U.S. Grid Energy Storage
--
Progress towards Commercialization

IMRE GYUK, PROGRAM MANAGER
ENERGY STORAGE RESEARCH, DOE

Energy Storage is becoming a Reality!

Some Large Storage Projects

27MW / 7MWh	2003	Fairbanks, AL
34MW / 245MWh	2008	Rokkasho. Japan
20MW / 5MWh	2011	Stephentown, NY
32MW / 8MWh	2011	Laurel Mountain, WV
14MW / 63 MWh	2011	Hebei, China
36MW / 24MWh	2012	No Trees, TX
8MW / 32MWh	2014	Tehachapi, CA
25MW / 75MWh	2014	Modesto, CA

Worldwide (CNESA)

2011 May	370 MW
2011 Aug.	455 MW
2011 Nov.	545 MW
2012 Feb.	580 MW
2012 June	605 MW
2013 Jan.	670 MW
2013 May	690 MW
2013 Dec.	738 MW

Beacon Flywheels

AES / A123 - Laurel Mountain

PNM – EastPenn - Ecoult

ARRA Stimulus Funding for Storage Demonstration Projects

Leveraged Funding: $185M vs. $585M

4 of 16 Projects completed

- Show technical feasibility
- Gather cost data
- Stimulate regulatory changes
- Generate follow-on projects

Frequency Regulation

FREQUENCY REGULATION

DOE Loan Guarantee – Beacon:
20MW Flywheel Storage for
Frequency Regulation in NY-ISO
Commissioned July 2011
275,000 MWh of FrequReg delivered!

►This project provided the basis for FERC to establish "PAY FOR PERFORMANCE"!

ARRA Project – Beacon
Hazleton, PA.
20MW Frequency Regulation for PJM.
Groundbreaking June 21, 2013
10 MW installed and providing Revenue
Commissioning of full 20MW June 2014

Frequency Regulation using
Energy Storage is now
a Commercially viable Business
in FERC compliant Regions!

ARRA – Duke Energy / Xtreme Power

36MW / 40 min battery plant – Remote Operation
Ramp control, Smoothing, Frequency Regulation
Linked to 153MW Wind farm at No-Trees, TX

Ribbon Cutting
March 28, 2013

- This project was crucial as a pilot for ERCOT's consideration to establish "PAY FOR PERFORMANCE"!

Clean Tech 100 in 2010 / 11

ESNA Best Project 2013

Key Outcomes of 2012 PNNL Study

- For every 10 MW of extra wind capacity approximately 0.8 – 1.5 MW of intra-hour balancing (minute-to-minute variability) need to be added.

Intra-hour balancing power requirements caused by wind variability in WECC area		
20% wind in WECC	Required MW Storage	Percentage of Installed Wind Capacity
AZ-NM-SNV	174.08	12.8
CA-MX	943.65	14.4
NWPP	1,071.26	11.0
RMPA	504.89	8.0

Kintner-Meyer 2012

Flow Batteries

ARRA- Primus Power:

25MW / 3hr battery plant for the Modesto, CA Irrigation District,
Providing equivalent flex capacity of a 50MW - $73M gas turbine

	Gas Turb	Storage
Cap Cost:	$73M	$50M
Ramp:	300 sec	5 sec
CO_2	66k met. tons	0
Area:	1 acre	¼ acre

2012- 50 Hottest Tech Startups
2011-GoingGreen Global 200

PRIMUS POWER

BOSCH

EnergyPod 250kW / 1MWh Power Box

Primus Power / Raytheon

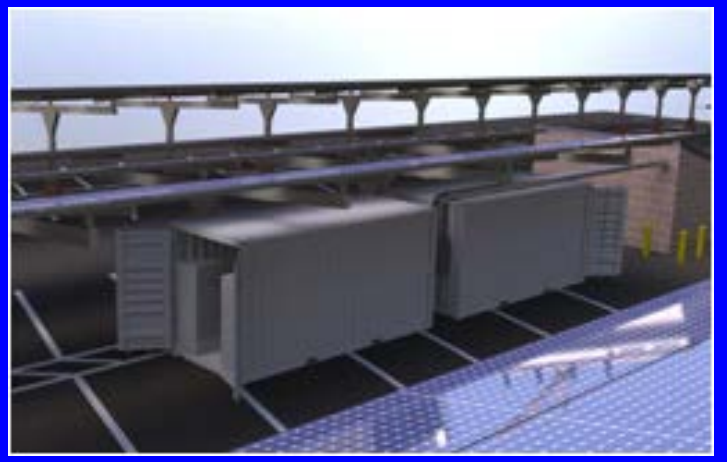
Marine Corps Air Station
Miramar, CA
An ESTCP Project

250kW- 4hr EnergyPod™ (ZnBr) for 230kW PV with micro-grid capability. Completion 2014

Mission critical backup power
Islanding and Peak Shaving capability

Miramar lost power in September 2011 Great Southwest Blackout

- **Training missions cancelled**
- **Planes grounded**
- **25% of diesel generators had trouble starting**

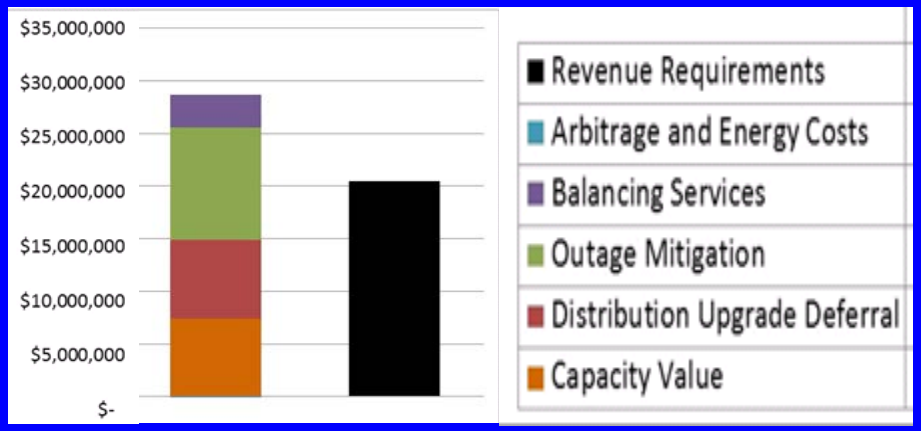


Battery system developed under ARRA

BPA / Puget Sound Grid Project:

PNNL Analysis Program selects cost-effective site and scale to optimize Value Stream

Primus Power, developed under ARRA funding to install 500kW / 2hr ZnBr Flow Battery



Primus Power Zn-Halogen Flowbattery

Modesto CA Irrig. District

ARPA-E project: 50 yr electrodes

ZnCl Technology Developed by EPRI

ARRA Demo 25MW/3hr

Bosch Group - Integration

BPA/Puget Sound 500kW / 2hr

Marine Corps Base PV + 250kW-4hr ESTCP Project

PNNL Site Analysis

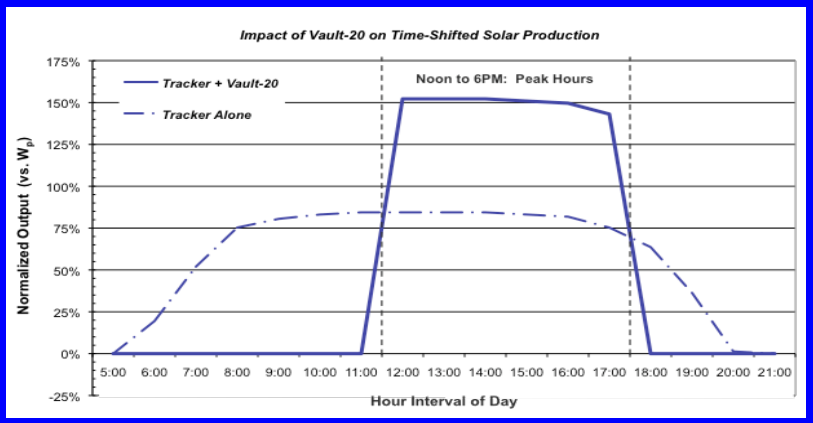
ARRA - Enervault:

250kW/4hr Fe-Cr Flow Battery

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

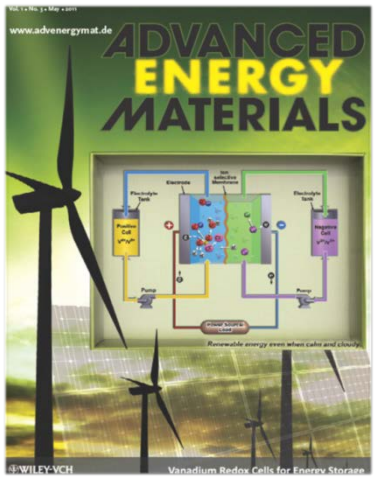
Tracking PV in Almond Grove

Installation of Tanks at Turlow



Leveraging PV with Storage

Materials Research at PNNL:



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

PNNL, Nov. 2011

Mixed Acid Electrolyte for V/V Flow Batteries yields 2x energy density

Licensed to:

- Imergy
- Joule-Watt
- UniEnergy (WA)

V/Fe Flow Battery technology

Licensed to: Aartha USA (WA)
Provides $1M for Development at PNNL

2012 Federal Laboratory Consortium Award for Technology Transfer

Washington State Clean Energy Fund:

Solicitation for $15M for Utility Energy Storage Projects

PNNL will participate in 3 Proposals, providing siting analysis and benefit optimization

- Avista – PNNL - UniEnergy Technology – WA State U
- Energy Northwest – PNNL – UniEnergy Technology
- Puget Sound – PNNL - UniEnergy Technology

Advanced Batteries

2 ARRA Projects using EastPenn Ultra-Batteries

Public Service NM:

500kW, 2.5MWh for smoothing of 500kW PV installation;
Commissioned Sep. 2011

EastPenn, PA

3MW Frequency Reg.
1MW 1-4hrs Load Management during Peak Periods

Commissioned June 2012
Over 700,000 kWh of regulation Services delivered to PJM !

Integrator: Ecoult

Hydro Tasmania,
Australia's largest battery
on King Island
Installed: December 2013

3MW / 1.6MWh
EastPenn Ultrabattery
for renewable integration
and a totally green Island!

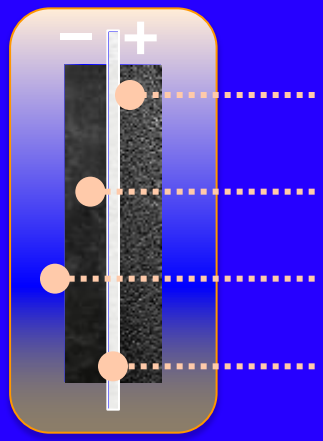
2013 Australia National
Innovation Award

Integrator: Ecoult

Reduces Diesel >65%

ARRA – Aquion Energy: Aqueous Hybrid Ion (AHI) Battery

Safe, Reliable, Sustainable, Cost Effective



Cathode: Manganese Oxide

Anode: Carbon composite

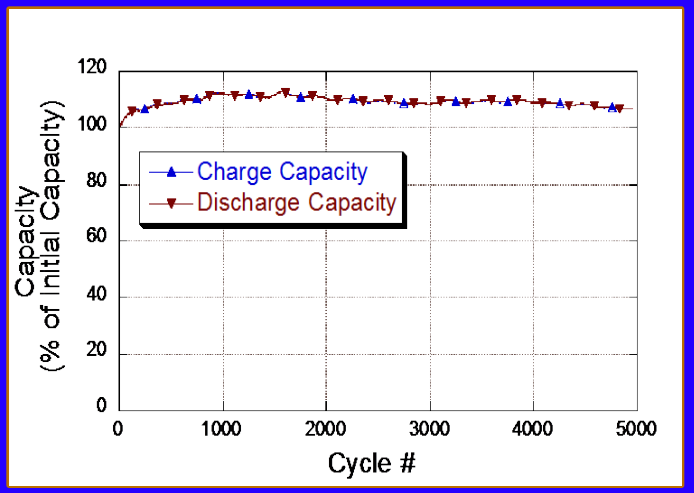
Electrolyte: Aqueous solution

Separator: Cellulosic material

- Above 85% round trip efficiency
- 5,000+ cycles demonstrated – up to 50°C
- Targeted pricing at scale : <$250/kWh
- Simple/inexpensive manufacturing
- High volume manufacturing Q4/2013

► DOE ARRA $5 M – VC $75 M

► Over 120 employees and growing!



Winner, 2011
World Technology Award

Compressed Air

ARRA - SustainX:

Development of a Totally Green Isothermal
Compressed Air Energy Storage System Using Hydraulics

1.5MW Engine in place

3000PSI 1MWh Storage tanks

Isothermal efficiency of 94.9% achieved
compared to 54% for adiabatic process.

Installation: Aug. 2013
Commission: Dec. 2013

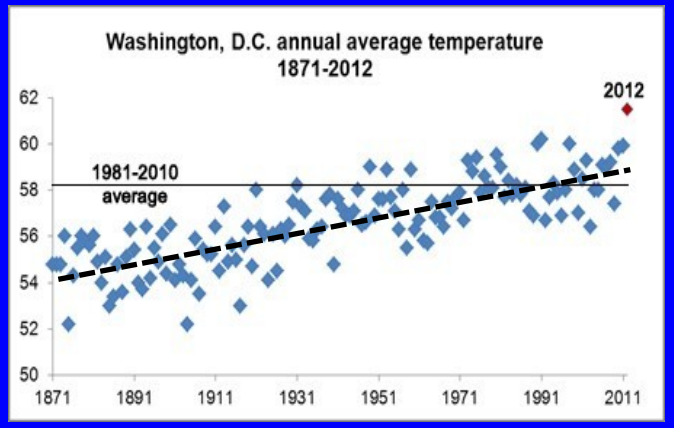
GE Ecomagination Award
2010/11/12 Global Cleantech

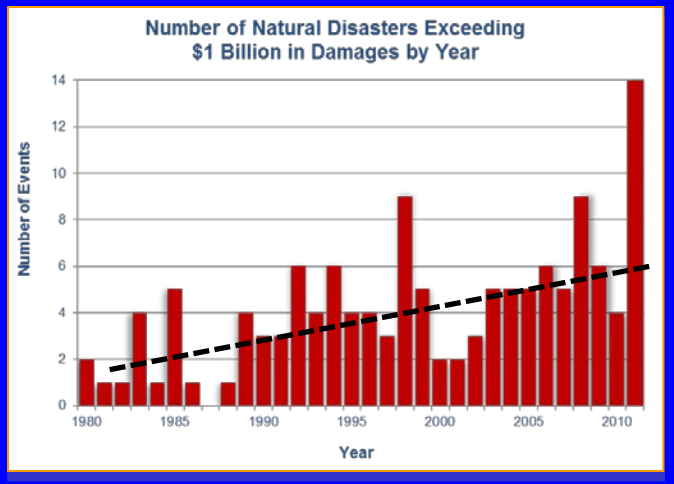
- MOU for Full Scale Deployment with
  Funding from POSCO ($10M)
  and Korean Ministry of Trade ($4M)

RESILIENCY

Energy Storage for Emergency Preparedness

Every $1 on protection measurements
Can prevent $4 in repairs after a storm!





Trends indicate the situation will get worse not better!!

Some 50% of Diesel Generators failed to start during the Sandy Emergency

Storage allows Microgrids to provide essential Services over an extended Time Period

During non-emergency Periods Storage can provide Demand Management for the User and compensated Services to the Grid

Apartment Buildings – Campuses – Schools – Shopping Centers – Community Centers – Nursing Homes – Hospitals – Police Stations – Gas Stations – etc. etc

Vermont Public Service Dept. – DOE
Green Mountain Power

Solicitation issued by VPS.

Joint funding:	$50K	VPS
	$250K	DOE-OE
	$3.4M	GMP

Rutland, VT
2MW / 3.4MWh of storage
Integrated with 2MW PV
Integrator: Dynapower

Ancillary grid services, peak shaving during high load periods

System can be islanded to provide emergency service for a highschool/emergency center, local gas stations, and a fire station

SAFETY

Energy Storage Safety is an Essential Concern

Sandia / PNNL Workshop
Feb. 17-18, 2014

Lack of Safety:

- Endangers Life
- Leads to Loss of Property
- Damages the Provider’s Reputation
- Leads to Costly Litigation
- Decreases Confidence in Storage

Safety Can be Increased through

- Careful Engineering
- Extensive Testing of System
- Establishment of Safety Protocols
- Development of Regulatory Standards
- Guidelines for Accident Responders
- Understanding of Failure Mechanism

The Importance of
Safety Considerations is
Enhanced by wider Application
Of Storage through Mandates
Like those of CA and NY!

As Part of the OE Storage Program
Safety Initiative
we have accepted an Industry Mandate
to develop a
National Energy Storage Safety Strategic Plan

INDUSTRY TOOLS

SNL Energy Storage System Analysis Laboratory

Reliable, independent, third party testing and verification of advanced energy technologies from cell to MW scale systems

GS-Yuasa at DETL

Energy Storage Test Pad (ESTP)

Milspray Deka Battery under testing

System Testing

- Scalable from 5 KW to 1 MW, 480 VAC, 3 phase, Both power and energy use tests.
- 1 MW/1 MVAR load bank for either parallel microgrid, or series UPS operations
- Subcycle metering in feeder breakers for system identification and transient analysis
- Safety Analysis
- In FY13 tested 3 grid scale systems providing key information to manufacturers. Resulting in system redesigns in all cases

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

An application specific Protocol providing a uniform way of measuring, quantifying and reporting the performance of EES systems in various applications. Developed by a Working Group of over 100 members. Released Oct. 2012 Basis for new IEEE standard and DoD FOB standard

pnl.gov/main/publications/external/technical_reports/PNNL-22010.pdf

DOE/EPRI 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, interconnection. Includes cost database. Released July ‘13

sandia.gov/ess/publications/SAND2013-5131.pdf

DOE International Energy Storage Data Base

energystorageexchange.org

844 energy storage projects from 49 countries

50 energy storage technologies are represented