Resource Planning Advisory Group Meeting

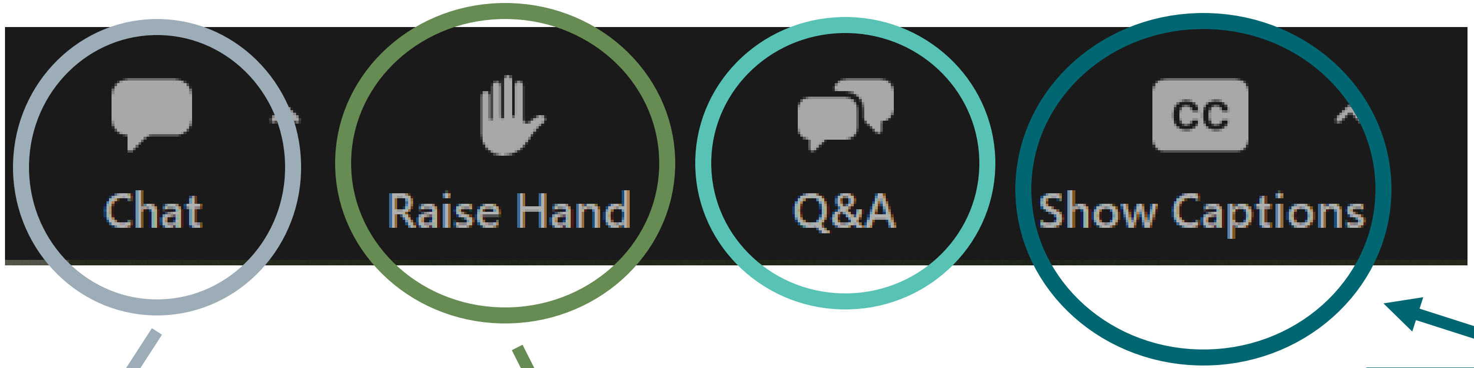
2025 Integrated Resource Plan

March 25, 2024

PUGET SOUND ENERGY

Welcome to the meeting!

The Q&A tool will be turned off during the meeting



Click to see real-time closed captioning

RPAG members and PSE staff are welcome to use the chat feature

During the public comment period, raise your hand if you would like to make a verbal comment

Safety moment

Outdoor gardening safety

- Wear gloves to protect your hands from soil, insects, and fertilizers
- Avoid prolonged repetitive motions; take breaks and rotate tasks to prevent injury
- Use tools, not your hands, for digging
- Use the right tool for the right job

Facilitator requests

- Engage constructively and courteously towards all participants
- Take space and make space
- Respect the role of the facilitator to guide the group process
- Avoid use of acronyms and explain technical questions
- Use the Feedback Form for additional input to PSE
- Aim to focus on the meeting topic
- Public comments will occur after PSE's presentations

Agenda

Time	Agenda Item	Presenter / Facilitator
12:00 p.m. – 12:05 p.m.	Introduction and agenda review	Sophie Glass, Triangle Associates
12:05 p.m. – 12:15 p.m.	Feedback summary and engagement roadmap	Kara Durbin, PSE
12:15 p.m. – 2:15 p.m.	Technology Assessment overview and electric resource alternatives	Elizabeth Hossner, PSE Gina Holland, Black & Veatch
2:15 p.m. – 2:30 p.m.	Break	All
2:30 p.m. - 3:50 p.m.	Regional transmission	Jens Nedrud, PSE Laxman Subedi, PSE
3:50 p.m. - 4:00 p.m.	Next steps and public comment opportunity	Sophie Glass, Triangle Associates
4:00 p.m.	Adjourn	All

Today's speakers

Sophie Glass

Facilitator, Triangle Associates

Kara Durbin

Director, Clean Energy Strategy, PSE

Phillip Popoff

Director, Resource Planning Analytics

Gina Holland and team

Black & Veatch Corporation

Elizabeth Hossner

Manager, Resource Planning and Analysis

Jens Nedrud

Director, Transmission, PSE

Laxman Subedi

Consulting Engineer, PSE

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Feedback summary and engagement roadmap

Kara Durbin, PSE

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February 13 RPAG meeting feedback summary

Public feedback included:

- Provide additional clarity on IAP2 spectrum and how public feedback is considered
- PSE's ethical obligations to customers related to decarbonization
- Desire to see how no new gas hookups will affect PSE and customers

RPAG feedback included:

- Model complete costs of decommissioning gas system and wide range of realistic potential futures
- Consider non-pipe and non-wire alternatives

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February 27 public webinar feedback summary

Feedback included:

- Concerns about the viability, costs, safety, and risk associated with advanced nuclear reactors
- Requests to give other emerging resources similar consideration, such as offshore wind, vehicle to grid, and geothermal
- Concerns about the level of engagement on the IAP2 spectrum
- Questions about the supply, cost, and constraints of alternative fuels

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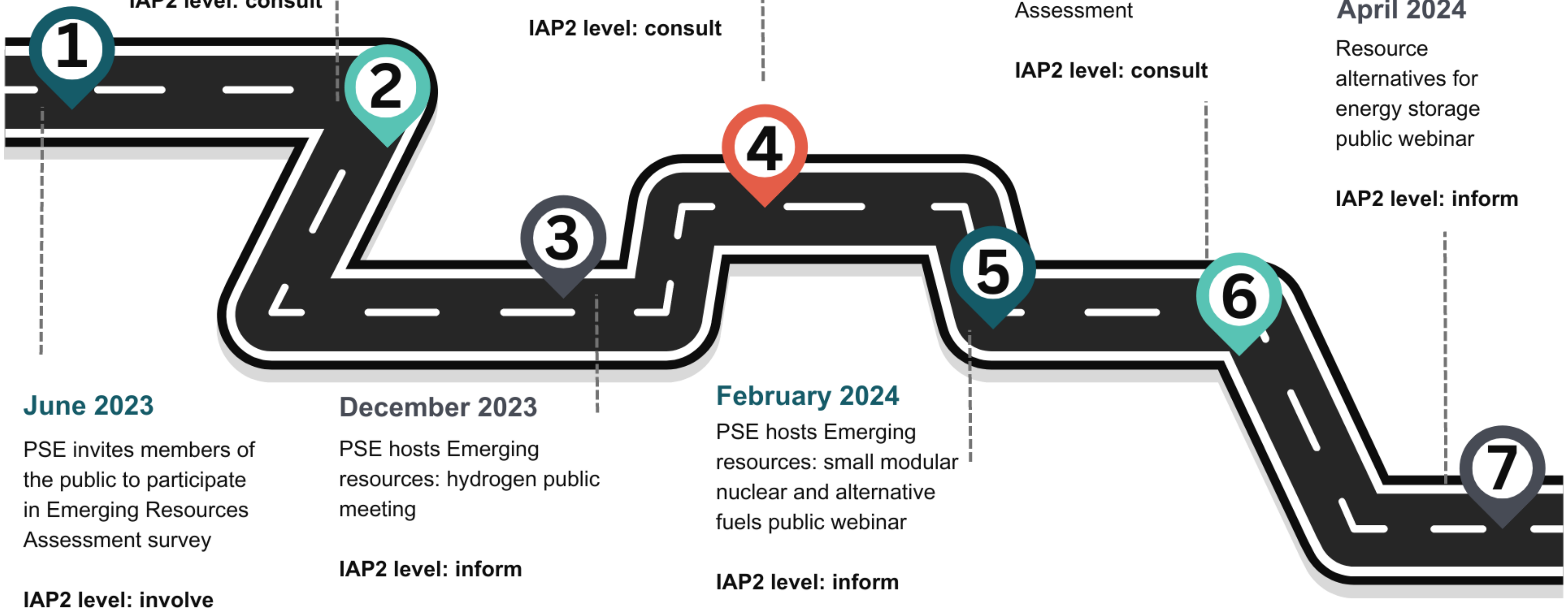
Emerging resources engagement roadmap (“involve”)



June 2023

PSE invites members of the public to participate in Emerging Resources Assessment survey

IAP2 level: involve

September 2023

PSE asks for public feedback on future IRP public webinar topics and files 2025 IRP work plan

IAP2 level: consult

December 2023

PSE hosts Emerging resources: hydrogen public meeting

IAP2 level: inform

January 2024

PSE discusses Emerging Resources Assessment overview in RPAG meeting and asks for public feedback

IAP2 level: consult

February 2024

PSE hosts Emerging resources: small modular nuclear and alternative fuels public webinar

IAP2 level: inform

March 2024

Resource alternatives RPAG meeting to discuss Emerging Resources Assessment

IAP2 level: consult

April 2024

Resource alternatives for energy storage public webinar

IAP2 level: inform

Technology Assessment overview and electric resource alternatives

Black & Veatch Corporation

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IAP2 Spectrum

	INFORM	CONSULT	INVOLVE	COLLABORATE	EMPOWER
PUBLIC PARTICIPATION GOAL	To provide the public with balanced and objective information to assist them in understanding the problem, alternatives and/or solutions.	To obtain public feedback on analysis, alternatives and/or decision.	To work directly with the public throughout the process to ensure that public concerns and aspirations are consistently understood and considered.	To partner with the public in each aspect of the decision including the development of alternatives and the identification of the preferred solution.	To place final decision-making in the hands of the public.
PROMISE TO THE PUBLIC	We will keep you informed.	We will keep you informed, listen to and acknowledge concerns and aspirations, and provide feedback on how public input influenced the decision.	We will work with you to ensure that your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision.	We will look to you for advice and innovation in formulating solutions and incorporate your advice & recommendations into the decisions to the maximum extent possible.	We will implement what you decide.

INCREASING IMPACT ON THE DECISION

Overview & introductions

Elizabeth Hossner

Manager, Resource Planning and Analysis, PSE

Electric resource alternatives

What is the purpose of the IRP?

- Establish the resource need
- Resources identified are not a resource acquisition shopping list
- Separate acquisition and evaluation process are used to select and acquire specific resources to meet capacity and energy needs, and CETA requirements

What is a generic resource?

- A place holder to help with evaluations, sizing, and creating a plan to meet future needs

What is an emerging resource?

- Technology that appears likely to be viable on the timeline required in the IRP

Objective: to discuss electric resource alternatives along with draft costs and operating characteristics

Emerging technology overview

2023 Electric Progress Report

- Public comment: Additional emerging technologies should be considered in PSE's 2025 Integrated Resource Plan

Feedback

- Released a survey in summer 2023 to received feedback and help guide conversation

Black & Veatch

- PSE hired Black & Veatch to perform an emerging tech assessment
- Evaluate emerging technology

Feedback

- Review technology and make recommendations to move forward to final evaluation
- Feedback received from Dec. 7 and Feb. 27 public meetings
- Feedback received from Jan. 12 RPAG meeting

Black & Veatch

- Review costs and evaluations of technology assessment and generic resources

We Are Here

PSE

- Final evaluation of technology taking into consideration feedback
- Technology will be modeled in the 2025 IRP

Feedback on generating resources - 2023

- ✓ Model varying battery configurations and durations
- ✓ Model BESS
- ✓ Model hybrid resources
- ✓ Provide more information about potential uses of hydrogen
- ✓ Update how PSE evaluates generic resources outside of NREL ATB
- ✓ Explore gravity storage

- ✓ Provide more information about how PSE may use SMR
- ✓ Explore more currently available technologies
- ✓ Create a diversified resource portfolio
- ✓ Update assumptions about hydrogen technology
- ✓ Provide consistency in how PSE is evaluating generating resources

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Feedback on generating resources – 2025 IRP

- ✓ Storage technologies:
  - Model Li-ion batteries
  - Expand battery storage
  - Model established technologies for generic resources for batteries
- ✓ Explore renewable resources like hydroelectric
- ✓ Provide additional regional transmission discussion

- ✓ Explore technologies:
  - ✓ Geothermal
  - ✓ Offshore wind
  - ✓ Thermal batteries
  - ✓ Battery storage
  - ✓ Vehicle to grid
  - ✓ Carbon capture and sequestration
- ✓ Mixed responses about modeling advanced nuclear

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Supply-side resource alternatives for the 2025 IRP

Energy Storage

- Short duration (Lithium-Ion 4 hour)
- **Medium duration (CAES 8-hour) - Emerging**
- **Long duration (Iron-Air 100-hour) - Emerging**

Wind

- Onshore wind
- **Offshore wind - Emerging**
- Hybrid and co-located with energy storage and solar

Solar Photovoltaic (PV)

- Utility scale
- Hybrid and co-located with energy storage and wind

Nuclear

- **Small Modular Reactor (SMR) - Emerging**

Combustion Turbine (peaker)

- Natural Gas with R99 backup
- **Hydrogen/NG blend with R99 backup - Emerging**
- R99

Distributed Energy Resources

- Solar
- Energy storage

Cost attributes for resource alternatives

Draft costs include:

- ✓ EPC (Engineer, Procure, Construct)
- ✓ Owner’s costs

Not included in the draft costs, but will be added later:

- χ Investment Tax Credit (ITC)
- χ Production Tax Credit (PTC)
- χ Interconnection costs
- χ Lease fees

Technology characterization

Gina Holland

Project Manager, Black & Veatch

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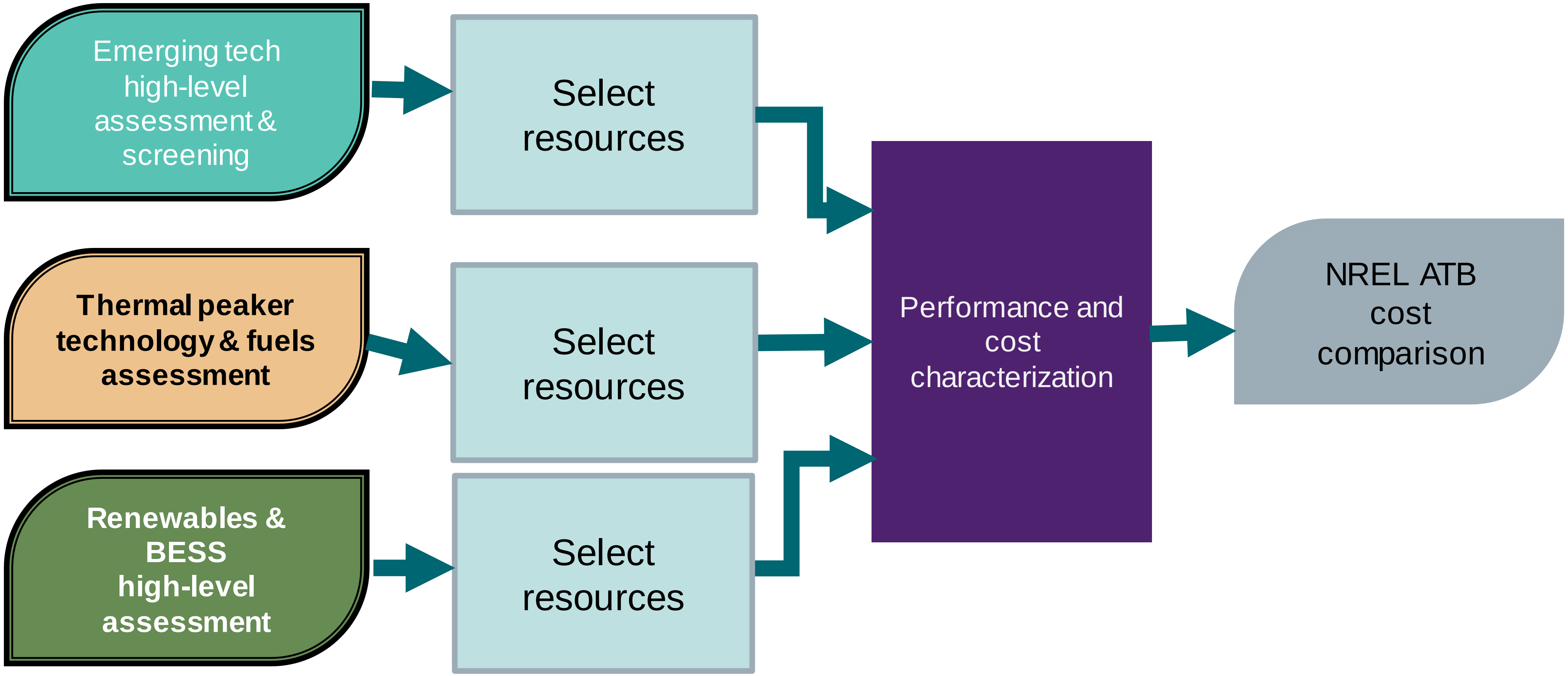
PSE IRP energy resource characterization process



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Technology Assessment

- Compressed air energy storage (CAES)
- Mechanical energy storage
- Long duration energy storage (LDES)
- Nuclear small module reactors (SMRs)
- Offshore wind – Grays Harbor
- Enhanced geothermal
- Carbon capture & sequestration (CCS)
- Distributed energy resource (DER)

Goal of the Technology Assessment

Provide information to select and further characterize technologies for potential implementation in the near-term (3 to 7 years)

Key Features

- Technology Readiness Level (TRL)
- Deployment of the technology in the US & globally
- Geological requirements
- Scalability of the technology
- Subcategories of the listed technologies and their TRLs

Technology Readiness Level (TRL)

TRL 1	• Basic principles observed and reported
TRL 2	• Technology concept and/or application formulated
TRL 3	• Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4	• Component and/or breadboard validation in a laboratory environment
TRL 5	• Component and/or breadboard validation in a relevant environment
TRL 6	• System/subsystem model or prototype demonstration in a relevant environment
TRL 7	• System prototype demonstration in an operational environment
TRL 8	• Actual system complete and qualified through test and demonstration
TRL 9	• Actual system proved through successful mission operations

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Emerging technologies: compressed air & mechanical energy storage

Michael Eddington, Black & Veatch

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Compressed air energy storage (CAES)

Mid-duration energy storage (8-24 hours)

What is it?

- Stores low-cost off-peak energy as compressed air or other gas
- Utilizes underground or above ground storage
- Compressed gas is released, heated, and directed into expansion turbine
- Cost-effectiveness limited by availability, design & size

Sub-categories

- **Adiabatic** – Stores heat from compression process and upon extraction of compressed air from storage, recovers stored heat prior to expansion
- **Diabatic** – Compressed stored air heated by combusting natural gas or hydrogen using conventional combustion turbines
- **Isothermal** – Heat removed continuously from air during compression process and added continuously during expansion; no combustion process needed

Compressed air energy storage (CAES)

Geological requirements	Technology / subcategory maturity	Scalability	Deployment
Salt caverns created by solution mining most common	TRL 9 **Diabatic**	100+ MW projects exist	Operational: 290 MWe project in Huntorf, Germany since 1978 110 MWe plant near McIntosh, Alabama, USA since 1991
Storage created by mining caverns into hard rock formations available in WA State	TRL 8 **Adiabatic / Advanced Adiabatic (AA)**	Sufficient demonstration to scale up to the 100 MW size or larger	Operational (2017): 60 MWe 5-hour Jiangsu Jintan AA-CAES Demonstration Project in China In Development (by Hydrostor): 500 MWe 8-hours Willow Rock Energy Storage Center in Kern County, CA,USA
None	TRL 6 **Isothermal**	Still in pilot / demonstration stage	Pilot Plant (2013): SustainX Inc 1.5 MWe 4-hour plant in Seabrook, New Hampshire, USA

Data derived primarily from Sandia National Laboratories, DOE Global Energy Storage Database, https://sandia.gov/ess-ssl/gesdb/public/, and Momentum building for Hydrostor's Willow Rock Energy Storage Center, March 4 2024, https://hydrostor.ca/momentum-building-for-hydrostors-willow-rock-energy-storage-center-as-company-reaches-key-permitting-and-interconnection-milestones/

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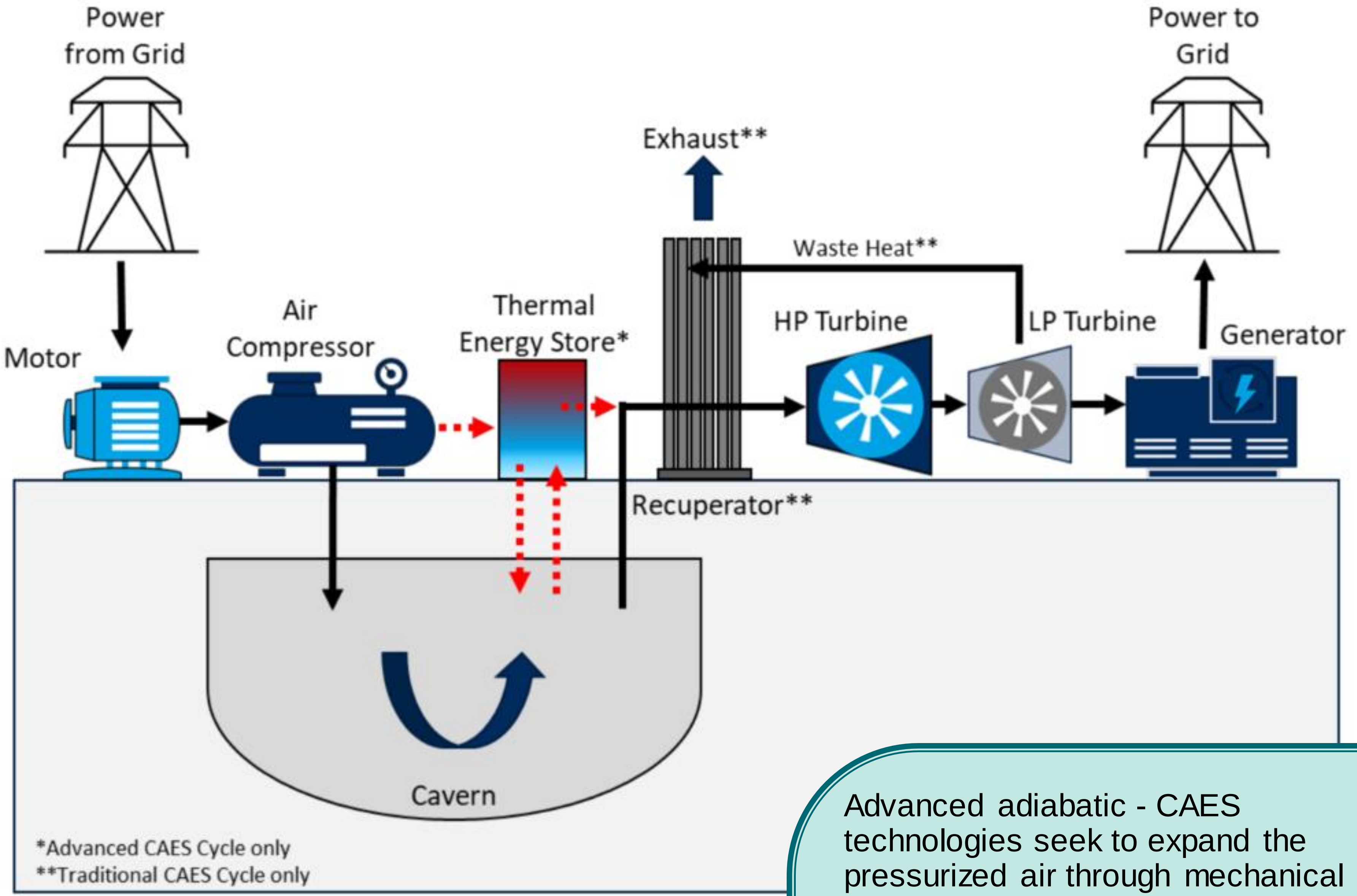
10-hour advanced adiabatic - CAES selected for further characterization



Advanced adiabatic - CAES technologies seek to expand the pressurized air through mechanical expanders to turn a generator to provide carbon-free electricity

Advanced adiabatic - CAES cost & performance characteristics

- Project development period is very project and site specific
- Initial construction may involve solution mining of salt or hard rock formations to create airtight storage
- Project development 1 to 2 years
- Construction 2 to 4 years

Technology characteristics	AA-CAES 100 MW (10 H duration)
Typical Operating Life (years)	50+
Typical Duty Cycle	Peaking – Intermediate
Net Plant Capacity (MW_e)	100
Round Trip Efficiency (%)(1)	60-70
Integrated Storage	10 hours
Capacity Factor (percent)	5-25
Total Project Cost ($/kW)(1)	1,500 - 2,500
Fixed O&M ($/kW-yr)	17.00 – 19.00
Variable O&M ($/MWh)	-
Land/Storage Area	Varies
Commercial Status	Commercial
Installed US Capacity (MW)	0

(1) Evaluating emerging long-duration energy storage technologies (https://doi.org/10.1016/j.rser.2022.112240)

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Advanced adiabatic-CAES – comparison to 2023 NREL ATB

Type	Characteristic	2023 PSE IRP Input	2023 NREL ATB	2025 PSE IRP input*
Costs	CAPEX ($/KW)	---	---	1970
	Fixed O&M ($/KW-yr)	---	---	18.00
	Variable O&M ($/MWh)	---	---	--

* This is the first year that AA-CAES has been considered by PSE for the IRP

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AA-CAES

Questions?

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Mid-duration energy storage (8-24 hours)

Mechanical energy storage (MES)

What is it?
Surplus energy on the grid is used to drive a mechanical process to store energy and then releases / converts the stored energy to electricity during peak periods

What did we study?
Based on the expected scale and application of energy storage needed, further evaluation considered liquid air energy storage and gravitational potential energy storage

Sub-Categories

- **Flywheels**
- **Hydraulic accumulators**
- **Liquid air energy storage (LAES)**
- **Gravitational potential energy storage**
- **Spring energy / mechanical battery storage**
- **Kinetic energy storage with rail systems**

* Pumped hydro is MES however PSE already has adequate information so it was not included in the study.

Liquid air energy storage (LAES)

What is it?

Thermo-mechanical storage that uses electricity to liquify cool air and store in an insulated, unpressurized vessel; liquid air is then warmed to convert back to a gaseous state to operate a turbine and generate electricity.

- Can utilize waste heat for the liquefaction and expansion processes improving efficiency
- Conceptually suitable for large grid-scale storage and offers duration storage of 10 hours

Advantages

Simplicity of the technology, scalability, flexibility, high energy density and attractive costs

Challenges

Infrastructure requirements for storage and handling of liquid air

Status

Near to market and currently prepared to be deployed in various locations

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Gravitational potential energy storage

What is it?

Converts stored energy into kinetic energy to generate electricity

- ❖ Rail, block and piston-based systems are advantaged over some other types as there is little to no self-discharge of stored energy, increasing efficiency
- ❖ Broad-based application: renewable shifting, peak capacity reduction, transmission and distribution grid investment deferral, and frequency regulation

Advantages

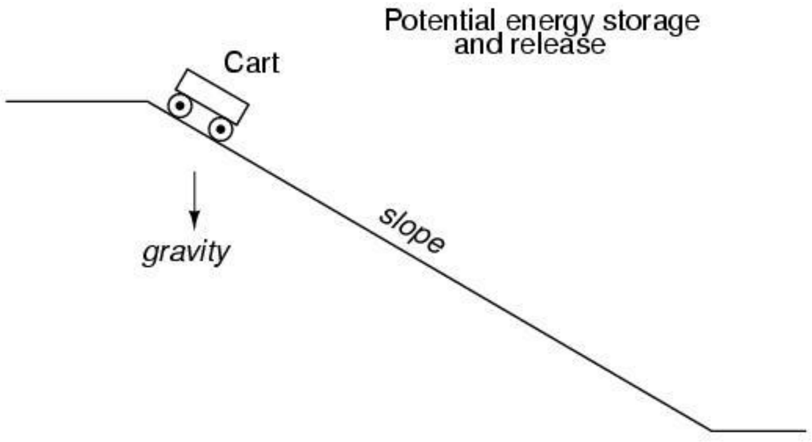
Potentially large grid-scale storage capacity with low environmental impact

Challenges

Site-specific requirements, safety concerns, and need for significant elevation differences

Status

Early-stage demonstration deployment phase, with commercial projects announced but not yet constructed



MES

Questions?

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Emerging technologies: long duration energy storage (LDES)

Prantik Saha, Black & Veatch

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Long duration energy storage (LDES)

What is it?

- **8-100 hours of energy storage**
- Grids require days-long energy storage for resiliency due to extended periods when renewables unavailable

What did we study?

Compared technical considerations and readiness for the (4) four major sub-categories

Sub-categories

- **Metal-Air Battery – Iron (FE)-Air or Zinc-Air**
- **Lithium-Ion Battery (8H)** – Lithium-nickel-manganese-cobalt oxide (NMC) and Lithium ferrous phosphate (LFP)
- **Sodium-Ion Battery** – Sodium-sulfur or Sodium-Metal-Halide require 300 to 400 deg C operating temperature
- **Flow Battery** – Stores energy in electrolytes using Vanadium Redox, Iron-Chloride, Zinc-Bromide or Metal Coordination

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Battery comparison – metal-air and lithium/sodium-ion

Technology	Geological requirements	Technology / subcategory maturity	Scalability	Deployment
Metal-air battery	None Large footprint (vs Li-Ion)	TRL 7	Up to 10 MW most common currently	Under Construction: 10 MW 10-hour **Iron-Air** battery pilot projects in Colorado and Minnesota, USA Planned: 4 MW 4-hour **Zinc-Air** battery pilot project in Virginia, USA
Lithium-ion battery	None	TRL 9	1 MW to 100+ MW exists in 1-hour to 4-hour capacities	Planned: A 75 MW **8-hour** project was announced with construction to begin in late 2025.
Sodium-ion battery	None	TRL 8 to 9		Operational: 108 MW 6-hour **Sodium-Sulfur** project in Abu Dhabi, UAE, since 2023 Planned: 120 MWh **Sodium-Metal-Halide** commercial project in Germany

Long duration battery comparison – flow

Technology	Geological requirements	Technology / subcategory maturity	Scalability	Deployment
Flow battery (fb)	None Large footprint (vs Li-Ion)	TRL 9 **Vanadium Redox FB**	100 MW+ scale commercial projects operational or planned	Operational: 100 MW 4-hour in Dalian, China in operation since 2022
		TRL 8 **Iron FB**		Under Construction: 200 MW 10-hour project in Sacramento, CA, USA
		TRL 7 **Zinc-Bromide FB**	Pilot projects at 2 to 10 MW scale underway	Under Construction: 2 MW 10-hour in CA, USA
		TRL 7 **Metal-Coordination Complex FB**		Pilot Project: 5 MW 8-hour project in Alberta, Canada

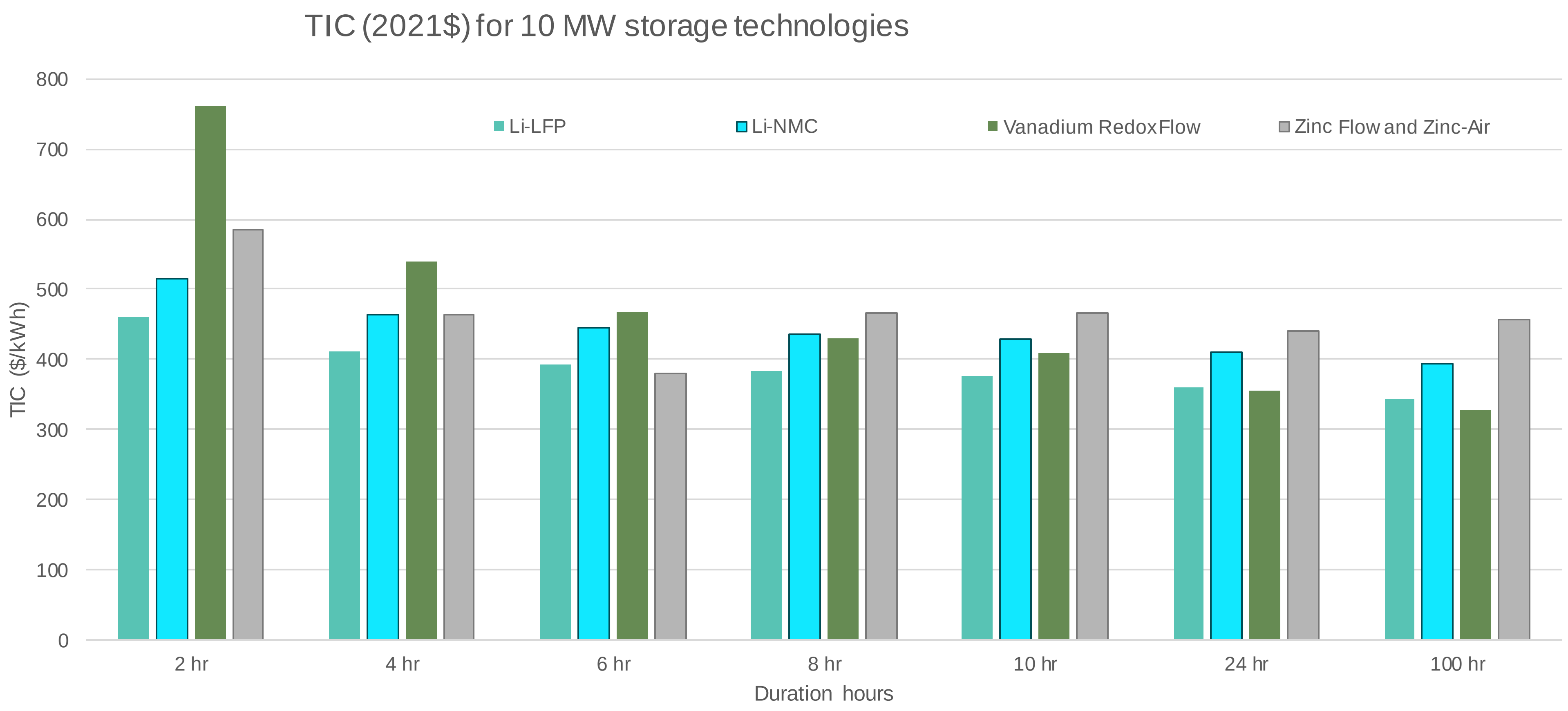
Safety concerns – lithium and metal-ion

Technology	Safety concerns
Lithium-ion battery	▪ Fire hazard due to **thermal runaway;** occurs due to the formation of lithium dendrite inside battery cells that short the electrodes o Of the two most common chemistries, lithium-nickel-manganese-cobalt oxide (NMC) is more fire-prone than lithium ferrous phosphate (LFP) due to lower thermal runaway temperature. o Next generation of lithium-ion batteries are working on reducing the thermal runaway occurrence as well as increased energy density. ▪ Fire **emits several toxic and flammable gases** like hydrogen, hydrogen fluoride, ethylene, etc. ▪ **Electrolyte spill** also occurs during fire
Metal-air battery	▪ Metal-air batteries do <u>not</u> pose any significant safety or fire hazards ▪ An alkaline **electrolyte** is used which is **mildly corrosive** ▪ Ceramic electrolyte is a solid-state ion conductor with **no** chemical spill or gas emission risk ▪ The **molten metal** can be a potential source of risk

Safety concerns – sodium-ion and flow

Technology	Safety concerns
Sodium-ion battery	▪ Fire hazard due to **thermal runaway** can occur ○ High operating temperature increases risk of thermal runaway; low reactivity of sodium compared to lithium makes the overall risk much lower ▪ Ceramic electrolyte is a solid-state ion conductor; **no** chemical spill or gas emission risk ▪ **Molten metal** can be a potential source of risk.
Flow battery	▪ Do not have any significant fire hazard like lithium-ion batteries ▪ **Vanadium oxide** used in vanadium flow batteries is highly acidic; it is **very corrosive** if spill occurs ▪ Iron flow battery uses iron chloride as the electrolyte which is safer than vanadium oxide ▪ **Bromine-based electrolytes** that are used in zinc-bromide batteries are **very corrosive**

Total installed cost (TIC) global averages



100 MW iron-air cost & performance characteristics

Technology characteristics	Iron-air 100 MW (100 h duration)
Typical Operating Life (years)	15 to 20
Net Plant Capacity (MW_e)	100
Maximum Storage Capacity (MWh)	10,000
Overbuilt Capacity (MW_e)	115
Integrated Storage	100 hours
Round Trip Efficiency (%)(1)	43
Energy Degradation (%/yr)	2
RTE Degradation (%/yr)	0.5
Total Project Cost ($/kW)(1)	2013
Fixed O&M ($/kW-yr)	18.00
Variable O&M ($/MWh)	-
Land Area (acres)	50
Commercial Status	Pilot under construction
Installed US Capacity (MW)	0

(1) All cost and techno-economic assumptions are based on Form Energy's "Recommended Approaches for Modeling Utility Electric Grids with Multi-Day Energy Storage" white paper.

- Total project cost includes development, design, construction and commissioning of battery plant ready for HV grid tie-in
- Includes overbuild of 15% for battery augmentation after 4 to 5 years of operation
- Actual initial capacity of plant with overbuild is 11,500 MWh
- Total project cost is based on Form Energy's expectation to manufacturer these systems at 1 GW/year starting in 2030

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LDES

Questions?

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Emerging technologies: nuclear small modular reactors (SMRs)

Adam Faircloth, Black & Veatch

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Nuclear small modular reactors (SMRs)

What is it?

Similar to traditional large scale nuclear reactors with key design and technology updates:

- Passive safety systems
- Smaller, simplified designs
- Modular construction
- Advanced fuels and coolants

What did we study?

Because there are no completed SMR projects to date, cost predictions and operating assumptions, are based on data from the three (3) sub-categories

Sub-categories

- **Nuscale VOYGR** – 77 MWe Pressurized Water Reactor (PWR). Most mature design with approval from the Nuclear Regulatory Commission.
- **GE BWRX-300** – 300 MWe Boiling Water Reactor (BWR). Project planned at the Darlington Nuclear Power Plant in Ontario.
- **Xe-100** – 80 MWe High-Temperature Gas Reactor (HGTR). No comparable designs in the US, but a demonstration plant in China has a similar design.

Nuclear Small Modular Reactors (SMRs)

Technology	Geological requirements	Technology / subcategory	Scalability	Deployment
Nuclear SMRs	Specific to design criteria	TRL 7 **Gen III+ Reactors**	300+ MWe	Site development: OPG Darlington SMR Project GE BWRX-300 TVA Clinch River Site GE BWRX-300
		TRL 3 **Gen IV Reactors**	80+ MWe	A few small demonstration plants under construction for proof of concept

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Nuclear SMRs selected for further characterization

The following SMR technologies were considered

NuScale VOYGR: 77-MWe Pressurized Water Reactor (PWR)

General Electric (GE) BWRX-300: 300-MWe Boiling Water Reactor (BWR)

X-Energy Xe-100: 80MWe High-Temperature Gas Reactor (HGTR)

SMRs are considered simpler and safer due to several **inherent design features** and **technological advancements**

Passive Safety Systems – Rely on natural physical principals such as gravity and natural circulation rather than an external power source or operator intervention.

Smaller, Simplified Design – Smaller core size and less moving parts

Modular Construction – Allows most of the reactor to be constructed under controlled factory conditions

Advanced Fuels and Coolants – Being designed to use nuclear fuels and coolants that can operate at higher temperatures without the risk of meltdown, further enhancing safety

Nuclear fuel

Fuel type	Availability	Applications	Cost*
HEU (Highly Enriched Uranium)	Restricted	Military & research reactors	Very expensive
LEU (Low Enriched Uranium)	Common, currently utilized in existing fleet	Nuscale BWRX-300 Holtec SMR-300	Recent doubling in price in last 6 months ($90/lb)
HALEU (High-Assay Low-Enriched Uranium)	Emerging, limited supply	TerraPower Xe-100	Current supply is controlled by the government
Thorium	Potential for future use	Not currently in US	Unknown due to still being developed

* Cost vary based on technological advancements, market demands, and regulatory changes

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Nuclear SMRs cost & performance characteristics

Technology characteristics	SMR 600 MW
Typical Operating Life (years)	50
Typical Duty Cycle	Baseload
Net Plant Capacity (MW_e)	600
Operating Range (%)	100
Degradation (%)	2.5
Capacity Factor (percent)	93
Total Project Cost ($/kW)	10,368
Fixed O&M ($/kW-yr)	100.00
Variable O&M ($/MWh)	3.14
Land Area (acres)	40
Commercial Status	2033
Installed US Capacity (MW)	0

- First-of-a Kind (FOAK) design with a long regulatory review associated with NRC licensing process
- Current project timelines indicate a target of ~ 8 to 10 years to build a plant
- Project level data is unavailable due to no commercial SMRs currently in existence in the US
- Actual costs will differ based on the specific circumstances of each project, including:
  - Technological advances
  - Changes in regulatory requirements
  - Scale of the project

Nuclear SMRs – comparison to 2023 NREL ATB

Type	Characteristic	2023 IRP input	2023 NREL ATB*	2025 IRP input
Costs	CAPEX ($/KW)	10930	10135	10368
	Fixed O&M ($/KW-yr)	114.00	119.00	100.00
	Variable O&M ($/MWh)	2.84	3.00	3.14
Performance	Heat Rate (MMBtu/MWh)	10.45	10.45	10.45
	Net Capacity Factor (%)	93%	93%	93%

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Nuclear SMRs

Questions?

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Emerging technologies: offshore wind – Grays Harbor

Georgia Beyersdorfer & Peter Clive, Black & Veatch

Offshore wind – Grays Harbor (coastal WA)

What is it?

- In operation globally for over 30 years
- Vast majority of installations involve turbines with fixed bottom foundation types (monopile, jacket, etc.)
- First floating offshore wind project, Hywind Scotland, became operational in 2017
- Relies on the same physical principles as onshore technology
- Governed by wind speed, air density, and turbine rotor swept area

Sub-categories

- Fixed foundation: monopiles or jacket design suitable for up to 60 meters in depth
- Floating platform: multiple design variations in design include spar-buoy, semi-submersible and tension leg for depths greater than 60 meters

Offshore wind comparison

<table>
<tr><th>Geological requirements</th><th>Technology / subcategory maturity</th><th>Scalability</th><th>Deployment</th></tr>
<tr><td>Up to 60 meters in ocean depth</td><td>TRL 9
Fixed foundation</td><td>1000+ MW</td><td><u>Outside USA</u>:
❖ Hornsea I, 1,218 MW
❖ Hornsea II,1,386 MW
❖ Seagreen Wind Energy, 1,075 MW
❖ Moray East Wind Farm– 950 MW
❖ Triton Knoll Wind Farm – 857 MW
<u>USA - 2024 COD:</u>
❖ South Fork Wind, 132 MW
❖ Vineyard Wind, 800 MW (Largest)</td></tr>
<tr><td>Over 60 meters in ocean depth</td><td>TRL 8
Floating platforms</td><td>< 100 MW Currently</td><td><u>Outside USA</u>:
❖ Hywind Tampen, 88 MW
❖ Kincardine Windfarm, 50 MW
❖ Hywind Scotland, 30 MW
<u>USA</u> : None</td></tr>
</table>

Offshore wind selected for further characterization

100 MWe off-shore wind (OSA) located in Grays Harbor area of coastal Washington
Development and analysis supports consideration of using semi-submersible floating platform technology in depths exceeding 60 meters
In shallower waters fixed-bottom foundations may be considered

In the US market, there are three main offshore wind turbine suppliers: **Vestas**, **General Electric (GE)** and **Siemens Gamesa**.
Currently the market offering for offshore applications is between 12 – 15 MW rated turbines with product developments reaching 18 MW and beyond.

There is increased scrutiny from the public, tighter economics, and permitting challenges in comparison with onshore wind due to the unknown factors
However, the first floating offshore wind project of this type in the U.S. is on the horizon

Floating OSW variability in LCOE market predictions (2020-2036)

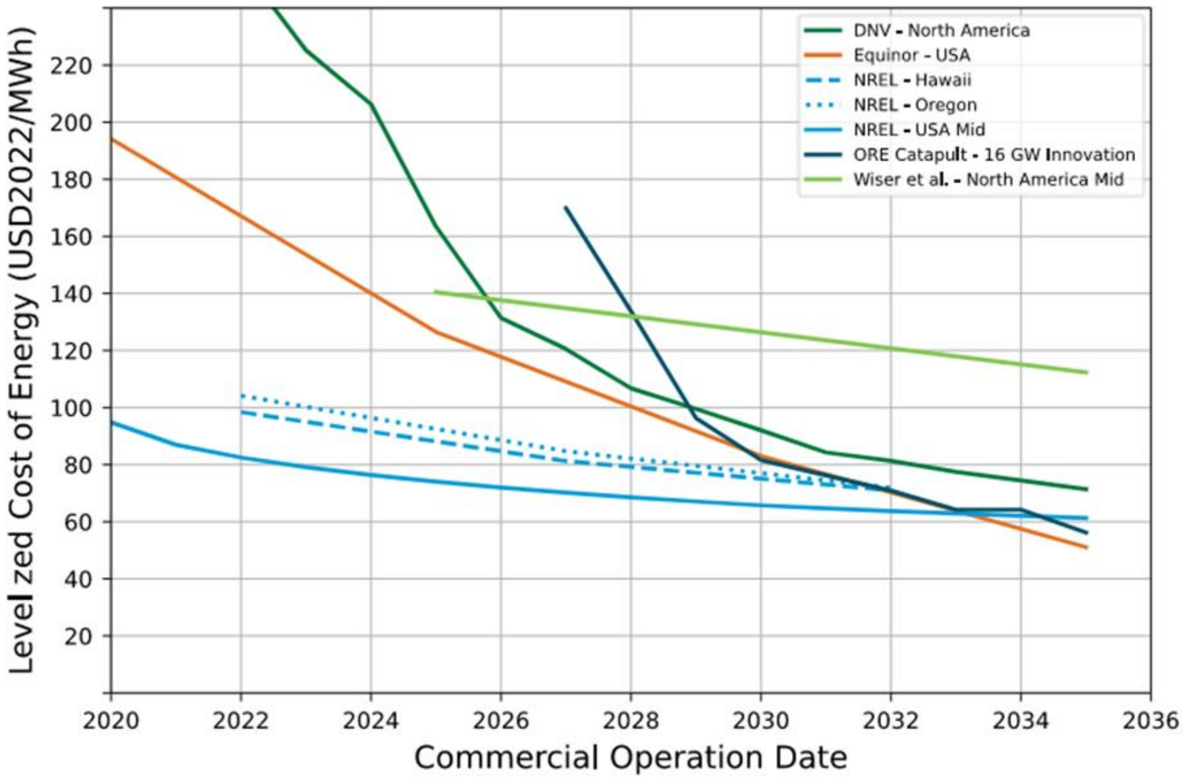


Figure 41. U.S. LCOE estimates for floating offshore wind technologies.

Sources: DNV (2022); Equinor (2021); NREL - Hawaii, Shields et al. (2021); NREL - Oregon, Musial et al. (2021); NREL - USA Mid, Averaged from NREL spatial cost studies; ORE Catapult (2021); Wiser et al. (2021).

- There is extensive research in the cost predictions for floating offshore wind
- Due to lack of executed projects on a global scale, projected costs are based on a combination of fixed-bottom offshore wind cost projections and the handful of floating offshore wind projects that have been constructed thus far.
- Full performance and cost characterization completed for both fixed and floating foundation types for the proposed Grays Harbor site

PUGET SOUND ENERGY

Fixed OSW cost & performance characteristics

Technology characteristics	Fixed OSW Grays Harbor
Typical Operating Life (years)	20
Typical Duty Cycle	Resource Availability
Net Plant Capacity (MW_e)	120
Operating Range (%)	100
Plant (& Wake) Losses (%)	17
Capacity Factor (%)	45
Total Project Cost ($/kW)	3,600
Fixed O&M ($/kW-yr)	120
Variable O&M ($/MWh)	Negligible
Commercial Status	2030
US Capacity (MW)	42MW Operating, 932MW Under Construction

- Current project timelines indicate a target of ~ 6 to 8 years for first projects installed along USA West Coast
- High Voltage AC connection from windfarm to onshore substation (ONS); no offshore substation platform (OSS)
- No port or navigation channel upgrades are included in costs
- Mature technology fully demonstrated with 69.6GW capacity installed globally by 2023

PUGET SOUND ENERGY

Floating OSW cost & performance characteristics

Technology characteristics	Floating OSW Grays Harbor
Typical Operating Life (years)	15
Typical Duty Cycle	Resource Availability
Net Plant Capacity (MW_e)	100
Operating Range (%)	100
Plant (& Wake) Losses (%)	17
Capacity Factor (%)	45
Total Project Cost ($/kW)	5,100
Fixed O&M ($/kW-yr)	120
Variable O&M ($/MWh)	Negligible
Commercial Status	2030
Installed US Capacity (MW)	0

- Current project timelines indicate a target of ~ 8 to 10 years due to First-Of-A-Kind (FOAK) in USA
- High Voltage AC connection from windfarm to onshore substation (ONS); no offshore substation platform (OSS)
- No port or navigation channel upgrades are included in costs
- Norway currently has the largest installed global capacity of Floating OSW at 171MW, where 60MW was commissioned in 2022.

PUGET SOUND ENERGY

Offshore wind – comparison to 2023 NREL ATB

Type	Characteristic	2023 IRP Input	2023 NREL ATB*	2025 IRP Input
Fixed Foundation	CAPEX ($/KW)	4728	3866	3600
	Fixed O&M ($/KW-yr)	70.76	114	120
	Variable O&M ($/MWh)	---	---	---
	Wind Class	6	6	6
Floating* Foundation	CAPEX ($/KW)	---	---	5100
	Fixed O&M ($/KW-yr)	---	---	120
	Variable O&M ($/MWh)	---	---	---
	Wind Class	---	---	6

* This is the first year floating foundation was considered by PSE in the IRP.

OFFSHORE WIND

Questions?

PUGET SOUND ENERGY

Emerging technologies: carbon capture and sequestration (CCS) & enhanced geothermal systems (EGS)

Leslie Ponder, Black & Veatch

PUGET SOUND ENERGY

Carbon capture & sequestration (CCS)

What is it?

- Pre-combustion technologies remove CO^2 from a byproduct stream of a process prior to combustion
- Post-combustion technologies remove CO^2 from the flue gas

What did we study further?

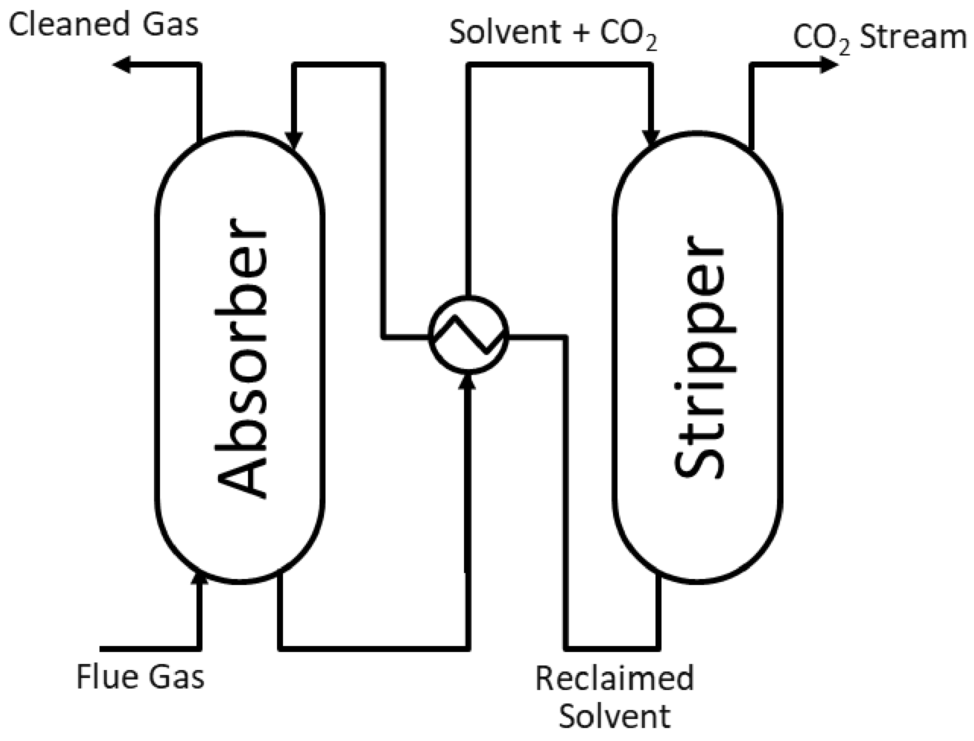
- Post-combustion liquid solvent absorption

Sub-categories:

The primary methods for the capture and separation of CO2 from post-combustion systems include:

- **Liquid solvent absorption**
- Physical adsorption
- Separation membranes
- Cryogenic separation

Amine-based solvent high-level process flow diagram



*Reboiler, reflux, direct contact cooler, and water wash/ makeup streams not shown

Technology has been demonstrated to separate CO_2 from dilute streams containing as low as 3 to 4 percent CO_2 by volume

Enhanced Geothermal System (EGS)

What is it?

- EGS are man-made structures/systems to inject a fluid, typically water below the earth's surface and extract the stored heat underground to generate electricity above ground.

Sub-categories

- Quaise Energy's system is based on an innovative drilling technology that uses millimeter wavelength waves to directly vaporize the rocks instead of the traditional mechanical drilling

- Fervo Energy is focused on deploying directional drilling technology perfected in the oil & gas industry, fiber optic sensing and advanced computational models to geothermal projects.

CCS & EGS

Technology features	Geological requirements	Technology / subcategory maturity	Scalability	Deployment
Carbon capture & sequestration (CCS)	Specific to site design criteria	TRL 9 **Amine CCS System w/Coal-fired Unit**	No limit, current largest installed facility is 1.4 Mmtpa	Two commercial units operating in North America
		TRL 8 **Amine CCS System NG-fired Combined Cycle**		Multiple FEED studies in progress for large natural gas combined cycle units
Enhanced geothermal System (egs)	Far from dense human settlement Not in earthquake prone areas	TRL 7 **Fervo Energy**	Unknown; most projects operating today < 10 MW Several demonstration projects but < 100 MWh	3.5 MW Project in Nevada, USA (Nov 2023)
		TRL 4 **Quiase Energy**		No deployed projects yet. Feasibility analysis via computer simulations Demonstration Project ~2024

PUGET SOUND ENERGY

CCS & EGS

Questions?

PUGET SOUND ENERGY

Emerging technologies: distributed energy resources (DER)

Gina Holland, Black & Veatch

PUGET SOUND ENERGY

Distributed energy resources

What is it?

- Combination of generating resources at a particular site, which are smaller than the utility scale versions, such as:
  - Virtual Power Plant
  - Demand-side Management (DSM)
  - Curtailing solar inverters, BESS dispatch, and microgrid systems

Sub-categories

- **Combined Heat and Power (CHP)** – Engine-generator, turbine-generator and Boiler-based (e.g. co-generation)
- **Solar Photovoltaic (PV)** – Rooftop, Ground Mount, Carport/Canopy and Floating
- **Wind** – Small Scale Horizontal and Vertical Axis
- **Battery Energy Storage Systems** (BESS)
- **Vehicle to Grid** (V2G) systems

DER solar PV & BESS – comparison to 2023 NREL ATB

Technology	Technical/cost category	2023 IRP input	2023 NREL ATB*	2025 IRP input
Solar PV[1] 5 MW In-front of meter	CAPEX ($/KW)	2287	3431	3250
	Fixed O&M ($/KW-yr)	25.48	36.00	32.50
	Variable O&M ($/MWh)	---	---	---
	Net Capacity Factor (%)	~15%	~15.0 %	~15%
BESS, Li-ion[2] **(LFP)** 5MW, 3-hr In-front of meter	CAPEX ($/KW)	3923	3681	3681
	Fixed O&M ($/KW-yr)[3]	98.06	92.00	92.00
	Variable O&M ($/MWh)	---	---	---
	Round-Trip Efficiency	85%	85%	85%
	Net Capacity Factor (%)	~11%	~11%	~11%

(1) NREL ATB Solar PV Distribution Residential system is based on fixed-tilt rooftop PV with 7.9 kWdc capacity using a factor of 1.2 kWac/kWdc to convert costs to kWac basis
(2) Black & Veatch cost based on NREL ATB BESS Distribution Residential system is based on AC coupled 5kW 12.5 kWh storage (4 hours) & PSE 2023 IRP Based on a 5kW 14.5 kWh system
(3) Following the 2023 NREL ATB, the FOM for Li-ion batteries is 2.5% of the capital cost

PUGET SOUND ENERGY

DER

Questions?

PUGET SOUND ENERGY

Thermal peaking resource: fuels assessment & characterization

Nikhil Karkhanis, Black & Veatch

Fuels & engine technology selection

Fuels assessment

Various fuels were assessed based on following criteria:

- Compatibility with engines
- Emissions from combustion
- Lifecycle greenhouse gas (GHG) emissions
- Availability
- Fuel pricing

Peaker unit assessment

- Siemens SGT800 shortlisted based on PSE requirements

Key Features

Feature	Details
Nominal Rating MW*	62
Simple Cycle Efficiency*	41.1
Heat Rate (Btu/kWh, LHV)*	8302
H_2 Capability in 2024 (% vol)	75 – DLE Burner
100% H_2 Timeline	2025 – DLE Burner
Liquid Fuel Capability (while maintaining H_2 capability)	Yes

* For operation on natural gas and at ISO conditions

PUGET SOUND ENERGY

Thermal peaker unit characterization

Natural Gas (NG) – performance & emissions summary

Performance

Ambient condition	Net capacity (MW)[1]	Net plant heat rate (BTU/KWH, HHV)[1]
Peak Winter (Full Load)	129.4	9335
Peak Summer (Full Load)	105.7	9848
Annual Average (Full Load)	119.6	9457

[1]Net capacity and net plant heat rate is at GSU LV side. No inlet air conditioning considered for CTG.

Plant emissions

Pollutant	Peak winter	Peak summer	Annual average
NO_x, ppmvd at 15% O_2	5	5	5
NO_x, lb/MBtu	0.0172	0.0173	0.0171
CO, lb/MBtu	0.002	0.002	0.002
CO_2, lb/MBtu	198.1	198.5	198.8

[1]Emissions are at full load and include the effects of SCR and CO catalysts and dry-low NO_x combustors.

PSE PUGET SOUND ENERGY

Thermal peaker unit characterization

Renewable Diesel (R99) - performance & emissions summary

Ambient condition	Net capacity (MW)(1)	Net plant heat rate (BTU/KWH, HHV)(1)
Peak Winter (Full Load)	97.7	9573
Peak Summer (Full Load)	89.7	9810
Annual Average (Full Load)	97.7	9505

(1)Net capacity and net plant heat rate is at GSU LV side. No inlet air conditioning considered for CTG.

Performance

Pollutant	Peak winter	Peak summer	Annual average
NO_x, ppmvd at 15% O_2	15	14.8	14.8
NO_x, lb/MBtu	0.0504	0.051	0.0481
CO, lb/MBtu	0.0021	0.0021	0.0021
CO_2, lb/MBtu	257.8	257.4	255.2

(1)Emissions are at full load and include the effects of SCR and CO catalysts and dry-low NO_x combustors.

Emissions

PUGET SOUND ENERGY

Thermal peaker unit characterization

Hydrogen (H_2) – Performance & emissions summary

Performance

Ambient condition	Net capacity (MW)[1]	Net plant heat rate (BTU/KWH, HHV)[1]
Peak Winter (Full Load)	104	10090
Peak Summer (Full Load)	81	10798
Annual Average (Full Load)	95.2	10269

[1]Net capacity and net plant heat rate is at GSU LV side. No inlet air conditioning considered for CTG.

Emissions

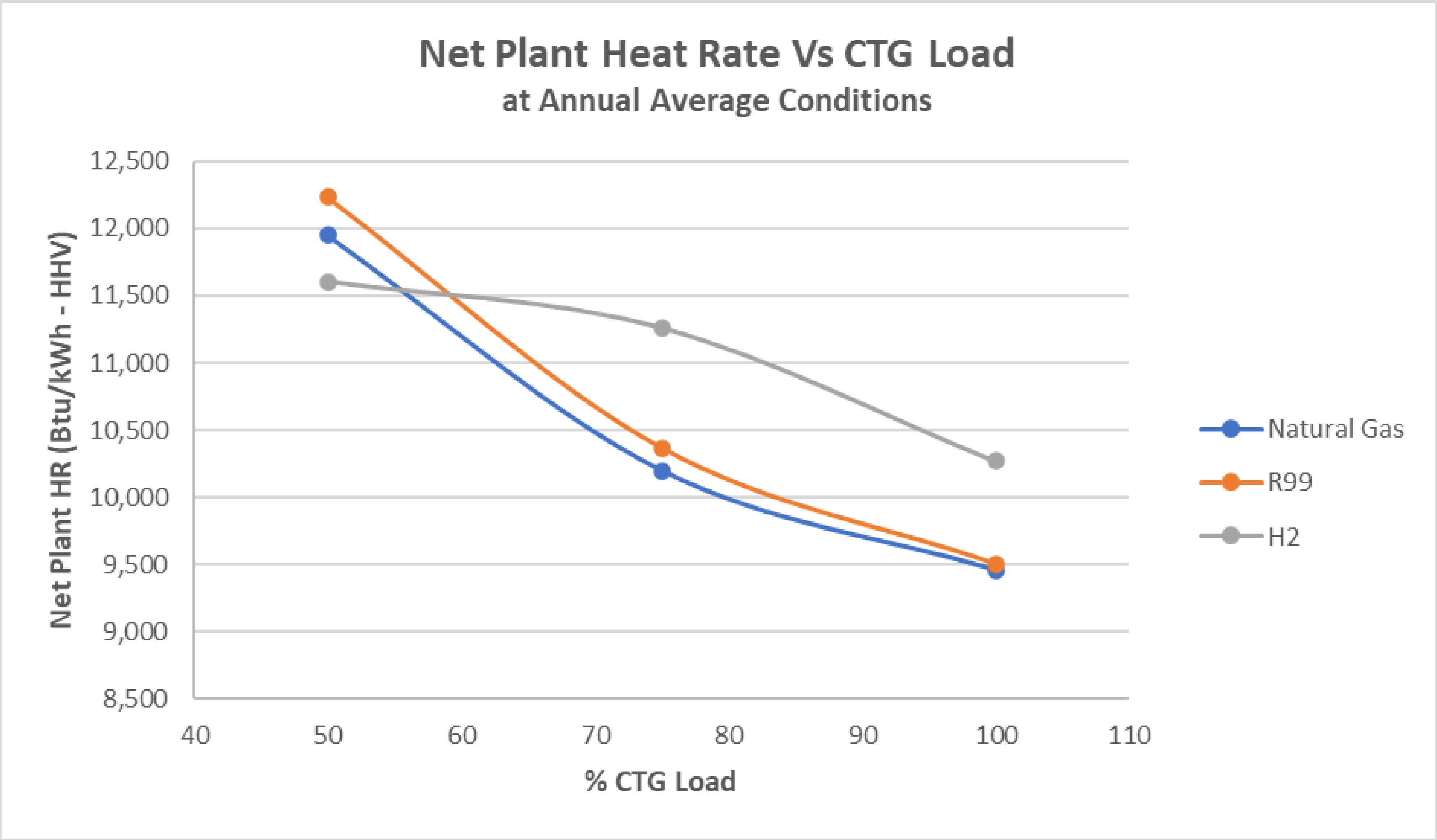
Pollutant	Peak winter	Peak summer	Annual average
NO_x, ppmvd at 15% O_2	14.8	15	15
NO_x, lb/MBtu	0.0435	0.0434	0.0428
CO, lb/MBtu	0	0	0
CO_2, lb/MBtu	Negligible	Negligible	Negligible

[1]Emissions are at full load and include the effects of SCR and CO catalysts and dry-low NO_x combustors.

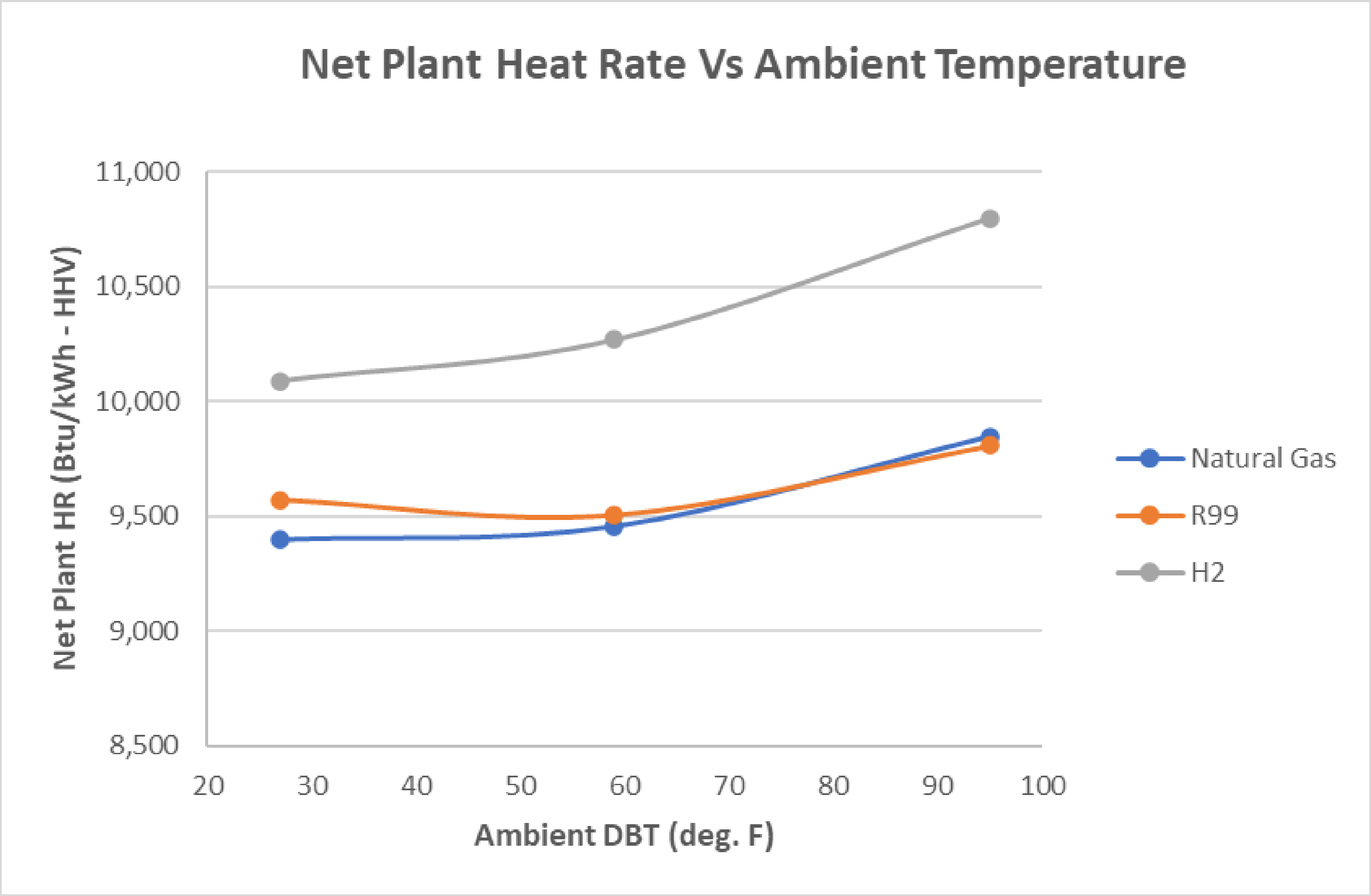
The SGT800 on 100% H2 is not formally released for sales. All performance and emissions numbers are subject to change.

PUGET SOUND ENERGY

Thermal peaker performance curves



Thermal peaker performance curves



Thermal peaker cost & performance characteristics

Technology characteristics	Natural gas / R99	H_2
Typical Operating Life (years)	20	20
Typical Duty Cycle	Peaking	Peaking
Net Plant Capacity (MW_e)	120 / 98	95
Operating Range (%)	100	100
Forced Outage Rate (%)	5 / 6	5
Degradation (%/yr)	0.15 / 0.20	0.15
Total Project Cost ($)	198	202
Total Project Cost ($/kW)	1648	1683
Fixed O&M ($/kW-yr)	13.20	13.20
Variable O&M ($/MWh)	35.80	35.80
Land Area (acres)	0.3	0.3
Commercial Status	Available	2025
Installed WW Capacity (GW)	25.2	0

Costs for NG/R99 unit/plant

- Cost for R99 fuel storage tanks for 72 hours storage is included in total project cost

Costs for H_2 unit/plant

Included:

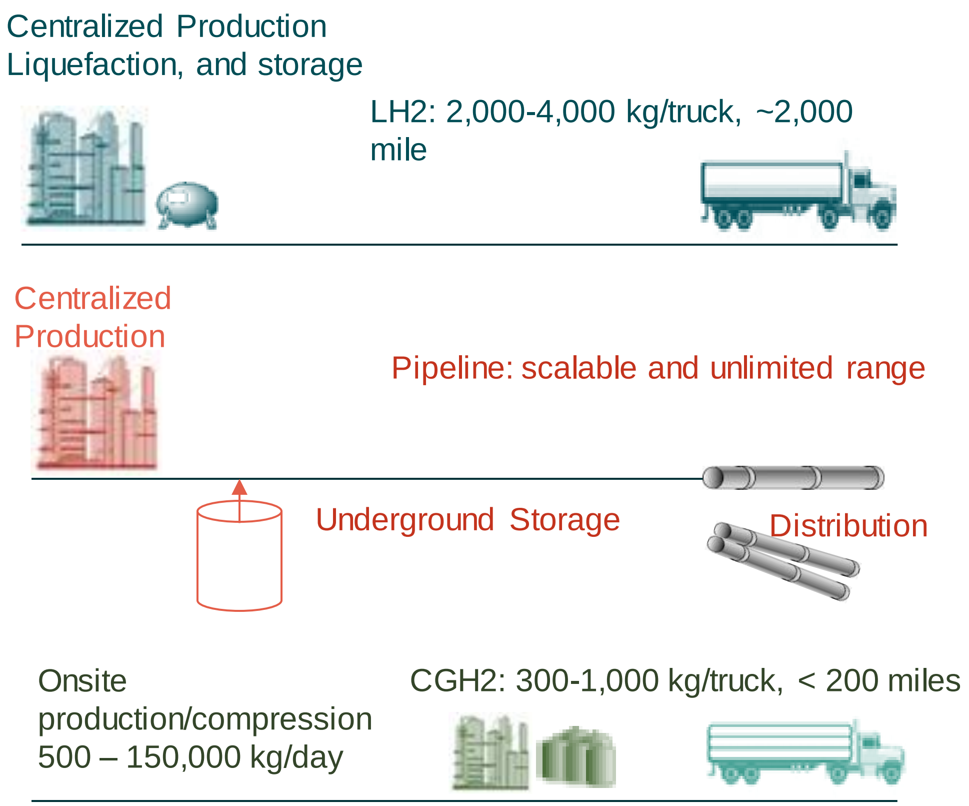
- OEM H2 package
- Blending skid
- H_2 piping within the plant
- H_2 related safety devices in BOP

Not included:

- On-site H_2 storage is expensive
- Pipeline or tanker/trailers should be included in fuel delivery costs

PUGET SOUND ENERGY

Hydrogen transportation overview



- **Pipelines** are the most cost-efficient way to transport large quantities over long distances
- **Gaseous tube trailers** best to serve small demand dispersed in a region
- **Liquefied hydrogen tankers** suitable to serve long distance with no existing infrastructure

PUGET SOUND ENERGY

Thermal peaker (NG / R99) – comparison to 2023 NREL ATB

Type	Characteristic	2023 PSE IRP input[1]	2023 NREL ATB[1]	2025 PSE IRP input
Costs	CAPEX ($/KW)	943	1120	1648
	Fixed O&M ($/KW-yr)	9.52	24.00	13.20
	Variable O&M ($/MWh)	1.02	12.88	35.80
Performance[2]	Heat Rate (MMBtu/KWh)	9720	9720	9457 / 9505
	NOx(lbs/MMBtu)	0	0.005	0.017 / 0.021
	CO2 (lbs/MMBtu)	118.6	119	199 / 255

1. 2023 and 2022 NREL ATB uses a F Class gas turbine (200+ MW) for its analysis. The significant difference in MW compared to the SGT800 result in differences in costs and performance numbers from the Black & Veatch estimates. NREL assumptions on the operating profile of the peaker may be different from Black & Veatch assumptions used in thermal modeling resulting in differences in variable O&M costs.
2. Performance values for operation on natural gas.

PUGET SOUND ENERGY

Thermal peaker (H_2) – comparison to 2023 NREL ATB

Type	Characteristic	2023 PSE IRP input[1]	2023 NREL ATB[1]	2025 PSE IRP input
Costs	CAPEX ($/KW)	943	1120	1683
	Fixed O&M ($/KW-yr)	9.52	24.00	13.20
	Variable O&M ($/MWh)	1.02	12.88	35.80
Performance[2]	Heat Rate (MMBtu/KWh)	9720	9720	9457
	NOx(lbs/MMBtu)	0	0.005	0.017
	CO2 (lbs/MMBtu)	118.6	119	199

1. 2023 and 2022 NREL ATB uses a F Class gas turbine (200+ MW) for its analysis. The significant difference in MW compared to the SGT800 result in differences in costs and performance numbers from the Black & Veatch estimates. NREL assumptions on the operating profile of the peaker may be different from Black & Veatch assumptions used in thermal modeling resulting in differences in variable O&M costs.
2. Performance values for operation on natural gas.

PUGET SOUND ENERGY

THERMAL PEAKER

Questions?

PUGET SOUND ENERGY

Utility scale renewables & BESS: Technology characterization

Gina Holland & Dan Corrigan, Black & Veatch

PUGET SOUND ENERGY

Utility scale PV solar cost & performance characteristics

Technology characteristics	100 MW utility scale PV solar
Typical Operating Life (years)	20
Typical Duty Cycle	Resource Availability
Net Plant Capacity (MW_e)	100
Operating Range (%)	100
Net Capacity Factor (%)	25%
Total Project Cost ($/kW)	1,291
Fixed O&M ($/kW-yr)	23.00
Variable O&M ($/MWh)	Negligible
Location	Goldendale, Eastern WA State, USA

- Total project cost includes development, design, construction and commissioning of battery plant ready for HV grid tie-in
- Mature commercially available technology

PUGET SOUND ENERGY

Utility scale BESS cost & performance characteristics

Technology characteristics	100 MW BESS (4-hour duration)
Typical Operating Life (years)	15
Net Plant Capacity (MW_e)	100
Maximum Storage Capacity (MWh)	400
Integrated Storage	4 hours
Round Trip Efficiency (%)	85
Total Project Cost ($/kW)[(1)]	1527
Fixed O&M ($/kW-yr)	40.00
Variable O&M ($/MWh)	Negligible
Location	Bellingham, Eastern WA State, USA

- Total project cost includes development, design, construction and commissioning of battery plant ready for HV grid tie-in
- Includes battery augmentation after every 4 to 5 years of operation; cost is included as part of the fixed O&M cost
- Mature commercially available technology

PUGET SOUND ENERGY

Onshore wind cost & performance characteristics

Technology characteristics	100 MW onshore wind
Typical Operating Life (years)	20
Typical Duty Cycle	Resource Availability
Net Plant Capacity (MW_e)	100
Operating Range (%)	100
Wind Class	6
Net Capacity Factor (%)	39%
Total Project Cost ($/kW)	1,615
Fixed O&M ($/kW-yr)	25
Variable O&M ($/MWh)	Negligible
Location	Pomeroy, Eastern WA State, USA

- Total project cost includes development, design, construction and commissioning of battery plant ready for HV grid tie-in
- Mature commercially available technology

Renewable & BESS resources cost summary

Comparison to 2023 NREL ATB summary				
Technology/Size	**Cost category**	**2023 PSE IRP input**	**2023 NREL ATB**	**2025 PSE IRP input**
PV Solar 100 MW, single axis tracking utility scale	CAPEX ($/KW)	1230	1291	1291
	Fixed O&M ($/KW-yr)	19.35	23.00	23.00
	Variable O&M ($/MWh)	---	---	---
BESS 100 MW, 4-hr Li-Ion (LFP), utility scale	CAPEX ($/KW)	1314	1587	1527
	Fixed O&M ($/KW-yr)	32.84	40.00	40.00
	Variable O&M ($/MWh)	---	---	---
Wind 100 MW, wind class 6 Onshore	CAPEX ($/KW)	1464	1363	1615
	Fixed O&M ($/KW-yr)	41.79	30.00	25.00
	Variable O&M ($/MWh)	---	---	---

Utility scale – co-located hybrid projects

The following combinations were used to determine cost characterization:

- 100 MW PV Solar + 50 MW 4-hour Li-ion (LFP) BESS
- 100 MW On-Shore Wind + 50 MW 4-hour Li-ion (LFP) BESS
- 100 MW PV Solar + 100 MW Onshore Wind + 50 MW 4-hour Li-ion (LFP) BESS

Additional analysis and scenario modeling may be completed to optimize the mix of resources based on resource availability and/or utility grid system requirements/constraints.

Utility scale - co-located hybrid project cost savings

- For indicative pricing, interconnection size equal to the nameplate of generating resource(s)
  - BESS will charge during grid off-peak periods when renewables are available & generating energy
  - BESS will discharge energy into the utility Grid when the renewables are unavailable
- For an actual project, PSE will need to right-size the battery to match the generation shape of the renewable resource

For 100 MW PV Solar (or Wind)
+ 50 MW BESS
GSU Transformer = 100 MWe

For 100 MW PV Solar
+ 100 MW Wind
+ 50 MW BESS,
GSU Transformer = 200 MWe

PUGET SOUND ENERGY

Co-located renewable + BESS hybrid plant

Comparison to 2023 NREL ATB summary				
Technology/size	**Cost category**	**2023 PSE IRP input**	**2023 NREL ATB**	**2025 PSE IRP input**
PV Solar + BESS 100 MW + 50 MW, 4-hr co-located hybrid	CAPEX ($/KW)	1147	2102	1362
	Fixed O&M ($/KW-yr)	---	62	43.00
	Variable O&M ($/MWh)	---	---	---
Wind + BESS 100 MW + 50 MW, 4-hr co-located hybrid	CAPEX ($/KW)	1310	---	1577
	Fixed O&M ($/KW-yr)	---	---	45.00
	Variable O&M ($/MWh)	---	---	---
PV Solar + wind + BESS 100MW+100MW+50MW, 4-hr co-located hybrid	CAPEX ($/KW)	1190	---	1463
	Fixed O&M ($/KW-yr)	---	---	68.00
	Variable O&M ($/MWh)	---	---	---

PUGET SOUND ENERGY

Renewables & BESS

Questions?

PUGET SOUND ENERGY

Supply-side resource alternatives for the 2025 IRP

Energy Storage
- Short duration (Lithium-Ion 4 hour)
- **Medium duration (CAES 8-hour) - Emerging**
- **Long duration (Iron-Air 100-hour) - Emerging**

Wind
- Onshore wind
- **Offshore wind - Emerging**
- Hybrid and co-located with energy storage and solar

Solar Photovoltaic (PV)
- Utility scale
- Hybrid and co-located with energy storage and wind

Nuclear
- **Small Modular Reactor (SMR) - Emerging**

Combustion Turbine (peaker)
- Natural Gas with R99 backup
- **Hydrogen/NG blend with R99 backup - Emerging**
- R99

Distributed Energy Resources
- Solar
- Energy storage

PSE IRP inputs vs NREL ATB comparison: summary

Gina Holland, Black & Veatch

Comparison to 2023 NREL ATB summary

Technology/Size	Cost Category	2023 PSE IRP input	2023 NREL ATB	2025 PSE IRP input
AA-CAES 100 MW	CAPEX ($/KW)	---	---	1970
	Fixed O&M ($/KW-yr)	---	---	18.00
	Variable O&M ($/MWh)	---	---	---
LDES iron-air battery 100 MW 100-HR	CAPEX ($/KW)	---	---	2013
	Fixed O&M ($/KW-yr)	---	---	18.00
	Variable O&M ($/MWh)	---	---	--
Nuclear SMR 600 MW	CAPEX ($/KW)	10930	10135	10368
	Fixed O&M ($/KW-yr)	114.00	119.00	100.00
	Variable O&M ($/MWh)	2.84	3.00	3.14
Offshore wind 100 MW, wind Class 6 Fixed Foundation	CAPEX ($/KW)	4728	3866	3600
	Fixed O&M ($/KW-yr)	70.78	114	120
	Variable O&M ($/MWh)	---	---	---
Offshore wind 100 MW, Wind Class 6 Floating Foundation	CAPEX ($/KW)	---	---	5100
	Fixed O&M ($/KW-yr)	---	---	120.00
	Variable O&M ($/MWh)	---	---	---
DER solar PV 5 MW In-Front of Meter	CAPEX ($/KW)	2287	3431	3250
	Fixed O&M ($/KW-yr)	25.48	36.00	32.50
	Variable O&M ($/MWh)	---	---	---
DER BESS Li-Ion (LFP), 5 MW-3 hr In-Front of Meter	CAPEX ($/KW)	3923	3681	3681
	Fixed O&M ($/KW-yr)	98.06	92.00	92.00
	Variable O&M ($/MWh)	---	---	---

Emerging technologies

PUGET SOUND ENERGY

Comparison to 2023 NREL ATB summary

Technology/Size	Cost Category	2023 PSE IRP input	2023 NREL ATB	2025 PSE IRP input
Thermal Peaker NG / R99 fuel (vs NG) 100 MW	CAPEX ($/KW)	943	1120	1648
	Fixed O&M ($/KW-yr)	9.52	24.00	13.20
	Variable O&M ($/MWh)	1.02	12.88	35.80
Thermal Peaker 100% H_2 fuel (vs NG) 100 MW	CAPEX ($/KW)	943	1120	1683
	Fixed O&M ($/KW-yr)	9.52	24.00	13.20
	Variable O&M ($/MWh)	1.02	12.88	35.80
PV Solar 100 MW, single axis tracking utility scale	CAPEX ($/KW)	1230	1291	1291
	Fixed O&M ($/KW-yr)	19.35	23.00	23.00
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Wind 100 MW, wind Class 6 Onshore	CAPEX ($/KW)	1464	1363	1615
	Fixed O&M ($/KW-yr)	41.79	30.00	25.00
	Variable O&M ($/MWh)	---	---	---
PV Solar + BESS 100 MW + 50 MW, 4-hr Co-located hybrid	CAPEX ($/KW)	1147	2102	1362
	Fixed O&M ($/KW-yr)	---	62.00	43.00
	Variable O&M ($/MWh)	---	---	---
Wind + BESS 100 MW + 50 MW, 4-hr Co-located hybrid	CAPEX ($/KW)	1310	---	1577
	Fixed O&M ($/KW-yr)	---	---	45.00
	Variable O&M ($/MWh)	---	---	---
PV Solar + Wind + BESS 100MW+100MW+50MW, 4-hr Co-located hybrid	CAPEX ($/KW)	1190	---	1463
	Fixed O&M ($/KW-yr)	---	---	68.00
	Variable O&M ($/MWh)	---	---	---

Current Technologies

PUGET SOUND ENERGY

NREL ATB COMPARISON

Questions?

PUGET SOUND ENERGY

Regional transmission

Elizabeth Hossner, PSE

PUGET SOUND ENERGY

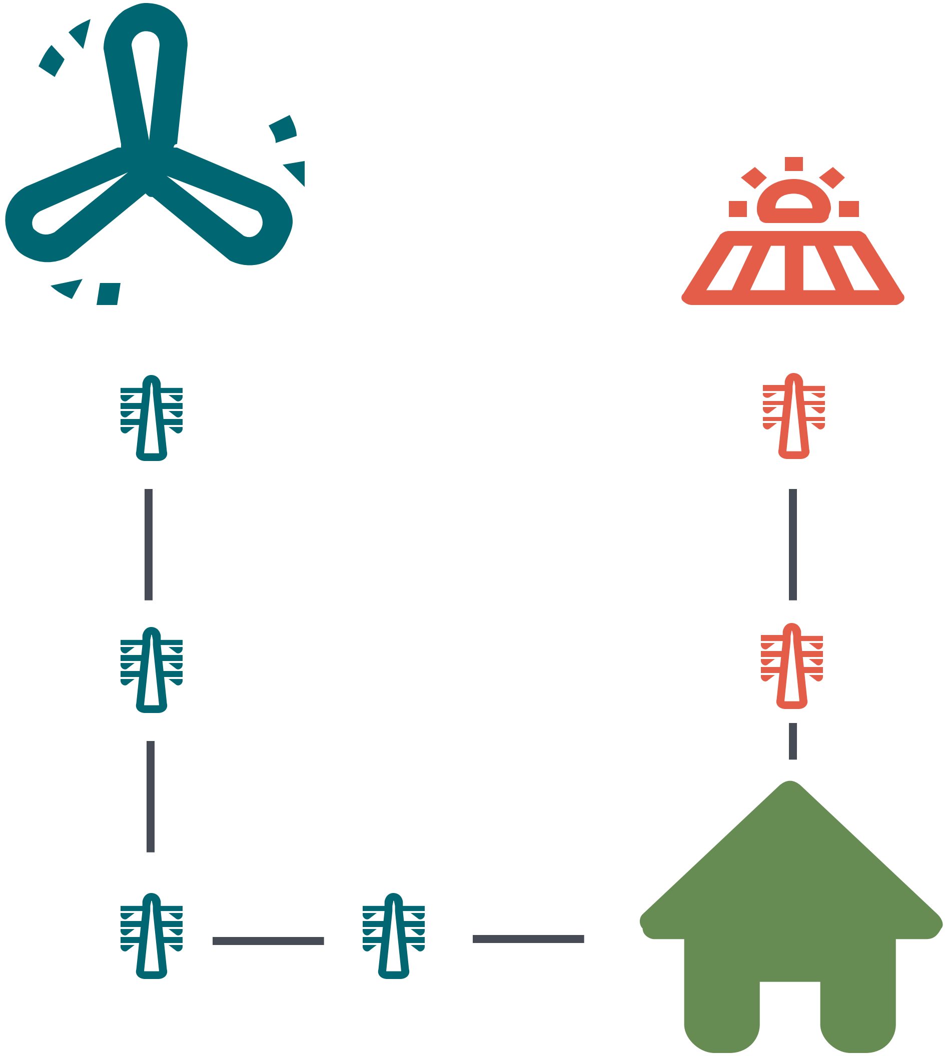
IAP2 Spectrum

	INFORM	CONSULT	INVOLVE	COLLABORATE	EMPOWER
PUBLIC PARTICIPATION GOAL	To provide the public with balanced and objective information to assist them in understanding the problem, alternatives and/or solutions.	To obtain public feedback on analysis, alternatives and/or decision.	To work directly with the public throughout the process to ensure that public concerns and aspirations are consistently understood and considered.	To partner with the public in each aspect of the decision including the development of alternatives and the identification of the preferred solution.	To place final decision-making in the hands of the public.
PROMISE TO THE PUBLIC	We will keep you informed.	We will keep you informed, listen to and acknowledge concerns and aspirations, and provide feedback on how public input influenced the decision.	We will work with you to ensure that your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision.	We will look to you for advice and innovation in formulating solutions and incorporate your advice & recommendations into the decisions to the maximum extent possible.	We will implement what you decide.

INCREASING IMPACT ON THE DECISION

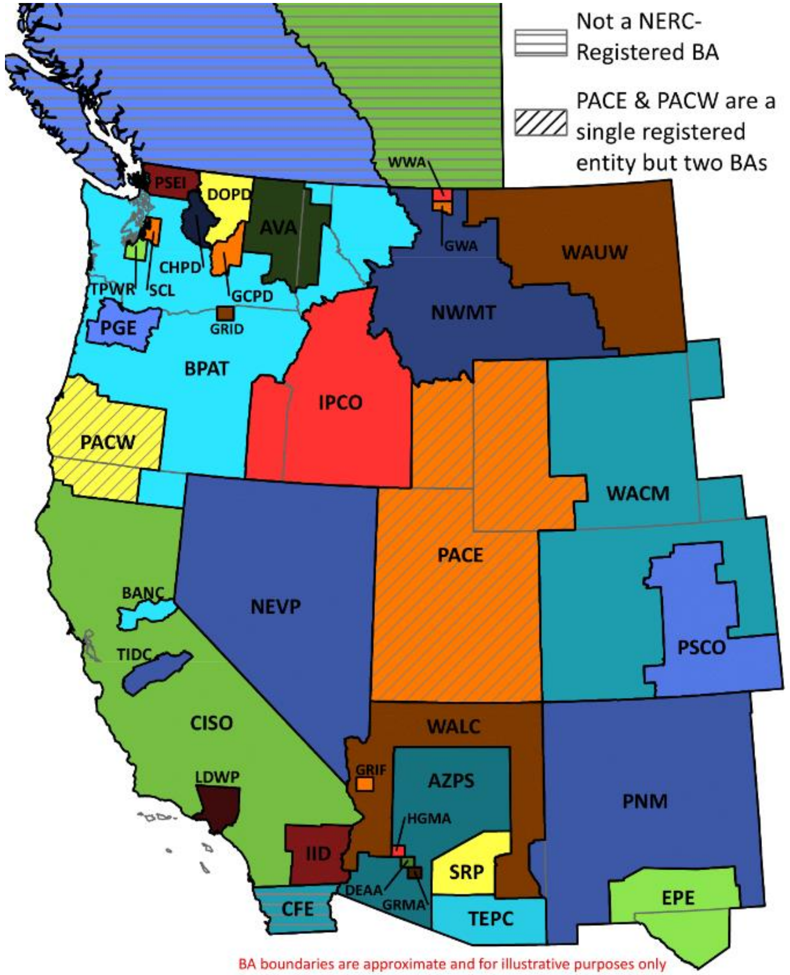
PUGET SOUND ENERGY

How transmission constraints shape power delivery



- PSE uses a capacity expansion model for generation planning
- The generation is optimized to meet PSE loads, peak capacity, and CETA targets
- Transmission constraints can shape what types of generation and amount of power that can be delivered back to PSE
- Cost and capacity are key transmission constraints

Challenge: acquiring transmission capacity for renewable generation

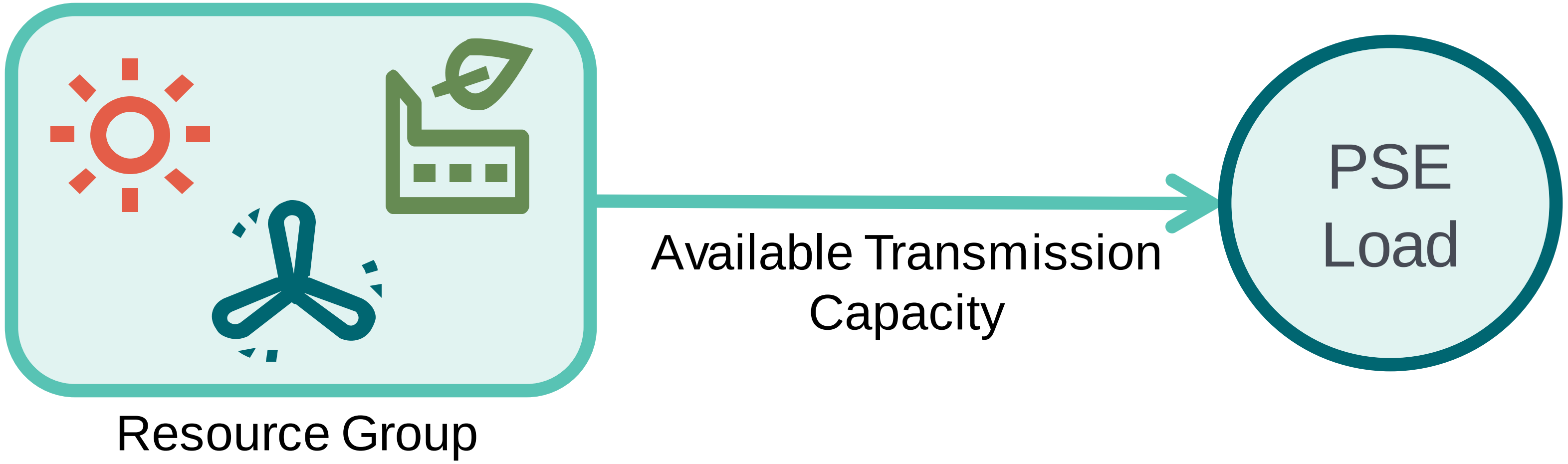


- PSE has a relatively small territory, localized in NW Washington
- Renewable resources are scattered across the Western Electricity Coordinating Council (WECC)
- PSE must work with surrounding balancing authorities to secure transmission across the WECC

PUGET SOUND ENERGY

Modeling transmission constraints

- Created ‘transmission regions’ – similar to the regional transmission zones from the Western Resource Adequacy Program (WRAP)
- These areas have been translated into Resource Groups in the capacity expansion model. This will allow different resources to be aggregated into unique transmission regions sharing a fixed transmission capacity.
- Transmission capacity will be modeled as a build limit for the resource group



What is a reference assumption vs. the preferred portfolio?

- Reference is a starting point assumption for the models
- Once we have established the reference assumptions and portfolio, we will then run various scenarios and sensitivities
- Preferred portfolio is the result of robust Integrated Resource Plan (IRP) analyses developed with input from interested parties, deterministic portfolio, risk, and portfolio benefit analyses

Objective: To discuss the reference assumptions for regional transmission along with capacity and costs, and potential sensitivities to test availability and any costs/benefits

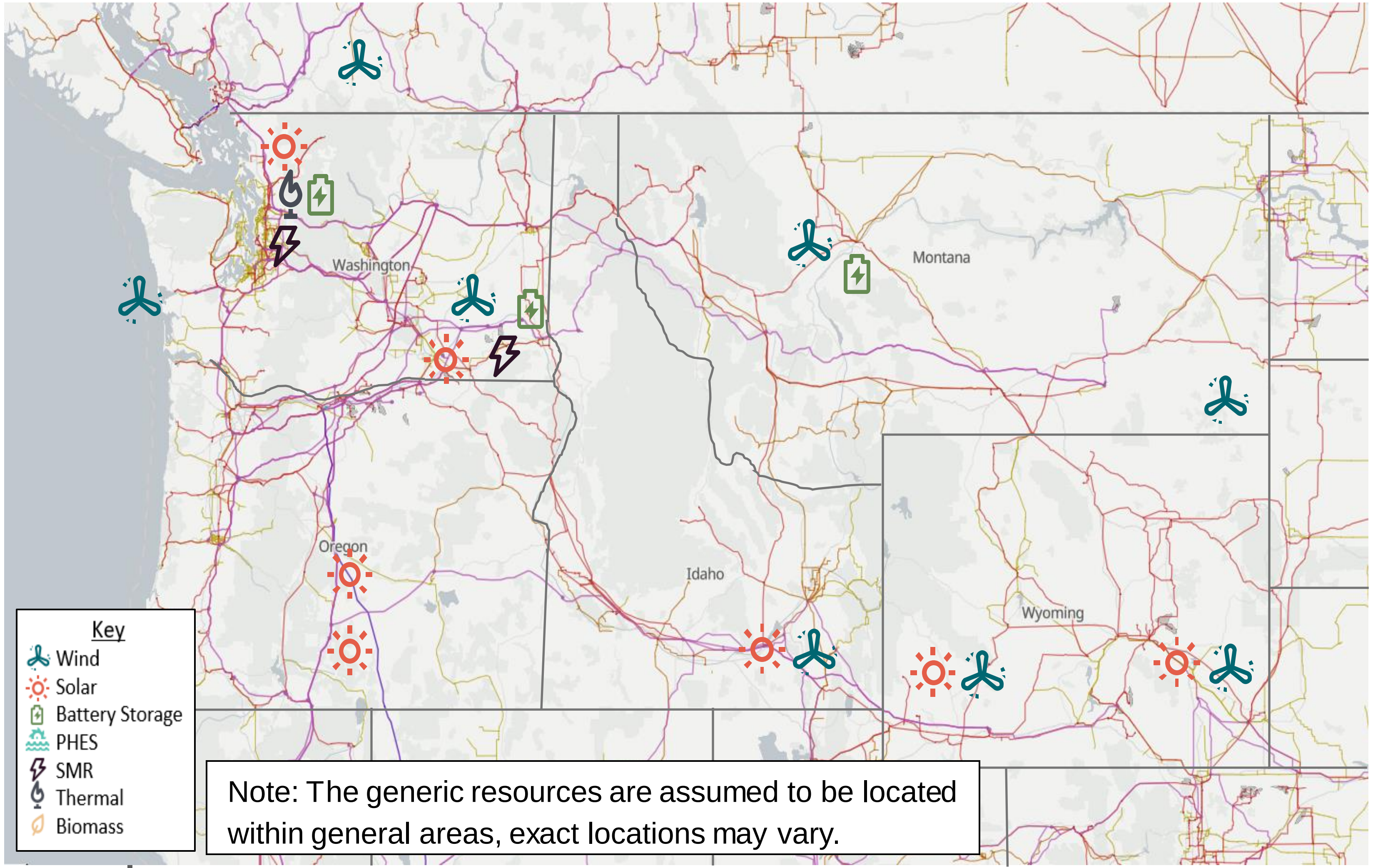
PUGET SOUND ENERGY

Transmission capacity constraints

Jens Nedrud, PSE

Laxman Subedi, PSE

Locating new resources across the region



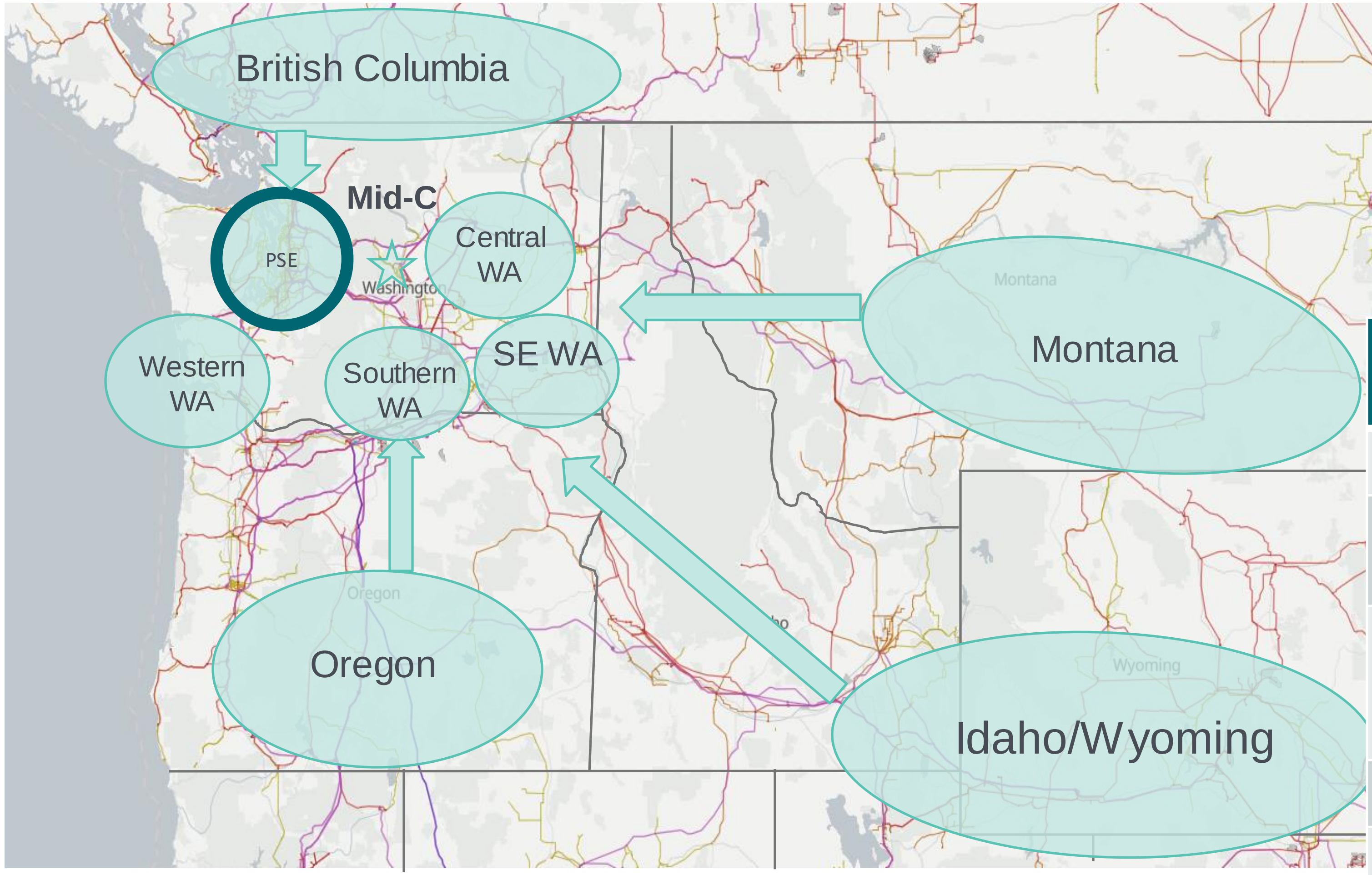
Note: The generic resources are assumed to be located within general areas, exact locations may vary.

Available renewable resources are geographically diverse.

The regional transmission groups are divided into:

- PSE
- Western Washington
- Eastern Washington (Central Washington, Columbia Gorge, and SW Washington regions)
- Central/Southern Oregon
- Montana
- British Columbia
- Idaho & Wyoming

Transmission groups to access Clean Energy Zones



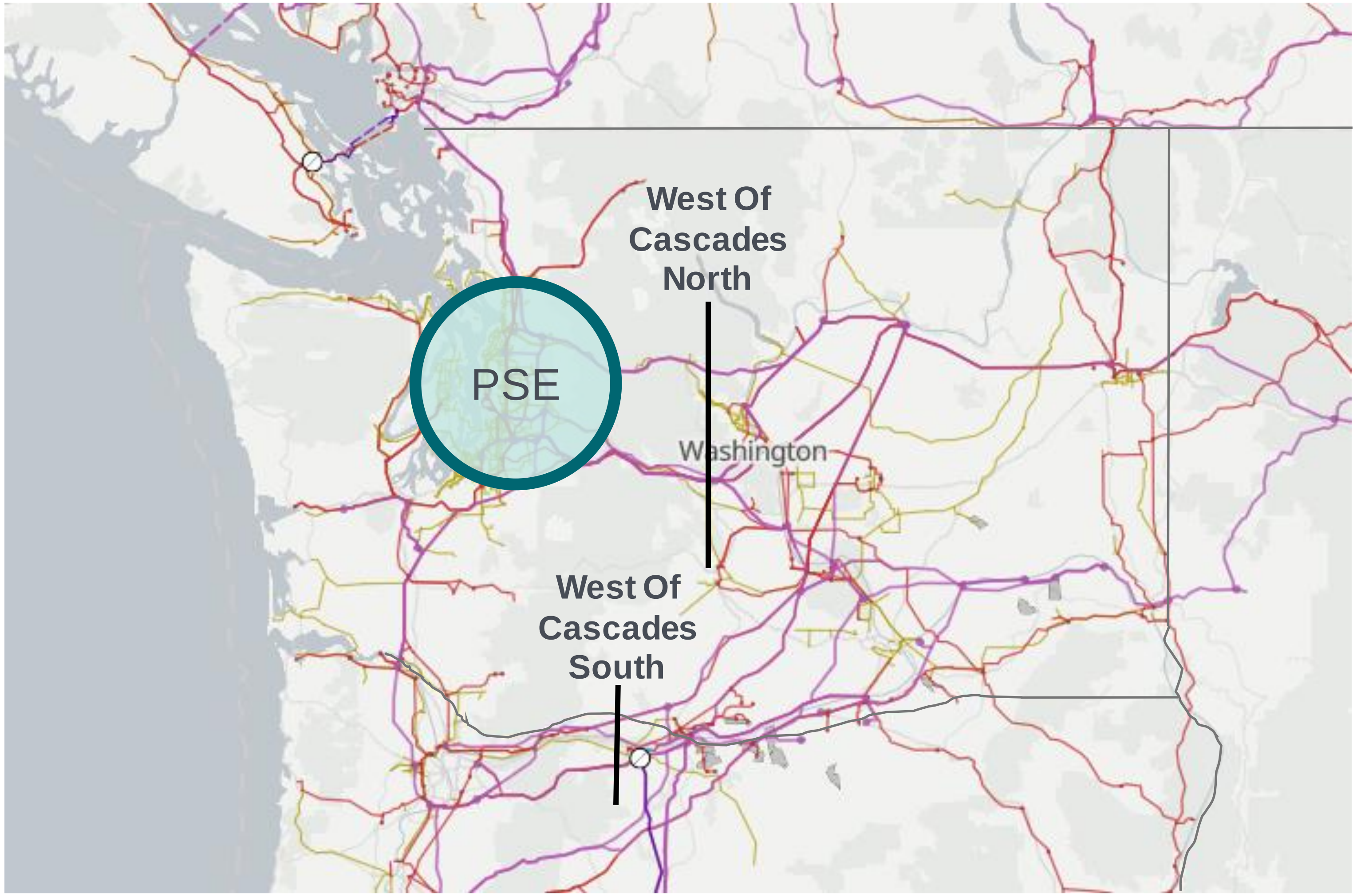
Open Infrastructure Map: https://openinframap.org/#2/26/12

PSE identified 9 regional clean energy zones (CEZ) which align with existing transmission resources and WRAP transmission zones.

- Zone 3 will be modeled in sub-zones

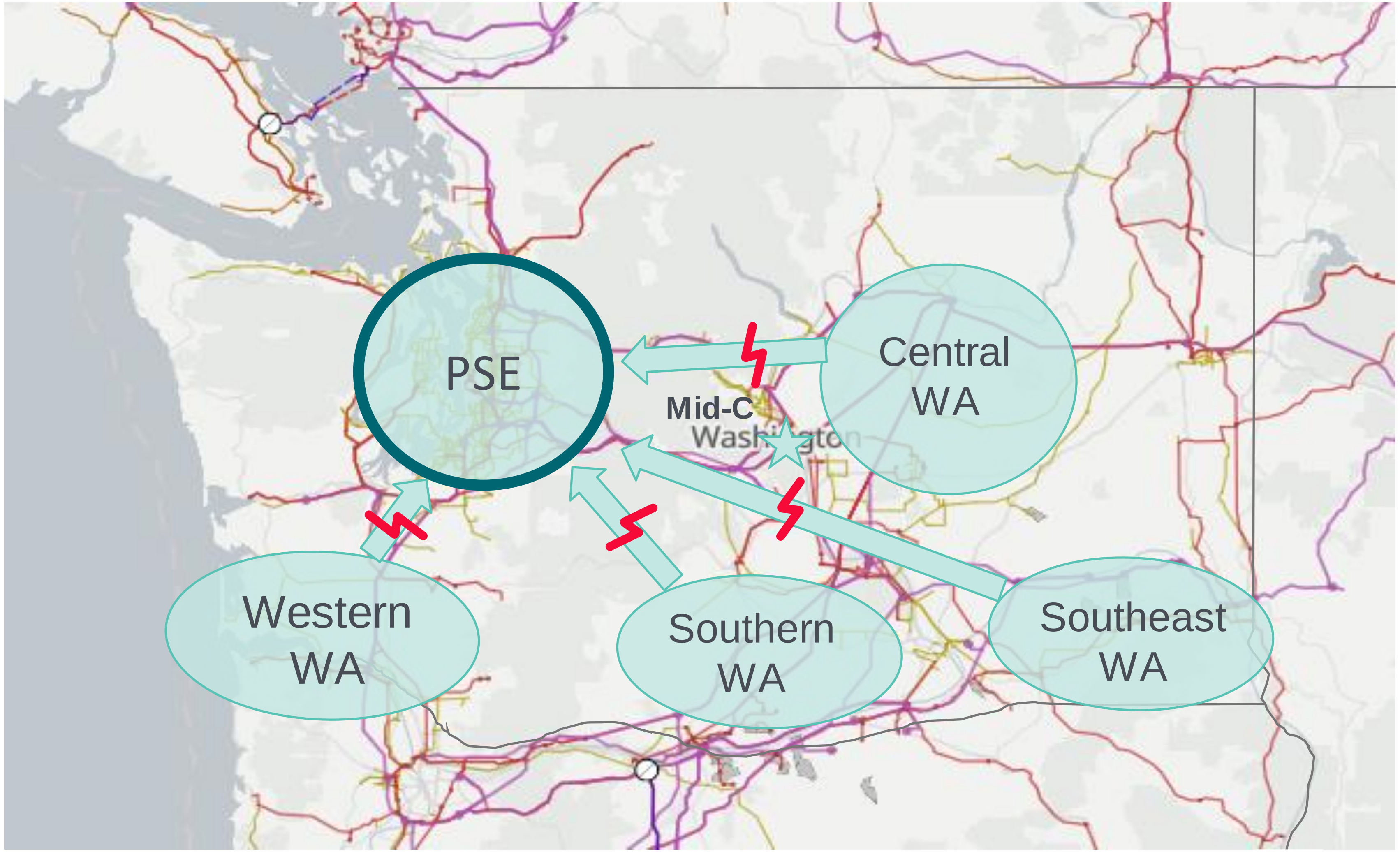
WRAP Transmission Zones		25 IRP Transmission Groups
Zone 1	British Columbia	British Columbia
Zone 2	Western WA, Northwest OR	Western WA, PSE
Zone 3	Eastern WA/OR, SW OR, Northern ID	Central WA, SE WA, Southern WA, Oregon
Zone 4	Montana	Montana
Zone 5	Southern ID	Idaho/Wyoming
Zone 6	Wyoming, Utah	Idaho/Wyoming

PSE relies on BPA to provide regional transmission



- Bonneville Power Administration (BPA) owns and operates the regional transmission system
- Existing BPA paths across the Cascades are fully subscribed
- No long-term firm transmission is available until ~2040

Transmission constraints to CEZs within Washington

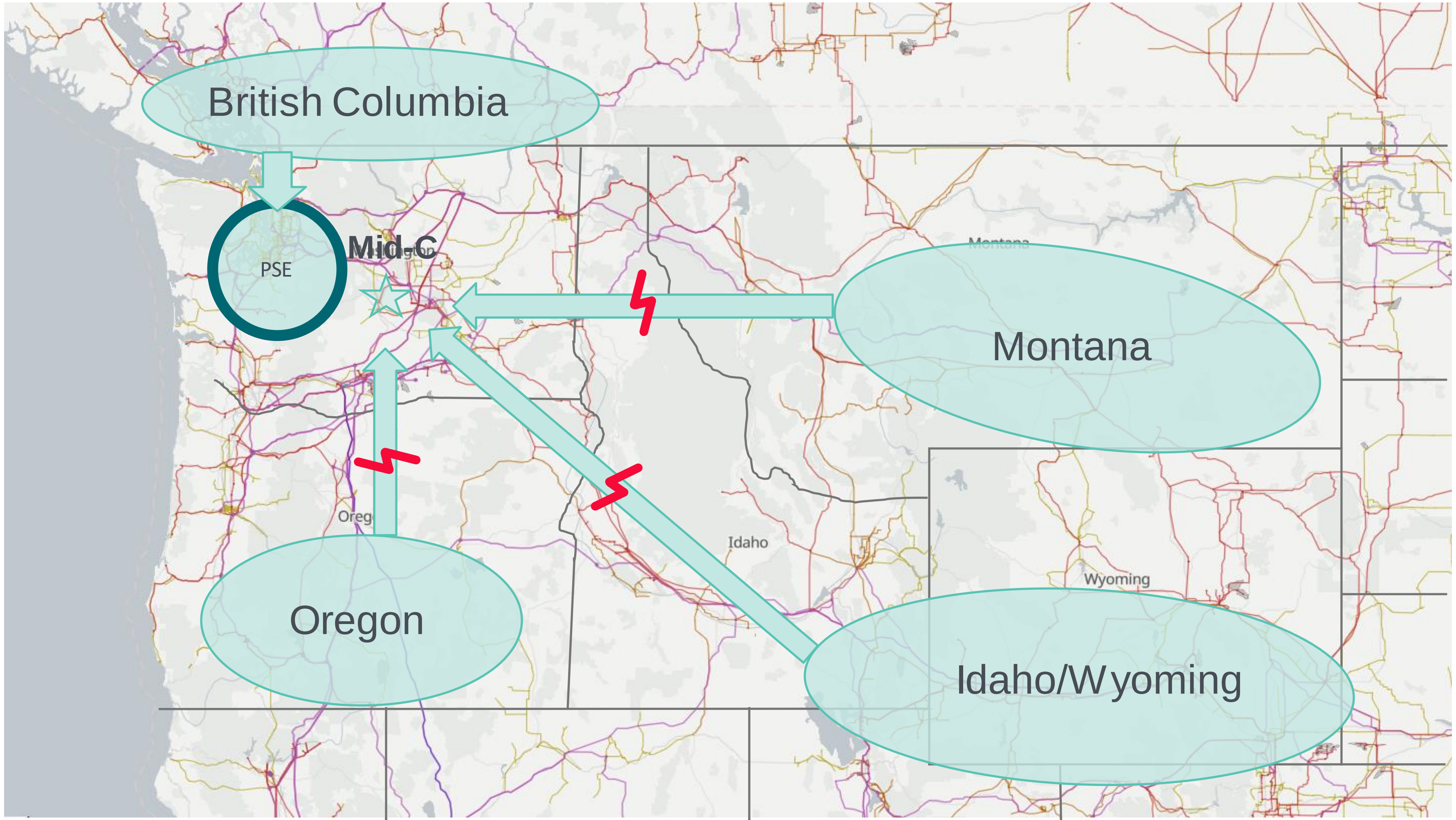


- Transmission within Washington state is constrained.
- PSE's existing rights Southeast Washington and on Mid-C can be utilized to deliver a portion of the resource need

Open Infrastructure Map: https://openinframap.org/#2/26/12

PUGET SOUND ENERGY

Transmission constraints across the region



Open Infrastructure Map: https://openinframap.org/#2/26/12

- Transmission across the region is significantly constrained
- Capacity from outside of Washington cannot be increased without significant transmission builds

PUGET SOUND ENERGY

Regional transmission groups

- Each resource group will contain a mix of generic resources
- The renewable resources will be distinct in each region
- Each renewable resource will be paired with a unique shape for the region, for example, wind in Eastern WA will have a different shape than wind in Montana

	Resource Group Region						
Generic Resources	**PSE Territory***	**Eastern WA**	**Western WA**	**Montana**	**Wyoming**	**Idaho**	**BC**
Wind		x		x	x	x	x
Solar	x	x			x	x	
Peaker (multiple fuels)	x						
Offshore Wind			x				
Nuclear		x	x				
DER Solar/Storage	x						
Storage Short Duration	x	x		x			
Storage Mid Duration	x	x					
Storage Long Duration	x	x					

**Not including the PSE IP Line (Cross Cascades) or Kittitas area transmission which is fully subscribed*

Future transmission capacity has reduced compared to the prior 2023 electric progress report (EPR)

The challenge to effectively access clean energy zones has increased due to limited future transmission capacity.

Cumulative (MW)	2025	2030	2035
Current Total	702	Up to 3,217	Up to 3,567
2023 EPR Total	1,280	5,670	6,670
Delta	-578	-2,453	-3,103
2023 EPR Preferred Portfolio Tx Need	900	3,399	4,496

*Does not include Beaver Creek and colocation opportunities

Discussion: What future transmission capacity assumptions should be included in the “reference” case?

Risk to secure transmission that may be available in the PNW varies with BPA’s cluster study potential being a key factor to consider.

Features	2025	2030	2035
Secured Tx Amount (MW)	548	1,246	1,496
Additional LSR Transmission (MW)	154	644	644
BPA Cluster Study Potential? (MW)	0	Up to 1,125	Up to 1,225
Cumulative Total (MW)	702	Up to 3,217	Up to 3,567

What portion of BPA Cluster study potential requested to PSE should be in the “reference case”?

PUGET SOUND ENERGY

The future transmission capacity from each CEZ to PSE is uncertain

PSE has assessed the status of transmission availability in the PNW and quantified potential new transmission capacity into three timelines:

Features	2025	2030	2035
Cumulative Amount (MW)	702	up to 3,217	up to 3,567
Composition	Contracted Tx	Repurposes Existing Tx + New Tx	New Tx with Longer Lead Times

PSE will model the total as a “reference” case and then model the following sensitivities:

- (A) PSE Self-Build transmission by 2035
- (B) BPA 2023 Cluster Study builds by 2040
- (A) and (B) combined

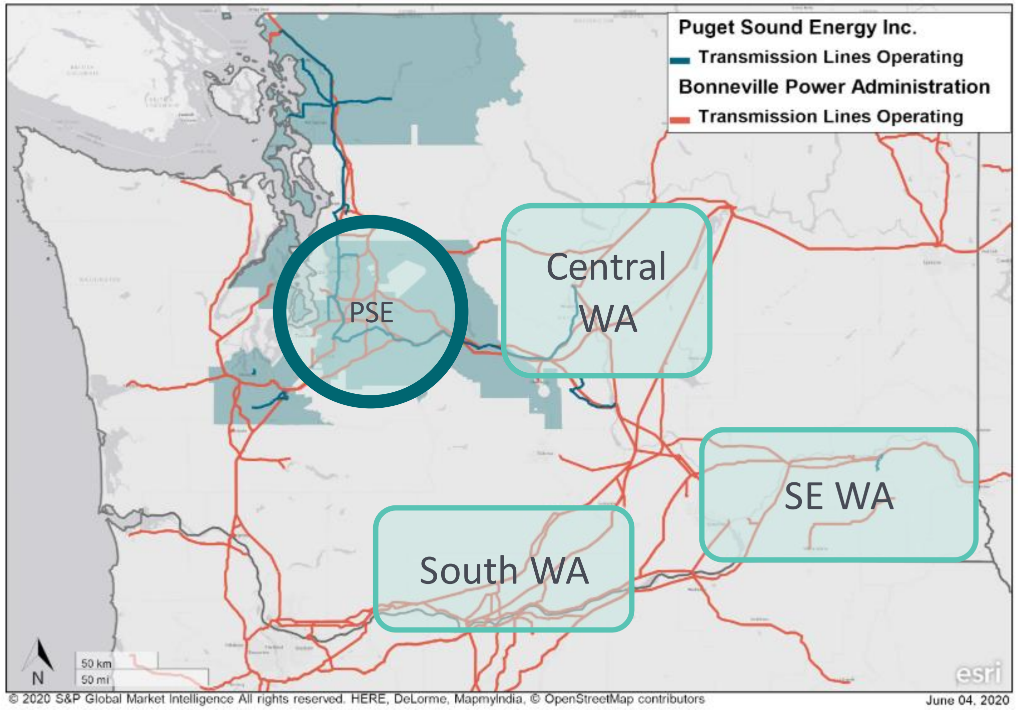
*colors represent increasing risk of uncertainty from green to red.

PUGET SOUND ENERGY

Transmission capacity* – Eastern/Central/Southern Washington

- Incremental transmission will be available for Lower Snake River wind farm expansion
  - 2026: 154 MW, 2028: 490 MW
- 1,400 MW Mid-C transmission historically reserved for Market Purchases
  - PSE's Mid-C transmission available for new resources connecting to or delivering to Mid-C
    - 1,000 MW of new resources before 2035
- Up to 1,125 MW of BPA transmission from prior cluster studies potentially available in these CEZs before 2030

*Tx capacity will model new resource build limit for each CEZ

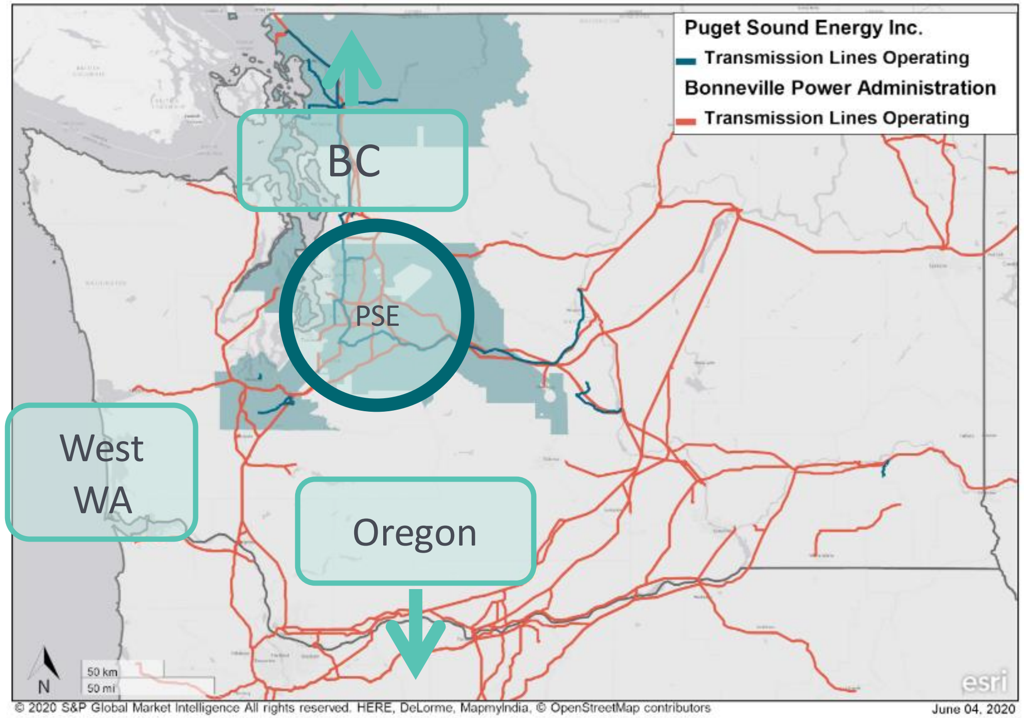


Total added transmission (MW)			
Region	2025	2030	2035
SE WA	154	1,069	1,069
Central WA	250	1,150	1,400
Southern WA	-	300	300

Transmission capacity – Oregon/Western Washington/British Columbia

- Oregon
  - Up to 300 MW of California Oregon Intertie (COI) transmission potentially available before 2030
  - Up to 100 MW of BPA transmission from prior cluster studies potentially available before 2035
- Western WA
  - 100 MW of BPA transmission for PSE's TransAlta PPA could be repurposed after 2025
- British Columbia
  - 250 MW of PSE transmission under contract from BC-US Border

*Tx capacity will model new resource build limit

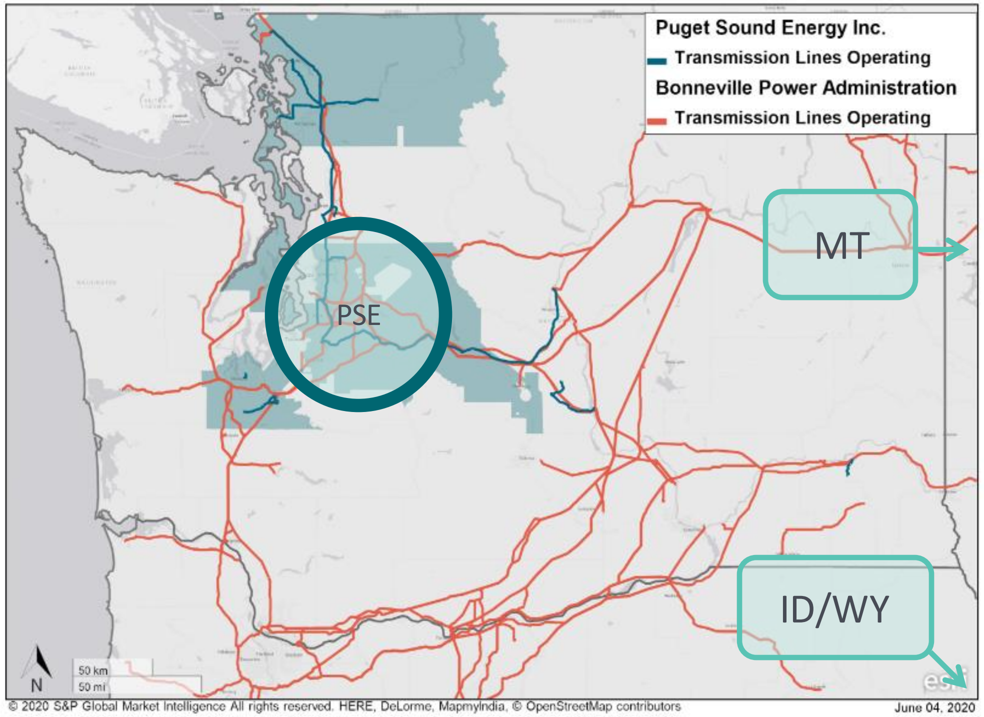


Total added transmission (MW)			
Region	2025	2030	2035
Oregon	-	200	400
Western WA	100	100	100
BC	250	250	250

Transmission capacity – Montana/Idaho & Wyoming

- Montana
  - Repurpose 363 MW of transmission available from Colstrip units 3 and 4 after 2025.
    - Beaver Creek wind farm: 315 MW
    - Remaining capacity: 48 MW
  - Potential to optimize 713 MW of contracted transmission with additional wind, solar, and/or battery resources
- Idaho & Wyoming
  - PSE exploring options to secure up to 400 MW of transmission from Eastern Wyoming on Gateway West and Boardman-to-Hemingway (B2H) projects

*Tx capacity will model new resource build limit



Total added transmission (MW)			
Region	**2025**	**2030**	**2035**
Montana	**48**	**48**	**48**
ID/WY	**-**	**-**	**-**

PUGET SOUND ENERGY

Transmission capacity – summary

Renewable Energy Area	Added Transmission (MW)		
	2025	2030	2035
SE Washington	154	1,069	1,069
Central Washington	250	1,150	1,400
Southern Washington/Gorge	0	300	300
Oregon	0	300	400
Western Washington	0	100	100
British Columbia	250	250	250
Montana	48	48	48
Idaho / Wyoming	0	0	0
TOTAL	702	3,217	3,567

*Tx capacity will model new resource build limit

PUGET SOUND ENERGY

Transmission Wheeling cost summary

Resource Group Region	Cost Type	Total Cost ($/kW-yr)* Wind	Total Cost ($/kW-yr)* Solar	Loss (%)
SE Washington	Tariff	32.6	29.04	2.09
Central Washington	Tariff	32.6	29.04	2.09
Western Washington	Tariff	32.6	29.04	2.09
Southern Washington/Gorge	Tariff	32.6	29.04	2.09
Central/Southern Oregon	Tariff	32.6	29.04	2.09
Montana	Tariff	55.9	52.36	2.7 (CTS) 2.09 (BPA)
ID / WY	Tariff	68.1	67	4.3 (PAC) 2.09 (BPA)
Canada (BC Hydro)	Tariff	102.6	-	6.28

* BPA annual rate increase modeled using an inflation rate of 4.75% vs past 3% projections

Sources:
https://www.bpa.gov/energy-and-services/rate-and-tariff-proceedings/transmission-rates
https://www.oasis.oati.com/woa/docs/PSEI/PSEIdocs/PSE_Current_OATT_Effective_09.08.2023.pdf
https://www.oasis.oati.com/woa/docs/PPW/PPWdocs/Rate_Table_20230601.pdf
https://www.bchydro.com/toolbar/about/strategies-plans-regulatory/tariffs-terms-conditions/oatt.html

* Total cost includes long term firm point-to-point transmission service cost plus applicable integration costs.

Co-location options

- PSE is considering co-location of new resources (solar, storage) at existing resource sites to optimize its existing transmission capacity
- PSE will continue to evaluate the feasibility and timing of these options

Resource Group Region	
Eastern Washington	Lower Snake River co-location (including expansion)
	Hopkins Ridge co-location
Central Washington	Wild Horse co-location
Southern Washington/Gorge	Goldendale co-location

PUGET SOUND ENERGY

BPA 2023 cluster study summary

- BPA's 2023 study included 16,000 MW of transmission service requests (TSRs)
- 5,000 MW of transmission capacity requested to PSE's system. PSE had 400 MW of TSRs in the study from B2H project to PSE system and MIDC
- Study identified multiple significant transmission upgrades on BPA system to acquire new transmission to PSE's system
- One critical transmission upgrade for the Puget Sound region ranged in cost from $0.9B to $1.3B with a 2038 timeline and utilized an incremental rate structure.
- BPA did not offer long-term conditional firm service (CFS)
- No new transmission will be available into PSE system until 2038 at the earliest

PSE PUGET SOUND ENERGY

Transmission capacity – BPA 2023 cluster study sensitivity

- PSE will model a build limit sensitivity for 2040 using the latest BPA cluster study results

Renewable Energy Zone	Added Transmission (MW) 2040
SE Washington	150
Central Washington	500
Southern Washington/Gorge	3,116
Oregon	1,120
Western Washington	0
British Columbia	N/A
Montana	100
Idaho / Wyoming	N/A
TOTAL	4,986

PUGET SOUND ENERGY

Transmission next steps and BPA backstop options

PSE is exploring multiple options to increase transmission capacity from renewable energy areas to PSE load

Cross-Cascades capacity need identified in the latest transmission plan (2023 PSE Plan*)

- 2,000 MW need in 2030
- 3,000 MW need by 2035
- Expect the need to increase

BPA Backstop

- Working with BPA on backstop options for specific identified projects
- Interest across the West of Cascades North flowgate and separate access to Montana.
- Additional BPA capacity to the Puget sound area requires $0.9-1.3B in new transmission and will use some form of "incremental" BPA transmission cost vs. a rolled in rate.

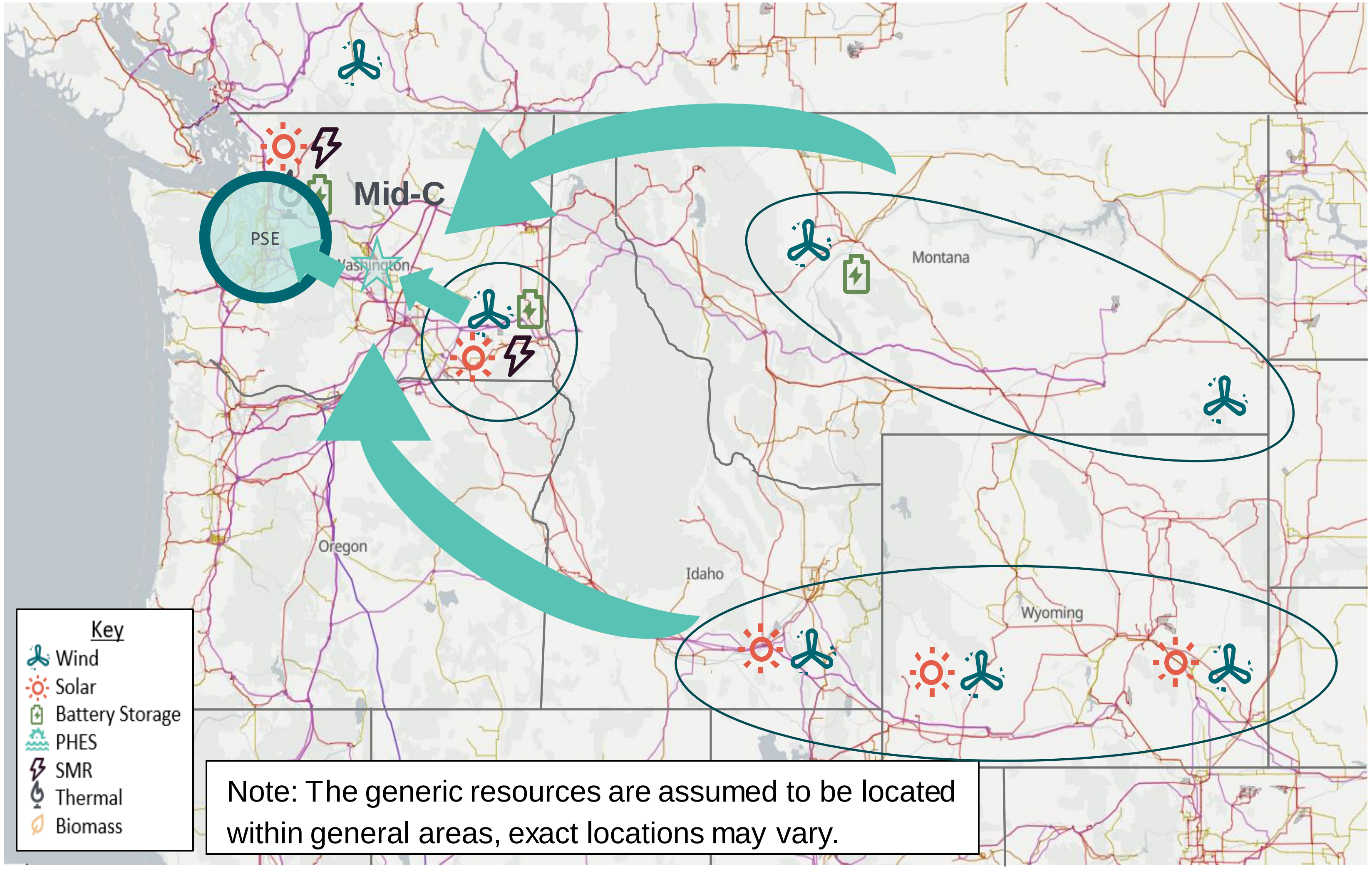
Self-build

- Self-build options to develop transmission across the Cascades and to other clean energy zones in MT, ID/WY, etc.

*2023 PSE Plan can be found at https://www.oasis.oati.com/woa/docs/PSEI/PSEIdocs/PSE_Plan_2023_Final.pdf

PSE PUGET SOUND ENERGY

Transmission expansion to enable clean energy delivery



Note: The generic resources are assumed to be located within general areas, exact locations may vary.

- Transmission capacity to deliver Clean Energy Zones (CEZ) to PSE's service territory will require transmission investment across multiple segments
- All capacity must flow across the Cascades parallel to the West of Cascades North (WOCN) path

Discussion – regional transmission constraints

- Given the constraints on the regional transmission for new resources, PSE will explore several options:
  - Co-location of resources into existing locations to optimize transmission
  - BPA solution in 2040
  - PSE self-build solution
  - Both BPA and PSE solution

Next steps

Sophie Glass, Triangle Associates

Upcoming activities

Date	Activity
April 1, 2024	Feedback form for March 25 RPAG meeting closes
April 17, 2024	RPAG meeting: Conservation potential assessment results, demand response programs, electric vehicle forecast

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Public comment opportunity

Please raise your “hand” if you would like to provide comment.

PUGET SOUND ENERGY

Thanks for joining us!

Appendix

Acronyms

Acronym	Meaning
AA	Advanced adiabatic
ARES	Advanced rail energy storage
BEPS	Building emission performance standard
BESS	Battery energy storage system
BPA	Bonneville Power Administration
BWR	Boiling water reactor
CAES	Compressed air energy storage
CCA	Climate Commitment Act
CCS	Carbon capture and sequestration
CEIP	Clean Energy Implementation Plan
CETA	Clean Energy Transformation Act
CFS	Conditional firm service
CHP	Combined heat and power
CO2	Carbon dioxide
COI	California Oregon Intertie
IAP2	International Association of Public Participation

Acronyms

Acronym	Meaning
IRA	Inflation Reduction Act
IRP	Integrated Resource Plan
kW	Kilowatt
kWh	Kilowatt hour
LAES	Liquid air energy storage
LCOE	Levelized cost of energy
LDES	Long duration energy storage
Li	Lithium ion
LFP	Lithium ferrous phosphate
LWR	Light water reactor
MES	Mechanical energy storage
MW	Megawatt
Mwe	Megawatt electric
MWh	Megawatt hour
NMC	Nickel-manganese-cobalt oxide
NREL ATB	National Renewable Energy Laboratory Annual Technology Baseline

Acronyms

Acronym	Meaning
O&M	Operations and maintainence
ONS	Onshore substation
ORC	organic rankine cycle
OSS	Offshore substation
PG&E	Pacific Gas and Electric
PHES	Pumped hydroelectric storage
PRM	Planning reserve margin
PUD	Public utility district
PV	Photovoltaic (solar panels)
PWR	Pressurized water reactor
RA	Resource adequacy
RPAG	Resource Planning Advisory Group
SMR	Small modular reactor
TIC	Total installed cost
TRL	Technology readiness level
TSR	Transmission service request

Mechanical energy storage (MES)

Technology	Geological Requirements	Technology / Subcategory Maturity	Scalability	Deployment
Mechanical energy storage	Specific to site and technology design criteria	TRL 8 **Liquid air energy storage (LAES)**	5 MW to 200 MW+	<u>Demonstration project</u>: Commercial 5 MW 3-hours <u>Under construction</u>: Carrington 50 MW 6-hours in Manchester, UK 200 MW 12.5-hours in Yorkshire, UK
		TRL 6 to 9 **Gravity-based rail, block or piston**		<u>Under construction</u>: 5 MW 15-min Advanced Rail Energy Storage (ARES) in Nevada, USA 25 MW 4-hours Energy Vault

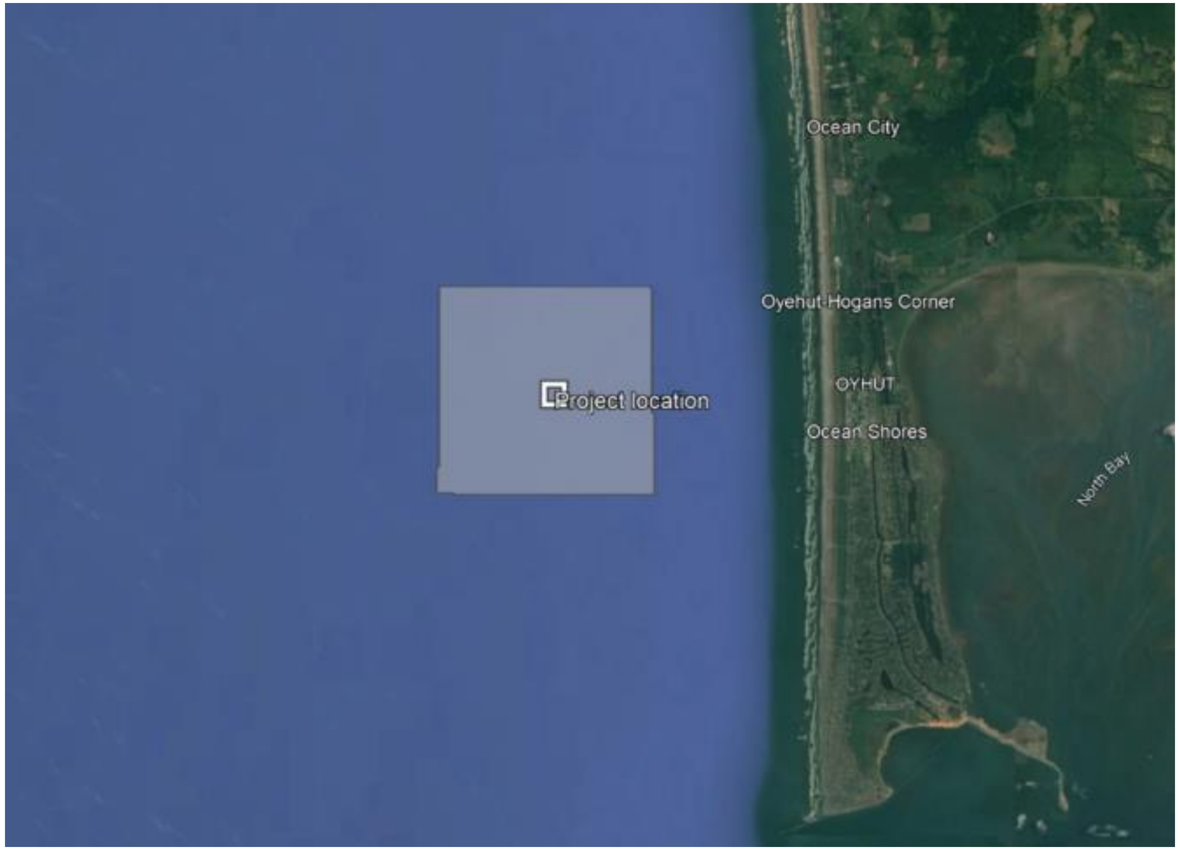
PUGET SOUND ENERGY

LDES iron-air battery – comparison to 2023 NREL ATB

Type	Characteristic	2023 PSE IRP input	2023 NREL ATB	2025 PSE IRP input*
Costs	CAPEX ($/KW)	---	---	2013
	Fixed O&M ($/KW-yr)	---	---	18.00
	Variable O&M ($/MWh)	---	---	--

* This is the first year that the Iron-Air battery has been considered by PSE for the IRP

Offshore wind – Grays Harbor



- The location of the project is 5 - 6km offshore at 47°.015, - 124°.257
- 100MW corresponds to an area of 25km^2 or 6,200 acres, shown opposite
- from 20-40m
- This indicates a fixed monopile foundation concept can be considered
- Water depths in the region vary