OAK RIDGE National Laboratory

The Novel Ground Level Integrated Diverse Energy Storage (GLIDES)

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ORNL is managed by UT-Battelle, LLC
for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

New Project Started in FY18

- Project is targeting the Cost Competitive Category under DOE Energy Storage Technologies Program

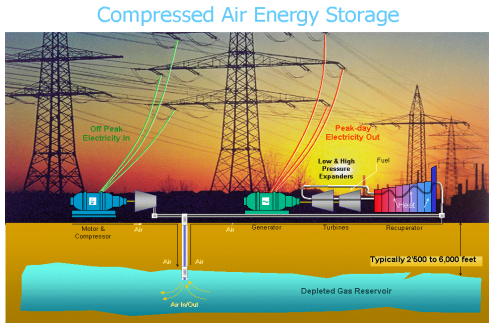
Competing Technologies: Challenges

Pumped Hydro

- Limited to very specific geographical locations
  - Typically remote areas (far from population/grid)
  - Large footprint
- Challenging to scale down
- Input: Electricity only (does not accept heat)

Compressed Air Energy Storage

- Low Efficiencies (~50%)
- Limited to very specific geographical locations
  - Need ground reservoir
- Challenging to scale down
- Input: Electricity and Heat



Battery

- Very expensive
- Need for replacement regularly
- Chemical and fire hazard
- Challenging to scale up
- Input: Electricity only (does not accept heat)

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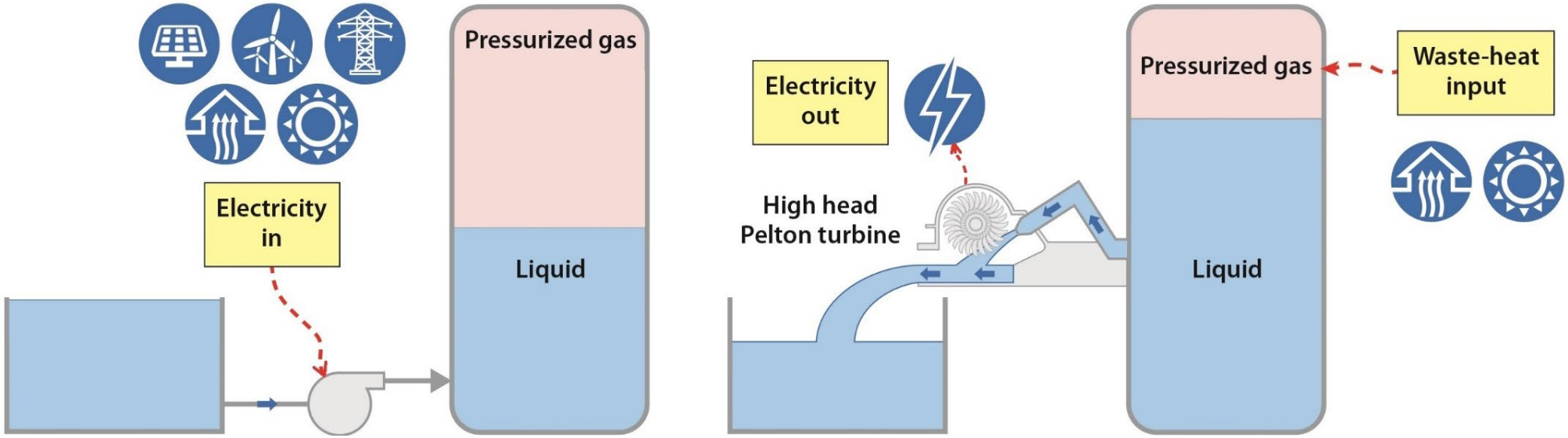
The Invented GLIDES System

- **Objective:** Develop a unique, low-cost, high roundtrip efficiency electricity storage technology



Key advantages	
Simple, low cost (expected to be at lower cost than batteries)	Dispatchable
Accepts heat and/or electricity as inputs	Long life
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.

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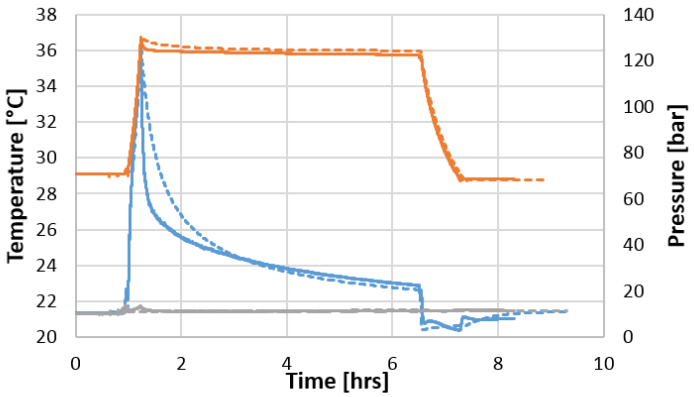
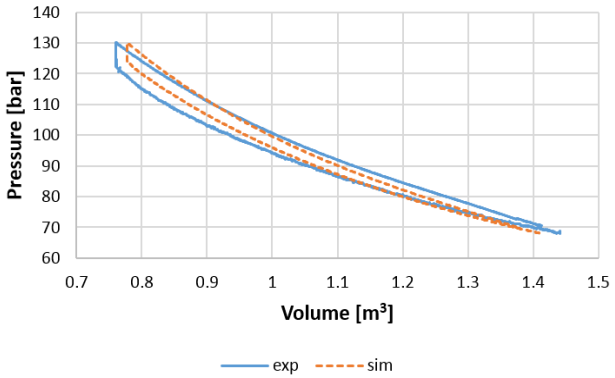
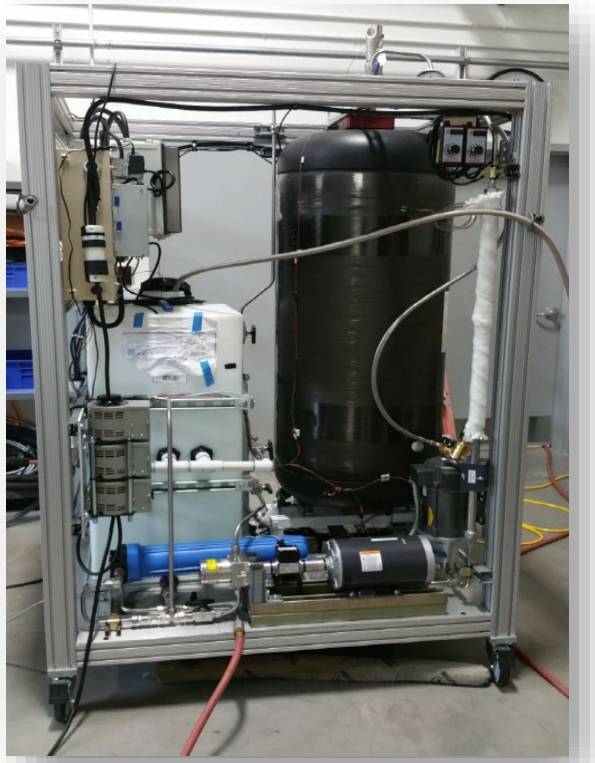
Initial Experimental Results





	T_G [°C]	T_L [°C]	p_G [bar]
RMSE [%]	0.1	1.03	1.9



2nd Prototype Characterization

System Size: 1 kWh
Vessel Volume: 1 * 287 L
P_{max}: 138 bar

1st Prototype Characterization

System Size: 3 kWh
Vessel Volume: 4 * 500 L
P_{max}: 160 bar

This work was developed in the previous LDRD

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Transient Model Formulation

Gas (air) energy equation:

$$m_G c_{v,G} \frac{dT_G}{dt} = -h_{G,L} A_{G,L} (T_G - T_L) - UA_G (T_G - T_{amb}) - p_G \frac{dV_G}{dt}$$

Liquid (water) energy equation:

$$m_L c_L \frac{dT_L}{dt} = h_{G,L} A_{G,L} (T_G - T_L) - UA_L (T_L - T_{amb}) + \dot{m}_L c_L (T_{amb} - T_L)\Big)$$

Tank walls energy equations:

$$m_{T,G} c_T \frac{dT_{T,G}}{dt} = h_{i,G} A_{i,G} (T_G - T_{T,G}) - h_o A_{o,G} (T_{T,G} - T_{amb})$$

$$m_{T,L} c_T \frac{dT_{T,L}}{dt} = h_{i,L} A_{i,L} (T_L - T_{T,L}) - h_o A_{o,L} (T_{T,L} - T_{amb})$$

Gas (air) continuity equation:

$$\frac{dV_G}{dt} = -\frac{\dot{m}_L}{\rho_L}$$

Liquid (water) continuity equation:

$$\frac{dm_L}{dt} = \dot{m}_L$$

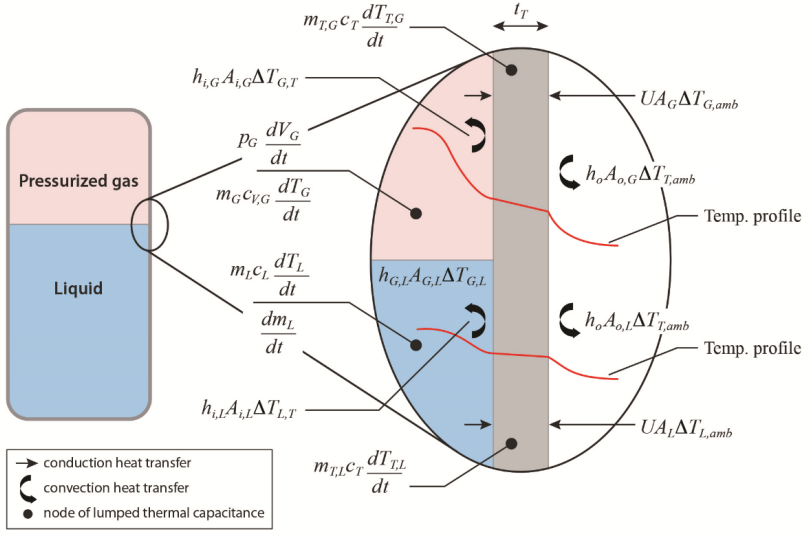
Tank wall overall conductances:

$$UA_G = \frac{1}{\left(\frac{1}{h_{i,G} A_{i,G}}\right) + \left(\frac{t_T}{k_T A_{ave,G}}\right) + \left(\frac{1}{h_o A_{o,G}}\right)}$$

$$UA_L = \frac{1}{\left(\frac{1}{h_{i,L} A_{i,L}}\right) + \left(\frac{t_T}{k_T A_{ave,L}}\right) + \left(\frac{1}{h_o A_{o,L}}\right)}$$

Modeling assumptions:

- No spatial temperature gradients
- Constant ambient temperature
- Constant thermophysical properties for tank wall
- Air behaves as a Redlich-Kwong ideal gas
- Negligible heat transfer between Tank1 and Tank2 masses
- Quasi-steady processes



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Preliminary GLIDES Equipment Cost Model

Storage Volume Equation

$$E_{st} = \frac{p_{max}\left(\frac{p_{max}}{p_{min}}\right)^{-\frac{1}{n}} - p_{min}}{n-1}$$

$$V_{st} = \frac{capacity \times storage\ time}{\eta_{RTE} \times E_{st}}$$

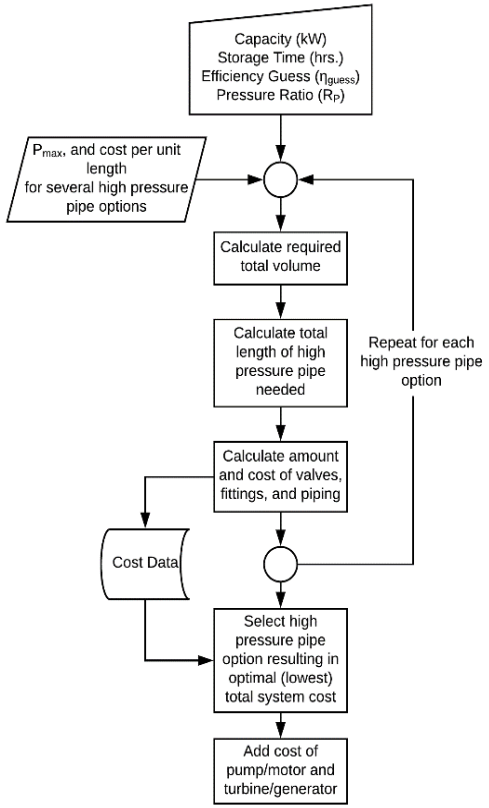
Polytropic process, n = 1.2

Inputs

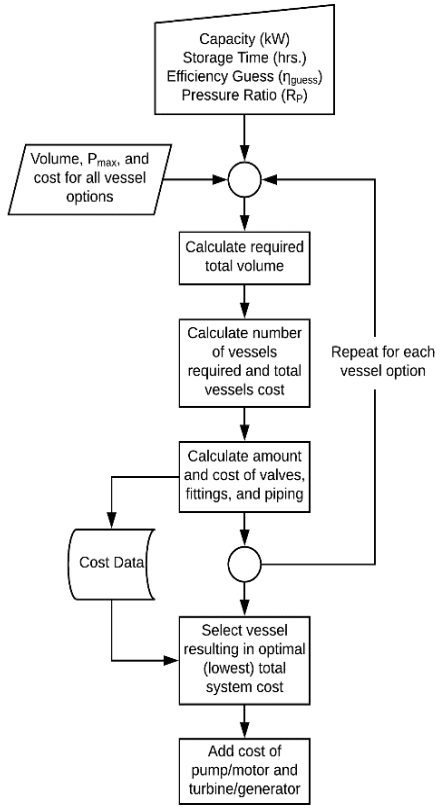
- Capacity
- Storage Time

Outputs

- Total Cost & $/kWh
- Volume/Number of Vessels



High-Pressure Pipe



Pressure Vessels

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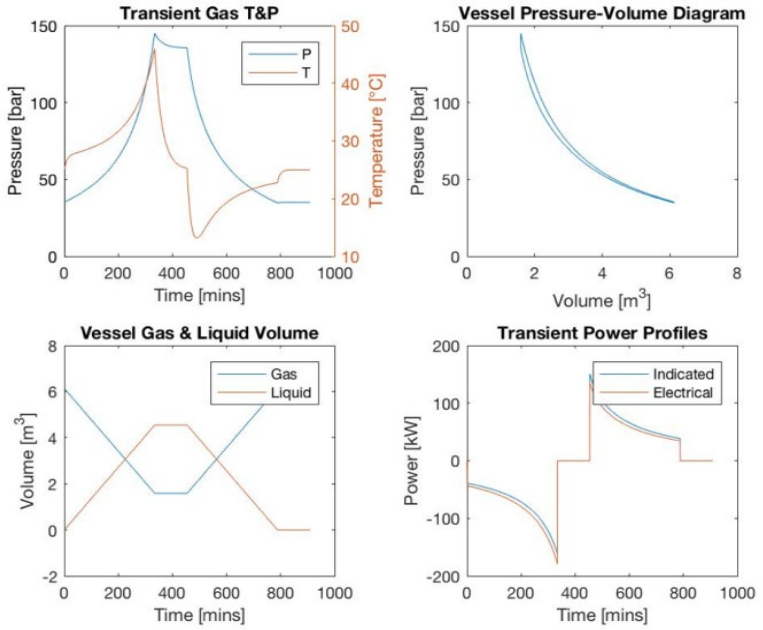
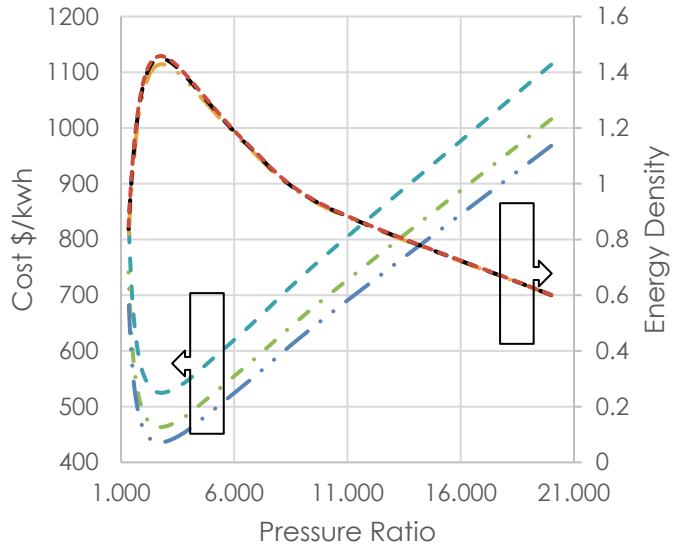
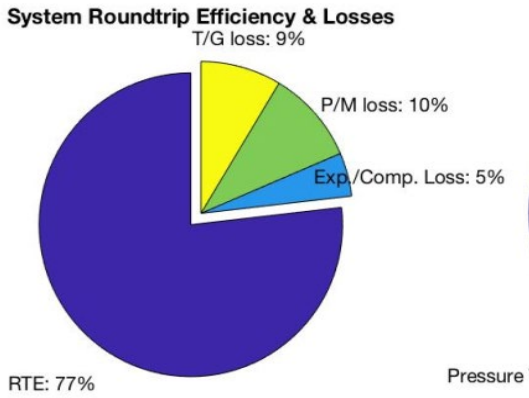
Results

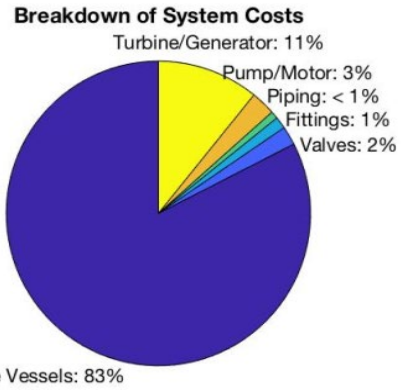
Storage Medium	Pipe Segments	Steel	Carbon Fiber
System Size MWh	60	60	60
Pressure Rating (bar)	145	206	248
% RTE	79	84	79
Energy Density kWh/m^3	1.46	0.51	2.5
Volume/vessel liter	6,251	3,000	900
$/kWh	345	4,627	2,001





High-Pressure Pipe Segments





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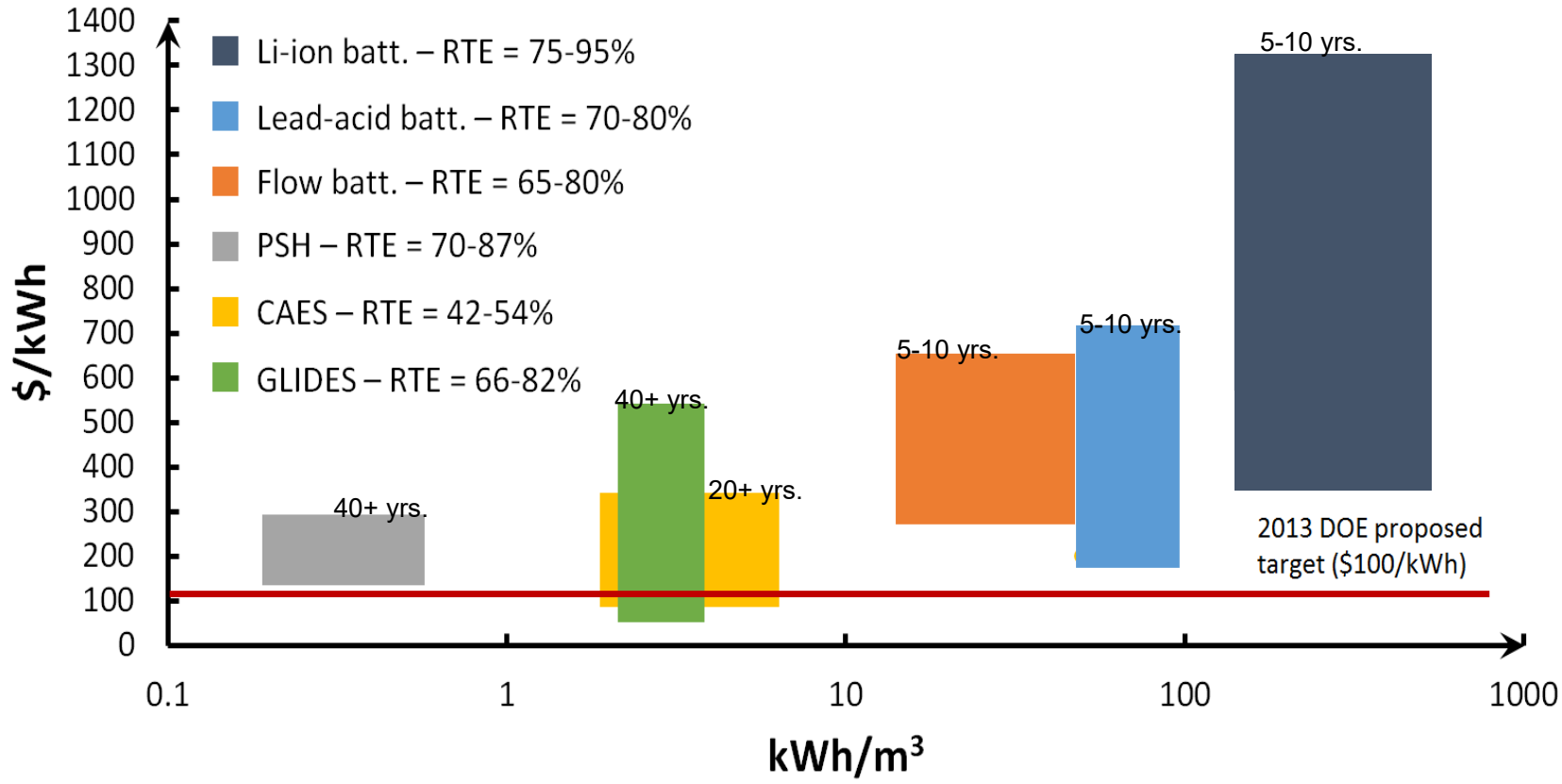
GLIDES: Preliminary Cost Analysis



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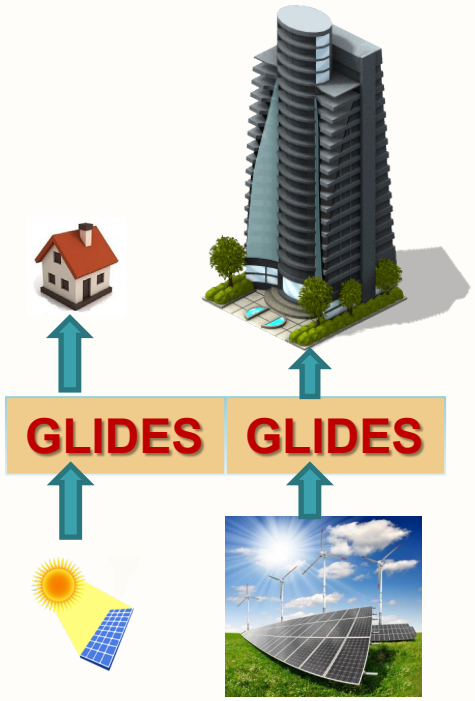
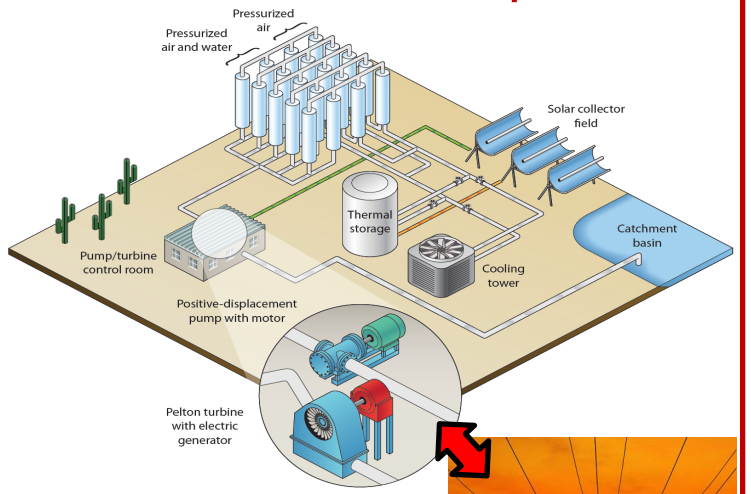
Enabling Technology for Grid Modernization + Penetration of Renewable Resources+ Leveraging Low Grade Heat (i.e. Transformer heat loss):

Small and Medium Scale Buildings



Grid Scale Modular Pump



Conceptual layout of Mega Watt scale GLIDES modular pump storage

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Progress and Accomplishments

Project Goal:

- Characterization of the power generation of GLIDES when integrated to an actual building/grid
- Developing the power conditioning systems for GLIDES to become grid-ready and a dispatchable energy storage system.

Accomplishments:

During the last 3 months, a preliminary cost model developed
Preliminary test results collected for alternative design (condensable gas).
The system integration to the actual load has been discussed

Market Impact:

	Lead Acid Battery	Proposed Technology
Storage efficiency %	70-85	70-82
Life span	3-7 yrs	>20 yrs
Cost	>$350/kWh	Targeting $180/kWh or below

Awards/Recognition:

A. Odukomaiya, A., et al., *Experimental and analytical evaluation of a hydro-pneumatic compressed-air Ground-Level Integrated Diverse Energy Storage (GLIDES) system.* Applied Energy, 2018. 221: p. 75-85.
B. M. Momen, K. J. Gluesenkamp, O. A. Abdelaziz, E. A. Vineyard, A. Abu-Heiba, A. O. Odukomaiya., "Near isothermal combined compressed gas/pumped-hydro electricity storage with waste heat recovery capabilities," US Provisional Patent Application filed 09-01-2016; serial number 15/254,137.
C. Odukomaiya, Wale O.; Abu-Heiba, Ahmad; Gluesenkamp, Kyle R.; Abdelaziz, Omar; Jackson, Roderick K.; Daniel, Claus; Graham, Samuel; Mehdizadeh Momen, Ayyoub (ORNL) Thermal analysis of near-isothermal compressed gas energy storage system. *Applied Energy*. 179 (October 2016) 948-960.

Lessons Learned:

Cost analysis show that more than 70% of the system cost belongs to the cost of the pressure vessels.

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Project Integration and Collaboration

Project Integration:

- Weekly meeting between ORNL team members

Partners, Subcontractors, and Collaborators:

- ORNL → Cost analysis, System design, prototype testing, integrating GLIDES to real-world applications
- Potential Partner: Recurrent Innovative Solutions → Integrating GLIDES to real-world applications

Communications:

- Applied Energy Journal
- Journal of Energy Storage
- ASME IMECE
- ASHRAE
- Leadership from congressional staff briefed on the technology

Next Steps and Future Plans

Next Steps:

- Complete cost model
- Alternative design improvement (condensable gas, underground/deep water, Al-Ce alloy vessels)
- Control system development
- Connecting GLIDES to residential building & evaluation

Future Plans:

- Improve the technology readiness level (TRL) of GLIDES from 2 to 4.
- Introduce a novel energy storage solution with the following features:
  - Frequency modulation
  - Fine load following capabilities
  - Fast response time
  - Achieve ≤ $200/kWh for grid storage
  - Storage life time > 20 years

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Acknowledgements and Collaboration

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Acknowledgment

ORNL

UTK

NREL