Progress in Grid Energy Storage

IMRE GYUK, PROGRAM MANAGER
ENERGY STORAGE RESEARCH, DOE

Energy Storage provides Energy

when it is needed

just as Transmission provides Energy

where it is needed

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.

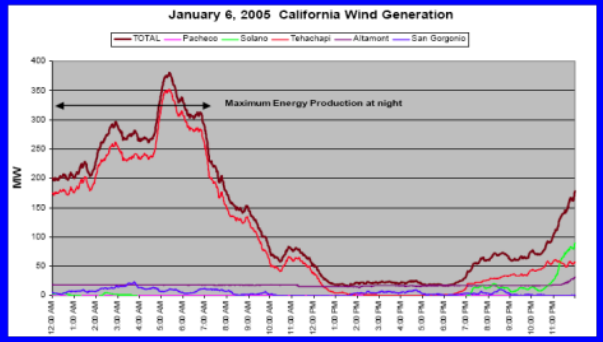
Chairman Wellinghoff, FERC, March 2010

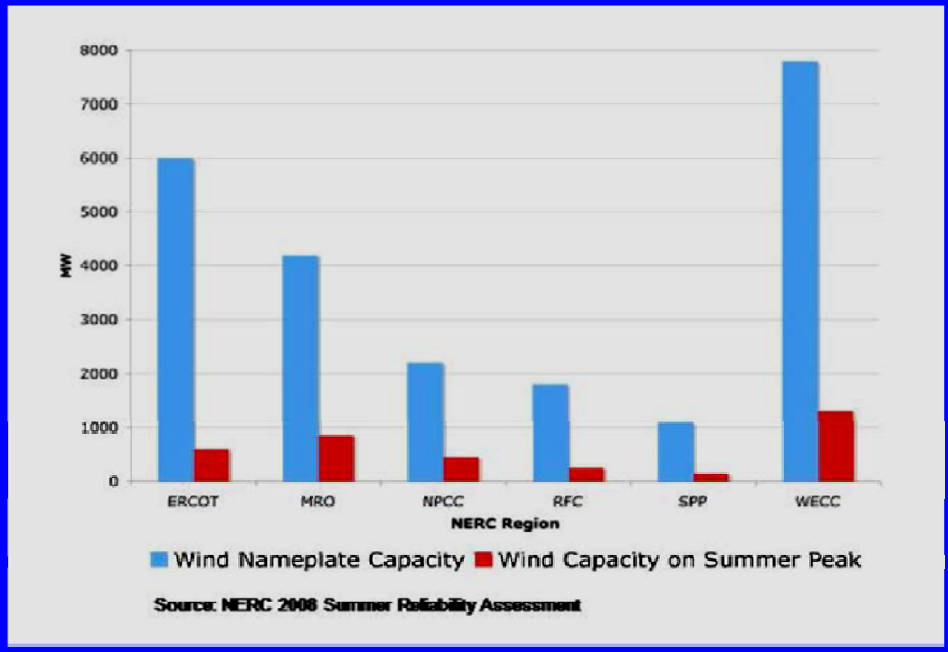
Transmission and storage capacity are key issues for energy resource planning. If you like wind power, you have to love transmission and storage.

Terry Boston , CEO, PJM, June 2010

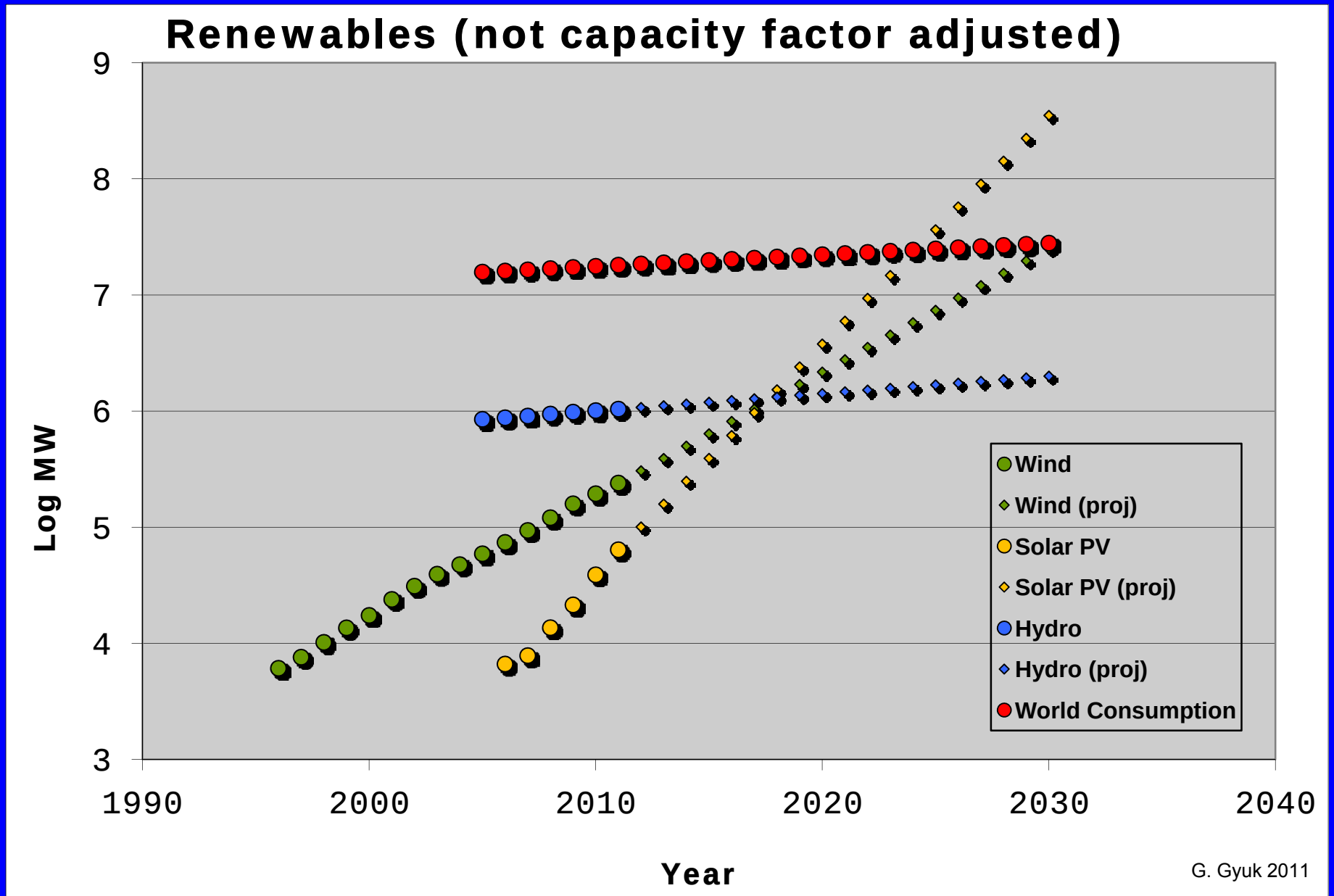
29 States have Renewable Portfolio Standards (RPS) Requiring 10-40% Renewables

On Peak Wind - the Reality!

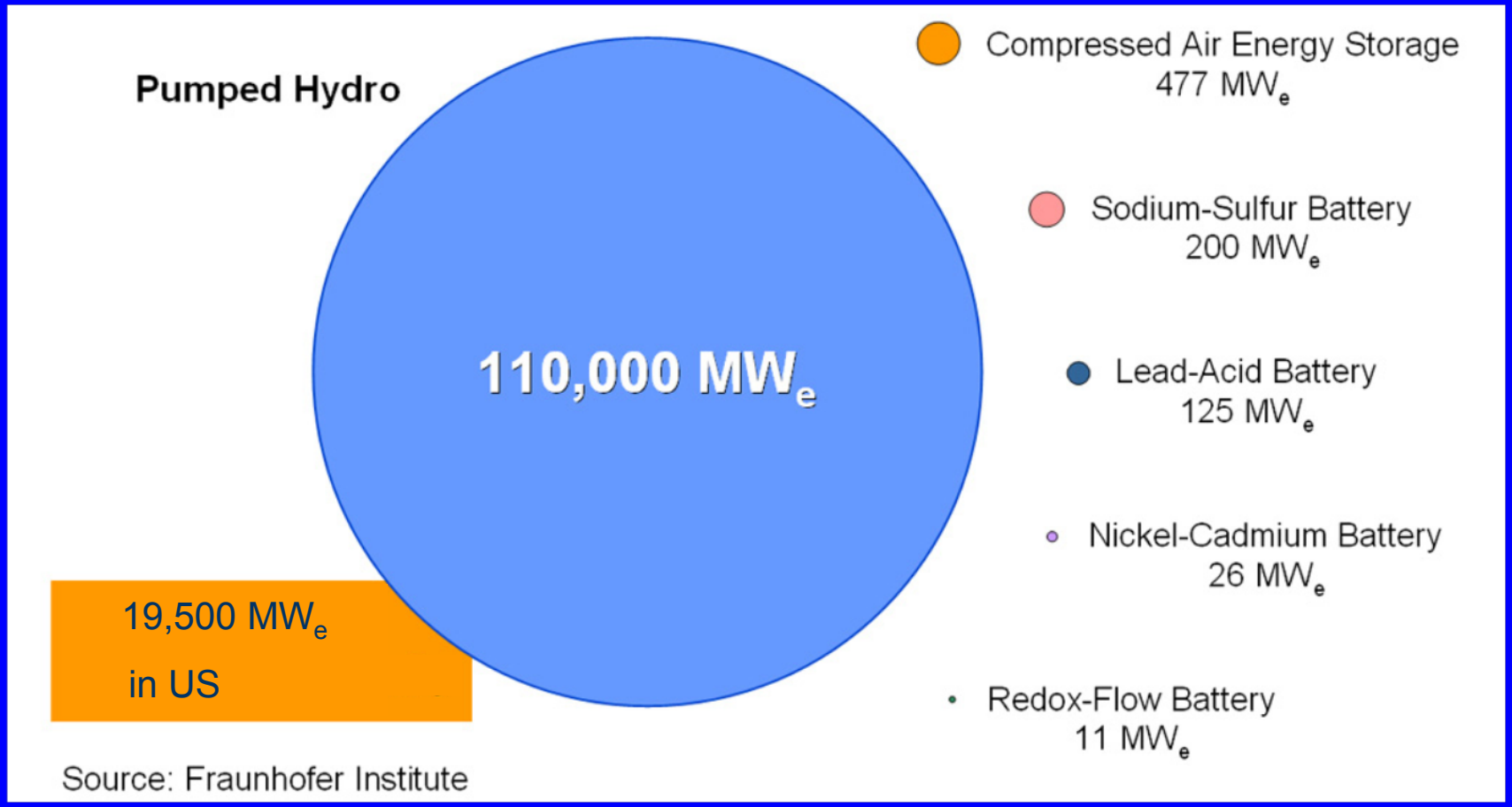




Cost effective Energy Storage yields better Asset Utilization


Renewables (not capacity factor adjusted)
Log MW
9
8
7
6
5
4
3
1990
2000
2010
2020
2030
2040
Year
Wind
Wind (proj)
Solar PV
Solar PV (proj)
Hydro
Hydro (proj)
World Consumption
G. Gyuk 2011

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:

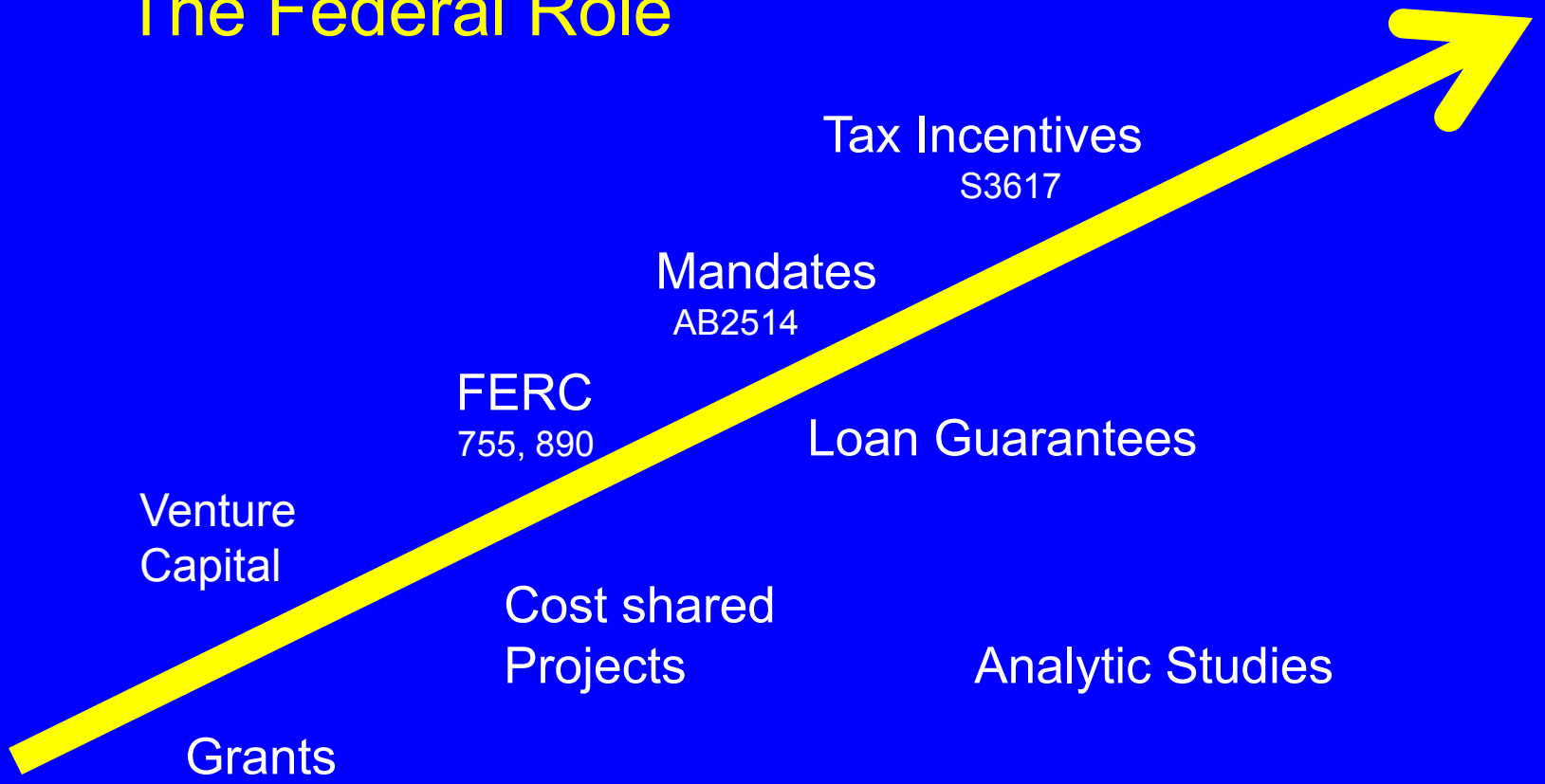
27MW / 7MWh	1995	Fairbanks, AL
34MW / 245MWh	2008	Rokkasho. Japan
20MW / 5MWh	2011	Stephentown, NY
32MW / 8MWh	2011	Laurel Mountain, WV
14MW / 63 MWh	2011	Hebei, China
8MW / 32MWh	2012	Tehachapi, CA
36MW / 24MWh	2012	No-Trees, TX
25MW / 75MWh	2013	Modesto, CA

Annual new Deployment

2011 : 121MW → 2021 : 2,353MW

(Pike Research)

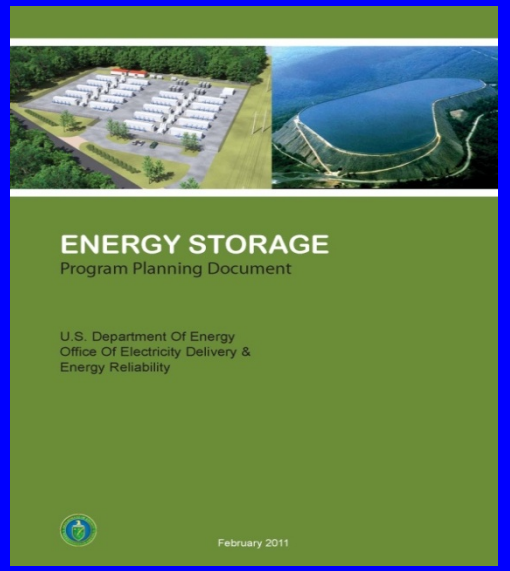
The Federal Role



Research Development Demonstration Niche Market Mass Market

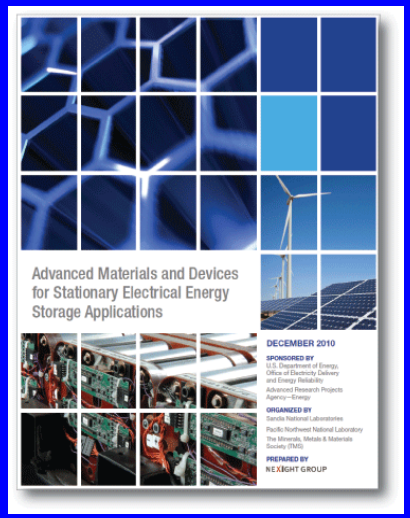
Stakeholder Workshops and OE Program Plan

Utility Requirements With EERE-PV



OE Energy Storage Program Plan

Under the Auspices of the Materials Society



Material Needs With ARPA-E

Research at PNNL:

Redox Flow Battery Development of 2 new Chemistries With >70% increase in capacity and 2x power

Planar Na–Metal halide Batteries leveraging ARPA-E work

Room Temperature Na-ion Batteries by using $Na_4Mn_9O_{18}$ nanowires as cathode

Low cost, long life Li-ion Batteries using self-assembled Nanostructured anode with LiFe(Mn)PO4

Detailed component cost model for redox batteries

Research at Sandia:

Sodium-Based batteries using solid state separator and aqueous or ionic liquids for a projected cost of <$100/kWh Teamed with university (EFRC) and industrial partners.

Developed new class of electrolytes including a metal atom as part of an ionic liquid thus also functioning as electrodes

Tested lead-carbon batteries with 10x cycle life. Currently studying enhancement mechanism while supporting grid-scale demonstration of PV/Pb battery system

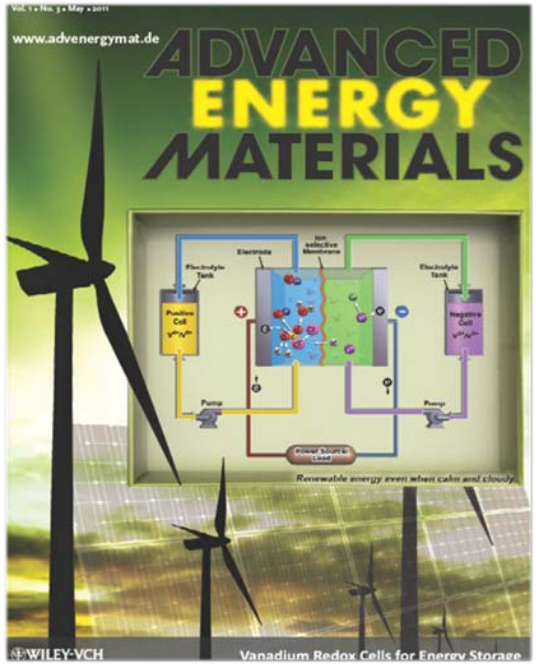
Supporting SBIR research leading to 2 recent R&D 100 awards

Developing a suite of analytical studies on market structure

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

Sandia, Nov. 2011

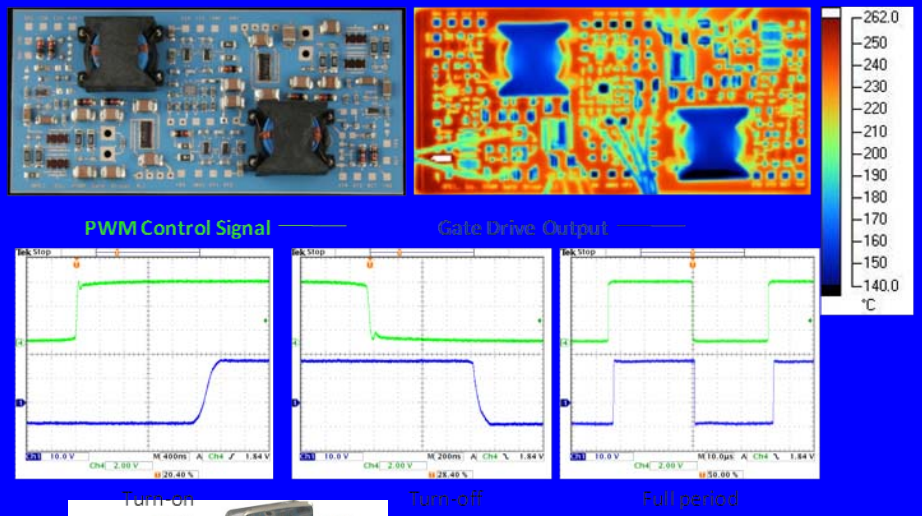
PNNL, May 2011

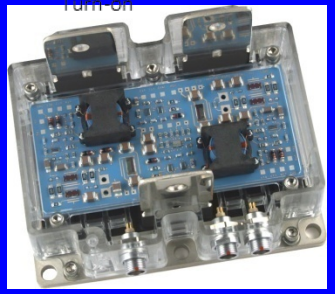


Liyu Li *et al.*, Stable Vanadium Redox Flow Battery with High Energy; 1, 394-400, 2011

APEI High-temperature Silicon Carbide (SiC) Power Module

Brief Description: It is the world's first commercial high-temperature (250 °C) silicon-carbide (SiC) based half-bridge power electronics module, with an integrated gate driver. The 50-kW (1200-V/150-A peak) SiC power modules are rated up to 250 °C. They can reduce system size and weight up to an order of magnitude over present state-of-the-art silicon-based solutions and can reduce energy losses by more than 50%. **SBIR Phase I, II, and III**





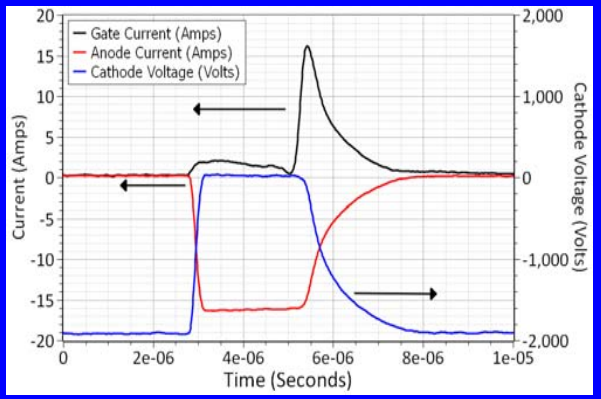
APEI SiC Power Module

2009 R&D100 Winner

GeneSiC Ultra-high-voltage Silicon-Carbide (SiC) Thyristor

Brief Description: These packaged power devices are the world's first commercially available, high-voltage, high-frequency, high-current, high-temperature, single-chip SiC-based thyristors; their ratings exceed 6.5kV, 200kHz (pulsed), 80A, and 200^{0}C. They can reduce next-generation SmartGrid power electronics system size and weight by up to an order of magnitude over the existing state-of-the-art Si-technologies. They have operating voltages almost 4x higher than other currently available SiC devices. They also offer greater than 100x higher operating frequencies than comparably rated state-of-the-art Si thyristors. **SBIR Phase I and II**

GeneSiC Semiconductor SiC Thyristors



Sandia National Laboratories

GeneSiC SEMICONDUCTOR

R&D 100

2011 R&D100 Winner

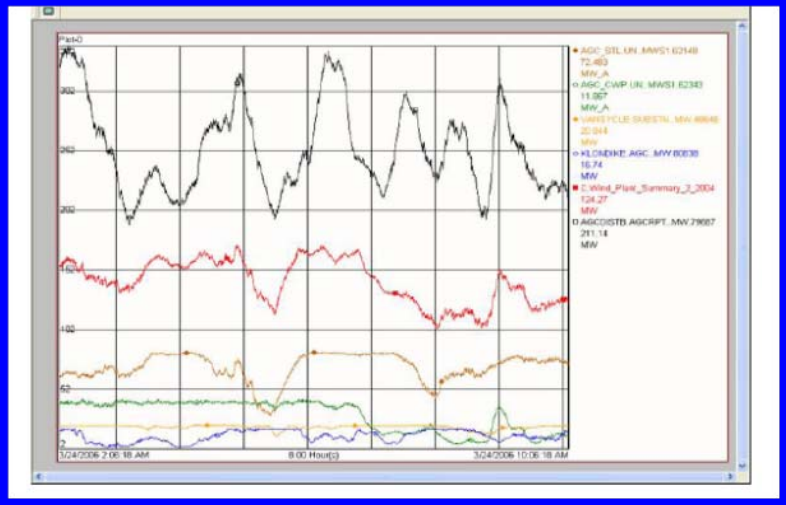
ARRA Stimulus Funding for Storage Demonstration Projects ($185M)

A ten-fold Increase in Power Scale!

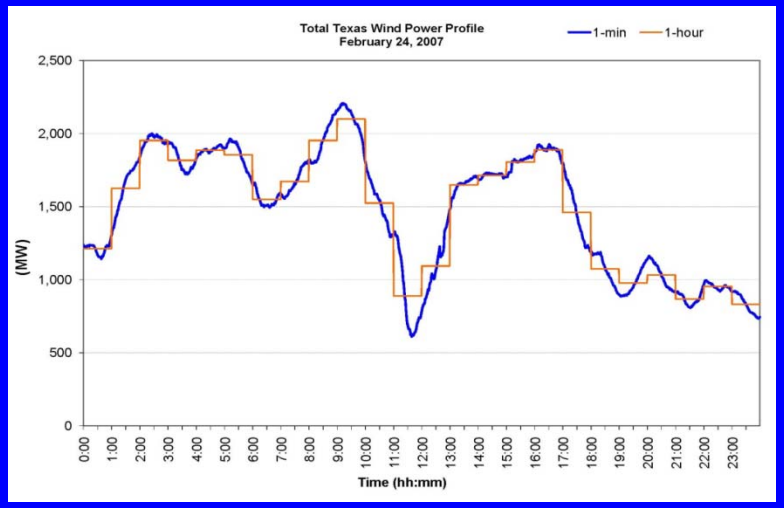
Large Battery System (3 projects,53MW)
Compressed Air (2 projects, 450MW)
Frequency Regulation (20MW)
Distributed Projects (5 projects,9MW)
Technology Development (5 projects)

533MW - $585M Costshare!

Large Batteries for Wind Integration



Coincident BPA Wind Ramps

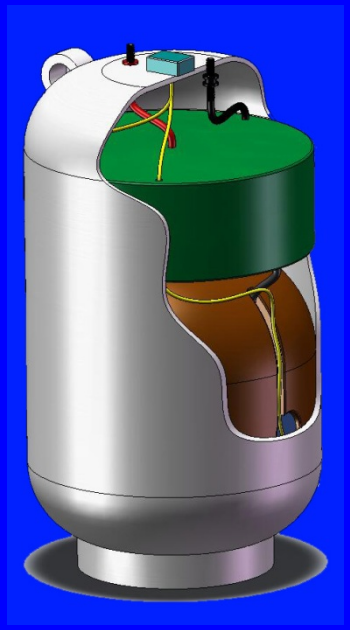


Feb. 24, 2007: 500MW / 2.5hr; 30x Spotprices
NREL: Δ = 25% @ 2days, Δ = 50% @ 1 week

3 Large Battery + Wind Projects = 53MW in Stimulus Package!

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 ZnCl electrolyte and
zinc and tungsten electrodes

ARRA - Southern California Edison / A123 – Li-Ion:

8 MW / 4 hr battery plant for wind integration at Tehachapi, CA.

A Tehachapi Wind Field

8MW Storage Plant under Construction

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!

Compressed Air Energy Storage
2 CAES Projects

Inexpensive Off-Peak Power to Compress Air for Storage in Aquifers, Salt Domes, Caverns, and abandoned Oil or Gas Wells. On-Peak, Compressed Air is used as Input for Gas Turbine Compressor, increasing Efficiency

McIntosh, Alabama, 110 MW

Huntdorf, Germany, 290 MW

ARRA – PG&E:

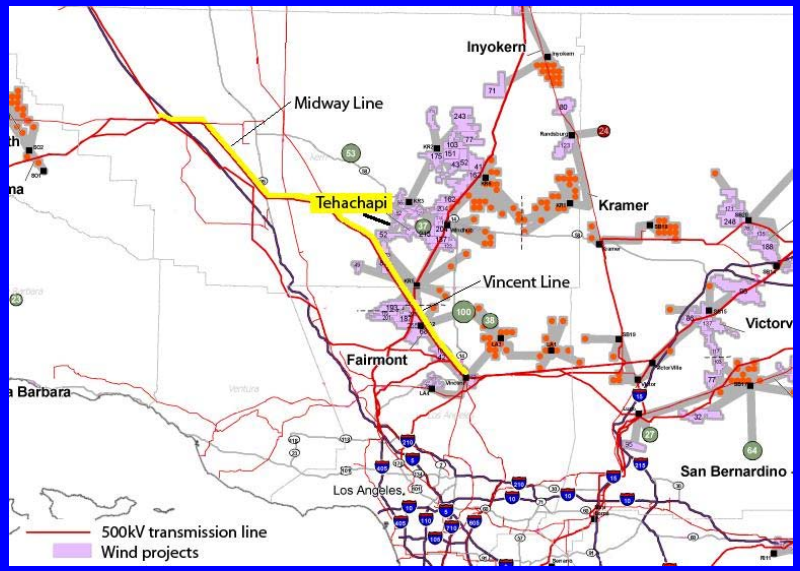
300 MW / 10hr Compressed Air Energy Storage Facility in Tehachapi, CA

Depleted Gas Wells

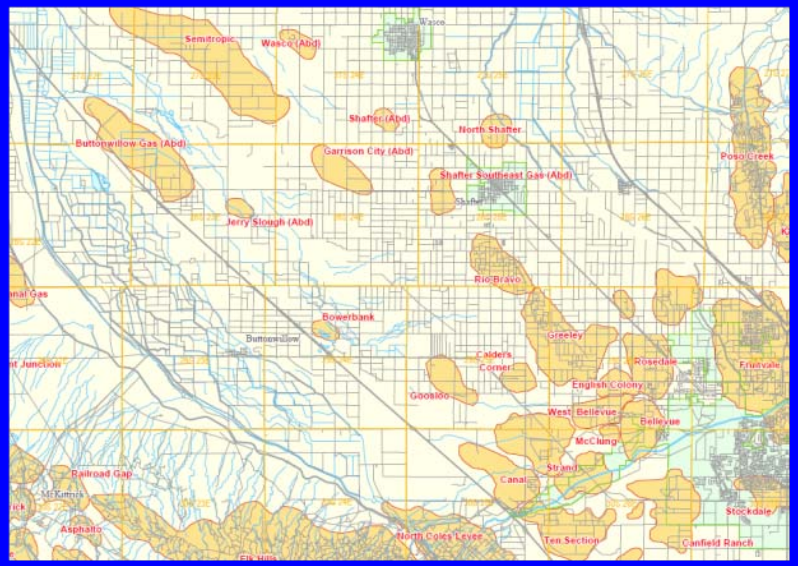
Gas Pipe Line

Existing 500kV Transmission Line

4 500 MW New Wind in 4-5 Years

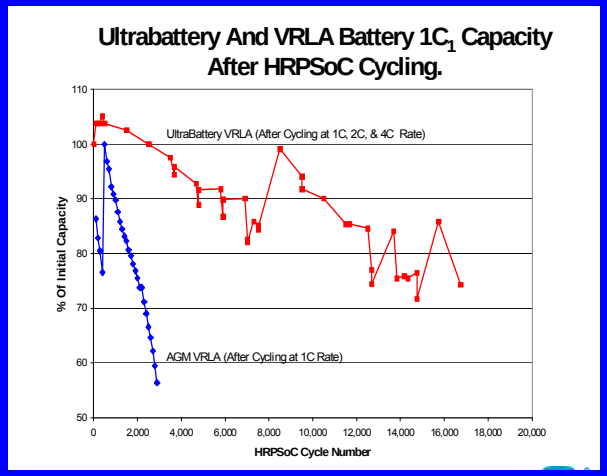


Location of Wind Resources



Location of Depleted Gas Fields

5 Distributed Projects = 9 MW Peak Shaving, Energy Management



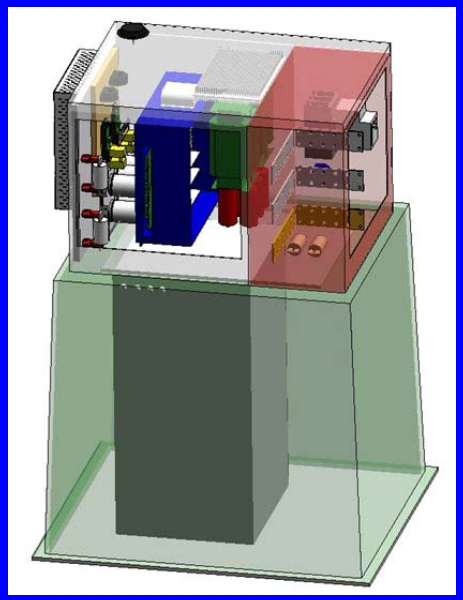
Testing at Sandia

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

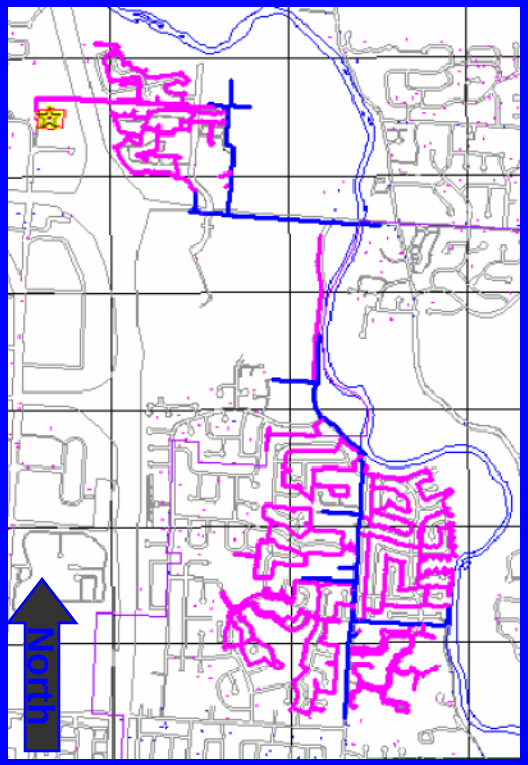
Commissioned Sep. 24, 2011

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

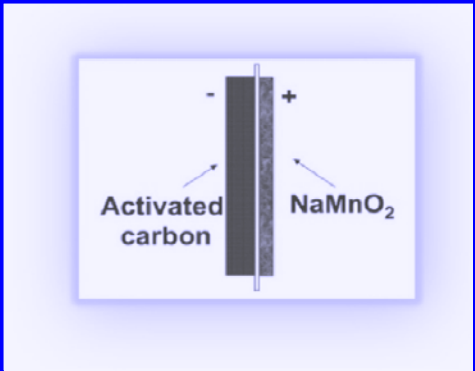


International Battery,
Entire Unit

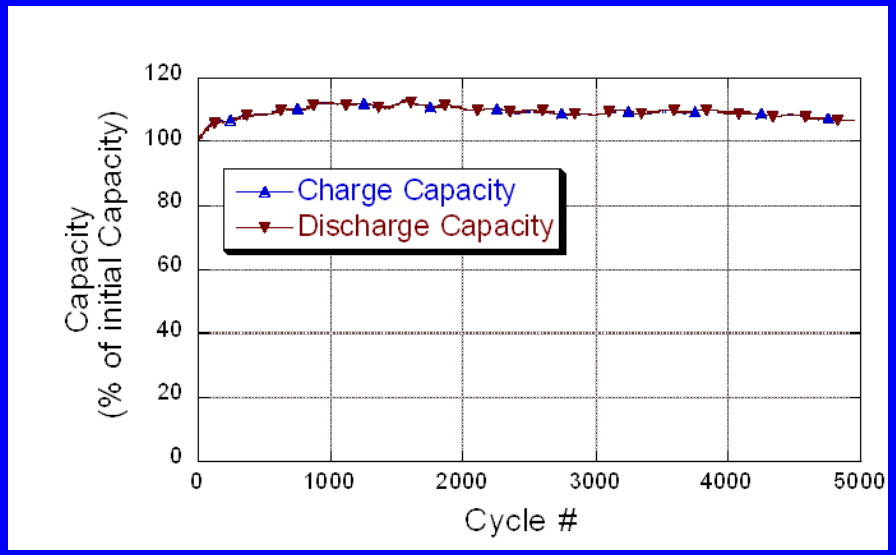


ARRA - Aquion Energy:
Aqueous Sodium Ion Battery

Winner, 2010
World Technology Award



- Cost Goal: <$200/kWh
- Lifetime cost: <$0.10/kWh
- Ubiquitous, low cost precursors
- Inexpensive manufacture
- Roundtrip Efficiency >85%
- 5000 cycles demonstrated



ARRA - SustainX:

Development of totally green Isothermal CAES

A site-anywhere solution – eliminates lengthy siting and risk associated with geologic storage

Superior thermodynamics – eliminates reliance on natural gas

Isothermal efficiency of 95% compared with 54% for adiabatic technique

Higher pressure and efficiency make pipe-type storage cost effective

A patented and demonstrated, low-cost, long lifetime ***energy*** storage solution

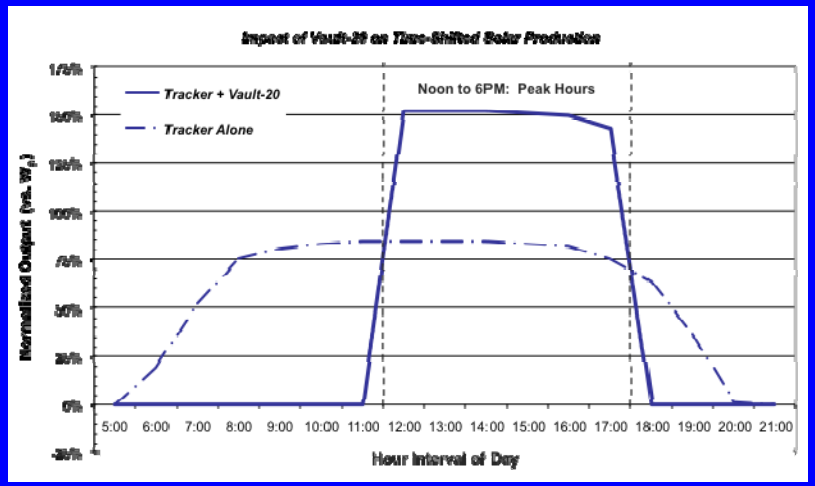
ARRA - Enervault:

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

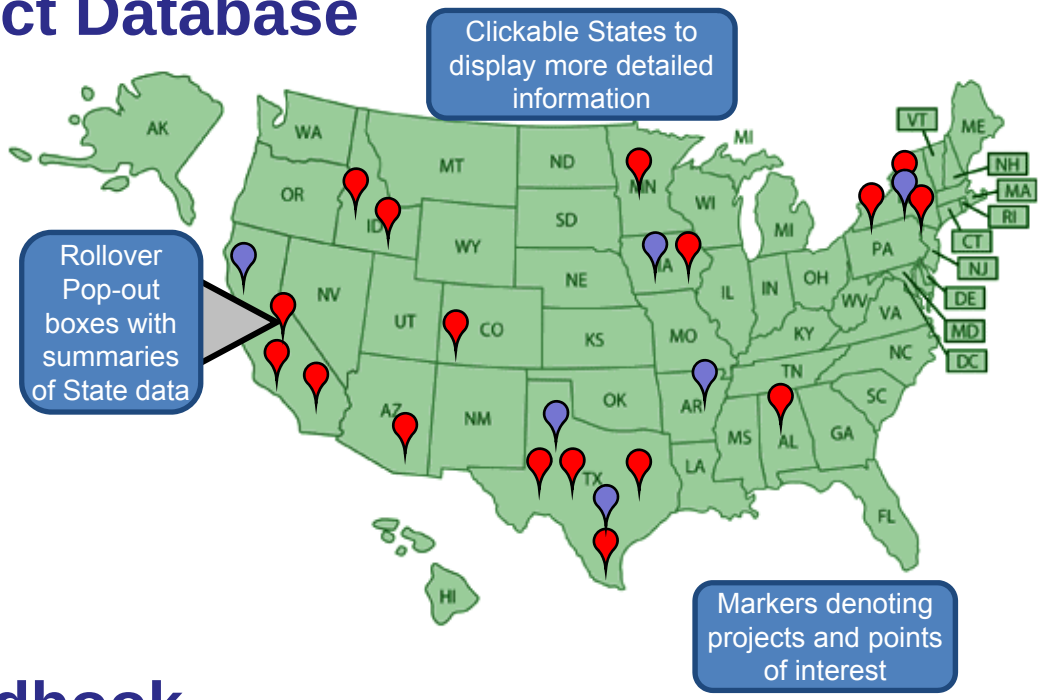
Consortium to Evaluate Re-use of EV Batteries

DOE – OE, Storage Program
DOE – EERE, EV Program
EPA – Vehicle and Fuel Emissions Lab
ORNL – Sustainable Electricity Program
General Motors, Nissan, BMW, Chrysler

Explore the possibility of re-using
EV batteries with 80% residual capacity
For Grid Storage Applications

Energy Storage Project Database

A publicly accessible database of energy storage projects world-wide, as well as state and federal legislation/policies.
Beta testing imminent!



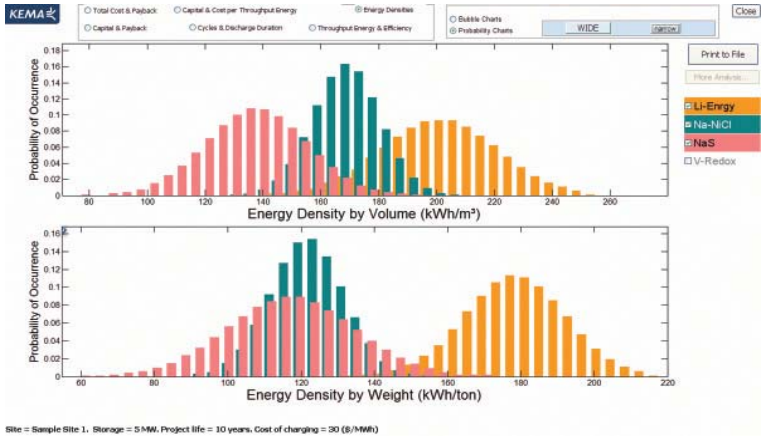
Energy Storage Handbook

Partnership with EPRI and NRECA to develop a definitive energy storage handbook:

- Details the current state of commercially available energy storage technologies.
- Matches applications to technologies
- Info on sizing, siting, interconnecting
- Includes a cost database

ES-Select: Energy Storage Selection Tool

- A tool for high-level decision makers to facilitate planning for ESS infrastructure:
  - High-level technical and economic review of storage technologies
  - Determine and size applicable energy storage resources
  - Develop a preliminary business case
- Educate potential owners, electric system
  - akeholders and the general public on
  - ergy storage technologies
  - eveloped by KEMA
  - line at Sandia.gov/ess



orage Guidebook for Regulatory Officials

- Inform regulators about Storage benefits
- Provide information on technical aspects of Energy Storage Systems
- Identify regulatory challenges to increased Storage System deployment
- Suggest possible responses/solutions to challenges
- Develop model PUC submissions requesting approval of rate base addition
- Advisory Committee comprised of industry and government experts
- Draft under review!

Development of a Protocol to Measure and Report Performance of Energy Storage technology

- We need a common language for technology providers and prospective users
- No uniform acceptable criteria exist for comparable statements of performance
- This causes confusion in the market and adversely affects technology acceptance
- DOE is leading an effort to develop an initial protocol (pre-standard)
  - Formation of representative stakeholder group
  - Clarification of anticipated application and use of the protocol by industry
  - Develop a pre-standard with reasonable consensus
  - Ongoing support as technology evolves
- Kickoff webinar Feb. 28

Collaboration with Clean Energy States Alliance

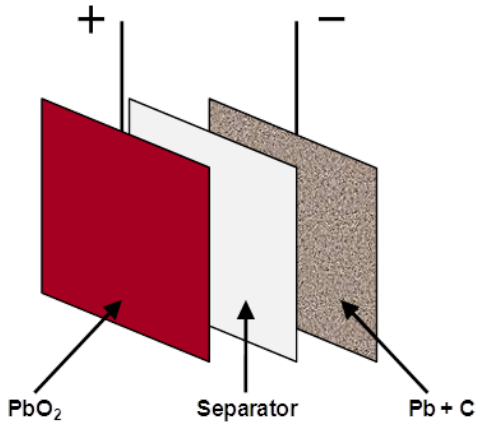
- Webinar Series on Policy Issues related to Energy Storage
- Provide information on technical aspects of Energy Storage Systems
- Identify regulatory challenges to increased Storage System deployment
- Suggest possible responses/solutions to challenges
- Develop model PUC submissions requesting approval of rate base addition
- Advisory Committee comprised of industry and government experts
- RFI kickoff Feb. 29

Carbon Enhanced Lead Acid Batteries

Sandia

Valve Regulated Lead Acid Batteries – common “back-up battery.

- Select carbons added to the negative anode material in lead-acid batteries dramatically increase battery cycle life, but phenomena poorly understood, limiting application and optimization.



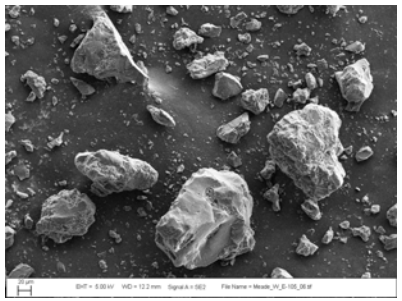
Schematic representation of a single cell from a carbon-modified or “Advanced” VRLA battery

Potential for High Impact:

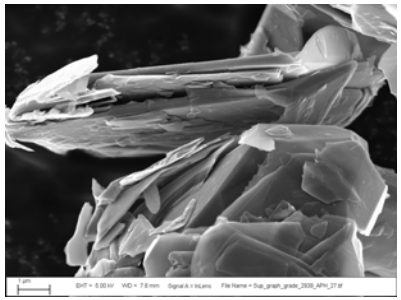
- *Understanding of enhancement mechanisms enables CELA optimization*
- *Bipolar designs improves performance and safety*
- *Application of mechanistic understanding to other batteries*

Benefit –10x cycle life improvement and 2x energy density, reduces life cycle cost and increases deployment options

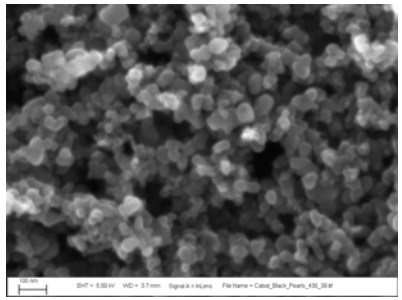
MeadeWestvaco E-105



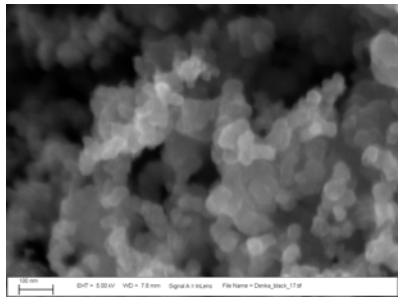
Superior Graphite 2939 APH



Cabot Black Pearls 430



Denka Black



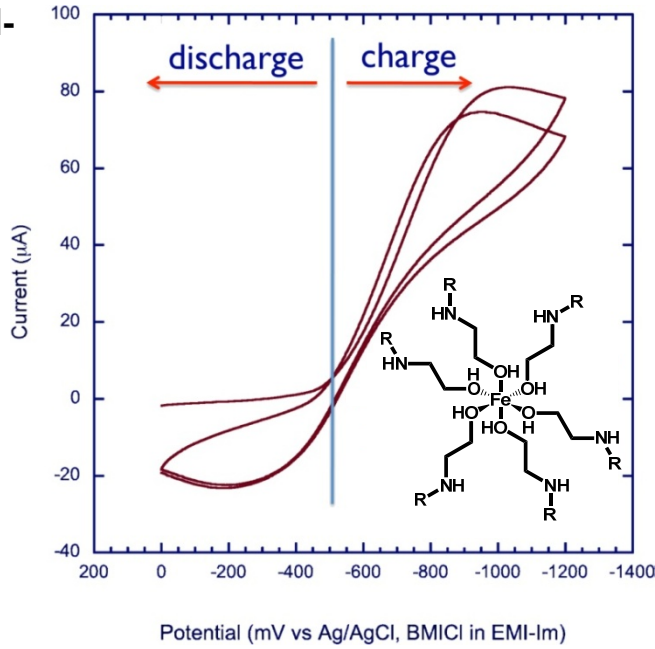
Redox Couples for Flow Batteries, Sandia

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



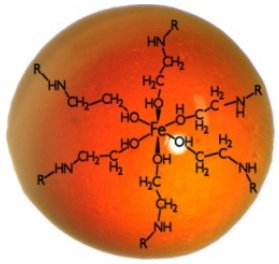
FY10: 12 MetILs synthesized and tested:

- 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

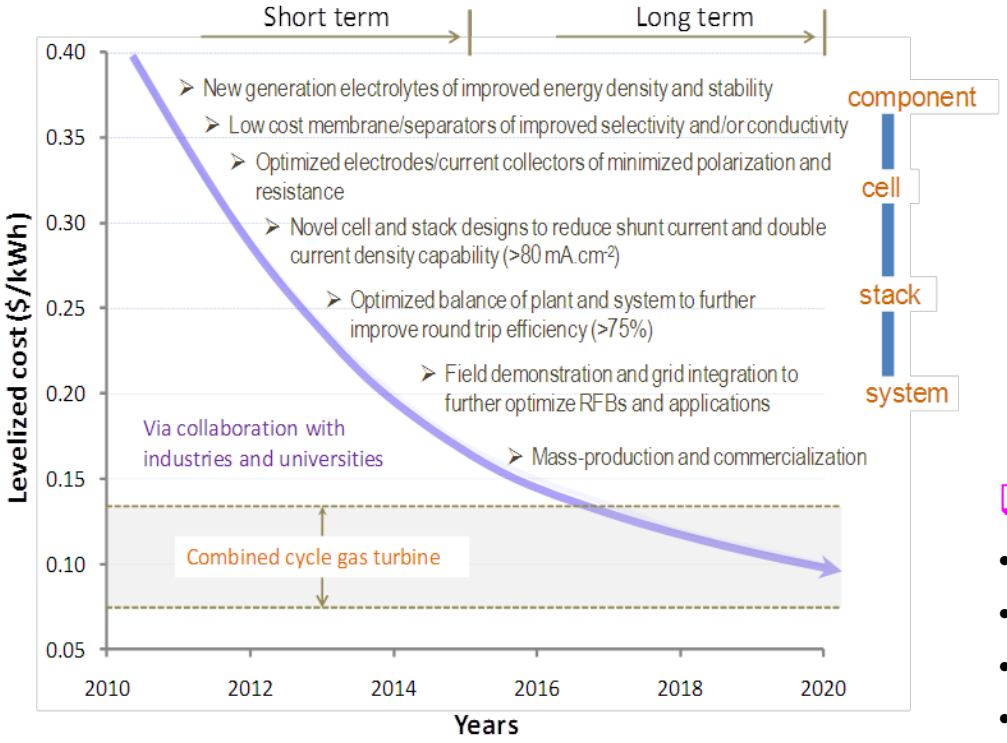
FY12: Test 5 MetIL for ionic conductivity and electrochemical Reversibility; test best candidates in benchtop flow battery prototype



Iron-containing "MetIL"

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

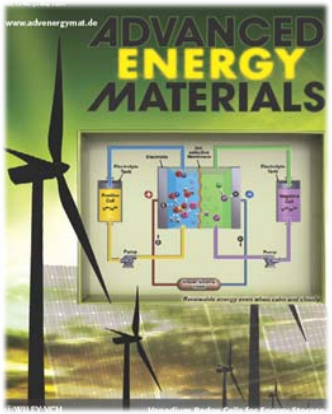


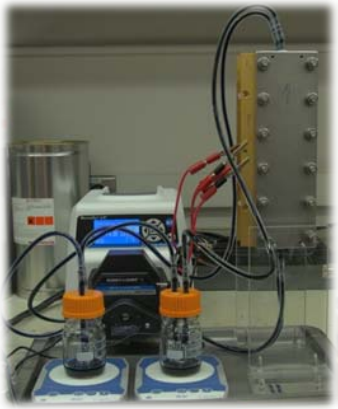
❑ FY11 accomplishments

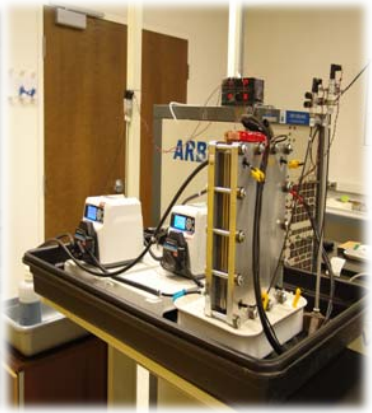
- Developed 3rd gen all vanadium RFB that demonstrated >70% increase in capacity, >80% extension in operating °C (-10~55°C) and 2x power at >75% efficiency
- Discovered Fe/V redox couples that made possible further reduction in capital cost by using low cost materials and elimination of gas evolution and management.

❑ FY 12 plan

- Develop novel cell designs and scale up
- Component integration
- Demonstrate 1 kW/4 kWh bench top system
- Transfer technologies





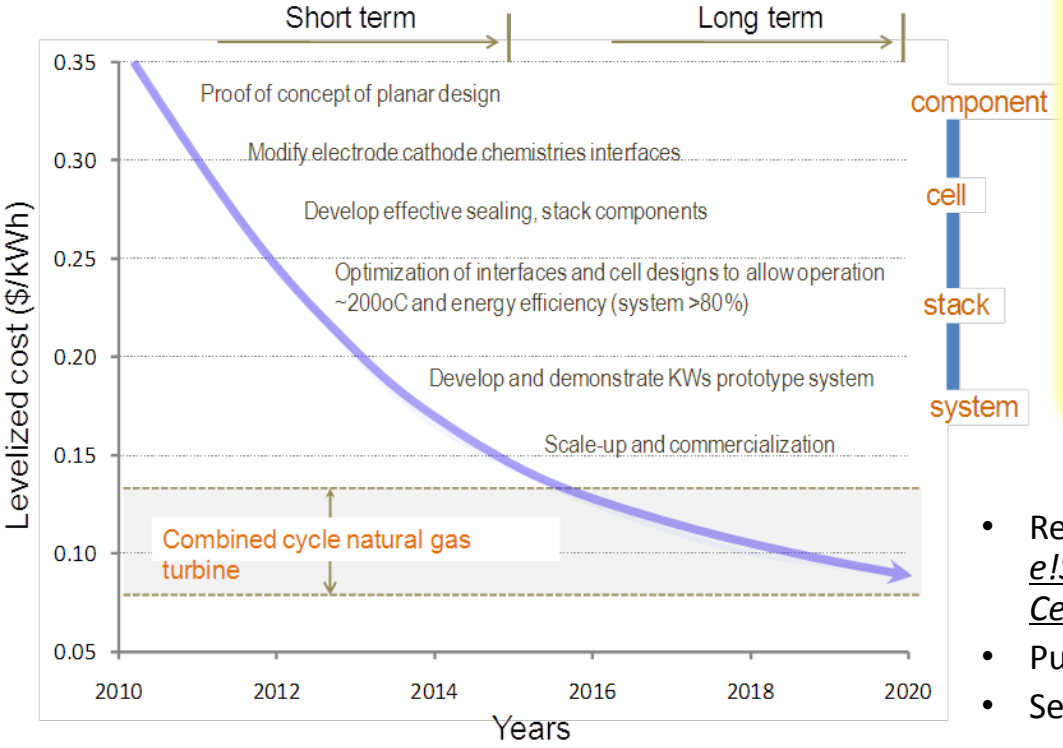


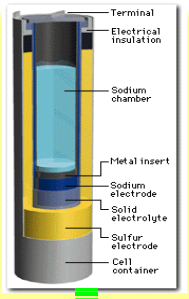
- Reported by *ScienceDaily*, *e!Science*, *Smart Grid News*, *Smart Grid Today*, *Materials Toady*, …,
- Published in *Adv. Energy Mat.*, *Chemical Reviews*, *Environ. & Energy Sci.*, *Electrochem. Comm.*, *J. Power Sources*, *etc.*
- Five US or Foreign patents filed
- Technology transfer ongoing

Planar Sodium (Na) - Metal Halide Batteries, PNNL

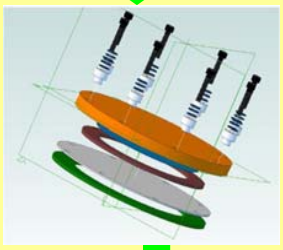
Develop novel Na-metal halide batteries that can meet cost and performance targets for renewable integration and grid applications, via introduction of planar designs and new minor chemistries and interfaces

- Leveraging ARPA-E and OE supports: with ARPA-E on planar design; OE on minor chemistries, interfaces and future demonstration; collaboration with Eagle Pitcher Inc. Interest for collaboration from POSCO (Korea)
- FY11 accomplishments: Proved concept of planar design; Developed and tested intermediate size cells (64 cm^2)
- Optimize cells and scale up in FY12





Traditional tubular Na – sulfur cell, operated >300-350°C



Newly developed planar sodium metal-halide cell, operated <250°C

Planar stack, operated <250°C

- Reported by *NBC News*, *ScienceDaily*, *e!Science*, *EnergyDaily*, *Smart Grid News*, *Ceramics*, *GreenCarCongress*, …,
- Published in *J. Power Sources*, *etc.*
- Seven US or Foreign patents filed