Hydrogen Bromine Flow Battery for Grid Scale Energy Storage

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Maria Schriver – PhD Mechanical Engineering 2012

Cleantech to Market
5/6/2011
Renewables Demand Storage

- Need to Control Renewable Generation
  - Lost value due to curtailment
  - Grid outage due to renewable variability

- ARPA-E Goal
  - Low cost storage that is dispatchable and rampable

Rapidly growing need for storage
Solution: HBr Flow Battery

- Independently optimize for energy and for power
- Low cost reactants
## Distinct Technology Advantages

### Competitors
- Pumped Hydro, CAES
- Natural Gas, CAES
- Other Batteries
- Other Flow Batteries, Flywheels

### Limitations
- Site Limited
- Carbon-emitting
- Slow to Ramp
- Energy Depends on Power
- Higher Cost

**HBr flow battery offers unique advantages**
Seek premium markets

- **High power**, fast storage stabilizes grid frequency
- **High energy**, low cost storage shifts generation and follows load
- **High availability** generation (hydro, coal, nuclear) provides base load
## Market Screens

<table>
<thead>
<tr>
<th></th>
<th>Transmission &amp; Distribution Deferral</th>
<th>Retail Time of Use</th>
<th>Grid Reliability</th>
<th>Renewables Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market size</td>
<td>$4B</td>
<td>$80B</td>
<td>$1.5B</td>
<td>$10B</td>
</tr>
<tr>
<td>Premium power</td>
<td>✓✓✓</td>
<td>✓✓✓</td>
<td>✓✓✓</td>
<td>✓</td>
</tr>
<tr>
<td>Fast response</td>
<td>✓</td>
<td>✓</td>
<td>✓✓</td>
<td>✓✓</td>
</tr>
<tr>
<td>Large capacity</td>
<td>✓</td>
<td>✓</td>
<td>✖</td>
<td>✓</td>
</tr>
<tr>
<td>Regulatory hurdles</td>
<td>✖</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Safety</td>
<td>✓</td>
<td>✖✖</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Time to market</td>
<td>✖</td>
<td>✓</td>
<td>✓</td>
<td>✖</td>
</tr>
</tbody>
</table>

Enter grid reliability and renewables integration markets
Recommendation: Grid Reliability First

Nearest opportunity is grid reliability

US Market Potential ($B)

- Grid Reliability: $1.5 B
- Renewables Integration: $8-12 B
- All Applications: $150-300 B

Estimates from Sandia 2010
## Grid Reliability - Features to Beat

<table>
<thead>
<tr>
<th></th>
<th>Vanadium Redox</th>
<th>Lead Acid</th>
<th>Lithium Ion</th>
<th>Flywheel</th>
<th>Natural Gas</th>
<th>HBr Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ramp Rate</strong></td>
<td>Full Ramp in Seconds</td>
<td>Full Ramp in Seconds</td>
<td>Full Ramp in Seconds</td>
<td>Full Ramp in Seconds</td>
<td>20 MW/min</td>
<td><strong>✓ ✓</strong></td>
</tr>
<tr>
<td><strong>Discharge Time</strong></td>
<td>4-5 hour</td>
<td>15 min-4 hour</td>
<td>15 min-4 hour</td>
<td>15 min</td>
<td>n/a</td>
<td><strong>✓</strong></td>
</tr>
<tr>
<td><strong>Power Capacity</strong></td>
<td>50 MW</td>
<td>100 MW</td>
<td>100 MW</td>
<td>20 MW</td>
<td>100 MW</td>
<td><strong>✓</strong></td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>70%</td>
<td>85%</td>
<td>90%</td>
<td>87%</td>
<td>n/a</td>
<td><strong>✓</strong></td>
</tr>
<tr>
<td><strong>Lifetime</strong></td>
<td>10-20 years</td>
<td>7-10 years</td>
<td>7-10 years</td>
<td>15-20 years</td>
<td>20 years</td>
<td>???</td>
</tr>
</tbody>
</table>

**Must extend lifetime to 20 years**

Estimates from EPRI 2010
Grid Reliability: Cost to Beat

Installed Costs

Assumption: 15-min discharge times, gas turbine figures averaged from PJM, CAISO & NYISO (Source: EPRI)

Need better metric

Background  Screen  Short Term  Long Term  Conclusion
Grid Reliability: Cost to Beat

Assumption: 15-min discharge times, cycle lifetimes from EPRI 2010, 5-17% capacity factor, gas turbine figures averaged from PJM, CAISO & NYISO (Source: EPRI)

Must beat $300/MWh
## Grid Reliability: Optimal Locations

<table>
<thead>
<tr>
<th></th>
<th>NYISO</th>
<th>PJM</th>
<th>ISO-NE</th>
<th>CAISO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market Size</td>
<td>💚</td>
<td>💚</td>
<td>🔴</td>
<td>💚</td>
</tr>
<tr>
<td>Tariff Favorability</td>
<td>💚</td>
<td>💚</td>
<td>🟠</td>
<td>🔴</td>
</tr>
<tr>
<td>Regulation Dynamics</td>
<td>💚</td>
<td>💚</td>
<td>💚</td>
<td>🟠</td>
</tr>
<tr>
<td>Government Support</td>
<td>💚</td>
<td>🟠</td>
<td>💚</td>
<td>💚</td>
</tr>
<tr>
<td>Wind Queue*</td>
<td>9 GW</td>
<td>7 GW</td>
<td>3 GW</td>
<td>11.3 GW</td>
</tr>
</tbody>
</table>

*As of March 2010

**New York ISO is the most favorable first market**
Second Market: Renewables Integration

Similarities to grid reliability:
- High power
- Long lifetime (20 years)

Difference:
- More tanks (4–8 hour discharge)

Low cost of added energy sets up renewables integration
Dynamically Changing Environment

Aggressive Competition

Emerging Techs

- Lead Acid
- Li Ion

Evolution of Storage Technology

- CAES
- Lead acid
- Flywheel
- Li Ion
- Flow battery
- Others
- Unknown/Multiple

Pilot projects: 44 existing; 105 planned
Source: EPRI 2010

Evolving Regulations

- National convergence
- Renewable and storage portfolio standards
- Valuing quality and accuracy of electricity delivery

Watch dynamic factors

Background → Screen → Short Term → Long Term → Conclusion
Key takeaways

- Must prove reliability for direct-to-grid
- Utility partners are crucial but risk averse
- HBr development timeline aligns with storage need
Recommendations and Research Focus

- Best applications
  - Grid reliability
  - Renewables integration
- Best location: NYISO
- Regulatory tailwinds
  - Storage portfolio standards
  - Pricing power quality
- Address challenges
  - Long Lifetime
  - Bromine Toxicity

Background

Screen

Short Term

Long Term

Conclusion

Chart showing growth from grid reliability, renewables integration, and all applications over time with estimates from 2010.
Thank You

- LBNL scientists
  - Venkat Srinivasan
  - Adam Weber
  - Vince Battaglia

- Commercial partners
  - Robert Bosch LLC
  - 3M Co.
  - Proton Energy Systems
  - DuPont Co.