Energy+Environmental Economics

Gordon Butte Pumped Storage

Colstrip 1&2 Replacement Analysis

Prepared by E3 for Absaroka Energy

December 2016

Analysis Overview

- Absaroka Energy asked E3 to compare the cost of two alternatives for providing energy (250 aMW) and capacity (300 MW) to replace Puget Sound Energy's share of Colstrip 1&2
  - **MT Alternative:** Gordon Butte Pumped Storage facility paired with 250 aMW of Montana wind (located at Martinsdale, MT) and 300 MW of existing long-term firm transmission rights from Montana to PSE
  - **PNW Alternative:** An Aeroderivative CT generator (located in Washington state) paired with 250 aMW of Washington wind (located at the Columbia Gorge)

Gordon Butte Overview

+ Gordon Butte Pumped Storage Facility

- 400 MW pumping / generating capacity
- Ternary units allow seamless transition between generating and pumping modes
- 8.5 available hours of storage
- 83% efficiency
- Sited to allow access to transmission currently used to deliver power from Colstrip coal plants in Montana. Some of this transmission capacity will become available when Colstrip 1&2 are retired (no later than 2022).
- FERC License issued December 14, 2016.

Analysis Scope

+ Quantified benefits of pumped storage

- Shaping of wind resource to maximize value, avoid curtailment, and increase transmission utilization
- Ability to provide firm capacity on demand (given available capacity)
- Emissions-free flexible resource helps with wind integration
- Time-based market arbitrage opportunities (given available capacity)

+ Potential benefits of pumped storage not considered here

- Ability to provide ancillary services (Load-following, Regulation, Spinning & Non-Spinning Reserves, Frequency Response)
- Sub-hourly energy dispatch savings
- Value derived from participation in the Energy Imbalance Market

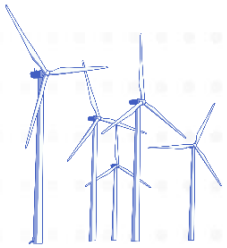
MT Alternative

Year = 2030

Dispatch value of energy provided to Puget Sound is determined by market prices at Mid-C

Washington

Montana



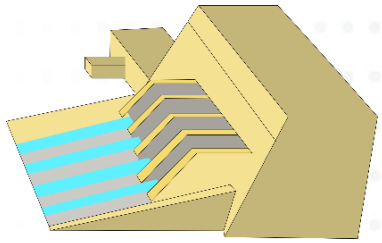
250 aMW Montana,
CF ~46%

Puget Sound Energy

300 MW
(1.5% Losses)

MT Sales

Mid-C Market



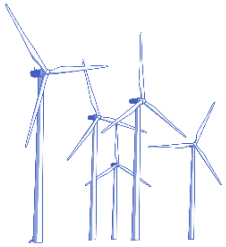
Gordon Butte Pumped Storage Facility

PNW Alternative

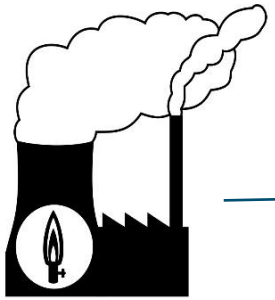
Year = 2030

Washington

Montana



250 aMW Columbia Gorge, CF ~34%



Aero CT Gas Plant

Mid-C Market

Puget Sound Energy

300 MW
(1.5% Losses)

MT Sales

Dispatch value of energy provided to Puget Sound is determined by market prices at Mid-C

Wind Capacity Credit

- Absaroka also asked E3 to investigate how geography-based differences in Effective Load Carrying Capability (ELCC) between wind sites might influence the results of the analysis
  - To achieve this, E3 sized both the pumped storage and Aero CT resources so that they provide 300 MW of capacity *when paired with the planning capacity assigned to wind resources*

Assumption	*WA Wind – Installed Capacity*	*WA Wind – Planning Capacity*	Aero CT Size	*MT Wind – Installed Capacity*	*MT Wind – Credited Capacity*	Pumped Storage Size
No Capacity Credit for Wind	*736 MW*	*0 MW*	**300 MW**	*548 MW*	*0 MW*	**300 MW**
Capacity Credit for Wind	*736 MW*	*37 MW (5%)*	**263 MW**	*548 MW*	*137 MW (25%)*	**163 MW**

Modeling Efforts

- **Fixed costs for the resources were calculated using E3 financial models and publicly available data sources**
- **Hourly dispatch values were calculated using an adapted version of the E3 REFLEX model**
  - REFLEX is a multi-stage production simulation model with integer variables formulated for high renewable penetrations
    - Hourly modeling of energy values and arbitrage opportunities
    - Hourly generation profiles for non-dispatchable (wind) generation
    - Priced-based dispatch of controllable resources
    - 24-hour optimization of storage resources

Data Sources – Wind Resource Characteristics

- **Wind shapes provided by Absaroka Energy**
  - E3 adjusted to reflect most recent capacity factors
    - Washington (Columbia Gorge): 34% Capacity Factor
    - Montana (Martinsdale, MT): 46% Capacity Factor
  - Nameplate capacity sized to output 250 aMW over the course of the year
    - Columbia Gorge: 736 MW
    - Martinsdale: 548 MW
- **Wind planning capacity based on location of wind resources**
  - Reasonable estimates based on previous E3 analysis
    - Washington (Columbia Gorge): 5% Capacity Value
    - Montana (Martinsdale, MT): 25% Capacity Value

Data Sources – Other Resource Characteristics

- **Aero CT characteristics based on generators in the TEPPC Common Case**
- **Pumped storage operational characteristics provided by Absaroka Energy** (see previous slide)
- **Transmission losses of 1.5% Montana to BPA**
  - Based on Colstrip Transmission System losses from Broadview to Garrison

Data Sources – Cost / Pricing Characteristics

- **Wind capital costs based on NREL data**
- **Aero CT capital costs taken from Northwest Power and Conservation Council's 7th Power Plan**
- **Gordon Butte Pumped Hydro capital costs from Absaroka Energy**
- **2030 gas prices based on Henry Hub forwards and basis spreads**
  - 2030 chosen to represent "typical" future gas and power market conditions
- **Cost of existing firm transmission rights treated as a sunk cost**

Key Financial Assumptions

Metric	Assumption	Source
MT Wind LCOE	40 $/MWh	NREL capital costs, 46% CF, 2018 commencement (for PTC)
WA Wind LCOE	65 $/MWh	NREL capital costs, 34% CF, 2018 commencement (for PTC)
CT Levelized Fixed Cost	192 $/kW-yr.	NWPCC 7th power plan, Aero GT East**
Gordon Butte Levelized Fixed Cost	350 $/kW-yr.	E3 estimate based on GBEP Financial Model
Mid-C Prices	Vary by Hour	E3 projection for 2030 based on historical price patterns, resource mix, and gas price projection
MT Price Discount, Hours with Constrained Tx	6.9 $/MWh	Discount (buying and selling) during hours when wind exceeds capacity of 300 MW of existing firm transmission to deliver to PSE (approximates cost to wheel from MT to Mid-C on hourly nonfirm transmission)
Discount Rate	10%	Taken from GBEP Financial Model

** http://www.brattle.com/system/publications/pdfs/000/004/827/original/Resource_Adequacy_in_California_Calpine_Pfeifenberger_Spees_Newell_Oct_2012.pdf?1378772133*
***https://www.nwcouncil.org/media/7149910/7thplanfinal_appdixh_gresources.pdf*

Results – With Wind Capacity Value

+ **MT Alternative provides substantial benefits to PSE ratepayers:**

  - **$300 million** reduction in capital costs
  - **$53 million** reduction in levelized annual costs
    - **$481 million** NPV over 25 years
  - **$24/MWh** reduction in levelized energy costs (250 aMW)

Results – Wind Provides Planning Capacity

	P-PNW	P-MT
GENERATION SUMMARY		
Wind Energy (aMW)	**250**	**250**
Wind Capacity (Nameplate MW)	**736**	**548**
Wind Planning Capacity (MW)	**37**	**137**
Aero CT Capacity (ME)	**263**	**-**
Pumped Hydro Capacity (MW)	**-**	**163**

	P-PNW	P-MT	MT BENEFITS
CAPITAL COSTS ($MILLIONS)			
Wind	$ 1,472	$ 1,096	
Aero CT	$ 290		
Pumped Hydro		$ 367	
Total	$ 1,762	$ 1,463	**$ 299**
	P-PNW	**P-MT**	**MT BENEFITS**
LEVELIZED FIXED COSTS ($millions)			
250 avg. MW Wind	$ 208	$ 153	
300 MW CT Capacity	$ 50	-	
300 MW Pumped Storage Capacity	-	$ 57	
Total	$ 258	$ 210	$ 48
ANNUAL DISPATCH VALUE ($millions)	$ 44	$ 49	$ 5
TOTAL ANNUAL BENEFITS ($millions)			**$ 53**
25-YEAR NPV BENEFITS ($millions)			**$ 481**
ENERGY COST BENEFIT ($/MWh)			**$24/MWh**

Results – Without Wind Capacity Value

- **Even ignoring the superior capacity value of MT wind, the MT Alternative provides significant benefits to PSE ratepayers:**
  - **$31 million** reduction in capital costs
  - **$18 million** reduction in levelized annual costs
    - **$163 million** NPV over 25 years
  - **$8/MWh** reduction in levelized energy costs (250 aMW)

Results – No Wind Planning Capacity

	P-PNW	P-MT
GENERATION SUMMARY		
Wind Energy (aMW)	**250**	**250**
Wind Capacity (Nameplate MW)	**736**	**548**
Wind Planning Capacity (MW)	**0**	**0**
Aero CT Capacity (ME)	**300**	**-**
Pumped Hydro Capacity (MW)	**-**	**300**

	P-PNW	P-MT	MT BENEFITS
CAPITAL COSTS ($MILLIONS)			
Wind	$ 1,472	$ 1,096	
Aero CT	$ 330		
Pumped Hydro		$ 675	
Total	$ 1,802	$ 1,771	**$ 31**
	P-PNW	**P-MT**	**MT BENEFITS**
LEVELIZED FIXED COSTS ($millions)			
250 avg. MW Wind	$ 208	$ 153	
300 MW CT Capacity	$ 57	-	
300 MW Pumped Storage Capacity	-	$ 105	
Total	$ 265	$ 258	$ 7
ANNUAL DISPATCH VALUE ($millions)	$ 44	$ 55	$ 11
TOTAL ANNUAL BENEFITS ($millions)			**$ 18**
25-YEAR NPV BENEFITS ($millions)			**$ 163**
ENERGY COST BENEFIT ($/MWh)			**$8/MWh**

Energy+Environmental Economics

Thank You!

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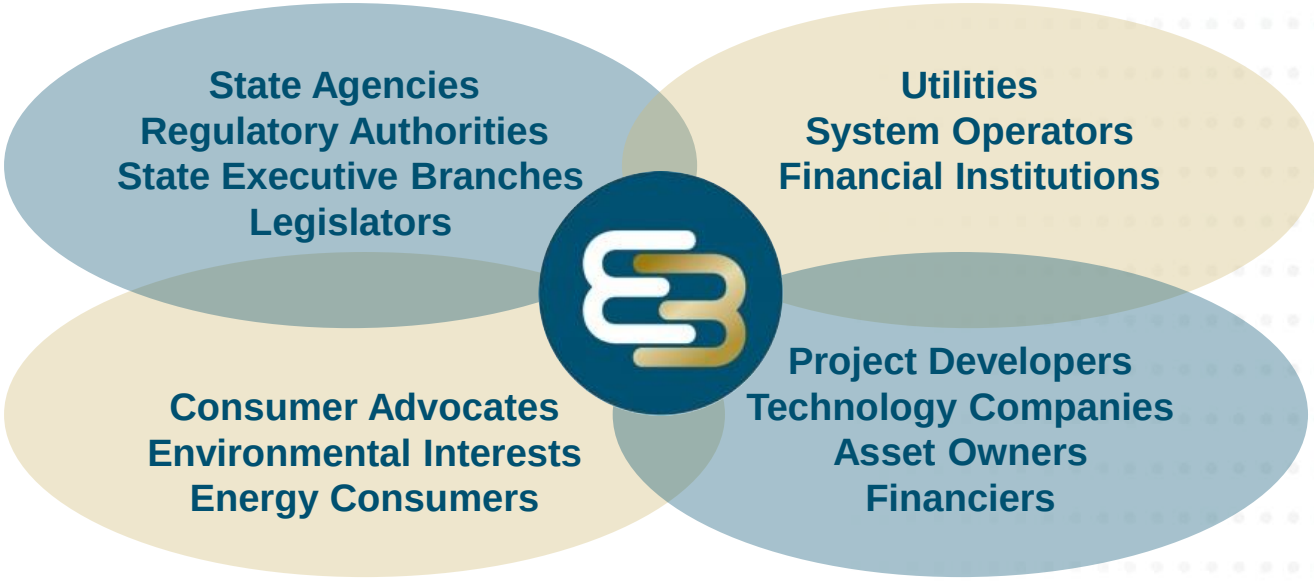
About E3

- Founded in 1989, E3 is an industry leading consultancy in North America with a growing international presence
- E3 operates at the nexus of energy, environment, and economics
- Our team employs a unique combination of economic analysis, modeling acumen, and deep institutional insight to solve complex problems for a diverse client base



Asset Valuation Overview

- E3 relies on the following key strengths to provide industry-leading consulting for asset valuation services

Reputation for high quality

Objectivity and transparency

Experience and integrity

Industry leading knowledge

- The Asset Valuation Group focuses on short and longer-term valuation analysis that provides unique insights for the following:

Traditional Bulk System Assets

Generation Assets
Renewable & Traditional
(Bulk and Distribution Level)

Energy Storage Assets
(Bulk and Distribution Level)

Pipeline Assets