GENERIC RESOURCES CAPITAL COSTS AND OPERATING ASSUMPTIONS

The following update summarizes the capital costs and operating assumptions that PSE will apply to supply-side generic resources considered in the 2023 Electric Progress Report (EPR). These assumptions were updated from assumptions presented in the March 22, 2022 webinar following suggestions from the stakeholder group, which were gathered through an online feedback form posted April 22, 2022. PSE thanks the EPR stakeholder group for their valuable questions and recommendations.

Based on stakeholder feedback, updates were made to the following costs and assumptions:

- **Hybrid Configurations:** The Montana wind and Montana pumped hydro energy storage (PHES) hybrid configurations are modeled as two separate resources in the 2023 EPR generic resource technology. These resources are located far away from each other, but need to utilize the same transmission line from Montana. The definition of a hybrid resource is co-location of resources that optimizes both interconnection and transmission.
- **Capital Costs:** Capital costs and capital cost curves were updated to reflect data provided in the National Renewable Energy Laboratory's (NREL) 2022 Annual Technology Baseline (2022 ATB). Additionally, PSE updated spur line lengths and interconnection costs for each generic technology considered in the 2023 EPR.
- **Operating Assumptions:** Operating life, fixed and variable operation and maintenance (O&M) costs, and battery cycling assumptions were updated to align with the 2022 ATB cost assumptions. However, thermal resources O&M data were sourced from Federal Energy Regulatory Commission (FERC) Form 1 data and the California Independent System Operator (CAISO) Variable Operations and Maintenance Cost Review, Final Proposal (CAISO 2020). Additionally, the British Columbia wind region is described.
- **Energy Storage Alternatives Survey:** PSE explored the possibility of modeling several alternative energy storage technologies, in addition to battery and PHES systems, which are included in the 2023 EPR. PSE determined these technologies to be inchoate, with too few data available to model with any sense of accuracy in the 2023 EPR.
- **Battery Cycling:** PSE's analysis aligned with the assumptions from the 2022 ATB that batteries will cycle no more than once per day. However, PSE is adjusting this assumption by implementing it as an annual limit of no more than 365 cycles for the year. The annual limit will allow the dispatch model to optimize the use of the battery by cycling more than once per day if needed and then not cycling on other days.
- **2021 Final IRP Stakeholder Feedback:** Stakeholder feedback from the final 2021 Integrated Resource Planning (IRP), as it relates to generic costs and operating assumptions, is addressed in the final section of this document.

The following sections provide a detailed description of these updates.

Hybrid Configurations for Montana Resources

PSE determined that modeling stand-alone Montana wind and PHES resources, each in 100 MW capacity increments, would better optimize PSE's 400 MWs of available transmission from Montana, then would a single, large (200 MW wind + 100 MW PHES), hybrid resource. PSE removed the Montana wind plus PHES hybrid configuration from the 2023 EPR generic resource technology options and adjusted how the stand-along resources in Montana were modeled. Furthermore, given the specific siting requirements for PHES and wind, these resources are more likely to be located in different places, resulting in separate spur line costs and nearly nullifying the capital cost savings of building the resources in tandem. However, the Montana PHES generic resource modeled in the 2023 EPR will retain the ability to charge from the Clearwater Wind Project, as well as generic Montana wind resources, and market purchases.

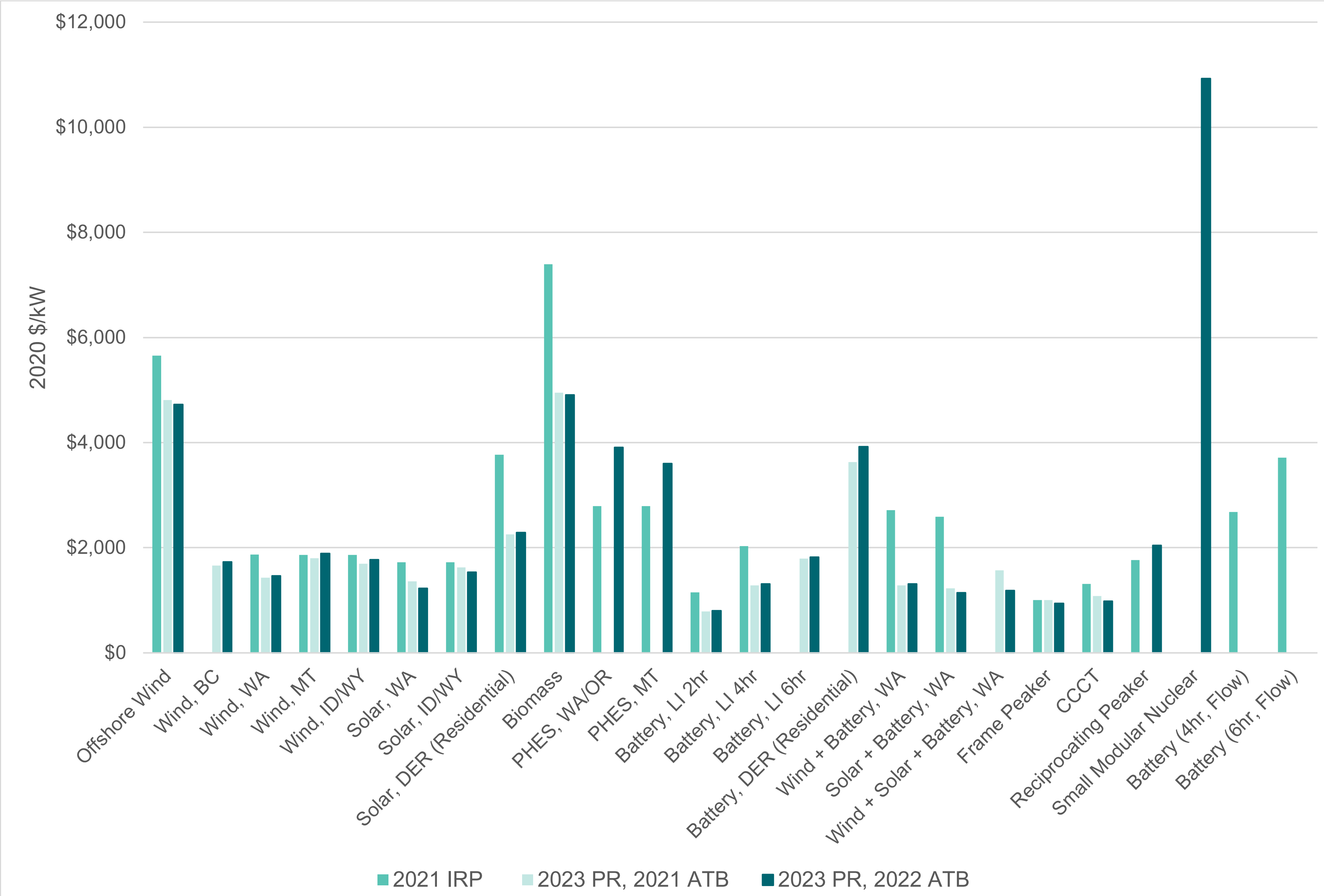
Capital Costs

Capital Cost Sources

Capital cost for generic resources were presented to stakeholders during the March 22, 2022 webinar. For the majority of resource technologies, PSE sourced capital cost data from the NREL 2021 ATB (2021 ATB), in response to stakeholder feedback. In June 2022, NREL released the 2022 ATB and PSE updated all relevant technology capital costs to align with this data. Reciprocating peaker technology was not included in the 2022 ATB, and capital cost data for this generic resource was sourced from the U.S Energy Information Administration's (EIA) Annual Energy Outlook (AEO) for 2022 (2022 AEO). Figure 1 presents the generic resource technology capital costs PSE is using in the 2023 EPR, in comparison to both the 2021 ATB capital costs presented in the March 22, 2022 meeting, as well as the capital costs PSE adopted for the 2021 Integrated Resource Plan (2021 IRP).

In the process of updating capital cost values to the 2022 ATB, PSE revised its assumptions around the storage capacity of battery energy storage systems (BESS). Under the 2021 ATB assumptions, PSE planned to incorporate at 20% cost adder to the storage block component of BESS to compensate for minimum and maximum state of charge constraints of lithium ion BESS. The 2022 ATB incorporates state of charge constraints in the revised methodology; removing the need to incorporate a separate cost adder.

Figure 1. Capital Cost Comparison, 2023 Vintage, 2020 Real Dollars



Note: The 2023 EPR capital cost numbers include the ATB costs plus the spur line and interconnection costs. A full breakdown of the costs is included in the excel file 2023_ElectricProgressReport_GenericResourcesCostAdjustments_Updated.xlsx at pse.com/IRP/get-involved under Sept. 13 meeting materials.

Spur Line Lengths

PSE performed a series of adjustments to capital costs for generic resources presented in the March 22, 2022 webinar, which included adding costs associated with a spur line to connect the generic resource to existing transmission. PSE assumed each resource would require a 5-mile spur line at a rate of $500,000 per mile. After receiving stakeholder feedback, PSE conducted further research and updated the spur line length for each resource technology and location. The following narrative presents the sources, reasoning, and results of this research. Results are summarized in Table 1.

Bidders responding to PSE's 2021 All Source Request of Proposals (2021 RFP; PSE 2021b) provided the basis from which PSE calculated new generic resource specific spur line lengths. Resources of a similar type and/or within a similar geographical location were grouped together to calculate the arithmetic mean. This number was then rounded to the nearest 0.5 mile. For example, wind, solar, and hybrid (wind + storage; solar + storage) resources proposals within eastern Washington had an average 4.4 mile spur line. This was rounded to 4.5 miles and applied to wind, solar, and hybrid generic resources located in Washington. Spur lines for batteries were rounded to 1.0 mile, and this length was additionally applied to generic thermal and small modular nuclear resources, since spur lines for thermal gas plants interconnected within PSE's service territory are typically less than 1 mile in length

Generic biomass resource spur lines were calculated from averaging spur line lengths from existing biomass resources within Washington, Oregon, Idaho, and Montana. PHES and offshore wind spur line lengths were calculated using a combination of information provided by developers for proposed projects and using GIS to calculate distances from the proposed projects to the nearest substation.

Using recently conducted interconnection studies for comparison, PSE assumed new spur line costs would be $2.8 million per mile for a new 115 kilovolt (kV) line and $4.5 million per mile for a new 230 kV line (PSE 2022). To account for equipment costs associated with tying the new spur lines into the substations, $3.0 million was added into the overall capital costs for the spur lines for each generic resource technology. Furthermore, PSE assumed all generic resource builds with a nameplate capacity greater than 300 megawatts (MW) would require a 230 kV line; otherwise PSE assumed a 115 kV spur line (PSE 2022).

Spur line lengths and resulting costs are provided in the *2023_ElectricProgressReport_GenericResourcesCostAdjustments_Updated.xlsx* workbook posted at pse.com/IRP/get-involved under Sept. 13 meeting materials, and are summarized in Table 1, below.

Table 1. Generic Resource Spur Line Lengths and Costs for the 2023 PR

Resource	Proposed Tie Line Length[9]	Tie Line Length Source	Capacity (MW)	Spur Line Size (kV)	Spur Line Cost (#M)	Total Spur Line Cost[10] ($)	Total Spur Line Cost $/kW
Wind, BC[4]	14.0	BC Hydro (2015)	100	115	2.8	2,200,000	422
Wind, WA[2]	4.5	PSE 2021 All Source RFP Bids	100	115	2.8	15,600,000	156

Resource	Proposed Tie Line Length[9]	Tie Line Length Source	Capacity (MW)	Spur Line Size (kV)	Spur Line Cost (#M)	Total Spur Line Cost[10] ($)	Total Spur Line Cost $/kW
Wind, MT[3]	40.5	PSE 2021 All Source RFP Bids	200	115	2.8	116,400,000	582
Wind, ID/WY[3]	40.5	PSE 2021 All Source RFP Bids	400	230	4.5	185,250,000	463
Solar, WA[2]	4.5	PSE 2021 All Source RFP Bids	100	115	2.8	15,600,000	156
Solar, ID/WY[3]	40.5	PSE 2021 All Source RFP Bids	400	230	4.5	185,250,000	463
Solar, DER (Residential)	--	--	300	--	--	--	
Biomass[5]	2.0	GIS Calculation	15	115	2.8	8,600,000	573
PHES, WA/OR[6]	17.0	GIS Calculation	100	115	2.8	50,600,000	506
PHES, MT[6]	6.0	GIS Calculation	100	115	2.8	19,800,000	198
Battery (2hr, Li-Ion)[7]	1.0	PSE 2021 All Source RFP Bids	100	115	2.8	5,800,000	58
Battery (4hr, Li-Ion)[7]	1.0	PSE 2021 All Source RFP Bids	100	115	2.8	5,800,000	58
Battery (6hr, Li-Ion)[7]	1.0	PSE 2021 All Source RFP Bids	100	115	2.8	5,800,000	58
Battery, DER (Residential)	--	--	NA	--	--	--	
Wind + Battery, WA[2]	4.5	PSE 2021 All Source RFP Bids	150	115	2.8	15,600,000	104
Solar + Battery, WA[2]	4.5	PSE 2021 All Source RFP Bids	150	115	2.8	15,600,000	104
Wind + Solar +Battery, WA[2]	4.5	PSE 2021 All Source RFP Bids	250	115	2.8	15,600,000	62
Frame Peaker[8]	1.0	PSE 2021 All Source RFP Bids	225	115	2.8	5,800,000	26
Combined-cycle combustion turbine (CCCT)[8]	1.0	PSE 2021 All Source RFP Bids	336	230	4.5	7,500,000	22
Recip Peaker[8]	1.0	PSE 2021 All Source RFP Bids	219	115	2.8	5,800,000	26
Small Modular Nuclear[8]	1.0	PSE 2021 All Source RFP Bids	600	230	4.5	7,500,000	13

Notes

1. *Assumptions based upon the Grays Harbor Wind Project, which is proposed to make landfall approximately 20 miles from Aberdeen, WA.*
2. *OR/WA wind, solar, and hybrid resources from the 2021 RFP were combined to create this overall average.*
3. *ID, MT, and WY wind, solar, and hybrid resources spur line lengths from projects submitted to PSE's 2021 RFP process were combined to create this overall average.*
4. *This is the average interconnection distance estimated for Shinish Creek and Pennask Wind Farms, located in south central BC.*
5. *Existing biomass plant interconnection distances were calculated using GIS for plants located in ID, MT, Northern OR, and WA.*
6. *The interconnection length for three proposed closed loop system PHES were averaged: Swan Lake (OR), Gordon Butte (MT), and Goldendale (WA).*
7. *The average interconnection length for all batteries proposed in the 2021 RFP process, with outliers removed. Actual value is 0.7.*
8. *Assumed to be have a similar interconnection length to the 2021 RFP batteries because the resource would be similarly sited.*
9. *Miles are rounded to the nearest 0.5 mile.*
10. *Includes a $3 million substation hook-up addition.*

Operating Assumptions

Operating Life

For the 2023 EPR, PSE adopted the operating life assumptions provided in the 2022 ATB, with the expectation of PHES, which was adjusted to align with the FERC permit time-period (Table 2). The 2022 ATB assumes battery storage will have an operating life of 30 years, with augmentation and/or repowering occurring every 10 years.

Table 2. Generic Resources Operating Life for the 2023 PR

Technology	Capital Recovery Period (Years)[1]
Offshore Wind, WA	30
Wind, BC	30
Wind, WA	30
Wind, MT	30
Wind, ID/WY	30
Solar, WA	30
Solar, ID/WY	30
Solar, DER (Residential)	30
Biomass	30
PHES, WA/OR[2]	40
PHES, MT	40
Battery (2hr, Li-Ion)	30
Battery (4hr, Li-Ion)	30
Battery (6hr, Li-Ion)	30
Battery, DER (Residential)	30
Wind + Battery, WA	30
Solar + Battery, WA	30
Wind + Solar + Battery, WA	30
Frame Peaker	30
CCCT	30
Recip Peaker	30
Small Modular Nuclear	30

Notes

1. *Source: NREL 2022.*
2. *Though the NREL 2022 ATB assumes a 100 year operating life, PSE assumes the operating life will be the length of the FERC permit. cycle, at 40 years.*

Operation and Maintenance Costs

To determine the fixed and variable operations and maintenance (O&M) costs for generic resources, PSE compared several different sources, listed below:

- *Generic Resource Costs for Integrated Resource Planning*, a report conducted by HDR on behalf of PSE and issued on January 23, 2019 (HDR 2019).
- *2021 PSE Integrated Resource Plan*, published on April 1, 2021 (PSE 2021a).
- The 2022 ATB (NREL 2022).
- PSE FERC Form 1s, accessed via the S&P Global IQ Platform on May 19, 2022 (S&P Global 2022).
- The proposed default O&M adder values from the *Variable Operations and Maintenance Cost Review,* published October 22, 2020 by the California Independent System Operator (CAISO 2020).

To maintain consistency with capital cost assumptions for generic resources, PSE chose to use fixed and variable O&M from the 2022 ATB to apply to all generic resource technologies except thermal technologies. Consistent with the 2022 ATB, fixed O&M for wind, solar, and battery technologies associated with a new-build decreases over the duration of the planning horizon. For example, a wind plant built in 2045 will have a lower fixed O&M compared to a wind plant built in 2030 (not accounting for inflation).

The 2022 ATB did not provide O&M costs for most of the hybrid configurations presented in the 2023 EPR. To calculate these costs, PSE combined the fixed O&M for each component within the hybrid system and used the respective capacities to generate a weighted average. The 2022 ATB did provide a fixed O&M cost associated with a solar plus 4-hr Li-ion battery storage hybrid system, which are higher than the weighted average. Though the literature indicated this O&M was based on stand-alone solar and battery fixed O&M, the precise method of combining these costs was not presented in the 2022 ATB. To maintain consistency with other hybrid systems in the 2023 EPR, PSE presents the solar plus battery storage hybrid resource using a weighted average. All hybrid resource fixed O&M are presented as a time series.

Generic CCCT and frame peaker fixed O&M were sourced from averaging PSE's existing costs, as reported in the 2021 FERC Form 1s. The fixed O&M reported for the Port Westward 2 facility was adopted as the generic reciprocating peaker fixed O&M (S&P Global 2022). Variable O&M was adopted from the CAISO Variable Operations and Maintenance Cost Review, Final Proposal (CAISO 2020).

Table 3 and Table 4 compare the fixed and variable O&M, respectively, and present the values PSE is applying to generic resources in the 2023 PR. Note that the fixed O&M values for renewable, battery, and hybrid technologies represent the value in the base year, 2023 only. Figure 2 demonstrates the trends in fixed O&M over time for renewable, battery, and hybrid technologies.

Table 3. Fixed O&M Cost Comparison and Costs for the 2023 PR

2023 Vintage, 2020 U.S. Dollars	Fixed Operating and Maintenance ($/kW-yr)	Comparison of Sources ($/kW-yr)				
	2023 Progress Report (NREL 2021; S&P Global 2022)	2019 HDR Report (HDR 2019)	2021 IRP Operating Assumptions (PSE 2021a)	2022 ATB[1] (NREL 2022)	FERC Form 1s[2] (S&P Global 2022)	CAISO Defaults Values (CAISO 2020)
Offshore Wind, WA	$70.78	$142.64	$118.55	$70.78	--	--
Wind, BC	$41.79	$43.98	--	$41.79	--	--
Wind, WA	$41.79	$43.98	$43.73	$41.79	--	--
Wind, MT	$41.79	$43.98	--	$41.79	--	--
Wind, ID/WY	$41.79	$43.98	--	$41.79	--	--
Solar, WA	$19.35	$25.21	$23.94	$19.35	--	--
Solar, ID/WY	$19.35	$25.21	--	$19.35	--	--
Solar, DER (Residential)	$25.48	$32.32	--	$25.48	--	--
Biomass	$151.00	$410.33	$222.92	$151.00	--	--
PHES, WA/OR	$17.82	$20.68	$17.23	$17.82	--	--
PHES, MT	$17.82	$20.68	$17.23	$17.82	--	--
Battery (2hr, Li-Ion)	$20.12	$24.42	$25.29	$20.12	--	--
Battery (4hr, Li-Ion)	$32.76	$38.23	$34.39	$32.76	--	--
Battery (6hr, Li-Ion)	$45.49	--	--	$45.49	--	--
Battery, DER (Residential)	$98.06	--	--	$98.06	--	--
Wind + Battery, WA[3]	$38.35	--	$69.02	--	--	--
Solar + Battery, WA[3]	$23.39	--	$49.23	$32.24	--	--
Wind + Solar + Battery, WA[3]	$30.69	--	--	--	--	--
Frame Peaker	$9.52	$4.67	$8.27	$28.00	$9.52	--
CCCT	$22.67	$16.83	$13.86	$21.00	$22.67	--
Recip Peaker	$14.53	$4.45	$6.90	--	$14.53	--
Small Modular Nuclear	$114.00	--	$10.77	$114.00	--	--

Notes

1. *FOM for wind, solar, battery storage, and hybrid resources are presented in the 2022 ATB as a curve. Vintage year 2023 only is presented in this table for comparison with other FOM costs.*
2. *From the S&P Global IQ screener tool, averaged the "fixed production expense," for PSE existing resources in 2021. The Port Westward 2 "fixed production expense" from 2021 was adopted as the reciprocating peaker fixed O&M.*
3. *Weighted averages (using nameplate capacities for hybrid configurations) are used to calculate the FOM for hybrid resources. Because FOM for the generating resource is a curve, the FOM for hybrid resources are also a curve.*

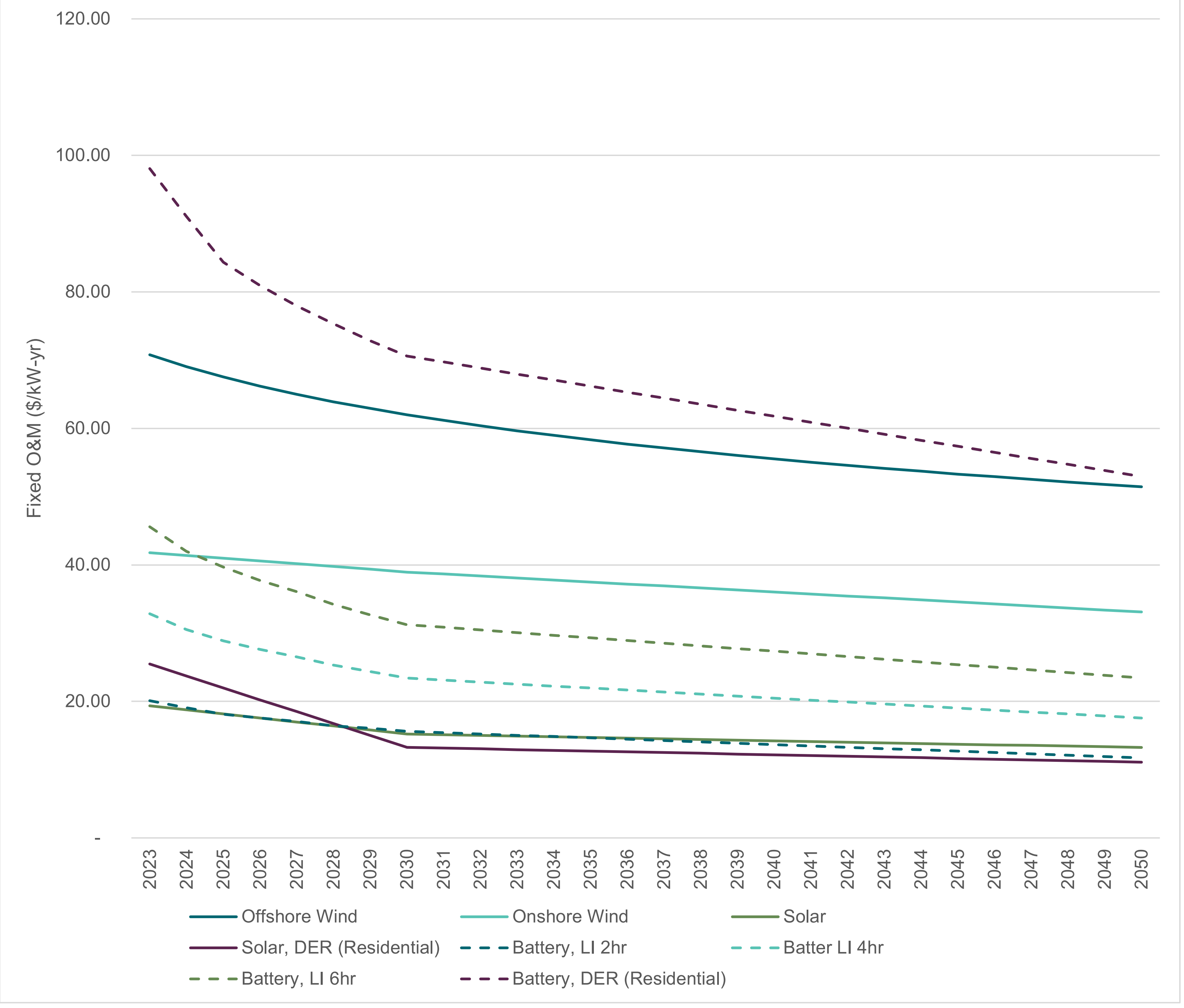
Table 4. Variable O&M Cost Comparison and Costs for the 2023 PR

2023 Vintage, 2020 U.S. Dollars	Variable Operating and Maintenance ($/MWh)	Comparison of Sources ($/MWh)				
	2023 Progress Report (NREL 2021; CAISO 2020)	2019 HDR Report (HDR 2019)	2021 IRP Operating Assumptions (PSE 2021a)	2022 ATB (NREL 2022)	FERC Form 1s[1] (S&P Global 2022)	CAISO Defaults Values (CAISO 2020)
Offshore Wind, WA	$0.00	$0.00	$0.00	$0.00	--	--
Wind, BC	$0.00	$0.00	--	$0.00	--	--
Wind, WA	$0.00	$0.00	$0.00	$0.00	--	--
Wind, MT	$0.00	$0.00	$0.00	$0.00	--	--
Wind, ID/WY	$0.00	$0.00	$0.00	$0.00	--	--
Solar, WA	$0.00	$0.00	$0.00	$0.00	--	--
Solar, ID/WY	$0.00	$0.00	$0.00	$0.00	--	--
Solar, DER (Residential)	$0.00	$0.00	$0.00	$0.00	--	--
Biomass	$5.80	$7.85	$6.67	$5.80	--	--
PHES, WA/OR	$0.51	$1.78	$0.00	$0.51	--	--
PHES, MT	$0.51	$1.78	$0.00	$0.51	--	--
Battery (2hr, Li-Ion)	$0.00	$0.00	$0.00	$0.00	--	--
Battery (4hr, Li-Ion)	$0.00	$0.00	$0.00	$0.00	--	--
Battery (6hr, Li-Ion)	$0.00	$0.00	$0.00	$0.00	--	--
Battery, DER (Residential)	$0.00	--	$0.00	$0.00	--	--
Wind + Battery, WA[3]	$0.00	--	$0.00	--	--	--
Solar + Battery, WA[3]	$0.00	--	$0.00	$0.00	--	--
Wind + Solar + Battery, WA[3]	$0.00	--	--	--	--	--
Frame Peaker	$1.02	$7.80	$8.47	$2.00	$48.83	$1.02
CCCT	$6.16	$3.00	$3.58	$5.00	$4.12	$6.16
Recip Peaker	$1.16	$6.30	$7.59	--	$4.45	$1.16
Small Modular Nuclear	$2.84	--	$7.54	$2.84	$0.00	--

Notes

1. *From the S&P Global IQ screener tool, averaged the "fixed production expense," for PSE existing resources in 2021. The Port Westward 2 "fixed production expense" from 2021 was adopted as the reciprocating peaker fixed O&M.*
2. *CAISO default values calculated by dividing the default minimum load adder of $1.74/run-hour/MW by PSE's 20-year forecasted capacity factor for CCCTs of 33% (PSE 2021 IRP), then adding the energy O&M adder of $0.59/MWh.*
3. *The CAISO default value appears low; however, CAISO also provides a startup O&M adder of $52.13/start/MW, which will be applied to generic frame peakers in the 2023 Electric Progress Report.*

Figure 2. Fixed O&M Cost Comparison and Costs for the 2023 Electric PR



Battery Cycling

For the 2023 EPR, PSE is aligning with the assumption in the 2022 ATB that batteries will cycle no more than once per day. However, PSE is adjusting this assumption by implementing it as an annual limit of no more than 365 cycles for the year. The annual limit will allow the dispatch model to optimize the use of the battery by cycling more than once per day if needed and then not cycling on other days. The cycling limit is discussed further in the NREL Cost Projections for Utility-Scale Battery Storage: 2021 Update (Cole et al. 2021). Under this limitation, augmentation and/or any necessary repowering of the battery array is included in the fixed O&M costs, and PSE can assume the battery array will perform at capacity throughout its lifetime. However, should the batteries cycle more than this, then the fixed O&M may not be adequate to offset degradation. Cole et al. (2021) indicates that cycling greater than one time per day should be included as a variable O&M, but the report does not provide any associated costs. In future planning efforts, and with additional time to accumulate battery cycling data, the variable O&M may be a parameter in which PSE could capture the cost of accelerated degradation due to increased cycling. For the 2023 EPR, PSE is employing an annual constraint on battery cycling, in alignment with the most up-to-date operating assumptions and cost data, while allowing AURORA the option to cycle a given battery more than one time per day if the need should arise.

Wind Regions

PSE is considering British Columbia wind resources, as well as six other wind regions, in the 2023 EPR. Table 5 presents the regions in which wind shapes were developed. A full list of operating assumptions will be provided in Appendix D of the 2023 EPR.

Table 5. Wind Shape Modeling Locations

2023 EPR Generic Onshore Wind Resource	Wind Shape Location	Latitude	Longitude
Washington Wind	Dodge, WA	46.523	-117.823
Montana Wind East	Miles City, MT	46.805	-106.221
Montana Wind Central	Harlowton, MT	46.524	-110.246
Wyoming Wind East	Medicine Bow, WY	41.943	-106.300
Wyoming Wind West	Point of Rocks, WY	41.730	-108.786
Idaho Wind	Downey, ID	42.424	-112.157

2023 EPR Generic Onshore Wind Resource	Wind Shape Location	Latitude	Longitude
British Columbia Wind	Peachland, BC	49.906	-120.098

Washington wind shapes were developed near Dodge, Washington, a small, unincorporated town situated close to PSE's existing wind resources, Hopkins Ridge Wind Facility, and Lower Snake River Wind Facility. Oregon wind was not modeled for the 2023 EPR.

British Columbia wind shapes were developed near the existing wind projects, Pennask and Shinish Creek Wind Projects, in the Thompson Okanagan region of British Columbia. Wind in this region has a 41% capacity factor with a shape that fits PSE's demand, and potentially provides an excellent option for PSE's future renewable resource investment. However, as of 2022, transmission limitations may bind the amount of potential builds in this region to no more than 160 MWs during the 2023 EPR modeling process.

Energy Storage Alternatives Survey

In response to input received from our stakeholders at the March 22 meeting regarding gravity energy storage, PSE examined alternatives to chemical batteries for storing energy. While the initial request was to specifically investigate gravity storage technology, PSE additionally investigated compressed air energy storage (CAES) and liquefied air energy storage (LAES). Five alternative energy storage technologies are discussed in the following subsections.

PSE decided to exclude these technologies during the 2023 EPR modeling because they are either emerging or novel uses of existing technologies, and reliable data was unavailable at this time. The data PSE was able to find (presented below) are likely based on a very small sample size and therefore cannot provide a robust estimate of potential cost. Furthermore, many of the available estimates come directly from the developers, who may be overly optimistic in order to market their product. Of the surveyed alternative storage technologies, LAES may be the most feasible for modeling. However, publicly available operating parameters and costs were not available at this time, and due to time constraints for the 2023 EPR process, PSE chose not to pursue modeling this technology during this planning cycle.

At this point in time, PSE plans to monitor progress as these technologies continue to develop. The potential for having a variety of energy storage alternatives ensures the most efficient and cost-effective options are available during PSE's modeling and selection of new resources.

Gravity Storage

Gravity storage involves moving mass to a high elevation and storing it there in the form of kinetic energy. Generally, the mass is moved when there is a surplus of energy generation. When there is a deficit of energy this mass can be lowered to drive turbines and generate electricity to meet the load demand. PHES is the most common and well-established form of gravity storage technology. In a PHES system, water is pumped from a lower reservoir to an upper reservoir during times of surplus energy generation, and then is released when needed to drive turbines as it flows downhill to the lower reservoir. Several alternative gravity storage configurations are approaching utility-scale viability and are detailed in the following sections. These alternatives generally involve driving a generator by lowering a solid mass with gravity.

Crane Kinetic Storage

The company EnergyVault is pioneering a storage technology involving raising and lowering large bricks. The company has developed two designs. The first, the Customer Demonstration Unit (CDU), is a modular system capable of storing 20-80 MWh of energy and delivering 4-8 MW of continuous power to the grid. This unit is currently connected to the Swiss energy grid. The second technology, the EVx™, utilizes an indoor elevator system to move large bricks up and down within a warehouse structure. This modular system can scale from 10 MWh up to over 1 GWh in 10 MWh increments. The EVx™ has not been successfully implemented at this time (EnergyVault 2022).

EnergyVault appears to be in the transition phase from startup to larger development stages; they are reportedly taking orders for full-fledged builds, but do not yet have completed projects other than the scaled down CDU in Switzerland. The lack of data from actual projects poses a challenge to incorporating this technology into the Integrated Resource Planning and progress report process, and is a drawback to pursuing this technology in the near term.

Table 6 presents information on the CDU technology obtained from company website and investor presentation published in September, 2021.

Table 6. EnergyVault's Customer Demonstration Unit Operating Parameters

Specification	Reported Value
Storage Capacity	10 MW / 40 MWh
Ramp up Time	NA
Duration (hours)	4
Tround Trip Efficiency (%)	84
Estimated Capital Cost	$1,375
Lifespan	NA

Source: EnergyVault 2022

Underground Kinetic Storage

The European company, Gravitricity, is developing a similar technology to crane storage, however, this technology ideally utilizes pre-existing subterranean resources, such as unused mineshafts, for the drop space. Locations without existing subterranean resources could potentially be drilled to accommodate this technology, however this would increase capital costs. The company has developed an above-ground prototype, currently operating in Scotland, and furthermore has a contract to build a larger scale facility in a mine in mainland Europe (Gravitricity 2022).

An advantage to underground kinetic storage is the smaller geographic footprint, compared to other storage technologies, and subsequently the possibility of locating this technology on the demand side (presuming the cost of drilling a custom shaft is not prohibitively high). Similar to crane kinetic storage, this technology is inchoate, with a lack of data to incorporate into a planning process. Furthermore, Gravitricity is currently oriented towards installing this technology in closed mines, significantly reducing suitable sites, particularly within a geographical area accessible to PSE.

Table 7 summarized information available for this technology.

Table 7. Gravitricity’s Underground Kinetic Storage Operating Parameters

Specification	Reported Value
Storage Capacity	10 MW / 25 MWh
Ramp up Time	Instantaneous
Duration (hours)	2.5-5
Tround Trip Efficiency (%)	80-90
Estimated Capital Cost	$5,203
Lifespan	50

Source: Gravitricity 2022.

Rail Kinetic Storage

The company Advanced Rail Energy Storage (ARES) is developing a technology named GravityLine™, which lowers cars loaded with weight down an inclining rail track. The company has been contracted to build a facility in Nevada which will supplement the CAISO grid. This project initially entered the planning phase in 2016 and is still in development with no confirmed online date at this time (S&P Global 2022).

A substantial benefit of this technology, compared to the previously discussed technologies, is the developer is located in the U.S. Furthermore, this technology is potentially easy to site and cost-competitive, especially as the company proposes reusing rail cars from decommissioned coal facilities (ARES 2022). However, similar to other alternative gravity storage technologies, rail kinetic storage has no operational units to provide planners the required capital cost and operational data at this time.

Table 8 provides the planned specifications for this technology. Note the capital cost is sourced from an early projection published in 2016 (Morris 2016).

Table 8. ARES’ Rail Kinetic Storage Operating Parameters

Specification	Reported Value
Storage Capacity	50 MW
Ramp up Time	3 second
Duration per car (hours)	0.25
Recharge Time (hours)	0.25
Rround Trip Efficiency (%)	90+
Estimated Capital Cost	1100
Lifespan	40
Minimum Elevation Differential (ft)	200

Sources: ARES 2022; Morris 2016.

Compressed Air Energy Storage

Compressed Air Energy Storage (CAES) technology uses excess energy to compress large volumes of air and then uses the pressure generated by releasing this air to drive turbines. Though CAES technology has been available for decades, is not widely implemented with only a handful of utility scale assets in existence. CAES is often located in underground salt caverns to mitigate temperature increases resulting from air compression, and subsequent siting considerations may limit the usefulness of this technology. Additionally, this technology has a lower round trip efficiency than other storage alternatives. However, CAES is an established and proven technology, with a longer discharge duration, capable of providing power for 12–24 hours. Furthermore, siting of this technology could be eased by repurposing depleted gas wells.

Table 9 summarizes cost and operational parameters, taken from Pacific Northwest National Laboratory’s (PNNL’s) Energy Storage Cost and Performance Database.

Table 9. CAES Operating Parameters

Specification	Reported Value
Storage Capacity[1]	100-1,000 MW
Ramp up Time	10 min
Duration (hours)	4-10
Rround Trip Efficiency (%)	52
Estimated Capital Cost[2]	$1,085
Lifespan	30

Source: PNNL 2022.

1. *This database lists storage capacities up to 10,000 MWs. PSE determined this was an error.*
2. *This is an average cost of the configurations presented in the PNNL database.*

Liquid Air Energy Storage

Liquid Air Energy Storage (LAES) technology involves super cooling air into a liquid state for storage in insulated tanks. As the air is reheated and expands back into a gaseous state, the pressure created moves a turbine. Highview Power, the company pioneering this technology, has constructed a working model in the UK, and is in the process of constructing a 50 MW LAES resource in Vermont and up to 2 GWh of storage in Spain. Avista modeled the LAES resources in their 2021 IRP.

The LAES technology utilizes a smaller footprint than CAES, has no other special siting requirements, and subsequently could potentially be deployed as a distributed resource. Furthermore, this technology has the capability of storing energy for long periods of time with little degradation and can provide long-duration discharge to the grid. Finally, additional insulated tanks are the main component required to scale up the size and capacity of an LAES system, making this technology modular, flexible, and inexpensive, compared to other storage alternatives. Operating parameters are summarized in Table 10.

Table 10. Highview Power's LAES Operating Parameters

Specification	Reported Value
Storage Capacity	50-250 MW
Ramp up Time	NA
Duration (hours)	10
Rround Trip Efficiency (%)	60-90
Estimated Capital Cost	$1,430
Lifespan	30

Source: Highview Power 2022.

Feedback from the 2021 Integrated Resource Plan

PSE received several comments from stakeholders regarding generic resource costs and operating assumptions, provided in response to the Final 2021 Integrated Resource Plan (2021 IRP). Table 11 presents the comments, anonymously, and provides a description of what PSE has done in this 2023 EPR to address stakeholder feedback.

Table 11. 2021 IRP Stakeholder Comment Matrix, Regarding Generic Resources Cost and Operating Assumptions

Comment From Final 2021 IRP	PSE's Action
Building new gas infrastructure is antithetical to CETA and creates significant financial risks of stranded assets for PSE and its customers due to large capital investment and limited use of the resource. The most recent Lazard's Levelized Cost of Energy Analysis compares new-build wind and solar against the marginal cost of operating existing combined-cycle gas units and shows that renewable resources are cost-competitive.	The 2023 EPR resource costs are based on the most up-to-date cost information available through the 2022 ATB. Capital costs form an important component in calculating the levelized costs of energy. Currently, new-build wind and solar resources base capital costs, as modeled PSE's 2023 PR, are higher in 2023 than CCCTs and frame peaker capital costs. However, by 2027, the capital cost for WA solar drops below the capital cost for all thermal resources. Though WA wind resource capital costs remain above the capital costs for CCCTs and frame peakers for most of the planning horizon, they remain cost-competitive with these thermal resources, after incorporating the social cost of greenhouse gas, and the climate commitment act carbon pricing. Furthermore, PSE's preferred portfolio has not included CCCT's for several IRP cycles.
Utility innovations in this field have shown that concepts like triple-hybrids consisting of wind + solar + batteries are also techno-economically viable generation resources.	PSE is including a Washington-located wind + solar + storage (4-hour Li-ion batteries) generic resource in the 2023 EPR.

Comment From Final 2021 IRP	PSE's Action
Typically solar or wind resources are coupled with a 4-hour duration Li-ion battery system to ensure sufficient MWhs are shifted from the generating resource to the battery during low-demand hours.	PSE is assuming all generic hybrid resources with a Li-ion battery component use a 4-hour duration battery.
We suggest that PSE consider at least 100-150 MW increments of nameplate capacity of pumped hydro with 8-, 10-, and 12-hour duration in their modeling to ensure the resource receives thorough consideration.	PSE is modeling 100 MW increments of PHES with an 8 hour duration. This would constitute 25 percent ownership increments in Gordon Butte and Swan Lake Pumped Storage Hydro Projects, and 8 percent ownership increments in Goldendale Energy Storage Project. An 8-hour duration was chosen to align with the Gordon Butte Pumped Hydro Project specifications, however PSE plans to re-evaluate the PHES duration for the 2025 IRP.
Apart from the generic AC-coupled systems, recent industry developments in DC-coupled systems have provided additional options to deploy hybrid resources...Modeling different operational configurations could similarly unlock benefits that change the composition and costs of PSE's resource portfolios.	PSE models AC-coupled systems in the 2023 EPR largely due to modeling restrictions in Aurora. A key advantage of DC-Coupled systems is the ability of solar cells to directly charge a battery energy storage system without the need to convert energy to AC through an inverter, a process which causes losses. All energy tracked in Aurora is modeled as AC power, so there is no way to account for the increased efficiencies of a DC-coupled system in the software. However, AC-coupled and DC-coupled both share important cost saving mechanisms such as a shared inverter and balance of plant components between the generator and storage system.
Given Swan Lake's location on the California-Oregon intertie at Malin substation, Swan Lake's presumed charging market is California (CAISO), rather than either Mid-C or PSE's system.	PSE does not currently model the CAISO market in the portfolio model. Furthermore, the Swan Lake Pumped Hydro Project is one of three PHES projects in PSE's modeling region. Therefore, PSE focused on capturing more generalized operating assumptions that are applicable to all potential PHES projects, rather than inputting resource-specific criteria. PSE did update the model to allow all storage resources to recharge from the Mid-C market.
[An] inaccurate assumption used by PSE in its Final [2021] IRP for pumped storage is that PSE limits pumped storage resources' operating range (or "state of charge") to 70% of the resource's storage capacity. This limiting assumption does not reflect the operational reality of how pumped storage resources operate.	The state of charge or operating range for all PHES resources has been updated to 100 percent for the 2023 IRP modeling cycle.
[PSE should] work with stakeholders developing [PHES] storage projects to refine PSE's modeling assumptions in order to produce a more accurate result.	For the 2023 EPR, PSE has updated PHES operating parameters based on stakeholder feedback from the Final 2021 IRP. Updates were made to the nameplate capacity, state of charge, and the resources available to charge the PHES system.

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