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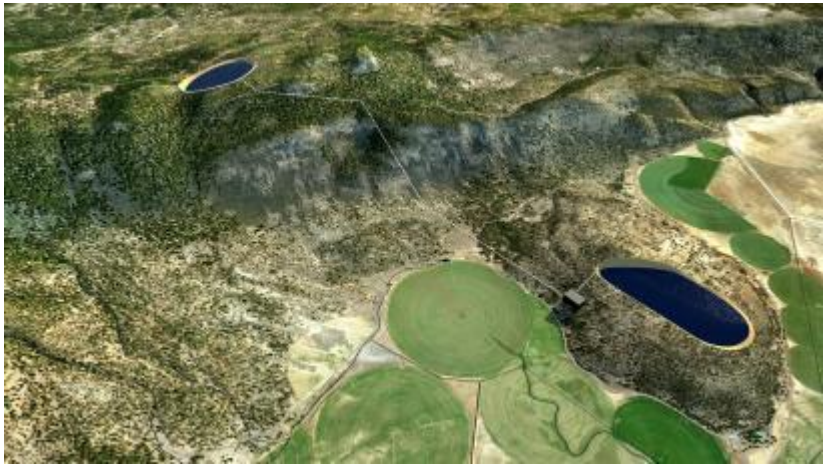
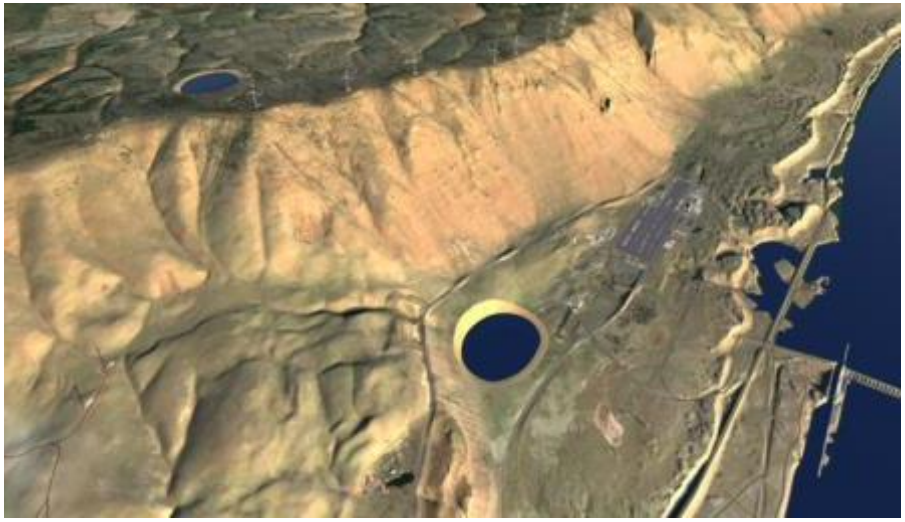
Pumped storage: long-duration bulk storage





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

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

National Grid – one of the world's largest investor-owned energy utilities

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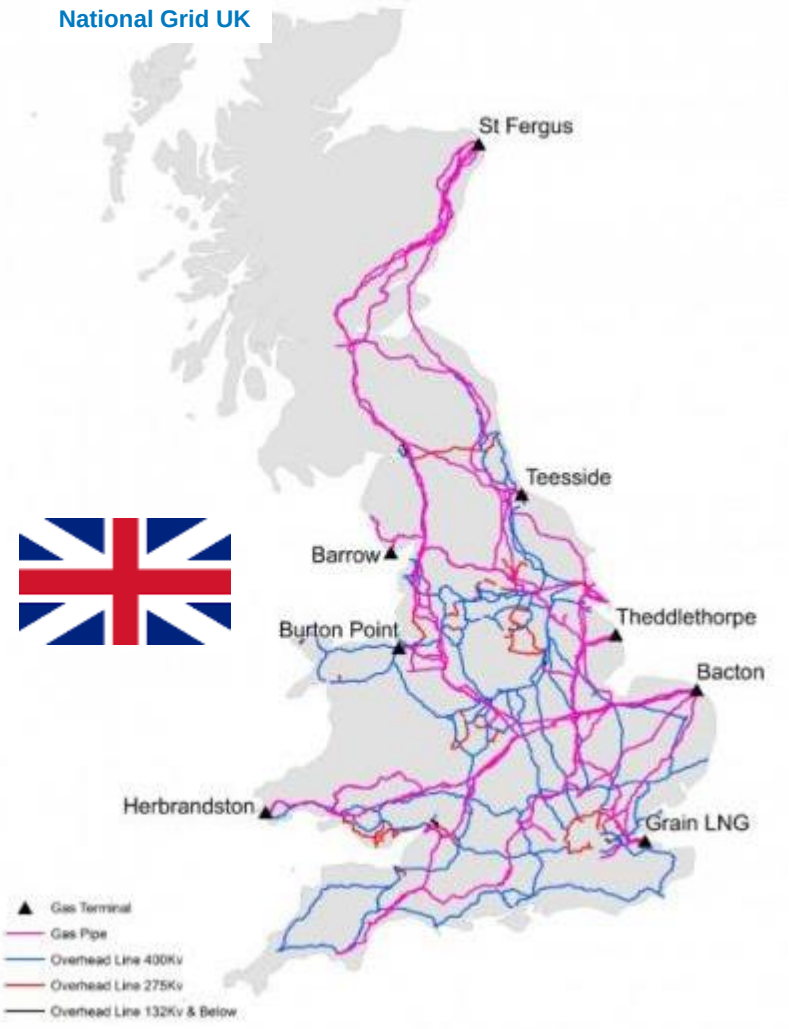
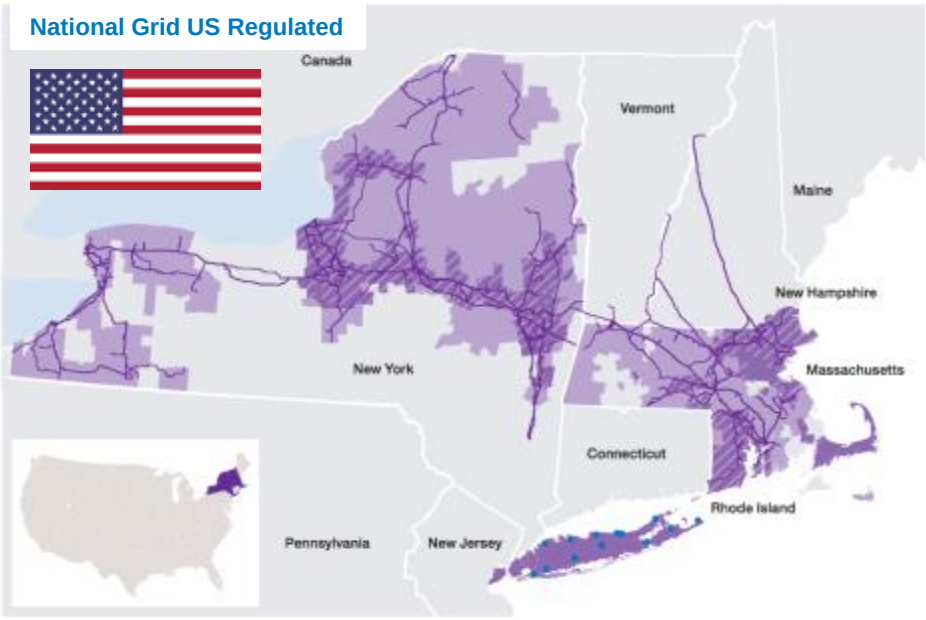
National Grid UK



National Grid US Regulated

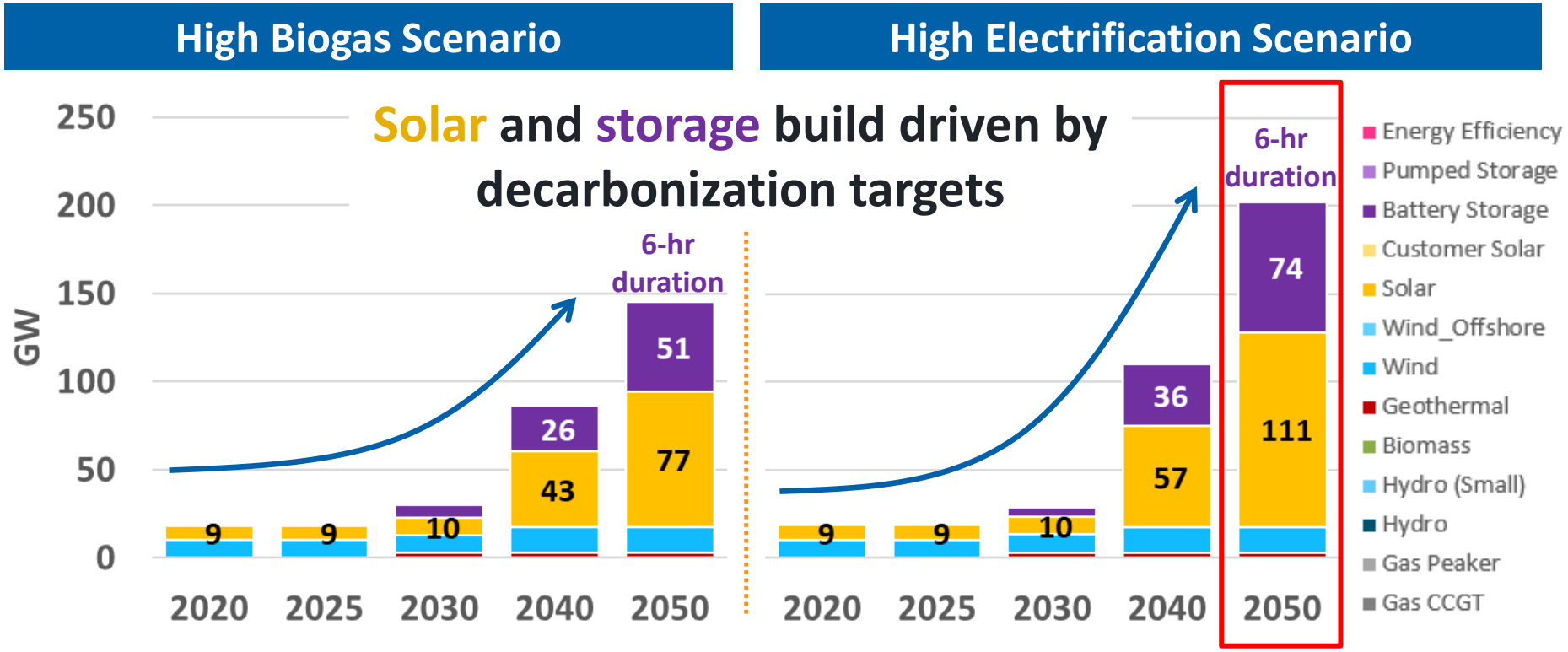


- Own/operate the electricity transmission network in England and Wales (i.e. System Operator or "SO")
- Operate, but do not own, the Scottish networks
- Own/operate the gas National Transmission System in UK

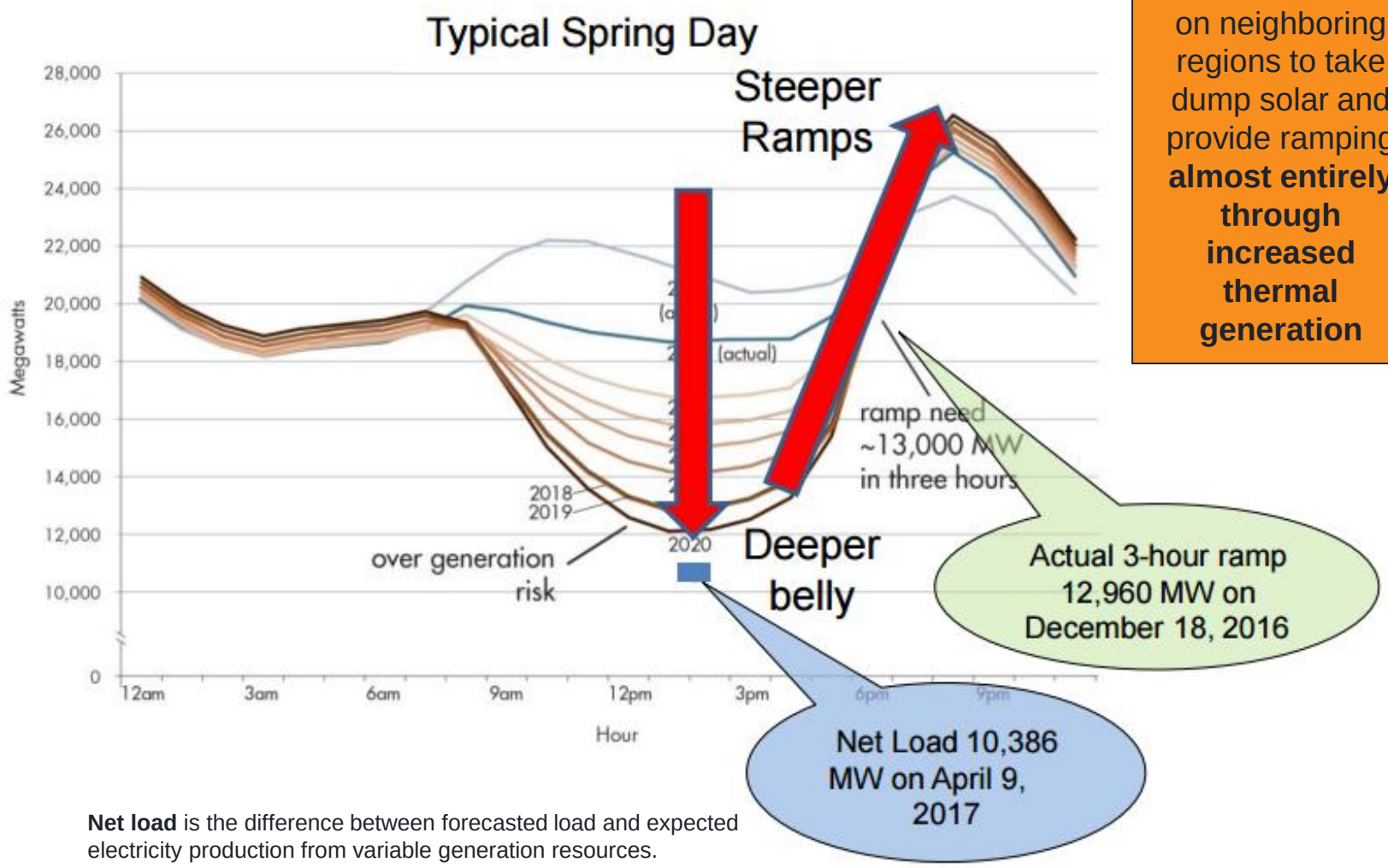
- Own/operate transmission facilities across upstate New York, Massachusetts, New Hampshire, Rhode Island and Vermont
- Own/operate electricity distribution networks in upstate New York, Massachusetts and Rhode Island
- Own/operate gas distribution networks across the northeastern US, located in upstate New York, New York City, Long Island, Massachusetts and Rhode Island.

CA 100% modeling selects mostly solar and storage to meet decarbonization goals

- 100%+ RPS achieved by 2050 in both scenarios
- RESOLVE utilizes a Planning Reserve Margin constraint but does not examine resource adequacy in detail



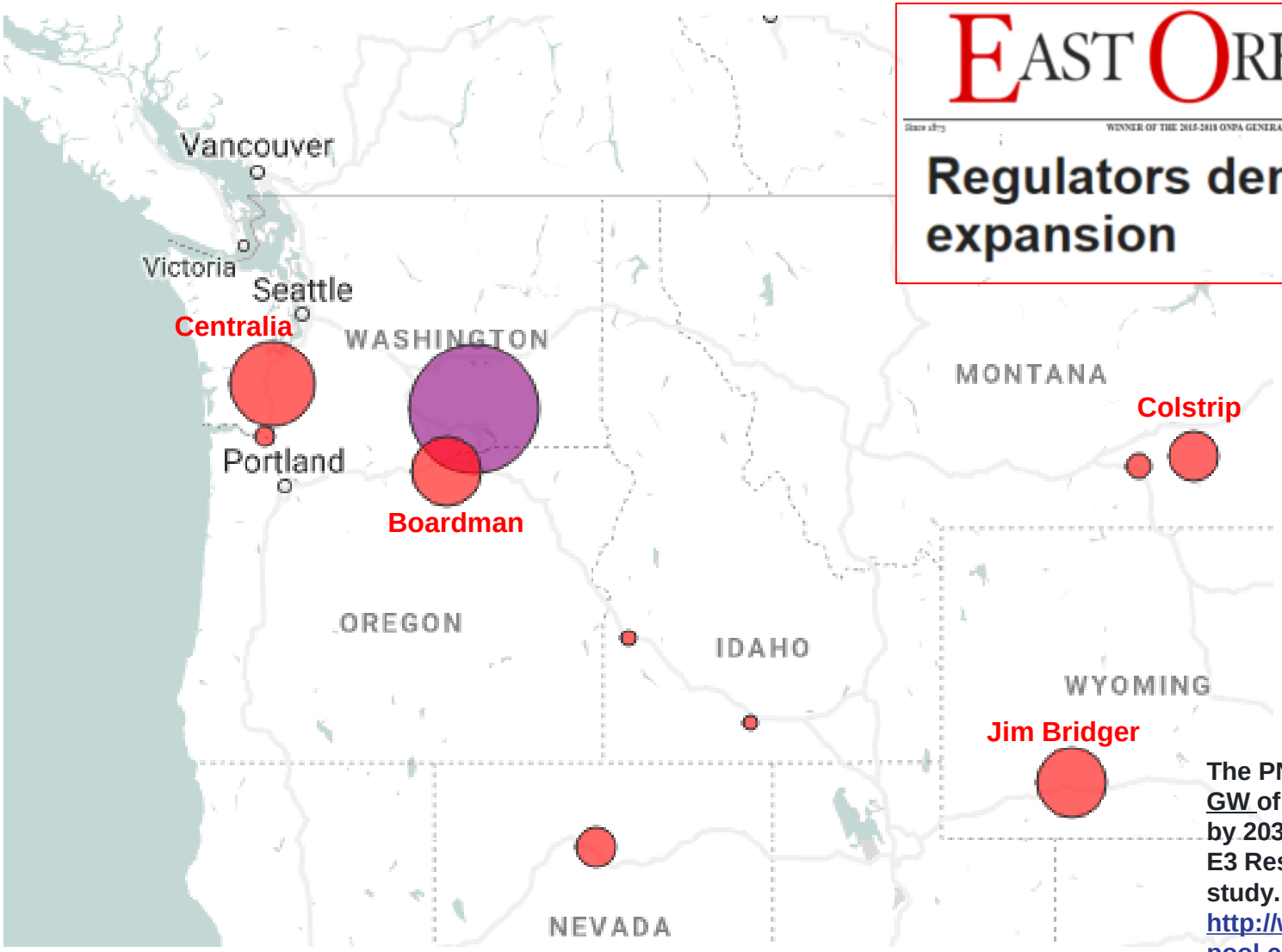
California's "duck curve" illustrates grid operational challenges with solar now and more future solar



California leaning on neighboring regions to take dump solar and provide ramping **almost entirely through increased thermal generation**

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

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

WINNER OF THE 2015-2018 ONPA GENERAL EXCELLENCE AWARDS

Regulators deny gas plant expansion

The PNW system will need 8 GW of new effective capacity by 2030, 20GW by 2045 per E3 Resource Adequacy study.
http://www.publicgeneratingpool.com/e3-carbon-study/

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

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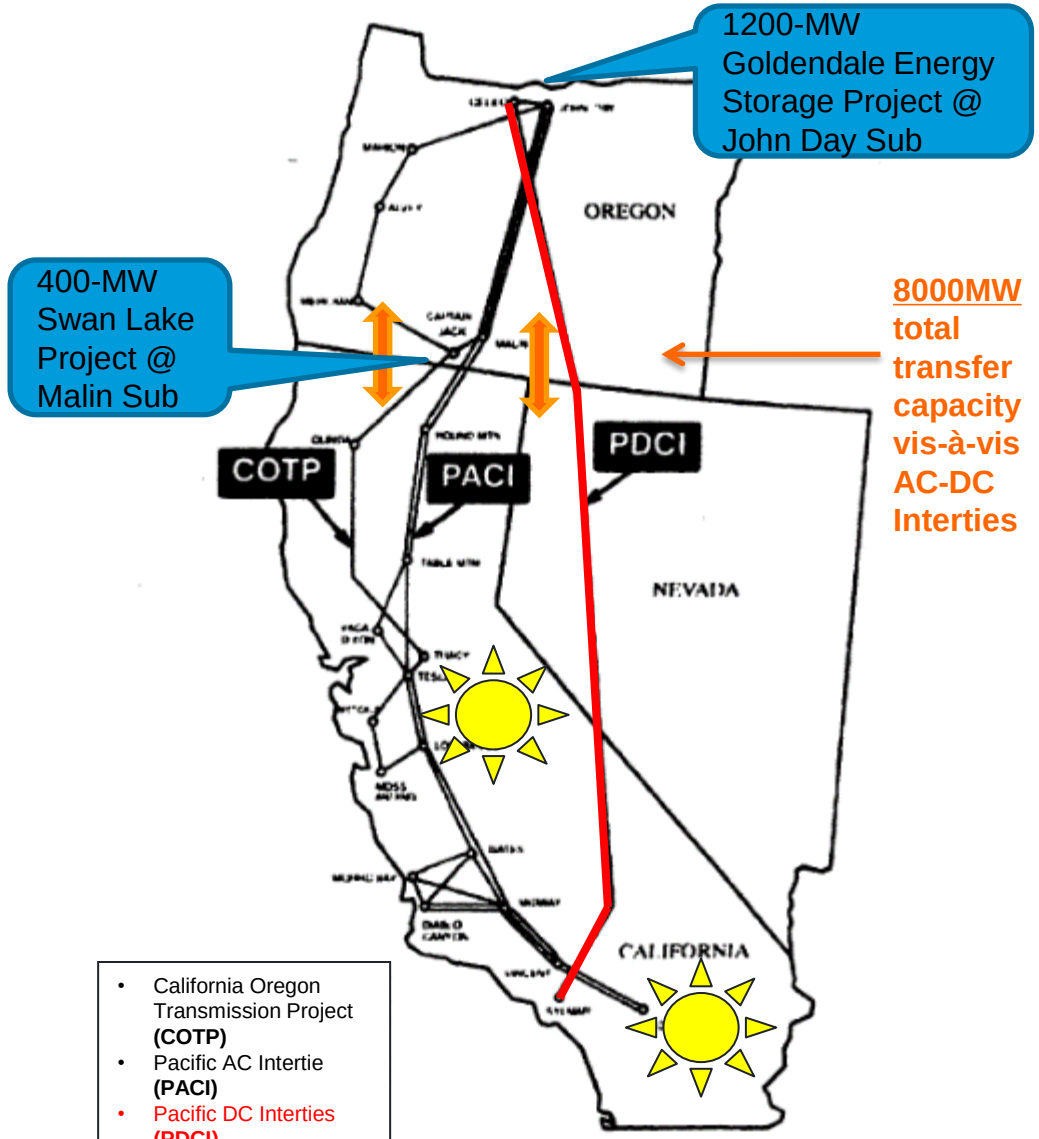

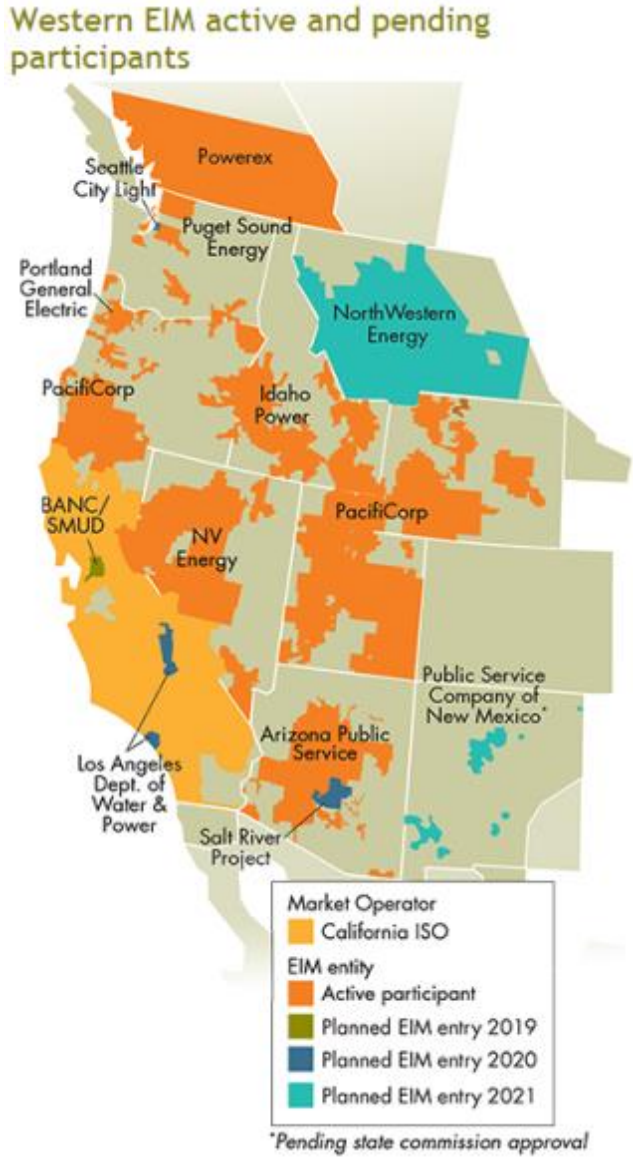

Significant PNW capacity needs in the near-term, particularly with WA 100% passing (i.e. no coal 2025)

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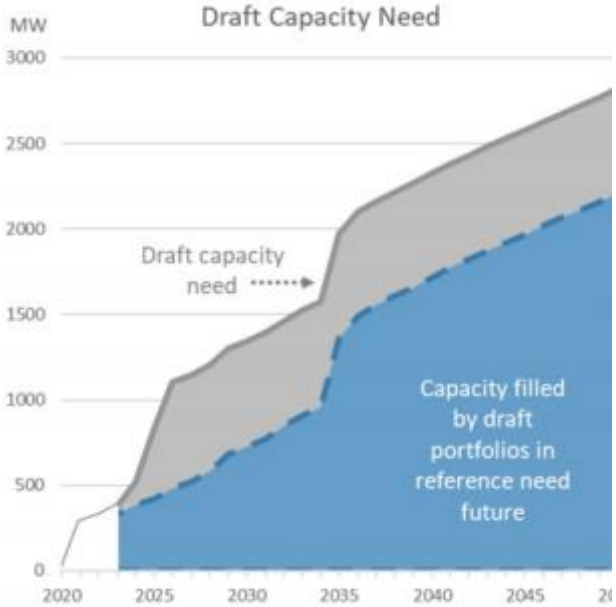
Portland General Electric



Draft Capacity Need, MW

Year	Low	Base	High
2025	474	828	1227
2030	875	1343	1990
2035	1288	1971	2848
2040	1431	2326	3416
2045	1478	2578	3873
2050	1530	2819	4308

PSE PUGET SOUND ENERGY

Electric Resource Capacity Need, Peak Deficit/(Surplus)

2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
36	171	253	565	551	557	623	717	759	837	908	1,015	1,128	1,624	1,695

Electric Resource Plan Forecast,
Cumulative Nameplate Capacity of Resource Additions

	2023	2027	2037
Conservation (MW)	374	521	714
Demand Response (MW)	103	139	148
Solar (MW)	266	378	486
Energy Storage (MW)	50	75	75
Redirected Transmission (MW)	188	188	188
Baseload Gas (MW)	0	0	0
Peaker (MW)	0	717	1,912

PACIFICORP

Early/accelerated coal plant retirement, no new gas given PGE and Carty 2;
60% of its coal units are uneconomic

Swan Lake in PGE IRP dispatchable resource portfolios

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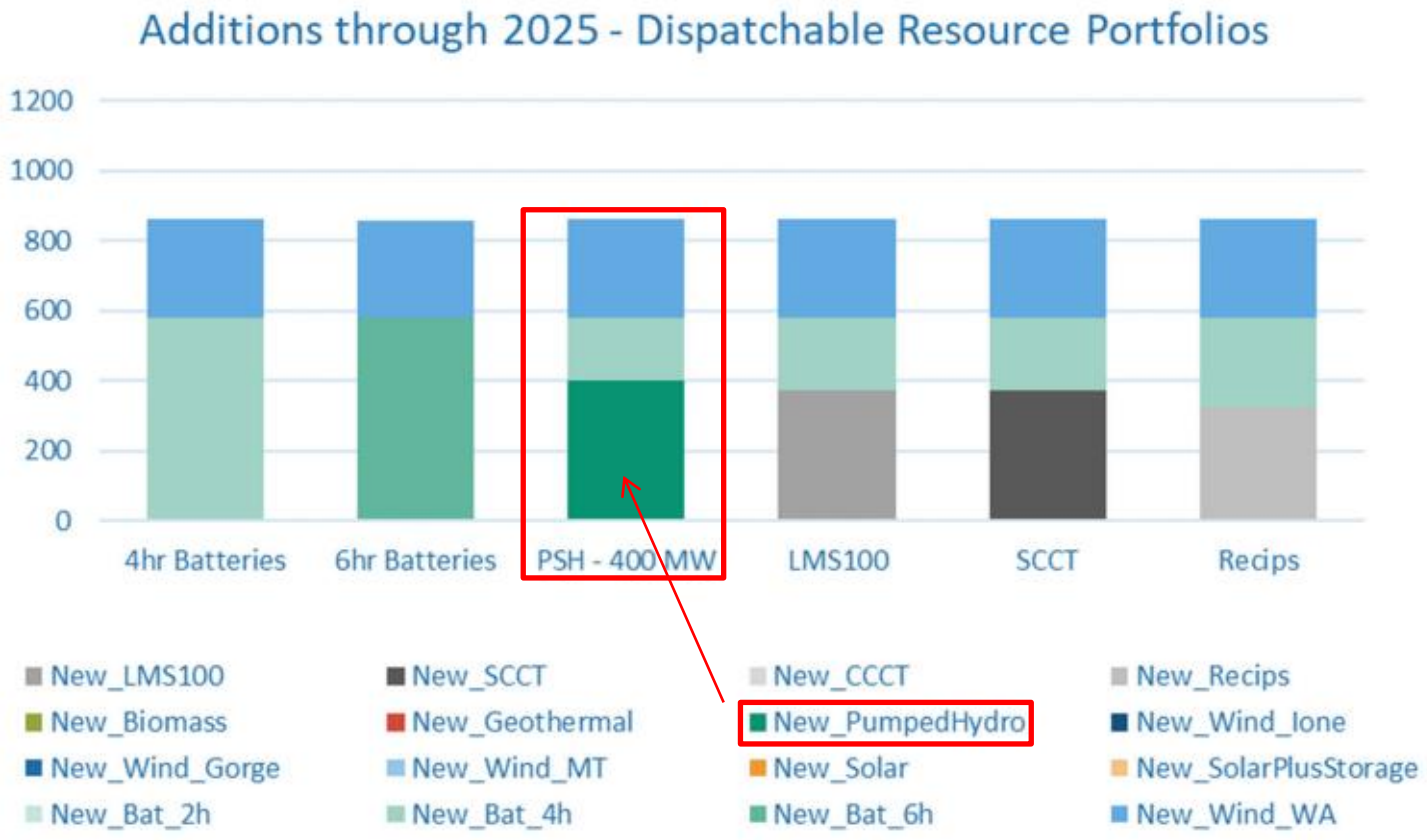
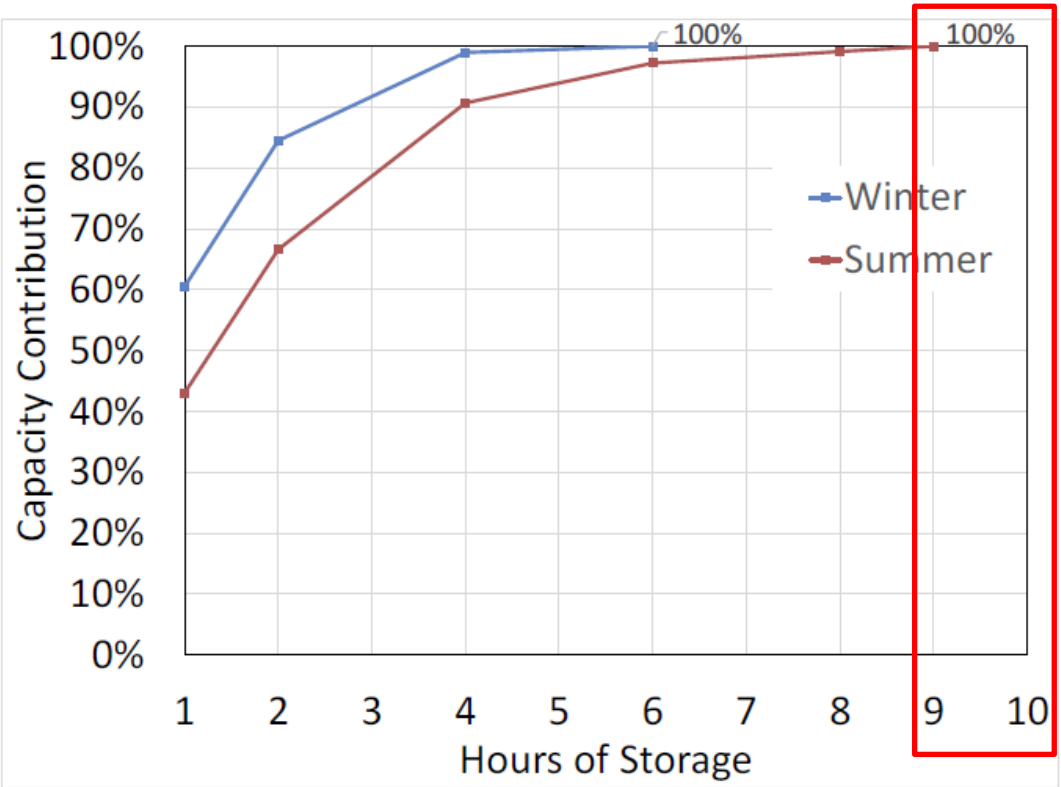
Draft Portfolios

Dispatchable Resource Portfolios

Portland General Electric



PacifiCorp energy storage capacity contribution and value of longer duration



- The maximum outage duration was nine hours in the reliability studies –nine hours of storage provides a 100% contribution.
- A four-hour resource covers just over 90% of summer events, and 99% of winter events.

Energy storage cumulative resource need and duration under various scenarios

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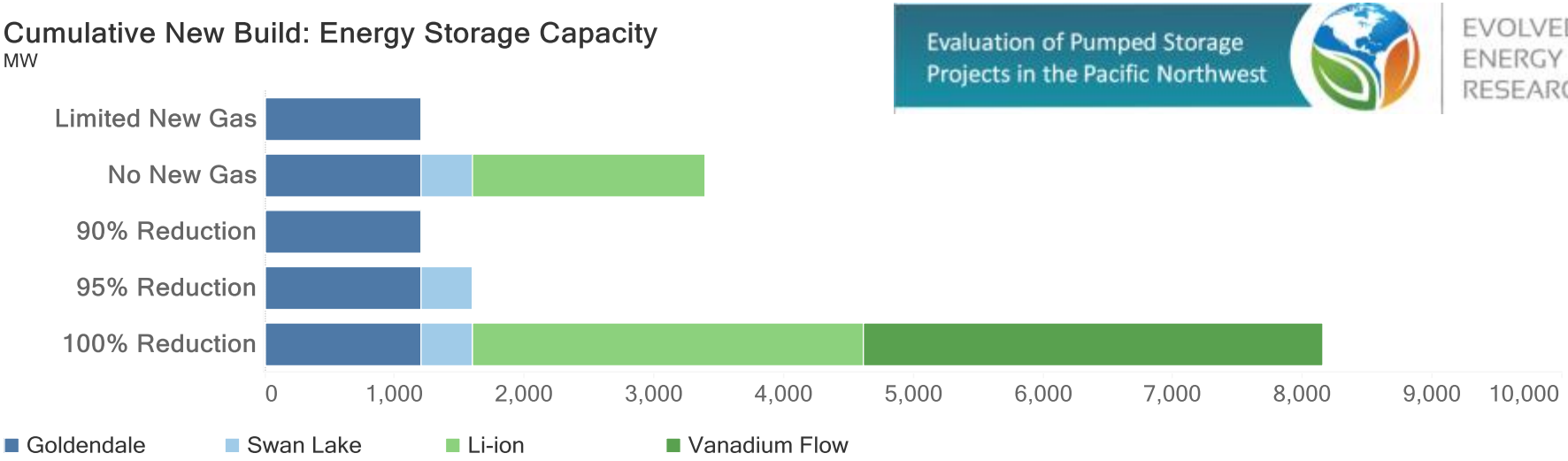
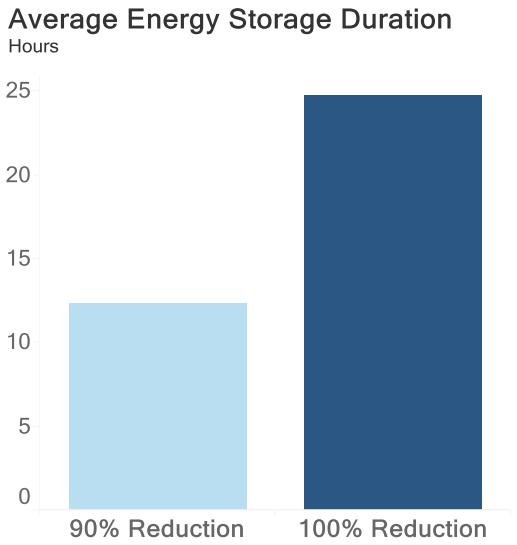
Evaluation of Pumped Storage Projects in the Pacific Northwest
EVOLVED ENERGY RESEARCH



- Capping or eliminating electricity sector emissions increases the average duration of new energy storage resources
- Average duration approximately doubles from 12 to 24 hours as emissions reductions increase from 90% to 100% below 1990 levels



Excess solar in CA can be exported to PNW vis-à-vis better transmission utilization of AC and DC Interties

- Our modeling shows that California's 100% clean electricity requirement results in significant amounts of excess renewable generation during the winter when loads are low
- Excess renewables could potentially be exported over *existing transmission* (i.e. flow south-to-north over COI & PDCI), allowing pumped storage to recharge and discharge to provide reliable supply on a daily basis