The Novel Ground Level Integrated Diverse Energy Storage (GLIDES)

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New Project Started in FY18

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

### Competing Technologies: Challenges

<table>
<thead>
<tr>
<th>Technology</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pumped Hydro</strong></td>
<td>• Limited to very specific geographical locations</td>
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<tr>
<td></td>
<td>- Typically remote areas (far from population/grid)</td>
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<tr>
<td></td>
<td>- Large footprint</td>
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<tr>
<td></td>
<td>• Challenging to scale down</td>
</tr>
<tr>
<td></td>
<td>• Input: Electricity only (<em>does not accept heat</em>)</td>
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<tr>
<td><strong>Compressed Air Energy Storage</strong></td>
<td>• Low Efficiencies (~50%)</td>
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<tr>
<td></td>
<td>• Limited to very specific geographical locations</td>
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<tr>
<td></td>
<td>- Need ground reservoir</td>
</tr>
<tr>
<td></td>
<td>• Challenging to scale down</td>
</tr>
<tr>
<td></td>
<td>• Input: Electricity and Heat (<em>does not accept heat</em>)</td>
</tr>
<tr>
<td><strong>Battery</strong></td>
<td>• Very expensive</td>
</tr>
<tr>
<td></td>
<td>• Need for replacement regularly</td>
</tr>
<tr>
<td></td>
<td>• Chemical and fire hazard</td>
</tr>
<tr>
<td></td>
<td>• Challenging to scale up</td>
</tr>
<tr>
<td></td>
<td>• Input: Electricity only (<em>does not accept heat</em>)</td>
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</table>
The Invented GLIDES System

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

<table>
<thead>
<tr>
<th>Key advantages</th>
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<tbody>
<tr>
<td>Simple, low cost (expected to be at lower cost than batteries)</td>
</tr>
<tr>
<td>Accepts heat and/or electricity as inputs</td>
</tr>
<tr>
<td>Round-trip efficiency &gt; 70-82%</td>
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Initial Experimental Results

<table>
<thead>
<tr>
<th>2nd Prototype Characterization</th>
<th>1st Prototype Characterization</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Size: 1 kWh</td>
<td>System Size: 3 kWh</td>
</tr>
<tr>
<td>Vessel Volume: 1 * 287 L</td>
<td>Vessel Volume: 4 * 500 L</td>
</tr>
<tr>
<td>$P_{max}$: 138 bar</td>
<td>$P_{max}$: 160 bar</td>
</tr>
</tbody>
</table>

This work was developed in the previous LDRD
Transient Model Formulation

Gas (air) energy equation:

\[
m_G c_v \frac{dT_G}{dt} = -h_{GL} A_{GL} (T_G - T_L) - U_{AG} (T_G - T_{amb}) - p_G \frac{dV_G}{dt}
\]

Liquid (water) energy equation:

\[
m_L c_T \frac{dT_L}{dt} = h_{GL} A_{GL} (T_G - T_L) - U_{AL} (T_L - T_{amb}) + m_L c_l (T_{amb} - T_L)
\]

Tank walls energy equations:

\[
m_{T,G} \frac{dT_{T,G}}{dt} = h_{GL} A_{G,T} (T_G - T_{T,G}) - h_{G,L} A_{L,T} (T_{T,G} - T_{amb})
\]

\[
m_{T,L} \frac{dT_{T,L}}{dt} = h_{L,L} A_{L,L} (T_L - T_{T,L}) - h_{L,G} A_{G,L} (T_{T,L} - T_{amb})
\]

Gas (air) continuity equation:

\[
\frac{dV_G}{dt} = -\frac{m_L}{p_G}
\]

Liquid (water) continuity equation:

\[
\frac{dm_L}{dt} = m_L
\]

Tank wall overall conductances:

\[
U_{AG} = \frac{1}{h_{G,L} A_{GL}} + \frac{1}{h_{GL} A_{G,L}} + \frac{\frac{T_T}{K_{avg,G}}} + \frac{\frac{1}{h_{G,L} A_{GL}}}
\]

\[
U_{AL} = \frac{1}{h_{L,G} A_{GL}} + \frac{1}{h_{GL} A_{G,L}} + \frac{\frac{T_T}{K_{avg,L}}} + \frac{\frac{1}{h_{L,G} A_{GL}}}
\]

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

This work was developed in the previous LDRD
Preliminary GLIDES Equipment Cost Model

Storage Volume Equation

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

\[ V_{SE} = \frac{\text{capacity} \times \text{storage time}}{\eta_{RT} \times E_{st}} \]

Polytropic process, \( n = 1.2 \)

Inputs
- Capacity
- Storage Time

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

High-Pressure Pipe
- Pressure Vessels

Inputs:
- Capacity
- Storage Time

Outputs:
- Total Cost & $/kWh
- Volume/Number of Vessels
## Results

<table>
<thead>
<tr>
<th>Storage Medium</th>
<th>Pipe Segments</th>
<th>Steel</th>
<th>Carbon Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Size MWh</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Pressure Rating (bar)</td>
<td>145</td>
<td>206</td>
<td>248</td>
</tr>
<tr>
<td>% RTE</td>
<td>79</td>
<td>84</td>
<td>79</td>
</tr>
<tr>
<td>Energy Density kWh/m³</td>
<td>1.46</td>
<td>0.51</td>
<td>2.5</td>
</tr>
<tr>
<td>Volume/vessel liter</td>
<td>6.251</td>
<td>3,000</td>
<td>900</td>
</tr>
<tr>
<td>$$/kWh</td>
<td>345</td>
<td>4,627</td>
<td>2,001</td>
</tr>
</tbody>
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### Pressure Ratio vs. Energy Density

- High-Pressure Pipe Segments

### System Roundtrip Efficiency & Losses
- T/G loss: 5%
- P/M loss: 10%
- Extra/Comp. Loss: 5%

### Breakdown of System Costs
- Turbine/Generator: 11%
- Pump/Motor: 3%
- Piping: < 1%
- Fittings: 1%
- Valves: 2%

### RTE: 77%

- Pressure Vessels: 83%
GLIDES: Preliminary Cost Analysis

- Li-ion batt. – RTE = 75-95%
- Lead-acid batt. – RTE = 70-80%
- Flow batt. – RTE = 65-80%
- PSH – RTE = 70-87%
- CAES – RTE = 42-54%
- GLIDES – RTE = 66-82%

2013 DOE proposed target ($100/kWh)
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
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:

<table>
<thead>
<tr>
<th></th>
<th>Lead Acid Battery</th>
<th>Proposed Technology</th>
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</thead>
<tbody>
<tr>
<td>Storage efficiency %</td>
<td>70-85</td>
<td>70-82</td>
</tr>
<tr>
<td>Life span</td>
<td>3-7 yrs</td>
<td>&gt;20 yrs</td>
</tr>
<tr>
<td>Cost</td>
<td>&gt;$350/kWh</td>
<td>Targeting $180/kWh or below</td>
</tr>
</tbody>
</table>

Awards/Recognition:

Lessons Learned:
Cost analysis show that more than 70% of the system cost belongs to the cost of the pressure vessels.
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
Acknowledgements and Collaboration

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Acknowledgment

ORNL

UTK

NREL