The Value of Hydropower to the Northwest Grid

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Executive summary

This report explores current Northwest electric power system trends, outlines the many values of hydroelectric power, and discusses how these values stack up in today’s power system. The key findings are that hydro is well suited for today’s Northwest power sector and that peak capacity and flexibility, which hydro can provide, are becoming increasingly valuable resource attributes.

Hydroelectric power is the bedrock of the Northwest power system. It provides over half the total electric energy generated inside the region and helps keep Northwest power low in emissions.1

The Northwest power system is changing. Historically, the Northwest planned to have adequate energy to meet annual and monthly demand and did not focus on the instantaneous demand of customers (peak capacity need). The energy concern was driven by the possibility of not having enough water to fuel hydro facilities over an extended period of time.

Today, the region experiences surplus energy on an annual level (individual utility positions will differ). Yet, there are growing concerns about having enough peak generating capacity to keep the system adequate for all hours of the year. This is partly due to four coal units retiring by mid-2022.2 And as more variable energy resources (wind and solar) are built, the need for flexible resources to balance the system will continue to increase.

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1 EIA data. Northwest as defined as all generation in ID, MT, OR, WA, plus Jim Bridger and 50% of Valmy.
2 Boardman and Centralia 1 offline at end of 2020, Colstrip 1 & 2 offline no later than July 2022.
The key findings from the report are:

**Hydropower is well-suited for today's Northwest power sector**

- Hydro can provide a full range of power products. Many hydro facilities in the Northwest can generate energy as well as provide peak capacity, flexibility and other services.

- Hydro's carbon free attribute increasingly beneficial as carbon regulations mature. Hydropower may receive a premium if sold into a market with greenhouse gas regulations.

**Peak capacity and flexibility, which hydropower can provide, becoming more valuable**

- Coal unit retirements may increase the value of peak capacity resources. The Northwest is forecast to have a capacity deficit in the next five years in part due to the retirement of coal units. This will decrease the amount of peak capacity generating resources in the region, potentially increasing the value of existing capacity resources.

- Variable energy resources are driving regional flexibility needs. Over 8,000 MW of wind power has been built in the Northwest in the past 15 years. Utilities have constructed flexible natural gas-fired units and are joining the Western Energy Imbalance Market to help integrate these resources and prepare for future developments. With more variable energy resources on their way, the value of flexibility in the Northwest may grow.

- Capacity and flexibility may become larger shares of the value of hydro. If energy prices remain low (as they are today), and the value of capacity and flexibility grows, then hydro owners may see relatively less value from energy and more value from capacity and flexibility. However, the Northwest currently lacks formal capacity and flexibility markets, making these values potentially difficult to realize for utilities with surplus hydro.

There is much activity in the evolving Northwest electric power sector. While this could bring challenges, it could also bring opportunities to find new values in legacy resources. PNUCC looks forward to furthering the discussion on the value of hydropower in this changing energy landscape.
Northwest power system trends

The Northwest power system has undergone many changes in the past few years, including:

- Shifting from a forecasted annual energy deficit to an annual energy surplus.
- Recognizing that peak capacity and flexibility are emerging as the most vital resource adequacy needs.
- Increased energy supply, tepid demand growth, and low fuel prices all leading to low wholesale market electricity prices.

Annual energy supply up, requirements down

Since the early 2000’s, on a regional annual energy basis, there has been an increase in electric energy resources in the Northwest and a decrease in firm requirements (load plus firm exports). As a result, the region today looks surplus regarding annual energy. ³

Looking at the figure above, the construction of natural gas-fired power plants and wind power increased annual energy resources. The decrease in requirements is a result of diminishing expectations for demand (partly due to energy efficiency) and fewer long term regional export contracts.

³ Each data point is year one of the forecast in a series of PNUCC Northwest Regional Forecasts. Firm resources are calculated using critical water conditions and include IPPs under long term contract (not spot purchases).
Capacity is region’s chief concern

For much of the Northwest’s history, peak capacity need was not the primary concern on the regional level for adequacy planning – more focus was given to annual and monthly energy metrics. For example, the PNUCC Northwest Regional Forecast began focusing on capacity in 2011 and the Northwest Power & Conservation Council’s 2016 7th Power Plan was the first Plan focused on capacity rather than energy.

Today, capacity, not energy, is the more acute regional adequacy metric. The PNUCC Northwest Regional Forecast shows the one hour January deficit growing to a concerning size by 2021, the Council’s 2016 Pacific Northwest Power Supply Adequacy Assessment shows a capacity shortage in 2021, and the BPA White Book sees a 120-hour capacity deficit in 2019 with a one hour deficit starting in 2021. One reason why these reports see 2021 as a key year are the retirements of the Boardman power plant and one unit of Centralia at the end of 2020 – over 1,300 nameplate megawatts of dispatchable generation in total. None of these reports focus on annual energy as a regional power system concern.

<table>
<thead>
<tr>
<th>Group/report</th>
<th>Metric</th>
<th>Year 2021 value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNUCC 2016 Northwest Regional Forecast</td>
<td>1-hour January load/resource balance</td>
<td>(4,100) MW</td>
</tr>
<tr>
<td>Council 2016 adequacy assessment</td>
<td>Loss-of-load probability (5% or under is the goal)</td>
<td>10% (13% without Colstrip 1&amp;2)</td>
</tr>
</tbody>
</table>

Although the BPA White Book and PNUCC Forecast both focus on critical water planning they differ in methodology. Most notably, the White Book includes around 3,000 MW of uncommitted generation from Northwest independent power producers in its calculations and the PNUCC Forecast does not.

Capacity adequacy in a hydro region

In the Northwest two types of long-term planning adequacy issues are most commonly discussed, energy and capacity. Energy curtailments are typically due to a lack of fuel (e.g. water for hydro projects) and are usually longer term events. Capacity curtailments are due to a lack of machine capability (not enough power plants available), and are shorter events.

Although the Northwest system is currently viewed as capacity rather than energy constrained over the next several years, water supply (fuel for the hydro system) is still a major factor. The hydro system has a large nameplate capacity, but its ability to peak for an extended duration is dependent on water supply. Generally, higher water years result in the hydro system having a greater sustained peaking ability than lower water years. As a result, in the Northwest, capacity adequacy issues are still partly a function of fuel.
**Flexibility, a potential concern**

There has been tremendous growth in variable energy resources over the past decade. In the Northwest this has largely been wind power, whereas the greater Western Interconnection has seen both wind and solar power. While these resources play a valuable role in providing energy and reducing emissions, they also increase the need for system flexibility. When wind or solar power generation increases or decreases, other resources must react to keep the system balanced.

One well known example of this increased need for flexibility comes out of California and is often portrayed with the “duck chart.” This flexibility need occurs when the net load (load minus wind and solar production) drops during the middle of the day, but then increases as the sun sets.

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**Figure 3 – The duck is here, CAISO, April 16, 2016**

In California, the resources used to offset the evening decrease in solar generation are often a combination of natural gas-fired units, California’s hydro system, and imports. Since California and the Northwest are frequent electricity trading partners, part of California’s future flexibility needs could be met using Northwest generation.5

Going forward, the California ISO recently implemented a flexible ramping product to “ensure that sufficient upward and downward ramping capability is available and efficiently dispatched in the CAISO real-time market” due to increasing levels of variable energy resources in California.6

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4 CAISO daily renewables watch. The term duck chart arises from the charts rough resemblance to a duck.

5 From 2011 to 2015, the average net flow on the AC and DC interties between Oregon and California was over 4,000 MWa from north to south, although some of this power may have originated outside the Northwest.

6 CAISO Tariff Amendment to Implement Flexible Ramping Product. Tariff implemented November 1, 2016.
Beyond California, the need for more flexibility in the Northwest may grow as well, in part due to the continued development of variable energy resources. Many utilities are beginning to position themselves with flexibility in mind as seen by the construction of flexible natural gas-fired power plants and the growing Western Energy Imbalance Market.

**Natural gas prices low and forecasted to remain low**

Market prices in the Northwest are often set by the production cost of natural gas-fired power plants. The price that a natural gas-fired plant can profitably sell into the wholesale market (and thus set market prices) depends on a number of factors including the price of natural gas.\(^7\) For a modern combined cycle combustion turbine a $1 change in the price per MMBtu of natural gas equates to a roughly $7 change in the cost to generate a megawatt hour of electricity.\(^8\)

<table>
<thead>
<tr>
<th>Cost of gas per MMBtu</th>
<th>Fuel cost per MWh for an efficient gas unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ 2.00</td>
<td>$ 14.00</td>
</tr>
<tr>
<td>$ 3.00</td>
<td>$ 21.00</td>
</tr>
<tr>
<td>$ 4.00</td>
<td>$ 28.00</td>
</tr>
<tr>
<td>$ 5.00</td>
<td>$ 35.00</td>
</tr>
</tbody>
</table>

Natural gas prices began to fall during the 2008 recession, and have stayed low in large part due to new production techniques (directional drilling combined with hydraulic fracturing) which increased supply. Current price forecasts for natural gas are lower than forecasts from a few years ago. If these expectations prove true, this will help keep Northwest wholesale power prices low.

**Figure 4 – Henry Hub natural gas prices\(^9\)**

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\(^7\) Other factors include unit heat rate and variable operations maintenance costs.

\(^8\) Assuming a heat rate of 7 MMBtu per MWh (commonly expressed as 7,000 Btu/kWh).

\(^9\) Historical data from Thomson Reuters via the EIA. Forecasts from EIA Annual Energy Outlook reports, futures from the Intercontinental Exchange (July 2016). Unless stated otherwise all dollar values in this report are nominal.
Impact on wholesale electricity prices

The combination of increased energy supply, decreased firm requirements and decreased fuel prices has created a climate of low wholesale electricity prices in the Northwest. Prices are low today compared to the recent past, and are forecasted to remain relatively low under business as usual.

Figure 5 – Mid Columbia power prices\(^\text{10}\)

The IRP blend forecasts above do not include carbon pricing (carbon pricing would likely increase prices). Also, note the similarity of historical power and natural gas prices. This is due to the large role natural gas prices have played in setting electric power market prices.

Caution – business as usual may not be

Today, wholesale electricity prices and price forecasts are low, but forecasts just five years ago were significantly higher, and in retrospect, missed the mark. A number of potential policies, largely related to carbon emissions and hydraulic fracturing, could push energy prices up. Beyond policy changes, there could be an increase in demand for electric power from electric vehicles, indoor agriculture, industry, or other users, leading to increased prices. On the other hand, if natural gas prices stay low and/or new variable energy resources increase the energy surplus, power prices could remain low or decrease. Utilities and others must make their own market forecasts taking all factors into consideration.

\(^\text{10}\) Blend of utility IRP forecasts, historical data from ICE via the EIA, and ICE futures (futures from July 2016).
The value of hydropower in the Northwest

This report discusses the value of hydropower in today’s Northwest power system. There are many factors that could change the system and the subsequent value of hydro in the Northwest. These factors include renegotiations on the Columbia River Treaty, future biological opinions impacting river operations, changes to runoff due to climate change, and potential electric power system regulations.

Different types of hydro projects

Every utility in the Northwest either owns hydro generation or has access to hydro generation via the federal power system. Roughly 60% of the region’s hydro generation comes from the federal system, with the remaining 40% split between public and investor owned utilities.11

The Northwest has hundreds of hydro projects that range in size from under one megawatt nameplate capacity to over 6,000 MW. Larger projects in the Northwest produce most of the region’s generation, as seen in Table 3.

<table>
<thead>
<tr>
<th>Annual energy under critical water</th>
<th>MWa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest hydro total</td>
<td>11,118</td>
</tr>
<tr>
<td>From dams &gt; 100 nameplate MW (approx.)</td>
<td>9,500</td>
</tr>
</tbody>
</table>

Each project has a unique set of resource characteristics. Hydroelectric facilities in the Northwest can be roughly classified as:

- **Storage projects** have reservoirs with the ability to store water for months at a time and can release the water when needed. Northwest storage dams are often found relatively upstream on rivers, allowing their storage to benefit downstream dams via coordination.

- **Run-of-river projects with pondage and upstream coordination** work with each other and storage projects to maximize the value of their generation.12 Many of the projects on the Columbia, Snake and other rivers fall into this category.

- **Run-of-river only projects** are not part of a coordinated system and have very limited storage. As such, their power generation is largely dependent on runoff patterns. In the Northwest these are typically smaller projects.

In addition to generating electricity, hydro facilities can provide flood control, irrigation, ecosystem functions, recreation and other functions. A hydro project’s ability to generate power can be significantly influenced and limited depending on the requirements of its other functions. Although greater storage and coordination tends to lead to increased peaking capability and flexibility, it is important to keep in mind that other factors affect hydroelectric generation as well.

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11 Data from the 2016 PNUCC Northwest Regional Forecast under critical water, yearly operations will vary.

12 Pondage is a term for limited storage.
Value does not equal price

This report explores various hydroelectric power attributes, and at times, attaches dollar values to those attributes. However, value and price are different for multiple reasons, including:

- In this report, the value of peak capacity and flexibility is presented as the avoided cost of new generation, and utilities may be able to find lower cost alternatives to provide these services.

- Not all Northwest utilities will benefit from the resource attributes discussed in this report and thus may not be willing to pay for them.

- The values are not necessarily cumulative. For example, a hydro project holding spinning reserves may have a decreased ability to provide other services.

- Prices are set by supply and demand. Less demand or greater supply for any power product will tend to lead to lower prices, all other factors being equal. And the inverse is true as well.

An example of this can be seen in the New England ISO forward capacity auction. For years, prices were below $40/kW-year due to “excess capacity in the region.” In recent years, due to supply concerns, auction prices increased to $80 - $120 per kW-year (see Figure 6). Similarly, in the California ISO the price for regulation (up and down) increased sharply in February 2016 following an increase in requirements that raised demand for the product.

![Figure 6 – ISO NE forward capacity auction clearing price](image)

An example of this can be seen in the New England ISO forward capacity auction. For years, prices were below $40/kW-year due to “excess capacity in the region.” In recent years, due to supply concerns, auction prices increased to $80 - $120 per kW-year (see Figure 6). Similarly, in the California ISO the price for regulation (up and down) increased sharply in February 2016 following an increase in requirements that raised demand for the product.

ISO NE. Costs converted from monthly to yearly for ease of comparison to values in this report.

**Energy value**

The energy output of hydro projects varies due to runoff patterns. During years with more runoff the hydro system generates more energy, all other factors being equal. The range of annual energy from the hydro system can be quite large – looking at the Northwest in aggregate, annual energy generation from 1990 to 2015 ranged from just over 11,000 MWa to nearly 20,500 MWa.\(^{15}\)

![Figure 7 – Hydro energy production in the Northwest varies year-to-year\(^{16}\)](image)

More hydropower is generated on-peak than off-peak, which increases the average value of hydro energy since electricity tends to be more expensive on-peak. However, due to natural runoff patterns, most projects generate more energy during the spring which is typically a low demand and price season.

For this report, the value of energy is quantified using a Mid-Columbia wholesale market price forecast. The concept is a utility buying energy would see a price based off the wholesale market, as would a utility selling energy. This is the market value of the power, not the production cost. On a production cost basis hydropower is usually one of the least expensive resources in the Northwest.

In order to capture the hourly and seasonal shape of hydro generation, a monthly on-and-off-peak forecast is paired with a historical hydro generation shape.\(^{17}\) The value of energy in this analysis is calculated at $38 per MWh (levelized over 20 years to compare to other values in this report).

Some utilities and organizations will have different price expectations for the Mid-Columbia market (or other methods for valuing energy) and thus a different energy value. Long term price forecasting is highly dependent on natural gas price forecasts, resource retirements/additions, and environmental policy forecasts.

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\(^{15}\) EIA data for total hydro generation in ID, MT, OR and WA.

\(^{16}\) *Ibid* for hydro gen, load forecast from 2016 PNUCC NRF. Note that the hydro generation varies by month.

\(^{17}\) 2013 and 2014 BPA data used for shape. Forecast blends a 2015 Mid-C monthly on/off peak for 2016-35 with an ICE Mid-C future strip and historical data (historical until June 2016, 50% ICE remainder year 2016, 25% ICE in 2017, 10% ICE in year 2018). Does not include carbon pricing.
Peak capacity value

Many hydro projects can flex to generate more power during high demand hours. This can be of significant value to a utility as it is necessary to have enough power to meet high demand hours. In the Northwest, the hydro system provides more peak capacity than all other resources combined, even under critical water conditions.\textsuperscript{18}

The value of having resources that can reliably generate power when needed varies by utility. One important factor is if the utility is peak capacity surplus or deficit. Surplus utilities have more peak capacity resources than they need for their system, whereas deficit utilities may need new peak capacity resources and/or rely on the power market for capacity.

— A peak capacity surplus utility may see value in selling their surplus if a buyer is available.

— A peak capacity deficit (or neutral) utility may see the value of hydro’s capacity as its avoided cost, i.e. how much it would cost to build/contract another peaking resource.

For this report the cost of a new natural gas-fired frame power plant is used as the avoided peak capacity value proxy and is estimated at $100/kW-year.\textsuperscript{19} Frame units are often seen in utility integrated resource plans as the next capacity resource of choice. The method to value capacity and the avoided cost of new resources differs by utility. A 2015 review of capacity costs by the Eugene Water and Electric Board found a range of costs from $24 to $144/kW-year.\textsuperscript{20}

Not all utilities will benefit from hydro’s peak capacity. For example, utilities with surplus capacity may have difficulty selling this surplus, in part due to the lack of a formal Northwest capacity market.

Lastly, the peak capacity value of hydro differs by project. Some projects, particularly storage or run-of-river projects with pondage and upstream coordination, are able to reliably provide high levels of peak capacity. Run-of-river projects without storage or coordination benefits may have their peak capacity contributions more dictated by run-off patterns.

\textsuperscript{18} 2016 PNUCC NRF data, sustained 1 hour Jan 2017 peak. Utility firm requirements and a 12% planning margin.
\textsuperscript{19} $100/kW-year includes stripping off the energy value of a frame unit, but not other ancillary service values.
\textsuperscript{20} Eugene Water and Electric Board memo. Costs converted from monthly to yearly for comparison to other values used in this report.
Flexibility value

As noted earlier, there is a need to have enough generating capacity to meet the highest electric power demand hours, and enough fuel to meet energy needs. Additionally, during all times, supply and demand must remain matched to ensure reliability. Hydropower projects, and other flexible resources, help keep the system in balance.

Electric resource flexibility is a broad and at times ambiguous term used to describe a plethora of functions performed to keep the system in balance. Three functions often placed under the flexibility umbrella are:

- Balancing the system on a second-by-second basis. This is achieved using resources that can provide frequency response (moment to moment balancing) and resources connected to automatic generator control (which provides sub-minute balancing known as regulation).

- Keeping the system in balance on a sub-hourly basis. This is accomplished using spinning and non-spinning resources. Spinning resources are online and ready to react to changes in the power system, whereas non-spinning resources must be able to turn on and provide power quickly (less than 10 minutes). These spin and non-spin resources are used to satisfy a number of reserve requirements.

- Meeting forecasted changes in demand. For example, California utilities depend on flexible resources to come online in the afternoon and take over for solar power as the sun goes down. This can be achieved by having resources that can quickly and reliably increase their generation.

The table below lists resource attributes along with the reserve services that they can provide. Keep in mind that the terminology used to define reserves may differ by organization and/or region.

<table>
<thead>
<tr>
<th>Resource is…</th>
<th>Can provide…</th>
<th>Time step</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinning with frequency response governor</td>
<td>Frequency control</td>
<td>Momentary</td>
</tr>
<tr>
<td>Spinning with automatic generation control</td>
<td>Regulation reserves</td>
<td>Sub minute to 10 min</td>
</tr>
<tr>
<td>Spinning</td>
<td>Operational reserves, load following, contingency reserves, etc.</td>
<td>Minute to hour</td>
</tr>
<tr>
<td>Non-spinning (but can be online &lt; 10 min)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Not all hydro projects can be used for flexibility. Some projects may be limited in how they can alter their generation for many reasons, including fish and wildlife, flood control and recreation. For example, downstream flow requirements and/or reservoir level requirements may constrain hydro flexibility.

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21 Spinning resources may also be used as non-spinning reserves.
Valuing flexibility/ancillary services

A look at data from the California ISO ancillary service market, as well as the avoided cost of a new flexible resource, provides a sense of the value of flexibility in this report.\(^{22}\)

In the CAISO, hydropower is used to provide many ancillary services, particularly spinning reserves. Hydro is likely preferred to natural-gas fired generation as a spinning reserve due to efficiency. Gas units often run at sub-optimal generation levels when providing spinning reserves.

![Figure 9 – CAISO ancillary service procurement by resource type (figure from CAISO)](image)

The table below shows the average price of ancillary services in the CAISO in 2015, both in day-ahead and real time.\(^{23}\) Prices in the Northwest would vary.

<table>
<thead>
<tr>
<th></th>
<th>Day ahead</th>
<th>Real time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation down</td>
<td>$3.13</td>
<td>$4.60</td>
</tr>
<tr>
<td>Regulation up</td>
<td>$5.50</td>
<td>$7.89</td>
</tr>
<tr>
<td>Spin</td>
<td>$3.68</td>
<td>$7.56</td>
</tr>
<tr>
<td>Non-spin</td>
<td>$0.50</td>
<td>$2.14</td>
</tr>
</tbody>
</table>

Another way to value flexibility is the price difference between a frame gas unit and an aeroderivative gas unit. The idea is a utility that just needs capacity would build a frame unit, whereas one that needs flexibility would build an aero unit. For this report an aero unit is priced at roughly $135/kw-year as compared to $100/kw-year for a frame unit, making the flexibility premium $35/kw-year.\(^{24}\)

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\(^{23}\) Regulation prices (up and down) can be volatile.

\(^{24}\) This includes stripping off the energy value.
Hydro flexibility helps integrate other renewable resources

Today, there are over 8,000 MW of nameplate wind generation in the Northwest, with over 4,500 MW of the total in the BPA Balancing Authority. Many of these projects, particularly those in the BPA Balancing Authority, are integrated in part by hydro projects. Integration generally entails making sure there is room to increase or decrease generation as wind/solar generation changes and if a forecast is missed (integration can be performed by other resources as well). The hydro system is well suited for this task as it can increase or decrease its generation by hundreds of megawatts within seconds.

Figure 10 – Wind generation has grown rapidly in the Northwest

Wind project owners pay fees of $3 to $7/MWh for integration in the BPA Balancing Authority (this is a fee wind owners pay to BPA, not the value of the hydro system per MWh). Other balancing authorities have different costs for balancing wind. For example, Idaho Power found in a 2013 study that the cost to integrate new wind resources was in excess of $15/MWh, and saw increasing costs of integration as wind penetration increases.

BPA has a separate fee to integrate solar power, approximately $1.50/MWh. Idaho Power has calculated the cost to integrate solar into their system at roughly the same cost provided there are less than 300 MW nameplate of solar in their balancing authority, and observed increasing integration costs with increased resource penetration.

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25 Including IPP and non-Northwest utility wind projects.
26 BPA Fact Sheet, “A Northwest energy solution: Regional power benefits of the lower Snake River dams.”
27 BPA 2016 rates assuming a 30% wind capacity factor (fee is per kW), does not include possible additional fees.
28 Idaho Power, Wind Integration Study Report, 2013. Note that the wind integration service that Idaho Power provides may differ from the service provided by BPA.
29 BPA 2016 rates assuming a 20% solar capacity factor (fee is per kW), does not include possible additional fees.
Renewable portfolio standard compliance value

Montana, Oregon and Washington have renewable portfolio standards (RPS) requiring many utilities to meet a percentage of their retail power sales with qualified renewable energy and/or renewable energy credits (RECs). Although the hydro system is largely excluded from RPS compliance, hydropower can play a limited role:

- Depending on the state, RECs can be generated from qualifying hydro efficiency upgrades, qualifying low impact hydro (limited), and approved new small hydro projects.
- BPA and Mid-Columbia power contracts can offset the need to comply with the RPS in Oregon.

There is a financial value for not having to purchase RECs or being able to sell excess credits. Most REC trading is done on bilateral markets, with near-term vintage RECs trading around $1 to $5 (REC prices tend to increase with later vintages).\(^{31}\) REC prices could increase in the future as Oregon moves to a higher RPS (50% by 2040) and as Washington RECs effectively become compliance mechanisms for the recently finalized state level Clean Air Rule.

**CO\(_2\)** offset value

Hydropower helps keep CO\(_2\) emissions low in the Northwest. Although hydropower generates the majority of electricity in the Northwest, the region depends on coal and natural gas-fired units as well. During years where the Northwest generates less hydropower, coal and natural gas-fired units run more and increase regional CO\(_2\) emissions. Figure 11 explores the inverse relationship between hydro generation and regional CO\(_2\) emissions.\(^{32}\)

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\(^{31}\) As noted in a 2012 Oregon PUC filing (Order 12 375).

\(^{32}\) Region defined as ID, MT, OR & WA, Jim Bridger & 50% of Valmy (with IPPs). Correlation (.85) from 2002 to 2015.
Thanks to hydropower, and other CO₂ free resources including wind and nuclear power, Northwest electricity has roughly half the carbon intensity of the US average. Figure 12 illustrates the annual average generating mix in the Northwest and the remaining US. In the Northwest CO₂ free resources, led by hydro, dominate the power generation picture, whereas the US is more dependent on coal and gas.

![Figure 12 – Average generation in Northwest and remaining US, 2013 to 2015](image)

Today, the Northwest does not have a formal carbon pricing program. This makes valuing the CO₂ free nature of hydropower difficult. Adding to the challenge is determining what resources are being displaced by hydropower.

To add perspective, Table 6 shows the CO₂ intensity of the Northwest power system as defined by this report, the larger Northwest Power Pool, and the Western Electricity Coordinating Council. It also estimates the premium one MWh of CO₂ free electricity might receive by multiplying the CO₂ intensity by the price paid for a ton of CO₂ at a recent California Air Resources Board cap-and-trade auction.

<table>
<thead>
<tr>
<th>Power intensity by area</th>
<th>CO₂ intensity</th>
<th>CARB price</th>
<th>CO₂ free premium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest average (PNUCC)</td>
<td>0.27/MWh</td>
<td>$13/ton</td>
<td>$3/MWh</td>
</tr>
<tr>
<td>NWPP average (EPA)</td>
<td>0.37/MWh</td>
<td>$13/ton</td>
<td>$5/MWh</td>
</tr>
<tr>
<td>WECC average (EPA)</td>
<td>0.43/MWh</td>
<td>$13/ton</td>
<td>$6/MWh</td>
</tr>
</tbody>
</table>

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33 EIA data. Northwest defined as all generation in ID, MT, OR & WA plus Jim Bridger and 50% of Valmy.
34 *Ibid*.
35 2009 data. This value will vary yearly depending on many factors, including hydro generation.
36 CARB and Quebec joint auction number 7, May 2016.
Storage value

All other factors equal, storage enhances the value of hydroelectric projects. Storage gives Northwest hydro projects fuel (water) to provide energy, capacity, flexibility and other services year-round.

The Northwest hydro system is somewhat limited in its storage ability relative to its runoff as compared to other regions of the US or the world. The Federal Columbia River Power System, the largest hydroelectric system in the Northwest, can store around 30% of its annual runoff. In comparison, the Colorado and Missouri systems can store 200% to 300% of their total runoff. This makes coordinated operations between hydro projects especially important in the Northwest since most of the water flows into the Pacific Ocean each year. This also makes Northwest hydro generation more dependent on runoff patterns.

Other ancillary services values

The hydro system can provide other ancillary services including but not limited to:

Reactive supply and voltage control

Healthy voltages are an indication of the wellbeing of the power system operation in real time. While the transmission system can provide some reactive supply in support of appropriate voltage levels (through capacitor banks, shunt reactors, and the lines themselves), the majority of the reactive supply needed to operate the Western grid comes from its rotating machines – generators. Northwest hydro generation is particularly useful as it can provide a relatively broad dynamic range of reactive supply, ‘boosting’ when voltage needs to be raised and ‘bucking’ when voltage needs to be lowered. Some hydro projects can also condense (provide reactive supply even when not generating).

Black start

Although widespread outages are rare, they can occur. When they do, recovering from the disturbance as quickly as possible is critical to minimizing their impact. If it is necessary to put the power system back together from a blackout, a generator that can restart quickly can aid in the effort. Some generation can take hours to days to be brought on line after an outage. Hydro resources can normally be operational very quickly to support the restoration, generally have adequate fuel supply, and can provide a sustained response.

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37BPA, The Columbia River System Inside Story.
**Power grid inertia**

Good frequency management in real time is another measure of a power system’s health and resilience. As the generation fleet continues to evolve away from large coal units and toward more wind and solar resources, one impact is the reduction of sources of inertia and governor response. Inertia provided by the large rotating mass of traditional generators has historically kept the Western Interconnection’s frequency response following a disturbance, such as the sudden loss of generation, from dropping too fast, and governor response limits the frequency decline.

Excessive and sustained low frequency can cause load loss and damage equipment. For this reason, frequency performance is subject to mandatory reliability criteria. The Northwest’s hydro resources have a lot of mass and provide significant inertia and governor response. These help arrest frequency decline and support speed recovery – both important reliability factors. In addition, the quantity of available inertia operating on the system is an important consideration in determining the amount and timing of remedial action schemes (RAS) in the west. Without RAS, safe transmission capacity limits must be lowered, limiting power transfers within the grid.

**RAS are controls that automatically make power system adjustments following the loss of either key generation or transmission. They allow higher transmission transfer capacity limits than would be possible without them.**

**Non-power values and environmental issues**

This paper focuses on the power values of the hydro system, and does not attempt to discuss or quantify non-power values including flood control, recreation, irrigation, fish and wildlife, and navigation. Nor does this paper weigh in on the continuing discussion on the environmental impacts of dams.
Putting it all together

Table 7 shows the sample values for the resource characteristics discussed in this report. Not all the values are directly comparable. Estimated values were not converted to the same units because each hydro project has different characteristics (without knowing total annual generation, value per MWh cannot be converted to value per kW-year). Additionally, the values are not necessarily cumulative. For example, a hydro project holding spinning reserves may have a decreased ability to provide other services.

Table 7 – Putting it all together

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Sample values (not cumulative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>$38/MWh</td>
</tr>
<tr>
<td>Peak capacity</td>
<td>$100/kW-year</td>
</tr>
<tr>
<td>Renewable integration</td>
<td>Not calculated</td>
</tr>
<tr>
<td>Flexibility/load following</td>
<td>$1 - $8/MWh (2015 CAISO prices)</td>
</tr>
<tr>
<td>CO₂</td>
<td>$3 - $6/MWh (est. CAISO premium)</td>
</tr>
<tr>
<td>REC value</td>
<td>$1 - $5+/MWh</td>
</tr>
<tr>
<td>Other services</td>
<td>Not calculated</td>
</tr>
</tbody>
</table>

Going forward, the value of capacity and flexibility may grow compared to the value of energy. Today, the Northwest is relatively surplus regarding annual energy, and fuel prices are low compared to a decade ago. If these trends continue, the value of wholesale electricity in the Northwest may remain low. However, the value of flexibility may increase as more variable energy resources are added to the system, and the value of capacity could grow as the Northwest power system sees forecasted deficits in part due to the retirements of large coal units.

Even though electricity is traded at a wholesale level, there is not much activity in trading capacity, flexibility and other products in the Northwest. This could make it difficult for a surplus utility/organization to capitalize on these values. This is not strictly a Northwest issue – in a 2016 report the US Department of Energy listed “enhanced market structures that appropriately compensate and incentivize new and existing hydropower” as roadmap action area to optimizing existing hydro and spurring new hydro development in the US.

As the needs of the power system change, so does the value of existing resources. While this could bring challenges, it could also bring opportunities to find new values in legacy resources. Hydropower today, with its ability to provide a full suite of power services, remains a valuable part of the Northwest power system. PNUCC looks forward to furthering the discussion on the value of hydropower, and other resources, in this ever changing energy landscape.

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38 US DOE, Hydropower Vision.
Appendix A – Trends in hydro system use

As part of this work, PNUCC reviewed historical hydro system operations in the Northwest to look for trends. The power system has changed in the last decade, becoming energy surplus on an annual basis, experiencing falling wholesale electricity prices, and having an influx of variable energy resources. This change has likely influenced how hydro projects are operated.

Although no clear answers emerged from the following analysis, it appears the range of hydro’s daily generation is smaller today than in 2005. This could imply less flexibility on the system. However, insufficient data were available to draw firm conclusions and it is difficult to tell if this trend is real or a reversion to the mean. Additionally, other non-flexibility related factors, including market prices and maintenance, also affect operations and can be difficult to control for. Going forward, it could be important to better understand the flexibility limits of the hydro system and how its ability to provide peak capacity and flexibility may be affected by the changing power system and non-power constraints.

Trends in daily hydro system range

Daily hydro generation range is defined here as the difference between the maximum and minimum amount of hydro generation over the course of a day, as shown in Table 8. To compare this change over time, the average daily range by month was calculated. For example, in August, the daily range was calculated for all 31 days, and then averaged.

Figure 13 shows the average daily range for three sets of dams in August from 2005 to 2015 (one set being the federal system). Water conditions in August as measured by volume at The Dalles (right y-axis) are plotted as well to give a sense of fuel constraints. The y-axis on the left has been normalized to compare the three sets of dams. For this comparison, 100% is equal to the greatest average daily range per set of dams. For example, if the greatest range for Dam set 3 was 2,000 MW; it occurred in 2006 when the red line is at 100%.

<table>
<thead>
<tr>
<th>Generation</th>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>2,000</td>
</tr>
<tr>
<td>Minimum</td>
<td>1,200</td>
</tr>
<tr>
<td>Range</td>
<td>800</td>
</tr>
</tbody>
</table>

Table 8 – Example hydro range calculation

Figure 13 – Hydro range trends, August 2005 to 2015
Figure 13 (previous page) shows a narrowing of the August hydro range from 2005 to today. This trend is also present in other months of the year. The data show a negative correlation between average monthly water flows and average monthly hydro range (this was only tested on two of the three dam sets due to data availability). There also is a negative correlation between monthly wind generation and hydro system range and a positive trend between hydro system range and load (these last two correlations were only tested on the federal system).\textsuperscript{39}

One of the datasets has values back to 1990. Looking at those data shows a different picture (Figure 14).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure14.png}
\caption{Average daily hydro range, August 1990 to 2015}
\end{figure}

In this dataset, the hydro system was running at a narrower range in the 1990’s than during the 2000’s, and then declines again around 2010. This decreased range in the 1990’s could be from less activity on power markets, different non-power constraints, and more flat load customers (via direct service industries). Or the wider range in the 2000’s could be the exception and the narrower range seen in the 1990’s and post 2010 the norm. As such, the decline in hydro’s daily range from 2005 to today could simply be a reversion to the mean.

As the need for power system flexibility grows, hydro generation may be used to meet this demand. It is important to recognize the hydro system is not without limits, and it could be important for system operators to prioritize how hydropower’s flexibility is used to maximize its value. PNUCC looks forward to examining and discussing this issue with Northwest utilities, BPA and other organizations.

\textsuperscript{39} There is a significant and positive correlation between water flows and wind generation in this dataset.
Appendix B – Hydro as compared to other resources

Hydroelectricity can provide a full suite of power system products including energy, peak capacity, flexibility and other services. Not all electric generating resources can provide this range of services, especially without carbon dioxide emissions.

The table below is adapted from a 2011 PNUCC report, “Capabilities of Electric Power Resources.” It shows the estimated abilities of various power resources.40

Table 9 – Sample resource characteristics of electric power resources

<table>
<thead>
<tr>
<th></th>
<th>Peak capacity</th>
<th>Annual energy</th>
<th>Regulation</th>
<th>Spin reserves</th>
<th>Non-spin reserves</th>
<th>Storage</th>
<th>CO2 free (at gen)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroelectric</td>
<td>yes, water dependent</td>
<td>yes, water dependent</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>(large project)</td>
<td>yes, water dependent</td>
<td>yes</td>
<td>yes, could be limited</td>
<td>yes, could be limited</td>
<td>yes, could be limited</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Gas (CCCT)</td>
<td>yes</td>
<td>yes</td>
<td>yes, could be limited</td>
<td>yes, could be limited</td>
<td>yes, could be limited</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Gas (frame SSCT)</td>
<td>yes</td>
<td>yes, could be limited</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Gas (flexible SSCT)</td>
<td>yes</td>
<td>yes, could be limited</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Coal</td>
<td>yes</td>
<td>yes</td>
<td>limited</td>
<td>limited</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Nuclear</td>
<td>yes</td>
<td>yes</td>
<td>limited</td>
<td>limited</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Biomass</td>
<td>yes</td>
<td>yes</td>
<td>yes, could be limited</td>
<td>yes, could be limited</td>
<td>yes, could be limited</td>
<td>no</td>
<td>depends on fuel</td>
</tr>
<tr>
<td>Geothermal</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Solar, PV</td>
<td>location dependent</td>
<td>yes, location dependent</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Solar, thermal</td>
<td>limited to yes</td>
<td>yes, location dependent</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Wind</td>
<td>location dependent</td>
<td>yes, location dependent</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Demand response</td>
<td>reduces peak need</td>
<td>no</td>
<td>program dependent</td>
<td>program dependent</td>
<td>program dependent</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>reduces peak need</td>
<td>reduces energy need</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Batteries</td>
<td>yes</td>
<td>uses energy</td>
<td>yes</td>
<td>yes, depends on size</td>
<td>yes, depends on size</td>
<td>yes</td>
<td>N/A</td>
</tr>
</tbody>
</table>

40 This table is for illustrative purposes only – it is not a definitive guide to resource characteristics. Utilities and other organizations may assume different characteristics from the same resources.
Report Sources


