An Introduction to Pumped Storage Hydropower
WestFAST Webinar, February 14, 2023

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OVERVIEW OF PSH TECHNOLOGIES AND THEIR ROLE IN ELECTRIC POWER SYSTEMS

Presented by:

VLADIMIR KORITAROV

Director, Center for Energy, Environmental, and Economic Systems Analysis (CEEESA)
ARGONNE NATIONAL LABORATORY
630-252-6711
koritarov@anl.gov

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A COUPLE OF QUOTES

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Pumped Storage Hydropower International Forum

International Forum on Pumped Storage, Second Meeting
25 May 2021

https://www.hydropower.org/events/2nd-meeting-of-the-international-forum-on-pumped-storage-hydropower

"Pumped storage hydropower is the only commercialized form of long-duration energy storage that is currently available." – Jennifer Granholm, U.S. Secretary of Energy

"Pumped storage hydropower can and will continue to play a crucial role in our fight against climate change." – Kelly Speaks-Backman, Acting Assistant Secretary, U.S. DOE

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PRESENTATION OUTLINE

- PSH energy storage concept and resource potential
- Brief overview of PSH technologies
- How PSH benefits the electrical grid?
- New and innovative PSH technologies
- How to determine the value of PSH projects?

PSH ENERGY STORAGE CONCEPT AND RESOURCE POTENTIAL

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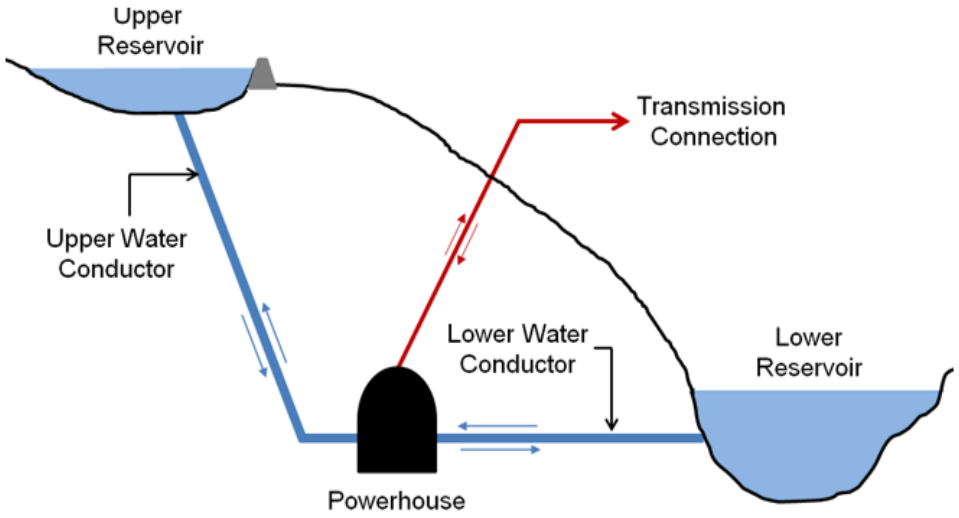
PSH ENERGY STORAGE CONCEPT

- First grid-scale energy storage
- Proven and reliable commercial technology
- Unit capacity from <1 MW up to 500 MW
- Plant capacity up to 3,000 MW (Bath County, VA)
- Large energy storage (typically 8-10 hours or longer)
- Technologies:
  - Fixed speed
  - Adjustable speed
  - Ternary
  - Quaternary

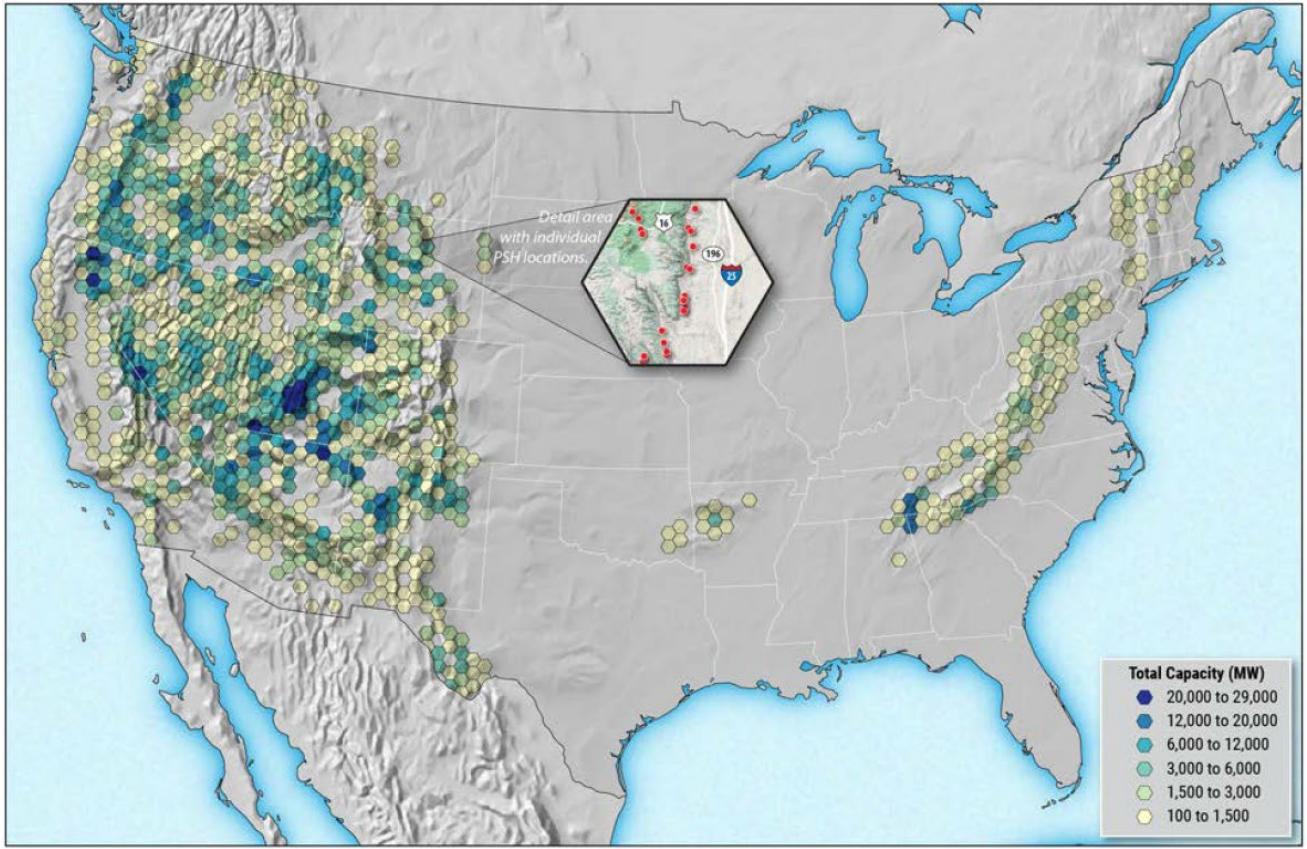
Typical configuration of PSH plant



Source: Koritarov et al. (2014) ANL/DIS-14/7

PSH RESOURCE POTENTIAL IN THE U.S.?

NREL study finds technical potential for 11,769 PSH sites in the continental U.S.



Source: Rosenlieb et al. (2022) NREL/TP-6A20-81277

BRIEF OVERVIEW OF PSH TECHNOLOGIES

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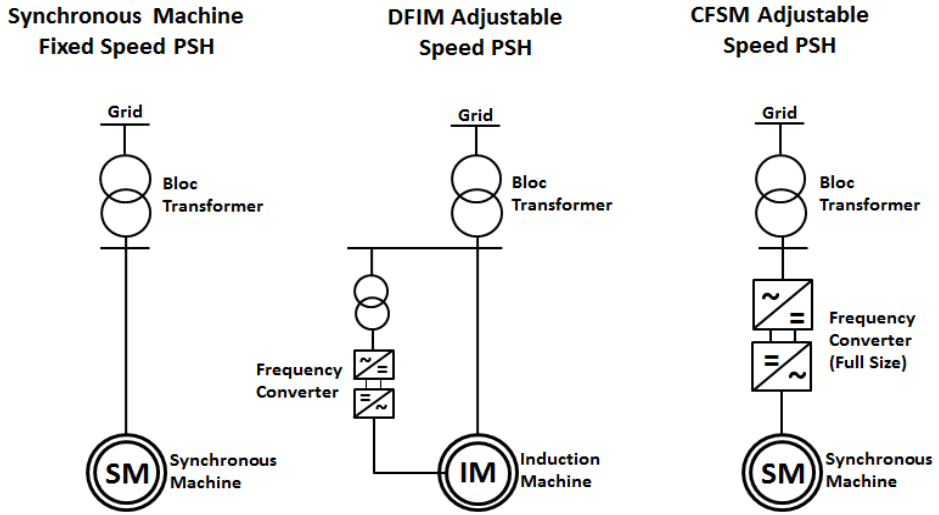
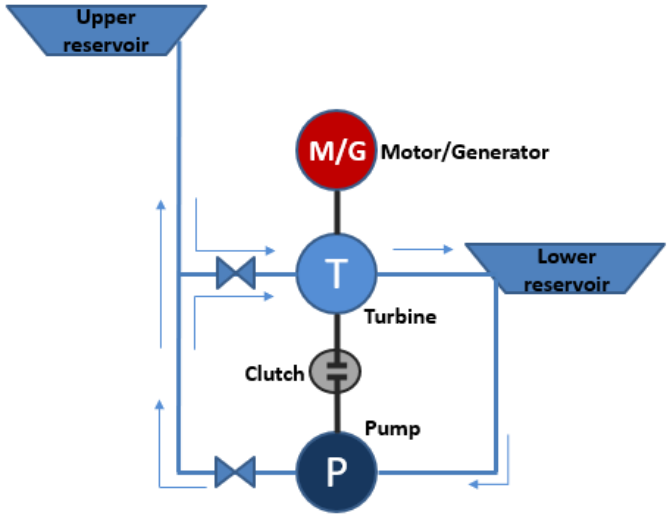
FIXED-SPEED AND ADJUSTABLE-SPEED PSH TECHNOLOGIES

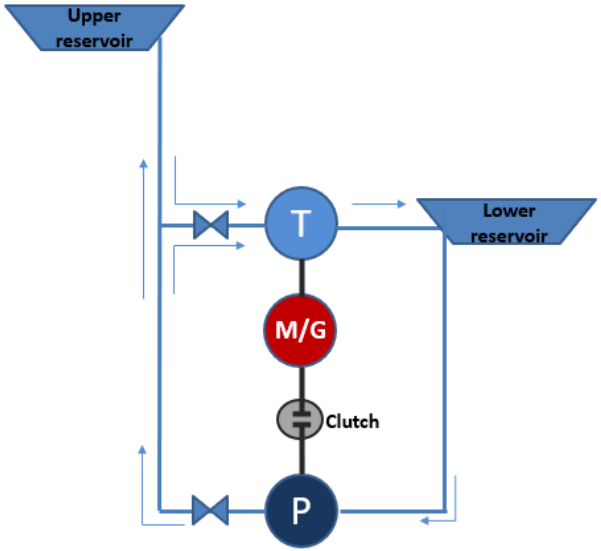
- Adjustable-speed PSH use doubly-fed induction machines (DFIM) or converter-fed synchronous machines (CFSM)
- Adjustable-speed PSH can operate in partial load pump mode, which allows them to provide regulation service also during pumping



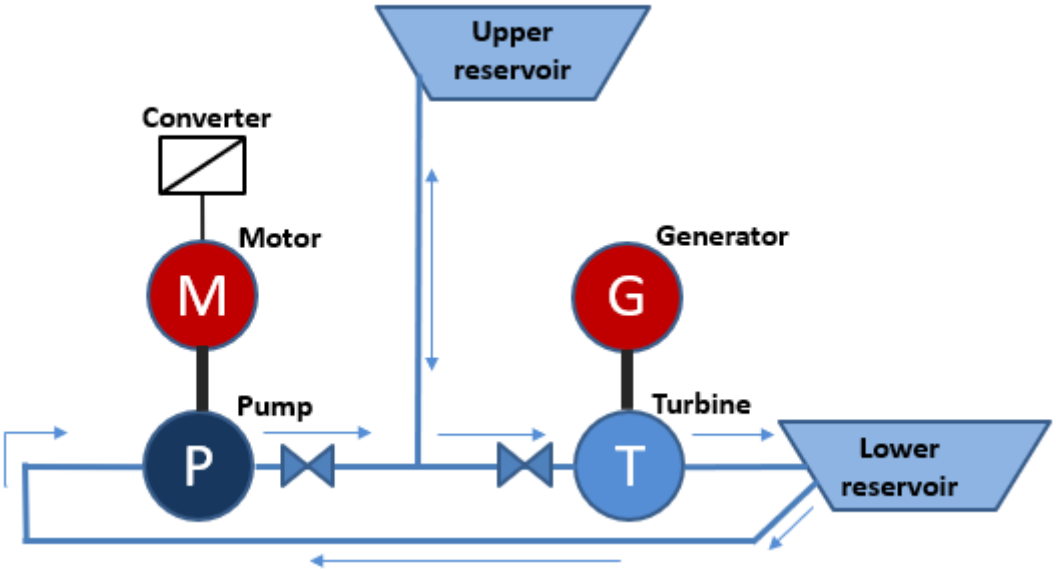
TERNARY PSH UNITS WITH HYDRAULIC SHORT CIRCUIT (HSC) ARE EVEN MORE FLEXIBLE

- All three components (turbine – motor/generator – pump) can operate at the same time and rotate in same direction (“hydraulic short circuit”)
- No need to stop and reverse rotation to change mode from generating to pumping and vice versa





QUATERNARY PSH TECHNOLOGY WITH HSC



Koritarov et al. (2022) ANL-22/08

HOW PSH BENEFITS THE ELECTRICAL GRID?

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PSH SUPPORTS GRID INTEGRATION OF VARIABLE RENEWABLES

- Clean energy goals require reliance on large amount of variable energy resources (VER), which makes electric grid difficult to manage
- PSH enables high penetration of VER:
  - Provides large quantities of energy storage and full range of ancillary services necessary for grid operation
  - Provides large amount of flexible dispatchable capacity with no greenhouse gas emissions
  - Can mitigate over-generation of VER through time-shifting and storing excess generation
  - Improves dynamic behavior and stability of power system

Image source: DOE *(www.energy.gov/eere/solar/solar-energy-technologies-office)*

Image source: DOE (*www.energy.gov/eere/wind/wind-energy-technologies-office*)

KEY CHALLENGES FOR LARGER INTEGRATION OF VARIABLE RENEWABLES INTO THE POWER GRID

- Clean electricity generation from variable energy resources (VER) is highly desirable, however, these generation sources are characterized by their **variability** and **uncertainty.**

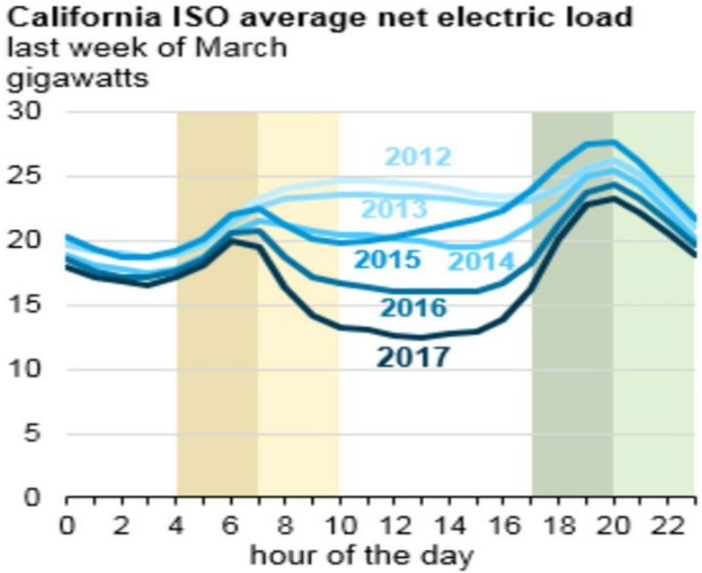

Image source: U.S. Energy Information Administration
www.eia.gov/todayinenergy/detail.php?id=32172

- Advanced forecasting reduces **uncertainty;** however, we still need to address the **variability.**
- More **flexibility** is needed to support variable generation.

PSH PROVIDES FLEXIBILITY TO THE GRID!

- **Load shifting from peak to off-peak periods**
  - Increases efficiency of system operation by reducing the operation of expensive peaking units
- **Contingency reserves (spinning, non-spinning, supplemental)**
  - PSH provides large amount of fast contingency reserves (e.g., for the outages of large generating units or transmission lines)
- **Regulation reserve**
  - Helps maintain system frequency at a narrow band around nominal system frequency by balancing supply and demand
- **Flexibility reserves and load following**
  - Provides a quick-ramping capacity
- **Energy imbalance reduction**
  - Balances the variability of wind and solar power and corrects the control area intertie exchanges

HOW PSH BENEFITS THE GRID?

- Bulk power capacity and energy services
  - Electric energy time-shift (arbitrage)
  - Dispatchable capacity
- Ancillary services:
  - Frequency regulation
  - Spinning reserves
  - Non-spinning reserves
  - Supplemental reserves
  - Voltage support
  - Black start service
- Power system stability services:
  - Synchronous inertia
  - Primary frequency response
- Indirect system benefits
  - Reduced overall system electricity production cost
  - Reduced cycling and ramping of conventional generating units
  - Reduced curtailments of variable generation
  - Reduced system emissions (depending on plant mix)
- Transmission benefits
  - Transmission congestion relief
  - Transmission investments deferral
- Additional non-energy benefits
  - Local economic development and job creation
  - Portfolio diversification
  - Reduced dependence on fossil fuels

Services that are currently being compensated in most electricity markets are highlighted BLUE

KEY CHALLENGES FACED BY PSH DEVELOPERS

- Investment risk:
  - High capital investment costs
  - Long licensing and permitting process
  - Long construction time and payback period
- Market uncertainties:
  - Many PSH services are currently not compensated
  - Lack of long-term power purchase agreements with offtakers
- Environmental issues:
  - Mostly related to open-loop PSH designs
- Public acceptance:
  - Opposition to large energy projects
- Inadequate PSH representation in power system modeling tools
  - The benefits and value of PSH projects not properly captured

NEW AND INNOVATIVE PSH TECHNOLOGIES

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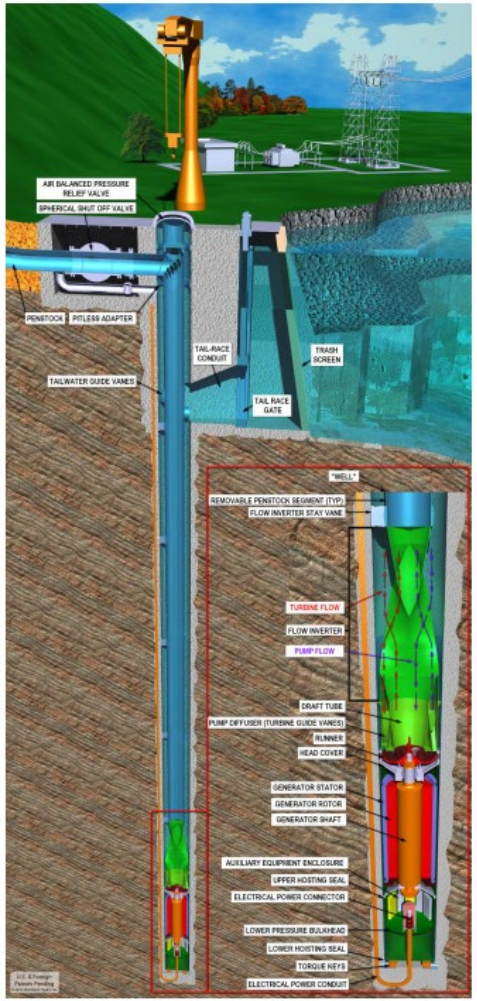
PSH USING SUBMERSIBLE PUMP/TURBINES & MOTOR/GENERATORS

Obermeyer Hydro is developing a new PSH design that does not require underground powerhouse

- Submersible pump/turbines and generators are compact and factory assembled and tested, reducing on-site work and construction costs.
- Concept applicable for PSH units from 1 MW to about 100 MW
- Geological risk and constraints are reduced, opening more potential sites to economical development
- Due to small space requirements, this technology may also be used to add PSH capabilities to existing hydropower plants



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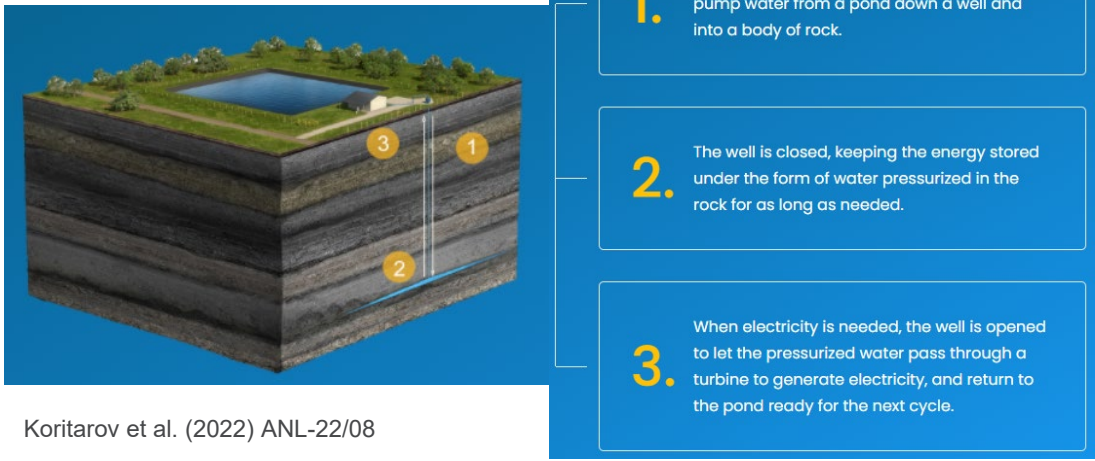
GEOMECHANICAL PUMPED STORAGE

Quidnet Energy is developing a novel PSH concept that could be widely deployable at low cost

- Subsurface rock layers are converted into energy storage facilities for large-scale renewables integration and grid management.
- Terrain-independent – no need for mountains, lakes, or pre-existing underground caverns.
- Cost-effective – structural cost advantage, with low per-MW installed costs.
- Modular – 1 to 40 MW well modules for flexible and precise deployment onto the grid.



Koritarov et al. (2022) ANL-22/08

HYBRID PSH+WIND PLANT

Concrete wind towers with water reservoirs around their base proposed by Max Bögl

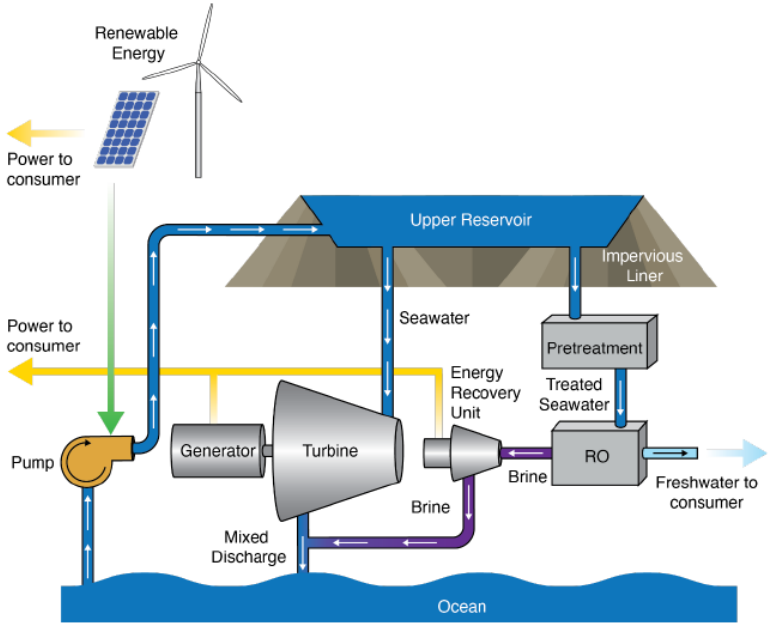
- Modular PSH-wind hybrid system allows for flexible configurations.

Koritarov et al. (2022) ANL-22/08

INTEGRATED PSH AND DESALINATION SYSTEM

Integrated Pumped Hydro Reverse Osmosis Clean Energy System (IPHROCES) proposed by Oceanus Power & Water

- PSH plant uses surplus grid electricity or onsite RE generation to pump seawater into upper reservoir
- Water released through reversible pump/turbine to produce electricity and through reverse osmosis (RO) desalination plant to produce fresh water
- Desalination plant powered by hydraulic pressure; no electricity needed
- Brine diluted with PSH turbine discharge and returned to the ocean



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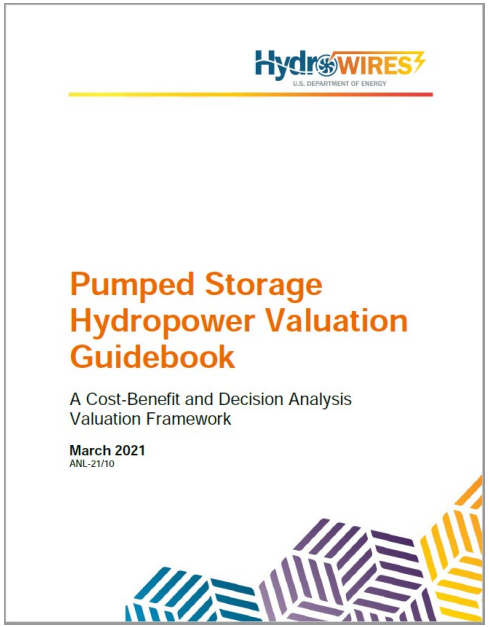
HOW TO DETERMINE THE VALUE OF PSH PROJECTS?

PSH VALUATION GUIDEBOOK

HydroWIRES
U.S. DEPARTMENT OF ENERGY



A comprehensive and transparent valuation process for assessments of existing and new PSH projects, or project upgrades.

Define Scope
- 1. Provide Project Overview and Technology Description
- 2. Define Valuation Question and Document Valuation Context
- 3. Identify the Set of Alternatives
- 4. Determine Relevant Stakeholders and Define Boundaries

Develop Valuation Criteria
- 5. Catalog Impacts and Metrics
- 6. Identify Key Impacts and Metrics for Valuation

Design Analysis
- 7. Determine Evaluation Approach and Address Uncertainties
- 8. Select Evaluation Methods and Tools
- 9. Develop Assumptions and Input Data

Determine and Evaluate Results
- 10. Assess Impacts for each Alternative
- 11. Perform Integration of Valuation Results
- 12. Conduct Cost-Benefit Analysis for each Alternative
- 13. Perform Risk Assessment
- 14. Perform Multi-Criteria Decision Analysis
- 15. Compare Values, Document Analysis, and Report Findings

https://publications.anl.gov/anlpubs/2021/03/166807.pdf

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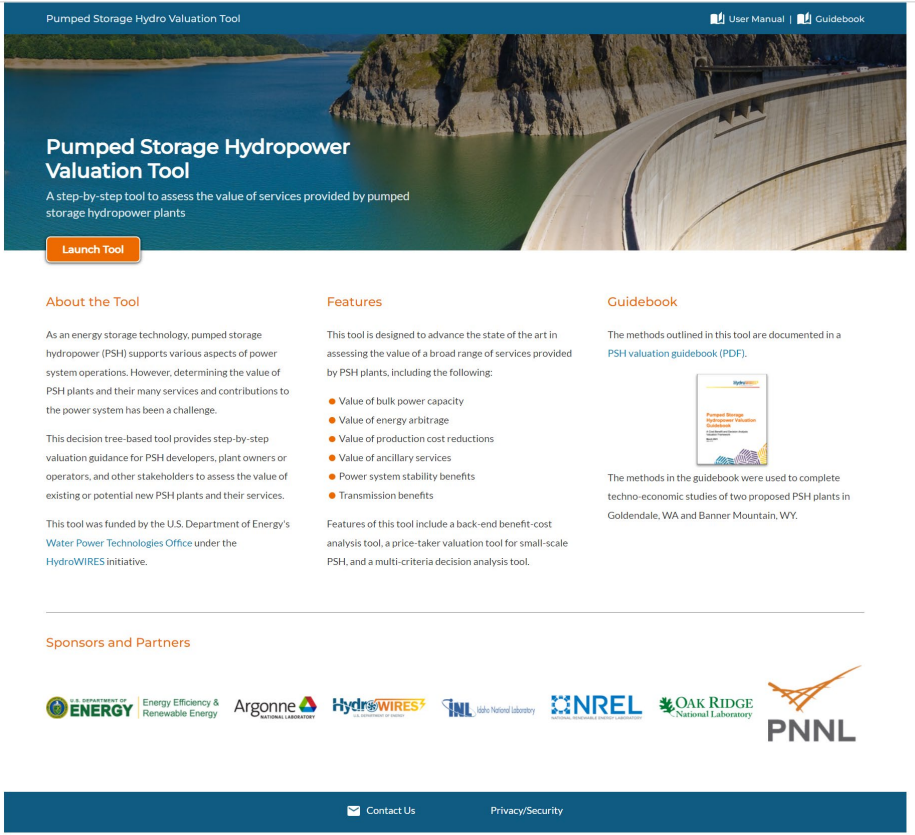
PUMPED STORAGE HYDROPOWER VALUATION TOOL (PSHVT)

- PSH tool provides step-by-step valuation guidance for PSH developers, plant owners or operators, and other stakeholders
- PSH tool advances the state of the art in evaluating a broad set of use cases from three perspectives: owner/operator, system, and society
- PSH tool has a number of advanced features:
  - Embedded price-taker and price-influencer models
  - Multi-criteria decision analysis (MCDA) tool
  - Embedded financial worksheets and benefit-cost analysis (BCA) model



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THANK YOU FOR YOUR ATTENTION!

QUESTIONS?