Improving Energy Resiliency with Flow Batteries

September 15, 2016
Housekeeping

All participants are in “Listen-Only” mode. Select “Use Mic & Speakers” to avoid toll charges and use your computer’s VOIP capabilities. Or select “Use Telephone” and enter your PIN onto your phone key pad.

Submit your questions at any time by typing in the Question Box and hitting Send.

This webinar is being recorded.

You will find a recording of this webinar, as well as previous Resilient Power Project webinars, online at:

www.resilient-power.org
Clean Energy Group (CEG)

www.cleanegroup.org
www.resilient-power.org
CEG’s Resilient Power Project

- Increase public/private investment in clean, resilient power systems
- Engage city officials to develop resilient power policies/programs
- Protect low-income and vulnerable communities
- Focus on affordable housing and critical public facilities
- Advocate for state and federal supportive policies and programs
- Technical assistance for pre-development costs to help agencies/project developers get deals done
- See [www.resilient-power.org](http://www.resilient-power.org) for reports, newsletters, webinars, and more.
Northeast Electrochemical Energy Storage Cluster (NEESC)

NEESC is a network of industry, academic, government and non-governmental leaders working together to help businesses provide energy storage solutions.

www.neesc.org
Today’s Guest Speaker

Adam Rauwerdink
Director of Sales Engineering
VIONX Energy
TRANSFORMING THE GRID
Proven Long Duration Energy Storage

Improving Energy Resiliency with Flow Batteries
Adam Rauwerdink, Director of Sales Engineering
Proven Long Duration Energy Storage

20 YEAR LIFETIME
Bankable, utility-grade asset designed for the long run.

6 - 10 HOUR RUNTIME
Operational flexibility and endurance for multiple applications.

LASTING CAPACITY
No degradation. No augmentation. No replacement.

160 kW / 640 kWh System at Ft Devens
Leveraging World-Class Strategic Partners
DEEP EXPERIENCE IN TECHNOLOGY, ENERGY, MANUFACTURING AND FINANCE

EQUITY OWNERS

STARWOOD ENERGY GROUP
United Technologies
VANTAGE POINT CAPITAL PARTNERS

STRATEGIC & TECHNOLOGY PARTNERS

SIEMENS
EPC & PCS Equipment

3M
Membrane

JABIL
System Fabrication

United Technologies Research Center
System Optimization, Ongoing R&D

LARGO RESOURCES
Vanadium Supply
Leveraging World-Class Technology
DECADES OF TECHNOLOGY AND MATERIALS VALIDATION BY UTC & 3M

INTERDIGITATED FLOW FIELD

High Power
Twice the power density of traditional stacks through an advanced flow field design

High Reliability
Low pressure operation enables 20-year stack life and maximizes reliability

Low Cost
Half the stack cost of other flow batteries and no replacement costs

UNIFIED ELECTRODE ASSEMBLY

Proven Materials & Performance
Decades of performance validation and established volume manufacturing

No Degradation. No Cycle Limits.
Maintains performance over a 20-year life with no limitations on how often the system is cycled

INDEPENDENTLY EVALUATED
No Performance Degradation With Cycling or Time

Vionx 10-Cell Stack Performance

- **Coulombic Efficiency**
  - >10,000 CYCLES
  - >3,000 CYCLES
  - <1% PERFORMANCE DEGRADATION

- **DC Energy Efficiency**
  - >10,000 HOURS OF OPERATION

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### The Superior Technology for Long Duration Storage

<table>
<thead>
<tr>
<th>Strong</th>
<th>Medium</th>
<th>Weak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Technology</td>
<td>Vanadium Redox Flow Battery</td>
<td>Lithium Ion Battery</td>
</tr>
<tr>
<td>Economic Runtime</td>
<td>6 - 10 hours</td>
<td>0.5 - 4 hours</td>
</tr>
<tr>
<td>20 Year LCOE ($/MWh)</td>
<td>$216 - $260</td>
<td>$260 - $270</td>
</tr>
<tr>
<td>Installed AC System Cost ($/kWh)</td>
<td>$500 - $700</td>
<td>$500+</td>
</tr>
<tr>
<td>Lifetime</td>
<td>20 years</td>
<td>10 years</td>
</tr>
<tr>
<td>Capacity Degradation</td>
<td>None</td>
<td>Yes ~30% in 10 years</td>
</tr>
<tr>
<td>Siting: Size (MWh/acre) &amp; Restrictions</td>
<td>100 Limited Restrictions</td>
<td>200 Limited Restrictions</td>
</tr>
<tr>
<td>Track Record</td>
<td>Demonstration/Deployment</td>
<td>Commercial</td>
</tr>
<tr>
<td>Safety</td>
<td>Stable, non-flammable</td>
<td>Fire Hazard</td>
</tr>
<tr>
<td>Competitors</td>
<td>Vionx Energy</td>
<td>Panasonic</td>
</tr>
</tbody>
</table>

**Sources:** Company; DOE/EPRI 2013 Electricity Storage Handbook; JPM Energy Storage Primer, 12/7/15; Lazard Levelized Cost of Storage Analysis, 11/15/15

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# Vionx VRB Beats Li-Ion Lifetime Cost

LITHIUM ION CAPACITY LOSS AND REPLACEMENTS DRIVE 20 YEAR LIFETIME COST

<table>
<thead>
<tr>
<th>Lifetime Cost ($/kWh)</th>
<th>Overbuild for Degradation</th>
<th>Augmentation</th>
<th>Replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vionx 500</td>
<td>33</td>
<td>175</td>
<td>283</td>
</tr>
<tr>
<td>Lithium Ion 500</td>
<td>0</td>
<td>491</td>
<td></td>
</tr>
<tr>
<td>Lost Energy Recovery &amp; Cell Replacement Lifetime Costs ($/kWh)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1,255</td>
<td>1,609</td>
<td></td>
</tr>
</tbody>
</table>

Initial Capital Expense

Lost Energy Recovery & Cell Replacements

Maintenance

Operating Expenses

End of Life Costs

Lifetime Total

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## Grid-Scale Validation

<table>
<thead>
<tr>
<th>System Type</th>
<th>Capacity</th>
<th>Benefits</th>
</tr>
</thead>
</table>
| **Military & Microgrids**    | 160kW / 640 kWh    | - Micro-Grid Control Compatibility  
|                              | System            | - Time-of-Use Rate Reduction  
|                              |                   | - Demand Charge Reduction  |
| **Wind Integration**         | 500kW / 3,000 kWh System | - Wind Integration (600kW Wind)  
| (Ft. Devens, MA)             |                   | - Time-of-Use Rate Reduction  
|                              |                   | - Demand Charge Reduction  |
| **Q3 2016**                  | Under Construction|                                               |
| **Solar Integration**        | 500kW / 3,000 kWh System | - PV Integration (605kW Solar)  
| (Everett, MA)                |                   | - Voltage Support  
|                              |                   | - Load Following  |
| **Q4 2016**                  |                   |                                               |
VNX1000 SERIES

1,000 kW / 6-10 Hours

Modular Architecture

Independent scaling of power and energy
- Optimal system sizing for each application
- Flexibility to add power or energy as project needs change over time

Simplicity

Maximizes power density & minimizes footprint to reduce material and site costs
- Reduces container spacing & pipe runs
- Reduces wetted electrolyte surfaces, minimal propensity for leaks
- Minimizes moving components via centralization of all pumps, controls, etc. in stack container
- Electrolyte containers have no moving parts

Durable, Quality Components

Maximize system life and minimize operational expense
- Materials meet chemical industry standards
- Containers are marine grade for maximum climate resistance
- Electrolyte 100% double walled/contained
## VNX1000 Specifications

<table>
<thead>
<tr>
<th>Energy Storage Module</th>
<th>VNX1000-6</th>
<th>VNX1000-8</th>
<th>VNX1000-10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Storage (MWh)</strong></td>
<td>6 MWh</td>
<td>8 MWh</td>
<td>10 MWh</td>
</tr>
<tr>
<td><strong>Usable Depth of Discharge</strong></td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Life</strong></td>
<td></td>
<td></td>
<td>20 years (unlimited cycles)</td>
</tr>
<tr>
<td><strong>Power Rating</strong></td>
<td>1 MW AC (2 Stack Containers)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DC Footprint</strong></td>
<td>185 m² / 2,000 ft²</td>
<td>195 m² / 2,100 ft²</td>
<td>205 m² / 2,200 ft²</td>
</tr>
<tr>
<td><strong>DC Efficiency (stack)</strong></td>
<td>78%</td>
<td>78%</td>
<td>78%</td>
</tr>
<tr>
<td><strong>DC Voltage</strong></td>
<td></td>
<td>500V-800V DC operating range</td>
<td></td>
</tr>
<tr>
<td><strong>AC Efficiency</strong></td>
<td>68%</td>
<td>68%</td>
<td>68%</td>
</tr>
<tr>
<td><strong>Signal Response</strong></td>
<td>&lt;1 Second electrolyte pumps ON • &lt;1 Minute electrolyte pumps OFF</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Interconnection Standard</strong></td>
<td></td>
<td>IEEE 1547</td>
<td></td>
</tr>
<tr>
<td><strong>Operating Ambient Temperature</strong></td>
<td>-40°C to +45°C / -40°F to 113°F</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Relative Humidity</strong></td>
<td>0 to 100%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Proven Long Duration Energy Storage Solution

Renewables Integration and Microgrids
- Dispatchable renewable power
- Increased capacity value and optimized energy delivery
- Improved thermal generation efficiency and reliability

T&D Deferral
- Flexible and capital-efficient grid design
- Rapid deployment and simplified siting
- Increased utilization of existing assets

Commercial and Industrial
- Improved utilization of local solar
- Lower demand charges and more reliable power
- Revenue from grid services

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Dispatchable 24x7 Solar Power

Solar + Vionx Long-Duration Storage = Dispatchable Power at 15¢/kWh Today and 10¢/kWh by 2020

- Solar + Vionx storage is cost effective today
- Leverage existing or new low-cost PV solar to create a complete clean energy system
- Reliable, independent, dispatchable power generation for remote users
- Enables more efficient T&D operations for renewable energy integration
- Eliminates or optimizes fossil fuel-fired generation
- No air emissions or water consumption

Note: Lazard methodology used for LCOE calculation. 80% debt and 20% equity. 16% pre-tax cost of equity. Solar installed cost of $1,600/kW in 2017 dropping linearly to $1,000/kW in 2020. Vionx DC costs declining commensurate with projections. 20 year project life. Solar data from NREL PVWatts.
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