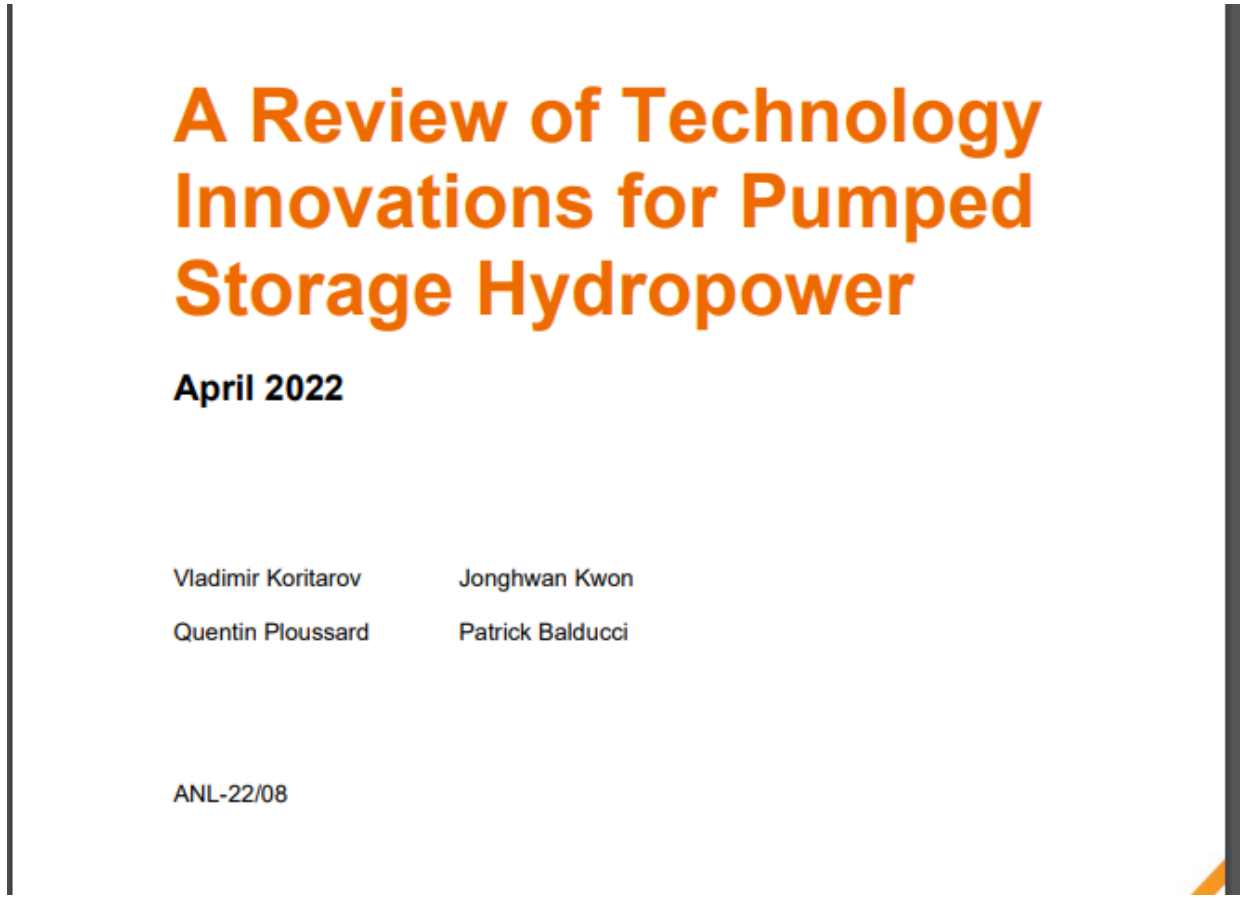
1.2.4.004 – PSH Portfolio Evaluation and Innovation Study



A Review of Technology Innovations for Pumped Storage Hydropower

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ANL-22/08

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Project Overview

Project Summary

- The objective was to provide a comprehensive view of the current state of pumped storage hydropower (PSH) technology, latest trends in plant design and configurations, and an objective assessment of proposed new PSH concepts and technology innovations. The study provides a detailed review of twelve innovative PSH concepts and technologies, using a set of predefined evaluation criteria. In addition to innovative PSH concepts, the project team also discussed potential ways to add PSH capabilities to existing hydropower plants by retrofitting them with reversible pump-turbines or converting them to pump-back PSH. Innovative excavation and construction methods that could accelerate the development of new PSH projects were also reviewed.

Intended Outcomes

- The study supports the development and deployment of innovative PSH technologies by identifying and benchmarking the most promising new technologies that may be able to significantly reduce the cost, time, and risk for PSH development. Technology evaluations and key findings of the study are published in a HydroWIRES technical report and presented at hydro conferences and other events. Using this information, DOE- and industry-funded R&D can better prioritize the most promising PSH technologies.

Project Information

Principal Investigator(s)

- Vladimir Koritarov, Quentin Ploussard, Jonghwan Kwon, Patrick Balducci

Project Partners/Subs

- Project team communicated with numerous PSH technology developers to obtain information about their PSH concepts and technologies, as well as with PSH industry experts who served in advisory and review role for this project.

Project Status

Completed

Project Duration

- Project Start Date: October 1, 2020
- Project End Date: September 30, 2021

Total Costed (FY19–FY21)

$300K

Project Objectives: Relevance

Relevance to Program Goals:

This project contributes to WPTO's mission of enabling research, development, testing and commercialization of new technologies to advance the next-generation hydropower and pumped storage systems for a flexible, reliable grid. Specifically, the project supports the following hydropower program goals and objectives stated in the WPTO Multi-Year Program Plan:

- **Challenge:** Untapped potential for hydro and pumped storage to support a rapidly evolving grid
- **Approaches and activities:** Develop innovative technologies, including new pumped storage designs, for improved grid service capabilities
- **Intermediate outcomes:** Commercialization of new PSH technologies, system designs, and methods to lower costs/increase cost-competitive PSH deployment
- **Long-term outcomes:** Deployment of new, cost-competitive PSH projects in the U.S.

Project Objectives: Approach

Approach:

1. Research current status of PSH technologies through literature review and communications with PSH experts and developers
2. Define evaluation criteria for review of new and innovative PSH concepts and technologies
3. Perform technology evaluations in consultation with PSH experts and developers
4. Discuss potential methods to add PSH capabilities to existing hydropower plants
5. Perform review of innovations in PSH excavation and construction methods

Evaluation Criteria
Estimated Project Cost ($/kW)
Estimated Levelized Cost of Storage (LCOS) ($/MWh)
Construction time
Project Development Risk
Scalability and Applicability
Operational Flexibility
Potential Market Size in the U.S.
Environmental Impacts
Physical Siting Limitations
Technology Readiness Level (TRL)

Stakeholder interactions:

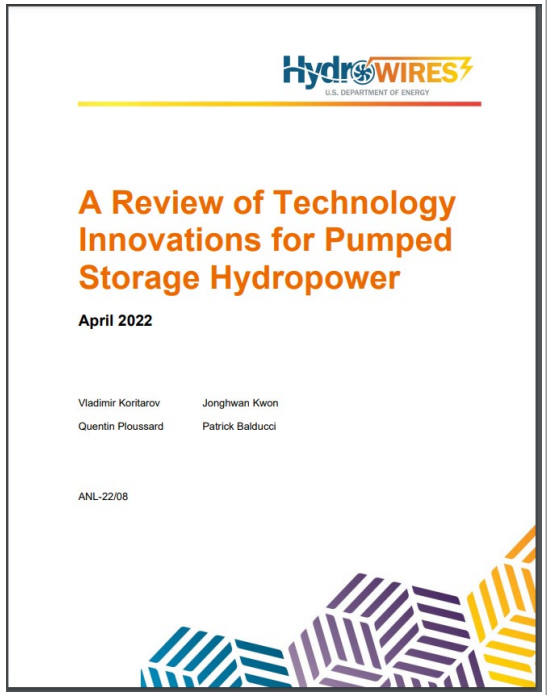
- Conducted industry workshop
- PSH technology developers had an opportunity to review and comment on evaluations
- Draft technical report reviewed by PSH experts in industry and academia

Project Objectives: Expected Outputs and Intended Outcomes

Outputs:

Technical report summarizing:

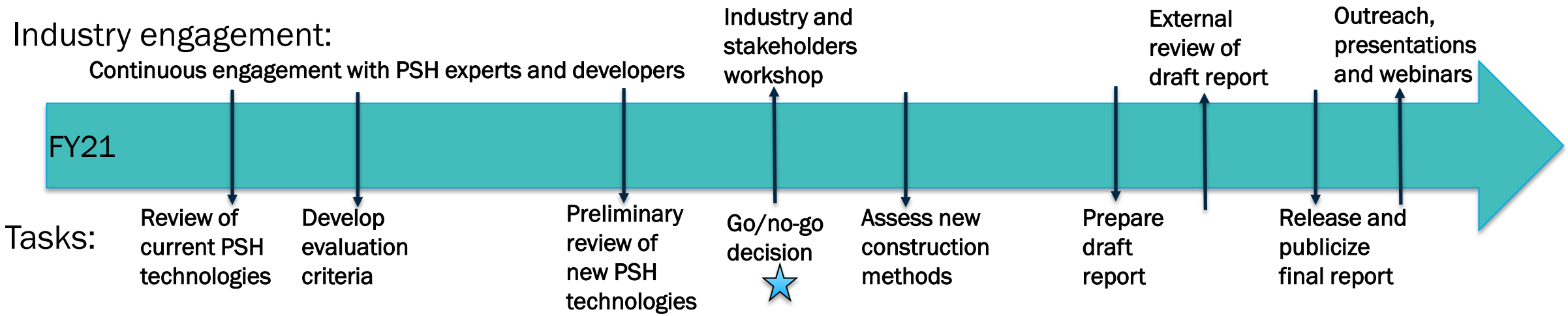
- The current status of PSH technology development
- New and innovative PSH concepts and configurations
- Review if innovative excavation and construction methods
- Summary of key findings



Outcomes:

- In the short-term, this study informs DOE and industry and allows them to prioritize their research toward the most promising new PSH technologies that have a potential to reduce costs, time, and risk for development of new PSH projects in the U.S.
- In the long-term (e.g., 2050), some fraction of the PSH projects built to meet increasing power system storage needs may include some of these new technologies at commercial scale.

Project Timeline, Milestones, and Management Plan



- Key milestones:
  - FY21 Q1: PSH Portfolio Review
  - FY21 Q2: Develop Evaluation Criteria
  - FY21 Q3: Perform Evaluation of Innovative PSH Technologies
  - FY21 Q4: Prepare Draft Project Report
- Management plan included close collaboration with PSH industry, researchers, and developers:
  - Communicated with PSH technology developers and industry experts throughout the project
  - Conducted industry/stakeholder workshop to present and review preliminary evaluations
  - Engaged PSH industry experts and researchers to review draft technical report

Project Budget

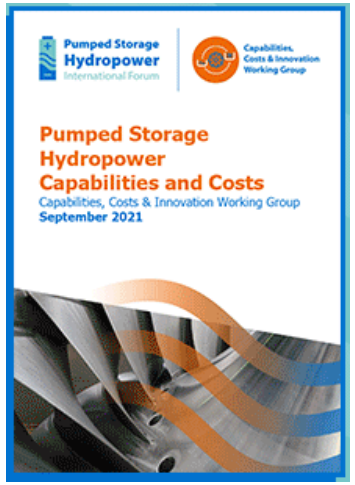
FY19	FY20	FY21	Total Actual Costs FY19–FY21
Costed	Costed	Costed	Total Costed
$0K	$0K	$300K	$300K

- The project was completed on budget and schedule.

End-User Engagement

- Stakeholder and end-user engagement strategy:
  - Intensive engagement with PSH industry, developers, experts and researchers
  - Communicated with dozens of PSH technology developers and innovators
  - Participated in the Working Group of International Forum on PSH (IFPSH) and contributed to white papers on PSH costs and capabilities and on Innovative PSH technologies (published by IHA – International Hydropower Association)
  - Organized and conducted PSH industry and stakeholder workshop to review preliminary evaluation results
  - Provided PSH technology developers with preliminary evaluation results for their technologies to review and comment
  - Engaged PSH industry and academia experts in reviewing of the draft project report

Pumped Storage Hydropower International Forum



External expert reviewers:
- Rick Miller (HDR)
- Michael Manwaring (Stantec)
- Matt Pevarnik (GE RE Hydro)
- Klaus Kruger (Voith)
- Prof. Alexander Slocum (MIT)
- Tracy Livingston and Thomas Conroy (Kinetic Power)
- Gordon Wittmeyer and Bis Dasgupta (SWRI)

- Target audience and beneficiaries
  - Developers of new PSH projects (IPPs and utilities)
  - Owners and operators of existing PSH plants
  - Industry associations (e.g., NHA, IHA)
  - Industry research organizations (e.g., EPRI) and academia
  - Lending and financial organizations

Dissemination

- Dissemination
  - Publicly available technical report published under HydroWIRES initiative
  - Webinar presentation to NHA Pumped Storage Council (June 1, 2022)
  - ESGC (Energy Storage Grand Challenge) seminar (June 30, 2022)
  - HydroVision International conference (July 12-14, 2022)
  - Clean Currents conference (October 18-20, 2022)
  - Publications in industry publications and media
- Technology transfer and commercialization plans
  - A follow-up PSH commercialization project will be helping developers and PSH innovators in advancing their technologies toward higher TRL levels and commercialization

HydroWIRES U.S. DEPARTMENT OF ENERGY

NHA National Hydropower Association

ENERGY STORAGE GRAND CHALLENGE U.S. DEPARTMENT OF ENERGY

HYDROVISION INTERNATIONAL

CLEAN CURRENTS2022™

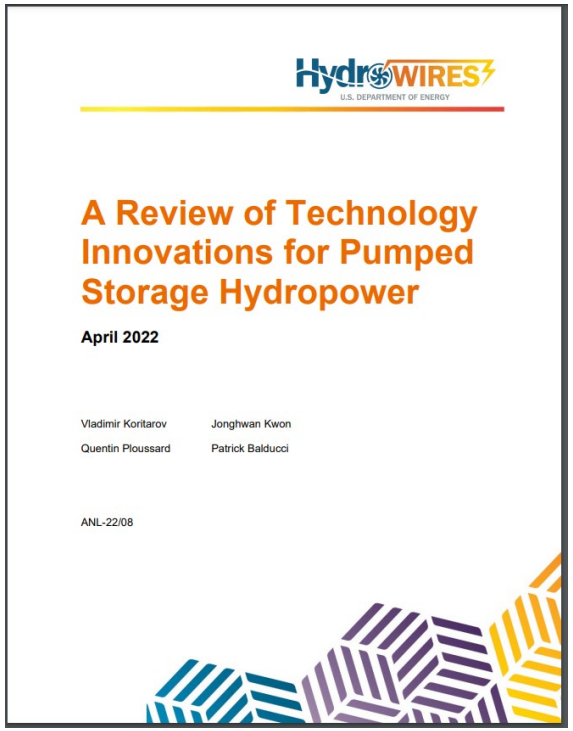
HYDRO REVIEW

ANL releases report on pumped storage hydropower

By hydroreviewcontentdirectors - 5.16.2022

Performance: Accomplishments

- Completed a comprehensive and objective review of technology innovations for PSH
- The study includes:
  - Overview of current PSH technologies (fixed and adjustable speed, ternary, quaternary)
  - Evaluation of key innovative PSH concepts and technologies
  - Review of innovations in PSH excavation and construction methods
- Study provide an objective evaluation of innovative PSH concepts and technologies based on a set of predefined evaluation criteria (No ranking of technologies!)
- Evaluation focused on potential application in the U.S. (e.g., when estimating potential market size, applicability, etc.)



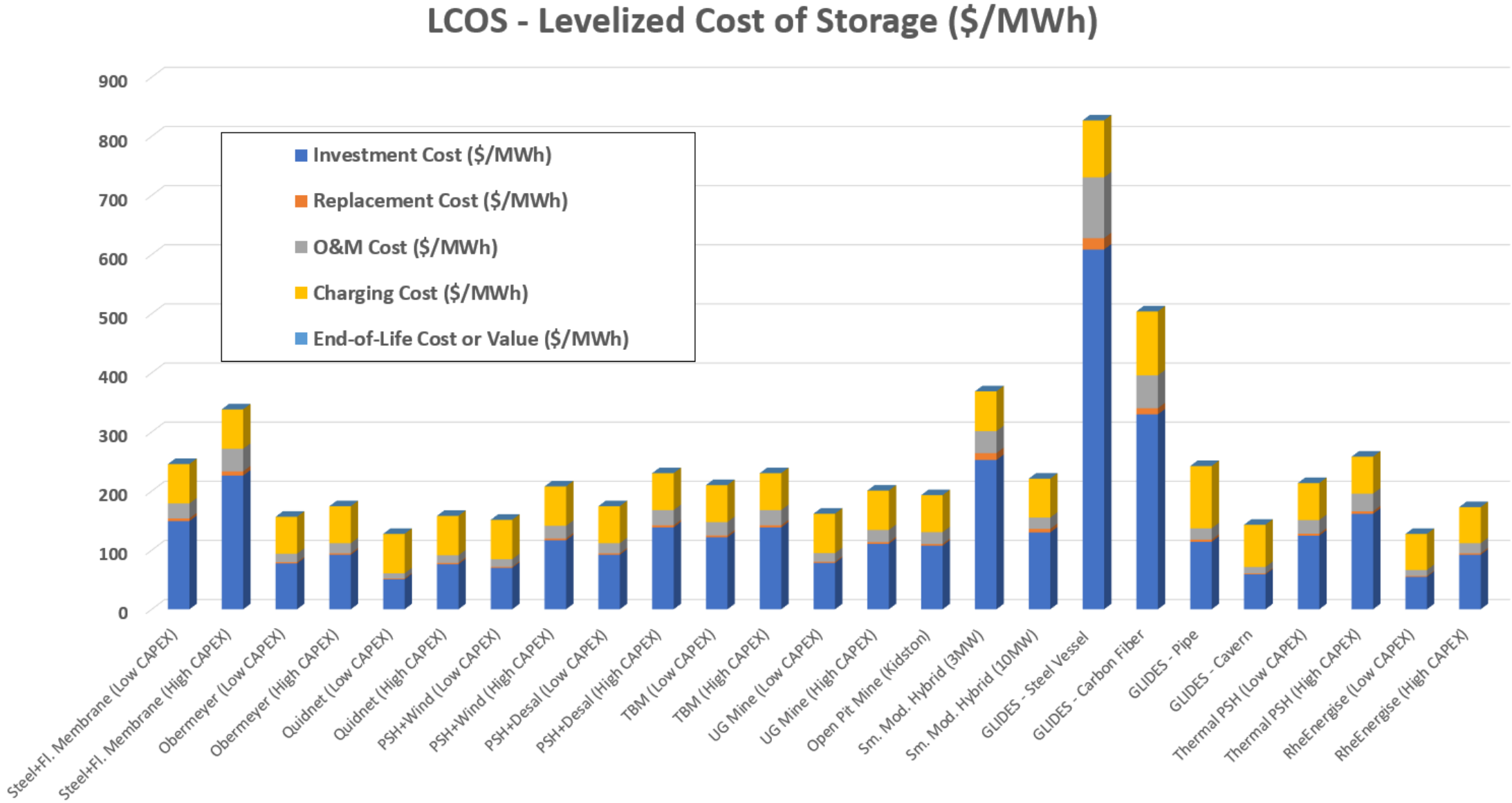
DISCLAIMER: The inclusion of any technology in this study does not imply its endorsement by DOE, national labs, or U.S. Government.

https://publications.anl.gov/anlpubs/2022/05/175341.pdf

Evaluation Criteria Used in the Study

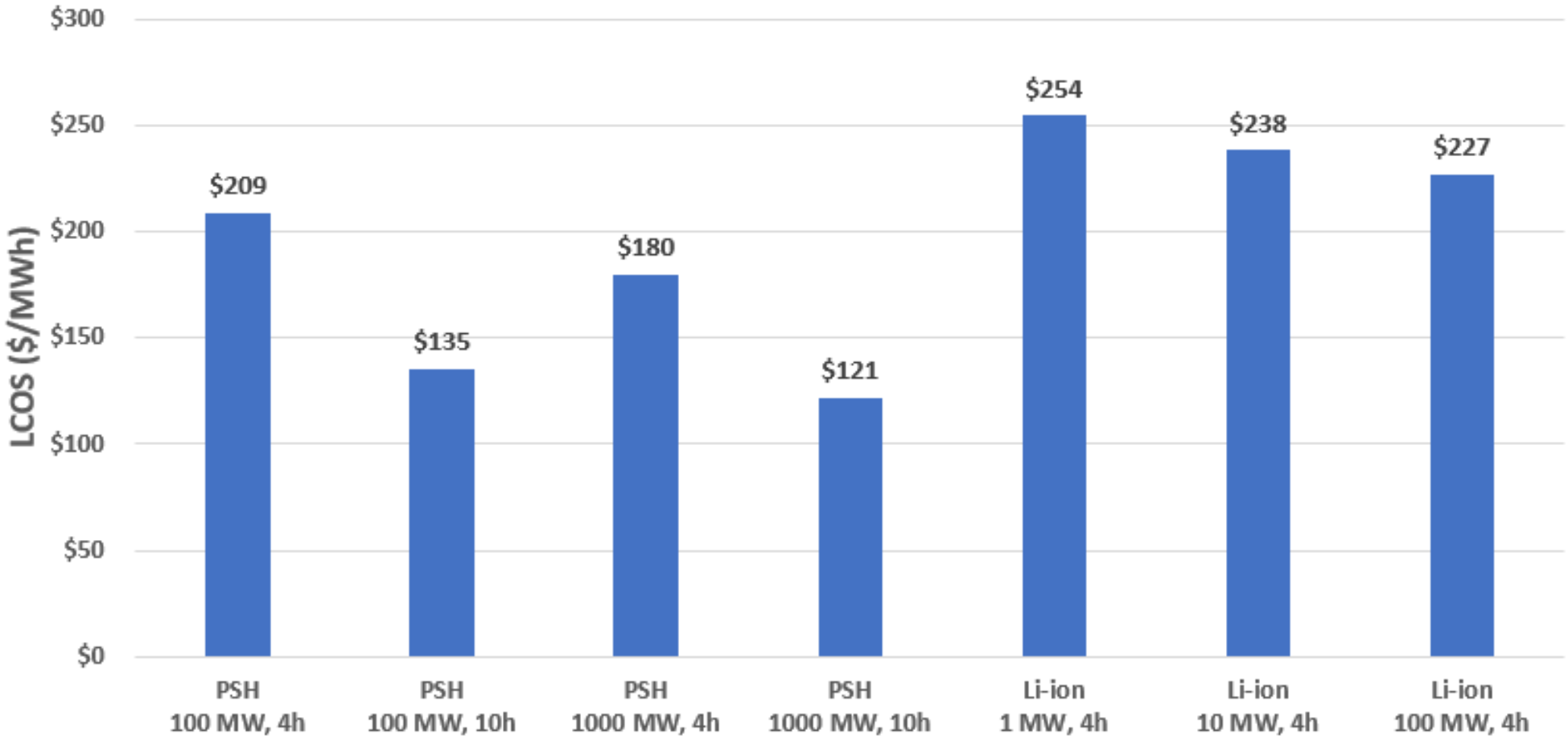
Criterion	Evaluation Parameters and Considerations	Metrics
Estimated Project Cost	Estimated investment cost or total capital expenditures to develop PSH project.	$/kW
Estimated Levelized Cost of Storage (LCOS)	Estimated LCOS over the lifetime of the project.	$/MWh
Construction time	Potential to reduce project construction time compared to current PSH technologies.	Years
Project Development Risk	Potential to reduce project development risks (e.g., by applying proven construction methods and technologies, employing simple project designs, etc.) compared to conventional PSH plants.	Qualitative
Scalability and Applicability	Whether the PSH design is scalable to allow for a range of capacities (e.g., modular design) and a variety of use cases.	Estimated minimum and maximum capacity range (MW)
Operational Flexibility	PSH technology potential to provide flexible operation (i.e., wide operating range, fast ramp rates, quick mode change times, etc.).	Estimated operating range
Potential Market Size in the United States	Estimated market potential for PSH technology in the United States.	MW of capacity or number of installations
Environmental Impacts	Discussion of potential impacts of PSH technology on the environment, including potential public acceptance issues.	Qualitative
Physical Siting Limitations	Geographical or topological limitations that may limit the siting opportunities.	Qualitative
Technology Readiness Level (TRL)	Estimated TRL of PSH technology.	TRLs 1-9

Example: Estimated Levelized Cost of Storage (LCOS)



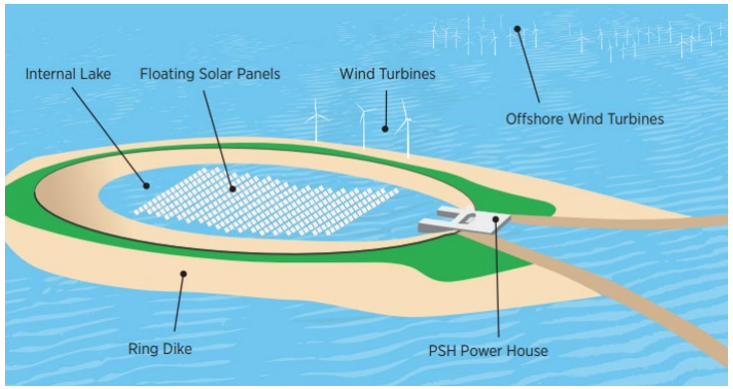
LCOS Values for Reference Technologies

Based on ESGC Energy Storage Technologies Cost and Performance report (Mongird et al. 2020)



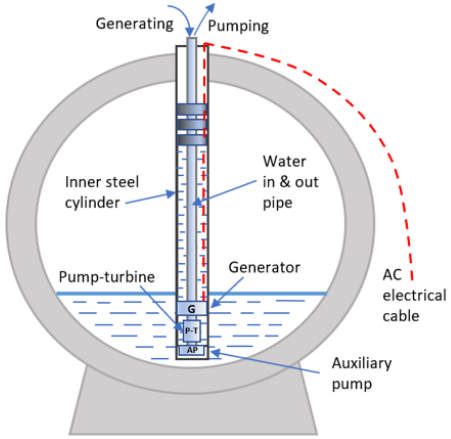
Study also Covered other Innovative Concepts and Technologies

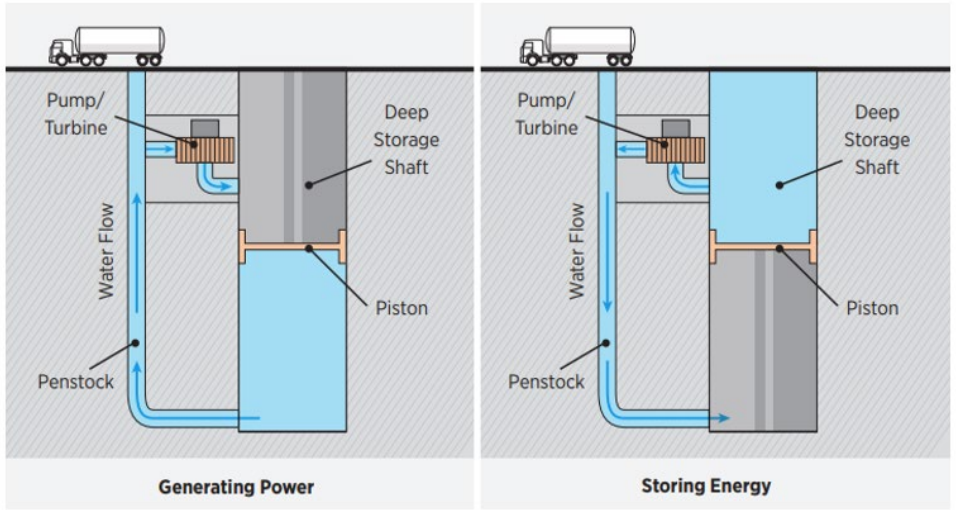
- Converting existing hydropower plants to PSH
  - Replacing existing turbine with reversible pump-turbine
  - Adding separate pumps and water conduits



- Hybrid PSH configurations

- Other PSH concepts
  - Deep-Sea PSH
  - Energy Island PSH
  - Hydraulic PSH
  - Aquifer PSH

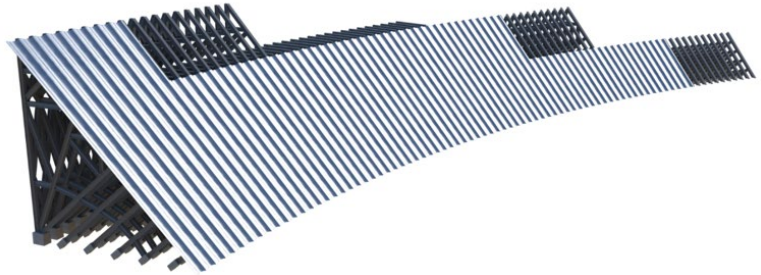




… and Advances in Excavation and Construction Methods

- Advances in PSH excavation methods:
  - Tunnel Boring Machines (TBMs) for underground reservoir excavation
  - Roadheader Machines (RHMs) and Oscillating Disc Machines (ODMs)

- New dam construction methods:
  - Modular dam construction
  - Steel dam construction



Key Findings of the PSH Innovation Study

- Many new and innovative PSH concepts and technologies are being proposed:
  - Improvements of existing PSH technologies
  - New PSH concepts
- Many proposed innovative PSH technologies have a potential to reduce cost and/or time for the construction of new PSH projects, and are cost-competitive in terms of levelized cost of storage (LCOS) with existing energy storage technologies
- Several promising PSH technologies for deployment in the U.S. have been identified:
  - PSH using submersible pump-turbines and motor-generators
  - Geomechanical PSH
  - Using open pit mines to develop new PSH plants
  - Hybrid PSH projects (e.g., PSH/desalination, PSH with solar/wind)
- Innovative excavation and construction techniques may also reduce cost and time for PSH development:
  - Using roadheader and oscillating disc machines for underground excavations
  - Modular dam construction methods (e.g., precast concrete blocks or steel dams)

Q&A