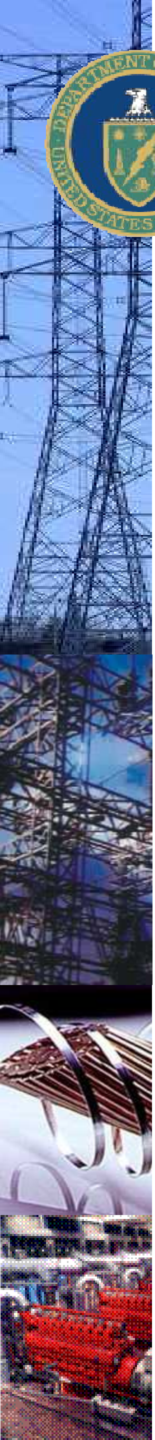


SAND2011-8307P

# Energy Storage Program Strategy and Plans

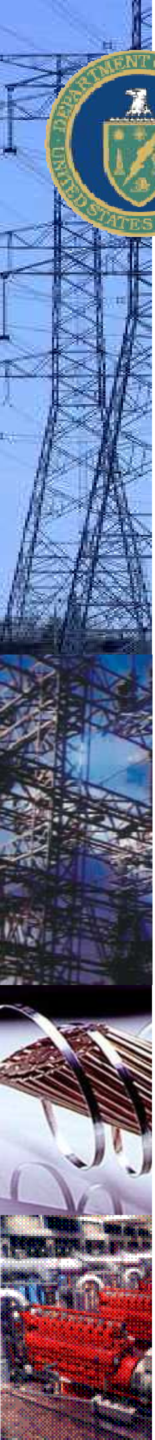
Dr. Karen Waldrip
Sandia National Laboratories

November 1, 2011

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

*Without technological breakthroughs in efficient, large scale energy storage, it will be difficult to rely on intermittent renewables for much more than 20-30 percent of our electricity.*

*--Secretary Chu, February 2010*



# Applications of Energy Storage

**Energy Storage moves energy through time to separate generation from use and to actively manipulate power in real time to improve quality, reliability and to maintain proper frequency.**

**Key to Greater Renewable Penetration**

- Reduce variability
- Ramp rate control
- Load shifting
- Improve dispatchability

**Provides Buffer for the Grid**

- Reduces peak load
- Reduces infrastructure requirements
- Minimizes congestion
- Improves duty factor

**Reduce Carbon Footprint**

- Minimize “peakers”
- Dispatchable renewables
- Emissionless regulation

**Smart Grid**

- Integrating tool

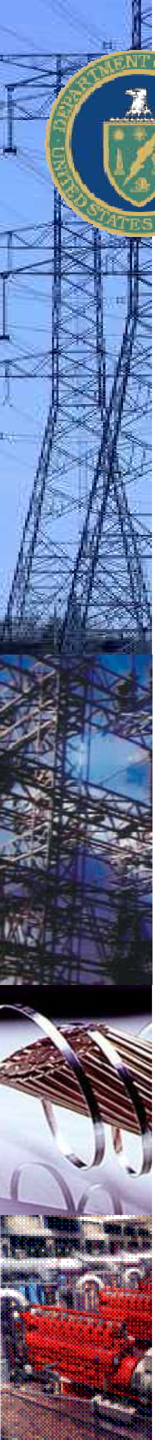
**Power Quality & Reliability**

- For digitized Technology

# ESS Program Strategy

Provide National Leadership in Developing and Integrating Stationary Energy Storage Technologies

- Maintain momentum from ARRA Energy Storage Demonstrations
- Test components, subsystems and systems to aid in development
- Create the next generation of Energy Storage devices and systems
- Analytical studies to guide development and deployment



# Energy Storage Challenges and Needs

## Challenges

- Cost of energy storage systems
- Reliability of energy storage systems
- Cost/Benefit ratio
- Regulatory treatment of energy storage

## Needs

- Improved materials and system integration
- Utility scale field tests to demonstrate reliability
- Identification of benefits and accruing multiple benefits from single system
- Educate regulators, PUCs, Congressional members

# Inter-Office Cooperation

- Regular meetings with ARPA-e managers
- Joint SBIR with BES (3 years)
- Co-located research with BES and ARPA-e
- Regional Storage Evaluation with BPA
- Colloquium for Univ. of MD EFRC
- Presentation for Loan Guarantee Office
- Program Review (November) featuring core program, ARRA demos, SBIR projects, and ARPA-e projects.

# Energy Storage Program Goals and Metrics

## Cell and component metrics

Double energy storage density of energy storage device by 2020

5 research projects have the potential to meet goal

## System metrics

Reduce installed system cost for a commercial system by 30% from $2500 (2007 AEP) to $1750/kW by 2015

## Long Term Goals

Reduce energy system installed cost by 50% from $417/kWh (2007 AEP) to $200/kWh by 2020

## Stretch Goal (ARPA-E)

$100/kwh

# Research Themes

Advanced Research & Development

Flow Batteries
Sodium batteries
Advanced Flywheels
Advanced Lead-Carbon
Transformative Technologies
    Materials, Electrodes
    Electrolytes, Couples

Impact on Grid
Economic Cost & Benefits
Electrochemical Modeling.

Modeling & Analysis

Component
System
Field

Testing

# Research Participants and Timelines

Long term research ⟷ Applied Research ⟷ Battery and Field Testing

**Goal: Seek breakthroughs in materials, components and cell designs for next generation technologies.**

- ❑ Novel electrodes,materials and membranes;
- ❑ New electrolyte and new redox chemistry;
- ❑ Next gen. redox flow batteries;
- ❑ Next gen. low cost Na batteries;
- ❑ State-of-the-art diagnostic/characterization.

**Goal: Improve key technologies for mid term applications in power management and other specialized applications.**

- ❑ Advanced lead-carbon batteries;
- ❑ Low cost Li-ion batteries;
- ❑ Advanced flywheels;
- ❑ Long life redox flow batteries;
- ❑ Supercapacitors.;
- ❑ Electrochemical modeling

**Goal: Test and validate grid relevant performance of components and systems:**

- ❑ Components and systems;
- ❑ Protocols and standards;
- ❑ Performance and cost;
- ❑ Grid viability and scalability;
- ❑ Non-electrochemical options

3-5 year | 2-3 year | 1-3 year

Universities, National Labs

National Labs, Universities, & Industry

Industry, National Laboratories

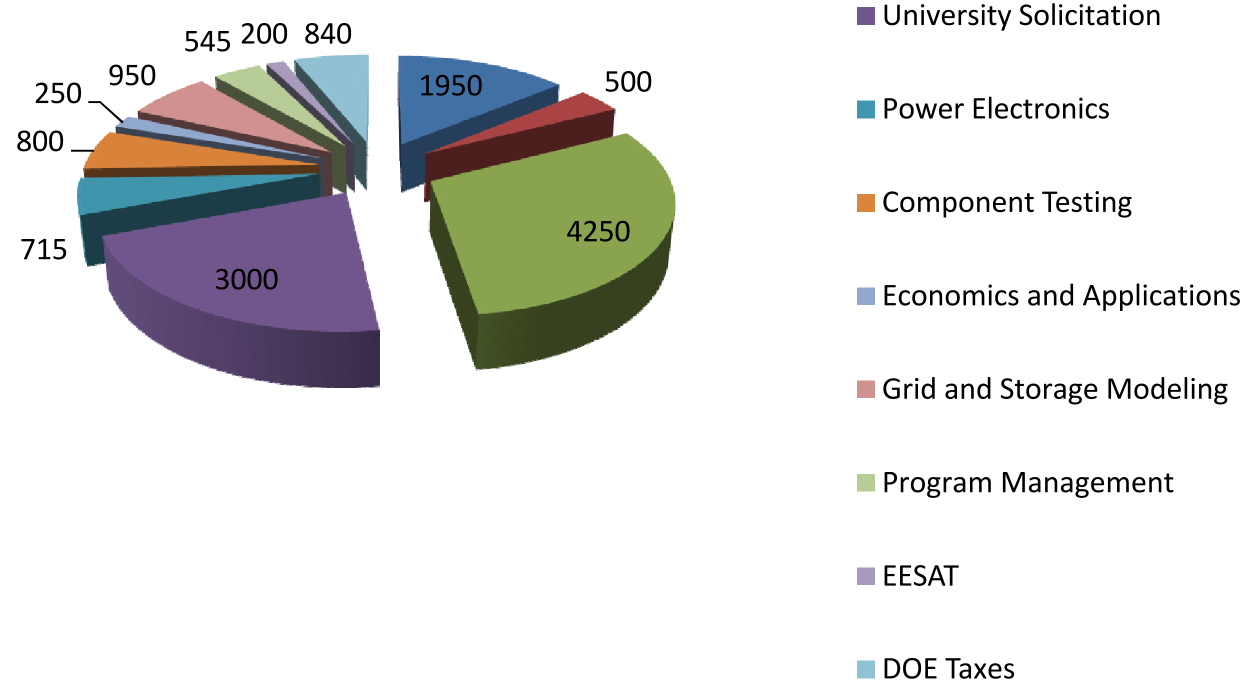
Cross-cutting activities:

Analysis, Modeling and Integration

**Goal: Defining storage needs, cost and performance requirements, value proposition and integration strategy**

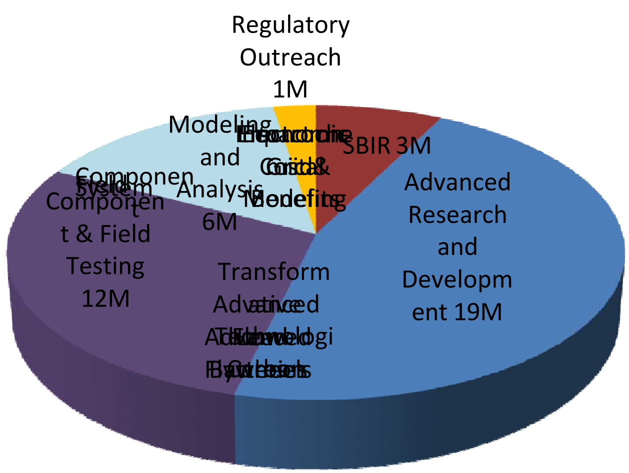
- ❑ Impact of renewable and storage on grid;
- ❑ Storage needs for different applications;
- ❑ System analysis and storage options;
- ❑ Cost and performance of different technologies;

# FY10 $14 M Budget Breakdown

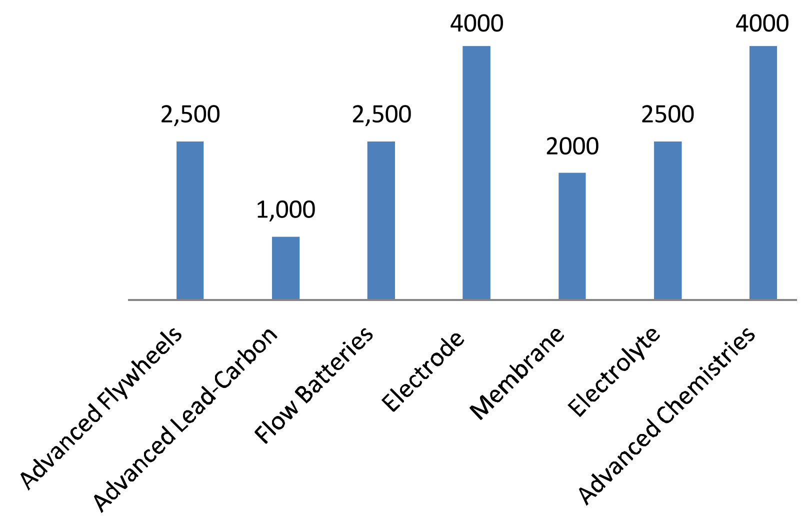


# FY11, 12 Budget Directions

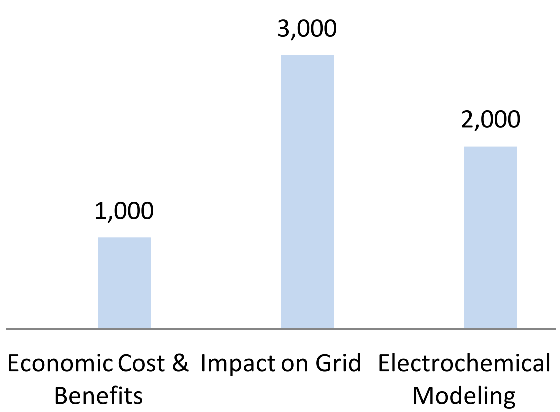
## Total $40 M Budget Breakdown



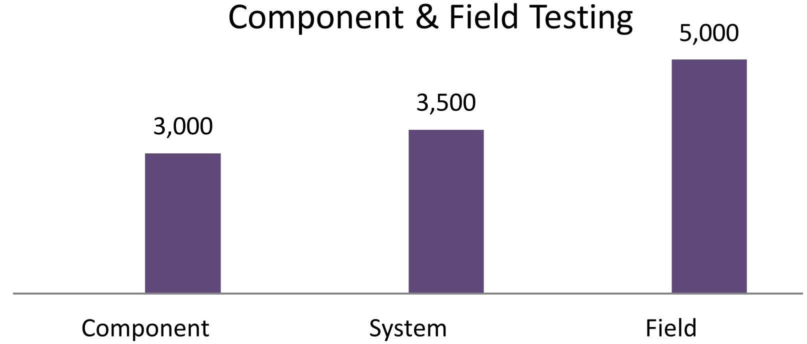

Advanced Research & Development




Modeling and Analysis




Component & Field Testing



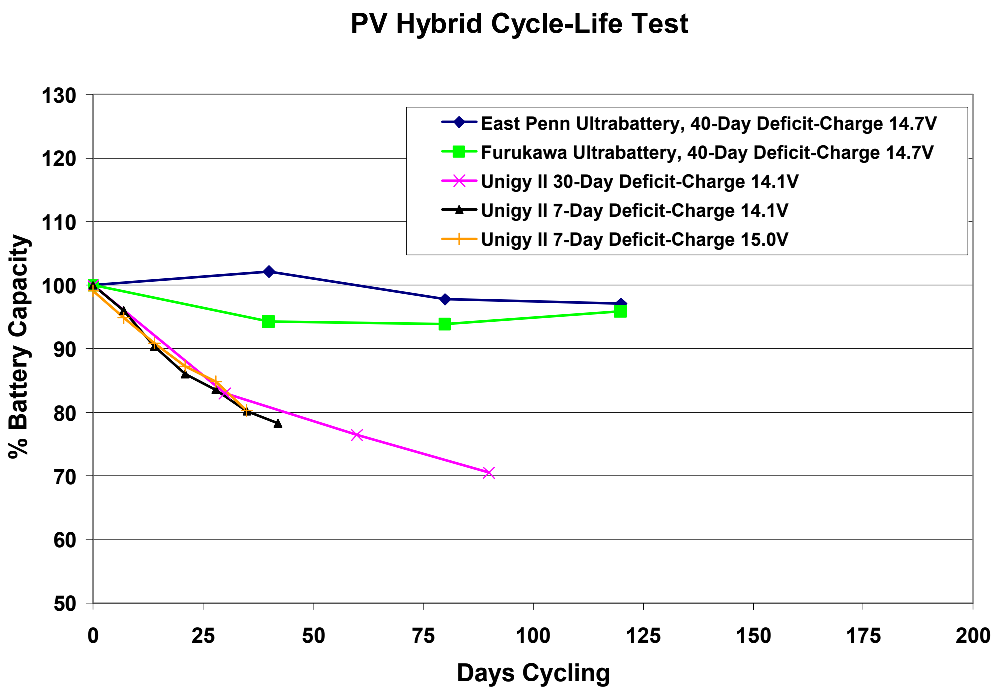
# Highly Leveraged State and Utility Energy Storage Collaborations

- California Energy Commission (CEC)
- New York State Energy Research and Development Authority (NYSERDA)
- Clean Energy States Alliance (CESA) – Potential FY10-11
- Utility Field Tests for new technologies and Applications

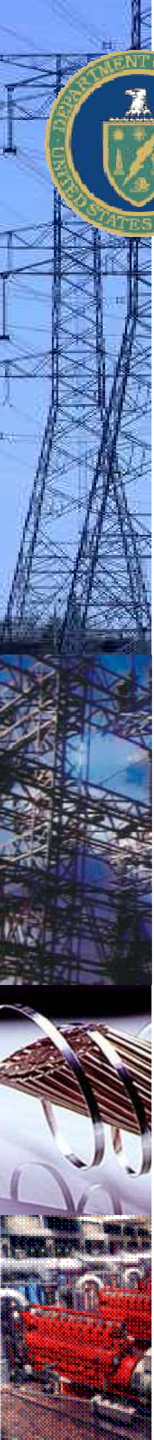
**DOE provides technical expertise to aid State Energy Agencies in determining and managing energy storage projects appropriate to local state requirements**

# Energy Storage Testing Program

## Collaborative with Industry, Utilities and States




Testing in simulated PV cycle shows the carbon enhanced ‘Ultra Batteries’ maintain capacity significantly better than conventional VRLA batteries

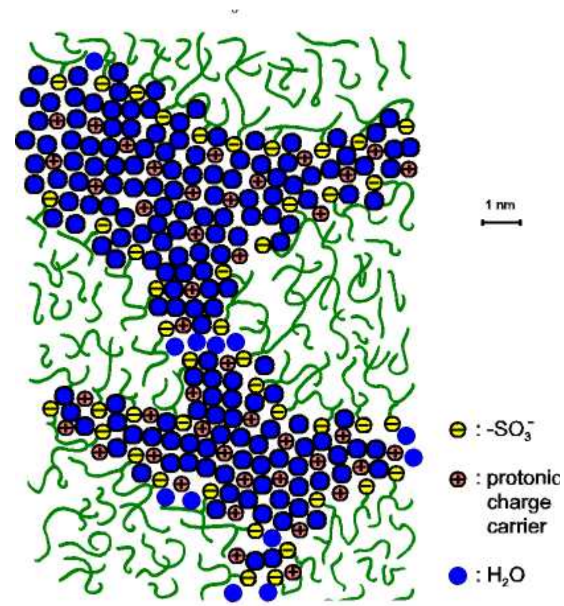


# University Research Programs

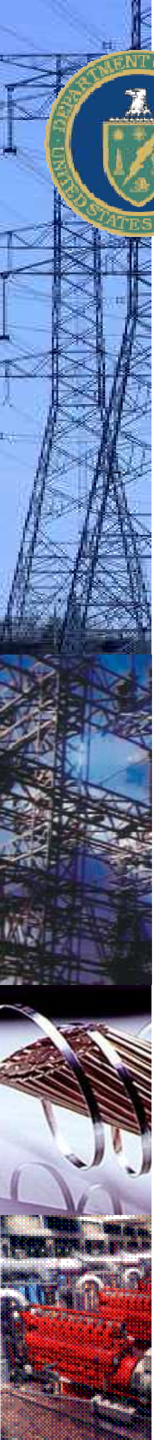
Sandia National Laboratories

## Fundamental breakthroughs in materials and components for next generation technologies and devices

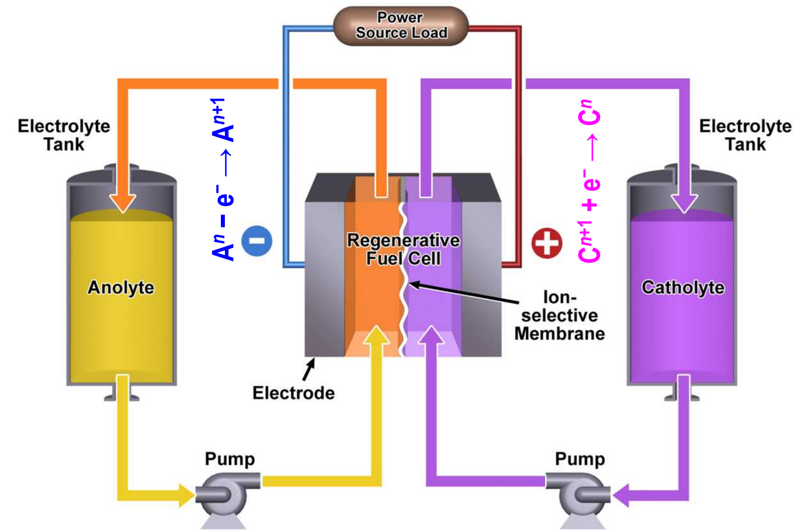
- Carbon- or graphite-based electrodes, nanocomposite materials for improved electrochemical activity, structural and chemical stability, and low electrical resistance.
- Fundamental understanding of the surface chemistry, electrochemical activity, degradation mechanism, electron and materials transport in complex carbon based electrode materials.
- Low cost, robust ion membranes with wide operating temperature range, good ionic conductivity, and no cross-contamination.
- Fundamental understanding of the complex electrochemical phenomena in the electrodes, electrolytes and at the interfaces.
- Novel concepts, mechanisms untraditional methods of energy storage using extremely low cost materials and environmentally friendly approaches.

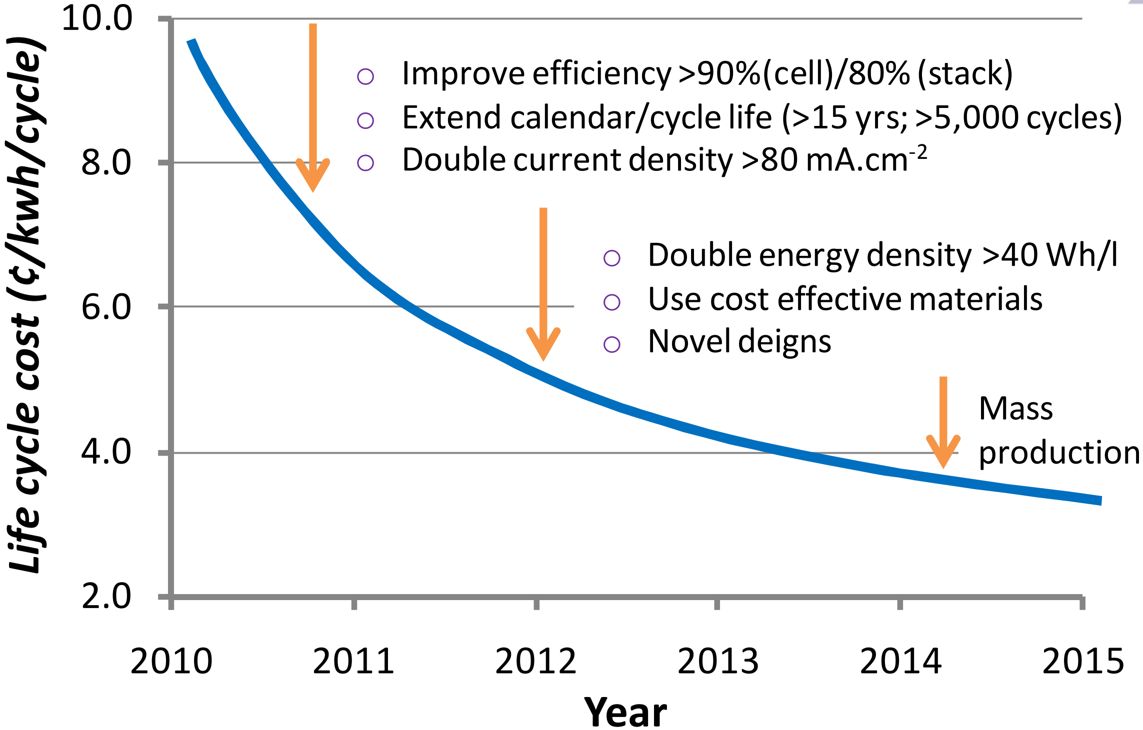


# High Performance, Low Cost Redox Flow Batteries from Fundamental Research to Application, PNNL



- Develop redox flow batteries (RFB) that can meet the performance and economic matrices for electrical grid applications
- Achieve via development of cost-effective, optimized electrodes, electrolyte, membrane and bipolar plates, along with implementation of novel cell/stack designs



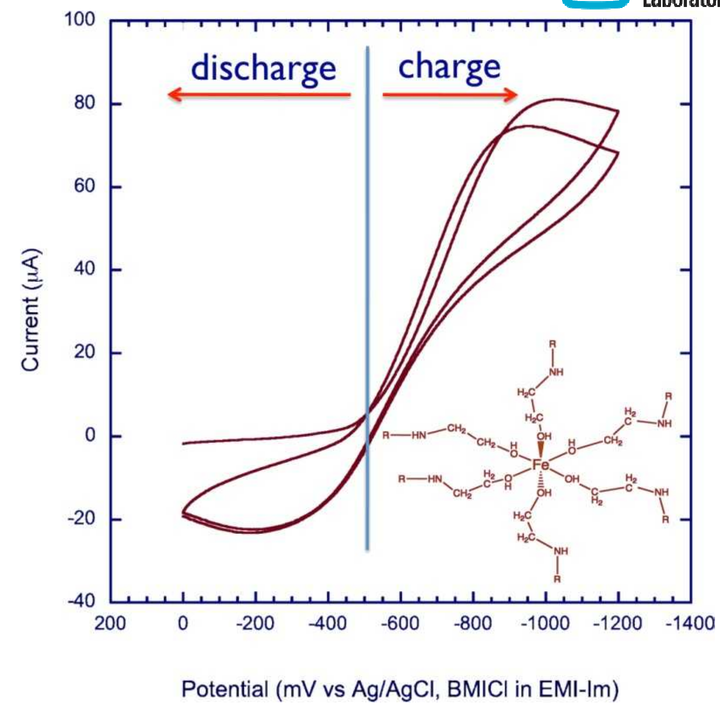




- Work with industries and universities to identify and solve core issues of RFB
- Establish RFB evaluation center and test bed to help industry R&D and demonstration efforts

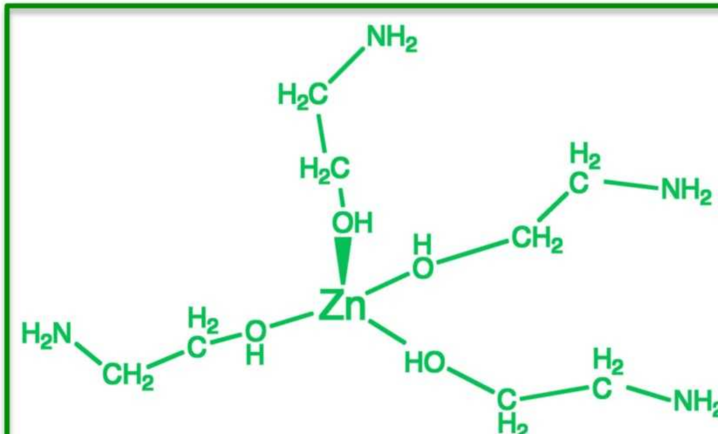
OE has funded three ARRA-RFB demonstration projects, and a number of SBIR and university efforts.

# New Redox Couples for Flow Batteries, Sandia

- Materials research and development for:
  1. Higher energy density materials
  2. Multi-functional materials – acts as both the electrolyte and energy storage medium
     - Multi-functionality engenders high energy density
  3. Low cost
  4. Safety
  5. Environmentally benign
  6. Cost effective scale-up options




Four different transition metal ionic liquids

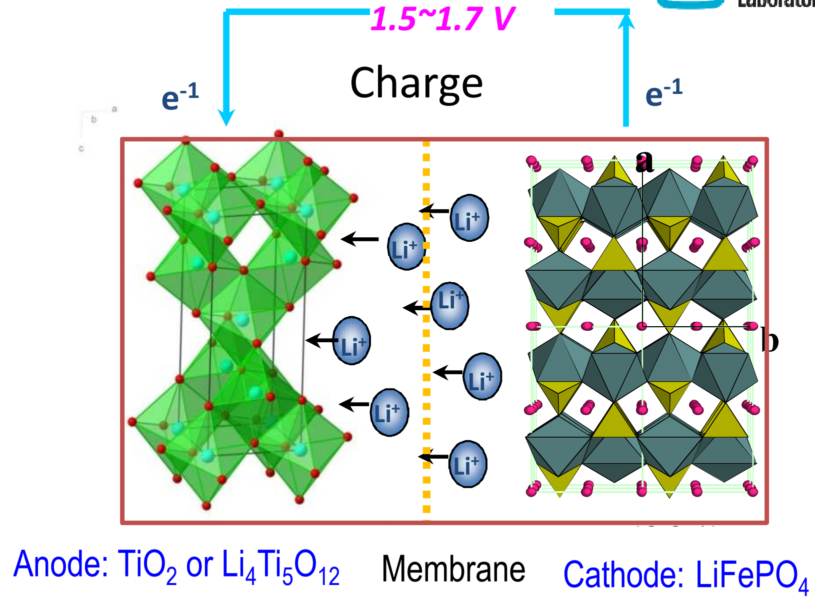


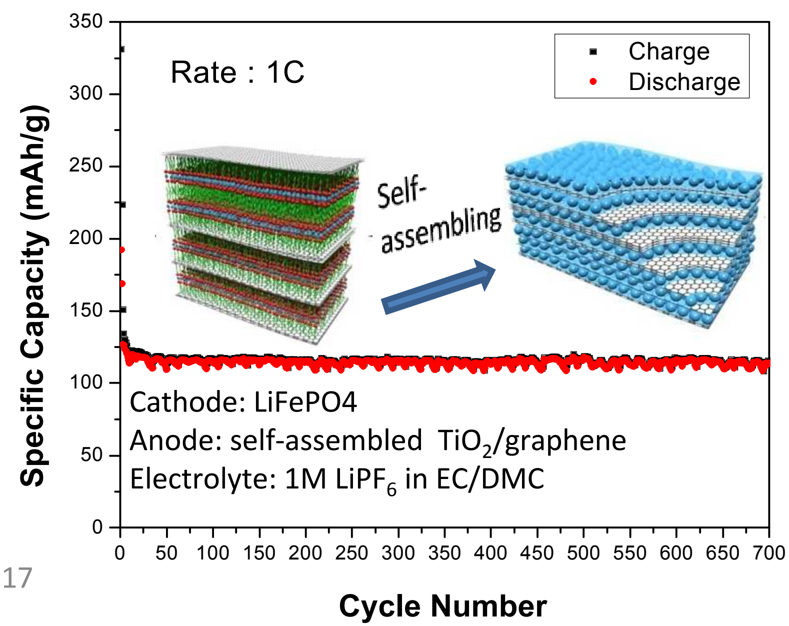

Zinc-based ionic liquid
(cation shown)

# Low Cost, Long Life Li-ion for Community Storage, PNNL

Sandia National Laboratories

- Develop unique Li-ion batteries that are advantageous over the conventional technologies in life and cost for community storage
- Focus on development of cost-effective, novel-structured electrodes and electrolytes, along with cell designs, for significant cost reduction (<$250/kWh) and much improved cycle life (>6,000 deep cycles)



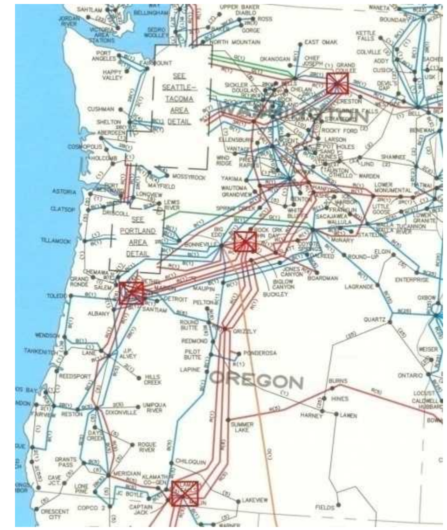

- Identified unique Li-ion chemistries: $TiO_2$ base anodes; $LiFePO_4$ base cathodes
- Developed nanostructured composite electrodes, using self-assembly and other novel approaches
- Demonstrated stable cell performance over 700 cycles, while involving a low reaction heat
- Engaging in materials optimizing and further cell investigation, along with cell designs

6 journal papers were published; two patents were filed.

# Analysis & Modeling to Answer Key Questions of Energy Storage, Renewable Integration and Grid Performance

## Long term questions

- How much stationary energy storage does the U.S. grid need in the near-term and long-term for different applications?
- What is the optimal distribution of that storage in terms of power to energy ratio?
- What are the cost and performance characteristics for the energy storage at desired scales and in different regions?
- What are the challenges to integrate energy storage into grid operations and transmission planning processes?
- What are the best practices, lessons-learned, and success storage of existing energy storage deployments and how can they be integrated to guide the future R&D agenda for energy storage?




**FY11 Plan:** National technical and economic assessment of energy storage potential to meet a high renewables RPS (wind and solar).

- ➢ Size
- ➢ Storage type
- ➢ Geographic locations
- ➢ Placement in the grid
  - ➢ Distribution system (community storage)
  - ➢ Transmission system (MWh sized system)

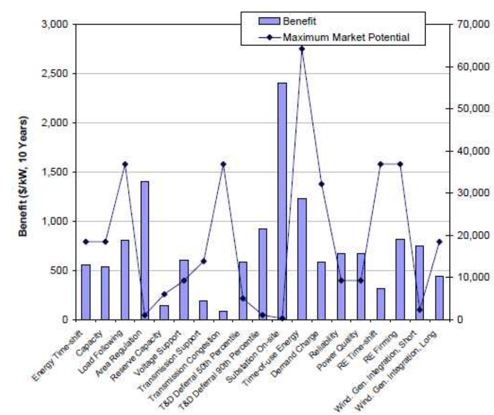
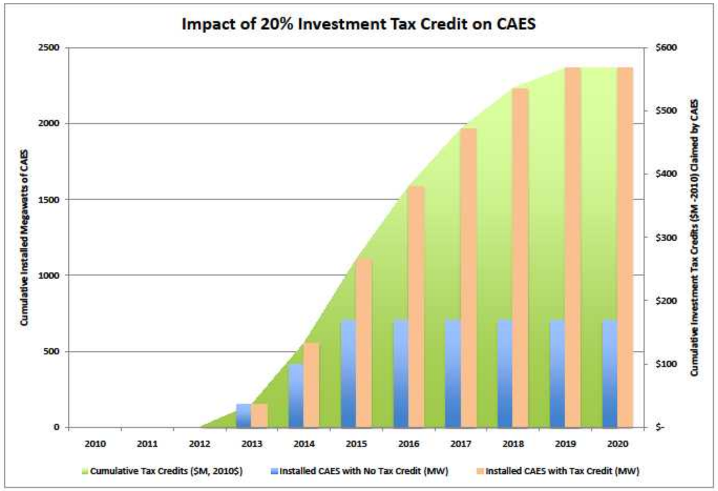


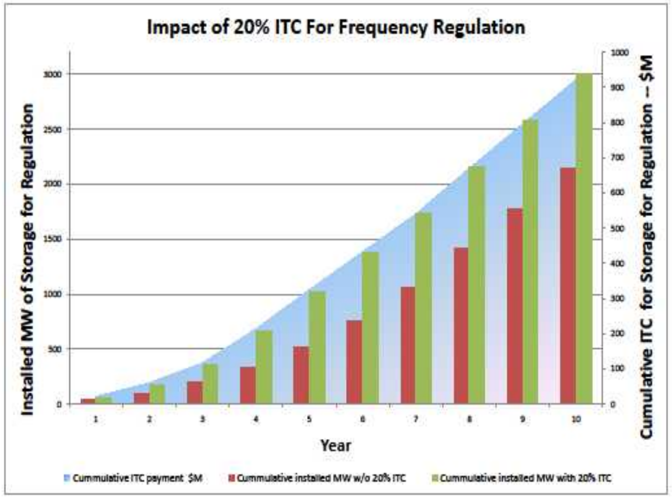

Figure ES-1. Application-specific 10-year benefit and maximum market potential estimates for the U.S.

➢ Develop supply curve of energy storage opportunities for grid applications by U.S. geographic regions.

# Industry 10 year Expectations



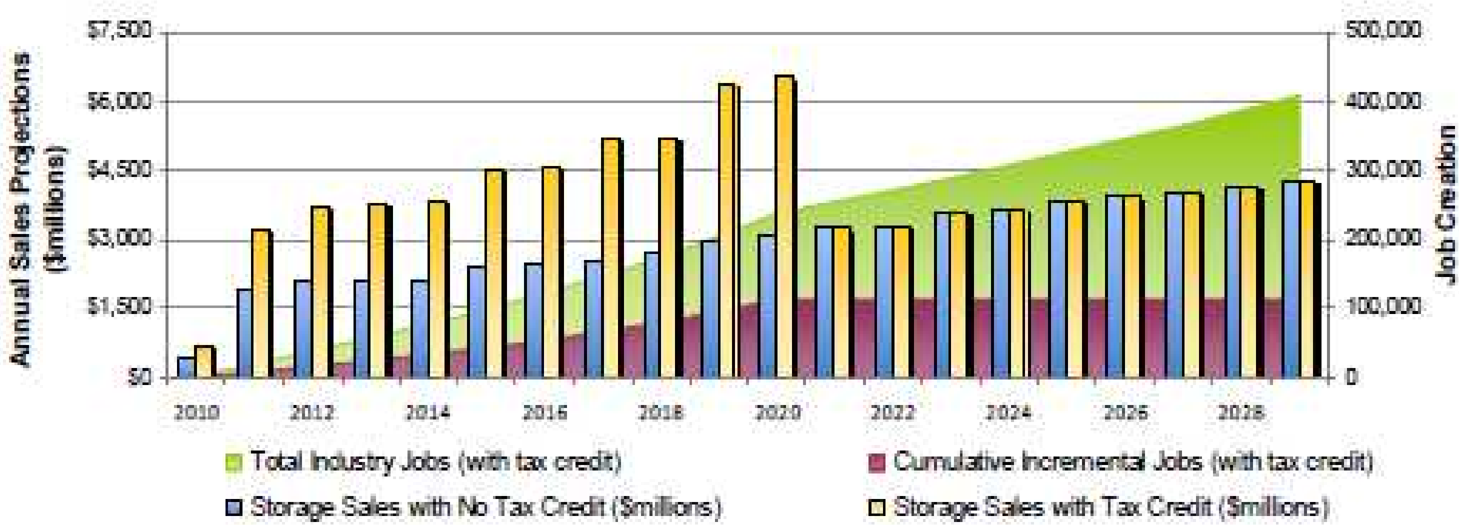

| | |
|---|---|
| 1,500 MW | Pumped Hydro |
| 700 MW | CAES |
| 1,500 MW | Renewable Integr. |
| 12,000 MW | T&D Support |
| 1,100 MW | Frequency Reg. |
| 2,100 MW | Thermal Storage |



# Energy Storage Jobs Report

The Electricity Storage Association funded a jobs study on the effect of the energy storage industry on US employment. The study was conducted by KEMA Inc.

- Estimated market size and penetration potential based on economic payback and the effect of Congressional incentives
- Over 250,000 jobs will created by 2020 with 114,000 due to the proposed investment tax credit



# Summary

Energy Storage Program Strategic Direction

- Provide leadership, develop integrated strategy and plan based on systematic analysis of the needs and technological gaps
- Maintain momentum
- Develop breakthrough energy storage technologies
- Collaborate with State Energy Programs, industry, utilities and academia
- Collaborate with DOE OS, ARPA-E, EERE

Make Energy Storage Ubiquitous

# Back Up Slides

- ARRA Projects
- SBIR Projects
- TRL for Energy Storage

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

A ten-fold Increase in Power Scale!

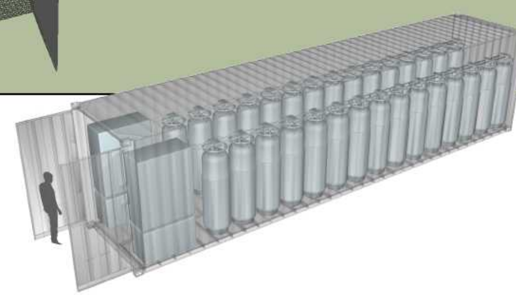
Large Battery System (3 projects,53MW)
Compressed Air (2 projects, 450MW)
Frequency Regulation (20MW)
Distributed Projects (5 projects,9MW)
Technology Development (5 projects)

$585M Costshare!

Sandia National Laboratories

# ARRA- Primus Power:

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

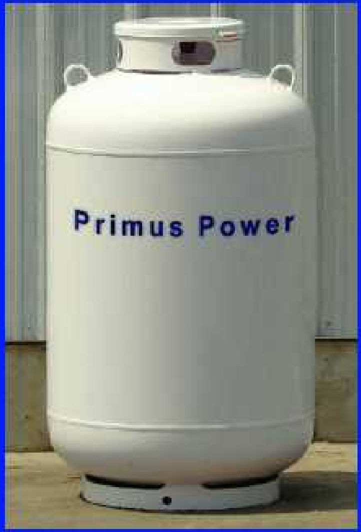
PRIMUS POWER

Primus Power Corporation
2450 Mariner Square Loop
Alameda, CA 94501

OLD

# ARRA- Primus Power:

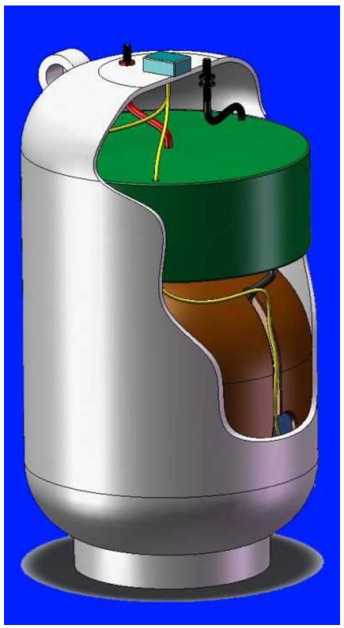
25MW / 3hr battery plant for the Modesto, CA Irrigation District, firming 50MW of Wind, replacing $75M of Gas fired Generation.




Totally sealed battery module
With a ZnCl electrolyte and
zinc and graphite electrodes

NEW

# ARRA - Primus Power:



# ARRA - NYSEG:

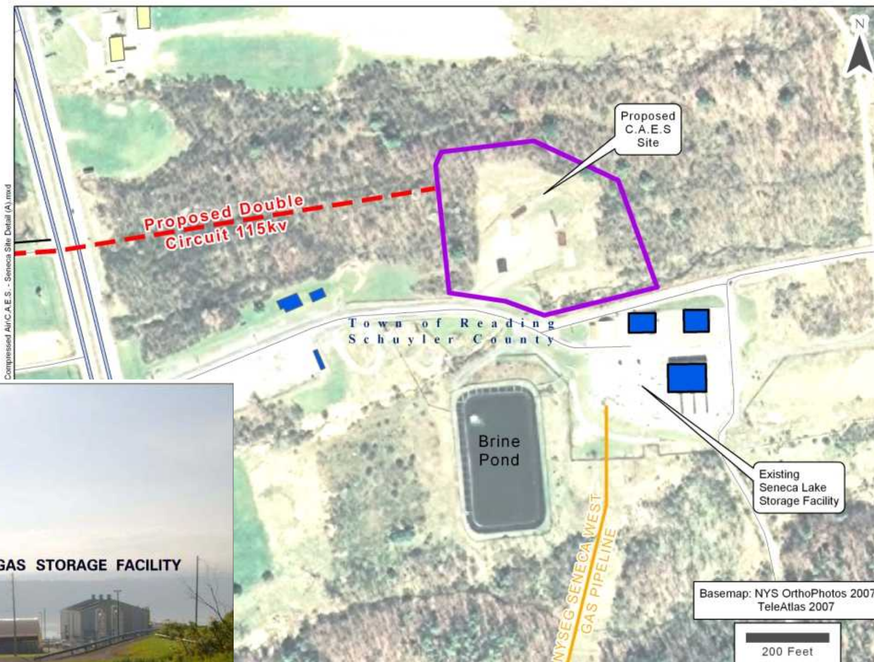
## 180 MW / 10hr Compressed Air Energy Storage Facility in Watkins Glen, NY

Layered Salt formation

Gas Pipe Line

Transmission Line

Installed Wind Generation

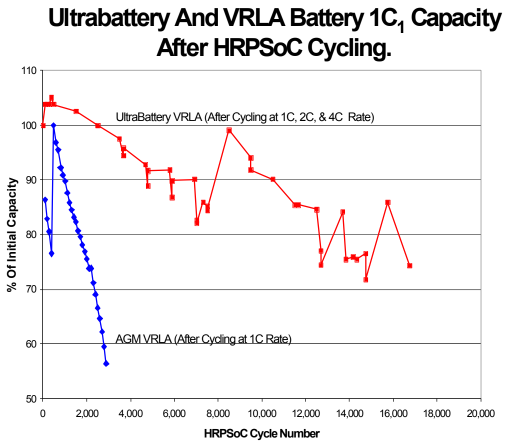



# ARRA - Beacon Power:

## 20MW Flywheel Storage for Frequency Regulation in PJM

# ARRA - East Penn:

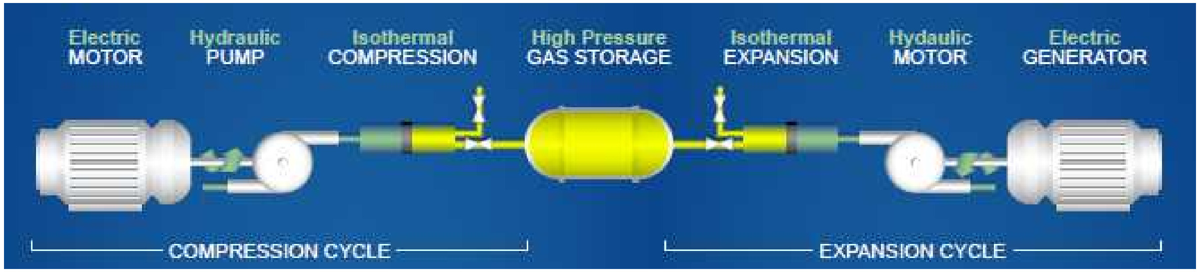
3MW Frequency Regulation + 1MW / 1hr Demand Management
Using new Lead-Carbon Technology




**New >200MW East Penn Battery Manufacturing Plant at Lyon Station, PA**

# ARRA - SustainX:

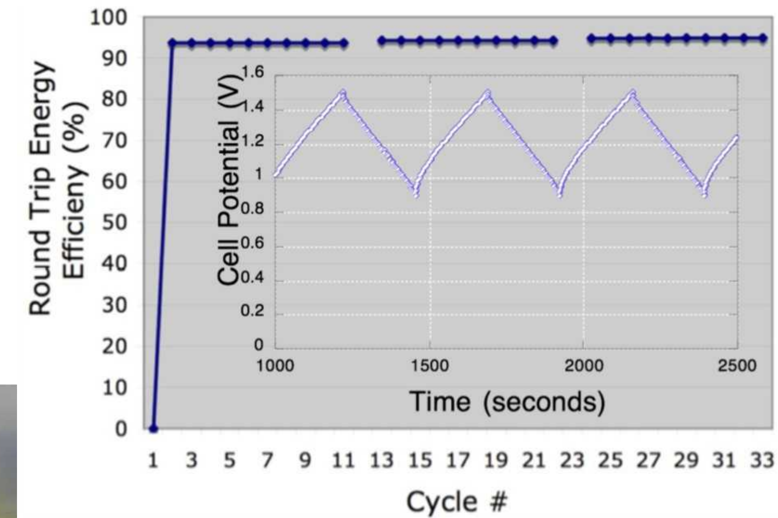
## Development of Isothermal Compressed Air Energy Storage Using Hydraulics

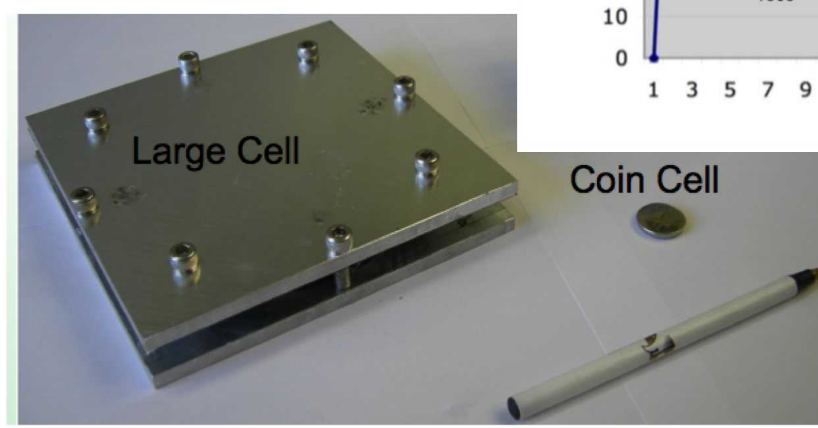


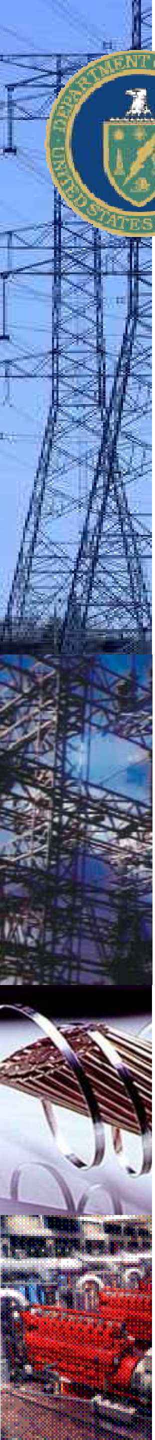

Experimental isothermal efficiency of 94.9% is achieved with the use of SustainX's technology as compared with 54% for an adiabatic technique.

# ARRA - Aquion Energy:
## Aqueous Sodium Ion Battery

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

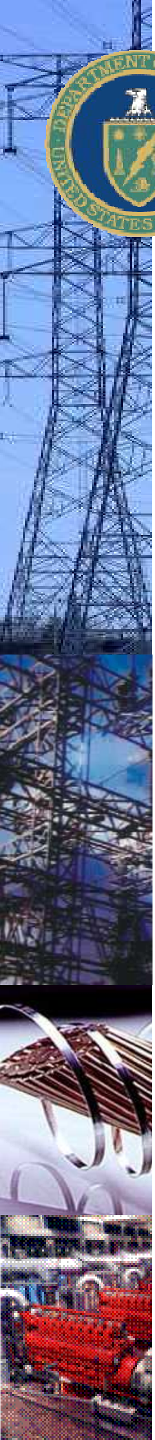




# SBIR Projects 1

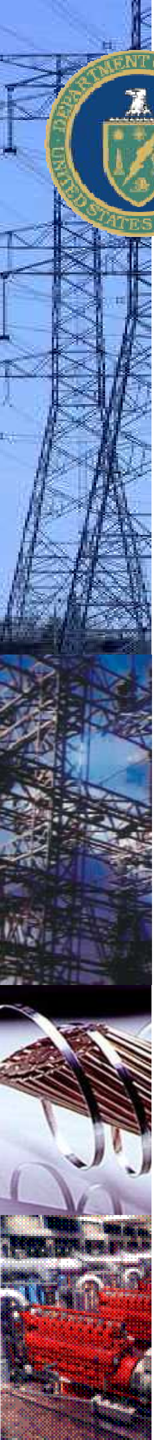
| Solicitation | Company | Project |
|---|---|---|
| FY09 Phase II Topic 6a (Energy Storage) | Excellatron Solid State, LLC | **Novel Solid State Electrolyte Development** (details) |
| FY09 Phase II Topic 6b (Energy Storage) | Enogetek, Inc. | **High Performance Hydroxyl Conductive Membrane For Advanced Rechargeable Alkaline Batteries** (details) |
| FY09 Phase I Topic 8a (Energy Storage) | Electrochemical Systems | **Development of High Energy, Low Temperature Rechargeable for Load Leveling Application** (details) |
| FY09 Phase I Topic 8a (Energy Storage) | Materials Modification | **Nanostructured Cathode for Magnesium Ion batteries** (details) |
| FY09 Phase I Topic 8a (Energy Storage) | Precision Energy and Technology | **Novel Hybrid Electrochemical Energy Storage Device** (details) |
| FY09 Phase I Topic 8b (Energy Storage) | Physical Sciences | **Non-Fracturing High Performance NiMH Negative Electrode** (details) |
| FY09 Phase I Topic 63a (Energy Storage) | NEI Corporation | **A Low Cost Utility-Scale Flow with a New Chemistry** (details) |
| F 09 Phase I Topic 63a (Energy Storage) | TDA Research | **Liquid Salt Redox Couples for Utility Scale Flow Batteries** (details) |
| FY 08 Phase I Topic 6a (Energy Storage) | NEI Corp. | **Membranes for Lithium Batteries** (details) |
| FY08 Phase I Topic 6b (Energy Storage) | Enogetek | **High Performance, Hydroxyl Conductive Membrane for Advanced, Rechargeable Alkaline Batteries** (details) |
| FY08 Phase I Topic 6b (Energy Storage) | Lynntech | **Solid Hydroxyl Conducting Electrolyte** (details) |
| FY08 Phase I Topic 6b (Energy Storage) | Giner | **Composite Alkaline Electrolyte with Improved Hydroxide-Ion Transport Number** (details) |
| FY08 Phase I Topic 29b (Power Electronics) | Power | **SiC-based Solid-state Fault Current Control System for Vulnerability Reduction of Power Distribution Networks** (details) |



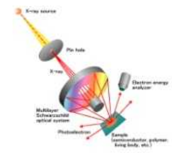
# SBIR Projects 2

| | | |
|---|---|---|
| FY08 Phase I Topic 29b (Power Electronics) | Electrocon Int'l, Inc. | **Simulating the Smart Electric Power Grid of the 21st Century** (details) |
| FY08 Phase I Topic 28a (Power Electronics) | Aegis Technology | **Advanced High Temperature Packaging with Non-Wire Bond Interconnection for SiC Switches** (details) |
| FY 08 Phase II Topic 45a (Power Electronics) | Genesic Semiconductor | **Large Area SiC GTO Thyristor Development: Wideband Gap High Voltage High Frequency Switches** (details) |
| FY 08 Phase II Topic 45a (Energy Storage) | Giner, Inc. | **Nano-engineered Carbon Electrochemical Capacitors** (details) |
| FY 07 Phase I Topic 45c (Energy Storage) | Technologies | **High Performance, Carbon Nanomaterials for Electrochemical Capacitors** (details) |
| FY 07 Phase I Topic 45c (Energy Storage) | Giner | **Nano-engineered Carbon Electrochemical Capacitors** (details) |
| FY 07 Phase I Topic 45a (Power Electronics) | Genesic Semiconductor | **Large Area SiC GTO Thyristor Development: Wideband Gap, High Voltage, High Frequency Switches** (details) |
| FY 07 Phase I Topic 45a (Power Electronics) | Semisouth Laboratories | **An Innovative Silicon Carbide (SiC) 6-KV, 1-KA Gate Turn Off (GTO) Thyristor** (details) |
| FY 07 Phase I Topic 45a (Power Electronics) | Solitronics | **High Voltage SiC Emitter Turn-off Thryristor** (details) |
| FY 06 Phase II Topic 1a (Power Electronics) | Aegis Technology | **An Advanced Power Converter System Using High Temperature, High Power Density SiC Devices** (details) |
| FY 06 Phase II Topic 1a (Power Electronics) | Power | **Very High Temperature (400+ °C), High Power Density (100kW), Silicon Carbide (SiC), Three-Phase Inverters** (details) |

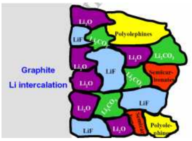
# Technology Readiness Level Definitions Related to Energy Storage

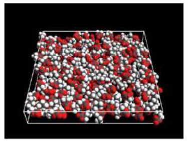


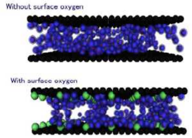
- **TRL-0: Scientific Capability for Research, Possibly Used for Energy Storage**
  - Example: New surface science instrument or supercomputer



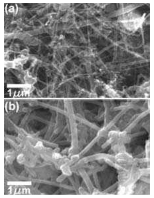
- **TRL-1: Basic Science Investigation**
  - Example: Validation of a new experimental method or insight or simulation of new chemistry or surface functionality

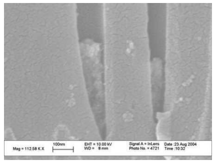


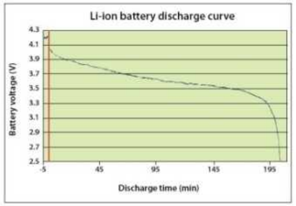


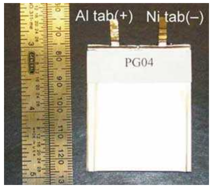

- **TRL-2: Platform Science Demonstrated or Formulated**
  - Example: Design, synthesis and characterization of nanostructures to study interfaces, or half-cell testing



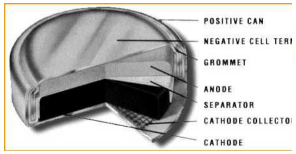
- **TRL-3: Proof-of-Concept Device Fabrication and Test**
  - Example: Basic experimental testing of new battery for basic functionality




**Basic & Exploratory Research**

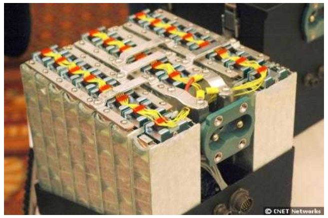
# Technology Readiness Level Definitions Related to Energy Storage




- **TRL-4: Component Level Development on Lab Scale**
  - Example: Development and testing of functional storage as proof-of-concept device, for example in coin or 18650 cell size.

- **TRL-5: Component Development and Test at Prototype Scale**
  - Example: Development of functional prototype storage <u>component</u> at bench scale, for instance 1-25kW power rating, and tested for functionality as system relevant hardware.

- **TRL-6: System / Subsystem Prototype**
  - Example: Development of functional prototype storage <u>system</u>, including power conditioning and control interface, at bench scale. For instance, system of 1-25kW power rating tested in a controlled, use relevant, environment.



**Applied Research & Technology Development**

# Technology Readiness Level Definitions Related to Energy Storage

- **TRL-7: System Prototype Validation Testing**
  - Example: Full-scale pilot-testing of a grid-scale storage system as hardware in the loop in a controlled test-bed, with capability for controlled environment testing.


- **TRL-8: Systems Qualification Testing**
  - Example: Full-scale pilot-testing of a grid-scale storage system as hardware on the grid in monitored test-bed under four-season environment conditions


- **TRL-9: Mission Deployment Assessment**
  - Example: Failure analysis or field reliability testing
  - of grid-deployed storage systems.


**Pilot Manufacturing, Testing, and Adoption**