

Grid Scale Energy Storage

IMRE GYUK, DIRECTOR,
ENERGY STORAGE RESEARCH, DOE-OE

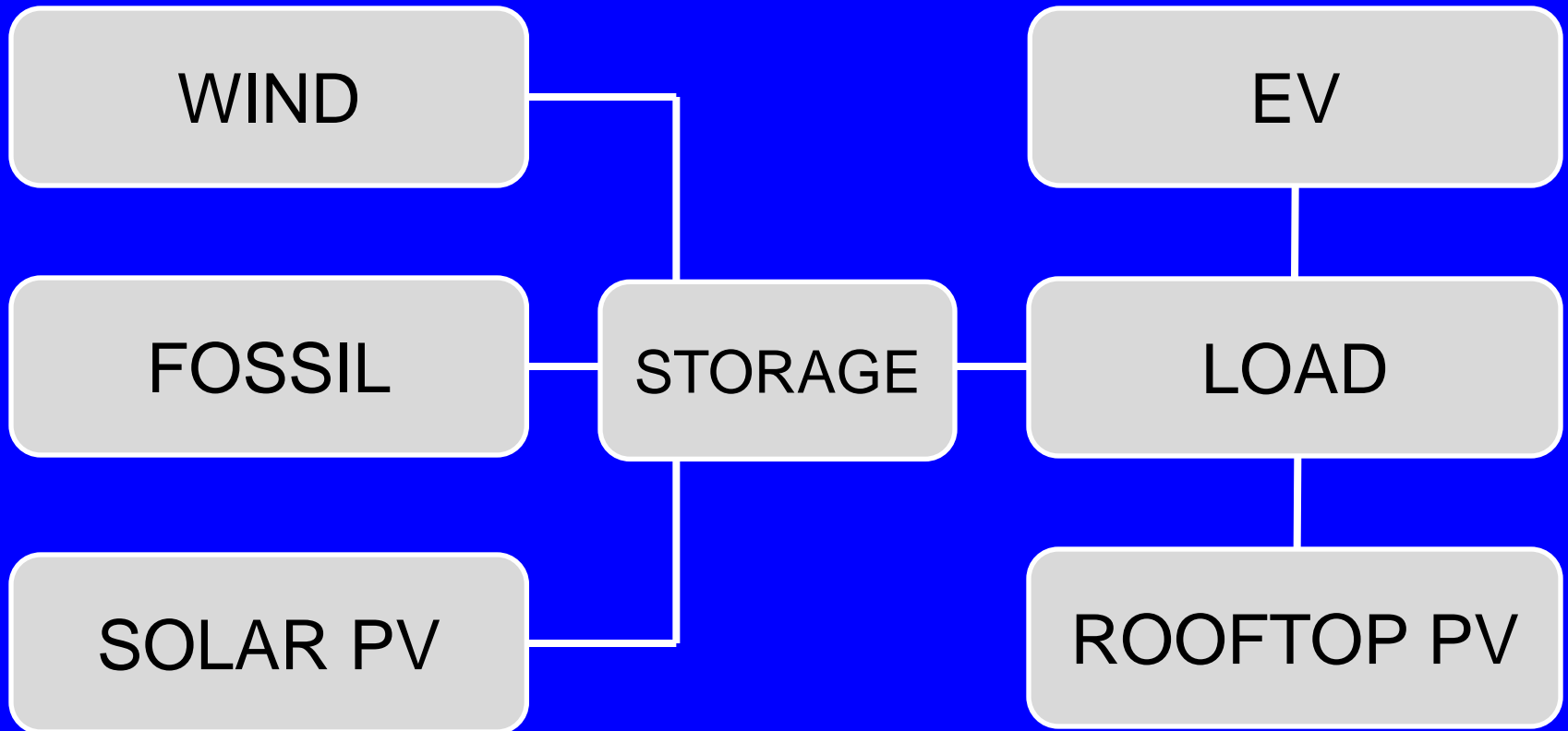
Energy Storage provides Energy

when it is needed

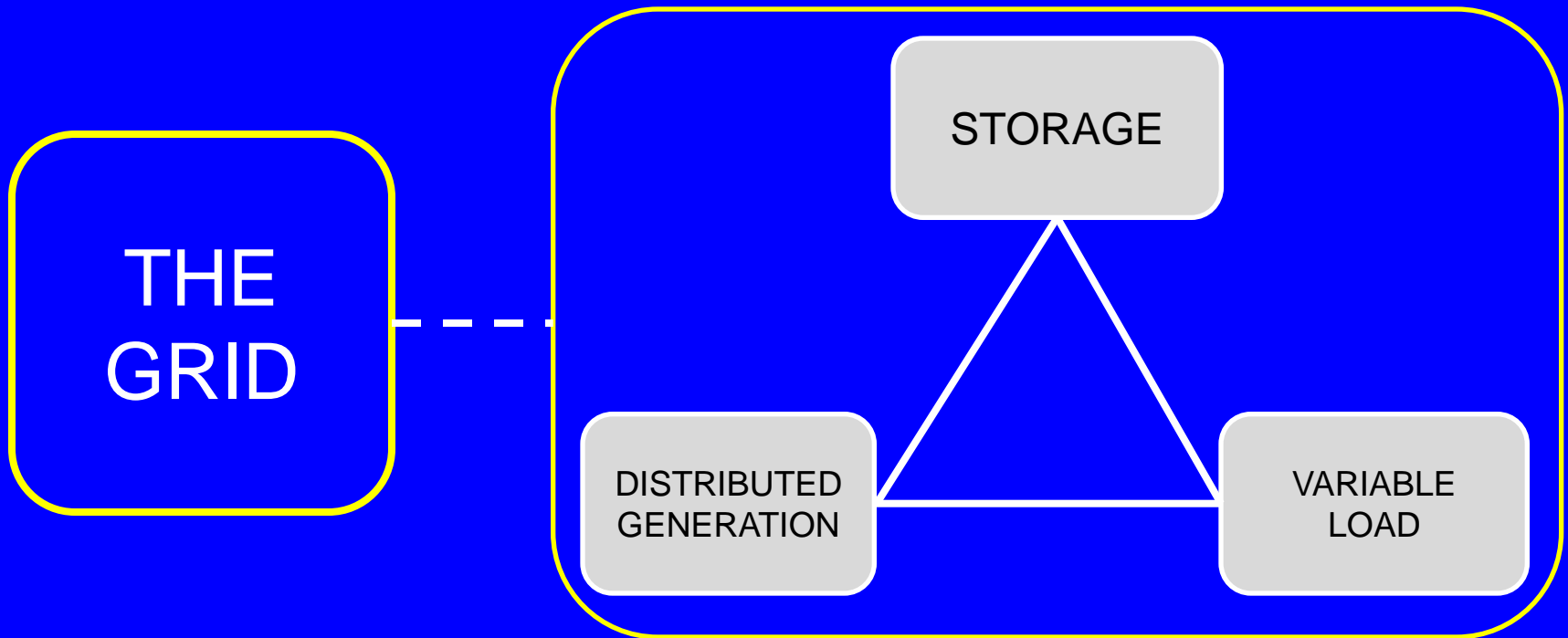
just as Transmission provides Energy

where it is needed

The grid has become stochastic!



An Autonomous Micro-Grid



ENERGY

Pumped Hydro
Compressed Air Energy Storage (CAES)
 Aquifer CAES
 Advanced Isothermal

PG&E
Iowa

Batteries

 NaS
 Flow batteries
 ZnBr
 Vanadium Redox
 Lead Acid
 Lead carbon
 Aqueous hybrid ion
 Lithium Ion

AEP, PG&E

Primus
UET, Vionx

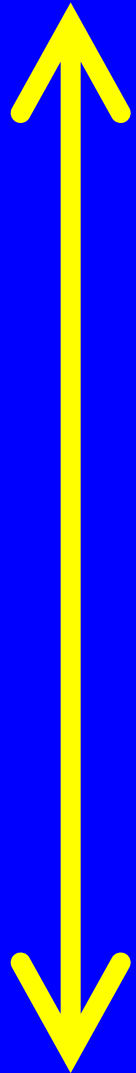
EastPenn
Aquion
SouCalEd, AES

Flywheels – Energy
 – Power

Amber
Beacon
Helix

Electrochemical Capacitors

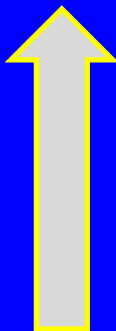
POWER



Storage Economics:



The **Cost** of a Storage System depends on the Storage Device, the Power Electronics, and the Balance of Plant



The **Value** of a Storage System depends on Multiple Benefit Streams, both monetized and unmonetized

LCOE depends on Application!

Power Electronics
20-25%

Energy Storage Device
25-50%

Facility 20-25%

Arbitrage

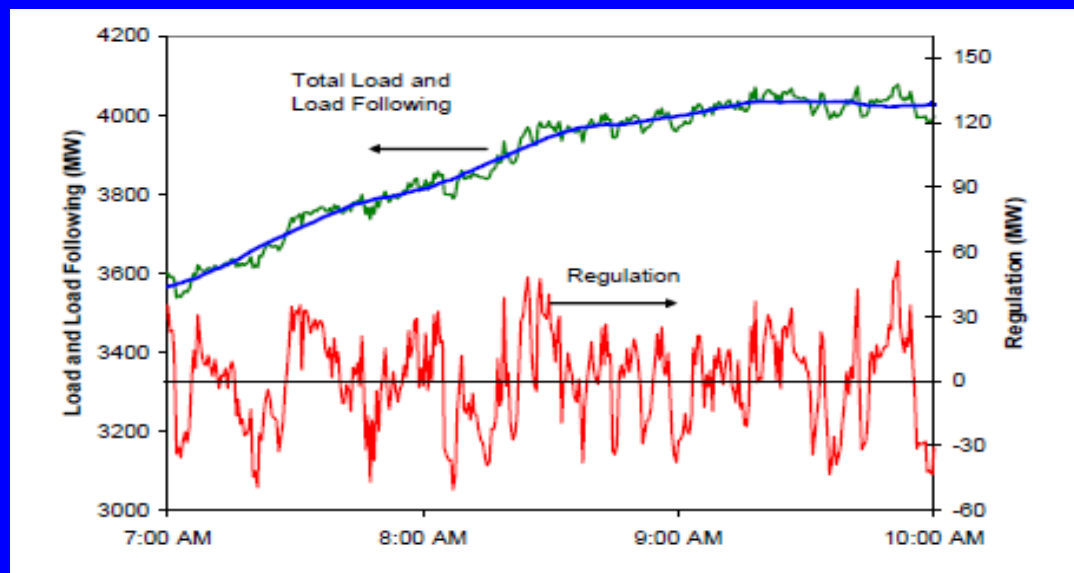
Frequ. Reg.

Dem. Charges
month, year

Resiliency

Power Systems

for Frequency Regulation or Renewable Smoothing





ARRA Project – Beacon
Hazleton, PA.
20MW Frequency Regulation for PJM.
Commissioned Aug. 2014

\$K 5,936/year potential revenue
R. Byrne, SAND 2016-1080C

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



ARRA – Duke Energy / Younicos
With 153MW Wind at No-Trees, TX
36MW / 40 min battery plant
Smoothing, Frequency Regulation
Commissioned March 2013

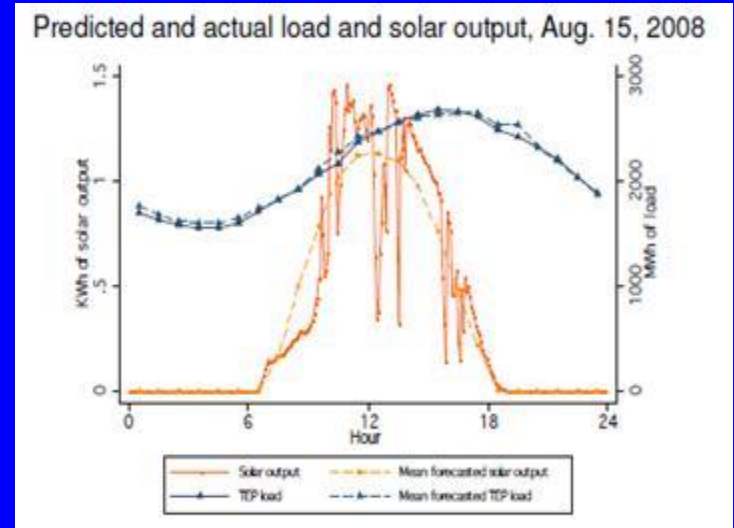
Frequency Regulation using Energy Storage is now a Commercially viable Business in FERC compliant Regions!

1999 - 2011, PJM utilities spent 48.8 cents
per MW of load on frequency regulation

2012 - 2016, PJM utilities spent 24.4 cents
per MW of load on frequency regulation

(SE Energy News 2016/11/28)

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



Load & PV Output in Tucson, AZ

Commissioned Sep. 2011 Integrator: Ecoult

King Island Hybrid System Hydro Tasmania – Ecoult/EastPenn

Peak Load: 2.5MW

Wind: 2.5 MW

Diesel: 6 MW

Lead Carbon Battery:
3MW-1.6MWh

Demand Management

>65% Renewable Energy:
A Green Island!



ARRA - Southern California Edison / LG Chem – Li-Ion:

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



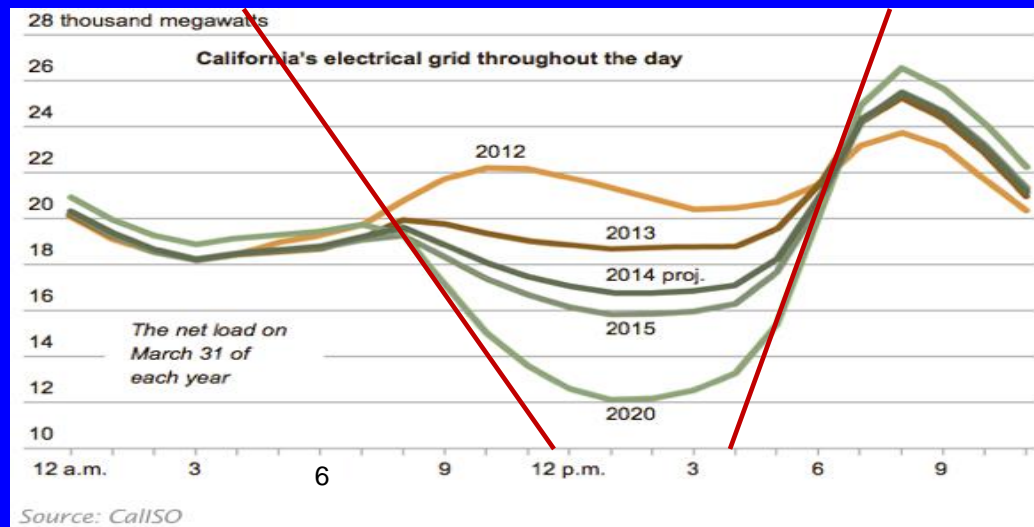
Tehachapi: 4,500MW Wind by 2015!

Commissioned: Sept. 2014
Integrator: ABB



8MW / 32MWh Storage Plant

Energy Storage Systems for Peakshaving, Loadshifting, Ramping



October 2013: California PUC sets target of 1.3GW of Storage by 2020

Research: Materials, Devices, Systems

Sandia, Pacific NW, Oak Ridge National Laboratories

Universities, Industry

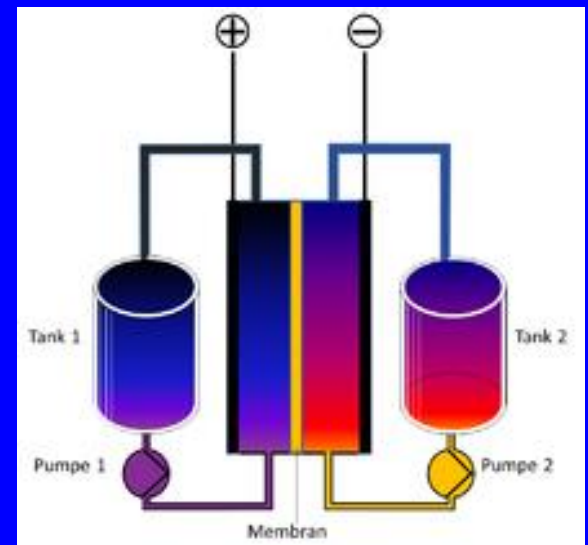
8 R&D 100 Awards!

Flow Batteries decouple Power from Energy:

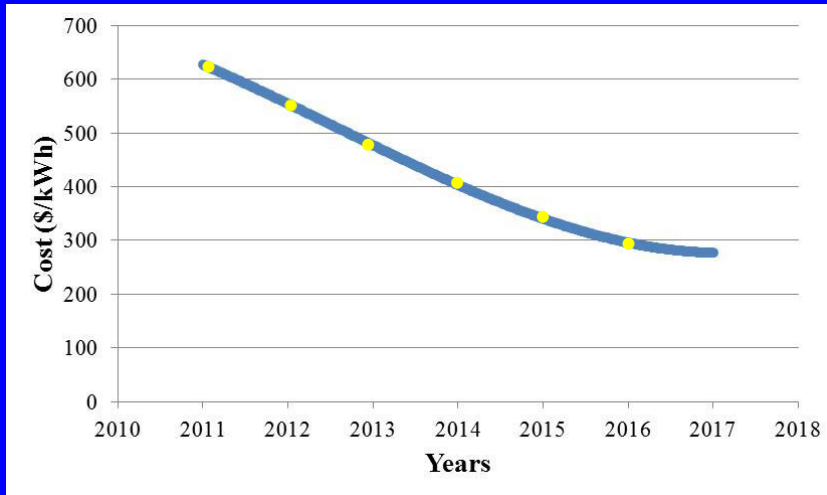
- Power is produced by a rechargable Electrochemical Cell
- Energy is stored in Tanks of electrolyte

This is analogous to a car:

- Power comes from the Engine
- Energy is in the gasoline Tank



Mixed Acid V/V Redox Flow Batteries, PNNL



3 Commercial Licenses
Award for Tech Transfer

- Temperature stability + 80%
- Energy density + 70%
- Projected system **cost** of \$300/kWh for 4 hour system



➡ Some 22MW/88MWh in play

UniEnergy 600 kW/2.2MWh battery system



UniEnergy – UET, Mukilteo, WA

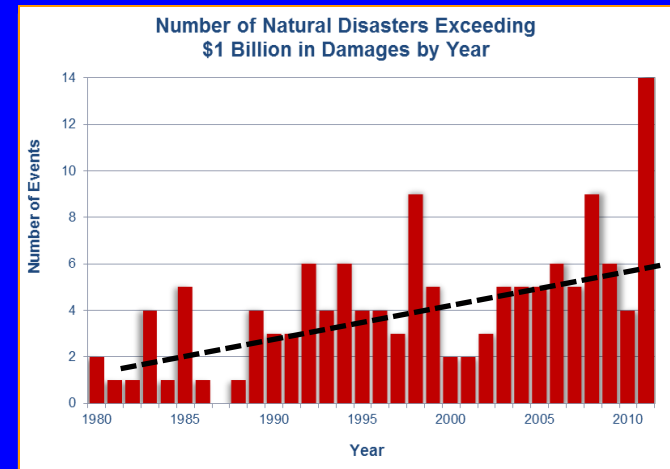
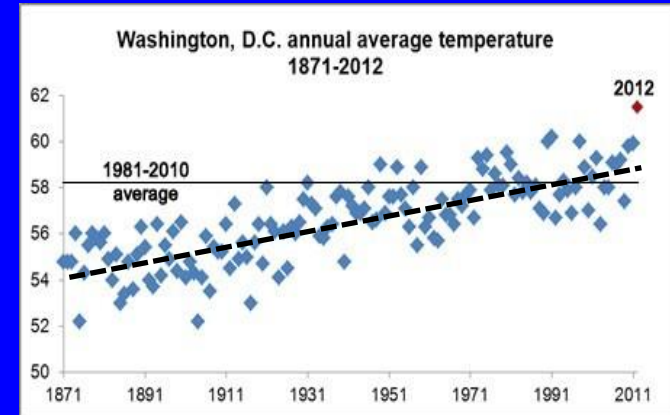
60 Employees, Capitalization: \$46.5M, 22 MW / 88 MWh in play

Energy Storage Systems for Grid Resiliency and Emergency Preparedness

DOE / State Initiatives

Energy Storage for Resilience

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



Trends indicate the situation
will get worse not better!!

Vermont Public Service Dept. – DOE - Green Mountain Power

Joint Solicitation issued by VPS/OE
Rutland, VT

4MW / 3.4MWh of storage
Integrated with 2MW PV
Integrator: Dynapower

Groundbreaking: Aug. 12, 2014
Ribboncutting: Sep. 15, 2015

Storage: Ancillary grid services, demand charge reduction
PV: Green power for the grid. Situated on Brown Field area

System can be islanded to provide emergency power for a resilient microgrid serving a highschool / emergency center.

Project referenced as model in VT Energy Strategic Plan!

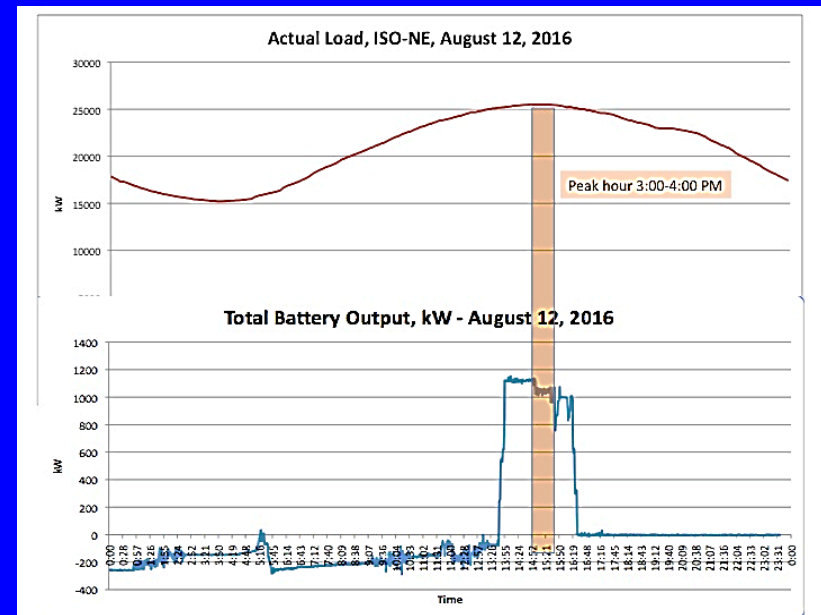


How to make the Microgrid Pay for itself:

Regional Network Service (RNS):
Payments for using transmission lines depend on **monthly peak** load.

Forward capacity market (FCM):
Payments for regional capacity reserves to cover load excursions depend on the **yearly peak** day/hour identified by ISO-NE,

In addition, there are financial benefits from frequency regulation and arbitrage.



Capturing the yearly peak,
\$200,000 from PV and storage!

Washington State Clean Energy Fund:

Solicitation for \$15M for Utility Energy Storage Projects

Selected projects with UET vanadium flow battery:

- Avista (1MW / 4MWh) -- PNNL -- WA State U
- Snohomish (2MW / 8MWh) – PNNL -- 1Energy -- U of WA

Under a DOE / WA MOU, PNNL will participate in both projects, providing use case assessment and performance analysis.

Vanadium technology with 1.7x Energy density developed at PNNL for DOE



Ribbon Cutting
Avista, April 2015



2nd Solicitation: Teaming with Avista

Sterling, MA: Microgrid/Storage Project

Sterling Municipal Light Department, \$1.5M Grant from MA Community Clean Energy Resiliency Initiative. DOE/Sandia. NEC 2MW/2hr storage In conjunction with existing 3.4 MW PV to provide **resiliency** for Police HQ and Dispatch Center



Sterling, MA, October 2016



Sterling, MA, December 2016

Description (1MW/1hr)	\$
Arbitrage (buy low, sell high)	13,321
Reduced Monthly Peak	98,707
Reduced Yearly Peak	115,572
Frequency Regulation	60,476
Total	288,076



R. Byrne
Sandia

For a capital cost of ~\$1.7M/MW, the simple payback is 6.67 years

Energy Storage Procurement, Guidance Document for Municipalities

Other Storage Projects:

Eugene, OR, Water & Energy Board

Resiliency Microgrid

500kW Storage + 125kW PV + Diesel gen sets
at 3 aggregated sites

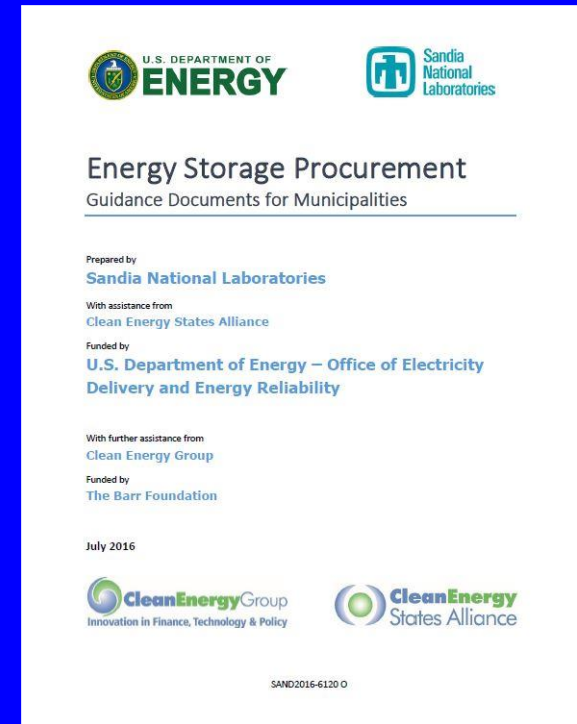
Cordova, AK, Study with ACEP

Hydropower Smoothing

Kona, HI, with NELHA and HELCO

Enabling more solar PV

100kW/500kWh of V/V Batteries



The Bigger Picture

Grid Energy Storage Safety Initiative

DOE identified *Validated Safety* as a critical need for the success of grid energy storage.

The ability to validate the safety of energy storage systems will:

- Decrease human and financial risk,
- Minimize installation costs,
- Accelerate acceptance of new technologies.

To address this need DOE is engaging key energy storage stakeholders:

- DOE OE Energy Storage Safety Workshop, February 2014
- PNNL Publication: Inventory of Codes and Standards
- *Strategic Energy Storage Safety Plan – December 2014*
- Established 3 ES Safety Working Groups – March 201
- DOE OE Energy Storage Safety Workshop, February 2016



ENERGY STORAGE SAFETY STRATEGIC PLAN



U.S. Department of Energy
Office of Electricity Delivery and Energy Reliability
December, 2014

Regular Webinars by Storage Experts
arranged by DOE and
the Clean Energy States Alliance

Energy Storage Technology Advancement Partnership (ESTAP)

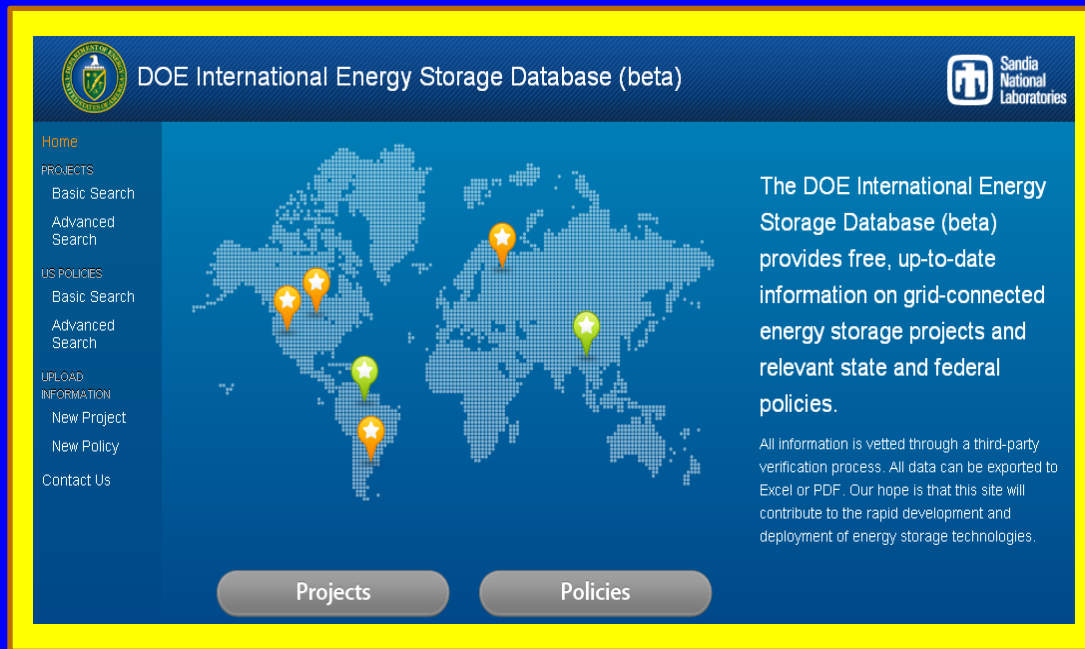
cesa.org/projects/energy-storage-technology-advancement-partnership/

*Measuring System Performance; Market Update; Procurement Guidance;
State of the Industry; Flow Batteries; Safety Strategic Plan; Upgrading
Distribution Resilience; Economics of Energy Storage; Oregon-DOE Storage
Solicitation; Making an existing PV System into a resilient Microgrid;
Connecticut and Massachusetts Storage Solicitations; Microgrid Technologies;
Commissioning Energy Storage; East Penn and Ecoult Battery Installations;
Smart Grid, Grid Integration, and Renewable Energy*

DOE International Energy Storage Data Base

energystorageexchange.org supported by Strategen

Over 1550 energy storage projects from 60+ countries.
50 energy storage technologies are represented

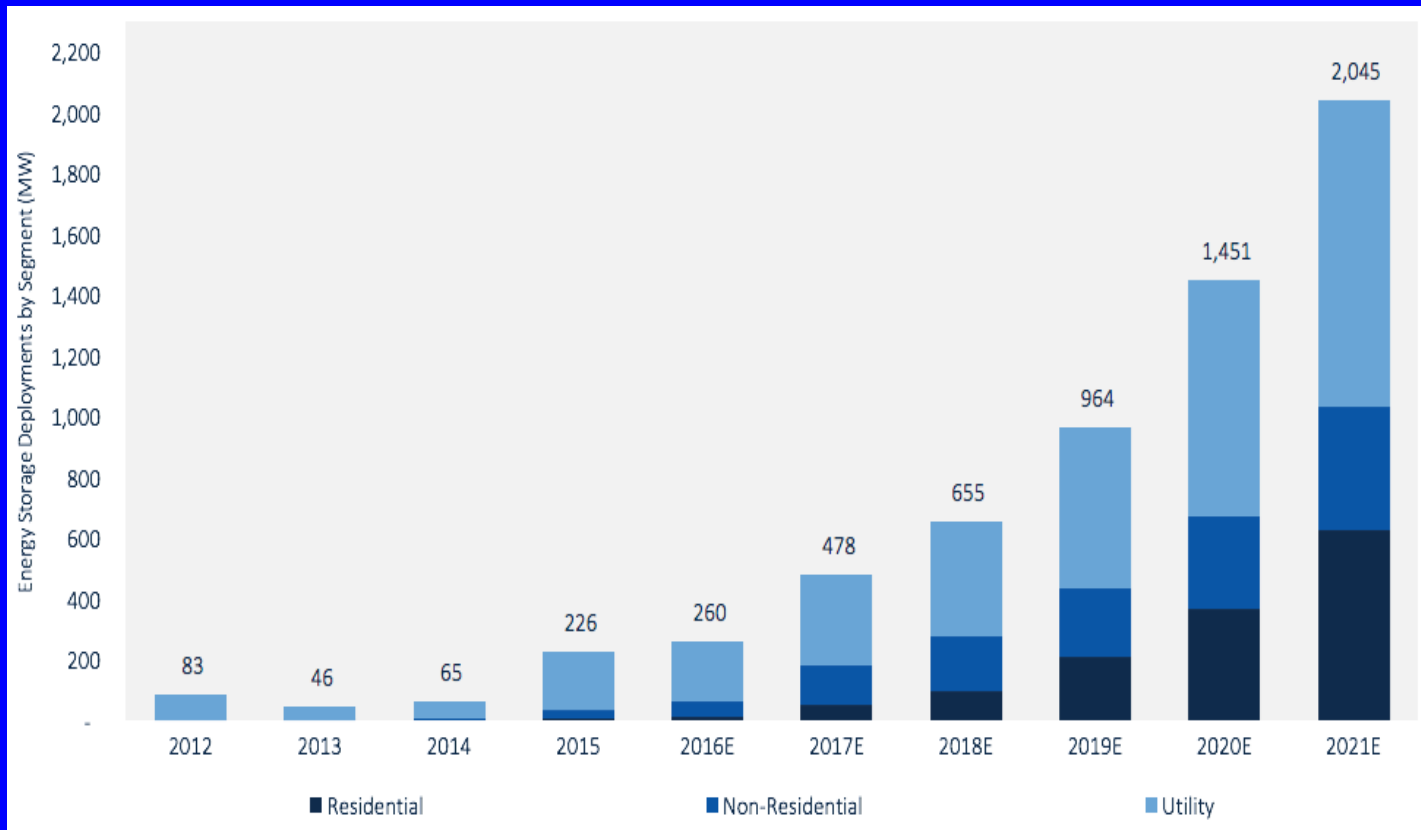


Partnerships with
Australian
Energy Storage
Alliance

Policy Database
in Development

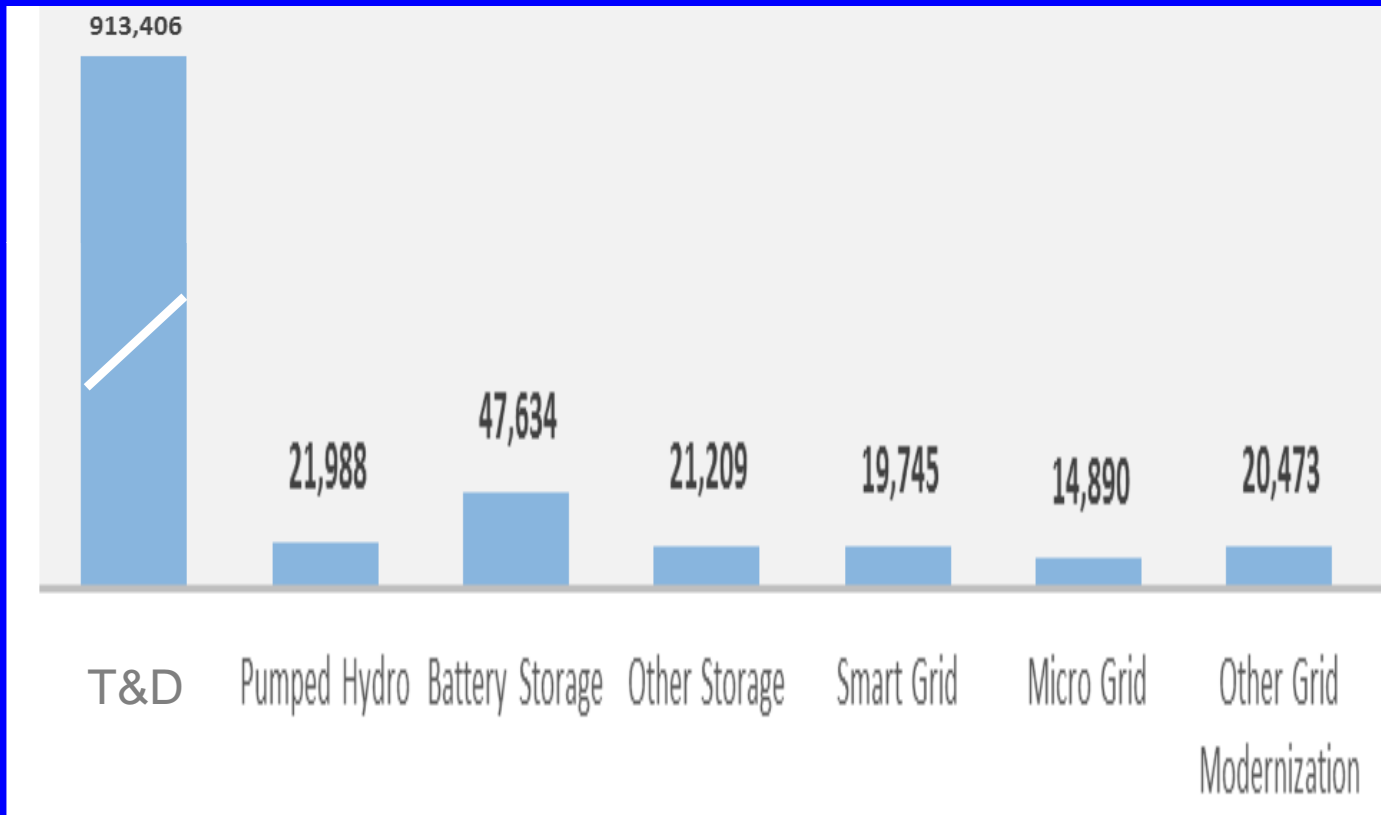
Partnership with EIA on Storage Reporting

Annual U.S. Energy Storage Deployments, 2012-2021



GTM Research / ESA U.S. Energy Storage Monitor

U.S. Energy and Employment Report, January 2017



Employment by Transmission, Distribution, and Storage Technologies Q1 2016

With new Technologies
Cost will go down, Safety and
Reliability will increase

With every successful Project
the Value Propositions will
continue to increase!

More jobs will be created!!