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Energy Storage Overview

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Outline

- Grid scale energy storage
- Value streams
- Storage on the grid today

Grid Scale Energy Storage

- Primary methods for energy storage
  - Electrochemical
    - Lithium batteries
    - Lead acid batteries
    - Flow batteries
  - Mechanical
    - Compressed air
    - Pumped hydro
    - Flywheels
  - Thermal
    - Molten salt
    - Ice
  - Electrical
    - Ultra Capacitors

SCE Tehachapi Plant, 8MW, 32 MWh

Why Do We Need Energy Storage?

- Major reasons for installing energy storage:
  - Renewable integration
  - Transmission and Distribution upgrade deferral
  - Power quality, e.g., UPS application, microgrids, etc.
  - Improved efficiency of nonrenewable sources (e.g., coal, nuclear)
  - Off-grid applications (not the topic of this presentation)

Electricity Storage Services

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Bulk Energy Services
Electric Energy Time-Shift (Arbitrage)
Electric Supply Capacity
Ancillary Services
Regulation
Spinning, Non-Spinning and Supplemental Reserves
Voltage Support
Black Start
Other Related Uses

Transmission Infrastructure Services
Transmission Upgrade Deferral
Transmission Congestion Relief
Distribution Infrastructure Services
Distribution Upgrade Deferral
Voltage Support
Customer Energy Management Services
Power Quality
Power Reliability
Retail Electric Energy Time-Shift
Demand Charge Management

Source: DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA

Additional information:
"Energy Storage for the Electricity Grid:
Benefits and Market Potential Assessment Guide"
http://www.sandia.gov/ess/publications/SAND2010-0815.pdf

Recent Storage Policy Breakthroughs

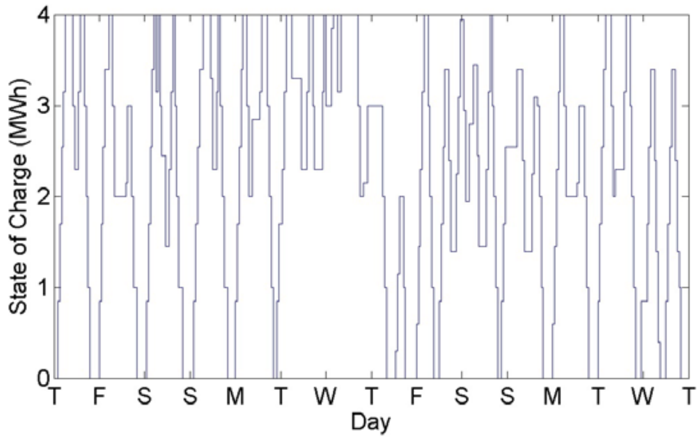
- American Recovery and Reinvestment Act (ARRA) of 2009 Energy Storage Demonstration Projects
  - 16 projects
  - Varying levels of technology maturity
  - 50% federal cost share ($600M for all 21 SGDPs)
- FERC order 755 and FERC order 784: "pay-for-performance"
  - More fairly compensates "fast responding" systems (e.g., storage)
  - Market redesign for frequency regulation compensation
    - Separate signals for "fast" devices
    - Mileage payment in addition to capacity payment
- California energy storage mandate (California Public Utilities Commission) 10/17/2013
  - 1.3 GW by 2020 (Note the units!)

California Energy Storage Mandate

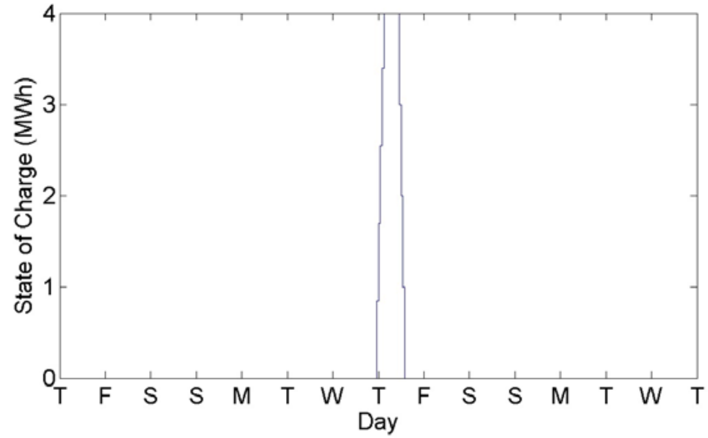
Storage Grid Domain Point of Interconnection	2014	2016	2018	2020	Total
Southern California Edison					
Transmission	50	65	85	110	310
Distribution	30	40	50	65	185
Customer	10	15	25	35	85
Subtotal SCE	**90**	**120**	**160**	**210**	**580**
Pacific Gas and Electric					
Transmission	50	65	85	110	310
Distribution	30	40	50	65	185
Customer	10	15	25	35	85
Subtotal PG&E	**90**	**120**	**160**	**210**	**580**
San Diego Gas & Electric					
Transmission	10	15	22	33	80
Distribution	7	10	15	23	55
Customer	3	5	8	14	30
Subtotal SDG&E	**20**	**30**	**45**	**70**	**165**
Total - all 3 utilities	**200**	**270**	**365**	**490**	**1,325**

Energy Storage Efficiency

- $Round\ Trip\ Efficiency = \frac{output\ MWh}{input\ MWh}$ (same SOC)
- Quoted efficiency can be confusing:
  - Typically AC-to-AC, sometimes quoted DC-DC
  - Does it include balance of plant (e.g., air conditioning, heating, etc.)?
  - What type of charge/discharge cycle?
- Example: 1MW, 4MWh system, 2 weeks, 85% efficiency, balance of plant = 2.9762 kW



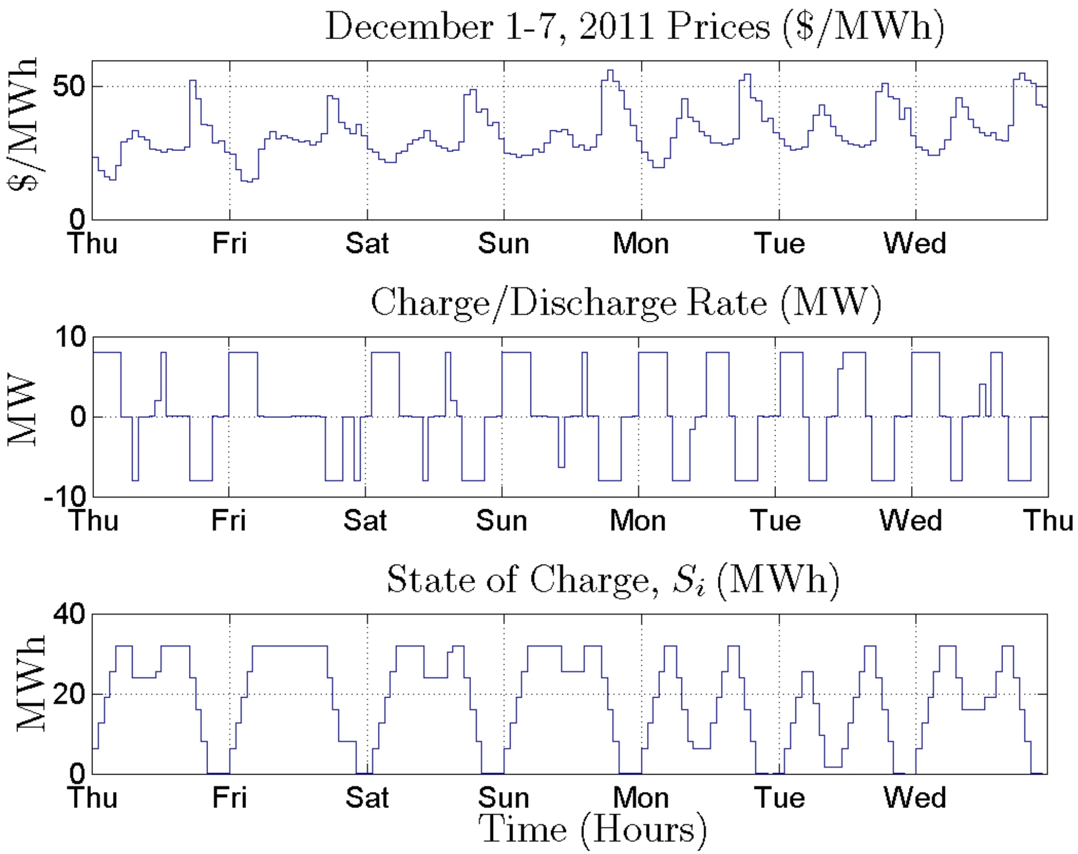
Efficiency = $\frac{78.95\ MWh}{92.8820+1\ MWh}$ = 84.1%



Efficiency = $\frac{4\ MWh}{4.7059+1\ MWh}$ = 70.1%

Energy Storage Value Streams

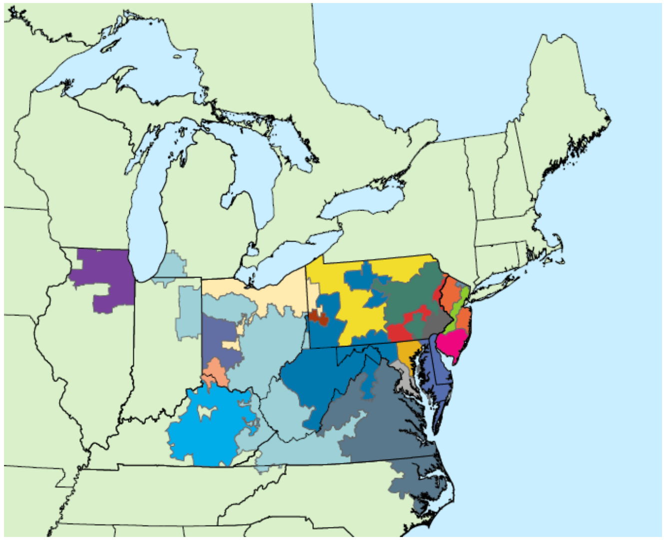
- Energy arbitrage – buy low, sell high
- Energy price swings must be larger than efficiency losses
- Rarely captures the largest value



Energy Storage Value Streams

- Frequency regulation
  - Used to maintain 60 Hz grid frequency
  - Second by second dispatch
  - Typically the most valuable service

Month	Year	$\% \ q^R$	$\% \ q^D$	$\% \ q^{REG}$	Revenue
Jun	2014	0.65	0.41	98.67	$487,185.94
Jul	2014	1.22	0.38	98.06	$484,494.90
Aug	2014	1.20	0.38	98.06	$354,411.61
Sep	2014	1.23	0.52	97.73	$401,076.97
Oct	2014	1.30	0.38	97.85	$535,293.84
Nov	2014	1.71	0.58	96.43	$431,106.41
Dec	2014	1.07	0.50	96.92	$341,281.46
Jan	2015	0.80	1.10	97.34	$443,436.10
Feb	2015	1.03	1.37	96.59	$998,392.65
Mar	2015	0.87	0.71	98.41	$723,692.29
Apr	2015	0.90	0.20	98.76	$527,436.11
May	2015	1.02	0.37	98.62	$666,290.70
				Total	$6,394,098.97

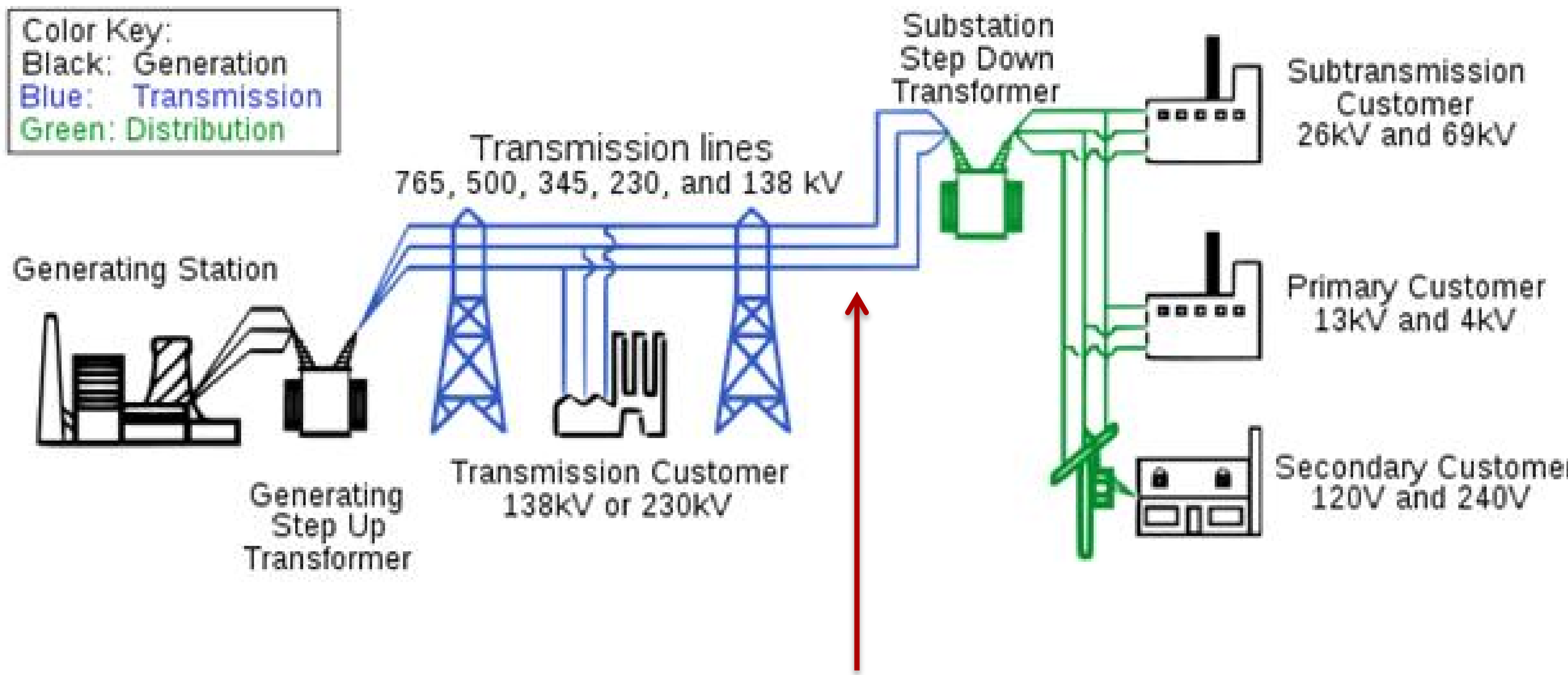


PJM results, 20MW, 5MWh 200-flywheel system

Beacon Power Flywheel

Energy Storage Value Streams

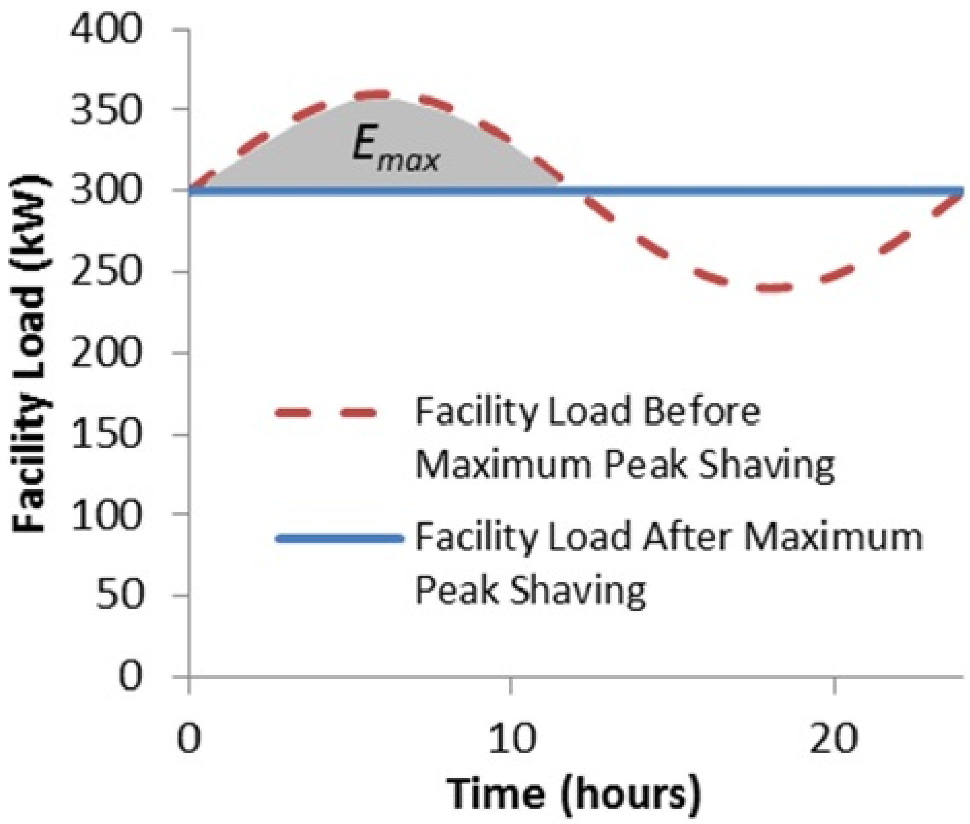
- Transmission and Distribution deferral
  - Can be a very large $$$$
  - Very location specific



Congestion (e.g.,
limit power flow)

Energy Storage Value Streams

- Reduction in demand charges (behind the meter)
- Large potential savings for industrial customers



Energy Storage Value Streams

- Pool transmission and capacity payments
- Example: ISO-NE
- Regional Network Service (RNS) payment for using pool transmission services – based on monthly peak load ($98.70147/kW-yr)
- Forward capacity market payment – based on annual peak load

ISO-NE Capacity Clearing Price	
Year	Price ($/kW-Month)
2010-2011	$4.254
2011-2012	$3.119
2012-2013	$2.535
2013-2014	$2.516
2014-2015	$2.855
2015-2016	$3.129
2016-2017	$3.150
2017-2018	$7.025
2018-2019	$9.551

Year	Price ($/kW-Month)	1 MW	2 MW	3 MW	4 MW
2015-16	$3.129	$51,477	$102,958	$154,443	$205,932
2016-17	$3.150	$51,822	$103,649	$155,479	$207,315
2017-18	$7.025	$115,572	$213,153	$346,744	$462,344
2018-19	$9.551	$157,128	$314,269	$471,424	$628,591

Assumptions: 9.6MW base load

Energy Storage Value Streams

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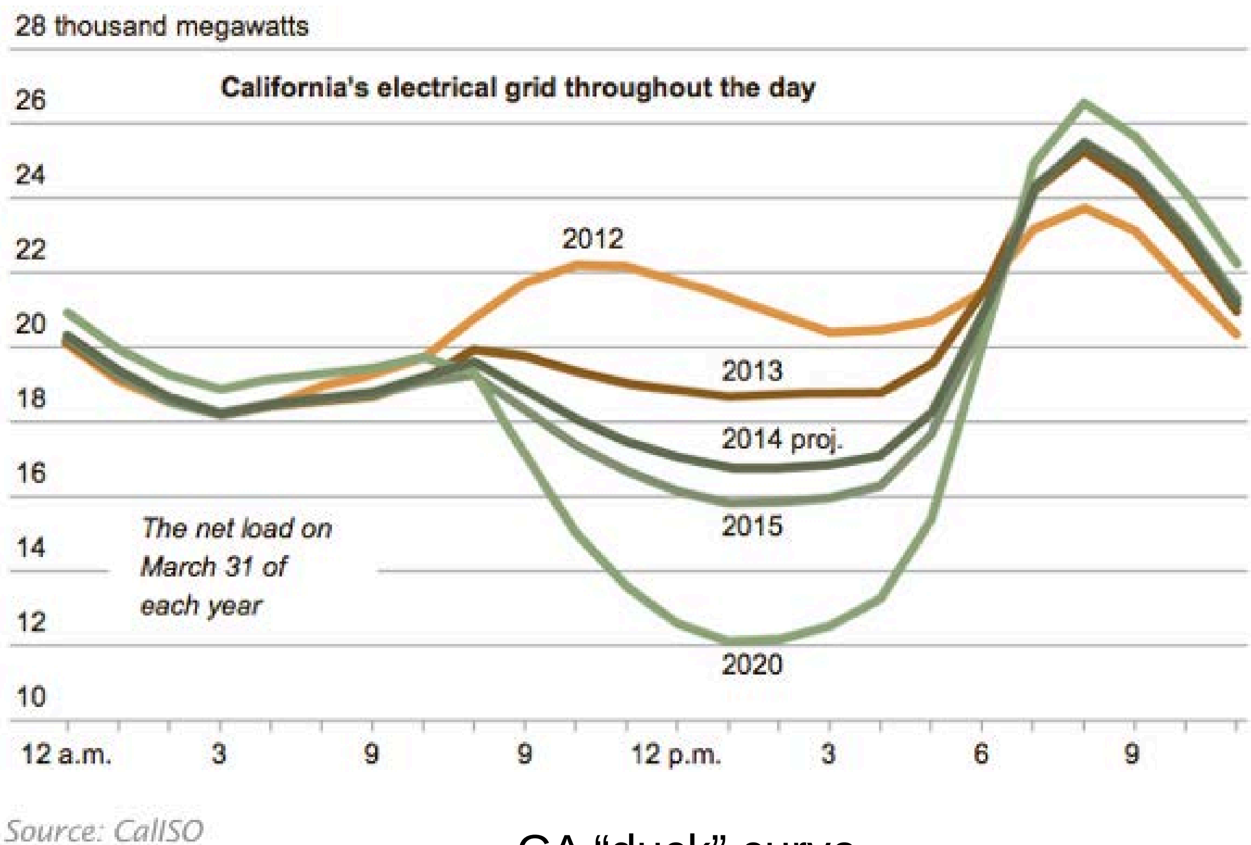
- Distribution level energy storage
  - Volt/VAR support
  - Islanding during outages
  - Frequency regulation
  - Renewable time shift
  - Peak shaving
  - Arbitrage

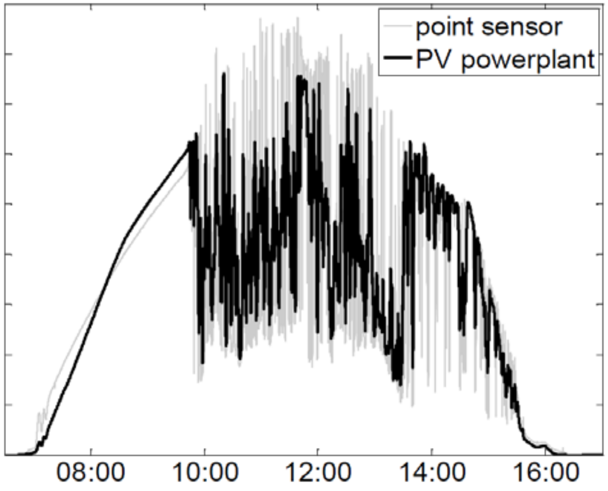
DTE ARRA energy storage demonstration project

Energy Storage Value Streams

- Renewable firming
  - Puerto Rico is penalizing rapid ramp rates
  - Duck curve (CA is starting to be concerned)



CA "duck" curve



Solar variability

For vertically integrated utilities – increased regulating and spinning reserves. In market areas, adding ramping products.

Why is Storage Valuation Difficult?

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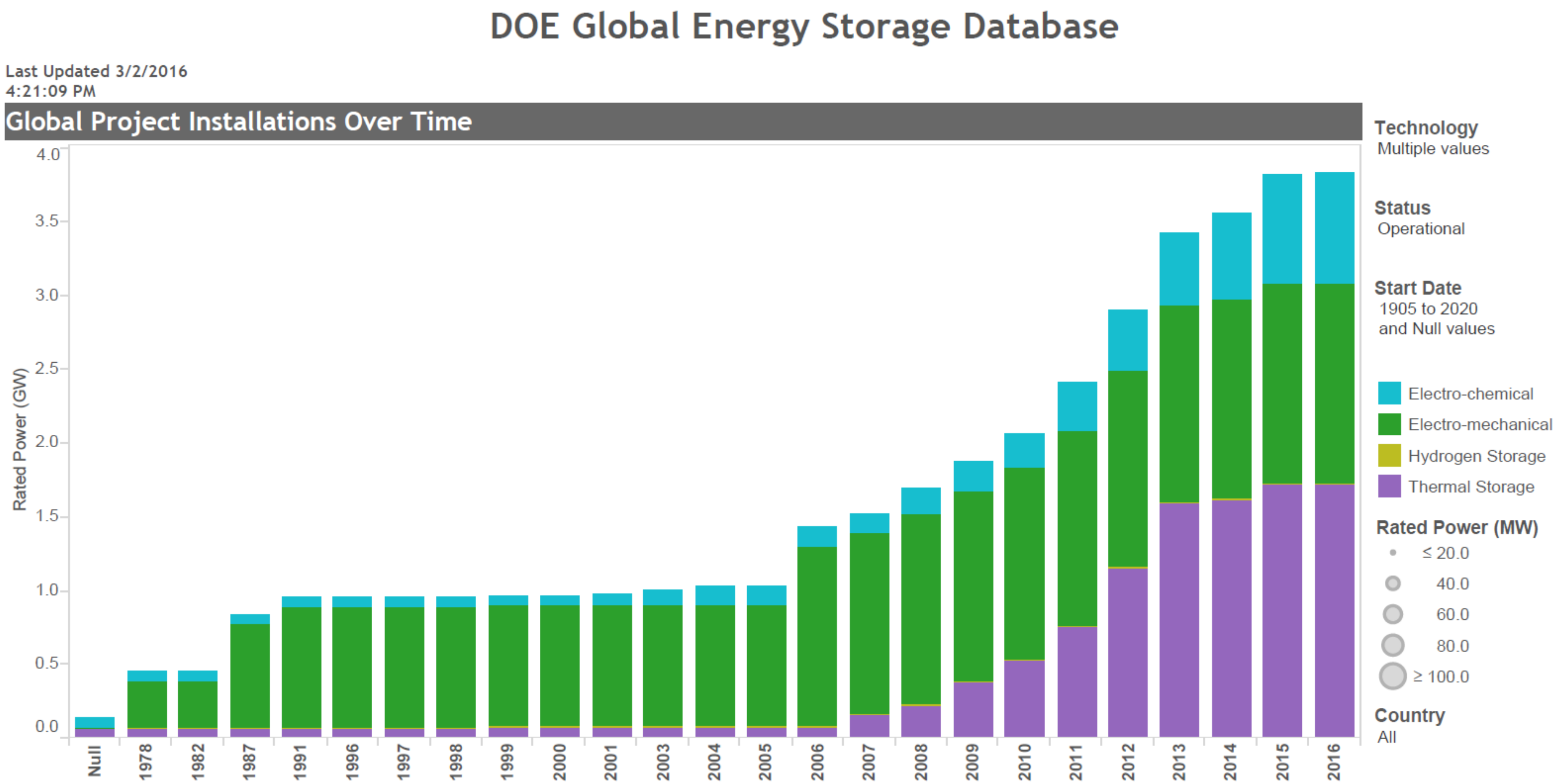
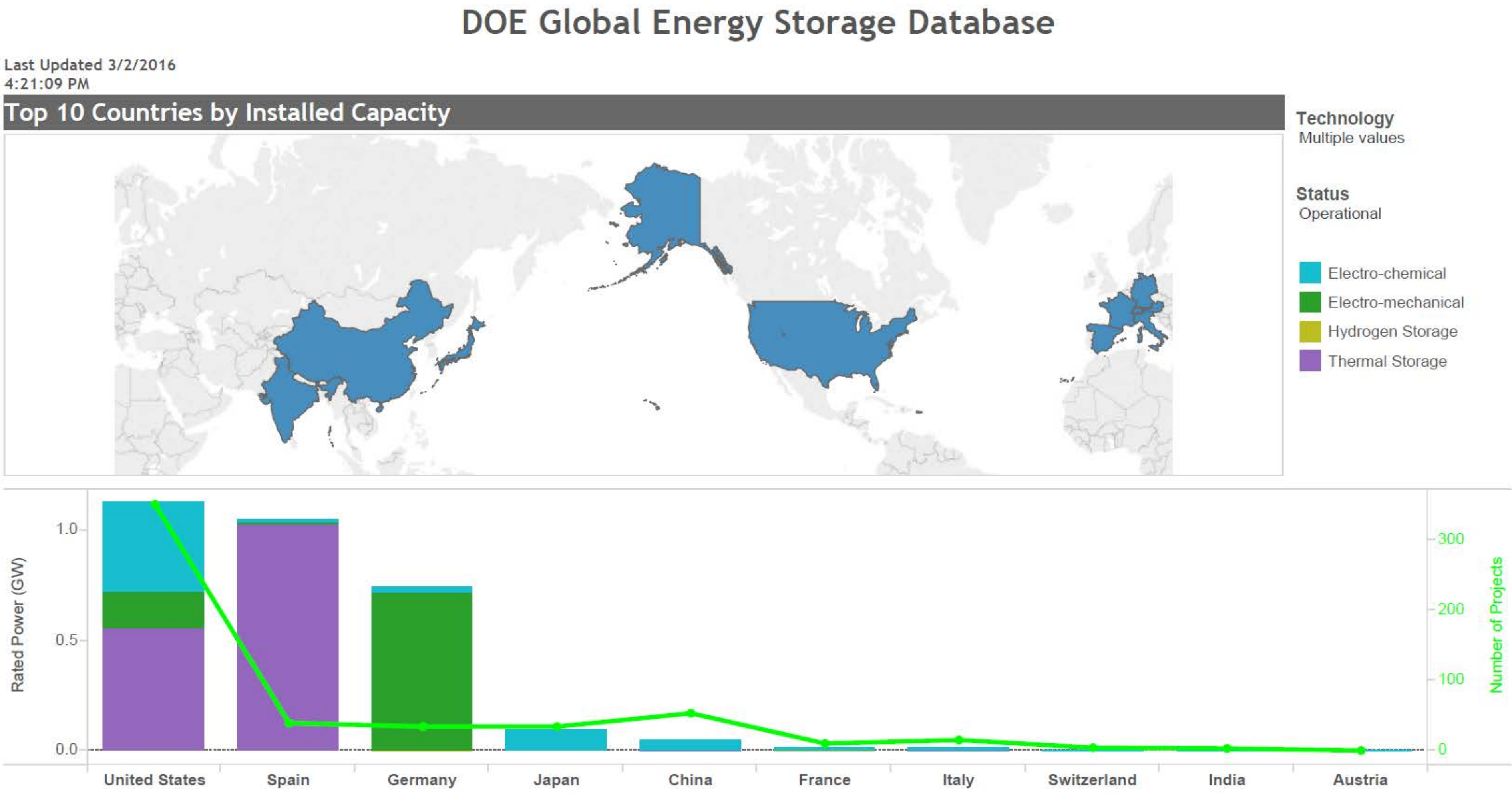
- Location/Jurisdiction
  - Market area, e.g., California ISO
  - Vertically integrated utility, e.g., PNM
  - Transmission and distribution deferral is very location specific
- Many applications require a combination of technical and financial analysis
  - Dynamic simulations (requires an accurate system model)
  - Production cost modeling (requires an accurate system model)
- Difficult to break out current cost of services, especially for vertically integrated utilities
- Identifying alternatives can be difficult
- Many storage technologies are not "off-the-shelf", proven technology (e.g., O&M costs, warranty????)
- Storage is expensive

Energy Storage on the Grid Today



Source: DOE Energy Storage Database

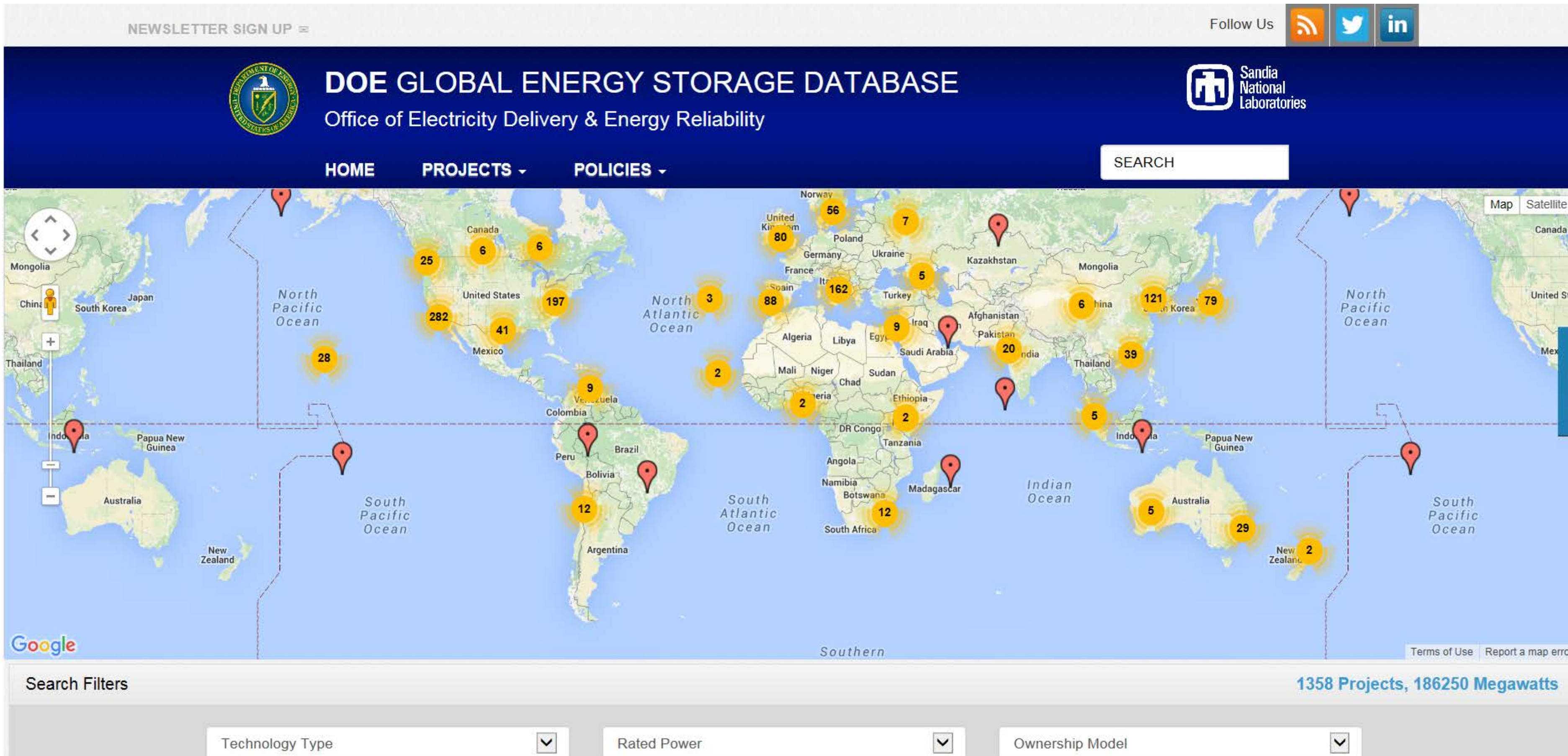
Energy Storage on the Grid Today



Source: DOE Energy Storage Database

DOE Energy Storage Database

- Two ways to find the web site:
  - http://www.energystorageexchange.org/
  - Google "DOE energy storage database"



Technology Maturities

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- **Deployed**
  - Pumped hydro
  - Compressed Air Energy Storage (CAES)
  - Batteries (NaS, Li-ion, Pb-Acid)
  - Flywheels
- **Demonstration**
  - Advanced Pb-acid and Flow batteries
  - Superconducting Magnetic Energy Storage (SMES)
  - Electrochemical Capacitors
- **Some early stage technologies**
  - Adiabatic CAES
  - Hydrogen
  - Synthetic Natural Gas

Source: U.S. Department of Energy, “Grid Energy Storage”, December 2013.

Technology Overview - CAES

- Compressed air energy storage (CAES)
  - Established technology in operation since the 1970’s
  - 110 MW (26+ hours) plant in McIntosh, Alabama – operational since 1991
  - Better ramp rates than gas turbines
- Applications
  - Energy management
  - Backup and seasonal reserves
  - Renewable integration
- Challenges
  - Geographic limitations
  - Lower efficiency
  - Slower than flywheels or batteries
  - Environmental impact

Solution-mined salt dome in McIntosh, AL

PG&E CAES feasibility study (porous rock)

SustainX isothermal CAES

Technology Overview – Pumped Hydro

- Pumped hydro energy storage
  - Developed and mature technology
  - Very high ramp rates
  - Most cost effective form of storage
- Applications
  - Energy management
  - Backup and seasonal reserves
  - Regulation service (variable speed pumps)
- Challenges
  - Geographic limitations
  - Plant site
  - Lower efficiency
  - High overall cost
  - Environmental impact

Mt. Elbert Pumped Hydro, 0.2MW, peaking plant, operational 1981.

Bath County Pumped Storage (Dominion Resources), 3 GW, operational December 1985

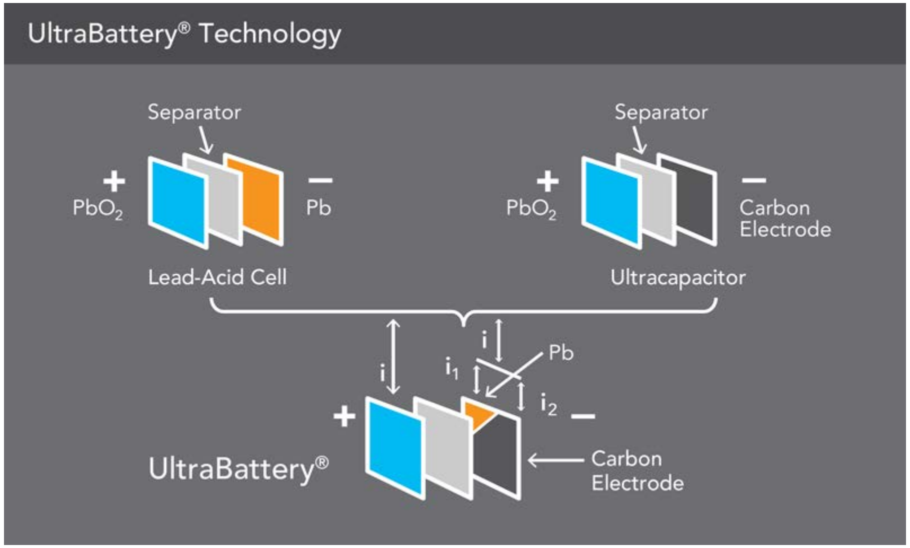
Technology Overview - Flywheels

- Flywheel energy storage
  - Modular technology
  - Long cycle life
  - High peak power
  - Rapid response
  - High round trip efficiency (~85%)
- Applications
  - Load leveling
  - Frequency regulation
  - Peak shaving
  - Transient stability
- Challenges
  - Rotor tensile strength limitations ($E \approx \omega^2$)
  - Limited energy storage time (frictional losses)

Beacon Power Hazle Township, PA plant. 20 MW, 5MWh. Operational September 2013. Stephentown, NY plant was built first.

Technology Overview – Lead Acid

- Advanced Lead Acid Energy Storage
  - Developed by Ecoult/East Penn Manufacturing
  - Carbon plates significantly improve performance
  - Mature technology
  - Low cost
  - High recycled content
  - Good battery life
- Applications
  - Load leveling
  - Frequency regulation
  - Grid stabilization
- Challenges
  - Low energy density
  - Limited depth of discharge
  - Large footprint



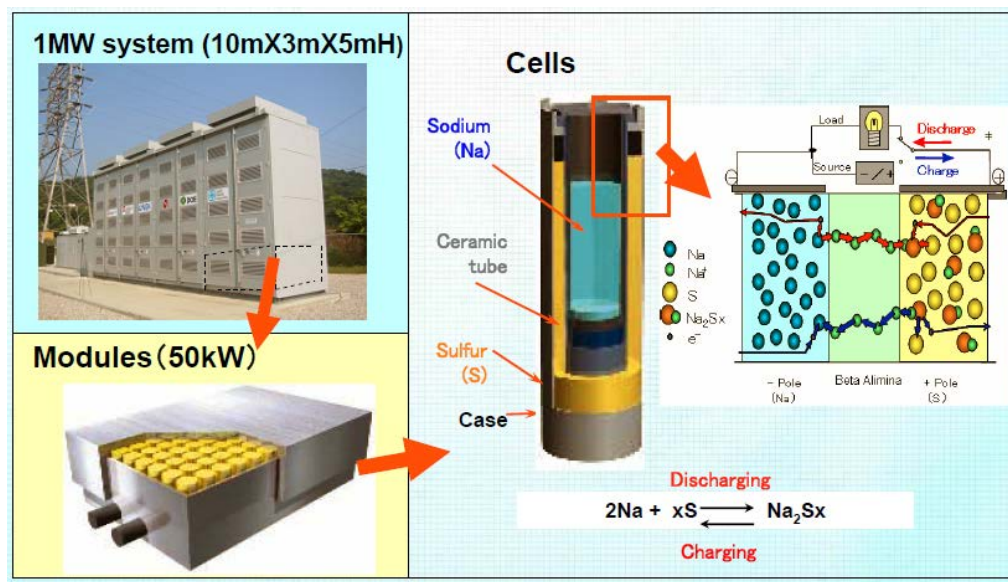
Albuquerque, NM

East Lyons, PA

Technology Overview - NaS

- Sodium Sulphur Energy Storage
  - High energy density
  - Long discharge cycles
  - Fast response
  - Long life
  - 190 sites in Japan
  - Developed by Ford in 1960's
  - Sold to Japan (NGK is largest manufacturer)
- Applications
  - Power quality
  - Congestion relief
  - Renewable integration
- Challenges
  - High operating temperature (250-300C)
  - Liquid containment issues

Los Alamos, NM. 1 MW, 6MWh.



Source: NGK

Technology Overview – Li-ion

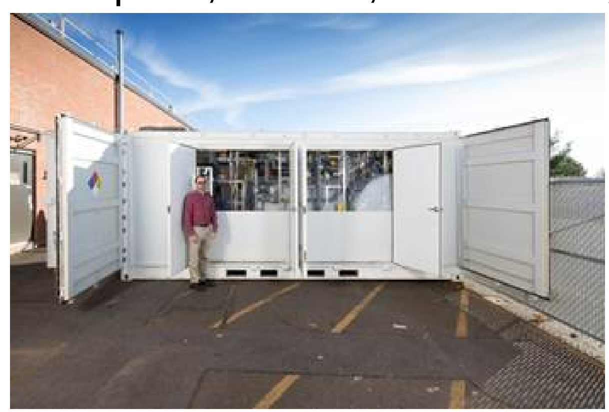
- Li-ion Energy Storage
  - High energy density
  - Good cycle life
  - High charge/discharge efficiency
- Applications
  - Power quality
  - Frequency regulation
- Challenges
  - High production cost
  - Extreme sensitivity to:
    - Over temperature
    - Overcharge
    - Internal pressure buildup
  - Intolerance to deep discharge

SCE Tehachapi plant, 8MW, 32MWh.

Technology Overview – Flow Batteries

- Flow Battery Energy Storage
  - Long cycle life
  - Power/Energy decomposition
  - Lower efficiency
- Applications
  - Ramping
  - Peak Shaving
  - Time Shifting
  - Power quality
  - Frequency regulation
- Challenges
  - Developing technology
  - Complicated design
  - Lower energy density

Enervault plant, Turlock, CA. 250kW, 1 MWh.



Vionx Vanadium Redox Flow battery, 65kW, 390kWh

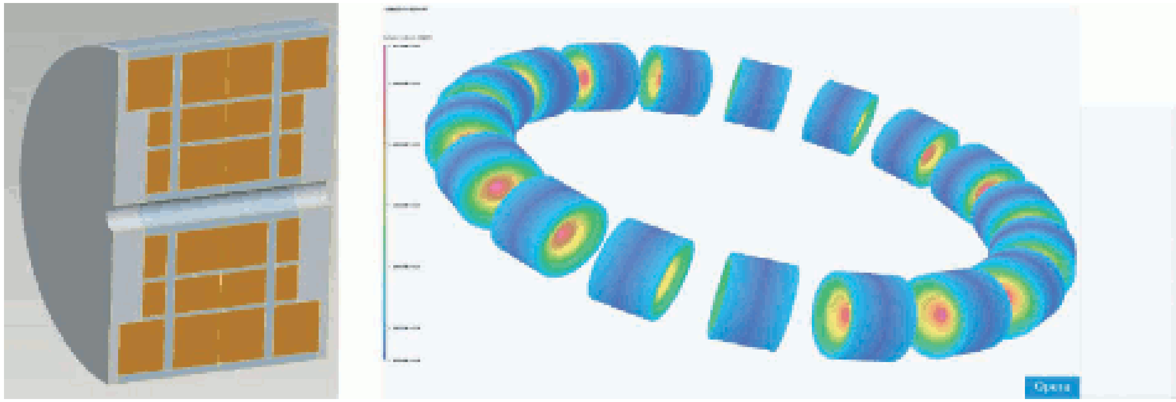
Technology Overview - Capacitors

- Capacitor Energy Storage
  - Very long life
  - Highly reversible and fast discharge, low losses
- Applications
  - Power quality
  - Frequency regulation
  - Regenerative braking (vehicles)
- Challenges
  - Cost

Ultra capacitor module, designed for vehicle applications (e.g., buses, trains)

Technology Overview - SMES

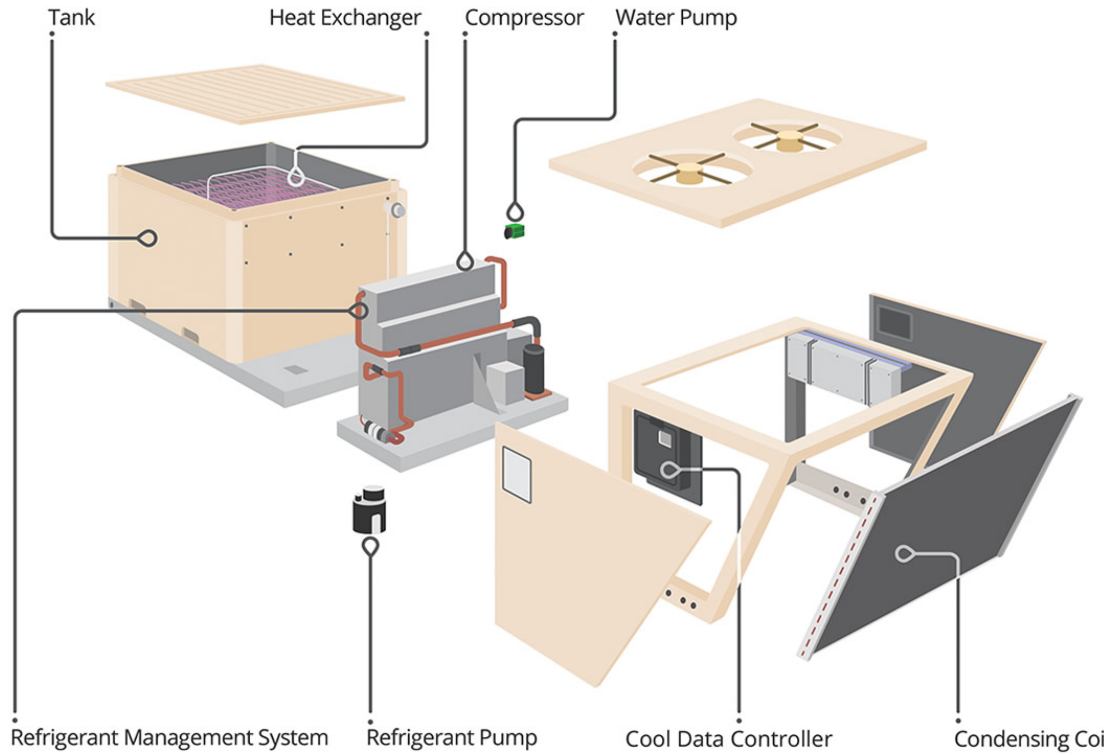
- Super Conductive Magnetic Energy Storage
  - Highest round trip efficiency (~95%)
- Applications
  - Power quality
  - Frequency regulation
- Challenges
  - Low energy density
  - Component and manufacturing cost



2010 SMES Project (ARPA-E)

Technology Overview – Thermal

- Thermal Energy Storage
  - Ice-based technology
  - Molten salt
- Applications
  - Energy time shift
  - Renewable firming
- Challenges
  - Lower efficiency (~70%) for electricity-electricity
  - Solar thermal plants more expensive than PV



Ice Energy's proven Ice Bear® system, www.ice-energy.com

Summary

- Additional information can be found at:
  http://www.sandia.gov/ess/
- Information on ARRA energy storage demonstration projects:
  https://www.smartgrid.gov/recovery_act/program_impacts/energy_storage_technology_performance_reports.html