DEMONSTRATION OF ENERGY STORAGE USING A
BREAKTHROUGH
REDOX FLOW BATTERY TECHNOLOGY

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Project Overview

- Develop EnerVault’s energy storage technology into a 21 kW utility-scale system building block
- Complete preliminary design of the Vault-250/1000 system

- Final design and build Vault-250/1000 beta system
- Install and commission system

- First Ever Design and Operation of MWh-scale Fe/Cr RFB System
- Commission and demonstrate Vault-250/1000 system
Milestones

- Achieve initial performance targets  Complete
- 2 kW prototype system  Complete
- Full scale 21 kW design, Engineered Cascade™  Complete
- Engineered Cascade™ demonstration  In process
- Completion of Vault-250/1000 beta system  In process
- Vault 250/1000 field demonstration  Scheduled 2013
- Final report to DOE  Dec 2013

Team is meeting the challenge of developing a breakthrough energy storage technology
Project Metrics and Benefits

- **Performance Metrics**
  - Energy dispatched, system availability, round trip efficiency, maintenance

- **Impact Metrics**
  - Electricity usage and production, peak load and generation, annual dispatch, average efficiency
Project Activities

- **EnerVault**
  - Engineered Cascade™
  - Architecture and design
  - Core electrochemistry
  - Flow Battery Operations

- **Raytheon Ktech**
  - Balance of system design and integration
  - Controls design and development
  - System fabrication
  - Testing and commissioning
Why Flow Batteries for Grid Scale?

- Independence of system power and energy – application flexibility

- Economics get better at higher energy to power ratio - 3-10 hrs
  - Peak shaving applications
  - Long duration back-up

- System safety at high energy capacity
  - < 10 minutes of energy is electrically connected at one time
Why Fe-Cr for Grid Scale?

- Abundant, high production volume = low cost

### Annual Production ESP/ TWh

- Na/S
- CrCl2/FeCl2
- Na/NiCl2
- Pb/Pb02
- Zn/Br2
- C6/LiFePO4
- Li/S
- C6/LiCoO2
- Mg/Sb
- V(SO4/V02 (HSO4)

### Couple Elements Cost $/kWh

- 1% 2009 U.S. Daily Elec. Use
- 5% 2007 World Daily Elec. Use

adapted from: Wadia et al., *J. Power Sources* 196 (2011) 1593-1598
Program Progress

- Multiple kW-Scale test systems operating:
  - 2 kW; 7 kW; 21 kW

- Cell stack manufacturing started; long lead system components on order

- Detailed system design and BMS software development nearly complete

- Refining operating conditions on large test systems
## Future Applications and Impact

- Modular, tailored solutions for multiple applications

### Market:
- Distributed Renewable Energy
- Commercial & Industrial
- Utilities and Grid

<table>
<thead>
<tr>
<th>App’s</th>
<th>Distributed Renewable Energy</th>
<th>Commercial &amp; Industrial</th>
<th>Utilities and Grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Range</td>
<td>250 kW to 5 MW</td>
<td>250 kW to 5 MW</td>
<td>500 kW to 100 MW</td>
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<tr>
<td>Energy Range</td>
<td>3 to 6 hours</td>
<td>3 to 12 hours</td>
<td>3 to 8 hours</td>
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<td>Demand Management</td>
<td>Extended Emergency Backup</td>
<td>Renewable Integration Demand Management T &amp; D Deferral Energy Arbitrage</td>
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</tbody>
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The Future

- Flow batteries provide grid-scale storage
  - 50 MW – 250 MWh system
  - Serving time shifting needs at the load centers
Developing a Novel Redox Flow Battery for Grid Applications

A Combination of Public and Private Support

Product Development

2009

Bench
2 W

Prototype
2-5 kW

Alpha
21 kW

Beta
250 kW

2013

Test System Development

Able
2 kW

Bravo
5 kW

Charlie
Delta
7 kW

Echo
21 kW

Project Support

NYSERDA

California Energy Commission

U.S. Department of Energy – ARRA Storage Demo

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Program Impact

- **Reduce the cost of sure and secure electricity**
  - reduced blackouts
  - improve grid stability
  - optimize existing T&D network

- **Cleaner, healthier environment**
  - provide clean peak electricity generated w/in distribution network
  - retire OTC plants (CA leading)

- **Electricity price predictability**
  - transform renewable but variable sources into dispatchable resources
  - state RPS become price hedge

- **US jobs**
  - KEMA: over 110,000 jobs

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Our project is the first MWh scale Fe/Cr redox flow battery demonstration in the US

EnerVault Engineered Cascade™ design validated

Scale-up testing underway

Detailed system design is nearly complete

Development, integration and build of Vault-250/1000 is underway

Successful demonstration of the Vault-250/1000 system in this application provides pathway to broad deployment for smart grid and renewable generation