

# *Overview of Stationary Energy Storage Program at PNNL*

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**Pacific Northwest National Laboratory**

Support from DOE Office of Electricity Delivery & Energy Reliability  
Energy Storage Program

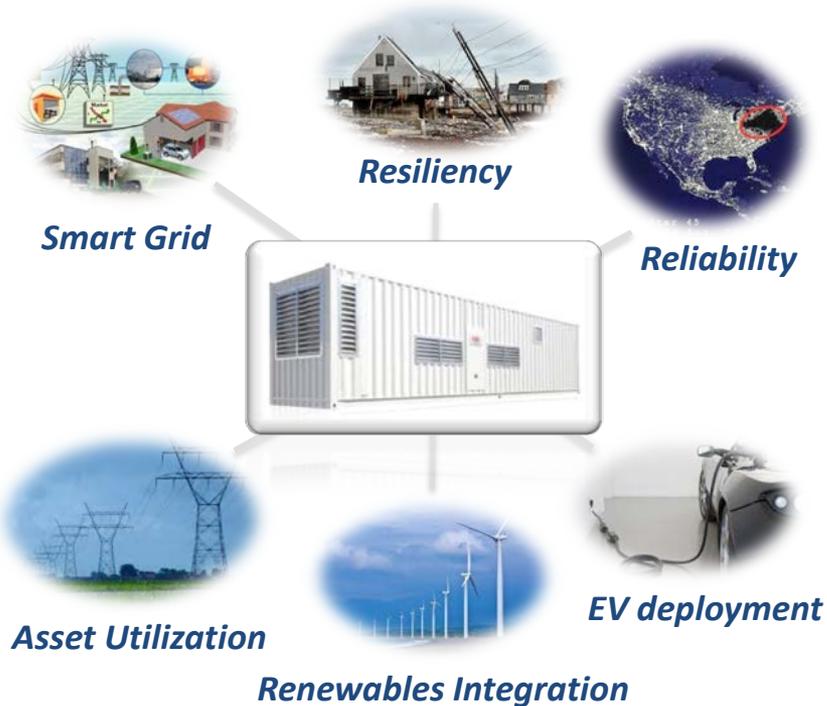
OE Energy Storage Peer Program Review  
Portland, OR  
September 22<sup>nd</sup>, 2015



# Energy Storage

**DOE ES 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.

## Strategic Goal:



## Challenges<sup>1</sup>

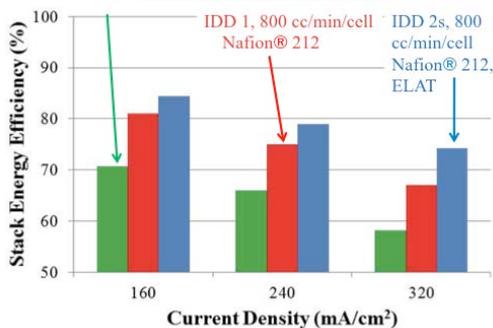
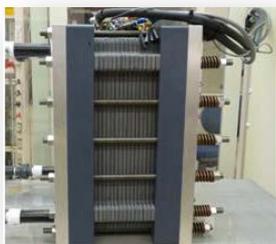
- **Cost competitive energy storage technologies**
  - Targeted scientific investigations of key materials and systems
- **Validated reliability & safety**
  - Independent testing of prototypic devices and understanding of degradation.
- **Equitable regulatory environment**
  - Enable Industry, Utility, Developer collaborations to quantify benefits provide input to regulators.
- **Industry acceptance**
  - Highly leverage field demonstrations and development of storage system design tools

# Cost Competitive Technologies

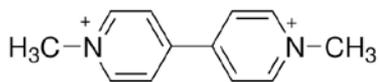
- Develop material and system enhancements to resolve key cost and performance challenges for energy storage devices.

## Redox Flow

High Performance V/V  
5 kW Prototype

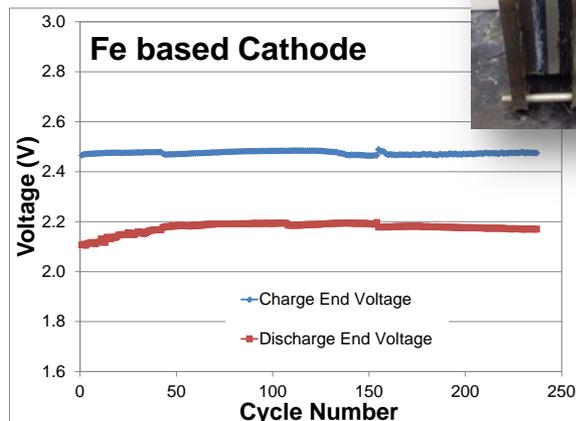


Aqueous Soluble Organic (ASO)



## Sodium Batteries

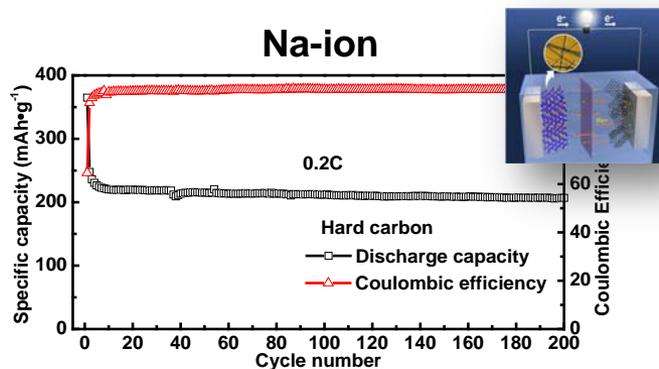
IT Na Metal Halide  
190°C



RT Na Battery

L. Shaw - IIT

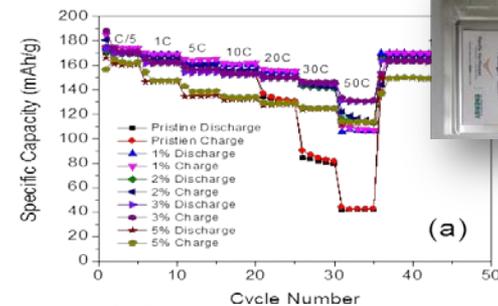
Na-ion



Na-ion Anode Development:

Y. Cui - Stanford, D. Wang - Penn State

## Li-ion

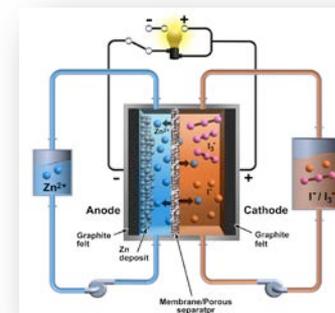


Solid State Li-ion

PNNL + X. Liu - WVU

## Novel Chemistries

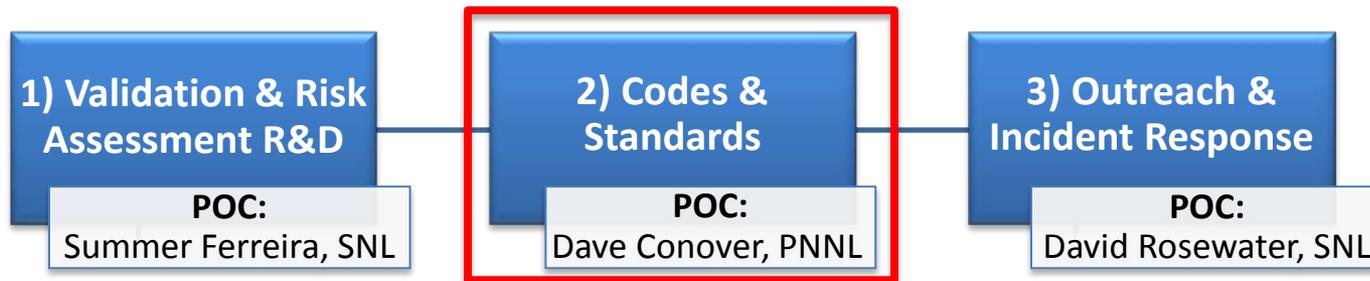
Zn-I<sub>2</sub> Flow Battery



# Safety and Reliability

- For energy storage systems to be ubiquitously accepted the technology must be demonstrated to be safe and reliable

- **Energy Storage Safety Working Group**



Codes 101



CSR Inventory

- **Energy Storage Reliability**

Planning workshop in FY16 with stakeholders to develop technology roadmap for validated reliability of energy storage systems.

# Equitable Regulatory Environment

- *Value propositions for grid storage depend on reducing institutional and regulatory hurdles to levels comparable with those of other grid resources.*
- **PNW Energy Storage Workshop**

Hosted Pacific Northwest utility regulatory commission workshop on energy storage with commissioners and staff from WA, OR, ID, and MT. (July 2015)

Provided information to commissions on valuation of energy storage assets.

- Presented at Washington UTC Energy Storage Workshop (Aug 2015)
- Planning expansion of Regional Workshops in FY16.



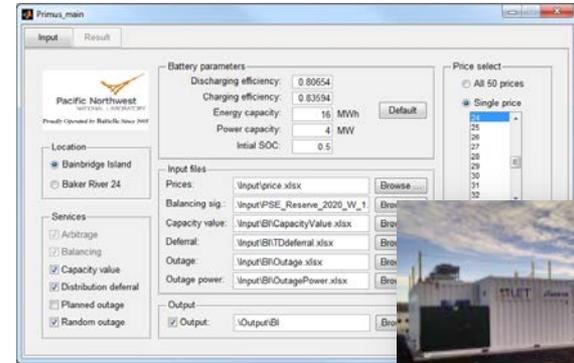
July 2015 Pacific Northwest Regulators Workshop Participants - Richland, WA

# Industry Acceptance

- Demonstrating the value, performance, and reliability of energy storage systems in both controlled and fielded deployments.

## ➤ WA State Clean Energy Fund

- PNNL evaluating use case economics for 7 MW/15MWh of energy storage deployments in WA.
- Utilizing Battery Storage Evaluation Tool (BSET) developed under BPA TIP program with Primus/PGE and DOE OE.



WA CEF

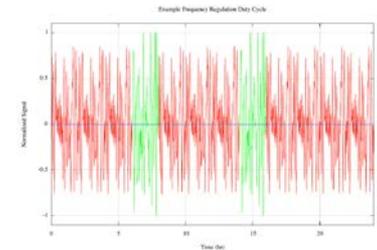


## ➤ Performance Protocols

- In coordination with SNL and industry working group, lead development of performance protocols for Volt-VAR support, Power Quality and Frequency Control (FY15)
- SNL/PNNL have completed 7 applications to date, and nearing completion on the 8<sup>th</sup>



## Performance Protocols



## ➤ BPA demonstrations

- Completed assessment of 120kW/500kWh Powin Li-ion system for wind integration (ENW), demand management (City of Richland), Solar Integration (PNNL).



Testing 125 kW/500 kWh Powin ESS at PNNL Solar Array.

# FY15 Accomplishments

## ► 14 peer reviewed publications

- Wei X, L Cosimbescu, W Xu, JZ Hu, M Vijayakumar, J Feng, MY Hu, X Deng, J Xiao, J Liu, VL Sprenkle, and W Wang. 2015. "Towards High-Performance Nonaqueous Redox Flow Electrolyte through Ionic Modification of Active Species." *Advanced Energy Materials* 5(1):Article No. 1400678. doi:10.1002/aenm.201400678
- Li G, X Lu, JY Kim, MH Engelhard, JP Lemmon, and VL Sprenkle. 2014. "The Role of FeS in Initial Activation and Performance Degradation of Na-NiCl<sub>2</sub> Batteries." *Journal of Power Sources* 272:398-403. doi:10.1016/j.jpowsour.2014.08.106
- Vijayakumar M, Z Nie, ED Walter, JZ Hu, J Liu, VL Sprenkle, and W Wang. 2015. "Understanding Aqueous Electrolyte Stability through Combined Computational and Magnetic Resonance Spectroscopy: A Case Study on Vanadium Redox Flow Battery Electrolytes." *ChemPlusChem* 80(2):428-437. doi:10.1002/cplu.201402139
- Wei X, B Li, and W Wang. 2015. "Porous Polymeric Composite Separators for Redox Flow Batteries." *Polymer Reviews* 55(2):247-272. doi:10.1080/15583724.2015.1011276
- Li B, Z Nie, M Vijayakumar, G Li, J Liu, VL Sprenkle, and W Wang. 2015. "Ambipolar zinc-polyiodide electrolyte for a high-energy density aqueous redox flow battery." *Nature Communications* 6:Article No. 6303. doi:10.1038/ncomms7303
- Wei X, W Xu, M Vijayakumar, L Cosimbescu, TL Liu, VL Sprenkle, and W Wang. 2014. "TEMPO-based Catholyte for High Energy Density Nonaqueous Redox Flow Batteries." *Advanced Materials* 26(45):7649-7653. doi: 10.1002/adma.201403746
- Kim JY, NL Canfield, JF Bonnett, VL Sprenkle, K Jung, and I Hong. 2015. "A Duplex  $\beta$ -Al<sub>2</sub>O<sub>3</sub> Solid Electrolyte Consisting of A Thin Dense Layer and A Porous Substrate." *Solid State Ionics* 278:192-197. doi:10.1016/j.ssi.2015.06.013
- Canfield NL, JY Kim, JF Bonnett, RL Pearson, III, VL Sprenkle, and K Jung. 2015. "Effects of Fabrication Conditions on Mechanical Properties and Microstructure of Duplex  $\beta$ -Al<sub>2</sub>O<sub>3</sub> Solid Electrolyte." *Materials Science and Engineering B: Advanced Functional Solid-state Materials* 197:43-50. doi:10.1016/j.mseb.2015.03.009
- Wei X, W Xu, J Huang, L Zhang, ED Walter, CW Lawrence, M Vijayakumar, WA Henderson, TL Liu, L Cosimbescu, B Li, VL Sprenkle, and W Wang. 2015. "Radical Compatibility with Nonaqueous Electrolytes and Its Impact on an All-Organic Redox Flow Battery." *Angewandte Chemie International Edition* 127(30):8808-8811. doi:10.1002/ange.201501443
- Reed DM, EC Thomsen, W Wang, Z Nie, B Li, X Wei, BJ Koeppel, and VL Sprenkle. 2015. "Performance of Nafion® N115, Nafion® NR-212, and Nafion® NR-211 in a 1 kW Class All Vanadium Mixed Acid Redox Flow Battery." *Journal of Power Sources* 285:425-430. doi:10.1016/j.jpowsour.2015.03.099
- Lu X, G Li, JY Kim, KD Meinhardt, and VL Sprenkle. 2015. "Enhanced Sintering of  $\beta$ -Al<sub>2</sub>O<sub>3</sub>/YSZ with the Sintering Aids of TiO<sub>2</sub> and MnO<sub>2</sub>." *Journal of Power Sources* 295, 167-174.
- Li G, X Lu, JY Kim, VV Viswanathan, KD Meinhardt, MH Engelhard, and VL Sprenkle. 2015. "Batteries: An Advanced Na-FeCl<sub>2</sub> ZEBRA Battery for Stationary Energy Storage Application." *Advanced Energy Materials* 5(12):, doi:10.1002/aenm.201570069
- Shamie, JS; Liu, CH; Shaw, LL; Sprenkle, VL "Room Temperature, Hybrid Sodium-Based Flow Batteries with Multi-Electron Transfer Redox Reactions": *SCIENTIFIC REPORTS*, 5 10.1038/srep11215 JUN 11 2015
- Chalamala BR, T Soundappan, GR Fisher, MA Anstey, VV Viswanathan, and ML Perry. 2014. "Redox Flow Batteries: An Engineering Perspective." *Proceedings of the IEEE* 102(6):976-999. doi:10.1109/jproc.2014.2320317

## ► 2 US patents granted, 3 invention reports FY2015.

# Acknowledgements

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