



High-level comparison between Swan Lake pumped storage-hydroelectricity and other types of generation and storage resources

The following represents a high-level comparison of pumped storage hydroelectricity (PSH), natural gas combined cycle power plants, and battery storage along several different metrics pertinent to project developers, investors, and local stakeholders. This not an exhaustive or definitive list and represents only one potential view of the differences among these energy storage and generation technologies. For reference, we consider both generic applications and specific examples in the Pacific Northwest context, such as Carty Generating Station built by Portland General Electric¹ and the proposed Swan Lake Pumped Storage Project in Klamath County, Oregon.

	Pumped Storage (Swan Lake PSH)	Battery Storage (Generic Lithium-Ion)	Natural Gas Combined Cycle (Carty Generating Station)
Capital Expenditure	\$1,750 to \$1,950/kW 400 MW, 9.5-hours of storage (~3,800 MWh), <\$700M to \$780M cost ²	\$3,088 to \$7,336/kW for an 8-hr Li-ion system ³ 100 MW, 8-hours of storage (800 MWh), \$309M to \$734M cost	\$1,166 to \$1,519/kW (based on original and final Carty Generating Station Cost). ⁴ 440 MW, \$514M original cost with overrun of ~\$150M
Annualized Capacity Cost⁵	\$243 to \$269/kW-year	\$542 to \$1,245/kW-year	\$167 to \$214/kW-year
Useful Life	60-year lifespan	20-year lifespan	30-year lifespan
O&M Costs (Fixed and Variable)	Fixed O&M costs of \$22 to \$34/kW-year are comparable to O&M costs for an NGCC plant. O&M costs for Swan Lake could be lower using low cost oversupply of daytime solar from California. Variable O&M costs are minimal.	Fixed O&M costs range from \$27 to \$56/kW-year for most installations. At the lower end, these costs are competitive with a NGCC plant. Variable O&M costs are minimal.	O&M costs are dependent upon plant utilization. Fixed O&M costs are approximately \$6 to \$11/kW-year. Variable O&M costs are approximately \$3 to \$5/MWh of generation. Total (fixed and variable) O&M costs for Carty, in the PNW, were ~\$24/kW-year recently. Future carbon pricing or taxes could contribute additional operating costs associated with CO2 emissions.

¹ <https://www.portlandgeneral.com/our-company/energy-strategy/how-we-generate-electricity/carty-generating-station>

² National Grid and Rye Development estimates

³ Lazard LCOS v2.0

⁴ http://www.oregonlive.com/business/index.ssf/2016/03/pge_sues_insurers_for_cost_ove.html

⁵ Levelized fixed cost of capacity under comparable financing costs. E3 Analysis.

Fuel/Charging Costs (Additional to O&M Costs)	Pumping (“charging”) is the primary variable cost of operation. If able to charge at zero or negative prices in future, these costs may be negligible or may even provide revenue.	Operating costs mostly consist of the cost of charging the batteries. If able to charge at zero or negative prices in future, these costs may be negligible or may even provide revenue.	Fuel cost is dependent on gas prices and supply, which can be volatile. Average U.S. gas price for power plants over past 12 months was \$3.50/MMBtu, but annual average has ranged from \$2.83 to \$9.27 in past 10 years.
Carbon Pricing	Not Applicable	Not Applicable	Applicable
History	Flexible, fast response variable speed pumped storage hydropower is an established, proven technology. Utility-scale solution to flexibility and overgeneration issues. Twenty-four existing pumped storage projects in operation in the US, ranging from 50 to 1800 MW in size.	Emerging technology, yet to be proven on a large 100+ MW scale. Is modular and can be built in small increments. There are a range of forecasts with a great deal of uncertainty around future costs. Cost of disposal and future remediation is uncertain.	Established technology with long track record of performance, but increasingly hard to permit due to tighter regulations and local opposition.
Climate/Environmental	Zero-carbon source of peak power (if charging from renewable sources). Increases deliverability of zero-carbon renewables and allows for more renewable integration. Closed-loop technology utilizes ground water only. No surface water or fish impacts. No threatened or endangered species issues. Oregon Water Resources Department Endorsement.	Zero-carbon source of peak power (if charging from renewable sources). Increases deliverability of zero-carbon renewables and allows for more renewable integration. Disposal and future remediation is uncertain. Lithium relies on mining and processing rare earth commodities.	Local air pollution, carbon emissions, air quality standards, and water impacts if not air cooled. Fast ramping and flexible technology like modern CCGTs can allow for more renewable integration compared to older thermal units although under highly renewable systems CCGTs would not be expected to be highly utilized.
Reliability/Capacity Value: Bulk vs. Local	Can only provide bulk system reliability/capacity value unless available transmission makes power deliverable to a constrained load pocket for local reliability/capacity value.	Can provide local distribution deferral value in addition to bulk system reliability/capacity value (if applicable) depending on location and size.	Can only provide bulk system reliability/capacity value unless available transmission makes power deliverable to a constrained load pocket for local reliability/capacity value.
Timescale/Applications	Short and Long duration storage, up to multiple days. Can integrate both diurnal solar generation, as well as wind generation which can have lulls/peaks that last days. Provides physical inertia to the system.	Typically, short duration, as the cost per additional hour of storage is currently relatively high. Does not provide physical inertia to the system.	Typically run continuously, following load (lower output off-peak). Expected to cycle and ramp up/down more frequently as penetration of intermittent renewables increases, driving up costs. Provides physical inertia to the system.

<p>EIM Participation and Cost Savings to Ratepayers</p>	<p>PSH can participate extensively in the EIM by flexibly buying and selling power at sub-hourly intervals. E3's Swan Lake modeling illustrates participation in the EIM could deliver \$35 to \$231/kW-yr (\$14 to \$90 million/yr) in incremental value in 2030 by absorbing costly market volatility due to energy imbalances.</p>	<p>Battery storage can participate extensively in the EIM by both buying and selling power at sub-hourly intervals. The rapid response time of battery storage makes it ideally suited to a balancing role at short time intervals, such as the 5-minute market within the EIM.</p>	<p>NGCCs can participate in the EIM by changing generation at sub-hourly intervals, but NGCC capacity is less flexible and more expensive to ramp up and down than energy storage. Advanced NGCCs with greater operational flexibility exist, but are also more expensive to build and operate.</p>
<p>Economic Impacts</p>	<p>Create 3,360 full year equivalent jobs during development. Once in operation, Swan Lake: 35 full time jobs annually; plus, a new source of tax revenue in Klamath County</p> <p>ECONorthwest's Analysis indicates that the construction of the Swan Lake Project will have cumulative, direct, indirect, and induced economic impacts in Oregon of \$523 million in output and 167 million in labor income.</p>	<p>Not assessed, but likely less localized due to concentrated and overseas manufacturing (e.g. Tesla's Gigafactory in Nevada, Samsung, Panasonic, etc.)</p>	<p>For Carty Generation Station 1 (440 MW): "100s of jobs during peak construction" and about 20 full-time workers during normal operation.⁶</p> <p>Early retirement (after 10 years) could cost PGE ratepayers average of 0.25c/kWh for another 10 years.</p>

⁶ <http://www.power-eng.com/articles/2016/06/construction-winding-down-at-pge-carty-natural-gas-plant.html>