Overview of U.S. DOE Office of Electricity Energy Storage Program and PNNL Efforts

Vincent Sprenkle, Cary Bloyd
Pacific Northwest National Laboratory

Support from DOE Office of Electricity Delivery & Energy Reliability Energy Storage Program
**Mission:** To enable energy storage to provide multiple benefits for critical grid applications, DOE is accelerating adoption of energy storage through: improving the technology, field demonstrations, and innovative market design.

**Challenges:**

- **Cost competitive energy storage technologies**
  - Targeted scientific investigations of key materials and systems

- **Validated reliability & safety**
  - Independent testing of prototypic devices and understanding of degradation.

- **Equitable regulatory environment**
  - Enable Industry, Utility, Developer collaborations to quantify benefits provide input to regulators.

- **Industry acceptance**
  - Highly leverage field demonstrations and development of storage system design tools

**Strategic Goal:**

- **Smart Grid**
- **Resiliency**
- **Reliability**
- **Asset Utilization**
- **Renewables Integration**
- **EV deployment**
OE Energy Storage Program Activities

Coordinated effort between Sandia National Laboratories, PNNL, and ORNL
The U.S. DOE Global Energy Storage Database Provides Information on 1620 Projects Worldwide*

### Data Visualization

<table>
<thead>
<tr>
<th>Technology Type</th>
<th>Projects</th>
<th>Rated Power (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electro-chemical</td>
<td>977</td>
<td>3062</td>
</tr>
<tr>
<td>Pumped Hydro Storage</td>
<td>352</td>
<td>183800</td>
</tr>
<tr>
<td>Thermal Storage</td>
<td>206</td>
<td>3622</td>
</tr>
<tr>
<td>Electro-mechanical</td>
<td>70</td>
<td>2616</td>
</tr>
<tr>
<td>Hydrogen Storage</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>Liquid Air Energy Storage</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

*http://www.energystorageexchange.org/*
**Market Acceptance**

**Market Drivers**

- Redox Flow, Na-metal, Na-ion
- Cost Effective
- Reliable
- Safe
- Cost Analysis

**Technology**

- Vanadium Redox Flow Battery
- Aqueous Soluble Organic RFBs
- IT Sodium Metal Halide Batteries
- Sodium-ion Batteries

**Vanadium Redox Flow Battery**

- Mixed acid increases $T_{op}$ by 80%, energy density 70%.
- Additives for sulfate V/V shows similar $T_{op}$
- 5X stack power without decreasing efficiency

**Aqueous Soluble Organic RFBs**

- At higher performance levels, Vanadium 55% of cost.
- Developing engineered molecules that can be drop in replacement for V/V systems

**IT Sodium Metal Halide Batteries**

- Decreased $T_{op}$ from 350°C to 190°C improving lifetime.
- DOE-KETEP MOU to leverage PNNL IT chemistry with RIST/POSCO scale-up efforts.

**Sodium-ion Batteries**

- Analog to Li-ion utilizing existing production capabilities.
- Offers potential for longer cycle-life and lower cost.

---

**Storage use-case analysis**

- 7MW/15MWh - WA CEF I
- EWEB – Eugene, OR (w/ Sandia)
- MA DOER - Northampton, MA
- WA CEF II (AVISTA, OPALCO)
- GMLC – PGE (Salem, OR), GMP (Rutland, VT), EPB (Chattanooga, TN), LMC (Los Alamos, NM)

---

**Safety Standards**

- Leading OE Safety Codes and Standards Working Group
- CSR 101
- CSR Inventory
- ESS Compliance Guide

**ESS Performance Protocols**

- Rev 2 released April - 2016
- 8 performance metrics developed for ESS Applications.
- International adoption TEC 120
- Basis for new standards from NEMA, IEE.

---

**Regulatory Support**

- PNW PUC Workshop July - 2015
- Supporting WA and OR dockets on ESS
- FERC engagement: barriers to bundled services, modeling cost-service tradeoffs.
Why Redox Flow Battery?

Key Aspects

- Power and Energy are separate enabling greater flexibility and safety.
- Suitable for wide range of applications 10’s MW to ~ 5 kw
- Wide range of chemistries available.
- Low energy density ~ 30 Whr/kg
Grid Energy Storage Diverse Markets Encourage Bundling and Cost Reduction.

Want energy storage systems that can provide *both*: Faster response balancing services *and* Longer duration (2+ hr) deferral and outage mitigation.
Energy storage optimization tool
Energy Storage Bundled Services:

PNNL-23040 Assessment of Energy Storage Alternatives in the Puget Sound Energy System

Energy price ($/MWh)

- Arbitrage only
- Arbitrage + Balancing
- Arbitrage + Balancing + T&D deferral
- Arbitrage + Balancing + T&D deferral + volt/var

Power output (MW)
Energy storage optimization tool output

Value stream ($000)
- Arbitrage: 5,336
- Balancing: 290,251
- Capacity value: 568,843
- Deferral: 622,631
- Outage mitigation: 1,066,852
- Total: 2,553,914

Hour distribution (hours)
- Standby: 5,763
- Arbitrage: 1,341
- Arbitrage + bal.: 1,593
- Capacity value: 1
- Deferral: 2
- Outage mitigation: 60

Bar chart showing:
- Arbitrage
- Balancing
- Capacity
- Deferral
- Outage mitigation

Pie chart showing:
- Standby: 66%
- Arbitrage only: 18%
- Arbitrage + bal.: 15%
- Outage mitigation: < 1%
Summary of results (NPV benefits and revenue requirements over 20-year time horizon) – Bainbridge Island

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Random Outages – Mid-C Capacity Value</th>
<th>Projected Outages – Mid-C Capacity Value</th>
<th>Random Outages – Peaker-Driven Capacity Value</th>
<th>Projected Outages – Peaker-Driven Capacity Value</th>
<th>Total Revenue Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$21,233,715</td>
<td>$21,453,652</td>
<td></td>
<td>$26,467,715</td>
<td>$20,340,000</td>
</tr>
<tr>
<td>2</td>
<td>$21,453,652</td>
<td>$21,233,715</td>
<td></td>
<td>$26,467,715</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$21,233,715</td>
<td>$21,453,652</td>
<td></td>
<td>$26,467,715</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$21,453,652</td>
<td>$21,233,715</td>
<td></td>
<td>$26,467,715</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Revenue Requirements</th>
<th>$53,299</th>
<th>$40,833</th>
<th>$53,299</th>
<th>$40,833</th>
<th>$20,340,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arbitrage and Energy Costs</td>
<td>$2,899,171</td>
<td>$2,898,352</td>
<td>$2,899,171</td>
<td>$2,898,352</td>
<td>$20,340,000</td>
</tr>
<tr>
<td>Balancing Services</td>
<td>$10,656,246</td>
<td>$10,889,467</td>
<td>$10,656,246</td>
<td>$10,889,467</td>
<td>$20,340,000</td>
</tr>
<tr>
<td>Outage Mitigation</td>
<td>$6,252,000</td>
<td>$6,252,000</td>
<td>$6,252,000</td>
<td>$6,252,000</td>
<td>$20,340,000</td>
</tr>
<tr>
<td>Distribution Upgrade Deferral</td>
<td>$1,373,000</td>
<td>$1,373,000</td>
<td>$6,787,000</td>
<td>$6,787,000</td>
<td>$20,340,000</td>
</tr>
<tr>
<td>Capacity Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$20,340,000</td>
</tr>
</tbody>
</table>

October 19, 2018
Energy storage provides multiple benefits

- Improved power quality and the reliable delivery of electricity to customers
- Improved stability and reliability of transmission and distribution systems
- Increased use of existing equipment, thereby deferring or eliminating costly upgrades
- Improved availability and increased market value of distributed generation sources
- Improved value of renewable energy generation
- Cost reductions through capacity and transmission payment deferral
Acknowledgements

- Support from US DOE Office of Electricity Delivery & Energy Reliability
  - Dr. Imre Gyuk, Energy Storage Program Manager