Progress in Grid Scale Flow Batteries

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Without technological breakthroughs in efficient, large scale Energy Storage, it will be difficult to rely on intermittent renewables for much more than 20-30% of our Electricity.

Secretary Chu, Feb. 2010

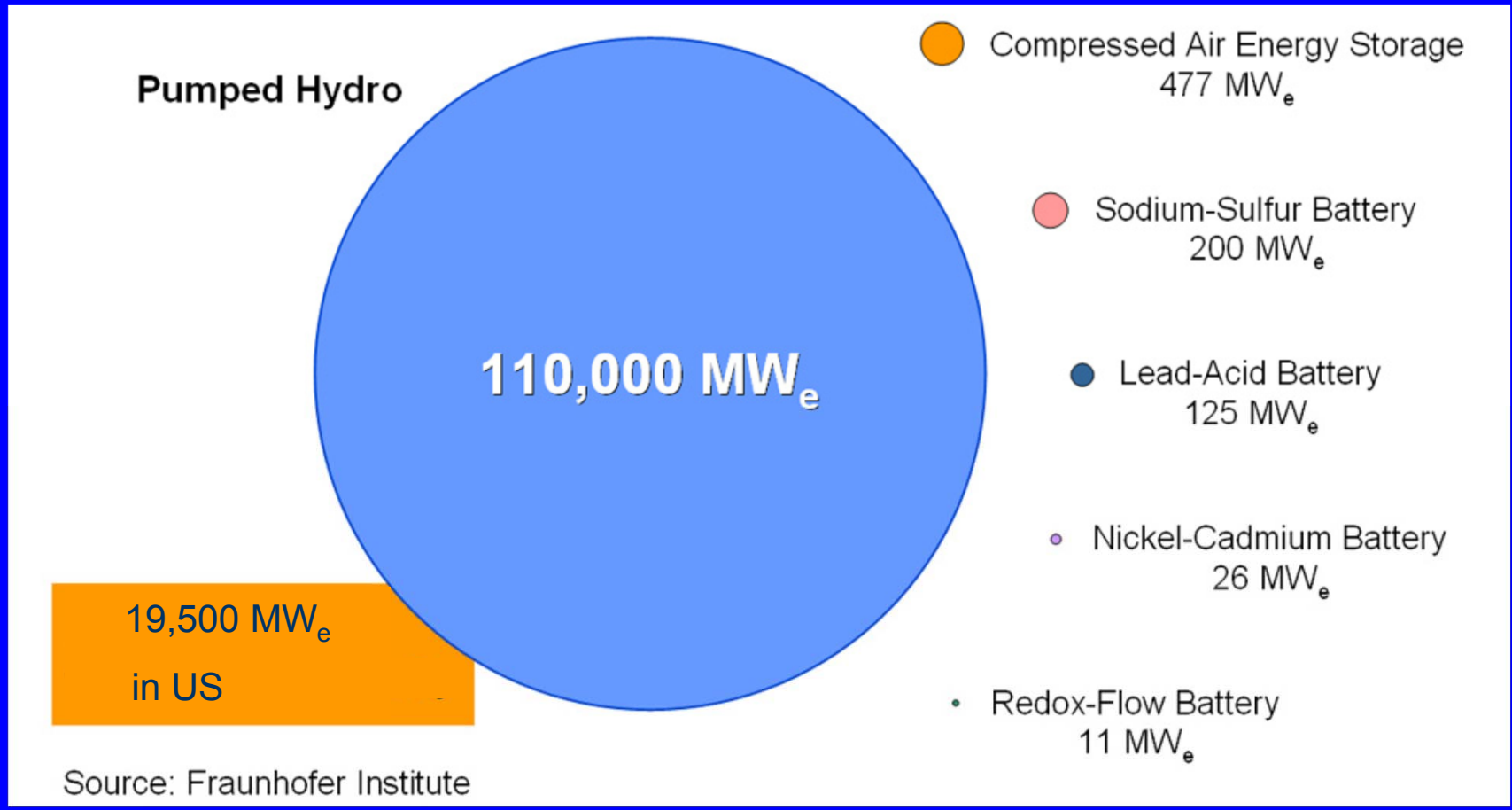
The need for regulation services can dramatically increase as the amount of variable renewable resources is increased. Local storage is among the best means to ensure we can reliably integrate renewable energy resources into the grid.

Chairman Wellinghoff, FERC, March 2010

Transmission and storage capacity are key issues for energy resource planning. If you like wind power, you have to love transmission and storage.

Terry Boston , CEO, PJM, June 2010

Worldwide installed storage capacity for electrical energy



Note: Pumped hydro represents 2.5 percent of U.S. electrical baseload capacity.

Some Large Energy Storage Projects:

27MW / 7MWh	1995	Fairbanks, AL
34MW / 245MWh	2008	Rokkasho. Japan
20MW / 5MWh	2011	Stephentown, NY
32MW / 8MWh	2011	Laurel Mountain, WV
14MW / 63 MWh	2011	Hebei, China
8MW / 32MWh	2012	Tehachapi, CA
25MW / 75MWh	2013	Modesto, CA

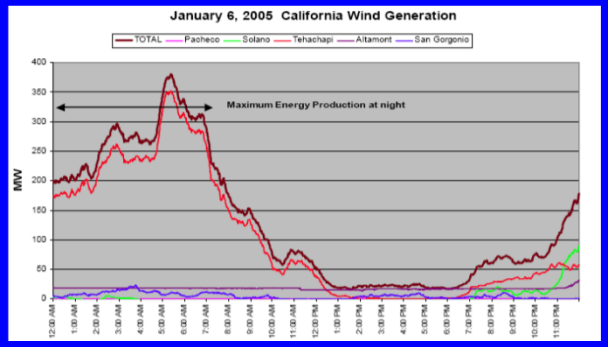
Annual new Deployment

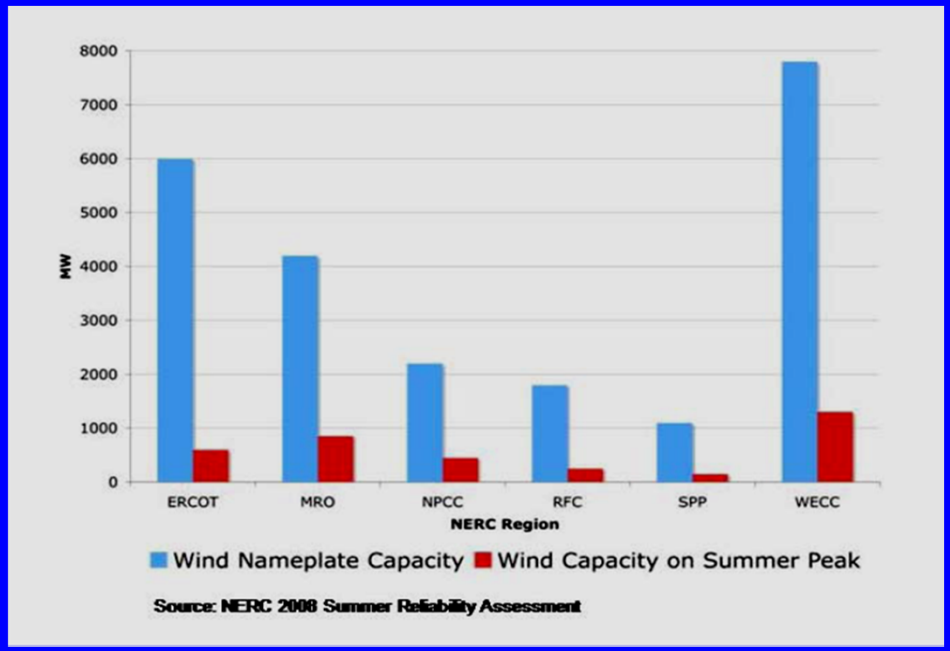
2011 : 121MW → 2021 : 2,353MW

(Pike Research)

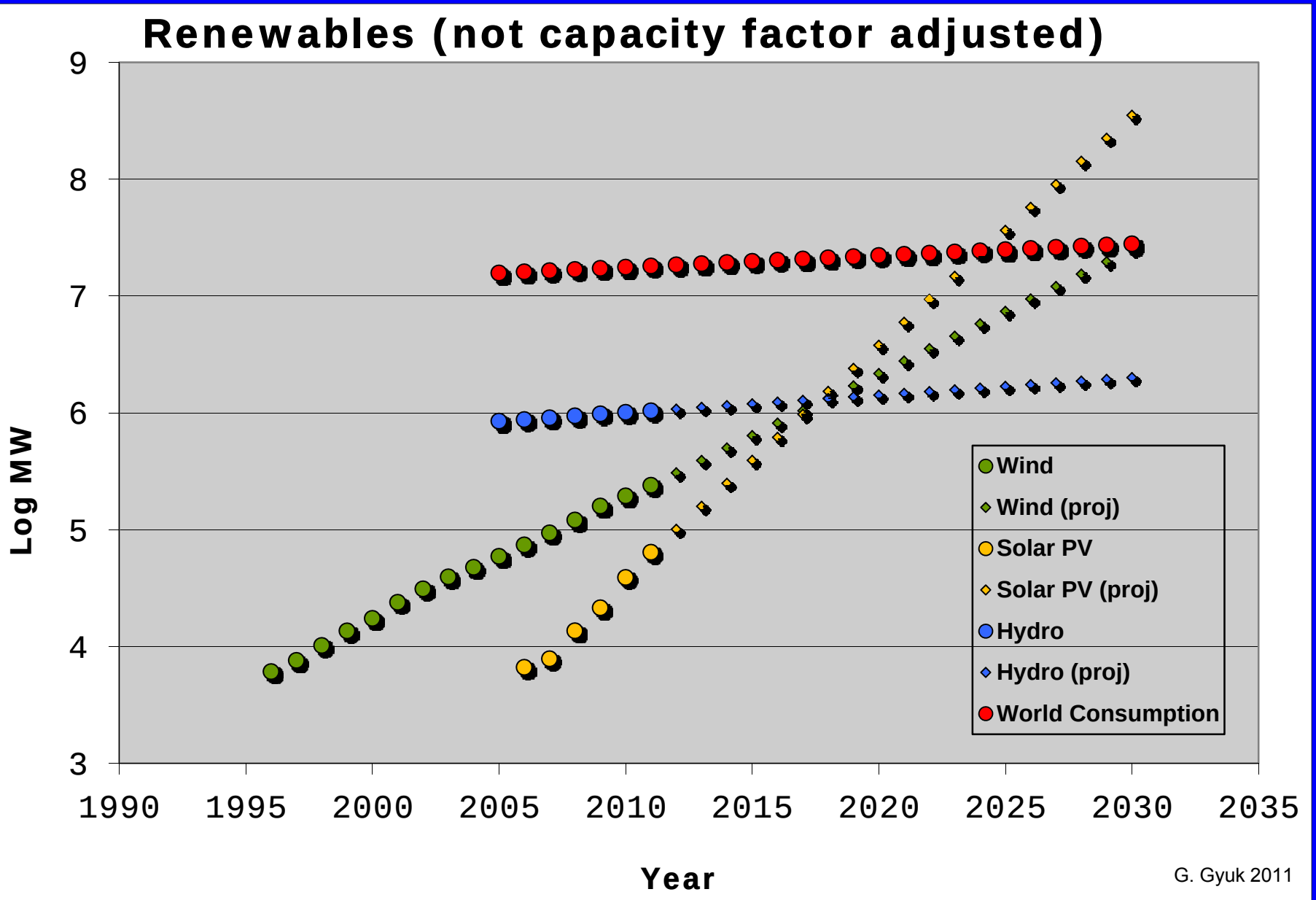
29 States have Renewable Portfolio Standards (RPS) Requiring 10-40% Renewables

On Peak Wind - the Reality!





Cost effective Energy Storage yields better Asset Utilization


Renewables (not capacity factor adjusted)
Log MW
9
8
7
6
5
4
3
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
Year
Wind
Wind (proj)
Solar PV
Solar PV (proj)
Hydro
Hydro (proj)
World Consumption
G. Gyuk 2011

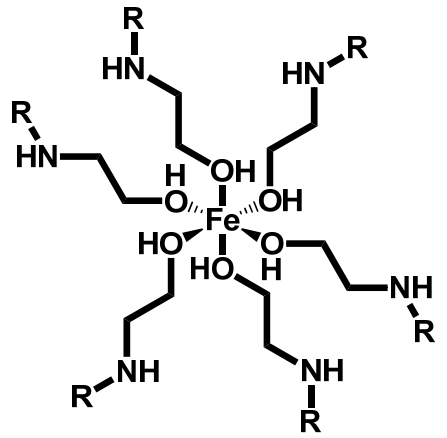
Flow Battery Research

at PNNL and Sandia

Redox Couples for Flow Batteries, Sandia

Sandia has developed a New Class of electroactive metal-containing ionic liquids ("MetILs")

*- Anderson, et al., Dalton Trans. **2010**, 8609–8612.*

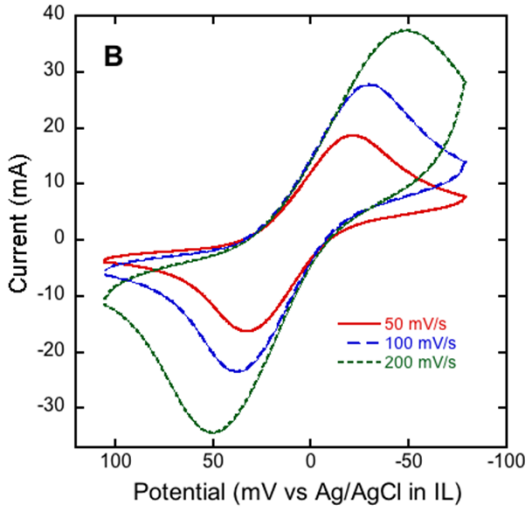


Materials research and development for:

1. Multi-functional materials act as both electrolyte and energy storage medium for high energy density
2. Low cost, Safety, Environmentally benign
3. Cost effective scale-up options

FY10: 12 MetILs synthesized and tested:

- Found 3 with high ionic conductivity & viscosity
- One with low ionic conductivity & viscosity
- One with high ionic conductivity & low viscosity: $Ce(NH_2C_2H_4OH)_8(CF_3SO_3)_3$



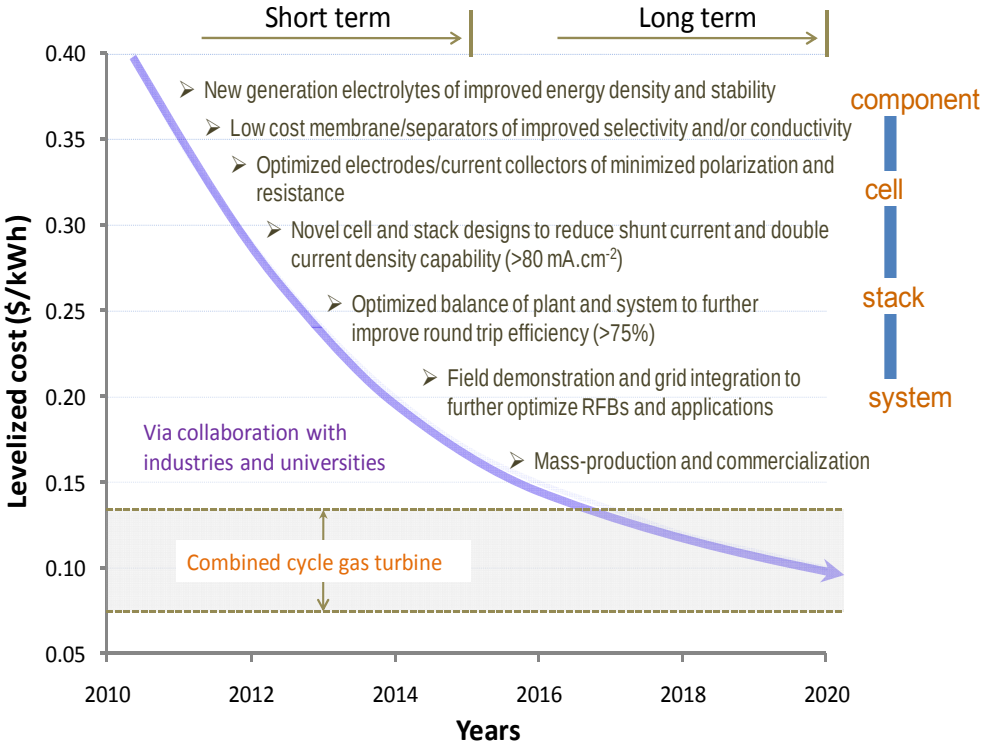
FY11: investigate effects of tailored molecular structures on viscosity, ionic conductivity, and electrochemical performance by

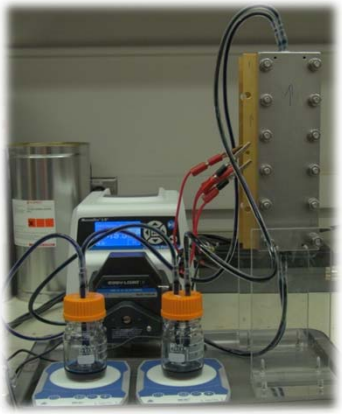
- Incorporating aromatic ligands into cation
- Altering the size of the anion

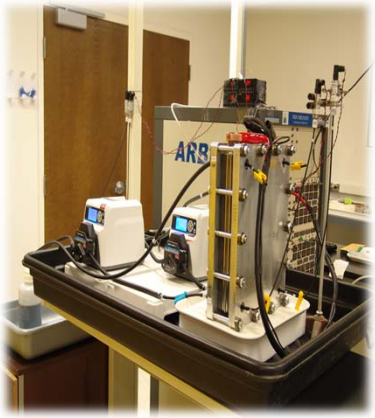
FY12: Test 5 MetIL for ionic conductivity and electrochemical Reversibility; test best candidates in benchtop flow battery prototype

New Generation Redox Flow Batteries, PNNL

Developed new generation redox flow battery (RFB) that can demonstrate substantial improvement in performance and economics, to accelerate its commercialization and market penetration, via collaborations with industries and universities







❑ FY11 Accomplishments

- Developed 3rd gen all vanadium RFB that demonstrated >70% increase in capacity, >80% better temp. range and 2x power at >75% efficiency
- Discovered Fe/V redox couples for further reduction in capital cost by using low cost materials and elimination of gas evolution

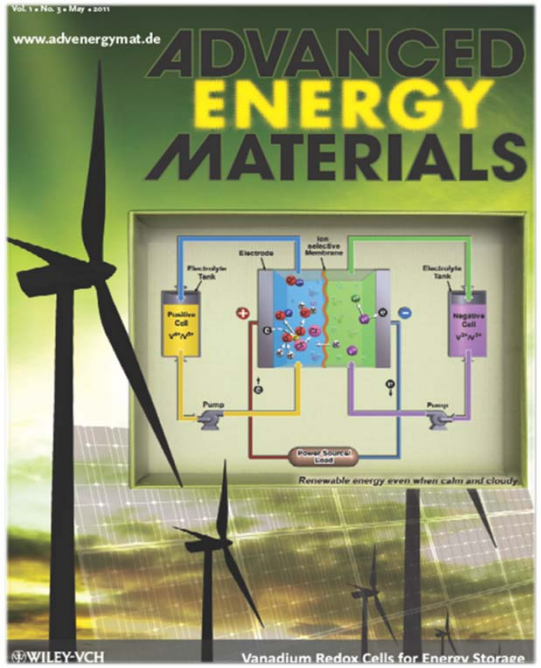
❑ FY 12 Plan

- Develop novel scalable cell design
- Component integration
- Build 1 kW/4 kWh bench top system
- Five U.S. Patents filed
- Technology Transfer to Industry

Anderson *et. al.* Synthesis of Ionic Liquids Containing Cu, Mn, or Zn Coordination Cations

Sandia, Nov. 2011

PNNL, May 2011



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

ARRA Stimulus Funding for Storage Demonstration Projects ($185M)

A ten-fold Increase in Power Scale!

Large Battery System (3 projects,53MW)
Compressed Air (2 projects, 450MW)
Frequency Regulation (20MW)
Distributed Projects (5 projects,9MW)
Technology Development (5 projects)

533MW - $585M Costshare!

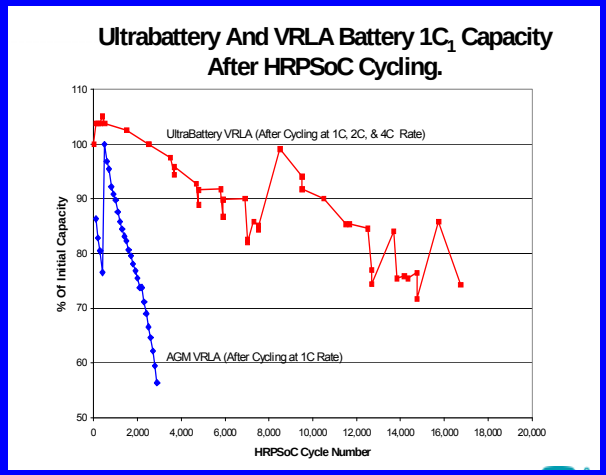
Three ARRA Storage Applications using Flywheels, PbC, an Li-Ion

FREQUENCY REGULATION

DOE Loan Guarantee – Beacon:
20MW Flywheel Storage for
Frequency Regulation in NY-ISO
20MW commissioned July 2011!
DOE ARRA Project in PJM coming.

DOE Loan Guarantee – AES / A123:
20MW Lithium Ion Battery for
Frequency Regulation in NY-ISO
8MW on Line!

5 Distributed Projects = 9 MW Peak Shaving, Energy Management



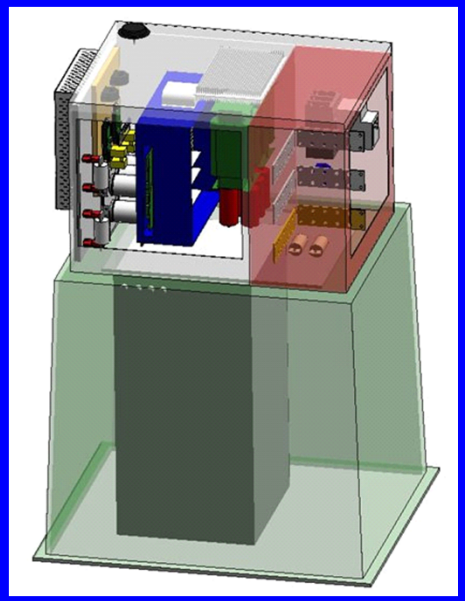
Testing at Sandia

ARRA – Public Service NM:
500kW, 2.5MWh for smoothing of 500kW PV installation; Using EastPenn Lead-Carbon Technology

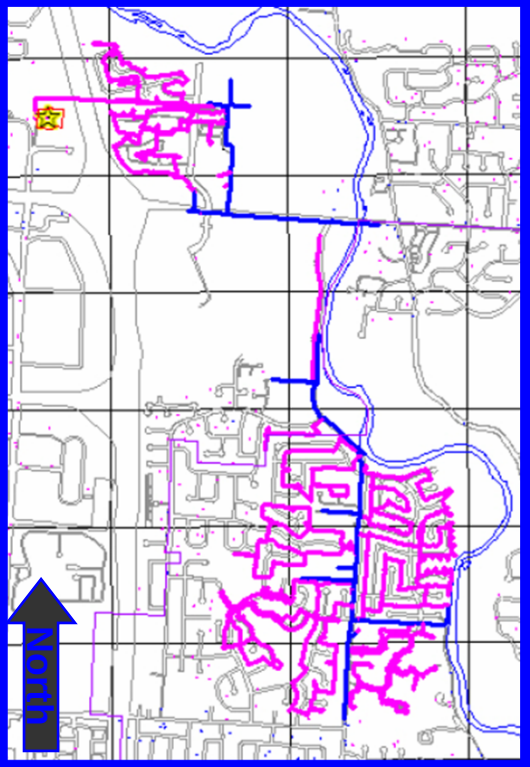
Commissioned Sep. 24, 2011

American Electric Power, Community Energy Storage ARRA Project in Columbus, OH

A fleet of 80 units,
25 kW/1hour each
2MW Peak shaving
for a 6.8MW Peak



International Battery,
Entire Unit



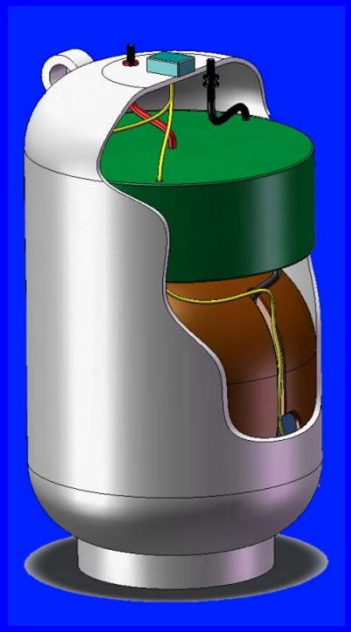
Columbus, Ohio

Four ARRA Storage Applications

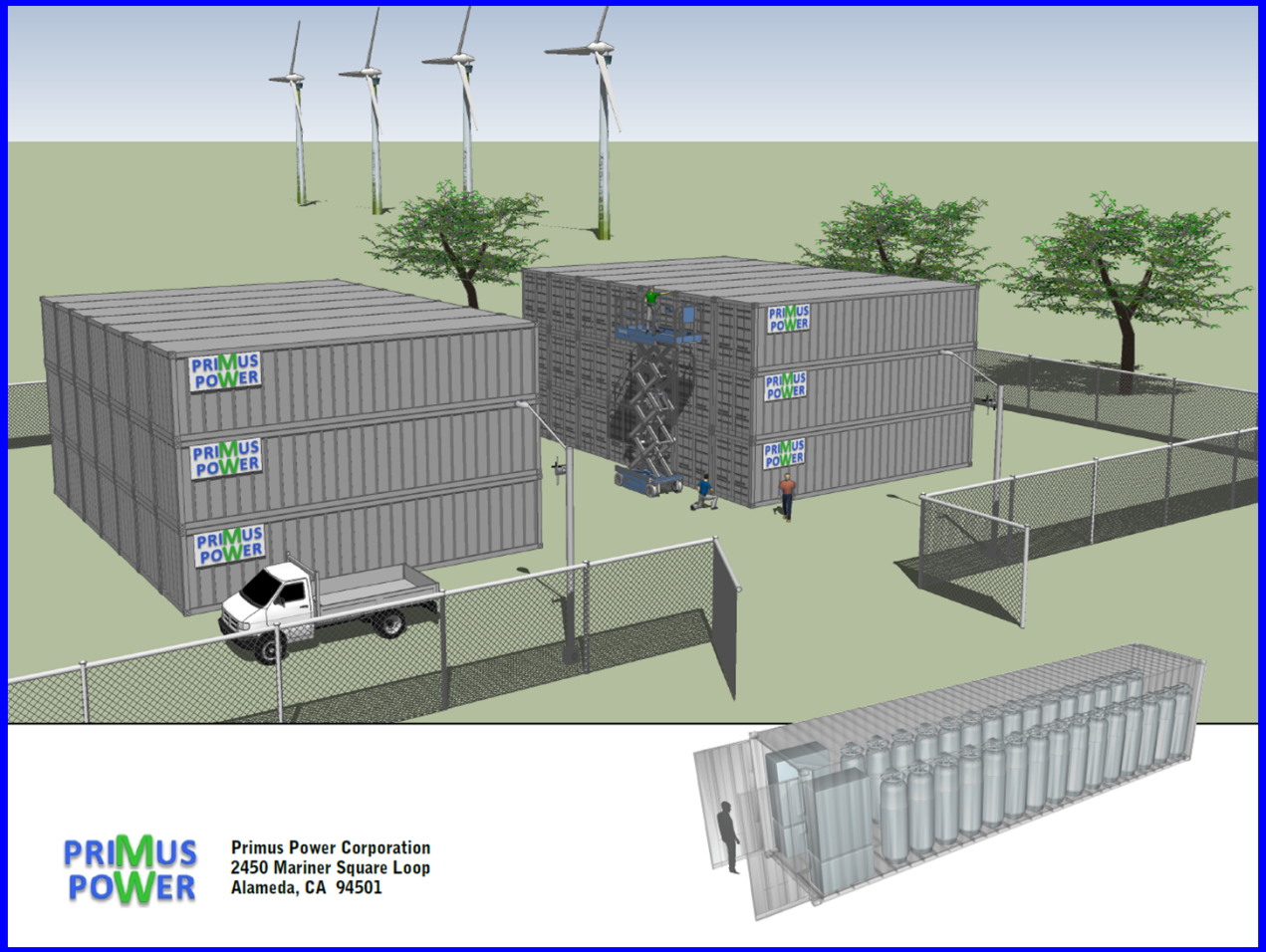
using Flow Batteries

ARRA- Primus Power:

25MW / 3hr battery plant for the Modesto, CA Irrigation District, firming 50MW of Wind, replacing $75M of Gas fired Generation.



Totally sealed battery module
With a Zn-Halogen electrolyte and zinc and tungsten electrodes

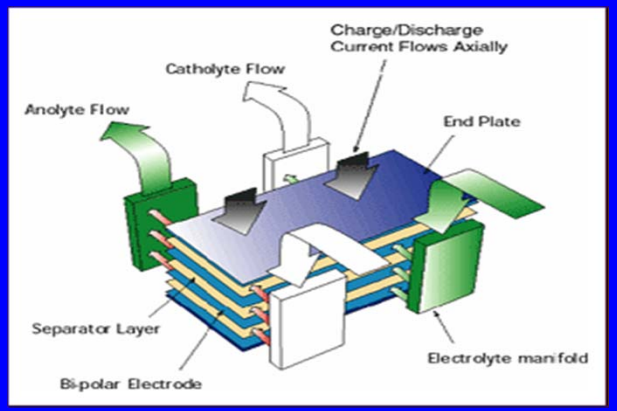


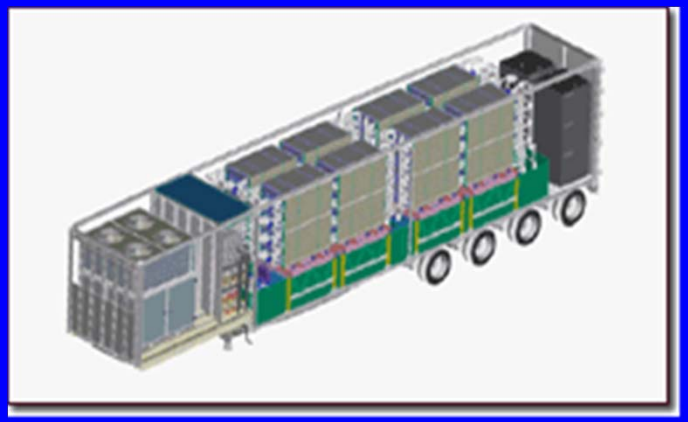
ARRA DistributedProject:

Premium Power

Installation of 5 Transflow 2000 500kW ZnBr Battery Systems at locations within SMUD and National Grid Utility Districts:

- 2 units at a substation in Syracuse
- 1 unit at Syracuse University
- 1 unit at SMUD HQ microgrid
- 1 unit at SMUD Solar Smart Homes Project





Ashlawn VanCharg™ Battery for the City of Painesville, Ohio

- US Produced Vanadium Redox Flow Battery for Bulk Storage/Peak Shaving scheduled for startup later this year.
- 8 MW Hour redox flow battery (1MW 8 hours)
- To be installed at Painesville Municipal Electric Plant (PMEP), a 32 MW coal fired facility to help maintain its daily power output requirements more efficiently while reducing carbon footprint.
- Assists Ashlawn in Establishing US Vanadium Redox Battery Manufacturing Base
  - Stack components/stack fabrication
  - Electrolyte
  - Power Conditioning System
- Demonstrates Efficacy/Reliability of latest Vanadium Redox Flow Battery Design
- Leverages technology insertions from National Labs
- Creates Advanced Energy Manufacturing Jobs

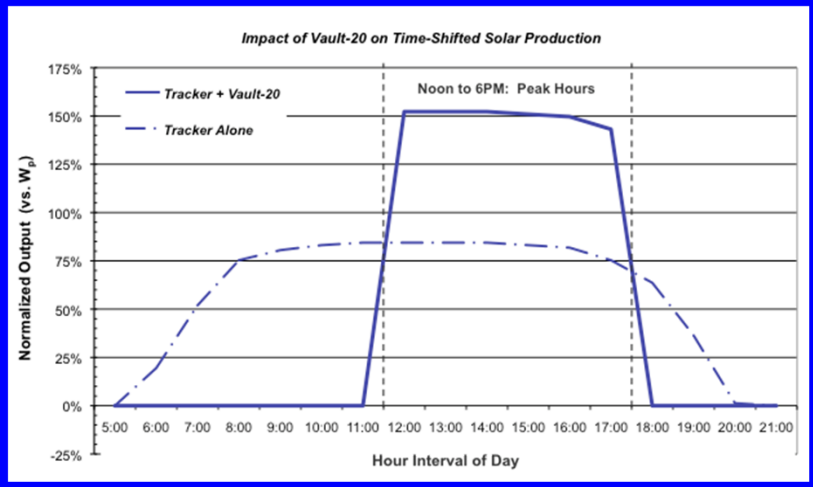
ARRA - Enervault:

250kW/4hr Fe-Cr Flow Battery for PV

PV: 300 kW
Storage: 250 KW
Peak output: 450kW
Storage Cost: +16%
Storage Value: +84%

Tracking PV in Almond Grove

Flow Battery Prototype



Leveraging PV with Storage

New Electrolytes
New Electrodes
New Membranes
New Stack Topologies

Think Cheep! Think Durable!
Think Safe! Think Small!

Remember PC Systems
Remember Hydraulics

Annual new Storage Deployment

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(Pike Research)