Valuation Guidance and Techno-Economic Studies for Pumped Storage Hydropower

1.2.1.001

Hydropower Program

October 8, 2019

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Argonne National Laboratory

Project Overview

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Project Summary

The objective of this project is to advance state of the art in the assessment of value of PSH plants and their role in the power system. The goal is to develop a detailed step-by-step valuation guidance and apply it to two competitively selected PSH sites to test the valuation methodology and assist the developers in understanding the value streams available from their projects.

Project Objectives & Impact

- Develop a comprehensive, repeatable, and transparent valuation guidance that will allow for consistent valuation assessments and comparisons of potential new PSH projects or project design alternatives
- Test the PSH valuation guidance and its underlying methodology by applying it to two selected PSH projects
- Transfer and disseminate the PSH valuation guidance to the hydropower industry, PSH developers, and other stakeholders

Project Information

Project Principal Investigator(s)

Vladimir Koritarov (ANL)
Thomas Mosier (INL)
Gregory Stark (NREL)
Boualem Hadjerioua (ORNL)
Patrick Balducci (PNNL)

WPTO Lead

Samuel Bockenhauer

Project Partners/Subs

Absaroka Energy
National Grid
Rye Development
NARUC

Project Duration

- Project Start Date: January 2018
- Project End Date: June 2020

Alignment with the Program

Hydropower Program Strategic Priorities

Environmental R&D and Hydrologic Systems Science

Big-Data Access and Analysis

Technology R&D for Low-Impact Hydropower Growth

R&D to Support Modernization, Upgrades and Security for Existing Hydropower Fleet

Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

Alignment with the Hydro Program

Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

- Understand the needs of the rapidly evolving grid and how they create opportunities for hydropower and PSH.
- Investigate the full range of hydropower's capabilities to provide grid services, as well as the machine, hydrologic, and institutional constraints to fully utilizing those capabilities.
- Optimize hydropower operations and planning—alongside other resources—to best utilize hydropower's capabilities to provide grid services.
- Invest in innovative technologies that improve hydropower capabilities to provide grid services

With the rapidly changing power system mix, energy storage technologies, such as PSH, are increasingly important for balancing the system generation and load, and for providing a variety of grid services that ensure reliable and economical grid operations.

Developing a PSH valuation guidance will enhance the understanding of the true value that PSH brings to the grid.

As a result, this will create more favorable conditions for new PSH projects to come online, provide greater support for grid operations, and enable high penetrations of variable resources in the system.

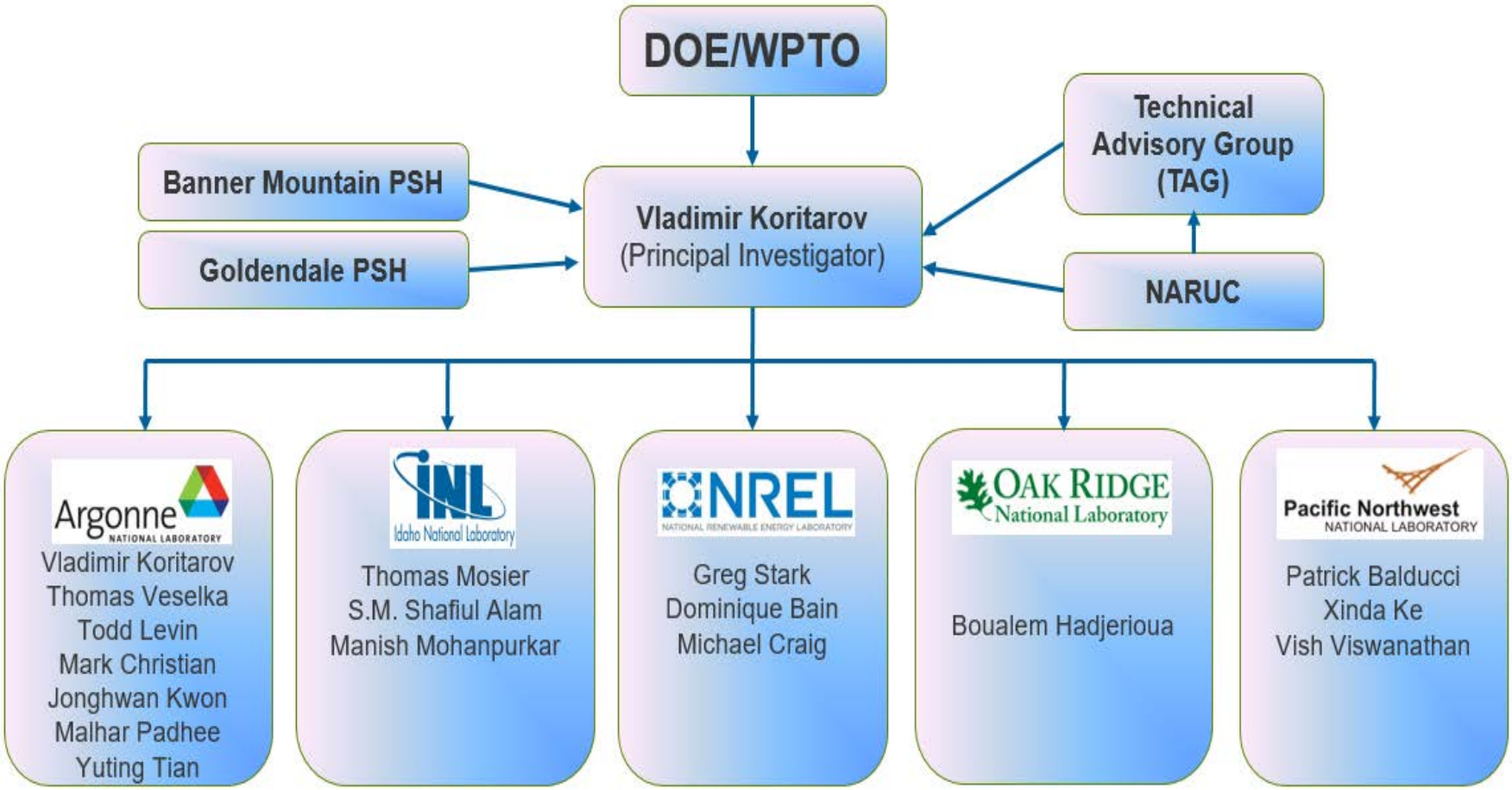
Project Budget

Lab	FY17	FY18	FY19 (Q1 & Q2 Only)	Total Project Budget FY17–FY19 Q1 & Q2 (October 2016 – March 2019)	
Lab	Costed	Costed	Costed	Total Costed	Total Authorized
ANL	$0K	$255K	$82K	$337K	$430K
INL	$0K	$97K	$28K	$125K	$245K
NREL	$0K	$142K	$74K	$216K	$396K
ORNL	$0K	$180K	$54K	$234K	$360K
PNNL	$0K	$193K	$88K	$281K	$336K
TOTAL	**$0K**	**$867K**	**$326K**	**$1,193K**	**$1,767K**

- The project is currently on time and budget

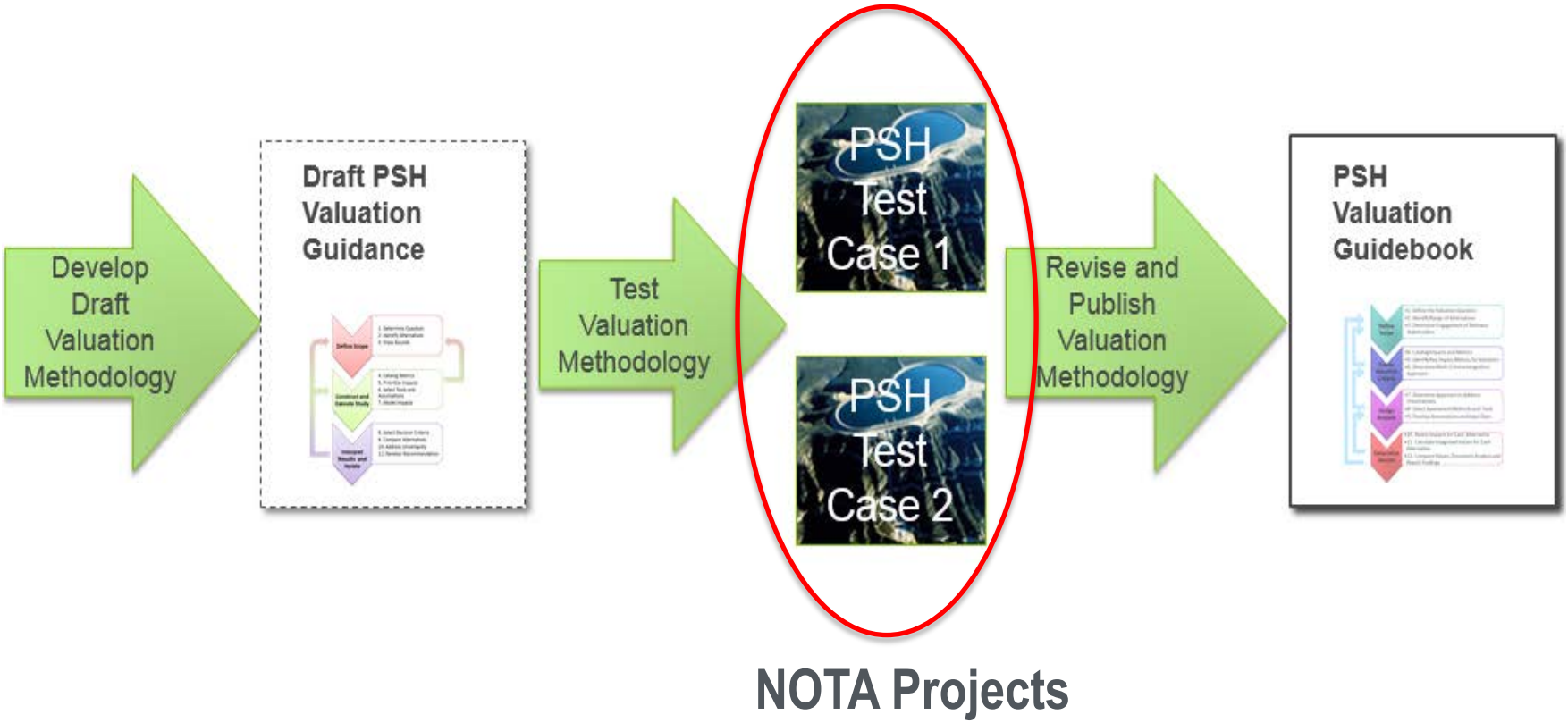
Management and Technical Approach

Project Organization Chart



Management and Technical Approach

Key Project Activities



NOTA – Notice of Opportunity for Technical Assistance

Management and Technical Approach

Key Project Tasks:

- ✓ Conduct valuation literature review *(Completed)*
- ✓ Perform a cost and performance comparison of PSH and competing technologies *(Completed)*
- ✓ Develop draft PSH valuation guidance *(Completed)*
- Conduct techno-economic studies for two selected PSH projects
- Analyze potential market revenues of two PSH projects
- Conduct two valuation case studies to test the guidance and its underlying methodology
- Revise PSH valuation guidance and document study findings

Management and Technical Approach

A variety of techno-economic studies will be carried out to assess the costs and benefits of various PSH services and contributions to the grid:

- Bulk power capacity and energy value over PSH lifetime
- Value of PSH ancillary services (regulation service, contingency reserves, etc.)
- Power system stability services (inertial response, governor response, transient and small signal stability, voltage support)
- PSH impacts on reducing system cycling and ramping costs
- Other indirect (system-wide or portfolio) effects of PSH operations (e.g., PSH impacts on decreasing overall power system production costs, benefits for integration of variable energy resources, and impacts on power system emissions)
- PSH transmission benefits (transmission congestion relief, transmission investments deferral)
- PSH non-energy services (water management services, socioeconomic benefits, and environmental impacts)

Management and Technical Approach

Project Tasks and Schedule

Task	Description	FY2018												FY2019												FY2020											
		O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
1	Industry Collaboration and Technical Advisory Group (TAG)																																		
2	Literature Review and Data Collection						Δ																												
3	Develop PSH Valuation Guidebook								Δ					Δ																						Δ
4	Comparative Analysis of PSH and Competing Technologies									Δ																										
5	Selection of Two PSH Sites for Valuation Analysis												Δ																							
6	Techno-Economic Studies for Two PSH Sites:																																			
	6.1 Scope and Analytical Approaches for TES															Δ																				
	6.2 Bulk Power Capacity and Energy Values																																			
	6.3 Value of PSH Ancillary Services																																			
	6.4 Power System Stability Benefits																																			
	6.5 Cycling and Ramping Costs and Benefits																																			
	6.6 Other System-wide (Portfolio) Effects of PSH																																			
	6.7 PSH Transmission Benefits																																			
	6.8 PSH Non-energy Services - Value and Impacts																																			
7	Power Market Analysis for Two PSH Projects																								Δ											
8	Valuation Analysis for Two PSH Projects																											Δ								
9	Financial Analysis for Two PSH Projects																													Δ						
10	Documenting Study Results, Dissemination and Reporting																																			Δ
11	Project Management and Coordination																																			
	Interactions with Technical Advisory Group																																			
	Industry and Stakeholders Engagement and Outreach																																			

Legend: Δ Major project deliverables
Interactions with TAG and industry

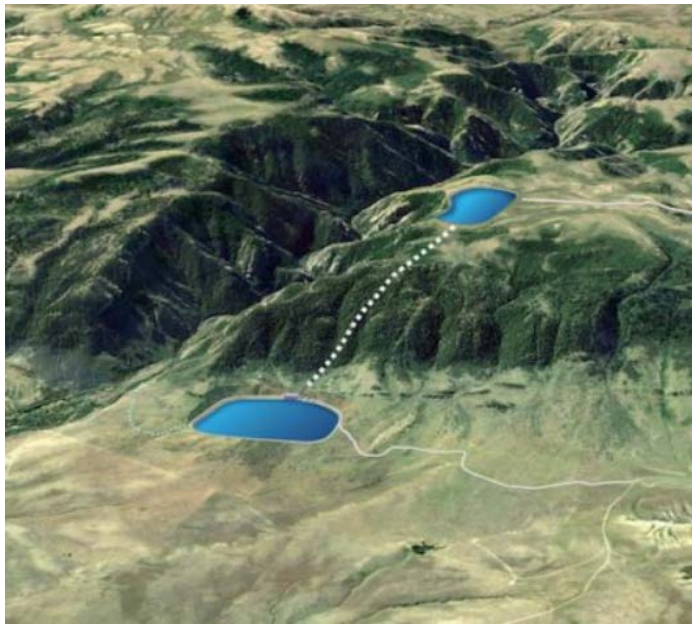
End-User Engagement and Dissemination Strategy

The Project Team is collaborating with two industry partners (NOTA projects):

Absaroka Energy

Banner Mountain PSH

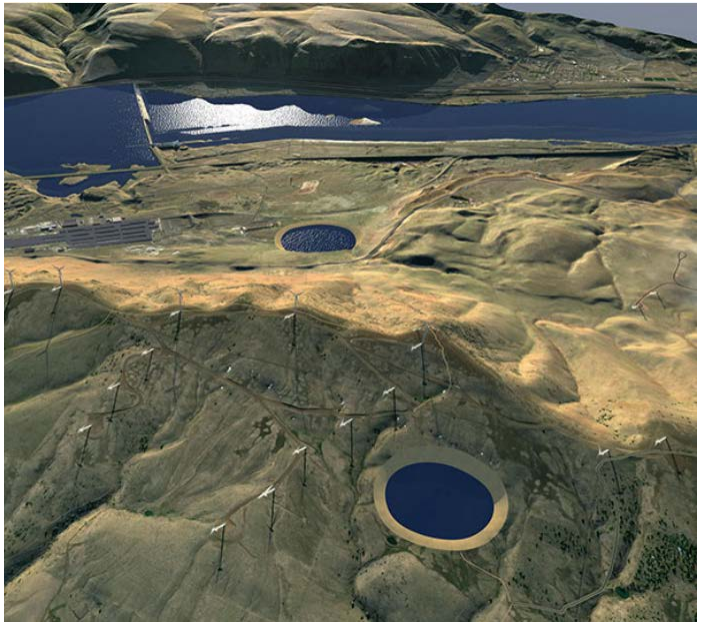
- 400 MW, quaternary technology
- Closed loop
- Located near Casper, WY



National Grid & Rye Development

Goldendale Energy Storage Project

- 1,200 MW, adjustable speed technology
- Closed loop
- Located on WA/OR border



End-User Engagement and Dissemination Strategy

Collaboration with Technical Advisory Group (TAG) and NARUC:

Denis Bergeron	Maine PUC
Norman Bishop	Knight Piesold
Brent Buffington	SCE – Southern California Edison
Wei Dang	PSE – Puget Sound Energy
Peter Donalek	Stantec
Christine Ericson	Illinois Commerce Commission
Don Erpenbeck	Stantec
Robert Fick	LADWP
Scott Flake	Scott Flake Consulting
Levi Gilbert	PG&E – Pacific Gas & Electric
Edward Hansen	PG&E – Pacific Gas & Electric
Elaine Hart	PGE – Portland General Electric
Udi Helman	Helman Analytics
Michael Manwaring	McMillen Jacobs Associates
Jay Mearns	PG&E – Pacific Gas & Electric
Denis Obiang	LADWP
Aidan Tuohy	EPRI
Bruno Trouille	Mott McDonald
Robert Williams	PSE – Puget Sound Energy

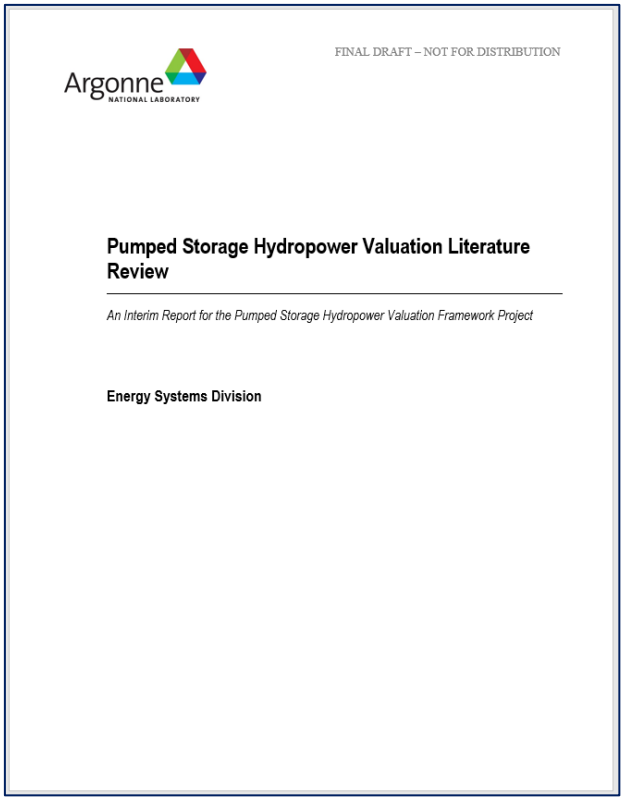
NARUC (National Association of Regulatory Utility Commissioners) is assisting the Project Team in coordinating TAG activities and in industry outreach:

- Danielle Sass Byrnett
- Kerry Worthington
- Dominic Liberatore

Technical Accomplishments

Performed valuation literature review:

- An internal project report summarized the review of valuation studies performed in the US and abroad
- The review included various technologies, such as hydro and PSH, solar, wind, energy storage, and others.
- The most relevant 148 studies and papers have been summarized in the report
- The purpose of the review was to inform the development of the valuation framework
- This is an internal project report and is not intended for public release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FINAL DRAFT – NOT FOR DISTRIBUTION

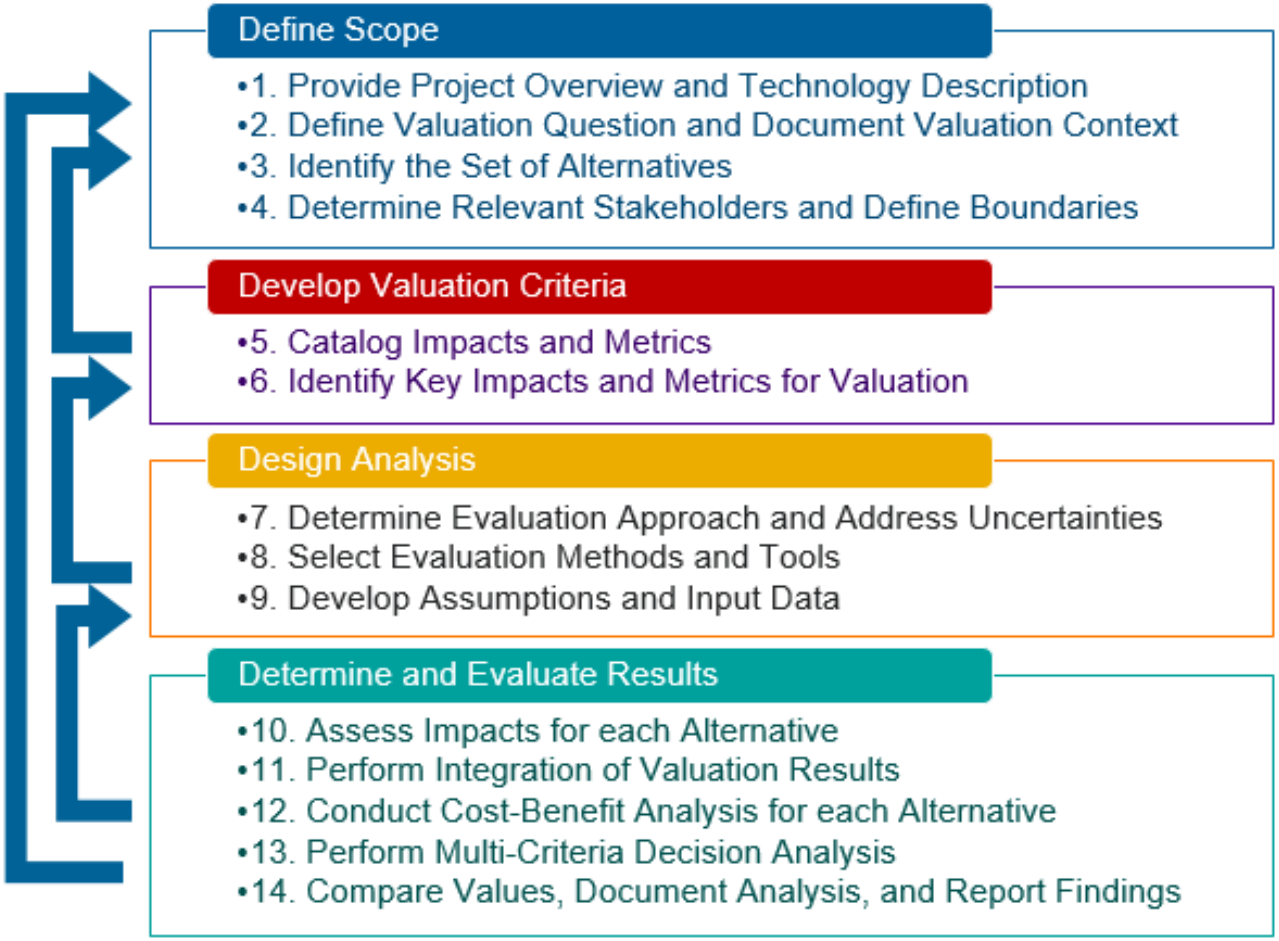
Pumped Storage Hydropower Valuation Literature Review

An Interim Report for the Pumped Storage Hydropower Valuation Framework Project

Energy Systems Division

Technical Accomplishments

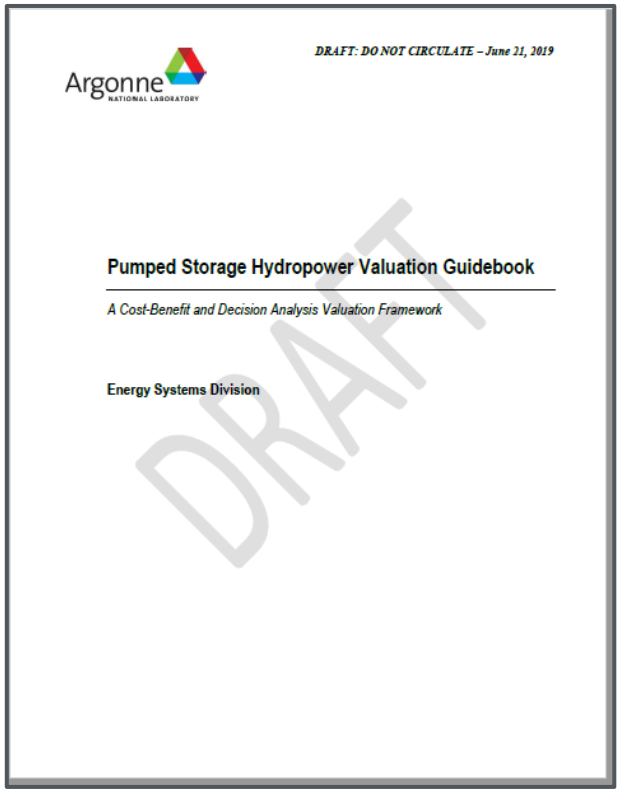
- Developed a cost-benefit and decision analysis valuation framework for valuing PSH projects.



Technical Accomplishments

Developed draft PSH Valuation Guidebook:

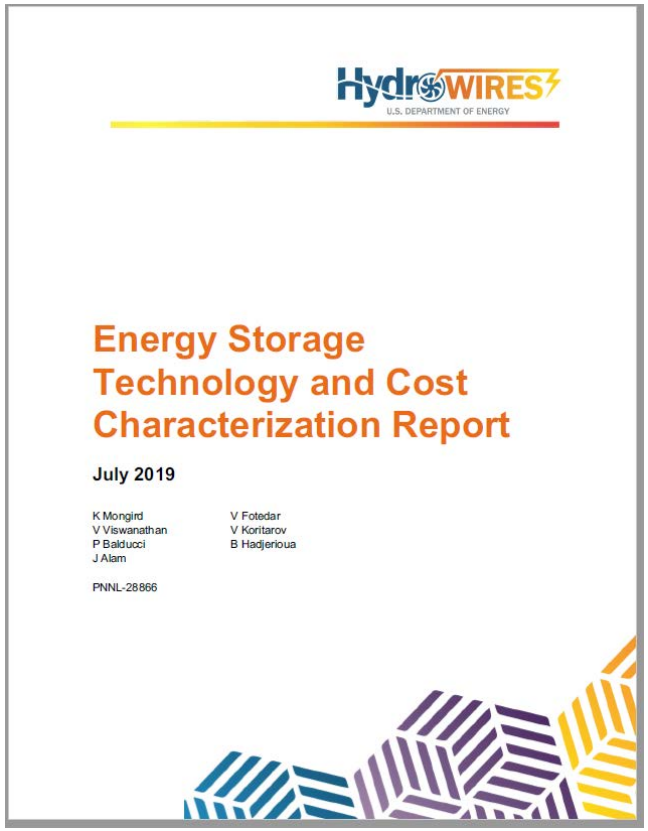
- A comprehensive technical report describing the PSH valuation framework and methodological approaches for the assessment of value of PSH services
- The PSH Valuation Guidebook will be publicly released at the end of the project
- An accompanying PSH Valuation Tool will be developed in a companion project to help users navigate through the PSH valuation process



Technical Accomplishments

Developed and published energy storage cost and performance study:

- To define and compare energy storage technology costs and to evaluate these technologies across a variety of performance parameters
  - Lithium-ion batteries
  - Lead-acid batteries
  - Redox flow batteries
  - Sodium-sulfur batteries
  - Sodium metal halide batteries
  - Zinc-hybrid cathode batteries
  - Pumped storage hydropower
  - Flywheels
  - Compressed air energy storage
  - Ultracapacitors



https://www.energy.gov/sites/prod/files/2019/07/f65/Storage%20Cost%20and%20Performance%20Characterization%20Report_Final.pdf

Technical Accomplishments

Techno-Economic Studies for NOTA projects (in progress):

- **ANL:** Capacity valuation using AURORAxmp model
- **ANL:** Electricity market analysis
- **ANL:** Black start service valuation (developing own model)
- **NREL:** Value of PSH ancillary services: regulation service, contingency reserves, and flexibility reserves (PLEXOS)
- **INL:** Power system stability services: inertial response, governor response (primary frequency control), transient and small signal stability, voltage support (DRTS)
- **NREL:** PSH impacts on reducing system cycling and ramping costs (PLEXOS)
- **ORNL:** Potential cost and performance impacts of increased PSH cycling and ramping operations (e.g., increased wear and tear of PSH units)
- **NREL:** Other system-wide effects of PSH operations (e.g., PSH impacts on system production costs, integration of variable energy resources, power system emissions) (PLEXOS)
- **PNNL:** PSH transmission benefits (transmission congestion relief, transmission investments deferral) (PSSE)
- **ORNL:** PSH non-energy services (e.g., water management services, socioeconomic benefits, and environmental impacts)

Techno-Economic Analysis Example – Capacity Valuation

- Goal is to determine long-term system value of PSH capacity
- Capacity expansion analysis for the WECC region using AURORAxmp
- Baseline expansion plan 2019-2043 (~30 hours run time)
- Alternative plans with Banner Mountain and Goldendale PSH
- Sensitivities considered: natural gas price, load growth, technology costs, environmental policy (e.g., no coal by 2030, no new gas-fired projects, cost of carbon, emission targets, etc.)

Sample capacity value results:

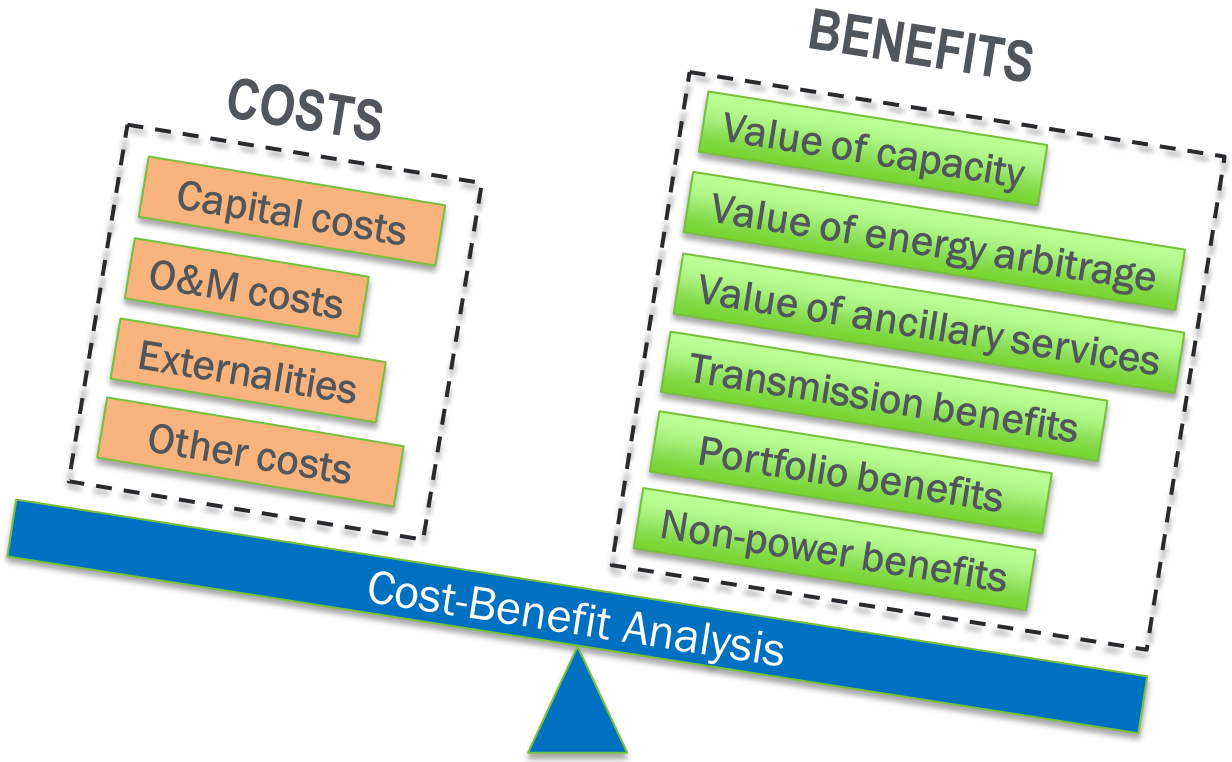
Techno-Economic Analysis Example – Market Analysis

- **Goals:**
  - Assess potential revenue streams for various market services and products
  - Investigate potential impacts of new market rules
- **Market analysis will consider multiple market participation models that the NOTA projects have access to**

Western Energy Imbalance Market (EIM)	CAISO	Balancing Authority (BA)	
		EIM Participating Resource	EIM Non-Participating Resource
Capacity	Non-market based resource adequacy framework	Bilateral contract	Bilateral contract
Energy	Day-ahead and real-time dispatch and settlement by CAISO	Base schedule by BA; Intra-hour dispatch and settlement by CAISO	Dispatch and settlement by BA
Ancillary Services	Regulation up/down, Spinning reserve, Non-spinning reserve, Flexible ramping products	Flexible Ramp Product (EIM); Ancillary Services procured by BA	Ancillary Services procured by BA

PSH Valuation Framework – Cost-Benefit Analysis

The results of various techno-economic studies will provide inputs for Cost-Benefit Analysis (CBA)

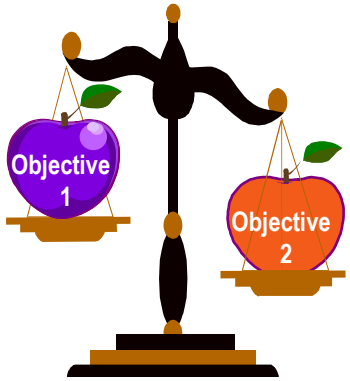


CBA will be used to calculate the net-present value (NPV), benefit-cost (B/C) ratio, etc.

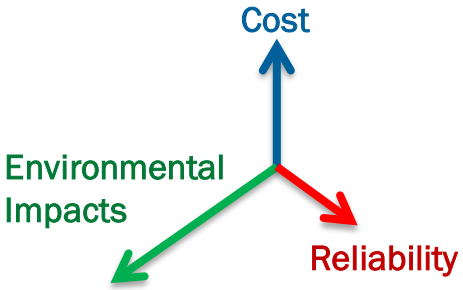
PSH Valuation Framework – Multi-Criteria Decision Analysis

Choosing among different alternatives with multiple attributes

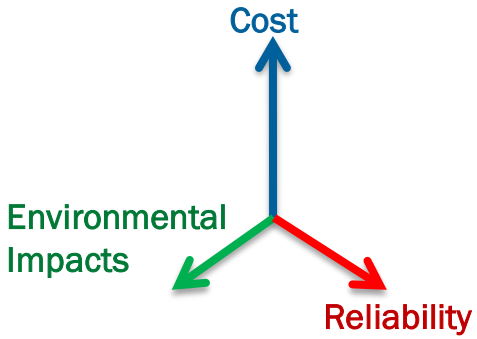
- Many PSH impacts are not easily monetized and have to be expressed in physical units or qualitatively
- How to compare different alternatives that are described by both monetized and non-monetized impacts?
- A decision-support system can help decision-makers choose among different alternatives defined by multiple attributes



Tradeoffs Among Objectives



Alternative 1



Alternative 2

Which alternative is better?

Future Work

Develop PSH Valuation Tool

Year 1

- Review valuation models and identify key attributes in successful models
- Define basic model structure
- Acquire stakeholder input through TAG participation, discussion at HydroVision, and through follow-on interviews
- Issue final report with model recommendations.

Year 2

- Model development
- Model testing and review
- Stakeholder engagement
- Final model with User's Guide