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Sandia National Laboratories

Energy Storage and the Future Electric Grid

Babu Chalamala

IEEE Phoenix Section, Oct 17, 2017

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About Sandia National Laboratories

- $3B in annual R&D spending
- Total Sandia workforce: 12,609
- Regular employees: 10,330
- Advanced degrees: 5,790 (56%)

Large multi-program research and engineering laboratory

Focused on National Security, including energy

The Grid Today

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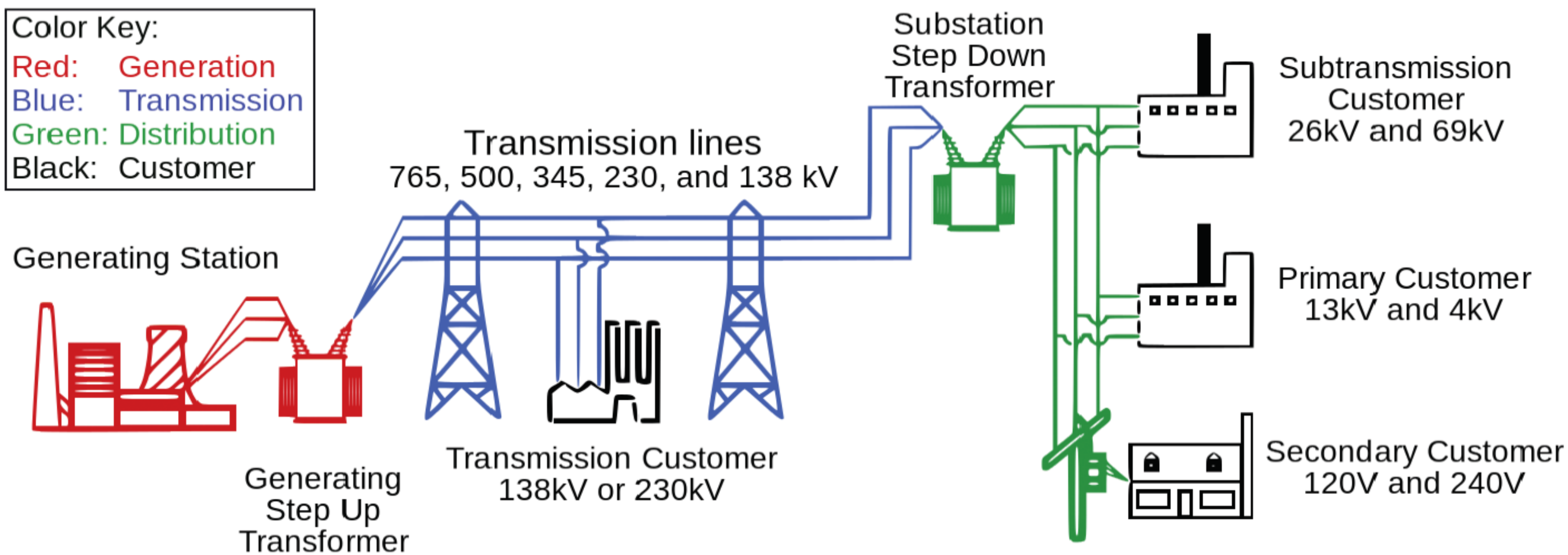
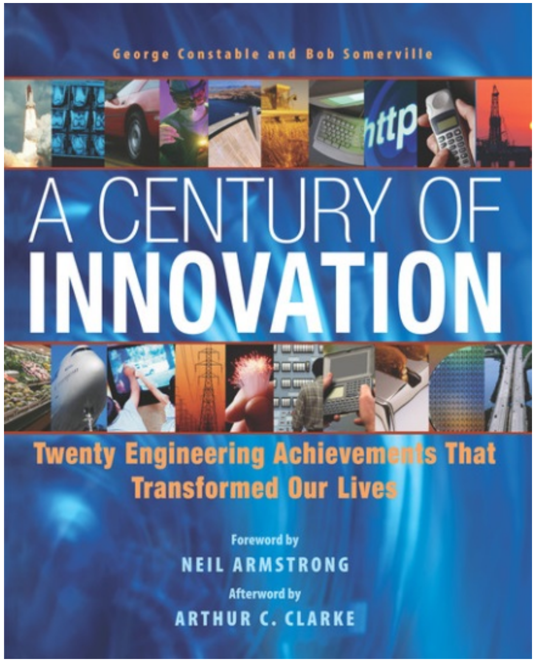


- Grid 1.0
  - A one way delivery system with very little flexibility, with generation and load always balanced
  - Utilities deliver reliable power at prices set by regulators in most markers, and variable market driven pricing in a few markets

NERC

The Success of the Grid

- Remarkably reliable and efficient
  - Large interconnected network
  - Just-in-time production and consumption
  - Highly reliable 99.999%
- Success rests on two important principles
  - Diversity of aggregated loads
    - Aggregated loads change is predictable
    - Control over generation, throttled to provide power as needed



Electrification ranks as the most important engineering achievement of the 20th century
National Academy of Engineering, 2003

U.S. Electricity Facts

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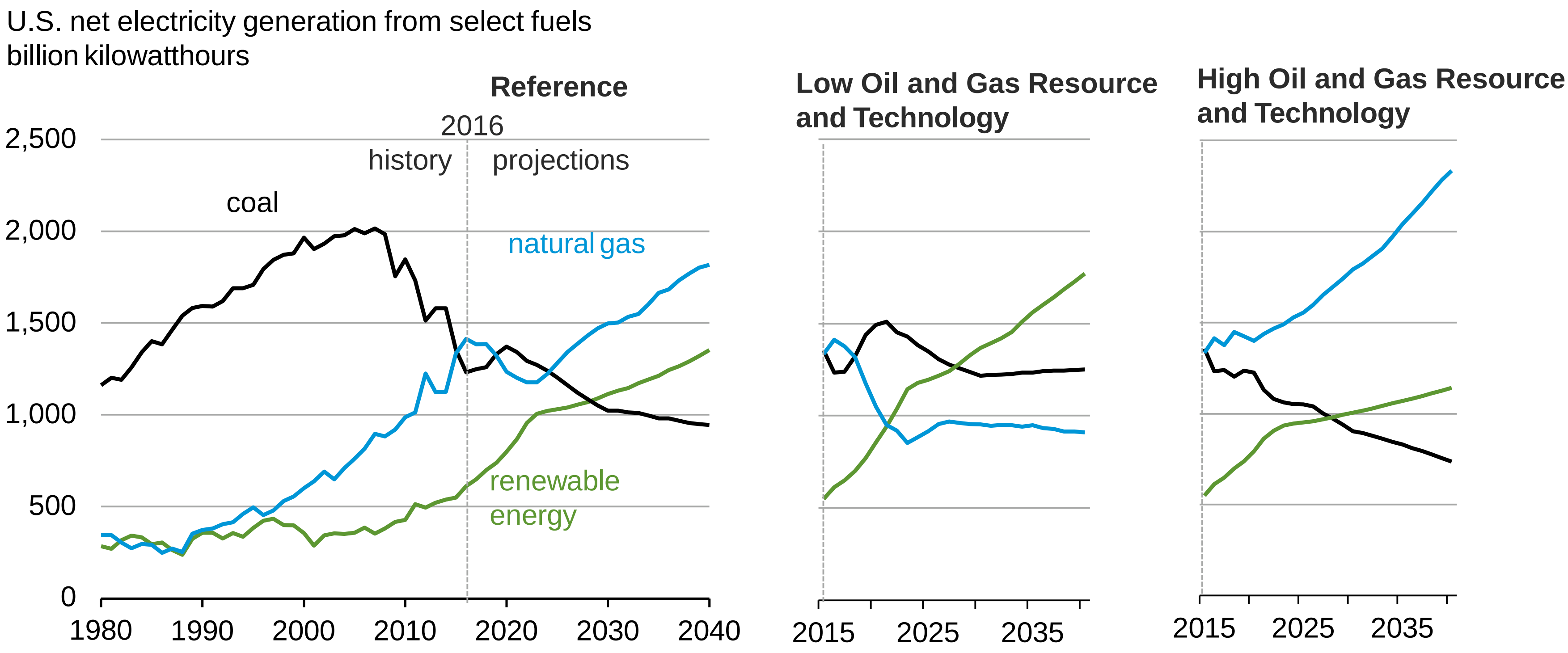
- Over 3,200 utilities, 60,000 substations, 160,000 miles of high-voltage transmission lines, 7 million miles of distribution circuit
- As of Dec 31, 2015, generation capacity of 1,176 GW. Summer peak load: 1070 GW, Baseload: 800 GW
- In 2015, total U.S. electricity generation was 4,087,381 GWh
  - U.S. investor-owned electric companies accounted for 1,489,472 GWh, or 36.4 percent, of total U.S. electricity generation
  - 13.4% of generation from renewables including 6.1% from Hydropower, 7.3% from other renewables including wind and solar.
- Total revenues of $388 billion, average revenue 10.42 cents/kWh

Sources: APPA, EIA, EEI

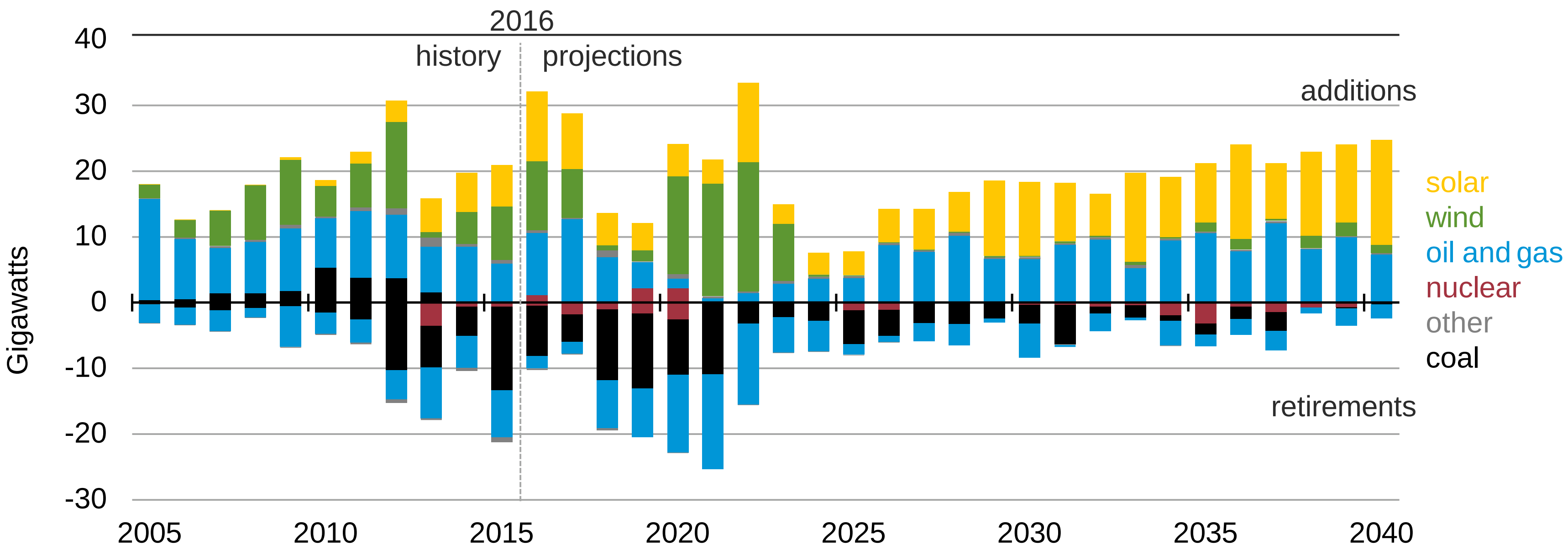
U.S Electricity Generation Mix



Source: EIA, Annual Energy Outlook 2017

Natural gas resource availability affects prices and plays a critical role in determining the mix of coal, natural gas, and renewable generation

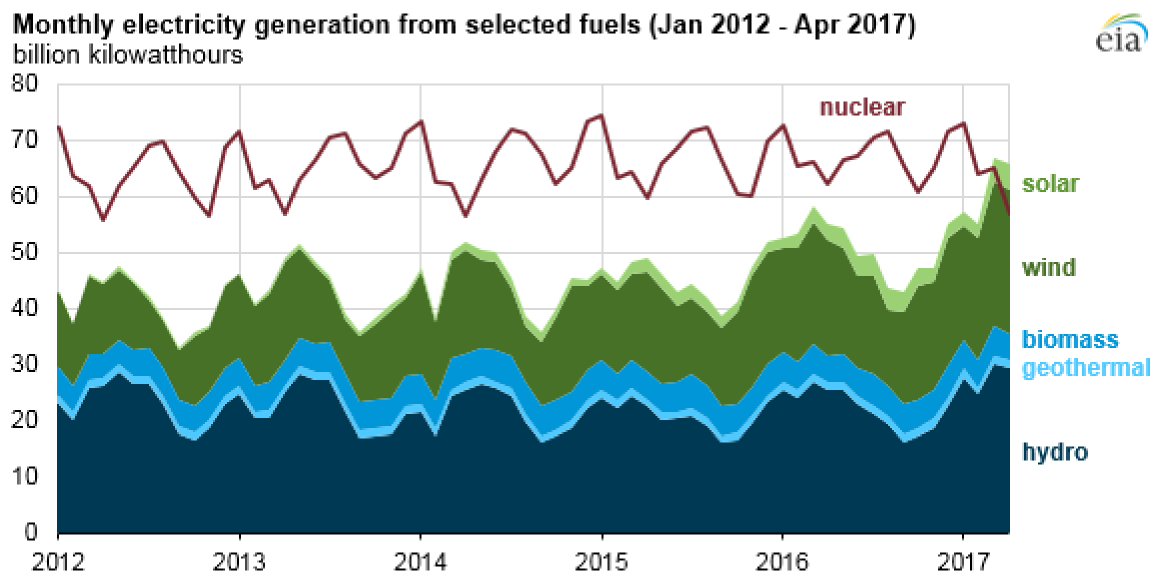
Capacity Additions and Retirements



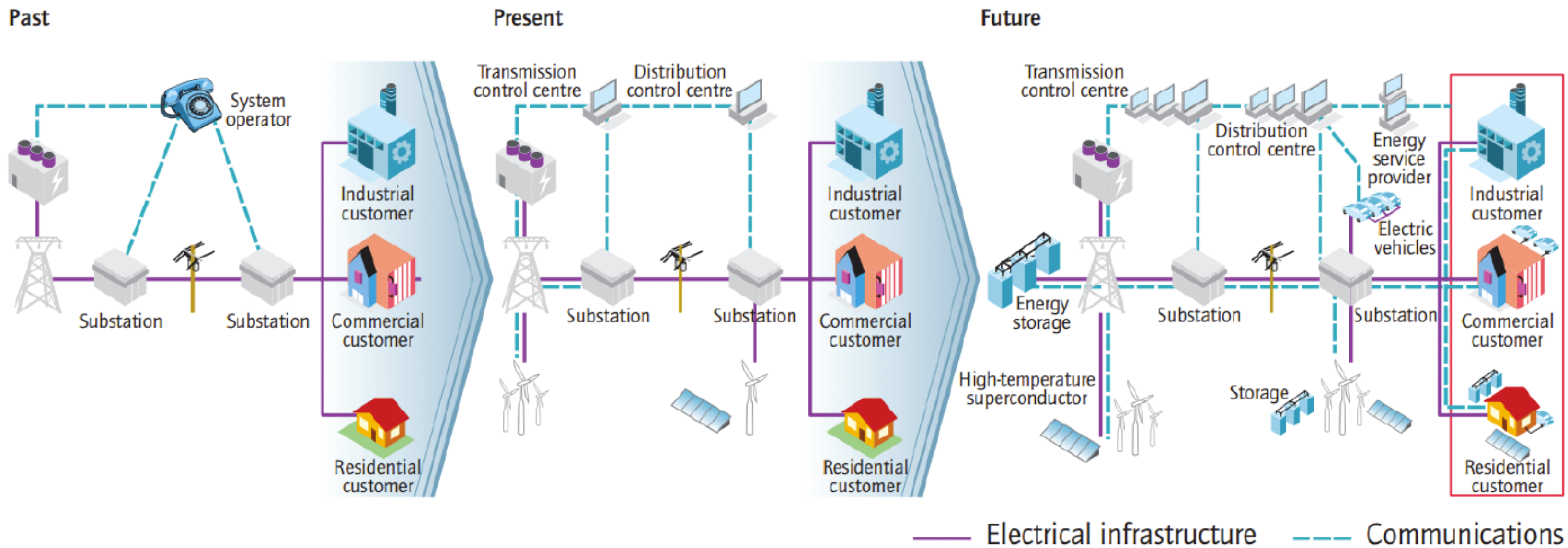
Source: EIA, Annual Energy Outlook 2017

Reductions in solar and wind capital costs and clean energy tax credits sustaining renewable growth. Coal-fired unit retirements primarily driven by low natural gas prices

Utility-scale Renewables Generation surpassed Nuclear Generation – April 2017



Future Grid will move towards a Hybrid Grid Architecture



Source: Quadrennial Technology Review US DOE, 2015

Grid 2.0

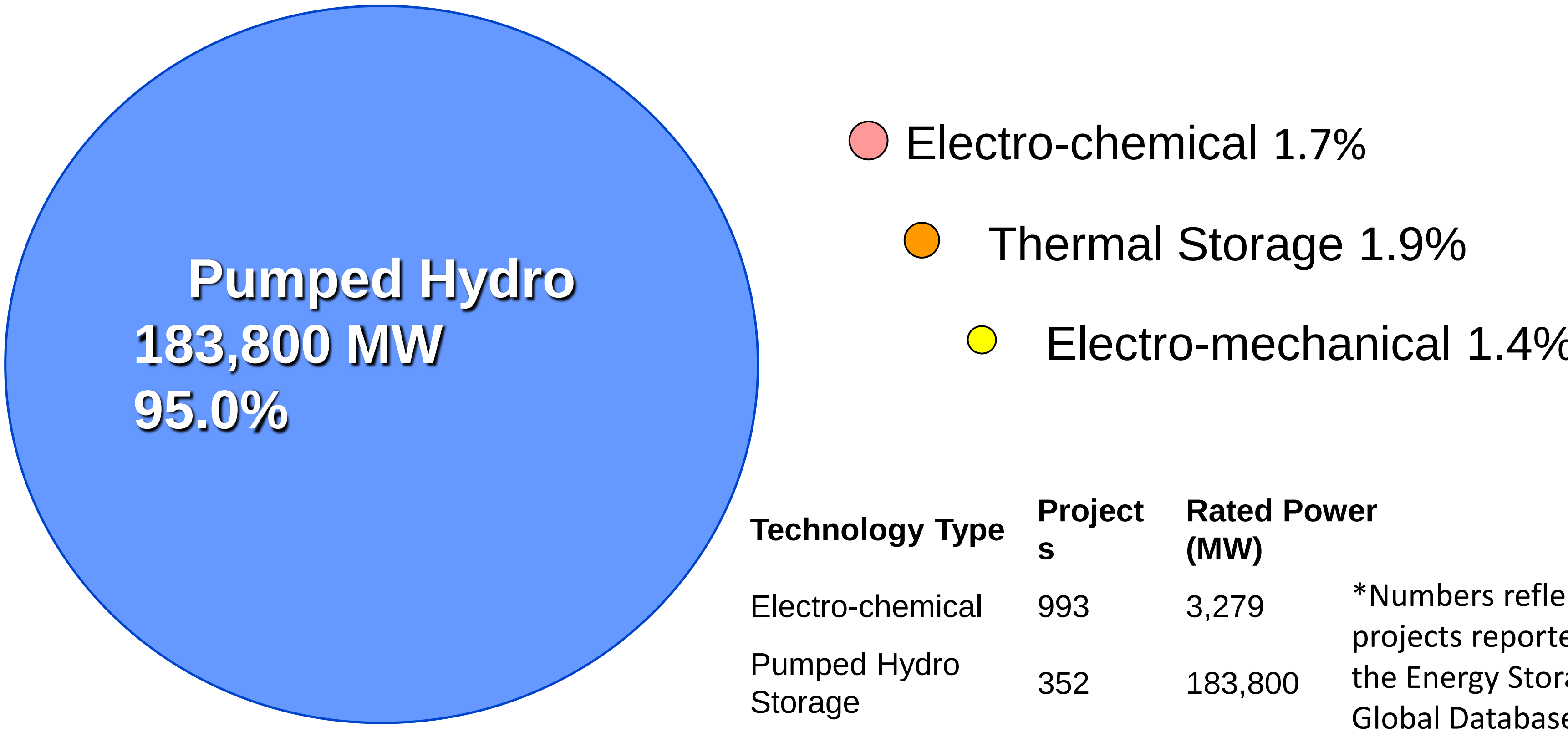
- Integration of renewables and distributed generation beginning to take off
- Minimal tools to manage grid instabilities

Future Grid

- Distributed generation and two-way energy flows
- Large scale renewable integration. Ability to manage diverse generation mix and intermittency

Energy Storage is integral to a future grid with two-way power flows and large scale renewables integration

Energy Storage in the Grid



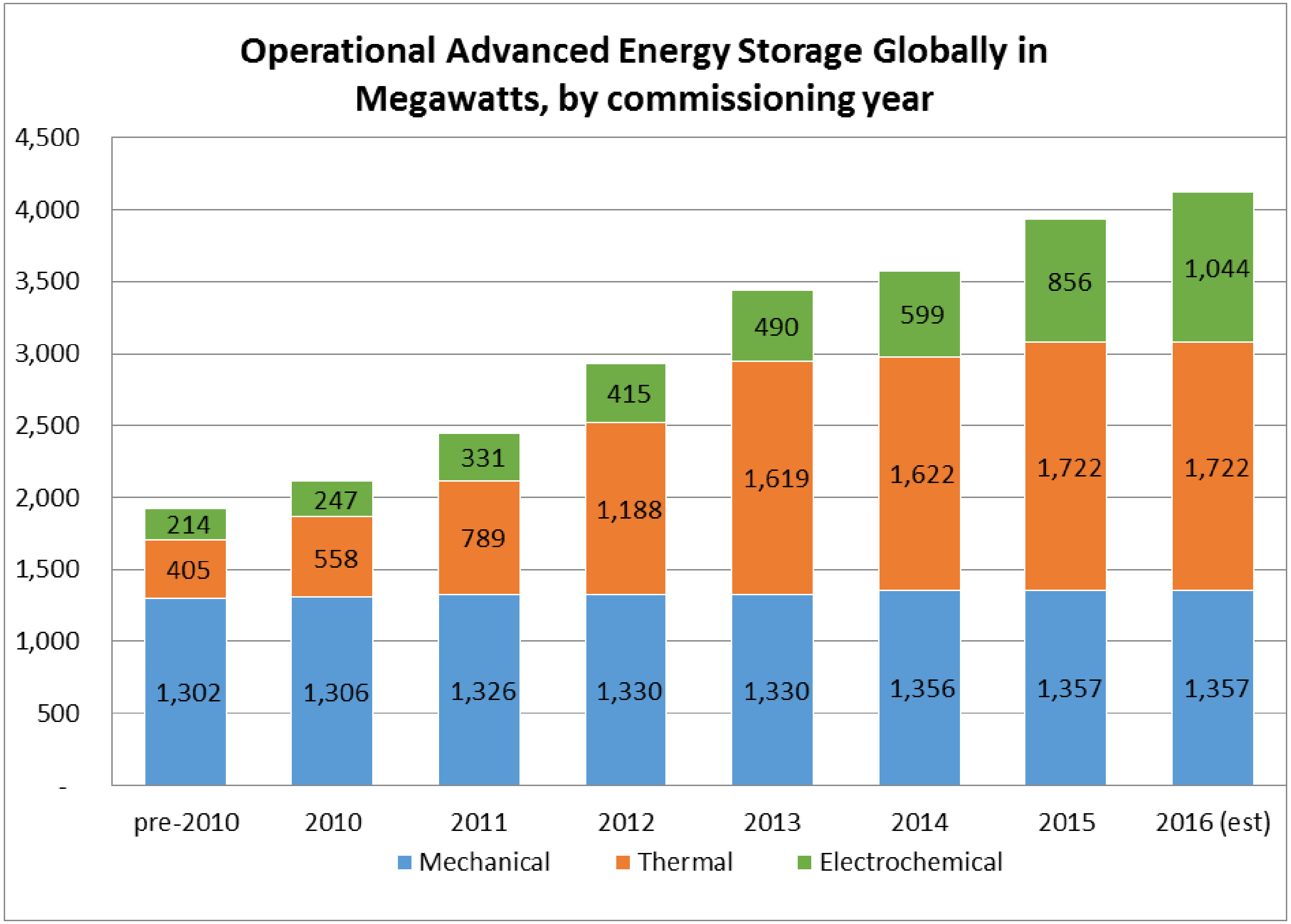
Technology Type	Projects	Rated Power (MW)
Electro-chemical	993	3,279
Pumped Hydro Storage	352	183,800
Thermal Storage	206	3,622
Electro-mechanical	70	2,616

*Numbers reflect projects reported to the Energy Storage Global Database as of (May 2017)

DOE ESS Database
http://www.energystorageexchange.org/

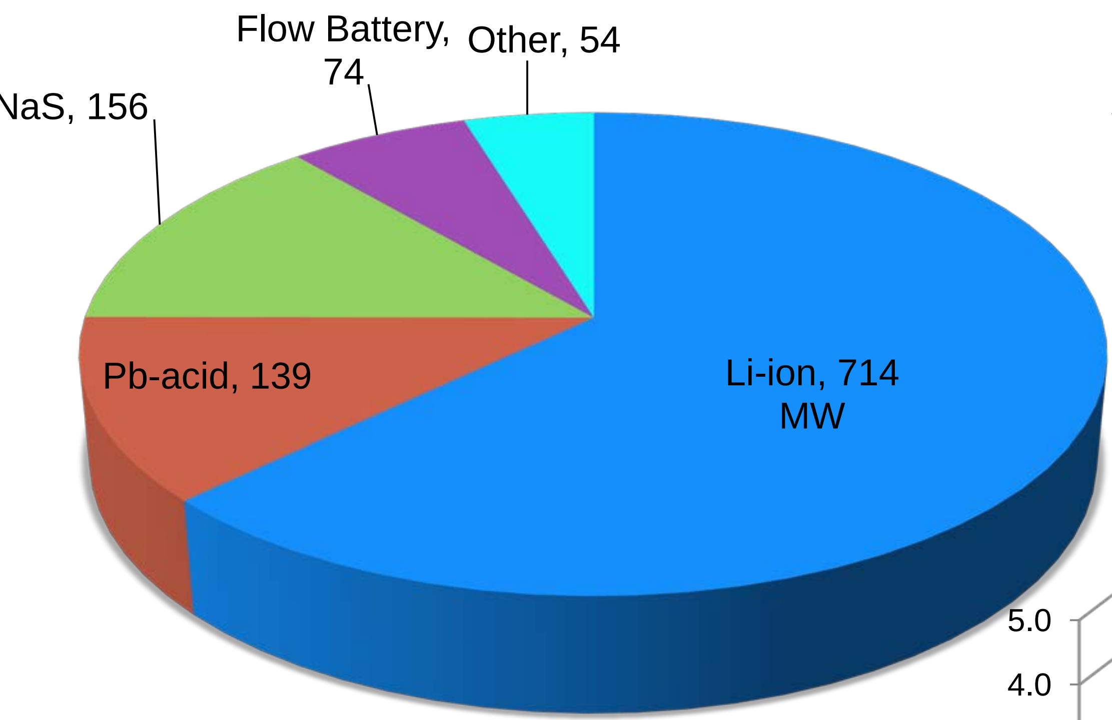
- US installed energy storage capacity of 32 GW represents 15 min ridethrough

Operational Advanced Energy Storage (MW)

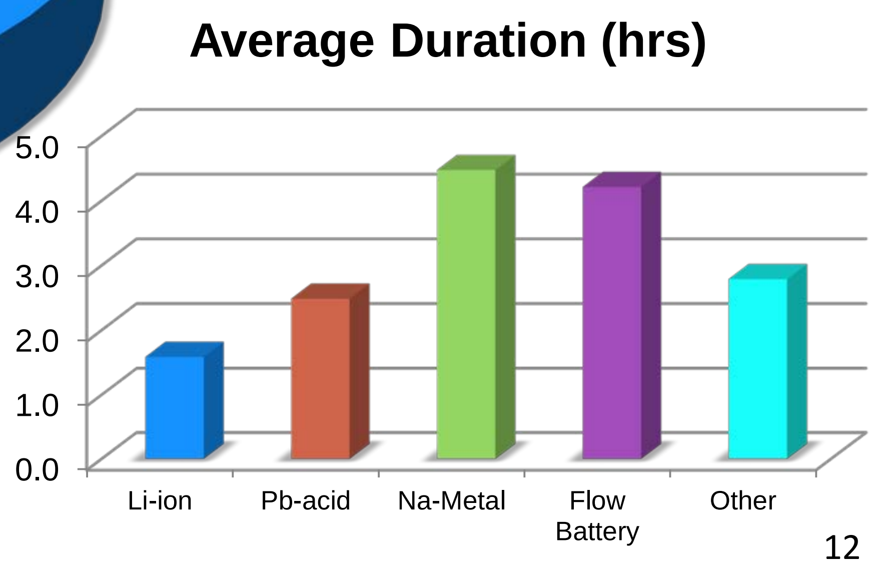


DOE Global Energy Storage Database, March 23, 2016:
www.energystorageexchange.org

Current Stationary ESS deployments (Battery Only)



~ 1.1 GW of Battery Energy Storage (US)



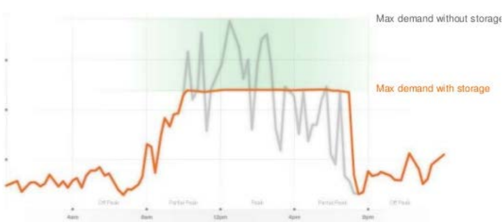
Source: *DOE Global Energy Storage Database*
http://www.energystorageexchange.org/

The Need for Energy Storage

Grid-scale energy storage can enable significant cost savings to industry while improving infrastructure reliability and efficiency

Mitigate $79B/yr in commercial losses from outages

Reduce $2T in required T&D upgrades



Reduce commercial and industrial electrical bills through demand charge management. 7.5 million U.S. customers are enrolled in dynamic pricing (EIA 2015)

Balance the variability of 825 GW of new renewable generation while improving grid reliability and efficiency.

Growth of Renewables

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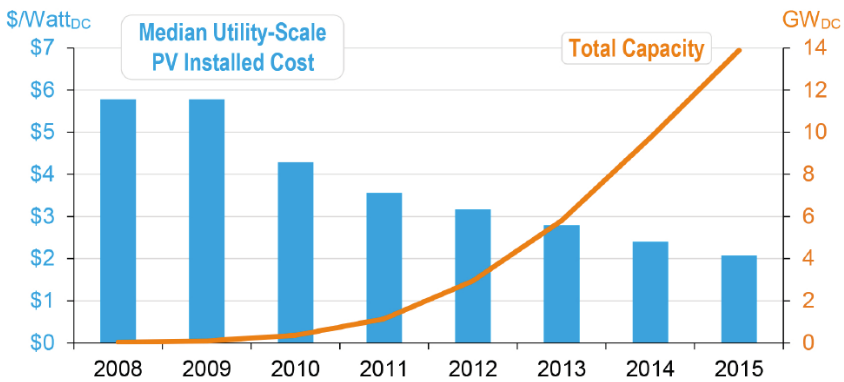
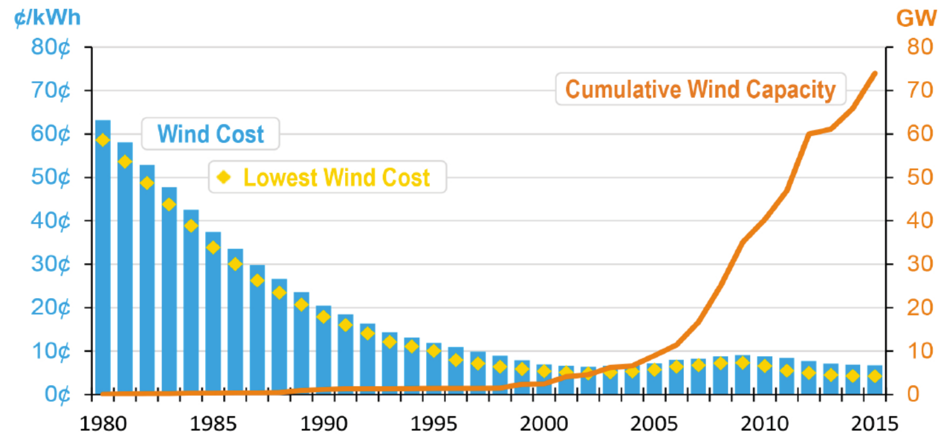
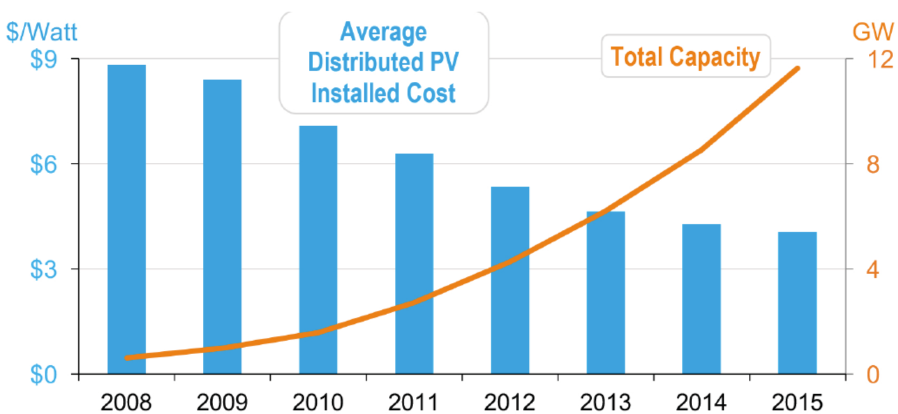
Solar PV: Utility-Scale





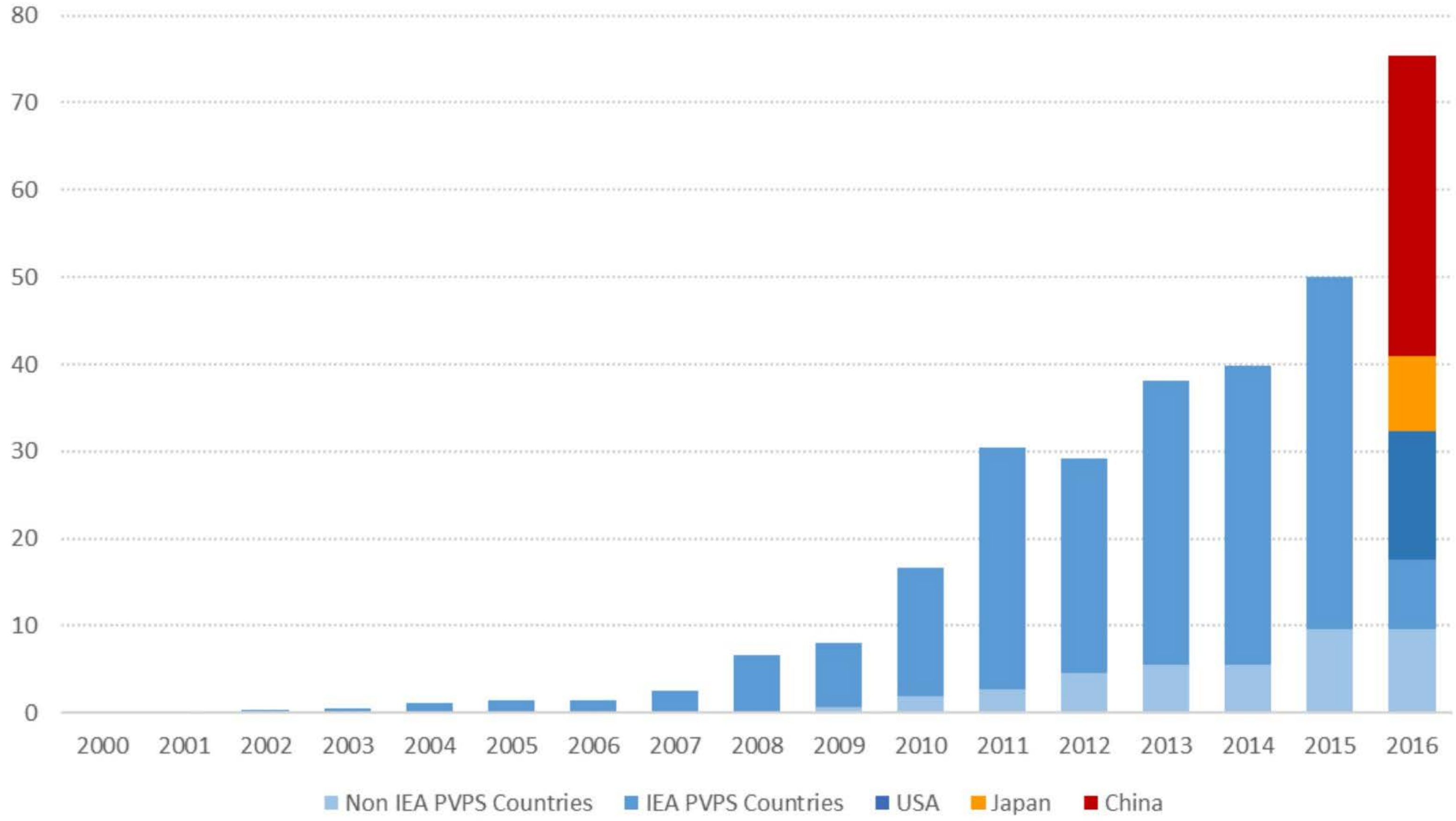
Solar PV: Distributed



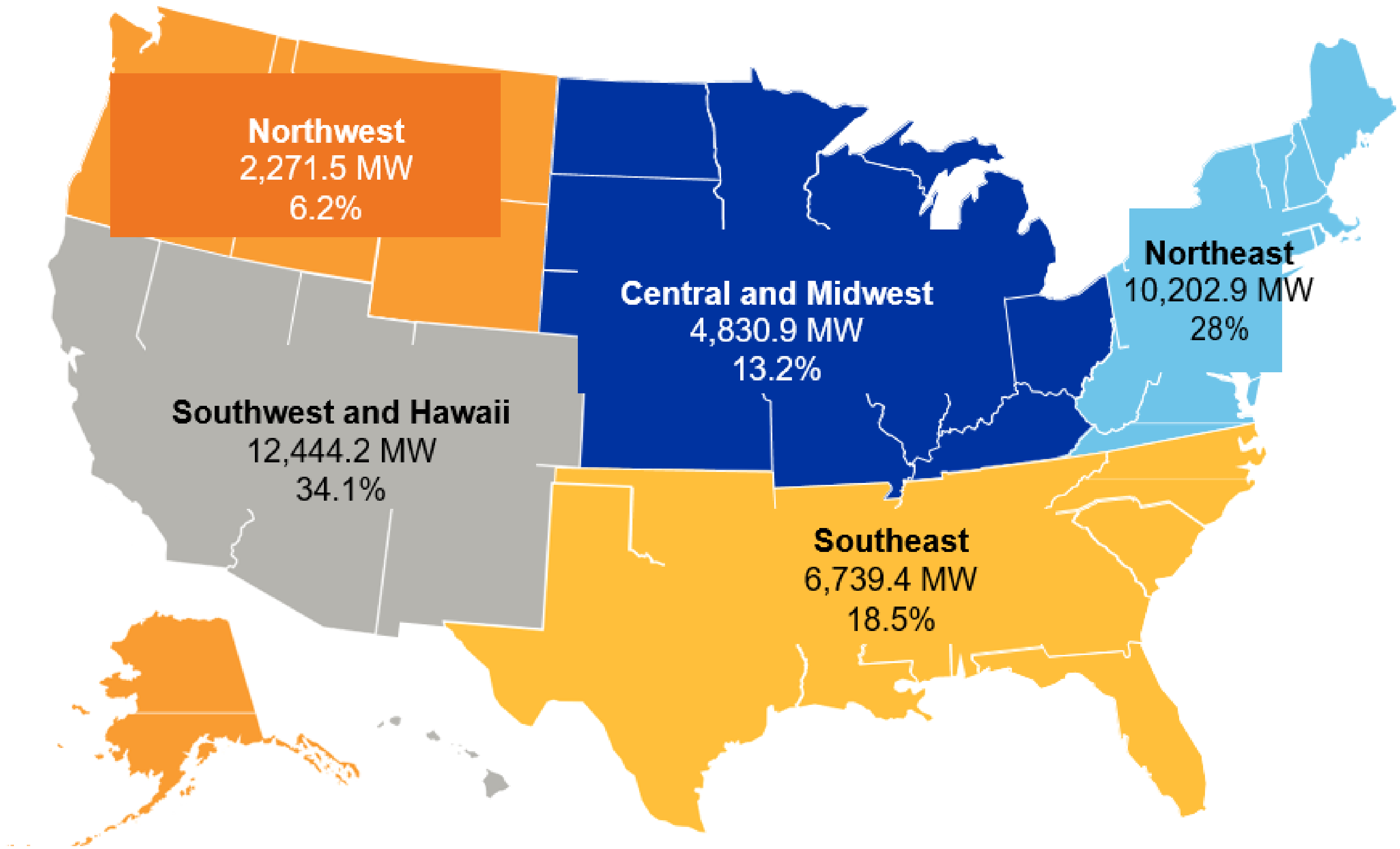
160 GW of renewables installed in 2016
49 GW of U.S. wind by 2020
15 GW of U.S. solar in 2016
60 GW of Corporate Procured Renewables projected in the next 7 years

The Future Arrives for Five Clean Energy Technologies – 2016 Update, US DOE
http://energy.gov/eere/downloads/revolutionnow-2016-update

Accelerating RE Deployments



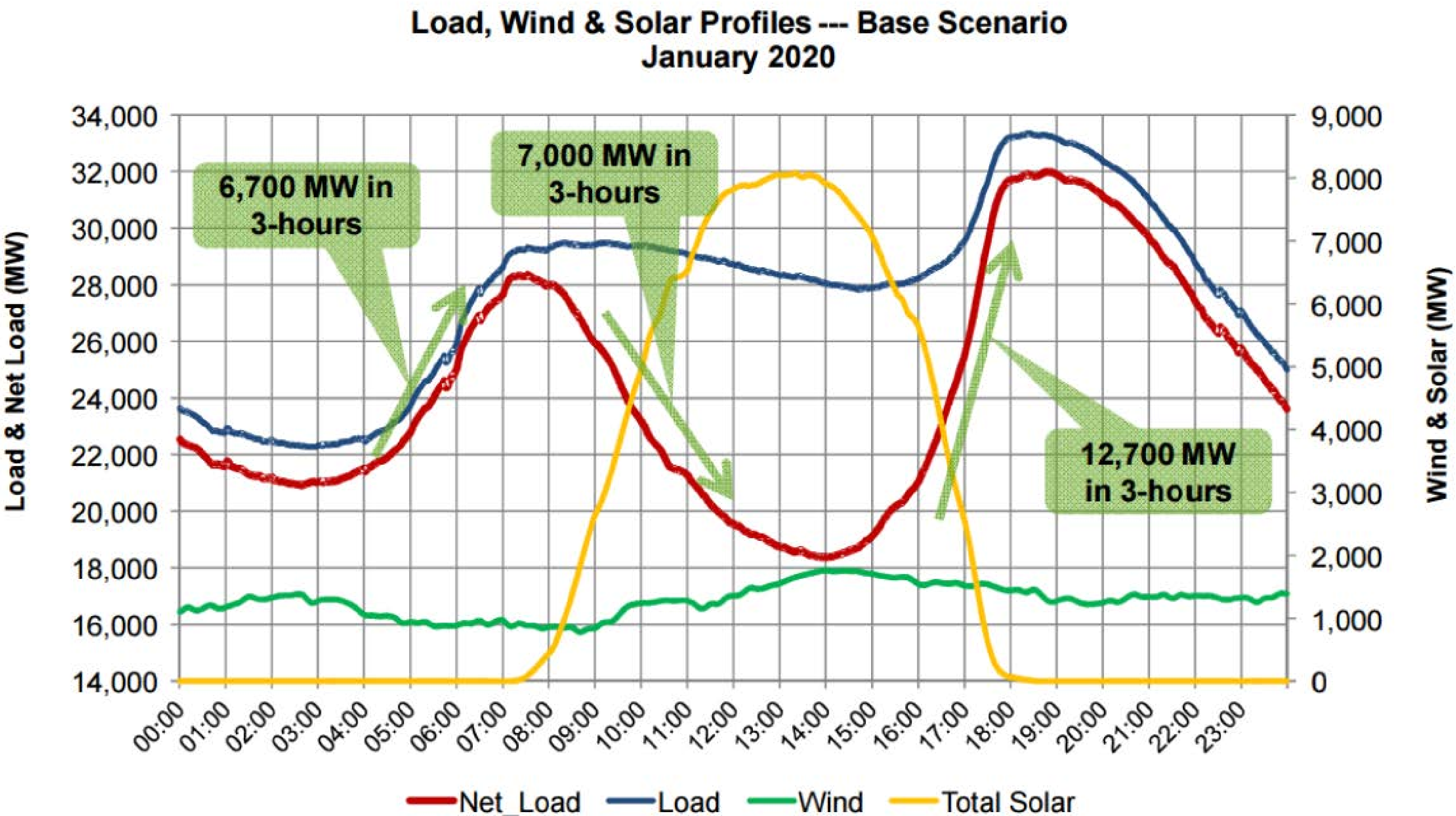
Projected Capacity Additions by Region (2017-2025)



In California by 2021, solar, storage and wind capacity additions will exceed natural gas (GTM Research)

Source: ESA, Navigant Consulting

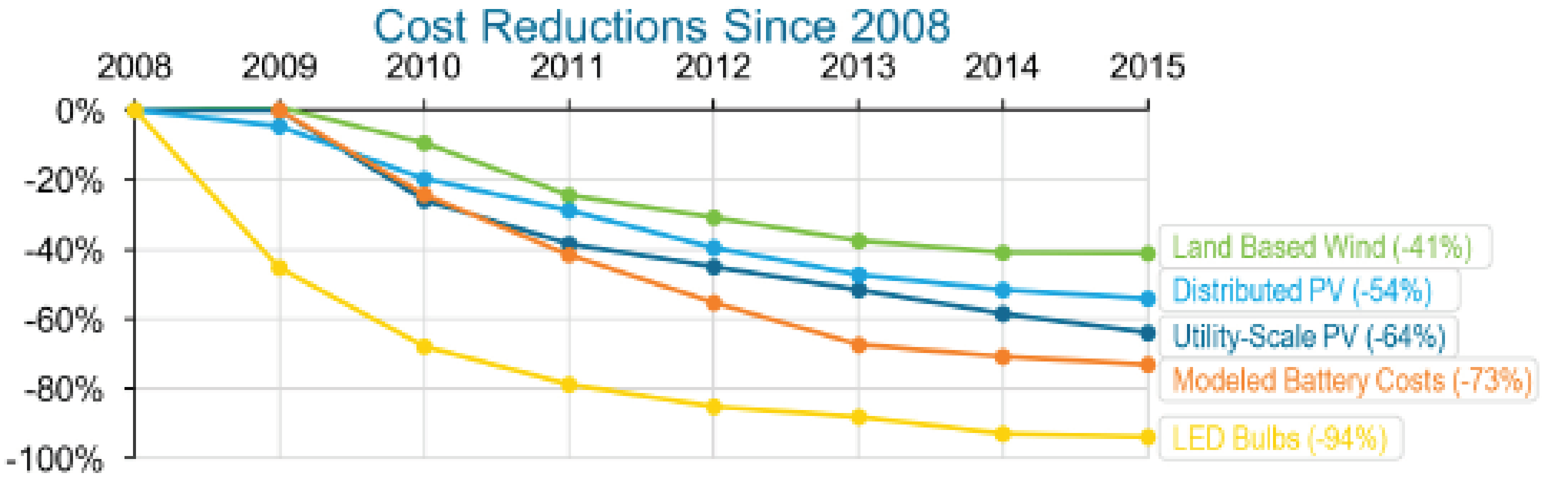
Wind and Solar Load Balancing (CAISO)



Increased renewable penetration creates system-wide load swings

Source: Rob Cummings, NERC, 2016

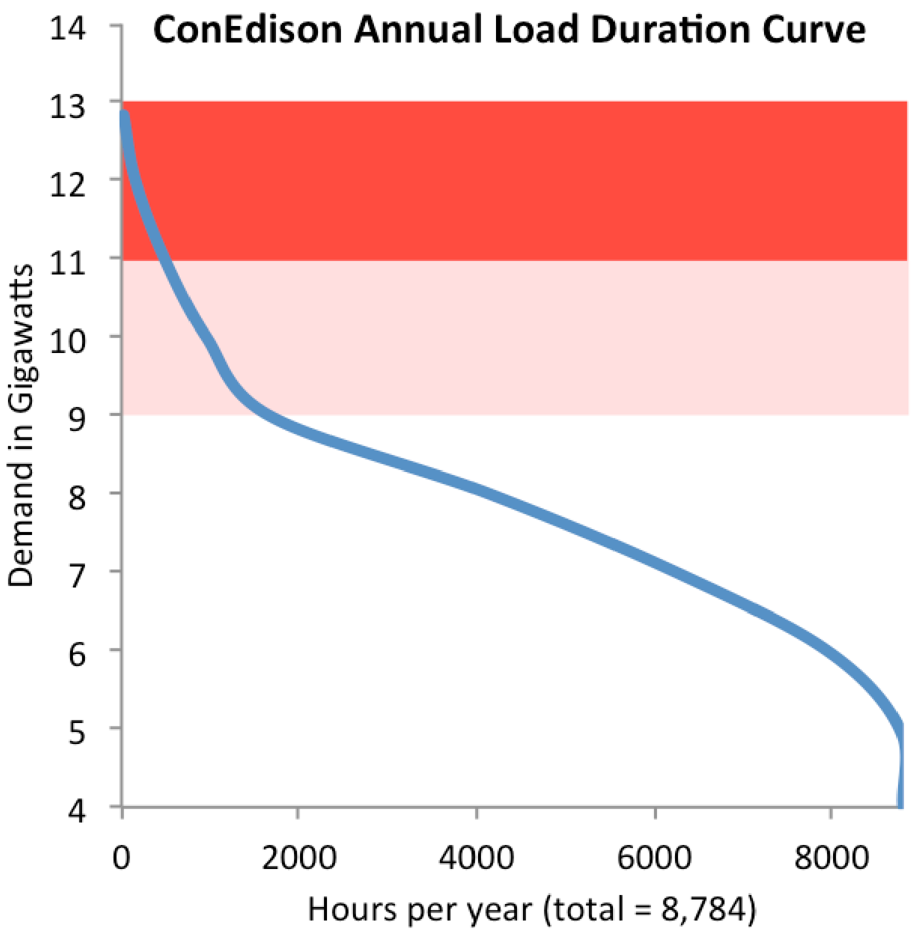
Driven by Steep Cost Reductions



Cost reductions primarily due to high volume manufacturing and large scale deployments

The Future Arrives for Five Clean Energy Technologies – 2016 Update, US DOE
http://energy.gov/eere/downloads/revolutionnow-2016-update

Peak Load is Driving System Costs



New York

Top 2 GW, 15% of total demand
runs 7 days/yr, <2% of the time
Cutting top 100 Hours: $1.7B

Massachusetts

Top 10% of Demand
= 40% of System Cost

Source: ConEdison, NYISO

Improving the Efficiency of Existing Generation Assets

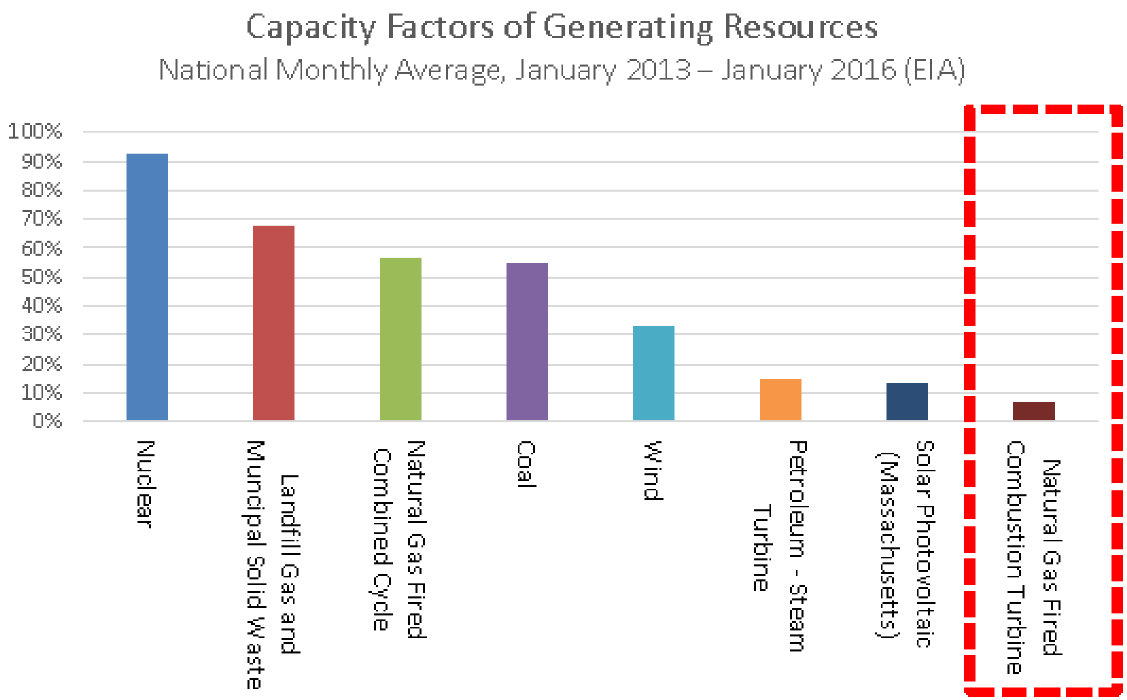


Figure 2-8: Average Monthly Capacity Factors[44]

EIA Electric Power Monthly, Table 6.7.A. Capacity Factors for Utility Scale Generators Primarily Using Fossil Fuels, January 2013-January 2016; https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_6_07_a

Drivers for Energy Storage

- Application drivers for large scale energy storage
  - Renewable integration
  - Grid resiliency
  - Transmission and Distribution upgrade deferral
  - Power quality, e.g., UPS application, microgrids, etc.
  - Improved efficiency of nonrenewable sources
  - Off-grid applications
- Market drivers
  - Steep cost declines

Has Energy Storage Arrived?

Solar + Storage

- January 2017 - Kauai Island Utility Cooperative signed a solar-plus-storage PPA at $0.11/kWh. This project at 28 MW of solar and 100 MWh of batteries — will displace the utility's current oil-fired baseload generation.
- May 2017 - Tucson Electric Power has signed a PPA with NextEra Energy for a solar-plus-storage system at "an all-in cost significantly less than $0.045/kWh over 20 years." PPA for the solar portion of the project at below $0.03/kWh. 100 MW PV and a 30 MW, 120 MWh energy storage system, both developed by an affiliate of NextEra Energy.
  - Examples of HECO/AES PPAs
  - May 2017 Tucson Electric Next ERA PPA

Aliso Canyon

SDG&E 30 MW/120 MWH lithium-ion battery energy storage system in Escondido, Calif.

SoCalGas relies on Aliso Canyon to provide gas for core customers—homes and small businesses—as well as non-core customers, including hospitals, local governments, oil refineries, and 17 natural gas-fired power plants with a combined generating capacity of nearly 10,000 megawatts.

As part of a multi-part response to the crisis, the California Public Utilities Commission in May 2016 fast-tracked approval of 104.5 MW of battery-based energy storage systems within the service areas of Southern California Edison (SCE) and San Diego Gas & Electric (SDG&E).

Technology Maturities

- **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

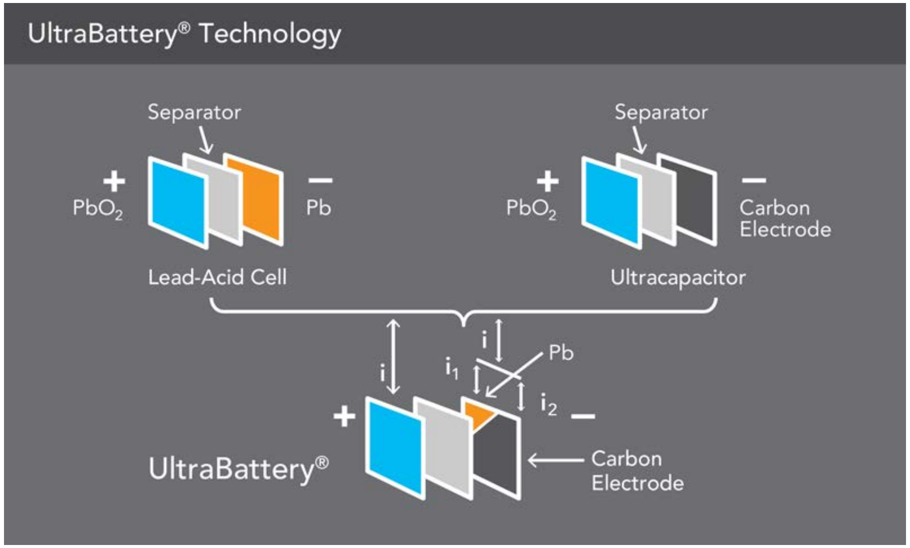
Technology Overview - Flywheels

- 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
  - High cost per unit energy stored
  - Lack of codes and standards for safe design and operation

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



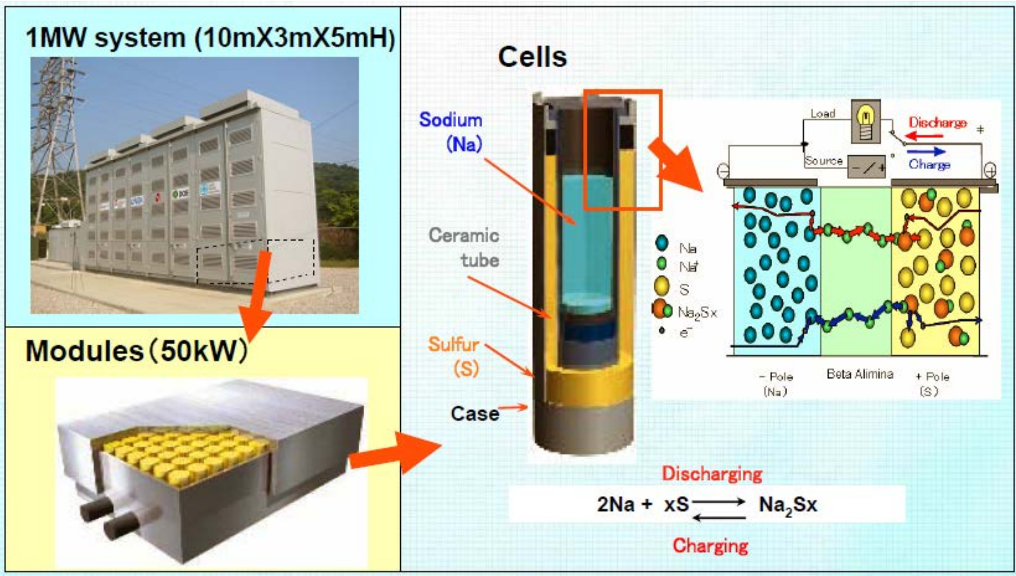
Albuquerque, NM

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

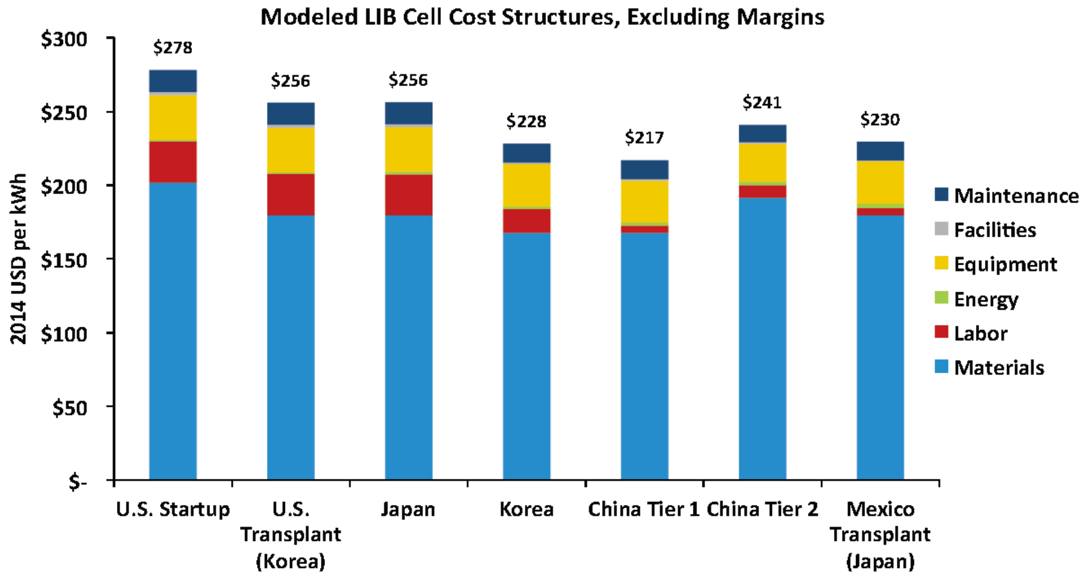
- Li-ion Energy Storage
  - High energy density
  - Good cycle life
  - High charge/discharge efficiency
- Applications
  - Power quality
  - Frequency regulation
- Challenges
  - High production cost
  - Extreme sensitivity to:
    - Over temperature
    - Overcharge
    - Internal pressure buildup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

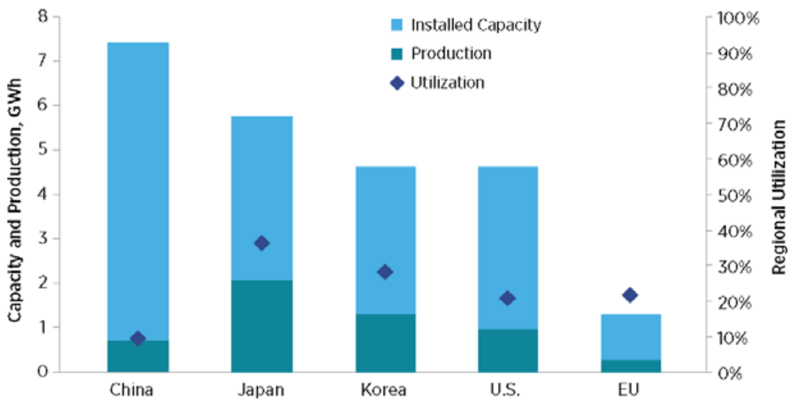
SCE Tehachapi plant, 8MW, 32MWh.

Lithium Ion Batteries

- First two generations driven by consumer electronics, newer chemistries geared for automotive applications
  - Li-Ion Chemistries, $LiCoO_2$ - dominant technology for consumer electronics
  - 2nd Generation Li-Ion Chemistries
    - Better performance, up to 300 Wh/kg with fast recharge
    - Wider temp range, Improved safety and potentially lower cost
  - Spill off into Power applications, competitive for power applications in the grid. Several installations for power regulation (2-20 MW)
- Li ion chemistry
  - Safety and reliability continues to be significant concerns
  - Power control and safety adds significant cost to Li ion storage
  - Packaging and thermal management add significant costs
  - Deep discharge cycle life issues for energy applications (1000 cycles for automotive)

Large Format LIB Manufacturing





Source: D. Chang, et al, Automotive Li-ion Battery (LIB) Supply Chain and U.S. Competitive Considerations, NREL/PR--6A50--63354, June 2015

Continued consolidation in the Automotive Li Battery business
Excess capacity driving the need for applications beyond EVs

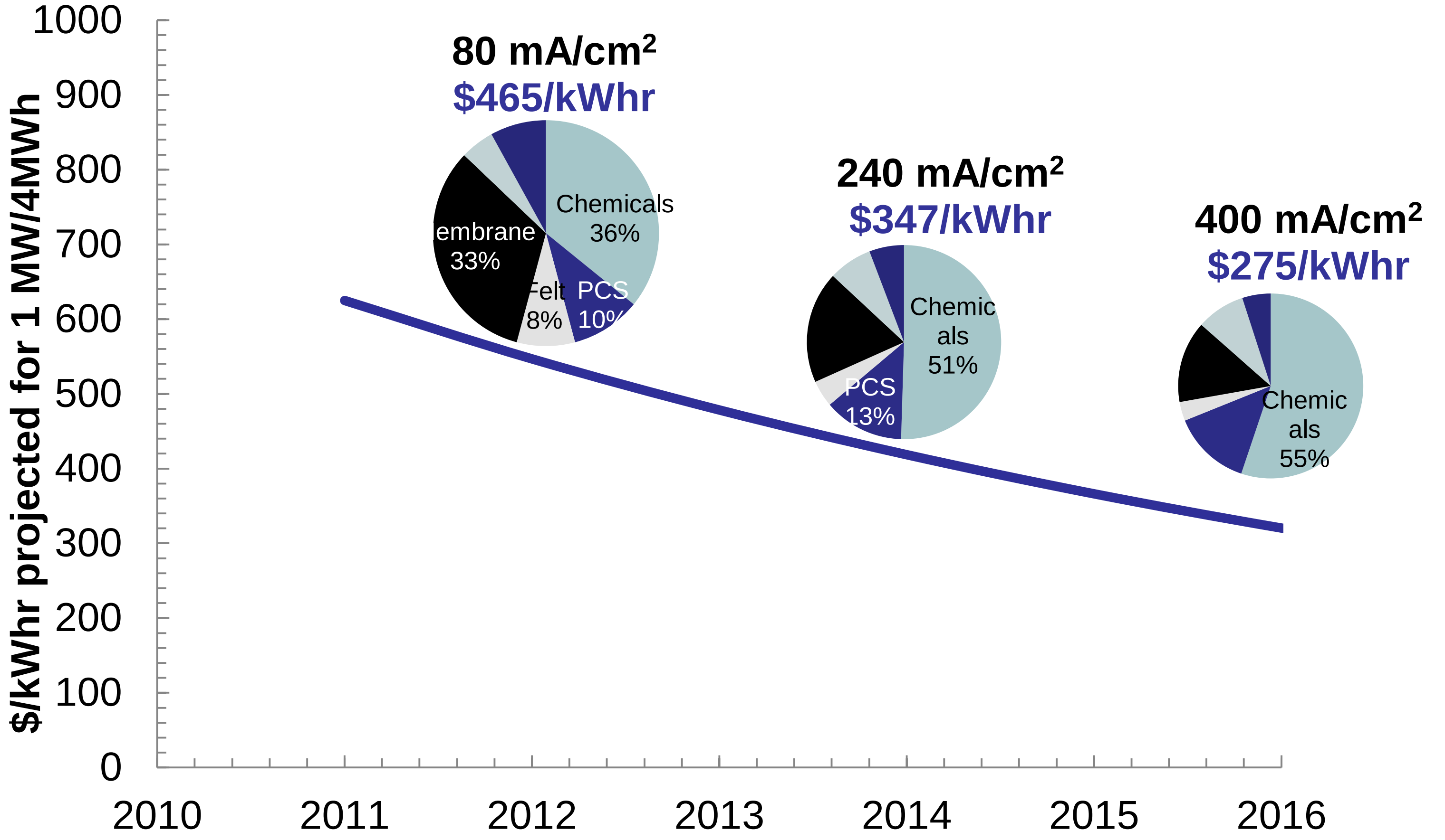
Technology Overview – Flow Batteries

- 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

Redox Flow System Component Cost Analysis



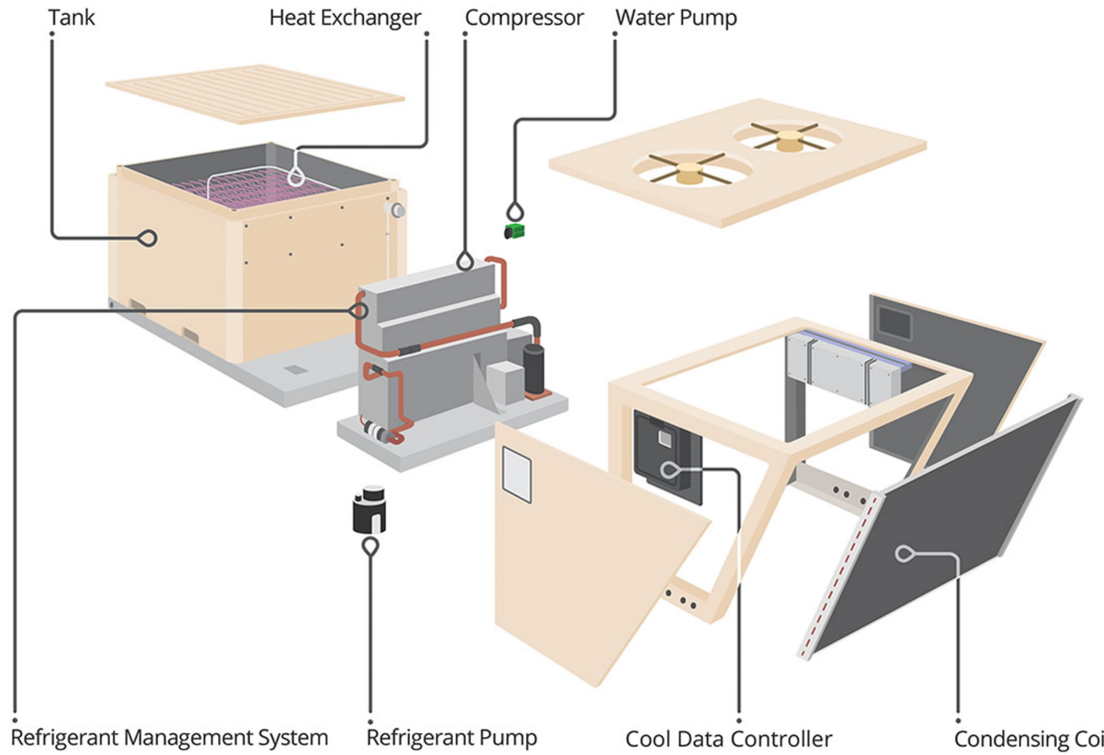
Technology Overview - Capacitors

- 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 – 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

Flow Batteries

- Flow Battery Energy Storage
  - Long cycle life
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- Applications
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Vionx Vanadium Redox Flow battery, 65kW, 390kWh

Flow Batteries - SOA

- Advantages
- Does not have the capacity limitations of LiB and LA, and scale is more and more economical
- No major IP issues, manufacturing currently not at scale, significant opportunity to scale up
- Opportunity to reduce material cost
  - New redox chemistries
  - Higher volumes of manufacturing
- Disadvantages
- Manufacturing currently not at scale
- Low energy densities (15-30 Wh/L), limited voltage window of aqueous electrolyte solutions (< 1.5 V)

Zn-MnO_2 Batteries

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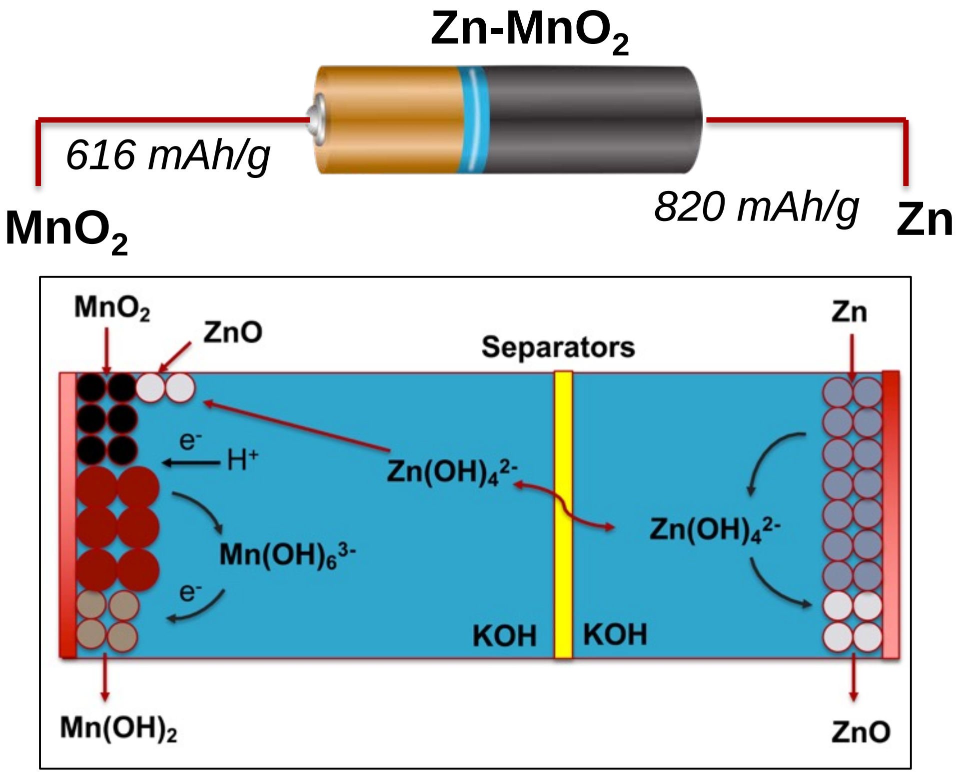
Advantages of Zn/MnO2 alkaline batteries:

- Traditionally primary batteries at ~$18/kWh with long shelf life
- Lowest bill of materials cost, lowest manufacturing capital expenses
- Established supply chain for high volume manufacturing
- Readily be produced in larger form factors for grid applications
- Do not have the temperature limitations of Li-ion/Pb-acid
- Are inherently safer, e.g. are EPA certified for landfill disposal.
- The ultimate challenge in Zn/MnO2 batteries is reversibility

Alkaline Zn/MnO_2 Batteries



Issues to be addressed

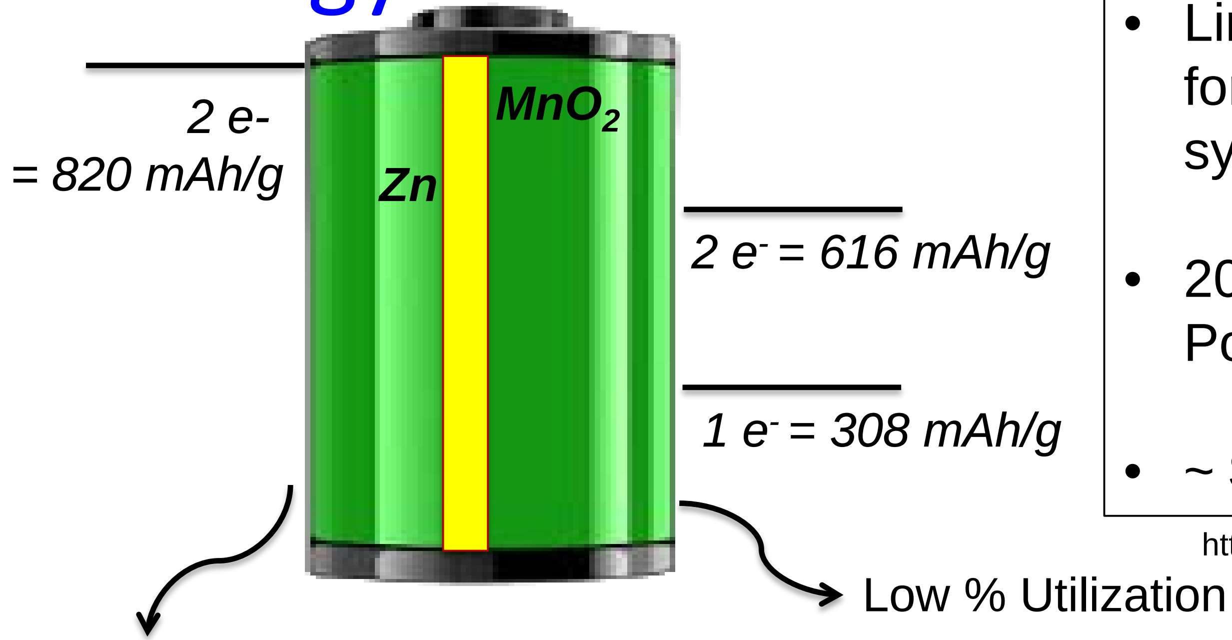
Cathode:
- Irreversibility of Cathode
- Susceptibility to Zinc poisoning

Separator:
- Zincate crossover

Anode:
- Shape Change
- Dendrite Growth
- Irreversible ZnO Passivation

Limiting Depth of Discharge has been shown to be a viable approach

Low DOD discharge is viable technology



Low % Utilization

- Limited DOD provides for highly reversible system
- 2013 Urban Electric Power startup in NYC
- ~ $100/kWh

http://www.urbanelectricpower.com

Low Cost and reversibility = Viable Technology

Opportunity exists to drastically increase capacity

Battery Technologies

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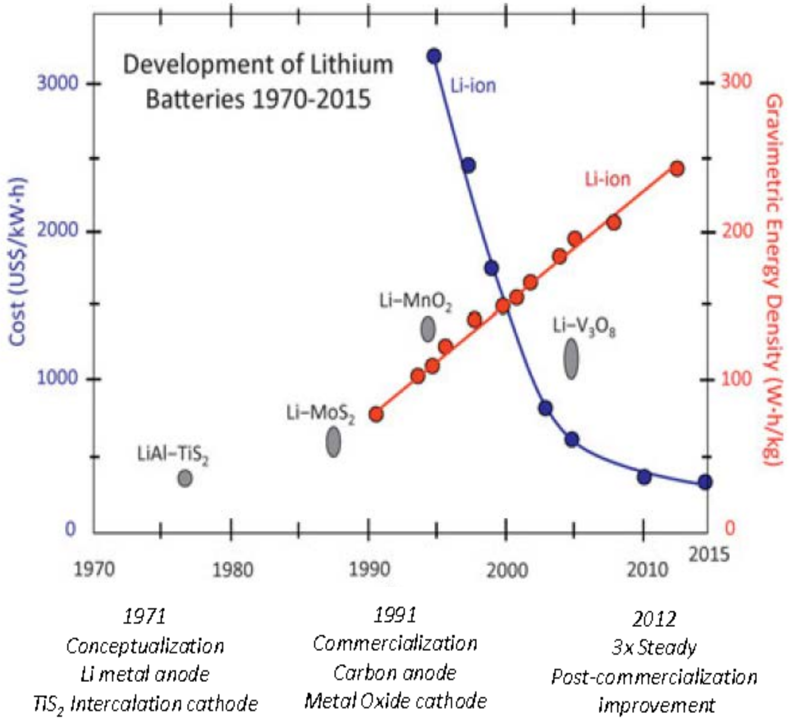
Mature Technologies				
	World Wide Capacity (GWh/y)	**Cost and Performance Improvements**	**Key Challenges for Energy Storage**	**Major Suppliers**
Lead Acid Batteries (LAB)	300	2%/year ((30 year data). $150/kWh	Cycle life. Advanced lead acid cycle life on par with EV grade LIB	JCI, GS Yuesa, EastPenn, EnerSys, Exide, Hagen, Amara Raja
Lithium Ion Batteries (LIB)	50	8%/year (20 year data). Cell level price reaching $200/kWh	Cycle life for deep discharge. Safety. Thermal management	Panasonic, Samsung, LG Chem, BYD, GS Yuesa (Nissan, Honda JVS), Lishen, JCI, A123, Toshiba. EV Batteries: Converging to NMC chemistry
Emerging Technologies				
NaS and NaNiCl	300 MWh	No economies of scale	High temperature chemistry. Safely, Cost	NGK, GE, FIAMM
Flow Batteries	<200 MWh	Not fully mature. Potential for lower cost. $400/kWh. Reach $270/kWh	Not mature. Has not reached manufacturing scale.	Sumitomo, UET, Rongke Power, ZBB, Gildenmeister. Only Sumitomo provides 18 yr. warranty
Alkaline chemistries (Na, Zn-MnO2,..)	<100 MWh	Not fully mature. Lowest cost BOM	Has not reached manufacturing scale.	Aquion (Na), UEP (Zn-MnO2), Fluidic Energy (Zn-air)

Capacity Scaling is Volumetric



Source: Crabtree, Kocs, Trahey, MRS Bulletin, Dec 2015

- There is no equivalent of Moore's law in battery technology. Microelectronics scaling laws don't apply. Storage is based on volumetric material properties.
- Major improvements will be based on increased cycle life, reliability, and safety of batteries.

Industrial lead acid: $150/KWh (high volume)

Large format LIB: cell level costs reached $200/kWh range

Battery to ES System

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Battery

- $/kWh
- Efficiency (%)
  Self Discharge
- Cycle life (#)

PCS/BOS

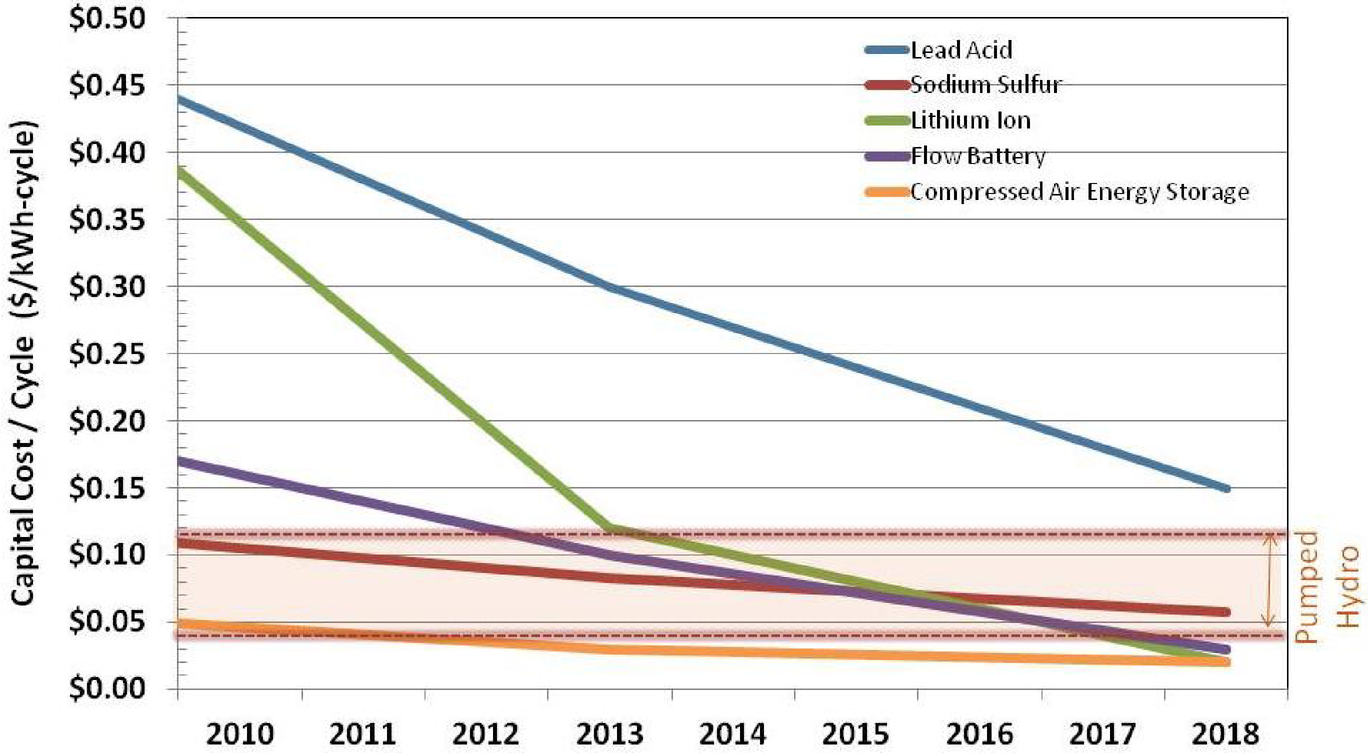
- Power Electronics
  $/kW
- BOS (Container, Safety, Thermal Management)

Softcosts

- Interconnection
- Permits
- O&M

Battery to a Storage System: doubling in cost, $500/kWh battery → $1000/kWh Storage System

Estimated Capital Costs



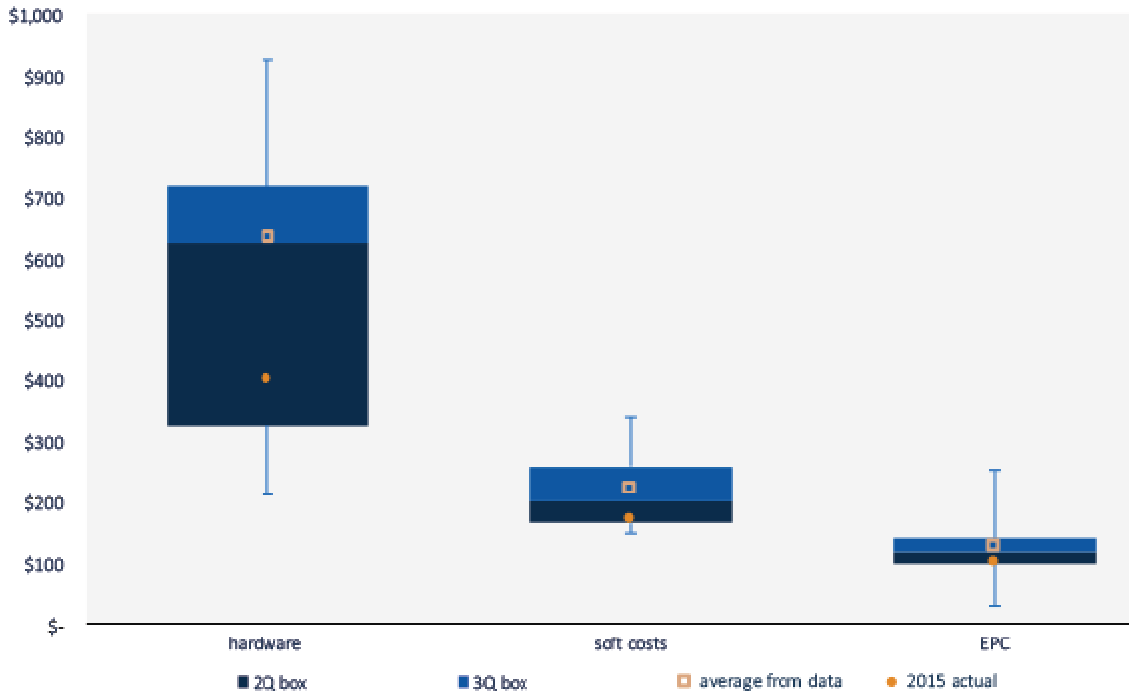
Source: Customized Energy Solutions and IESA
(State of Charge Report, MassCEC, 2016)

Energy Storage Applications

- Energy storage application time scale
  - "Energy" applications – slower times scale, large amounts of energy
  - "Power" applications – faster time scale, real-time control of the electric grid

Energy Applications	**Power Applications**
Arbitrage	Frequency regulation
Renewable energy time shift	Voltage support
Demand charge reduction	Small signal stability
Time-of-use charge reduction	Frequency droop
T&D upgrade deferral	Synthetic inertia
Grid resiliency	Renewable capacity firming

Balance of System Costs



GTMResearch, Grid-Scale Energy Storage Balance of Systems 2015-2020: Architectures, Costs and Players, January 2016; http://www.greentechmedia.com/research/report/grid-scale-energy-storage-balance-of-systems-2015-2020

Energy Storage Applications

- The grid needs energy storage – right now there are several barriers
  - Expensive, especially in energy markets
  - Electricity markets/utilities do not properly allocate payments/costs for services provided
    - Voltage support
    - Inertia
    - Renewable integration
    - Reliability
- The future ….
  - Higher energy prices – storage starts looking better
  - Lower technology costs – storage starts looking better
  - Efficient market design – helps pay for storage costs

Gaps for ES Implementation

- Permanence data
- Validation of storage
- Organizational adaptability of new technologies

Sandia Grid Energy Storage R&D

- Critical challenges for energy storage are high system cost and cycle life
  - Existing storage solutions are too expensive
  - Deep discharge and longer cycle life
  - Safe and reliable chemistry
  - Scalable technology to cover all markets
- To make storage cost competitive, we need advances across all major areas:
  - Batteries, power electronics, PCS
  - BOS and Integration
  - Engineered safety of large systems
  - Codes and Standards
  - Optimal use of storage resources across the entire electricity infrastructure

Sandia ES Program Goals and Objectives

Solving critical problems to make energy storage safe, reliable, and cost effective across all markets.

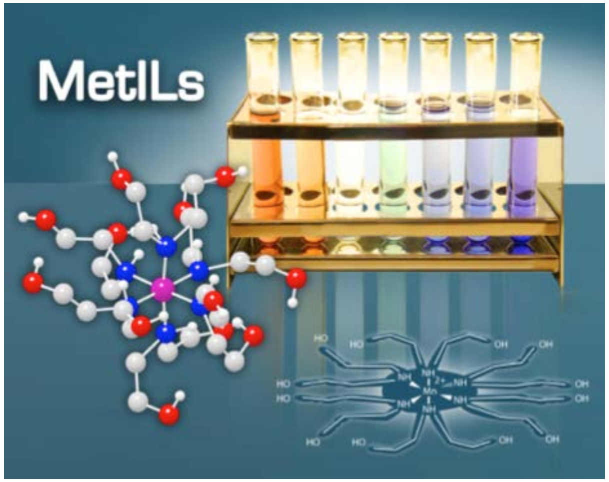
Strategic goals are:

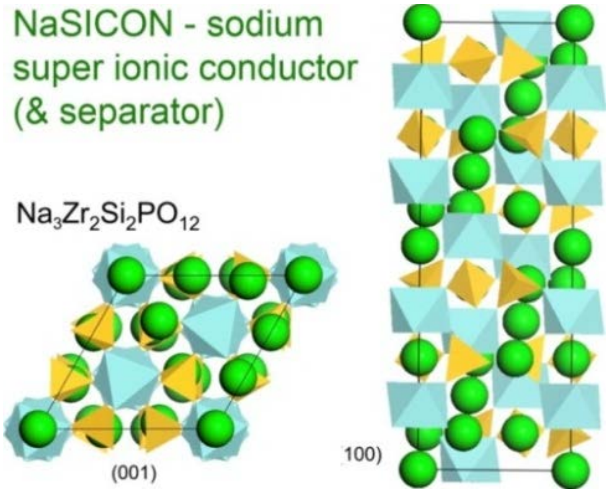
- **Advancing new battery chemistries through technology development and commercialization**
- **Optimization at the interface between power electronics and electrochemistry**
- **Excellence in energy storage safety. Predictive models for storage systems safety – safety through large scale systems simulation and optimization**
- **Controls and analytics for integration of utility class energy storage systems**
- **Defining role in the Grid of the Future**

Materials & Systems Development

Battery chemistry and component technologies:

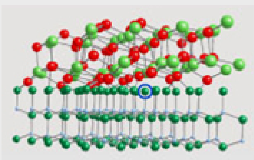
- Low Cost Membranes for Flow Batteries
- Sodium Based Batteries
- Advanced Materials for Ionic Liquid Flow Batteries
- High Voltage Capacitors
- Soft Magnetics
- Lightweight Composites for Flywheels
- Wide Bandgap Materials and Devices for Power Electronics

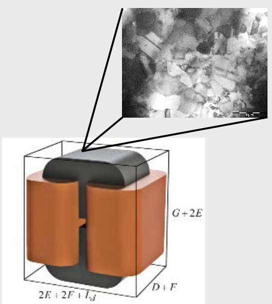




Power Electronics

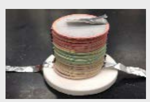
Materials R&D





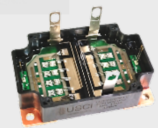
- Gate Oxide R&D
- Advanced Magnetics

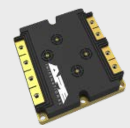
Devices



- ETO
- SiC Thyristors
- Monolithically integrated SiC transistors
- WBG Characterization & Reliability
- High energy dielectric capacitors

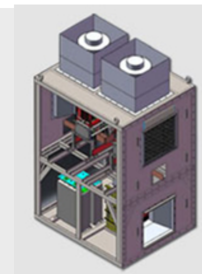
Power Modules





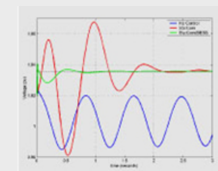
- SiC High Temp/density Power Module
- HV SiC JFET Module
- HV, HT Reworkable SiC half-bridge modules

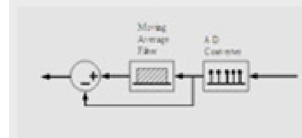
Power Conversion System

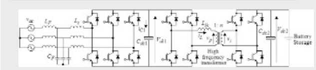


- Dstatcom plus energy storage for wind energy
- Optically isolated MW Inverter
- High density inverter with integrated thermal management
- High temp power inverter

Applications







- FACTS and Energy Storage
- Power smoothing and control for renewables
- Dual active bridge for advanced energy storage system designs

Safety and Reliability

Sandia National Laboratories

Energy Storage Safety Working Groups

- Validation & Risk Assessment
- Codes & Standards
- Outreach & Incident Response

Sandia National Laboratories | Pacific Northwest National Laboratory | Oak Ridge National Laboratory

- National leader in battery safety research and abuse testing with a focus on electric vehicle application
- Focus on developing a fundamental understanding of safety and reliability of grid storage
- Advanced simulation and modeling of energy storage systems


Energy Storage Test Pad (ESTP)


Cell Lab


Battery Abuse Testing Laboratory

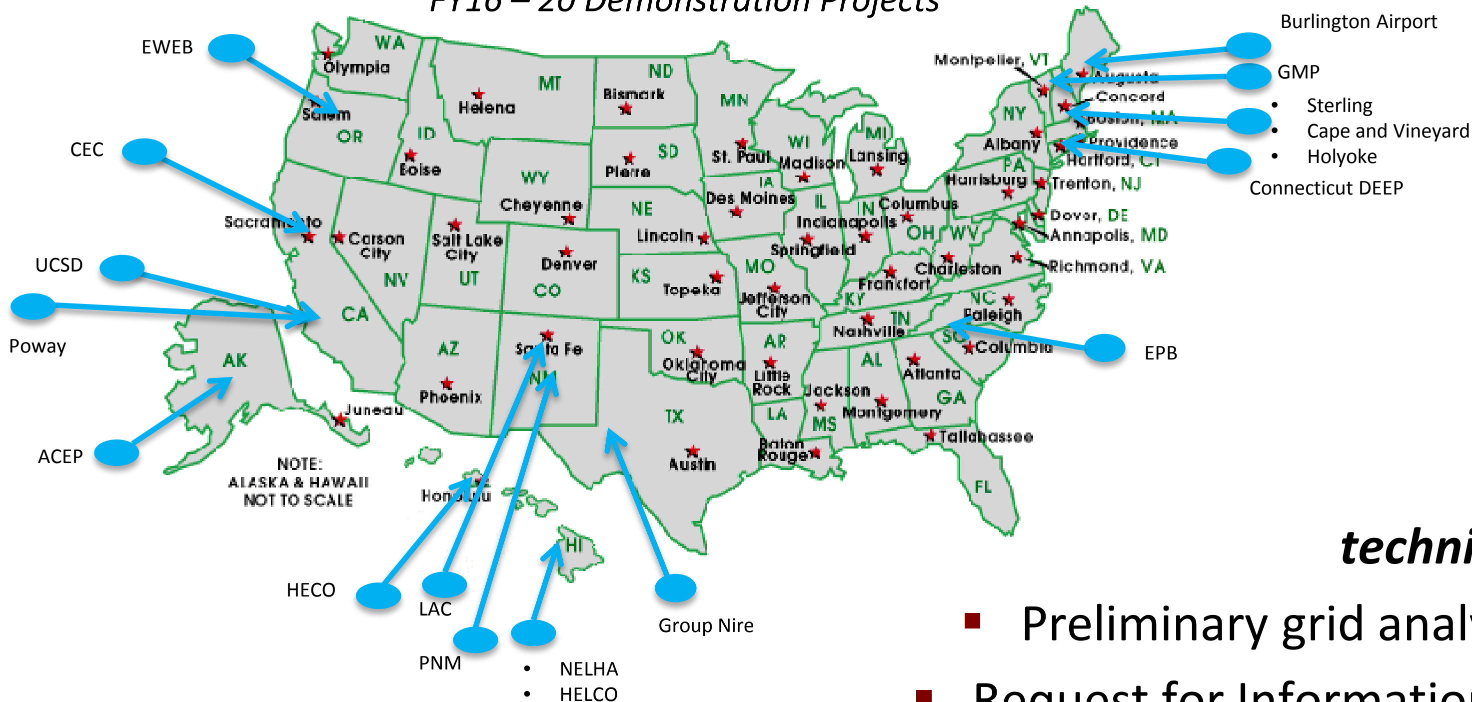
Industrial Acceptance through Demonstrations

Sandia National Laboratories

Where we have been	***Where we are today***	***Where we are going***
		
ARRA - Initial evaluation of grid connected ES projects	Additional projects to enable applications in renewables, resiliency, and critical infrastructure	World wide adaption of ES based on our work
PAST	**PRESENT**	**FUTURE**

Demonstrations

FY16 – 20 Demonstration Projects



International Projects:

- Canada – WEICAN
- Singapore

Providing technical support for:

- Preliminary grid analysis & modeling
- Request for Information and Proposals
- Project design, procurement specifications, and construction
- Data Acquisition Systems
- Commissioning plan
- Operational test data and system optimization algorithms

Recent and Ongoing Projects

State Projects (CESA):

- Alaska – Cordova Electric Co-Op
- Connecticut DEEP
- Massachusetts DOER/CEC – Sterling Power, Cape and Vineyard, Holyoke, Northhampton (PNNL)
- Oregon Dept. of Energy/Eugene Water & Electric Board
- Vermont – GMP, Burlington Airport
- New Mexico – EMNRD, PNM

California/Hawaii:

- California CEC
- HECO
- HELCO
- NELHA
- Sunpower
- UCSD

Other Projects:

- DCICON (DoD)
- Group Nire, TX
- Los Alamos County

International support:

- Singapore
- WEICan (Canada)

Industry Support

- GS Yuasa
- Helix
- Primus Power
- UET
- Transpower
- East Penn/ECOULT
- Aquion Energy
- MegaAmp (S. Africa)

GMLC Project Lead:
ES Demonstration - Validation and Optimization.
Partners: PNNL, ORNL

2017 Demonstration Projects

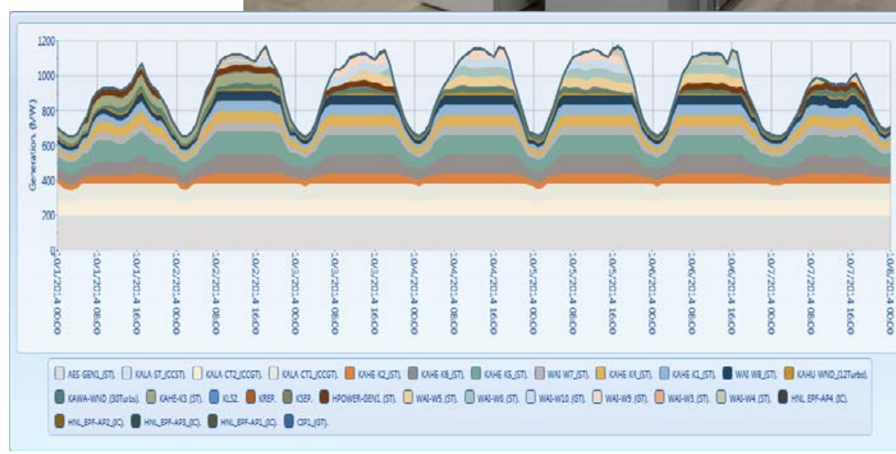
250kW/1MWh UET Reflex flow battery system at Sandia Energy Storage Testpad

2 MW/3.9 MWh ES System at Sterling Municipal Light Department, Sterling, MA

100kW/400kWh Vanadium Redox Flow Battery
EPB, Chattanooga, TN

Analytics and Policy

- Estimating the value of energy storage
- Control strategies for energy storage
  - Wide area damping control
  - Maximizing revenue
- Public policy
  - Identifying and mitigating barriers
- Standards development
- Project evaluation
  - Technical performance
  - Financial performance
- Model development
  - Dynamic Simulation



Energy Storage Analytics

- Estimating the value of energy storage
- Control strategies for energy storage
  - Wide area damping control
  - Maximizing revenue
- Public policy: identifying and mitigating barriers
- Standards development
- Project evaluation
  - Technical performance
  - Financial performance
- Model development (e.g. for dynamic simulation)

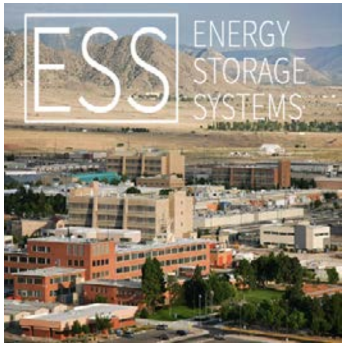
Project Evaluation

- Support the demonstration program with data analysis
- Current efforts
  - ISO-NE
  - Los Alamos
  - EMA CRADA

Los Alamos, NM 1 MW, 6MWh NaS system

Outreach

Sandia National Laboratories



ESS Website: 8479 hits
Nov 2016-Jan 2017

DOE Global Energy Storage Database: 1600+ Projects; 2.2Million page visits (2016 Status Report)

iSTORAGE
DOE/OE PEER REVIEW 2016
September 25-28, 2016 • Washington DC

DOE/EPRI One-stop shop for Current ES Technologies and Applications, Life Cycle System Cost Methodology, 10000+ Downloads in FY17

2016 SW Regional PUC Open Forum Information Sharing

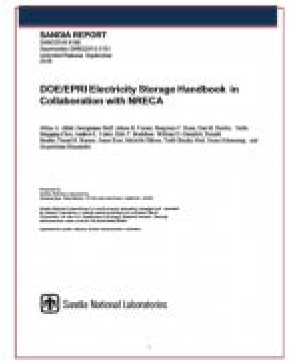
Annual assessment of technical projects funded by DOE; 2016 Results w 148 Attendees:

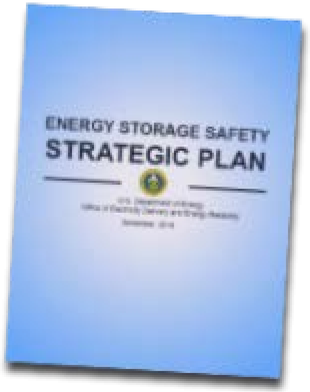
- 40 Oral Presentations
- 32 Posters
- 48% Industry
- 45% National Labs
- 7% Academia

Major Annual Events

Resources

- DOE Energy Storage Website (www.sandia.gov/ess/)
- DOE Global Energy Storage Database (www.energystorageexchange.org)
- Energy Storage Association (www.energystorage.org)
- 2015 DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA





Acknowledgements

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Questions?

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