1.2.1.606 – PSH TES Tool

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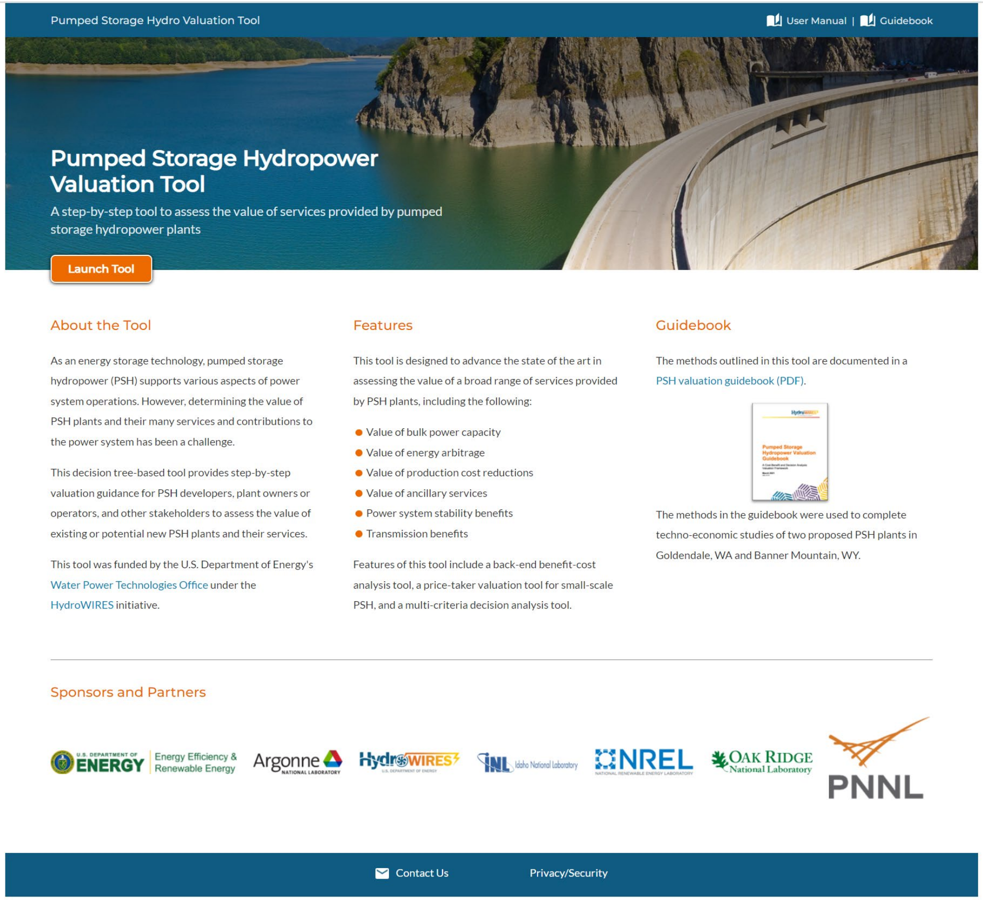


Project Overview

Project Summary

- The Pumped Storage Hydropower Valuation Tool (PSHVT) brings the Pumped Storage Hydropower Valuation Guidebook to life. The PSHVT steps the user through a 15-step benefit-cost analysis process with information on how to use production cost and power flow models to determine the value of potential projects from a developer, system and societal point of view. The tool provides a price-influencer model for facilities that are large enough to influence market prices and a price-taker model for smaller facilities. The PSHVT also includes a multi criteria decision analysis tool to extend the analysis to include non-economic benefits.

Intended Outcomes

- The project built a web-based tool that enables the user to determine the economic feasibility of modifying an existing pumped storage hydro (PSH) project or developing a new facility.
- Developed a decision tree-based, price-influencer model that advances the state of the art in evaluating a broad set of use cases from three perspectives: owner/operator, system, and society.
- Developing a system-based, price influencer model.
- Developing a downloadable tool.

Project Information

Principal Investigator(s)

- Rojan Bhattarai, Greg Stark, Srijib Mukherjee, Vladimir Koritarov, Di Wu

Project Partners/Subs

- Idaho National Laboratory, National Renewable Energy, Oak Ridge National Laboratory

Project Status

On-going

Project Duration

- October 2018
- September 2022

Total Costed (FY21)

$966K

Project Objectives: Relevance

Relevance to Program Goals:

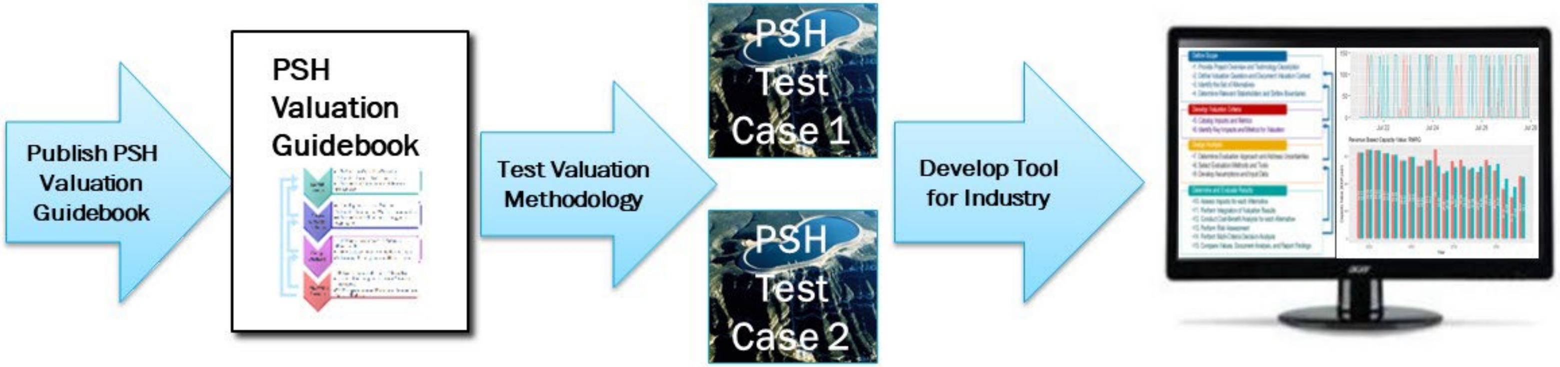
Program Challenge	Outcome	Impact
Untapped potential for hydro and PSH to support a rapidly evolving grid	The tool will help optimize grid planning by providing the appropriate mix of PSH with other grid resources	Improve economic outcomes while considering deep decarbonization goals
	Facilitate access to a comprehensive and transparent valuation guidance that will allow for consistent valuation assessments and comparisons of PSH projects	Reduce risk/uncertainty associated with PSH development
Lack of access to information to support decision-making	The tool will help the PSH stakeholder community to assess the value and range of services PSH can provide in terms of grid services, accounting for the constraints associated with PSH operations	Improve financial performance of PSH, expanding prospects for financing and building future PSH
	The tool can evaluate new hydropower technologies by comparing the costs of the new technology with the values that the facility can generate	Enhance PSH efficiency and impact of PSH on grid operations

Project Objectives: Approach

Objective: Advance the state of the art in the assessment of value of PSH plants and their role and contributions to the power system.

Approach:

- Examine existing models/tools and determine attributes common among most successful tools; seek industry feedback on what was needed for valuing PSH
- Select model type - decision tree-based model and the price-taker model in one tool allowing user the option to choose the best model based on PSH design
- Establish Tool Review Team to provide input during tool development
- Build and test tool



Pumped Storage Hydro Valuation Program Approach

Project Objectives: Expected Outputs and Intended Outcomes

Outputs:

- Analysis of different tools to determine best approach for tool development
- Develop the Pumped Storage Hydropower Valuation Tool
- Demonstrations
- Tutorials
- Journal article

Outcomes:

- Improved understanding and valuation methods for PSH
- Widespread application of the PSH Guidebook
- The project will engage the PSH user community to use the tool in order to value potential projects
  - Currently the web-based tool has roughly 50 users
  - Price-taker tool version at PNNL has been used to conduct 29 analyses
- Future outcomes will be to facilitate development and improve performance of future PSH facilities

Project Budget

FY19	FY20	FY21	Total Actual Costs FY19–FY21
Costed	**Costed**	**Costed**	**Total Costed**
$46K	$55K	$966K	$1,068K

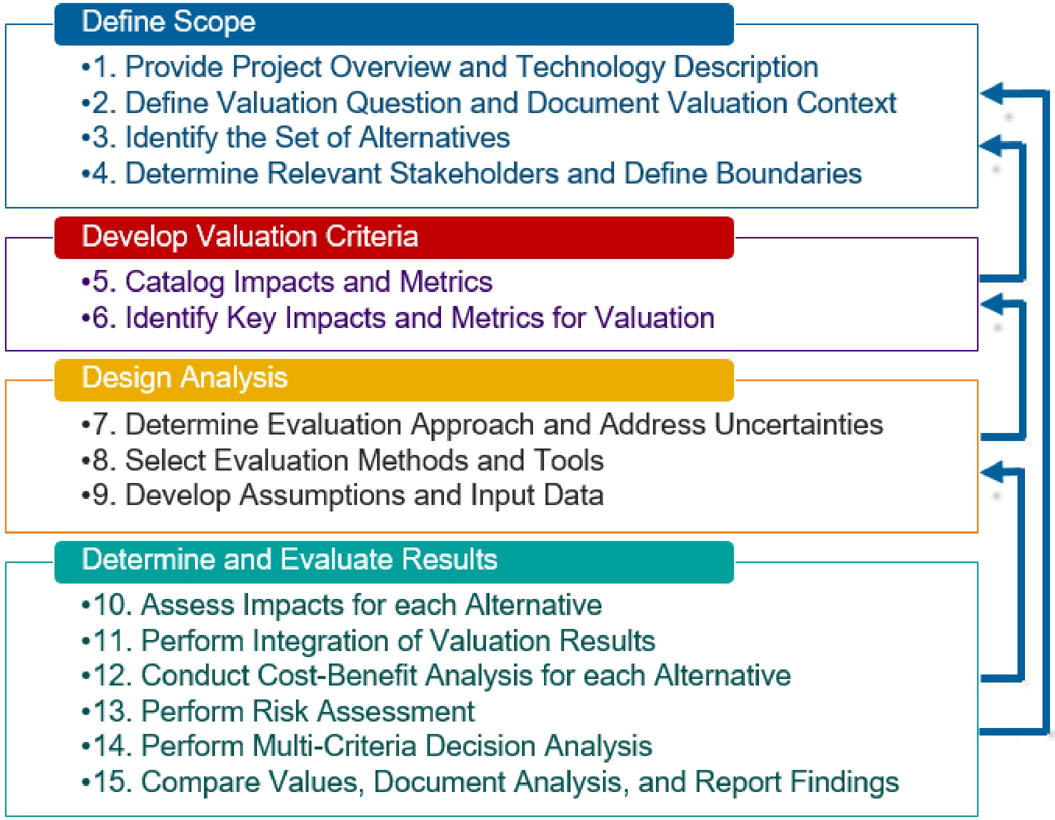
- The project accomplished the finalized tool 22 days late, but the budget was underspent
- PNNL significantly underspent the Price-taker tool. ANL slightly underspent its budget in developing the web-based PSHVT. INL, NREL, and ORNL spent slightly less than their allocations building wireframes for the tool

End-User Engagement and Dissemination

- Stakeholders were identified and queried for input into needs in evaluating project and relevant approaches understanding the value of PSH
- PSH owner/developers, system operators, regulators, and the public will benefit from appropriate valuation and improved grid reliability
- A Tool Review Team was engaged during the tool development, they reviewed the initial tool approach, and the intermediate tool, and their comments were incorporated into the tool
  - The tool review team included developers, regulators, consultants, and other government entities interested in PSH development
- The tool has been demonstrated; more tutorials and journal articles will be provided
  - Clean Currents (October 2021), HydroVision International (July 2019 & July 2022), Pacific Northwest Regional Economic Conference (May 2021 & May 2022), DOE Energy Storage Finance Summit (May 2021 & January 2022)
  - Two tutorials in 2022 and as needed
  - Journal article on Price-taker model published 2022

Performance: Accomplishments and Progress

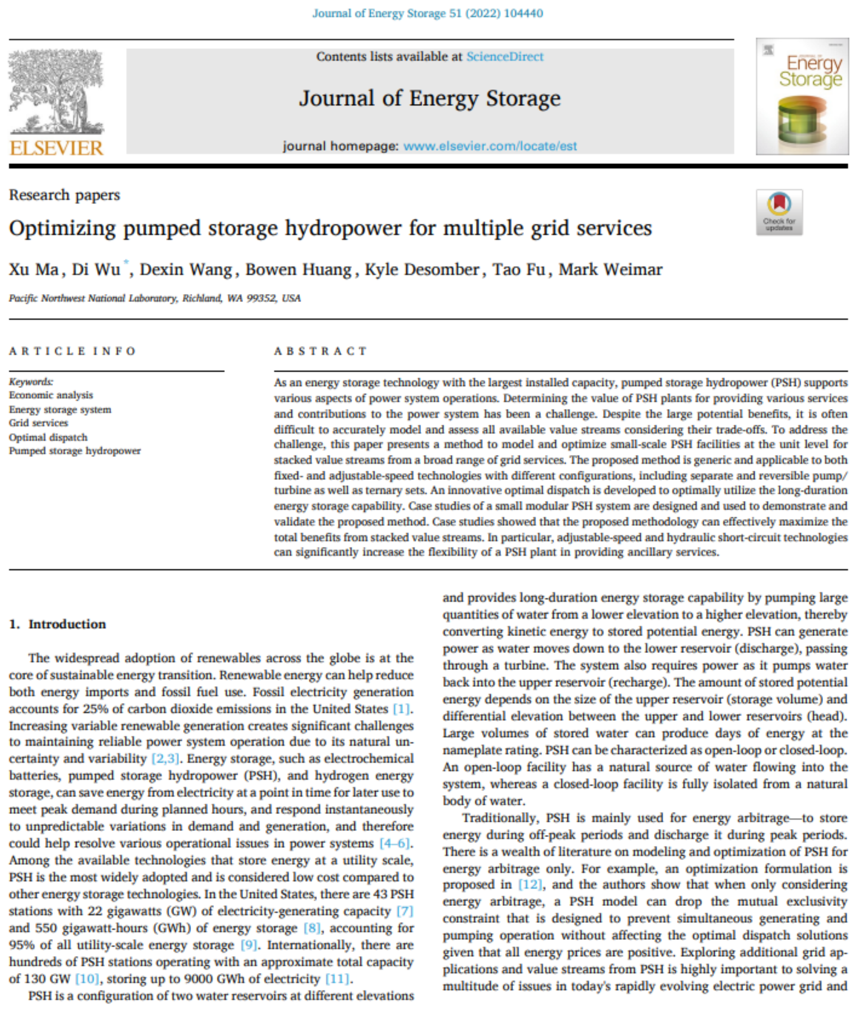
- The completion of the PSH Valuation Tool is the single most important accomplishment
  - Stakeholders can use qualitative, physical or monetary metrics to evaluate PSH projects from a system, owner-operator or societal perspective and with two different approaches to better understand value
    - Provides an embedded price-taker model for a complete end-to-end user experience for smaller PSH facilities
    - Provides a financial tool to evaluate net present value, internal rate of return and payback period
    - Provides an ability to evaluate risks associated with a project
    - Provides a multi-criteria decision analysis tool
    - Provides a downloadable report for dissemination



Cost-Benefit and Decision Analysis Framework Embedded in PSHVT

Performance: Accomplishments and Progress (cont.)

- No patents, awards, or other important recognition have resulted from this project.
  - A peer reviewed paper on the Price Taker Model was published in the Energy Storage Journal
    - Ma X, D Wu, D Wang, B Huang, K Desomber, T Fu, M W "Optimizing pumped storage hydropower for multiple grid services." In Journal of Energy Storage. Volume 51. July 2022



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Research papers

Optimizing pumped storage hydropower for multiple grid services

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ABSTRACT

As an energy storage technology with the largest installed capacity, pumped storage hydropower (PSH) supports various aspects of power system operations. Determining the value of PSH plants for providing various services and contributions to the power system has been a challenge. Despite the large potential benefits, it is often difficult to accurately model and assess all available value streams considering their trade-offs. To address the challenge, this paper presents a method to model and optimize small-scale PSH facilities at the unit level for stacked value streams from a broad range of grid services. The proposed method is generic and applicable to both fixed- and adjustable-speed technologies with different configurations, including separate and reversible pump/turbine as well as ternary sets. An innovative optimal dispatch is developed to optimally utilize the long-duration energy storage capability. Case studies of a small modular PSH system are designed and used to demonstrate and validate the proposed method. Case studies showed that the proposed methodology can effectively maximize the total benefits from stacked value streams. In particular, adjustable-speed and hydraulic short-circuit technologies can significantly increase the flexibility of a PSH plant in providing ancillary services.

1. Introduction

The widespread adoption of renewables across the globe is at the core of sustainable energy transition. Renewable energy can help reduce both energy imports and fossil fuel use. Fossil electricity generation accounts for 25% of carbon dioxide emissions in the United States [1]. Increasing variable renewable generation creates significant challenges to maintaining reliable power system operation due to its natural uncertainty and variability [2,3]. Energy storage, such as electrochemical batteries, pumped storage hydropower (PSH), and hydrogen energy storage, can save energy from electricity at a point in time for later use to meet peak demand during planned hours, and respond instantaneously to unpredictable variations in demand and generation, and therefore could help resolve various operational issues in power systems [4–6]. Among the available technologies that store energy at a utility scale, PSH is the most widely adopted and is considered low cost compared to other energy storage technologies. In the United States, there are 43 PSH stations with 22 gigawatts (GW) of electricity-generating capacity [7] and 550 gigawatt-hours (GWh) of energy storage [8], accounting for 95% of all utility-scale energy storage [9]. Internationally, there are hundreds of PSH stations operating with an approximate total capacity of 130 GW [10], storing up to 9000 GWh of electricity [11].

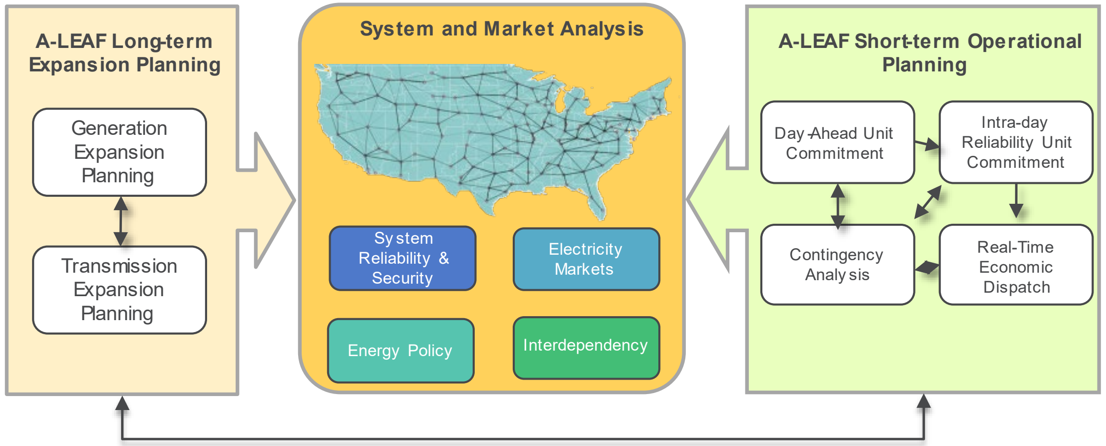
PSH is a configuration of two water reservoirs at different elevations and provides long-duration energy storage capability by pumping large quantities of water from a lower elevation to a higher elevation, thereby converting kinetic energy to stored potential energy. PSH can generate power as water moves down to the lower reservoir (discharge), passing through a turbine. The system also requires power as it pumps water back into the upper reservoir (recharge). The amount of stored potential energy depends on the size of the upper reservoir (storage volume) and differential elevation between the upper and lower reservoirs (head). Large volumes of stored water can produce days of energy at the nameplate rating. PSH can be characterized as open-loop or closed-loop. An open-loop facility has a natural source of water flowing into the system, whereas a closed-loop facility is fully isolated from a natural body of water.

Traditionally, PSH is mainly used for energy arbitrage—to store energy during off-peak periods and discharge it during peak periods. There is a wealth of literature on modeling and optimization of PSH for energy arbitrage only. For example, an optimization formulation is proposed in [12], and the authors show that when only considering energy arbitrage, a PSH model can drop the mutual exclusivity constraint that is designed to prevent simultaneous generating and pumping operation without affecting the optimal dispatch solutions given that all energy prices are positive. Exploring additional grid applications and value streams from PSH is highly important to solving a multitude of issues in today's rapidly evolving electric power grid and

PSHVT Publication in Journal *Energy Storage*

Future Work

- The project is in the process of developing:
  - An embedded price influencer model
  - A downloadable version of the tool for individuals that worry about dissemination of proprietary data
- Development of the embedded Price-Influencer Model will allow a third leg in the tool for those that don't have access to capacity expansion or production cost models
- The downloadable tool has a decision point:
  - The main software used in the project has now instituted a license requirement
  - Trying to understand how to pay for the license, while user responsible for requirements
- Currently there is adequate resources available to complete the project



Argonne Low-carbon Electricity Analysis Framework

Q&A