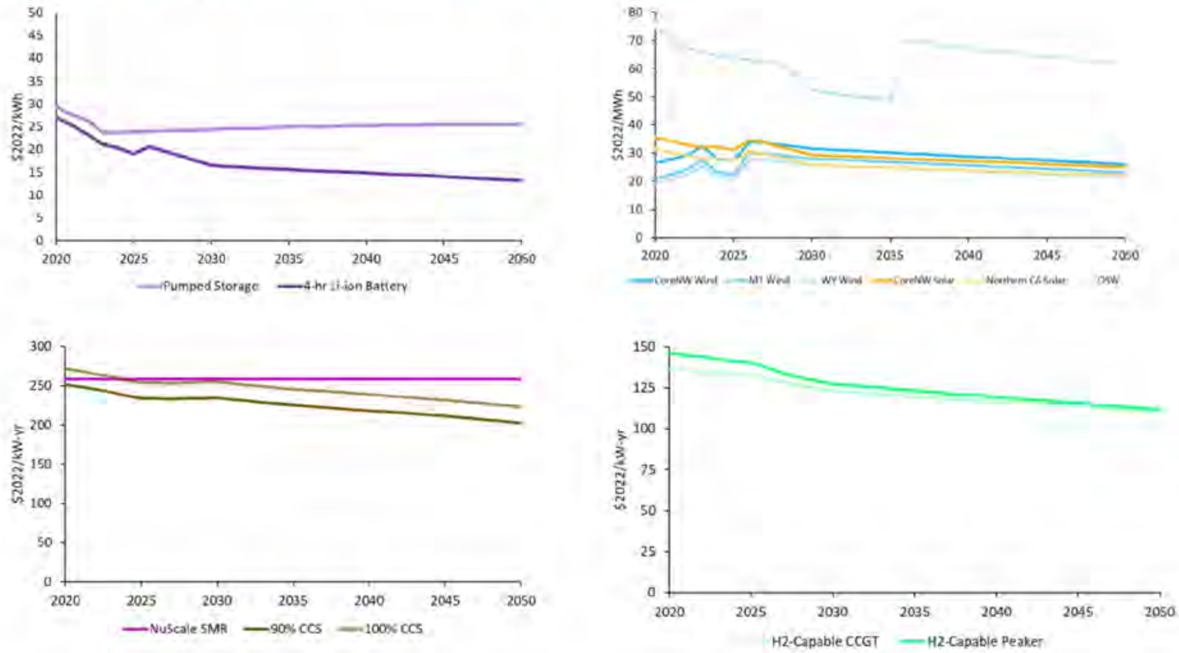
Candidate resource costs

The technology fixed costs trajectories for candidate resource options are shown in Figure 25 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.[41]
+ 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

[41] 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 25. All-in fixed costs for candidate resource options[42]



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 26:

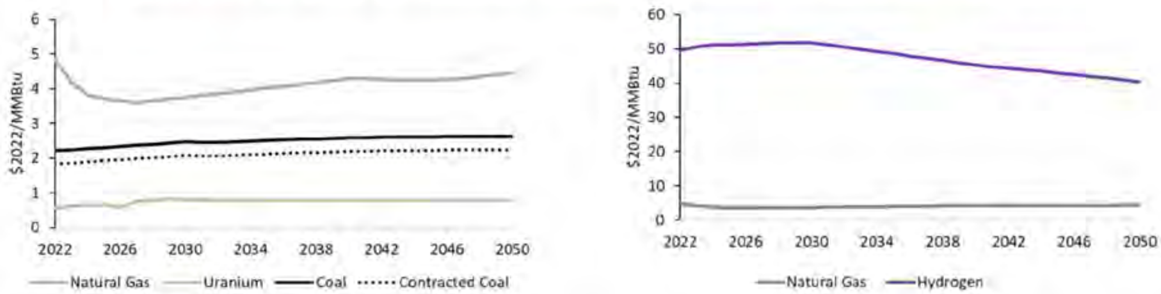
+ **Natural gas prices:** In near term, SNL NG price forecasts (i.e., for 2022-2026); and in long term, the EIA's AEO 2040 forecasts are used. Recent fuel cost increases due to market disruptions are excluded from the price trajectory.

---

[42] Storage costs are shown in $/kWh of energy storage. Renewable costs are shown in $/MWh. Clean firm resources (nuclear, CCS, hydrogen CCGT or peakers) are shown in $/kW-yr, since their $/MWh costs are a function of their runtime that RESOLVE would determine endogenously.

- **Coal prices:** EIA's AEO forecast are used
- **Uranium prices:** E3's in-house analysis
- **Hydrogen prices:** Conservative prices are used assuming no large-scale hydrogen economy, and thus electrolyzer capital costs and efficiencies are assumed to improve over time only slightly. Other assumptions include above ground hydrogen storage tanks and delivery via trucks from about 225 miles distance. Electrolyzers use dedicated off-grid Core NW wind power to produce hydrogen.

Figure 26. Fuel price forecasts for natural gas, coal, uranium, and hydrogen

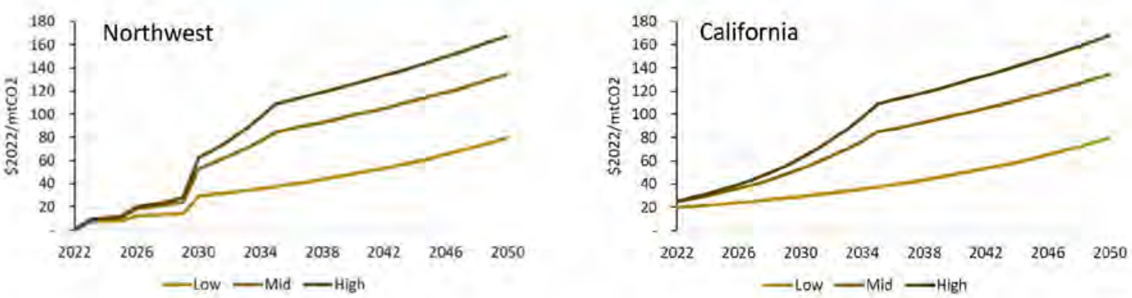


Annual average gas prices are further shaped according to a monthly profile to capture seasonal trends in the demand for natural gas and the consequent impact on pricing.

Carbon prices

For carbon pricing, it is assumed that Washington's cap-and-trade program starts in 2023 at around 50% of California carbon prices. For Oregon, it is assumed that a carbon price policy will be effective by 2026 for the electric sector. Prior to 2026, the Northwest carbon price is a load weighted share of carbon prices in WA and OR. Additionally, it is assumed that both states will converge to California's floor price by 2030. California's carbon prices are adopted from the Final 2021 IEPR GHG Allowance Price Projections (December 2021). Mid carbon prices presented in Figure 27 are used in modeled cases.

Figure 27. Carbon price forecasts for Northwest and California



Scenario 1b assumes no carbon price in the CoreNW zone.

Operating Reserves

It is assumed that all coal, gas, hydro, and storage resources within the Northwest zone can provide operating reserves. Additionally, RESOLVE allows renewable generation to contribute to meeting the needs for load following down; to allow for variable renewable generation curtailment to balance forecast error and sub-hourly variability. The following three types of operating reserve requirements are considered within the Core Northwest to ensure that in the event of a contingency, sufficient resources are available to respond and stabilize the electric grid:

+ **Spinning reserves:** Modeled as 3% of hourly load in agreement with WECC and NWPP operating standards

+ **Regulation up and down:** Modeled as 1% of hourly load

+ **Load following up and down:** Modeled as 3% of hourly load

Modeling of Imports and Exports

The Northwest RESOLVE model includes a zonal representation of the WECC. In modeling hourly dispatch during representative days, it considers the least-cost dispatch solution across the WECC, based on resource economics, resource operational limits, fuel and carbon prices, operating reserve requirements, and zonal transmission transfer limits. Imports to the CoreNW zone can occur from other neighboring zones; when they do a carbon adder is included for unspecified imports, while specified imports do not receive a carbon adder. Exports from the CoreNW zone may occur as deemed economic by RESOLVE, subject to other model constraints.

Minimum and maximum capacity limits are applied to the zonal representation of transmission between connected zones. These zonal transfer limits are shown in Table 13. Transmission hurdle rates as well as carbon hurdle rates (with regional carbon price adders) are applied to imports and exports.

Table 13. Transmission Capacity Limits between the CoreNW and other Zones

Transmission Constraint	Transmission from	Transmission to	Min Flow (MW)	Max Flow (MW)
CoreNW to OtherNW	CoreNW	OtherNW	-6,036	2,550
CoreNW to CA	CoreNW	CA	-6,820	5,433
CoreNW to SW	CoreNW	SW	0	0
CoreNW to NV	CoreNW	NV	-300	300
CoreNW to RM	CoreNW	RM	0	0

Contracted imports (such as imported coal and/or wind power) are included in the resource adequacy accounting captured in the planning reserve margin constraint. New remote resources include transmission cost adders to deliver them into the CoreNW zone. Additional unspecified imports are not assumed in RESOLVE's resource adequacy accounting.

Additional LSR Dam Power System Benefits (not modeled)

As described in this report, RESOLVE covers replacement of most power services provided by the LSR dams. However, RESOLVE does not model transmission grid operations (power flow, voltage and frequency, dynamic stability, etc.). Therefore, E3 notes that the LSR dams may provide the following additional essential reliability services to the transmission grid. In general, E3 expects that the replacement of these services can be achieved either through siting and operations of the incremental replacement capacity selected or by additional local transmission investments. The scale of these transmission investments requires more detailed study.

- **Reactive power and voltage control**: the LSR dams, like hydropower resources generally in the Northwest, provide significant reactive power capabilities that supports reliable power flow by optimally controlling voltage levels. Replacing this function likely requires siting additional resources with reactive power capabilities in a similar section of the transmission grid as the LSR dams.
- **Frequency response and inertia**: the LSR dams provide both primary and secondary frequency response capabilities. As synchronous generators they also provide system inertia that would be lost if the LSR dams are removed and as other synchronous generators retire. New efforts are underway to allow renewable generators or battery storage to provide "synthetic inertia" (or equivalent fast frequency response services), but this provision has not yet been proven to date at scale. The LSR dams are also highly tolerant of operating during high and low frequency events without sustaining blade damage.
- **Blackstart**: Large hydro resources have the capability to provide black start services when required, though not all hydro plants are chosen to provide this capability.
- **Participation in remedial action schemes**: Hydropower is a robust resource for participation in remedial action schemes because it can withstand being suddenly tripped off-line as part of a RAS action.
- **Short circuit and grounding contribution**: Synchronous generators (like hydropower) provide a large short circuit current that is important for the proper operation of protective relaying schemes.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, July 18, 2022 7:15 AM
To: James,Eve A L (BPA) - PG-5
Cc: Koehler,Birgit G (BPA) - PG-5; Arne Olson
Subject: [EXTERNAL] Re: Agency meeting today at 10 AM

Ok. I'm still available. Will need to breeze through to get down to 20 mins, so will jump quickly to results.

Get [Outlook for iOS]

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Monday, July 18, 2022 6:58:06 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Arne Olson <arne@ethree.com>
Subject: Agency meeting today at 10 AM

Hi Aaron-

Sorry the agency meeting got scheduled on such short notice. Let me know if you didn't get the invitation. Hopefully 10 AM still works for you. I believe the briefing is the E3 study as well as a salmon paper so I would assume only 20 min for presentation time and some QA.

Thanks,

Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, March 8, 2022 9:47 AM
To: James,Eve A L (BPA) - PG-5
Subject: [EXTERNAL] Re: BPA-22-C-89829: Lower Snake River Dam Study: FE

Hi Eve,

Yes, you can send that to me. We're updating RESOLVE now and reviewing the hydro assumptions therein as part of that. Understanding their Pmax, Pmin, monthly energy budgets for good, bad, and normal hydro years are the typical RESOLVE inputs. But we can discuss what customizations if any may be required to best represent the lower snake dams in our model.

Thanks,
Aaron

Get Outlook for iOS

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, March 8, 2022 9:00:59 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: BPA-22-C-89829: Lower Snake River Dam Study: FE
Good Morning Aaron-
I am putting together some information on the capabilities of the LSN river dams that needs to be replaced. Who would be the best person for me to be working with at E3 for receiving that information and coordinating if anything additional is needed?
Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, March 4, 2022 8:57 AM
To: Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Cc: Peterson,Melissa J (BPA) - NSSF-4400-2 <mjpeterson@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: [EXTERNAL] RE: BPA-22-C-89829: Lower Snake River Dam Study: FE
Thanks very much for clarifying.
Aaron

From: Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Sent: Friday, March 4, 2022 8:50 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Peterson,Melissa J (BPA) - NSSF-4400-2 <mjpeterson@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: RE: BPA-22-C-89829: Lower Snake River Dam Study: FE
Aaron,
Your understanding is correct, invoices have to come to me.
I also need deliverables which I will work with the BPA side of the project team to confirm acceptance on
BPA team will also work to keep me informed.

I don't need to be on all communication but if anything was to need to be changed, and/or extended those would also be important and we would work with Melissa from there.
Hope that helps!
Please feel free to reach out with any questions
Steve

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

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, March 4, 2022 8:09 AM
To: Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>
Cc: Peterson,Melissa J (BPA) - NSSF-4400-2 <mjpeterson@bpa.gov>
Subject: [EXTERNAL] RE: BPA-22-C-89829: Lower Snake River Dam Study: FE
Steve,
Can you please clarify how and when I should loop you into our project coordination? I understand that we should be sharing final deliverables, invoices, etc. with you and that – in addition to the project team – you will help to approve them to release payment for each task. Is that a correct understanding?
Thanks,
Aaron

From: Peterson,Melissa J (BPA) - NSSF-4400-2 <mjpeterson@bpa.gov>
Sent: Friday, March 4, 2022 6:56 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Jack Moore <jack@ethree.com>
Cc: Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Adam Foote <Adam.foote@ethree.com>
Subject: BPA-22-C-89829: Lower Snake River Dam Study: FE
Good morning,
Attached is a copy of the fully executed contract for your records. Please work with Steve to coordinate schedules of work.
Thankyou,

Melissa J. Peterson
Contracting Officer | 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) [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

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, March 3, 2022 8:58 PM
To: Peterson,Melissa J (BPA) - NSSF-4400-2 <mjpeterson@bpa.gov>; Jack Moore <jack@ethree.com>
Cc: Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Adam Foote <Adam.foote@ethree.com>
Subject: [EXTERNAL] RE: BPA-22-C-89829: Lower Snake River Dam Study: Notice of Award
Thank you Melissa. See attached for executed contract and certificate of insurance.
Aaron

From: Peterson,Melissa J (BPA) - NSSF-4400-2 <mjpeterson@bpa.gov>
Sent: Thursday, March 3, 2022 10:41 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Jack Moore <jack@ethree.com>
Cc: Bellcoff,Steve (BPA) - PGPR-5 <srbellcoff@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: BPA-22-C-89829: Lower Snake River Dam Study: Notice of Award
Good morning Aaron,

Bonneville Power Administration has completed its review and evaluation of your offer submitted in response to BPA-22-RFP-02242022 and is pleased to inform you that your offer has been accepted. This letter is your Notice of Award, Contract Number BPA-22-C-89829 in the amount of $175,000.00. Attached is the contract. Please review, sign and email the entire contract to mjpeterson@bpa.gov. Please submit your Certificate of Insurance, as well.

The Contracting Officer's Representative (COR) for this contract is Steve Bellcoff. Attached is a copy of the COR Delegation memo outlining their role and authorities. Please contact the COR for any scheduling requirements or to request technical information. They can be reached at 503-230-3319 or srbellcoff@bpa.gov.

For all contractual questions please contact me at 360-949-3952 or mjpeterson@bpa.gov.

Pending Actions:

Signed Contract	Award issued 03/03/2022
Certification of Insurance	Send to: mjpeterson@bpa.gov

Thank you,

Melissa J. Peterson
Contracting Officer | 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) [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

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Wednesday, March 23, 2022 8:49 AM
To:	Riley,Erin A (BPA) - PGPR-5
Cc:	James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5; Egerdahl,Ryan J (BPA) - PGPR-5
Subject:	[EXTERNAL] Re: BPA-E3 Check-In - 3-22 action items

Deliberative; FOIA-exempt

Thanks Erin. We'll dig into this data and follow up if we have any questions.

All the best,
Aaron

Get Outlook for iOS

From: Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>
Sent: Wednesday, March 23, 2022 8:10:53 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>
Subject: BPA-E3 Check-In - 3-22 action items

Deliberative; FOIA-exempt

Hi Aaron,

I've attached some hourly modeled output for the CYs you requested that I have on the shelf. See if that will suit your needs to create your pmin/ pmax curves.

These data are initialized from a monthly model, that monthly model has split Aprils & August, the second halves begin on the 16th. The incremental flows are interpolated from the monthly flows, so there is a smoothed component relative to actuals. You will notice that the diurnal pattern has a monthly change, this is part of that modeling: the shape of coulee is modeled after actual shaping in recent operations, and the daily peak power shaping is based on maximizing value during peak loads/ prices. The model is not provided with prices, it is provided hours during which to peak. There is some shaping to load in our forebay requests, but inherently the underlying logic assumes unlimited purchases and sales. There is a breakout in the data of the reserves that the projects are holding.

This model reflects the spill in the 2020 EIS: 125% flex spill.

Data notes: The model was run on the FY, as indicated by the "trace" column. For CY I provided the Oct-Dec of the following FY trace. I did not correct the date to be continuous because:

This model simulation, generation is peaking during these dates in the datetime column:

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

Depending on your analysis you might want to include or exclude these. For the weather events, we draft coulee 3 days fairly aggressively, then target coulee to be back on track over the next week. In particular, you might want to exclude July 3-5 as I think this operation might be violating July4 holiday targets.

I can also re-run to exclude this logic.

Data dictionary:

"*.Power" = hourly generation in MW

"*.GN_Max_HK_ModelCap" = one hour capacity.
"*.Rsrv_DEC_Sim" = Dec reserves held at that project, or total if * is BPA
"*.Rsrv_INC_Sim" = Inc reserves held by that project, or total is * is BPA
Please let me know if you need data based on actuals instead.
The attached data are only for the purpose of the contracted work. Thank you.
Best,
Erin

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

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

Many thanks,
Aaron Burdick, Associate Director
Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500 | San Francisco, CA 94104
818-807-6499 | aaron.burdick@ethree.com
Erin Riley
Operations Research Analyst
PGPR- Long Term Power Planning
Bonneville Power Administration
503-230-3717

From:	James,Eve A L (BPA) - PG-5
Sent:	Thursday, June 2, 2022 3:28 PM
To:	Aaron Burdick; Koehler,Birgit G (BPA) - PG-5
Cc:	Arne Olson
Subject:	RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

We're just trying to make sure the math behind that number is clear. I think 4.9 million households is what your math shows below. I'm not sure how many Tier 1 household customers there are and I think industrial loads fall in a different bucket but I would have to check with our rates folks.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 3:20 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Ok, hopefully last clarifying question:

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

By "how many customers or households" **do you mean the number of customers or households of public power customers we assume will be impacted?** In other words, if we took the BPA's Tier 1 annual sales we assume (~58,686 GWh/yr per FY2022 BPA forecast) and our assumed 1,000 kWh per month per household, how many households would that be? Doing this we get 4.9 million households. Is this in line with BPA's expectation of Tier 1 customers? Of course, there are some distinctions between household electric use and C&I electric use (surely there are C&I Tier I loads as well as residential), making this calculation a bit imperfect...

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 2, 2022 2:44 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Sounds good to me Aaron

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 1:01 PM

To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

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

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

DELIBERATIVE FOIA EXEMPT

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

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

DELIBERATIVE FOIA EXEMPT

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

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

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

Other comments below.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 12:25 PM

To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

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

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

Aaron

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

DELIBERATIVE FOIA EXEMPT

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

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

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

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

- 2b: With today's carbon reduction policies, total costs would be $2.8 billion in upfront capital costs, with ~$110 million per year for operational cost. $7.5 billion total NPV costs

Thanks,
Aaron

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

DELIBERATIVE FOIA EXEMPT

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

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DELIBERATIVE FOIA EXEMPT

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Subject: [EXTERNAL] RE: BPA-E3

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Thanks,

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Meeting password: 5UKeHJ2kK@2

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Join by phone

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Global call-in numbers

Join from a video system or application

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

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Sent: Tuesday, May 31, 2022 7:55 AM
To: Aaron Burdick; Koehler,Birgit G (BPA) - PG-5
Cc: Arne Olson
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Thanks Aaron-
The average annual generation with the updated CRSO EIS assumptions on the LSN projects is 862 aMW for the 90 year streamflow set.

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Meeting password: 5UKeHJ2kK@2

Tap to join from a mobile device (attendees only)

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Join by phone

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Global call-in numbers

Join from a video system or application

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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

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All the best,
Aaron

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DELIBERATIVE FOIA EXEMPT

Hi Aaron-
Let me know if you have any questions on the notes we sent over. I'm hoping we can get version today if possible in case another iteration is needed. We'll need to start sending out briefing materials next week for decision makers.

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

Please remember to say what CES stands for.

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

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

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From: James,Eve A L (BPA) - PG-5
Sent: Wednesday, April 6, 2022 12:14 PM
To: Aaron Burdick
Subject: RE: BPA-E3 Check-In

DELIBERATIVE FOIA EXEMPT

Thanks for sending along Aaron. This looks good to me. I'm not very familiar with the DOE folks that will be attending but know that two are pretty technical and one used to work at one of the national labs so I think the level is okay. I do not know what type of questions or interest they have other than the methodology and data inputs.

As far as edits, the only concern I have is the table on Slide 9. On the row that says "1b – no fish constraints". Could that get rephrased to "1b – Emergency Actions capability" and then in the Other category rephrase "Fish constraints removed, increasing LSR outputs" to "Emergency Actions increase LSR outputs" Under the emergency actions some fish constraints continue (MOP and some other things) so I don't want give the impression that all fish constraints are removed.

(b)(6) [redacted]

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, April 6, 2022 11:56 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

DELIBERATIVE FOIA EXEMPT

Here is a draft deck. I still need some more time to fill out 2 slides on the scenarios and a basic diagram of the LSR in/out approach, but sharing now in case you want to review and provide any feedback. (b)(6) [redacted] I'll get to those slides and any of your suggested edits probably late this afternoon or tonight.) Is this too much technical detail for this audience? What type of questions or interest are you expecting?

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, April 5, 2022 7:05 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: BPA-E3 Check-In

DELIBERATIVE FOIA EXEMPT

Hi Aaron- I see I missed the starting time and will add you to the meeting invitation. I meant to type April 7 from 9 – 10 AM Pacific Time. If you could put together materials on data inputs and methodology that would be really helpful. I really want to make sure they understand that BPA provided input on the capability of the projects but this is an independent study by E3. I am happy to present an introduction but if you are willing to present on the methodology and data inputs for your RESOLVE model and field any specific technical questions.

We can offer to brief them once there is a draft of model results and maybe offer an opportunity for DOE folks to do a peer review at the end but I don't want any coordination that will slow down your work or that could taint perceptions of the independence of your work. We'll talk more at the meeting this morning.

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Hi Eve,

I could be available from 7:45-9 and possibly 7:45-10 if necessary. Let me know the schedule and whether you need E3 coverage for the entire time; if so, I'll need to seek who else may be available to supplement my schedule.

Would you be seeking for us to present or provide you with any materials to present? I could also whip up some materials on data inputs and methodology fairly quickly.

I'll share an update shortly to the larger group about the RESOLVE modeling progress.

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Monday, April 4, 2022 11:34 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: BPA-E3 Check-In

DELIBERATIVE FOIA EXEMPT
Hi Aaron-
DOE staff were asking for a meeting to get insight into how the scenarios, assumptions, and methodology of the E3 study. Would someone from E3 be available to attend a meeting Thursday April 7 - 10 AM Pacific Time (12 – 1 Eastern)? I can discuss the scenarios at a high level but if there are specific technical questions I would need some support from an E3 staff member.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, March 29, 2022 10:45 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

DELIBERATIVE FOIA EXEMPT

Hi Eve,

Below is the updated scenario matrix. The four primary scenarios did not change (1, 2, 2a, 2b), but I updated sensitivities to reflect the feedback from Birgit and Rob last week. Tentative sensitivities are now on the baseline scenario, considering earlier retirement or removal of fish constraints. However, we agreed to finalize what sensitivities will be run after we have the results of the 4 primary scenarios next week.

Let me know if you have any questions.

Each scenario will be run twice: with and without the lower snake river dams

Scenario	Scenario Name	Loads	Clean Energy Policy
1	Baseline - 100% clean retail sales	Baseline	100% retail sales by 2040-45
2	Deep Decarb	High Electrification	0 MMT by 2045
2a	Deep Decarb - limited tech	High Electrification	0 MMT by 2045
2b	Deep Decarb - emerging tech	High Electrification	0 MMT by 2045
1a	Baseline - earlier LSR removal	High Electrification	0 MMT by 2045
1b	Baseline - no fish constraints	High Electrification	0 MMT by 2045
0	No policy reference	Baseline	No policy

Runs w/o LSR dams will be labeled "1_noLSR", etc.

Technology Scenarios:
Mature + H2: solar, wind, bat
Mature + emerging: adds gas
Mature + no new gas: exclud

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 <eajames@bpa.gov>
Sent: Tuesday, March 29, 2022 10:25 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Hi Aaron-

I'm okay with cancelling the check-in if you could provide a copy of the updated scenarios after the meeting last week. I want to make sure I'm clear on where the 4 primary scenarios landed.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, March 29, 2022 10:16 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

I don't have any agenda topics for today so I'd like to propose that we cancel this check-in, unless BPA has specific items to discuss.

Providing a general update on progress below:

- Per last week's discussion + email exchanges, we are moving forward with the hydro operating parameters and capacity value that Angineh and I shared via email
- We are initiating RESOLVE runs now and are targeting to have draft results for the 4 primary scenarios by next week
- We are concurrently working on Task 1 (Regional Capacity Needs and Role of Hydropower) and Task 3 (Documenting value streams not captured in RESOLVE) and expect to share draft deliverables for these tasks next week as well

Let me know if you would like to meet today, otherwise I'll send a cancellation.

All the best,
Aaron

-----Original Appointment-----
From: Aaron Burdick
Sent: Wednesday, March 2, 2022 4:53 PM
To: Aaron Burdick; Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; rjdiffely@bpa.gov; Angineh Zohrabian; Sierra Spencer
Subject: BPA-E3 Check-In
When: Tuesday, March 29, 2022 11:00 AM-12:00 PM (UTC-08:00) Pacific Time (US & Canada).
Where: https://ethree.webex.com/ethree/j.php?MTID=m228a4e26c5b763d73adb84c525782f42

Updating series from 30 mins to 1 hr.

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

-~-

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Meeting password: c5BSkxM2Sm8

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You can also dial 173.243.2.68 and enter your meeting number.

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From:	James,Eve A L (BPA) - PG-5
Sent:	Friday, March 11, 2022 12:56 PM
To:	Aaron Burdick; Koehler,Birgit G (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5
Cc:	Arne Olson; Jack Moore; Angineh Zohrabian; Sierra Spencer
Subject:	RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Hi Aaron-

Costs: The 50-year forecast is based on the 2019 Whitebook numbers but is modified based on expected changes in availability over time.

Plant	Annual Generation (MWh) based on 2019 Whitebook	Average Cost of Generation ($/MWh) based on 50 year forecast 2022 (not public)
Lower Granite	2,195,963	18.54
Little Goose	2,237,402	11.64
Lower Monumental	2,636,258	9.12
Ice Harbor	1,996,142	11.27

For Arne's question: The 50- year forecast is the O&M and Capital budget numbers. They are not the all in costs (e.g. no fish and wildlife, residential exchange, or other BPA overheads allocated to the facilities). Financing (debt service) is ignored here so capital numbers are effectively treated like expense.

Operational Constraints: I will compile the energy data using those streamflow years with the same modeled hydro operations. I will think about the constraints but worry that the method below of the min gen, max gen, and daily MWh of particular historical years will not capture the fish constraints during spring and summer and may show higher energy. However, some of the capability is accessible in energy emergencies but we don't want to plan to violate fish constraints. Rob was mentioning the Genesys modeling that was done in the EIS used trapezoidal approximation curves to develop tables that feed into the model to limit peaking and minimum generation with and without the LSN projects if that is helpful at all for RESOLVE.

Plant capacity: The nameplate capacity in the CRSO EIS matches the Whitebook with the nameplate capacity of 3,483 MW so please use those values (I'm not sure the source of the EIA numbers).

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, March 11, 2022 12:03 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Thanks Eve for this.

- **Re: costs**, what annual generation is assumed for each plant to derive these $/MWh values?

- **Operational data**: We have historical hourly plant level data that our team is reviewing currently to inform Min gen, Max gen, and daily MWh energy budgets for the LSR dams. RESOLVE currently uses 2001 for its low hydro year, 2005 for its mid year, and 2011 for its high year. We are not planning to change these years at this point. Process wise, we need a couple more days to run our analytical process to pull out the proposed operating constraints for the aggregate 4 LSR dam resource and expect to have that information by the middle of next week. We could then compare these to BPA's assumptions if you're able to pull relevant data (monthly Max Gen, Min Gen, and daily MWh are the primary values). Note: we're still confirming calendar vs. water year for those years, so if you pull 2000-2001, 2004-2005, and 2010-2011 for each dam that will allow us to confirm via calendar or water year. As I'm sure you understand there are some practical limits to how granularly we can represent the hydro constraints in RESOLVE without additional development work that might not be possible within our timeline.
- **Plant nameplate capacity**: we've seen some conflicting numbers between EIA and the BPA whitebook. EIA says 6 units for each plant w/ lower monumental @ 810 MW, lower granite @ 810 MW, ice harbor @ 603 MW, and little goose @ 810 MW; total = 3,033 MW. 2019 whitebook shows lower monumental @ 930 MW, lower granite @ 930 MW, ice harbor @ 693 MW, and little goose @ 930 MW; total = 3,483 MW. Can you please confirm if we should use the Whitebook values and if there are any factors to consider (gross vs. net capacity, etc.)?

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 <eajames@bpa.gov>
Sent: Thursday, March 10, 2022 3:55 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Deliberative; FOIA-exempt
Thanks for the slides Aaron- it was nice to meet you all yesterday as well.

I'm sending along the easy information first- the levelized cost data for the lower Snake River dams is:

Plant	Average Cost of Generation ($/MWh) based on 50 year forecast 2022 (not public yet but will be in April)
Lower Granite	18.54
Little Goose	11.64
Lower Monumental	9.12
Ice Harbor	11.27

We are internally discussing which year to assume the retirement in the no LSR dam scenarios and will send that along soon.

For #3 do you want us to provide that information for high, med, low hydro and for the different months of the year? Or specific months such as February and August for a winter/summer peak load? I can put together various operational limitations but want to make sure it is useful with how the model works. If you would prefer a meeting to discuss the operational constraints with phone call or a meeting with a smaller technical group I can be available Friday or Monday.

Regards,
Eve
(phone 503-230-5558)

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, March 10, 2022 3:22 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

Deliberative; FOIA-exempt

Nice to meet everyone yesterday. I've attached E3's slides.

As a follow up to the data needs question, we have confirmed that we have hourly historical generation by hydro plant so can use that to develop a disaggregation of the NW hydro resource from the lower snake river dam resource in RESOLVE. However, we still need a few data points:

1. **Cost data** on the lower snake river dams
    a. This includes $/MWh variable O&M and $/kw-yr fixed costs. The fixed costs would include fixed O&M and sustaining capex. We use levelized costs in RESOLVE, but feel free to provide in whatever format is available.
2. **Year to assume retirement** in the no LSR dam scenarios
3. **Max. continuous 1/2/3/4 hour output / ramp rates / any other critical operational limitations**
    a. We have a way of estimating some of this via historical data, but feel free to advise if there are specific constraints you can share for these dams.

All the best,
Aaron

-----Original Appointment-----
From: Aaron Burdick
Sent: Wednesday, March 2, 2022 12:15 PM
To: Aaron Burdick; Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; rjdiffely@bpa.gov; Angineh Zohrabian; Sierra Spencer
Subject: BPA-E3 Check-In
When: Wednesday, March 9, 2022 4:00 PM-4:30 PM (UTC-08:00) Pacific Time (US & Canada).
Where: https://ethree.webex.com/ethree/j.php?MTID=m97e494b356576770da19622bd6b15564

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

-~-

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Meeting password: iMWiBmfh368

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From: James,Eve A L (BPA) - PG-5
Sent: Friday, March 11, 2022 10:40 AM
To: Aaron Burdick
Subject: RE: BPA-E3 Check-In

Deliberative; FOIA-exempt
Hi Aaron- Do you have a contact number you could send me for who would be best technical person to talk to about what information is needed for the operational constraints? I want to make sure I'm putting together what works with the model and I'm guessing there is a tight turnaround needed so would like to get started as soon as possible.

Thanks,
Eve

From: James,Eve A L (BPA) - PG-5
Sent: Thursday, March 10, 2022 3:55 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: BPA-E3 Check-In

Deliberative; FOIA-exempt
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Regards,
Eve
(phone 503-230-5558)

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, March 10, 2022 3:22 PM

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

Deliberative; FOIA-exempt

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2. **Year to assume retirement** in the no LSR dam scenarios
3. **Max. continuous 1/2/3/4 hour output / ramp rates / any other critical operational limitations**
    a. We have a way of estimating some of this via historical data, but feel free to advise if there are specific constraints you can share for these dams.

All the best,
Aaron

-----Original Appointment-----
From: Aaron Burdick
Sent: Wednesday, March 2, 2022 12:15 PM
To: Aaron Burdick; Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; rjdiffely@bpa.gov; Angineh Zohrabian; Sierra Spencer
Subject: BPA-E3 Check-In
When: Wednesday, March 9, 2022 4:00 PM-4:30 PM (UTC-08:00) Pacific Time (US & Canada).
Where: https://ethree.webex.com/ethree/j.php?MTID=m97e494b356576770da19622bd6b15564

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

-~-

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From:	James,Eve A L (BPA) - PG-5
Sent:	Tuesday, April 19, 2022 4:09 PM
To:	Aaron Burdick; Angineh Zohrabian; Riley,Erin A (BPA) - PGPR-5
Cc:	Koehler,Birgit G (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5; Egerdahl,Ryan J (BPA) - PGPR-5; Sierra Spencer; Arne Olson; Jack Moore
Subject:	RE: BPA-E3 Check-In - 3-22 action items

Deliberative; FOIA-exempt

For 2001 the historical generation would since there wasn't spill operations that year but 2005 and 2011 were operating on spill operations. I could send a file from Erin that has modeled what the LSN generation for the "emergency capabilities" scenario would be but I think the early retirement scenario would take priority.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, April 19, 2022 3:58 PM
To: Angineh Zohrabian <angineh.zohrabian@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>; Sierra Spencer <sierra.spencer@ethree.com>; Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In - 3-22 action items

Deliberative; FOIA-exempt

BPA team,

Regarding the "emergency capabilities" scenario, can you confirm per Angineh's March 25 email below that we can use the historical generation we previously pulled for daily MWh, Pmin/max, etc. to represent this case? We previously switched to the BPA provided historical dataset w/ adjustments for increased spill. Does the actual historical WECC data appropriately represent the "emergency capabilities" with less spill?

Thanks,
Aaron

From: Angineh Zohrabian <angineh.zohrabian@ethree.com>
Sent: Friday, March 25, 2022 1:47 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>; Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>; Sierra Spencer <sierra.spencer@ethree.com>; Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>
Subject: RE: BPA-E3 Check-In - 3-22 action items

Hi All,

Please find attached the updated characteristics and RESOLVE inputs for LSR and Core NW hydro. From BPA's provided hydro generation data, we combined Jan-Sep from trace2001 and Oct-Dec from trace2002 to get to 2001 calendar year (similarly for 2005 and 2011). The logic was that a fiscal year is named by the year that ends in September. However, the dates in the data were confusing (for example, Jan 1, 2024 is trace2001 whereas Dec 31, 2023 is trace2002). Please let us know if we should treat this differently.
We also included the values calculated based on WECC historical generation data for comparison, and in case of future use in the sensitivity run.

Thank you. Feel free to reach out with any questions.
- Angineh

Sent from Mail for Windows

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, March 25, 2022 11:17:02 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>
Cc: Angineh Zohrabian <angineh.zohrabian@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>; Sierra Spencer <sierra.spencer@ethree.com>; Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>
Subject: RE: BPA-E3 Check-In - 3-22 action items

Deliberative; FOIA-exempt

Hi Aaron-
Sounds good about updating with the information provided by Erin for the scenarios. I will send an updated "no spill" constraint sensitivity data set since the historical data for 2011 and 2005 have higher summer spill amounts than the current spill program and have spill during the spring as well.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, March 25, 2022 11:10 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>
Cc: Angineh Zohrabian <angineh.zohrabian@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>; Sierra Spencer <sierra.spencer@ethree.com>; Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In - 3-22 action items

Deliberative; FOIA-exempt

Hi Eve,

Angineh has used replaced our historical hydro hourly output for the plants provided by Erin. This means our min/max gen and daily MWh budgets will be updated accordingly, to align with the latest spill requirements. This is the baseline set of hydro assumptions we plan to start modeling in RESOLVE. Angineh or I will share an updated summary document shortly.

If we decide later to model a "no updated spill constraint" sensitivity as Birgit suggested, would switching back to our historical data suffice to capture that difference in max gen and daily MWh?

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, March 25, 2022 8:13 AM
To: Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>
Subject: RE: BPA-E3 Check-In - 3-22 action items

Deliberative; FOIA-exempt
Thanks for sending this along while I was out of the office Erin.

Aaron let me know if this covers what you need- I am available today except for 1 – 2 PM if you need to call and talk through anything.

Thanks,
Eve

From: Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>
Sent: Wednesday, March 23, 2022 8:11 AM
To: aaron.burdick@ethree.com
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>
Subject: BPA-E3 Check-In - 3-22 action items

Deliberative; FOIA-exempt

Hi Aaron,

I've attached some hourly modeled output for the CYs you requested that I have on the shelf. See if that will suit your needs to create your pmin/ pmax curves.

These data are initialized from a monthly model, that monthly model has split Aprils & August, the second halves begin on the 16th. The incremental flows are interpolated from the monthly flows, so there is a smoothed component relative to actuals. You will notice that the diurnal pattern has a monthly change, this is part of that modeling: the shape of coulee is modeled after actual shaping in recent operations, and the daily peak power shaping is based on maximizing value during peak loads/ prices. The model is not provided with prices, it is provided hours during which to peak. There is some shaping to load in our forebay requests, but inherently the underlying logic assumes unlimited purchases and sales. There is a breakout in the data of the reserves that the projects are holding.

This model reflects the spill in the 2020 EIS: 125% flex spill.

Data notes: The model was run on the FY, as indicated by the "trace" column. For CY I provided the Oct-Dec of the following FY trace. I did not correct the date to be continuous because:

This model simulation, generation is peaking during these dates in the datetime column:

Wednesday, December 6, 2023	Friday, December 8, 2023
Wednesday, January 3, 2024	Friday, January 5, 2024
Wednesday, February 7, 2024	Friday, February 9, 2024

Wednesday, July 3, 2024	Friday, July 5, 2024
Wednesday, August 21, 2024	Friday, August 23, 2024

Depending on your analysis you might want to include or exclude these. For the weather events, we draft coulee 3 days fairly aggressively, then target coulee to be back on track over the next week. In particular, you might want to exclude July 3-5 as I think this operation might be violating July4 holiday targets.
I can also re-run to exclude this logic.

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

Please let me know if you need data based on actuals instead.

The attached data are only for the purpose of the contracted work. Thank you.

Best,

Erin

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

Deliberative; FOIA-exempt

Action items from today's check in:

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

Many thanks,

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

Erin Riley
Operations Research Analyst
PGPR- Long Term Power Planning
Bonneville Power Administration
503-230-3717

From: James,Eve A L (BPA) - PG-5
Sent: Tuesday, April 26, 2022 12:00 PM
To: Aaron Burdick
Cc: Bas,JoAnn L (BPA) - P-6
Subject: RE: BPA-E3 Check-In

Thanks Aaron- May 5 had some conflicts with key attendees so if you could present the draft results Thurs April 28 that would probably be best. JoAnn does shifting the meeting to 3:30 – 4:30 work for calendars?

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, April 26, 2022 11:54 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Bas,JoAnn L (BPA) - P-6 <jlbas@bpa.gov>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

Hi Eve,

May 5th would be ideal since we are rerunning our cases after catching a few input errors and won't have the updated results documented until ~May 2.

I'm free 3:20-4:30pm on Thursday April 28 and if we had to meet then I can present the draft results. I do not suspect the LSR value conclusions to change directionally, but the final numbers will be a bit different with the case reruns. These reruns include the 2024 retirement case, which I can't say yet whether we'd have done by Thursday.

Let me know how you'd like to proceed.

Thanks,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, April 26, 2022 9:46 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Bas,JoAnn L (BPA) - P-6 <jlbas@bpa.gov>
Subject: RE: BPA-E3 Check-In

Hi Aaron-
Actually would the 4/28 from 3:00 – 4:00 Pacific Time work for you or someone at E3? That time works best for some key attendees on our side.

Thanks,
Eve

From: James,Eve A L (BPA) - PG-5
Sent: Tuesday, April 26, 2022 9:15 AM
To: Aaron Burdick <aaron.burdick@ethree.com>

Cc: Bas,JoAnn L (BPA) - P-6 <jlbas@bpa.gov>
Subject: RE: BPA-E3 Check-In

Hi Aaron-
Could we set up some time to present results to some of the BPA Executives prior to the DOE meeting on May 6? Would one of these times work for you or someone from E3 to present:
4/27 – 3-4
4/28 – 3-4
5/5 – 11-12

JoAnn will help set up a WebEx when we hear back on your availability.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, April 25, 2022 5:15 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>; Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>
Subject: [EXTERNAL] RE: BPA-E3 Check-In

BPA team,

The original recurring Tue 11am meeting has run out. We are still cranking on some minor updates to the last round of cases and adding the early retirement case, so we don't have much new to share tomorrow. I can jump on if you have additional feedback on the draft deliverables, or we can skip tomorrow and meet next week to review the final RESOLVE results.

Please advise how you'd like to proceed.

Thanks,
Aaron

-----Original Appointment-----
From: Aaron Burdick
Sent: Wednesday, March 2, 2022 4:53 PM
To: Aaron Burdick; Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; rjdiffely@bpa.gov; Angineh Zohrabian; Sierra Spencer
Subject: BPA-E3 Check-In
When: Tuesday, April 19, 2022 11:00 AM-12:00 PM (UTC-08:00) Pacific Time (US & Canada).
Where: https://ethree.webex.com/ethree/j.php?MTID=m228a4e26c5b763d73adb84c525782f42

Updating series from 30 mins to 1 hr.

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

-~-

-- Do not delete or change any of the following text. --

When it's time, join your Webex meeting here.

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Meeting number (access code): [redacted]
Meeting password: c5BSkxM2Sm8

Tap to join from a mobile device (attendees only)
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Global call-in numbers

Join from a video system or application
Dial [redacted]@ethree.webex.com
You can also dial 173.243.2.68 and enter your meeting number.

If you are a host, click here to view host information.

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

From: James,Eve A L (BPA) - PG-5
Sent: Thursday, June 2, 2022 4:20 PM
To: Arne Olson; Aaron Burdick; Koehler,Birgit G (BPA) - PG-5
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Could you send the slides as PPT this time? I will add the BPA perspective slides at the end and then PDF the file for DOE.

Thanks,
Eve

From: Arne Olson <arne@ethree.com>
Sent: Thursday, June 2, 2022 3:28 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] RE: BPA-E3

I imagine only about 40% of the sales are residential, so the 4.9 million would be closer to 2 million, which is in the ballpark of what I would have expected. We can get more exact numbers from EIA Sales & Revenue if needed.

So $750 million per year divided by 2 million customers is about $375 per customer per year, or a total NPV of around $3000 per customer.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, June 2, 2022 3:20 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Ok, hopefully last clarifying question:

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

By "how many customers or households" **do you mean the number of customers or households of public power customers we assume will be impacted?** In other words, if we took the BPA's Tier 1 annual sales we assume (~58,686 GWh/yr per FY2022 BPA forecast) and our assumed 1,000 kWh per month per household, how many households would that be? Doing this we get 4.9 million households. Is this in line with BPA's expectation of Tier 1 customers? Of course, there are some distinctions between household electric use and C&I electric use (surely there are C&I Tier I loads as well as residential), making this calculation a bit imperfect...

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, June 2, 2022 2:44 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Sounds good to me Aaron

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

DELIBERATIVE FOIA EXEMPT

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

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

DELIBERATIVE FOIA EXEMPT

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

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

DELIBERATIVE FOIA EXEMPT

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

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

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

DELIBERATIVE FOIA EXEMPT

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

Other comments below.

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

DELIBERATIVE FOIA EXEMPT

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

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

Aaron

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

DELIBERATIVE FOIA EXEMPT

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

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

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

- Slide 17: "by 2045" vs "after 2045". I prefer "by" since it implies costs before 2045 as well. "After" to me implies the costs are only occurring after 2045. By works- I meant to put the added words after the text 2045
- Question re: slide 3 feedback:

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

Thanks,
Aaron

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

DELIBERATIVE FOIA EXEMPT

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

Thanks,
Eve

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

DELIBERATIVE FOIA EXEMPT

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

All the best,
Aaron

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

DELIBERATIVE FOIA EXEMPT

Updated deck is attached.

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

Aaron

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

DELIBERATIVE FOIA EXEMPT

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

Thanks,
Eve

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

DELIBERATIVE FOIA EXEMPT

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

Aaron

From: Aaron Burdick
Sent: Thursday, May 26, 2022 8:32 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

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

All the best,
Aaron

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

DELIBERATIVE FOIA EXEMPT

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

Thanks,
Eve

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

DELIBERATIVE FOIA EXEMPT

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

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

Aaron

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

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

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Thursday, April 28, 2022
3:30 PM | (UTC-07:00) Pacific Time (US & Canada) | 1 hr

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Meeting password: 5UKeHJ2kK@2

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Join by phone

+1-415-527-5035 US Toll

Global call-in numbers

Join from a video system or application

Dial [redacted]@mybpa.webex.com

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From: James,Eve A L (BPA) - PG-5
Sent: Monday, July 18, 2022 7:08 AM
To: Aaron Burdick
Subject: RE: Briefing at 10am today

Hi Aaron- sorry my internet has been slow this morning and I think our emails crossed paths. Sorry the 10 AM briefing got scheduled so late in the weekend so hopefully this time still works for you (I think you had a hold on your calendar for the agency or department briefing last week). I have a conflict with the first 30 min of the meeting but Birgit will be on the whole call and will introduce you. I'm not sure if the E3 study is first or second on the agenda.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, July 18, 2022 6:53 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: [EXTERNAL] Briefing at 10am today

Is there a briefing at 10am today? Saw I got an invite forwarded over the weekend.

Aaron

Get Outlook for iOS

From:	James,Eve A L (BPA) - PG-5
Sent:	Monday, June 27, 2022 3:36 PM
To:	Aaron Burdick
Cc:	Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian; Arne Olson
Subject:	RE: Draft Exec Summary
Attachments:	E3_ExecSummaryDraft_062422-eaj bgk.docx

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

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.

[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.

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.

Table 1. Scenario Design

Scenario	Clean Energy Policy	Load Growth	Technology Availability
1 100% Clean Retail Sales[1]	100% retail sales (85% carbon reduction)	8^{th} 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)

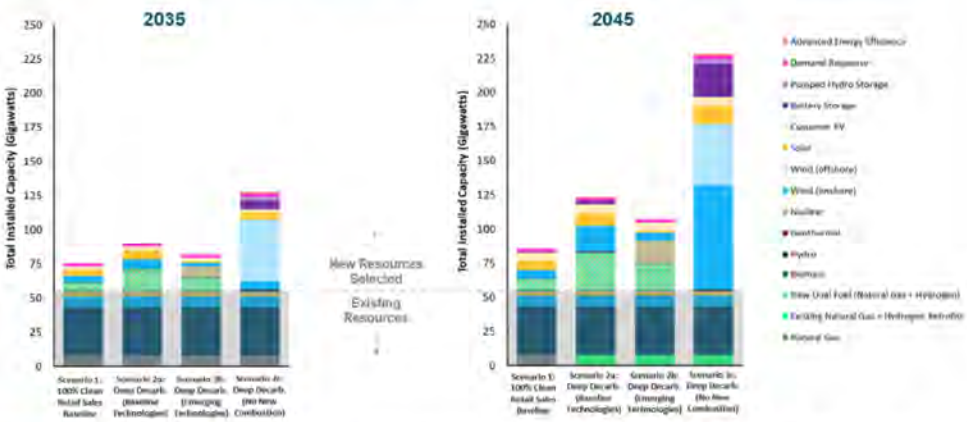
Even with the dams not breached, the region's clean energy goals and potential electrification load growth drive a significant need for new resources. In all scenarios, significant energy efficiency and customer solar is embedded into the load forecast, based on the NWPCC's 8^{th} Power Plan. Additionally, 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- 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(-P4]: 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(-P5]: 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 [EAJ6]: 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 advanced EE + 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%]

[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:	James,Eve A L (BPA) - PG-5
Sent:	Tuesday, July 12, 2022 2:26 PM
To:	Aaron Burdick
Subject:	RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Yep- got it- our email must have crossed paths. Thanks!

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, July 12, 2022 2:25 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Both, I sent an updated version of both on another email chain.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, July 12, 2022 2:08 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Thanks Aaron- is this issue just in the slide deck or does the final report need to be updated as well?

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, July 12, 2022 1:54 PM
To: Chad Madron <CMadron@NWCouncil.org>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Kendra Coles <kcoles@nwcouncil.org>; Jennifer Light <JLight@NWCouncil.org>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.
Importance: High

Apologies, we found a graph error in slide 14 and am therefore sending an updated version of E3's slides.

Aaron

From: Chad Madron <CMadron@NWCouncil.org>
Sent: Tuesday, July 12, 2022 11:14 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Kendra Coles <kcoles@nwcouncil.org>; Jennifer Light <JLight@NWCouncil.org>; Arne Olson <arne@ethree.com>; Aaron Burdick <aaron.burdick@ethree.com>
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Correct, all times are Pacific since we are in Spokane.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, July 12, 2022 11:11 AM
To: Chad Madron <CMadron@NWCouncil.org>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Kendra Coles <kcoles@nwcouncil.org>; Jennifer Light <JLight@NWCouncil.org>; Arne Olsen (arne@ethree.com) <arne@ethree.com>;

aaron.burdick@ethree.com
Subject: RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

Thanks Chad- just to confirm that is 3:15 PDT and not Mountain time?

From: Chad Madron <CMadron@NWCouncil.org>
Sent: Tuesday, July 12, 2022 10:50 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Kendra Coles <kcoles@nwcouncil.org>; Jennifer Light <JLight@NWCouncil.org>; Arne Olsen (arne@ethree.com) <arne@ethree.com>; aaron.burdick@ethree.com
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Subject: [EXTERNAL] RE: Memo/Background for Members ahead of July 7 E3 presentation for this Wed.

For this afternoon:

I will have the ppt loaded on a computer I have with me – then I will give one of you "keyboard and mouse control" to advance the slides. We can practice this at 3:15 at the break if you like. We find this works well rather than having to make you be the presenter or having to do the dreaded "next slide" thing... Please let me know who should have control (it can be shared as well).

More tips for webinar presenters are here:
https://www.nwcouncil.org/presentation-guidelines

Agenda: https://www.nwcouncil.org/meeting/council-meeting-july-12-2022

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Tuesday, July 12, 2022 9:57 AM
To: Kendra Coles <kcoles@nwcouncil.org>; 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: 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: 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, April 19, 2022 4:12 PM
To: Aaron Burdick; Diffely,Robert J (BPA) - PGPL-5; Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian; Sierra Spencer
Subject: RE: TIER 1 System

Yes- I think the S1 100% Clean Retail Sales with the carbon price makes sense for that sensitivity case.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, April 19, 2022 2:05 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: TIER 1 System

Hi Eve,

We should be able to squeeze that case in. We previously discussed to run it on the S1 100% Clean Retail Sales (including a carbon price) scenario – please confirm this is still your suggested base case for that sensitivity.

Thanks,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, April 19, 2022 1:53 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: TIER 1 System

I talked with Jill and she thinks it would be important to have the removal date of 2 years out to match the EIS work if it fits within the contract budget.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, April 19, 2022 1:32 PM
To: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: TIER 1 System

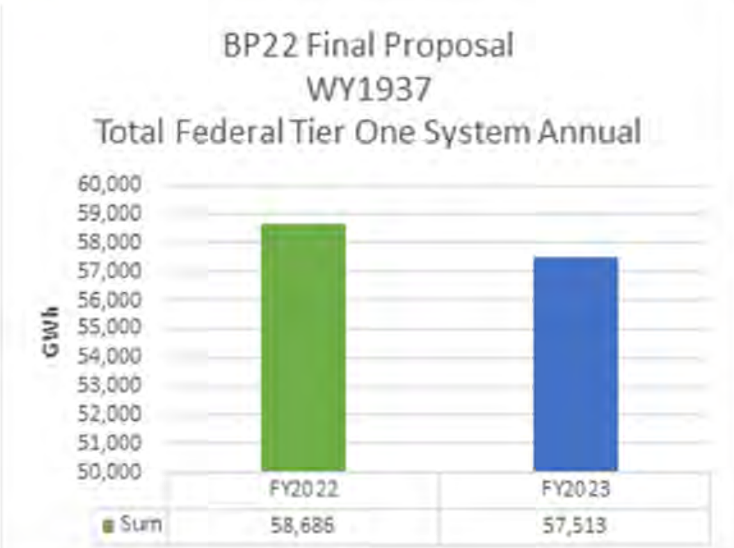
Thanks Rob. With that update the % increase went from 14-37% to 20-50%, based on an updated range of 0.7-1.8 cent/kWh impact.

All the best,
Aaron

From: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Sent: Tuesday, April 19, 2022 1:26 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Arne Olson <arne@ethree.com>; Jack Moore <jack@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: TIER 1 System

For the TIER 1 system, E3 can use FY2022 of 58,686 GWhrs. The difference between the two is primarily the 2 year refueling cycle of CGS.

Rob



-----Original Appointment-----
From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, March 2, 2022 4:54 PM
To: Aaron Burdick; Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5; Angineh Zohrabian; Sierra Spencer
Subject: BPA-E3 Check-In
When: Tuesday, April 19, 2022 11:00 AM-12:00 PM (UTC-08:00) Pacific Time (US & Canada).
Where: https://ethree.webex.com/ethree/j.php?MTID=m228a4e26c5b763d73adb84c525782f42

Updating series from 30 mins to 1 hr.

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

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Energy+Environmental Economics

BPA Lower Snake River Dams Project
Draft Final Results

May 4, 2022

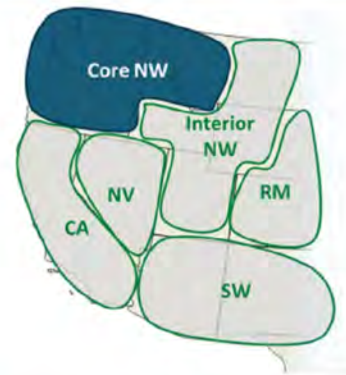
Arne Olson, Sr. Partner
Aaron Burdick, Associate Director
Sierra Spencer, Sr. Consultant
Dr. Angineh Zohrabian, Consultant
Sam Kramer, Consultant
Jack Moore, Sr. Director

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



+ **Key tasks:**
  1. **Regional capacity needs + role of hydropower**
     – Summarize CA/OR/WA policies, capacity needs, and the role of hydropower
  2. **RESOLVE capacity expansion analysis**
     – Scenario analysis to calculate the NPV replacement cost of breaching the LSR dams + replacement resource needs
  3. **Qualitative benefits**
     – Summarize additional electric system benefits from the LSR dams beyond those captured in RESOLVE
  4. **Project report**

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Lower Snake River Dams

+ **The lower snake river dams:**
  - Are ~10% of the Northwest regional hydropower capacity
  - Provide relatively low-cost and flexible carbon free power

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

* 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.

Summary of Regional Capacity Needs

Executive Summary
E3 View of California, Oregon, and Washington

+ **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 can take advantage of wholesale market opportunities in California, or reliability-driven need in the Pacific Northwest (PNW), or 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

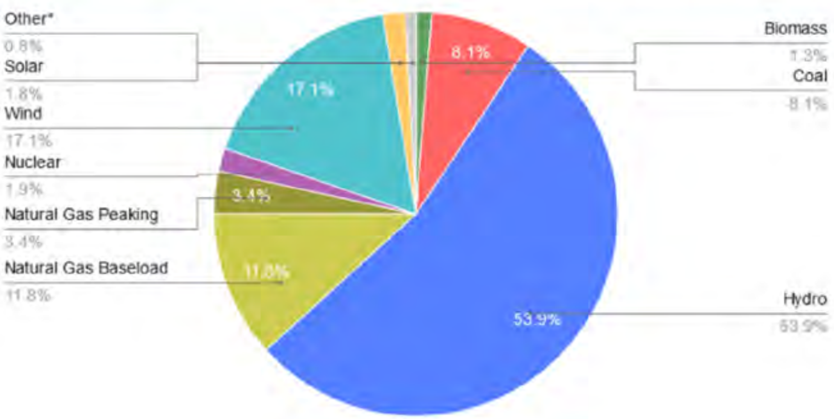
	RPS or Clean Energy Standard?	Coal Prohibition?	Cap-and-Trade?	New Gas?	Economy-Wide Carbon Reduction?
WA	✓ Carbon neutral by 2030, 100% carbon free electricity by 2045	✓ Eliminate by 2025	✓ Cap-and-invest program established in 2021, SCC in utility planning	✓	✓ 95% GHG emission reduction below 1990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

Northwest Installed Capacity and Historical Energy Production

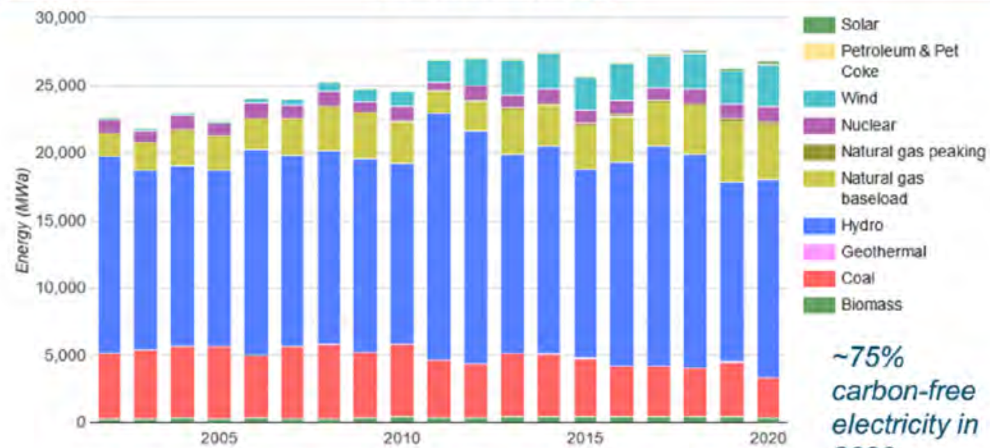
+ Hydropower dominates historical generation, followed by coal and natural gas

- 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



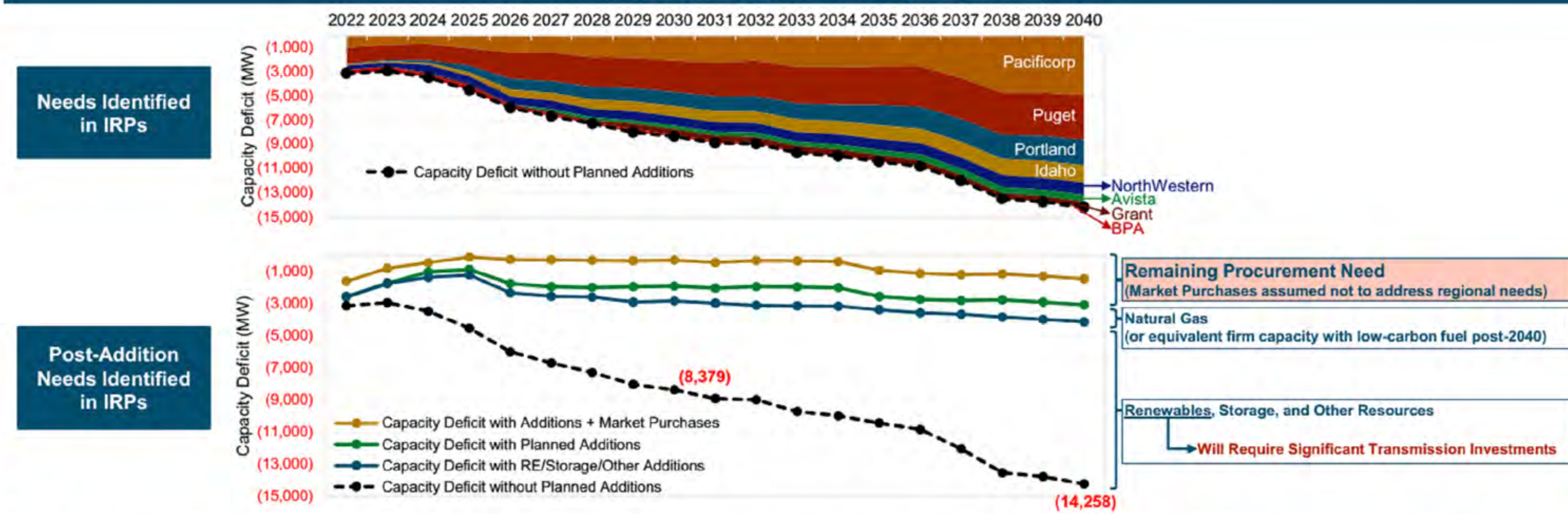
~75% carbon-free electricity in 2020

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

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



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.

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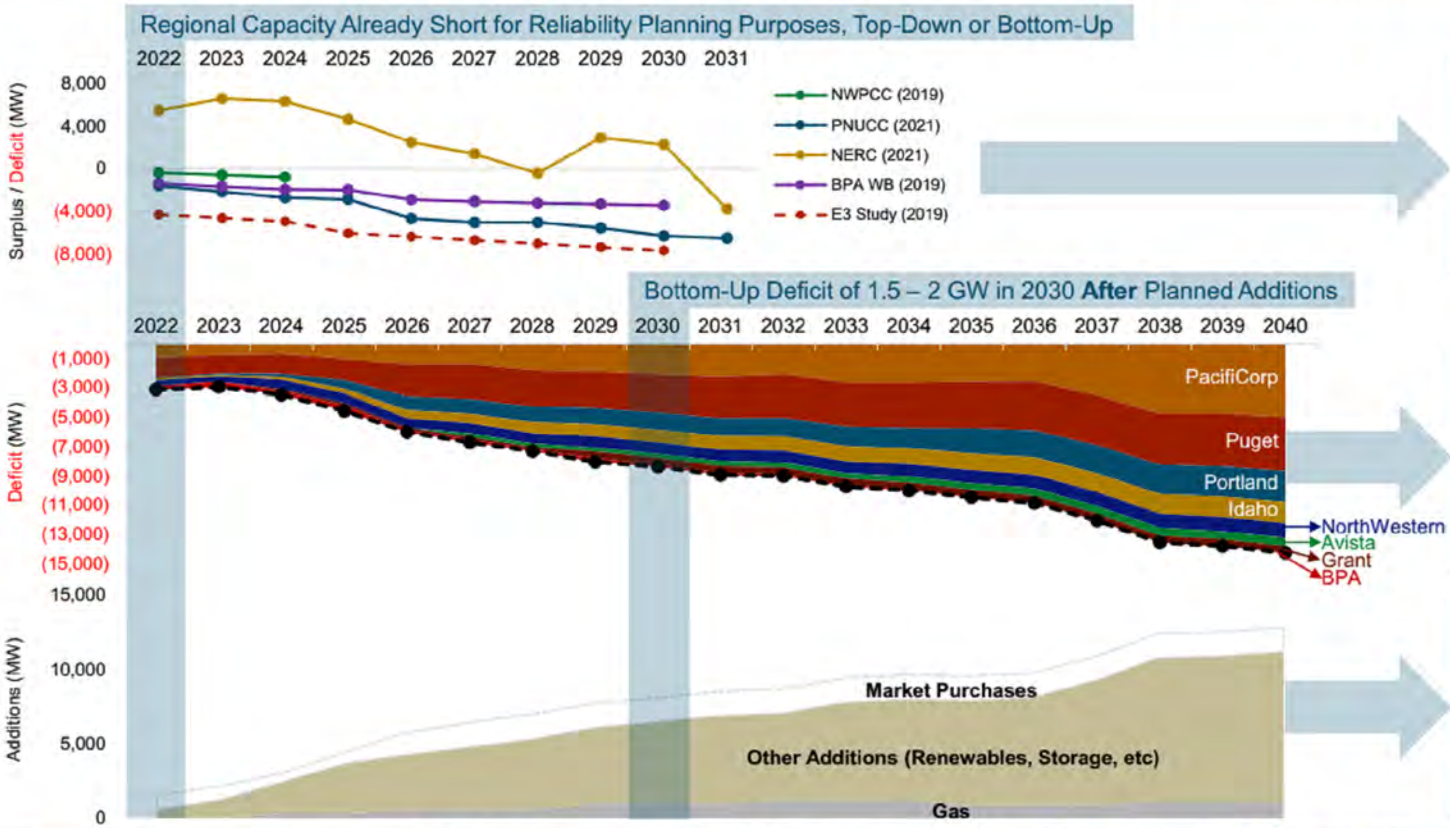
PNW Capacity Need vs. Planned Additions

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



Top-Down Regional Assessments

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

Bottom-Up Utility IRP Review

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

IRP Planned Additions

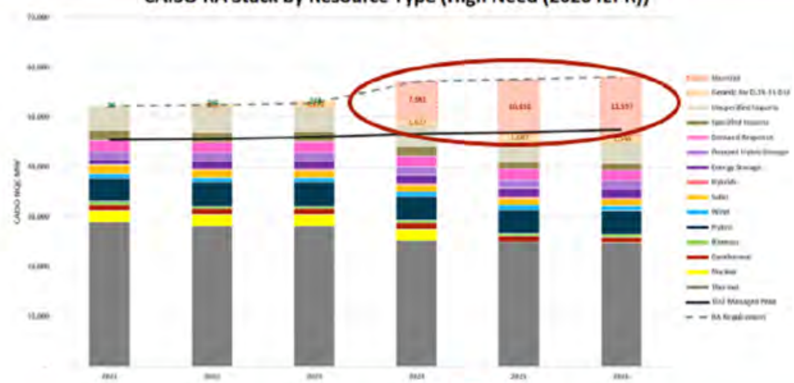
~6.5 GW effective capacity additions by 2030 (up to ~14 GW nameplate capacity), **significantly exceeding average capacity expansion rate for 2010-2020 (~1 GW/year)**

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

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

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

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

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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

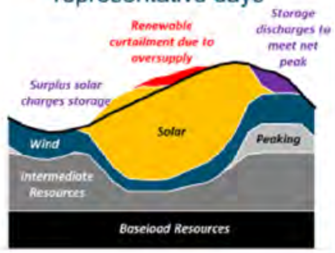
RESOLVE Modeling Approach and Scenarios

RESOLVE: Optimal Capacity Expansion Under Aggressive Clean Energy Goals

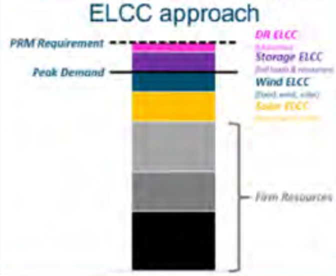
+ **RESOLVE is a linear optimization model explicitly tailored to the study of electricity systems with high renewable & clean energy policy goals**

+ **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**

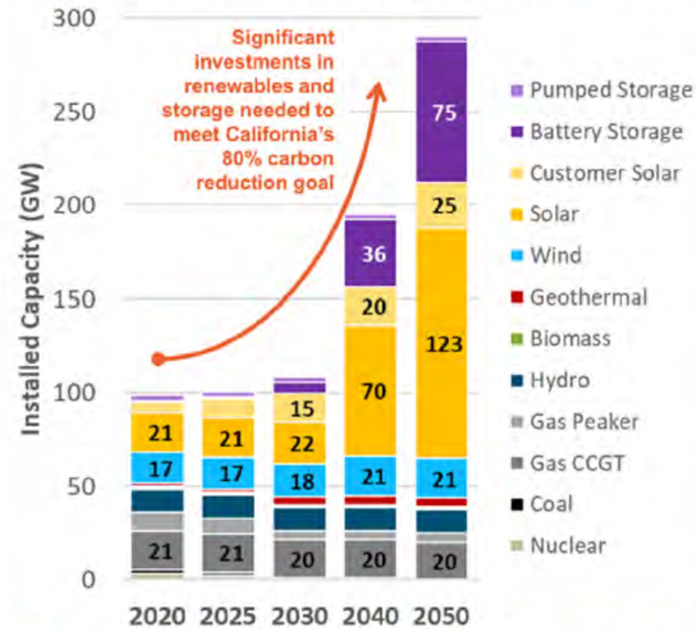
Operational module simulates hourly system operations for a sample of representative days



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)

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RESOLVE Co-optimizes Investment and Operational Decisions

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

RESOLVE Objective Function

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

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

Technology Availability

Technology Scenarios

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

Unavailable	Available

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

+ Mature Technologies

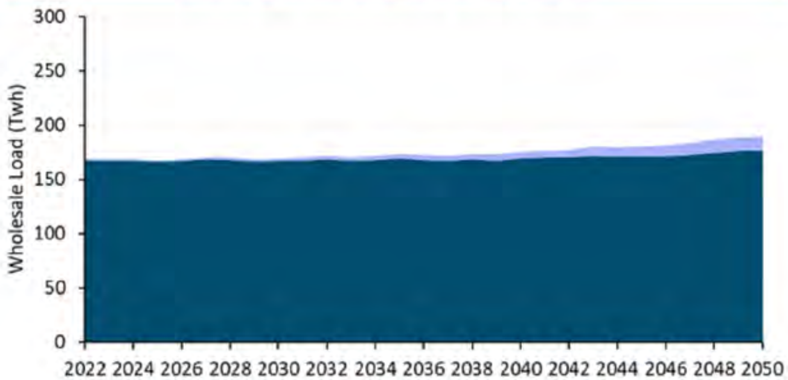
- Renewables provide low-cost form of zero-carbon energy w/ limited capacity value
  - Solar, wind (onshore)
- Storage resources support renewable integration but show limited value in the Northwest with the large hydro fleet
  - Battery storage, pumped hydro
- Demand response supports peak reduction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

+ Emerging technologies

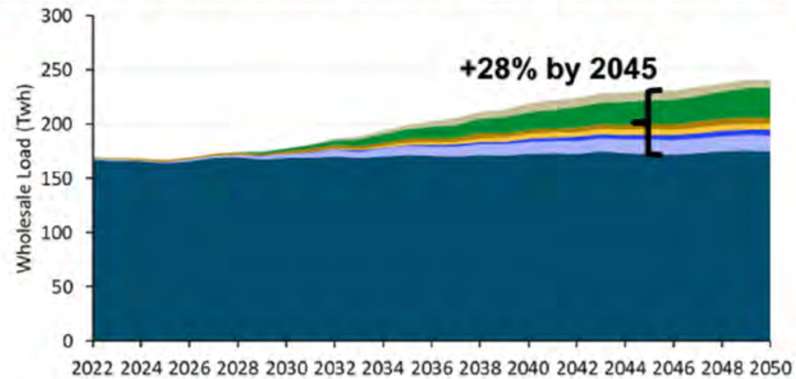
- "Clean peakers" such as new H2, new NG+H2, or NG→H2 retrofits provide low-cost form of capacity with very high energy cost (when burning hydrogen)… hydrogen assumed to be via dedicated off-grid production
- Gas w/ CCS provides a moderately high cost source of energy and capacity
- Nuclear SMR provides 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

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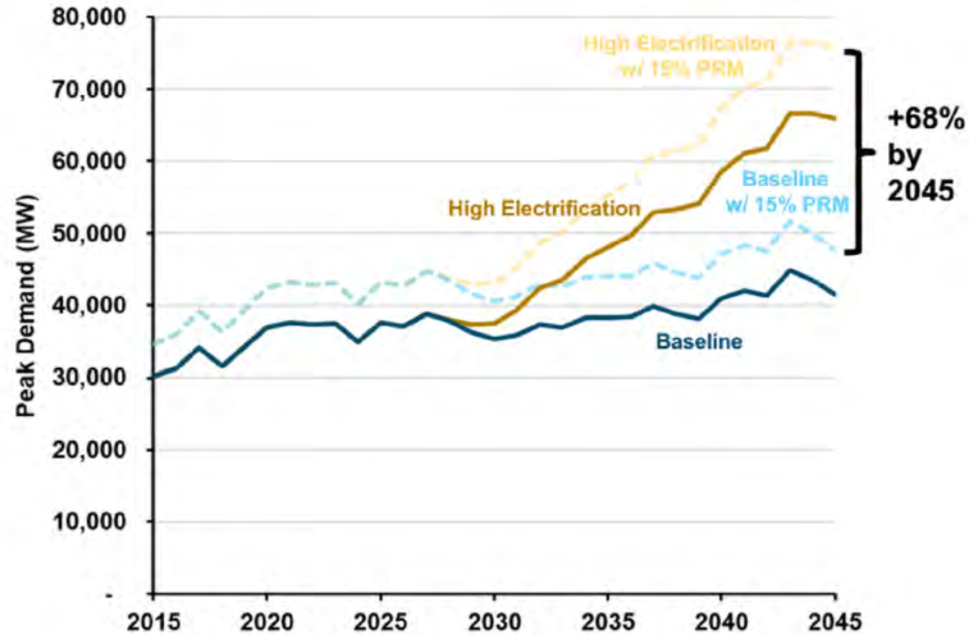
Electrification Load Growth (Peak Demand)

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



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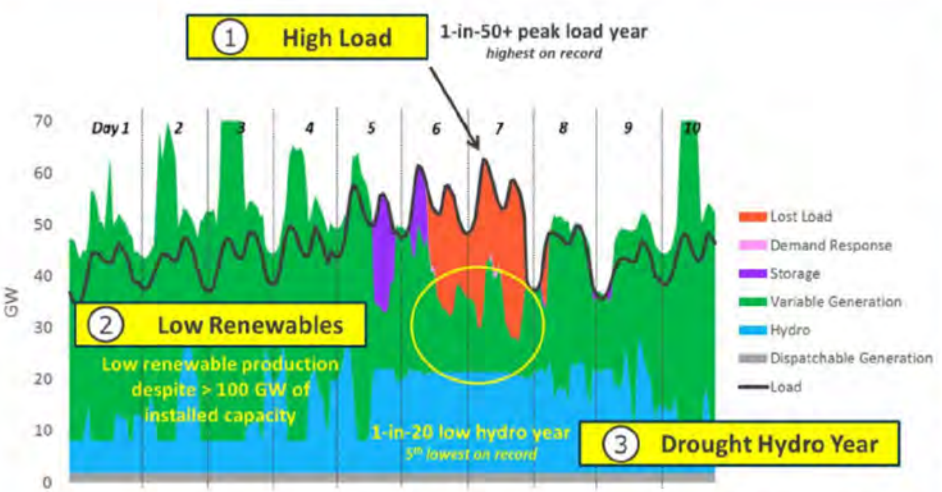
Resource Adequacy Resource Options

+ Storage and hydro show antagonistic interactions, which limit energy storage reliability value

- Northwest reliability risk is driven by high loads, low renewables, and low hydro output
- In these "energy-limited" conditions, 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	Study method based on 10-hr sustaining output in 1937 water year (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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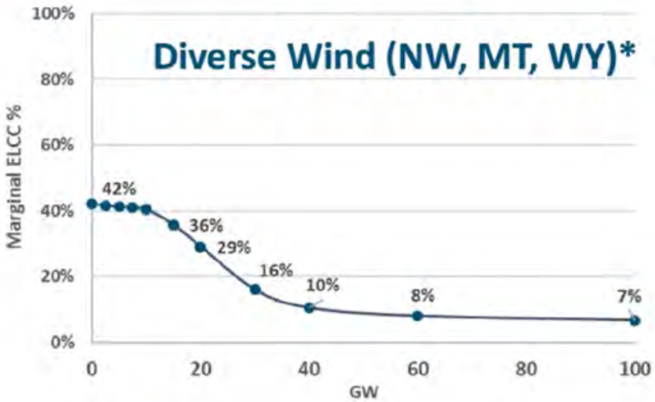
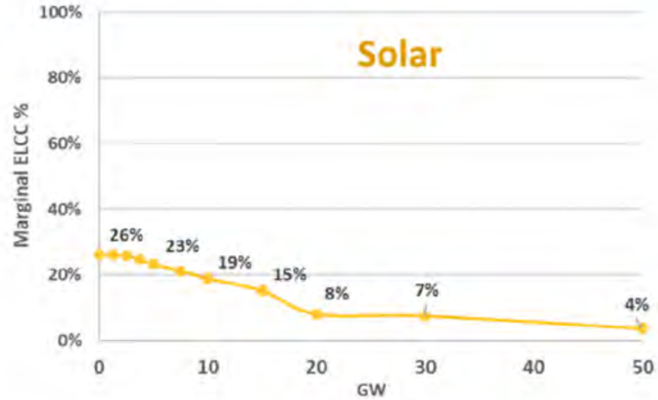
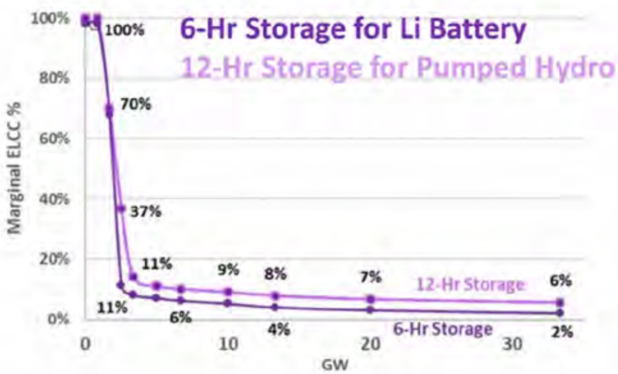
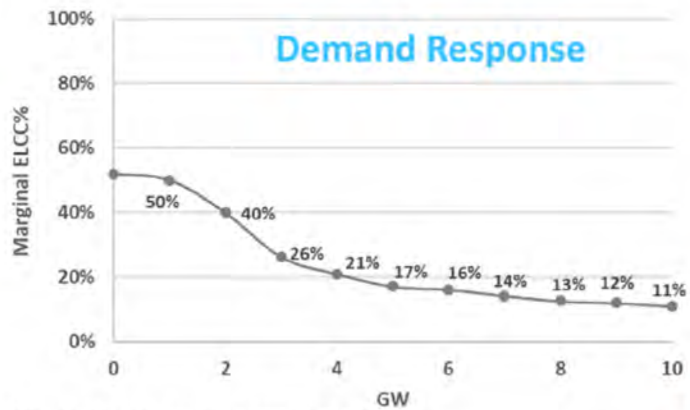
Incorporating Declining Capacity Contributions of Renewables, Storage, and DR









- 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

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

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

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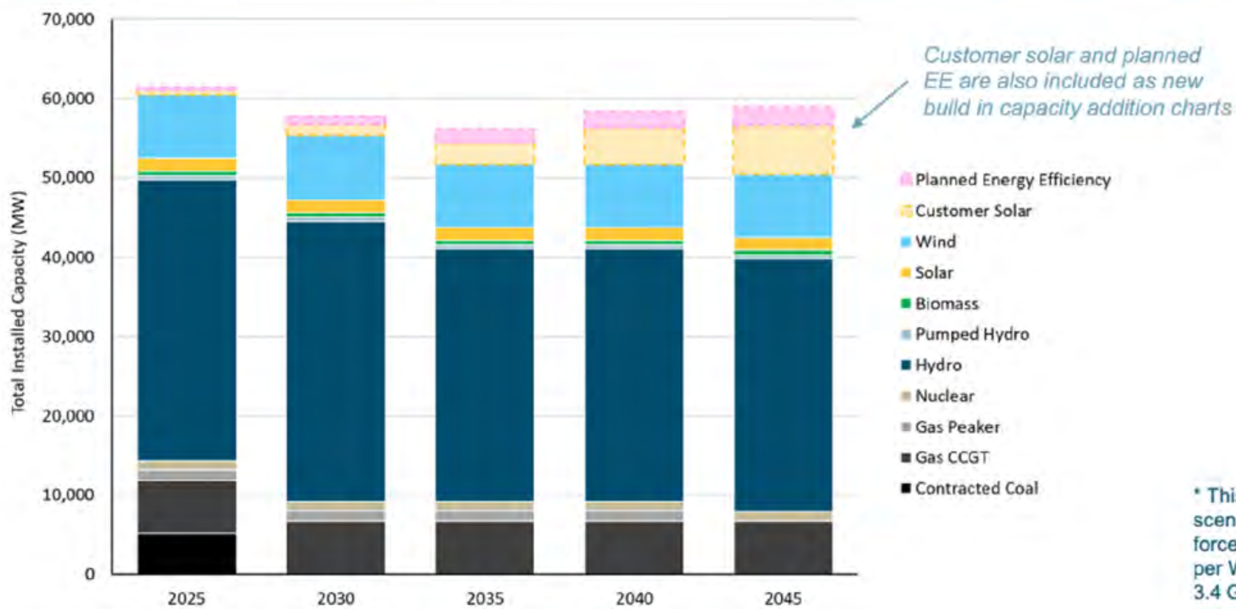
Baseline Resources

+ **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



* 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

- **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 hydrogen are needed

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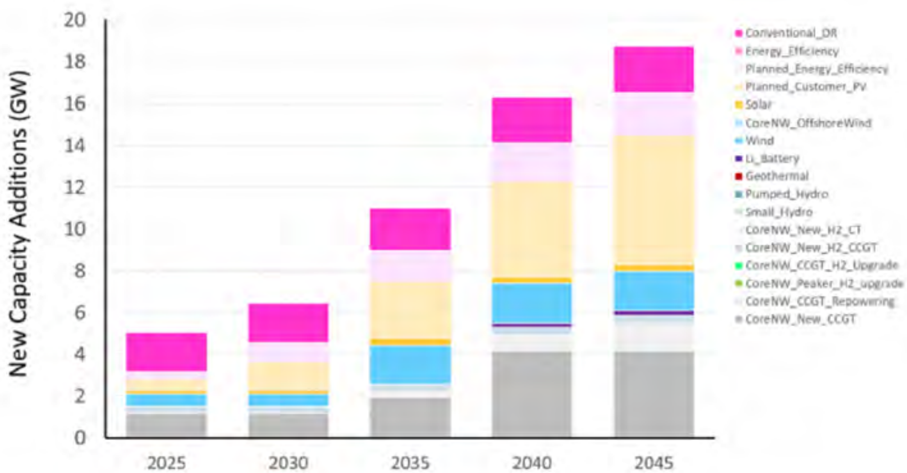
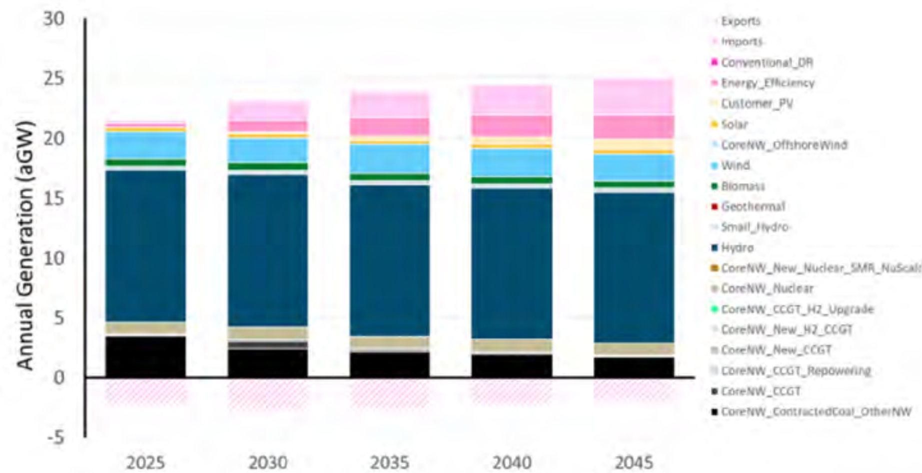
Scenarios with the Lower Snake River Dams

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





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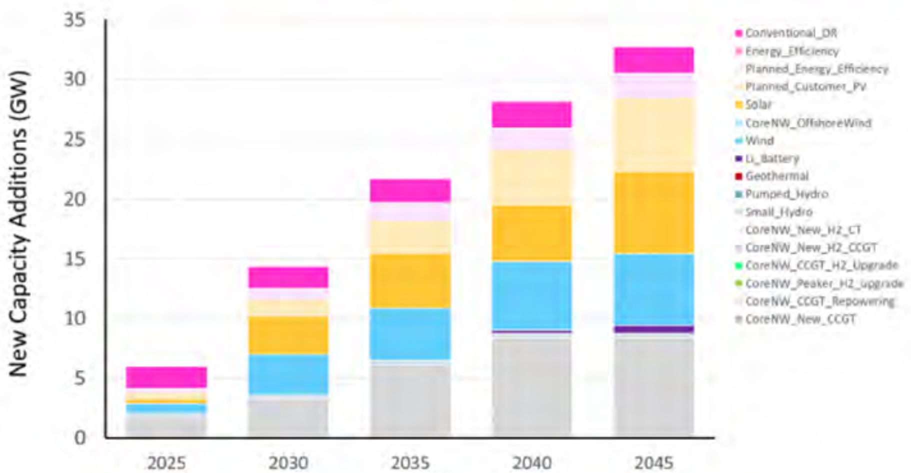
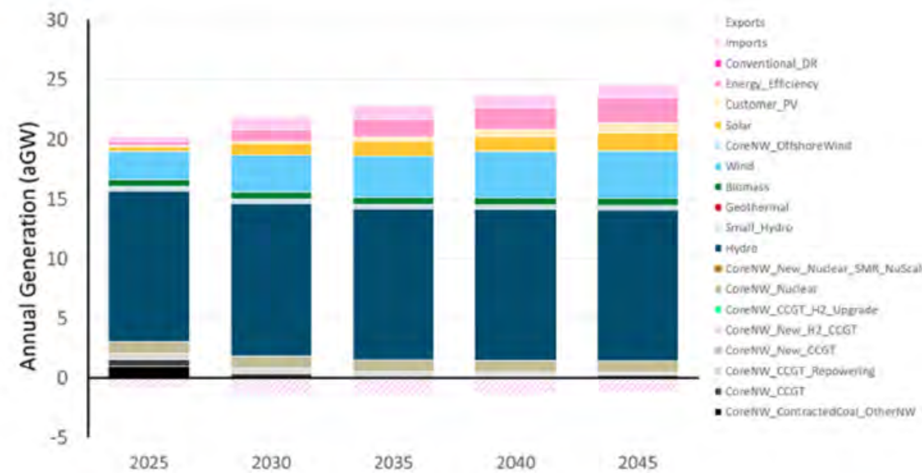
S1: Baseline – 100% Clean Retail Sales

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%, with carbon price driving 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

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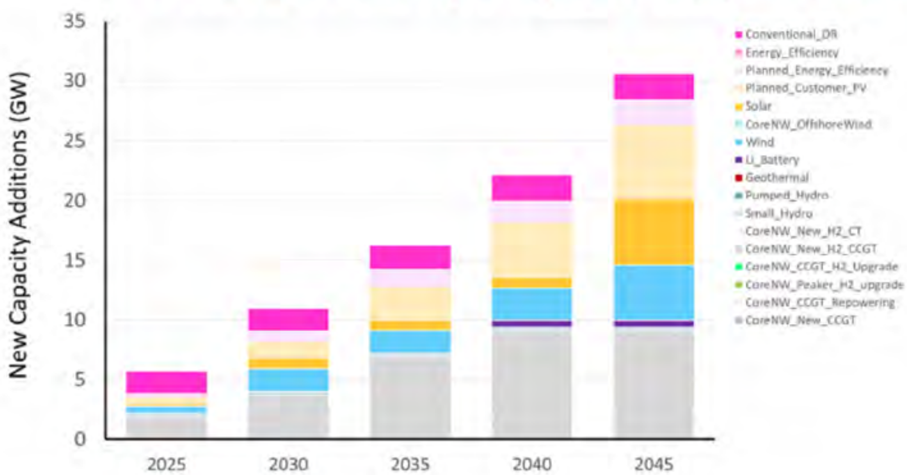
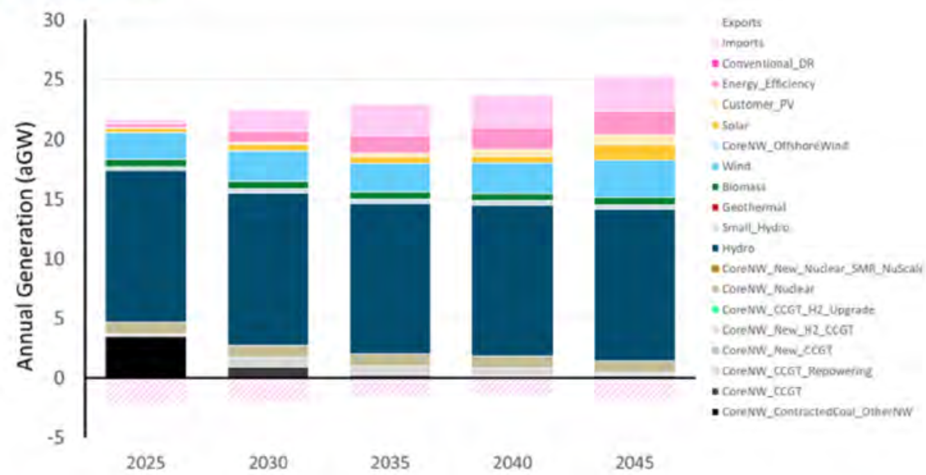
S1a: Baseline – 100% Clean Retail Sales

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





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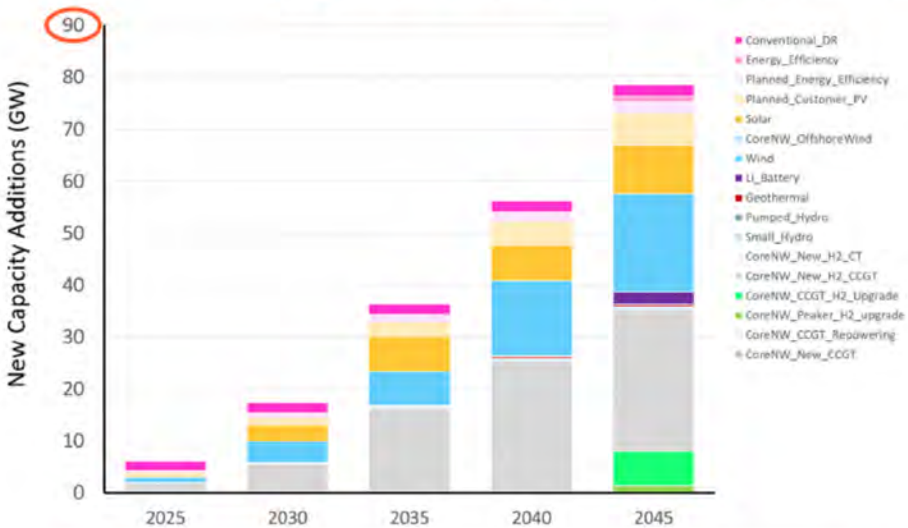
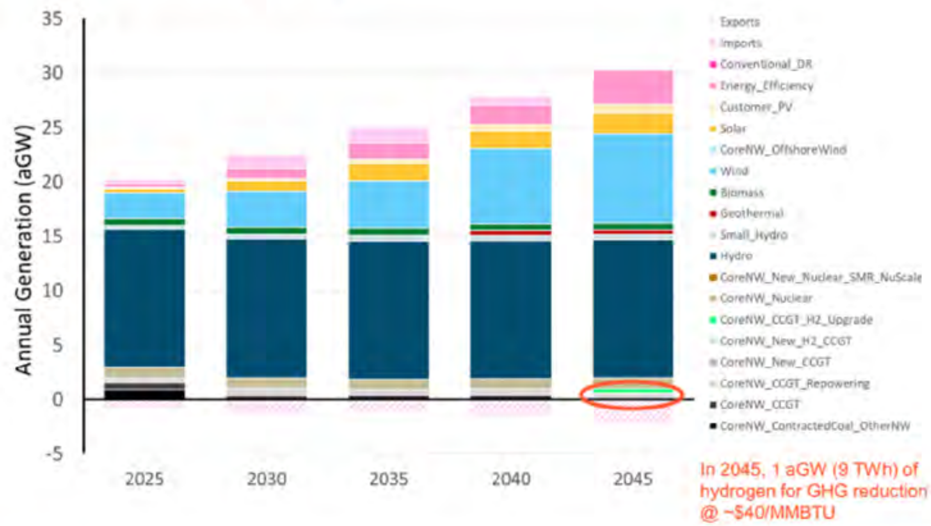
S2: Deep Decarbonization

+ **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





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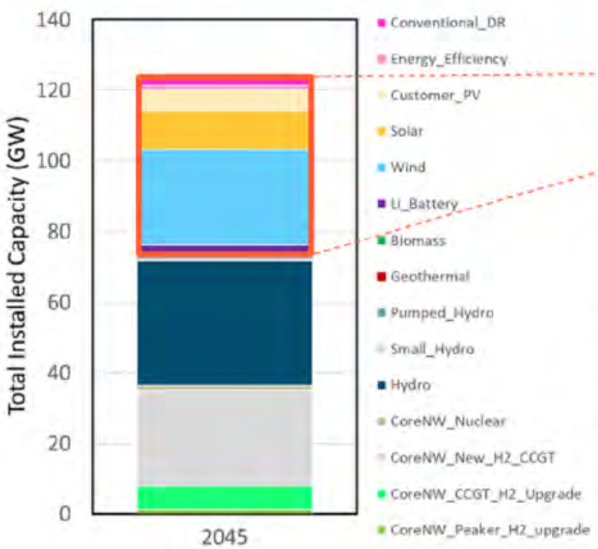
S2: Deep Decarbonization – Resource Adequacy Needs

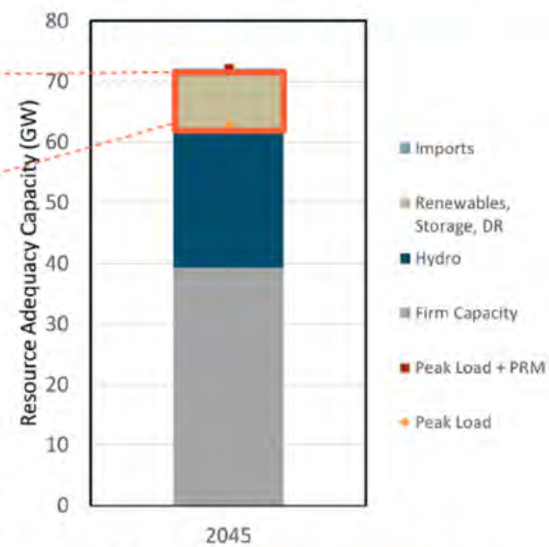
"Non-firm" solar, wind, batteries, and DR provide limited resource adequacy value in the Northwest, requiring "clean firm" capacity backup

2045 Deep Decarbonization Scenario Results*

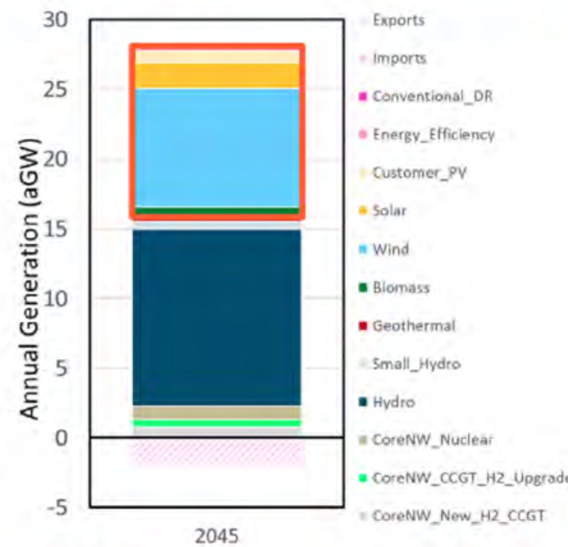
Installed Nameplate Capacity (GW)



Resource Adequacy Capacity (GW)



Annual Generation (TWh)



Renewables, storage, and DR provide significant installed MW…

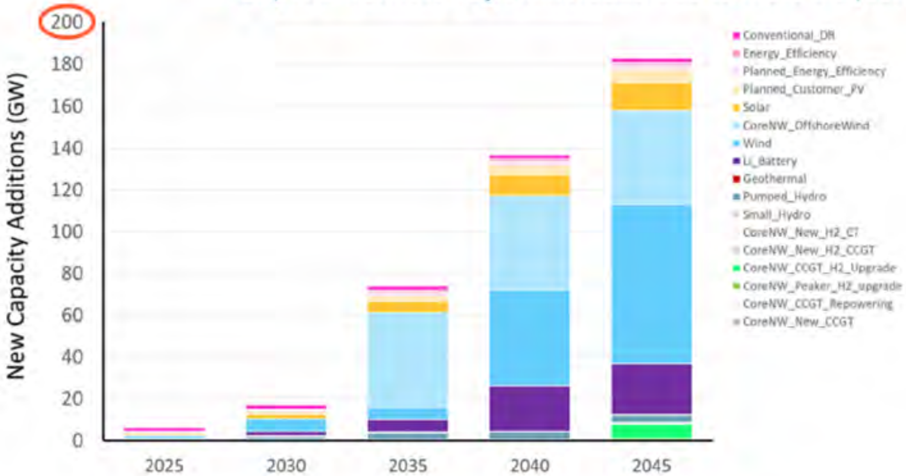
… but declining ELCCs mean their RA contributions become limited, requiring "clean firm" capacity backup (hydrogen in this case)…

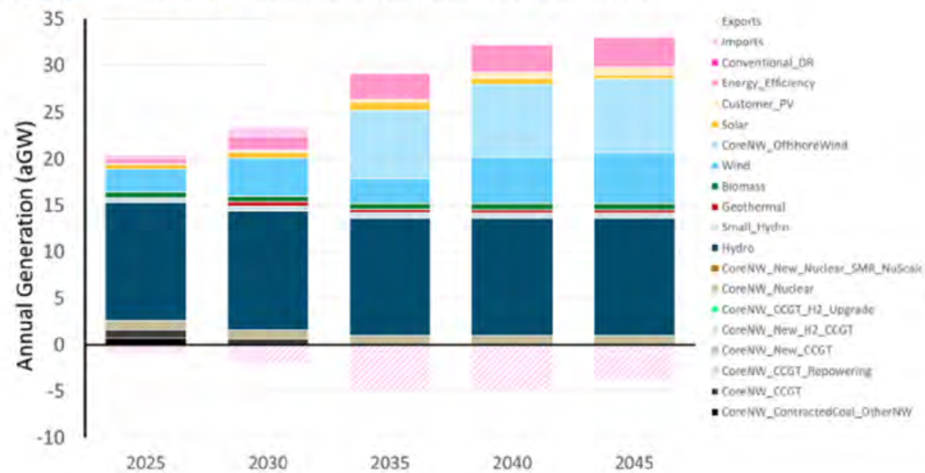
…due to high costs, hydrogen generation is limited to low hydro, low renewable periods; renewables + hydro + nuclear provide 95% of annual energy

* 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





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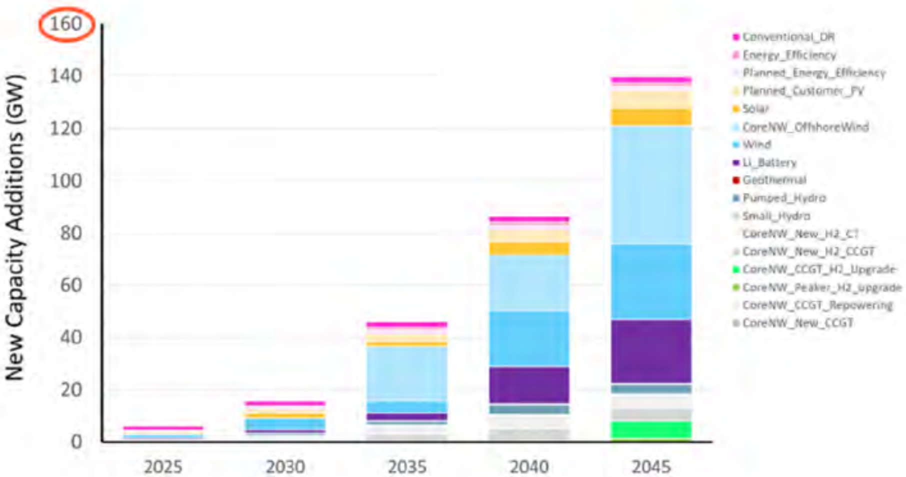
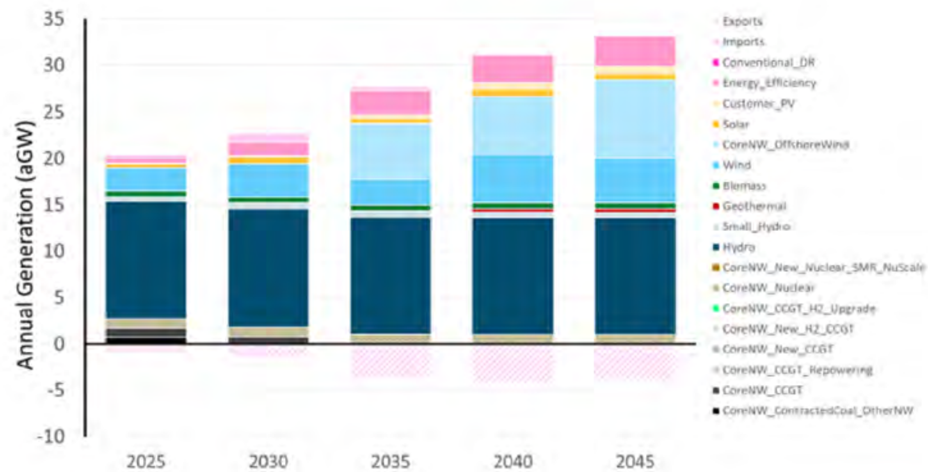
S2a2: Deep Decarbonization – Limited Tech w/ No New Gas (Limited H_2 Allowed)

+ **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

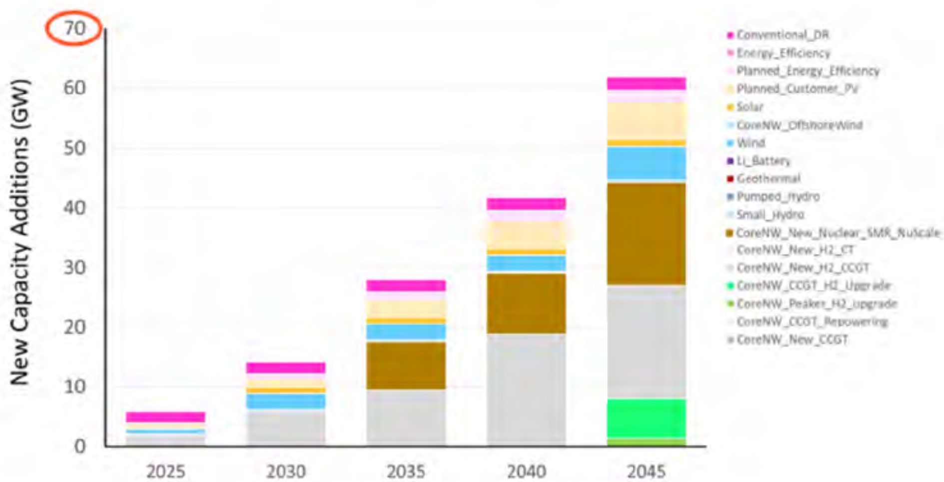


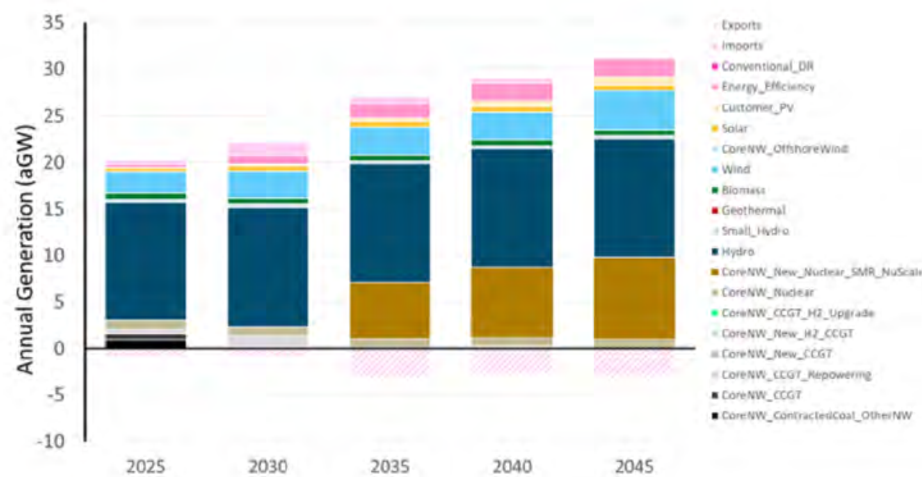


S2b: Deep Decarbonization – Emerging Technology

+ 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





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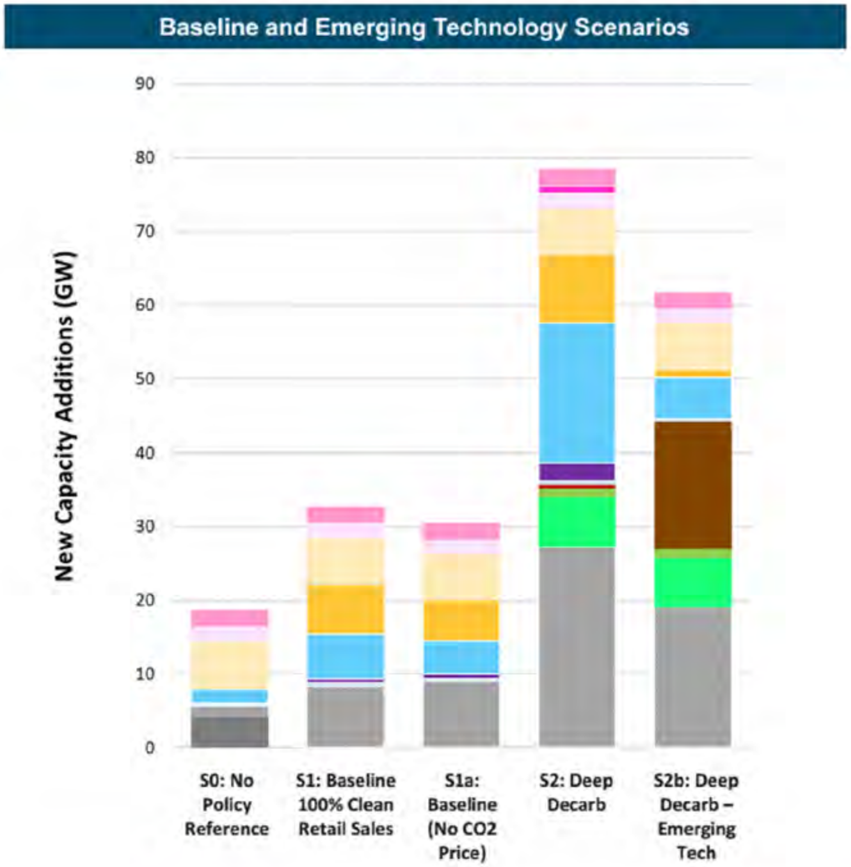
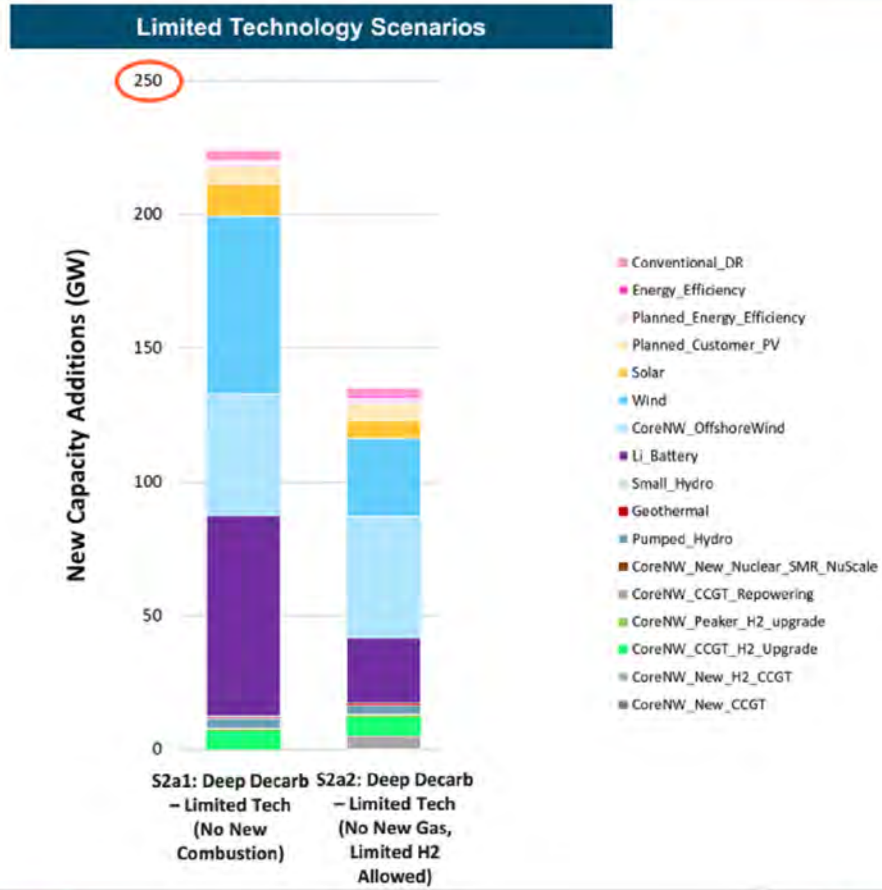
Comparison of 2045 Cumulative Selected Capacity





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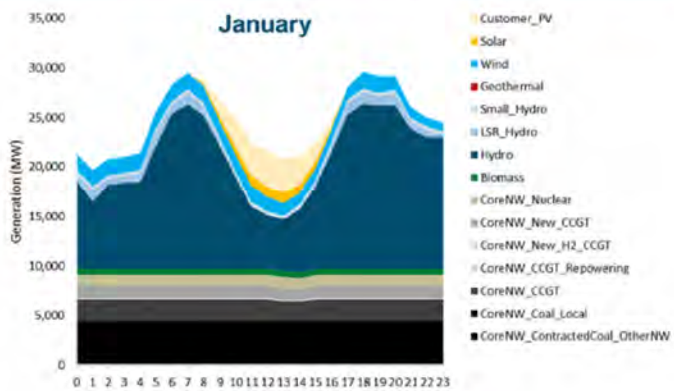
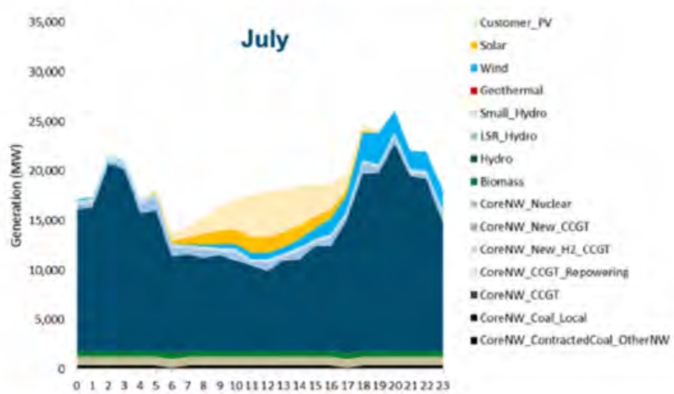
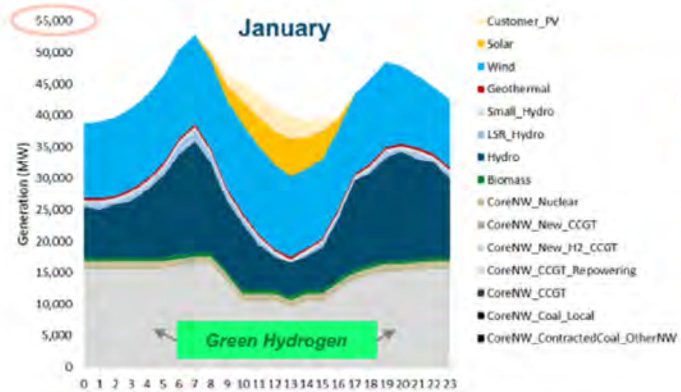
Resource Dispatch in 2045

S0: No Policy Reference

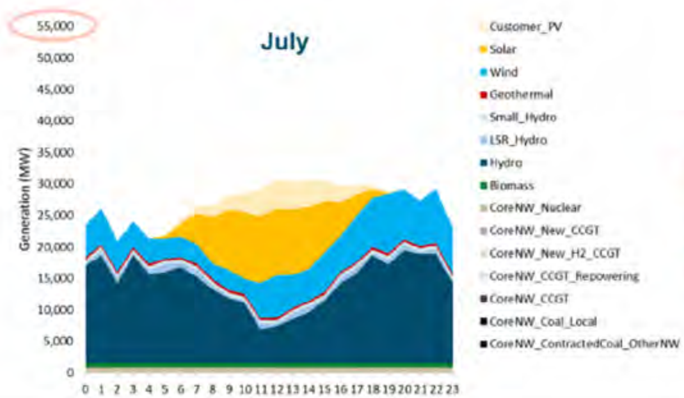




S2: Deep Decarbonization



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



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

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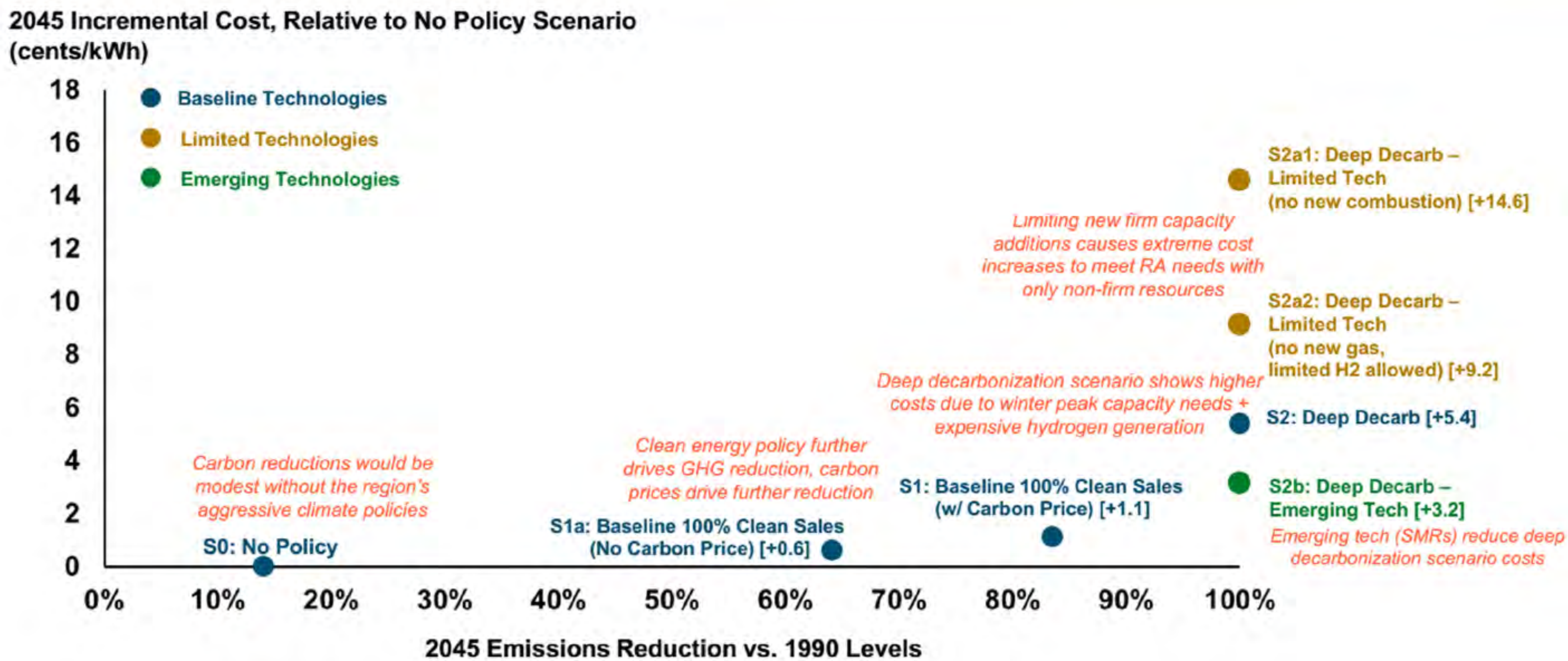
Decarbonization Scenarios Cost Impacts



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

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Land Use Impacts

+ **Summary of direct and indirect land use impacts**

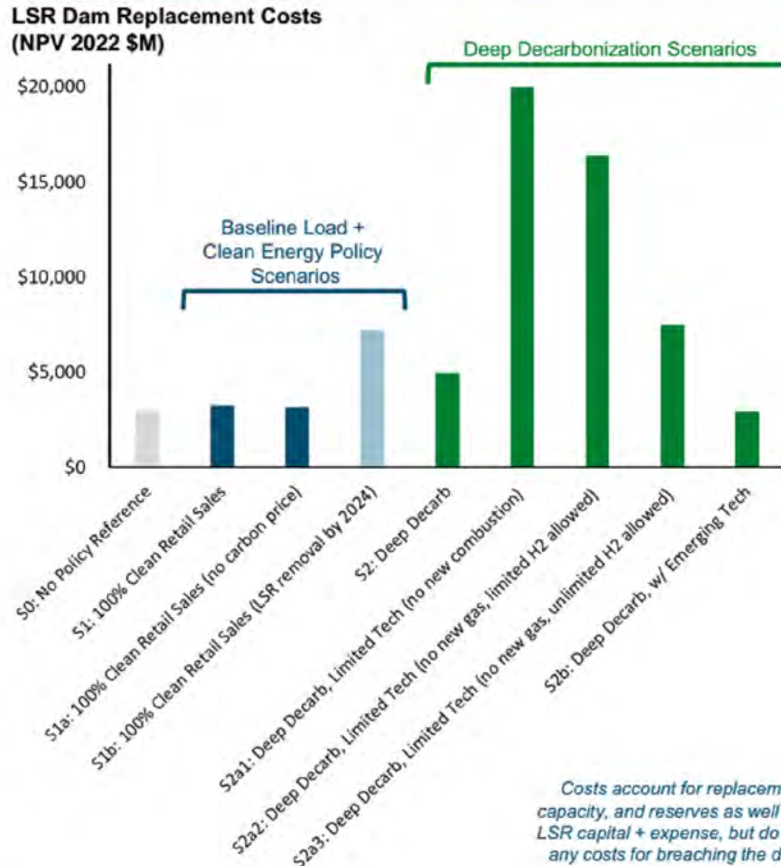
E3 will update land use impacts for the final version of this report

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)



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.

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LSR Dam 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.

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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

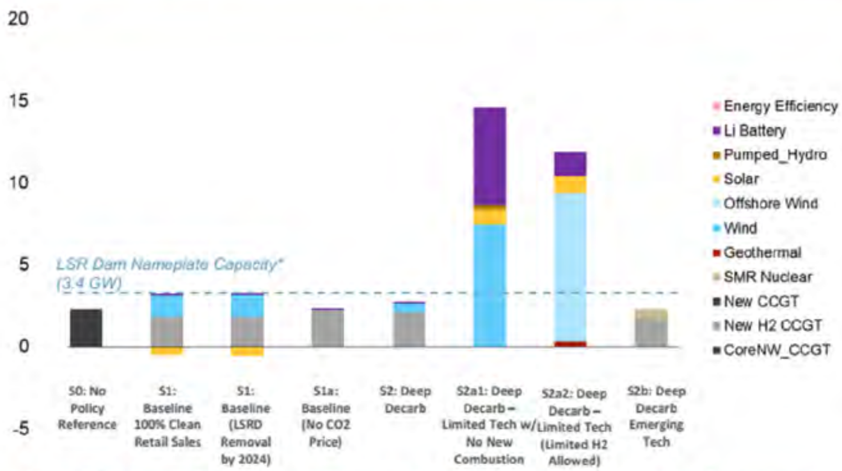
Outlier cases

Scenario	2045 Costs to replace LSR Generation** (real 2022 $/MWh)	2045 Incremental BPA Customer Costs*** (real 2022 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

* 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 Dam Replacement

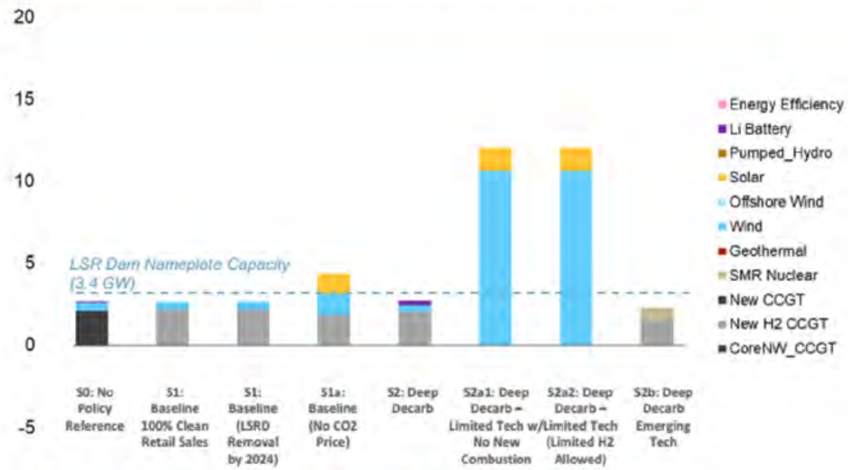
LSR Dam Replacement Portfolio in 2035 (GW)



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

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

LSR Dam Replacement Portfolio in 2045 (GW)



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

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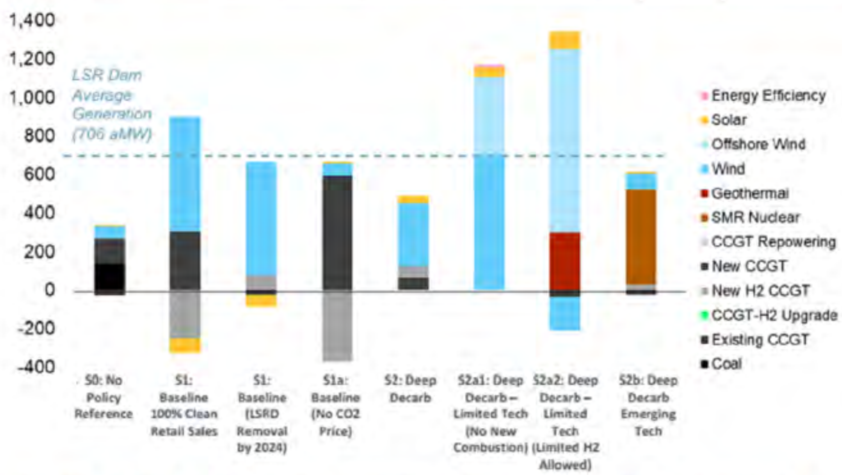
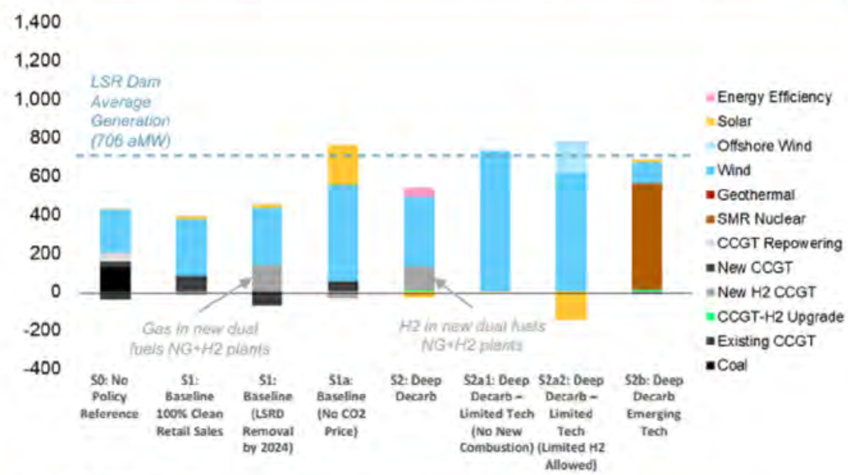
Additional Energy Generation for Dam Replacement

LSR Dam Replacement Generation in 2035 (aMW)



LSR Dam 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
  - Some generation may be replaced by thermal generation (natural gas in scenarios that allow it or hydrogen in scenarios that do not) or imports

* NOTE: scenarios w/ lower aGW replacement than LSR dam aGW indicate replacement with higher imports or lower exports

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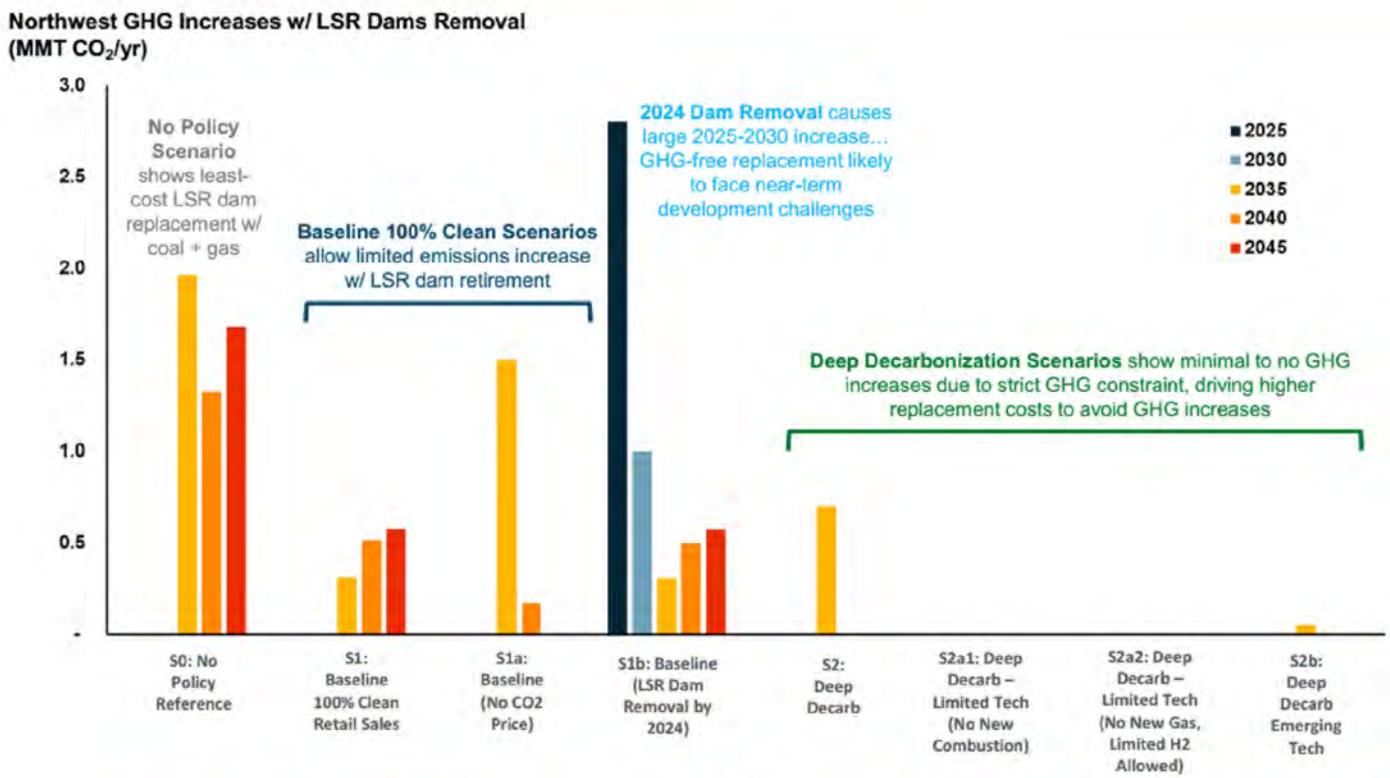
Carbon Emissions Impacts of LSR Dams Removal



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

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

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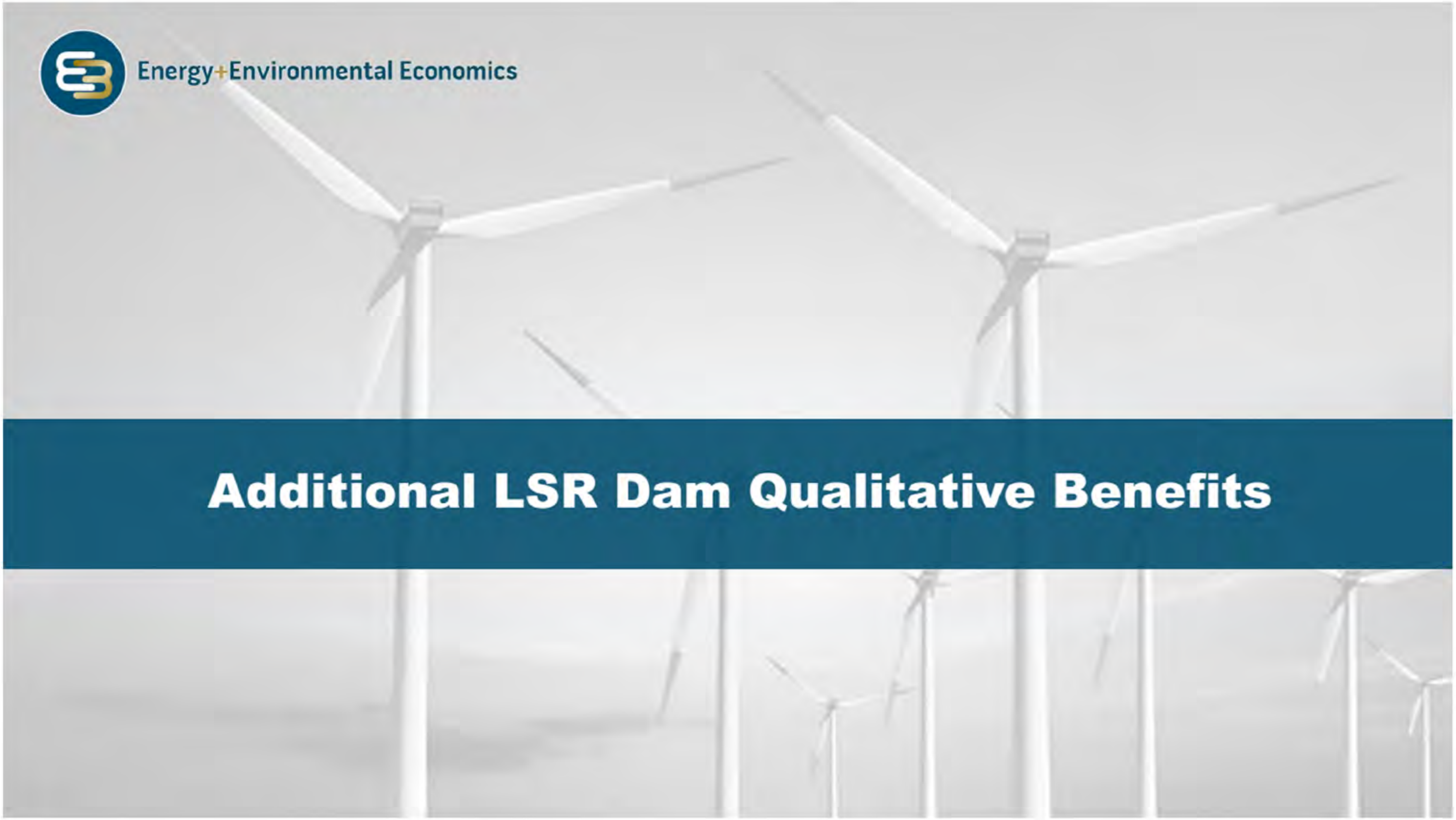


Additional LSR Dam Qualitative Benefits

Hydropower provides direct and indirect grid benefits

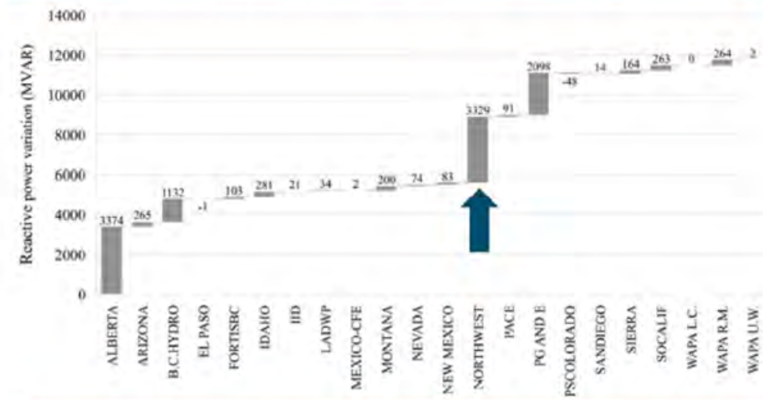
Grid Benefit	Captured in RESOLVE
Energy (MW)	☑
Instantaneous and Sustained Capacity (MW)	☑
Reserve Carrying Capability (MW)	☑
Fast Ramping	☑
Voltage and Reactive Support	☒
Frequency and Inertial Response	☒
Blackstart Capability	☒
Short-Circuit and Grounding Contribution	☒
Voltage and Frequency Excursion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

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

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**
  - However, renewables are expected to reduce the *need* for inertia at the same time (NREL 2020)
  - 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

Energy+Environmental Economics

Thank You

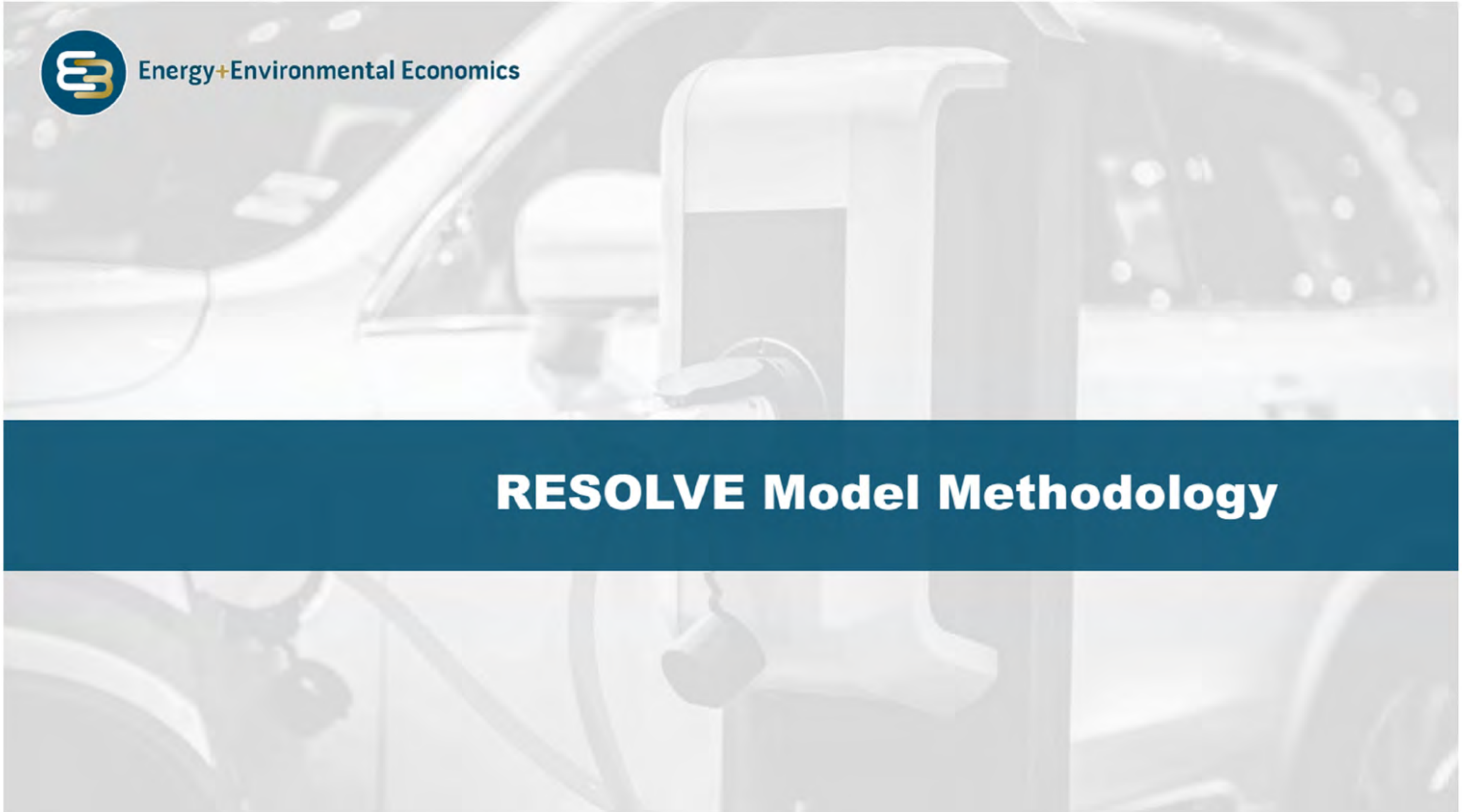
Questions, please contact:

Aaron Burdick, aaron.burdick@ethree.com

Energy+Environmental Economics

Appendix

Energy+Environmental Economics



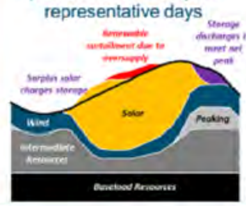
RESOLVE Model Methodology

RESOLVE optimizes investments to meet clean energy targets reliably

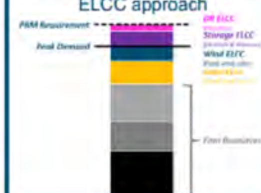
RESOLVE is an optimal capacity expansion model specifically designed to identify least-cost plans to meet reliability needs and achieve compliance with regulatory and policy requirements

- **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**

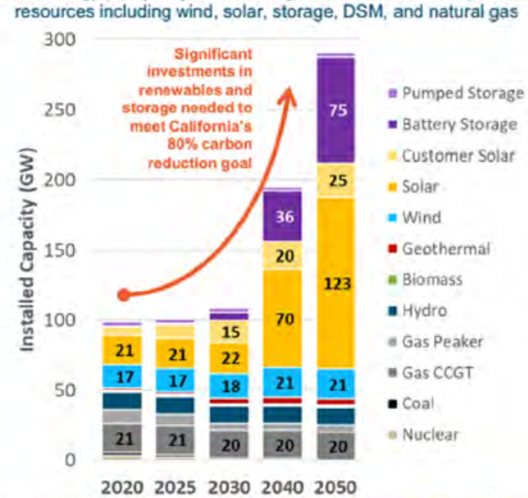
Operational module simulates hourly system operations for a sample of representative days



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



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

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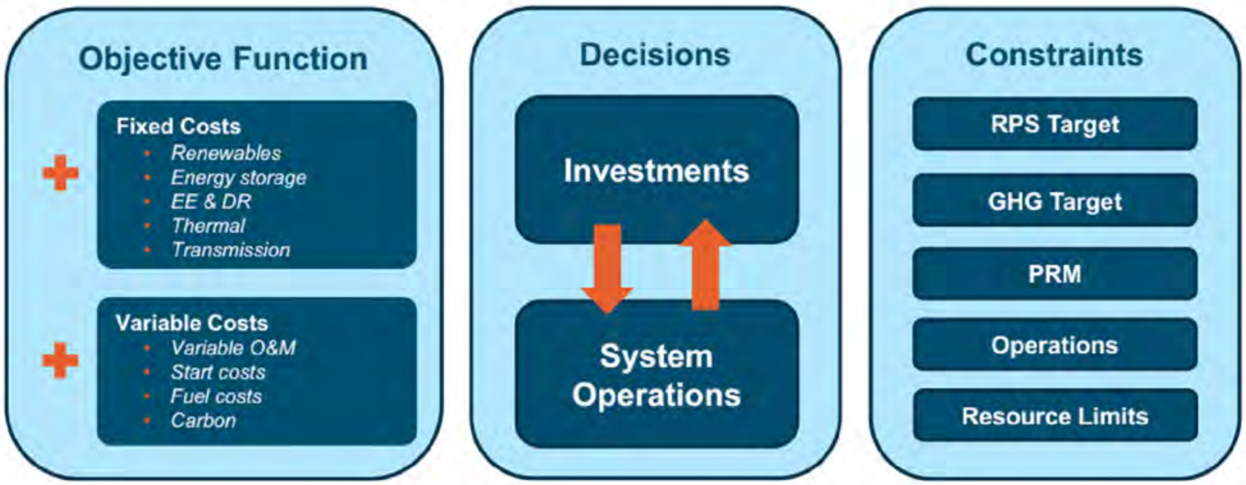
Investment and Operational Decisions in RESOLVE

+ **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

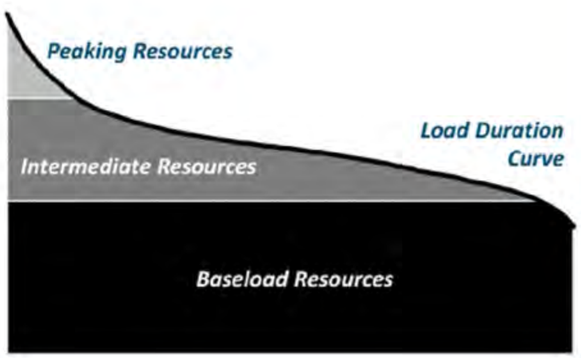


Evolving Considerations in Planning

System Operations

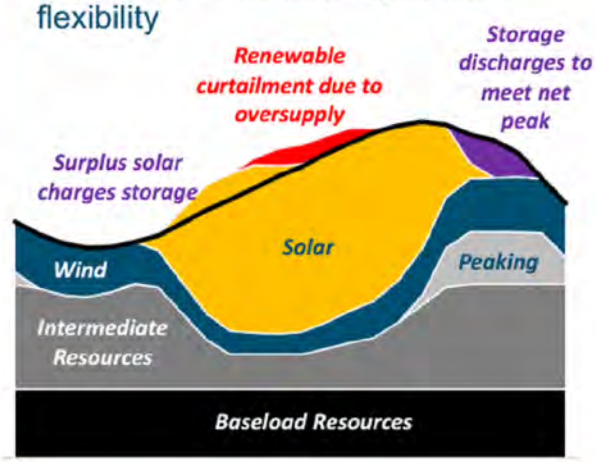
Traditional Planning Paradigm

- 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



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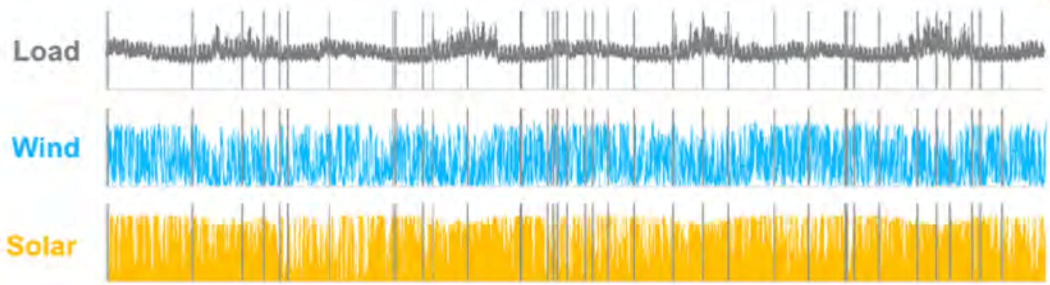
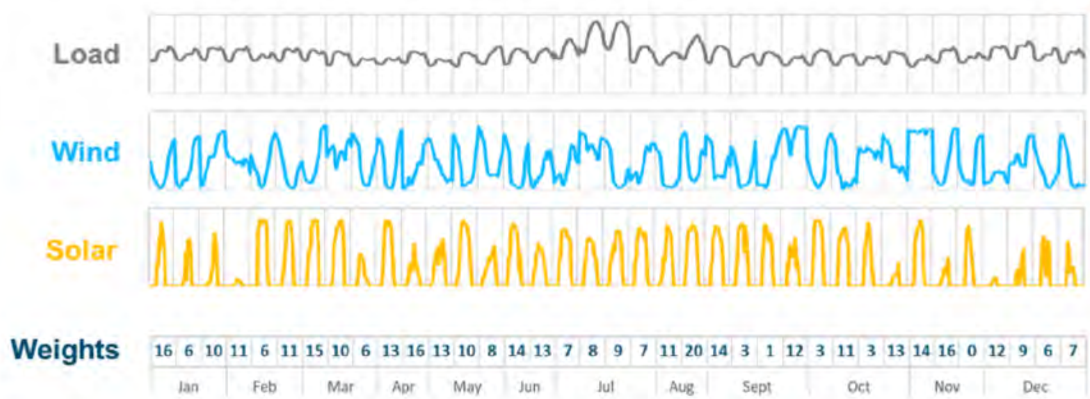
Downsampling historical data sets to a subset of representative days



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

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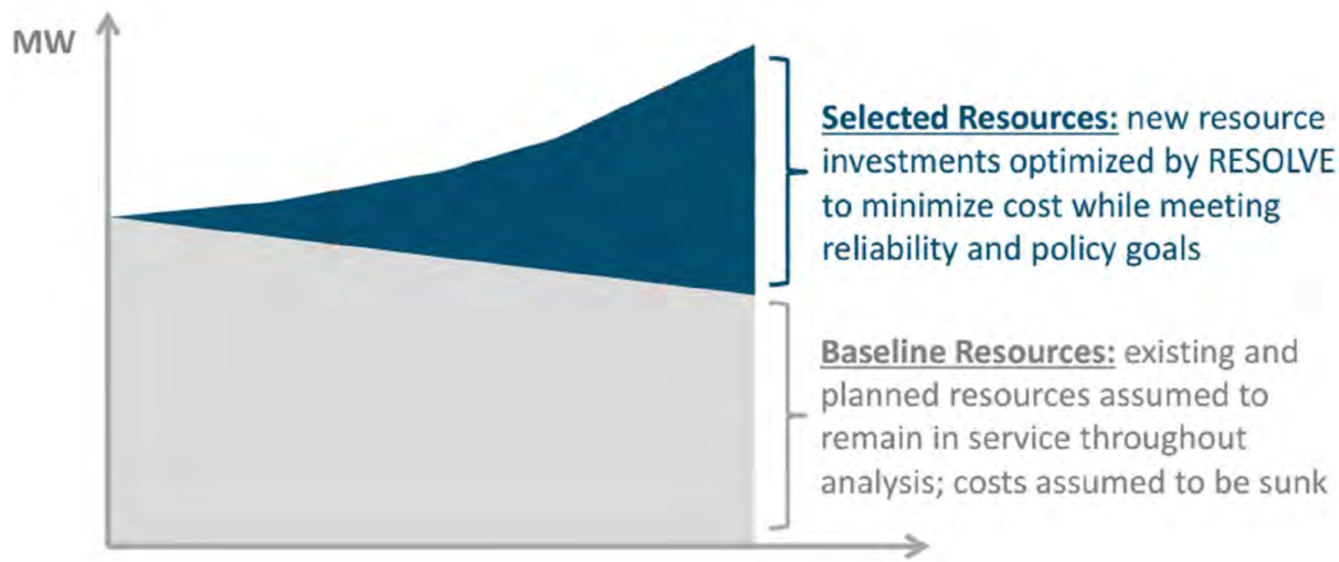
Planned vs. Selected Resources

+ **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



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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

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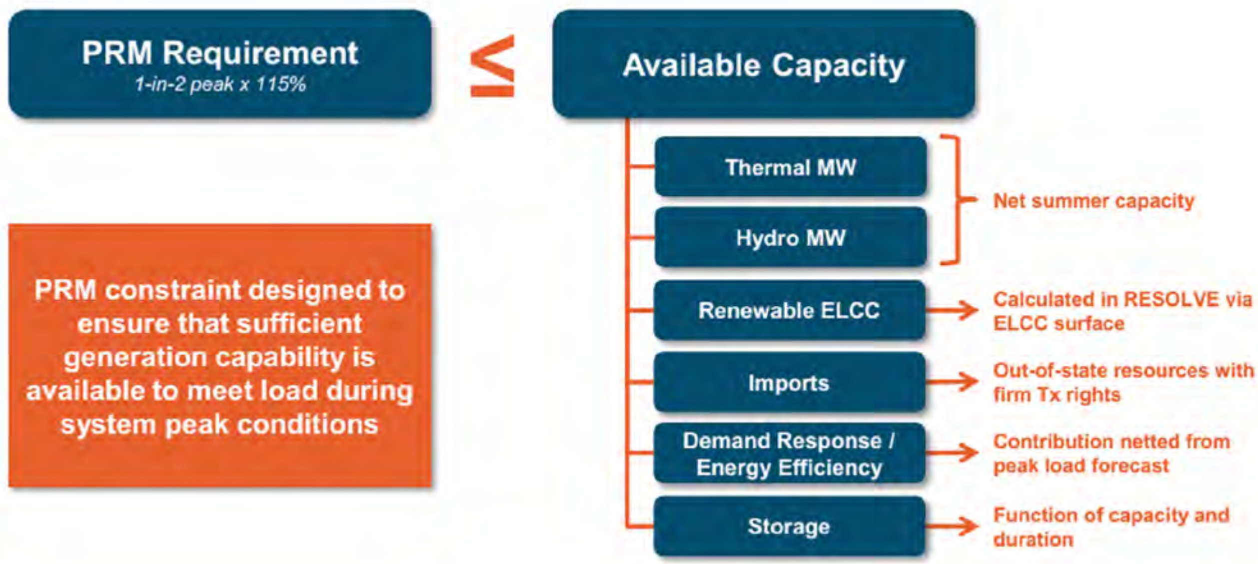
Resource adequacy needs maintained with a planning reserve margin

- 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



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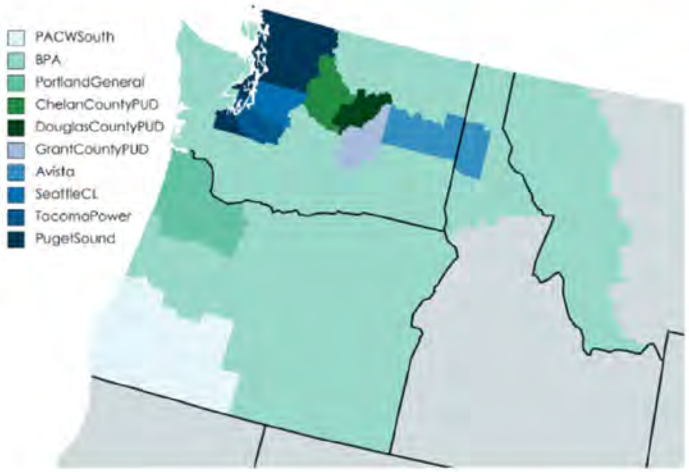
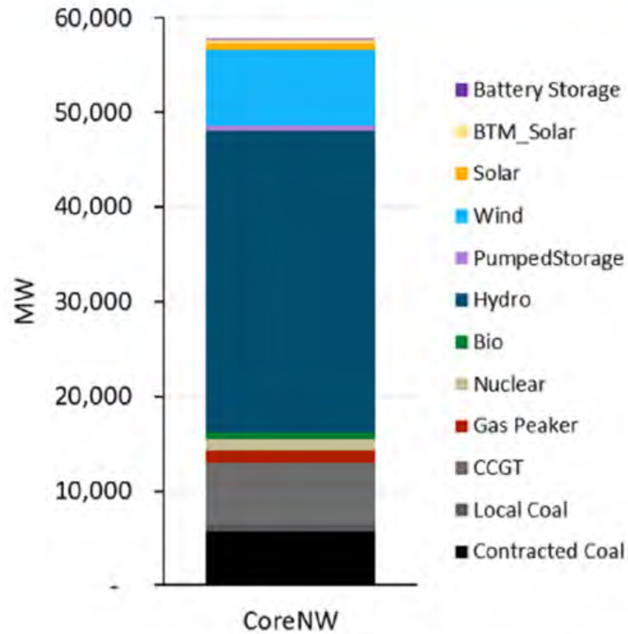
RESOLVE Inputs

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



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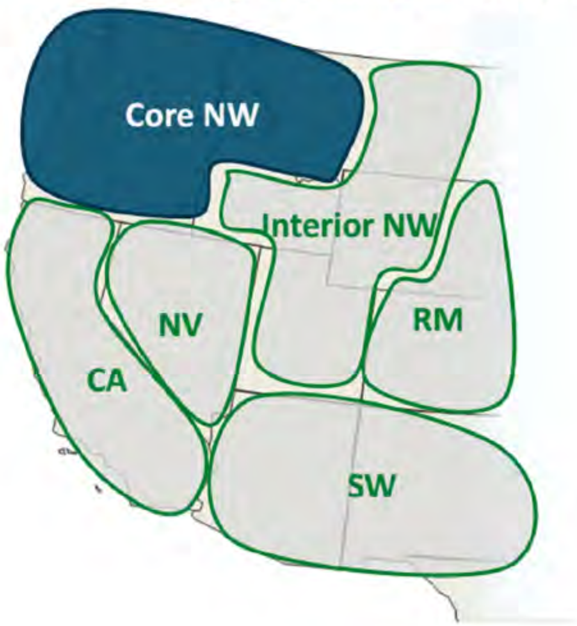
External Zone - Approach

+ **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%

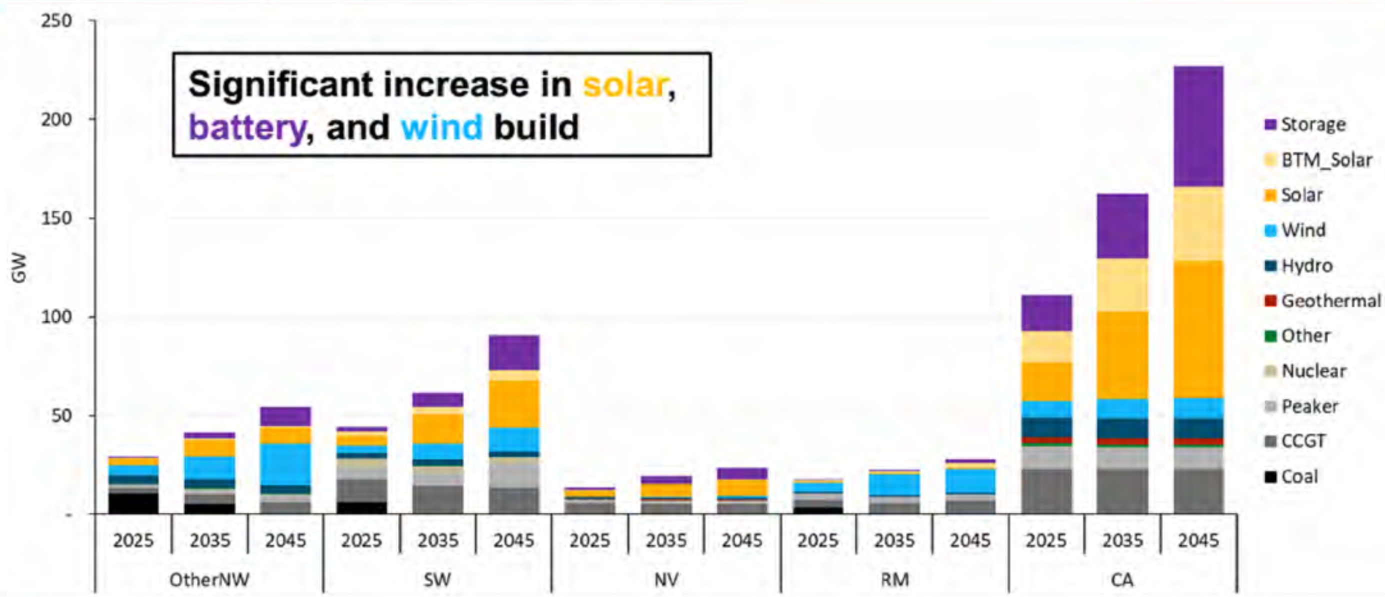
Notes:

- **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



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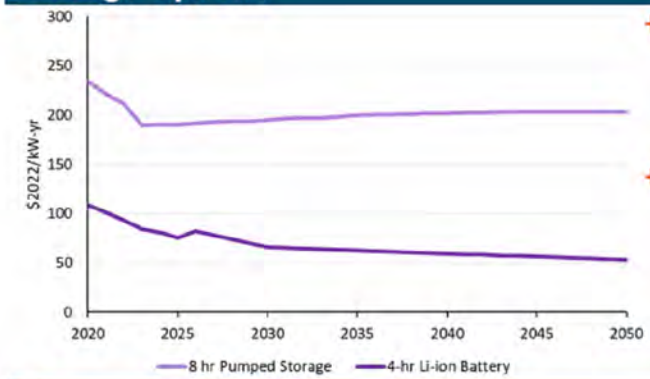
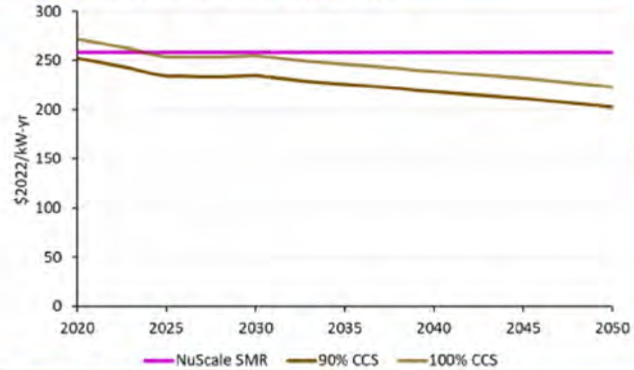
New Resource Options
All-in Fixed Costs

Storage Options



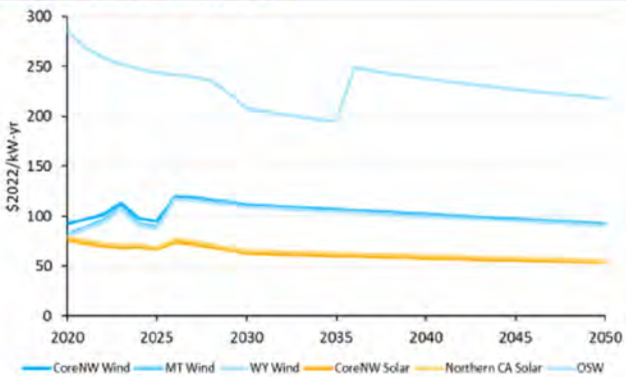
- Battery Storage costs derived from E3's inhouse and Lazard LCOS 7.0 (Oct 2021)
- Pumped storage is from Lazard's last published PHS costs (LCOS 4.0). Assumes CAPEX and FO&M are flat + financing cost trends same for battery storage.

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

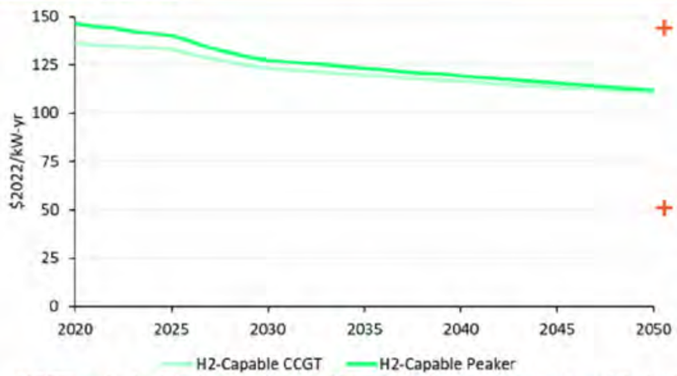
Renewable Options



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

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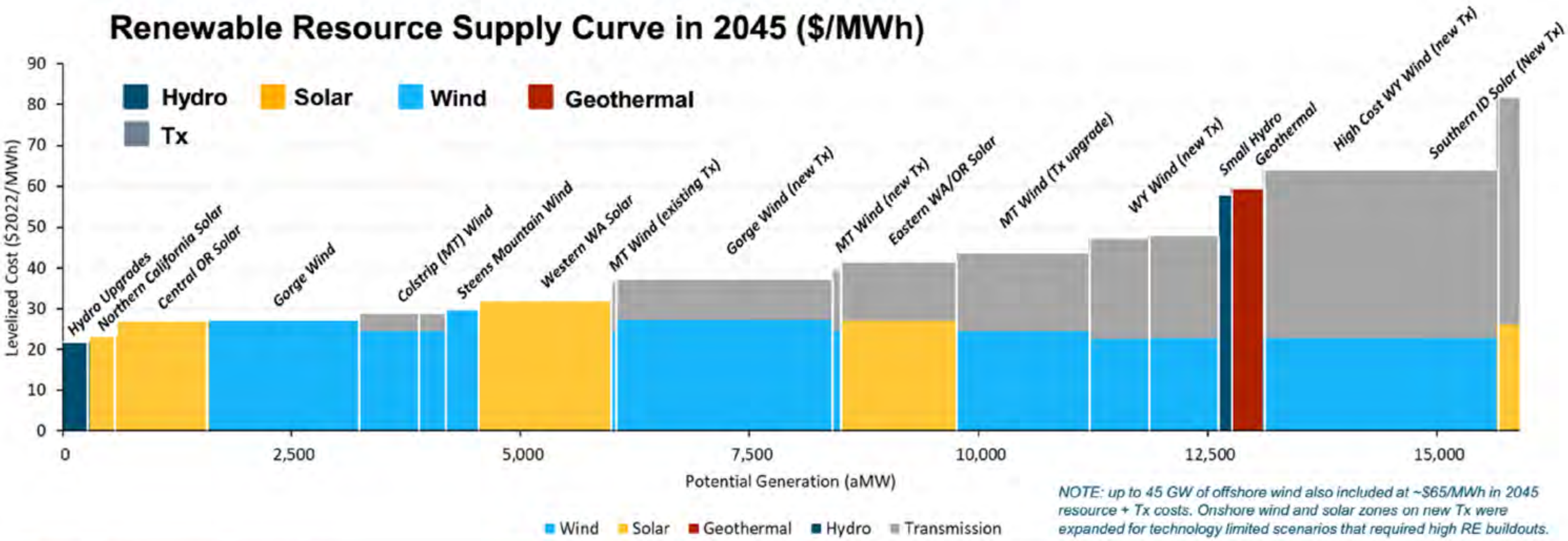
New Resource Options
Renewables

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

Renewable Resource Supply Curve in 2045 ($/MWh)



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

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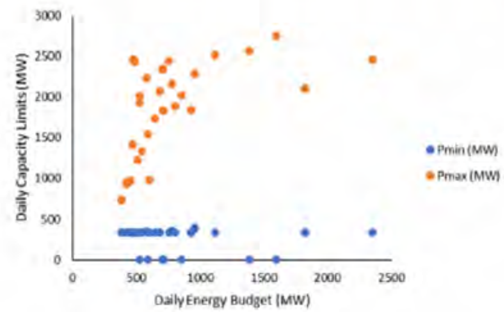
Hydro Operating Data

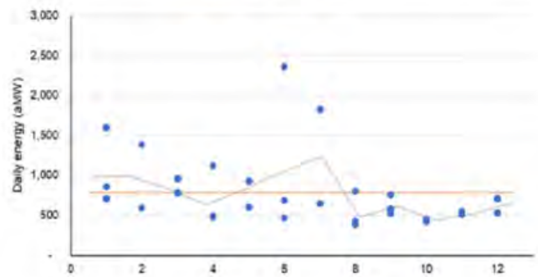
- **Key RESOLVE inputs (for each representative RESOLVE day)**
  - Max generation MW
  - Min generation MW
  - Daily MWh hydro budget
  - Ramp
- **Hydro operating data is parameterized using representative conditions for 3 low/mid/high historical years (2001, 2005, 2011)**
  - Lower Snake River and Lower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

LSR Hydro

Ramp Rates

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

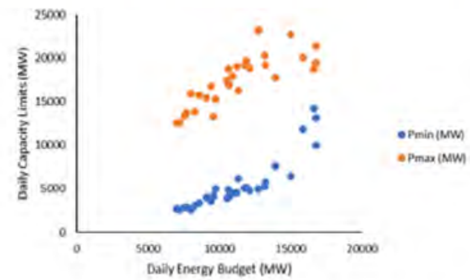


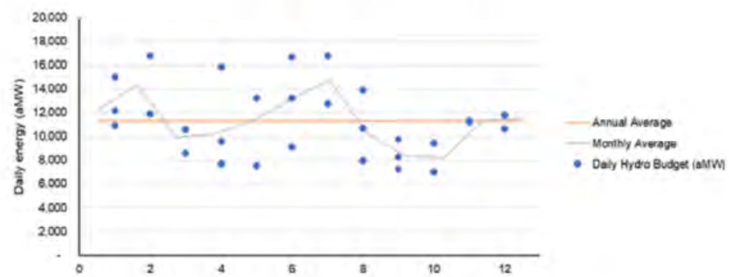


Non-LSR NW Hydro

Ramp Rates

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





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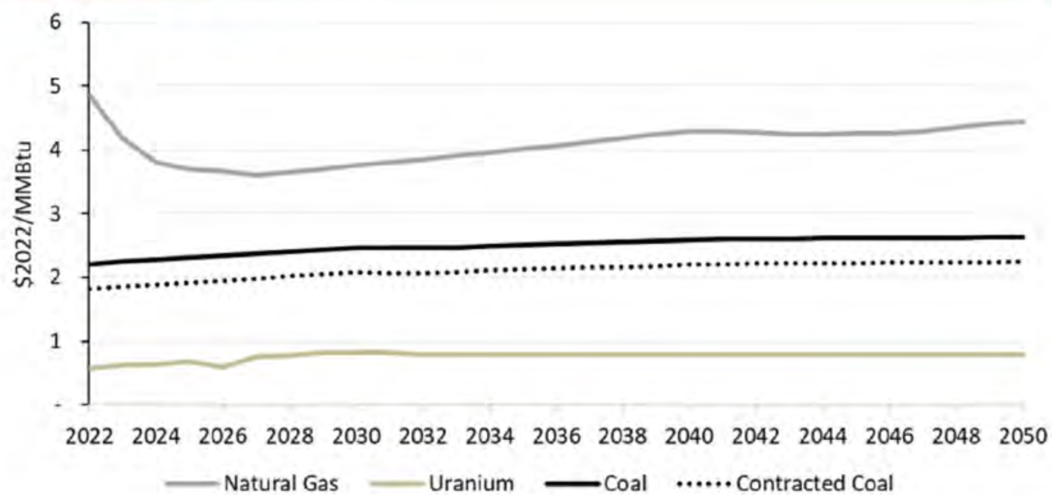
Fuel Prices

+ 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



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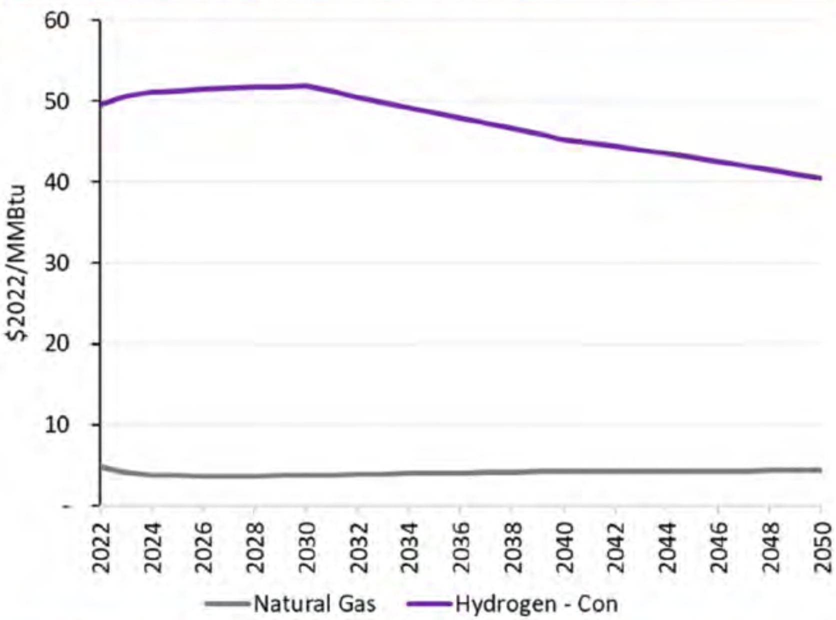
Fuel Prices - Hydrogen

Hydrogen price forecast (2020$/MMBtu)*

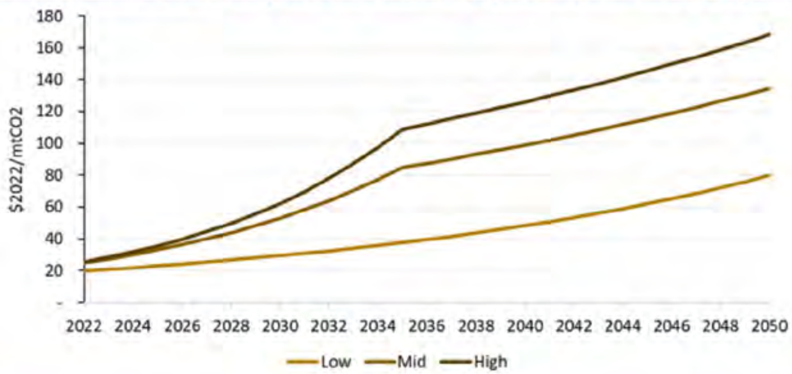


*Note the optimistic fuel price in the near term is not currently viable. It is shown for illustrative purposes under the assumption underground storage and dedicated pipelines are actively in use today.

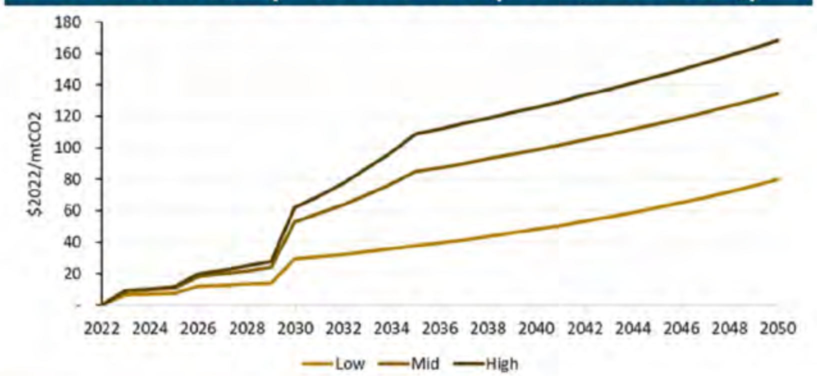
- **The conservative hydrogen price is used as the basis for all scenarios. It assumes:**
  - There is not a massive H_2 economy and thus electrolyzer capital costs and efficiencies have only slightly decreased
  - H_2 is stored in above ground tanks and delivered via trucks.
- **Conservative assumes 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**

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Key Data Sources

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

Climate Change Impacts

+ We haven't done any new work here, so will need to determine what climate impacts if any were in the power plan load forecast and summarize that. Can note we're not adjusting hydro.

Update

Energy+Environmental Economics

BPA Lower Snake River Dams Project
Draft Results

April 15, 2022

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

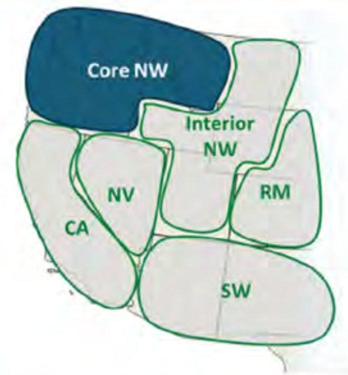
Contents

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
- **Key tasks:**
  1. **Regional capacity needs + role of hydropower**
     - Summarize CA/OR/WA policies, capacity needs, and the role of hydropower
  2. **RESOLVE capacity expansion analysis**
     - Scenario analysis to calculate the NPV replacement cost of breaching the LSR dams + replacement resource needs
  3. **Qualitative benefits**
     - Summarize additional electric system benefits from the LSR dams beyond those captured in RESOLVE
  4. **Project report**



Lower Snake River Dams

+ **The lower snake river dams:**
  - Are ~10% of the Northwest regional hydropower capacity
  - Provide relatively low-cost and flexible carbon free power

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

* 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 Capacity Needs

Executive Summary
E3 View of California, Oregon, and Washington

+ **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 can take advantage of wholesale market opportunities in California, or reliability-driven need in the Pacific Northwest (PNW), or 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

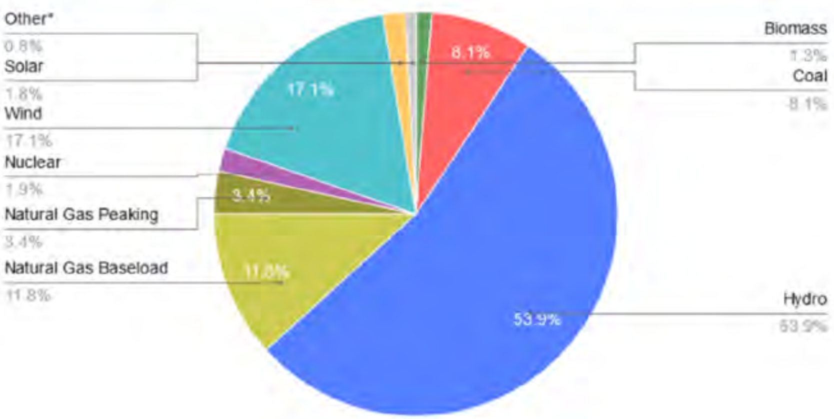
Policy Landscape: Washington, Oregon, California

	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

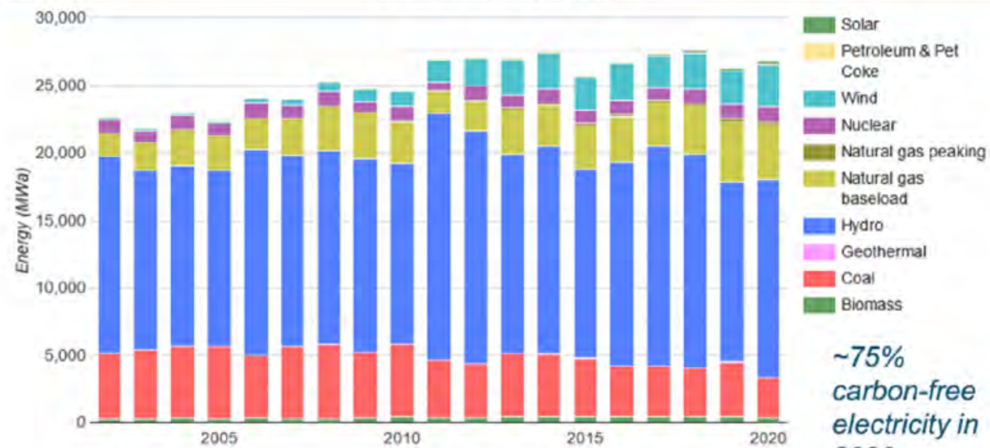
Northwest Installed Capacity and Historical Energy Production

+ **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/

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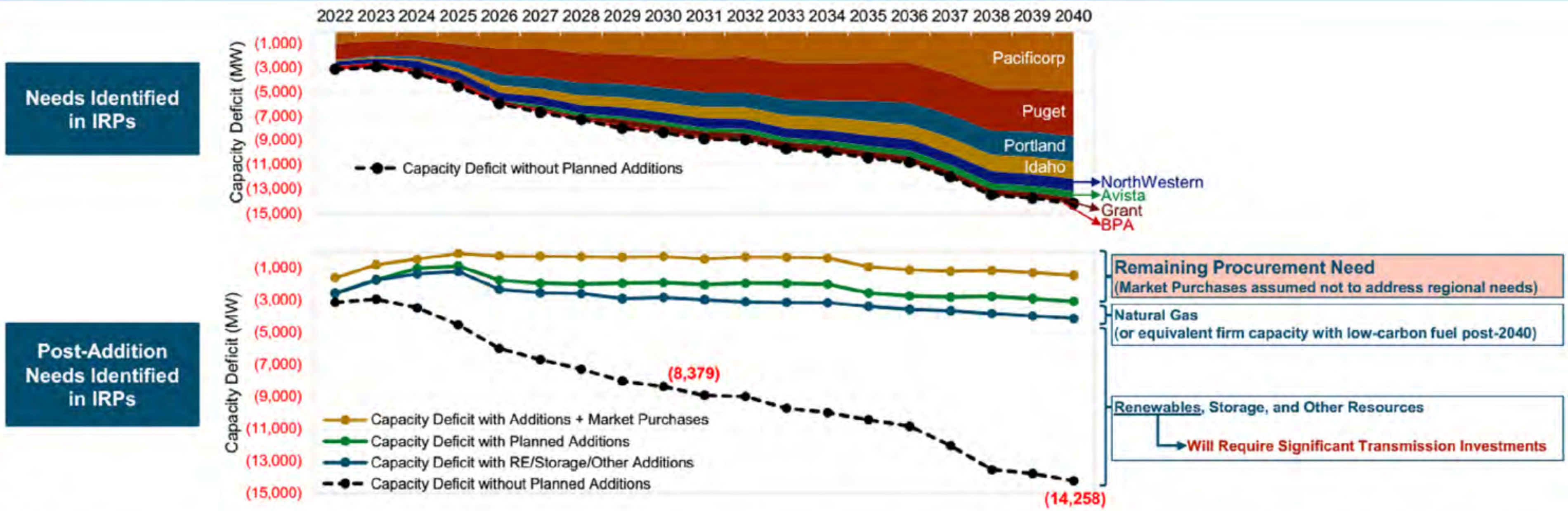
PNW Near- to Mid-Term Capacity Need
Bottom-Up Capacity Need vs. Planned Additions

+ **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



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.

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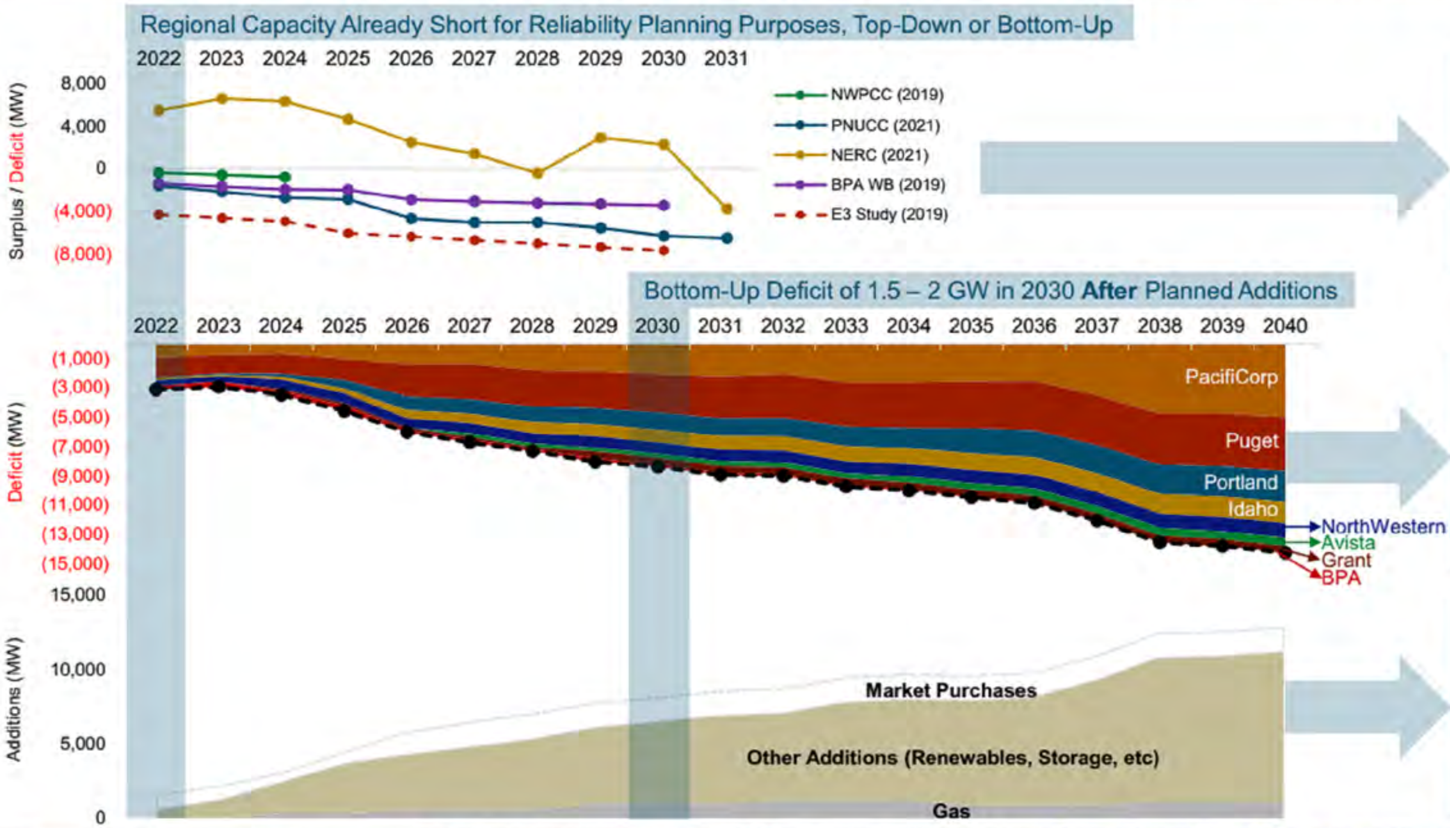
PNW Capacity Need vs. Planned Additions

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



Top-Down Regional Assessments

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

Bottom-Up Utility IRP Review

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

IRP Planned Additions

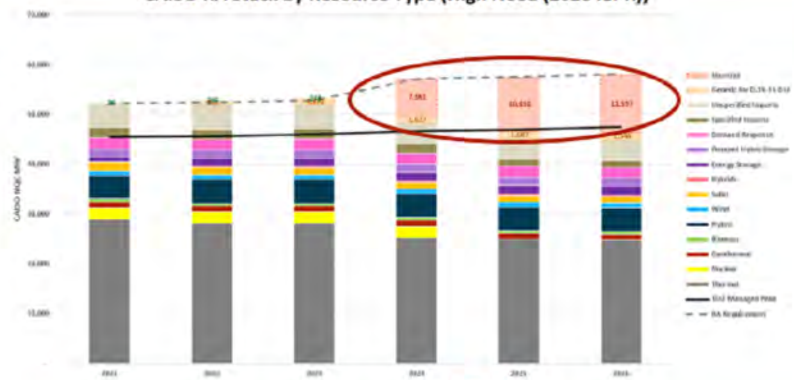
~6.5 GW effective capacity additions by 2030 (up to ~14 GW nameplate capacity), **significantly exceeding average capacity expansion rate for 2010-2020 (~1 GW/year)**

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

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

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

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



CPUC Mid-Term Reliability Procurement Order

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

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

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

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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

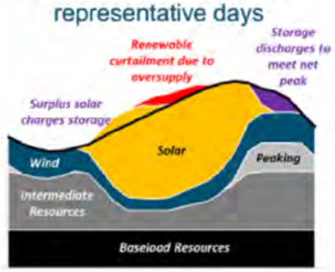
RESOLVE Modeling Approach and Scenarios

RESOLVE: Optimal Capacity Expansion Under Aggressive Clean Energy Goals

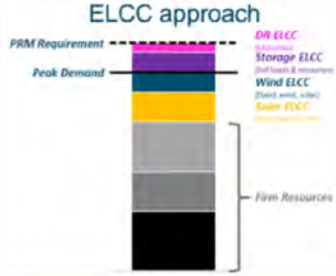
- **RESOLVE is a linear optimization model explicitly tailored to the study of electricity systems with high renewable & clean energy policy goals**

- **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**

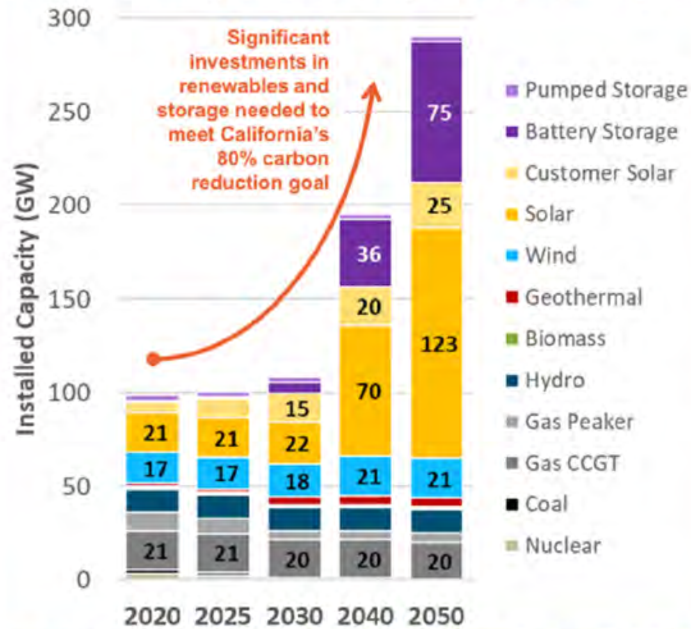
Operational module simulates hourly system operations for a sample of representative days



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 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		
$ 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
  - **Technology availability**: impacts resources available to support reliability + policy goals
    - **Baseline**: includes mature technologies + new dual fuel natural gas + H2 plants
    - **Emerging Tech**: baseline technologies + gas w/ CCS, offshore wind, and nuclear SMR
    - **Limited Tech:** baseline but excludes either 1) all new combustion plants, 2) no new natural gas plants but new H2-only plants allowed

	Scenario Name	Loads	Clean Energy Policy	Technology Availability	Removal Year	Directional LSR hydro value change
0	No Policy Reference	Baseline	None	Mature + H2	2032	Decrease
1	Baseline	Baseline	100% retail sales by 2045	Mature + H2	2032	Baseline
1a	Baseline (no carbon price)	Baseline	100% retail sales by 2045	Mature + H2	2032	Baseline
2	Deep Decarb	High Electrification	0 MMT by 2045	Mature + H2	2032	Increase
2a1	Deep Decarb – limited tech (no new combustion)	High Electrification	0 MMT by 2045	Mature + no new gas or H2	2032	Further increase
2a2	Deep Decarb – limited tech (no new gas, H2 allowed)	High Electrification	0 MMT by 2045	Mature + no new gas	2032	Further increase
2b	Deep Decarb - emerging tech	High Electrification	0 MMT by 2045	Mature + emerging	2032	Decrease

+ **Pending initial findings, additional sensitivities may be explored, such as:**
  - Hydro "emergency actions capability", increasing LSR dam output
  - Earlier LSR dam removal

Technology Availability

Technology Scenarios

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

Unavailable | Available

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

+ Mature Technologies

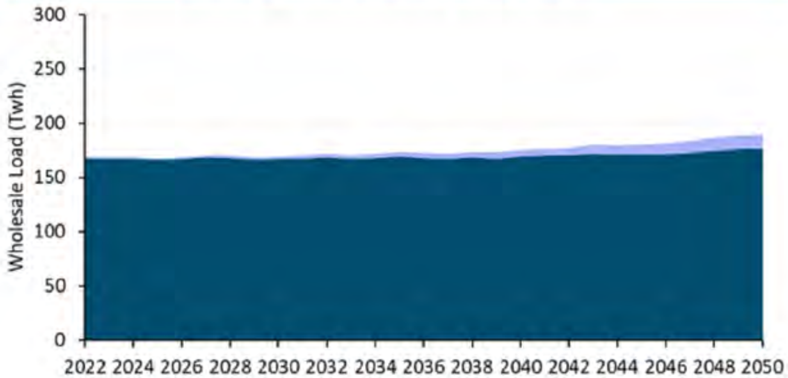
- Renewables provide low-cost form of zero-carbon energy w/ limited capacity value
  - Solar, wind (onshore and offshore)
- Storage resources support renewable integration but show limited value in the Northwest with the large hydro fleet
  - Battery storage, pumped hydro
- Demand response supports peak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

+ Emerging technologies

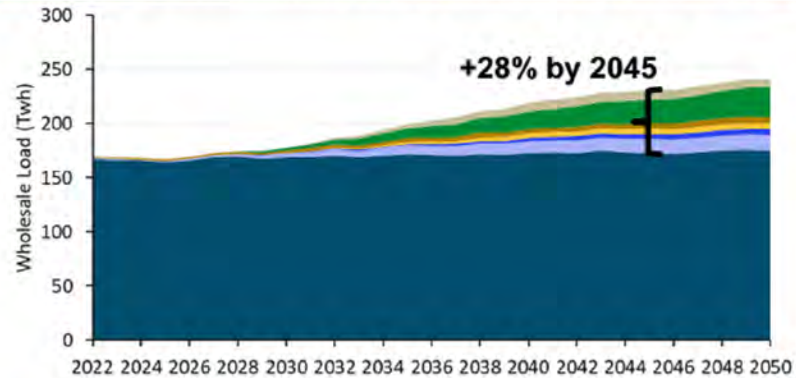
- "Clean peakers" such as new H2, new NG+H2, or NG→H2 retrofits provide low-cost form of capacity with very high energy cost (when burning hydrogen)
- Gas w/ CCS provides a moderately high cost source of energy and capacity
- Nuclear SMR provides moderately high capital cost but low operating cost source of firm zero-carbon energy

Electrification Load Growth (Annual GWh)

Base Forecast for Core NW



High Electrification Load Forecast for Core NW

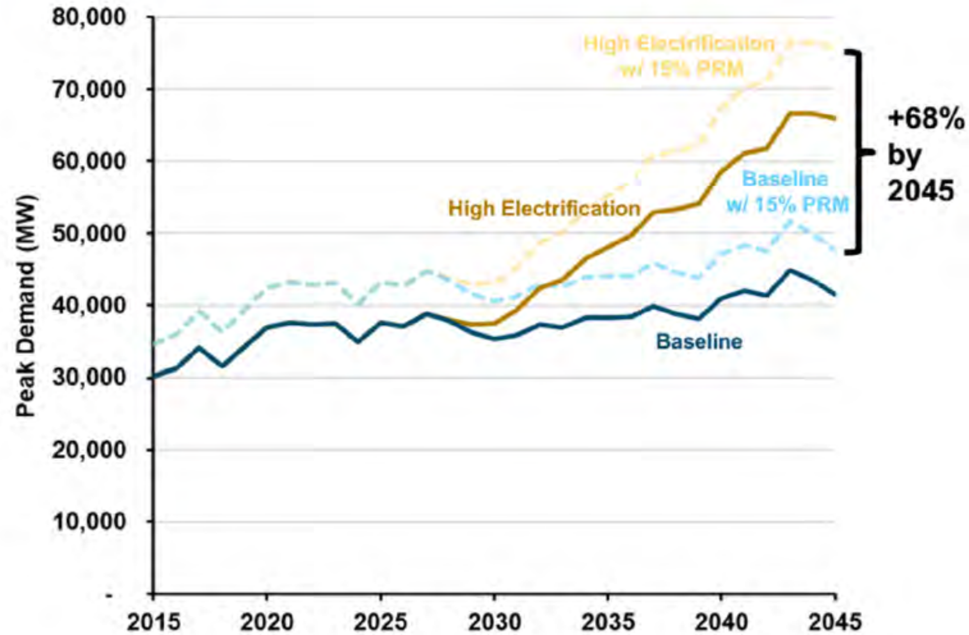


+ **Base load forecast is from NWPCC 2021 Plan benchmarked to E3's boundary of Core NW**
  - Includes EE+DR in the Power Plan + incremental selectable EE+DR

+ **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)
  - Gas/electric hybrids heat pumps



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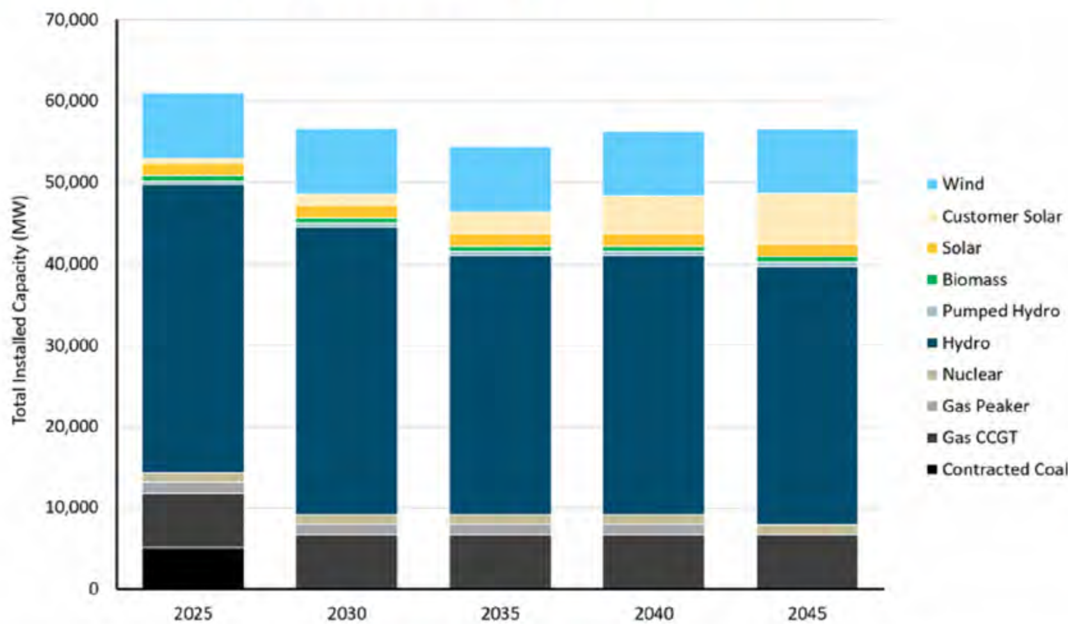
Baseline Resources

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



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

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Energy+Environmental Economics

RESOLVE Results

Summary of RESOLVE Results

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

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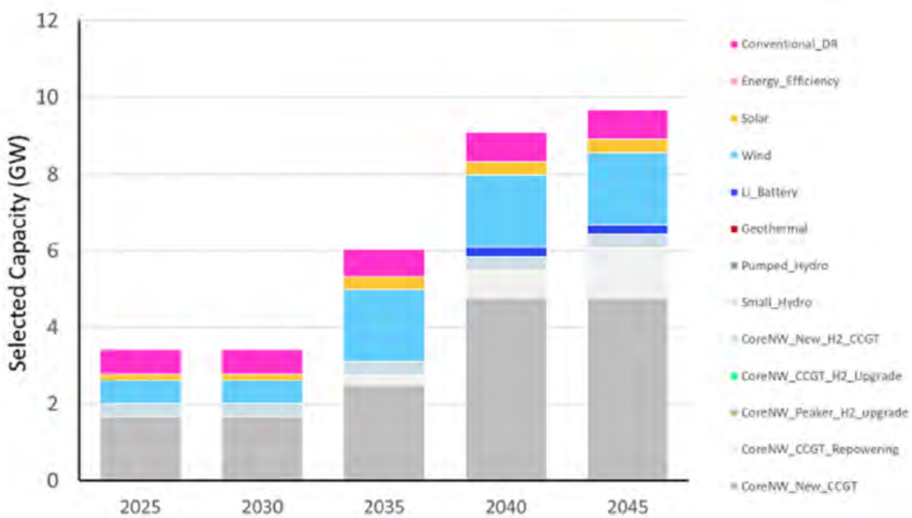
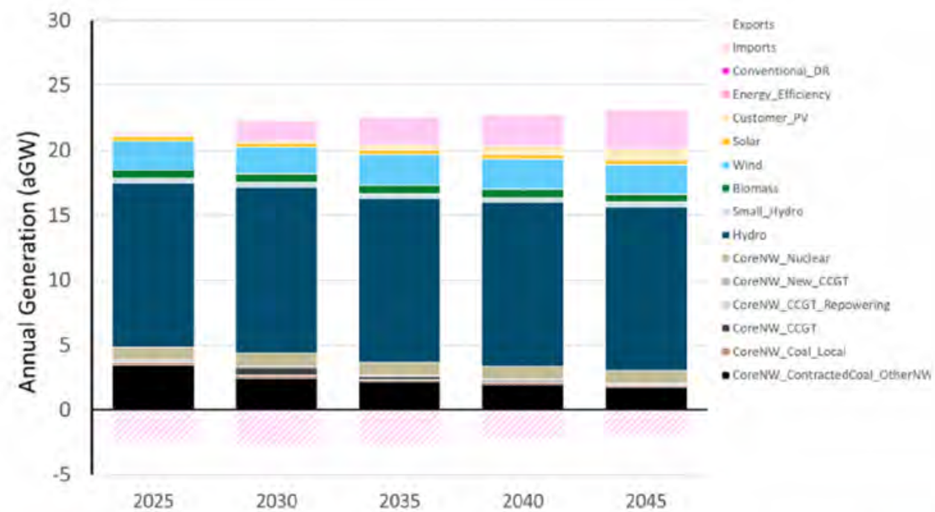
S0: No Policy Reference

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

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





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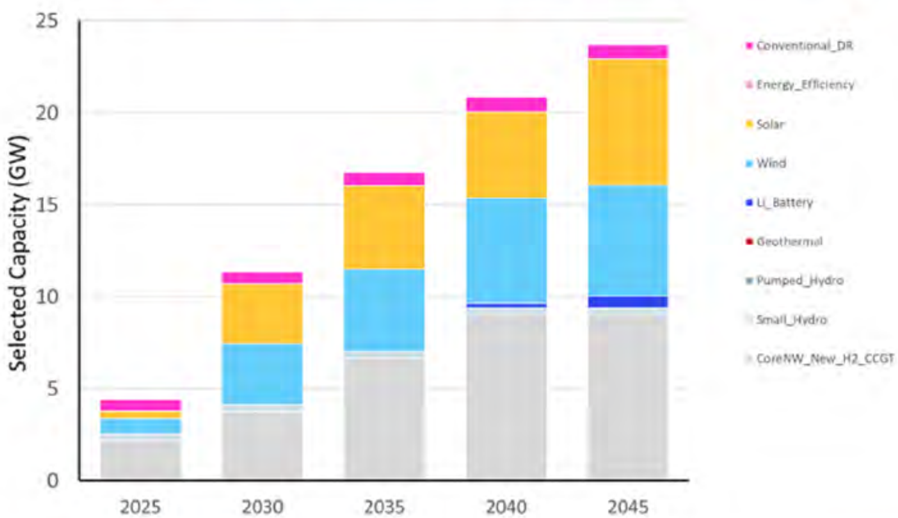
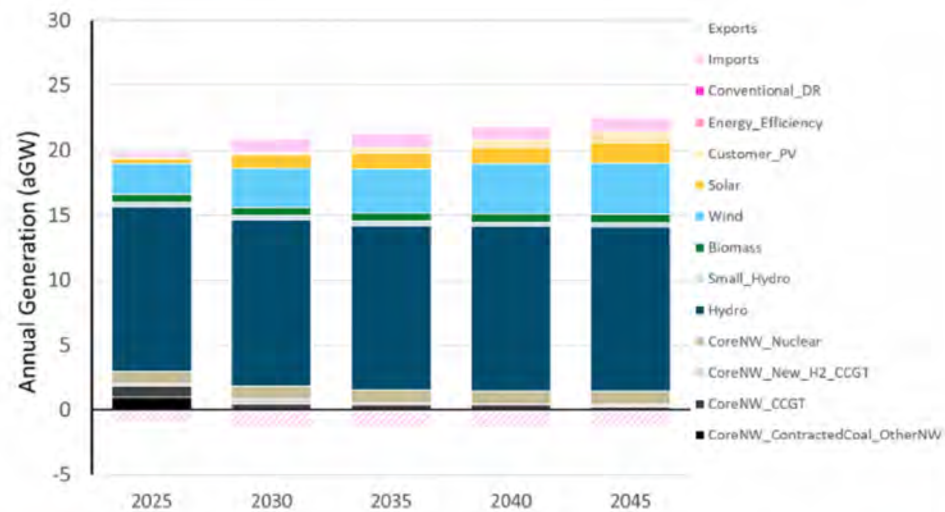
S1: Baseline – 100% Clean Retail Sales

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





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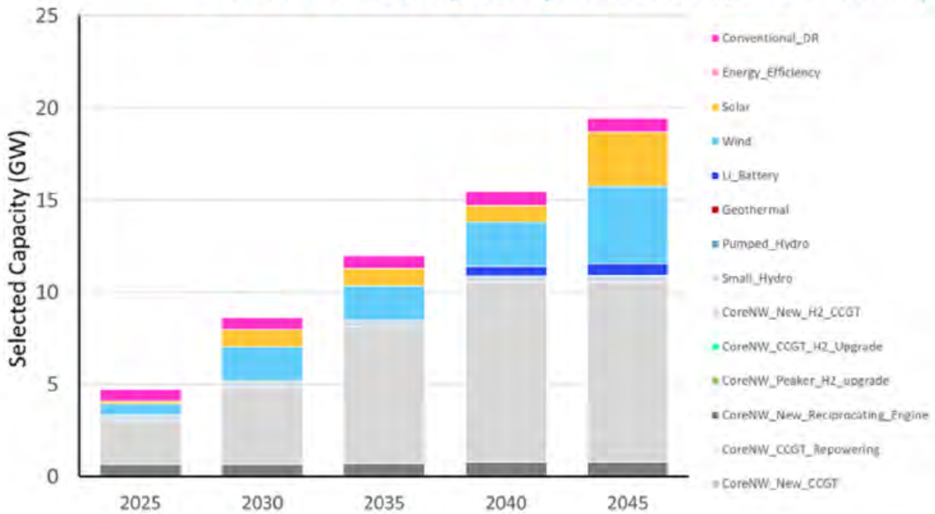
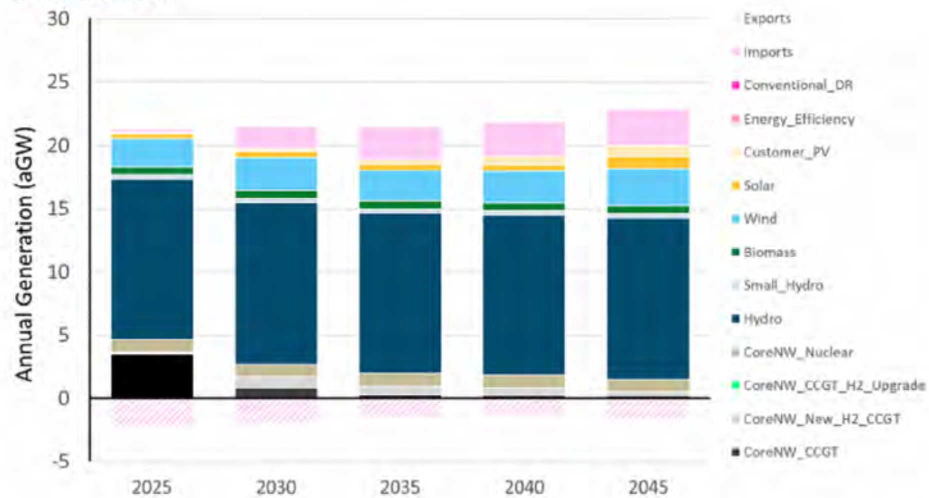
S1a: Baseline – 100% Clean Retail Sales

Without Carbon Price

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





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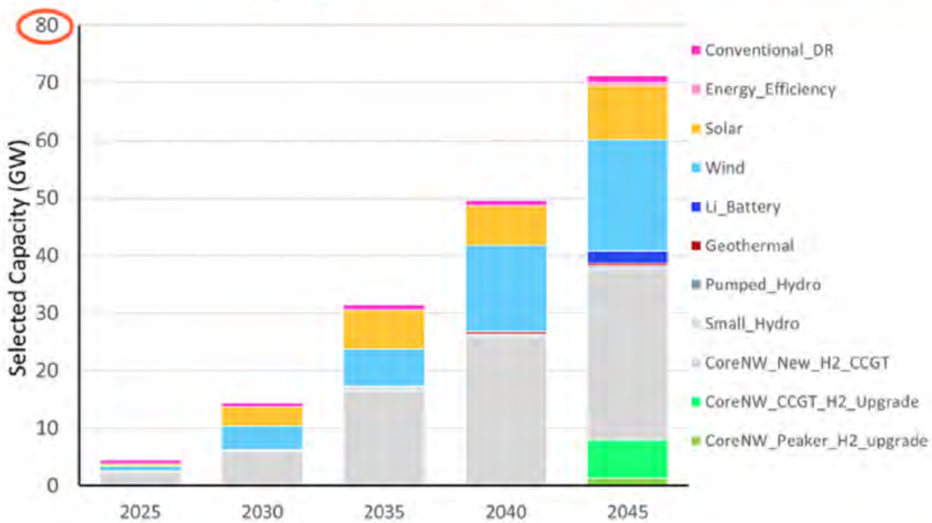
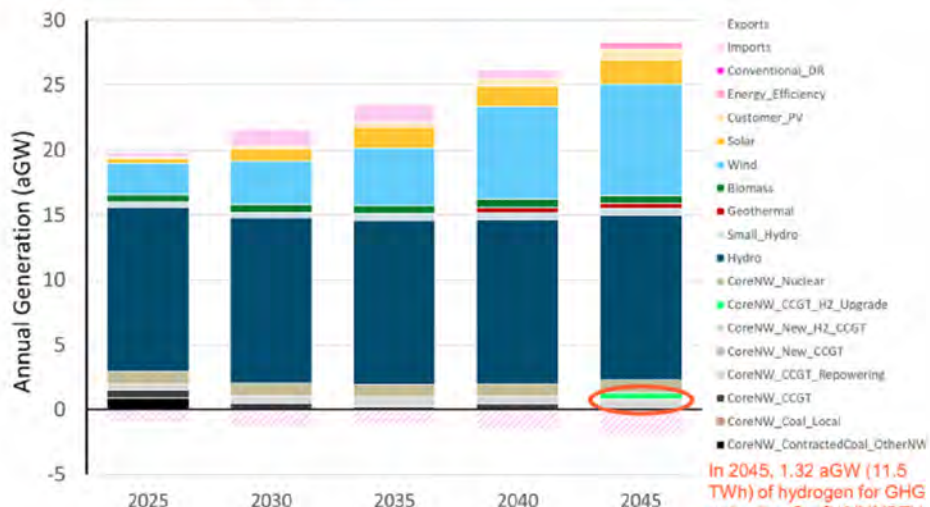
S2: Deep Decarbonization

+ **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





In 2045, 1.32 aGW (11.5 TWh) of hydrogen for GHG reduction @ ~$40/MMBTU

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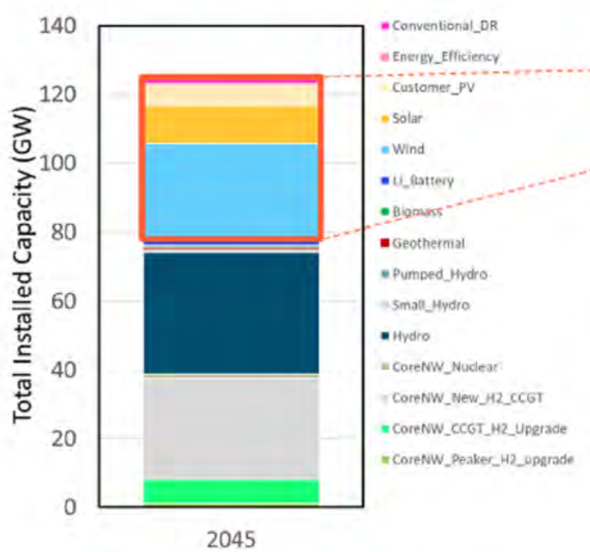
S2: Deep Decarbonization – Resource Adequacy Needs

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

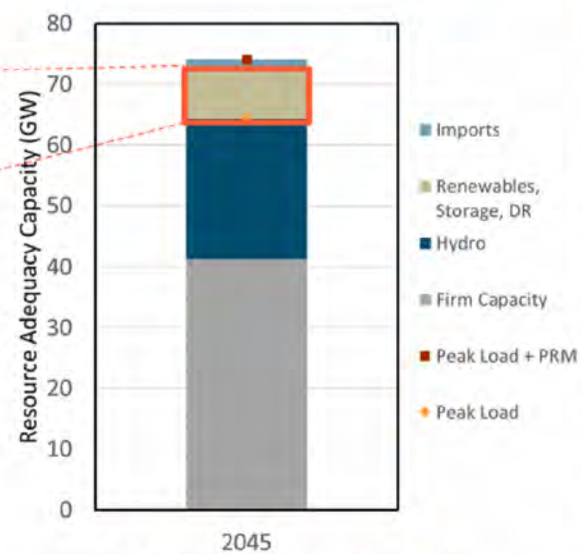
2045 Deep Decarbonization Scenario Results

Installed Nameplate Capacity (GW)



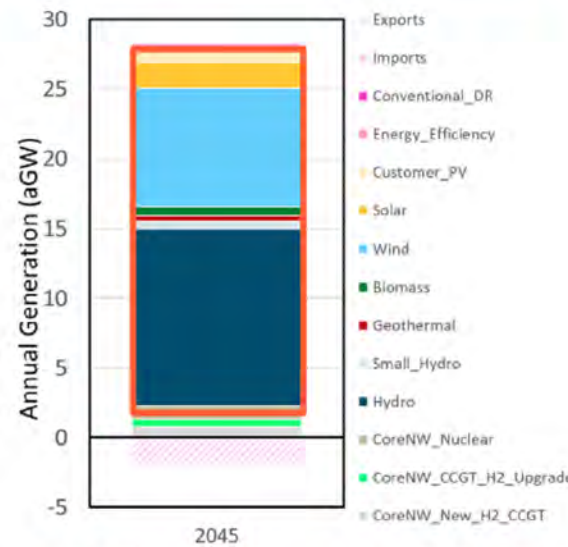
Renewables, storage, and DR provide significant installed MW…

Resource Adequacy Capacity (GW)



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

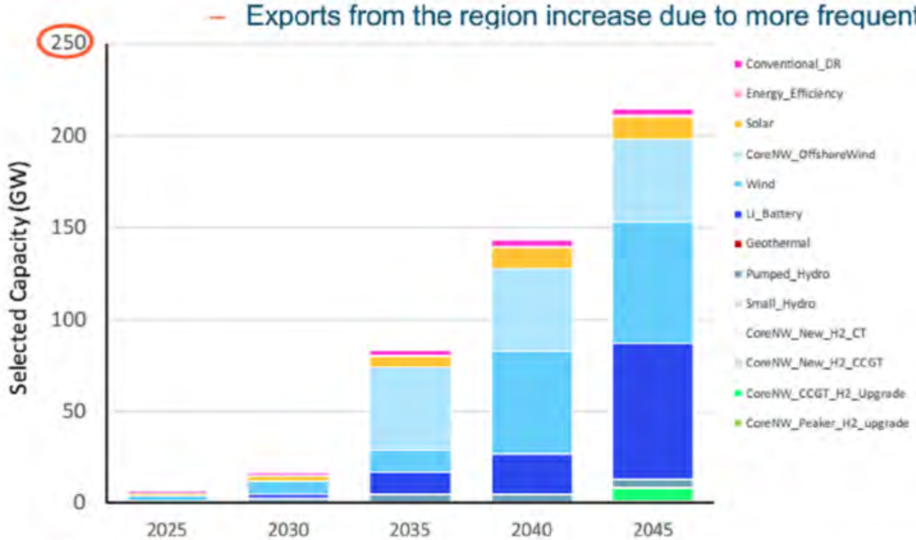
Annual Generation (TWh)

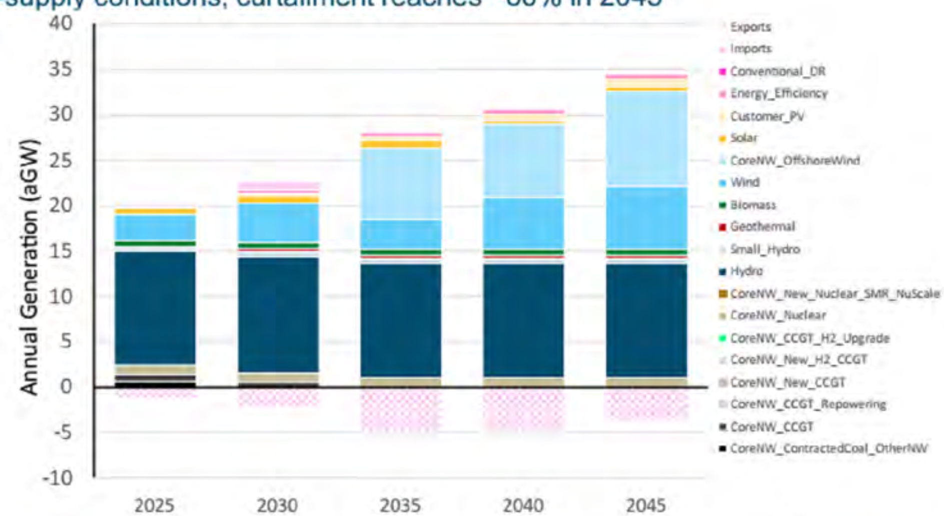


…due to high costs, hydrogen generation is limited to low hydro, low renewable periods; renewables + hydro + nuclear provide 95% of annual energy

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

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





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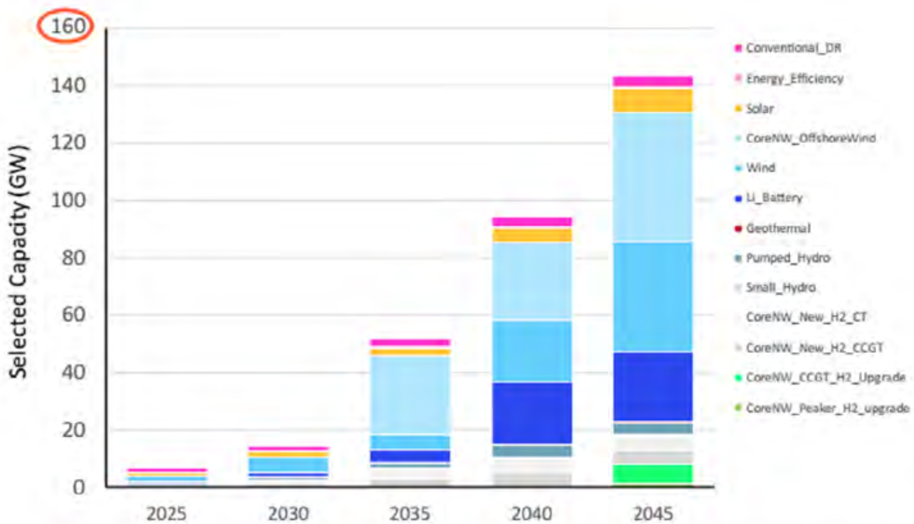
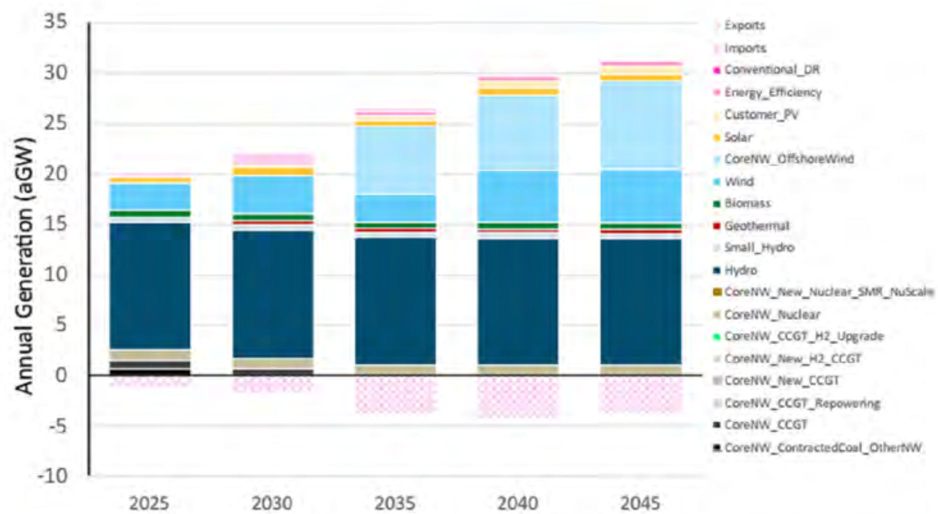
S2a2: Deep Decarbonization – Limited Tech w/ No New Gas (H_2 Allowed)

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





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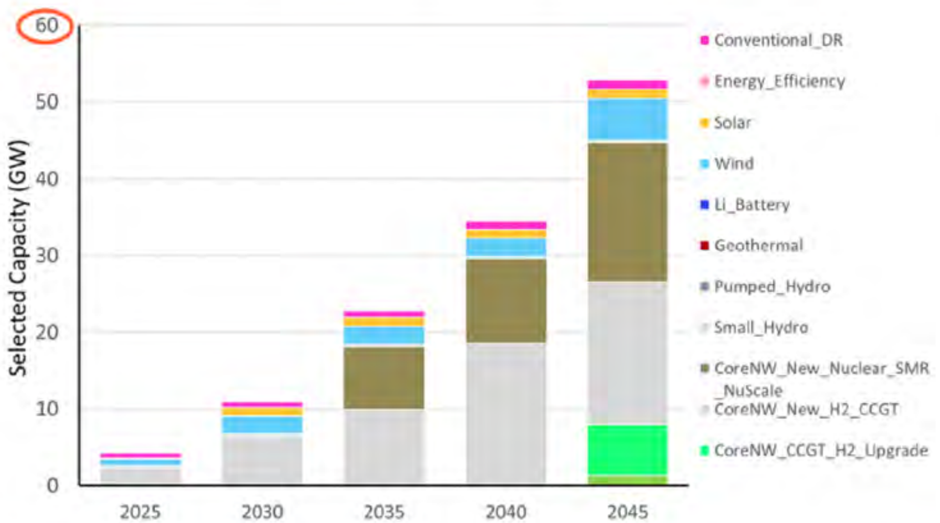
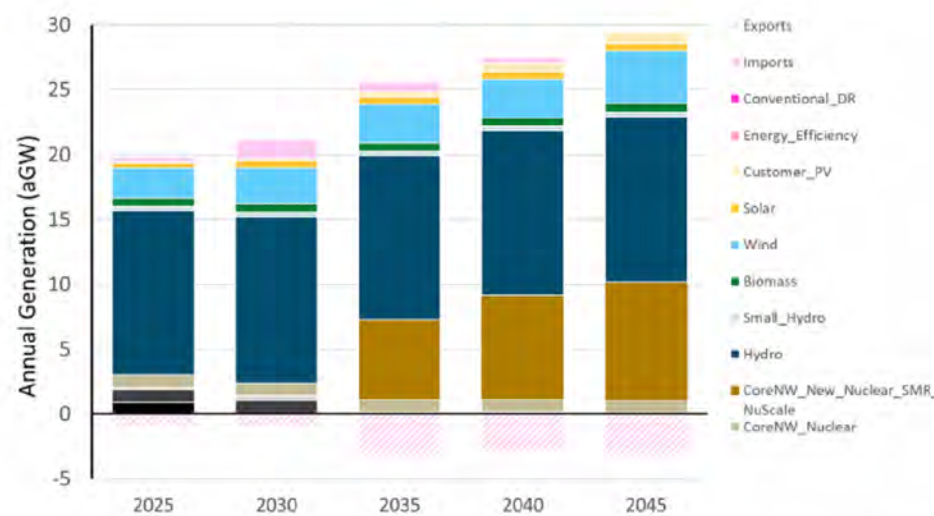
S2b: Deep Decarbonization – Emerging Technology

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





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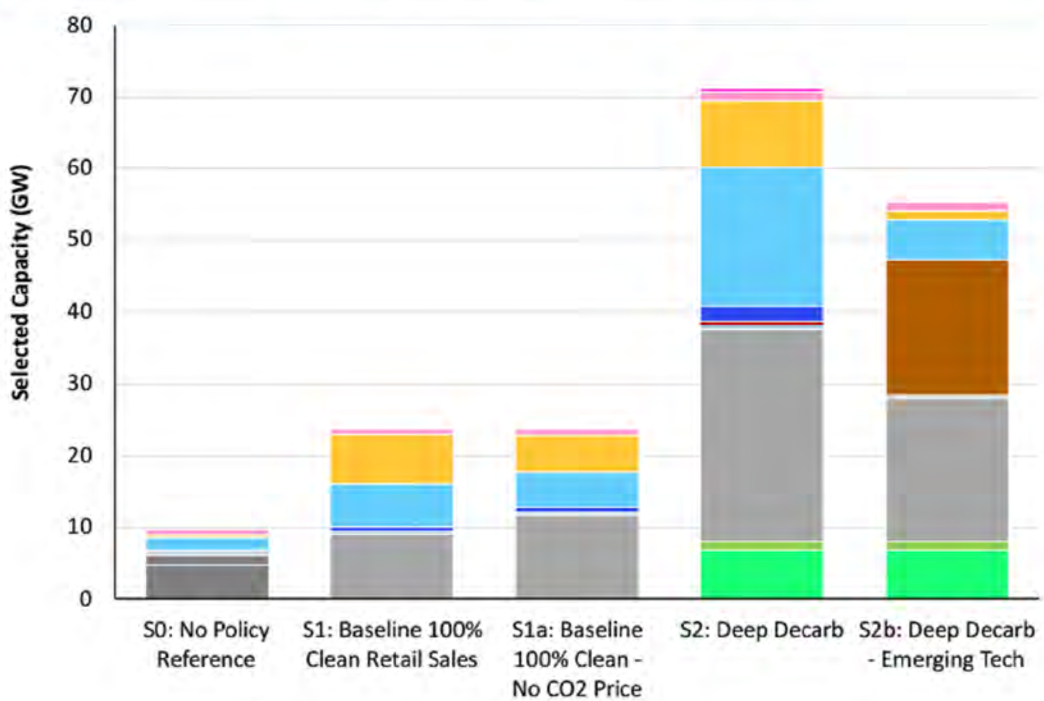
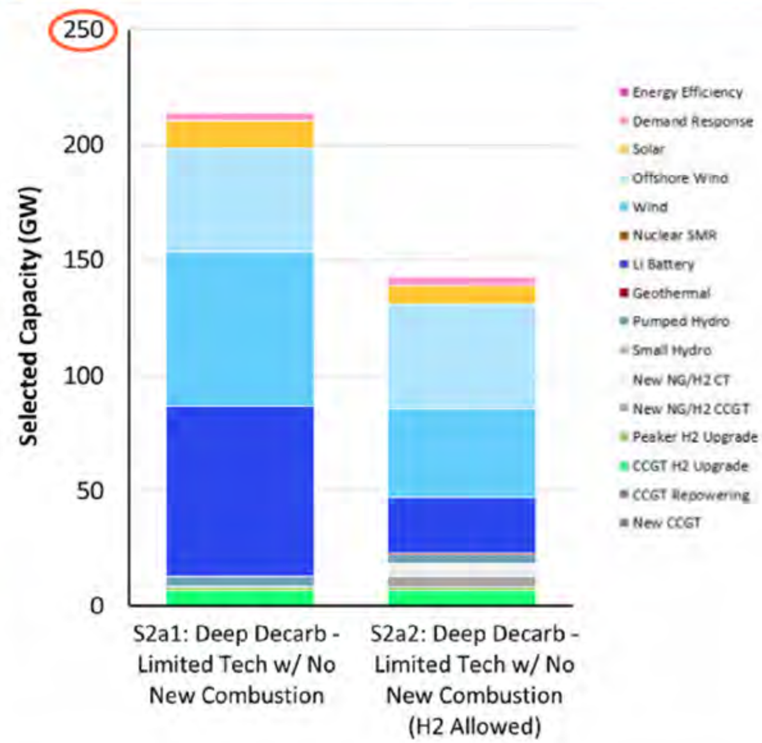
Comparison of 2045 Cumulative Selected Capacity

Baseline and Emerging Technology Scenarios



Limited Technology Scenarios



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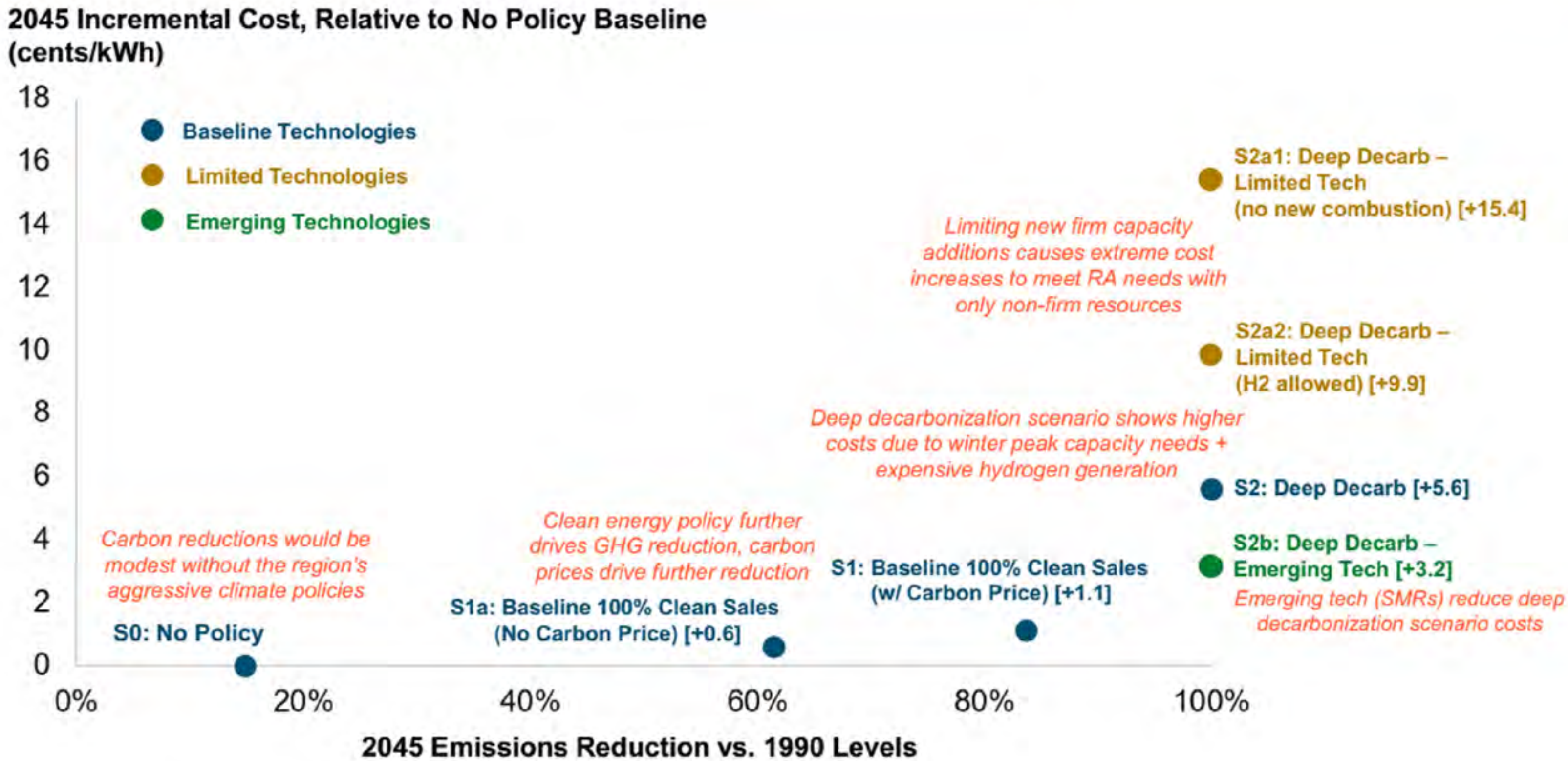
Decarbonization Scenarios Cost Impacts



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

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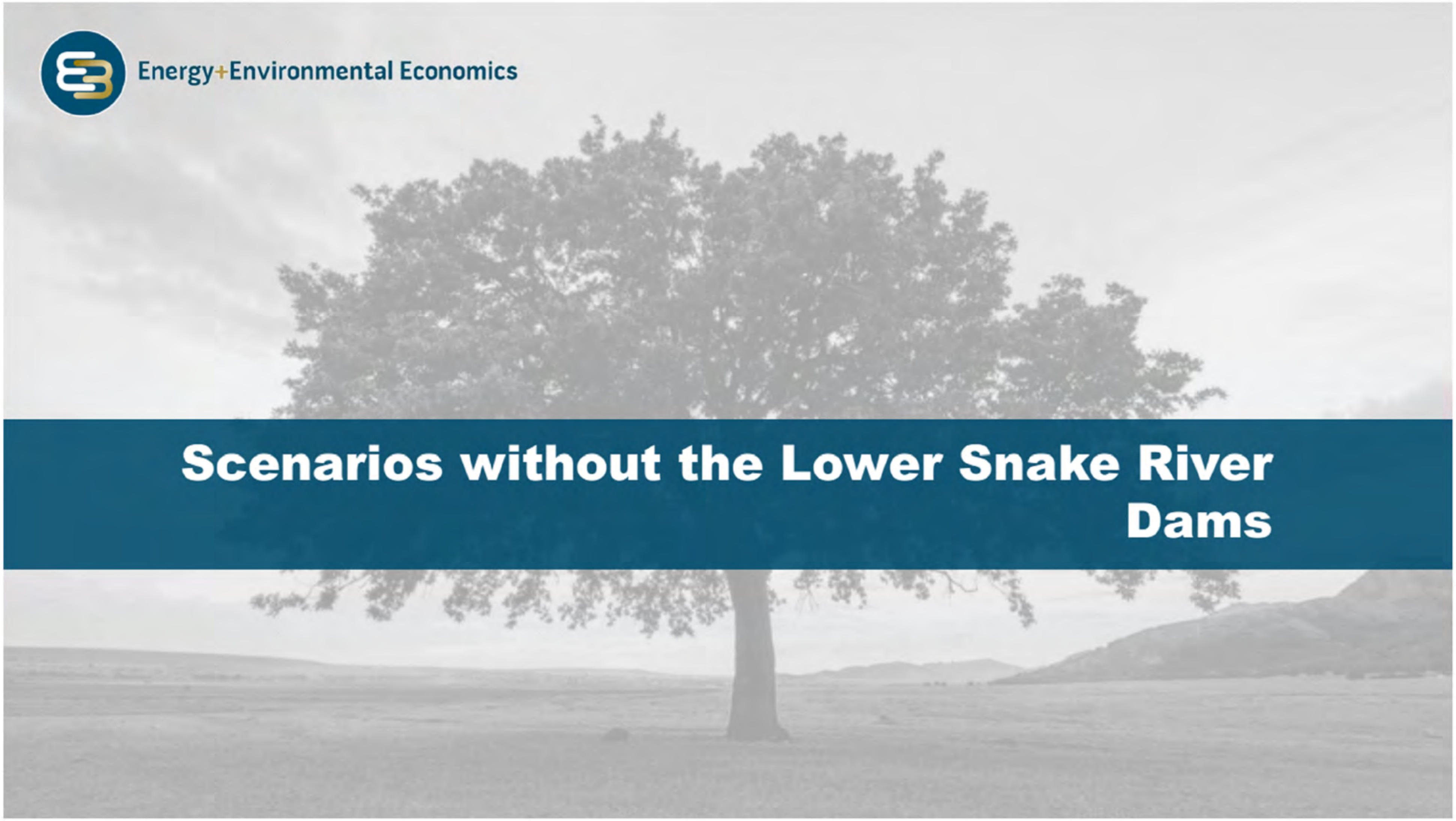

Scenarios without the Lower Snake River Dams

LSR Dam Replacement Costs + Resource Needs

		2035		2045		
	NPV Increase ($M)	Cost Increase ($M)	Resource Needs (GW)	Cost Increase ($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 Costs

BPA customer cost impacts pending BPA team review

- **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 ~0.5-1.3 cents/kWh**
  - An increase of ~14-37% 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 BPA Customer Costs** (real 2022 cents/kWh)
	S0: No Policy Reference	$85/MWh	+ 0.5 cents/kwh
	S1: 100% Clean Retail Sales	$95/MWh	+ 0.6 cents/kwh
	S1a: 100% Clean Retail Sales (no carbon price)	$90/MWh	+ 0.6 cents/kwh
	S2: Deep Decarb	$189/MWh	+ 1.3 cents/kwh
	S2b: Deep Decarb, w/ Emerging Tech	$87/MWh	+ 0.5 cents/kwh
Outlier cases	S2a1: Deep Decarb, Limited Tech (no new combustion)	$535/MWh	+ 4.1 cents/kwh
Outlier cases	S2a2: Deep Decarb, Limited Tech (no new gas, H2 allowed)	$427/MWh	+ 3.3 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 annual sales (~80 TWh/yr per average forecasted 2021 and 2022 BPA power sales)

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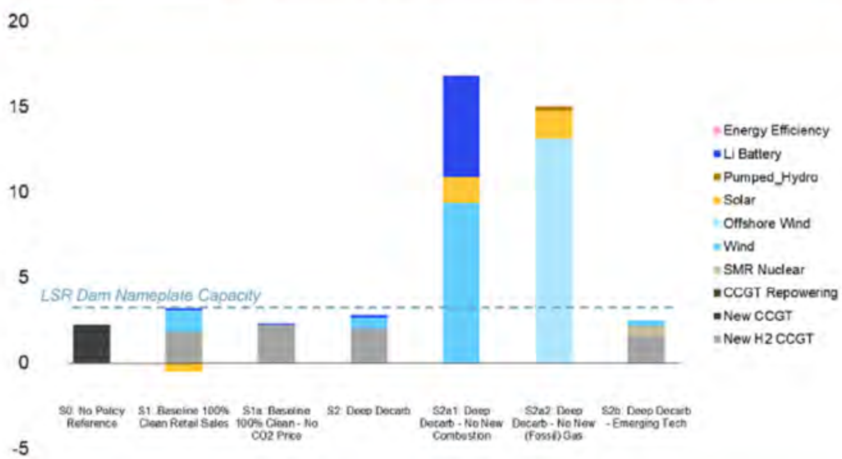
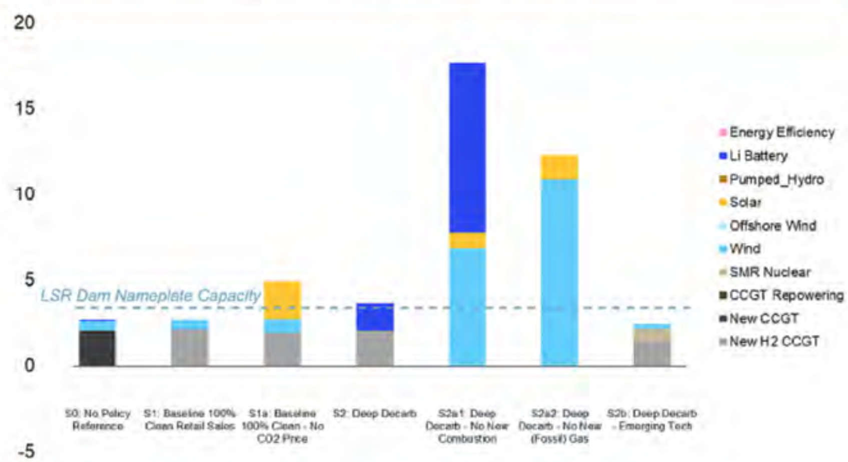
Replacement Resource Needs

LSR Dam Replacement Portfolio in 2035 (GW)



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

LSR Dam Replacement Portfolio in 2045 (GW)



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

NOTE: final results will include an energy comparison as well

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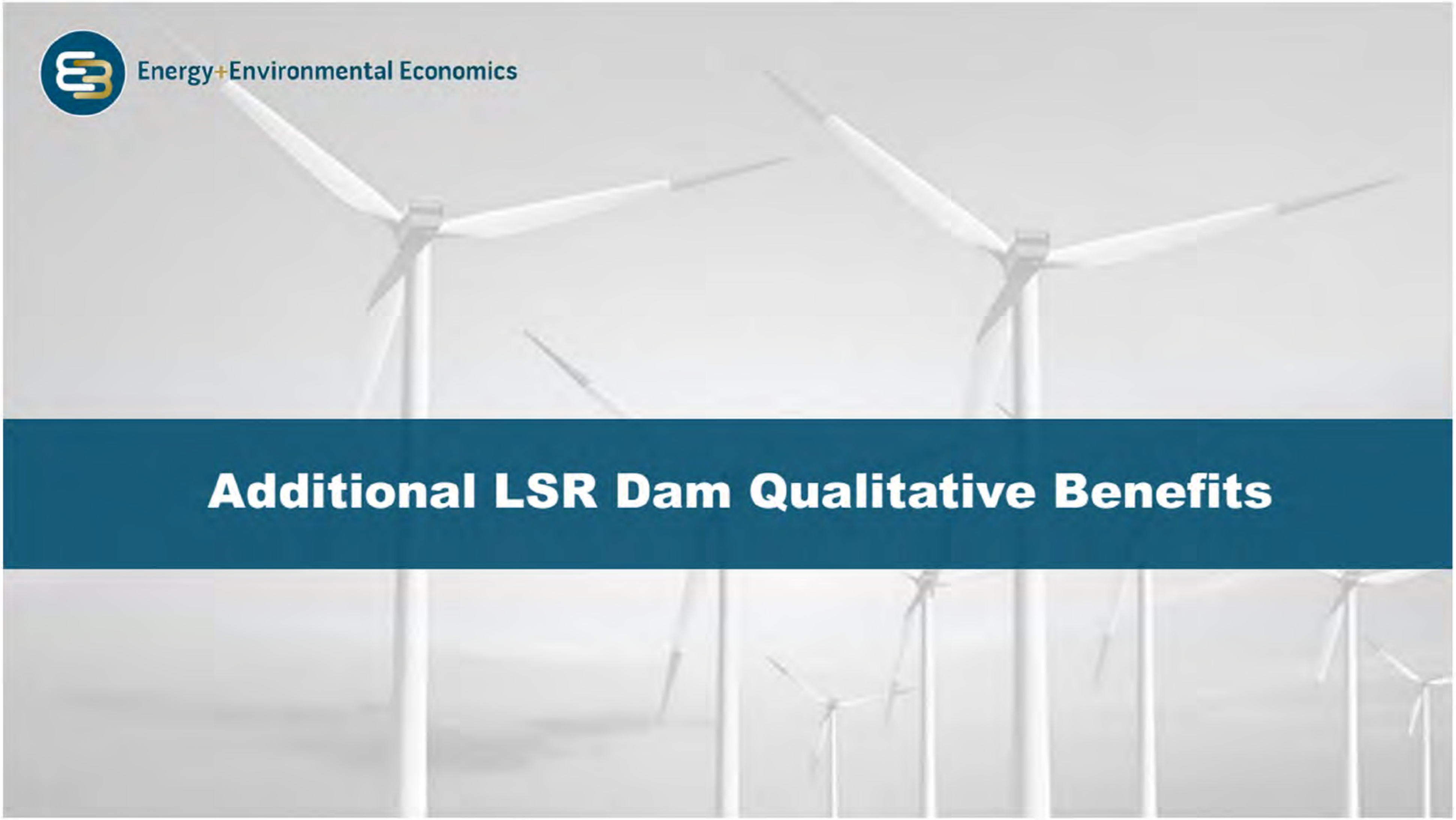
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Additional LSR Dam Qualitative Benefits

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	☒

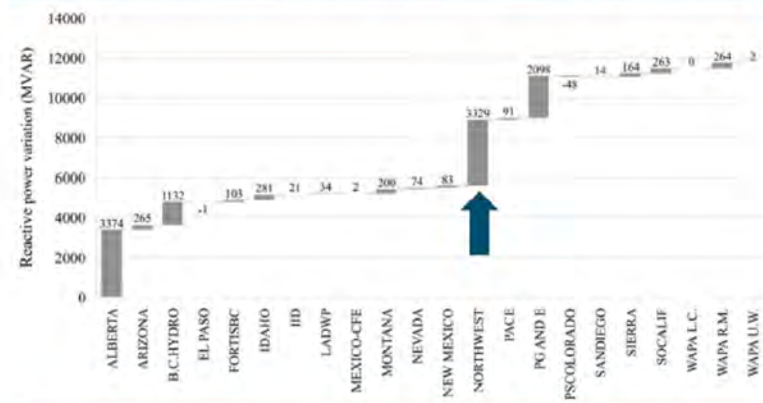
+ **Hydroelectric generation produces additional benefits not directly captured in E3's RESOLVE model**
  - Those benefits are described qualitatively in these slides
+ **Most ancillary benefits can be provided by any turbine-based generation resources …**
  - However, hydropower supplies benefits without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

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**

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

The PNW Supplies WECC with Reactive Power …



… and Hydro is the Key Contributing Resource

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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**
  - However, renewables are expected to reduce the *need* for inertia at the same time (NREL 2020)
  - 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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Next Steps to Finalize Project Results

Next steps + sensitivities

+ Next steps

- Confirm and run any additional sensitivities (pending E3 budget check)
- Brief DOE staff with near-final PPT deck (late April or early May)
- Complete Word report (mid-May), followed by BPA review and final doc (by June 1)

+ Additional cases or sensitivities under consideration

- Earlier LSR removal – for Scenario 1 (100% clean retail sales)?
  - Likely to drive additional near-term RA and avoided fuel cost value
- LSR dam emergency operations (increased annual energy output)?

Energy+Environmental Economics

Thank You

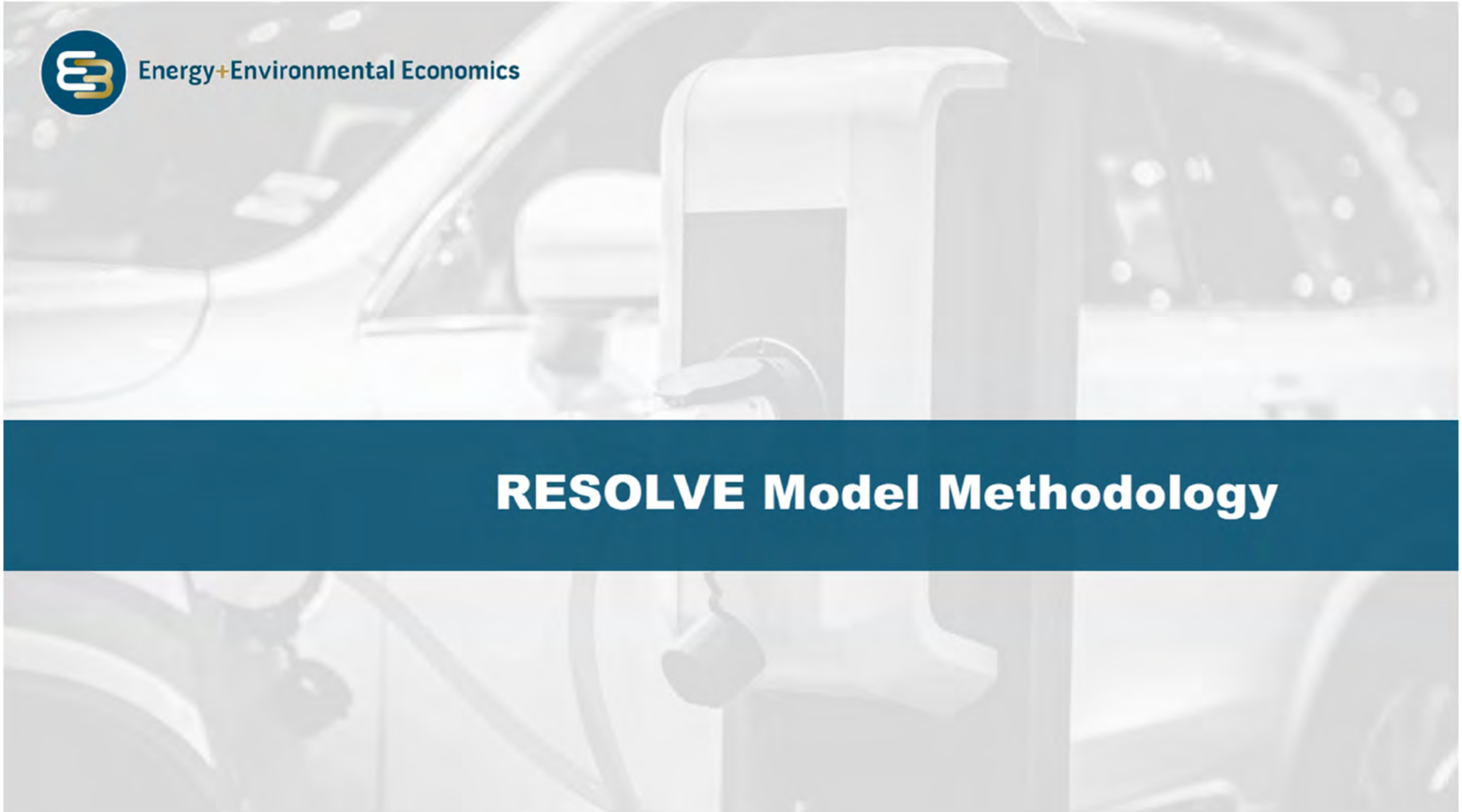
Questions, please contact:

Aaron Burdick, aaron.burdick@ethree.com

Energy+Environmental Economics

Appendix

Energy+Environmental Economics



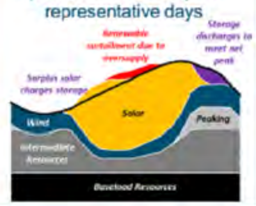
RESOLVE Model Methodology

RESOLVE optimizes investments to meet clean energy targets reliably

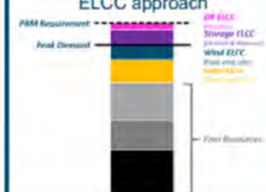
RESOLVE is an optimal capacity expansion model specifically designed to identify least-cost plans to meet reliability needs and achieve compliance with regulatory and policy requirements

+ **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**

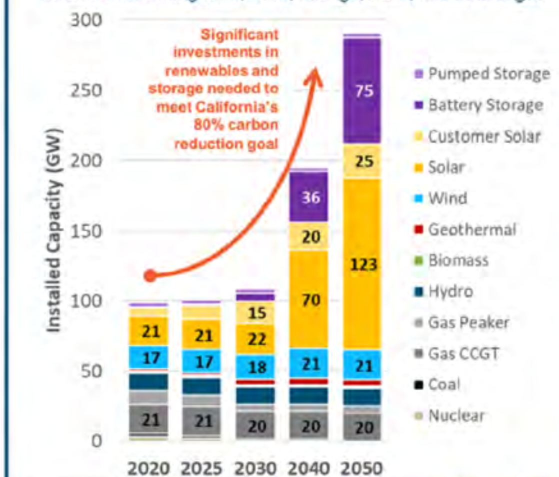
Operational module simulates hourly system operations for a sample of representative days



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



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

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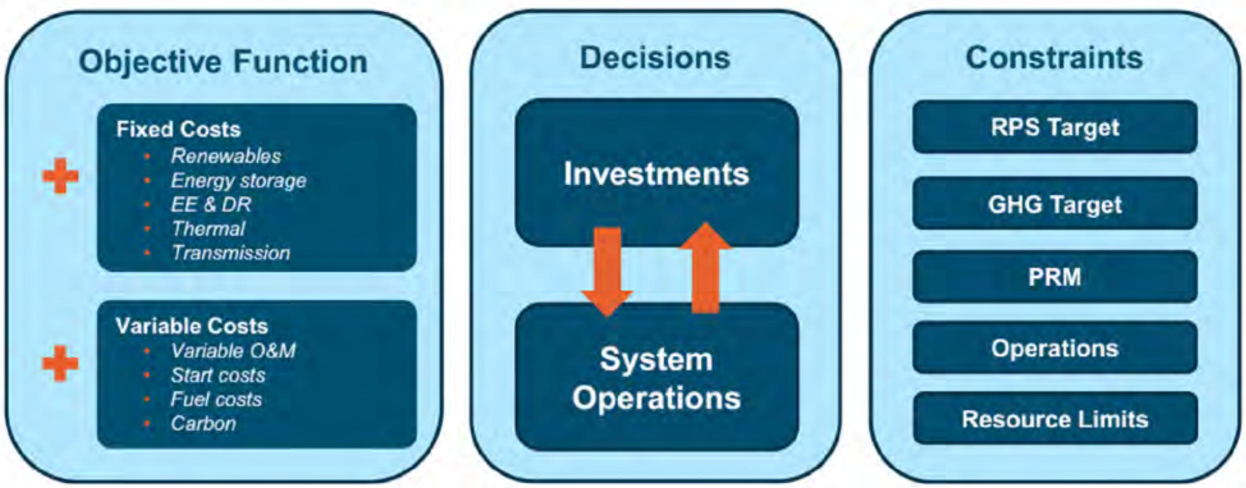
Investment and Operational Decisions in RESOLVE

+ **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



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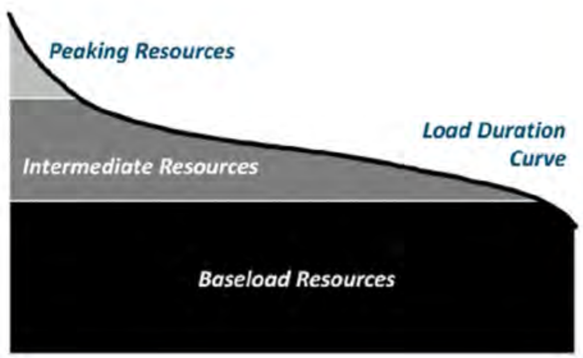
Evolving Considerations in Planning
System Operations

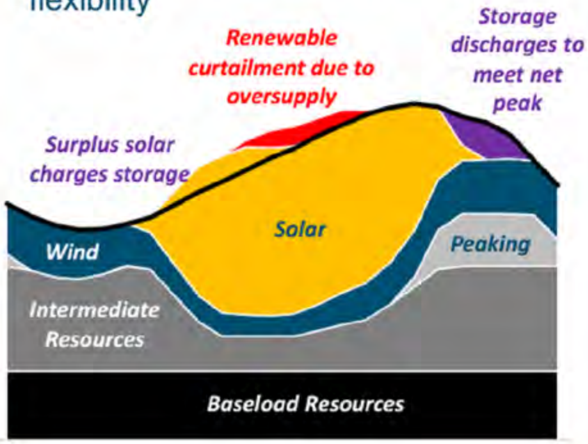
Traditional Planning Paradigm

+ 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



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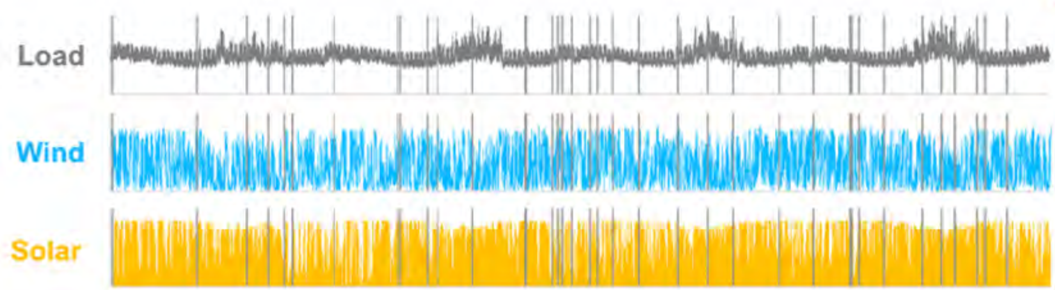
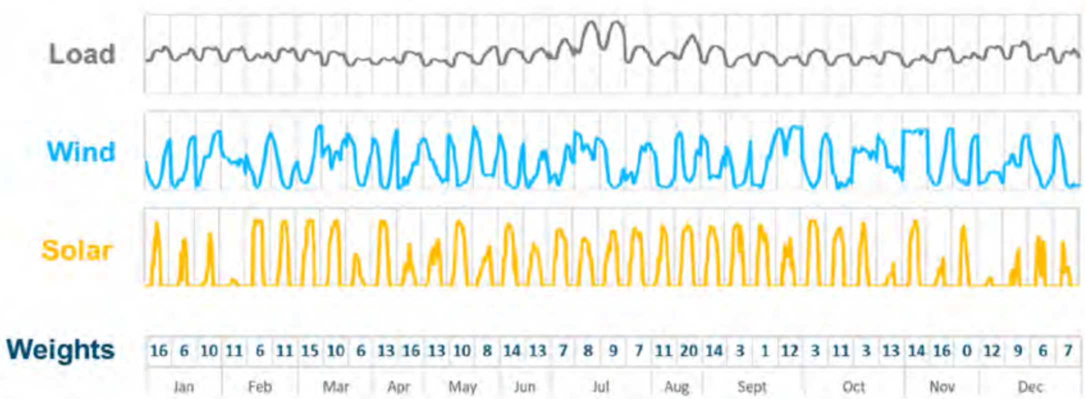
Downsampling historical data sets to a subset of representative days



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

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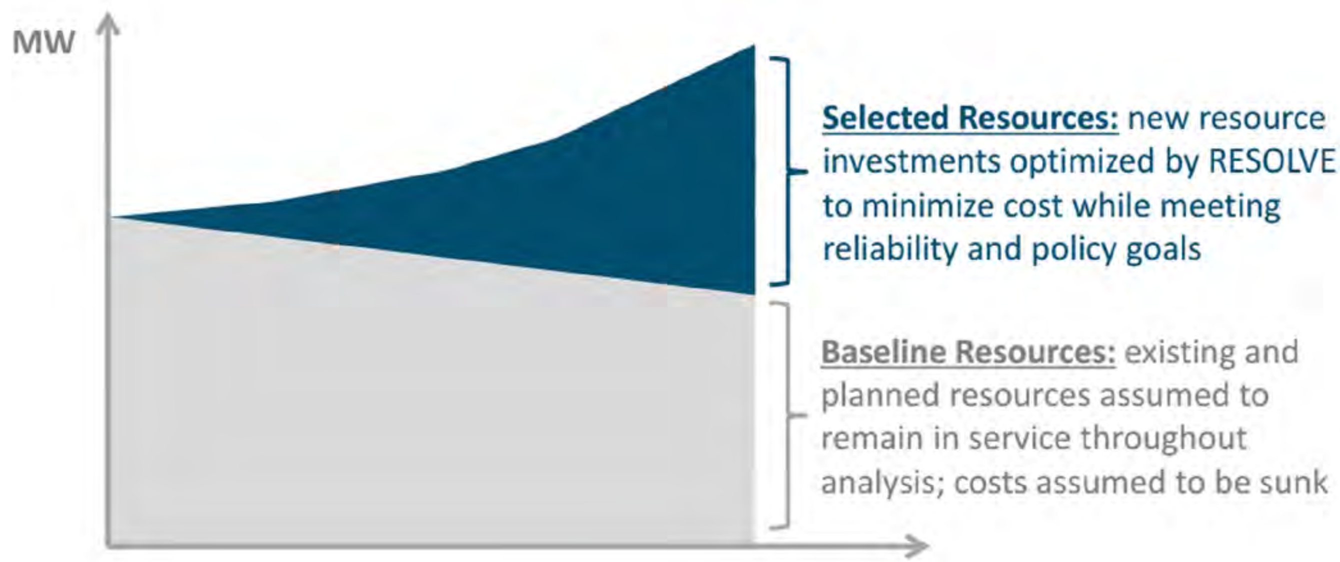
Planned vs. Selected Resources

+ **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



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

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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
  - 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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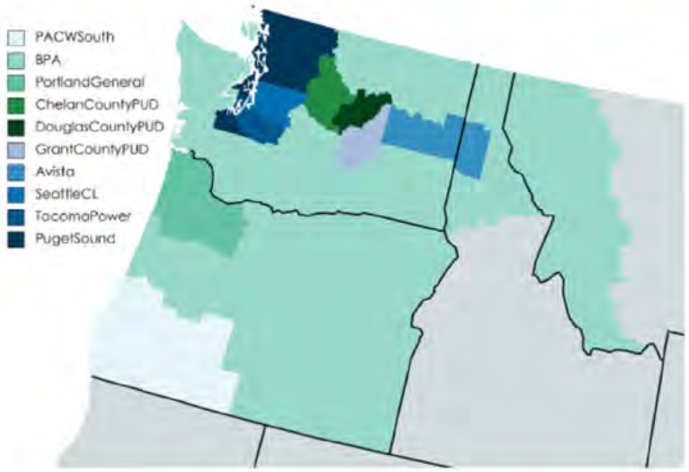
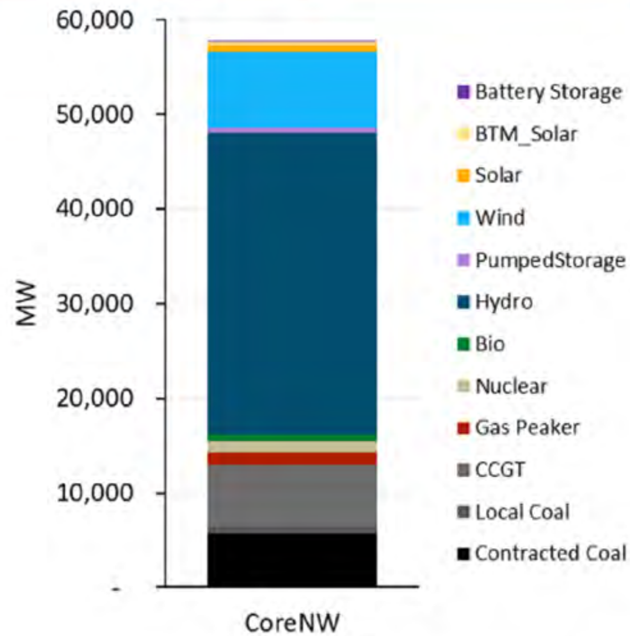
RESOLVE Inputs

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



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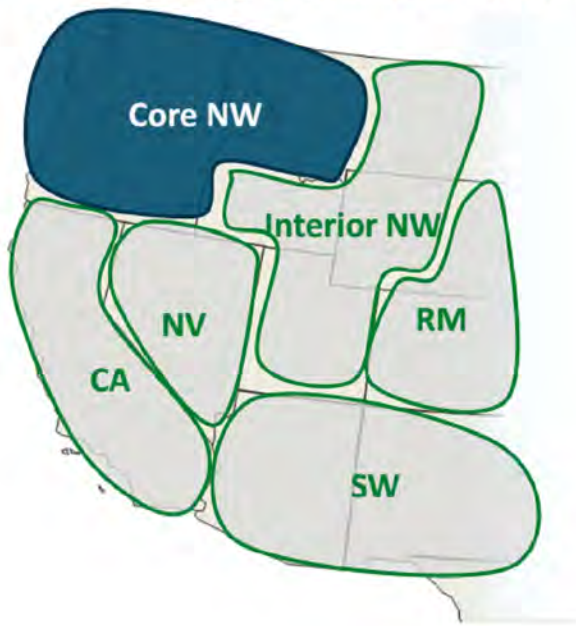
External Zone - Approach

+ 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%

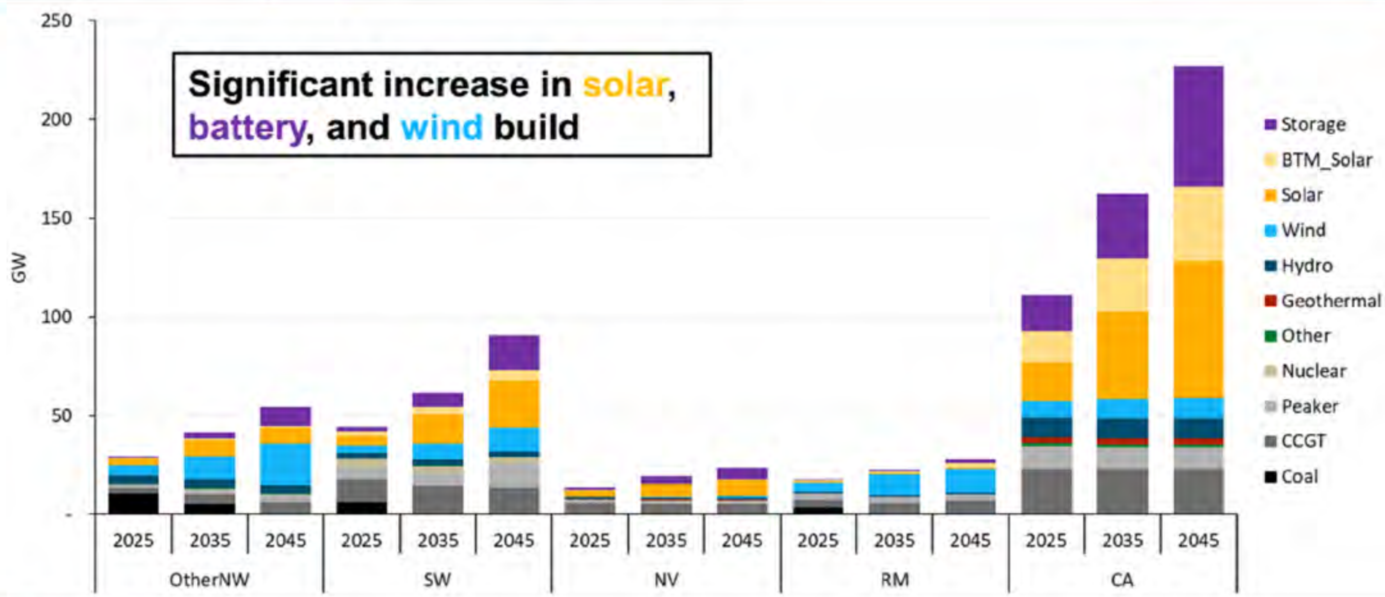
Notes:

- 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

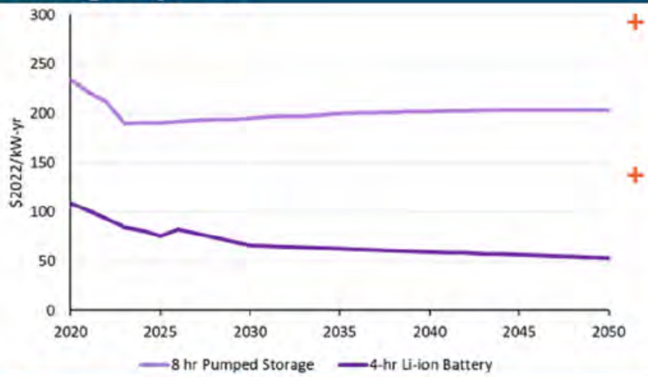
+ **There is a significant increase in solar and battery capacity installed capacity due to the more aggressive RPS targets, assumed electrification, and the decline of technology cost forecasts**
  - Load is based on 2018 Electrification Futures Study and E3 internal incremental electrification impact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

Total Installed Capacity for External Zones



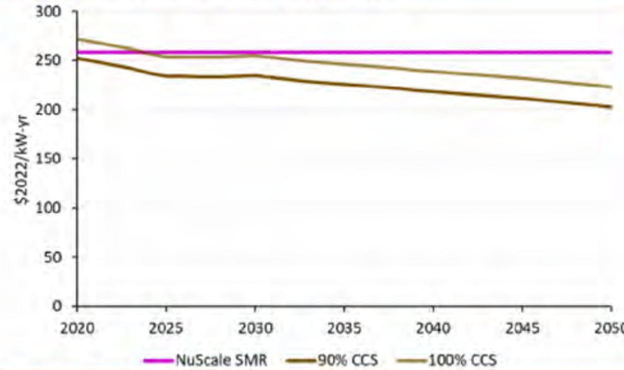
New Resource Options
All-in Fixed Costs

Storage Options



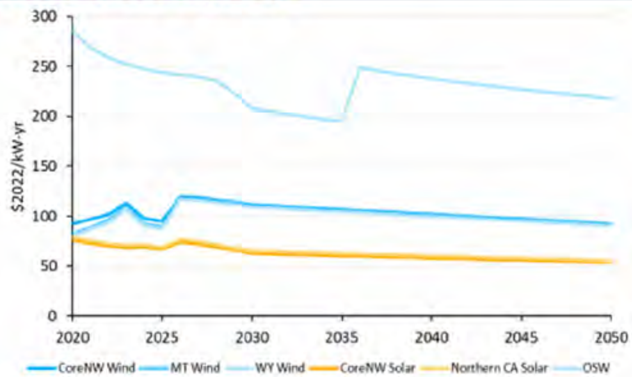
- Battery Storage costs derived from E3's inhouse and Lazard LCOS 7.0 (Oct 2021)
- Pumped storage is from Lazard's last published PHS costs (LCOS 4.0). Assumes CAPEX and FO&M are flat + financing cost trends same for battery storage.

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

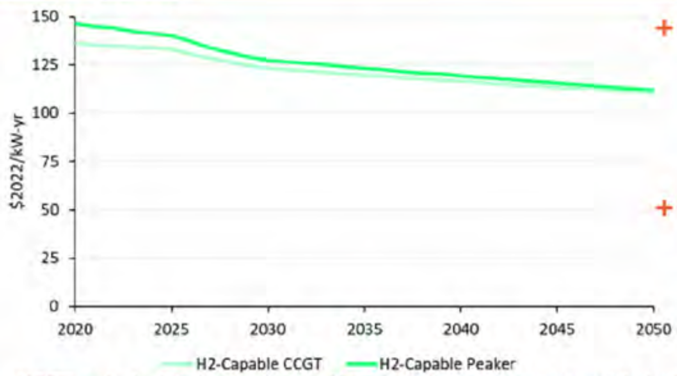
Renewable Options



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

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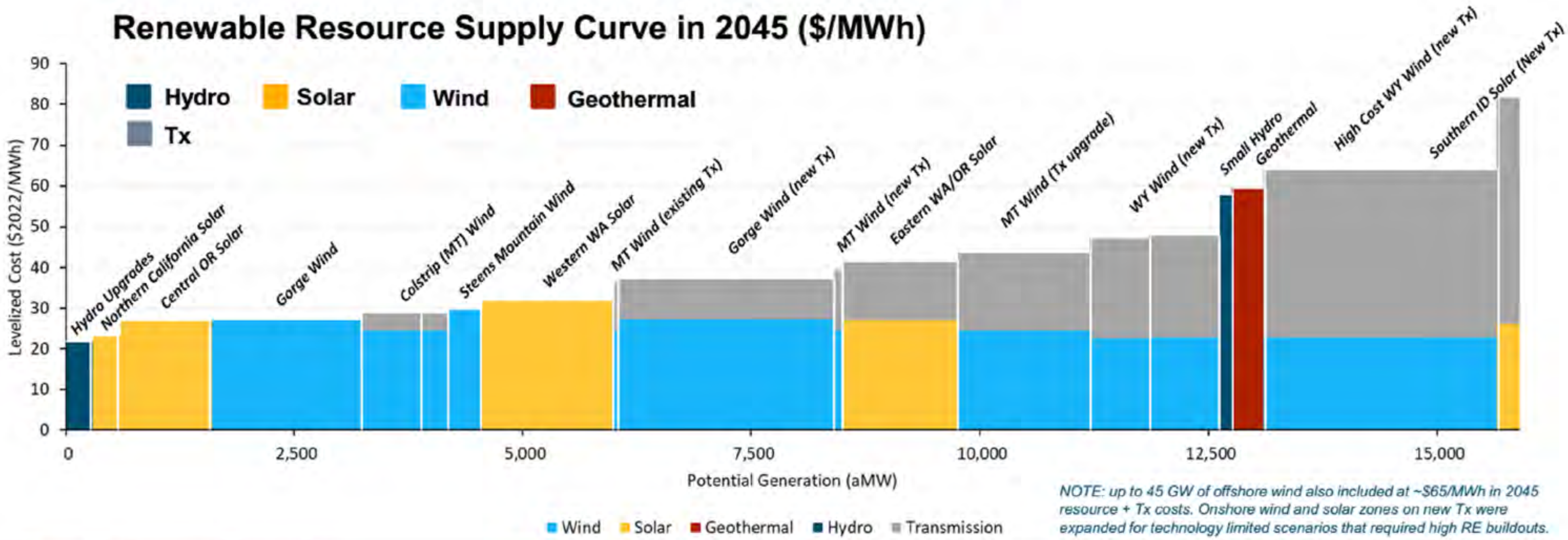
New Resource Options
Renewables

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



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

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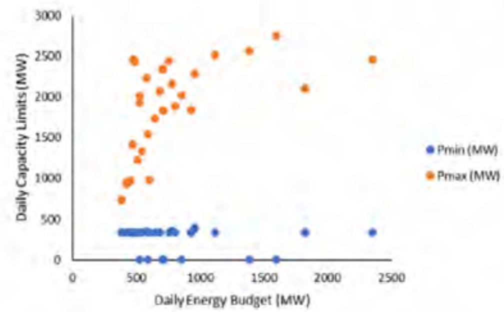
Hydro Operating Data

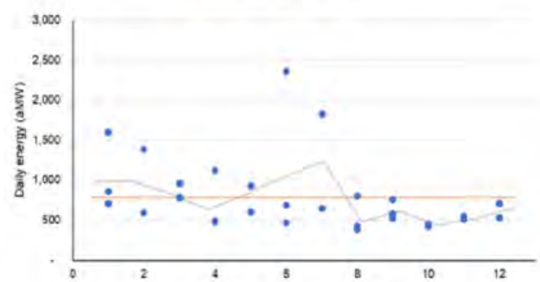
- **Key RESOLVE inputs (for each representative RESOLVE day)**
  - Max generation MW
  - Min generation MW
  - Daily MWh hydro budget
  - Ramp
- **Hydro operating data is parameterized using representative conditions for 3 low/mid/high historical years (2001, 2005, 2011)**
  - Lower Snake River and Lower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

LSR Hydro

Ramp Rates

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

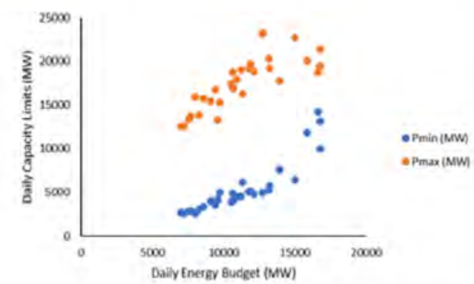


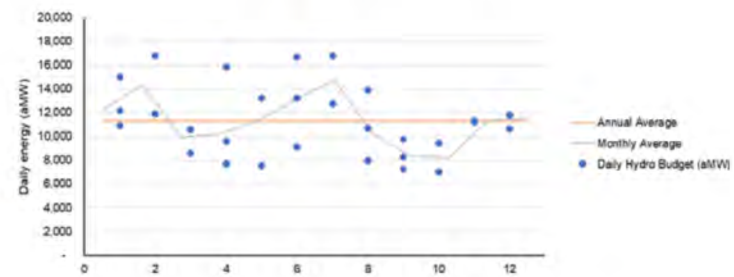


Non-LSR NW Hydro

Ramp Rates

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

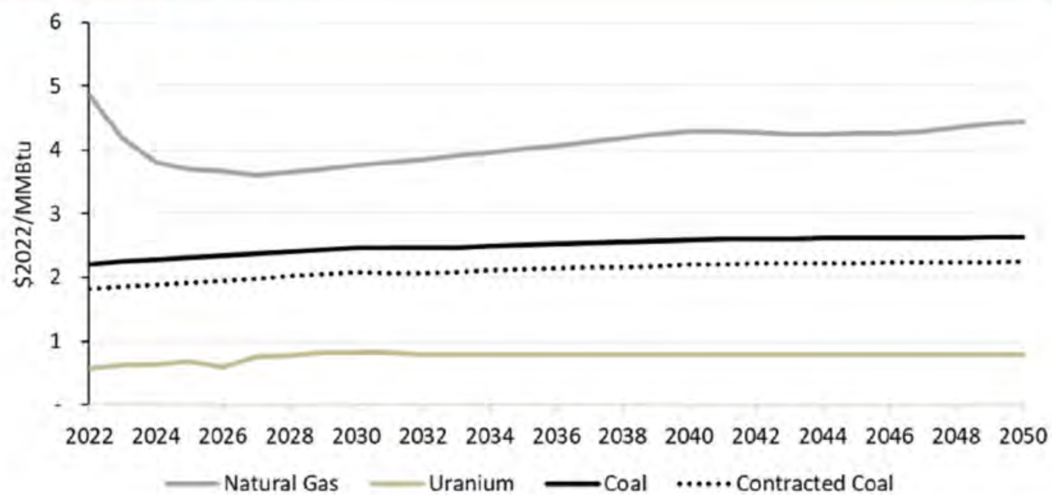




Fuel Prices

+ 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



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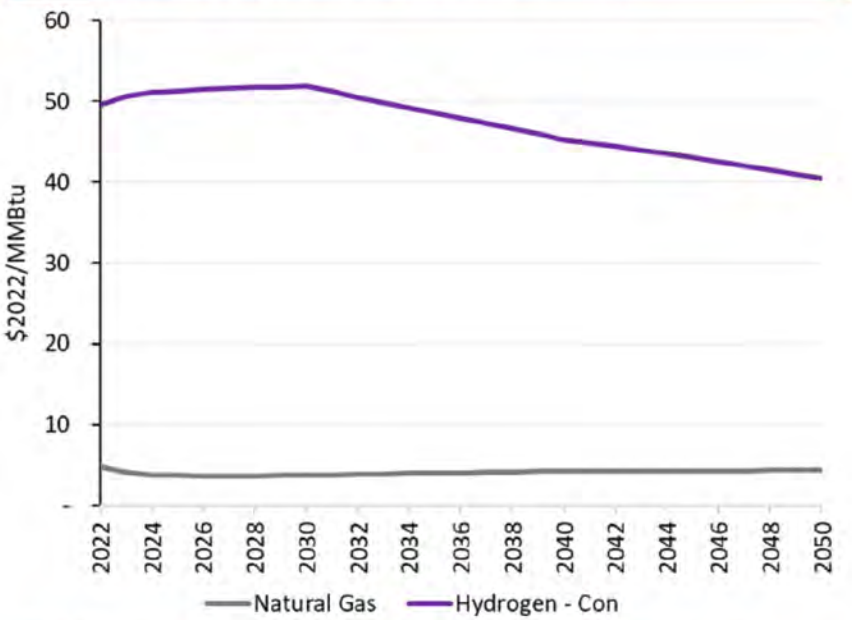
Fuel Prices - Hydrogen

Hydrogen price forecast (2020$/MMBtu)*

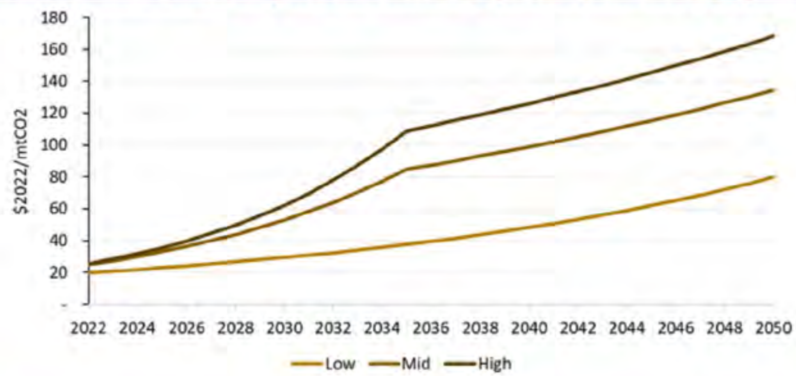


*Note the optimistic fuel price in the near term is not currently viable. It is shown for illustrative purposes under the assumption underground storage and dedicated pipelines are actively in use today.

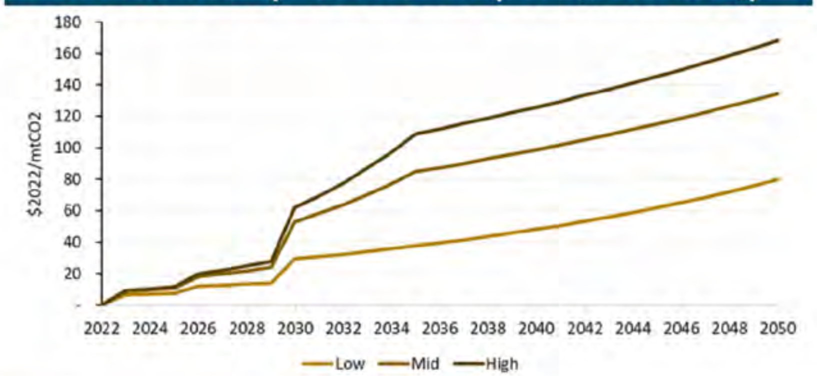
+ **The conservative hydrogen price is used as the basis for all scenarios. It assumes:**
  - There is not a massive H_2 economy and thus electrolyzer capital costs and efficiencies have only slightly decreased
  - H_2 is stored in above ground tanks and delivered via trucks.
+ **Conservative assumes 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**

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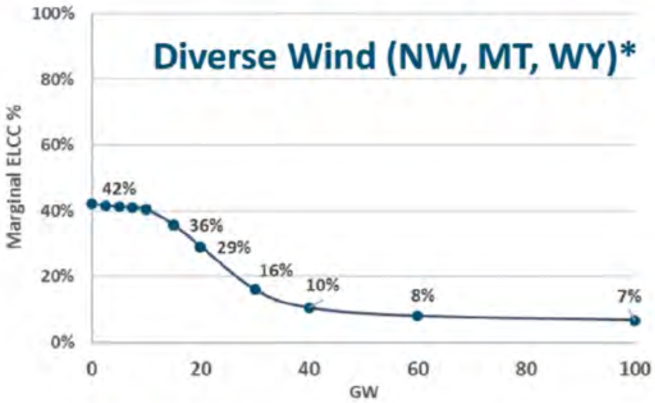
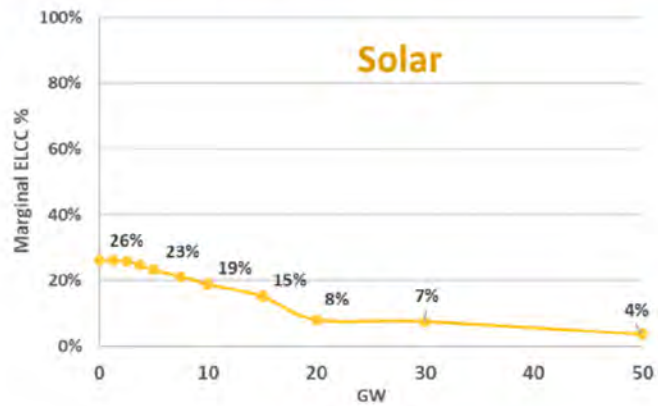
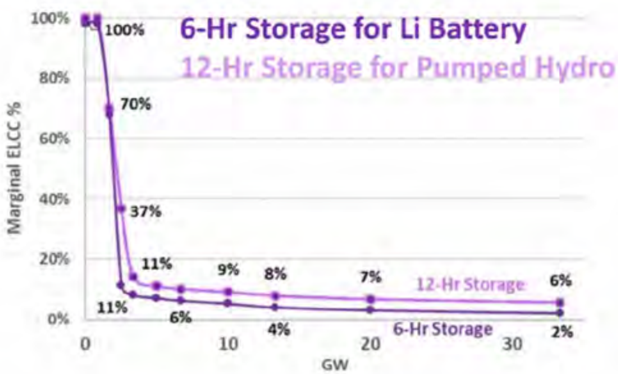
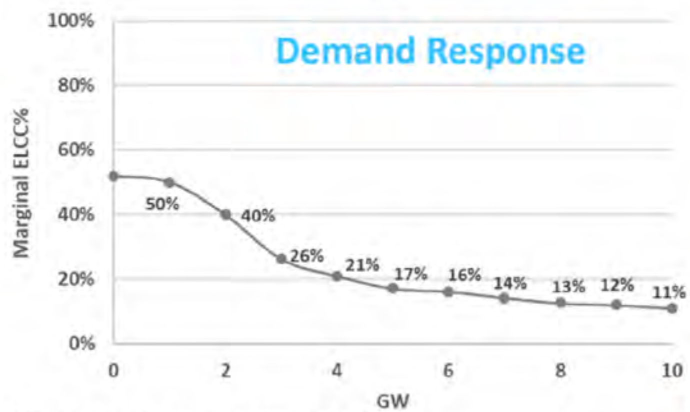
Incorporating declining capacity contributions of renewables, storage and DR









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

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

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

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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

From:	Koehler,Birgit G (BPA) - PG-5
Sent:	Thursday, August 4, 2022 9:20 AM
To:	Arne Olson; James,Eve A L (BPA) - PG-5
Cc:	Aaron Burdick
Subject:	RE: McMorris Rodgers, Risch Lead PNW Delegation in Calling Out White House Efforts to Breach LSR Dams

Hi Arne,

I did see the letter that went to our administrator. We can provide clear answers on when external groups held things up, and what BPA or E3 did by their own choice. I'm not too worried. I was not aware of the letters to the other agencies, but they are not surprising.

Birgit

From: Arne Olson <arne@ethree.com>
Sent: Thursday, August 4, 2022 9:03 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: McMorris Rodgers, Risch Lead PNW Delegation in Calling Out White House Efforts to Breach LSR Dams

DELIBERATIVE FOIA EXEMPT

Hi Birgit,

I just saw this. Yikes! With respect to the late changes to the report, I know you know those were entirely at E3's initiative. I hope they don't cause more trouble than they were worth. With respect to the study review process, in my opinion it was almost entirely above board. The comments and questions provided by DOE and CEQ were helpful and offered without any hint of undue pressure. I would be happy to say so publicly if helpful.

Arne

Begin forwarded message:

> **From:** Kyle VonEnde <kyle.vonende@mail.house.gov>
> **Date:** August 4, 2022 at 6:30:51 AM PDT
> **To:** sjwpdx@gmail.com
> **Subject: McMorris Rodgers, Risch Lead PNW Delegation in Calling Out White House Efforts to Breach LSR Dams**
> **Reply-To:** kyle.vonende@mail.house.gov

FOR IMMEDIATE RELEASE
August 4, 2022

Contact: Kyle VonEnde, 202-802-0539
Chavonne Ludick, 202-940-5654

McMorris Rodgers, Risch Lead PNW Delegation in Calling Out White House Efforts to Breach LSR Dams

Biden Administration Fails to Lead on Columbia River System With Facts or Science

Washington, D.C. – Eastern Washington Congresswoman Cathy McMorris Rodgers (WA-05) and Senator James Risch (R-ID), along with their colleagues from the Pacific Northwest, today called out the Biden administration for its lack of transparency and political intervention in processes that could lead to breaching the Lower Snake River dams.

The series of letters comes just weeks after the White House Council on Environmental Quality (CEQ) released a draft report from the National Oceanic and Atmospheric Administration (NOAA) recommending at least one Lower Snake River dam be breached in order to recover endangered salmon, as well as an analysis commissioned by the Bonneville Power Administration (BPA) outlining the scenarios under which the power benefits of the four dams could be replaced.

In response, Rodgers and Risch were joined in sending letters to CEQ, NOAA, BPA and the Department of Energy (DOE) by Senators Mike Crapo (R-ID) and Steve Daines (R-MT), and Representatives Dan Newhouse (WA-04), Russ Fulcher (ID-01), Jaime Herrera Beutler (WA-03), and Cliff Bentz (OR-02).

Below are highlights and excerpts from the letters:

"As members of the Northwest delegation, we write to express our deep concern about recent actions taken by this administration which have demonstrated a seeming disregard for scientific integrity. Specifically, we were appalled by the lack of transparency and obvious political intervention in processes regarding the recent release of the National Oceanic and Atmospheric Administration (NOAA) draft "report" relating to the Columbia River Basin. Even more alarming, we have received further indication of political maneuvering by this administration to prevent information on the costs of replacing the power generated by the Lower Snake River dams on the Federal Columbia River Power System from being made public prior to the release of the previously mentioned NOAA draft 'report.'

"The infrastructure on the Columbia River System provides invaluable benefits to the Pacific Northwest, including carbon-free energy, flood control mitigation, irrigation, navigation, and recreation benefits. Balancing these vital interests with species conservation is not an easy task. It is made significantly more difficult when science and collaboration is replaced by politically-motivated intervention.

"The recent actions by this administration have sown complete distrust in this administration's ability to lead with facts, science, and transparency regarding the Columbia River System. These actions will undoubtedly have long-term and damaging effects on this administration's ability to bring diverse stakeholders together to chart a path forward on species recovery and preservation of the vital benefits of the Columbia River System."

CLICK HERE to read the letter to DOE Secretary Jennifer Granholm.

CLICK HERE to read the letter to NOAA Administrator Richard Spinrad.

CLICK HERE to read the letter to CEQ Chair Brenda Mallory.

CLICK HERE to read the letter to BPA Administrator John Hairston.

NOTE: In March, Rodgers and Risch also led PNW lawmakers in demanding answers from ten federal agencies involved in the White House Council on Environmental Quality (CEQ)'s exploration of plans to breach the Lower Snake River dams. Click here to read those letters.

###

From: Arne Olson <arne@ethree.com>
Sent: Thursday, August 4, 2022 8:03 AM
To: Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5
Cc: Aaron Burdick
Subject: [EXTERNAL] FW: E3 Response to Renewables Northwest Critique of 4 LSRD study
Attachments: E3 Renewables-NW Response 2022-08-01.docx

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
[redacted]

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

Hi Mark and Dan,

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

Thanks,

Arne

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

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[redacted]

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44 Montgomery Street | Suite 1500 | San Francisco, CA 94104 | 415.391.5100 | www.ethree.com

Response to Renewable Northwest Op-Ed

August 6

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

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

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

By contrast, E3's study considers the resources needed to replace the dams *while also reducing carbon emissions to zero* or near zero by 2045, finding replacement costs of $450-800 million per year or $12-19 billion NPV. On these future power systems, the ability of wind

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

and solar to contribute to resource adequacy, even when augmented with diurnal energy storage, is significantly diminished due to saturation. In fact, study after study has found that some form of "clean firm" generation – carbon-free generation that can run whenever needed – is necessary to achieve carbon emissions reductions beyond approximately 80% due to the limitations of variable renewables and short-duration storage.[2]

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

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

While a warming climate, diminishing snowpack, and deteriorating load-resource balance will almost certainly lead to summertime reliability challenges in the Northwest over the next decade, meeting wintertime electric heating demands will be the largest reliability issue in the

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

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

long run, even for southern systems such as California[4] and Texas[5]. Maintaining resource adequacy in the Pacific Northwest will require fully replacing the Lower Snake River dams' wintertime peaking capabilities. The op-ed disappointingly does not mention electrification or appear to consider its impact on regional electric loads.

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

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

- The op-ed suggests that a full-year production simulation model would be better able to capture the complementary nature of wind, solar, batteries, and hydro. In fact, RESOLVE's internal production simulation algorithms are fully capable of simulating these operational dynamics. Indeed, RESOLVE likely *over-optimizes* the joint dispatch of storage and renewable resources relative to hybrid resources with operational constraints caused by reliance on a single inverter, interconnection limit, or limitations on charging from the grid. Neither RESOLVE nor full-year production simulation models can simulate the ability of various resources to contribute to resource adequacy. That's why RESOLVE uses results from a Loss-of-Load Probability model,

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

[5] https://energy.utexas.edu/sites/default/files/UTAustin%20%282021%29%20EventsFebruary2021TexasBlackout%20%20210714.pdf

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

E3's RECAP model which was used in our 2019 Study *Resource Adequacy in the Pacific Northwest*[7], to characterize the capacity contribution of various resources over time.

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

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

+ The op-ed's criticism of E3's reliance on historical weather data to characterize the resource adequacy contribution of the dams is fair. Utilization of projected climate-altered weather and hydro conditions would likely have shown more reliability challenges in the summertime when the dams' peaking capability is reduced. To evaluate this possibility, E3 included a sensitivity case with the dams' peaking

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

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

capability reduced from 2.3 GW to 1.0 GW. The replacement costs were estimated to be 14-33% lower than in the base scenarios.

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

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

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Thursday, July 21, 2022 12:12 PM
To:	James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5
Cc:	Arne Olson
Subject:	[EXTERNAL] RE: [EXTERNAL] RE: E3 briefing request

Ok, confirming I heard from Arne and he is available.

Thanks,
Aaron

From: Aaron Burdick
Sent: Thursday, July 21, 2022 11:56 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: [EXTERNAL] RE: E3 briefing request

Looks like Arne has accepted, so we should be good. I'll ping him separately to confirm if he's available to respond while out this week.

Aaron

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

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

Thanks,
Eve

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

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

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

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Monday, July 18, 2022 1:45 PM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>

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

Got it. Sharing Tue-Thurs availabilities:

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

All the best,
Aaron

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

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

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

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

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

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

Thanks,
Eve

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

Here are some times (focusing on Monday and Friday but let me know if you want other days). The earliest Mon or Fri we're both available in 8/5 (actually that's the earliest of any weekday), but we can proceed with one of us if you need a briefing sooner than that.

- Fri 7/22: 9-5 (Aaron only, Arne OOO)
- Mon 7/25: 8-9, 10-11, 12-2 (Arne only, Aaron OOO)
- Fri 7/29: both unavailable
- Mon 8/1: 8:30-2pm (Aaron only, Arne OOO)
- Fri 8/5: 8:30-11 (both Aaron and Arne)

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, July 14, 2022 3:35 PM
To: Arne Olson <arne@ethree.com>; Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: E3 briefing request

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

Thanks,
Eve

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Tuesday, May 31, 2022 9:58 AM
To:	James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5
Cc:	Arne Olson
Subject:	[EXTERNAL] RE: BPA-E3

DELIBERATIVE FOIA EXEMPT

Thanks Eve. We could move some of the NW hydro daily MWh budget over to the LSR dams to try to top off our 706 aMW vs. the 862 aMW... but given budget and timing, we could also just add a note that says 700-900 aMW* (* 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).

Let me know if you need me to make that update for the public deck version sent on Friday.

Aaron

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Sent: Tuesday, May 31, 2022 7:55 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Arne Olson <arne@ethree.com>
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DELIBERATIVE FOIA EXEMPT

Thanks Aaron-
The average annual generation with the updated CRSO EIS assumptions on the LSN projects is 862 aMW for the 90 year streamflow set.

Thanks,
Eve

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Meeting number (access code): [redacted]

Meeting password: 5UKeHJ2kK@2

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Join by phone

+1-415-527-5035 US Toll

Global call-in numbers

Join from a video system or application

Dial [redacted]@mybpa.webex.com

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https://mybpa.webex.com/mybpa/j.php?MTID=m90c20a2372398102deac9a0e3860f270

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Meeting number (access code): [redacted]

Meeting password: [redacted]

Tap to join from a mobile device (attendees only)

+1-415-527-5035,,[redacted] US Toll

Join by phone

+1-415-527-5035 US Toll

Global call-in numbers

Join from a video system or application

Dial 27627102796@mybpa.webex.com

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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

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Meeting password: [redacted]

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+1-415-527-5035,,[redacted] US Toll

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Dial 27627102796@mybpa.webex.com

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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**?

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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

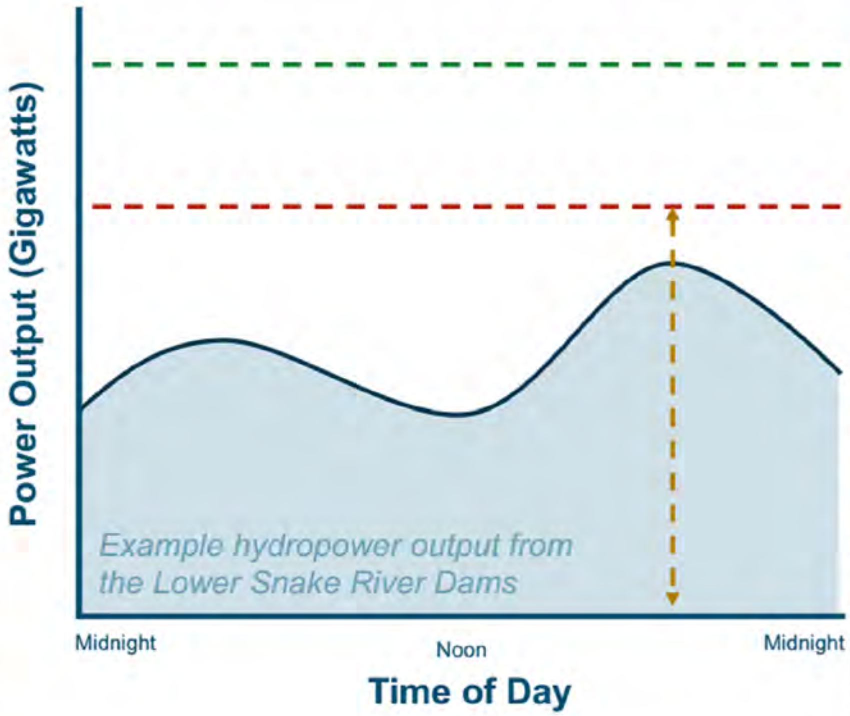
What grid services do the Lower Snake River Dams provide?

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)	Available	Available	Available	Available
Hydrogen (existing natural gas retrofits)	Available	Available	Available	Available
Hydrogen (new dual fuel natural gas + hydrogen)	Available	Available	Available	Not available
Nuclear (small modular reactors)	Not available	Not available	Available	Not available
Natural Gas w/ Carbon Capture and Storage	Not available	Not available	Available	Not available
Offshore Wind (floating)	Not available	Not available	Available	Available

Available
Not available

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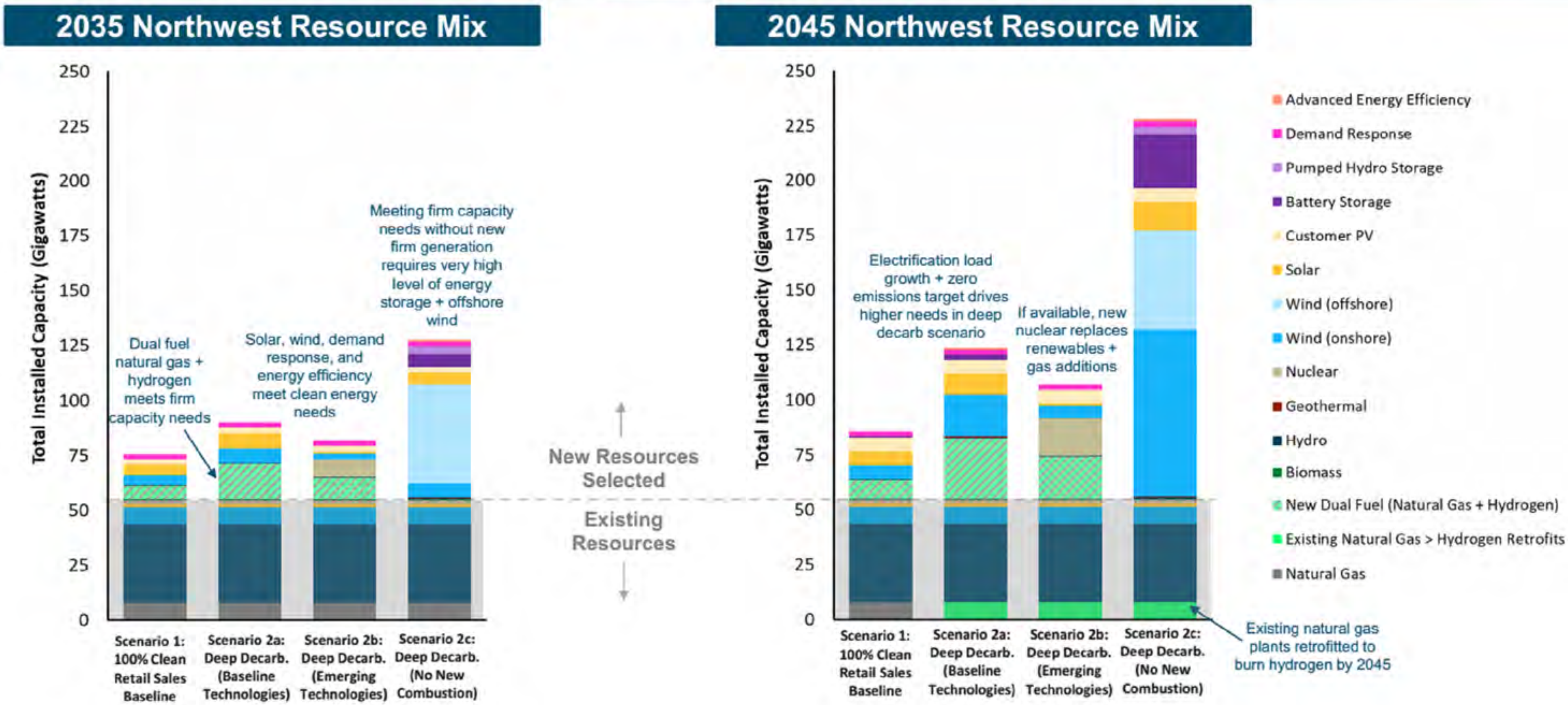
Northwest Resource Needs in Scenarios With the Lower Snake River Dams

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



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Replacing the Power from the Lower Snake River Dams

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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

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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 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

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).

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

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

Incremental LSR Dam Replacement Resource Costs

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

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

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

** Replacement $/MWh costs are calculated as CoreNW revenue requirement increase with LSR dams breached divided by the annual MWh of the LSR dams. 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

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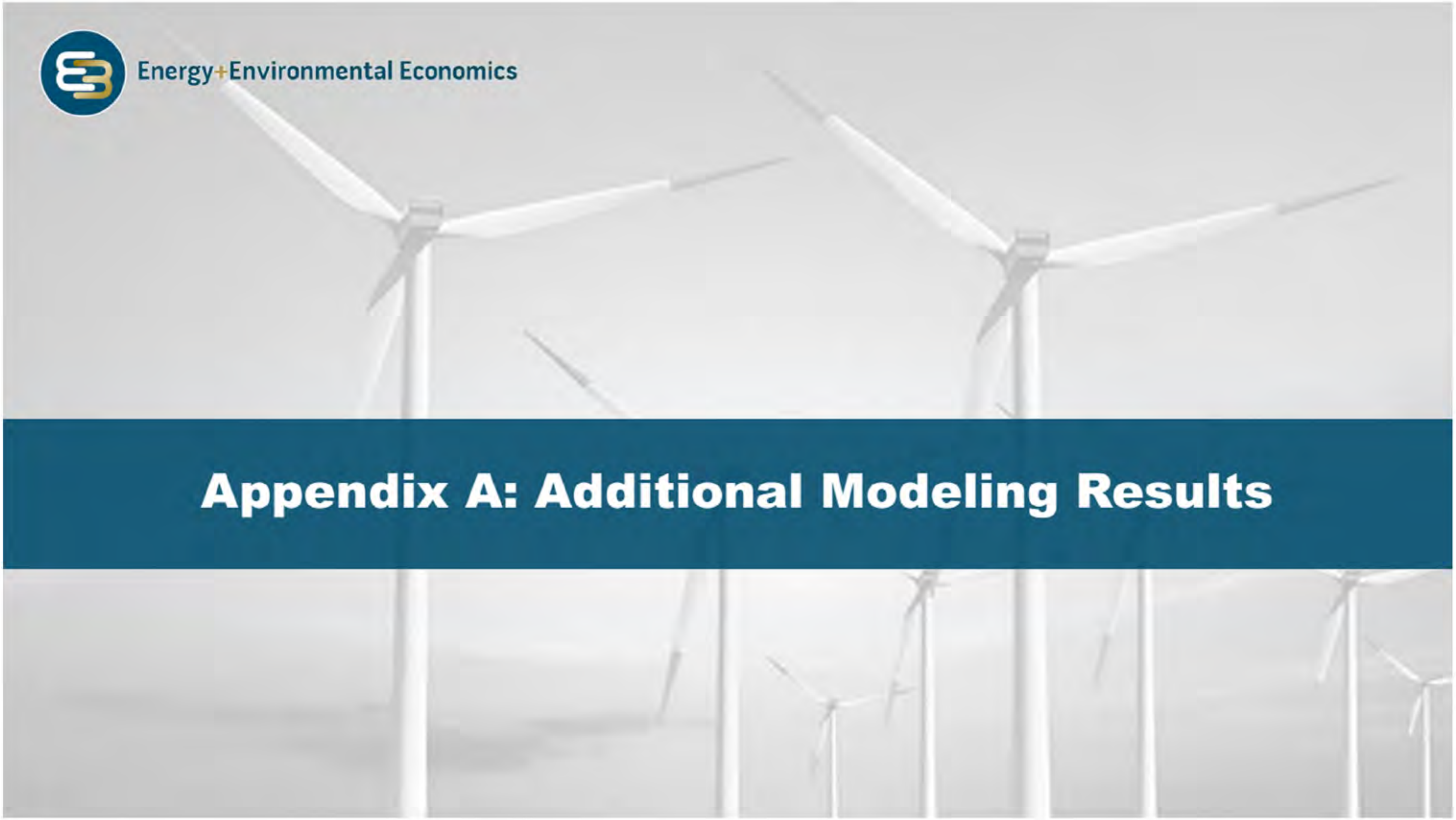
Thank you

Questions, please contact:

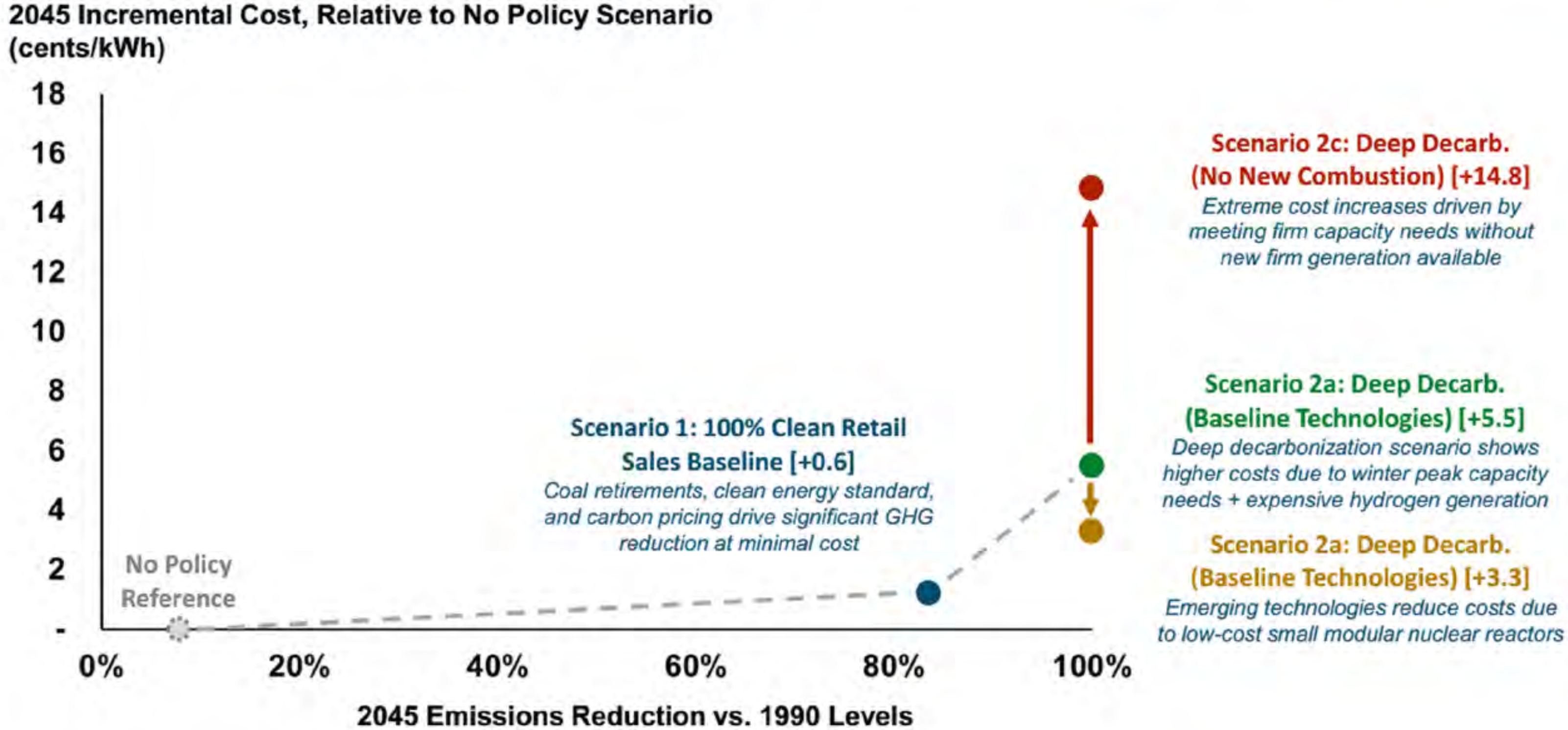
Arne Olson, arne@ethree.com

Aaron Burdick, aaron.burdick@ethree.com



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

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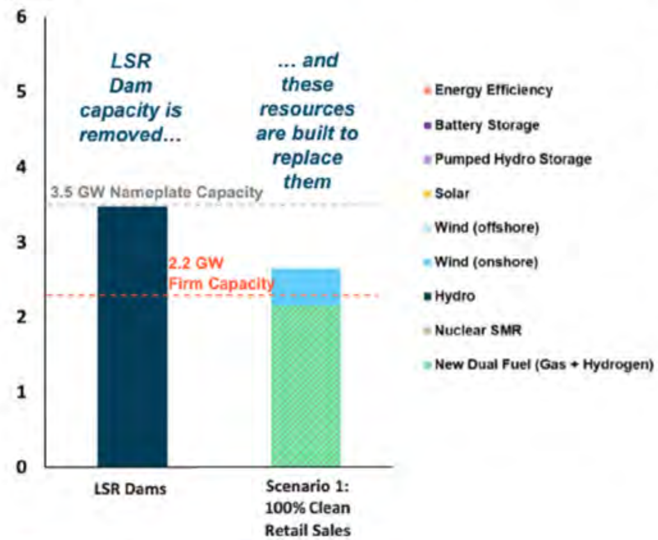
Replacing the Lower Snake River Dams
Scenario 1: 100% Clean Retail Sales

- Capacity replaced with 2.2 GW of dual fuel natural gas + hydrogen turbines and 0.5 GW wind
- Wind and imports provide the most energy replacement, but gas plant is needed for meeting extreme weather peak load events to avoid power shortages
- 2045 GHG emissions increase ~11% as not all LSR generation needs to be replaced to still meet 100% clean retail sales target

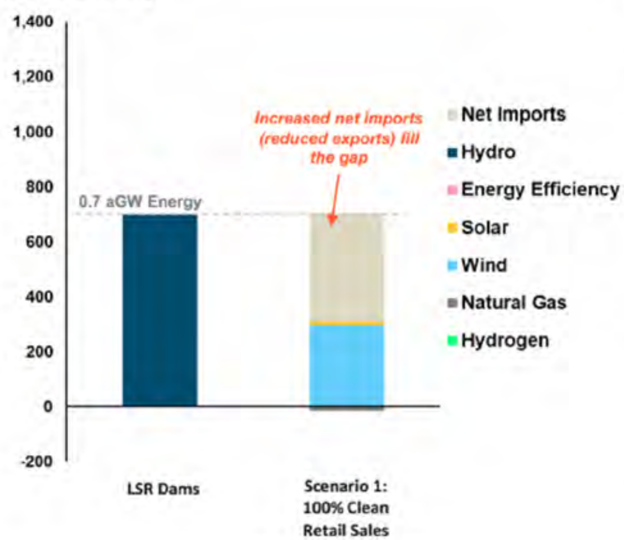
Additional Resources Built to Replace LSR Dams (2045)

2045 Capacity (GW)



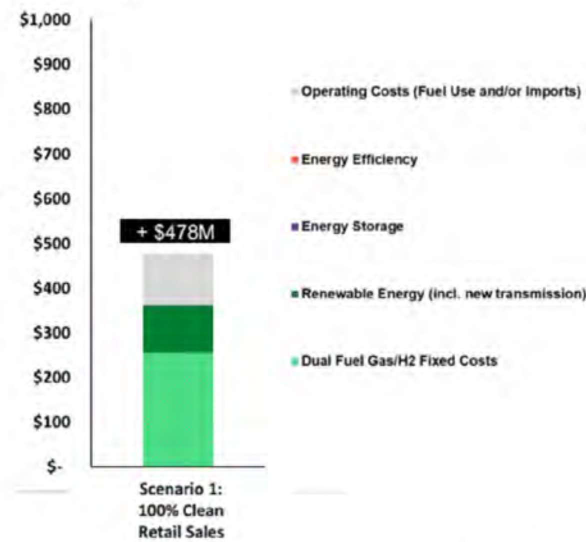
Additional Generation to Replace LSR Dams (2045)

2045 Generation (Annual GWh)



Additional Cost (2045)

2045 Annual Cost Increase ($ million)



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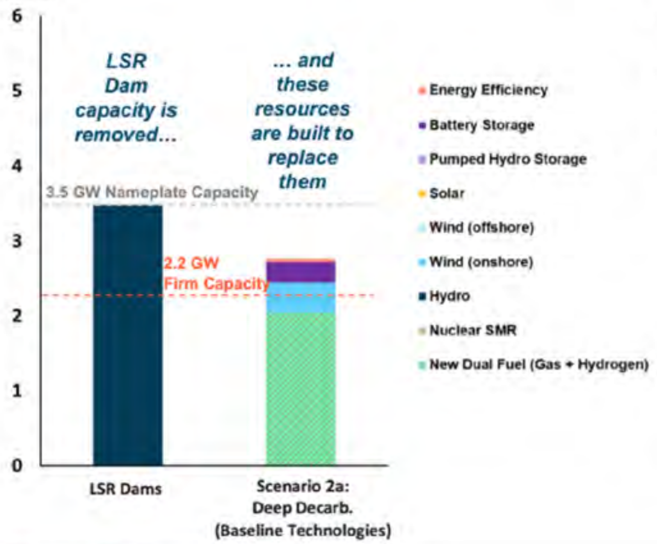
Replacing the Lower Snake River Dams
Scenario 2: Deep Decarbonization (Baseline Technologies)

- 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)

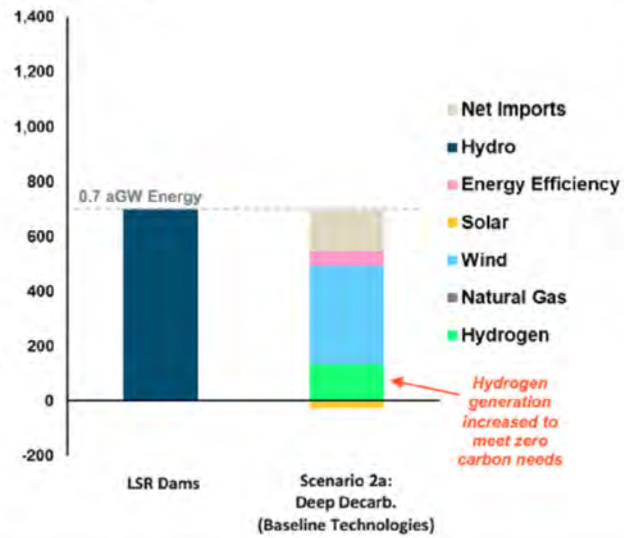
Additional Resources Built to Replace LSR Dams (2045)

2045 Capacity (GW)



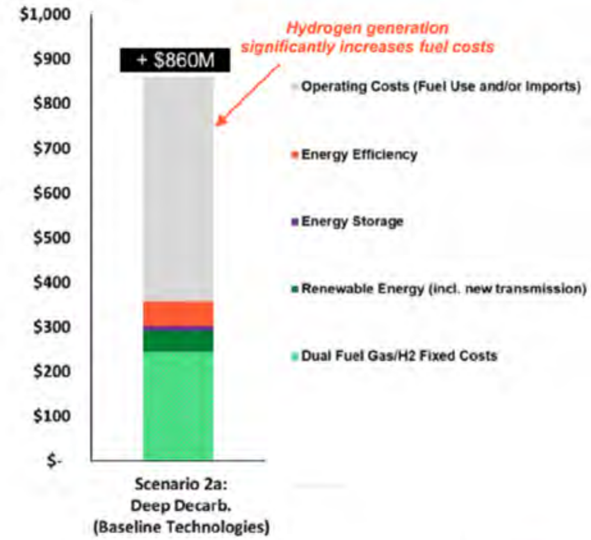
Additional Generation to Replace LSR Dams (2045)

2045 Generation (Annual GWh)



Additional Cost (2045)

2045 Annual Cost Increase ($ million)



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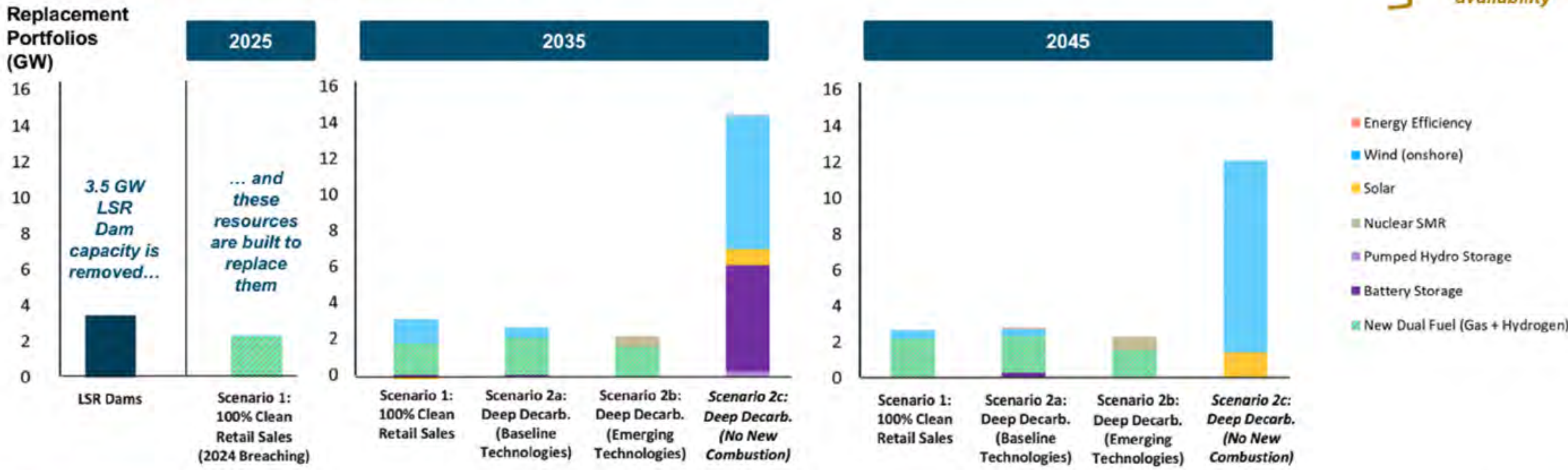
Replacing the Lower Snake River Dams Capacity Across All Scenarios

+ 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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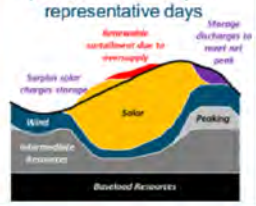
Appendix B: Additional Modeling Inputs

RESOLVE optimizes investments to meet clean energy targets reliably

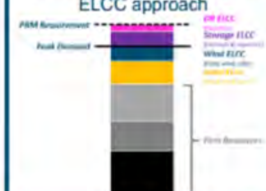
RESOLVE is an optimal capacity expansion model specifically designed to identify least-cost plans to meet reliability needs and achieve compliance with regulatory and policy requirements

+ **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**

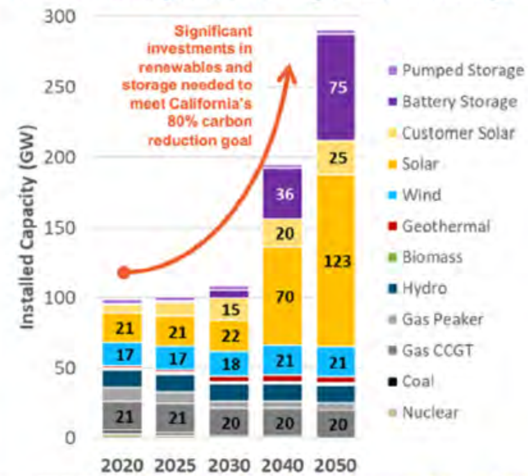
Operational module simulates hourly system operations for a sample of representative days



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)

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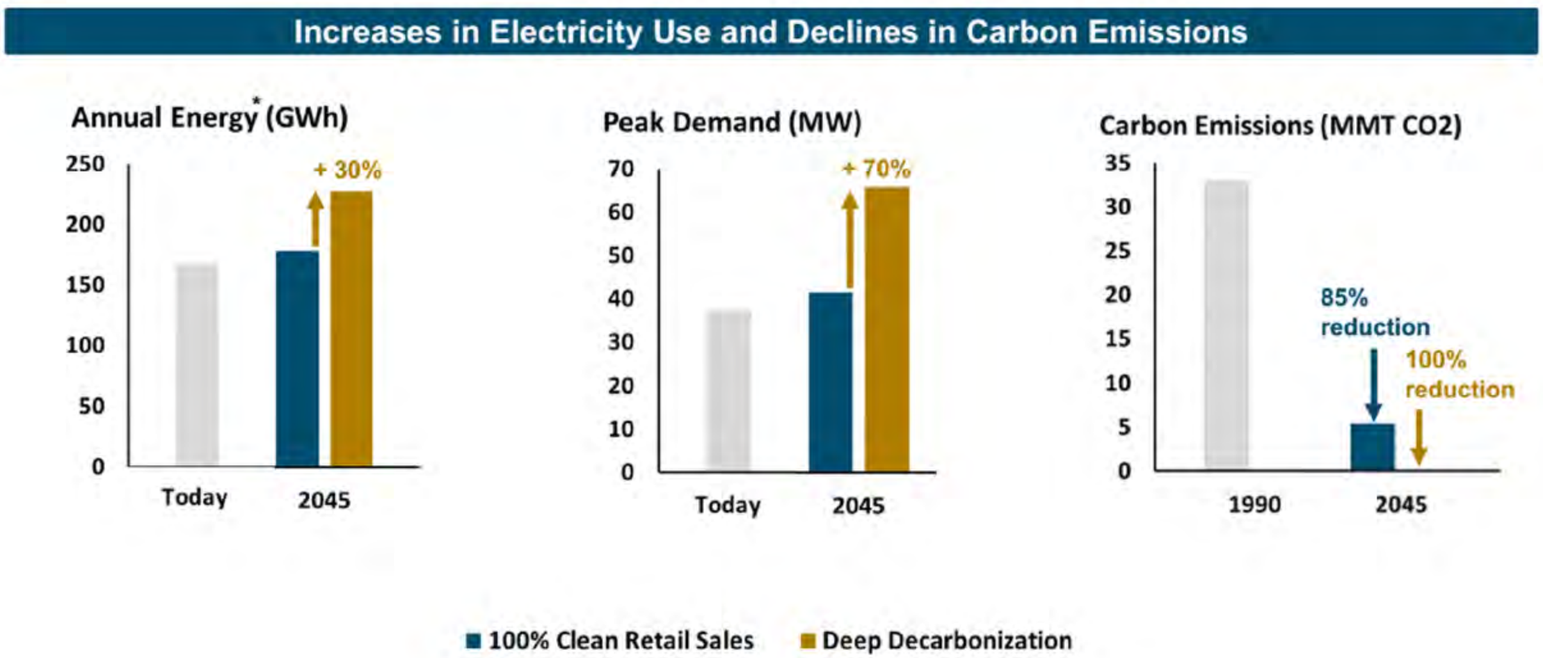
Load growth and carbon emissions in two clean energy scenarios modeled



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

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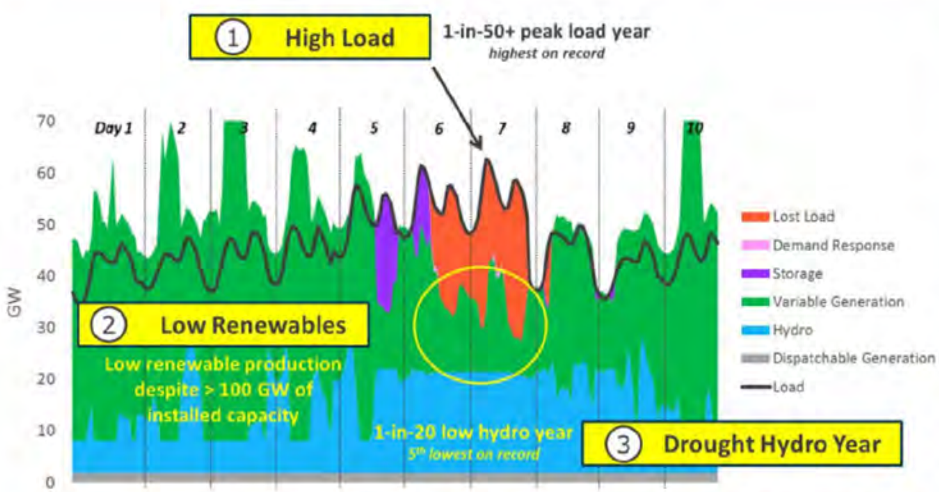
Resource Adequacy Resource Options

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

Key Drivers of Future Pacific Northwest Reliability Events



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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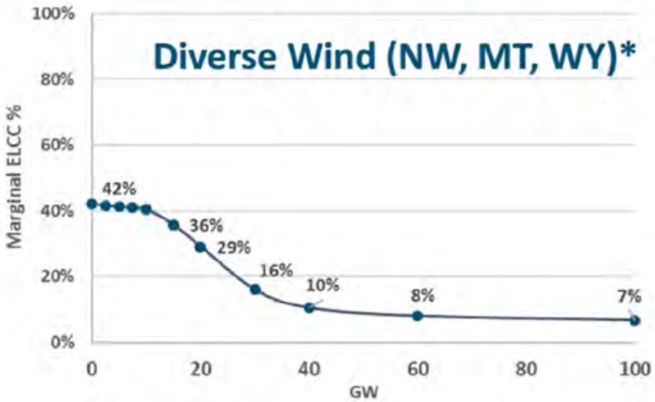
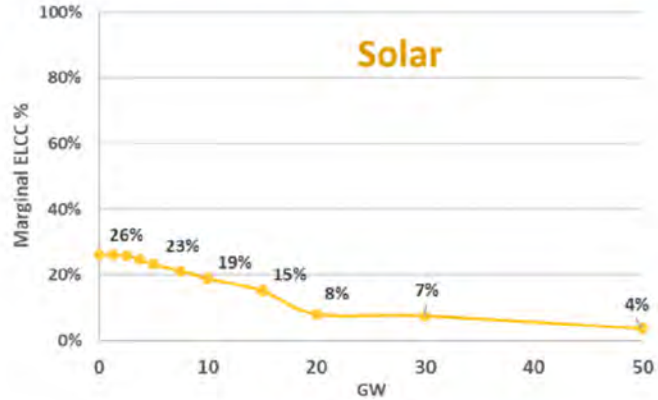
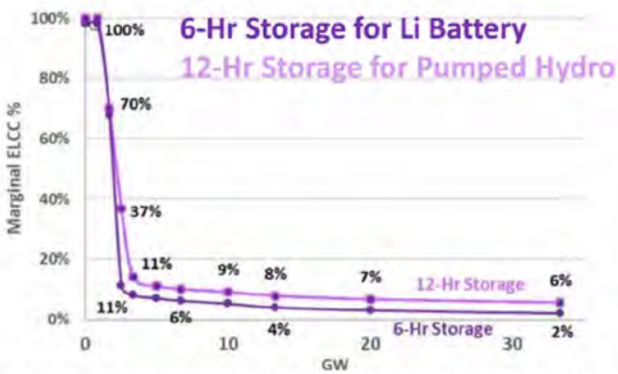
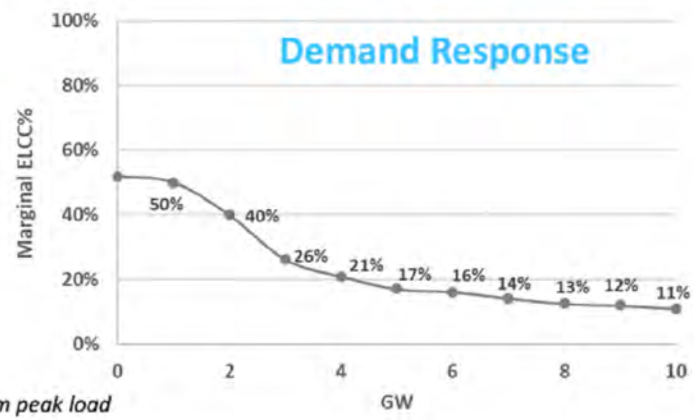
Incorporating Declining Capacity Contributions of Renewables, Storage, and DR









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

* 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.

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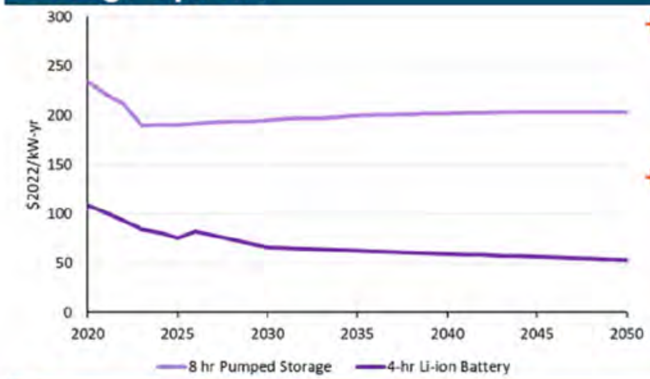
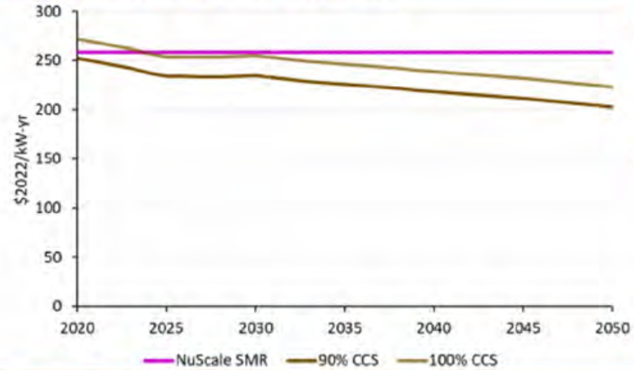
New Resource Options
All-in Fixed Costs

Storage Options



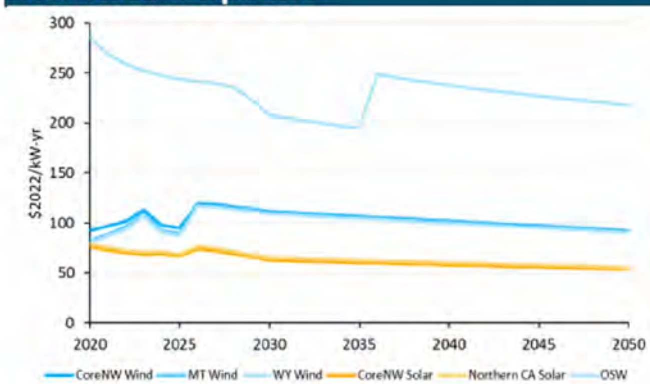
- Battery Storage costs derived from E3's inhouse and Lazard LCOS 7.0 (Oct 2021)
- Pumped storage is from Lazard's last published PHS costs (LCOS 4.0). Assumes CAPEX and FO&M are flat + financing cost trends same for battery storage.

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

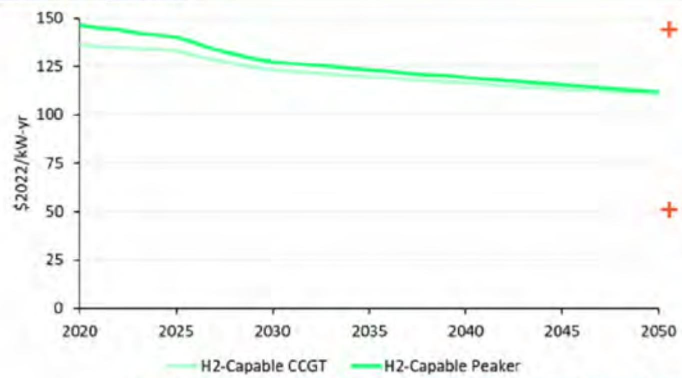
Renewable Options



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

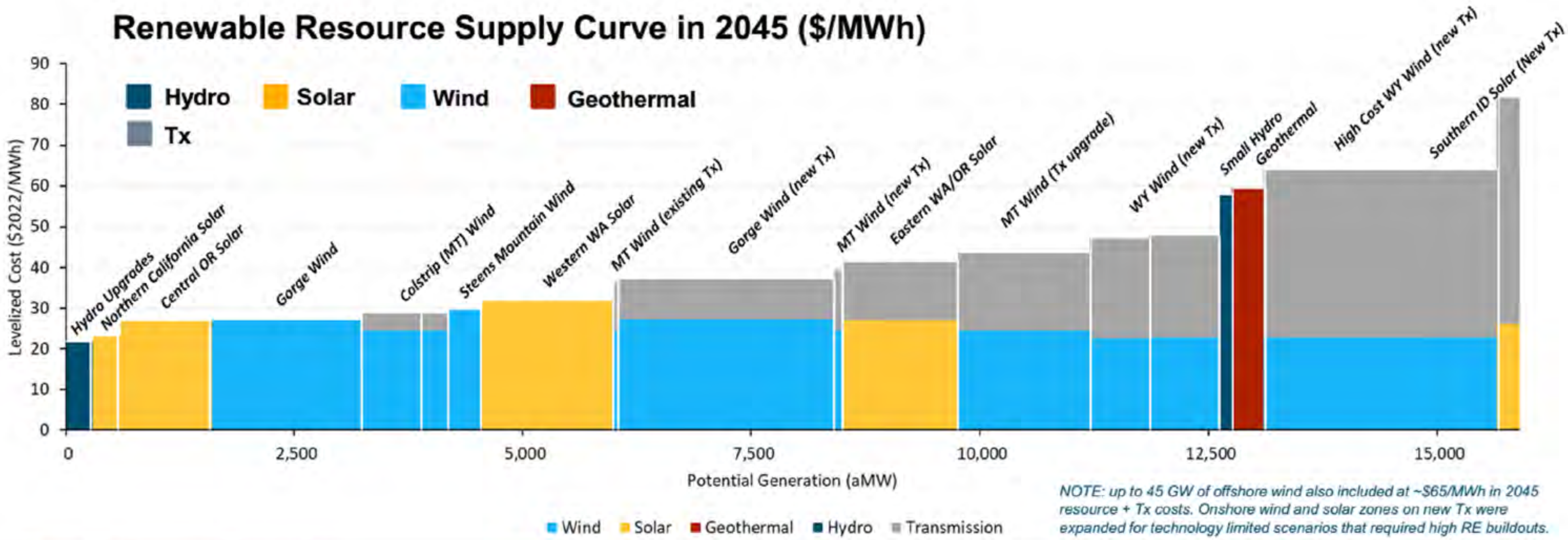


- CCGT and peaker costs are derived from E3's inhouse ProForma which integrates NREL ATB 2021
- New Hydrogen or upgrades include a ~10% additional cost that converges by 2050

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
+ The "no new combustion" scenario required increases the supply of wind on new transmission (Northwest, MT+WY, and offshore) to enable a feasible solution



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

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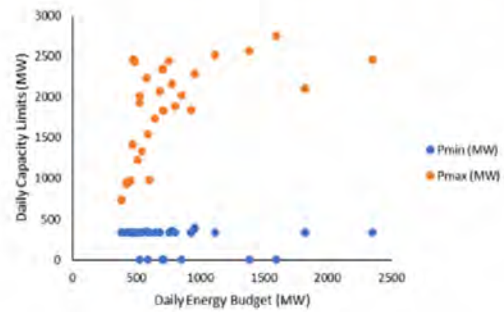
Hydro Operating Data

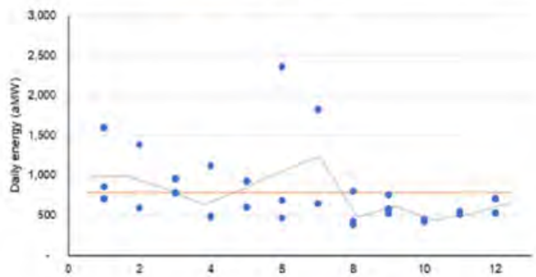
+ **Key RESOLVE inputs (for each representative RESOLVE day)**
  - Max generation MW
  - Min generation MW
  - Daily MWh hydro budget
  - Ramp
+ **Hydro operating data is parameterized using representative conditions for 3 low/mid/high historical years (2001, 2005, 2011)**
  - Lower Snake River and Lower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

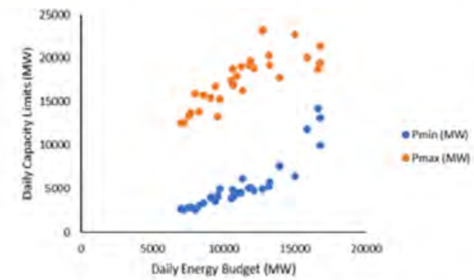


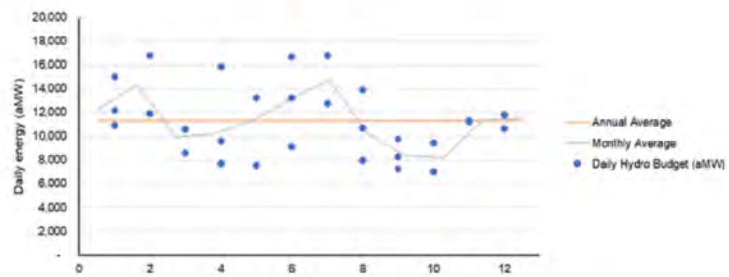


Non-LSR NW Hydro

Ramp Rates

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





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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**?

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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

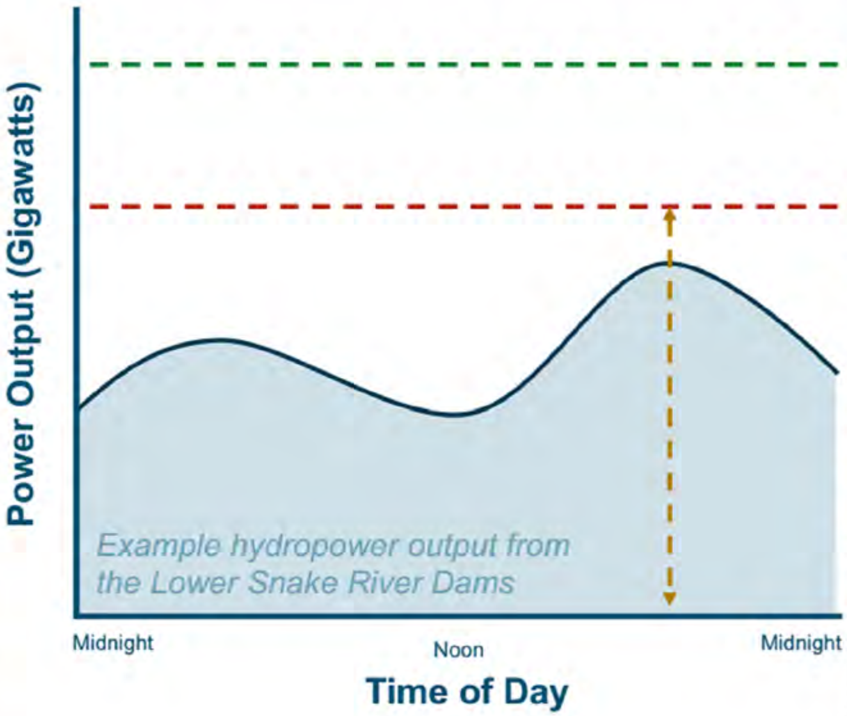
What grid services do the Lower Snake River Dams provide?


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

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

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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 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)	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

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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)	Available	Available	Available	Available
Hydrogen (existing natural gas retrofits)	Available	Available	Available	Available
Hydrogen (new dual fuel natural gas + hydrogen)	Available	Available	Available	Not available
Nuclear (small modular reactors)	Not available	Not available	Available	Not available
Natural Gas w/ Carbon Capture and Storage	Not available	Not available	Available	Not available
Offshore Wind (floating)	Not available	Not available	Available	Available

Available
Not available

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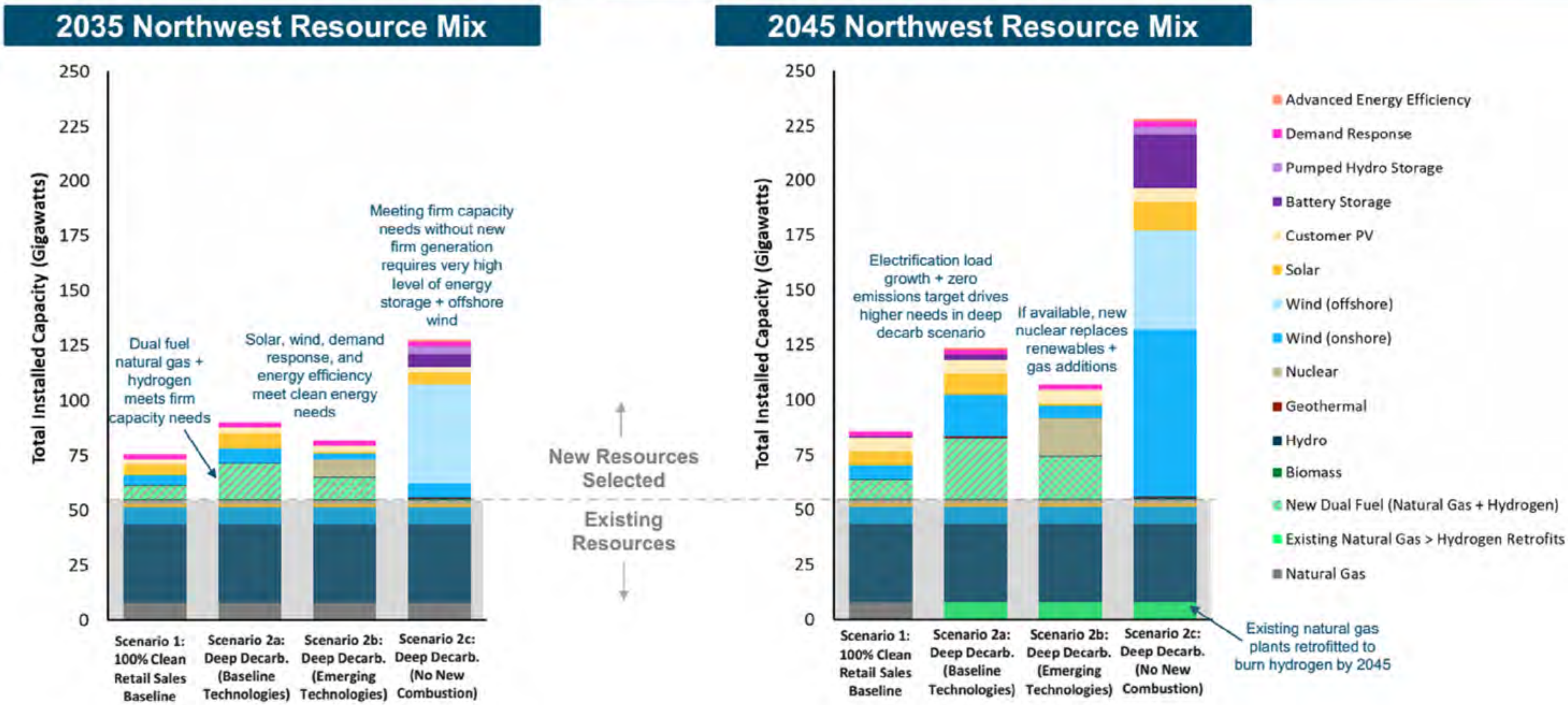
Northwest Resource Needs in Scenarios
With the Lower Snake River Dams

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



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Replacing the Power from the Lower Snake River Dams

Detailed Replacement Costs + Resource Needs

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

Scenario	Replacement Resources Selected, Cumulative by 2045 (GW)
Scenario 1: 100% Clean Retail Sales	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
Scenario 2a: Deep Decarb. (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW 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

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

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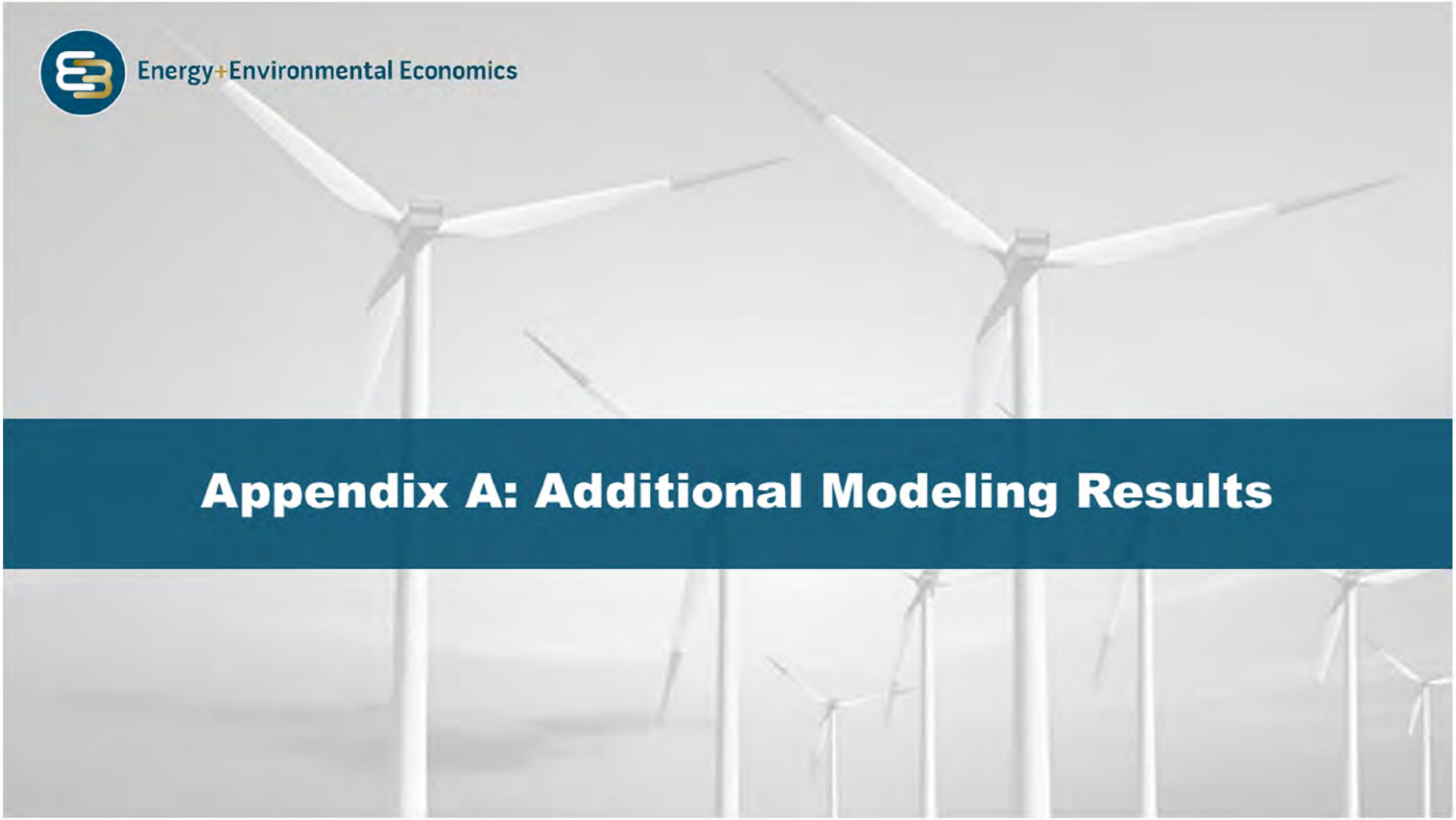
Thank you

Questions, please contact:

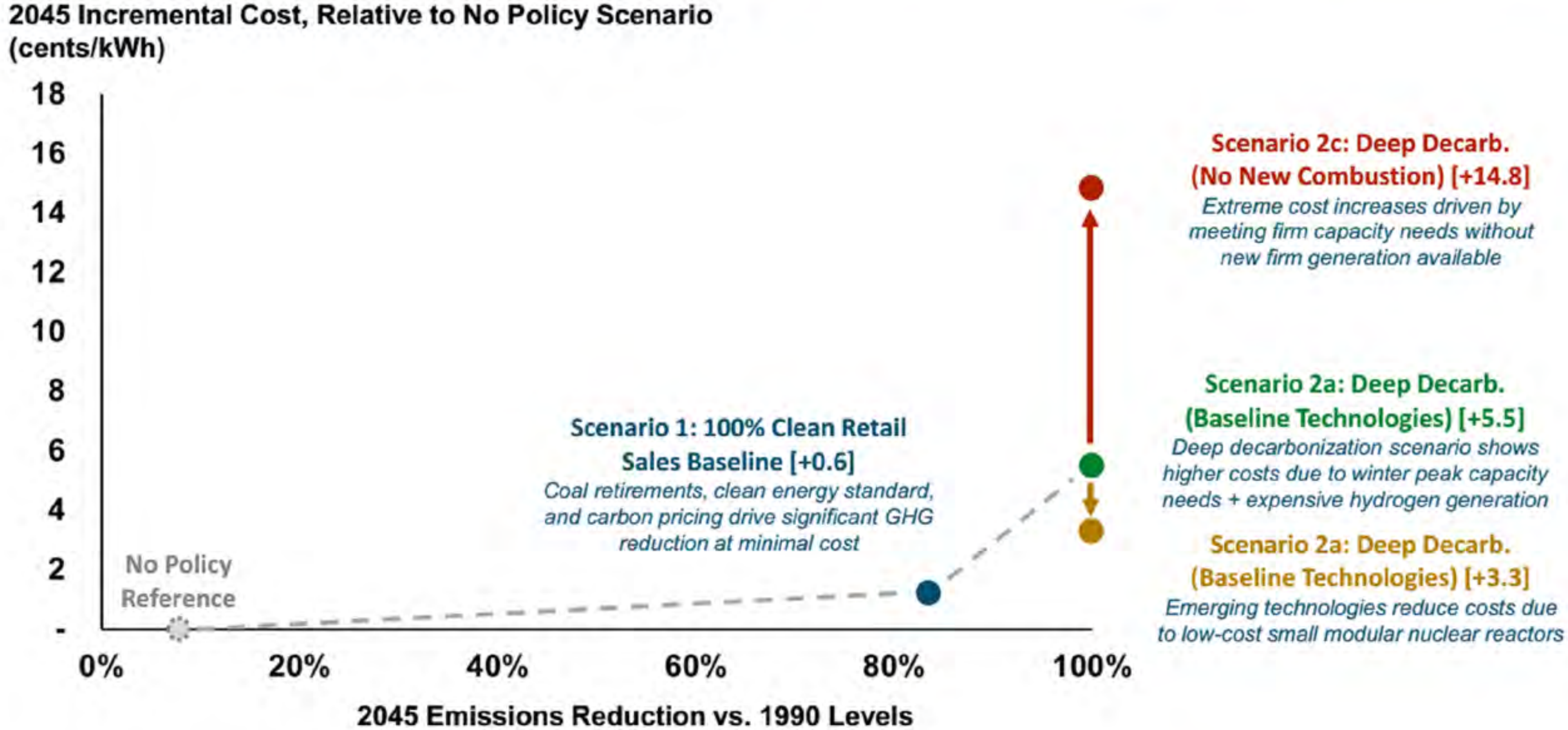
Arne Olson, arne@ethree.com

Aaron Burdick, aaron.burdick@ethree.com



Appendix A: Additional Modeling Results

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

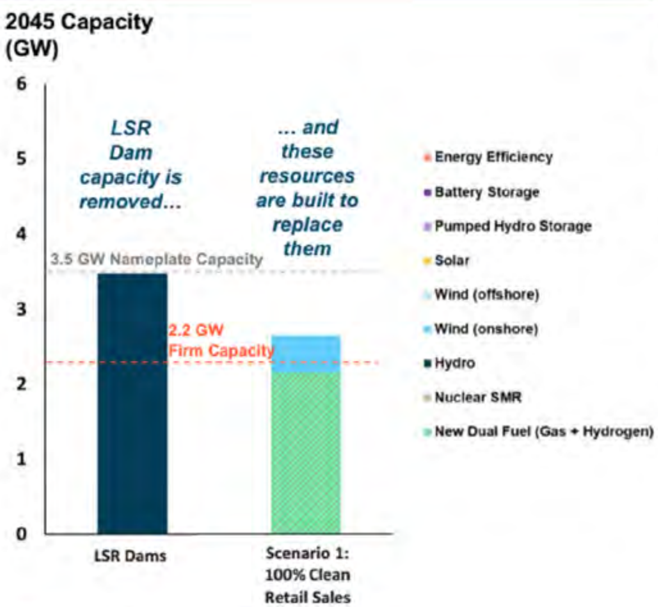


NOTES:
- 2020 average retail rates for OR and WA were 8-9 cents/kWh; 1990 electric emissions were ~33 MMT
- High electrification scenarios would avoid natural gas infrastructure costs, which would offset some of the electric peaking infrastructure cost increase

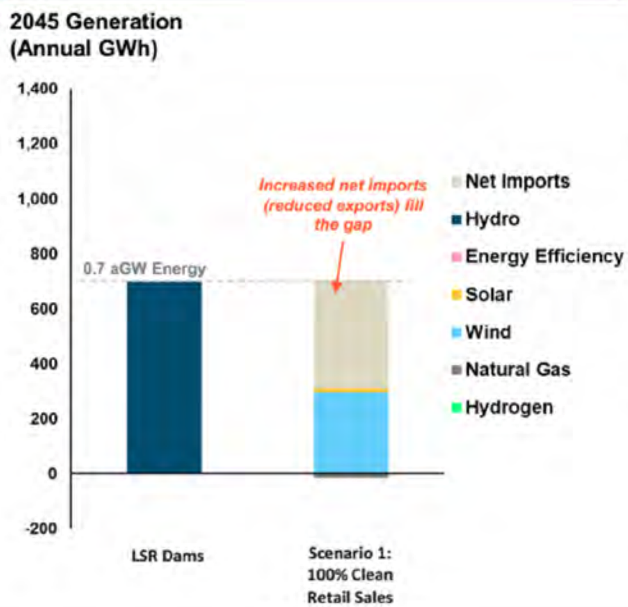
Replacing the Lower Snake River Dams Scenario 1: 100% Clean Retail Sales

- 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

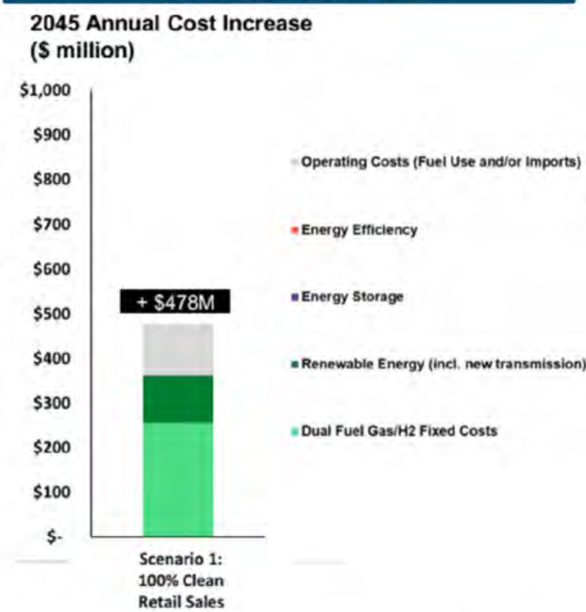
Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)



Additional Cost (2045)



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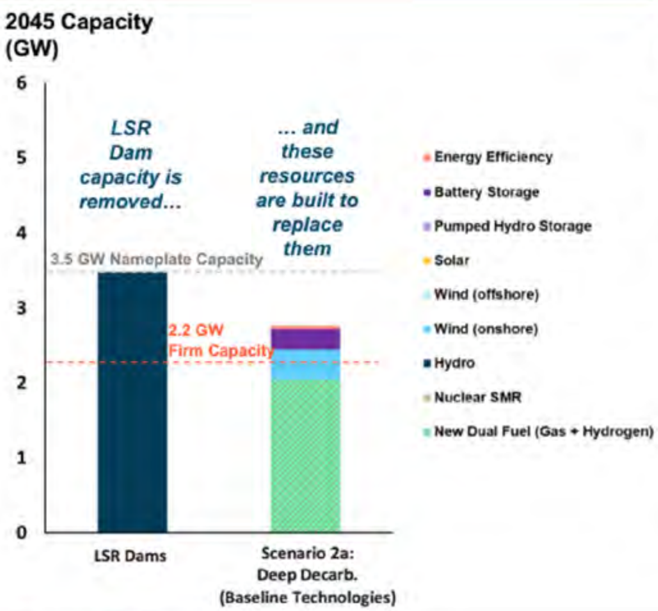
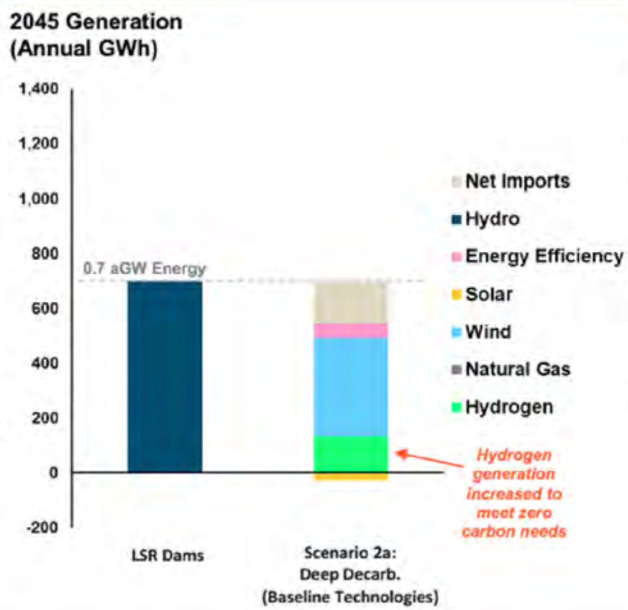
Replacing the Lower Snake River Dams
Scenario 2: Deep Decarbonization (Baseline Technologies)

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

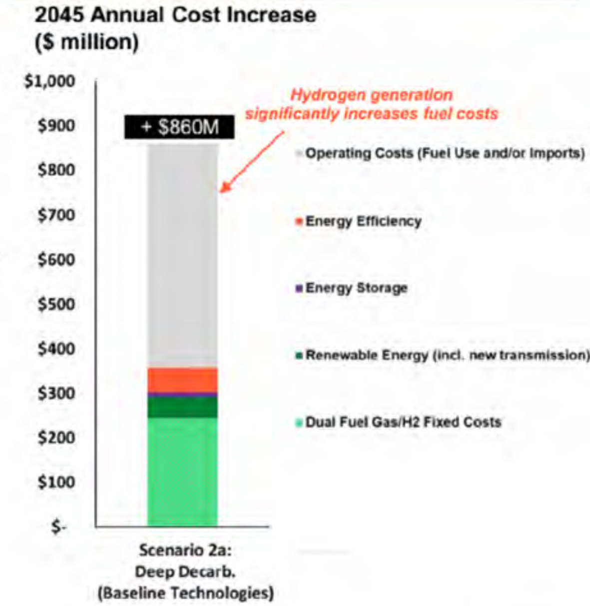
Additional Resources Built to Replace LSR Dams (2045)



Additional Generation to Replace LSR Dams (2045)



Additional Cost (2045)



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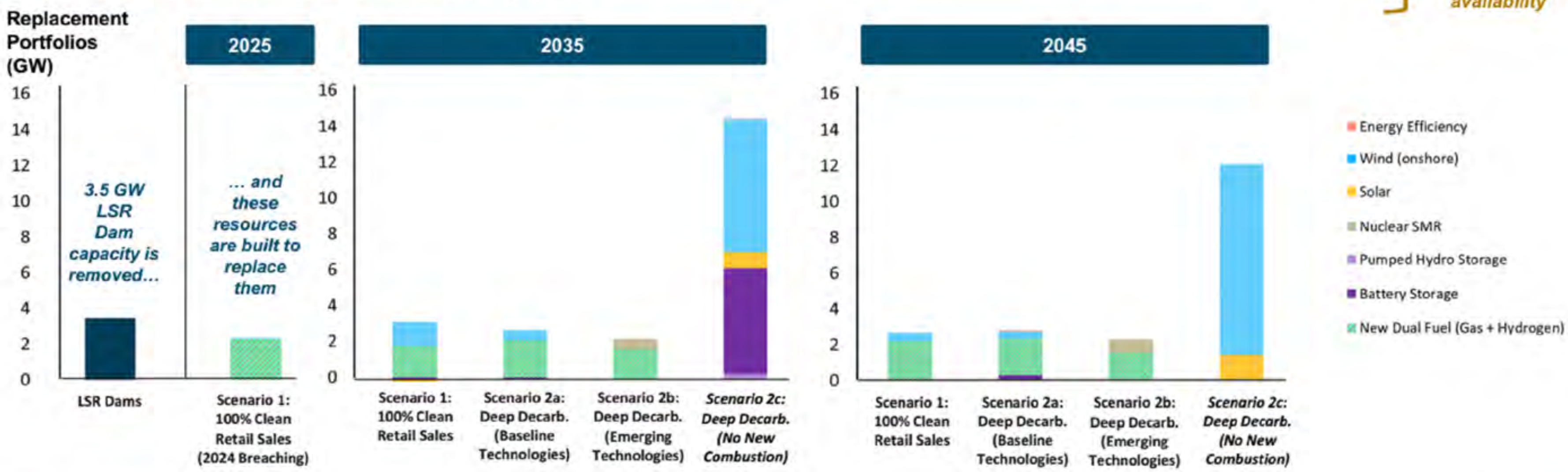
Replacing the Lower Snake River Dams Capacity Across All Scenarios

+ 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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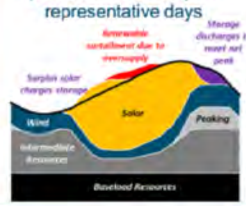
Appendix B: Additional Modeling Inputs

RESOLVE optimizes investments to meet clean energy targets reliably

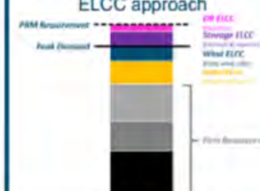
RESOLVE is an optimal capacity expansion model specifically designed to identify least-cost plans to meet reliability needs and achieve compliance with regulatory and policy requirements

- 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

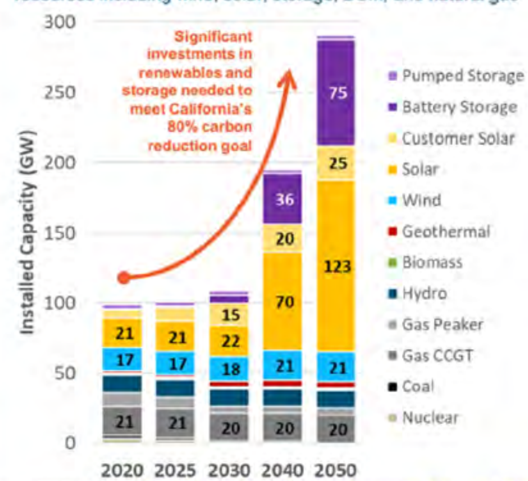
Operational module simulates hourly system operations for a sample of representative days



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)

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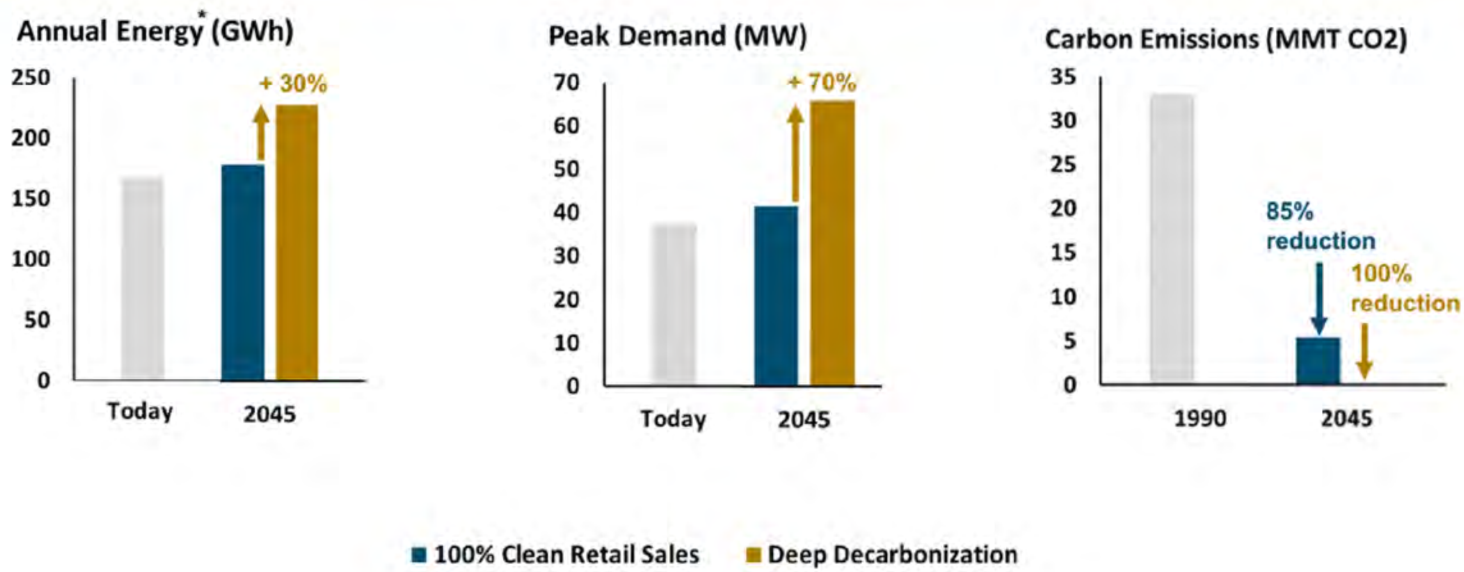
Load growth and carbon emissions in two clean energy scenarios modeled

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)

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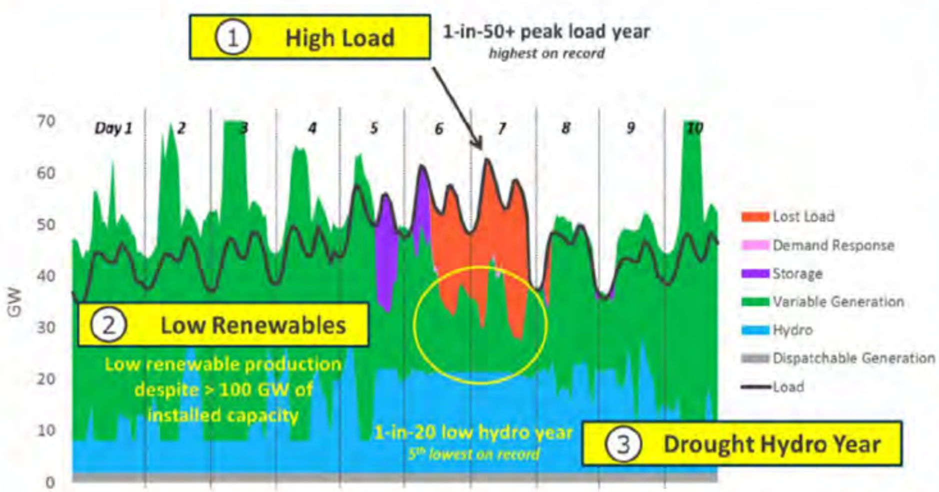
Resource Adequacy Resource Options

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

Key Drivers of Future Pacific Northwest Reliability Events



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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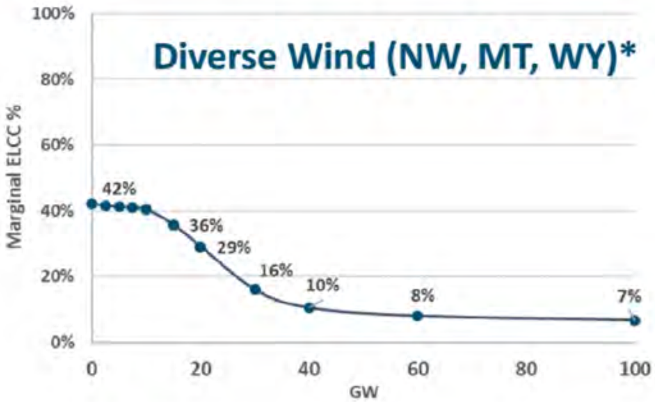
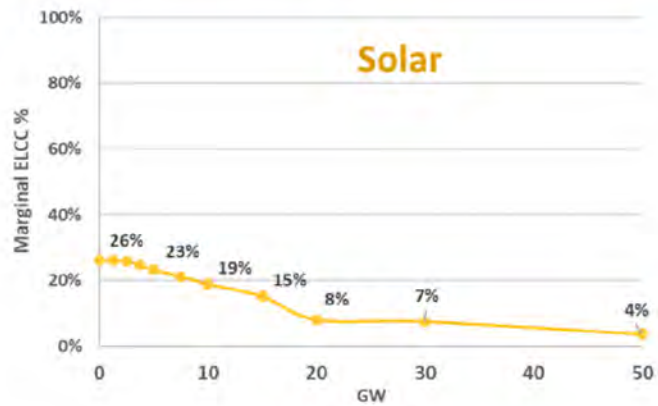
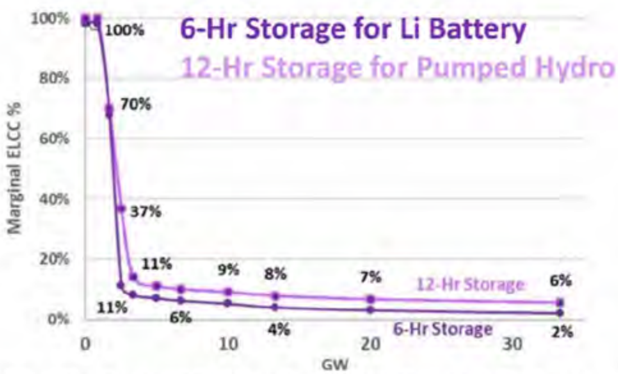
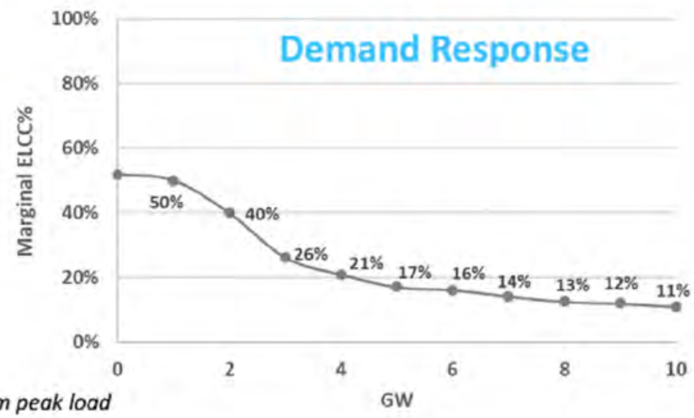
Incorporating Declining Capacity Contributions of Renewables, Storage, and DR









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

* 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.

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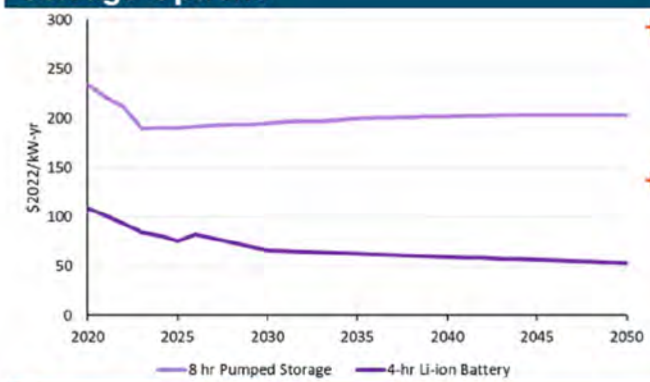
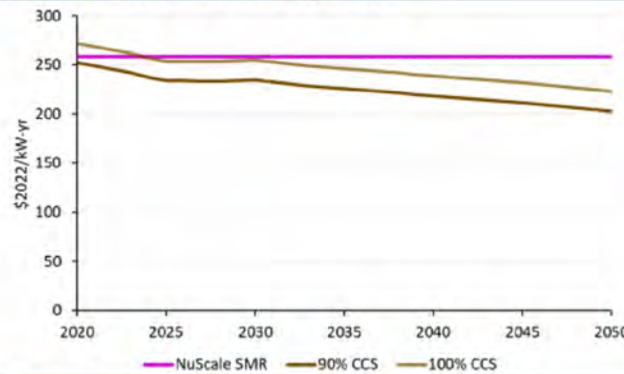
New Resource Options
All-in Fixed Costs

Storage Options



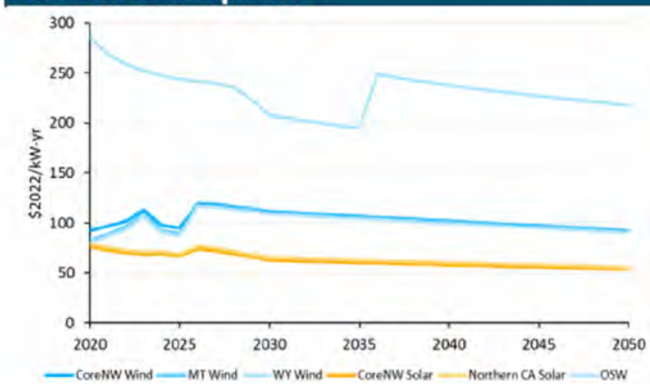
- Battery Storage costs derived from E3's inhouse and Lazard LCOS 7.0 (Oct 2021)
- Pumped storage is from Lazard's last published PHS costs (LCOS 4.0). Assumes CAPEX and FO&M are flat + financing cost trends same for battery storage.

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

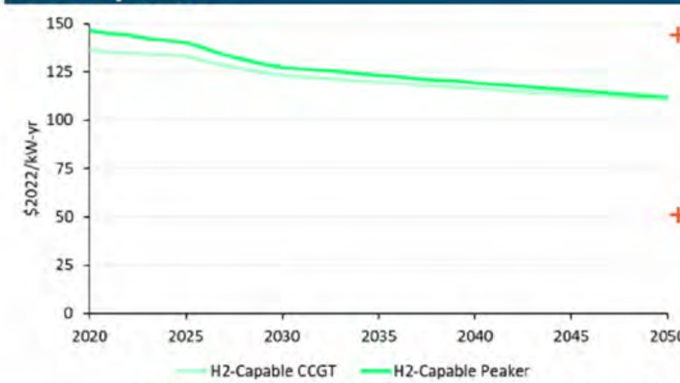
Renewable Options



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



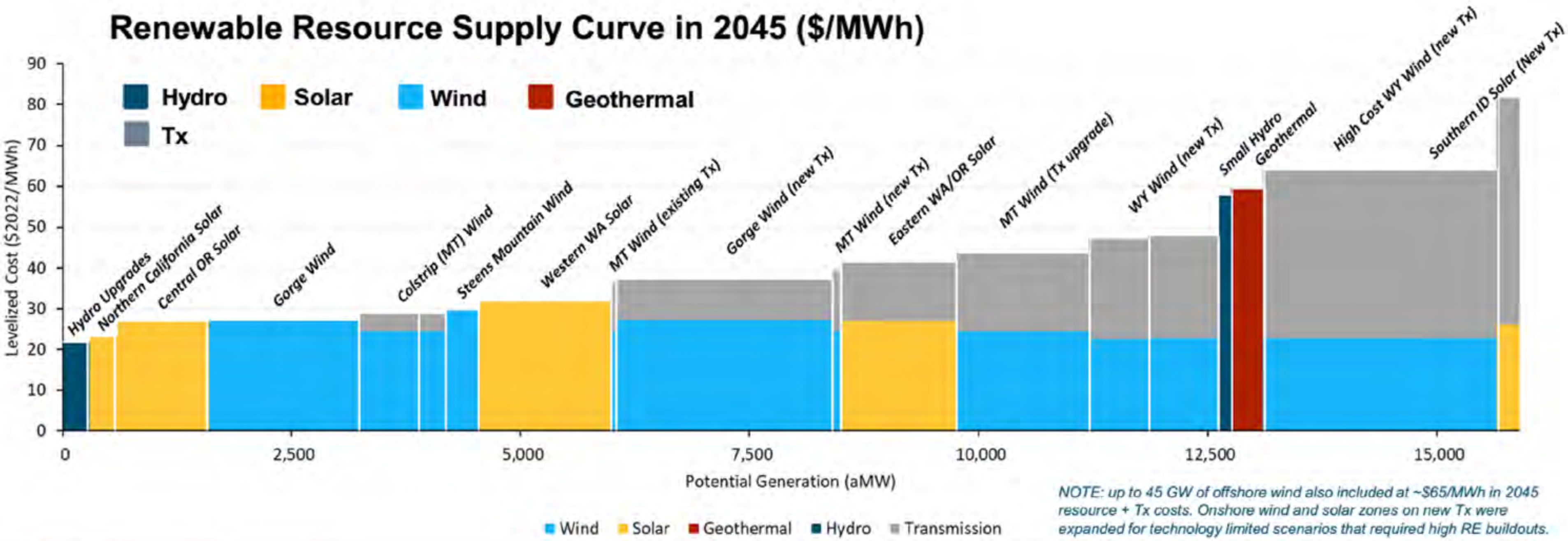
- CCGT and peaker costs are derived from E3's inhouse ProForma which integrates NREL ATB 2021
- New Hydrogen or upgrades include a ~10% additional cost that converges by 2050

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
- 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.

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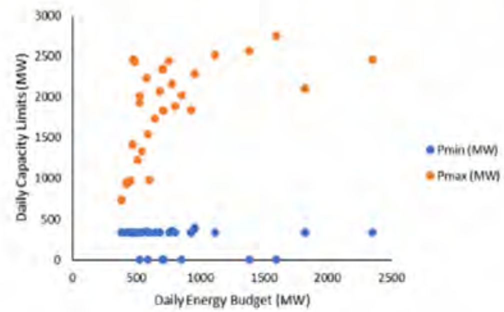
Hydro Operating Data

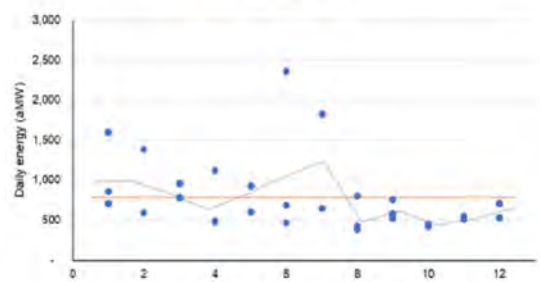
+ **Key RESOLVE inputs (for each representative RESOLVE day)**
  - Max generation MW
  - Min generation MW
  - Daily MWh hydro budget
  - Ramp
+ **Hydro operating data is parameterized using representative conditions for 3 low/mid/high historical years (2001, 2005, 2011)**
  - Lower Snake River and Lower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

LSR Hydro

Ramp Rates

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

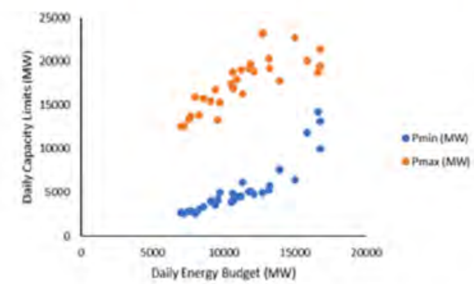


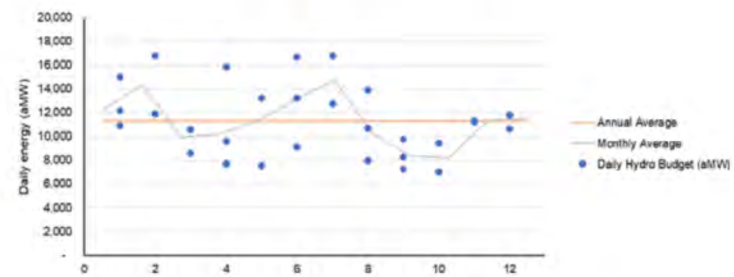


Non-LSR NW Hydro

Ramp Rates

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





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From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Tuesday, April 12, 2022 11:00 AM
To:	Arne Olson; Jack Moore; Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5; Angineh Zohrabian; Sierra Spencer
Subject:	[EXTERNAL] RE: BPA-E3 Check-In

Agenda for our 11am meeting:

1. Task 1 capacity needs: overview + executive summary
2. Task 3 qualitative benefits: preview + request for feedback from BPA
3. Task 2 RESOLVE: preview of initial results
    a. Looking to schedule another briefing on TH or FR to walkthrough a more detailed PPT deck we are currently finalizing

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

Updating series from 30 mins to 1 hr.

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

_~_

-- Do not delete or change any of the following text. --

When it's time, join your Webex meeting here.

Join meeting

More ways to join:

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https://ethree.webex.com/ethree/j.php?MTID=m228a4e26c5b763d73adb84c525782f42

Join by meeting number
Meeting number (access code) (b)(6) [redacted]
Meeting password: c5BSkxM2Sm8

Tap to join from a mobile device (attendees only)
+1-408-418-9388[redacted]## United States Toll

Join by phone
+1-408-418-9388 United States Toll
Global call-in numbers

Join from a video system or application
Dial [redacted]@ethree.webex.com
You can also dial 173.243.2.68 and enter your meeting number.

If you are a host, click here to view host information.

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

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Friday, March 25, 2022 11:10 AM
To:	James,Eve A L (BPA) - PG-5; Riley,Erin A (BPA) - PGPR-5
Cc:	Angineh Zohrabian; Koehler,Birgit G (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5; Egerdahl,Ryan J (BPA) - PGPR-5; Sierra Spencer; Arne Olson; Jack Moore
Subject:	[EXTERNAL] RE: BPA-E3 Check-In - 3-22 action items

Deliberative; FOIA-exempt

Hi Eve,

Angineh has used replaced our historical hydro hourly output for the plants provided by Erin. This means our min/max gen and daily MWh budgets will be updated accordingly, to align with the latest spill requirements. This is the baseline set of hydro assumptions we plan to start modeling in RESOLVE. Angineh or I will share an updated summary document shortly.

If we decide later to model a "no updated spill constraint" sensitivity as Birgit suggested, would switching back to our historical data suffice to capture that difference in max gen and daily MWh?

All the best,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, March 25, 2022 8:13 AM
To: Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>
Subject: RE: BPA-E3 Check-In - 3-22 action items

Deliberative; FOIA-exempt
Thanks for sending this along while I was out of the office Erin.

Aaron let me know if this covers what you need- I am available today except for 1 – 2 PM if you need to call and talk through anything.

Thanks,
Eve

From: Riley,Erin A (BPA) - PGPR-5 <eariley@bpa.gov>
Sent: Wednesday, March 23, 2022 8:11 AM
To: aaron.burdick@ethree.com
Cc: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Egerdahl,Ryan J (BPA) - PGPR-5 <rjegerdahl@bpa.gov>
Subject: BPA-E3 Check-In - 3-22 action items

Deliberative; FOIA-exempt

Hi Aaron,

I've attached some hourly modeled output for the CYs you requested that I have on the shelf. See if that will suit your needs to create your pmin/ pmax curves.

These data are initialized from a monthly model, that monthly model has split Aprils & August, the second halves begin on the 16th. The incremental flows are interpolated from the monthly flows, so there is a smoothed component relative to actuals. You will notice that the diurnal pattern has a monthly change, this is part of that modeling: the shape of coulee is modeled after actual shaping in recent operations, and the daily peak power shaping is based on maximizing value during peak loads/ prices. The model is not provided with prices, it is provided hours during which to peak. There is some shaping to load in our forebay requests, but inherently the underlying logic assumes unlimited purchases and sales. There is a breakout in the data of the reserves that the projects are holding.

This model reflects the spill in the 2020 EIS: 125% flex spill.

Data notes: The model was run on the FY, as indicated by the "trace" column. For CY I provided the Oct-Dec of the following FY trace. I did not correct the date to be continuous because:

This model simulation, generation is peaking during these dates in the datetime column:

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

Depending on your analysis you might want to include or exclude these. For the weather events, we draft coulee 3 days fairly aggressively, then target coulee to be back on track over the next week. In particular, you might want to exclude July 3-5 as I think this operation might be violating July4 holiday targets.
I can also re-run to exclude this logic.

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

Please let me know if you need data based on actuals instead.

The attached data are only for the purpose of the contracted work. Thank you.

Best,

Erin

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, March 22, 2022 12:57 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian

<angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] BPA-E3 Check-In - 3-22 action items

Deliberative; FOIA-exempt

Action items from today's check in:

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

Many thanks,

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

Erin Riley
Operations Research Analyst
PGPR- Long Term Power Planning
Bonneville Power Administration
503-230-3717

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Wednesday, March 2, 2022 12:13 PM
To:	Koehler,Birgit G (BPA) - PG-5; James,Eve A L (BPA) - PG-5
Cc:	Jack Moore; Arne Olson
Subject:	[EXTERNAL] RE: BPA-E3 Project Check-Ins

Thanks for the quick response. I'll set up a check in for next Wed and then a recurring check in for Tuesdays after that.

All the best,
Aaron

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Wednesday, March 2, 2022 11:21 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Aaron Burdick <aaron.burdick@ethree.com>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3 Project Check-Ins

Tuesday at 11 works best for me as well. Wed at 4 is OK. Thursdays at 2 I would have a couple of weeks when I am not available.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Wednesday, March 2, 2022 10:54 AM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: BPA-E3 Project Check-Ins

Hi Aaron-
Tuesday at 11 or Thurs at 2 work best but I can make Wed at 4 work if needed. Could you also please add rjdiffely@bpa.gov to your meeting invitation as well?

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Wednesday, March 2, 2022 10:41 AM
To: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] BPA-E3 Project Check-Ins

Hi Birgit and Eve,

Nice to meet you virtually and looking forward to discussing this project soon. I'll be the PM on the E3 side. I've been coordinating with Melissa on the contract and, after some back and forth, she should have what she needs now.

I would like to set up a weekly check-in starting next week and going through mid-April as we focus on the draft deliverables for tasks 1-3. Tuesday at 11am, Wednesday at 4pm, or Thursdays at 2pm would work well for myself/Arne/Jack. Do any of these times work well for your team? (Arne is out next Tue, so at least next one the Wed or Thurs slots work better.)

Let me know if there are any other staff from BPA I should include when sending out the invite.

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:	Arne Olson <arne@ethree.com>
Sent:	Tuesday, July 12, 2022 2:12 PM
To:	James,Eve A L (BPA) - PG-5; Aaron Burdick; Koehler,Birgit G (BPA) - PG-5
Subject:	[EXTERNAL] RE: E3 presentation to Departments and Agencies

Yes we have that on our calendars.

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, July 12, 2022 1:58 PM
To: Arne Olson <arne@ethree.com>; Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: E3 presentation to Departments and Agencies

Hi Arne and Aaron-
I'm back in the office and still catching up on things I missed. I want to make sure you have a hold on your calendar for Thursday at 11 AM. CEQ would like to have a presentation to the departments and agencies on the analysis that was released this morning. My understanding is that E3 will go first and then someone from NOAA or FWS will cover the salmon document. Let me know ASAP if there are any issues with that timeslot.

See you at 3:30!

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
Cc: Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian; Arne Olson
Subject: [EXTERNAL] RE: Draft Exec Summary
Attachments: BPA Final Report_Draft_v2.docx

Deliberative, FOIA exempt

Eve,

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

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

All the best,
Aaron

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

Deliberative, FOIA exempt

Eve,

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

All the best,
Aaron

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

Deliberative, FOIA exempt
Hi Aaron-

Attached are some comments on the Executive Summary for your consideration.

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

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, June 24, 2022 3:12 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] Draft Exec Summary

Deliberative, FOIA exempt

Hi Eve,

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

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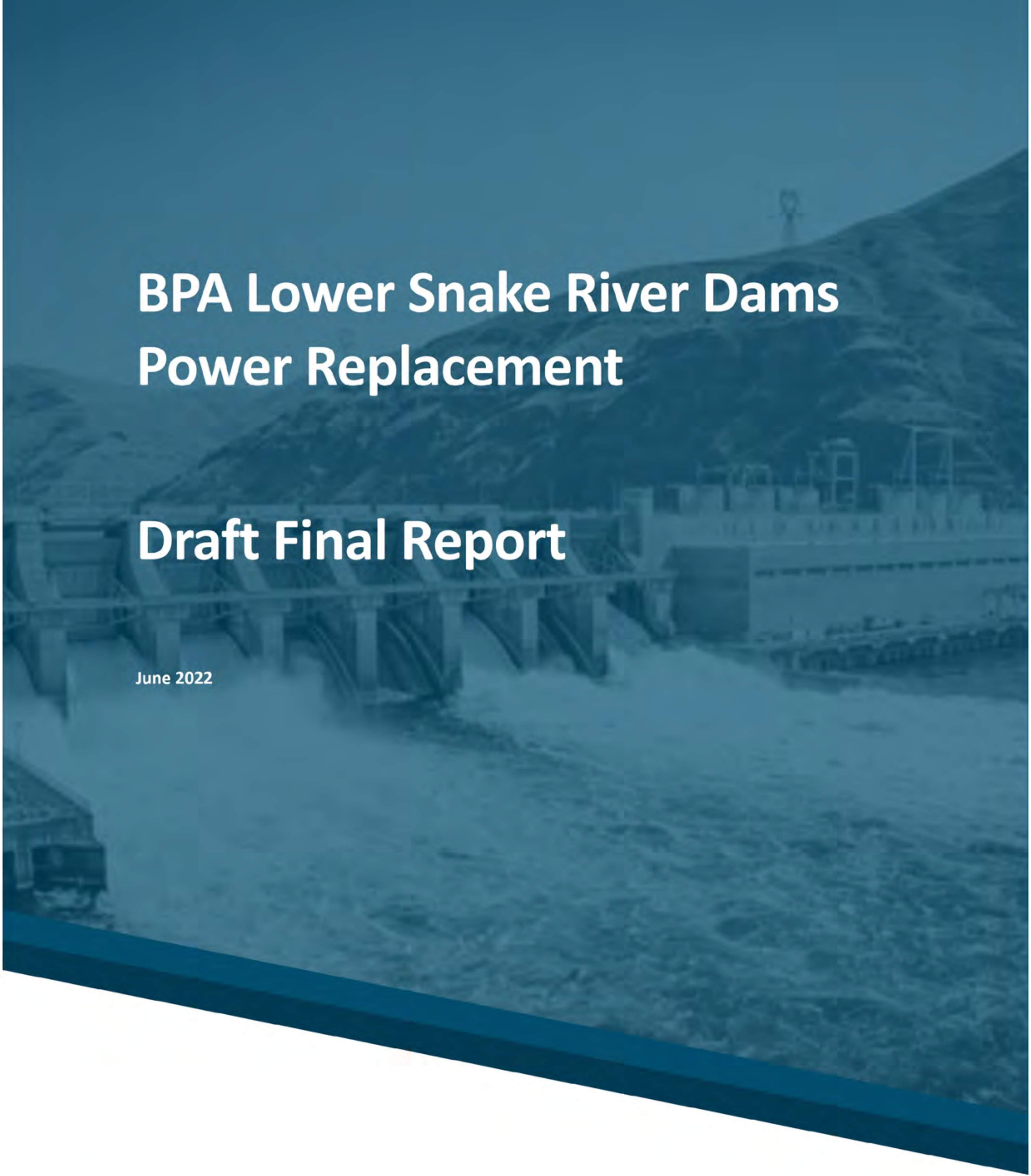
All the best,

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

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



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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Project Team:

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Aaron Burdick

Sierra Spencer

Dr. Angineh Zohrabian

Sam Kramer

Jack Moore

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Acronym and Abbreviation Definitions

Acronym	Definition
LSR	Lower Snake River
NW	Northwest
CA	California
NV	Nevada
SW	Southwest
RM	Rocky Mountains
WECC	Western Electricity Coordinating Council
ELCC	Effective load carrying capability
DR	Demand response
PRM	Planning Reserve Margin
BPA	Bonneville Power Administration
PNUCC	Pacific Northwest Utilities Conference Committee
CES	Clean Energy Standard
NERC	North American Electric Reliability Corporation
CCS	Carbon capture and storage
SMR	Small modular reactor
CCGT	Combined cycle gas turbine
EE	Energy efficiency

Executive Summary

E3 was contracted by the Bonneville Power Administration to conduct an independent study of the value of the lower Snake River dams ("LSR dams") to the Northwest power system. The dams provide approximately 3,500 megawatts ("MW") of total capacity[1] and over 2,200 MW of firm peaking capability[2] to support regional reliability. They also generate approximately 900 average MW of zero-carbon energy each year, provide essential grid services such as operating reserves and voltage support, and their operational flexibility helps support renewable integration. If the dams are breached, these power services will need to be replaced to ensure the Northwest power system can continue to provide reliable electricity service. Replacing the dams is complicated by the clean energy policies adopted either statutorily or voluntarily by jurisdictions and utilities throughout the region, which will necessitate a transformation of the power system over time toward non-emitting resources even as electricity demand grows substantially due to electrification of the transportation and building sectors.

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. 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. RESOLVE calculates optimal investment and operations for each scenario to enable the "Core Northwest" region – consisting of

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

---

[1] Hydro traditionally operates above nameplate an
peak generation values in hydro licensing. The "t
Historical peak generation was 3,431 MW.

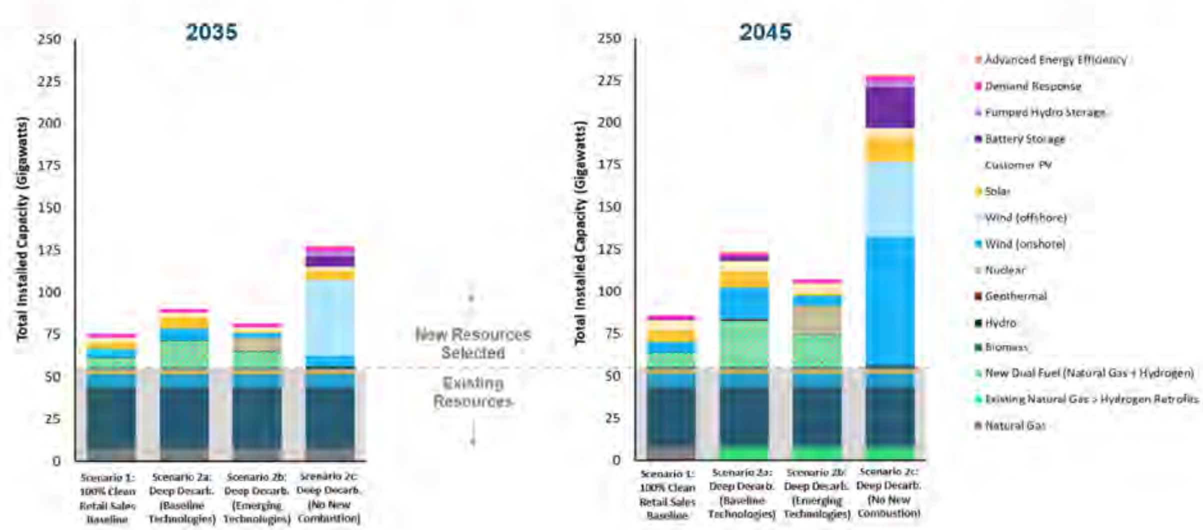
[2] LSR dam firm capacity contributions were estimat
validated by looking at LSR Dam wintertime pow
considered estimates on the impact of a lower firm capacity value in section 4.3.

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.

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) 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 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 also added to meet the region's resource adequacy needs.

Though all scenarios require more "firm capacity" resources – resources that can start when needed and operate for as long as needed – to meet higher winter peak demand, these resources are in higher demand in Scenario 2, in which all greenhouse gas emissions are eliminated from the regional power system by 2045, while electrification results in much higher electric loads. Higher wintertime peaks are driven by electrification of natural gas space heating in the buildings that drives wintertime reliability needs. 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 small modular nuclear reactors ("SMRs") by 2045, in lieu of selecting the firm capacity provided by natural gas generators while reducing the required quantities of wind, solar and batteries. 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



If the generation from the dams is 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 burn additional hydrogen on low wind days to replace the carbon-free energy provided by the dams. Scenario 2b selects nuclear SMRs in lieu of selecting some of the wind and gas plant additions. 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 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 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

Scenario	Replacement Resources Selected, Cumulative by 2045 (GW)	NPV Replacement Costs[3]	Annual Replacement Costs[4]			Public Power Rate Impact[5]
			2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind	$7.4 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	$8.6 billion	$495 million/yr	$466 million/yr	$509 million/yr	0.8 ¢/kWh [+9%]
Scenario 2a: Deep Decarbonization	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery	$11.3 billion	-	$496 million/yr	$860 million/yr	1.5 ¢/kWh [+18%]

[3] 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.

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

[5] 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.

(Baseline Technologies)	+ 0.4 GW wind + 0.05 GW advanced EE + 1.2 TWh H2-fueled generation					
Scenario 2b: Deep Decarbonization (Emerging Technologies)	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR	$6.7 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	$46 billion	–	$1,953 million/yr	$3,199 million/yr	5.5 ¢/kWh [+65%]

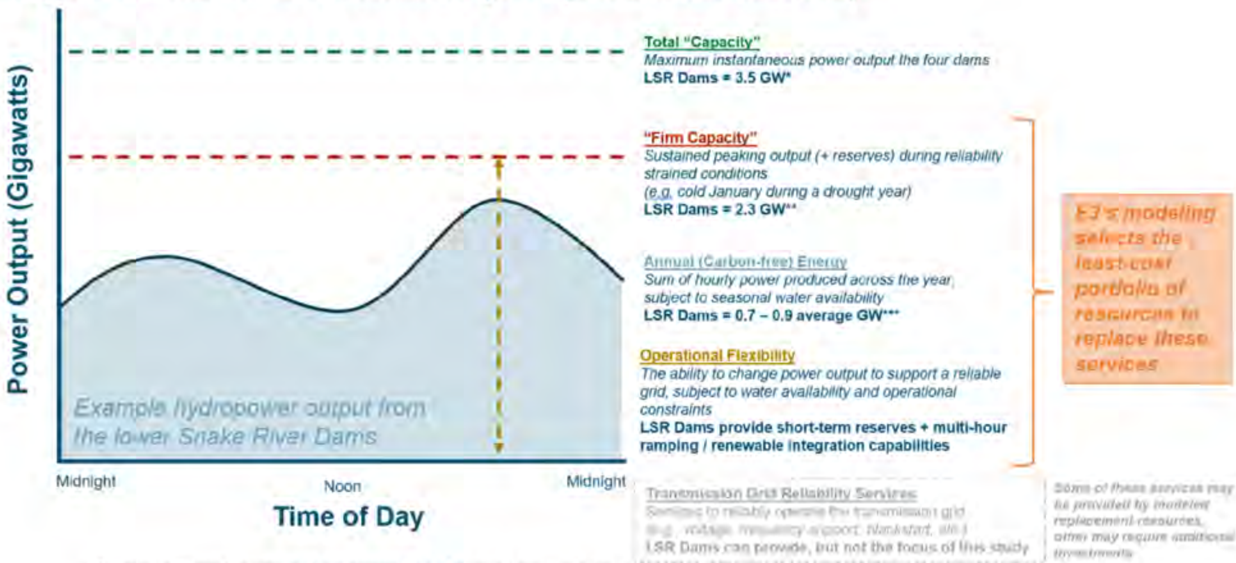
KEY FINDINGS:

- ***Replacing the four lower Snake River dams while meeting clean energy goals and system reliability is possible but comes at a substantial cost***, even assuming emerging technologies are available:
    - Requires 2,300 – 2,700 MW of replacement resources
    - An annual cost of $415 million – $860 million by 2045
    - Total net present value cost of $6.7 – 11.3 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)

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 and the replacement resource needs and costs if the dams were breached. The dams are ~3,500 MW of total capacity[6] 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. Figure 2 shows the power services that were the focus of this study and those that were out of scope.

Figure 2. Power Services Considered for Replacement in this Study



* Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. Historical peak generation was 3,431 MW.

** Firm capacity assumed in this study is consistent with the ~65% Northwest hydro capacity value assumed by PNUCC (the Pacific Northwest Utilities Conference Committee).

[6] 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.

*** 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.

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.

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 included ensuring that the region meets its aggressive clean energy policy goals, including both decarbonization of electricity, as well as scenarios of 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 was 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.

This modeling framework ensures that when the LSR dams are not modeled in the Northwest power system, a least-cost replacement mix of new investments and operational changes is found. Through the constraints of the optimization, this least-cost replacement mix meets the same clean energy policy and level of reliability as a system with the LSR dams still intact. This dynamic approach considers replacement resource needs in the context of the evolving long-term system load and policy drivers, not just the near-term resource mix and needs of the system today. It recognizes that significant levels of new renewable energy and other resources are already needed to meet long-term regional needs, ensuring that the replacement resource mix selected is incremental to the long-term buildout, not just an interim solution before clean energy policies reach their apex in the 2040's.

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 understanding 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, per legislative decree, coal power must be phased out in the Northwest during this decade and carbon will be priced via a market-based cap-and-trade mechanism. 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 who 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. The list of policies for the Northwest and California is summarized in Table 3.

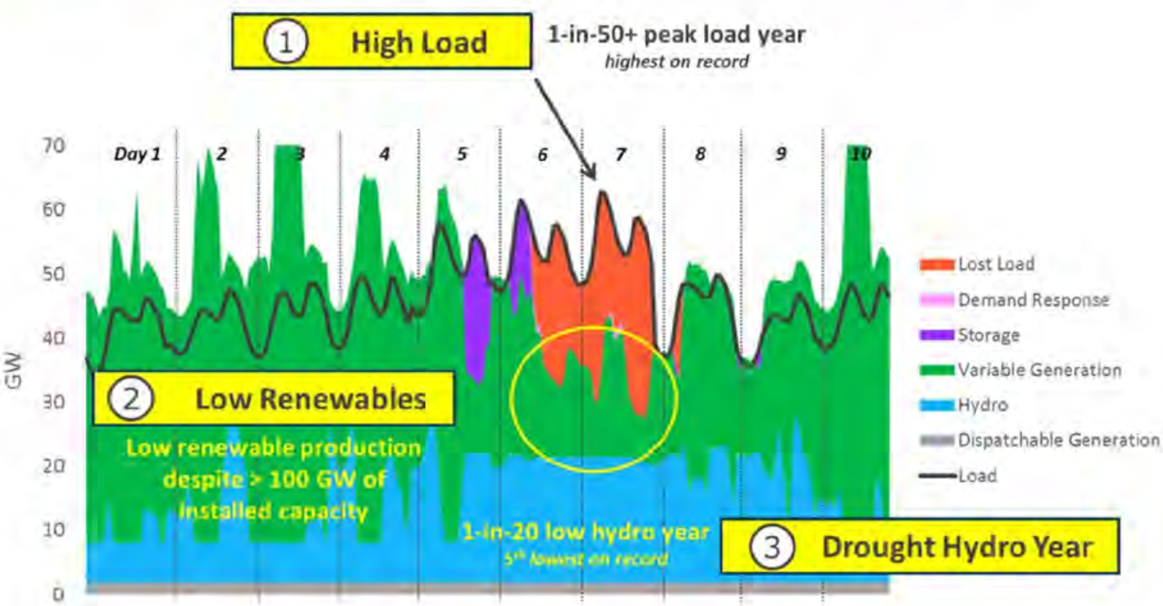
Table 3. Policy landscape in Washington, Oregon, and California

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

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.[7] 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 the more of them are added (the decline in capacity contributions of these resources is known as "saturation effects"). Figure 3 shows a graph from E3's 2019 study that illustrates the key drivers of reliability in a decarbonized grid: high load, low renewables, and low hydro conditions. Unlike a summer peaking *capacity constrained* system like the desert southwest, these conditions make it particularly challenging for battery storage to replace the Northwest's firm capacity resources, since batteries are unable to charge during *energy constrained* periods of low renewable energy and low hydro availability. The study concluded therefore that additional firm generating capacity may be needed, even in scenarios that add significant amount of non-firm solar, wind, batteries, and demand response. The resource adequacy constraints in RESOLVE and the capacity value of LSR dam replacement resource options are described in section 3.4.6.

Figure 3. Key Drivers of Pacific Northwest Reliability Events in a Decarbonized Grid



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

Since the 2019 study, "emerging" technologies are increasingly seen as potentially viable option to reduce all of the carbon emissions in the Northwest. "Clean firm" resources like green hydrogen, gas with carbon capture and storage, and nuclear small modular reactors provide the firm capacity necessary to backup renewable resources and can provide the zero-carbon energy needed on low renewable days to operate a zero-carbon grid. While their costs and commercialization trajectories remain uncertain, this LSR dams replacement study considers various scenarios of their availability.

Table 4. Summary of Resource Adequacy Capacity Contributions of LSR Dam Replacement Resource Options

Replacement Resource Option	RA Capacity Contributions
Battery storage	Sharply declining ELCCs
Pumped storage	Sharply declining ELCCs
Solar	Declining ELCCs
Wind	Declining ELCCs
Demand Response	Declining ELCCs
Energy Efficiency	Limited potential vs. cost
Small Hydro	Limited potential
Geothermal	Limited potential
Natural gas to H2 retrofits	Clean firm, but not fully commercialized
New dual fuel natural gas + H2 plants	Clean firm, but not fully commercialized
New H2 only plants	Clean firm, but not fully commercialized
Gas w/ 90-100% carbon capture + storage	Clean firm, but not fully commercialized
Nuclear Small Modular Reactors	Clean firm, but not fully commercialized

2.3 Scenarios Modeled

This study focuses on three key variables (clean energy policy, load growth, and emerging technology availability) that impact the cost to replace the dams.

Clean Energy Policy

Clean energy policy for the electric sector was 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 requires ~85% carbon reduction compared to 1990 levels by 2045. 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 was modeled, based on the forecast in the NWPCC 8th Power Plan. A second high electrification scenario was developed based on the high electrification case in the Washington State Energy Strategy.[8] Based on E3's analysis of the electrification of transportation, buildings, and industry in that study, this scenario results in an additional annual energy increase of 28% by 2045 (above the baseline scenario) and an additional winter peak demand increase of 68%. The peak demand increase is high due to the electrification of space heating end uses, which requires replacing the gas system winter peaking capacity with electric system winter peaking capacity.

Technology Availability

It was 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 included "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 were developed as follows:

1. **Baseline technologies**: mature technologies and dual fuel natural gas + hydrogen combustion plants
2. **Emerging technologies**: mature technologies, dual fuel natural gas + hydrogen combustion plants, small modular nuclear reactors, natural gas with carbon capture and storage, and floating offshore wind
3. **No new combustion**: mature technologies and floating offshore wind

All scenarios assume that the existing natural gas capacity fleet can convert to green hydrogen powered zero-carbon fuels, and hence are focused on the key technologies to serve the resource adequacy needs of firm resource retirements and load growth.

Table 5. Scenario Design shows a summary of the four scenarios that were the focus of this study.

Table 5. Scenario Design

Scenario	Clean Energy	Load Growth	Technology

[8] See Washington State's *2021 State Energy Strategy*, https://www.commerce.wa.gov/growing-the-economy/energy/2021-state-energy-strategy/

	Policy		Availability
1 100% Clean Retail Sales[1]	100% retail sales (85% carbon reduction)	8^{th} Power Plan Baseline	Baseline (incl. natural gas / hydrogen dual fuel plants)
2a Deep Decarbonization (Baseline Tech.)	100% carbon reduction	High Electrification	Baseline
2b Deep Decarbonization (Emerging Tech.)	100% carbon reduction	High Electrification	Baseline + offshore wind, gas w/ CCS, nuclear SMR
2c Deep Decarbonization (No New Combustion)	100% carbon reduction	High Electrification	Baseline (excluding natural gas / hydrogen dual fuel plants)

3 Modeling Approach

3.1 RESOLVE Model

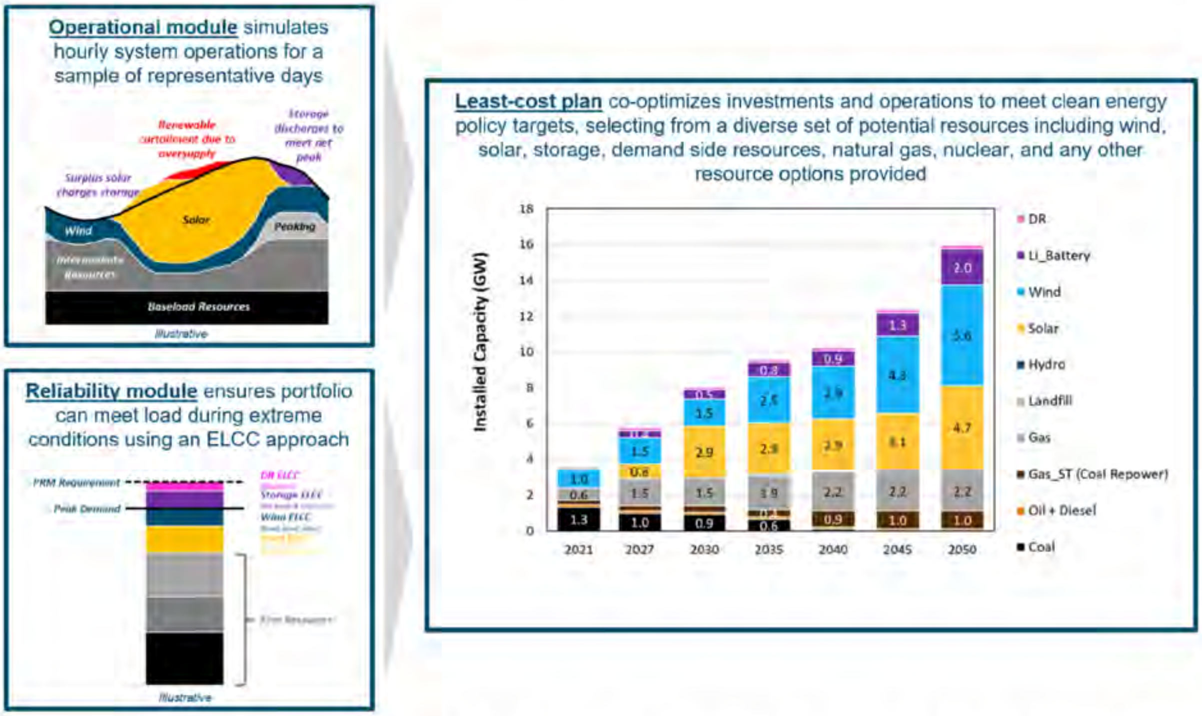
E3 used its Renewable Energy Solutions Model (RESOLVE) to perform a portfolio optimization of Northwest system's electric generating resource needs between 2025 and 2045. RESOLVE is an optimal capacity expansion and dispatch model that uses linear programming to identify optimal long-term generation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

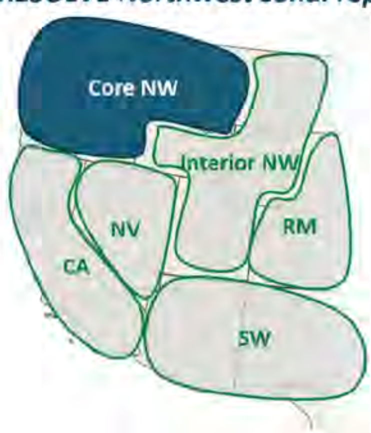
The Northwest RESOLVE model was developed in 2017 for E3's *Pacific Northwest Low Carbon Scenario Analysis* study.[9] It uses a zonal transmission topology to simulate flows among the various regions in the Western Interconnection. In this study, RESOLVE is designed to include six zones: the Core Northwest 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 predominantly Washington and Oregon, with a small portion of Idaho and Montana loads that covers

[9] 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

the loads of BPA and Avista in those states. Note that this study's footprint is slightly different from the Northwest Regional Planning Area established by the Pacific Northwest Electric Power Planning and Conservation Act, in order to focus on regions with more progressive decarbonization policies. The remaining balancing authorities outside of the Core Northwest are grouped into five additional zones: (1) Other Northwest, (2) California, (3) Southwest, (4) Nevada and (5) Rockies. For these zones, investments are not optimized; rather, the trajectory of new builds is forced in 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. E3's WECC-wide resource mix incorporates aggressive climate policy across the interconnection, as described in section 3.4.2.

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.

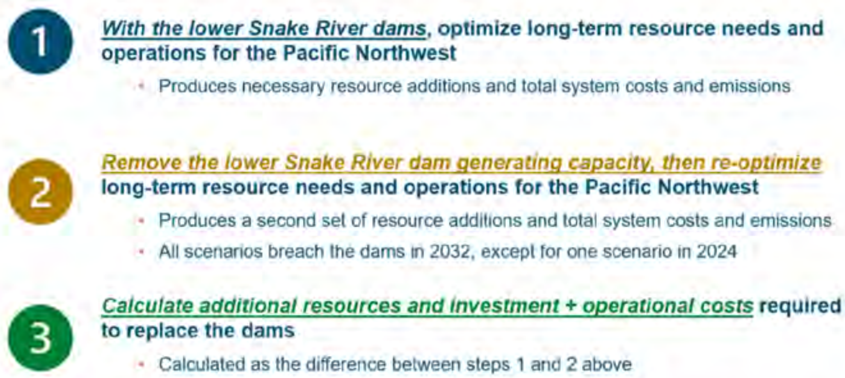
Figure 5. RESOLVE Northwest zonal representation



3.3 LSR Dams Modeling Approach

The four LSR dams are modeled aggregated as one single 3.5 GW hydro resource within the Core Northwest zone in RESOLVE. 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. Only one sensitivity assumes an earlier retirement of LSR dams, in 2024. 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.[10] NPV replacement costs were calculating using a 5% real discount rate; a sensitivity table showing the use of a 3% discount rate is provided in the appendix. A 5% real discount rate is consistent with the expected weighted average cost of capital (WACC) of investor-owned utilities in the Northwest, but a public power utility (such as BPA customers impacted by LSE dams' replacement costs) would typically have a lower cost of capital due to a greater share of debt financing.

Figure 6. Modeling Approach to Calculate the LSR Dams Replacement Resources and Costs



This modeling approach inherently considers the benefits of avoiding the LSR dams ongoing fixed and variable costs. The costs associated with breaching the LSR dams themselves are not included in this study. Other power services (i.e., transmission grid reliability services provided by the dams) are also not included but are summarized qualitatively in the Appendix.

[10] 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.

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, we modeled a high Electrification scenario 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, load grows by about 28% by 2045 across all sectors, most noticeably in commercial and transportation 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 were modeled in RESOLVE by scaling normalized hourly shapes with annual energy forecasts. The normalized shapes were adopted from a 2017 E3 study *PNW Low Carbon Scenario Analysis.*[11]

Figure 7. Annual energy load forecasts for Core Northwest

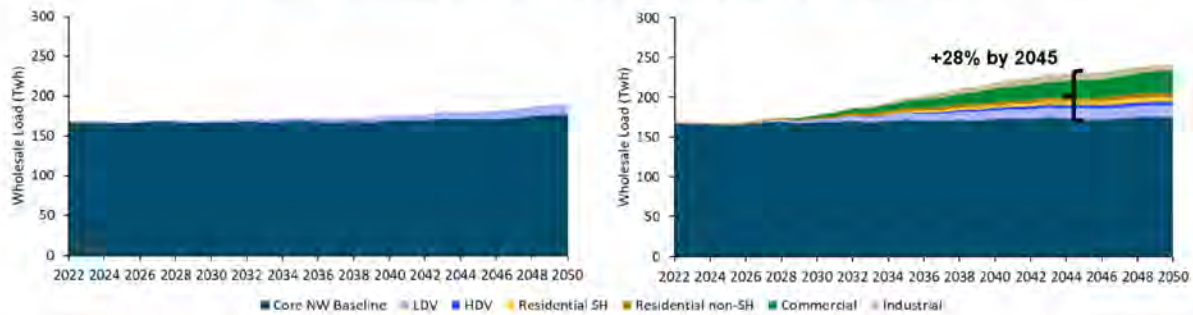
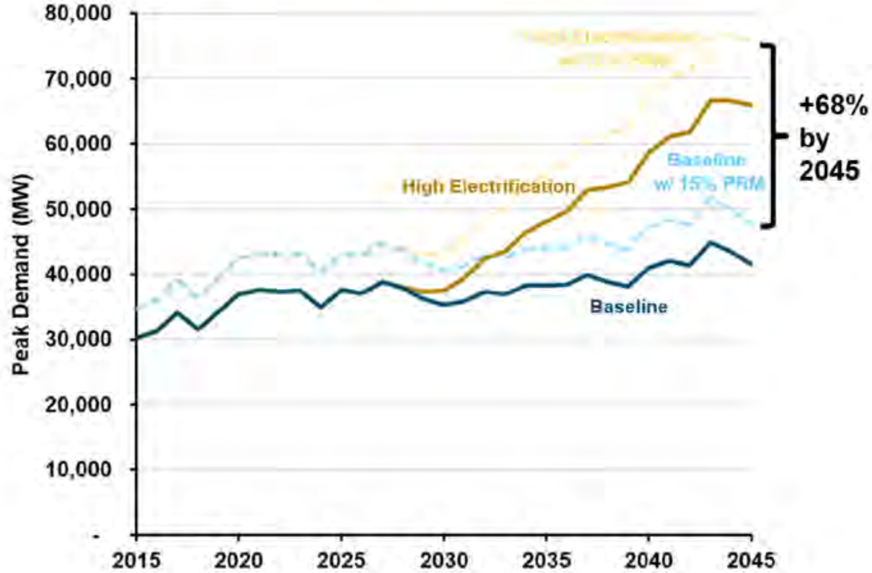


Figure 8 shows the peak demand impacts (including the 15% planning reserve margin) of the high electrification case relative to the baseline, showing a 68% increase by 2045. This high growth is driven by the winter peaking capacity required to replace the gas system peaking capacity to serve peak space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

[11] 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

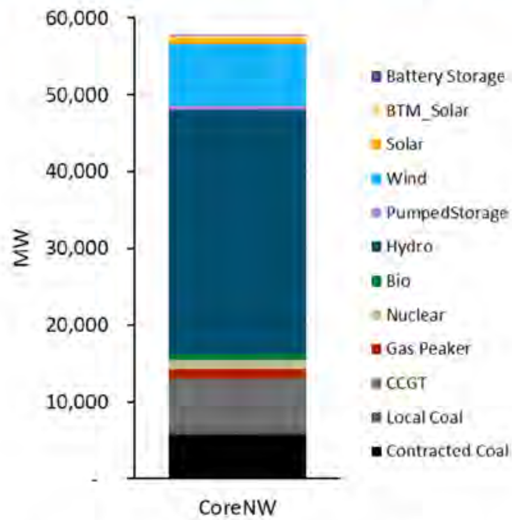
Figure 8. Peak demand forecasts for Core Northwest



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 coal is retiring by 2030. The WECC 2020 Anchor Data Set was used for Northwest's existing and planned resources. By 2045, about 5.8 GW additional customer PV was included as planned capacity to capture the growth in behind-the-meter generation forecasted in NWPCC 2021 Power Plan.

Figure 9. Northwest resource capacity in 2022

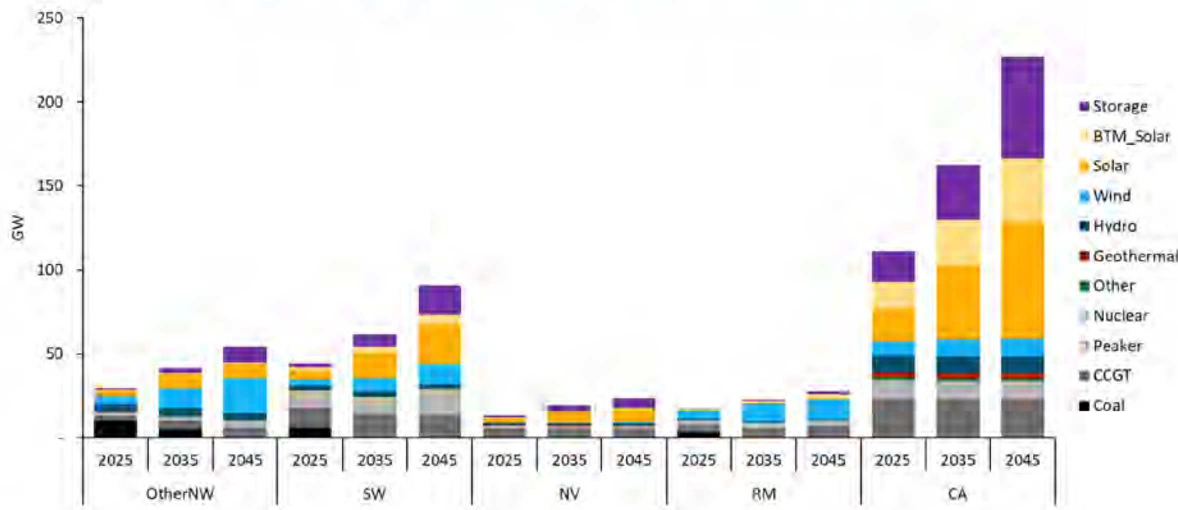


The investment decisions for external zones are pre-determined based on the results of another WECC-wide capacity expansion model developed by E3 that accounts for policy targets in each zone as summarized in Table 6. The new builds consist of significant increase in solar and battery capacity additions due to the more aggressive RPS targets, assumed electrification, and the decline of technology cost forecasts (see Figure 10). All future builds in these zones include mature technologies but as discussed in the next section, emerging technologies are made available for RESOLVE to optimize the future resource portfolios in the Northwest zone. There is significant solar and battery storage growth in California, the Southwest, and Nevada that generally lower the marginal value of solar energy produced across the WECC.

Table 6. Policy targets for builds in external zones

State	Requirement	Policy	2050 Renewable Target
AZ	40% by 2030; 60% by 2045	Transitions to CES	70%
CA	60% by 2030; 100% by 2045	Transitions to CES	100%
CO	30% by 2020; 50% by 2030, 76% by 2050 (Xcel reaches 100% while other utilities stay at 50%)	Transitions to CES	75%
ID	90% by 2045 (ID Power's announced utility goals)	RPS	90%
MT	87% by 2045 (state carbon reduction goal)	RPS	87%
NM	40% by 2025; 100% by 2045	Transitions to CES	100%
NV	50% by 2030; 100% by 2050	Transitions to CES	95%
UT	50% by 2030; 55% by 2045 (PacifiCorp's IRP)	RPS	55%
WY	50% by 2030, 55% by 2045 (PacifiCorp's IRP)	RPS	55%

Figure 10. Total installed capacity for external zones



3.4.3 Candidate resource options, potential, and cost

A wide range of technologies and resources were 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. As for geothermal, it is high cost and potential limited but provides "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 were 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 only allowed to be available in 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 they are generally higher cost than onshore wind while providing a similar annual capacity factor to high quality Montana and Wyoming wind.

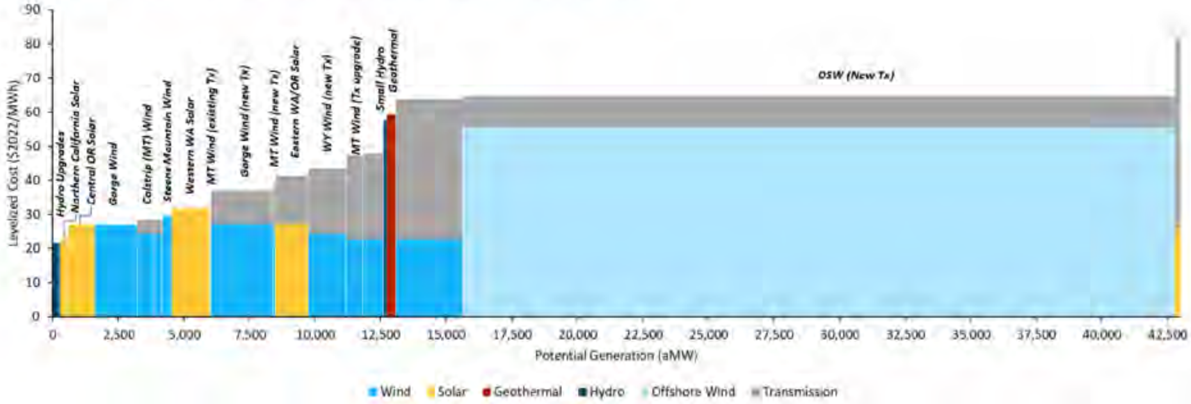
Table 7. Available technologies in each modeled scenario

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	×	✓	×

Some of these resources have physical potential limit such as solar and wind; thus, 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.[12] The supply curve for renewables in the year 2045 is presented in Figure 11 which shows that there is more onshore wind potential than solar and depending on location, solar could be more or less expensive than onshore wind. Offshore wind, however, is the most expensive resource but has more potential than other renewable resources. More detail information on technology cost trajectories and data sources can be found in the Appendix.

[12] Note: certain solar resources (i.e., Western WA solar) might require new transmission lines to bring the supply to load centers, which were not captured.

Figure 11. Renewable resource supply curve in 2045



3.4.4 Clean energy policy targets

RESOLVE enforces a clean energy standard ("CES") requirement as a percentage of retail sales to ensure that the total quantity of energy procured from renewable resources meets the CES target in each year. The clean energy standard percentage is calculated as follows, and the target values are summarized in Table 2:

$$CES\ \% = \frac{Annual\ Renewable\ Energy\ or\ Zero\ Emitting\ Generation}{Annual\ CoreNW\ Retail\ Electric\ Sales}$$

Eligible renewable energy and zero-emitting resources include: solar, wind, geothermal, hydropower, nuclear, biomass, green hydrogen, and natural gas with carbon capture and storage.

Regarding GHG emissions, RESOLVE enforces a greenhouse gas constraint on the CoreNW region such that total annual emission generated in the zone must be less than or equal to the emissions cap. The greenhouse gas accounting for the Northwest zone is a consumption-based approach, following the rules established by the California Air Resources Board. The CoreNW carbon emissions baseline is set as 33 MMT at the 1990 level. The total greenhouse gas emissions attributed to the Core Northwest region include:

+ **In-region generation**: all greenhouse gas emissions emitted by fossil generators (coal and natural gas) within the region, based on the simulated fuel burned and fuel-specific CO_2 emissions intensity;
+ **External resources owned/contracted by Core Northwest utilities:** greenhouse gas emissions emitted by resources located outside the Core Northwest but currently owned or contracted by utilities that serve load within the region, based on fuel burn and fuel-specific CO_2 emissions intensity; and
+ **"Unspecified" imports to the Core Northwest:** assumed emissions associated with economic imports to the Core Northwest that are not attributed to a specific resource but represent unspecified flows of power into the region, based on a deemed emissions rate of 0.43 tons/MWh.

Table 8. Annual CES and carbon emissions targets modeled for CoreNW in RESOLVE

Resource	2025	2030	2035	2040	2045

Clean energy standard % (used in Scenarios 1 and 2)	29%	49%	68%	88%	100%
Carbon reduction emissions target (used only in Scenario 2)	22.7 MMT	17.0 MMT	11.3 MMT	5.7 MMT	0 MMT

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 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 were 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 used 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 relied on historical hydro dispatch data used to develop the TEPPC 2022 Common Case dataset. Using muti-year historical hydro operational data allows to capture the complete set of physical and institutional factors, such as cascading hydro, streamflow constraints, fish protection, navigation, irrigation, and flood control, that limit the amount of flexibility in the hydro system.

For each RESOLVE sampled day, the hydro daily energy budget was calculated as the average of daily electricity generated in the month of each sampled RESOLVE day in its corresponding matched hydro year.[13] The maximum and minimum hydro generation levels (P_{min} and P_{max} in Figure 12) were 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 were 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 allowed for 5% of the hydro energy in each day to be shifted around within two months to capture additional flexibility for day-to-day hydro energy shift. These inputs are presented in Figure 12 and Table 9. Hydro firm capacity contribution for both LSR dams and other

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[13] LSR dams generate about 700-900 average MW. Thus, relying on the three years modeled in RESOLVE resulted in ~700 average MW generation for LSR dams, making it a conservative estimate for generation relative to a longer-term expected average of ~900 MW.

Northwest hydro is assumed to be 65% of nameplate, per PNUCC methodology (based on 10-hr sustaining peaking capacity).

Figure 12. RESOLVE Hydro inputs for LSR Dams and other Northwest hydro

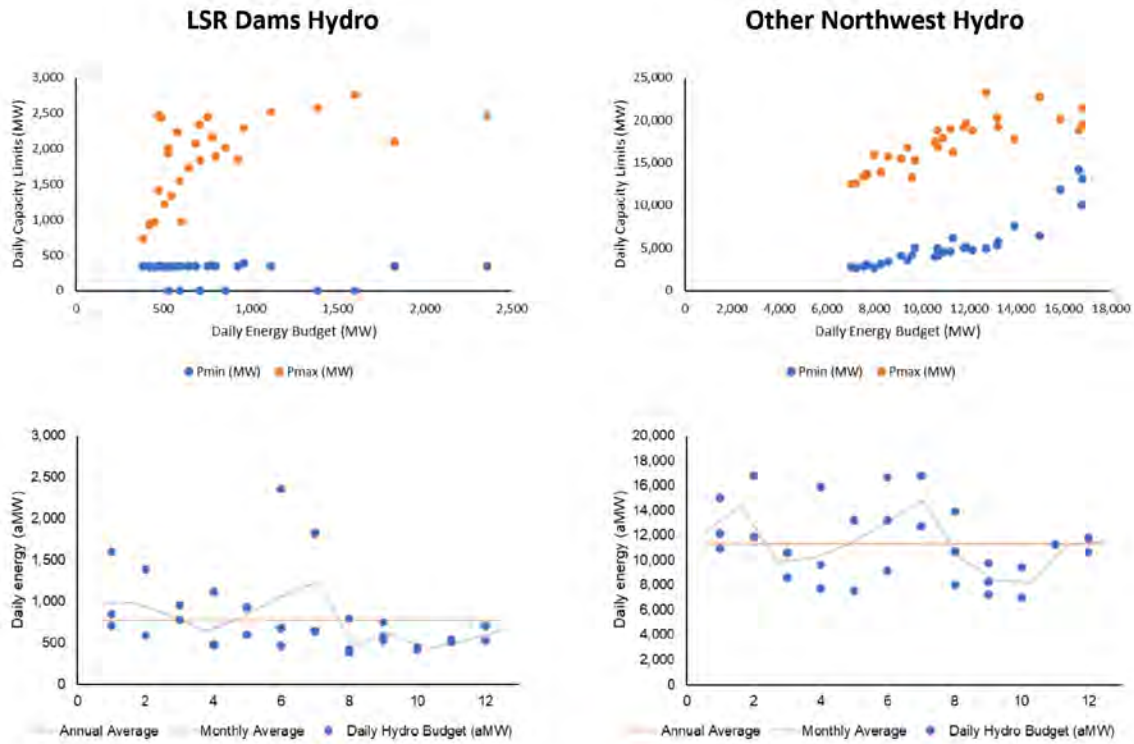


Table 9. Multi-hour ramping constraints applied to Northwest hydro

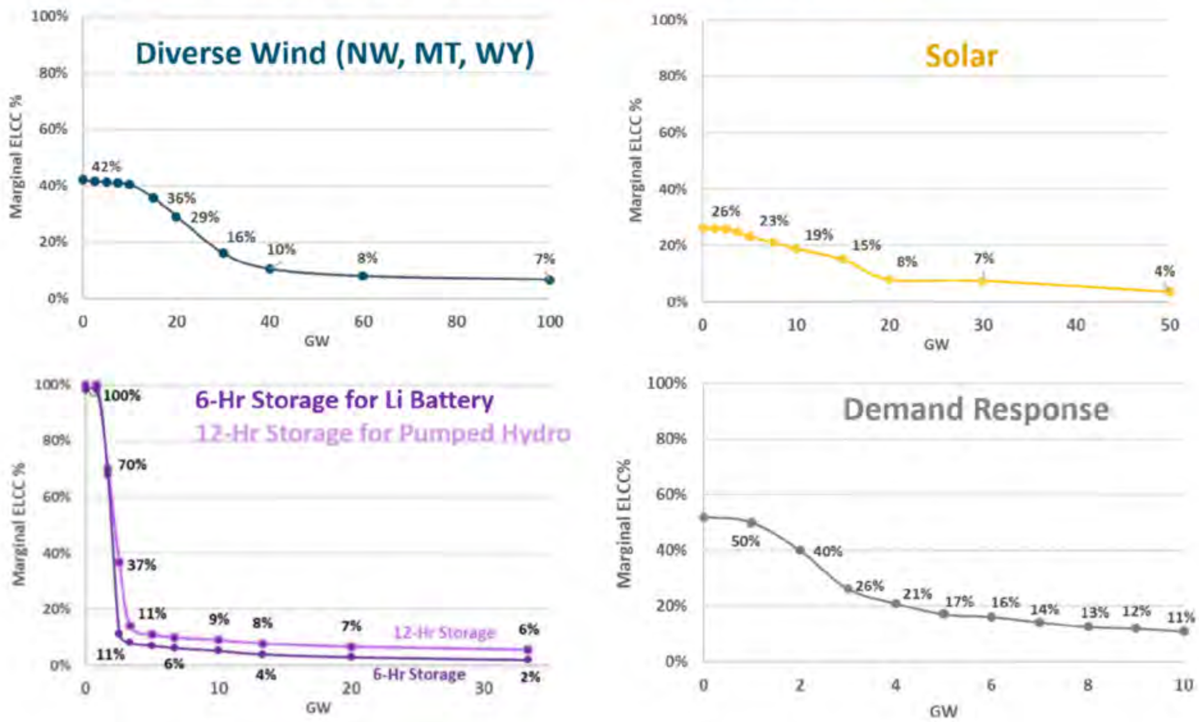
	One hour	Two hours	Three hours	Four hours
LSR Dams Hydro	36%	43%	45%	48%
Other Northwest Hydro	14%	23%	29%	32%

3.4.6 Resource Adequacy Needs and Resource Contributions

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.[14] 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.

[14] 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



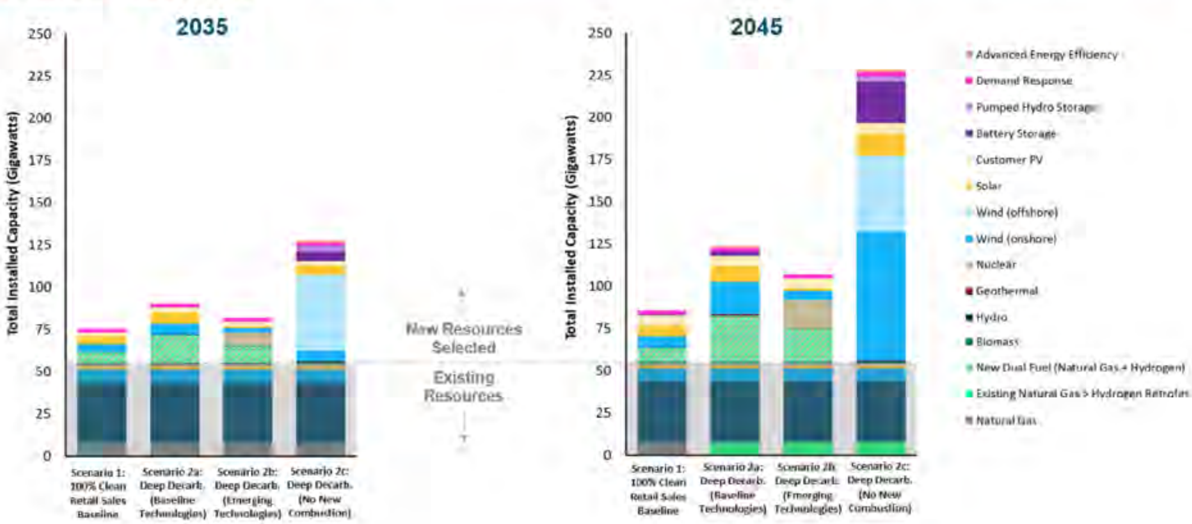
4 Results

RESOLVE was run for 2025-2045 in five-year increments and produced 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

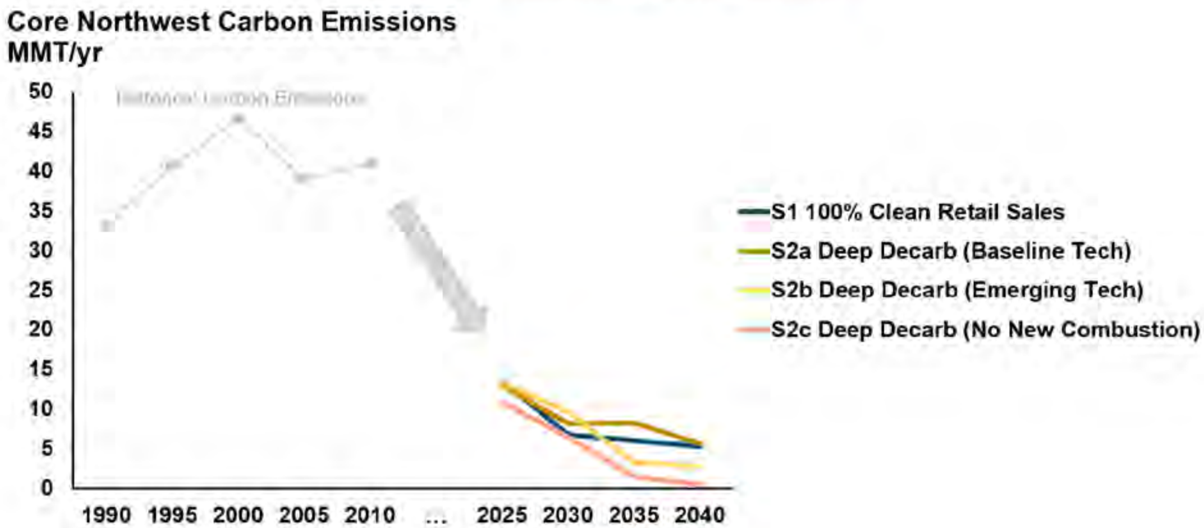
In the baseline scenarios, large capacities to utility-scale solar PV, onshore wind, offshore wind, hydrogen-capable combined cycle, and some amounts of energy efficiency and demand response were selected to meet the growing electricity demand, PRM and emissions reductions. Electrification load growth along with zero emissions target drives higher needs in deep decarbonization scenarios (i.e., S2a, S2b and S2c) compared to the reference scenario (S1) in both snapshot years of 2035 and 2045. Since the resources are primarily build for PRM needs, firm clean technologies such as SMR nuclear was selected in the least cost portfolio in S2b in lieu of additional onshore wind, solar and dual-fuel CCGT selected in S2a and S2c. 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 were almost five time of new builds in S1. These capacity additions increase even more substantially by 2045.

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



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

Figure 15. Northwest Carbon Emissions

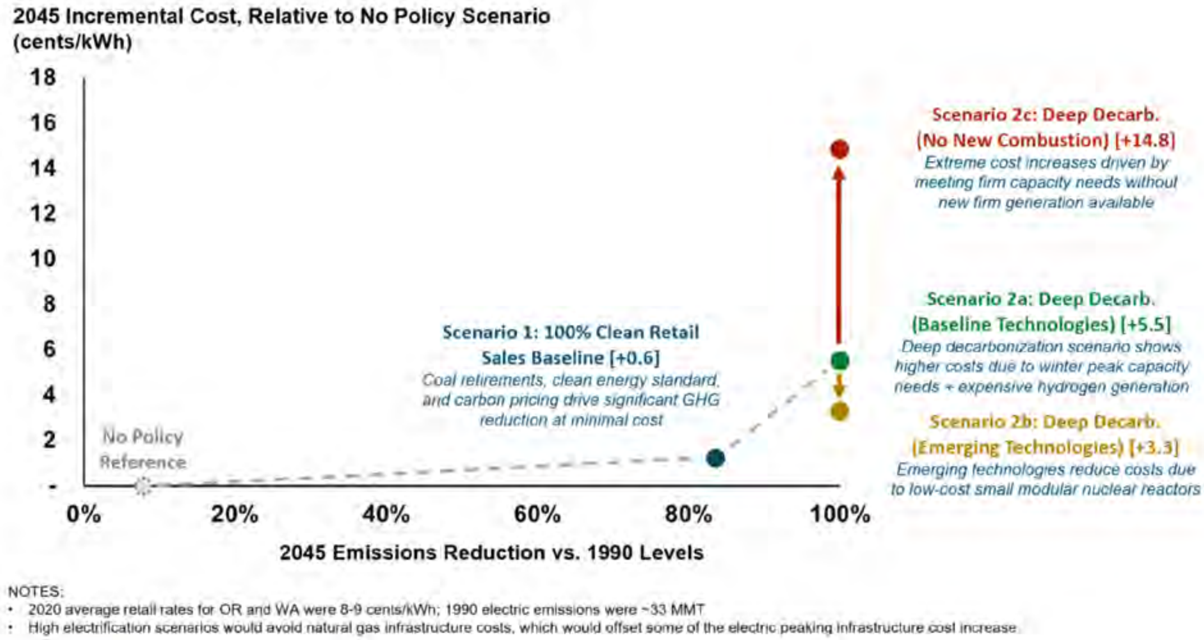


To put cost impacts in context, a "No Policy Reference" case was run, which uses the baseline load forecast and removes all electric clean energy policies, leading to retaining the region's coal power with little emissions decline. The four clean energy futures modeled were compared against this reference 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 minimal 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)[15] or other emerging technologies are

[15] 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.

available, showing that relying only on non-firm resource additions (renewable energy, demand side resources, and short- to medium-duration storage) leads to much higher costs.

Figure 16. Cost Impacts Compared to Emissions Reduction Impacts



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 dams capacity is replaced by renewables in scenarios 1 and 2a, mostly by wind resources and some battery storage. In scenario 2c, with the absence of combustion and 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

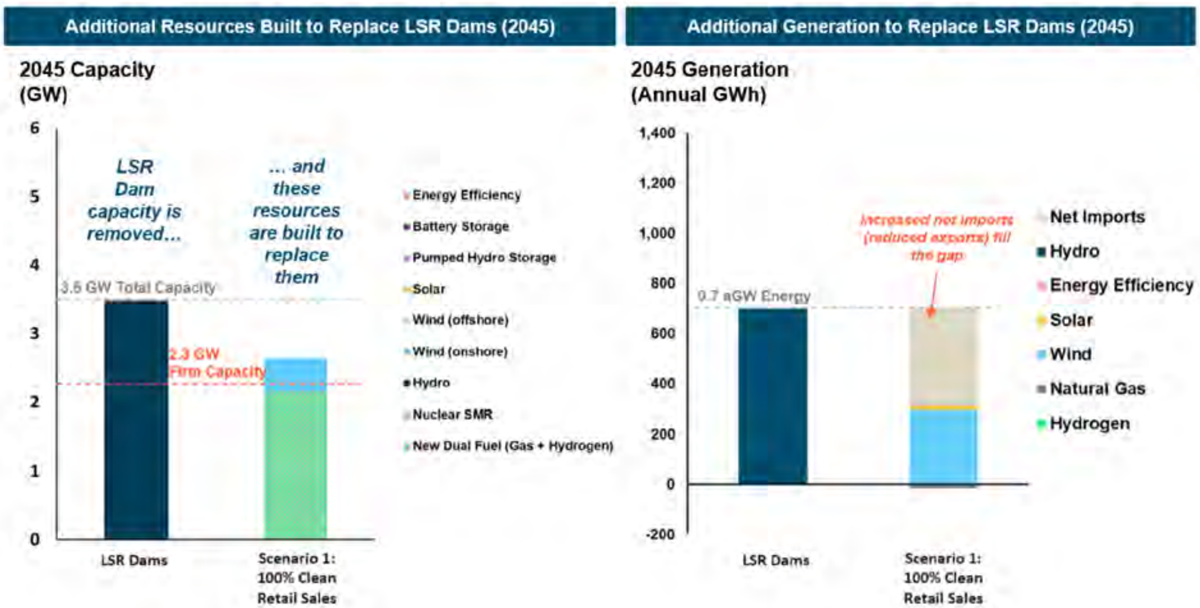
Scenario	Replacement Resources Selected, Cumulative by 2035[16] (GW)	Replacement Resources Selected, Cumulative by 2045 (GW)
Scenario 1: 100% Clean Retail Sales	+ 1.8 GW dual fuel NG/H2 CCGT - 0.5 GW solar + 1.3 GW wind + 0.1 GW li-ion battery	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
S1b: 100% Clean Retail Sales (2024 dam removal)	+ 1.8 GW dual fuel NG/H2 CCGT - 0.5 GW solar + 1.4 GW wind + 0.1 GW li-ion battery	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
Scenario 2a: Deep Decarbonization (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.6 GW wind + 0.1 GW li-ion battery	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW advanced EE + 1.2 TWh H2-fueled generation
Scenario 2b: Deep Decarbonization (Emerging Technologies)	+ 1.7 GW dual fuel NG/H2 CCGT + 0.6 GW nuclear SMR	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR
Scenario 2c: Deep Decarbonization	+ 9.1 GW offshore wind + 0.1 GW wind	+ 10.6 GW wind + 1.4 GW solar

[16] 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[17]



[17] 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 did not need to build enough new generation to fully replace the LSR dams output. For instance, the region could export less hydropower to California and other neighbors to replace the LSR dams output without necessarily increasing carbon emissions.

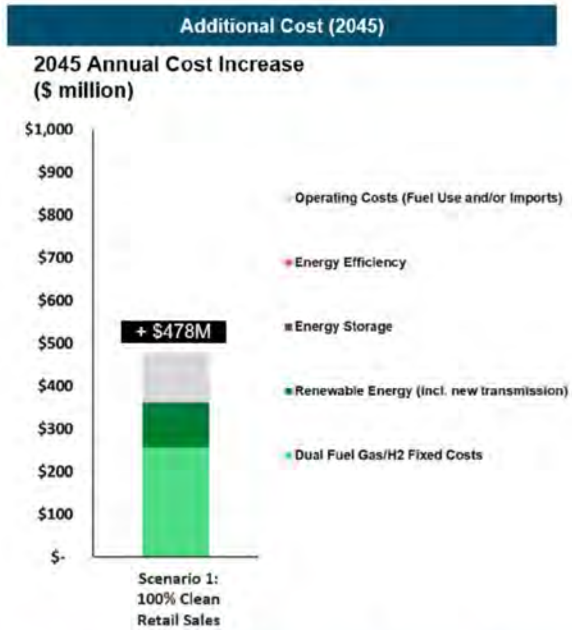
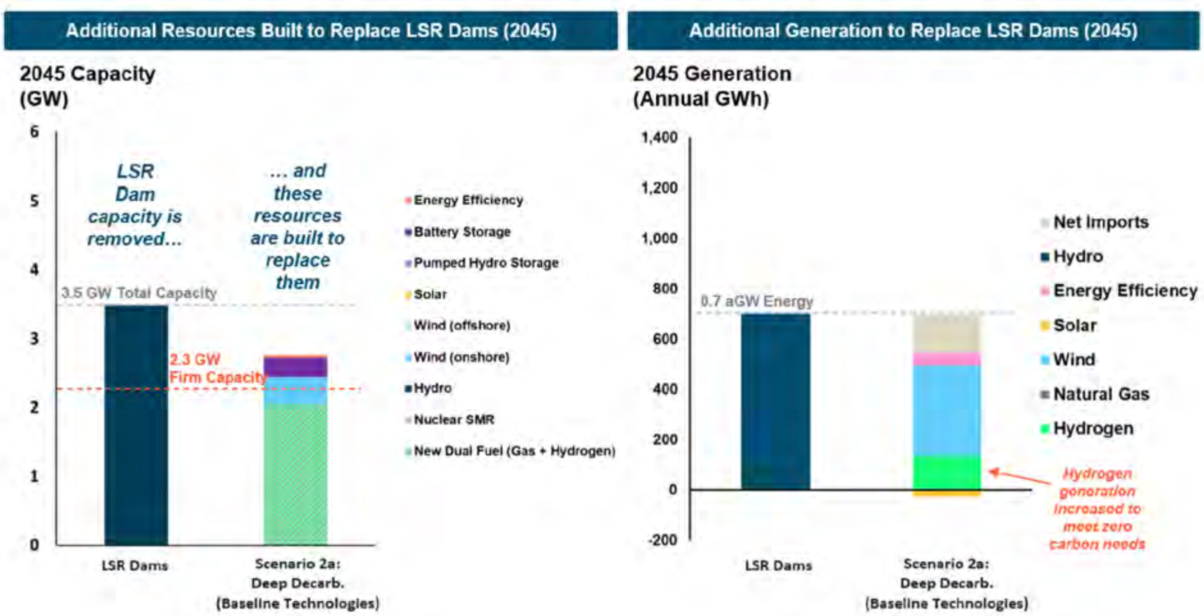
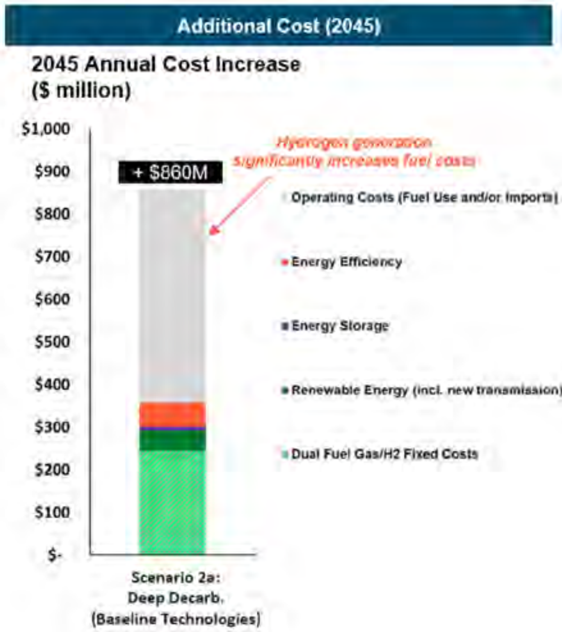


Figure 18. Scenario 2a Capacity Replacement, Energy Replacement, and Costs





4.2.2 Replacement costs

The LSR dams provide a relatively low-cost source of GHG-free energy and firm capacity, particularly because their initial capital investments were recovered long ago. 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[18]); they are calculated by taking the incremental fixed and variable investment costs for the no LSR RESOLVE runs and dividing them by the LSR annual generation being replaced. See the details in Table 11.

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[18] BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) facilities which is in the range of \$13/MWh without LSRCP and \$17/MWh with LSRC. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat.2917) to offset fish and wildlife losses caused by construction and operation of the four lower Snake River projects.

Table 11. Incremental costs to replace LSR generation in 2045

Scenario	Incremental costs in 2045[19] (Real 2022 $/MWh)
Scenario 1: 100% Clean Retail Sales	$77/MWh
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$82/MWh
Scenario 2a: Deep Decarb. (Baseline Technologies)	$139/MWh
Scenario 2b: Deep Decarb. (Emerging Technologies)	$69/MWh
Scenario 2c: Deep Decarb. (No New Combustion)	$517/MWh

The LSR dams' total replacement costs (in net present value) and annual replacement costs for 2025, 2035, and 2045 are shown in Table 12. NPV replacement costs are calculated discounted to the year of breaching (e.g. 2032 or 2022) based on costs modeled in RESOLVE 2025-2045 (plus 20 years added to account for end effects). Scenario 1 (100% clean retail sales) replacement costs are approximately $7.4 billion in net present value (NPV) in the year of breaching (in 2032); costs increase to $9.1 billion NPV if breached in 2024. Total replacement costs are similar in the Deep Decarbonization scenario when emerging technology is available (scenario 2b), showing $6.7 billion NPV. Replacement costs are significantly higher in scenario 2c where no new combustion resources are allowed ($46 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.

In terms of annual costs, they 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 retail rates). In these scenarios, public power households would see an increase in annual

[19] 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.

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.[20]

Note that these incremental cost increases include the ongoing LSR dams costs avoided by breaching the dams, but do not include the costs of breaching. The rate impacts show are only for the LSR dams replacement, they do not include the additional rate increases driven by higher loads or clean energy needs (that are covered in section 4.1 above).

Table 12. Total LSR Dams replacement costs[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%]

[20] 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.

[21] 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.

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. This analysis found that cases that breached the dams in 2032 generally saw a small carbon emissions increase (less than 0.7 MMT/yr) in the mid-term (2035). However, since emissions are declining this small bump could be as high as an 8-10% increase in the region's 2035 carbon emissions.

In the 100% clean retail sales, the 2024 LSR dams breaching scenario did show substantial increases to carbon emissions in 2025 and 2030, in the range of 1-2.8 MMT/yr or 15-25% of the annual Northwest emissions. This near-term increase is allowed by RESOLVE because the clean energy policy did not bind until later in the planning horizon, so the GHG-free energy from the LSR dams did not need to be replaced in the near-term. The near-term increase declined by 2035-2045 as the 100% clean retail sales target became more stringent. However, carbon pricing already incentivized the region to be higher than 100% clean retail sales, meaning that even in 2045, the 100% clean retail sales scenario saw a small emission increase (of ~0.5 MMT/yr) when the LSR dams were breached (i.e., the region went from >100% clean retail sales to being closer to the 100% clean target binding).

The deep decarbonization cases all reach zero carbon emissions by 2045, so there is no emissions impact in that year of breaching the dams, because RESOLVE builds all the resources needed to replace 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.[22]

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[22] 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

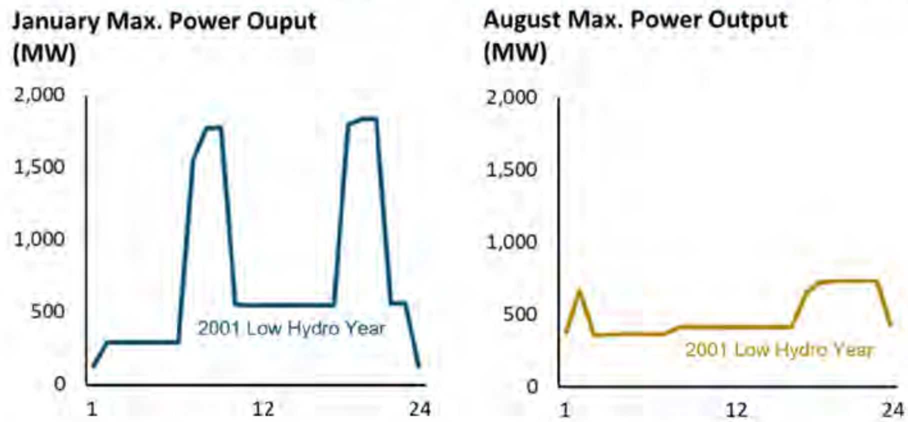
Uncertainty of the LSR dam value was considered under:

- **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:

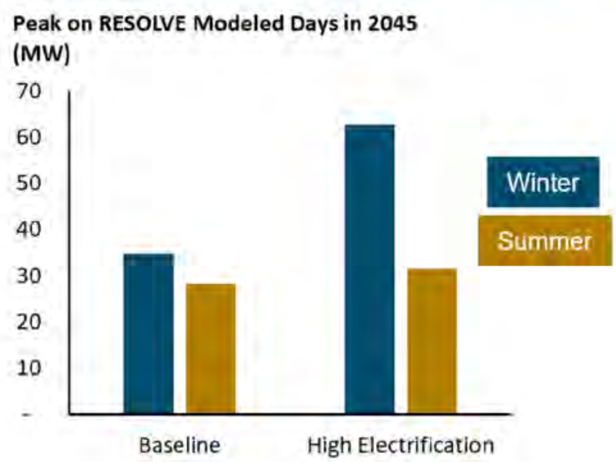
- **Annual energy output**: E3's existing RESOLVE model data used historical hydro years 2001, 2005, and 2011 as representative of the long-term average low/mid/high hydro year conditions. However, for the LSR dams, this led to a relatively low output of ~700 average MW, whereas the dams may generate ~900 average MW on average across a range of hydro conditions – according to BPA data post EIS spill constraints. Therefore, E3's analysis likely underestimates the energy value of the dams and costs for replacing that extra GHG-free energy.
- **Firm capacity counting**: as resource adequacy was 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 used a regional hydro capacity value estimate for the LSR dams in this study. More detailed follow on ELCC studies could be done to confirm the LSR dams capacity value, though proper and coordinated dispatch of the Northwest hydro fleet would be necessary to develop an accurate and fair value of the LSR dams within the context of the overall hydro fleet.
  - This study validated the assumed 2.28 GW of firm capacity from the dams by considering BPA modeled LSR dams dispatch under 2001 conditions using the EIS spill constraint adjusted model. Maximum January output (plus 100-250 MW of operating reserves) was 1.9-2.1 GW (~56-60% of total capacity), slightly less but close to the 65% regional hydro value E3 assumed.

Figure 19. BPA-Modeled LSR Dam Output During the 2001 Low Hydro Year



- o The other capacity value uncertainty is whether the Northwest will remain winter reliability challenged or whether reliability events will shift to the summer due to climate impacts on load patterns and hydro output. If reliability challenges did shift to the summer, the LSR dam firm capacity contribution would be significantly lower than assumed. However, E3 believes it is reasonable to assume under high electrification scenarios that the region will remain winter challenged due to peak space heating needs, as shown in figure below.

Figure 20. Winter vs. Summer Peak Loads



- o To address the capacity value uncertainty, E3 estimated that a 1.5 GW firm capacity value (43%) for the dams would lower the NPV replacement costs by 9-20% and a 1.0 GW firm capacity value (29%) would lower the NPV replacement costs by 14-33%.

+ **Replacement 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 did not focus on the transmission grid reliability services provided by the LSR dams. These services likely can be replaced by a combination of the new resources selected by RESOLVE and additional local transmission system investments. A qualitative summary of the transmission grid reliability services of the dams is summarized in the appendix of this report.

5 Conclusions and Key Findings

This study'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. RESOLVE calculates optimal investment and operations for each scenario 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.

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) 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 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 also added to meet the region's resource adequacy needs.

Though all scenarios require more "firm capacity" resources – resources that can start when needed and operate for as long as needed – to meet higher winter peak demand, these resources are in higher demand in Scenario 2, in which all greenhouse gas emissions are eliminated from the regional power system by 2045, while electrification results in much higher electric loads. Higher wintertime peaks are driven by electrification of natural gas space heating in the buildings that drives wintertime reliability needs. 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 small modular nuclear reactors ("SMRs") by 2045, in lieu of selecting the firm capacity provided by natural gas generators while reducing the required quantities of wind, solar and batteries. 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.

If the generation from the dams is 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 burn additional hydrogen on low wind days to replace the carbon-free energy provided by the dams. Scenario 2b selects nuclear SMRs in lieu of selecting some of the wind and gas plant additions. 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 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 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 $6.7 – 11.3 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)

6 Appendix

6.1 Additional Inputs Assumptions and Data Sources

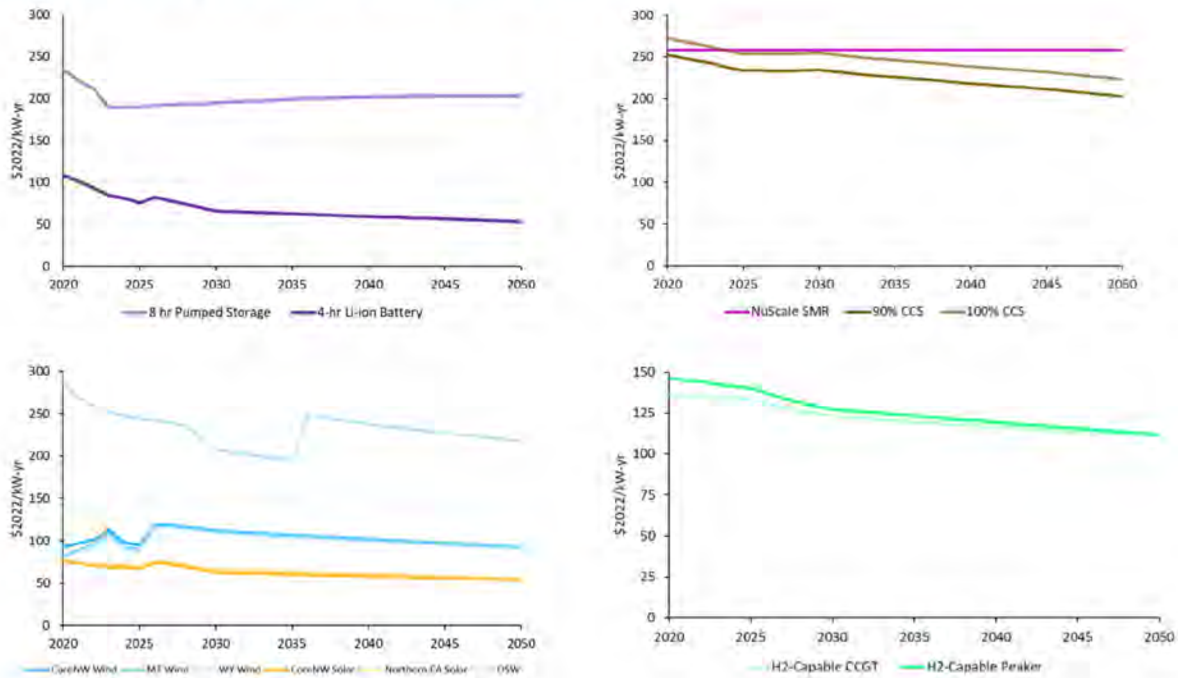
6.1.1 Candidate resource costs

The technology fixed costs trajectories for candidate resource options are shown in **Error! Reference source not found.** 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.[23]
- **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

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

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

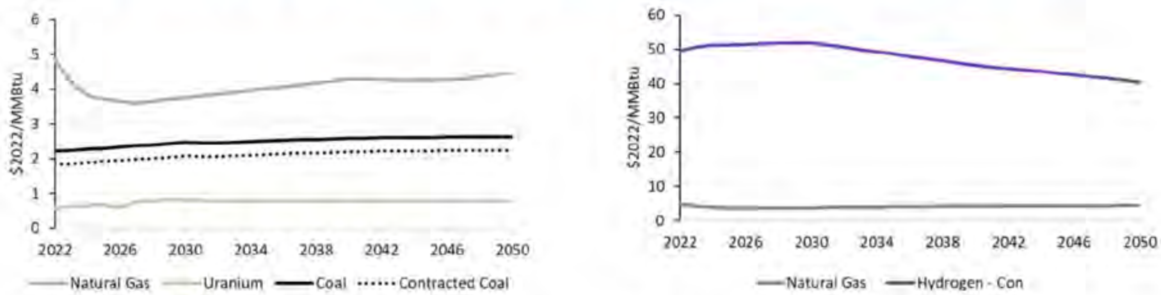


6.1.2 Fuel prices

The fuel price forecast used in this study is 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. At which point 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 were used. Recent fuel cost increases due to market disruptions are excluded from the price trajectory.
+ **Coal prices:** EIA's AEO forecast were used
+ **Uranium prices:** E3's in-house analysis
+ **Hydrogen prices:** Conservative prices were used assuming no large-scale hydrogen economy, and thus electrolyzer capital costs and efficiencies were assumed to improve over time only slightly. Other assumptions include above ground hydrogen storage tanks and delivery via trucks from about 225 miles distance. Electrolyzers use dedicated off-grid Core NW wind power to produce hydrogen.

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

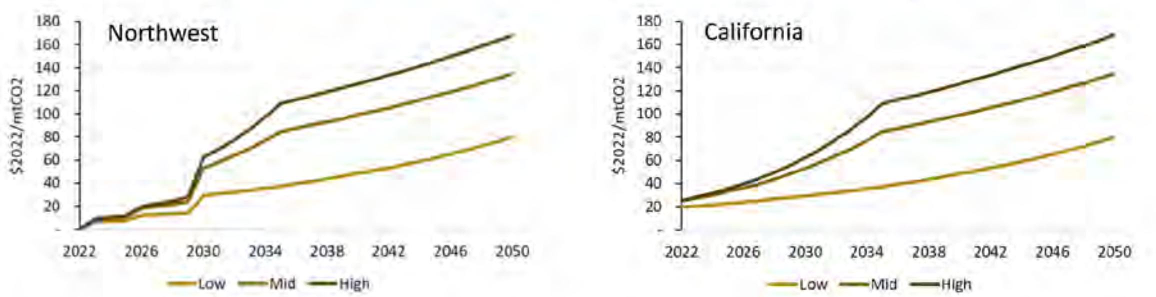


Annual average gas prices are further shaped according to a monthly profile to capture seasonal trends in the demand for natural gas and the consequent impact on pricing.

6.1.3 Carbon prices

For carbon pricing, it was assumed that Washington's cap-and-trade program starts in 2023 at around 50% of California carbon prices. For Oregon, it was 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 was assumed that both states will converge to California's floor price by 2030. California's carbon prices were adopted from the Final 2021 IEPR GHG Allowance Price Projections (December 2021). Mid carbon prices presented in Figure 23 were used in modeled cases.

Figure 23. Carbon price forecasts for Northwest and California



6.1.4 Operating Reserves

It was assumed that all coal, gas, hydro, and storage resources within the Northwest zone can provide reserve requirements. 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 NERC 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 NPV Under an Alternative 3% Discount Rate

Total NPV costs of resources replacing LSR dams are estimated in the year of breaching the dams, 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. NPV replacement costs were calculating using a 5% real discount rate. A sensitivity table showing the use of a 3% discount rate is provided as Table 13 below. A 5% real discount rate is consistent with the expected weighted average cost of capital (WACC) of investor-owned utilities in the Northwest, but a public power utility (such as BPA customers impacted by LSR dams' replacement costs) would typically have a lower cost of capital due to a greater share of debt financing.

Table 13. Comparison of NPV Replacement Costs using a 5% and a 3% Discount Rate

	NPV Total Costs (Real 2022 $) 5% discount rate	NPV Total Costs (Real 2022 $) 3% discount rate
	In the year of breaching (2032 or 2024)	In the year of breaching (2032 or 2024)
Scenario 1: 100% Clean Retail Sales	$7.4 billion	$9.7 billion
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$8.6 billion	$11.7 billion
Scenario 2a: Deep Decarb. (Baseline Technologies)	$11.3 billion	$15.1 billion
Scenario 2b: Deep Decarb. (Emerging Technologies)	$6.7 billion	$8.7 billion
Scenario 2c: Deep Decarb. (No New Combustion)	$46 billion	$61 billion

6.3 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.

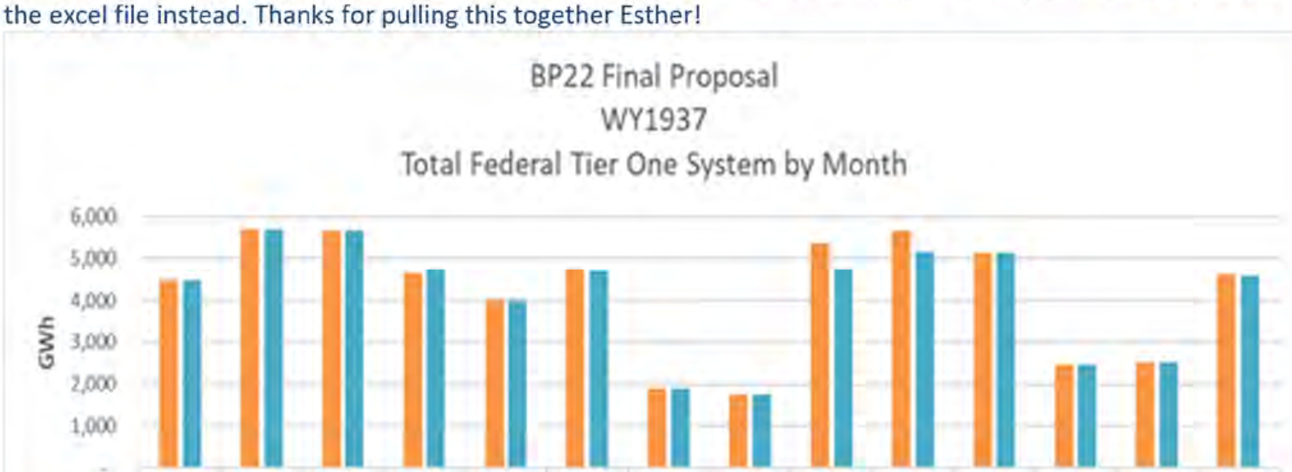
From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Friday, April 15, 2022 9:57 PM
To:	James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5; Neuls,Esther T (BPA) - PGPR-5
Cc:	Angineh Zohrabian; Arne Olson
Subject:	[EXTERNAL] RE: Recent BPA Tier 1 sales

Thanks for this. We ended up using a comparison to the estimated current total average BPA generation rate. Per my note in the email I just sent, we'll seek your input next week on the right cost impact metrics and how we should calculate those.

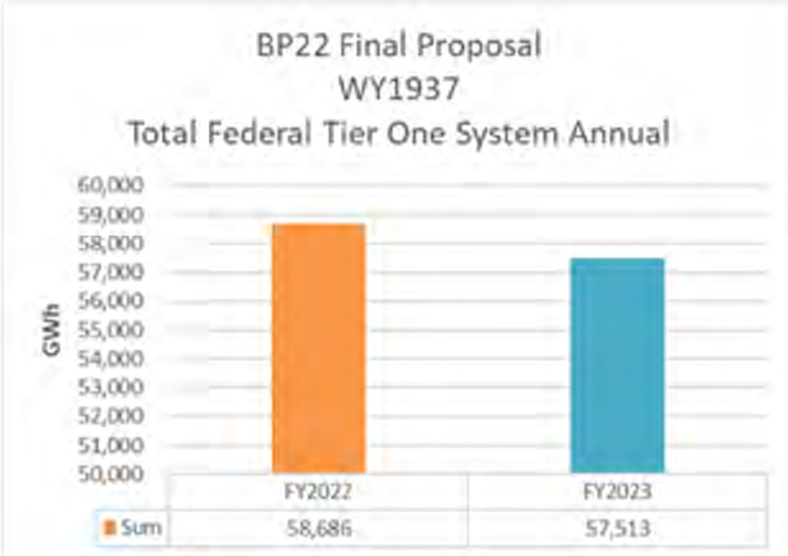
Have a nice weekend,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Friday, April 15, 2022 3:48 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; Neuls,Esther T (BPA) - PGPR-5 <etneuls@bpa.gov>
Cc: Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: RE: Recent BPA Tier 1 sales

Hi Aaron-
Please see below for the FY2022 and 2023 data based on our most recent BP22 Final Proposal. Let us know if you'd like the excel file instead. Thanks for pulling this together Esther!



	Oct	Nov	Dec	Jan	Feb	Mar	Apr1	Apr16	May	Jun	Jul	Aug1	Aug16	Sep
FY2022	4,482	5,696	5,675	4,668	3,992	4,748	1,911	1,758	5,361	5,659	5,141	2,469	2,511	4,614
FY2023	4,473	5,684	5,665	4,737	3,980	4,721	1,898	1,744	4,739	5,160	5,131	2,467	2,507	4,607



From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, April 15, 2022 2:14 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Cc: Angineh Zohrabian <angineh.zohrabian@ethree.com>; Arne Olson <arne@ethree.com>
Subject: [EXTERNAL] Recent BPA Tier 1 sales

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

Thanks!

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

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, May 17, 2022 3:39 PM
To: James,Eve A L (BPA) - PG-5
Cc: Arne Olson; Koehler,Birgit G (BPA) - PG-5; Angineh Zohrabian
Subject: [EXTERNAL] RE: check-in

DELIBERATIVE FOIA EXEMPT

Ok, thanks for confirming. We're nearing a first draft of the public slide deck and plan to share it in the next day or two.

Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Tuesday, May 17, 2022 3:35 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: RE: check-in

DELIBERATIVE FOIA EXEMPT

Hi Aaron-

Sorry I missed that part of your question. I think we will need to show the 2024 removal sensitivity in the public materials since that was in the EIS. I know it is a little odd compared to the other scenarios but we will likely get questions around how this study relates to the EIS.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Tuesday, May 17, 2022 12:19 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>; Angineh Zohrabian <angineh.zohrabian@ethree.com>
Subject: [EXTERNAL] RE: check-in

DELIBERATIVE FOIA EXEMPT

Eve,

Can you confirm if you want the replacement resources and costs shown for both S1 (2032 removal) and for the 2024 removal sensitivity? I suspect there is only a meaningful difference in the pre-2035 replacement mix. The other option is to just show the 2032 removal scenarios only and not the 2024 removal case.

Thanks,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, May 12, 2022 12:33 PM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: check-in

DELIBERATIVE FOIA EXEMPT

Hi Aaron-
I think that's a good plan. The Baseline and Deep Decarbonization policies with differing levels of technology looks like the right set to me as well.

Thanks,
Eve

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, May 12, 2022 12:20 PM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] RE: check-in

DELIBERATIVE FOIA EXEMPT

For the public materials, I would like to suggest reducing the scenarios we show. (I'll also work to simplify the names.)

Specifically, I recommend we show:

- S1: Baseline 100% clean sales
- S2: Deep decarb (baseline tech)
- S2b: Deep decarb (emerging tech)
- S2a1: Deep decarb (limited tech)

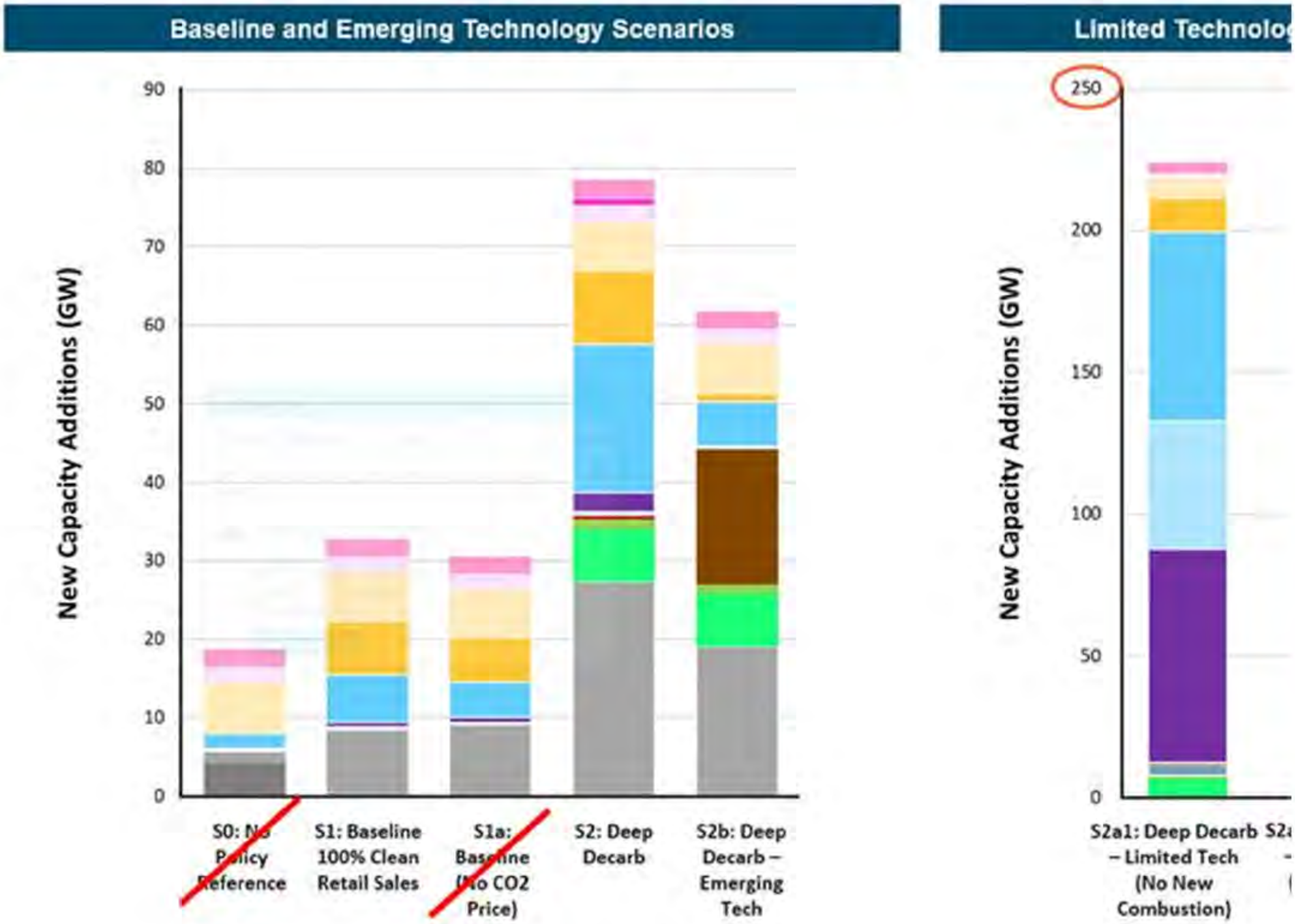
The following scenarios would be removed:

- S0: No policy
- S1a: Baseline w/o carbon price
- S2a: Deep decarb (limited tech but some H2 allowed) – could keep this, but doesn't provide much extra beyond S2 and S2a1

We'd keep the 2024 removal sensitivity in the no LSR cases.

Can you let me know if you agree with this plan for the public materials?

Thanks!
Aaron



From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, May 12, 2022 11:18 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: RE: check-in

DELIBERATIVE FOIA EXEMPT

Great- I'll let Katie know so she can block some time off to help with review and messaging.

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Thursday, May 12, 2022 11:16 AM
To: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: [EXTERNAL] RE: check-in

DELIBERATIVE FOIA EXEMPT

Hi Eve,

I heard from contracting so will respond to them today. Re: timeline, I expect to have an initial draft by early to mid next-week. Does that timing work?

Thanks,
Aaron

From: James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>
Sent: Thursday, May 12, 2022 7:18 AM
To: Aaron Burdick <aaron.burdick@ethree.com>
Cc: Arne Olson <arne@ethree.com>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Subject: check-in

DELIBERATIVE FOIA EXEMPT
Good Morning Aaron-
I think contracting should be reaching out to you today for the modification to include the extra policy level materials. If you have thoughts on the timeline I can let Katie know when she can expect that we'll start pulling her in to help with the high level messaging. Also, the technical power point materials were sent to DOE with an ask that they provide peer review comments by May 18.

Thanks,
Eve

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Monday, July 11, 2022 10:00 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 Report_071122.docx

Ok, see public report attached with relevant updates made in the public deck reflected (corrected final NPV values, added scenario 1b w/ binding CES target, added range for scenario 2c).

Will send PDF for report next.

Aaron

From: Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Sent: Monday, July 11, 2022 5:17 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

I was just about to hit send on this when Aaron's email arrived with the ppt....

Here's BPA's plan regarding timing.

I'll take a quick look when I get the documents then send them to our communications staff. One person will be up at 5:30 am to set up a 6 am post on BPA's web site. (We recently switched or set up a new system for something posting automatically, but since it is new and this one's important, they didn't want to risk it.) So, while I don't want you to have to work all night, I also don't want you racing so fast that you don't have time to be careful. Send them to me when you're ready.

- ----------

Not urgent for tonight, but to keep you in the loop:
BPA communications decided not to set up a formal session with the media now that reports will have the report and not just the ppt tomorrow. You should feel free to respond to the media on any questions related to your analysis and conclusions. We expect BPA will get inquiries about the process on this strange roll-out. If you do get many requests and want to set up a media briefing, I could ask our folks to help facilitate that if you'd like.

BPA will offer briefings to Congressionals, probably one general session and one for Senator Murray's office as per last week's plan. If there are significant changes to your availability since last Wed please let us know, maybe even extend into next week.

From: Koehler,Birgit G (BPA) - PG-5
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

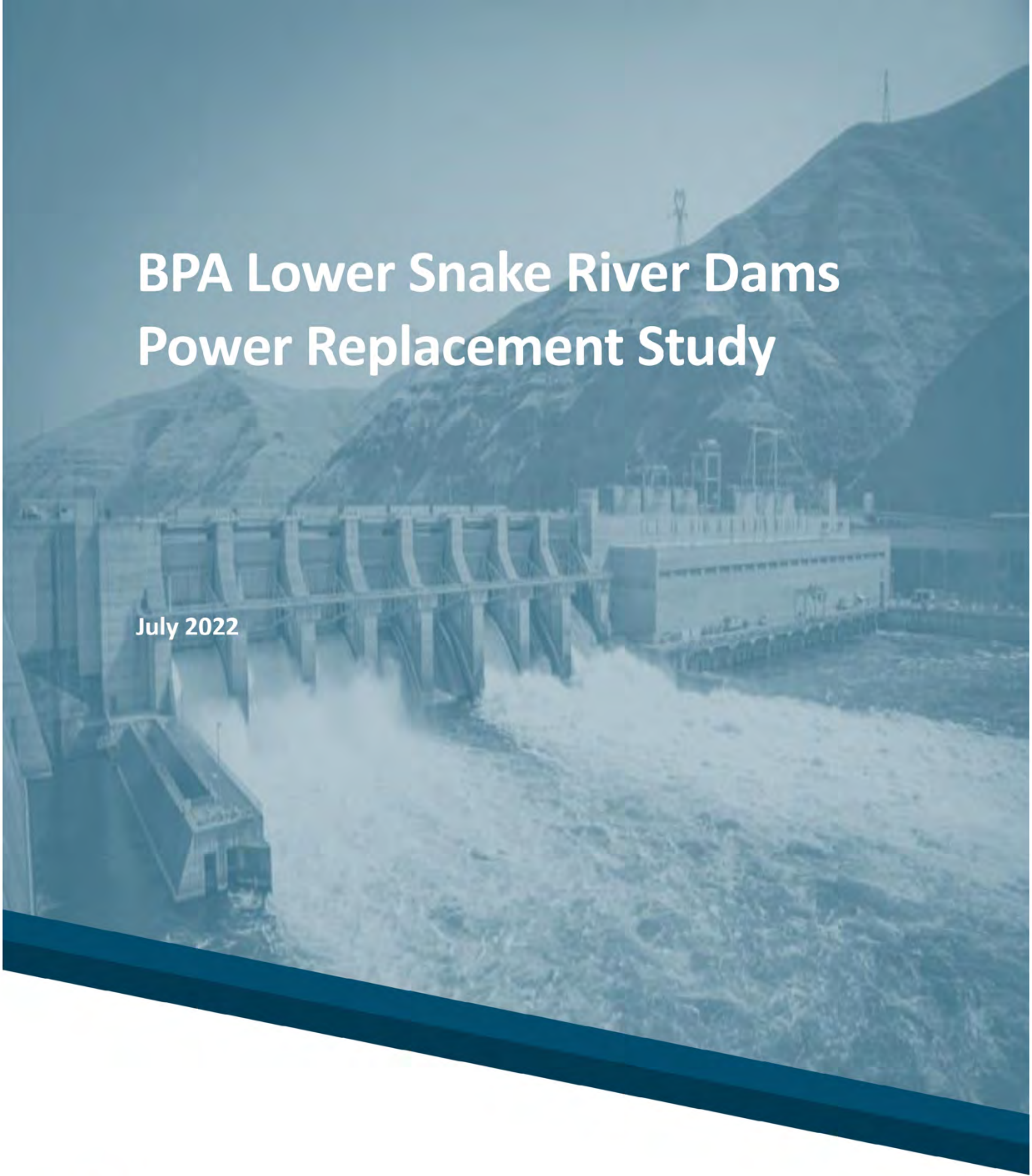
Hello Arne and Aaron,

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

BPA Lower Snake River Dams Power Replacement Study

July 2022



Energy+Environmental Economics

BPA Lower Snake River Dams Power Replacement Study

July 2022

Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500
San Francisco, CA 94104

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Project Team:

Arne Olson

Aaron Burdick

Dr. Angineh Zohrabian

Sierra Spencer

Sam Kramer

Jack Moore

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Acronym Definitions

Acronym	Definition
BPA	Bonneville Power Administration
BTM Solar	Behind-the-meter Solar
CA	California
CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
CES	Clean Energy Standard
CRSO EIS	Columbia River System Operations Environmental Impact Statement
DR	Demand response
EE	Energy efficiency
EIA	Energy Information Administration
ELCC	Effective load carrying capability
HDV	Heavy-duty vehicles
H2	Hydrogen
LDV	Light-duty vehicles
LSR	Lower Snake River
NERC	North American Electric Reliability Corporation
NG	Natural Gas
NV	Nevada
NW	Northwest
PNUCC	Pacific Northwest Utilities Conference Committee
PRM	Planning Reserve Margin
RM	Rocky Mountains
RPS	Renewable Energy Standard
SMR	Small modular reactor
SW	Southwest
WECC	Western Electricity Coordinating Council

Executive Summary

E3 was contracted by the Bonneville Power Administration to conduct an independent study of the value of the lower Snake River dams ("LSR dams") to the Northwest power system. The dams provide approximately 3,500 megawatts ("MW") of total capacity[1] and approximately 2,300 MW of firm peaking capability[2] to support regional reliability. They also generate approximately 900 average MW of zero-carbon energy each year[3], provide essential grid services such as operating reserves and voltage support, and operational flexibility to support renewable integration. If the dams are breached, these power services will need to be replaced to ensure the Northwest power system can continue to provide reliable electricity service. Replacing the dams is complicated by the clean energy policies adopted either statutorily or voluntarily by jurisdictions and utilities throughout the region, which will necessitate a transformation of the power system over time toward non-emitting resources even as electricity demand grows substantially due to electrification of the transportation and building sectors.

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho, and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability. RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[4]. Using RESOLVE allows for a dynamic optimization that considers replacement resource needs in the context of long-term system load and policy drivers, not just the near-term resource mix

---

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

[2] LSR dam firm capacity contributions are estimated using the PNUCC regional hydropower 65% capacity value, which was validated by looking at LSR Dam wintertime power and reserve provision during low hydro conditions. Additionally, E3 considered estimates on the impact of a lower firm capacity value in the results chapter.

[3] The data for the LSR dams was adjusted to reflect the Preferred Alternative operations defined in the Columbia River Systems Operation Environmental Impact Statement (CRSO EIS). E3's RESOLVE model uses 2001, 2005, and 2011 hydro years, which resulted in ~700 average MW of lower Snake River dams generation, making it a conservative estimate of the dams' GHG-free energy value.

[4] Pacific Northwest Low Carbon Scenario Analysis, December 2017, https://www.ethree.com/projects/study-policies-decarbonize-electric-sector-northwest-public-generating-pool-2017-present/; Pacific Northwest Zero-Emitting Resources Study, January 2020, https://www.ethree.com/e3-examines-role-of-nuclear-power-in-a-deeply-decarbonized-pacific-northwest/

and needs of the system today. The dams are assumed to be breached in 2032, except for one sensitivity that considered 2024 breaching.

This study's scenario design focuses on three key variables – clean energy policy, load growth, and emerging technology availability – that impact the cost to replace the dams. The scenarios and key assumptions are show in Table 1.

Table 1. Scenario Design

Scenario	Clean Energy Policy	Load Growth	Technology Availability
1 100% Clean Retail Sales	100% retail sales (65-85% 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

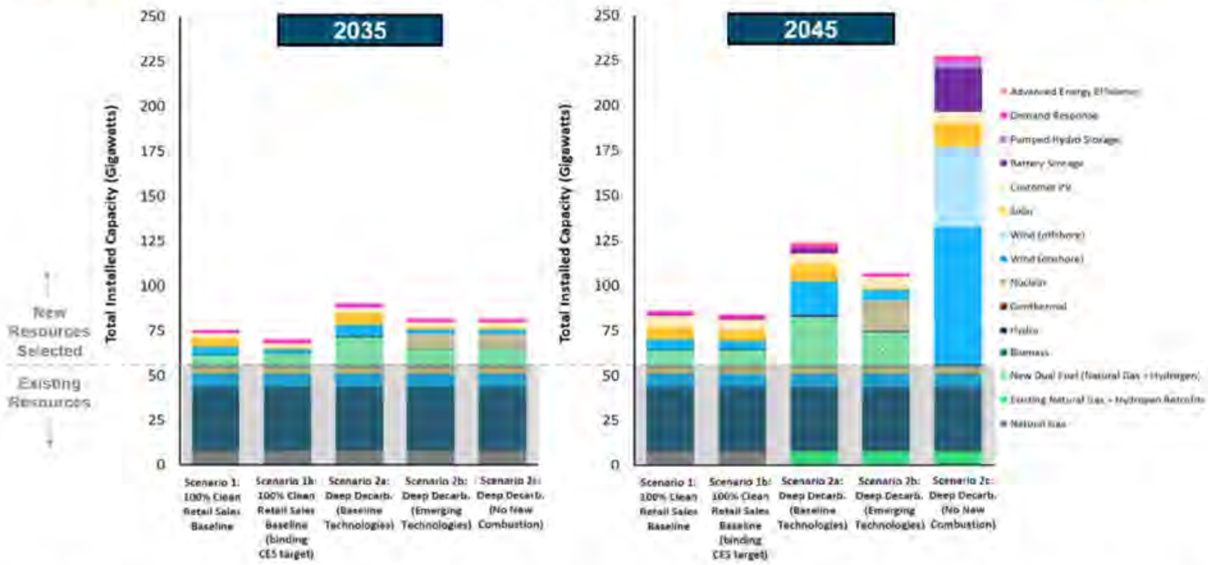
Even with the dams in place, the region's clean energy goals and potential electrification load growth drive a significant need for new resources. In all scenarios, significant energy efficiency and customer solar is embedded into the load forecast, based on the NWPCC's 8th Power Plan. Additionally, 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 5.5-7 GW of solar and 4.6-6 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.[5]

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

[5] E3 ran two versions of scenario 1. 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. 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. The values shown here represent the range of additions across both scenarios.

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 and solar power and the firm capacity with dual fuel natural gas and hydrogen combustion plants. Small amounts of additional energy efficiency and battery storage are also selected in some scenarios. By 2045, the dual fuel plants added burn additional hydrogen on low wind days to replace the carbon-free energy provided by the dams. Scenario 2b selects additional nuclear SMRs in lieu of some of the wind and gas resources. Scenario 2c disallows the new combustion plants, even those that would burn green hydrogen, and other emerging technologies, requiring a very large buildout of wind and solar power to replace both the firm capacity and the carbon-free energy of the dams.

The long-term emissions impact of removing the generation of the lower Snake River dams will depend on the implementation of the Oregon and Washington electric clean energy policies. Both a 100% clean retail sales and a zero-carbon emissions target require replacement of most or all of the LSR dams' GHG-free energy. However, without additional earlier carbon-free resource investments beyond those modeled in this study to meet clean energy policy trajectories, carbon emissions may increase initially when the dams are breached, before declining by 2045 as the carbon policy becomes more stringent.

Table 2. Summary of LSR Dams Replacement Resources and Cost Impacts (costs in the table below and throughout this report are shown in real 2022 dollars)

Scenario	Replacement Resources Selected, Cumulative by 2045 (GW)	NPV Replacement Costs[6]	Annual Replacement Costs[7]			Public Power Rate Impact[8]
			2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind	$12.4 Billion	-	$434 million/yr	$478 million/yr	0.8 ₵/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam removal)	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind	$12.8 Billion	$495 million/yr	$466 million/yr	$509 million/yr	0.8 ₵/kWh [+9%]
Scenario 1b: 100% Clean Retail Sales (binding CES target)	+ 1.8 GW dual fuel NG/H2 CCGT + 1.3 GW solar + 1.2 GW wind	$12.0 Billion	-	$445 million/yr	$473 million/yr	0.8 ₵/kWh [+9%]
Scenario 2a: Deep Decarbonization (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW advanced EE + 1.2 TWh H2-fueled generation	$19.6 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	$11.2 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	$42 – 77 billion[9]	-	$ 1,045 – 1,953 million/yr	$1,711 – 3,199 million/yr	2.9 – 5.5 ₵/kWh [+ 34 – 65%]

KEY FINDINGS:

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[6] These NPV values are calculated assuming a 3% discount rate to represent the public power cost of capital, discounting 50-year of costs starting from the year of breaching (either 2032 or 2024).

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

[8] 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.

[9] 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 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 – 4,300 MW of replacement resources
    - An annual cost of $415 million – $860 million by 2045
    - Total net present value 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
- 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 $42 – 77 billion NPV cost)

Background

E3 was contracted by the Bonneville Power Administration to conduct an independent study of the value of the lower Snake River dams ("LSR dams") to the Northwest power system. The dams provide approximately 3,500 megawatts ("MW") of total capacity[10] and approximately 2,300 MW of firm peaking capability[11] to support regional reliability. They also generate approximately 900 average MW of zero-carbon energy each year, provide essential grid services such as operating reserves and voltage support, and operational flexibility to support renewable integration. Figure 2 shows the power services that are the focus of this study and those that are out of scope.

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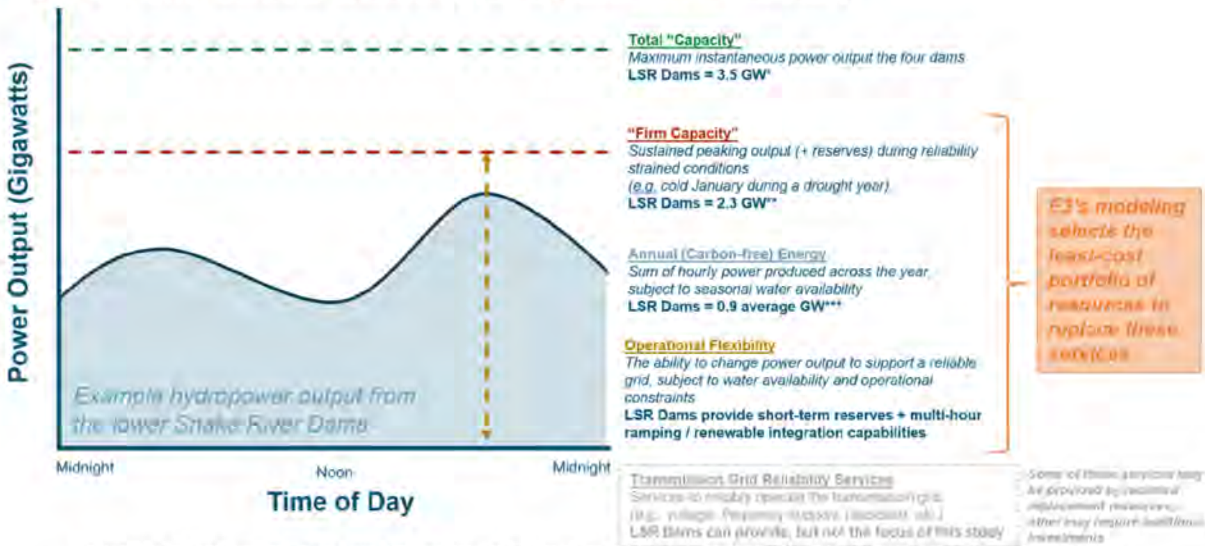
[10] Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. The "total capacity" refers to the overload capacity, not the nameplate capacity. Historical peak generation was 3,431 MW.

[11] LSR dam firm capacity contributions are estimated using the PNUCC regional hydropower 65% capacity value, which was validated by looking at LSR Dam wintertime power and reserve provision during low hydro conditions. Additionally, E3 considered estimates on the impact of a lower firm capacity value in the results chapter.

Figure 2. Power Services Considered for Replacement in this Study



* Hydro traditionally operates above nameplate and closer to overload capacity (~15% above nameplate) and FERC uses these peak generation values in hydro licensing. Historical peak generation was 3,431 MW.

** Firm capacity assumed in this study is consistent with the ~65% Northwest hydro capacity value assumed by PNUCC (the Pacific Northwest Utilities Conference Committee).

*** Average GW means that on average across an average year the plant generated at 0.9 GW, though its hourly output may be above or below that amount. The data for the LSR dams was adjusted to reflect the Preferred Alternative operations defined in the Columbia River Systems Operation Environmental Impact Statement ("CRSO EIS"). E3's RESOLVE model uses 2001, 2005, and 2011 hydro years, which resulted in ~700 average MW of lower Snake River dams generation, making it a conservative estimate of the dams' GHG-free energy value.

If the dams are breached, these power services will need to be replaced to ensure the Northwest power system can continue to provide reliable electricity service. Replacing the dams is complicated by the clean energy policies adopted either statutorily or voluntarily by jurisdictions and utilities throughout the region, which will necessitate a transformation of the power system over time toward non-emitting resources even as electricity demand grows substantially due to electrification of the transportation and building sectors.

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability.

RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[12]. 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.[13]

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.[14]

This modeling framework ensures that when the LSR dams are removed from the Northwest power system, a least-cost replacement mix of new investments and operational changes is found. Through the constraints of the optimization, this least-cost replacement mix meets the same clean energy policy and level of reliability as a system with the LSR dams still intact. This dynamic approach considers replacement resource needs in the context of the evolving long-term system load and policy drivers, not

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[12] 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/

[13] The study examines LSRD breaching in 10 years (2032) and in 2 years (2024), based on with the approach used in the CRSO EIS.

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

just the near-term resource mix and needs of the system today. It recognizes that significant levels of new renewable energy and other resources are already needed to meet long-term regional needs, ensuring that the replacement resource mix selected is incremental to the long-term buildout, not just an interim solution before clean energy policies reach their apex in the 2040s.

Scenario Design

Regional Policy Landscape

To properly understand the resources needed to replace the power services of the lower Snake River dams, it is critical to consider the regional policy landscape of the Pacific Northwest. In the last few years, the states of Oregon and Washington have adopted some of the most aggressive clean energy policies in the nation. While the Pacific Northwest was already a leader in renewable energy production due to its abundant hydropower resource, these aggressive policies will require key changes to the region. First, coal power must be phased out in the Northwest during this decade and, at least in Washington, carbon will be priced via a market-based cap-and-trade mechanism[15]. 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.

[15] For simplicity, this study assumes a uniform carbon price across the Core Northwest region beginning in 2023.

Table 3. Policy landscape in Washington, Oregon, and California

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

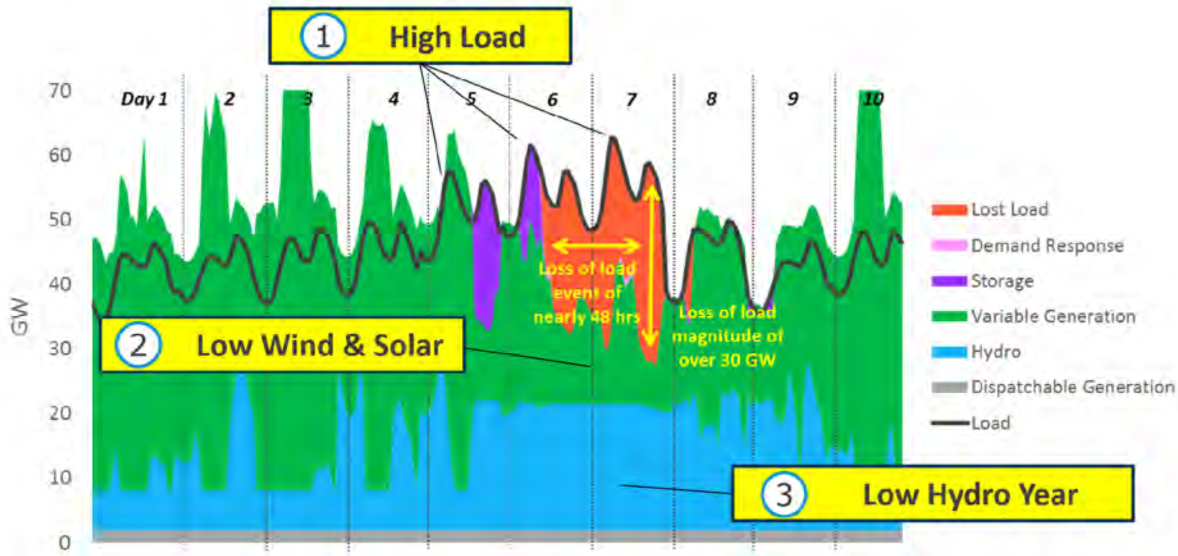
Maintaining Resource Adequacy in Low-carbon Grids

Like other regions pursuing aggressive climate policies, the Northwest faces a key decarbonization challenge: how to maintain a reliable electricity supply, while simultaneously increasing electric loads and retiring the firm, but emitting, capacity that currently supports regional reliability. In 2019, E3 used its RECAP loss of load probability model to study how decarbonizing the electricity supply impacts regional reliability.[16] 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

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

additional firm generating capacity may be needed, even in scenarios that add significant amounts of non-firm solar, wind, batteries, and demand response. The resource adequacy modeling approach is described further in the section *Resource Adequacy Needs and Resource Contributions*.

Figure 3. Key Drivers of Pacific Northwest Reliability Events in a Decarbonized Grid



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Since the 2019 study, "emerging" technologies are increasingly seen as potentially viable options to reduce all of the carbon emissions in the Northwest. "Clean firm" resources like green hydrogen, gas with carbon capture and storage, and nuclear small modular reactors provide the firm capacity necessary to backup renewable resources and can provide the zero-carbon energy needed on low renewable days to operate a zero-carbon grid. While their costs and commercialization trajectories remain uncertain, this LSR dams replacement study considers various scenarios of their availability.

Table 4. Summary of Resource Adequacy Capacity Contributions of LSR Dam Replacement Resource Options

Replacement Resource Option	RA Capacity Contributions

Battery storage	Sharply declining ELCCs[17]
Pumped storage	Sharply declining ELCCs
Solar	Declining ELCCs
Wind	Declining ELCCs
Demand Response	Declining ELCCs
Energy Efficiency	Limited potential vs. cost
Small Hydro	Limited potential
Geothermal	Limited potential
Natural gas to H2 retrofits	Clean firm, but not fully commercialized
New dual fuel natural gas + H2 plants	Clean firm, but not fully commercialized
New H2 only plants	Clean firm, but not fully commercialized
Gas w/ 90-100% carbon capture + storage	Clean firm, but not fully commercialized
Nuclear Small Modular Reactors	Clean firm, but not fully commercialized

Scenarios Modeled

This study focuses on three key variables (clean energy policy, load growth, and emerging technology availability) that impact the cost to replace the dams.

Clean Energy Policy

Clean energy policy for the electric sector is modeled at either 100% clean retail sales or zero-carbon by 2045. A 100% clean retail sales policy requires serving 100% of electricity sold on an annual basis to be met by clean energy resources. This allows generation not used to serve retail sales (i.e., transmission and distribution losses) to be met by emitting resources. It also allows emitting generation or unspecified imports in one hour to be offset by exported generation in another hour of the year. In the baseline load scenario, reaching 100% clean retail sales by 2045 results in ~65-85% 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.

[17] E3 performed a sensitivity with battery ELCCs that do not decline so sharply. This sensitivity shows minor changes in the LSR dam replacement resources, but little to no change in the replacement costs.

Load Growth

With aggressive clean energy policies, load growth determines the amount of new zero-emitting resources that must be added to the Northwest power system. A baseline load growth scenario is modeled, based on the forecast in the NWPCC 8th Power Plan. A second high electrification scenario is developed based on the high electrification case in the Washington State Energy Strategy.[18] Based on E3's analysis of the electrification of transportation, buildings, and industry in that study, this scenario results in an additional annual energy demand increase of 28% by 2045 (above the baseline scenario) and an additional winter peak demand increase of 68%. The peak demand increase is high due to the electrification of space heating end uses, which requires replacing the significant quantities of energy provided by the natural gas system during extreme wintertime cold weather events with electricity.

Technology Availability

It is expected that the availability of emerging technologies may be critically important for replacing the LSR dam power services while reaching a deeply decarbonized grid. All scenarios include "mature technologies" such as solar, wind, battery storage, pumped hydro storage, demand response, energy efficiency, small hydro, and geothermal. Three scenarios of emerging technology availability are developed as follows:

A. **Baseline technologies**: mature technologies and dual fuel natural gas + hydrogen combustion plants
B. **Emerging technologies**: mature technologies, dual fuel natural gas + hydrogen combustion plants, small modular nuclear reactors, natural gas with carbon capture and storage, and floating offshore wind
C. **No new combustion (limited technologies)**: mature technologies and floating offshore wind

All scenarios assume that the existing natural gas capacity fleet can convert to green hydrogen, i.e., hydrogen produced using zero-carbon electricity. However, new firm resources are needed in all scenarios to replace retiring resources and meet growing electric loads.

Table 5 shows a summary of the four scenarios that are the primary focus of this study.

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[18] See Washington State's *2021 State Energy Strategy*, https://www.commerce.wa.gov/growing-the-economy/energy/2021-state-energy-strategy/

Table 5. Scenario Design

Scenario	Clean Energy Policy	Load Growth	Technology Availability
1 100% Clean Retail Sales	100% retail sales (65-85% 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)

The following additional sensitivities were considered:

- **Scenario 1: 100% Clean Retail Sales (2024 dam removal)**: same as scenario 1, but with 2024 LSR Dams breaching instead of 2032.
- **Scenario 1b 100% Clean Retail Sales (Binding CES Target)**: E3 ran two versions of scenario 1. 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. In scenario 1b, no carbon price was assumed and the 100% CES target is binding in 2045, causing the need to fully replace the GHG-free energy output of the LSR dams.
- **High Storage ELCC Sensitivity**: sensitivities were run on both Scenarios 1 and 2a to test whether a higher Northwest storage ELCC would change the marginal resources and replacement costs for the LSR dams.

Modeling Approach

RESOLVE Model

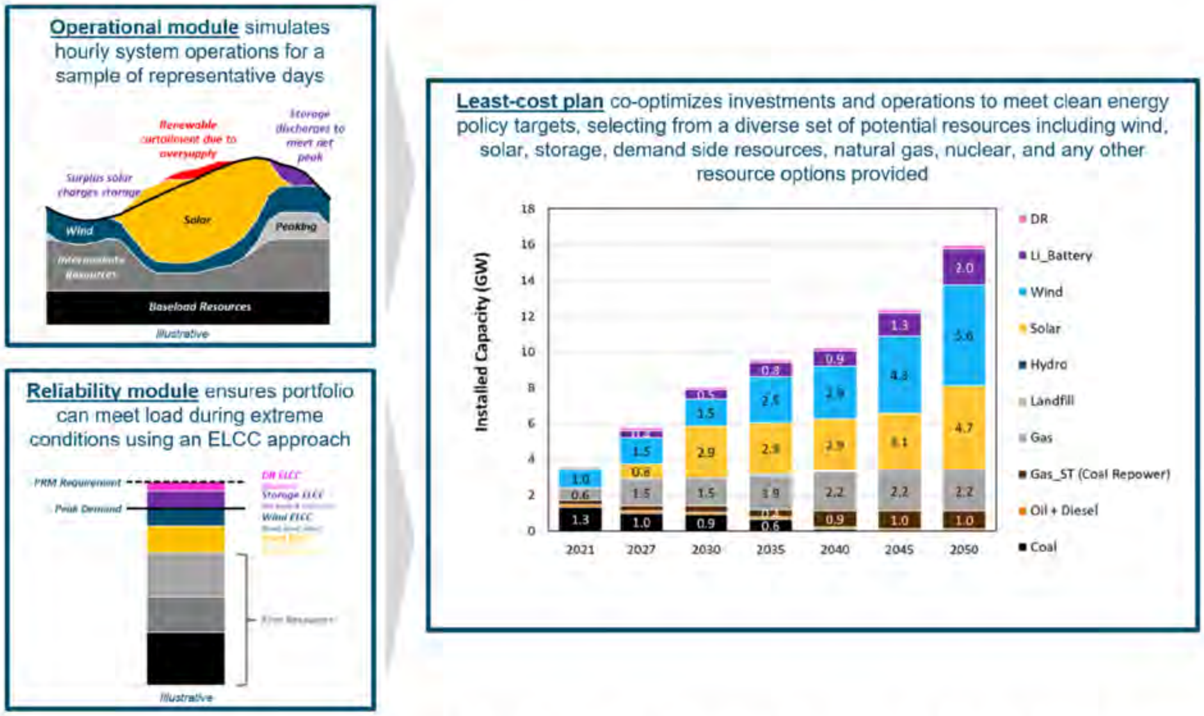
E3's Renewable Energy Solutions Model (RESOLVE) is used to perform a portfolio optimization of Northwest system's electric generating resource needs between 2025 and 2045. RESOLVE is an optimal capacity expansion and dispatch model that uses linear programming to identify optimal long-term generation and transmission investments in an electric system, subject to reliability, operational, and policy constraints. Designed specifically to address the capacity expansion questions for systems seeking to integrate large quantities of variable energy resources, RESOLVE layers capacity expansion logic on top of a production cost model to determine the least-cost investment plan, accounting for both the up-front capital costs of new resources and the variable costs to operate the grid reliably over time. In an environment in which most new investments in the electric system have fixed costs significantly larger than their variable operating costs, this type of model provides a strong foundation to identify potential investment benefits associated with alternative scenarios.

The three primary drivers of optimized resource portfolios include:

- **Reliability:** all portfolios ensure system meets resource adequacy requirements. In this case, the target reliability need is to meet 1-in-2 system peak plus additional 15% of planning reserve margin (PRM) requirement.
- **Clean Energy Standard ("CES") and/or carbon reduction targets:** all portfolios meet the clean energy standard and/or a carbon-reduction trajectory
- **Least cost**: the model's optimization develops a portfolio that minimizes costs

Figure 4 illustrates the use of RESOLVE's operational module, which tracks hourly system operations including cost and greenhouse gas emissions across a representative set of days, and RESOLVE's reliability module, that uses exogenously calculated input parameters to characterize system reliability of candidate portfolios using effective load carrying capability (ELCC) for solar and wind resources.

Figure 4. Schematic Representation of the RESOLVE Model Functionality



RESOLVE develops least-cost portfolios using key inputs and assumptions including loads, existing resources, new resource options, retirement or repowering resource options, resource costs, resource operating characteristics including resource adequacy contributions, a zonal transmission transfer topology, and new resource transmission costs.

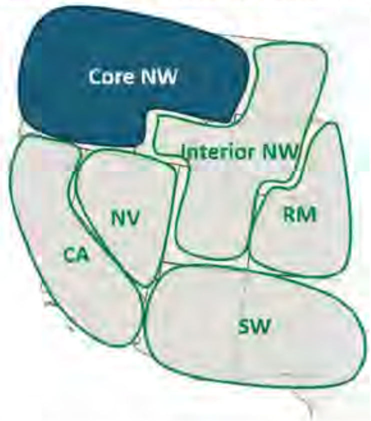
Northwest RESOLVE Model

The Northwest RESOLVE model was developed in 2017 for E3's *Pacific Northwest Low Carbon Scenario Analysis* study.[19] 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

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

outside of the Core Northwest are grouped into five additional zones: (1) Other Northwest, (2) California, (3) Southwest, (4) Nevada and (5) Rockies. For these zones, investments are not optimized; rather, the trajectory of new builds is established based on regional capacity needs to meet PRM targets, as well as renewable needs to comply with existing RPS and GHG policies in their respective regions, and held constant across all scenarios. E3's WECC-wide resource mix incorporates aggressive climate policy across the interconnection, as described in section *Baseline resources*.

Figure 5. RESOLVE Northwest zonal representation

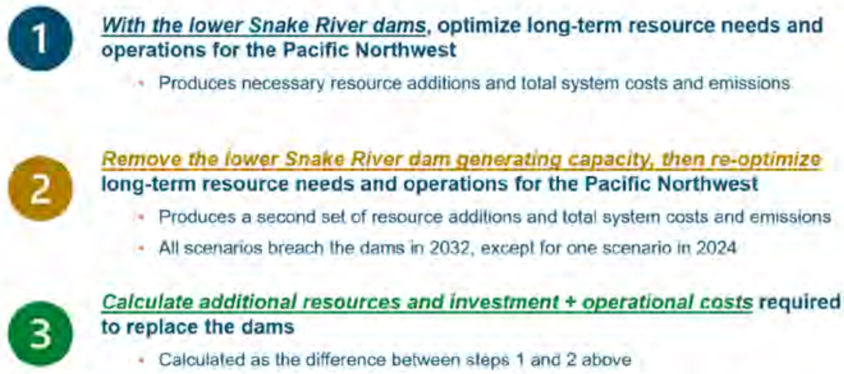


The Northwest RESOLVE model simulates the operations of the WECC system for 41 independent days sampled from the historical meteorological record of the period 2007-2009. An optimization algorithm is used to select the 41 days and identify the weight for each day such that distributions of load, net load, wind, and solar generation match long-run distributions. Daily hydro conditions are sampled separately from dry (2001), average (2005), and wet (2011) hydro years to provide a complete distribution of potential hydro conditions. This allows RESOLVE to approximate annual operating costs and dynamics while limiting detailed operational simulations of grid operations to 41 days.

LSR Dams Modeling Approach

The LSR dams' capacity and operation are characterized with several input parameters that are presented in Section *Hydro parameters*. The approach taken in this analysis is to model LSR dams as an *in/out* resource to determine the dams' replacement costs and replacement portfolio. In other words, "in" scenarios include LSR dams in the existing resource portfolio of Core Northwest throughout the entire modeling period (i.e., 2025-2045); whereas "out" scenarios exclude LSR dams with preset 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.[20] NPV replacement costs are calculating using a 3% discount rate to represent the public power cost of capital.

Figure 6. Modeling Approach to Calculate the LSR Dams Replacement Resources and Costs



This modeling approach inherently considers the benefits of avoiding the LSR dams ongoing fixed and variable costs. The costs associated with breaching the LSR dams themselves are not included in this study. Other power services (i.e., transmission grid reliability services provided by the dams) are also not included but are summarized qualitatively in the Appendix.

Key Input Assumptions

Load forecast

Base load forecast is from NWPCC 2021 Plan and is adjusted to E3's boundary of Core Northwest which roughly represents 87.5% of load of the Northwest system in the NWPCC 2021 Plan. Additionally, a high electrification scenario is modeled which takes Washington's State Energy Strategy high electrification load, scaled up and benchmarked to the Core Northwest region. The baseline high electrification load trajectories are displayed in Figure 7. It is notable that in the high electrification scenario, electric energy demand grows by about 28% by 2045 across all sectors, most noticeably in the commercial building and

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[20] 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.*[21]

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

Figure 7. Annual energy load forecasts for Core Northwest

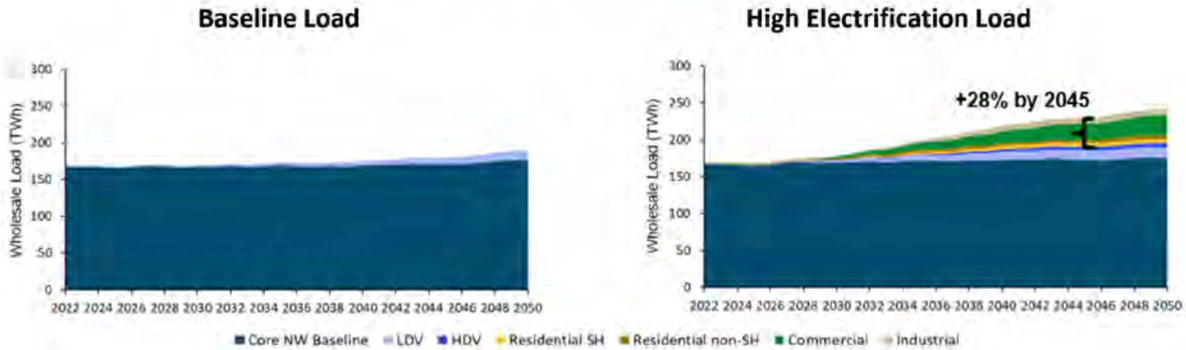
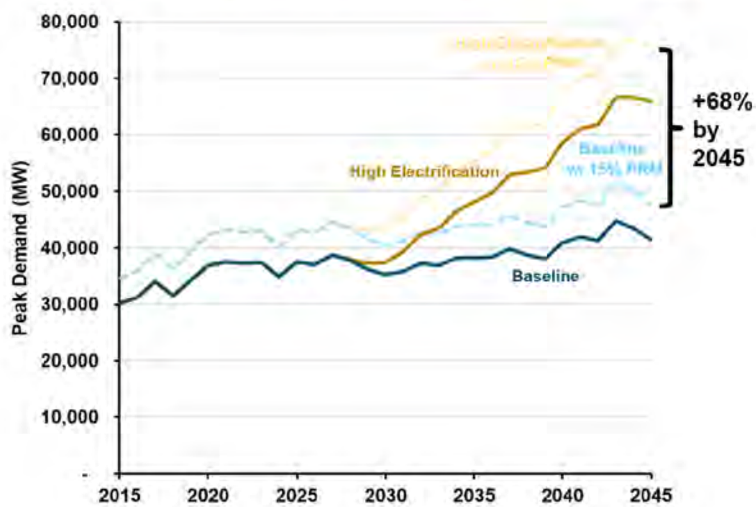


Figure 8 shows the peak demand impacts (including the 15% planning reserve margin) of the high electrification case relative to the baseline, showing a 68% increase by 2045. This high growth is driven by the winter peaking capacity required to replace the gas system peaking capacity to serve peak space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

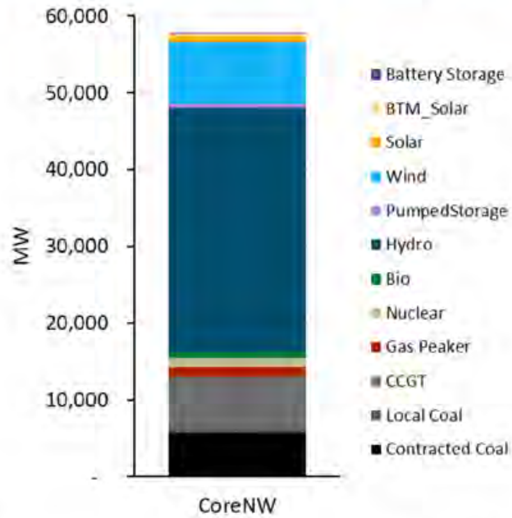
Figure 8. Peak demand forecasts for Core Northwest



Baseline resources

Baseline resources include the existing conventional resources such as natural gas and coal-fired technologies, existing nuclear capacity, hydro as well as pumped storage, battery storage, solar PV, BTM PV and onshore wind technologies. As shown in Figure 9, today's Northwest system has 58 GW capacity. The 1,185 MW nuclear capacity in the Northwest zone remains active throughout the modeling period while the 670 MW local coal capacity is retired by 2025 and the 5,700 MW contracted out of region coal capacity is retired by 2030. The WECC 2020 Anchor Data Set is used for Northwest's existing and planned resources. By 2045, about 5.8 GW additional customer PV is included as planned capacity to capture the growth in behind-the-meter generation forecasted in NWPCC 2021 Power Plan.

Figure 9. Northwest resource capacity in 2022



The investment decisions for external zones are pre-determined based on capacity expansion analysis completed by E3 that accounts for policy targets in each zone as summarized in Table 6. The new builds consist of significant increases in solar and battery capacity additions due to the more aggressive RPS targets, assumed electrification, and the decline of technology cost forecasts (see Figure 10). All future builds in these zones include mature technologies but as discussed in the next section, emerging technologies are made available for RESOLVE to optimize the future resource portfolios in the Northwest zone. There is significant solar and battery storage growth in California, the Southwest, and Nevada that generally lower the marginal value of solar energy produced across the WECC.

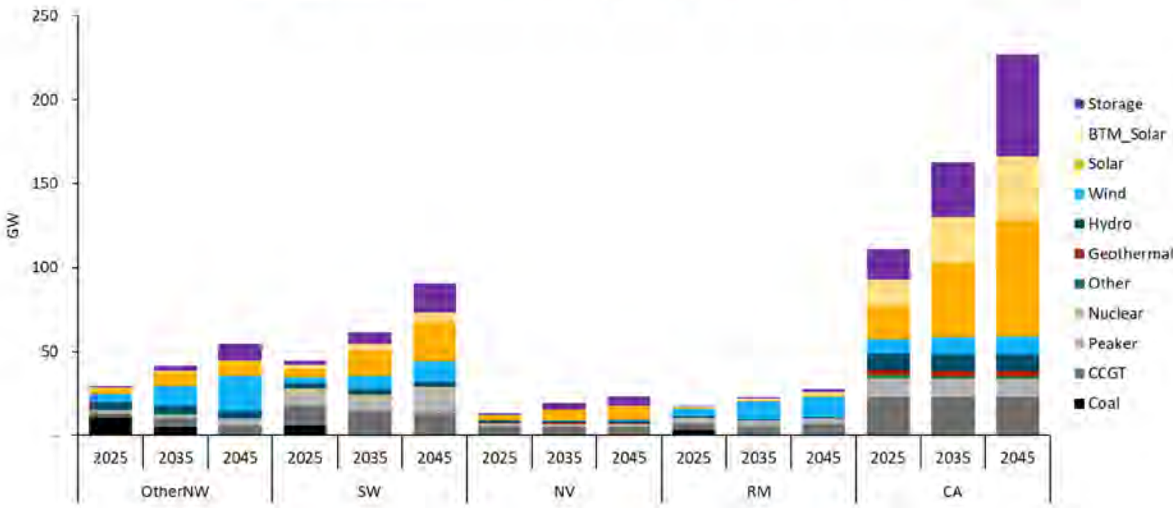
Table 6. Policy targets for builds in external zones

State	Requirement	Policy	2050 Renewable Target
AZ	40% by 2030; 60% by 2045	Transitions to CES[22]	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%

[22] CES = "Clean Energy Standard", an annual based clean generation standard.

MT	87% by 2045 (state carbon reduction goal)	RPS	87%
NM	40% by 2025; 100% by 2045	Transitions to CES	100%
NV	50% by 2030; 100% by 2050	Transitions to CES	95%
UT	50% by 2030; 55% by 2045 (PacifiCorp's IRP)	RPS	55%
WY	50% by 2030, 55% by 2045 (PacifiCorp's IRP)	RPS	55%

Figure 10. Total installed capacity for external zones



Candidate resource options, potential, and cost

A wide range of technologies and resources are made available in RESOLVE, including mature and emerging technologies. The list of technologies made available in each modeled scenario is presented in Table 7. Some technologies such as solar and onshore wind are low-cost zero-carbon energy resources with limited resource potential and declining capacity values. Storage resources such as battery storage and pumped hydro support renewable integration but show limited capacity value given the large shares of hydro in the Northwest region. Demand response supports peak reduction but also faces declining ELCCs. Energy efficiency supports energy and peak reduction but increasingly competes against low-cost renewables. Geothermal is relatively high cost and has limited potential but provides highly valuable "clean firm" capacity.

Some emerging technologies are also made available in several scenarios to allow for firm zero-carbon technologies to be selected from. Hydrogen-capable generators such as dual fuel combustion turbines and combined cycles (i.e., capable of burning both natural gas and hydrogen) as well as retrofits of existing gas generators to burn hydrogen are modeled. These technologies provide low-cost capacity options with very high energy cost when burning expensive hydrogen fuel, therefore RESOLVE selects them for firm capacity needs but limits their hydrogen energy production. Natural gas with carbon capture and storage (CCS) technologies are moderately high cost in terms of both energy and capacity. Nuclear SMR provides moderately high capital cost but low operating cost for firm zero-carbon energy generation. This technology is made available to the model after 2035, to account for the time needed for technology development, licensing, and installation. Floating offshore wind is also modeled as an emerging technology which address onshore resource and land constraints but is generally higher cost than onshore wind while providing a similar annual capacity factor to high quality Montana and Wyoming wind.

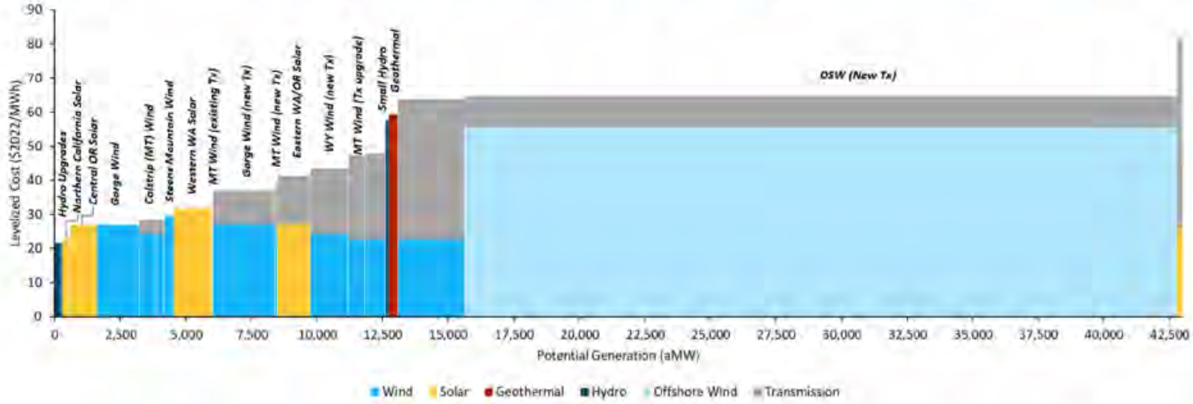
Table 7. Available technologies in each modeled scenario

Resource	A. Baseline	B. Emerging Tech	C. No New Combustion (Limited Tech)
Mature resources: solar, wind, battery storage, pumped storage, demand response, energy efficiency, small hydro, geothermal	✓	✓	✓
Natural gas to hydrogen retrofits	✓	✓	✓
Dual fuel natural gas + hydrogen plants	✓	✓	×
Natural gas with 90-100% carbon capture and storage	×	✓	×
Nuclear small modular reactors	×	✓	×
Floating offshore wind	×	✓	✓

There are physical limits to the quantity of renewable resources that can be developed in each 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.[23] 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.

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

Figure 11. Renewable resource supply curve in 2045, including transmission cost adders



Clean energy policy targets

RESOLVE enforces a clean energy standard ("CES") requirement as a percentage of retail sales to ensure that the total quantity of energy procured from renewable resources meets the CES target in each year. The clean energy standard percentage is calculated as follows, and the target values are summarized in Table 2:

$$CES\ \% = \frac{Annual\ Renewable\ Energy\ or\ Zero\ Emitting\ Generation}{Annual\ CoreNW\ Retail\ Electric\ Sales}$$

Eligible renewable energy and zero-emitting resources include: solar, wind, geothermal, hydropower, nuclear, biomass, green hydrogen, and natural gas with carbon capture and storage.

Regarding GHG emissions, RESOLVE enforces a greenhouse gas constraint on the CoreNW region such that total annual emission generated in the zone must be less than or equal to the emissions cap. The greenhouse gas accounting for the Northwest zone follows the rules established by the California Air Resources Board. The CoreNW carbon emissions baseline is set as 33 MMT at the 1990 level. The total greenhouse gas emissions attributed to the Core Northwest region include:

+ **In-region generation:** all greenhouse gas emissions emitted by fossil generators (coal and natural gas) within the region, based on the simulated fuel burned and fuel-specific CO_2 emissions intensity;
+ **External resources owned/contracted by Core Northwest utilities:** greenhouse gas emissions emitted by resources located outside the Core Northwest but currently owned or contracted by utilities that serve load within the region, based on fuel burn and fuel-specific CO_2 emissions intensity; and
+ **"Unspecified" imports to the Core Northwest:** assumed emissions associated with economic imports to the Core Northwest that are not attributed to a specific resource but represent unspecified flows of power into the region, based on a deemed emissions rate of 0.43 tons/MWh.

Table 8. Annual CES and carbon emissions targets modeled for CoreNW in RESOLVE

Resource	2025	2030	2035	2040	2045
Clean energy standard %	29%	49%	68%	88%	100%

(used in Scenarios 1 and 2[24])					
Carbon reduction emissions target (used only in Scenario 2)	22.7 MMT	17.0 MMT	11.3 MMT	5.7 MMT	0 MMT

Hydro parameters

RESOLVE characterizes the generation capability of the hydroelectric system by including three types of constraints from actual operational data: (1) daily energy budgets, which limit the amount of hydro generation in a day; (2) maximum and minimum hydro generation levels, which constrain the hourly hydro generation; and (3) multi-hour ramp rates, which limit the rate at which the output of the collective hydro system can change from one to four hours. Combined, these constraints limit the generation of the hydro fleet to reflect realistic seasonal limits on water availability, downstream flow requirements, and non-power factors that impact the operations of the hydro system.

In this analysis, hydro operating data are parameterized using conditions for three different hydrological years, i.e., 2001 for dry, 2005 for average and 2011 for wet conditions. For LSR dams, we use hourly generation data provided by BPA, which are adjusted for latest fish protection and spill constraints. For the remainder of the northwest hydro fleet, we rely on historical hydro dispatch data used to develop the TEPPC 2022 Common Case dataset. Using muti-year historical hydro operational data allows capturing the complete set of physical and institutional factors, such as cascading hydro, streamflow constraints, fish protection, navigation, irrigation, and flood control, that limit the amount of flexibility in the hydro system.

For each RESOLVE sampled day, the hydro daily energy budget is calculated as the average of daily electricity generated in the month of each sampled RESOLVE day in its corresponding matched hydro year.[25] The maximum and minimum hydro generation levels (P_{min} and P_{max}) are calculated as the absolute min and max of generation in the month of each sampled RESOLVE day in its corresponding matched year. Multi-hour ramp rates are estimated based on the 99th percentile of upward ramps observed across the three hydrological years of hourly data. In addition, for non-LSR Northwest hydro, the model allows 5% of the hydro energy in each day to be shifted to a different day within two months to capture additional flexibility for day-to-day hydro energy shift.

[24] 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.

[25] LSR dams generate about 900 average MW of energy during an average hydro year. However, during the three years modeled in RESOLVE, the LSR dams produced only ~700 average MW generation for LSR dams. This means our estimate of the replacement cost of the dams is quite conservative relative to a longer-term expected average of ~900 MW.

Figure 12. RESOLVE Hydro inputs for LSR Dams and other Northwest hydro

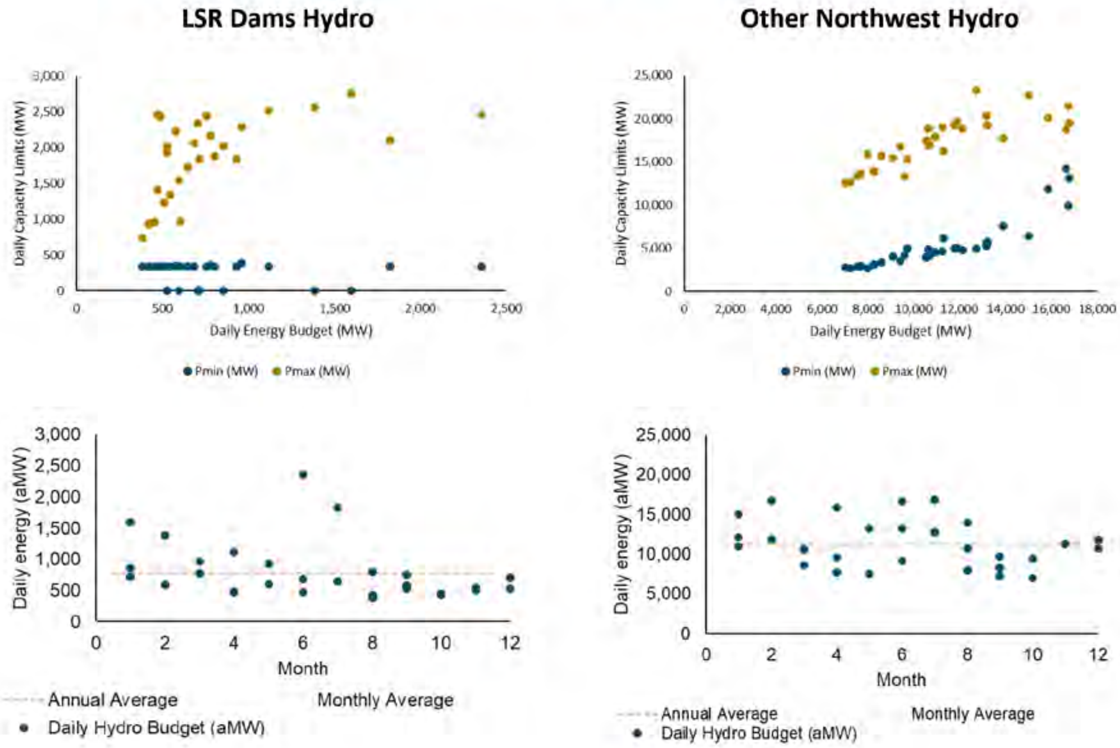


Table 9. Multi-hour ramping constraints applied to Northwest hydro

	One hour	Two hours	Three hours	Four hours
LSR Dams Hydro	36%	43%	45%	48%
Other Northwest Hydro	14%	23%	29%	32%

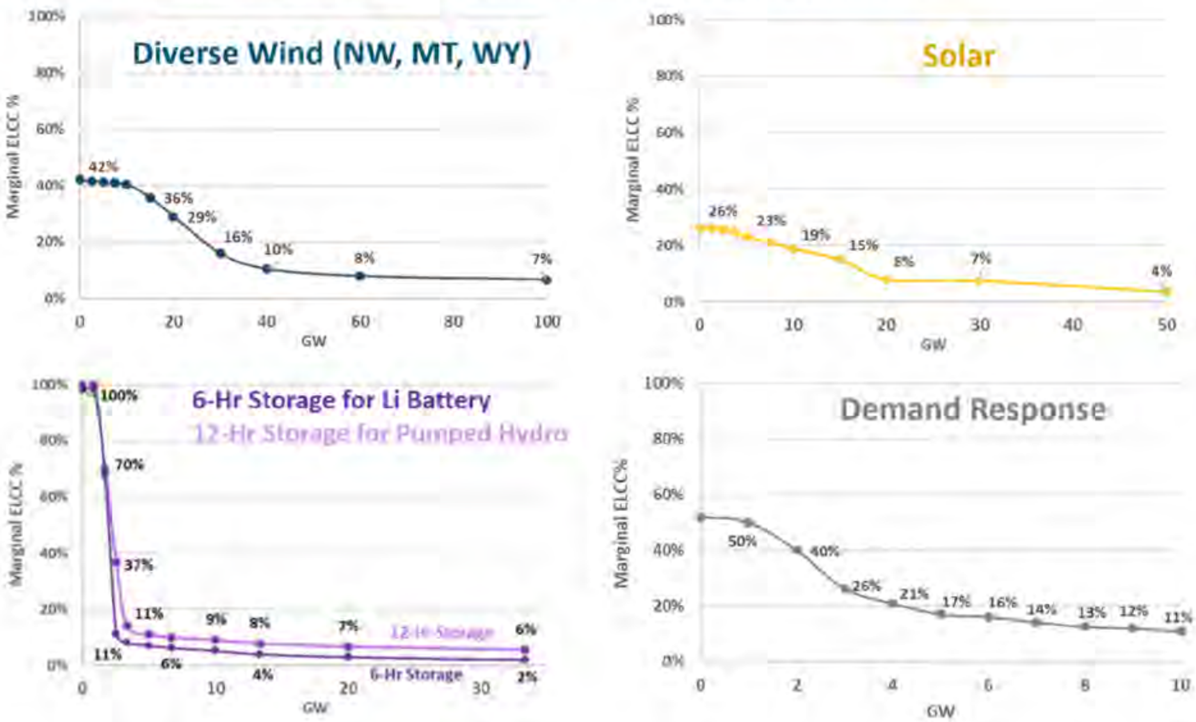
Resource Adequacy Needs and Resource Contributions

Hydro firm capacity contribution for both LSR dams and other Northwest hydro is assumed to be 65% of nameplate, per PNUCC methodology (based on 10-hr sustaining peaking capacity). This means that the LSR dams provide 2,284 MW of firm capacity that must be replaced if the dams are breached. This assumption was validated based on BPA modeled LSR dam performance data during the 2001 dry hydro year, as described in the section *Key Uncertainties for the Value of the Lower Snake River Dams*, which also describes estimates of the NPV impact of assuming a lower firm capacity value for the dams.

Resource adequacy needs are captured in RESOLVE by ensuring that all resource portfolios have enough capacity to meet the peak Core Northwest median peak demand plus a 15% planning reserve margin. Firm capacity resources are counted at their installed capacity. Hydro resources are counted at the 65% regional value used in PNUCC's 2021 resource adequacy analysis. Solar, wind, battery storage, pumped hydro storage, and demand response are counted at their effective load carrying capability ("ELCC") based on E3's RECAP modeling from its 2019 *Resource Adequacy in the Pacific Northwest* study.[26] 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.

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

Figure 13. Solar, Wind, Storage, and Demand Response Capacity Values



The capacity value for energy storage resources shown in Figure 13 are very different from those in other regions, such as California or the Desert Southwest, declining much more quickly as a function of penetration. There are two reasons for this. First, the Pacific Northwest is a winter peaking region in which loss-of-load events are primarily expected to occur during extreme cold weather events that occur under drought conditions in which the region faces an energy shortfall. These events, such as the one illustrated in Figure 3 above, result in multi-day periods in which there is insufficient energy available to charge storage resources, severely limiting their usefulness. This is unlike the Southwest, where the most stressful system conditions occur on hot summer days in which solar power is expected to be abundant and batteries can recharge on a diurnal cycle. Second, the Pacific Northwest already has a very substantial amount of reservoir storage which can shift energy production on a daily or even weekly basis. Thus, the Pacific Northwest is already much closer to the saturation point where additional diurnal energy shifting has limited value.

Nevertheless, recognizing that the capacity value of energy storage is still being researched, in the Northwest and elsewhere, we include a sensitivity case in which energy storage resources are assumed to have much higher ELCC values, similar to what is expected in the Southwest at comparable penetrations. This test case was used to assess whether a higher energy storage ELCC would change the replacement resources and replacement cost of the LSR dams. The results are presented in the section *Replacement Resources Firm Capacity Counting*.

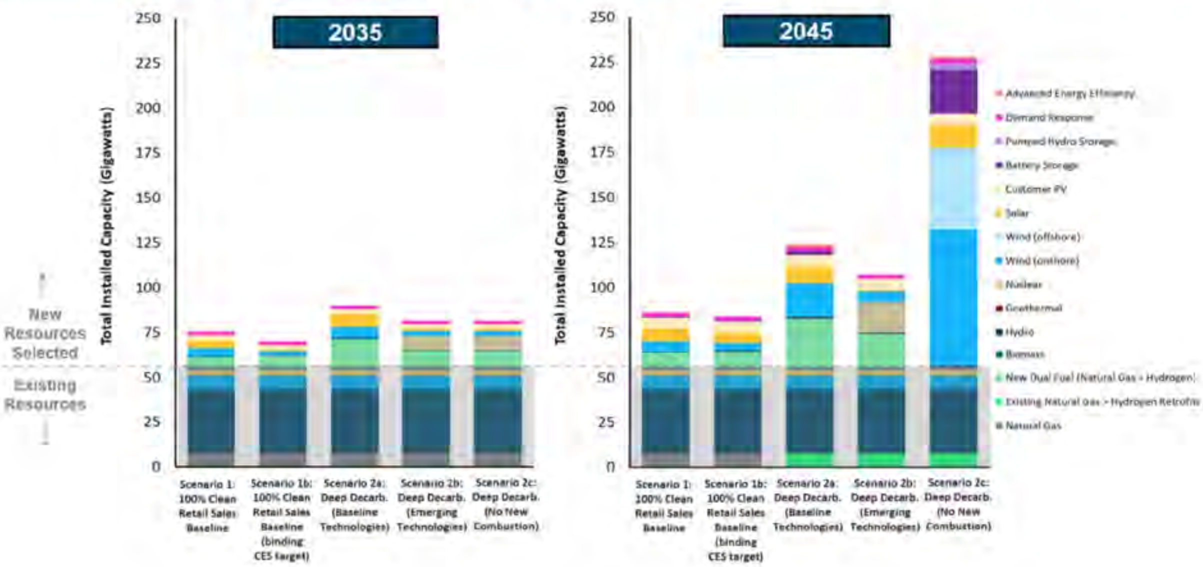
Results

RESOLVE model runs for the 2025-2045 period produce optimal resource portfolios of additions and retirements by resource type, as well as metrics of annual and hourly resource generation, carbon emissions, and total system costs. This section presents the RESOLVE modeling results, focused on the years of 2035 and 2045 to highlight the mid-term and long-term resource needs. Following that, the result of the RESOLVE runs with the LSR dams breached are presented, with the replacement resource and costs to replace the dams' power services.

Electricity Generation Portfolios with the Lower Snake River Dams Intact

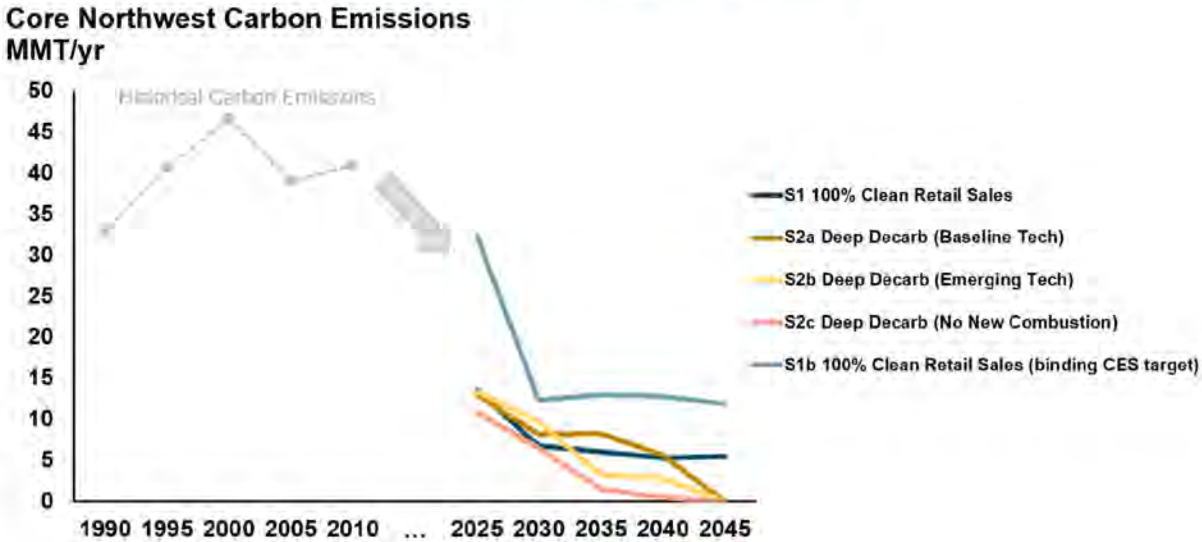
In the scenarios that do not assume breaching of the LSR dams, large amounts of utility-scale solar PV, onshore wind, offshore wind, hydrogen-capable combined cycle, and some amounts of energy efficiency and demand response are selected to meet the growing electricity demand, PRM, and emissions reductions. Electrification load growth along with zero emissions targets drive higher needs in deep decarbonization scenarios (i.e., S2a, S2b and S2c) compared to the reference scenario (S1) in both snapshot years of 2035 and 2045. In S2b, clean firm technologies such as SMR nuclear are selected in place of additional onshore wind, solar and dual-fuel CCGT selected in S2a. In the absence of clean firm technologies (no new combustion) in S2c, massive amounts of offshore wind (~45 GW) as well as more battery storage, pumped storage, demand response, and energy efficiency are selected as early as 2035 such that in this scenario, the new resource additions are almost five time the new builds in S1. These capacity additions increase even more substantially by 2045.

Figure 14. Large levels of new resource additions to meet the growing load, PRM needs and emissions reductions (assumes LSR Dams are NOT breached)



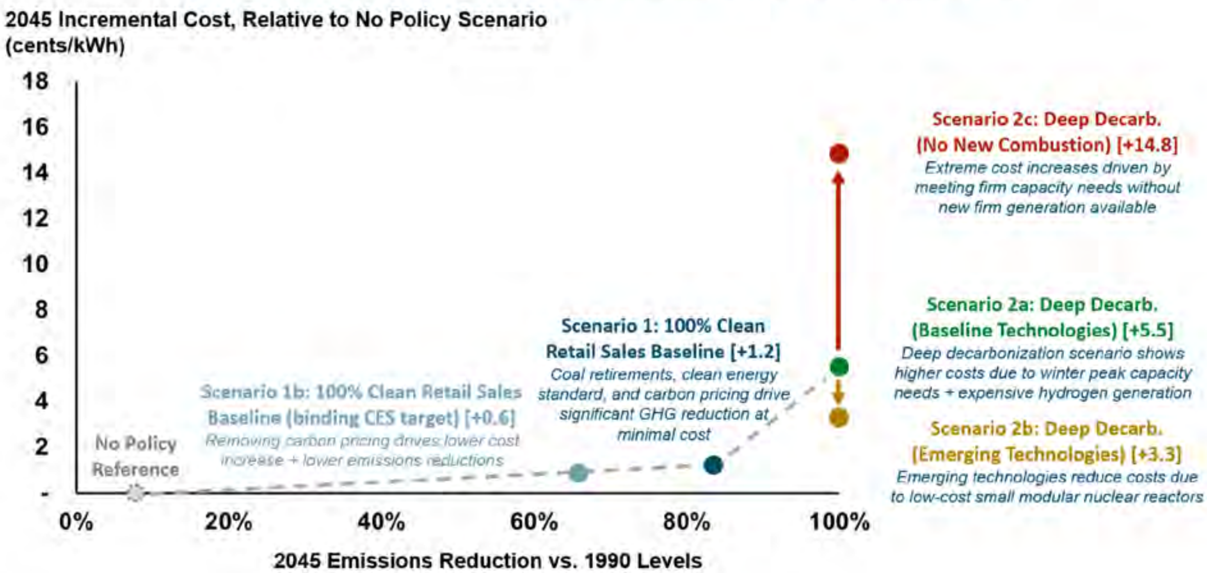
As shown in Figure 15 below, all four scenarios result in a sharp near-term decline in carbon emissions, driven by Washington and Oregon policies that drive coal retirement this decade. By 2045, Scenario 1, which requires 100% clean retail sales, shows an ~85% decline in carbon emissions relative to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

Figure 15. Northwest Carbon Emissions



To put cost impacts in context, a "No Policy Reference" case uses the baseline load forecast and removes all electric clean energy policies, retaining the region's coal power with little emissions decline. The four clean energy futures modeled are compared against this Reference Case on A) their cost impacts, measured in incremental cents/kWh relative to the Reference, and B) their carbon emissions reductions, relative to 1990 levels. By 2045, as shown in Figure 16, with the region's aggressive carbon policies in place, emissions can be reduced by over 80% with a relatively small cost impact (+1.2 cents/kWh relative to the region's current average retail rate of 8-9 cents/kWh). Without a carbon price (scenario 1b), emissions are reduced ~65% with a cost impact of 0.6 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)[27] or other emerging technologies are available[28], showing that relying only on non-firm resource additions (renewable energy, demand side resources, and short- to medium-duration storage) leads to much higher costs.

Figure 16. Cost Impacts Compared to Emissions Reduction Impacts



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

LSR Dams Replacement

The resource replacement portfolios and costs of replacing the LSR dams are reported in this section.

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

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[27] 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.

[28] Floating offshore wind was allowed in the no new combustion case since it was required to allow a feasible solution without making any other firm capacity additions available in the model.

natural gas and hydrogen combustion plants selected to replace the LSR dams' capacity in Scenarios 1, 1b, 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, solar, and a small amount of 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 S1 with 2024 removal, but the replacement portfolio remains similar.

Table 10. Optimal portfolios to replace the LSR dams

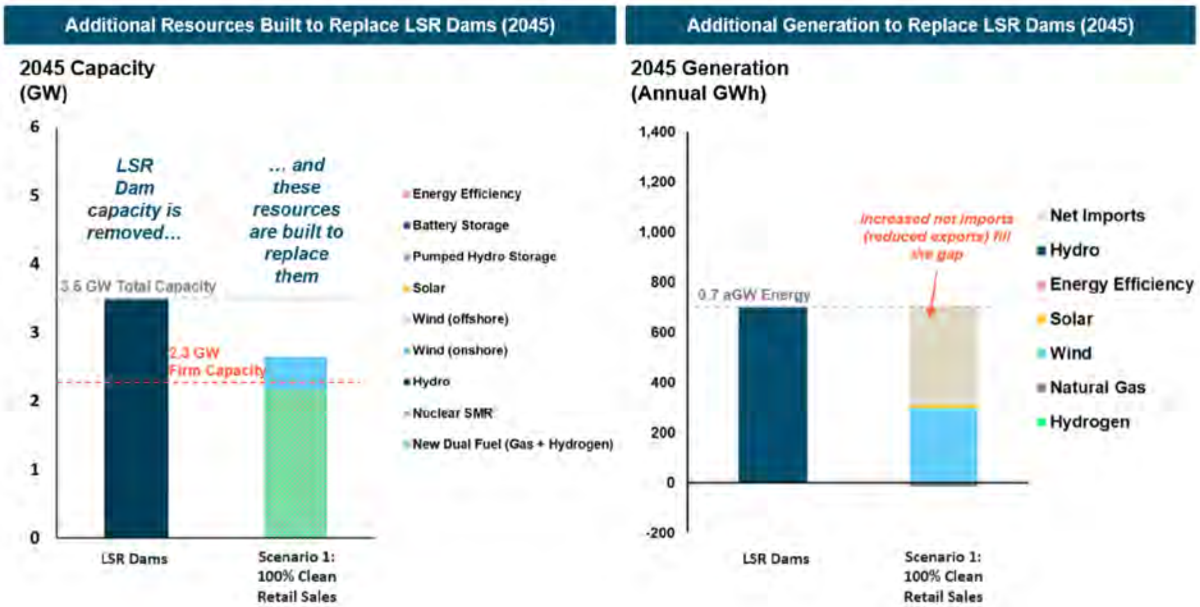
Scenario	Replacement Resources Selected, Cumulative by 2035[29] (GW)	Replacement Resources Selected, Cumulative by 2045 (GW)
Scenario 1: 100% Clean Retail Sales	+ 1.8 GW dual fuel NG/H2 CCGT - 0.5 GW solar + 1.3 GW wind + 0.1 GW li-ion battery	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind
Scenario 1: 100% Clean Retail Sales (2024 dam removal)	+ 1.8 GW dual fuel NG/H2 CCGT - 0.5 GW solar + 1.4 GW wind	+ 2.1 GW dual fuel NG/H2 CCGT + 0.5 GW wind

[29] Replacement resources are calculated by comparing the "with LSR dams" RESOLVE portfolio to the "without LSR dams" RESOLVE portfolio. This means some resources may be built in 2035, such as 0.3 GW of geothermal in scenario 2c, that are not built when the dams are included. However, those resources may have already been selected in the "with LSR dams" case by 2045, hence do not show up as additional resource replacement needs in 2045. This explains the different resource changes between 2035 and 2045.

	+ 0.1 GW li-ion battery	
Scenario 1b: 100% Clean Retail Sales (binding CES target)	+ 2.2 GW dual fuel NG/H2 CCGT + 0.1 GW li-ion battery	+ 1.8 GW dual fuel NG/H2 CCGT + 1.3 GW solar + 1.2 GW wind
Scenario 2a: Deep Decarbonization (Baseline Technologies)	+ 2.0 GW dual fuel NG/H2 CCGT + 0.6 GW wind + 0.1 GW li-ion battery	+ 2.0 GW dual fuel NG/H2 CCGT + 0.3 GW li-ion battery + 0.4 GW wind + 0.05 GW advanced EE + 1.2 TWh H2-fueled generation
Scenario 2b: Deep Decarbonization (Emerging Technologies)	+ 1.7 GW dual fuel NG/H2 CCGT + 0.6 GW nuclear SMR	+ 1.5 GW dual fuel NG/H2 CCGT + 0.7 GW nuclear SMR
Scenario 2c: Deep Decarbonization (No New Combustion)	+ 9.1 GW [illegible] + 0.1 GW wind + 1.0 GW solar + 0.3 GW geothermal + 1.5 GW li-ion battery	+ 10.6 GW wind + 1.4 GW solar

Figure 17 through Figure 21 show details of the capacity replacement, energy replacement, and cost breakdown for Scenarios 1, 1b, 2a, 2b, and 2c. LSR dams energy in these scenarios is replaced with wind, solar, 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[30]



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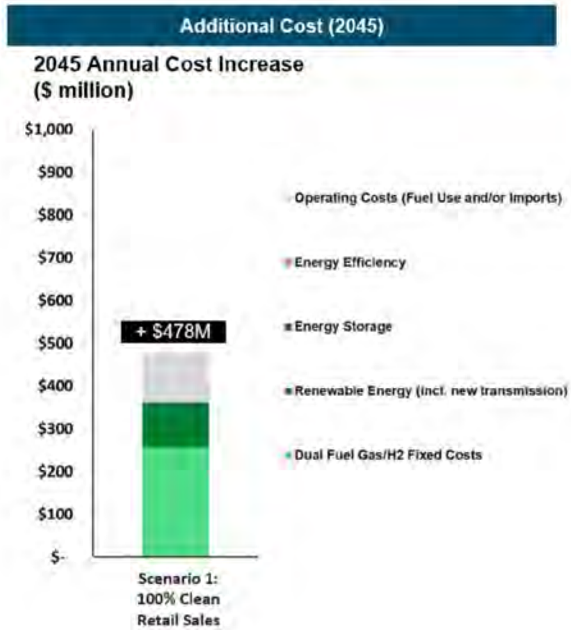
[30] Regarding the "net imports" component of the energy replacement, this refers to either increased imports, decreased exports (generally of carbon-free energy), or a combination of both, such that RESOLVE does not need to build enough new generation to fully replace the LSR dams output. For instance, the region could export less hydropower to California and other neighbors to replace the LSR dams output without necessarily increasing Northwest carbon emissions in Scenario 1.



Additional Cost (2045)
2045 Annual Cost Increase
($ million)
$1,000
$900
$800
$700
$600
$500
$400
$300
$200
$100
$-
+ $478M
Scenario 1:
100% Clean
Retail Sales
Operating Costs (Fuel Use and/or Imports)
Energy Efficiency
Energy Storage
Renewable Energy (incl. new transmission)
Dual Fuel Gas/H2 Fixed Costs

Figure 18. Scenario 1b Capacity Replacement, Energy Replacement, and Costs

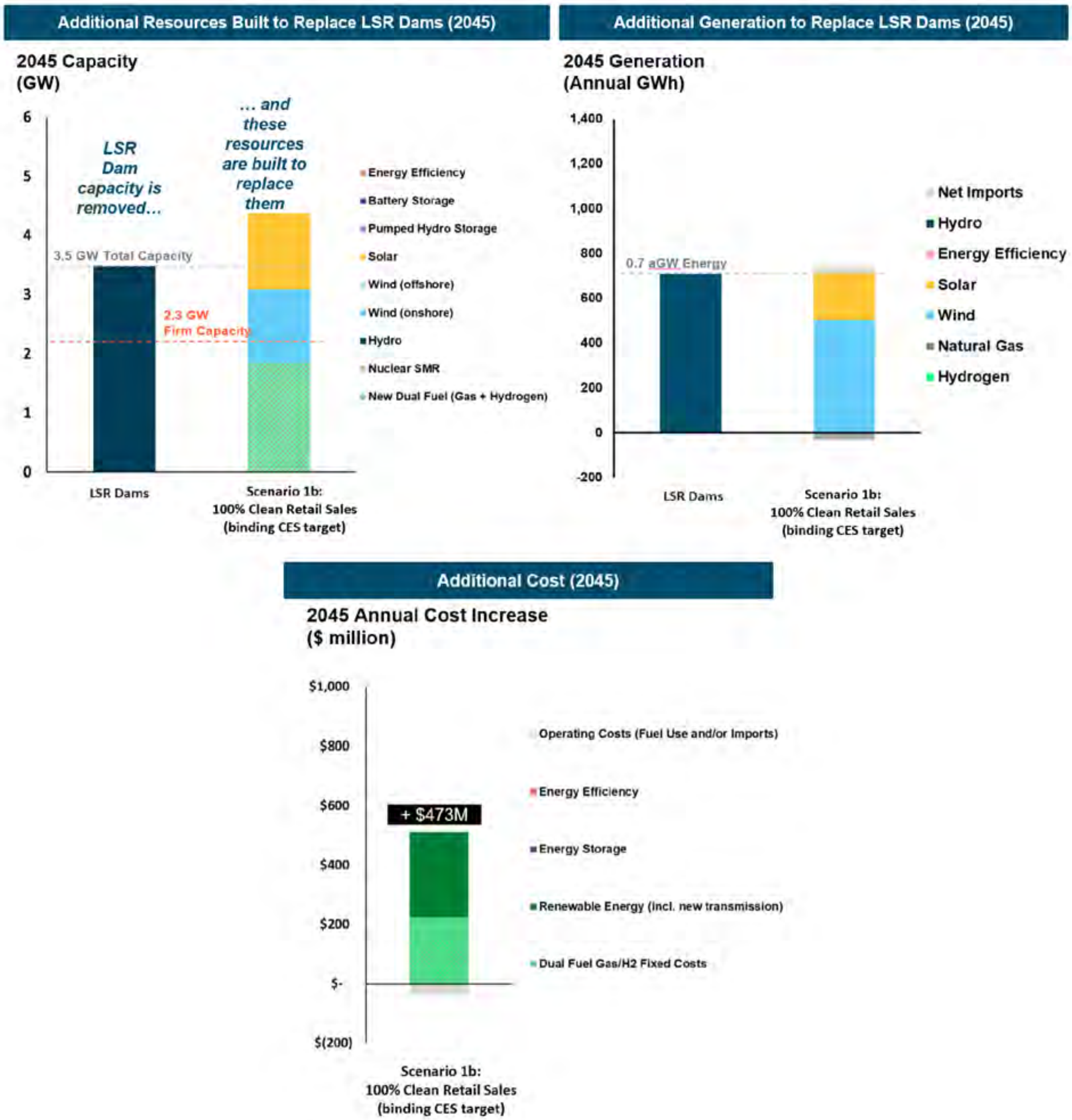


Figure 19. Scenario 2a Capacity Replacement, Energy Replacement, and Costs

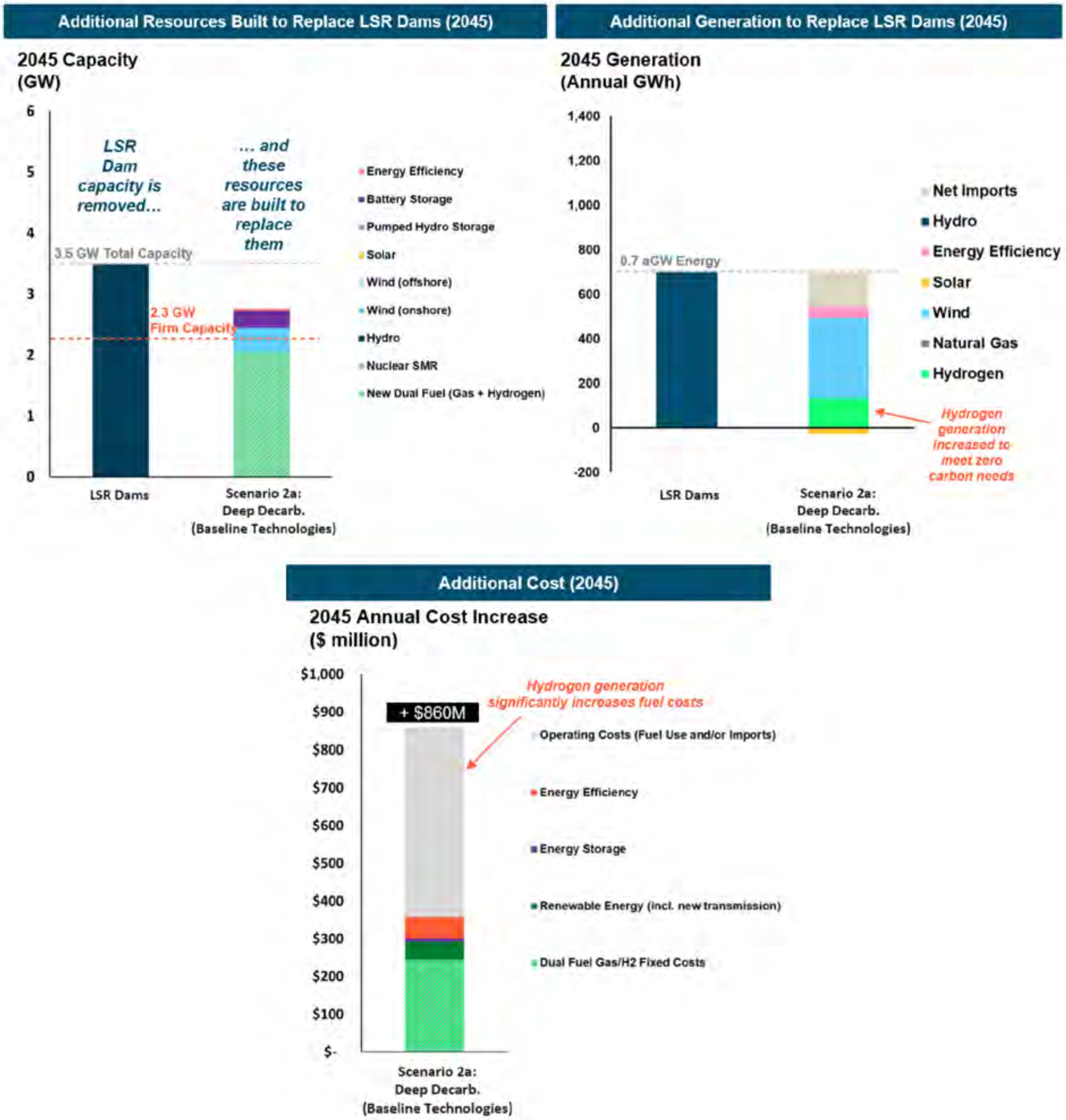


Figure 20. Scenario 2b Capacity Replacement, Energy Replacement, and Costs

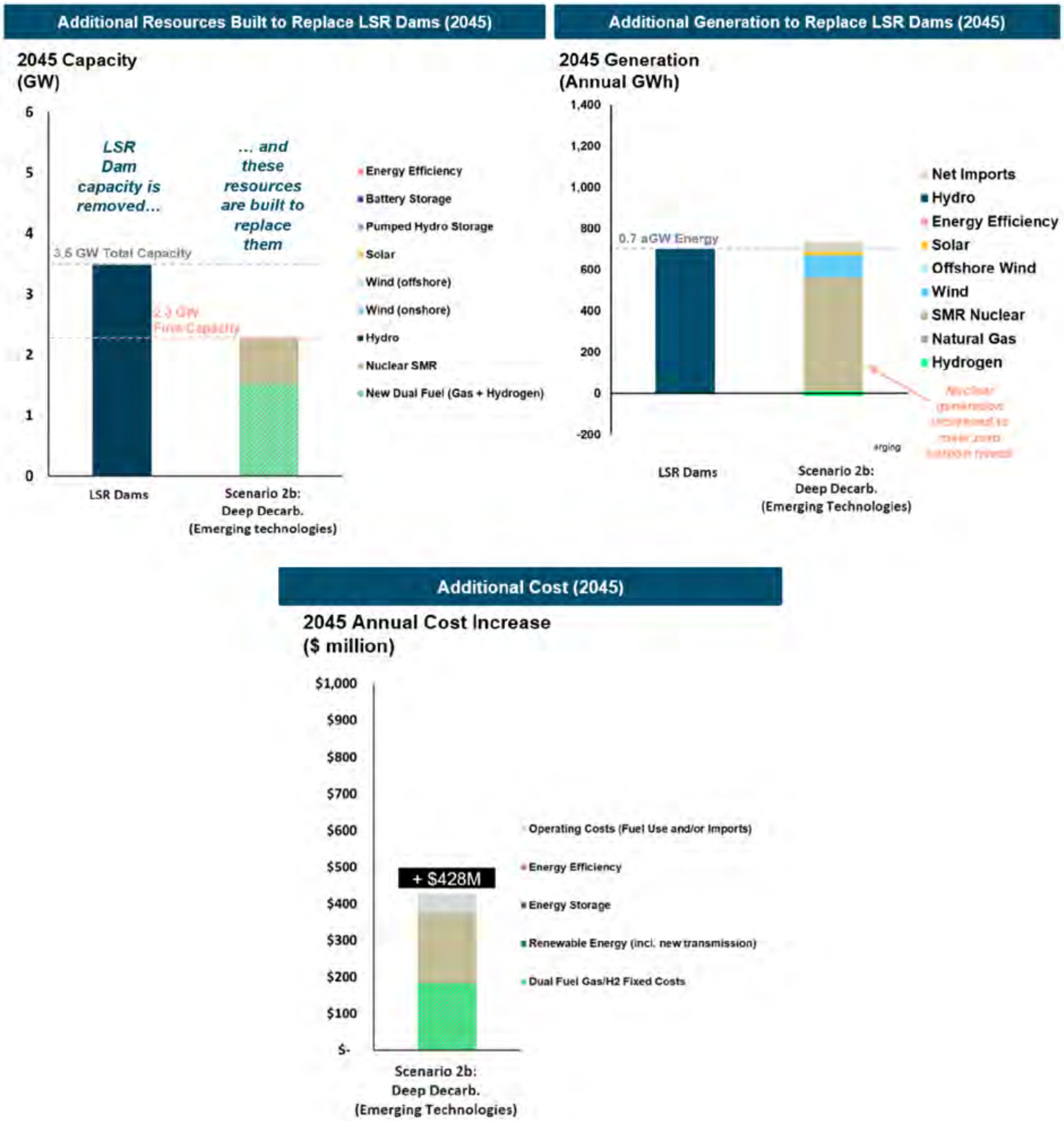
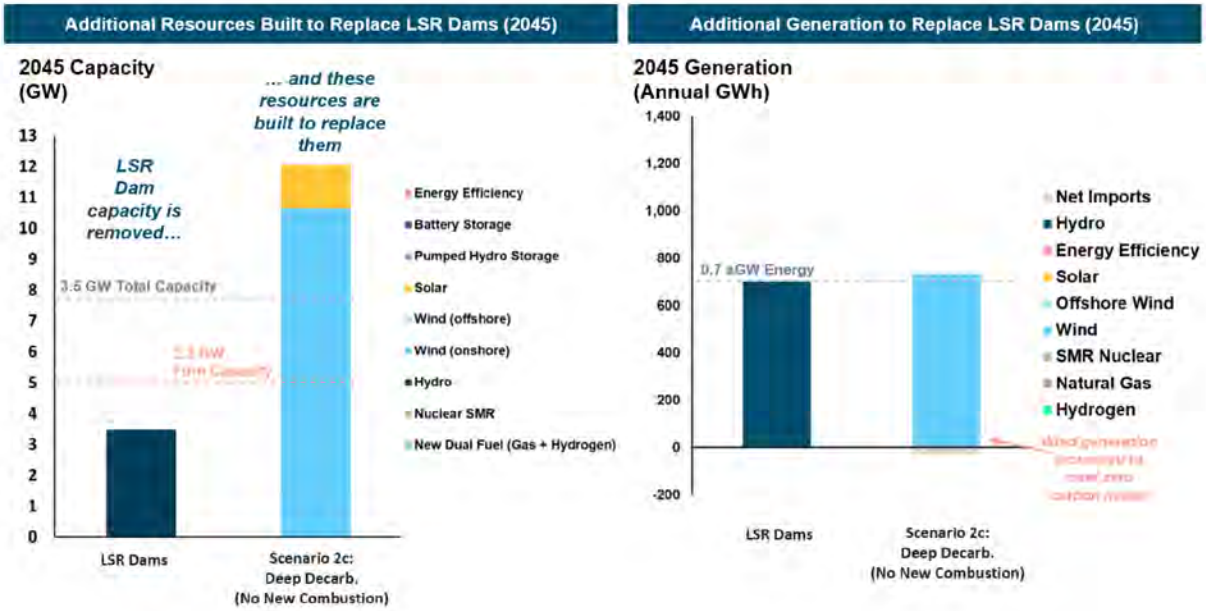


Figure 21. Scenario 2c Capacity Replacement, Energy Replacement, and Costs[31]



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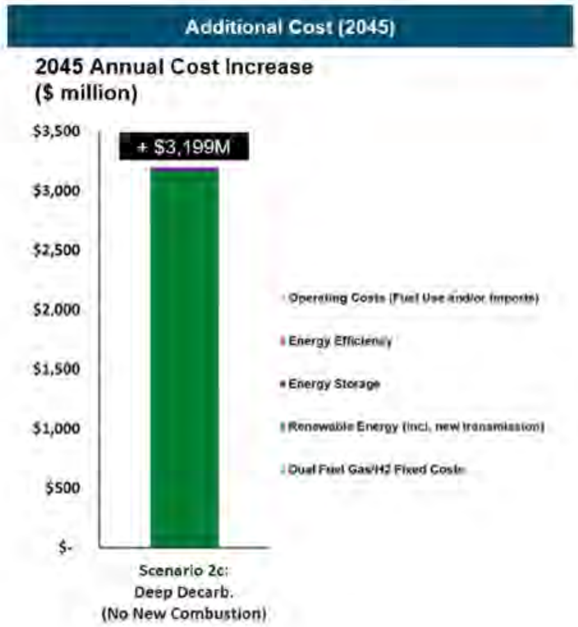
[31] NOTE: the energy replacement does not show the total potential energy output of the wind built to replace the dams, because much of the potential energy output is curtailed due to oversupply of wind built for resource adequacy needs.



Replacement costs

The LSR dams provide a relatively low-cost source of GHG-free energy and firm capacity. Incremental costs for replacement resources are summarized in this section. All costs are shown in real 2022 dollars. Incremental costs to replace the power services of the LSR dams ranges from $69-139/MWh across most scenarios. Scenario 2c, however, shows a much higher replacement power cost of $277-517/MWh. These incremental costs are much higher than costs of maintaining the LSR dams (i.e., $13-17 per MWh[32]); 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.

[32] BPA directly funds the annual operations and maintenance of the Lower Snake River Compensation Plan (LSRCP) facilities. The cost of generation at the lower Snake River dams is in the range of $13/MWh without LSRCP and $17/MWh with LSRCP. Congress authorized the LSRCP as part of the Water Resources Development Act of 1976 (90 Stat.2917) to offset fish and wildlife losses caused by construction and operation of the four lower Snake River projects.

Table 11. Incremental costs to replace LSR generation in 2045

Scenario	Incremental net costs in 2045[33], including avoided LSR dam costs (Real 2022 $/MWh)	Incremental gross costs in 2045[34], 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 1b: 100% Clean Retail Sales (binding CES target)	$77/MWh	$94/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)	$277-517/MWh	$294-534/MWh

The LSR dams' total replacement costs (in net present value) and annual replacement costs for 2025, 2035, and 2045 are shown in Table 12. NPV replacement costs are calculated based on discounting at a 3% discount rate, representative of the approximate public power cost of capital, over a 50-year time horizon following the date of breaching. Scenario 1 (100% clean retail sales) replacement costs are approximately $12-12.4 billion in net present value (NPV) in the year of breaching (in 2032); costs increase to $12.8 billion NPV if breached in 2024. Total replacement costs are similar in the economy-wide deep decarbonization scenario when emerging technology is available (scenario 2b), showing $11.2 billion NPV. Replacement costs are significantly higher in scenario 2c where no new combustion resources are allowed ($42-77 billion NPV). The economy-wide deep decarbonization (baseline technology scenario), 2a, shows more costly replacement ($19.6 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

[33] 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.
[34] 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.

growth. The 2045 cost increases translate to 8-18% growth in BPA's public power customers costs in scenarios 1, 1b, 2a and 2b (assuming current retail rates are about 8.5 ₵/kWh based on OR and WA average retail rates). In these scenarios, public power households would see an increase in annual electricity costs of $100-230/yr in 2045. In Scenario 2c, rate impacts could be as high as 34-65%, which is equivalent to annual residential electricity bills raising by up to $450-850 per year.[35] Note that these incremental cost increases include the ongoing LSR dams costs, such as operations and maintenance costs, avoided by breaching the dams, but do not include the costs of breaching. The rate impacts shown are only for the LSR dams' replacement, they do not include the additional rate increases driven by higher loads or clean energy needs (that are covered in the section *Electricity Generation Portfolios with the Lower Snake River Dams Intact* above), which apply even without removing generation from the LSR dams.

Table 12. Total LSR Dams replacement costs

	NPV Total Costs (Real 2022 $)[36]	Annual Costs Increase (Real 2022 $)			Incremental Public Power Costs[37]
	In the year of breaching (2032 or 2024)	2025	2035	2045	2045
Scenario 1: 100% Clean Retail Sales	$12.4 billion	n/a	$434 million	$478 million	0.8 ₵/kWh [+9%]
Scenario 1: 100% Clean Retail Sales (2024 dam breaching)	$12.8 billion	$495 million	$466 million	$509 million	0.8 ₵/kWh [+9%]
Scenario 1b: 100% Clean Retail Sales (binding CES target)	$12.0 billion	n/a	$445 million/yr	$473 million/yr	0.8 ₵/kWh [+9%]
Scenario 2a: Deep Decarb. (Baseline Technologies)	$19.6 billion	n/a	$496 million	$860 million	1.5 ₵/kWh [+18%]
Scenario 2b: Deep Decarb. (Emerging Technologies)	$11.2 billion	n/a	$415 million	$428 million	0.7 ₵/kWh [+8%]

[35] 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.

[36] NPV replacement costs are based on discounting at a 3% discount rate, representative of the approximate public power cost of capital, over a 50-year time horizon following the date of breaching.

[37] 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)	$42 – 77 billion[38]	-	$ 1,045 – 1,953 million/yr	$1,711 – 3,199 million/yr	2.9 – 5.5 ¢/kWh [+ 34 – 65%]

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, carbon emissions increases are observed in the mid-term (0.7-1.5 MMT/yr. or ~10% of the region's carbon emissions in 2035). Scenario 1b, when the CES target binds in 2045, shows to GHG increases in 2045, since the GHG-free energy of the LSR dams is replaced by solar and wind power. 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 to meet the zero-carbon constraint.

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.

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

[38] 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.

Uncertainty of the LSR dam value is considered under scenarios of:

- **Clean energy policy**: replacement of carbon-free power becomes increasingly critical to reach a zero-emissions electricity grid
- **Load growth**: replacement energy and capacity needs may change with increased electrification and peak higher winter space heating needs
- **Technology availability**: replacement is more expensive with fewer emerging technology resource options
- **Timing**: replacement was focused on breaching in 2032, but a 2024 sensitivity was also considered
- **Carbon pricing**: a sensitivity scenario was considered for scenario 1 that considered no carbon pricing, which causes the 100% CES target to bind

Additional uncertainties regarding the value of the dams are:

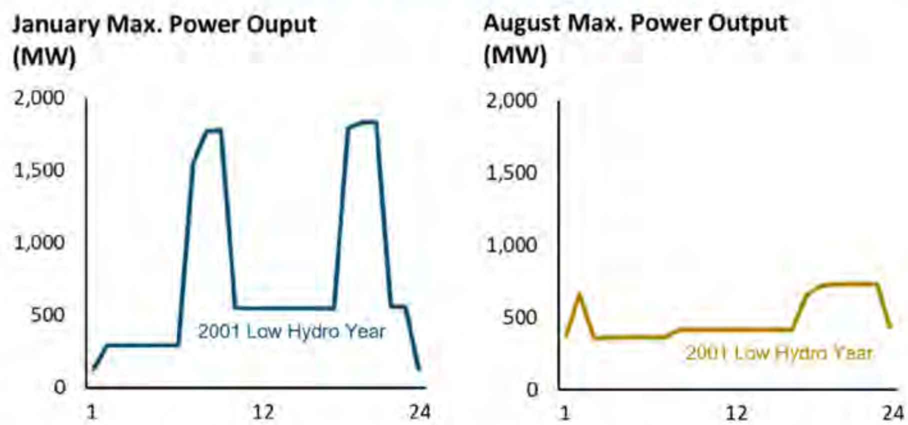
- **LSR dams annual energy output**: E3's existing RESOLVE model data uses historical hydro years 2001, 2005, and 2011 as representative of the regional long-term average low/mid/high hydro year conditions. The data for the Columbia River System dams was adjusted to reflect the Preferred Alternative operations defined in the CRSO EIS. However, for the LSR dams, these selected historical hydro years resulted in a relatively low output of ~700 average MW, whereas the dams may generate ~900 average MW on average across the full historical range of hydro conditions. Therefore, E3's analysis likely underestimates the energy value of the dams and costs for replacing that extra GHG-free energy.
- **LSR dams firm capacity counting**: as resource adequacy is found to be a key driver of future resource needs, the firm capacity contributions of the LSR dams is a key driver of their value. See below for further discussion of this uncertainty.
- **Replacement resource capacity contributions**: if Northwest reliability challenges dramatically shift into the summer, this would also impact the capacity value of replacement resources. Directionally, this would likely increase the capacity value of energy storage, and change the relative value of solar and wind. It is expected that additional battery storage would be part of the regional capacity additions in lieu of dual fuel natural gas + hydrogen plants. See below for further discussion of this uncertainty.
- **Replacement of transmission grid services:** this study does not focus on the transmission grid reliability services provided by the LSR dams. These services likely can be replaced by a combination of the new resources selected by RESOLVE and additional local transmission system investments. A qualitative summary of the transmission grid reliability services of the dams is summarized in the appendix of this report.

LSR Dams Firm Capacity Counting

Since resource adequacy is found to be a key driver of future resource needs, the firm capacity contribution of the LSR dams is a key driver of their value. E3 uses a regional hydro capacity value estimate for the LSR dams in this study, based on the PNUCC regional hydro capacity value assumption. More detailed follow-on ELCC studies could be done to confirm the LSR dams' capacity value, though proper and coordinated dispatch of the Northwest hydro fleet would be necessary to develop an accurate and fair value of the LSR dams within the context of the overall hydro fleet.

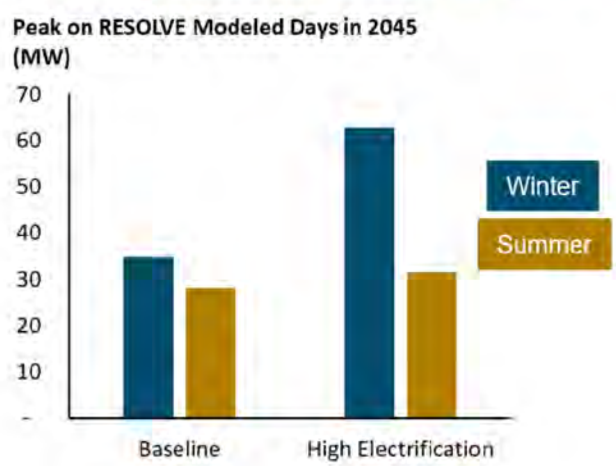
This study validated the assumed 2.28 GW of firm capacity from the LSR dams by considering BPA modeled LSR dams dispatch under 2001 dry hydro year conditions using the CRSO EIS spill constraint adjusted hourly modeling provided by BPA. Maximum January output (plus 100-250 MW of operating reserves) was 1.9-2.1 GW (~56-60% of total capacity), slightly less but close to the 65% regional hydro value the study assumes.

Figure 22. BPA-Modeled LSR Dam Output During the 2001 Low Hydro Year with CRSO EIS Preferred Alternative operations



The other capacity value uncertainty is whether the Northwest will remain winter reliability challenged or whether reliability events will shift to the summer due to climate impacts on load patterns and hydro output. If reliability challenges did shift to the summer, the LSR dam firm capacity contribution would be significantly lower than assumed. However, E3 believes it is reasonable to assume under high electrification scenarios that the region will remain winter challenged due to peak space heating needs, as shown in figure below.

Figure 23. Winter vs. Summer Peak Loads

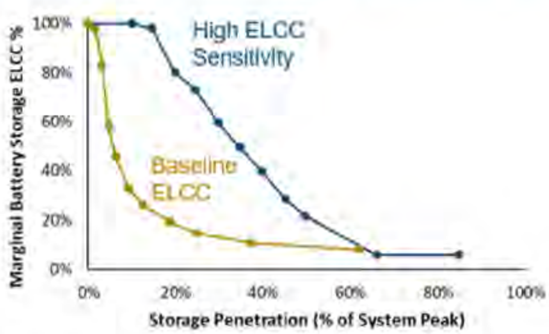


To address the capacity value uncertainty, a post-processing analysis was performed based on the replacement resources selected for firm capacity replacement. Based on this analysis performed on scenarios 1 and 2a, relative to the 2.28 GW assumption used in this study, it is estimated that a 1.5 GW firm capacity value (43%) for the dams would lower the NPV replacement costs by 9-20% and a 1.0 GW firm capacity value (29%) would lower the NPV replacement costs by 14-33%.

Replacement Resources Firm Capacity Counting

If Northwest reliability challenges dramatically shift into the summer, this would also impact the capacity value of replacement resources. One key input assumption this would change is the capacity value of battery storage additions, which were previously limited due to the Northwest wintertime energy-constrained reliability events causing charging sufficiency challenges for energy storage resources. To test whether higher energy storage ELCCs would impact the LSR dams replacement resources and replacement costs, a high storage ELCC sensitivity scenario was analyzed, per the ELCC inputs shown in Figure 24 below. This analysis was performed on scenarios 1 and 2a.

Figure 24. Inputs for High Battery Storage ELCC Sensitivity



In Scenario 1, with the LSR dams intact, higher battery ELCCs cause another 1.5 GW of batteries to be selected and 1.4 GW less dual fuel natural gas and hydrogen plants. In Scenario 2a, with the LSR dams intact, higher battery ELCCs cause another 2.4 GW of batteries and another 0.3 GW of wind to be selected, with 3.6 GW less dual fuel natural gas and hydrogen plants.

When the LSR dams are assumed to be breached, the differences in replacement resources are relatively small. In Scenario 1, an additional ~0.2 GW of battery storage, an additional 0.2 GW of wind, and 0.2 GW less dual fuel natural gas and hydrogen plants are selected to replace the dams. In Scenario 2a, an 0.3 GW less battery storage, 0.3 GW less wind, and an additional 0.1 GW of dual fuel natural gas and hydrogen plants are selected to replace the dams. This is because scenario 2a builds more wind and batteries in the base case already with the dams not breached, so the model prefers to select fewer of those resources for LSR dams replacement. Annual replacement costs in 2045 are 2% lower in scenario 1 and the same in scenario 2a. These results indicate that higher storage ELCCs would allow the region to build less dual fuel natural gas and hydrogen plants, but because energy storage ELCCs eventually saturate in either case, the replacement resources for the dam are not significantly changed and there is little impact on the replacement costs.

Conclusions and Key Findings

This study uses E3's Northwest RESOLVE model to study optimal capacity expansion scenarios with and without the lower Snake River dams, to determine the replacement resources and cost impacts to replace the dams' power output. RESOLVE is an optimal capacity expansion and dispatch model that determines a least-cost set of investment and operational strategies to enable the "Core Northwest" region – consisting of Washington, Oregon, Northern Idaho, and Western Montana – to achieve its long-term clean energy policy goals at least-cost, while ensuring resource adequacy and operational reliability. RESOLVE has been used in several prior studies of electricity sector decarbonization in the Pacific Northwest[39]. 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 5.5-7 GW of solar and 4.6-6 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.[40]

Though all scenarios require more "firm" resources – resources that can generate when needed and operate for as long as needed – to meet peak loads, these resources are in higher demand in Scenario 2,

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[39] 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/

[40] E3 ran two versions of scenario 1. 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. 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. The values shown here represent the range of additions across both scenarios.

in which all greenhouse gas emissions are eliminated from the regional power system by 2045. This scenario also assumes that electrification results in much higher electric loads, particularly in wintertime due to electrification of natural gas space heating in buildings. The baseline scenario (2a) selects additional wind, solar, and geothermal to meet clean energy needs as well as demand response, some battery storage, and 27 GW natural gas and hydrogen dual fuel combustion plants to meet reliability needs. An alternative "emerging technology" scenario selects 17 GW of advanced nuclear technology (small modular reactors or "SMRs") by 2045, in place of the firm capacity provided by natural gas generators while reducing the required quantities of wind, solar and batteries that are needed. The "no new combustion" scenario does not allow emerging clean firm technologies such as hydrogen combustion turbines, gas generation with carbon capture and sequestration (CCS) or SMRs. As a result, it requires impractically high levels of additional onshore wind, offshore wind, and battery storage to meet firm capacity and carbon reduction needs, quadrupling the total installed MW of the Northwest grid by 2045.

When the power services provided by the dams are removed from the regional power system, RESOLVE selects an optimal, i.e., least-cost portfolio of replacement resources that meets the Northwest's clean energy and system reliability needs. These replacement resources require a large investment and come at a substantial cost that increase over time as the region's clean energy goals become more stringent. In the latter years, the replacement costs are highly dependent on scenario-specific assumptions about the availability of emerging technologies. RESOLVE primarily replaces the carbon-free energy from the dams with additional wind and solar 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 – 4,300 MW of replacement resources
    - An annual cost of $415 million – $860 million by 2045
    - Total net present value 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

+ 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 $42-77 billion NPV cost)

Appendix

Additional Inputs Assumptions and Data Sources

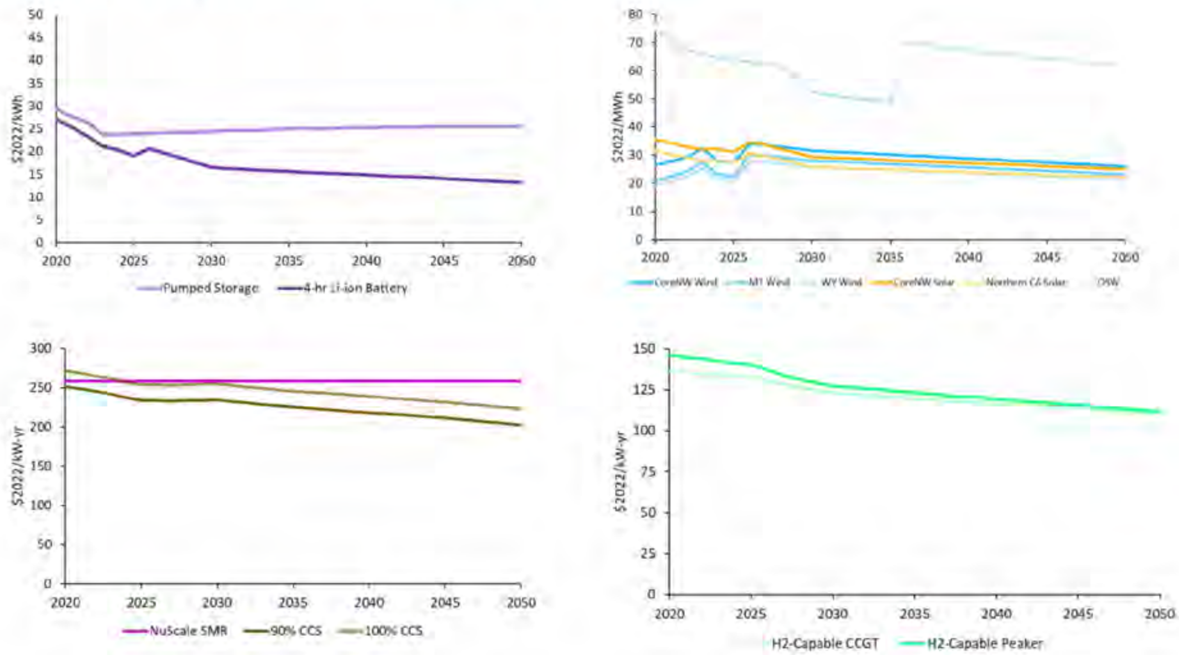
Candidate resource costs

The technology fixed costs trajectories for candidate resource options are shown in Figure 25 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.[41]
- 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

[41] 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 25. All-in fixed costs for candidate resource options[42]



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 26:

+ **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.

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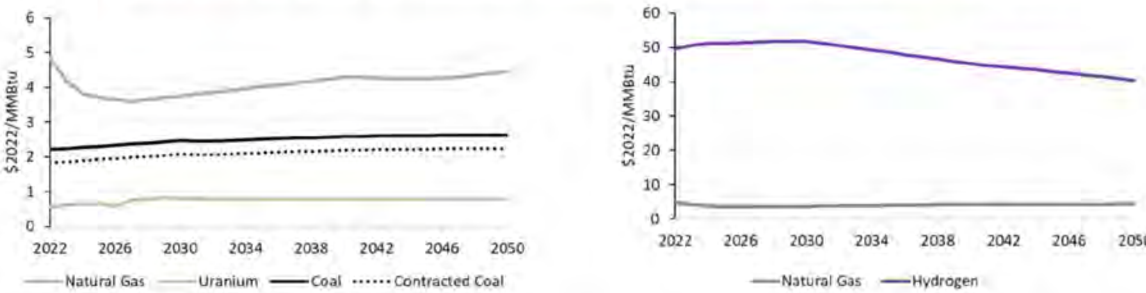
[42] Storage costs are shown in $/kWh of energy storage. Renewable costs are shown in $/MWh. Clean firm resources (nuclear, CCS, hydrogen CCGT or peakers) are shown in $/kW-yr, since their $/MWh costs are a function of their runtime that RESOLVE would determine endogenously.

- **Coal prices:** EIA's AEO forecast are used
- **Uranium prices:** E3's in-house analysis
- **Hydrogen prices:** Conservative prices are used assuming no large-scale hydrogen economy, and thus electrolyzer capital costs and efficiencies are assumed to improve over time only slightly. Other assumptions include above ground hydrogen storage tanks and delivery via trucks from about 225 miles distance. Electrolyzers use dedicated off-grid Core NW wind power to produce hydrogen.

Figure 26. Fuel price forecasts for natural gas, coal, uranium, and hydrogen

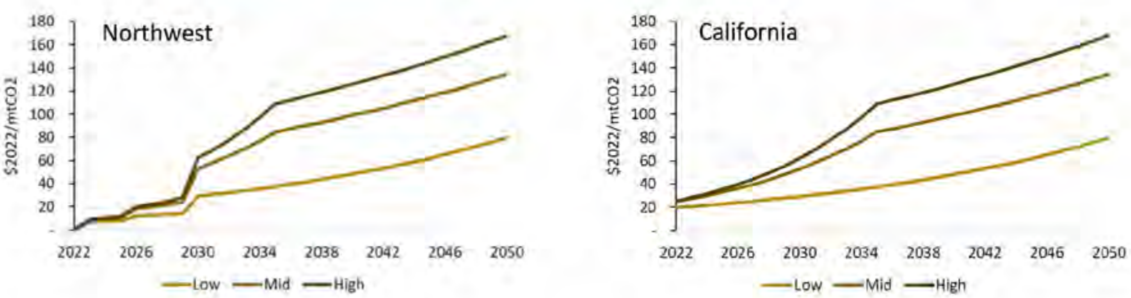


Annual average gas prices are further shaped according to a monthly profile to capture seasonal trends in the demand for natural gas and the consequent impact on pricing.

Carbon prices

For carbon pricing, it is assumed that Washington's cap-and-trade program starts in 2023 at around 50% of California carbon prices. For Oregon, it is assumed that a carbon price policy will be effective by 2026 for the electric sector. Prior to 2026, the Northwest carbon price is a load weighted share of carbon prices in WA and OR. Additionally, it is assumed that both states will converge to California's floor price by 2030. California's carbon prices are adopted from the Final 2021 IEPR GHG Allowance Price Projections (December 2021). Mid carbon prices presented in Figure 27 are used in modeled cases.

Figure 27. Carbon price forecasts for Northwest and California



Scenario 1b assumes no carbon price in the CoreNW zone.

Operating Reserves

It is assumed that all coal, gas, hydro, and storage resources within the Northwest zone can provide operating reserves. Additionally, RESOLVE allows renewable generation to contribute to meeting the needs for load following down; to allow for variable renewable generation curtailment to balance forecast error and sub-hourly variability. The following three types of operating reserve requirements are considered within the Core Northwest to ensure that in the event of a contingency, sufficient resources are available to respond and stabilize the electric grid:

- **Spinning reserves:** Modeled as 3% of hourly load in agreement with WECC and NWPP operating standards
- **Regulation up and down:** Modeled as 1% of hourly load
- **Load following up and down:** Modeled as 3% of hourly load

Modeling of Imports and Exports

The Northwest RESOLVE model includes a zonal representation of the WECC. In modeling hourly dispatch during representative days, it considers the least-cost dispatch solution across the WECC, based on resource economics, resource operational limits, fuel and carbon prices, operating reserve requirements, and zonal transmission transfer limits. Imports to the CoreNW zone can occur from other neighboring zones; when they do a carbon adder is included for unspecified imports, while specified imports do not receive a carbon adder. Exports from the CoreNW zone may occur as deemed economic by RESOLVE, subject to other model constraints.

Minimum and maximum capacity limits are applied to the zonal representation of transmission between connected zones. These zonal transfer limits are shown in Table 13. Transmission hurdle rates as well as carbon hurdle rates (with regional carbon price adders) are applied to imports and exports.

Table 13. Transmission Capacity Limits between the CoreNW and other Zones

Transmission Constraint	Transmission from	Transmission to	Min Flow (MW)	Max Flow (MW)
CoreNW to OtherNW	CoreNW	OtherNW	-6,036	2,550
CoreNW to CA	CoreNW	CA	-6,820	5,433
CoreNW to SW	CoreNW	SW	0	0
CoreNW to NV	CoreNW	NV	-300	300
CoreNW to RM	CoreNW	RM	0	0

Contracted imports (such as imported coal and/or wind power) are included in the resource adequacy accounting captured in the planning reserve margin constraint. New remote resources include transmission cost adders to deliver them into the CoreNW zone. Additional unspecified imports are not assumed in RESOLVE's resource adequacy accounting.

Additional LSR Dam Power System Benefits (not modeled)

As described in this report, RESOLVE covers replacement of most power services provided by the LSR dams. However, RESOLVE does not model transmission grid operations (power flow, voltage and frequency, dynamic stability, etc.). Therefore, E3 notes that the LSR dams may provide the following additional essential reliability services to the transmission grid. In general, E3 expects that the replacement of these services can be achieved either through siting and operations of the incremental replacement capacity selected or by additional local transmission investments. The scale of these transmission investments requires more detailed study.

- **Reactive power and voltage control**: the LSR dams, like hydropower resources generally in the Northwest, provide significant reactive power capabilities that supports reliable power flow by optimally controlling voltage levels. Replacing this function likely requires siting additional resources with reactive power capabilities in a similar section of the transmission grid as the LSR dams.
- **Frequency response and inertia**: the LSR dams provide both primary and secondary frequency response capabilities. As synchronous generators they also provide system inertia that would be lost if the LSR dams are removed and as other synchronous generators retire. New efforts are underway to allow renewable generators or battery storage to provide "synthetic inertia" (or equivalent fast frequency response services), but this provision has not yet been proven to date at scale. The LSR dams are also highly tolerant of operating during high and low frequency events without sustaining blade damage.
- **Blackstart**: Large hydro resources have the capability to provide black start services when required, though not all hydro plants are chosen to provide this capability.
- **Participation in remedial action schemes**: Hydropower is a robust resource for participation in remedial action schemes because it can withstand being suddenly tripped off-line as part of a RAS action.
- **Short circuit and grounding contribution**: Synchronous generators (like hydropower) provide a large short circuit current that is important for the proper operation of protective relaying schemes.

From:	Aaron Burdick <aaron.burdick@ethree.com>
Sent:	Friday, March 25, 2022 6:16 PM
To:	Diffely,Robert J (BPA) - PGPL-5; James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5
Cc:	Jack Moore; Arne Olson; Angineh Zohrabian; Sierra Spencer
Subject:	[EXTERNAL] Re: Trap Results for the preferred and Mo3

Thanks Rob. In that case, we'll use the PNUC/whitebook based hydro capacity value.

Have a nice weekend.

Aaron

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From: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Sent: Friday, March 25, 2022 3:32:29 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: RE: Trap Results for the preferred and Mo3

The conclusion that we have so far, is that it is an artifact of the Council's TRAP model. The TRAP model is less conservative than anything we have developed at BPA. So, I would use BPA derived data/models to draw conclusions.
Rob

From: Aaron Burdick <aaron.burdick@ethree.com>
Sent: Friday, March 25, 2022 11:07 AM
To: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G (BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: [EXTERNAL] RE: Trap Results for the preferred and Mo3

DELIBERATIVE; FOIA EXEMPT

Hi Rob,

Can you provide more background info here? Is one of these scenarios without the LSR dams (the MO3 case) and one with (the PA case)? The differences in 10hr peaking capacity are ~3-5 GW, which is more than the LSR dam nameplate, so there must be something else going on too.

As a baseline we are planning to use the latest PNUCC (whitebook based) regional hydro value (65%) and apply it to the LSR dams and to the NW hydro non-LSR dams. The no LSR dam case will simply have the LSR MW * PNUCC 65% firm capacity value removed, with the need to replace that level of firm capacity other resource additions. Do you have any concerns with this approach or suggestions to use a more LSR-specific capacity value based on the data you provided?

Many thanks,
Aaron

From: Diffely,Robert J (BPA) - PGPL-5 <rjdiffely@bpa.gov>
Sent: Tuesday, March 22, 2022 12:03 PM
To: Aaron Burdick <aaron.burdick@ethree.com>; James,Eve A L (BPA) - PG-5 <eajames@bpa.gov>; Koehler,Birgit G

(BPA) - PG-5 <bgkoehler@bpa.gov>
Cc: Jack Moore <jack@ethree.com>; Arne Olson <arne@ethree.com>; Angineh Zohrabian <angineh.zohrabian@ethree.com>; Sierra Spencer <sierra.spencer@ethree.com>
Subject: Trap Results for the preferred and Mo3
Please let me know if you have questions.

From:	Riley,Erin A (BPA) - PGPR-5
Sent:	Wednesday, March 23, 2022 8:11 AM
To:	aaron.burdick@ethree.com
Cc:	James,Eve A L (BPA) - PG-5; Koehler,Birgit G (BPA) - PG-5; Diffely,Robert J (BPA) - PGPL-5; Egerdahl,Ryan J (BPA) - PGPR-5
Subject:	BPA-E3 Check-In - 3-22 action items
Attachments:	RW_output_selectCYs_Big10.xlsx

Deliberative; FOIA-exempt

Hi Aaron,

I've attached some hourly modeled output for the CYs you requested that I have on the shelf. See if that will suit your needs to create your pmin/ pmax curves.

These data are initialized from a monthly model, that monthly model has split Aprils & August, the second halves begin on the 16th. The incremental flows are interpolated from the monthly flows, so there is a smoothed component relative to actuals. You will notice that the diurnal pattern has a monthly change, this is part of that modeling: the shape of coulee is modeled after actual shaping in recent operations, and the daily peak power shaping is based on maximizing value during peak loads/ prices. The model is not provided with prices, it is provided hours during which to peak. There is some shaping to load in our forebay requests, but inherently the underlying logic assumes unlimited purchases and sales. There is a breakout in the data of the reserves that the projects are holding.

This model reflects the spill in the 2020 EIS: 125% flex spill.

Data notes: The model was run on the FY, as indicated by the "trace" column. For CY I provided the Oct-Dec of the following FY trace. I did not correct the date to be continuous because:

This model simulation, generation is peaking during these dates in the datetime column:

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

Depending on your analysis you might want to include or exclude these. For the weather events, we draft coulee 3 days fairly aggressively, then target coulee to be back on track over the next week. In particular, you might want to exclude July 3-5 as I think this operation might be violating July4 holiday targets.
I can also re-run to exclude this logic.

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

Please let me know if you need data based on actuals instead.

The attached data are only for the purpose of the contracted work. Thank you.

Best,

Erin

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

Deliberative; FOIA-exempt

Action items from today's check in:

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

Many thanks,

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

Erin Riley
Operations Research Analyst
PGPR- Long Term Power Planning
Bonneville Power Administration
503-230-3717

From:	James,Eve A L (BPA) - PG-5
Sent:	Thursday, March 10, 2022 3:26 PM
To:	Cooper,Suzanne B (BPA) - P-6; Armentrout,Scott G (BPA) - E-4; Leady Jr,William J (BPA) - K-7
Cc:	Koehler,Birgit G (BPA) - PG-5
Subject:	E3 Study Scenarios
Attachments:	UNTITLED.pptx

Deliberative; FOIA-exempt

Hello-
The coordination on model assumptions is progressing with E3. BPA technical modelers met today on what scenarios would be good to complete by the April timeline and wanted to run them by you all to make sure we are on the right track. For some context I've attached an E3 slide about different possible scenarios that they brainstormed. We are meeting Tuesday at 11 AM to discuss what scenarios we would like them to prioritize so please provide any concerns before Tuesday and we will incorporate them into our discussion. We are going to propose:

Base Case

- Includes CETA and Clean Energy for All (OR HB 2021).
- CETA carbon neutral by 2030 and 100 percent clean by 2040
- OR house bill bans the construction of new gas power facilities. Requires (Electricity Sector) 80 percent clean by 2030, 90 percent by 2035, and 100 percent by 2024
- Therefore, the base case should not include any new gas plants and no coal after 2030

De-carbonization Scenario (Policy goals)

- OR (economy wide so includes electrification of transport and building) 80% below 1990 by 2050
- WA (economy wide so includes electrification of transport and building) 45% by 2030, only 5% allowed by 2050 (the 5% must be offset)

If there is time for another scenario we are interested in a "Resource Availability" that varies the emerging technologies available. Due to the limited timeline we were not interested in the varying gas cost scenarios.

We are also internally discussing when to assume the LSR dams retire. Instead of picking an arbitrary year 10, 15, or 20 years in the future we are considering having them run the model with and without the dams from the beginning to see how long the model takes to build the resources needed to get the region back in a reliable state as a guidepost to inform a "take the dams out no earlier" date. This would also align with the assumption in the EIS. Let me know if this is on the right track or if you want us to consider a different proposal before our discussion with E3 on Tuesday.

Thanks,
Eve

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

* [illegible]

From:	James,Eve A L (BPA) - PG-5
Sent:	Thursday, June 2, 2022 5:11 PM
To:	Godwin,Mary E (BPA) - LN-7; Leary,Jill C (BPA) - LN-7
Cc:	Koehler,Birgit G (BPA) - PG-5; Pruder Scruggs,Kathryn M (BPA) - E-4
Subject:	E3-BPA presentation deck for DOE
Attachments:	E3RESOLVE_BPA_PublicDeck.pdf

Deliberative, FOIA exempt

Hi Jill and Mary-

Attached is a slide deck of the E3 study for DOE review. Please let me know if you see any red flag issues and I can fix them quickly. If you don't see any issues we can send this to DOE to get comments from them for a CEQ presentation. I am still waiting to hear from TX to confirm some language I added on TX build timing but DOE can still review if I haven't heard back from them. I'm not sure who works on the scheduling for the CEQ presentation but we would like to incorporate DOE feedback.

Thanks,

Eve

From: Koehler,Birgit G (BPA) - PG-5
Sent: Friday, April 29, 2022 9:42 AM
To: Armentrout,Scott G (BPA) - E-4
Subject: FW: BPA-E3
Attachments: BPA_RESOLVE_ExecSummary_DRAFT_v1_042822.pdf

DELIBERATIVE FOIA EXEMPT

This is the advance copy they sent us. They clarified a couple of minor points in the version they displayed

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

DELIBERATIVE FOIA EXEMPT

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

Thanks,
Aaron

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

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

You can forward this invitation to others.

Conference Room Services 1 is inviting you to a scheduled Webex meeting.

Thursday, April 28, 2022

3:30 PM | (UTC-07:00) Pacific Time (US & Canada) | 1 hr

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Meeting password: 5UKeHJ2kK@2

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Join by phone

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Global call-in numbers

Join from a video system or application

Dial [redacted]@mybpa.webex.com

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Energy+Environmental Economics

BPA Lower Snake River Dams Replacement

Draft Results

BPA Executive Briefing

April 27, 2022

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

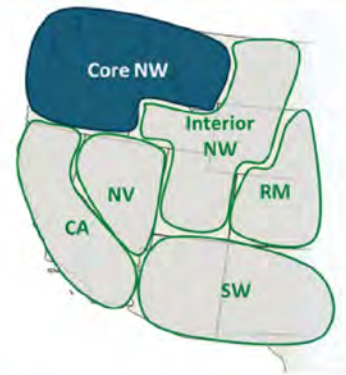
Contents

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
+ **Key tasks:**
    1. **Regional capacity needs + role of hydropower**
        - Summarize CA/OR/WA policies, capacity needs, and the role of hydropower

Focus of today's presentation

2. **RESOLVE capacity expansion analysis**
    - Scenario analysis to calculate the NPV replacement cost of breaching the LSR dams + replacement resource needs
3. **Qualitative benefits**
    - Summarize additional electric system benefits from the LSR dams beyond those captured in RESOLVE
4. **Project report**



Lower Snake River Dams

+ The lower snake river dams:

- Are ~10% of the Northwest regional hydropower capacity
- Provide relatively low-cost and flexible carbon free power

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

* 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.