Hydroelectric Pumped Storage Potential and Renewable Energy Integration in the Northwest

Wind generation on Bonneville Power Administration's (BPA) system in the Northwest grew from almost nothing in 1998 to more than 4,515 megawatts (MW) in 2014 (Figure 1). The majority of this existing and future potential wind resource is located in the Columbia River Gorge (Figure 2). BPA's integration of wind is the highest amount as a percentage of load of any utility in the country.

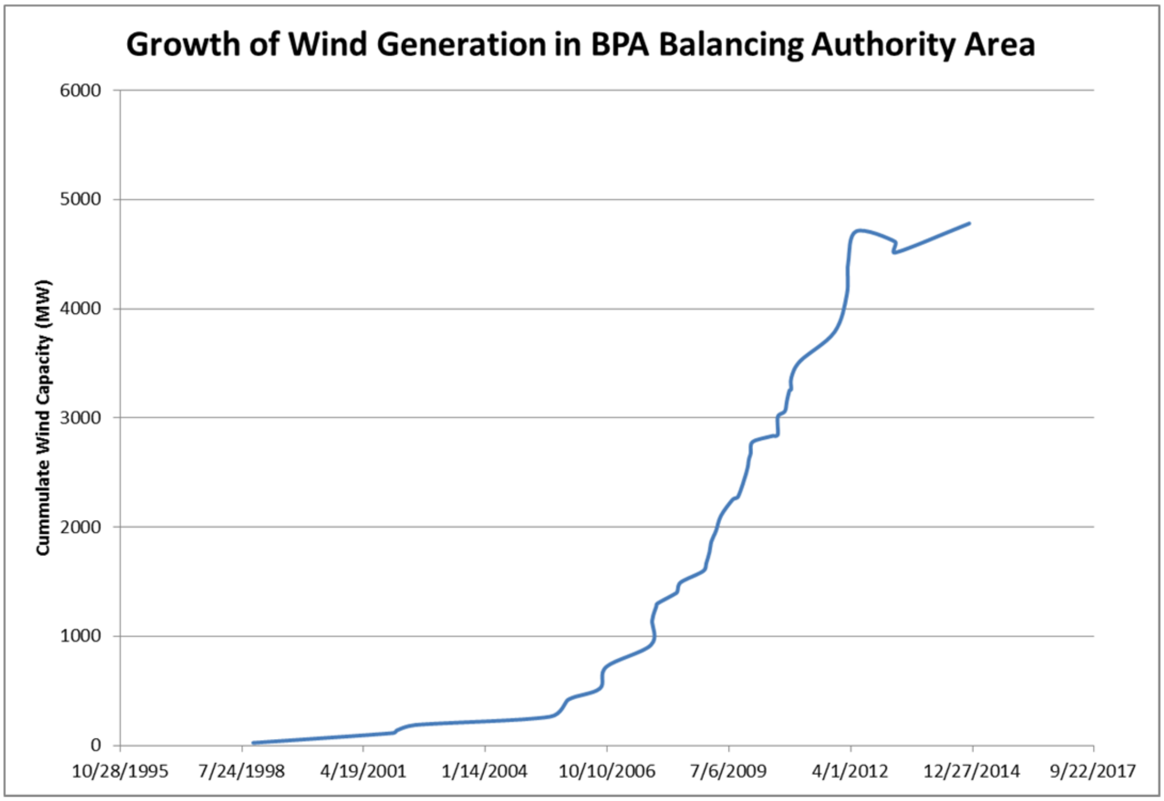

Figure 1 – 4,515MW of Wind Generation Capacity currently in BPA Balancing Authority

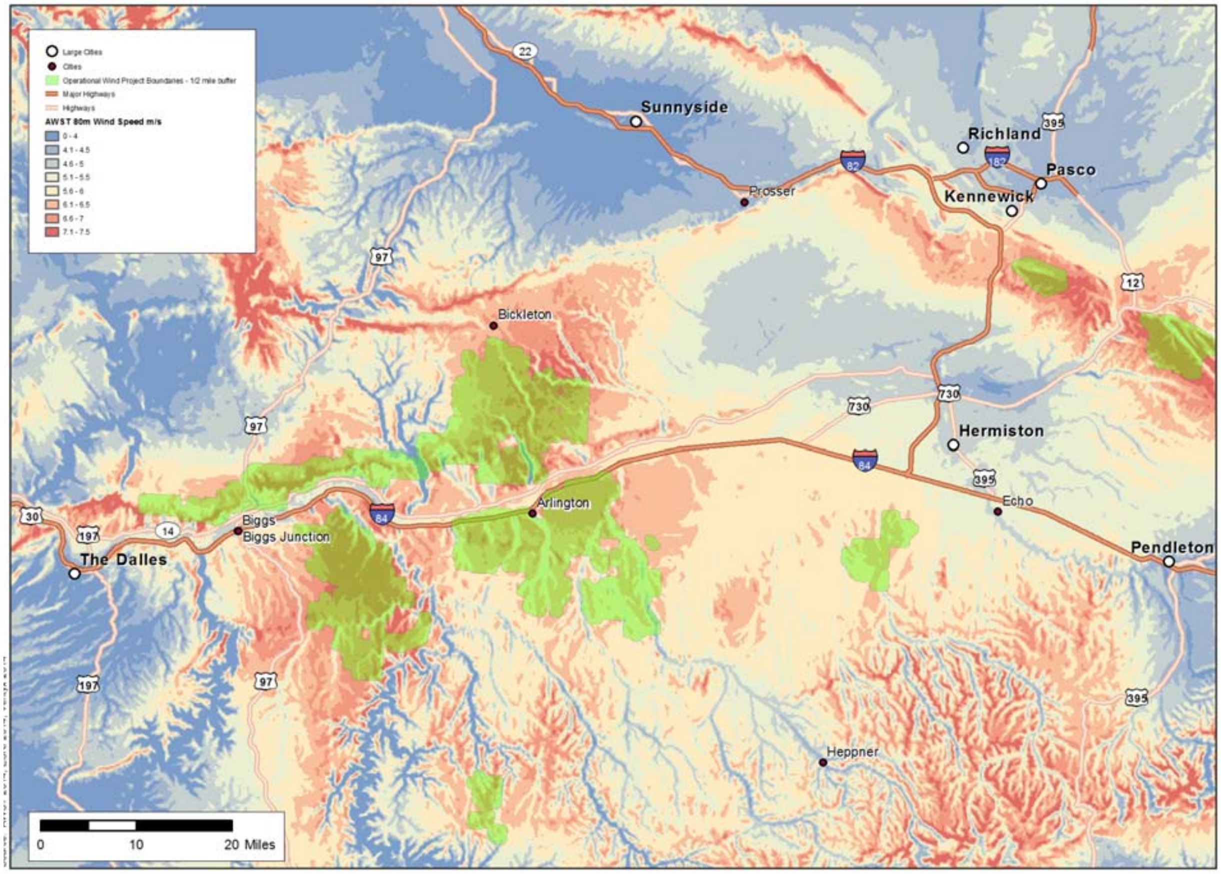

Figure 2 – 80m Wind Speed & Columbia Gorge Area Operation Projects

With improvements in turbine technology, wind energy is one of the most affordable forms of electricity today to meet clean energy and carbon reduction goals. However, the challenges and Achilles' heel of wind integration lie in the intra-hour variability and uncertainty of wind, making wind energy a difficult resource to dispatch. The challenge is to find a way to make energy created by wind generation, solar and other intermittent resources available on demand to meet current and future load growth. BPA has already experienced large unplanned ramping events of several hundred megawatts of wind output occurring within an hour that is out of phase with load (Figure 2). As the percentage of wind penetration grows, the risk increases of having a major system failure event from large ramping events.

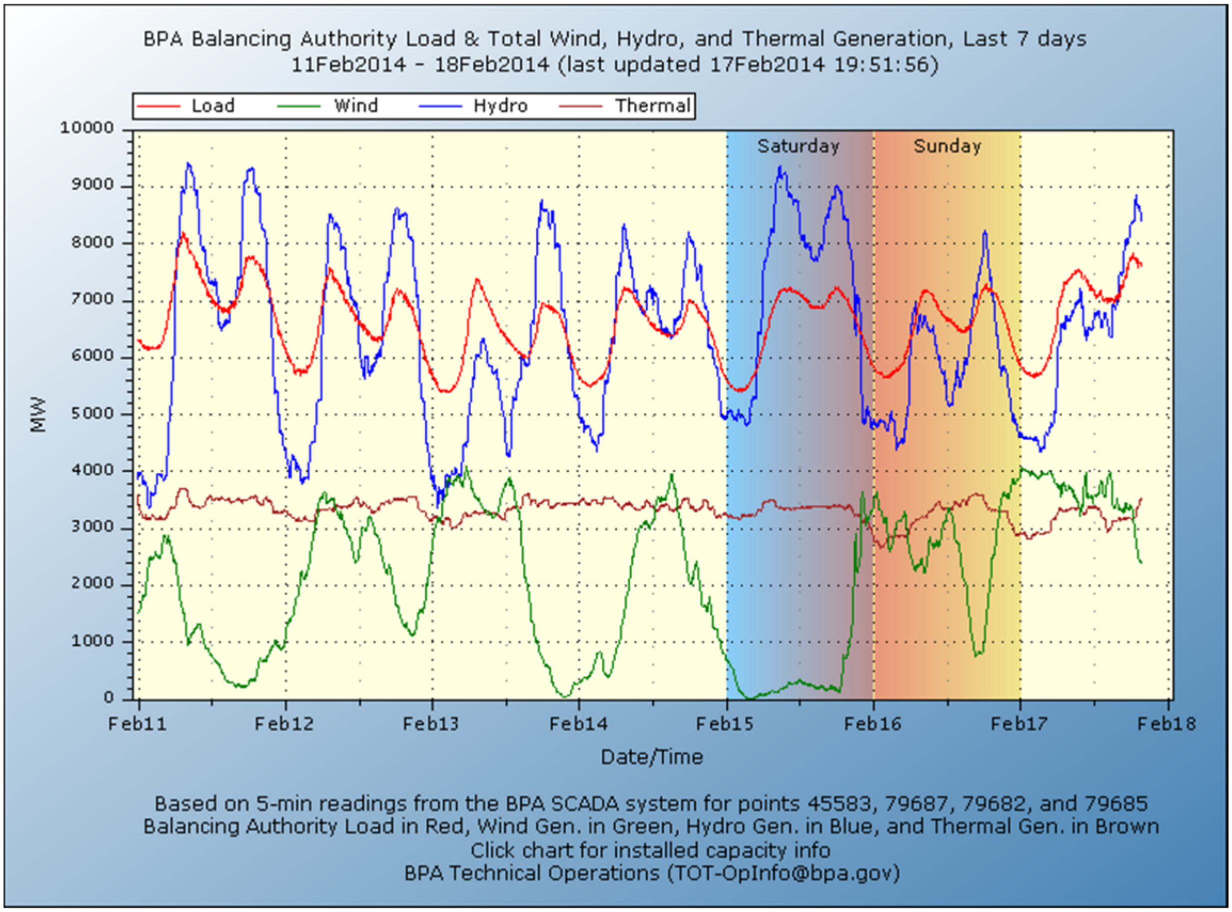

Figure 3 – Example of a typical ramping event on BPA's system

Pumped storage is the only proven utility-scale storage solution and consists of pumping or generating by moving energy in the form of water through a powerhouse between an upper and lower reservoir (Figure 3). Pumped storage offers the ability to store energy produced from wind or other renewable resources when it is difficult to utilize these resources on the power grid or integrate them into the power system, and to release the energy at a time when it is needed, most often during peak load periods, at a higher value. Different than the historical view of pumped storage and peaking operations, net-load is the concept of determining the load to be served by the bulk power system as the aggregate of customer demand reduced by variable generation power output. Flexible and dispatachable resources must be adjusted to maintain a balance with net load.

Figure 4 – 1095-MW Rocky Mountain Pumped Storage Project in Rome, GA

With the clean energy goals of the region and the carbon emissions reductions from the Environmental Protection Agency's proposed Clean Power Plan Section 111(d), the Northwest is facing the retirement of over 3,000-MW of coal-fired generation, further exacerbating the need for dispatchable energy assets. Current plans suggest much of the replacement generation will be natural gas-fired units with a small increment of new renewable sources, primarily wind.

There is an alternative, lower-emissions alternative to this planning scenario. It has been well documented that grids with similar variable supply portfolios, such as in Denmark/Norway and Spain/Portugal, rely on the flexible supply of conventional hydropower to successfully integrate a growing wind fleet. Properly designed pumped storage projects that are focused on providing energy services, once built and integrated into the Northwest grid, can assist with integration of intermittent wind energy resources for an economical regional dispatch that would be less dependent on new, GHG-producing generation.

Pumped storage sites require two water reservoirs with different elevations, so energy can be stored in the upper reservoir and released when needed to generate electricity (Figure 4). When power is cheap or when other facilities would need to shed load, lower water reservoir water is pumped up to the upper reservoir through the same water conveyance that is comes down. When the elevation difference between the reservoirs is large, more energy can be stored using smaller reservoirs, smaller water conveyance conduits, and smaller physical equipment sizes, usually resulting in lower investment costs. A dedicated off-stream ("closed loop") pumped storage project does not have operational restrictions imposed such as those that occur on the Columbia River and hence can freely start, stop, reverse, and fluctuate as needed by the power system without negatively impacting the aquatic species as well as meeting other needs such as food control, navigation irrigation and recreation.

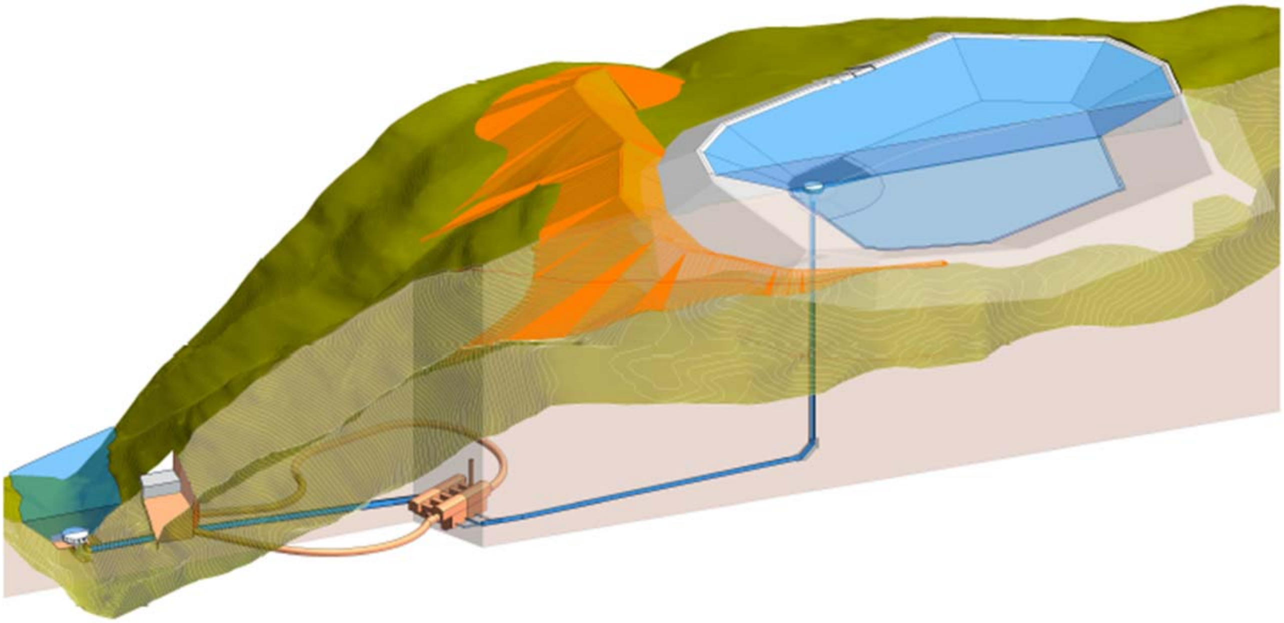

Figure 5 – 3-Dimensional Concept Sketch of a Pumped Storage Plant

By investing in the newest technology available, adjustable speed or ternary units, pumped storage projects can not only supply load following and rapid ramping grid services, but are one of the fastest response stations on the power system. It can offer frequency regulation whether pumping or generating, and can allow pumping at less than full load, thereby increasing the flexibility to integrate the pumped storage project specifically with wind or solar energy resources (Figure 5). The big improvement with the new asynchronous, variable speed pump turbines technology is that frequency regulation and load following are also possible in pumping mode, providing additional flexibility and value. However, more analysis is required to quantify the full valuation of various grid services under different market structures and at different levels of renewable energy generations such as the Department of Energy's $1.8 million study titled *Modeling and Analyses of Value of Advanced Pumped Storage Hydropower in the U.S*.

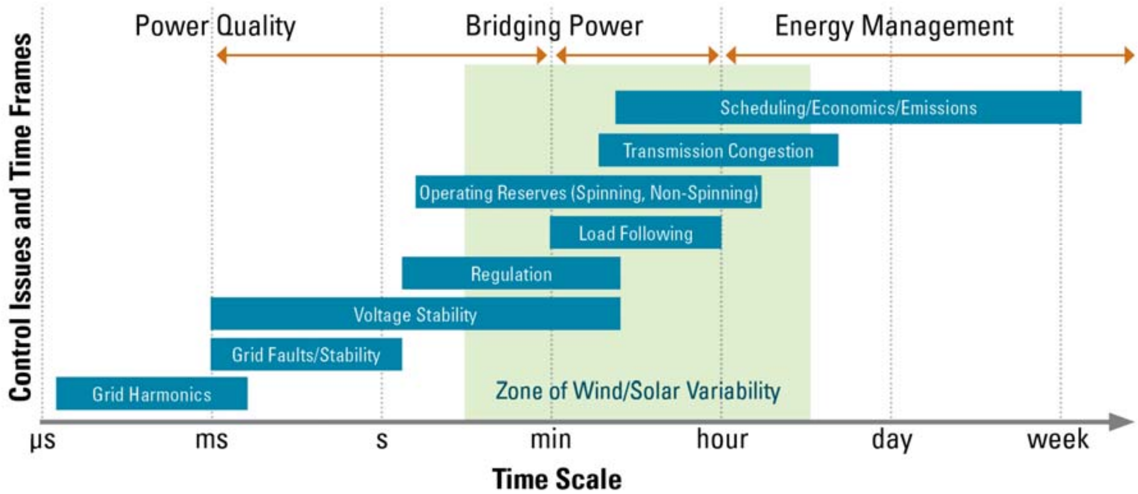

Figure 6 – Power system control function needs by new generation for operational flexibility

California holds an example for the Northwest to illustrate of the future challenge of increased penetration of renewables. California's 33% Renewable Portfolio Standard (RPS) is, independent of market forces and physics, driving the development of both wind and solar projects on the scale of hundreds, and collectively thousands of megawatts of variable supply. This expanding variable supply will demand greater flexibility from the electric power grid. Up until the past two years, the majority of the new renewable energy supply has been from wind and distributed photovoltaic solar. In-state wind development is now transitioning to an expanded role for solar energy due to the decreasing cost for solar and the reliability challenges created by a predominance of wind energy at night during low load demand periods in California. California Independent System Operator (CA-ISO) is now predicting significant build-out of solar in Southern California (Figure 6).

The net-load graph shows the projected impacts of expanded solar generation in California (Figure 6). This graph predicts there may be excess energy supply from 12:00PM to 3:00 PM, and then beginning around 4:00PM, the solar output significantly decreases just as air conditioning load ramps up for the peak of the day. This rate of change is significantly greater than with just the load alone. The effect to the grid, and the opportunity for a pumped storage project, is that the excess energy supply would incentivize the market to utilize the project to pump in the middle of the day, and then rapidly turnaround to generate as quickly as possible to meet the increased ramping rate virtually every afternoon. By comparison, a combined cycle gas turbine would need to operate during the 12PM time hour, in a potentially negative energy price market, in order to increase their output in time to provide the incremental reserves and ramping services needed at 4:00PM in the afternoon.

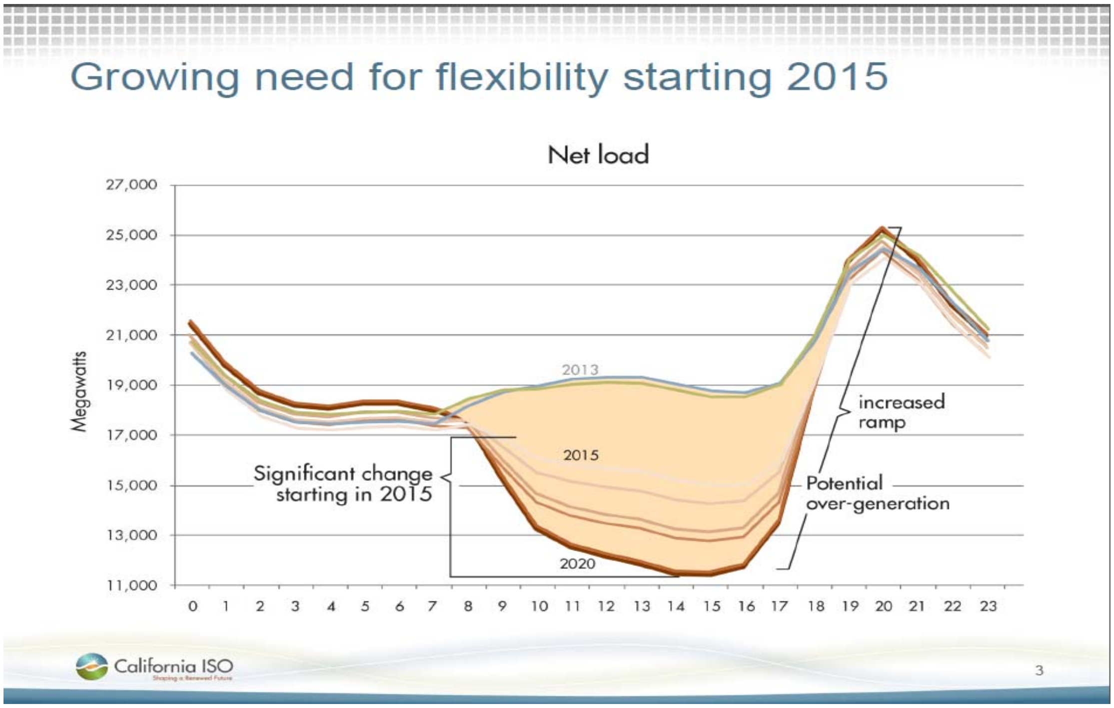

Figure 7 – CA-ISO projected net load pattern changes 2012 through 2020 ("Duck Curve")

This California example presents challenges and opportunistic storage solutions that are not mutually exclusive from the Northwest given our existing major transmission interconnections such as the California Oregon Intertie (COI) and the Pacific DC Intertie from Celilo to Sylmar Converter stations with 8,600-MW of transmission capacity (Figure 7). The present transmission congestion, under or oversupply and overload could be reduced by having a pumped storage project located near significant high-voltage transmission to take advantage of Northwest and Southwest geographic diversity of loads and output from renewable resources, inter-regional exchanges and to mitigate the steep ramping needs and overgeneration risk depicted by the "Duck Curve" under a 33% RPS. Storing energy produced by wind and solar, even a portion during critical times, could allow that same power to flow at a time when the congestion is reduced the power or is needed on other parts of the system.

Figure 8 – COI and the Pacific DC Intertie with 8,600 MW of transmission capacity

To maintain overall dynamic performance and stability of the transmission system, BPA has used Special Protection Schemes (SPS) to deal with system disturbance events. These demand side actions include shedding of large industrial loads and in some cases renewable resources. A pumped storage project could reduce the frequency of these events that can have significant financial consequences to the owner/operator of the industrial loads and mitigate potential demand side fatigue.

The operation of a pumped storage project requires understanding that the near continuous cycle duty on the equipment at varying loads will affect the life of the equipment, in particular the generator components. More frequent maintenance outages are required than for base loaded equipment. Some of this is caused by thermal cycling, and some of this is caused by operation under less than ideal conditions and being operated not at optimal efficiency set points. The use of adjustable speed generation can eliminate some of the fatigue in turbine components and some of the stress imposed by starting and stopping, because of reduced vibrations and smoother operation. Otherwise, operation and maintenance practices are similar to those in conventional hydroelectric projects.

Use of pumped storage provides a cycle efficiency of 75% to 82% that must be overcome by rate structures for arbitrage and ancillary services if investment in a pumped storage project is to be financially viable. Even though there are over 60 gigawatts of pumped storage projects in Federal Energy Regulatory Commission (FERC), licensing and permitting, not one is under construction. The time has come to consider the financial viability as well as the funding mechanisms for grid scale energy storage, since no entity will be interested in operating a facility that does not earn enough revenues. To make pumped storage economically viable, especially in the environment of increased wind or solar energy penetration, the full value of ancillary services is required, besides the arbitrage gains between rates when buying and selling power.

Pumped storage is one solution that offers maximum flexibility to resolve the challenge of wind integration and returning additional reserves operational flexibility to the Federal Columbia River Power System that could be used to support ecosystem functions (Figure 8). In the design of pumped storage project, bundling as many features and capabilities as possible into the project to realize all the potential revenue streams increases the economic viability of the project

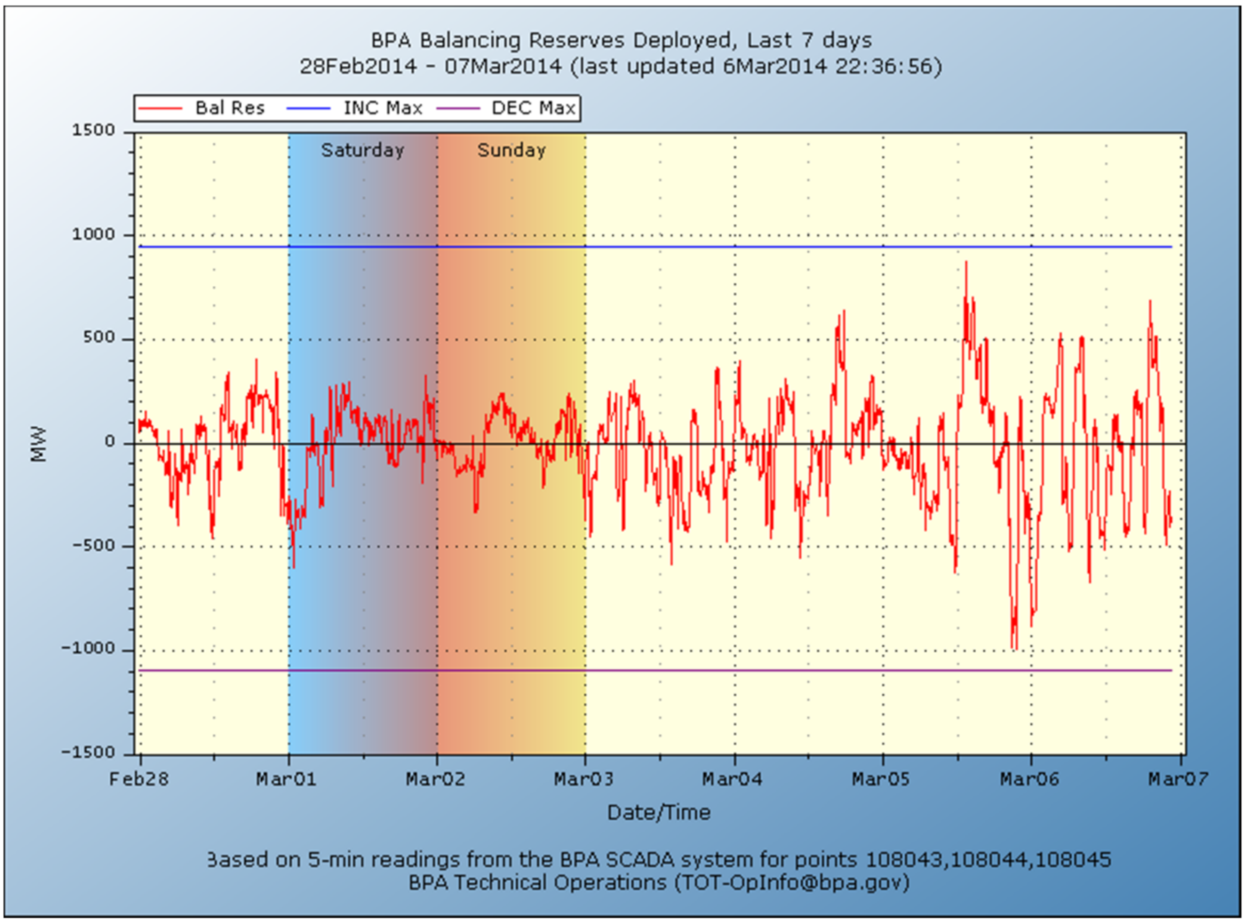

Figure 9 – BPA utilization of available system reserves

There are a number of potential pumped storage sites that were identified in the Northwest during the past 30 years. Some are now in the FERC licensing process. Of the projects in the FERC licensing process, the table below represents the most attractive projects from a technical perspective (Figure 9).

FERC Docket Number (P-) (old docket number is in parentheses)	Project Name	Licensee / Permit Holder / Applicant	State	Capacity (MW)	Closed Loop?	L/H Ratio	Estimated Energy Storage (MWh)
13333	JD Pool	PUD No.1 of Klickitat County, WA	WA	1000	Yes	4.58	15000
13318	Swan Lake North	Swan Lake North Hydro, LLC	OR	600	Yes	4.98	10000
2753	Brown's Canyon	Douglas County PUD	WA	1000	No	0.00	37000
14329 (13296)	Banks Lake Pumped Storage (Alternative 1 - North Banks Lake Development)	Grand Coulee Hydro Authority	WA	1000	No	28.29	8000
14329 (13296)	Banks Lake Pumped Storage (Alternative 2 - South Banks Lake Development)	Grand Coulee Hydro Authority	WA	1040	No	3.18	8084
14416 (13241)	Lorella (Klamath County)	FFP Project 111, LLC	OR	1000	Yes	4.81	15625
13642	Gordon Butte	GB Energy Park, LLC	MT	400	Yes	3.88	3422
--	Yale-Merwin	PacifiCorp	WA	255	No	N/A	2550

Figure 10 – Technically attractive pumped storage sites in the Northwest

The permitting, designing, procuring equipment and constructing a pumped storage project is a long term process requiring at least 6 to 7 years with 10 to 12 years to complete construction more likely. Much of the time is in the up-front licensing and permitting process that is required, but it also takes significant time to build systems of tunnels, reservoirs and a power plant. A large scale pumped storage project has never been accomplished by independent power producers in the United States. These projects have only been constructed by government, major utilities with significant financial resources and most importantly with rate-based treatment allowing for recovery of costs. New innovative ways such as Public-Private-Partnerships (P3) and fast-track permitting and licensing, as well as tendering and financing should be explored for projects where environmental issues are agreed upon by the stakeholders to be benign.

Because of the timeline for new projects, short term measures will be required. Notably, the one and only pumped storage site in the Northwest is the Bureau of Reclamation's John W. Keys III Pump-Generating Plant utilizing Banks Lake at Grand Coulee Dam with an installed pumped storage capacity of 314-MW. Although not ideal from a transmission congestion perspective due to east-west power flows, and significant hydraulic challenges due to the physical constraints of the project, an enhanced utilization of this site may be able to be part of the short term plan. Although more distant, there are several pumped storage projects in active development such as Électricité de France Renewable Energy's (EDF-RE) Swan Lake North Pumped Storage Project and Public Utility District No. 1 of Klickitat County, Washington's (KPUD) John Day Pool (JD Pool) Pumped Storage Project (Figure 10).

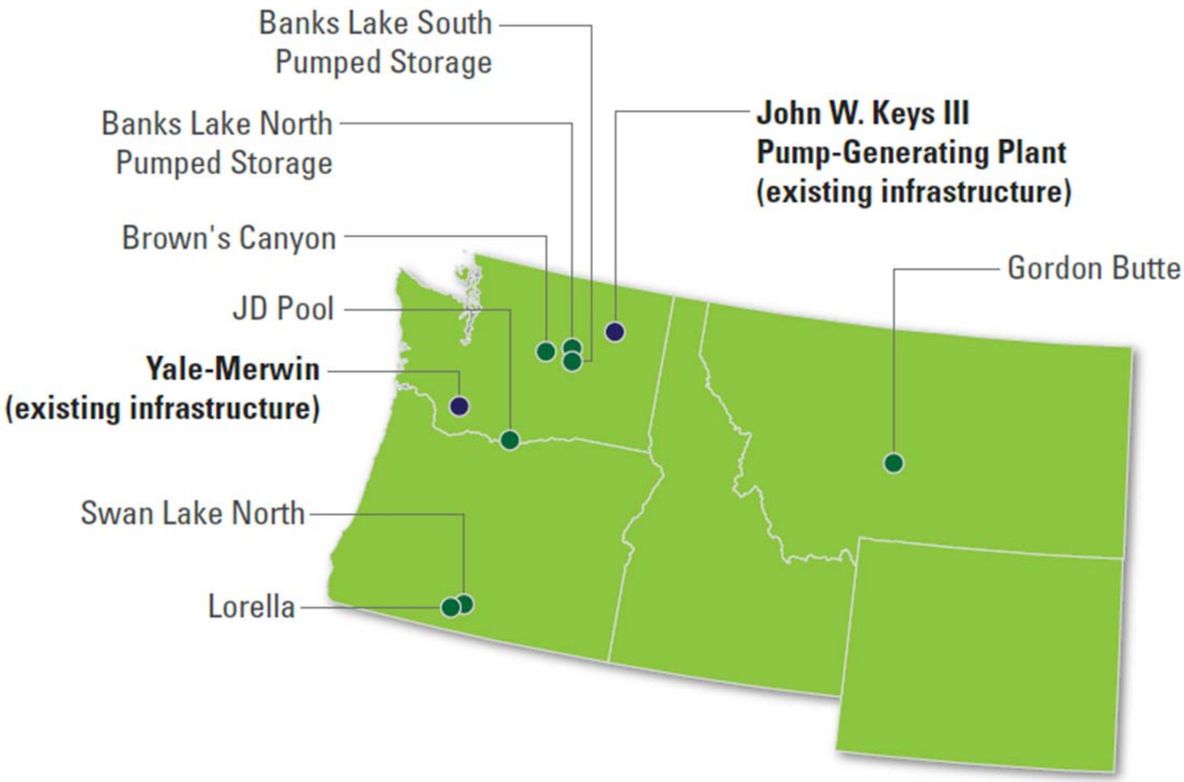

Figure 11 – Map of existing and proposed technically attractive pumped storage projects in the Northwest