Quadrennial Technology Review: Electrical Energy Storage

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National Energy Goals Depend on Transformation in Stationary Energy Storage

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

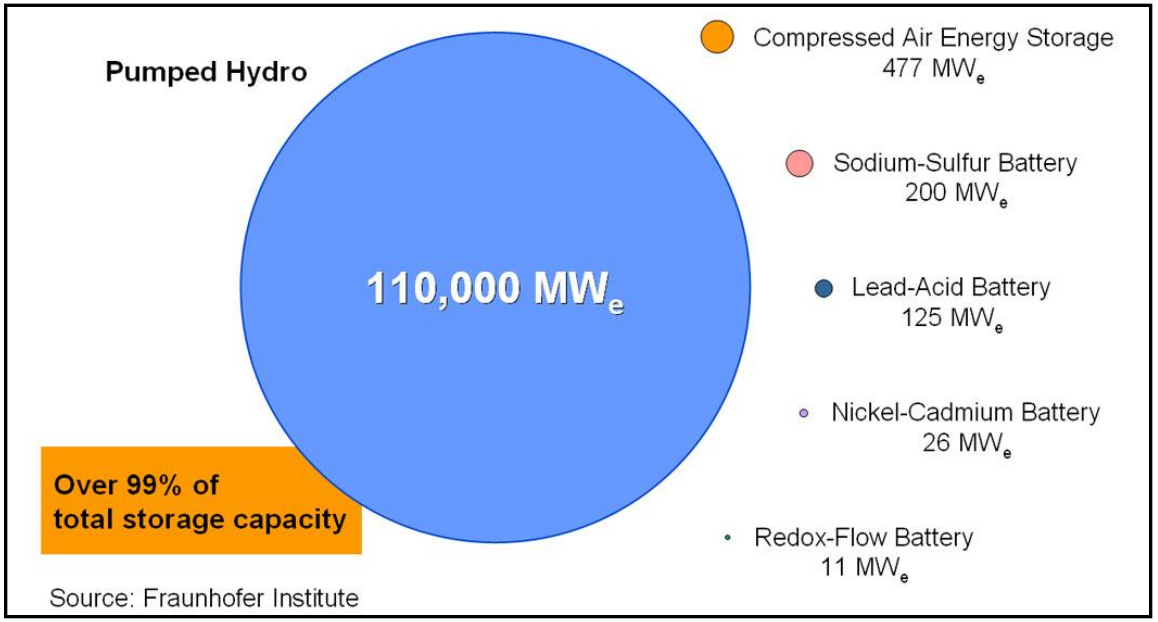
U.S. DEPARTMENT OF ENERGY STRATEGIC PLAN 2011:
Modernize the Grid

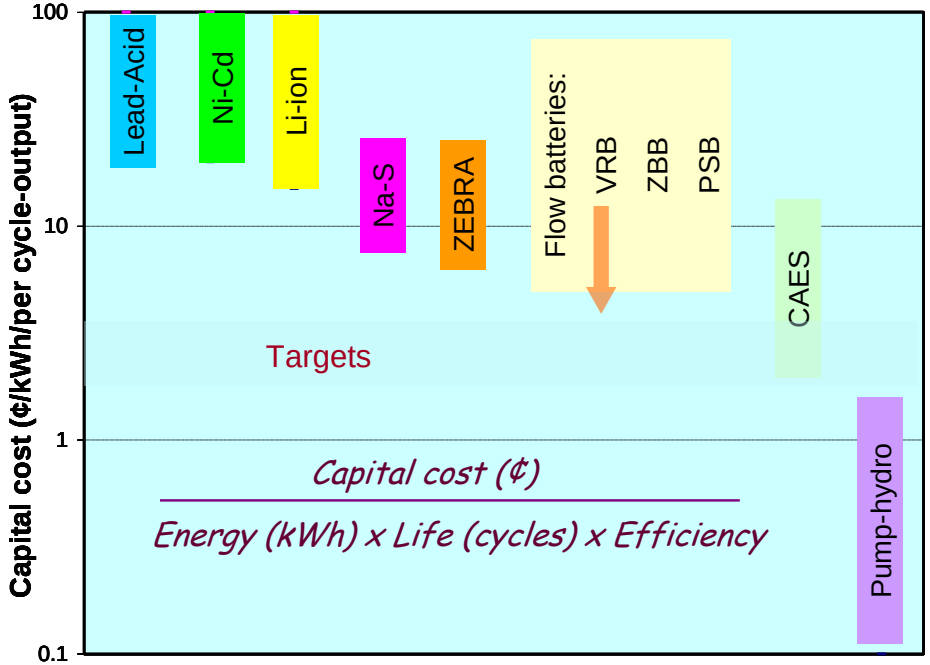
- **Reduce utility-scale energy storage costs 30% by 2015**

Energy Storage Provides Multiple Values for the Electric Grid

- **Enhancing system stability**
  - Reduces peak load
  - Reduces infrastructure requirements
  - Minimizes congestion
  - Improves base-load capacity factor
  - Defer transmission and distribution investment
  - Provides VAR support
  - Can provide black start capability
- **Enabling large-scale/utility RE integration**
  - Reduce variability
  - Ramp rate control
  - Load shifting
  - Firms RE to improve dispatchability
- **Enabling DG and EV deployment**
  - Reduce variability
  - Interacts and supplements vehicle-based storage
  - Improves power quality
  - Provides voltage support

Worldwide Installed Grid Storage



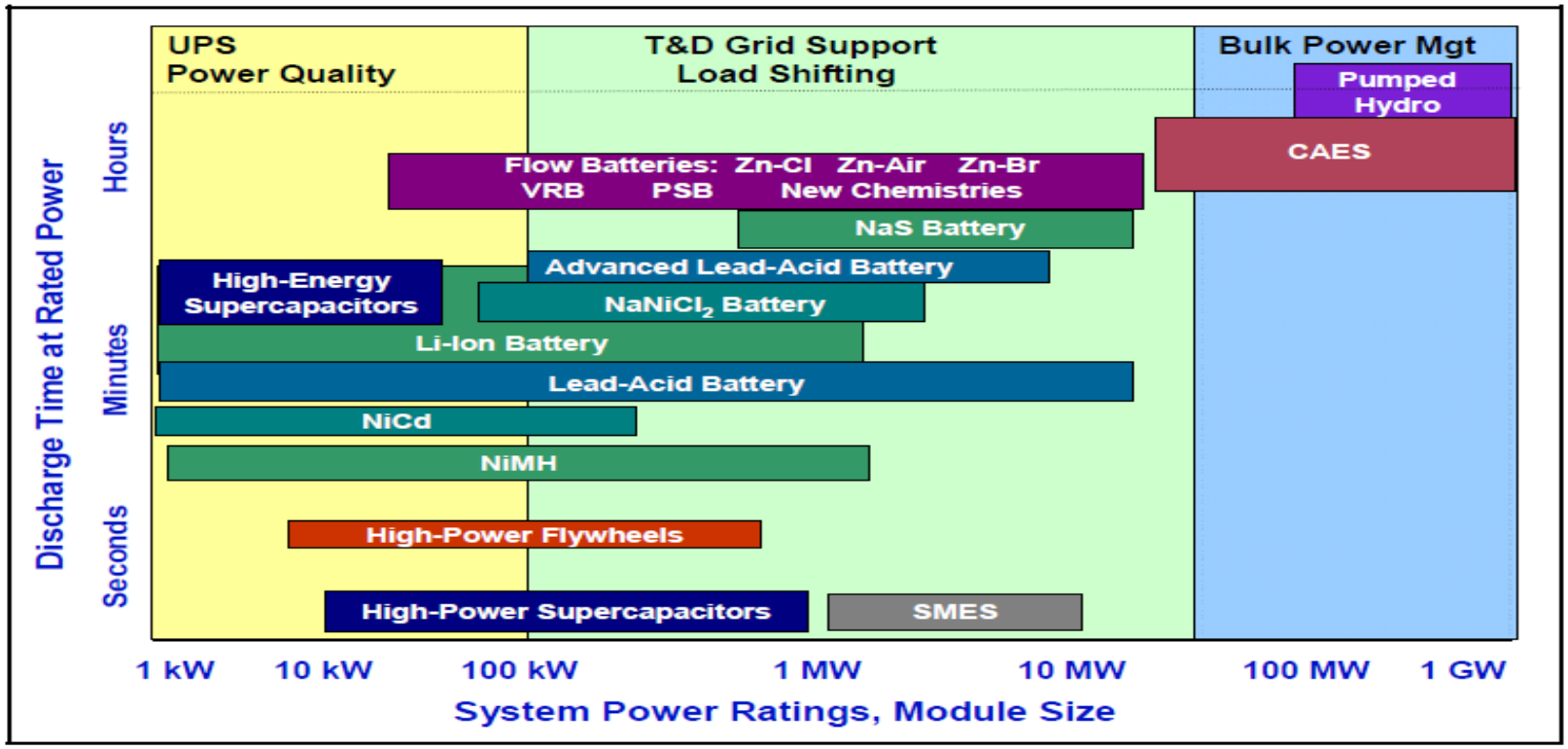


Economic Status

"the energy storage business could grow from $1.5 billion in 2010 to a $35 billion industry by 2020"

Pike Research, 2010

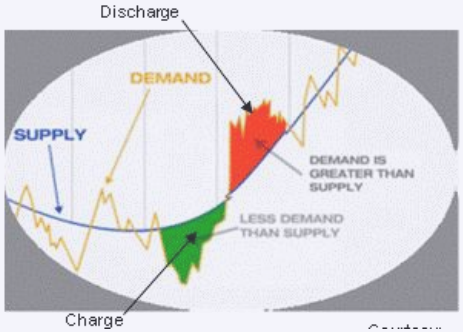
Storage Technologies are Applications



Energy Storage Applications – Time Scales

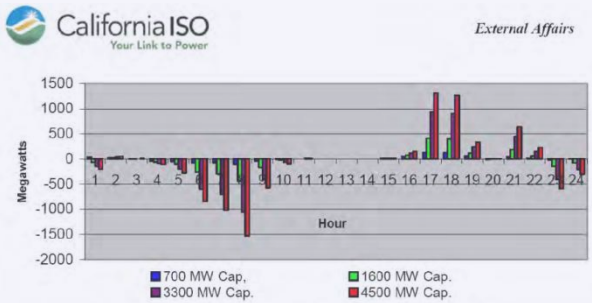
Seconds to Minutes

Regulation



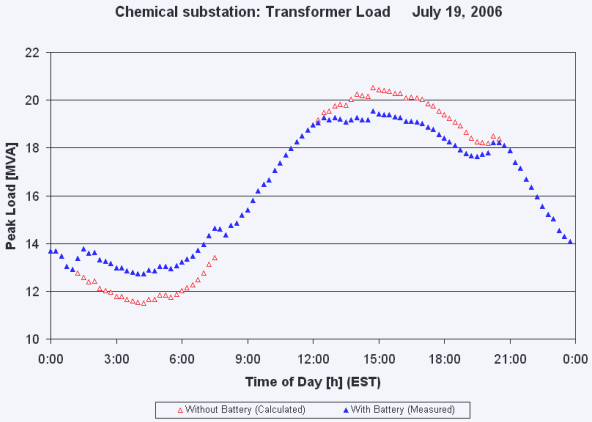
Minutes - one Hour

Ramping



Several Hours - one Day

Peak shaving, load leveling



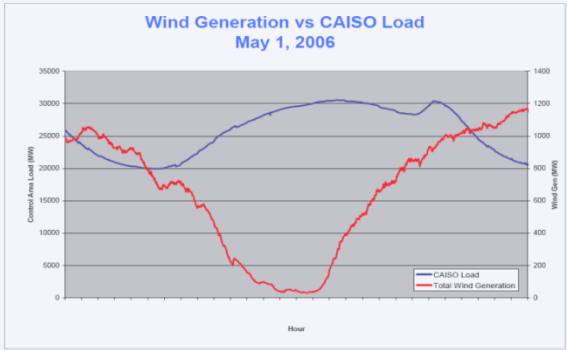
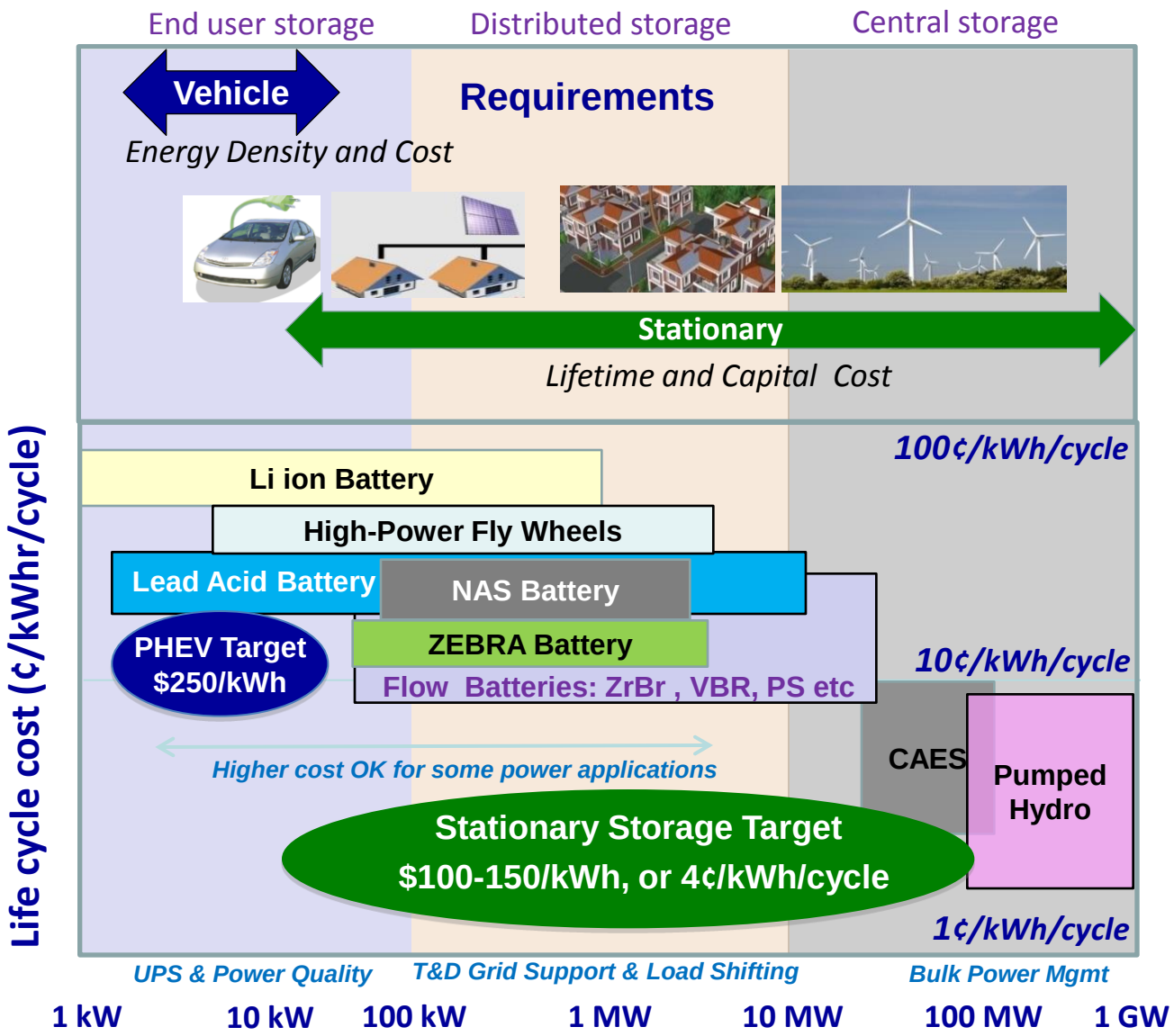


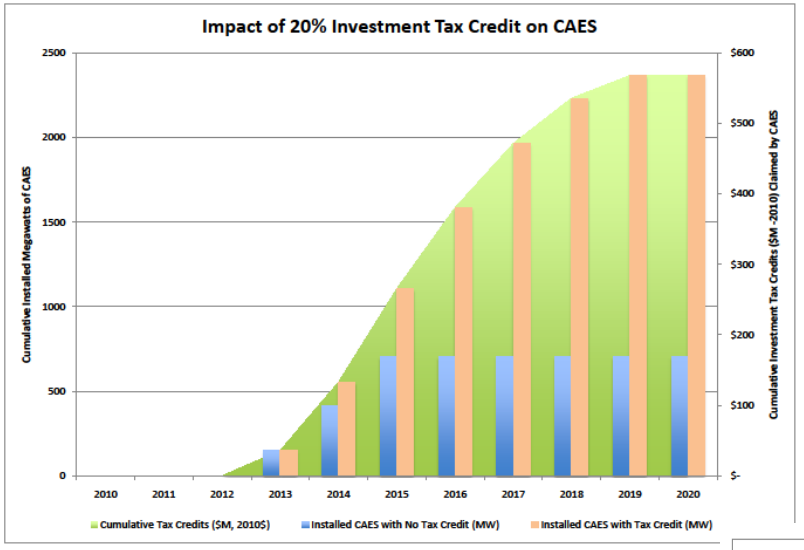
Figure 11: Total Wind vs. CAISO Load

Different Time Regimes
will Require
Different Storage Solutions

Energy Storage Requirements and Targets



Industry 10 year Expectations

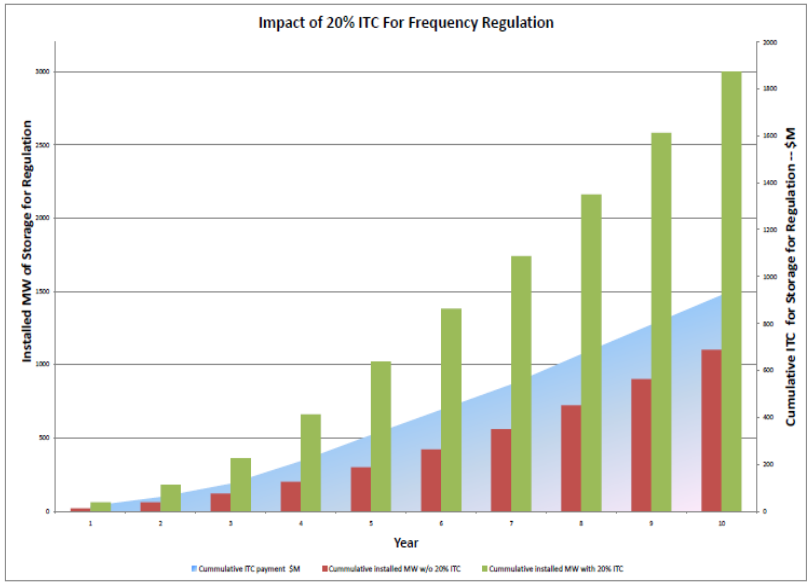


Without Investment Tax Credit:

1,500 MW	Pumped Hydro
700 MW	CAES
1,500 MW	Renewable Integration
12,000 MW	T&D Support
1,100 MW	Frequency Reg.
2,100 MW	Thermal Storage

18,900 MW	

20% Investment Tax Credit for Storage Facilities Currently proposed in Congress



Pumped Hydro & CAES (Central-station plants for Bulk Energy Management)

Helms plant California

CAES plant Huntorf, Germany

CAES plant in McIntosh, Alabama

Pumped Hydro

- Over 99% of existing grid storage, ~22GW = 2.5% U.S. generation
- Capital intensive, long lead times, large scale of economy, site specific

CAES

- Two plants world-wide (salt geology) -~400MW
- Site geology-specific
- Output exceeds input (1.1) due to fuel firing

Potential for High Impact:

• Improve turbo-hydraulic design to increase ramp rate and shorten mode-changeover time

•Establish closed-loop and marine systems

Benefit – Enable broader application for ancillary services increasing value of potential 30GW now in planning stage

Potential for High Impact:

• Adiabatic and isothermal operating cycles

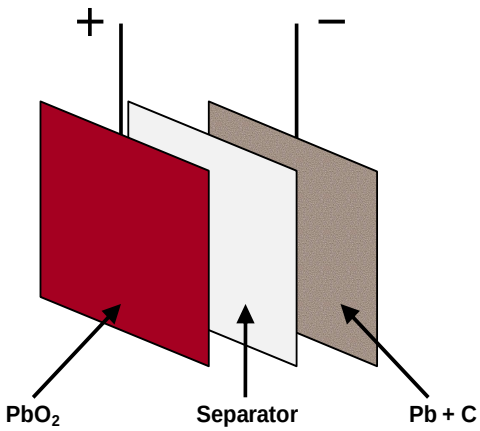
• Surface storage concepts

Benefit – No fuel usage for isothermal reduces O&M & emissions, independence from site geology enables ubiquitous use

Carbon Enhanced Lead Acid Batteries

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.



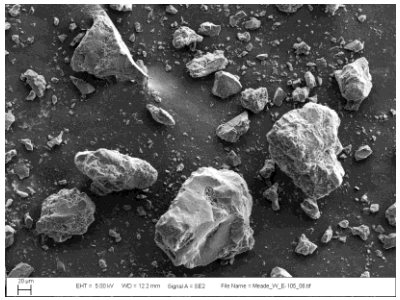
Schematic representation of a single cell from a carbon-modified or “Advanced” VRLA battery

Potential for High Impact:

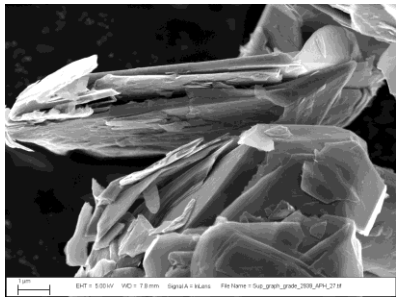
- *Understanding of enhancement mechanisms enables CELA optimization*
- *Bipolar designs improves performance and safety*
- *Application of mechanistic understanding to other batteries*

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

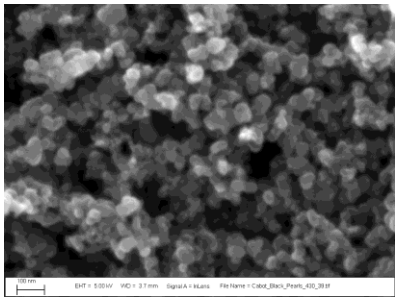
MeadeWestvaco E-105



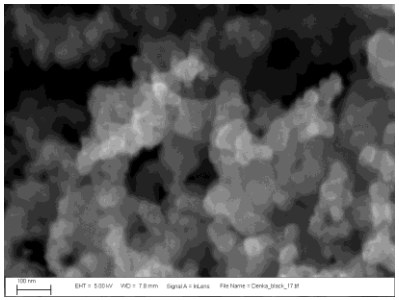
Superior Graphite 2939 APH



Cabot Black Pearls 430

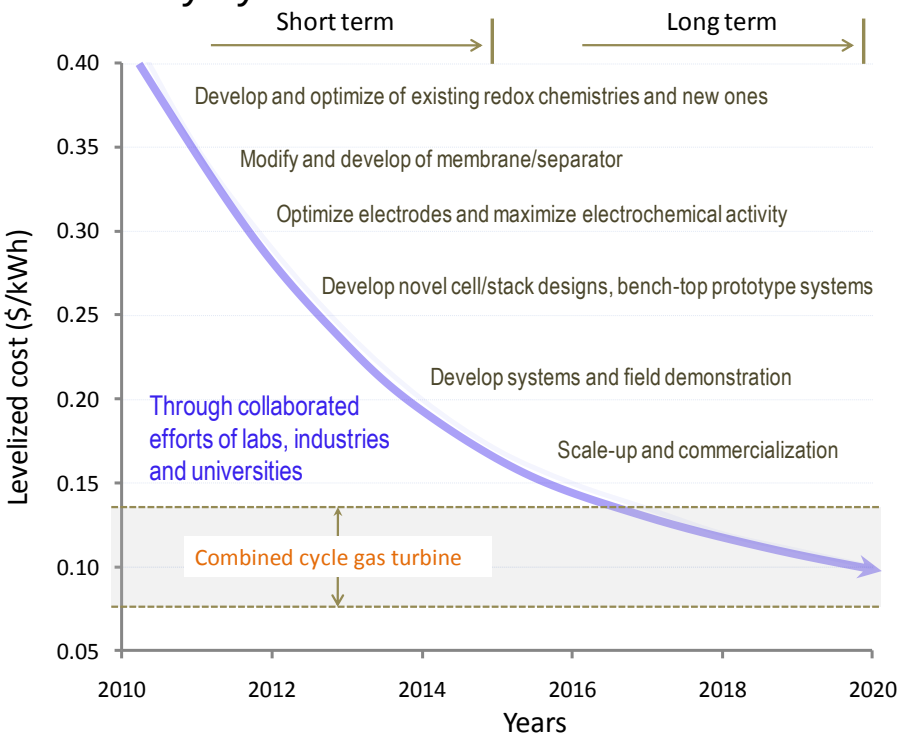


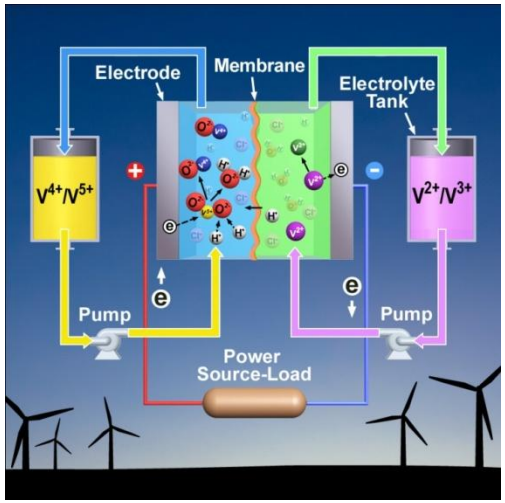
Denka Black

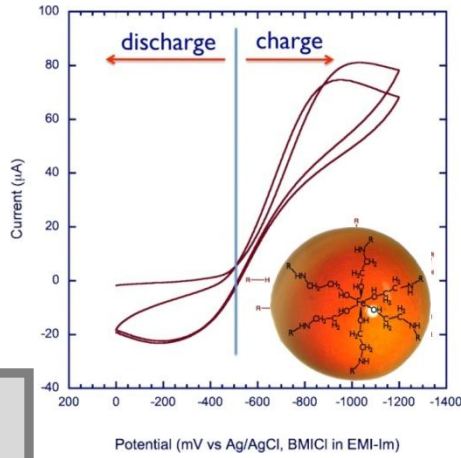


Redox & Advanced Flow Batteries

- Power determined by cell/stack, energy determined by electrolyte tank capacity
- Cost, stability, energy density are challenges
- Many system chemistries







Iron-containing "MetIL"

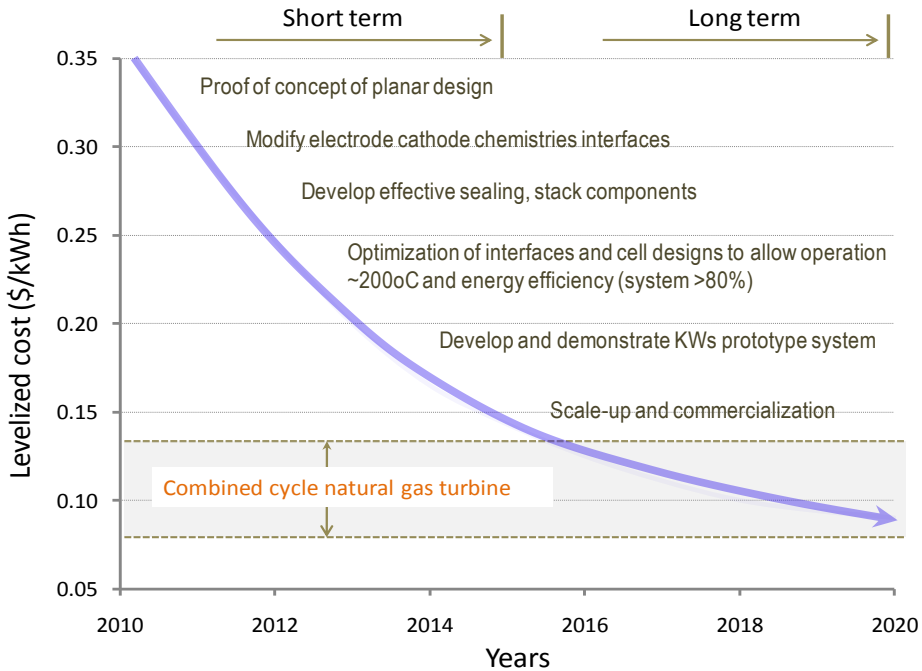
Potential for High Impact:

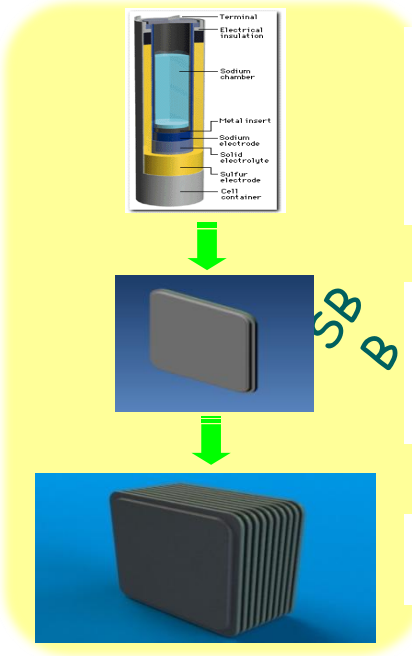
- *Improved membranes enables higher electrolyte ion concentrations, low maintenance*
- *Increased electrolyte ion concentration increases energy density, range of operation*
- *Novel liquid-metal and redox chemistries, durable electrodes*

Benefit – 2x energy density, greater cycle life, improved efficiency, 2x cost reduction

Sodium-based Batteries

- High efficiency & energy density, but high temperature and cost limit deployment
- New planar design enables reduced temperature and cost, and more advanced sodium ion concepts may be room temperature

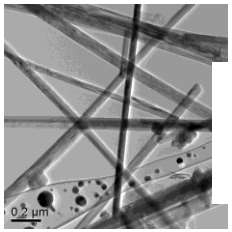




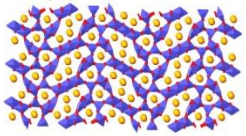
Traditional tubular sodium – sulfur cell, operated >300-350°C

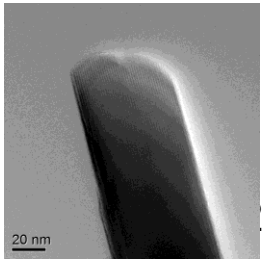
Newly developed planar sodium metal-halide cell, operated <250°C

Planar stack, operated <250°C



Mn_2O_3 orthorhombic lattice





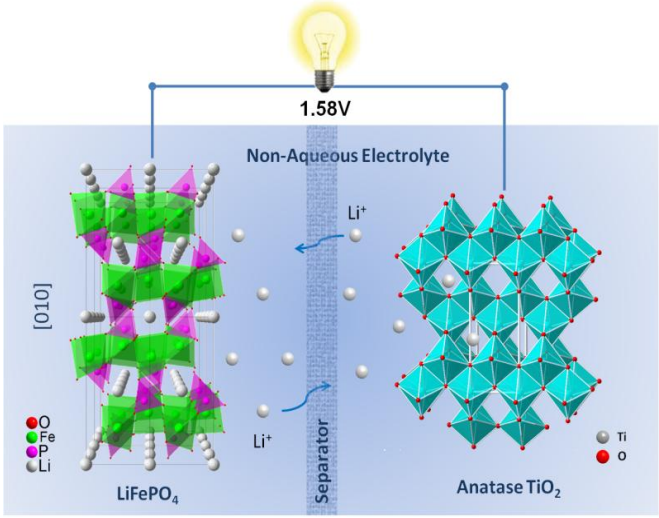
Potential for High Impact:

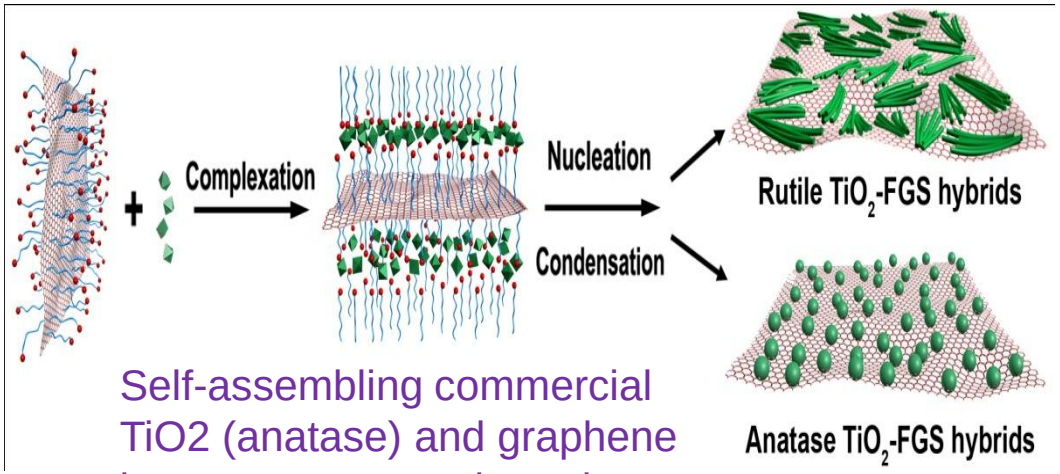
- *Improved sealing and thin solid electrolytes enable planar design*
- *Cathode optimization enables reduced temperatures*
- *Novel nanofiber synthesis enables room temperature sodium-ion system*

Benefit - 2x power density, 50% energy density improvement, 2x cost reduction

Stationary Li-ion Batteries

- Design for much higher cycle life, improved safety, and lower cost than automotive applications,
- Employ self assembly synthesis methods, novel cathodes and electrolytes





Self-assembling commercial TiO2 (anatase) and graphene into nanostructured anode

Potential for High Impact:

- *Improved, self-assembled, nano-structured electrodes from commercial materials*
- *Modified chemistries for long cycle life*
- *Improved, aqueous electrolytes, inexpensive electrodes*

Benefit – 2x reduction in cost, >3x cycle life, much improved fire safety

Flywheel Storage for Power

- Fast, full cycle operation, but low energy density and costly
- 20MW plants economical for regulation now.
- Can reduce regulation requirements by factor of 2-24 over conventional generation

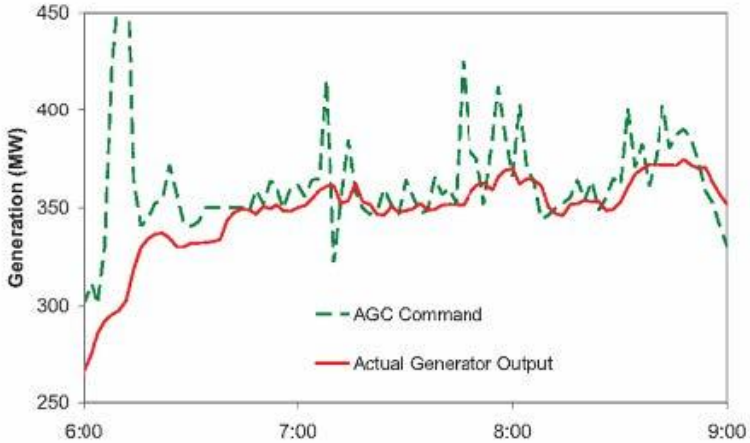
20 MW plant in Stephentown, NY

Potential for High Impact:

• Development of hubless flywheels to expand economical ancillary services

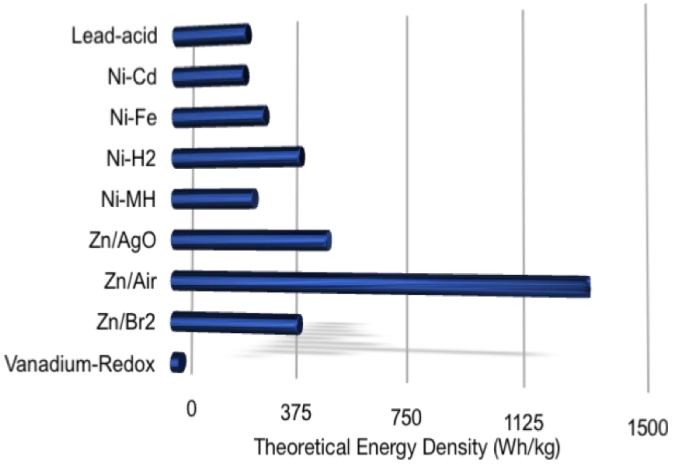
•Ultra-high speed flywheels levitated by superconducting magnetics, nano-structured silicon fibers for very high energy density.

Benefits – 8x cost/kWh reduction



Emerging Storage Technologies

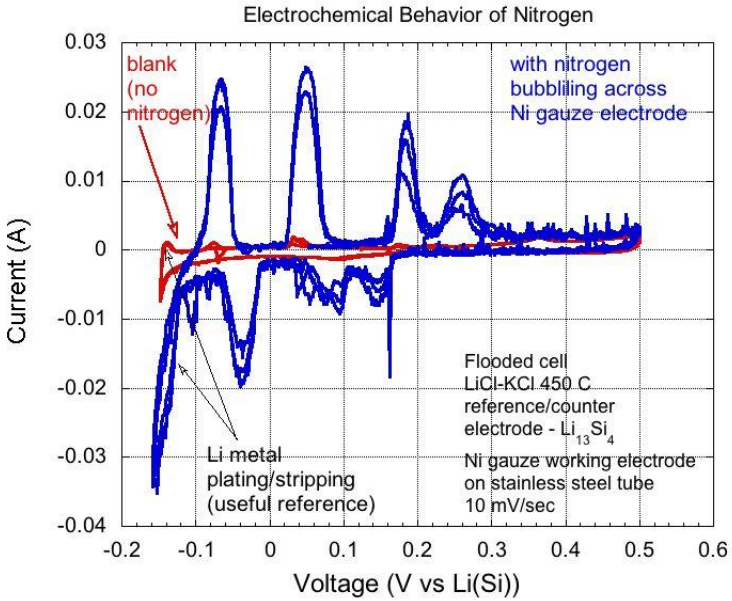
- Metal-air Batteries – highest energy storage density, but not yet a regenerative system
- Liquid metal batteries
- Novel N_2/O_2 battery concept
- New regenerative fuel cell systems



Potential for High Impact:

- *Establish metal-air regenerative electrochemistry*
- *Establish proof of principle for N2/O2 battery systems*
- *Establish viable liquid metal battery*
- *Explore new regenerative fuel cell chemistries*

Benefit – 10x increase in energy density and cost reduction



U.S. Industry has shown its Readiness to Invest in Energy Storage

DOE provided $185M in ARRA Stimulus Funding and received a Costshare of $585M !

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

533MW and a ten-fold Increase in Power Scale!

Potential for High Impact Benefits

- **Different technologies serve different grid requirements**
- **Modest improvement potential for established technologies – PHS & CAES**
- **Significant potential for selected electrochemical technologies:**
  - **Lead-Carbon Batteries**
  - **Sodium-based systems**
  - **Redox and Advanced Flow batteries**
  - **Stationary Li-ion**
- **Flywheel potential is significant with advanced technology**
- **Emerging concepts offer greater benefit but much higher risk**