Stationary (Grid-level) Energy Storage Technologies

Mark Johnson, Program Director

Advanced Research Projects Agency – Energy

Imre Gyuk, Program Manager

Electricity Delivery and Energy Reliability

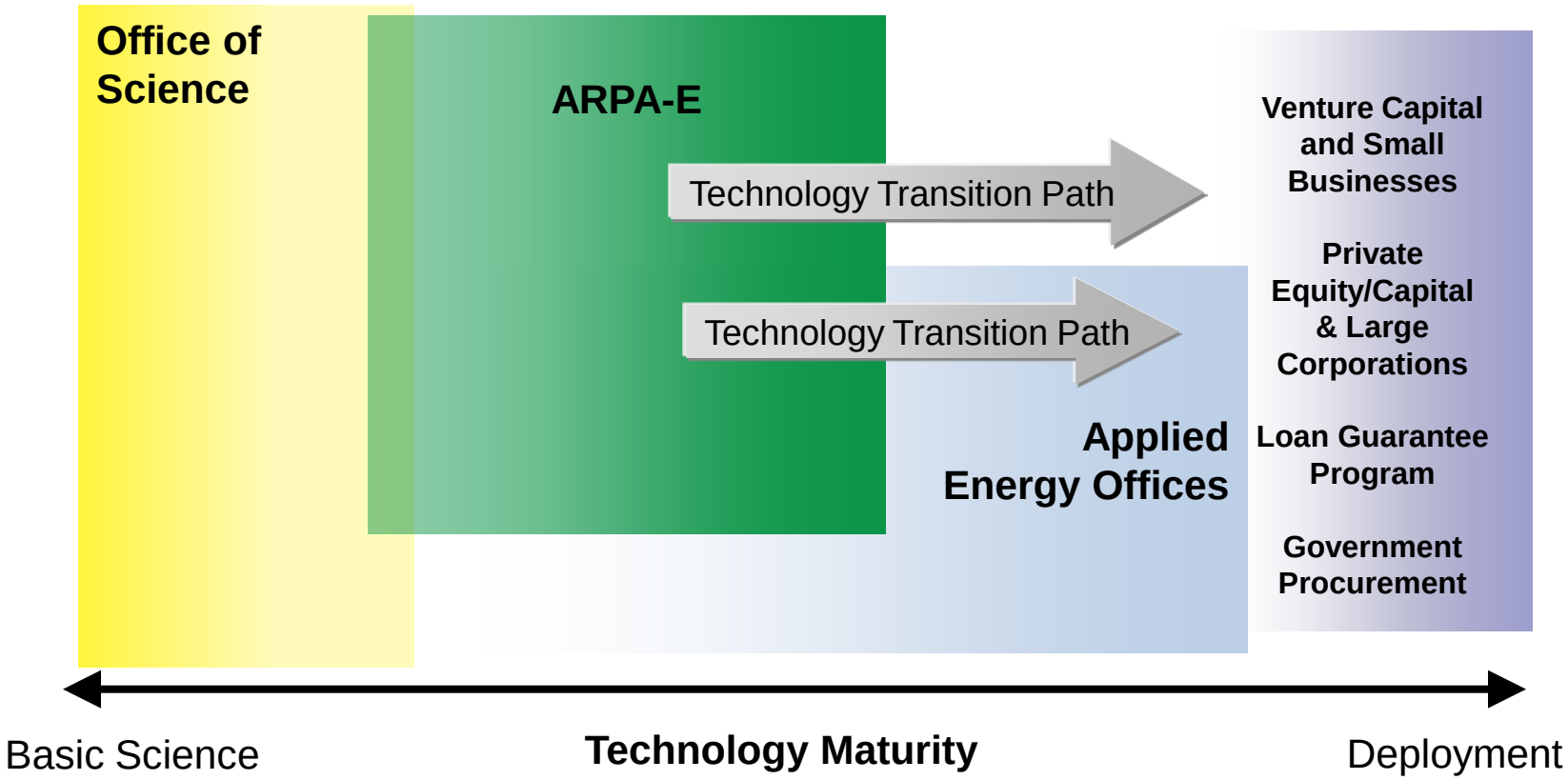
October 21, 2011

Overview of Stationary Energy Storage

Energy Storage at ARPA-E

OE Energy Storage Program

Energy Innovation Pipeline – Partner Across Boundaries

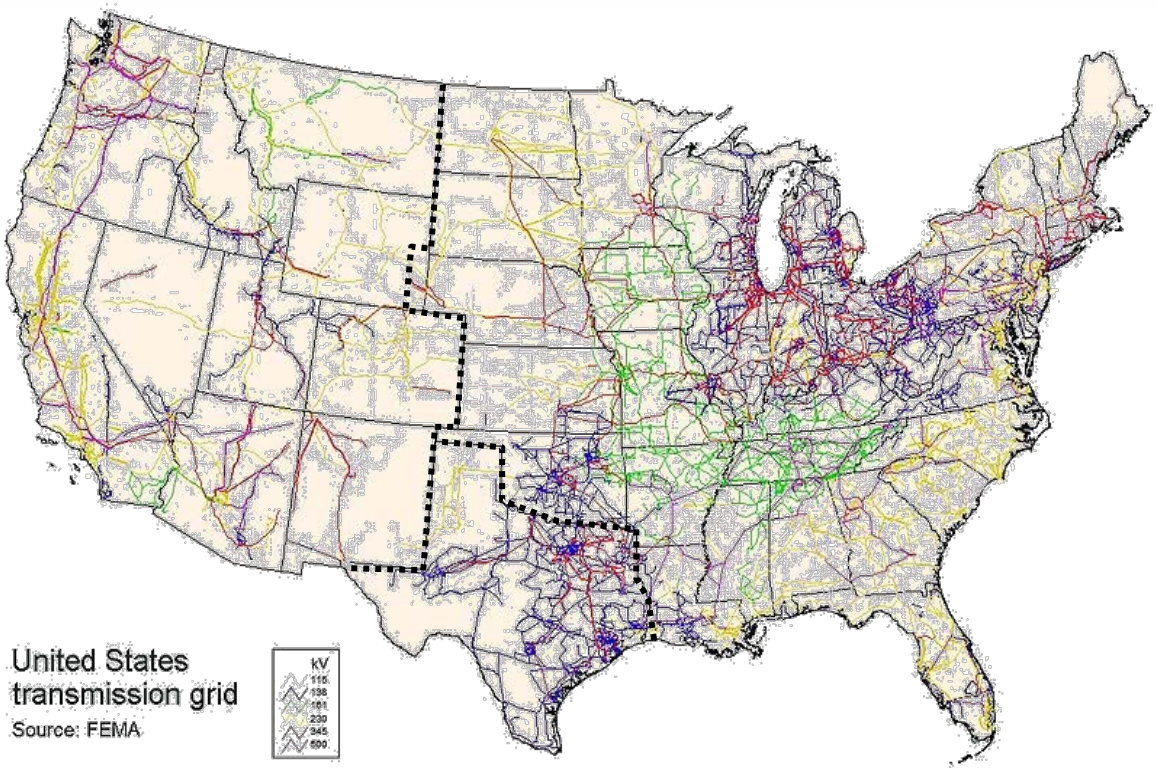


US Power Grid: World Largest Supply Chain With No Warehouse

Electric Grid: Premier Achievement of 20th Century [NAE]

Harness Renewable Power: #1 Challenge for 21st Century

Storage Separates Electric Generation and Load in Space and Time



Rule of Warehouses: Low Storage Cost Matters

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

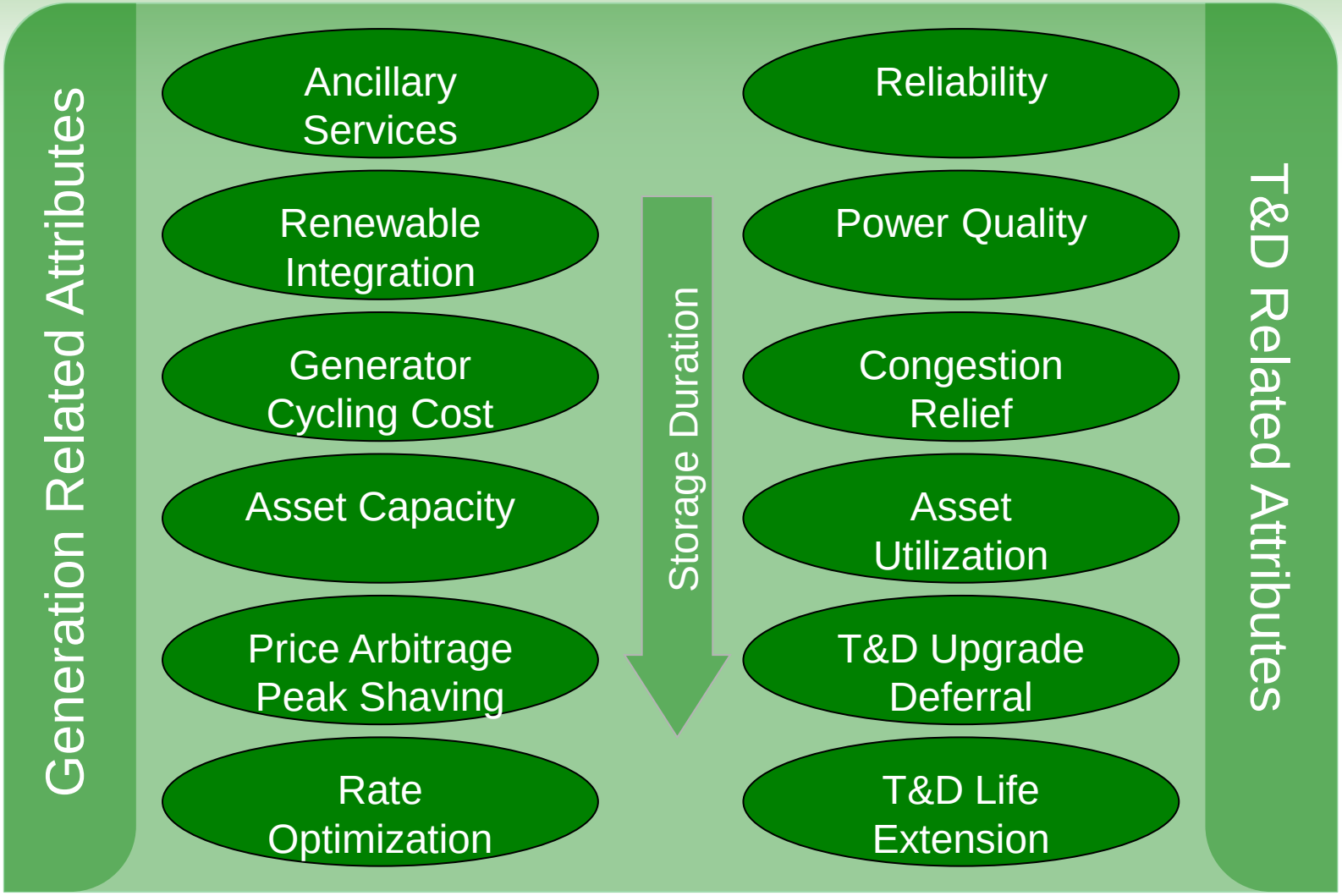
The need for regulation services can dramatically increase as the amount of variable renewable resources is increased. Local storage is among the best means to ensure we can reliably integrate renewable energy resources into the grid.

FERC Chairman Wellinghoff, 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

Electric Energy Storage Applications



Differentiation: Capacity (Power), Duration (Energy), Ramp Rate (Rate of Change) and Cycle-Life

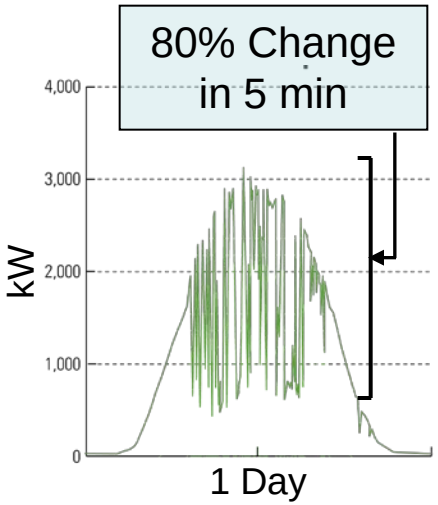
Overview of Stationary Energy Storage

Energy Storage at ARPA-E

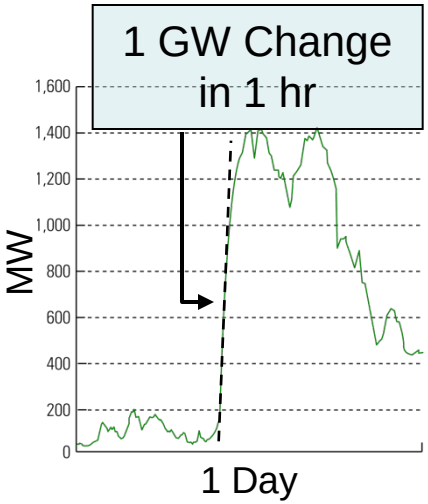
OE Energy Storage Program

Example: Storage For Firming Renewable Generation

Solar PV in AZ (TEP)



Wind in OR (BPA)



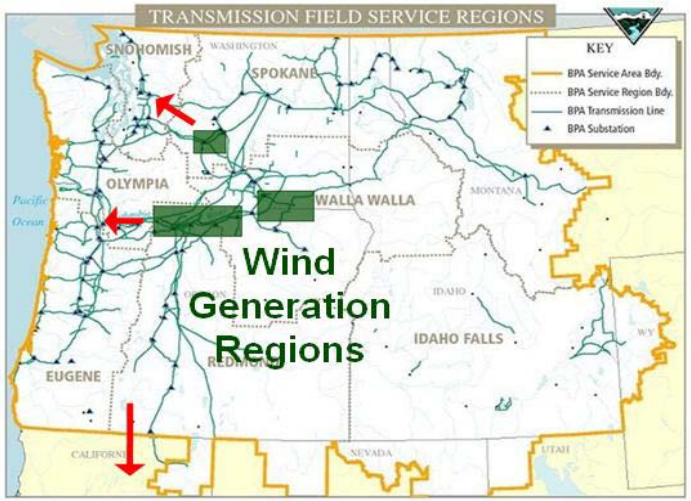
Problem:
Minutes-to-Hours Changes in Power

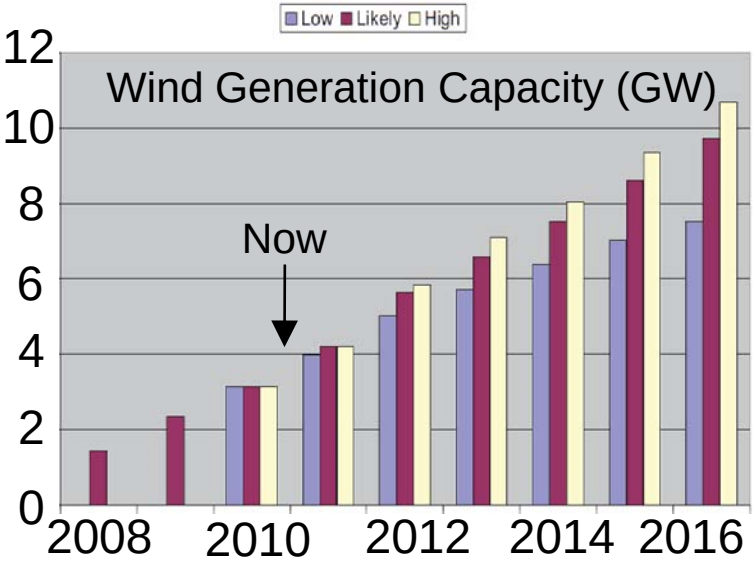
Need: Grid Storage that is Dispatchable and Rampable
ARPA-E: Energy Storage to Enable High Penetration of Renewables

High Renewable Generation Integration

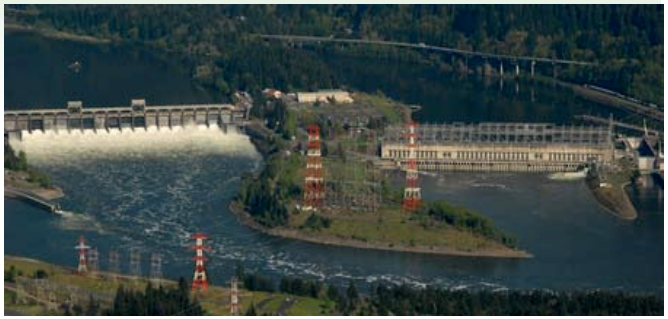
Challenge is a Grid Problem, not a Storage Problem

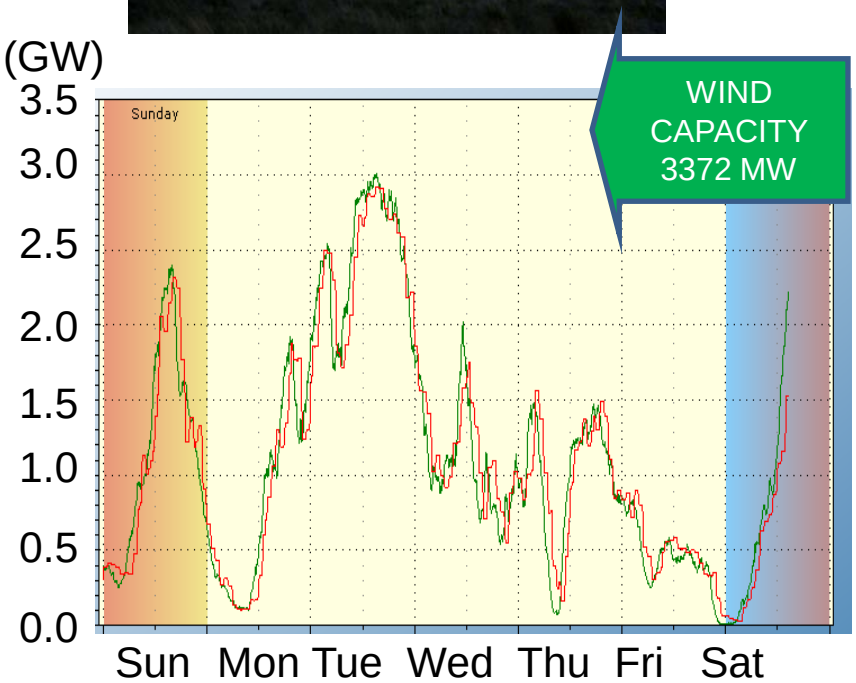
- Larger Balancing Authority
- Increase Transmission Capacity
- Improved Situational Awareness
  - Real Time Knowledge
  - Improved Weather Models
  - Generation Protocols
- New Storage Technologies



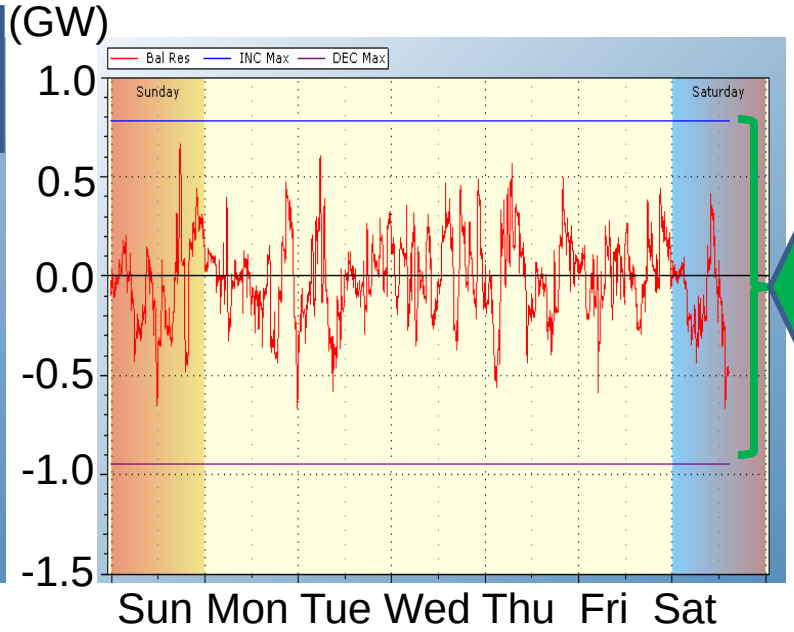


Balancing Reserves Firming Wind Generation for High Renewable Penetration on Power Grid





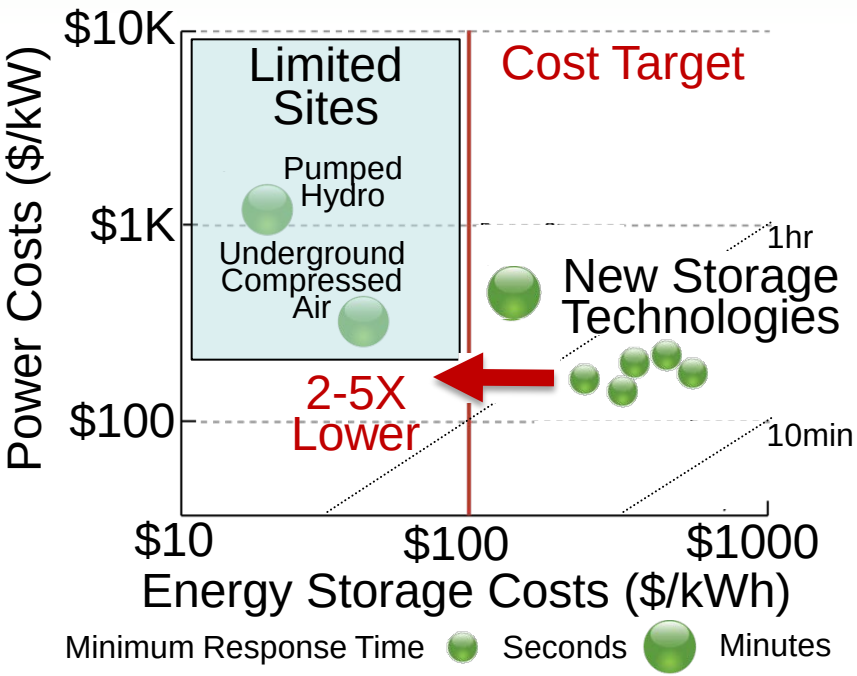
WIND CAPACITY 3372 MW



HYDROPOWER RANGE 1600-2000MW

System Challenge: Efficient Energy Storage at Minutes to Hours Duration to Firm Ramping Balance

Grid-scale Rampable Intermittently Dispatchable Storage (GRIDS) Metrics



Economics of Hydro / Deployable Anywhere

Technology Agnostic:
Chemical, Mechanical, Electromagnetic

Connect Across Industry for Handoffs

Needs: Low Cost, Highly Reliable, Scalable, Highly Efficient Energy Storage

Focus: Transformational approaches to energy storage to enable low cost

New Technology Need: Cost-Effective Energy Storage Solutions

Portfolio of Projects: ARPA-E Gridscale Rampable Intermittently Dispatchable Storage (GRIDS) Program

UNIVERSITY/ LAB

USC UNIVERSITY OF SOUTHERN CALIFORNIA

Rechargeable Fe-Air Battery

BERKELEY LAB

Advanced Flow Battery

CUNY The City University of New York

Rechargable $Zn\text{-}MnO_2$ Battery

SMALL BUSINESS

PRIMUS POWER Smart Grid Storage

New Flow Battery Electrode

FLUIDIC ENERGY

High Power Metal-air Storage

Proton ENERGY SYSTEMS

Neutral Water Fuel Cell

Beacon POWER

Long Duration Flywheel

GENERAL COMPRESSION expanding clean power

Fuel-Free Isothermal Compression

CORPORATION

United Technologies Research Center

Advanced Flow Battery

GENERAL ATOMICS AND AFFILIATED COMPANIES

Soluble Lead Flow Battery

ABB

2G-HTS SMES

BOEING

High-Energy Flywheel

Transformative Electrochemical Flow Storage System

United Technologies Research Center

Clipper

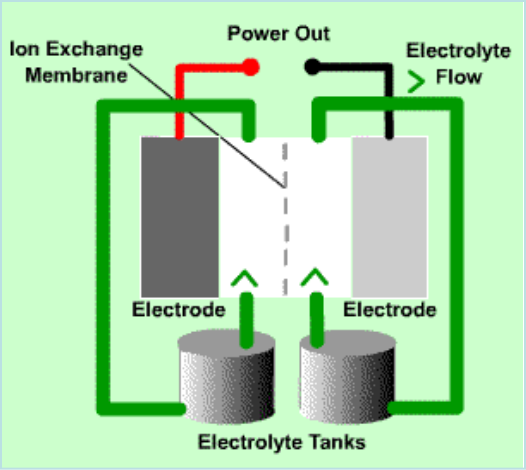
Pratt & Whitney
A United Technologies Company

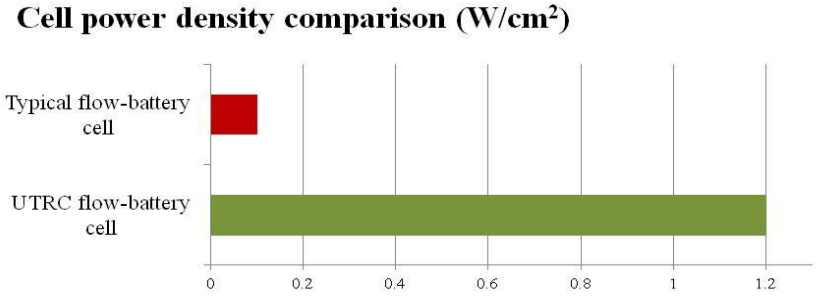
Pratt & Whitney Rocketdyne, Inc.

A unique flow battery cell that provides 10X increase in power density

Novel cell design will reduce system cost by 2-4X

Jump-starts domestic effort in redox flow batteries, which had migrated out of North America





Rechargeable Iron-Air Battery

Cell Reaction:

$$Fe + H_2O + \tfrac{1}{2} O_2 \Leftrightarrow Fe(OH)_2$$

Anode: *(discharge)*

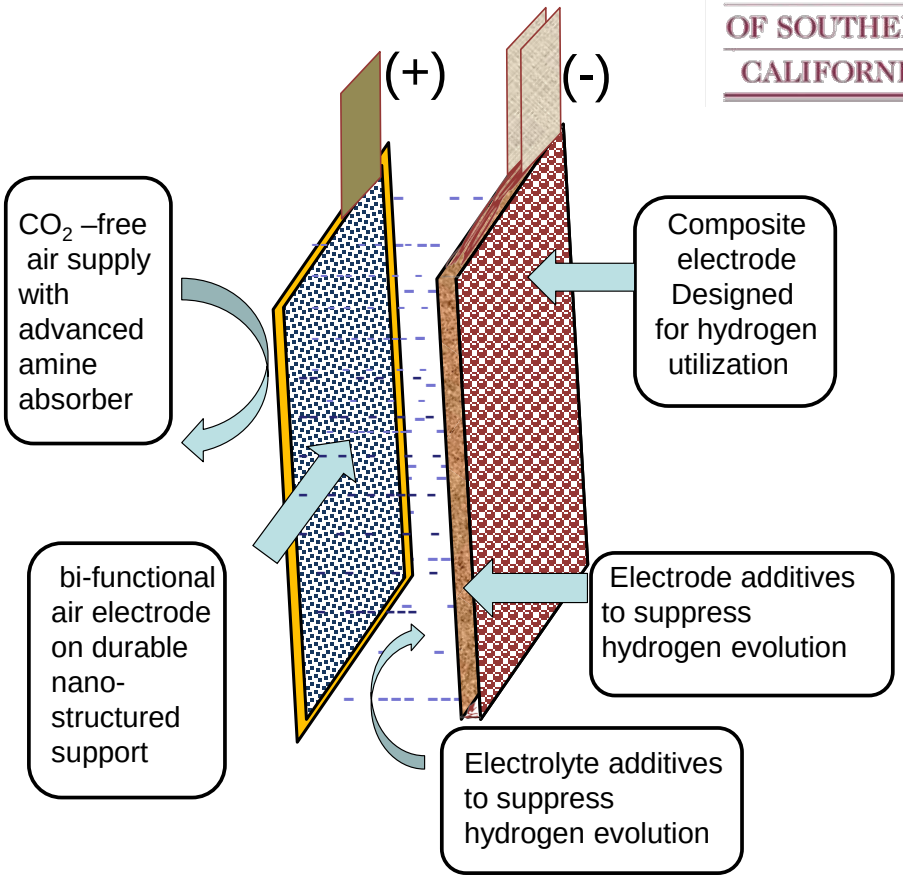
$$Fe + 2OH^- \Rightarrow Fe(OH)_2 + 2e^-$$

Cathode: *(discharge)*

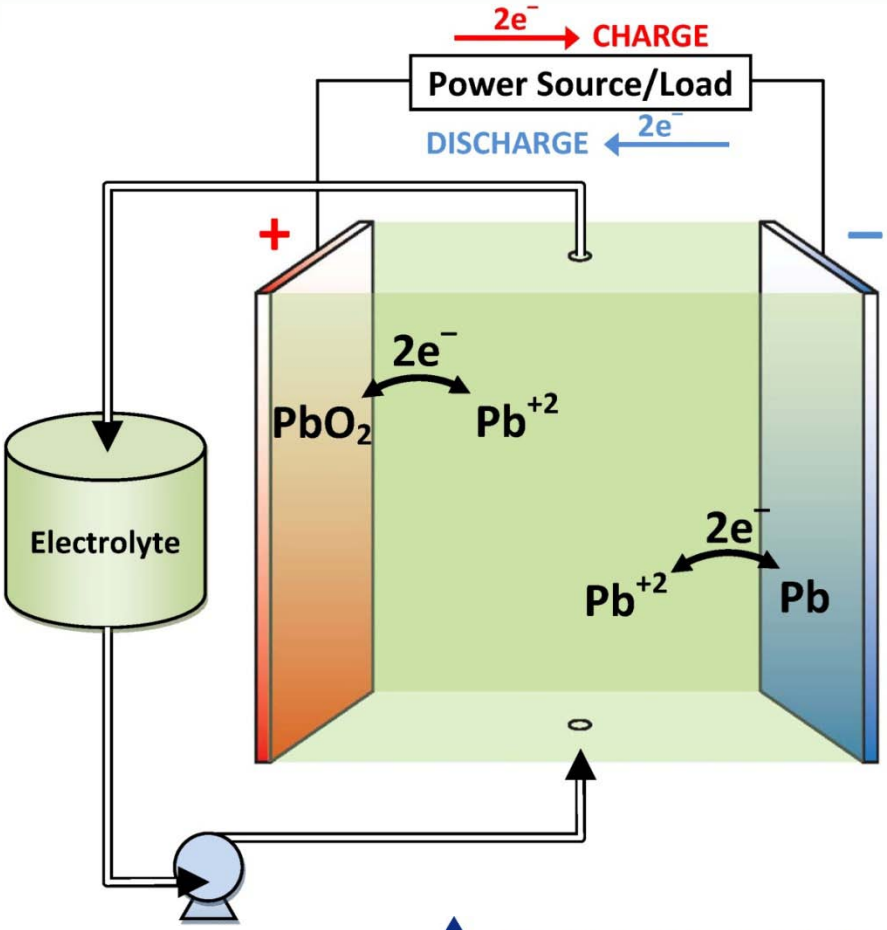
$$\tfrac{1}{2} O_2 + H_2O + 2e^- \Rightarrow 2OH^-$$

< $100/kWh & >5000 cycles high power, low cost, electrochemical storage

"Iron is Cheap, Air is Free"



Grid Scalable Lead Acid Battery



Innovations

- MSA-based electrolyte
- Carbon-based electrodes
- Flow-battery design

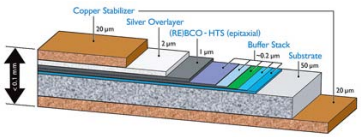
Impact

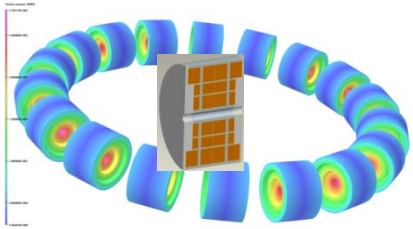
- Cost Reduction
- Grid Scalable
- Cycle-life Improvement

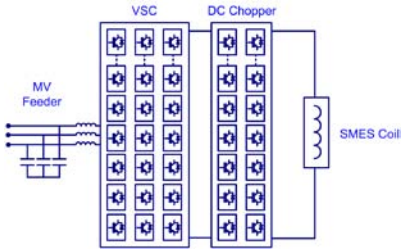
GENERAL ATOMICS

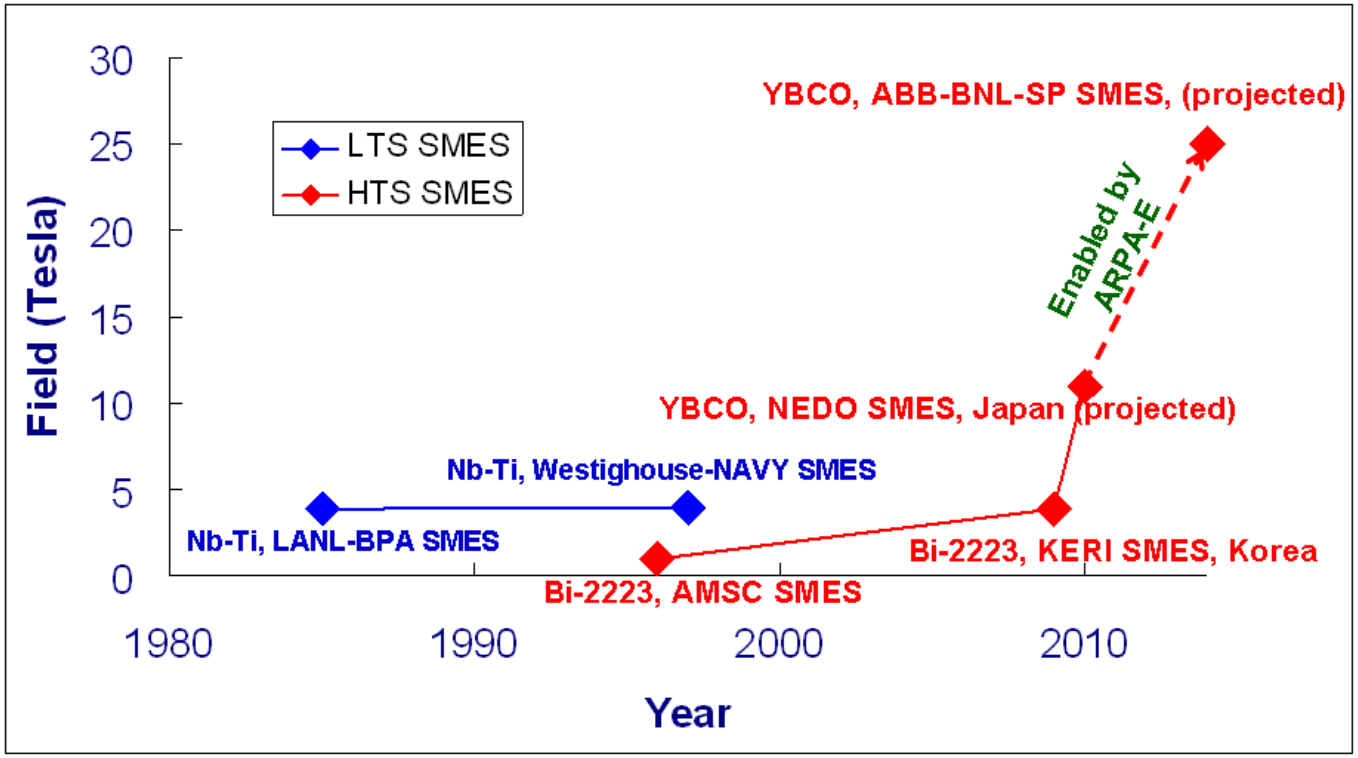
UCSD Jacobs | Department of NanoEngineering

End Stationary Storage Technology is Not All Just Electrochemistry: Superconducting Magnet Energy Storage

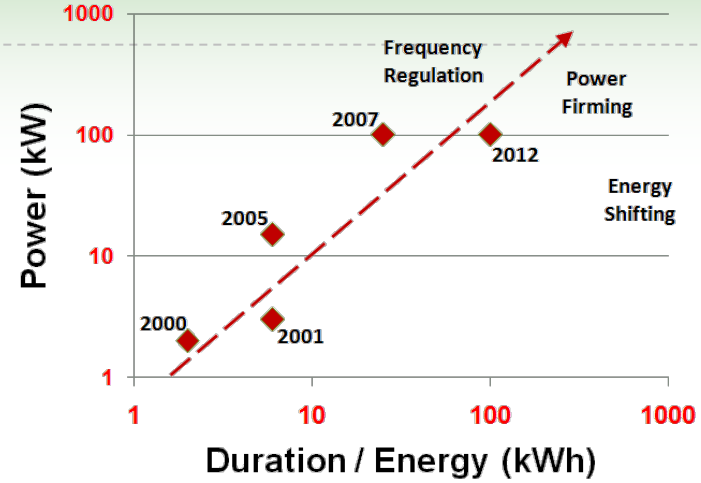








End Stationary Storage Technology is Not All Just Electrochemistry: Flywheel Storage



Beacon POWER

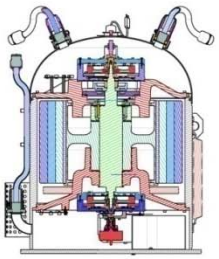
100 KWH
ARPA-E Supported

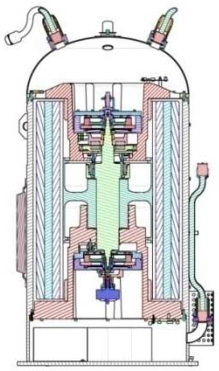
25 KWH
2002060

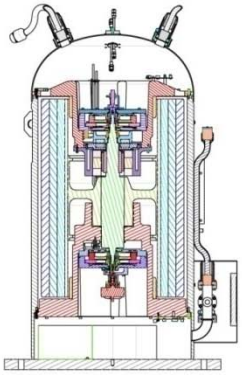
DEMO
2002053

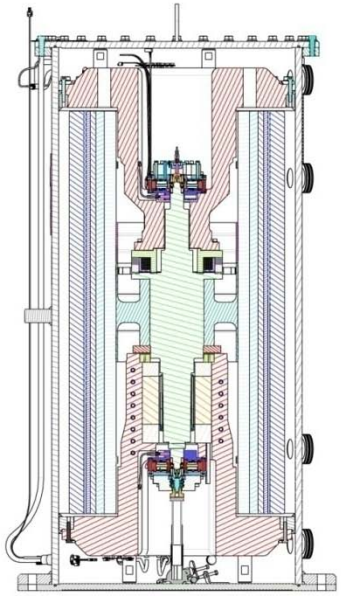
6 KWH
2002046

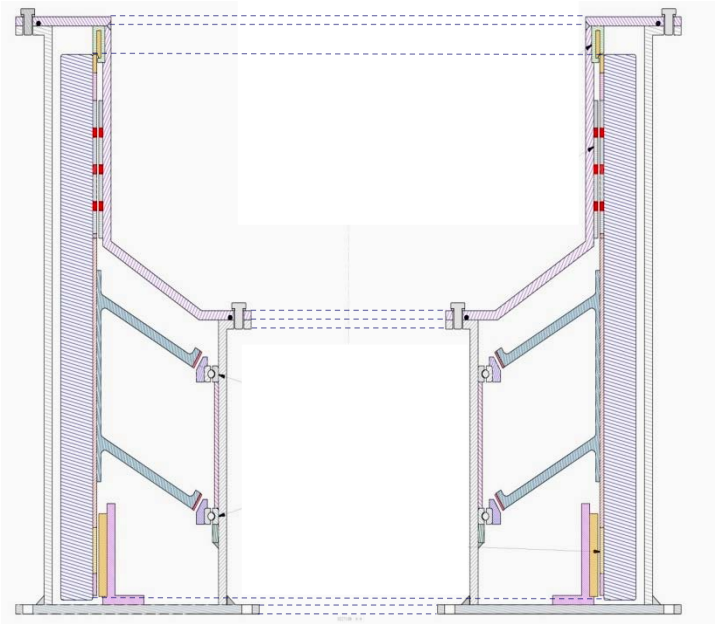
2 KWH
2002044











2000 **2001** **2005** **2007** **2012**

Overview of Stationary Energy Storage

Energy Storage at ARPA-E

OE Energy Storage Program

OE Stationary Storage Program

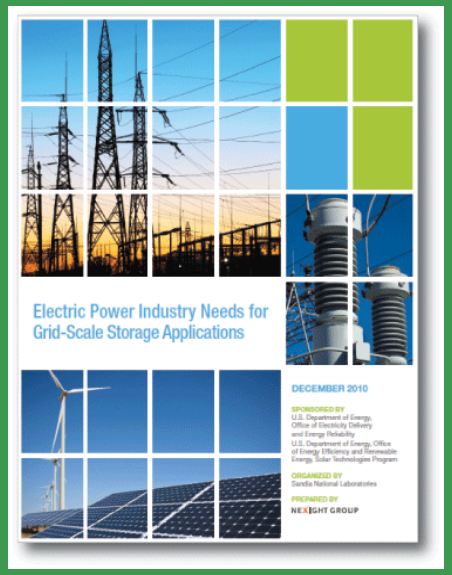
OE stationary storage program pursues
research in developing new chemistries and devices,
pioneering demonstrations and deployments,
and stimulates new approaches through use case analysis

OE storage program currently leverages expertise at Sandia, PNNL, and Oak Ridge, supports university research projects, manages 6 SBIR projects jointly with BES.

OE partners with ARPA-E to translate stationary storage projects towards commercial adoption.

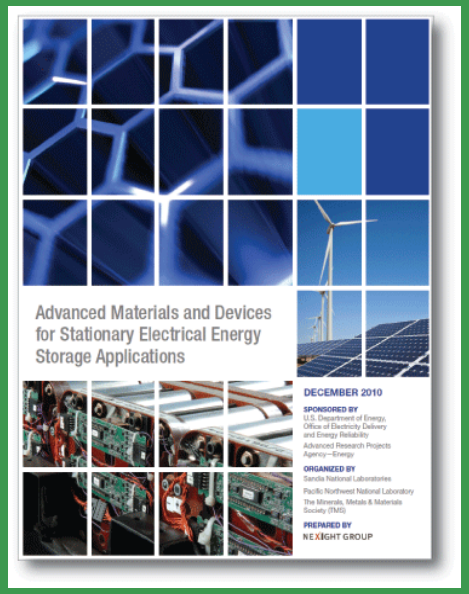
OE program manages the ARRA Smart-Grid Storage Demonstration Program through NETL.

Stakeholder Workshops and Integrated DOE Stationary Storage Applied Technology

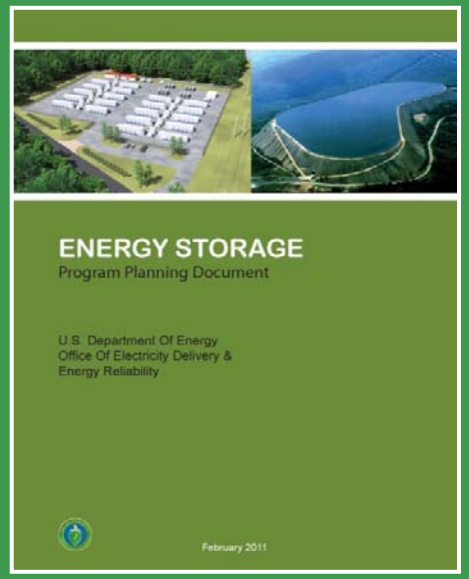


Utility Requirements With EERE-PV

Under the Auspices of the Materials Society



Material Needs With ARPA-E



OE Energy Storage Program Plan

Stationary Storage 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 $LiFe(Mn)PO_4$

Detailed component cost model for redox batteries

Stationary Storage 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

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

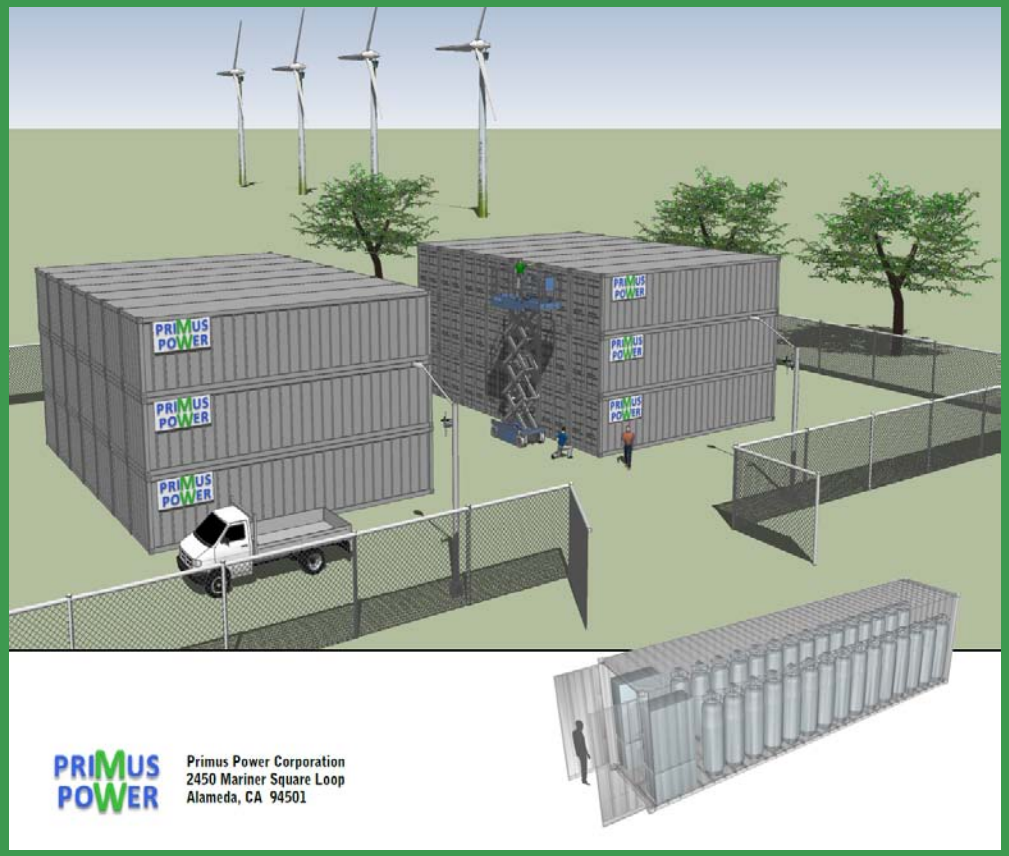
A ten-fold Increase in Power Scale!

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

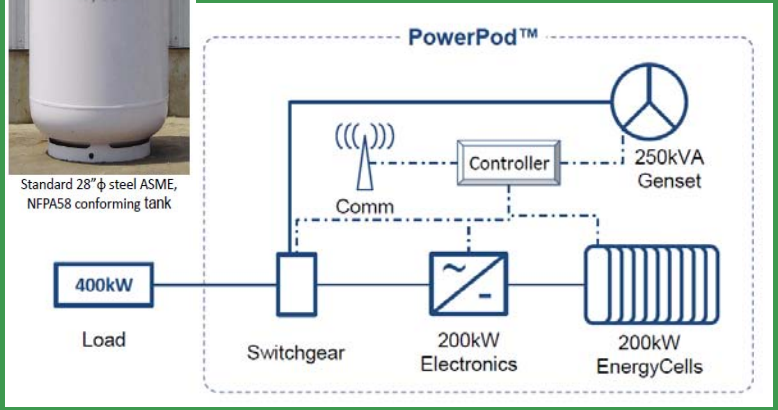
533MW - $585M Costshare!!

ARRA- Primus Power:

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



Standard 28"ϕ steel ASME, NFPA58 conforming tank



Totally sealed battery module with a Zn-Halogen electrolyte and long-life metal electrodes developed with ARPA-E support

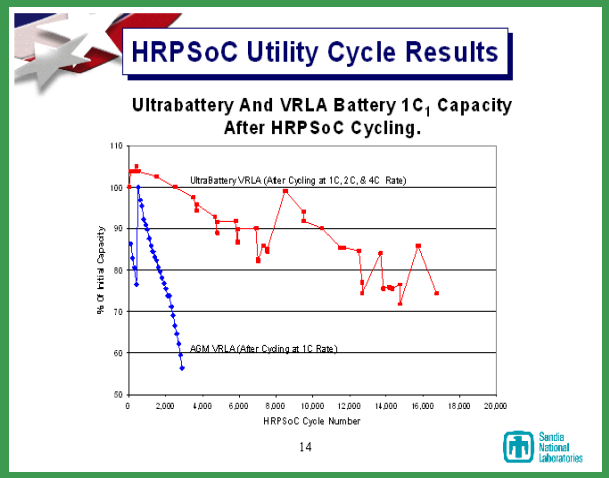
ARRA - Southern California Edison / A123 – Li-Ion:

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

A Tehachapi Wind Field

8MW Storage Plant under Construction

5 ARRA Distributed Projects = 9 MW Peak Shaving, Energy Management



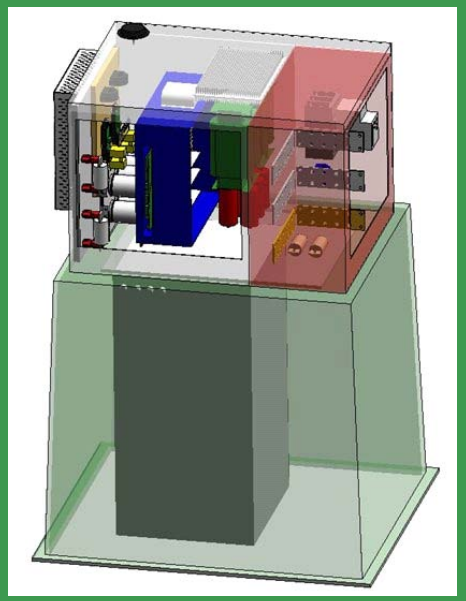
Testing at Sandia: PbC Batteries have 10x cycle Life at Lead-Acid price

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

Commissioned Sep. 24, 2011

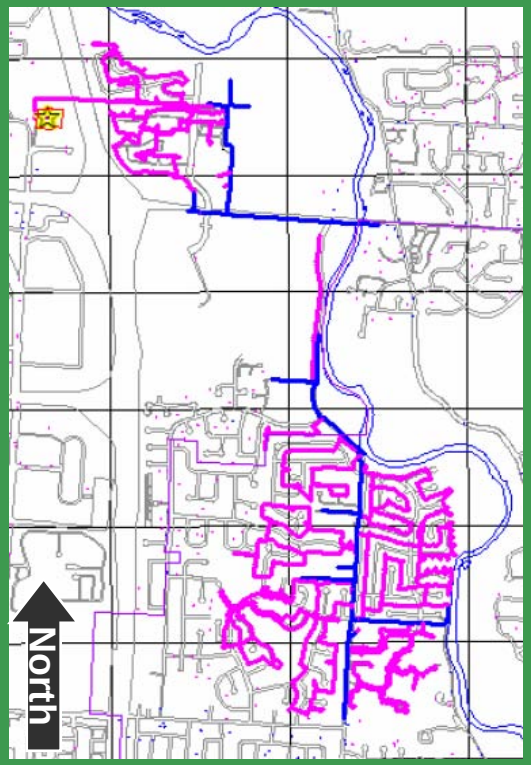
American Electric Power: Community Energy Storage ARRA Project in Columbus, OH

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



Entire Unit

Above Ground



Columbus, Ohio

Frequency Regulation

ARRA - Beacon Power: 20MW Flywheel Storage in PJM

Working with ARPA-E
On developing a Hub-
Less flywheel with 4x
cycle length = 1 Hour

Coming: Pay for Performance Doubles Return!

ARRA – PG&E: Compressed Air

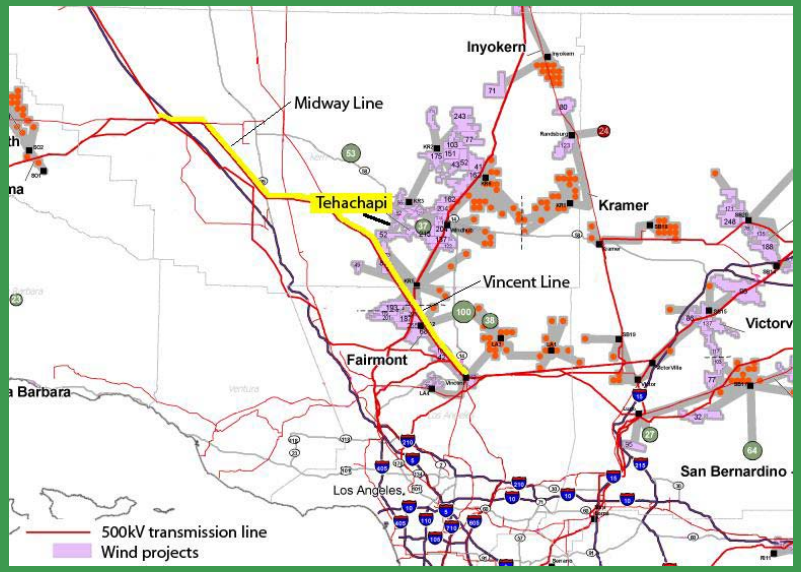
300 MW / 10hr Compressed Air Energy Storage Facility in Tehachapi, CA

Depleted Gas Wells

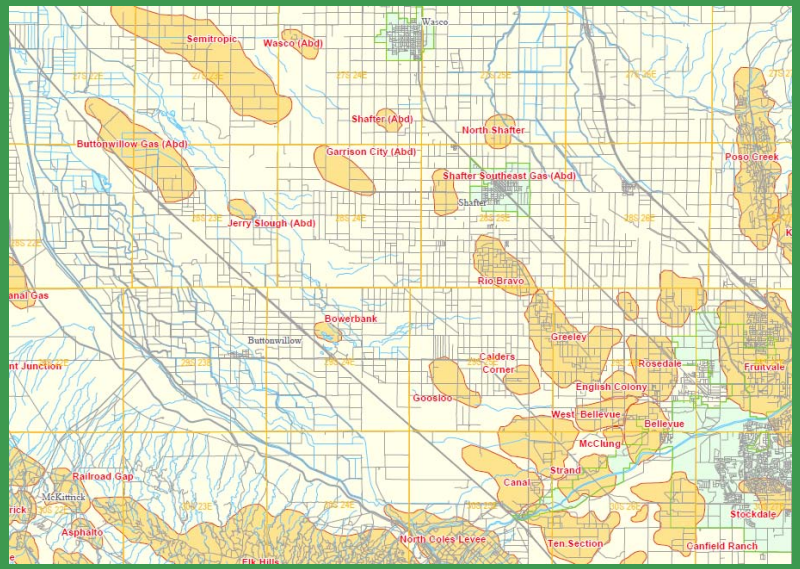
Gas Pipe Line available

Existing 500kV Transmission Line

4 500 MW New Wind in 4-5 Years



Location of Wind Resources



Location of Depleted Gas Fields

ARRA: 5 New Technology Projects

Sodium Ion Battery: Aquion
- Low cost, long life, aqueous sodium ion electrolyte

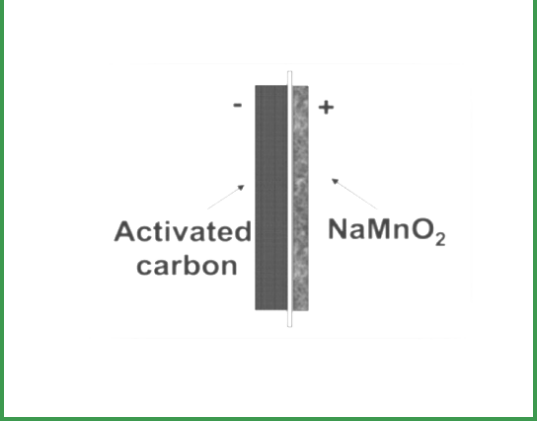
Flywheels: Amber Kinetics
- Low cost bulk energy storage; 50kW, 50kWhr

Iron Chromium Redox: Enervault
- PV Smoothing and peakshifting; 250kW, 1 MWhr

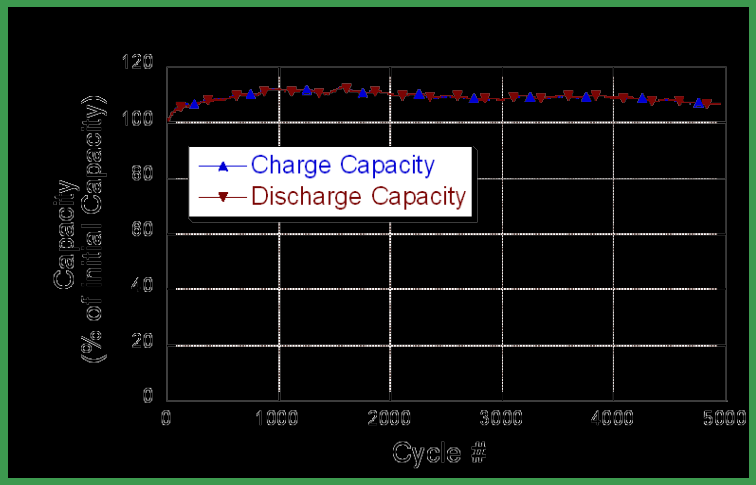
Low cost Li-Ion: Seeo
- Nanostructured polymer electrolyte

Compressed Air Energy Storage
- Hydraulic pump and motor; 1MW

ARRA - Aquion Energy:
Aqueous Sodium Ion Battery

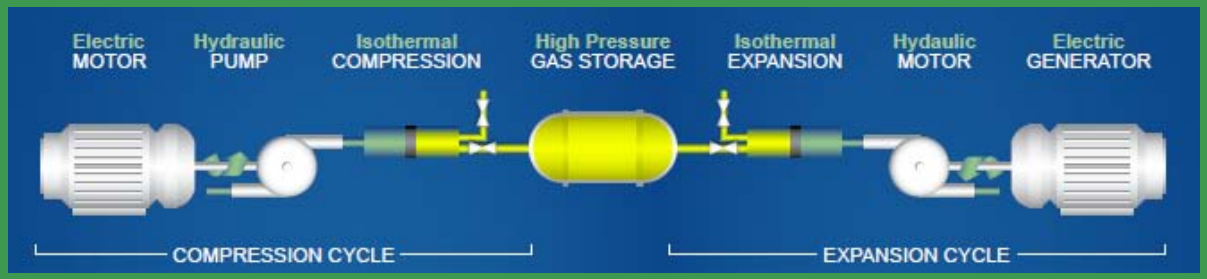


- Cost Goal: <$200/kWh
- Lifetime cost: <$0.10/kWh
- Ubiquitous, low cost precursors
- Inexpensive manufacture
- Roundtrip Efficiency >85%
- 5000 cycles demonstrated



ARRA - SustainX:

Development of 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.

OE Storage Program collaborates with BES, EERE and ARPA-E, as well as academia and industry.

Increasing role of Stationary Storage: Electric Energy Storage Applied Technology (EESAT) Conference held this week has attracted some 400 attendees from 15 countries.

The OE Program Review, also held this week, will bring together projects from OE, ARPA-E, BES-OE SBIR research and ARRA projects.

Summary

- Stationary Storage has range of science and technology needs and opportunities

- Low-Cost, Highly Cycle-able approaches of high potential impact

- Leveraged approaches critical some, but not exclusive, impact

- New thinking needed – Creates new opportunities for technology translation