State & Federal
Energy Storage Technology
Advancement Partnership
(ESTAP)

Todd Olinsky-Paul
Clean Energy States Alliance
Thank You:

Dr. Imre Gyuk
U.S. Department of Energy,
Office of Electricity Delivery and
Energy Reliability

Dan Borneo
Sandia National Laboratories
ESTAP is a project of CESA

Clean Energy States Alliance (CESA) is a non-profit organization providing a forum for states to work together to implement effective clean energy policies & programs:

- Information Exchange
- Partnership Development
- Joint Projects (National RPS Collaborative, Interstate Turbine Advisory Council)
- Clean Energy Program Design & Evaluations
- Analysis and Reports

CESA is supported by a coalition of states and public utilities representing the leading U.S. public clean energy programs.
ESTAP* Overview

**Purpose:** Create new DOE-state energy storage partnerships and advance energy storage, with technical assistance from Sandia National Laboratories

**Focus:** Distributed electrical energy storage technologies

**Outcome:** Near-term and ongoing project deployments across the U.S. with co-funding from states, project partners, and DOE

* (Energy Storage Technology Advancement Partnership)
ESTAP Key Activities

- Disseminate information to stakeholders
  - ESTAP listserv >500 members
  - Webinars, conferences, information updates, surveys

- Facilitate public/private partnerships at state level to support energy storage demonstration project development
  - Match bench-tested energy storage technologies with state hosts for demonstration project deployment
  - DOE/Sandia provide $ for generic engineering, monitoring and assessment
  - Cost share $ from states, utilities, foundations, other stakeholders
Contact Information

Project website:
www.cleanenergystates.org/projects/energy-storage-technology-advancement-partnership/

CESA Project Director:
Todd Olinsky-Paul (Todd@cleanegroup.org)

Sandia Project Director:
Dan Borneo (drborne@sandia.gov)
Flow Batteries for Grid Energy Storage:
It’s easy to make a Battery: 2 Electrodes and an Electrolyte
A rechargeable Battery uses 2 Half-Cells with different Electrolytes separated by a Membrane.
Power depends on the Fuel Cell, Energy depends on the Electrolyte
Standard potential (V) of redox couples

- Zn\(^{2+}/Zn\)
- Ti\(^{3+}/Ti^{2+}\)
- S/S\(^{2-}\)
- Cr\(^{3+}/Cr^{2+}\)
- Cu\(^{2+}/Cu^{+}\)
- TiOH\(^3+\)/Ti\(^{3+}\)
- VO\(^{2+}/VO^{2+}\)
- VO\(^{3+}/VO^{2+}\)
- V\(^{3+}/V^{2+}\)
- Fe\(^{3+}/Fe^{2+}\)
- Fe\(^{3+}/Fe^{2+}\)
- BrCl\(^2-/Br^-\)
- Cr\(^{5+}/Cr^{4+}\)
- Cr\(^{4+}/Cr^{3+}\)
- Co\(^{3+}/Co^{2+}\)
- Mn\(^{3+}/Mn^{2+}\)
- MnO\(^4-/MnO_2\)
- Ce\(^{4+}/Ce^{3+}\)

\(E^\circ = 1.26\text{V}\)

We want high Potential!
We want low Cost!
Examples:

Zn Br – Primus Power (ARRA Project)
   Premium Power (ARRA Project)
   ZBB (Early Demos)
   Redflow (Testing at Sandia)

V-V – Prudent Power
   Ashlawn (ARRAProject)
   UniEnergy (Based on PNNL Research)

Fe Cr – Deeya
   Enervault (ARRA Project)
ARRA – Primus Power

25 MW / 3hr battery plant to firm 50MW of wind for the Modesto Irrigation District in CA, providing equivalent flex capacity to 50 MW of natural gas engines costing $73M

High power metal electrodes

Fully self-contained, hermetically sealed flow battery modules

250kW/750kWh EnergyPods™

4MW/12MWh incremental “Plug & Play” deployment

2012-TiE50 Hottest Tech Startups
2011-GoingGreen Global 200
Anderson et al. Synthesis of Ionic Liquids Containing Cu, Mn, or Zn Coordination Cations

Liyu Li et al., Stable Vanadium Redox Flow Battery with High Energy; 1, 394-400, 2011
Applications for Redox Flow Batteries

Bret Adams
Dir. Business Development

December 20, 2012

BAdams@EnerVault.com
Why Redox Flow Batteries for Grid Scale?

- Independent configuration 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 any time
RFB market share will grow to a 17% market share by 2017, with the highest growth rate.

2017 Grid Storage Mix

- Lithium-ion Energy: 29% at $750/kWh
- Sodium Nickel Chloride: 19% at $475/kWh
- Sodium Sulfur: 24% at $475/kWh
- Redox Flow: 17% at $750/kWh
- Zinc Bromine Flow: 11% at $500/kWh

Source: Lux Research Grid Storage Demand Forecaster, 2012
Contact: Brian Warshay, Brian.Warshay@luxresearchinc.com
Energy Storage Demonstrations in the U.S. Planned or Under way – List is Not Complete
Market Opportunity

<table>
<thead>
<tr>
<th>System Power (kW)</th>
<th>UPS, Pwr Qual</th>
<th>Load Shifting, EM, T&amp;D Grid Support, REI</th>
<th>Bulk Power Mgmt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pumped Hydro</td>
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<td></td>
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<td>CAES</td>
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<tr>
<td></td>
<td>Li-Ion and</td>
<td>Flywheels, Super Caps</td>
<td></td>
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<tr>
<td></td>
<td>Lead Acid</td>
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<tr>
<td></td>
<td>Batteries,</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Integrated</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Cells</td>
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</tbody>
</table>

Storage Duration: Seconds, Minutes, Hours

Gap
RFB Fills The Gap

Redox Flow Batteries
- Cost Effective
- Capital and O&M
- Flexible
- kW vs kWh
- Safe

UPS, Pwr Qual | Load Shifting, EM, T&D Grid Support, REI | Bulk Power Mgmt
---|---|---

Storage Duration
- Seconds
- Minutes
- Hours

System Power (kW)
- 10
- 100
- 1000
- 10000
- 100000
- 1000000

Pumped Hydro
CAES
Conventional Redox Flow Battery

**Safe**
- liquid reactants
- no thermal runaway
- decoupled P & E

**Long-life**
- dissolved reactants

**Flexible Design**
- tailored energy / power ratio

**Chemistries**

<table>
<thead>
<tr>
<th>Couple</th>
<th>Anolyte (negative)</th>
<th>Catholyte (positive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vanadium-Vanadium</td>
<td>V^{2+} / V^{3+}</td>
<td>V^{5+} / V^{4+}</td>
</tr>
<tr>
<td>Iron-Vanadium</td>
<td>V^{2+} / V^{3+}</td>
<td>Fe^{3+} / Fe^{2+}</td>
</tr>
<tr>
<td>Iron-Chromium</td>
<td>Cr^{2+} / Cr^{3+}</td>
<td>Fe^{3+} / Fe^{2+}</td>
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</table>
RFB Design Flexibility

larger straw ➔ drink faster

larger cup, more liquid ➔ drink longer

Energy

Power
## Utility Applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Duration hrs</th>
<th>Min. Power</th>
<th>RFB</th>
<th>Conventional Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Generation Grid Integration, Long Duration</td>
<td>3.5</td>
<td>0.2 kW</td>
<td>▲</td>
<td>$</td>
</tr>
<tr>
<td>T&amp;D Upgrade Deferral 90th percentile</td>
<td>4.5</td>
<td>250 kW</td>
<td>▲</td>
<td>$</td>
</tr>
<tr>
<td>Time-of-use Energy Cost Management</td>
<td>5</td>
<td>1 kW</td>
<td>▲</td>
<td>$</td>
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<tr>
<td>Renewables Capacity Firming</td>
<td>3</td>
<td>1 kW</td>
<td>▲</td>
<td>$</td>
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<tr>
<td>Renewables Energy Time-Shift</td>
<td>4</td>
<td>1 kW</td>
<td>▲</td>
<td>$$</td>
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<tr>
<td>Electric Energy Time-Shift</td>
<td>5</td>
<td>1 kW</td>
<td>▲</td>
<td>$$</td>
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<tr>
<td>Electric Supply Capacity</td>
<td>5</td>
<td>1 MW</td>
<td>▲</td>
<td>$$$</td>
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<tr>
<td>T&amp;D Upgrade Deferral 50th percentile</td>
<td>4.5</td>
<td>250 kW</td>
<td>▲</td>
<td>$$</td>
</tr>
<tr>
<td>Transmission Congestion Relief</td>
<td>4.5</td>
<td>1 MW</td>
<td>▲</td>
<td>$$$</td>
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<tr>
<td>Demand Charge Management</td>
<td>8</td>
<td>50 kW</td>
<td>▲</td>
<td>$$$</td>
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<tr>
<td>Load Following</td>
<td>3</td>
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<tr>
<td>Electric Supply Reserve Capacity</td>
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<tr>
<td>Substation On-site Power</td>
<td>12</td>
<td>1.5 kW</td>
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<td>$$$</td>
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<tr>
<td>Voltage Support</td>
<td>&lt; 1</td>
<td>10 MW</td>
<td>▼</td>
<td>$$$</td>
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<tr>
<td>Electric Service Reliability</td>
<td>&lt; 1</td>
<td>0.2 kW</td>
<td>▼</td>
<td>$$$</td>
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<tr>
<td>Area Regulation</td>
<td>&lt; 1</td>
<td>1 MW</td>
<td>▼</td>
<td>$$$</td>
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<tr>
<td>Wind Generation Grid Integration, Short Duration</td>
<td>&lt; 1</td>
<td>0.2 kW</td>
<td>▼</td>
<td>$$$</td>
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<tr>
<td>Electric Service Power Quality</td>
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<td>▼</td>
<td>$$$</td>
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<tr>
<td>Transmission Support</td>
<td>&lt;&lt;</td>
<td>10 MW</td>
<td>▼</td>
<td>$$$</td>
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</tbody>
</table>

Adapted from:

▲ Ideal Application $ Good Value to Cost per kWh

■ Good Application $$ Med Value to Cost per kWh

▼ Not Ideal Application $$$ Low Value to Cost per kWh
Summary-Present Value Installed Cost $ / kW

Notes: All costs in 2012$; Costs will vary significantly based on site-specific conditions;
Financials: IOU ownership; 15 year life; $30/MWH off-peak charging costs; natural gas @ $3/MBtu for CAES
Industrial Application

200kW nominal power and 400kWh storage capacity.

Courtesy Gildemeister Energy Solutions
The combined system of 5MWh Vanadium Flow Battery and 100kW Solar (concentrating type) has been constructed in Sumitomo’s Yokohama Works.

Examination started last week.
1000 kWh VRB-ESS® - China

CEPRI – Hebei, China
Capability: 500 kW, 1000 kWh
Commissioning date: March 2011
Application: Wind smoothing

Prudent Energy
VRB® Systems
Emerging market telecom sites often have poor, intermittent grid electricity supplemented by diesel generators and lead acid batteries.

Deeya Energy’s ESP flow batteries are operating in multiple emerging market countries to improve the cost and reliability of customers’ electricity.

~2/3 of today’s installs are grid connected.

Proven value proposition in dozens of wireless telecom customer installations:

- Up to 70% energy savings
- < 2.5 years payback
- Reduction or elimination of diesel generator use
# EnerVault Overview

<table>
<thead>
<tr>
<th>Business</th>
<th>Developer of MWh-scale Redox Flow Battery (RFB) Systems for:</th>
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<tbody>
<tr>
<td></td>
<td>1) <strong>Commercial &amp; Industrial</strong>: Peak Demand Management</td>
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<tr>
<td></td>
<td>2) <strong>Wind &amp; PV PPA</strong>: Time-shift and intermittency</td>
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<td></td>
<td>3) <strong>DoD</strong>: Micro-grid and energy security</td>
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<td></td>
<td>4) <strong>Utility &amp; IPP</strong>: T &amp; D deferral and renewables integration</td>
</tr>
</tbody>
</table>

| Investors & Awards | Total S.A., Mitsui Global Investment, 3M Corporation, Tokyo Electron, Commercial Energy, Oceanshore Ventures, U.S. Invest; DOE, CEC, NYSERDA |

- **Power**: 250 kW & higher
- **Energy**: 1 MWh & higher
- **Fully integrated system**
  - AC to AC
  - DC (PV/wind) to AC
- **Scalable to 10s and 100s MW**
Engineered Cascade™ Benefits

- Decoupled Power & Energy
- Non-Volatile Electrolyte
- Fault Tolerant System
- Minimal Personnel & Environmental Hazard

Safe Storage

- Durable and Proven Materials
- Steady-State Operation
- Reduced System Complexity
- Simplified PCS

Reliable

- Reduced Pump Losses
- Low-Cost, High-Efficiency PCS
- Inexpensive Materials
- Unlimited Electrolyte Life

Cost Effective
DOE ARRA Storage Demonstration Project

225 kW irrigation pump

250 kW / 1000 kWh (4 hr)

located near Turlock, CA
“... multi-megawatt energy storage solutions using—and I have no idea what this is—vanadium redox fuel cells... that’s one of the coolest things I’ve ever said out loud.”

President Obama, February 22, 2011
Thank You

www.enervault.com