U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Ground-Level Integrated Diverse Energy Storage (GLIDES)

CID: 32983

Hydropower Program

October 8-10, 2019

Ahmad Abu-Heiba

PI: Ayyoub M. Momen

momena@ornl.gov

Oak Ridge National Laboratory, ORNL

Project Overview

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Project Summary

- This project explores the value proposition of a modular pumped-storage hydropower (mPSH) technology with the potential to fill the technology gap between small-scale battery technology and large grid-scale pumped storage hydropower (PSH). GLIDES—invented at ORNL—is a cost-effective, scalable, and flexible storage system that can provide a broad range of ancillary services and mitigate many of the market and regulatory barriers faced by PSH.

Project Objective & Impact

- This project aims to quantify the value proposition, identify cost reduction opportunities, and prioritize future research directions for the newly invented GLIDES mPSH technology. This analysis identifies the most promising market segments to target for commercializing GLIDES as well as the cost and performance targets necessary to reach commercial competitiveness.

Project Information

Project Principal Investigator(s)

Ayyoub M. Momen

WPTO Lead

Marisol Bonnet

Project Partners/Subs

University of Tennessee (UT)

Project Duration

- Project Start Date: October 2016
- Project End Date: September 2019

Conventional PSH

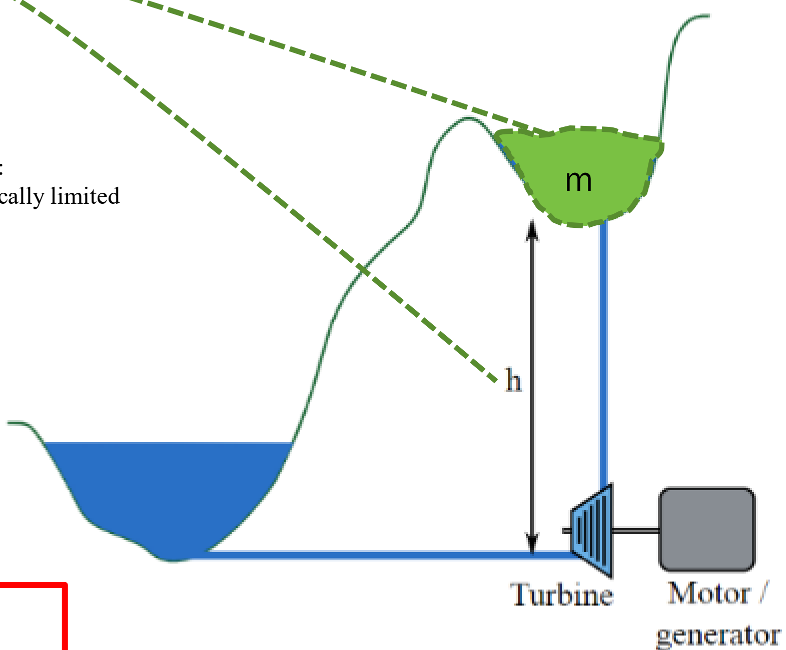
$$E\ [\text{jouls}] = m.\,g.\,h$$

Two options to improve energy density:

- Increasing m
- Increasing h

Larger reservoir:
- Greater environmental impact
- High excavation costs

Larger head:
- Geographically limited



Conventional PSH:

h ~ 100 (m)

Innovation →

GLIDES:

h ~ 1,000-8,000 (m)

~40X improvement in energy density which translates into lower cost, smaller foot print and modularity

Innovative PSH: The GLIDES System

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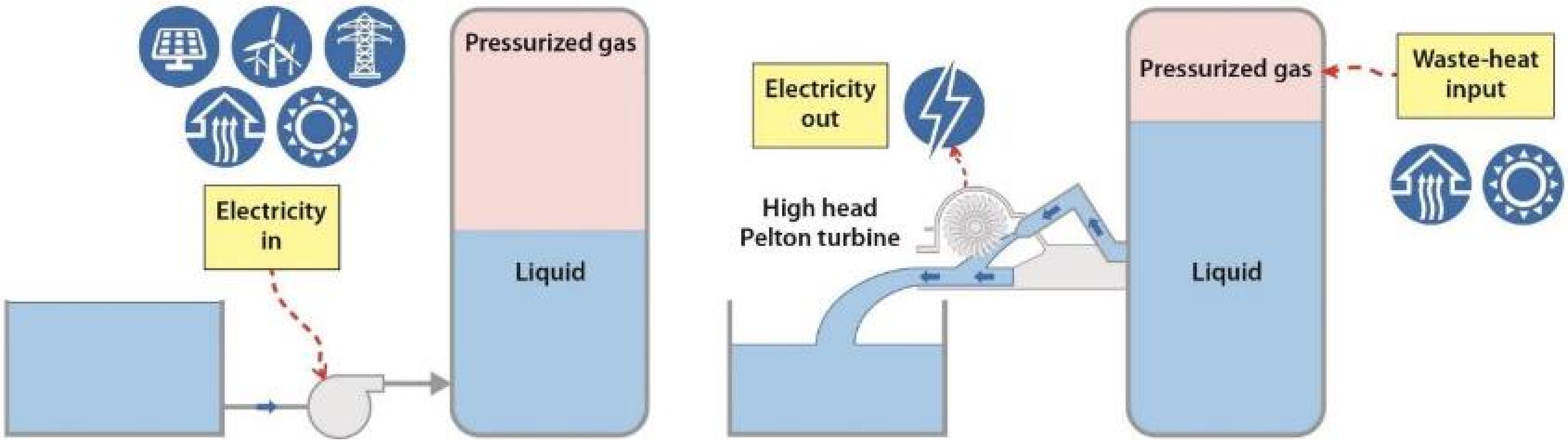
- **Objective: Develop a unique, low-cost, high round trip efficiency electricity storage technology for a) small scale building applications b) large scale /grid scale modular pump hydro storage.**



Key advantages	
Simple, low cost (expected to be at lower cost than batteries)	Dispatchable
Accepts heat and/or electricity as inputs	Scalable
Round-trip efficiency>70-82%	Terrain independent

ORNL Provisional patent filed : Ayyoub. M. Momen, O. Abdelaziz, K. R. Gluesenkamp, and E. A. Vineyard, “High-Efficiency Ground-Level Pumped-Hydro Electricity Storage,” Provisional patent filed, DOE S-124,766, Serial number 62/221,322.

Alignment with the Program

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Hydropower Program Strategic Priorities

Environmental R&D and Hydrologic Systems Science

Big-Data Access and Analysis

Technology R&D for Low-Impact Hydropower Growth

R&D to Support Modernization, Upgrades and Security for Existing Hydropower Fleet

Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

Alignment with the Hydro Program

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Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

- Understand the needs of the rapidly evolving grid and how they create opportunities for hydropower and PSH.
- Optimize hydropower operations and planning—alongside other resources—to best utilize hydropower's capabilities to provide grid services.
- Invest in innovative technologies that improve hydropower capabilities to provide grid services

- Developed an innovative PSH system that reduces costs and increases energy density compared to conventional PSH.
- Modeled operation of a GLIDES system in four different markets (CAISO, PJM, ISONE, and NYISO), demonstrating that GLIDES can provide generation, operating reserve, and regulation services.

Project Budget

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FY17	FY18	FY19 (Q1 & Q2 Only)	Total Project Budget FY17–FY19 Q1 & Q2 (October 2016 – March 2019)	
Costed	Costed	Costed	Total Costed	Total Authorized
[$34K]	[$579K]	[$217K]	[$830K]	[$1,100K]

This technology was invented in 2014 and multiple programs across EERE have shown interest in the technology for different applications:

- 2014-2016: ORNL's LDRD funding, GLIDES proof of concept prototype (3 kW) development.
- 2016-2017: EERE's Building technology office BENEFIT FOA, Feasibility of utilizing GLIDES for residential building energy storage tied into the condenser of air conditioning system.
- 2016-2019: WPTO: Preliminary feasibility study of GLIDES modular PSH.

Management and Technical Approach

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- Project team members include staff from ORNL's Building Equipment Research Group (BERG), BTO, WPTO, OE, and staff and PhD candidate from the University of Tennessee.
- Staff expertise, state-of-the-art facilities, and supporting management of a variety of specialized groups enable the center's research efforts, while the program office within the center administratively coordinates multidisciplinary projects, drawing resources from across the laboratory.
- Major milestones include a GLIDES Capital and Operating Cost Model, a System Performance Model, and a Market Analysis.

Milestone	FY17				FY18				FY19			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Develop scope of work				▲								
Identify planned cost-reduction and market analysis research priorities					▲ ★							
Develop GLIDES Capital and Operating Cost						▲						
Develop model to capture system performance characteristics							▲					
Develop GLIDES Techno-Economic Assessment Model								▲				
Identify final cost reduction opportunities									▲			
Preliminary market analysis of GLIDES in four market regions										▲		
Identify remaining gaps and future research pathways											▲	
Submit final report documenting GLIDES value and research opportunities												▲

▲ Milestone Report

★ Go/no go Phase

End-User Engagement and Dissemination Strategy

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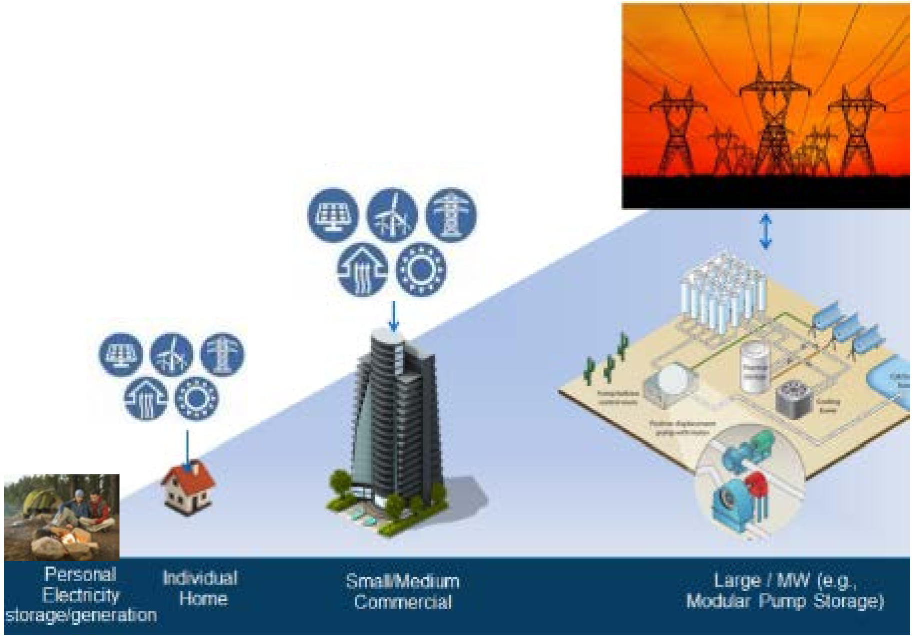
End Users and Partners:

- End users include electric utilities and the electric sectors, residential buildings, military applications, and commercial buildings.
- Partners in this project are the Department of Energy's Water Power Technologies Office (WPTO), the Department of Energy's Building Technologies Office (BTO), the Department of Energy's Office of Electricity (OE), University of Tennessee (UT), and Oak Ridge National Laboratory's Manufacturing Demonstration Facility (MDF).

Dissemination:

- ORNL shares the results with scientific community and the industry mainly through journal and conference publications.
- Tours and demos are scheduled frequently to raise awareness of the technology among the public and potential stakeholders.
- ORNL is actively seeking for a partner to commercialize the technology.
- ORNL's technology transfer office has received a license application and currently negotiating on the terms.



Technical Approach

The methodology consisted of four focus areas:

1. **Storage Vessels:** Identify potential cost reduction opportunities in GLIDES's largest cost center—its storage vessels.
2. **Cost Model:** Develop detailed model to calculate the capital cost of a GLIDES system.
3. **Performance Model:** Develop model to simulate the performance of the specified GLIDES system based on the system's characteristics (e.g., capacity, storage medium, maximum pressure).
4. **Market Analysis:** Integrate the cost and performance models to perform a market analysis for GLIDES across diversity of US electricity markets and at selected market scales.

Technical Accomplishments
Storage Vessels

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Steel Tanks

Original

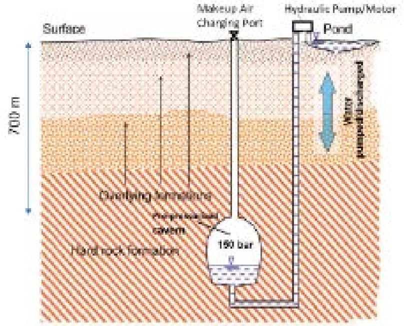
Carbon-Fiber Tanks

Pipe Segments

Most Promising

Underground Reservoirs

Underground Caverns



Abandoned Pipelines

Others

Proof-of-Concept Prototypes

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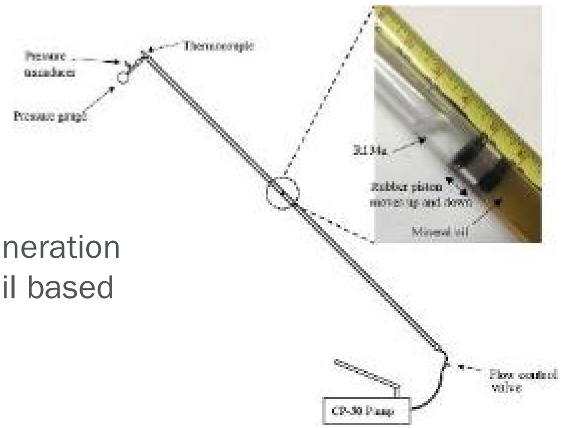
- 1st Generation Prototype
  - Steel Pressure vessels
  - Motor, hydraulic pump
  - Pelton turbine, generator

- 2nd Generation Prototype
  - Carbon Fiber vessel
  - Reversable motor/generator
  - Reversable pump/turbine
  - Spray cooling/heating

- 3rd Generation Prototype
  - Using R134a and mineral oil



GLIDES 3rd generation
Refrigerant/oil based

GLIDES 2nd generation
Carbon Fiber Vessel
1 kWh

GLIDES 1st generation
Steel Vessels
3 kWh

GLIDES 1st Generation Operation

Technical Accomplishments
Cost Model

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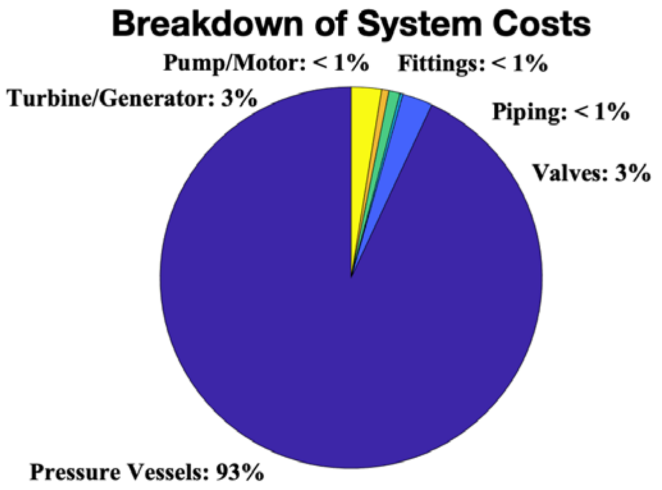
- Developed a cost model to compare the costs associated with the systems using steel vessels, carbon fiber pressure vessels, and high-pressure pipe segments.
- Model inputs include the desired system size (kWh), an estimated roundtrip efficiency value, a pressure ratio (max/min pressure), and the cost and specs (diameter, height, volume, maximum pressure, and price per vessel) from the manufacturers.
- The model then solves for the lowest $/kWh.



GLIDES costs as low as $13/kWh and $346/kWh and roundtrip efficiencies as high as 80% can be achieved using depleted oil/gas reservoirs and high-pressure pipe segments as pressure reservoirs, respectively.

Technical Accomplishments
Performance Model

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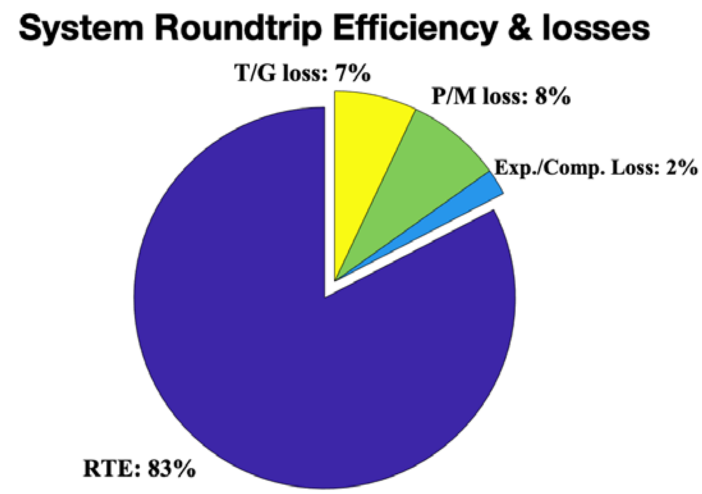
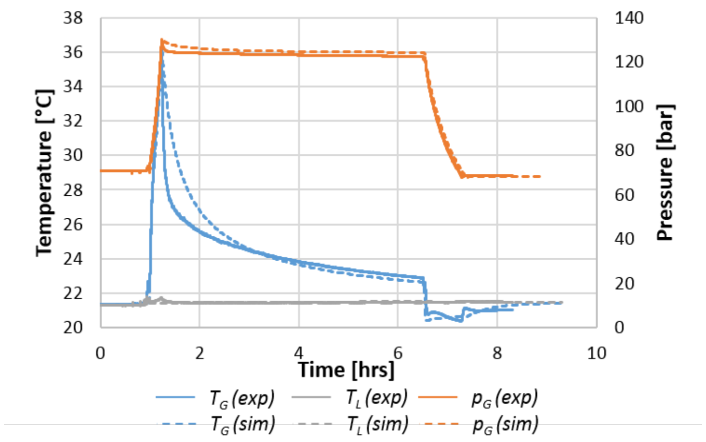
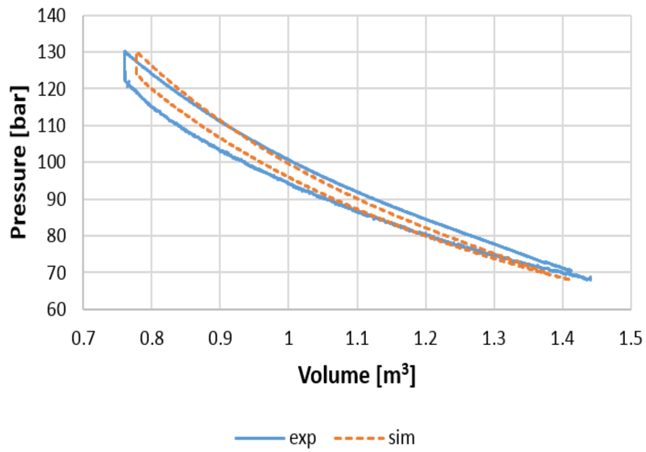
- Developed a detailed physics-based performance model to simulate the performance of the GLIDES system.
- The model simulates the compression/expansion process, integrates the pump/motor and turbine/generator efficiencies, and produces the transient profiles of pressure, temperature, volume, as well as power, efficiency, and energy density.







Technical Accomplishments
Market Analysis

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- System size: 60MW-1h
- Data range: 06/2017-06/2018
- Services: arbitrage, operating reserve, regulation
- Time scale: 5-min price data
- Markets: CAISO, PJM, ISONE, NYISO
- Liquid volume in the pressure vessels was treated as the main decision variable that can be controlled by actual charging/discharging.

Maximize Objective		Arbitrage+Reserve+Regulation			
Value Streams		Arbitrage	Reserve	Regulation	Total
CAISO	KERN	1,916,339	845,516	2,441,565	5,203,420
	ANAHEIM	2,466,736	831,997	2,362,203	5,660,936
PJM	AEP	1,206,431	676,233	6,593,403	8,476,067
	PSEG	1,319,613	667,893	6,652,196	8,639,702
NYISO	CENTRAL	1,504,128	1,034,100	3,090,690	5,628,918
	LONGIL	2,242,638	1,299,817	2,861,677	6,404,132
ISONE	MAINE	1,614,179	757,457	7,579,008	9,950,644
	BOSTON	1,599,708	754,510	7,519,672	9,873,890

Markets		ROI (years)		
Locations		Steel Vessels	Carbon Fiber Vessels	Pipe Segments
CAISO	KERN	72.1	33.5	6.1
	ANAHEIM	66.3	30.8	5.6
PJM	AEP	44.3	20.6	3.7
	PSEG	43.4	20.2	3.7
NYISO	CENTRAL	66.6	31.0	5.6
	LONGIL	58.6	27.2	4.9
ISONE	MAINE	37.7	17.5	3.2
	BOSTON	38.0	17.7	3.2

Publications

- A. Odukomaiya, A. Abu-Heiba, K.R. Gluesenkamp, O. Abdelaziz, R.K. Jackson, C. Daniel, S. Graham, A.M. Momen, Thermal analysis of near-isothermal compressed gas energy storage system, Appl. Energy 179 (2016) 948–960, https://doi.org/10.1016/j.apenergy.2016.07.059.

- A. Odukomaiya, A. Abu-Heiba, K.R. Gluesenkamp, O. Abdelaziz, R.K. Jackson, C. Daniel, S. Graham, A.M. Momen, Thermal analysis of near-isothermal compressed gas energy storage system, Appl. Energy 179 (2016) 948–960, https://doi.org/10.1016/j.apenergy.2016.07.059.

- A. Odukomaiya, E. Kokou, Z. Hussein, A. Abu-Heiba, S. Graham, and A. M. Momen, "Near-isothermal-isobaric compressed gas energy storage," *Journal of Energy Storage,* vol. 12, pp. 276-287, 2017.
- Abu-Heiba, A., Ridge, O., Gluesenkamp, K. R., Ridge, O., Connor, P. O., & Ridge, O. (2018). Diverse energy storage technology 1, 1–12.
- A. Odukomaiya, A. Abu-Heiba, S. Graham, A.M. Momen, Experimental and analytical evaluation of a hydro-pneumatic compressed-air Ground-Level Integrated Diverse Energy Storage (GLIDES) system, Appl. Energy 221 (2018) 75–85, https:// doi.org/10.1016/j.apenergy.2018.03.110.
- Y. Chen, A. Odukomaiya, S. Kassaee, P. O'Connor, A.M. Momen, X. Liu, B.T. Smith, Preliminary analysis of market potential for a hydropneumatic ground-level integrated diverse energy storage system, Appl. Energy 242 (2019) 1237–1247, https://doi.org/10.1016/j.apenergy.2019.03.076.
- Kassaee, S., Abu-Heiba, A., Raza, M., Mench, M. M., Liu, X., Odukomaiya, A., ... Momen, A. M. (2019). PART 1- techno-economic analysis of a grid scale Ground-Level Integrated Diverse Energy Storage (GLIDES) technology. *Journal of Energy Storage*, *25*(February), 100792. https://doi.org/10.1016/j.est.2019.100792

Future Work

<u>FY20 proposal approved by WPTO to explore new use case:</u>

- Co-location GLIDES within a hydropower plant to provide value in:
  - Facilities challenged by hourly, daily, and seasonal requirements to pass water at inefficient or equipment damaging power levels;
  - Run-of-river facilities in which the timing of flow and must-run generation is not revenue-optimal; and
  - Power system contexts where the localized need for grid services exists due to physical grid conditions or local market conditions.
- The system will also recover transformer waste heat to increase energy density within the storage vessel.

Team Members

ORNL


Ayyoub Momen


Ahmad Abu-Heiba


Kyle Gluesenkamp


Xiaobing Liu

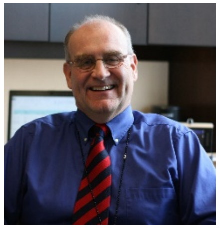

Moonis Ally


Yang Chen

WPTO


Brennan Smith


Thomas King Jr


Timothy Welch

UTK


Saiid Kassaee


Matthew Mench

Thank you

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Questions / Discussion