User Guide for the PSH Valuation Tool

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HydroWIRES

In April 2019, WPTO launched the HydroWIRES Initiative[1] to understand, enable, and improve hydropower and pumped storage hydropower's (PSH's) contributions to reliability, resilience, and integration in the rapidly evolving U.S. electricity system. The unique characteristics of hydropower, including PSH, make it well suited to provide a range of storage, generation flexibility, and other grid services to support the cost-effective integration of variable renewable resources.

The U.S. electricity system is rapidly evolving, bringing both opportunities and challenges for the hydropower sector. While increasing deployment of variable renewables such as wind and solar have enabled low-cost, clean energy in many U.S. regions, it has also created a need for resources that can store energy or quickly change their operations to ensure a reliable and resilient grid. Hydropower (including PSH) is not only a supplier of bulk, low-cost, renewable energy but also a source of large-scale flexibility and a force multiplier for other renewable power generation sources. Realizing this potential requires innovation in several areas: understanding value drivers for hydropower under evolving system conditions, describing flexible capabilities and associated tradeoffs associated with hydropower meeting system needs, optimizing hydropower operations and planning, and developing innovative technologies that enable hydropower to operate more flexibly.

HydroWIRES is distinguished in its close engagement with the DOE National Laboratories. Five National Laboratories—Argonne National Laboratory, Idaho National Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory—work as a team to provide strategic insight and develop connections across the HydroWIRES portfolio as well as broader DOE and National Laboratory efforts such as the Grid Modernization Initiative.

[1] Hydropower and Water Innovation for a Resilient Electricity System ("HydroWIRES")

Research efforts under the HydroWIRES Initiative are designed to benefit hydropower owners and operators, independent system operators, regional transmission organizations, regulators, original equipment manufacturers, and environmental organizations by developing data, analysis, models, and technology research and development that can improve their capabilities and inform their decisions.

More information about HydroWIRES is available at https://energy.gov/hydrowires.

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Executive Summary

The rapidly evolving electricity system with increasing variable renewable energy (VRE) resources provides both opportunities and challenges for the hydropower sector. With the significant ramps and intermittency associated with VRE resources, the requirements for flexible resources are increasing. Pumped storage hydropower (PSH) projects support various aspects of power system operations including flexibility, ramping capabilities, energy, ancillary services, and stability services. The significant potential of hydropower requires understanding the different value drivers to the electricity system specific to the location of a project and then optimizing the plant for the different system values. Thus, determining the value of PSH projects and the many services and contributions to the system they provide can be a challenge.

The Pumped Storage Hydropower Valuation Tool (PSHVT) helps the user determine and optimize the value of an existing plant or a proposed new plant. The tool is primarily self-contained, but this User Guide provides additional information about the tool including explanations and tips for using the tool. The PSHVT provides a 15-step decision-tree framework to walk users through the methodology developed in the Pumped Storage Hydropower Valuation Guidebook (Guidebook).[1] The tool contains links to the Guidebook within the tool for deeper explanations of the methodology if required. The PSHVT steps the user through the decision tree by defining the scope of the project in terms of the technology used and the point of view of the user (owner-operator, system-owner, or society); developing the valuation criteria including the metrics and their key impacts; designing the analysis including assumptions and selection of tools to undertake the analysis; and lastly evaluating and integrating the use-case results, performing benefit-cost analysis, evaluating and comparing each alternative through multi-criteria decision analysis (MCDA) and comparing the outcomes, and developing a report of the analysis. The PSHVT steps are not necessarily linear, and some steps may be performed in parallel. The tool assesses the value of a broad range of services including bulk power capacity, energy arbitrage, production cost reductions, ancillary services such as frequency regulation, power system stability benefits, and transmission benefits such as congestion relief and transmission upgrade deferral. The tool also provides guidance on valuing non-energy or societal benefits. The tool is intended for use by developers, system operators, regulators, financial lending organizations, policy makers, and consultants. The tool can help these stakeholders decide whether to invest, approve or finance a project.

The tool can be used to evaluate large- and small-scale PSH facilities. For large-scale facilities, the PSHVT walks the user through each use valuation case for PSH projects that could influence market prices. The tool provides guidance to the user to undertake the valuation process using existing system or Price-influencer models such as production cost, expansion, and power flow models. Aurora or PLEXOS are two examples of the models that can be used but are not embedded in the tool. The tool provides an overview of multiple model types, segmented by primary application.

The tool includes three embedded tools: a Price-taker evaluation tool to evaluate small PSH facilities, a back-end benefit-cost analysis tool, and a MCDA tool. The Price-taker tool in intended for use in evaluating small projects that won't influence market prices (usually less than 10 MW), but it can be used to undertake a quick evaluation of larger projects. The Price-taker tool automatically optimizes the use

[1] Koritarov, Vladimir, Balducci, Patrick, Levin, Todd, Christian, Mark, Kwon, Jonghwan, Milostan, Catharina, Ploussard, Quentin, Padhee, Malhar, Tian, Yuting, Mosier, Thomas, Alam, S.M. Shafiul, Bhattarai, Rojan, Mohanpurkar, Manish, Stark, Gregory, Bain, Dominique, Craig, Michael, Hadjerioua, Boualem, O'Connor, Patrick, Mukherjee, Srijib, Stewart, Kevin, Ke, Xinda, & Weimar, Mark. *Pumped Storage Hydropower Valuation Guidebook: A Cost-Benefit and Decision Analysis Valuation Framework.* United States. https://doi.org/10.2172/1770766.

cases to determine the amount and value of each use case to undertake. The benefit-cost tool provides the framework to understand the feasibility of a project. It requires accurate costs and integration of use cases to provide a reliable analysis. The MCDA tool steps users through an alternatives analysis to determine which alternative best meets the decisionmaker's goals and objectives, based on their criteria and weights for each criterion. The MCDA process also allows the user to include non-monetary and qualitative criteria in the analyses.

The PSHVT supports the Microsoft Windows 10 and MacOS 10.12 and newer. Google Chrome's latest stable version works best in either platform. Firefox (latest stable version) and Microsoft Edge will work on the Microsoft platform. Safari will also work on the MacOS 10.12 platform. The PSHVT requires JavaScript to be enabled. A security protocol newer than SSLv3 is supported.

The PSHVT can be accessed at: https://pshvt.egs.anl.gov. For help with logon difficulties, call 630-252-9999 or email help@anl.gov. For difficulties with the tool itself, please use the comment tab on each web page or email PSHsupport@anl.gov. Someone will be with you as soon as possible.

Acronyms and Abbreviations

A-LEAF	Argonne's Least-Cost Electricity Modeling Framework
ANL	Argonne National Laboratory
ARIMA	Autoregressive integrated moving average
BCA	Benefit-cost analysis
BCR	Benefit-cost ratio
CFS	Cubic feet per second
DOE	Department of Energy
HSC	Hydraulic short circuit
MCDA	Multi-criteria decision analysis
MW	Megawatt
MWh	Megawatt hour
NPV	Net present value
PNNL	Pacific Northwest National Laboratory
PSH	Pumped Storage Hydropower
PSHPVT	Pumped Storage Hydro Valuation Tool
T&D	Transmission and distribution
TOU	Time of Use
VAR	Volt Amperes Reactive
VRE	Variable Renewable Energy
WPTO	Water Power Technologies Office

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1.0 Overview of Tool

1.1 Tool Purpose and Features

The Pumped Storage Hydropower Valuation Tool (PSHVT) is a step-by-step tool designed to assess the value of services provided by pumped storage hydropower (PSH) plants as developed in the voluminous Pumped Storage Hydropower Valuation Guidebook (Koritarov et al 2021). The Tool provides an easy-to-follow step by step process to work through the Guidebook's 15-step decision framework. This decision tree-based tool provides valuation guidance for PSH developers, plant owners or operators, and other stakeholders such as regulators, policymakers and consultants to assess the value of existing or potential new PSH plants and their services.

The tool is designed to the state of the art in assessing the value of a broad range of services provided by PSH plants, including:

- Bulk power capacity,
- Energy arbitrage,
- Production cost reductions,
- Ancillary services,
- Power system stability benefits, and
- Transmission benefits.

Features of this tool include a back-end benefit-cost analysis tool, a Price-taker valuation tool for small-scale PSH, and a multi-criteria decision analysis tool.

When evaluating large-scale PSH that could influence market prices, this tool walks the user through a valuation process using existing system or Price-influencer models such as Aurora or PLEXOS. It does provide an overview of multiple model types, segmented by primary application. It does not currently include an embedded model for large-scale PSH valuation. With that noted, planned investments in the tool include customization and installation of Argonne's Least-Cost Electricity Modeling Framework (A-LEAF) model and development of a downloadable version of the tool.

1.1.1 Browser and Other System Recommendations

The PSHVT supports the following modern desktop web browsers.

Microsoft Windows 10

- Google Chrome (latest stable version)
- Firefox (latest stable version)
- Microsoft Edge (latest stable version; Chromium-based only)

MacOS 10.12 and newer

- Google Chrome (latest stable version)
- Safari (latest stable version)

For best results, use the latest version of Google Chrome.

The PSHVT requires the following features with any supported browser:

- JavaScript is enabled.
- A security protocol newer than SSLv3 is supported.

1.1.2 Need Help?

For help with logon difficulties, call 630-252-9999 or email help@anl.gov. For difficulties with the tool itself, please use the comment tab on each web page or you can directly email PSHsupport@anl.gov. In addition, a comment form is attached to the menu bar just beside the link to the Guidebook and this User Guide of the tool.

1.1.3 Overview of 15-step Framework

The PSH valuation framework consists of fifteen steps (illustrated in Figure 1) that are grouped into four main activities: define scope, develop valuation criteria, design analysis, and determine and evaluate results. Based on the findings of some steps, you may be directed to go back and revisit previous steps, as illustrated by the feedback loops on the right-hand side of the figure.

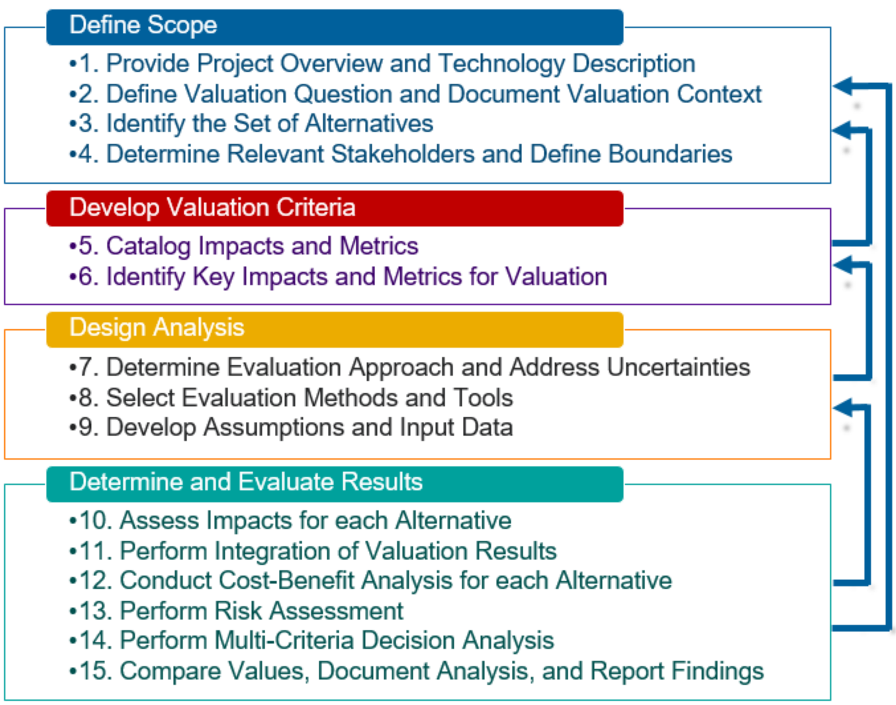


Figure 1. Benefit-Cost and Decision Analysis Framework

The PSH valuation framework used in this tool utilizes a traditional benefit-cost analysis (BCA) approach to compare the expected cost and benefit streams over the economic life of a PSH plant. In addition, if non-monetized project impacts also need to be taken into consideration, the tool presents a multi-criteria decision analysis (MCDA) approach that can be used to compare different alternatives described with

both monetized and non-monetized attributes and explore the tradeoffs among the different attributes. The four main activities are defined below in more detail:

- Define Scope. This activity includes four steps that aim to provide the overall context for the valuation study. It starts with providing an overview of the project, defines the valuation question (i.e., why valuation analysis is performed), identifying alternatives, and determining relevant stakeholders.

- Develop Valuation Criteria. This activity includes two steps dealing with the identification of key impacts and metrics for valuation.

- Design Analysis. The three steps in this activity deal with designing the analysis that will enable the analyst to assess and measure the key impacts identified in the previous activity.

- Determine and Evaluate Results. The fourth activity includes running the models and performing simulations to assess and evaluate the impacts, performing the cost-benefit and risk assessment analyses, conducting an optimal multi-criteria decision analysis and comparing the results for various alternatives, and documenting the results of analysis and reporting findings to decision makers.

Note that your progress is tracked along the left-hand side of the tool. The step you are working in will be highlighted. Once a step is completed, it remains highlighted and the circle around the step number turns green. This approach ensures that the user will always know where they are in the 15-step process.

1.2 Overview of Embedded Tools

There are three tools embedded in the PSHVT: the Price-taker valuation model, the MCDA model, and the back-end financial BCA model. Each of these tools is discussed in more detail later in this User Guide.

The user is allowed to select the Price-taker model path in Step 5: Analysis Perspective. If selected, the user then progresses along another branch of the decision tree-based model. The Price-taker model assumes that the PSH facility is small enough that its operation has little or no impact on system or market prices. The Price-taker model evaluates bulk energy, ancillary, transmission, distribution, and customer energy management services. It allows the user to perform a co-optimization procedure to ensure there is not double counting of benefits. It enables optimization across single or multiple services customized by users, optimization without performance foreknowledge of prices, power and energy limit specifications, and optimization around power and energy capacities. The Price-taker model inputs are defined in more detail in Section 2.6.

The MCDA model is a decision support tool that enables diverse stakeholders to consider a variety of concurrent goals when decisions on energy policies, initiatives, and infrastructure investments. The MCDA model is embedded in Step 14: Multi-Criteria Analysis. MCDA provides a flexible method for analyzing complex multi-objectives (e.g., sustainability, resilience, reliability, flexibility, affordability) and priorities that are hard to quantify in monetary terms (e.g., climate equity, social equity, resilience) with a structured decision-making process. MCDA also accounts for stakeholder-specific weighting of considered objectives. With appropriate weighting to reflect the relative importance of competing objectives, MCDA can be applied for valuation assessments and decision-support focused on transition to equitable, resilient, and sustainable energy.

The back-end BCA model runs the user through a series of data requests. The model enables the user to define alternative scenarios, evaluate many use cases, and consider alternative debt structures, alternative depreciation methods, tax implications, salvage value, all capital and operations and maintenance costs, and refurbishment costs. The BCA calculator produces several financial metrics, including a benefit-cost ratio (BCR), discounted payback period, net present value (NPV), and internal rate of return for each case.

2.0 Running a Simulation

2.1 Launching the Tool and Registering Your Account

The PSHVT is accessible via https://pshvt.egs.anl.gov. To begin accessing the tool, click the orange Launch Tool button on the tool's homepage (**Figure 2**). An Argonne Collaborator Account is required to access and use the site. If you are not a current Argonne account holder, you can create a collaborator account at https://apps.anl.gov/registration/collaborators/ and request accessibility by sending an email to PSHsupport@anl.gov.

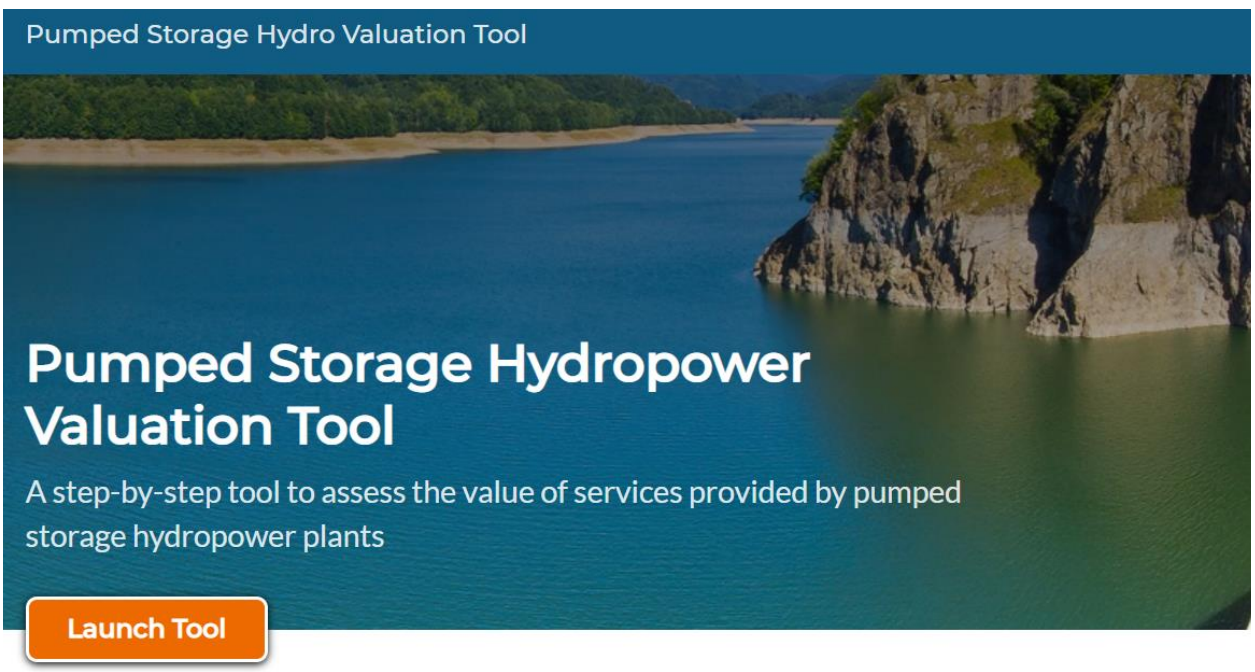
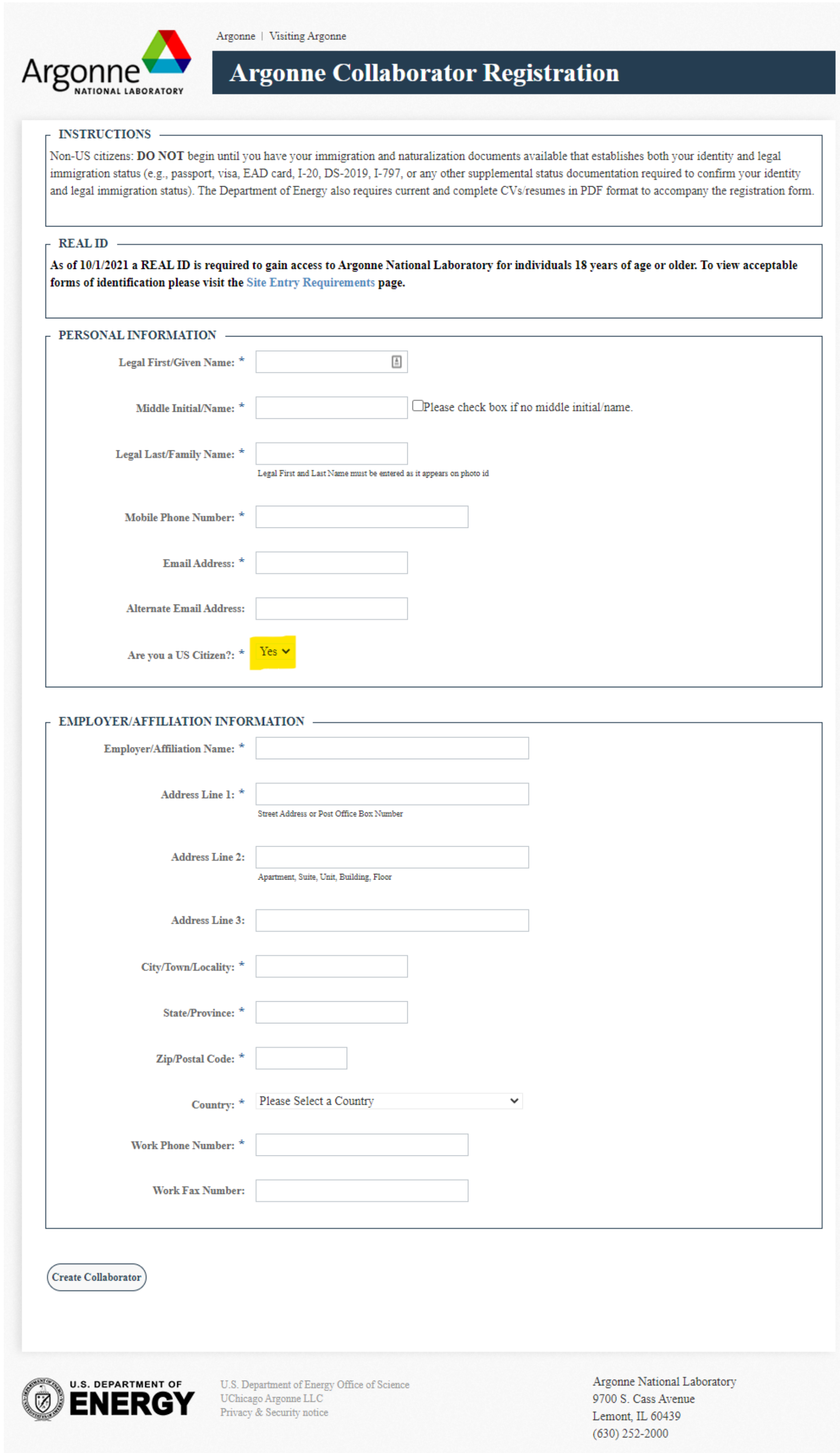


Figure 2. Launch page

To establish an Argonne Collaborator Account (Figure 3), the user will be asked for a sponsor email and a reason for the account. The user may use pbalducci@anl.gov for the sponsor email and "Access the PSHVT" as the reason for account. The user will then be taken to a terms and conditions where they must accept them. The next page provides an online Argonne Collaborator Registration form. If the user identifies as a U.S. Citizen, the form shortens as shown below. Once that form is complete and the create collaborator button is clicked, the user is allowed to select a username. If the user is not a U.S. citizen, they will need to complete additional forms and receive approval before using the PSHVT. The user will receive an email where they are provided a temporary password. The user will then receive an additional email message with password change instructions when the account has been approved. Finally, the user can log in, establish their permanent password, and start using the tool.



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Argonne Collaborator Registration

INSTRUCTIONS

Non-US citizens: **DO NOT** begin until you have your immigration and naturalization documents available that establishes both your identity and legal immigration status (e.g., passport, visa, EAD card, I-20, DS-2019, I-797, or any other supplemental status documentation required to confirm your identity and legal immigration status). The Department of Energy also requires current and complete CVs/resumes in PDF format to accompany the registration form.

REAL ID

As of 10/1/2021 a REAL ID is required to gain access to Argonne National Laboratory for individuals 18 years of age or older. To view acceptable forms of identification please visit the Site Entry Requirements page.

PERSONAL INFORMATION

Legal First/Given Name: *

Middle Initial/Name: * Please check box if no middle initial/name.

Legal Last/Family Name: *
Legal First and Last Name must be entered as it appears on photo id

Mobile Phone Number: *

Email Address: *

Alternate Email Address:

Are you a US Citizen?: * Yes

EMPLOYER/AFFILIATION INFORMATION

Employer/Affiliation Name: *

Address Line 1: *
Street Address or Post Office Box Number

Address Line 2:
Apartment, Suite, Unit, Building, Floor

Address Line 3:

City/Town/Locality: *

State/Province: *

Zip/Postal Code: *

Country: * Please Select a Country

Work Phone Number: *

Work Fax Number:

Create Collaborator

U.S. DEPARTMENT OF ENERGY

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Argonne National Laboratory
9700 S. Cass Avenue
Lemont, IL 60439
(630) 252-2000

Figure 3. Argonne Collaborator Short Form

2.2 Establish Project and Add Cases

Once you have established an account and successfully launched the tool. You can add a project and edit it as often as you wish. You can also add additional project and cases to an existing project. Figure 4 presents the project homepage for the PSHVT. The project in question is called Waterville II, Oregon. Note the “Edit button on the project box next to the garbage bin icon, which allows for an easy deletion of any project. To add new projects, simply click on the Add Project button in the upper right corner of the page.

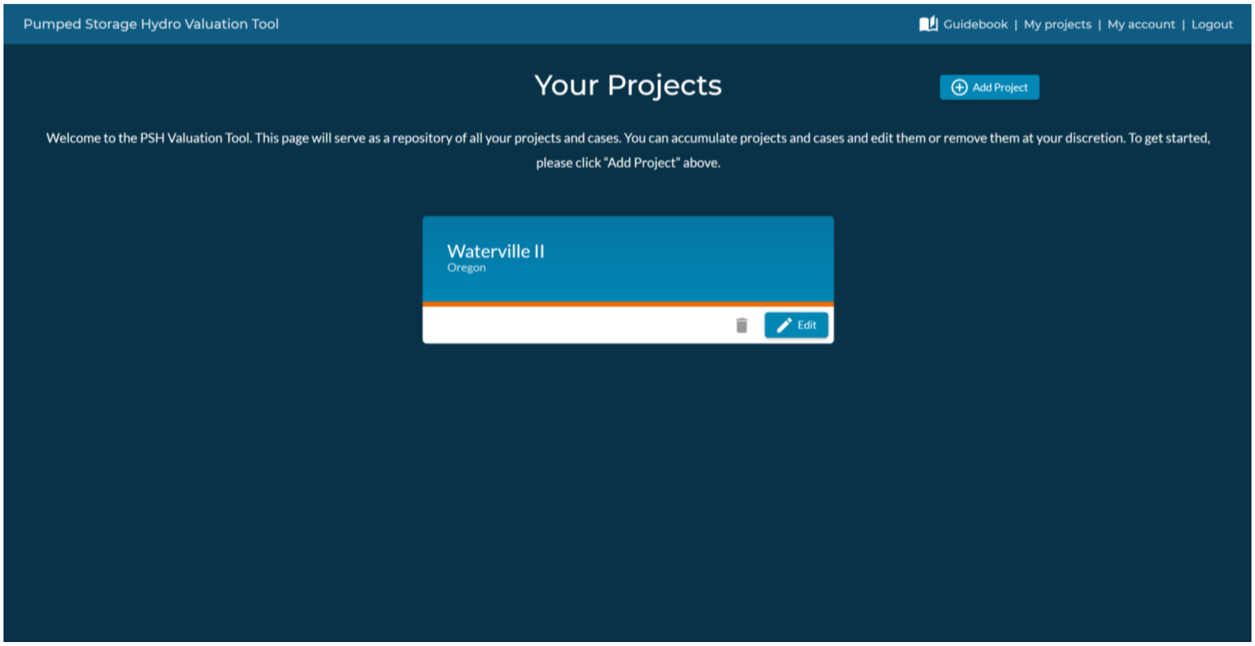

Figure 4. PSHVT project page

When you select edit, the tool takes you to the project homepage where you can store all your cases for that individual project. On that page (Figure 5), you can click on the Create New Case Study button to begin a new case study from Step 1. If you want to modify an existing case, click the file button next to the case name to make a copy of that case. Doing that will copy over all the data inputs into the previous case, allowing you to retain all the data previously input in order to evaluate the results of making small changes to an existing case.

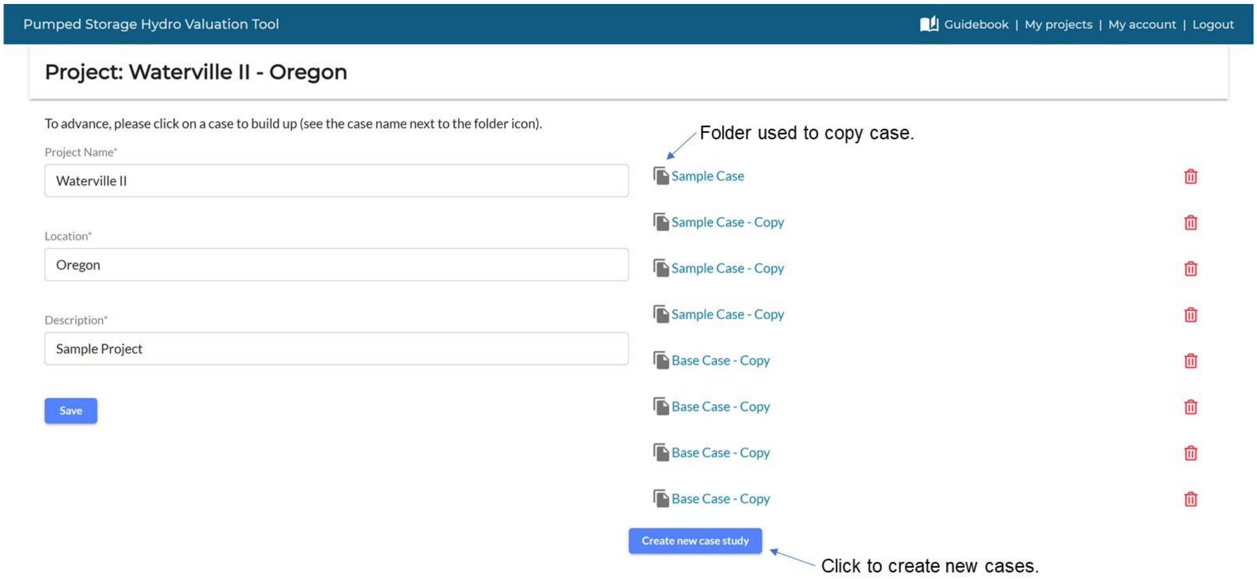

Figure 5. Creating new case studies and editing existing cases

2.3 Define Project Parameters

Steps 1-4 define the scope of the PSH project. Here you will define the PSH plant configuration, PSH unit parameters, reservoir characteristics, system costs, the type of organization undertaking the analysis, and other key elements. You will also define the alternatives you wish to evaluate and document your stakeholder engagement process. On each page, the site provides a definition of each data requirement on the left-hand side of the page and input windows to the right. The units of measure are defined above each input window.

2.4 Data Input and Flow Through

Data input throughout the early steps of the model automatically flow through to the Price-taker model, back-end BCA model, and final report. The data do not flow through to the MCDA model because the model has no predefined metrics. Throughout the process, all fields marked with an asterisk (*) are required. The user cannot advance to the next page without first providing all required inputs on the current page. Once all required input is entered and the user advances to the next page, the tool automatically saves all data input on the previous page. Therefore, data is automatically stored and will remain available to the user throughout the valuation process.

2.5 Define Valuation Question

Steps 5 and 6 define the analysis perspective, identify the use cases that will be evaluated, determine whether the Price-taker or Price-influencer path should be followed, and define the metrics to be measured for each use case. Selections made in these steps define the information and data screens for steps 7-10.

2.5.1 Price-Influencer versus Price-taker

The decision to use the Price-taker approach versus the Price-influencer approach depends on a) whether you believe your project is too small to influence the market prices and/or b) whether you would like to get a quick answer to your project's profitability as the Price-taker model provides a solution where prices are fixed and not influenced by the actions of your facility. The Price-Taker model assumes that the PSH facility is small enough that its operation will have little or no impact on the prices in the system. As such it is intended for projects that are small enough not to impact market prices. One approach to determine if it won't affect market prices is to use the Herfindahl-Hirschman Index (HHI) (available at https://www.ftc.gov/sites/default/files/attachments/merger-review/100819hmg.pdf) for the specific market being evaluated. The HHI is the sum of the square of the percentages for each participant share in the specific market being evaluated. If adding your plant changes the index by more than 100, the addition of the plant may impact prices (DOJ 2010) and you should use the Price-influencer approach.

2.5.2 Beneficiaries, Use Cases and Metrics

PSH plants are highly versatile technologies that can provide many grid services and other benefits to the power system. In addition to the energy (or power) services, some of the impacts of PSH plant operations may go beyond the power system and can have wider societal effects. The first step in cataloging impacts and metrics is to identify the perspective from which you wish the analysis is to be conducted, which reflects the system or entity to which the benefits will accrue. Beneficiary options include PSH owner or operator, power system, and society. Each beneficiary has a different set of use cases. Even in cases where a use case (e.g., primary frequency response) can be evaluated form both a PSH owner/operator or system perspective, the approach used to assign value to the case may change when evaluating it from multiple perspectives. Metrics can be categorized into three broad groups: (1) monetary, (2) physical or numerical, and (3) qualitative:

- Monetary metrics: Monetary metrics are used to describe services and impacts that can be expressed in monetary units (e.g., U.S. dollars). Services and impacts that are sold and bought in electricity markets are the easiest ones to monetize and are defined in terms of market-based revenue. Other services (e.g., transmission congestion relief) may result in cost avoidance that, while monetizable, fails to generate revenue for the developer. These avoided costs are still quite relevant and worthy of definition.

- Physical metrics: Most often, services and impacts are expressed in physical units. Services and impacts expressed in physical units can sometimes be easily monetized, while at other times it is very difficult or even impossible to explicitly monetize their value. Physical metrics include both energy-based metrics, such as electricity generation in megawatt hours (MWh), and non-energy service metrics such as gallons of water provided for irrigation purposes.

- Qualitative metrics: Some services or impacts can also be described using qualitative metrics. Typically, qualitative metrics use descriptive units, such as "low," "medium," and "high," or a predefined or constructed scale (e.g., from 0 to 1, or from 0 to 100) to describe the quality or benefit provided by a certain service or impact. Since the quality or value of services and impacts is judged by experts performing the analysis, this is a very subjective process. Typical examples of qualitative units include fuel diversity, resilience, and environmental sustainability.

A single case can include only one beneficiary but can include multiple use cases and metrics. Table 1 presents the full list of beneficiaries, use cases, and metrics available for evaluation in the model.

Table 1. List of beneficiaries, use case and metrics evaluated in the PSHVT

Beneficiary	Cost/Benefit Category	Use Case	Types of Metrics Used to Describe Services/Impacts
PSH Owner or Operator	Bulk Energy Services	Electricity price arbitrage	Monetary
		Bulk power capacity	Qualitative, physical and monetary
	Ancillary Services	Frequency regulation	Monetary
		Spinning reserve	Monetary
		Non-spinning reserve	Monetary
		Black start service	Qualitative, physical and monetary
	Stability Services	Primary frequency response	Qualitative, physical and monetary
		Voltage support	Qualitative, physical and monetary
	Transmission Benefits	Transmission upgrade deferral	Qualitative, physical and monetary
		Transmission congestion relief	Qualitative, physical and monetary
Power System	Power System Stability (Dynamic Performance)	Primary frequency response	Qualitative, physical and monetary
		Voltage support	Qualitative, physical and monetary
		Transient stability	Qualitative and physical
	Power System Indirect Benefits	Frequency regulation	Monetary
		Spinning reserve	Monetary
		Non-spinning reserve	Monetary
		Reduced electricity generation cost	Monetary
		Reduced curtailments of variable generation	Qualitative, physical and monetary
	Transmission Infrastructure Benefits	Transmission upgrade deferral	Qualitative, physical and monetary
		Transmission congestion relief	Qualitative, physical and monetary
Society	Non-Energy Services	Employment and economic activity	Qualitative, physical and monetary
		Irrigation	Qualitative, physical and monetary
		Public, municipal, and industrial water supply	Qualitative, physical and monetary
		Navigation	Qualitative, physical and monetary
		Flood control	Qualitative, physical and monetary
		Environmental services	Qualitative, physical and monetary
		Recreation	Qualitative, physical and monetary
	Energy Benefits	Avoided outages due to voltage support	Qualitative, physical and monetary
		Avoided outages due to primary frequency response	Qualitative, physical and monetary
		Emissions reductions	Physical

Depending on the selections made in this step the model customizes the path forward, walking the user through the calculation of each selected metric for each selected use case. As shown in Table 1, not all metrics are available for all use cases. For example, the transient stability service is not monetized but can

be evaluated from a physical or qualitative perspective. Additional detail regarding the definition of the beneficiaries, use cases, and key metrics can be found in Sections 3.3 and 4 of Koritarov et al. (2021).

2.6 Price-taker model inputs-outputs

The Price-taker is an embedded model within the PSHVT and requires a set of inputs and outputs to operate properly. The inputs and outputs and the requirements for the files are discussed in the following subsections.

2.6.1 Price-taker Requirements from the User

The Price-taker model requires two sets of inputs from the user: PSH techno-economic parameters and inputs for modeling and evaluating grid and end-user services.

- PSH techno-economic parameters characterize system configuration, unit specifications, as well as operational costs of the PSH facility under study. Specifically, system configuration parameters include usable water volume (in acre-feet), gross head (in feet), and number of units for the development of the facility rating. Each unit can be configured as a reversible set, a ternary set, or one with separate pumps and turbines. Furthermore, users can select either fixed- or adjustable-speed generator/motor technology and add hydraulic short circuit (HSC) operation modes to enhance the overall flexibility of the PSH system. As for unit specifications, users should provide the unit-level rated generating/pumping capacity (in MW), minimum generating/pumping capacity (in MW), and generating/pumping efficiency parameters as well. Operational costs include generating/pumping start-up costs (in $/ea.) and variable operation and maintenance costs (in $/MWh).

- Inputs of grid and end-user services, such as service prices, tariff structure, and load profile are also required for the economic evaluation of PSH systems. Depending upon the services selected, grid service inputs include hourly energy price, regulation price, spinning reserve price, T&D deferral events and upgrade cost, etc. All energy arbitrage, regulation, and spinning reserve take hourly prices for a historical or representative year as inputs. End-user service inputs include hourly energy charge, monthly demand charge, and load profile.

2.6.2 What services are available in your area

Depending on the use cases and geographical regions, PSH systems can be used to generate revenue from participating electricity markets, reduce operational costs for vertically integrated utilities, and perform bill management for distribution utilities or large commercial and industrial customers. Energy and ancillary services are commonly available in most electricity markets in the United States.

Another important issue in power system planning is to ensure sufficient resources to meet future demand, either through capacity markets or integrated resource planning. Capacity is not actual electricity, but rather the ability to produce electricity in future years. A PSH system can be utilized to provide peaking capacity. The corresponding economic benefits are capacity payments for market participants, or capacity charge reduction in a market environment or through bilateral contracts or saving from replacing or reducing the need for new peaking resources in vertically integrated utilities.

2.6.3 Wholesale vs Bi-lateral Markets

Where wholesale markets don't exist, there may be an opportunity to obtain bi-lateral contracts from load serving entities to provide the services. These services could be for capacity services, Transmission and Distribution (T&D) deferral, black start services and/or any of the use cases for which there isn't an organized market. Where wholesale markets exist, wholesale prices can be obtained from the market operators' websites.

2.6.4 Plant Configuration, PSH Unit Types, Variable Operators; PSH Unit Parameters

If the user went directly to the Price-taker model, they must go back to Step 1 – PSH Technology Overview Sections of the PSH Valuation Tool and fill in all the modeling data there for the Price-taker model to work. Plant configuration parameters have dependencies on the system sizing and individual unit sizing. These parameters include:

- **Closed Loop** – All PSH systems analyzed by the price taker will be considered as closed loop. This means no natural flow is considered "in to" or "out of" the upper or lower reservoir.

- **Usable Water Volume** – The usable water volume (in acre-feet) characterizes the effective energy stored in the PSH system.

- **Number of Units** – Users may select the number of units (10 in maximum) used to develop the facility rating. For example, if a facility rating of 500MW is selected, and a user selects 10 units, each unit will be sized for 50MW. Moreover, all units are assumed identical in the price taker model. Do not input the total MW for the facility.

- **Gross Head** – An average head differential (in feet) between the upper and lower reservoir.

PSH facilities provide for long-term energy storage by pumping large quantities of water from a lower elevation to a higher elevation, thereby converting kinetic energy to stored potential energy. The large volume of water can produce days of energy at the facilities' nameplate rating. Various technologies having different operational and related financial benefits are used in the construction of pumped storage. Three pumped storage technologies (PSH unit types) are considered in the price-taker model:

- **Reversible Set** – A reversible set consists of a pump/turbine and a motor/generator connected to a single shaft. In pumping mode, it moves water to the upper reservoir. In generating mode, it can vary output over a wide range (typically 20% – 110% of its nameplate rating) by throttling flows through wicket gates.

- **Ternary Set** – A ternary set consists of a generator/motor, a turbine, and a pump coupled on a single shaft. The generator/motor is synchronous, operating at one speed. The pump and turbine rotate in the same direction and flows from the pump can be routed through the turbine in an HSC. For a ternary unit, the pump typically operates at a fixed speed with a fixed flow to overcome the head. Partial loads, relative to nameplate rating, are stored by routing a portion of the pumped flow through the turbine. Moreover, the pump may be coupled and uncoupled from the shaft depending on operational requirements.

- **Separate Pumps and Turbines** – Separate pumps/motors and turbines/generators are pumps and turbines that are not mechanically coupled and so may be housed in separate facilities. A pump

and turbine may be connected to a single penstock or may use multiple penstocks. Advantages of separate pumps and turbines include the ability to use different combinations of pump ratings and turbine ratings that are readily available, high efficiency, and specifically suited for an operating scenario.

The PSH variable operators include fixed- or adjustable-speed technology as well as hydraulic short circuit (HSC) modes. With fixed-speed technology, both the motor and generator can operate at a synchronous speed. In comparison, adjustable-speed technology allows the motor to rotate at a non-synchronous speed. By varying motor speed, the pump curve can be shifted, so that the improved efficiency can be achieved over a range of flow rates.

The PSHVT also supports the modeling of HSC modes at both unit and plant level. The unit-level HSC pairs pumps and turbines, connecting inlets of turbines to discharges of pumps. The plant-level HSC allows inlets of turbines and discharges of pumps for all units, regardless of technology selected, to be connected. The HSC modes increase the PSH operation flexibility by allowing variable flows to be pumped to the upper reservoir. Note that a ternary unit must have unit-level HSC selected and a unit with reversible pump/turbine must have unit-level HSC unselected.

The PSH Unit Parameters section allows users to define the minimum and maximum generating/pumping power (in MW) and the corresponding generating/pumping water discharge (in cfs, i.e., cubic feet per second) per unit. Users can specify operational costs such as generating/pumping start-up costs (in $/ea.) and variable operation and maintenance costs (in $/MWh).

2.6.5 Inputs of Grid and End-User Services

The inputs of grid and end-user services require users to upload profiles for service prices, tariff structure, load profile, etc. All these files should be in a comma-separated values (.csv) format. Users can download default files as a template, modify the input data based on their own use case scenarios, and then upload these files to the system by dragging and dropping them onto the dotted region shown on the webpage.

2.6.6 Modeling Method Overview

The following sub-sections describe the methodology used for energy and ancillary services and how it differs for capacity value and transmission and distribution (T&D) deferral. In addition, the approach taken to developing and using forecast prices is discussed.

2.6.6.1 Energy and Ancillary Services Versus Capacity Value and T&D Deferral

Most of the grid services (e.g., energy arbitrage and frequency regulation) are evaluated via a model predictive control (MPC) based approach. In each day, a look-ahead optimal dispatch is formulated based on information available at the current scheduling stage. The length of the look-ahead window is set to 24 hours. The optimal dispatch problem is solved to determine the base operating point and how a PSH facility is scheduled for different services in each day. The actual PSH operation is then simulated with an appropriate time resolution based on additional information available in each operating hour, e.g., regulation signals. This process repeats through a historical or representative year.

Both the capacity value and T&D upgrade deferral use cases require the PSH to meet certain peak demand during a few given hours within a year. Performing these two services has little impact on the economic benefits received from other grid services. Therefore, the price taker model evaluates capacity

value and T&D upgrade deferral via pre-processing. Other uses cases (e.g., congestion relief, volt-VAR support, and power reliability), in comparison, are evaluated via post-processing using the optimal dispatch solution obtained from the MPC.

2.6.6.2 Forecasting to Determine the Optimal Use Cases

The price taker model allows users to select forecast prices to perform the economic assessment for PSH systems. Specifically, day-ahead hourly wholesale market prices are forecast using an annual hourly price profile. For each grid service, this procedure is described as follows: (1) extract prices for selected months (e.g., November and December) from the input data and group those prices by hour; (2) fit an autoregressive integrated moving average (ARIMA) model for each hour; (3) starting from the first day of the year, forecast the hourly price using the ARIMA model; (4) update the ARIMA model parameters based on the actual hourly prices of the current day; and (5) forecast hourly prices for the next day using the updated ARIMA model.

2.6.7 Price Taker Service Selection (Use cases)

The price taker model enables users to bundle multiple grid and end-user services and capture stacked value streams. Users can customize their own PSH evaluation by checking the boxes that correspond to their preferred services. After this step, the tool will only provide input windows for the services that are selected. In this section, we describe in detail the modeling and required inputs for different use cases. The default files are associated prices in 2018 for Independent System Operator-New England, but in general it is just format for price file.

2.6.7.1 Energy Arbitrage

Energy arbitrage refers to the operation of energy storage facilities (including PSH plants) that generate electricity when the demand and/or electricity prices are high and consumes electricity when the demand and/or prices are low. Since this type of energy storage operation reduces the net system load during peak hours and increases the load during off-peak hours, it is also often referred to as load leveling or load shifting. Energy arbitrage can be performed in both a vertically integrated system and in wholesale electricity markets. The economic reward is the price or cost differential between pumping and generating electrical energy, minus the cost of losses during the full generating/pumping cycle including variable O&M costs.

To perform energy arbitrage, the price taker model requires users to input a profile of hourly energy market prices (in $/MWh) for a historical or representative year, including components such as energy and congestion. Historical energy price profiles can be found from the official website of an electricity wholesale market. If it is a bilateral agreement used to provide services, the prices need to be filled in by the hour according to the pricing in the contract using the same format as in the default file.

2.6.7.2 Capacity Value

The value of generation capacity is primarily derived from its contribution to resource adequacy and system reliability. PSH plants typically provide peaking capacity since they are very flexible and can be quickly dispatched with a high ramp rate to meet peak demands. The peaking capacity of PSH plants can also replace or reduce the need for new peaking thermal resources. The capacity value of PSH can be high when there is a shortage of peaking capacity in the system and low if the system already has sufficient peaking capacity.

Users can either use default values or upload their own data for the capacity value evaluation. Note that for small modular systems, this value might be less than 100% of the capacity price. The net capacity of the plant is the average hourly generation derated by forced outages including both full and partial outages. This does not include planned outages. Plants may also choose to bid less than their calculated capacity so they can bid into other services and to avoid penalties for the lack of performance.

The upload file contains information for forecast dates and hours when the capacity will be called by the system operator, as well as the months when the project has bid to deliver capacity. The capacity requirement is a percentage of the plant's capability that is being bid into the market (for annual markets, the monthly amounts will be the same.) The capacity price could be the same every month (1/12 of the $/MW-year value for annual markets). In certain circumstances, it could be a value (in $/MW-mo) for markets with monthly prices, which reflect seasonal pricing. Historical capacity price data can be obtained from a capacity market or from a bilateral contract.

2.6.7.3 Frequency Regulation

Electric power systems must maintain a near-real-time balance between generation and load. Frequency regulation services are required to continuously balance generation and constantly changing demand under normal conditions. The operation of a PSH plant is flexible and can provide frequency regulation services in both generating and pumping mode (with adjustable-speed technology). The regulation capacity is limited by the capability to deviate from the scheduled power to increase (regulation up) and decrease power output (regulation down).

Most markets have implemented pay-for-performance to calculate rewarding credit based on regulation capacity, regulation mileage, and performance factor/score. The capacity payment is calculated based on the capacity prices and regulation capacity. In some markets, the performance factor is used to adjust the capacity payment. The mileage payment is calculated based on the mileage prices, regulation mileage, and performance score. The inputs for regulation services include capacity and mileage prices and performance score. Moreover, some regions split regulation into an up service and a down service, while others treat it as a controllable range.

The current price taker model does not differentiate regulation up and regulation down services. It requires users to upload regulation price profile, including capacity (in $/MW) and mileage prices (in $/MWh), together with a performance score. Besides, users should input a range (typically from 0 – 5%) to limit the PSH plant's regulation capacity. Automatic generation control (AGC) signals are also required for a real-time simulation of regulation services in the price taker model.

2.6.7.4 Spin and Non-spin Reserve

Contingency or operating reserves are called to restore the generation and load balance in the event of a contingency such as a sudden, unexpected loss of a generator. Any resource that can respond quickly and long enough can supply contingency reserves. A PSH facility can be used to provide both spinning and non-spinning reserves. Spinning reserve is provided by resources already online and synchronized to the grid that can increase the output immediately in response to a major generator or transmission outage, and can reach full output quickly (e.g., 10 minutes). Unlike frequency regulation that is exercised from hour to hour, spin reserve is not called upon unless the contingency occurs. Considering the typical prices and required energy reserve, using a PSH to provide spinning reserve is generally more valuable than non-spinning reserve. Therefore, only spinning reserve is considered in the price taker model. Only a spinning reserve price profile (in $/MW) is required from users to evaluate this service.

2.6.7.5 Transmission Congestion Relief

Transmission congestion is defined as a condition that arises on the transmission system when one or more restrictions prevents the economic dispatch of electric energy from serving loads, as detected by power transferring at the thermal, voltage, and stability limits in certain areas of the transmission network. A PSH plant can be used to enhance the operational flexibility of the transmission system and reduce the cost associated with transmission congestion. A location marginal price (LMP) is a cost of optimally supplying an increment of load at a particular location while satisfying all operational constraints. It is the change of the total production cost to deliver an additional increment of load to the location. An LMP consists of three components: system energy price, transmission congestion, and marginal losses. The congestion component reflects the marginal cost of congestion at a given node relative to the load-weighted average of the system node prices and can be used to calculate the change in congestion cost associated with different PSH operations.

In the price taker model, the congestion component of LMP is uploaded with energy arbitrage inputs. This service is also evaluated via post-processing. Specifically, the hourly benefits of transmission congestion relief are the product of the congestion component of LMP and PSH output power obtained from the optimal dispatch solution.

2.6.7.6 Volt-Var (Reactive Power) Support

Power system voltage is sensitive to the injection and withdrawal of reactive power. Volt-VAR (Volt Amperes Reactive) support involves the control of reactive power to maintain acceptable voltages throughout the system under normal and contingency conditions. Various pieces of equipment on the transmission and distribution system such as capacitors, inductors, and transformer tap changes provide relatively inexpensive voltage control and reactive power. A PSH plant's ability to provide reactive power is related to its ability to produce and consume real power but not linearly. The need for reactive power support changes from time to time and from location to location. Market-based reactive power compensation mechanisms are not yet well established or consistent. One approach provides no compensation and simply requires response within a given power factor range. Other approaches include compensation based on their revenue requirements for reactive power capability as a capacity payment and locational prices developed by system operators for reactive power supply based on typical cost estimates or generator and transmission system offers.

The required inputs for Volt-VAR support include apparent power capability, which is a constant or a function of power factor and generation/pumping, as well as an approximate annual payment to PSH (in $/MVar-year). The prices may be obtained from the LSE. The sizing is similar to capacity percentages but focused on reactive power. The benefits from Volt-VAR support are typically much lower than other services. Therefore, the price taker model estimates its benefits via post-processing, where the dynamic reactive power capability is determined based on real power profile from the optimal dispatch and annual benefits are calculated accordingly.

2.6.7.7 T&D Upgrade Deferral

A PSH plant can play an important role by reducing the peak load on a specific portion of the transmission and distribution (T&D) system, and thereby help defer or postpone specific projects and T&D system upgrades that otherwise would be needed earlier to meet the growing demands. Depending on the circumstances, the benefits can be quite significant, especially if the upgrade that is deferred is expensive. In most situations, a PSH for this application is only used for a very small portion of the year

when the load exceeds the T&D equipment's capacity. The same PSH can be used for numerous other applications in the remaining time.

The inputs for T&D deferral economic assessment include existing load profile, load growth rate, existing infrastructure capacity, and planned upgrade cost. Load profiles and growth rates can be obtained from Integrated Resource Plans. Planned upgrade costs need to be estimated using tools available to user such as utility, reliability coordinator, or system operator cost guides. Based on the existing load profile and load growth rate, the peak demand for future years is calculated and compared with the existing infrastructure capacity to determine the year when T&D investment needs to be made. Annual peak minimization problems are formulated and solved repeatedly to determine the year when the T&D upgrade must be made. Based on the upgrade cost and the years when T&D investment needs to be made with and without a PSH plant, present-value costs are calculated, and T&D deferral benefits are estimated.

2.6.7.8 Behind the Meter Use Cases

Behind the Meter (BTM) cases are for small projects such as in-line generators that can be used in irrigation or aquifer pumped storage. The projects can offset energy costs and reduce outage time for the user. In certain areas, the generation from pumped storage can be used to improve power reliability by reducing outage times for the utility. The generation can also be used for Customer Energy Management by managing Time-of-Use charges and to peak shave for Demand Charge reductions.

Power Reliability Data

Power Reliability outage data can be collected from your utility for the lines that your facility reduces outages. In addition, they may be able to provide you with the number of residential, commercial and industrial Customers. This information will be needed to obtain the value of power reliability from the ICE calculator (https://icecalculator.com/home).

Time of Use (TOU) Charge Management

A PSH plant can be operated to reduce customer charges for electric energy when the price is specific to the time (season, day of week, time-of-day) when the energy is purchased. TOU benefits are derived from the difference between peak time savings by supplying electricity from storage and cost of the electricity used to charge the PSH plant during an off-peak period. The PSH plant can be used to store energy during low-price off-peak periods and then avoid higher-cost peak energy. In the price-taker model, users are required to input the energy rate for evaluating TOU charge management.

Demand Charge Management

A PSH plant can be operated to reduce the maximum power draw by electric load to reduce peak demand charges. By pumping at off-peak hours and generating at peak hours, a PSH facility can be operated to reduce the maximum power draw by electric load over a billing period. In the price taker model, users need to upload demand charge rate for the evaluation of this service.

2.6.8 Output

After the price taker output webpage being loaded, it will automatically run the back-end optimization engine to perform the economic evaluation. The computation may be slow, and we have set a 20-minute

time limit for running the price taker model. If the evaluation cannot be completed in 20 minutes, the webpage will stop the optimization process. If you don't get an answer, send an email to PSHsupport@anl.gov. An email will be sent to both ANL and PNNL. When the evaluation is successfully completed, it will show a "Next" button for users to check the results obtained from the price taker model. Price-taker optimizes and integrates the use cases; thus Step 11 can be skipped, and the user can move to Step 12 BCA.

The PSH tool provides annual benefits by service and PSH usage in hours by service, as shown in **Figure 6** and **Figure 7**, respectively. Users can download all the graphics as .png files by hovering over the graphic and clicking the "Download" button.

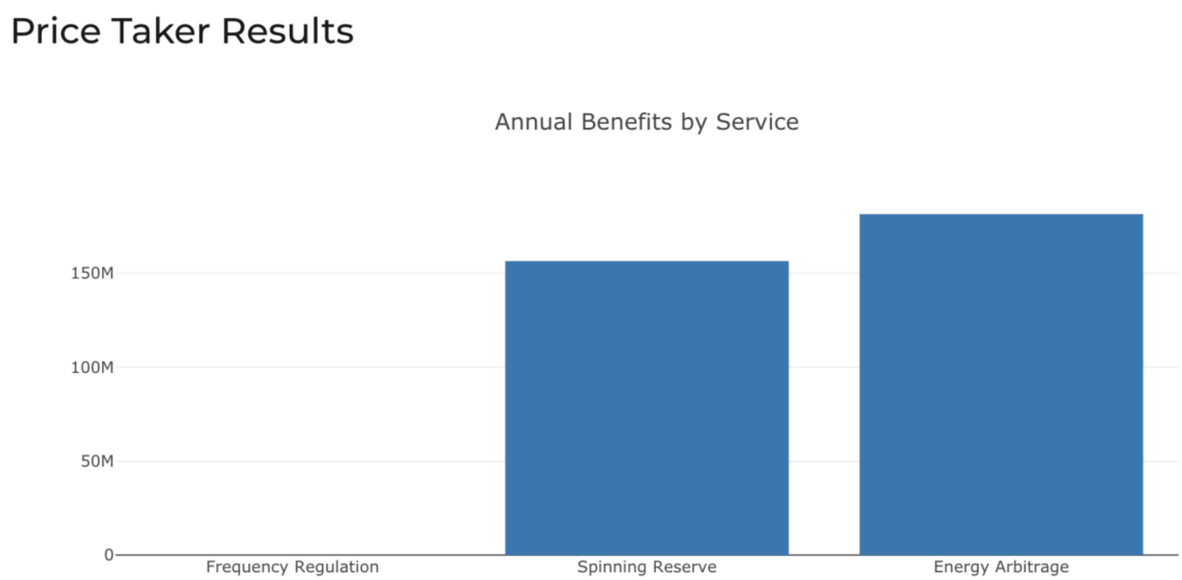

Figure 6. PSH annual benefits by service

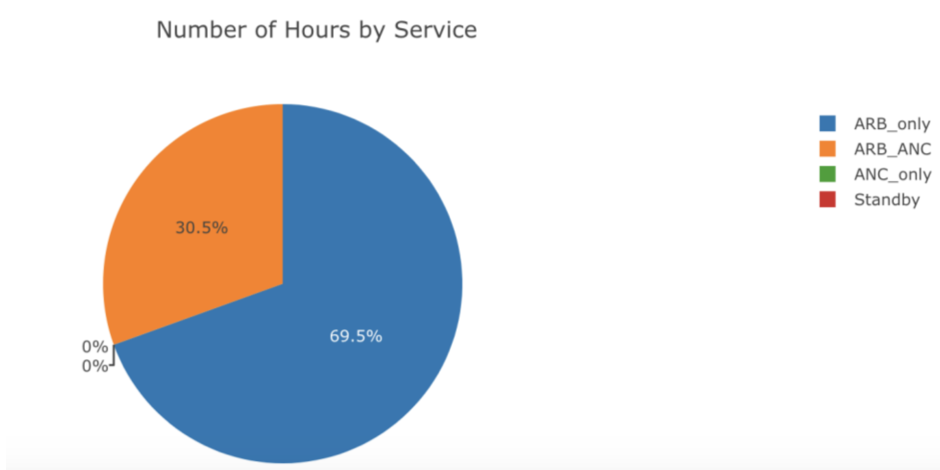

Figure 7. Number of hours by service

The PSHVT also enables users to view detailed PSH operation (both at the unit- and system-level) throughout a year, as shown in **Figure 8** below. The scheduled and/or actual PSH operation as well as its water volume state profile are plotted and synchronized in time. Note that a positive PSH power means

generating and corresponds to a decreased water volume state and pumping corresponds to increased water volume.

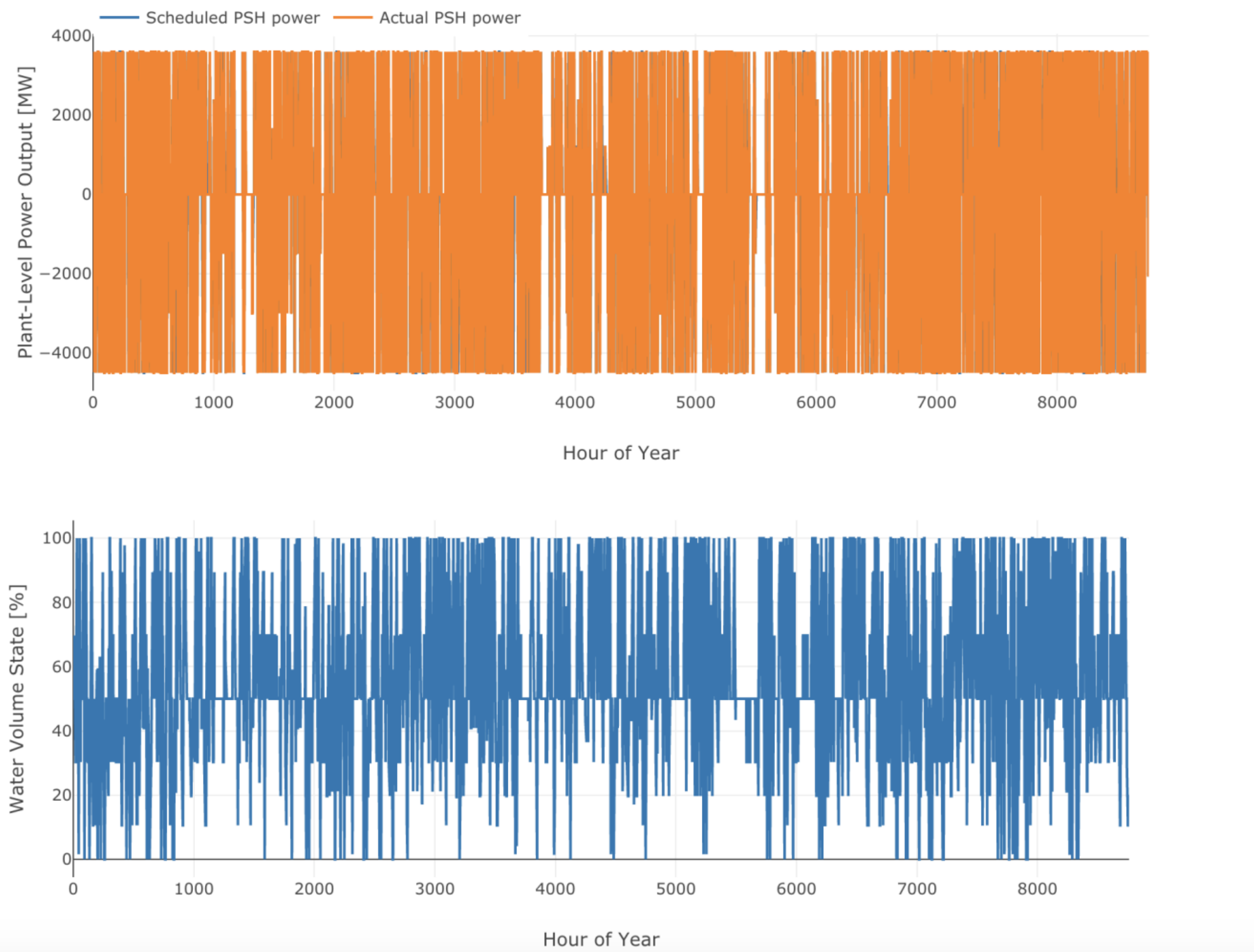

Figure 8. PSH plant-level operation and water volume state

2.7 Financial/cost data input and running of BCA model – inputs/outputs.

In Step 12, a BCA is performed to determine the economics of each alternative identified in Step 3 and every scenario identified for each use case. Technical and cost data from Step 1 are combined with data collected through the Price-taker modeling process, and additional financial and cost data collected in Step 12 to perform a BCA and produce several financial metrics that feed into a report produced in Step 15.

2.7.1 Price-taker input-outputs

Revenue from Price-taker model is automatically loaded into the BCA model. However, the annual rate of revenue increases must be input. As mentioned previously, the Price-taker optimally integrates the use cases and thus the share of the revenue for each use case value included is 100 percent. Project life, discount rates, debt interest rates and Federal and state tax rates need to be added. Variable costs must be

added even though they are included in the optimization process. Those costs are not transferred to the BCA. All O&M and refurbishment costs and year of refurbishment need to be input. Care must be taken to include all potential taxes. Annual property taxes and insurance may or may not be included in estimated burdened annual O&M costs. The user needs to check with data provider. If not, they need to be added as a line item. In addition, some states require gross receipts taxes and those must be added.

2.7.2 Price Influencer Input/outputs.

Price influencer data are collected and stored through most steps of the 15-step BCA process. Technical project information, cost information, use case, scenarios, and cost financial data are collected through the first 11 steps of the PSHVT. It is important to note that the model will only consider one case at a time, comprised of a single alternative for a single project with a defined set of use cases with one scenario defined for each use case. It is therefore important to think through the commonality of the scenarios you wish to evaluate in Step 12 when inputting information in Steps 7-10. That is, you would want to select the same scenario (e.g., high variable renewable energy penetration) for each use case when evaluating a single case in Step 12. The user can always select new scenarios (e.g., high natural gas prices) when evaluating a new case.

When providing data in Step 12, it is important to understand the numeric conventions. A nominal discount rate, for example, would include the effects of inflation. A real discount rate would be lower because the user would deduct the impact of inflation on the discount rate. The base year for discounting is the one prior to when discounting begins. If the user wishes to discount future values back to the year before the PSH plant begins operation, the value 0 should be input. If the base year is the first year of operation, the value input would be 1. While the user is walked through the valuation process in Steps 7-10, the results of the external modeling exercise is input in Step 12 where the annual system value, annual escalation or revenue growth rate, and year when the system value first escalates is defined. Note that the year would be defined in terms of project years (e.g., Year 1 or Year 2) rather than calendar years (e.g., 2028 or 2029).

The BCA model enables the user to define alternative scenarios, evaluate many use cases, and consider alternative debt structures, alternative depreciation methods, tax implications, salvage value, all capital and operations and maintenance costs, and refurbishment costs. The model can take up to 20 minutes to run the model. Do note close your browser while the model is running. The Next button will be enabled when finished.

2.8 MCDA modeling –inputs/outputs

MCDA is a decision support tool that enables diverse stakeholders to consider a variety of concurrent goals when deciding on energy policies, initiatives, and infrastructure investments. In enables the user to broaden the analytical perspective beyond traditional monetary metrics to include broader environmental, resilience, social equity, and other goals. It follows a four-step process as defined in Figure 9. The PSHVT walks the use through all four steps in the MCDA process.

Appendix A of Koritarov et al. (2021) presents over 100 metrics that could be used in the MCDA process, including those covering the following objectives (number of metrics in parenthesis): reliability (32), resilience (15), flexibility (20), sustainability (20), affordability (21), security (14), power quality (3), stability (8), and economy (9). The model allows the user to select from several broad categories of metrics. The user defines each metric. The user can define up to 20 metrics to include in the MCDA evaluation. The user may select multiple metrics for a single objective. Note that the data do not flow through from previous steps to the MCDA model because the model has no predefined metrics.

The MCDA model is designed to produce performance indices for each alternative selected for analysis. An investment generating a higher performance index is more desirable, even if goals are designed around minimizing the metrics. The results of the MCDA model are carried forward and presented in the report produced in Task 15.

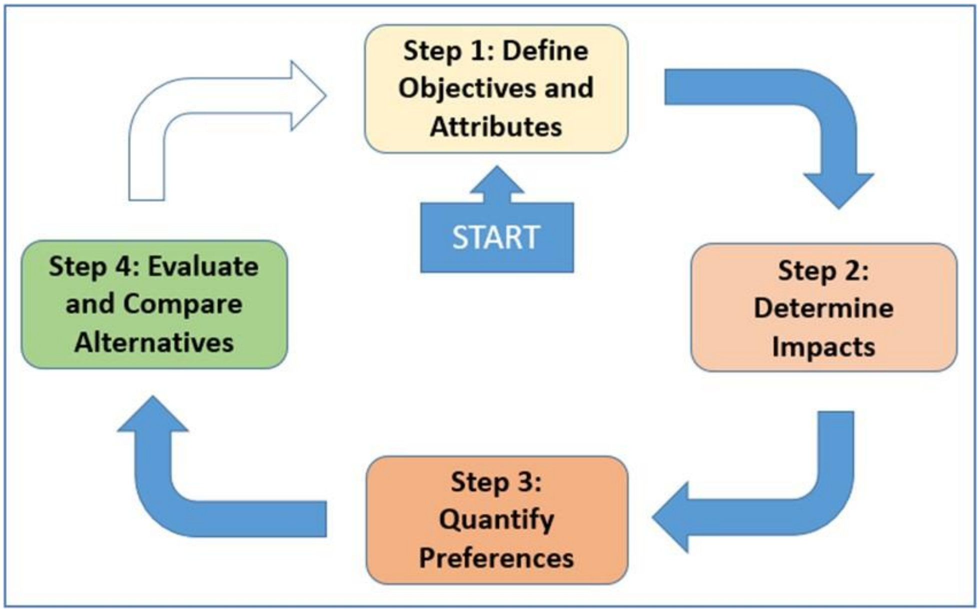

Figure 9. Creating New Case Studies and Editing Existing Cases

2.9 Viewing results and reporting.

When the BCA model has completed its run, it produces five key financial metrics:

- **Net present value (NPV) (end-of-the-year method).** Difference between the present value of cash inflows and the present value of cash outflows over the CBA period. With the end-of-the-year method, discounting works as though all the cash outflows occur on the last day of each period. A project with an NPV > 0 demonstrates positive net benefits.
- **NPV (mid-year method).** Difference between the present value of cash inflows and the present value of cash outflows over the CBA period. With the mid-year method, discounting works as though the cash outflows occur evenly throughout the period. A project with an NPV > 0 demonstrates positive net benefits.
- **Benefit cost ratio (BCR).** Ratio between the discounted total revenues of the project and the discounted total costs. A project with a BCR in excess of 1.0 demonstrates positive net benefits.
- **Internal rate of return or IRR.** Highest discount rate for which the NPV of the project is positive, or the annual average rate of return on a project.
- **Discounted payback period.** Number of years it takes to break even from undertaking the initial expenditure, by discounting future cash flows and accounting for the time value of money.

The MCDA model presents a performance index for every alternative defined by the user in Step 14. The performance index value varies between 0 and 100 based on the weights, values, and scores assigned by the user for each alternative defined for the analysis. The alternative with the highest performance index is the one judged most preferable based on the MCDA results.

In the 15th, and final, step the PSHVT produces a final report that documents key user input throughout all 15 steps, and reports the results of the BCA, MCDA, and if used, price taker model.

3.0 References

DOJ – Department of Justice and Federal Trade Commission. 2010. Horizontal Merger Guidelines. Available at https://www.ftc.gov/sites/default/files/attachments/merger-review/100819hmg.pdf

Koritarov, Vladimir, Balducci, Patrick, Levin, Todd, Christian, Mark, Kwon, Jonghwan, Milostan, Catharina, Ploussard, Quentin, Padhee, Malhar, Tian, Yuting, Mosier, Thomas, Alam, S.M. Shafiul, Bhattarai, Rojan, Mohanpurkar, Manish, Stark, Gregory, Bain, Dominique, Craig, Michael, Hadjerioua, Boualem, O'Connor, Patrick, Mukherjee, Srijib, Stewart, Kevin, Ke, Xinda, & Weimar, Mark. *Pumped Storage Hydropower Valuation Guidebook: A Cost-Benefit and Decision Analysis Valuation Framework.* United States. https://doi.org/10.2172/1770766

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