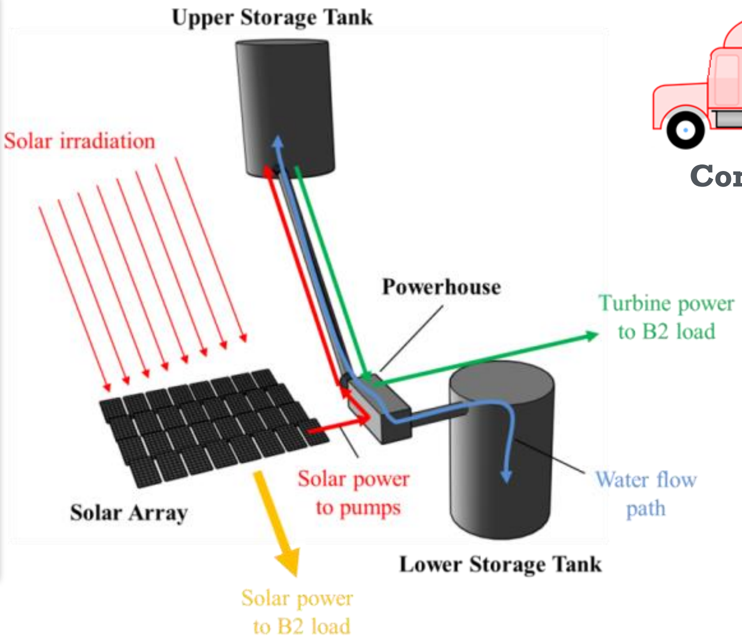
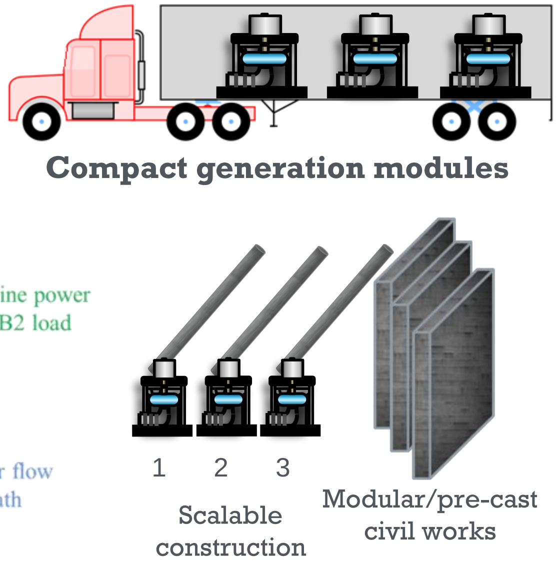
Conventional Pumped Storage

Modular Pumped Storage (m-PSH)





Alternative designs

Modular Pumped Storage Hydropower Feasibility and Economic Analysis

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Project Overview

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Modular Pumped Storage Hydropower Feasibility and Economic Analysis:

- Assess the cost and design dynamics of small modular PSH (m-PSH) development
- Explore whether the benefits of modularization are sufficient to outweigh the economies of scale inherent in utility scale development
- Measure the economic competitiveness of m-PSH against alternative distributed storage technologies (i.e. batteries).

The Challenge:

- Scalability of PSH projects, and whether small modular PSH has competitive advantages over alternative energy storage technologies

Partners: MWH Consulting, Knight Piésold Consulting, Revelo Pumped Storage Company, Biosphere 2, University of Arizona

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Next Generation Hydropower (HydroNEXT)

Optimization

- Optimize technical, environmental, and water-use efficiency of existing fleet
- Collect and disseminate data on new and existing assets
- Facilitate interagency collaboration to increase regulatory process efficiency
- Identify revenue streams for ancillary services

Growth

- Lower costs of hydropower components and civil works
- Increase power train efficiency for low-head, variable flow applications
- Facilitate mechanisms for testing and advancing new hydropower systems and components
- **Reduce costs and deployment timelines of new PSH plants**
- Prepare the incoming hydropower workforce

Sustainability

- Design new hydropower systems that minimize or avoid environmental impacts
- Support development of new fish passage technologies and approaches
- Develop technologies, tools, and strategies to evaluate and address environmental impacts
- Increase resilience to climate change

Next Generation Hydropower (HydroNEXT)

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The Impact

- Small, modular pumped storage hydropower (PSH) systems could present a significant avenue to cost-competitiveness through direct cost reductions, and by avoiding many of the major barriers facing large conventional designs
- Initial Construction Cost (ICC) target of ~$2,000/kW - $3,000/KW
- Cost estimates, design options, potential revenue streams, and feasibility indicators provide industry with an idea of m-PSH viability

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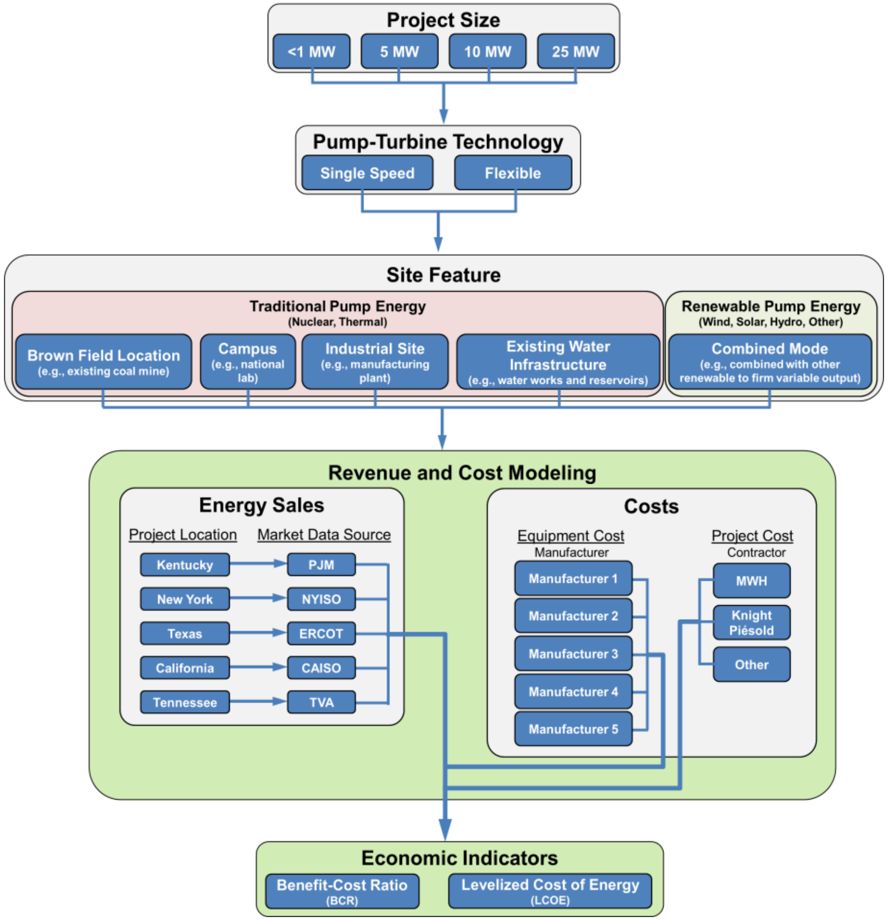
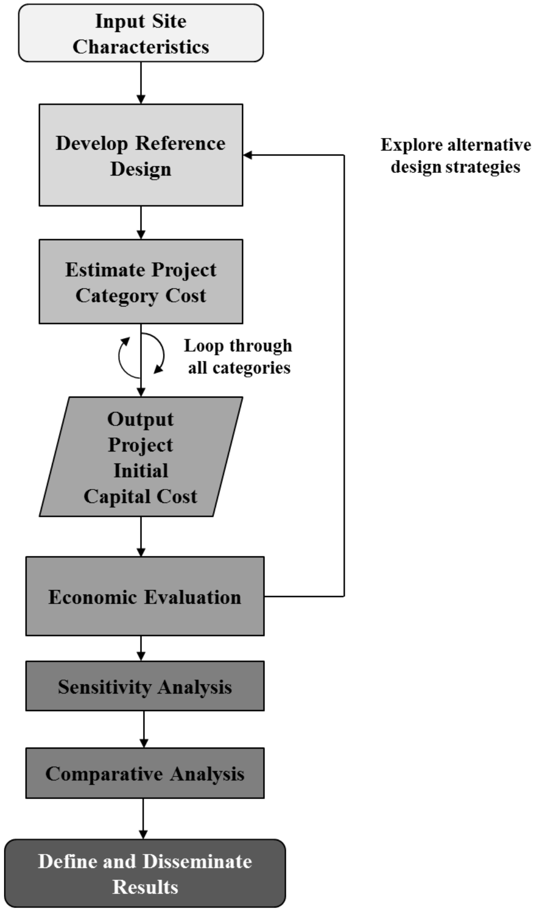
The m-PSH project consists of two technical approaches:

1. Targeted case studies



2. Cost modeling tool



Technical Approach: Case Studies

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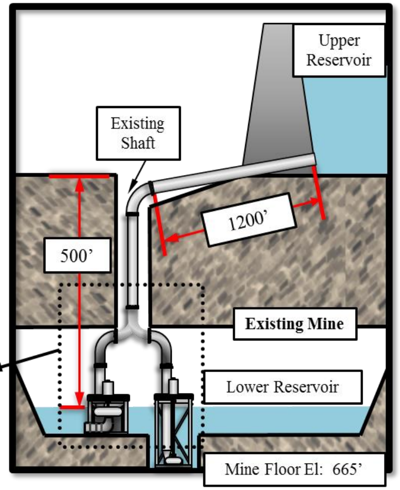
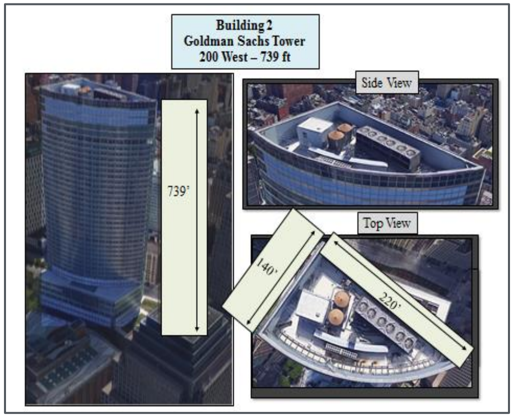
Coal Mine (5MW)

- ICC: $1,700–$2,400/kW (10 hours of storage)
- Closed-loop
- Existing infrastructure
- PJM RTO market
- Regulatory uncertainty and poor regional economic indicators



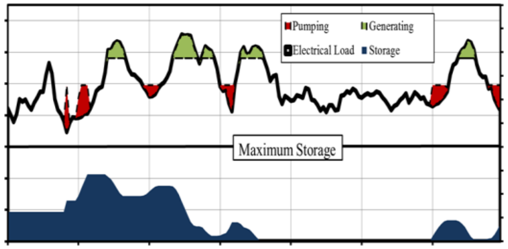
Buildings (305kW)

- ICC: >$3,500/kW (<1 hour of storage)
- Low energy density
- Prohibitive storage tank volume required
- Unrealistic cost-benefit
- Limited market prospects



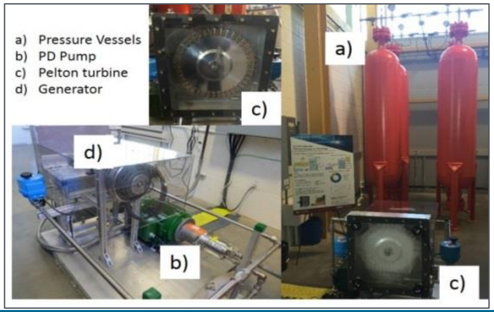
ORNL Campus (5MW)

- ICC: $4,100–$4,700/kW (10 hours of storage)
- Open loop
- No existing infrastructure
- Integrated TVA market
- High costs and low market revenue potential



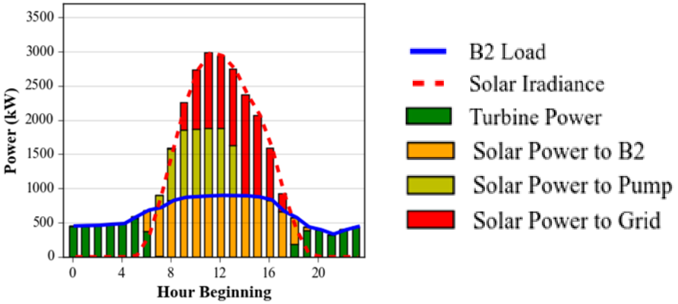
GLIDES (1 kW)

- ICC: >$18,000/kW (10 hours of storage)
- Compressed air/PSH hybrid
- 1 kW prototype at ORNL
- Pressure vessels are major cost driver of economic infeasibility

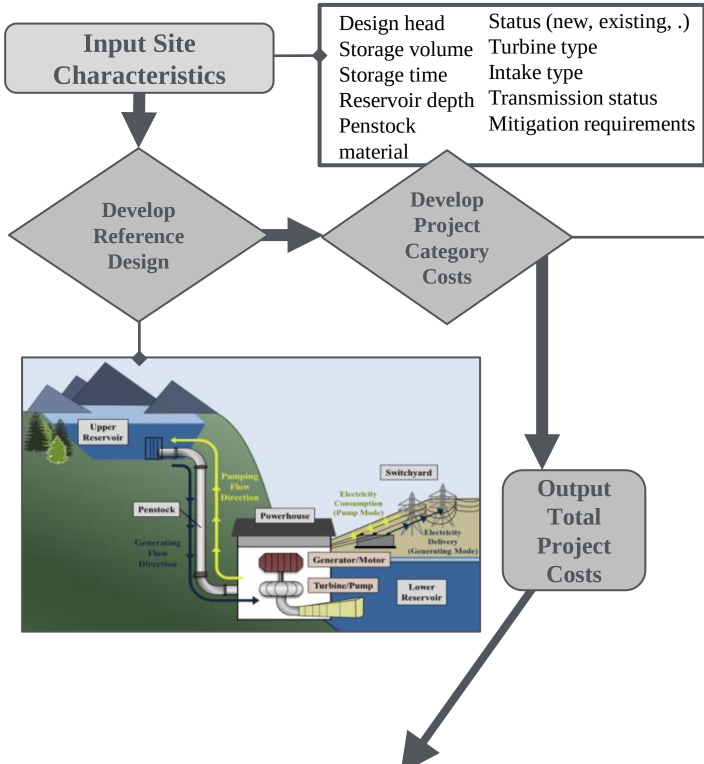


Biosphere 2 Hybrid (463 kW)

- ICC: $13,600/kW (~13 hours of storage)
- Investigate 'solar powered' m-PSH – store solar for off-peak consumption
- Costs of storage tanks are major driver of economic infeasibility



Technical Approach: Cost Model



1. Earth and Civil Works

Upper Reservoir, Lower Reservoir, Conveyances, Powerhouse, Site Access, …

2. Electro-Mechanical Equipment

Major Equipment, Ancillary Plant Electrical, Ancillary Plant Mechanical, …

3. Electrical Infrastructure

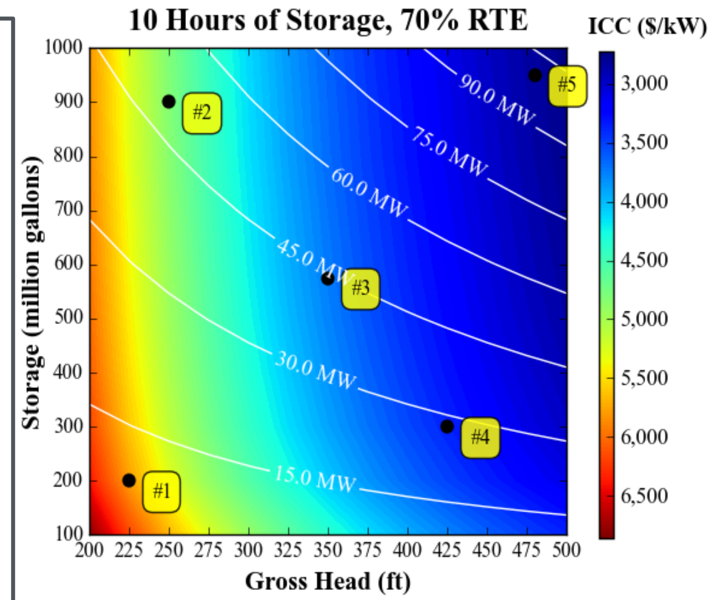
Transmission Lines, Transformers, Switchyard, Substation, …

4. Environmental Mitigation and Compliance

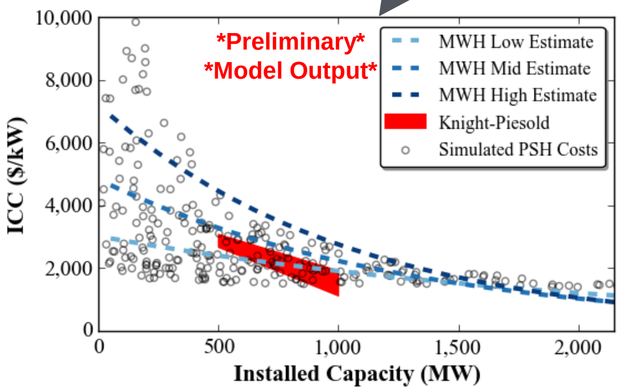
Fish and Wildlife Mitigation, Water Quality Monitoring and Mitigation, Recreation Facilities, Aesthetics, Historical Preservation, …

5. Project Soft Costs

Engineering Construction Management, Owner's Costs, Licensing, …



Cost model estimates at installed capacities between 15 MW and 100 MW



At small installed capacities, cost distributions can be analyzed at several 'test points':

- Storage costs are proportionately more expensive as head is reduced
- Conventional approach is prohibitively expensive at installed capacities < 100MW – ***innovation is needed***

Technical Accomplishments:

- Site visit of decommissioned coal mine and evaluation for m-PSH potential (2014)
- Case study of m-PSH at ORNL completed for campus sustainability initiative (2015)
- Technical Paper of the Year (2nd Place) at HydroVision International (FY 2015)
- Technical memorandum on cost scaling of GLIDES delivered to DOE (2015)
- Site visit of Biosphere 2 and evaluation of m-PSH and solar potential (2016)
- Catalog of m-PSH equipment and construction costs developed (2016)
- Cost estimating tool complete and available for widespread use (2016).

Publications:

- Technical paper on economic viability of two case studies presented at HydroVision International (FY 2015)
- Technical report on economic viability of three case studies delivered to DOE (ORNL/TM-2015/559, FY 2015)
- Technical paper on m-PSH cost model tool development presented at HydroVision International (FY 2016)
- Technical report on solar/m-PSH hybrid case study delivered to DOE (ORNL/TM-2016/591, FY 2016)
- Technical report on cost model tool and results delivered to DOE (ORNL/TM-2016/590, FY 2016)

Project Plan & Schedule

- Project started October 2014 and ended September 2016.
- All milestones and deliverables were completed on time and within budget.
- Key deliverables were (1) a set of detailed case studies assessing the preliminary feasibility of m-PSH projects and (2) a comprehensive cost estimating tool for closed loop m-PSH projects.

Project Budget

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Budget History					
FY2014		FY2015		FY2016	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$750K	$0K	$400K	$0K	$200K	$0K

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators:

- Oak Ridge National Laboratory: Dr. Boualem Hadjerioua, Dr. Adam Witt, Dol Raj Chalise, Rebecca Brink, Miles Mobley, Dr. Ayyoub Mehdizadeh Momen, Dr. Omar Abdelaziz, Dr. Kyle Glueskamp, Adewale Odukomaiya, Ahmad Abu-Heiba
- MWH Consulting: Michael Manwaring
- Knight Piésold Consulting: Norm Bishop Jr.
- Revelo Pumped Storage Company: John Matney
- Biosphere 2: John Adams
- University of Arizona: Dr. Kevin Lansey, Chris Horstman

Communications and Technology Transfer:

- Presentation at HydroVision Conference in Environmental/Social Track (2015)
- Poster presentation at HydroVision Conference (2016)
- Disseminate all technical documents at http://hydropower.ornl.gov/

Next Steps and Future Research

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FY17 / Current Research: Project ended in 2016

Proposed Future Research

- Quantification of the m-PSH type resources present in the US
- Improvements in the cost of storage, either through cost reductions in the civil works associated with storage construction or through strategic siting
- Innovative technical R&D on new designs and manufacturing strategies for modular reversible pump-turbines, and alternative construction strategies and materials
- New models and simulations to better understand how m-PSH can be strategically used as an energy storage technology
- Explore economic feasibility of m-PSH projects that enable greater penetration of intermittent renewables