"Closed-loop" Pumped Storage Hydropower

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Long-duration bulk storage

Pumped storage is only proven, cost-effective storage technology at scale

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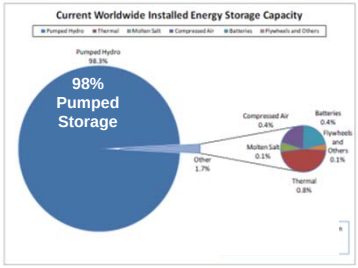
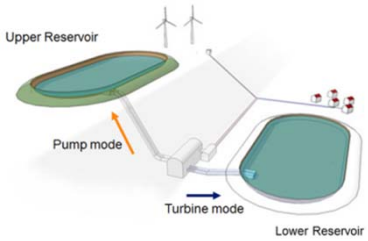
- **Pumped storage** is the only **proven**, **cost-effective** storage at **scale**
- Consists of pumping or generating by moving energy in the form of water through a powerhouse between an upper and lower reservoir
- **Pumped storage is prolific** in the **US** – there are **39 pumped storage plants** in operation with a total installed capacity of about **22,000 MW; however, over 2 decades since last built in US**
- **Globally**, there is nearly **131,000 MW** of pumped storage capacity currently in operation; **currently building all over world but US**
- **Batteries** still very expensive, uncertainty viability in replacing thermal plants, don't last nearly as long and come with mining/toxic waste issues

Current Worldwide Installed Energy Storage Facility Capacity





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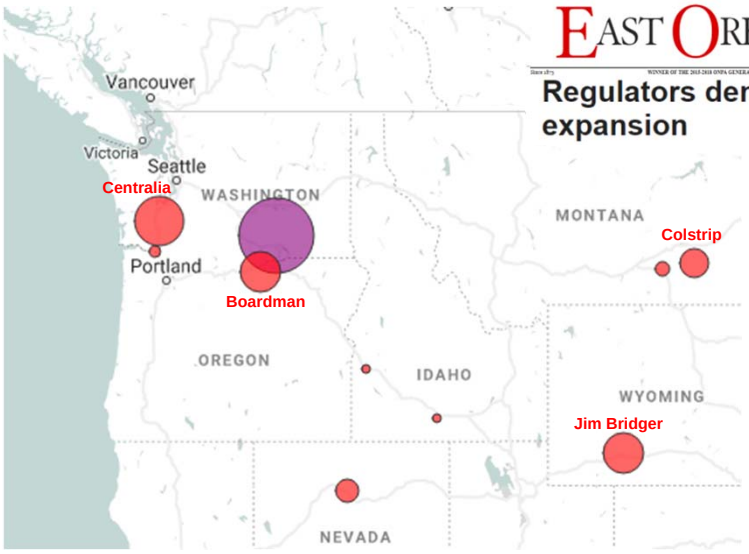
Over 6 GWs of spinning mass/inertia slated for retirement & very difficult (if not impossible) to build new gas-fired plants



EAST OREGONIAN
OCTOBER 10, 2018

Regulators deny gas plant expansion

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Utility view of renewable's capacity contribution

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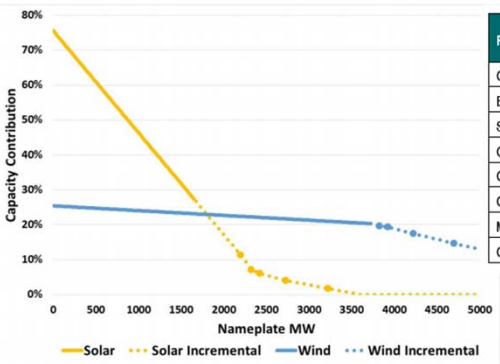
Capacity Contribution vs. System Capacity by Technology

PACIFICORP



Effective Load Carrying Capability (ELCC)

PSE PUGET SOUND ENERGY

Resource	Peak Capacity Credit Based on 5% LOLP
Generic gas-fired generation	100%
Existing Wind	11%
Skookumchuck (DNV GL data[4])	40%
Generic Montana Wind (DNV-GL data)	49%
Generic Washington Wind (DNV-GL data)	16%
Generic Offshore Washington Wind (DNV-GL dat	51%
Market Reliance	99%
Generic Washington Solar	0%

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California's "Duck Curve" – negative impacts (and opportunities) for the Pacific Northwest?

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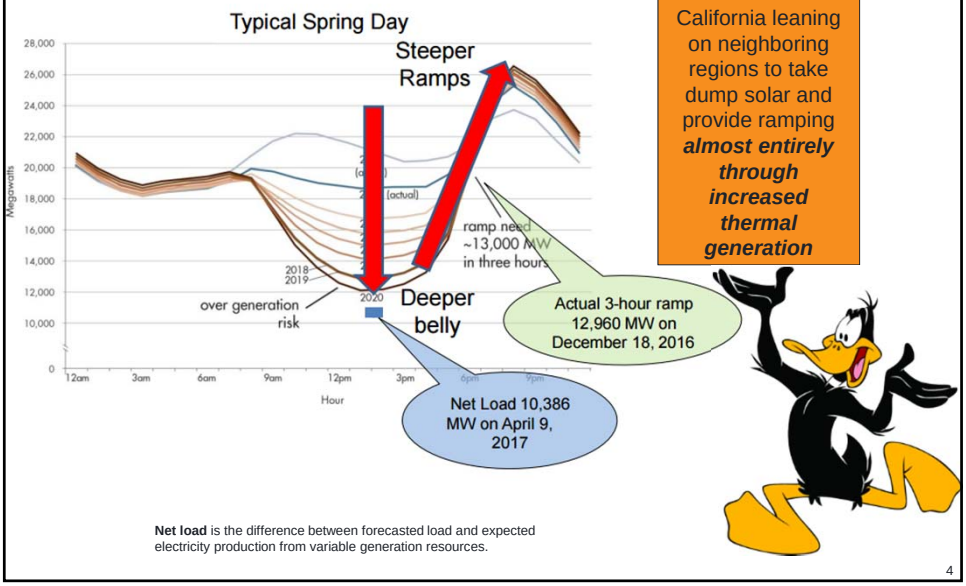

Net load is the difference between forecasted load and expected electricity production from variable generation resources.

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Regionalization – Western EIM being used to help balance renewables, or at least the story goes…

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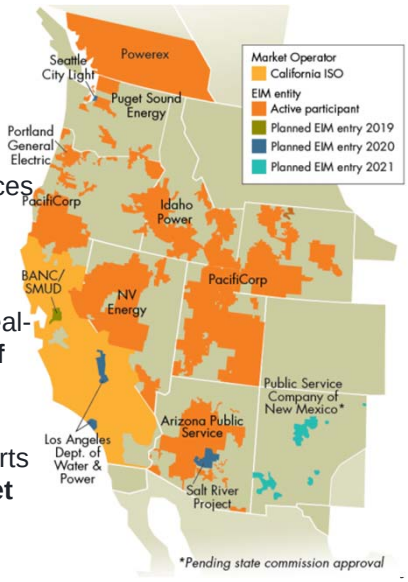
- Real-Time 5 and 15-minute market
- Reduces amount of costly reserves; makes more efficient use of regional transmission system
- Export daily California solar oversupply; can access out-of-state peaking resources for late afternoon/early evening ramp (**currently primarily natural gas**)
- However, only a **small portion** of total EIM system transactions are made in real-time; **benefits current largely result of "free" transmission**
- CA SB350 regionalization/governance language sunsets January 1, 2019; efforts underway to **extend Day-Ahead market to EIM entities**; **remove CA-ISO import/export fees?**



Success of EIM – will participants bring enough "beer to the party" for a robust market?

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Pumped storage strategically located in grid for new carbon-free flexible capacity

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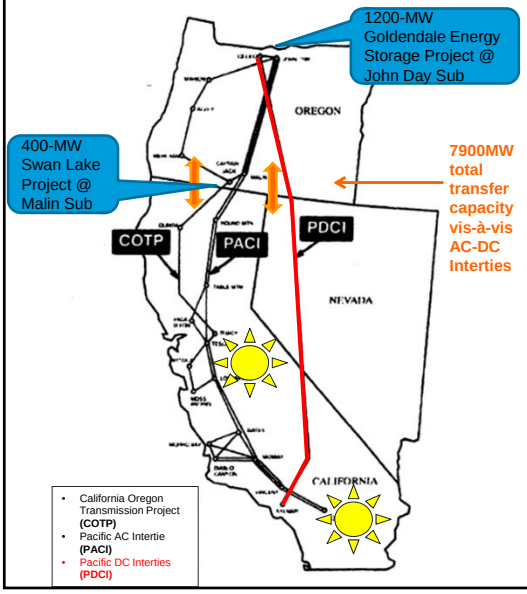

- Viable/constructable "closed-loop" projects interconnecting into existing high-voltage transmission that leverages major import/export path to California (i.e. AC & DC Interties)
- Proven storage solution strategically located in grid to support regional decarbonization goals affordably and reliably
- Projects support continued history of beneficial regional bulk power exchanges between California and the Pacific Northwest evolving from seasonal to daily
- Hundreds of millions of dollars in annual potential cost-saving/ revenue regionally to grid based on E3 modeling; over 6000 jobs during multi-year construction period

400-MW “closed-loop” Swan Lake Pumped Storage Project in southern Oregon

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- Mature design prepared by Stantec (formerly MWH) & EDF-CIH
  - 2,414 active storage (3M cubic meters)
  - 1,674 feet of head (510 m)
  - 3 x 134MW GE pump-turbine/generator units
  - **3556 MWh** energy storage
  - **9 Hours** of duration
  - Plant efficiency 78%
- Achievable in-service date **2024/2025**
- License to construct expected in April 2019 from FERC
- Interconnection SIS in-process with PacifiCorp at 500-kV Malin Substation; de minimum Affect System cost at COI (i.e. ~$2M)
- Stantec Opinion of Probable Project Costs $882M - $1B

1200-MW “closed-loop” Goldendale Energy Storage Project in eastern Washington

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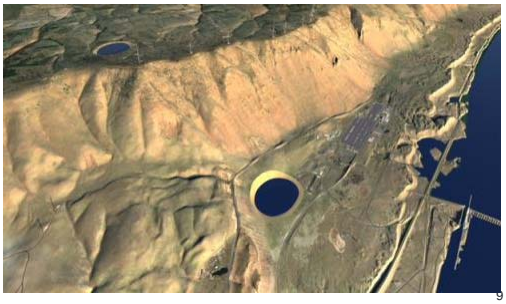
- Conceptual Study prepared by HDR
  - 11,800 active storage (14,5M cubic meters)
  - 2,360 feet of head (719 m)
  - 3 x 400MW pump-turbine/generator units)
  - **25,506 MWh** energy storage
  - **20 Hours** of duration
  - Plant efficiency 89.7%
- FERC Preliminary Permit issued March 8, 2018
- Achievable in-service date 2027/2028
- Interconnection Feasibility Study performed by Bonneville Power Administration at 500-kV John Day Substation; cost $11M
- HDR Opinion of Probable Construction Cost $2B - $2.5B



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Good utilities are starting to model pumped storage in their future planning (e.g. PGE)

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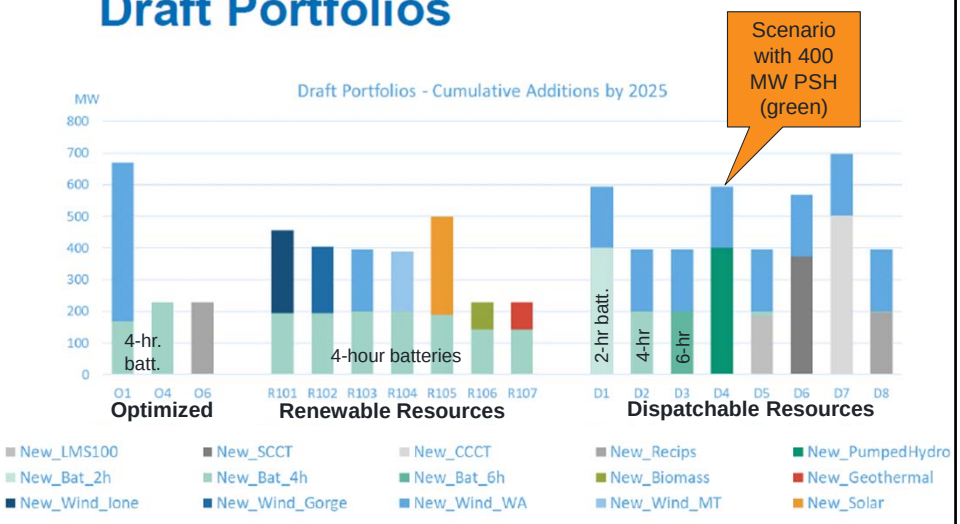
Draft Portfolios



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Consequence : The battle for flexibility

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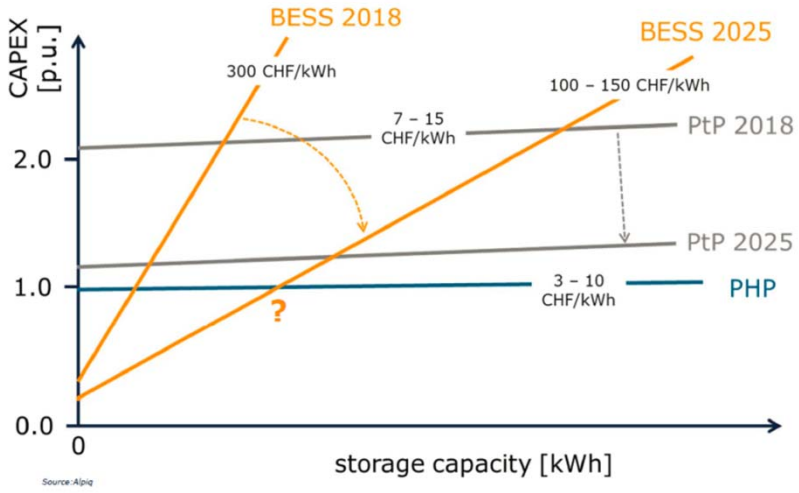
P&S vs other solutions



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Economic modeling needed for procurement/ commercialization of new pumped storage

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- Carbon-free flexibility/storage will be critical for higher penetrations of renewables and reliability
- However, benefits storage not adequately valued in fragmented, deregulated markets and IRP processes
- Additionally, IRPs do not expressly model or **address market prices that can result from a tight capacity market** (WUTC's concern on PSE's 2017 IRP in acknowledgement letter)
  - Game of "capacity chicken" going on in PNW with building new capacity
  - Everybody knows there is a potential problem but nobody wants to own it
- Bottom line, **need adequate economic modeling tools** at the granular level necessary to show full value of storage both as generation and transmission for regulatory approval/cost-recovery to procure/commercialize
- Additionally, **regulators need to encourage/incentivize** utilities for **upfront capital intensive, long-lead time projects** such as pumped storage hydropower

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