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Energy Storage and the Electric Grid

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Sandia National Laboratories

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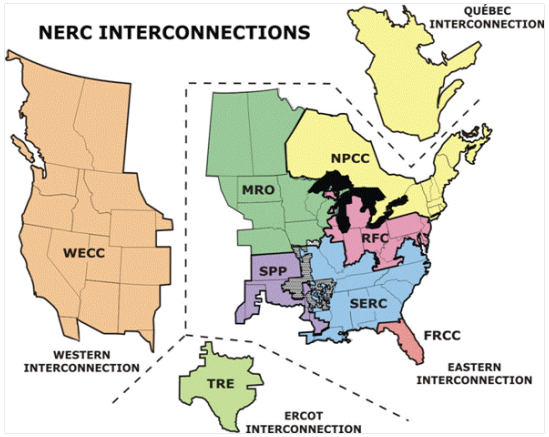
U.S. Electric Grid Today

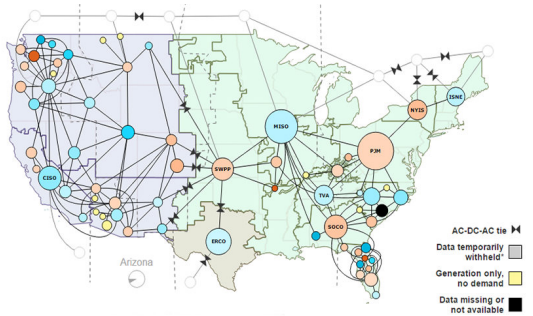
Big interconnected system with ~850GW baseload, 1250 GW summer peak, 7,000 operational power plants

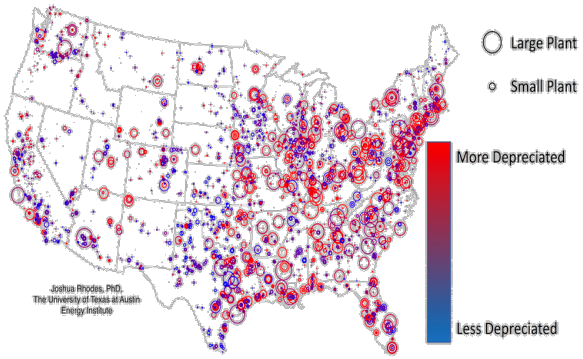
- 3,200 utilities, 60k substations, 642k miles of HV transmission lines, 6.2 million miles of distribution circuit, 159 million customers.
- Revenues reaching $400 B, ~10.42 c/kWh avg
- Increasing NG and renewable generation

Four interconnect regions and a number of balancing authorities:

- Eastern Interconnection (31 US, 5 Canada)
- Western Interconnection (34 US, 2 Canada,1 Mexico)
- ERCOT, Hydro-Quebec







Sources: EIA, EEI

http://www.nerc.com

Electricity Industry – Current Changes

Major grid infrastructure is aging

Accelerating retirements of coal fired power plants

Stalled replacement/expansion of nuclear generation

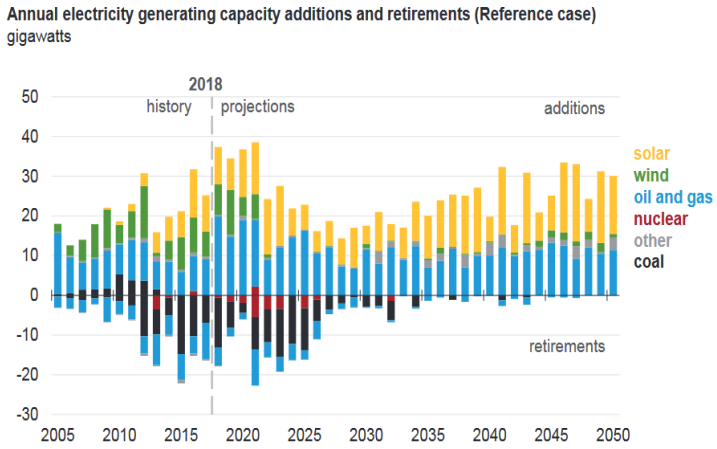
Growth of NG and renewables

T&D congestion starting to impact deployment of renewables

Meagre demand growth

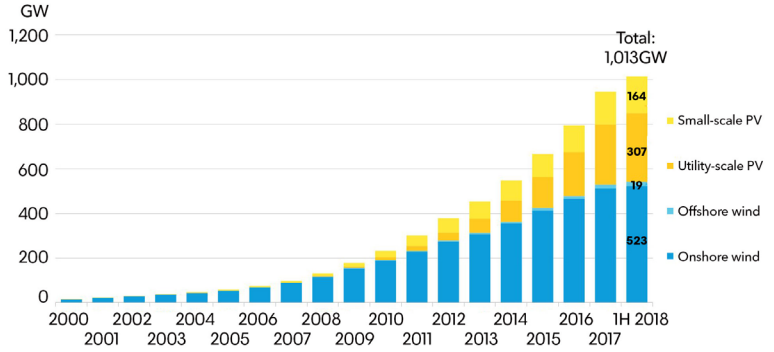
Rapid changes at the grid edge

Capacity Additions and Retirements



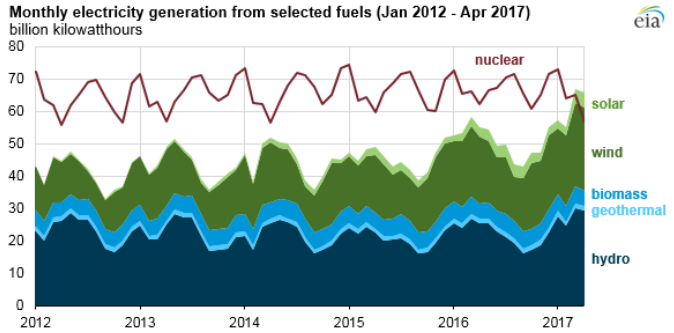
EIA Annual Energy Outlook 2019

Cumulative global solar and wind capacity (June 2018)

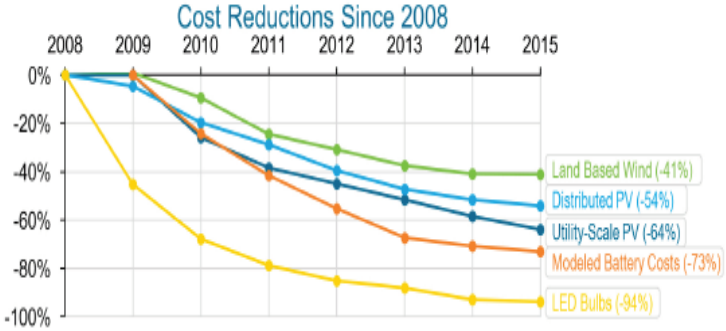


Source: Bloomberg NEF. Note: 1H 2018 figures for onshore wind are based on a conservative estimate; the true figure will be higher. BNEF typcally does not publish mid-year installation numbers.

Utility-scale Renewables Generation surpassed Nuclear Generation (April 2017)



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



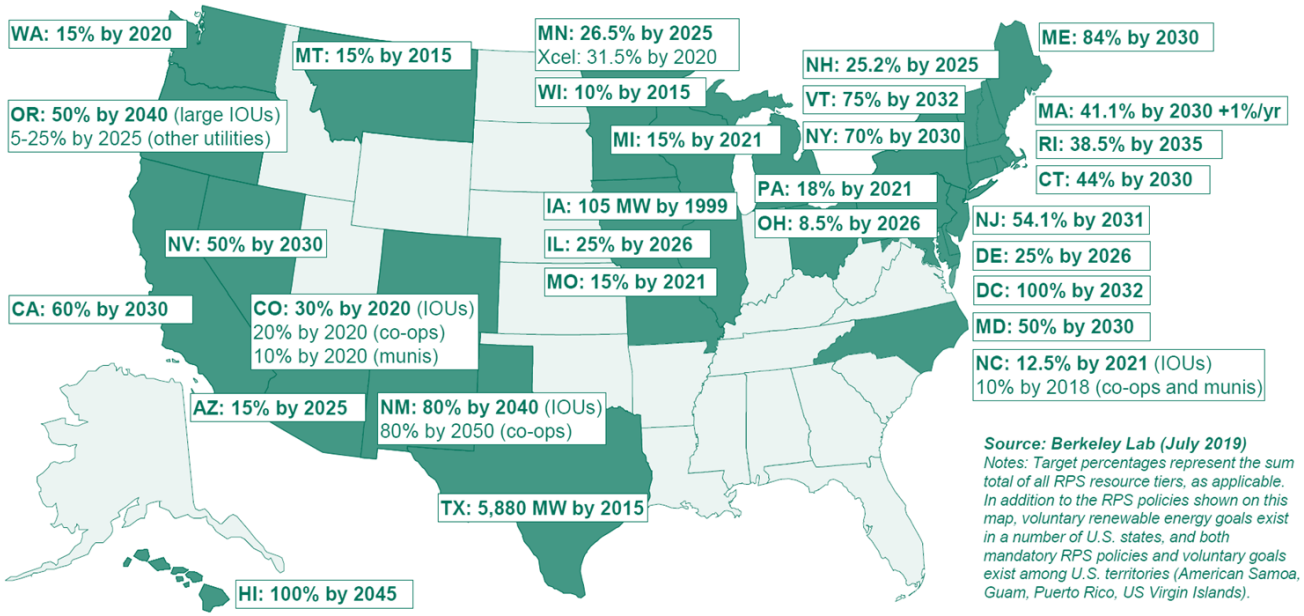
http://energy.gov/eere/downloads/revolutionnow-2016-update

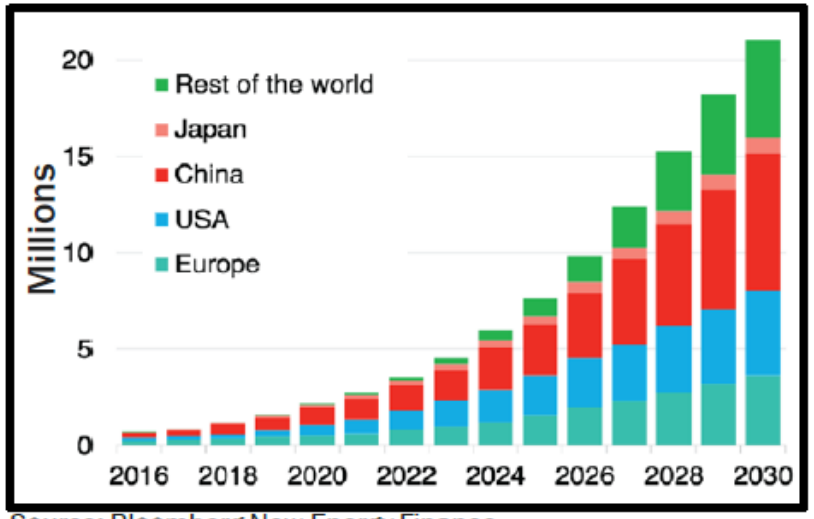
Coal-fired unit retirements driven by low NG prices (EIA, 2017)

In California, solar, storage and wind capacity additions expected to exceed NG by '21(GTM)

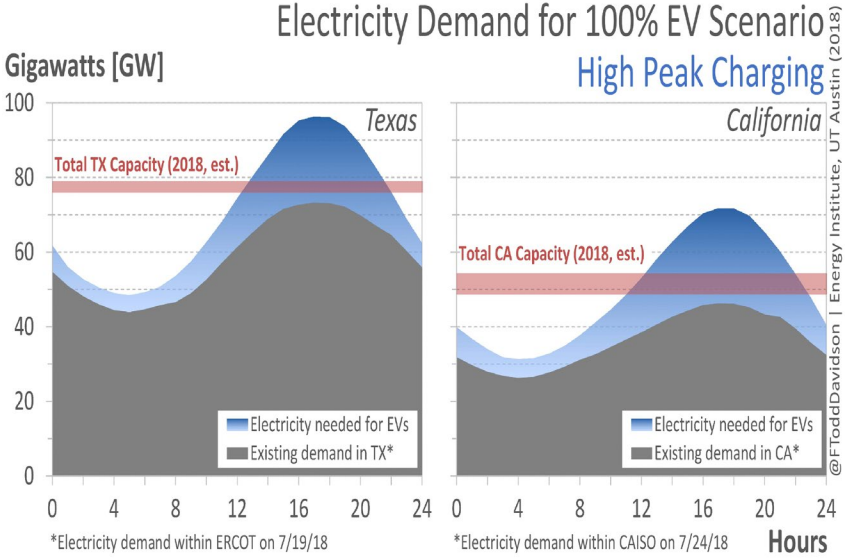
Electricity Industry - Coming Changes

- Electrification of transportation
  - Annual production of EVs reaching 20M by 2030, 130M-230M EVs on the road optimistic case (BNEF, IEA, 2018)
- RPS becoming wide spread across all states
- Drive towards fossil free generation

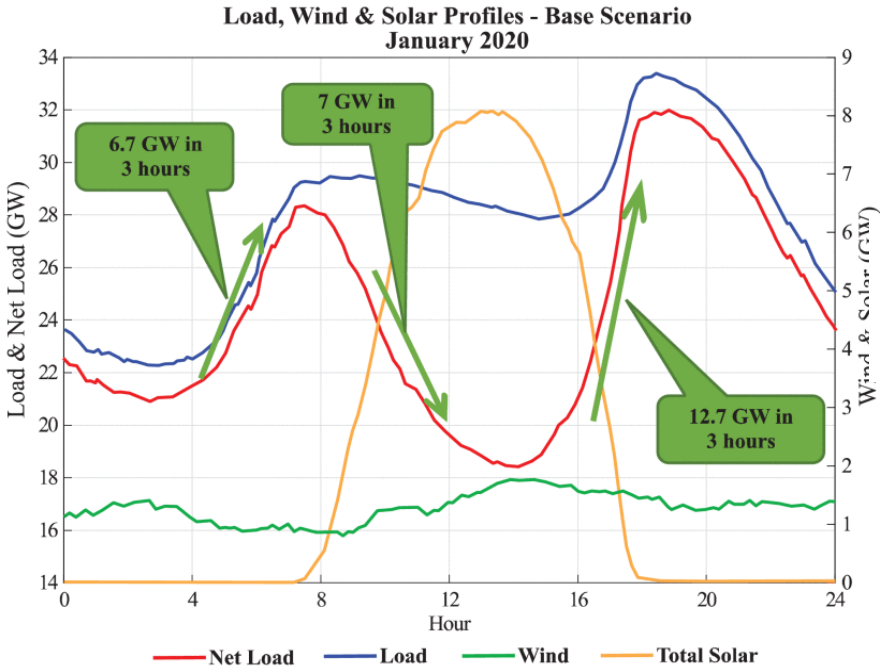




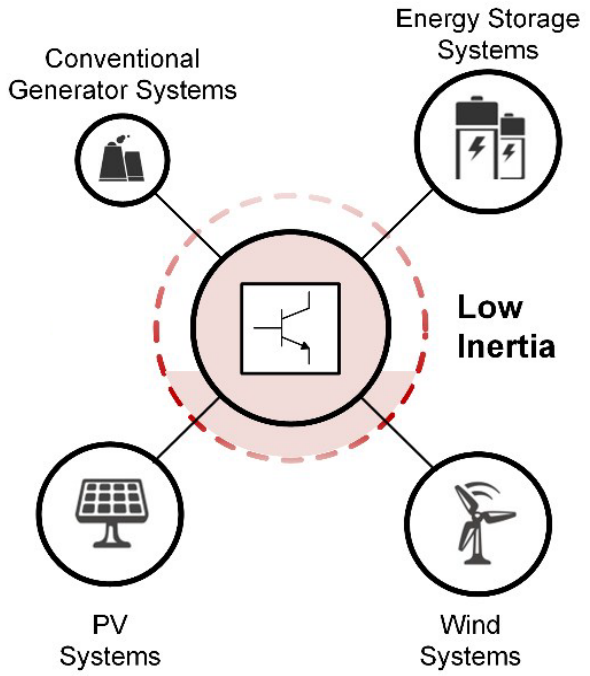
Source: Bloomberg New Energy Finance



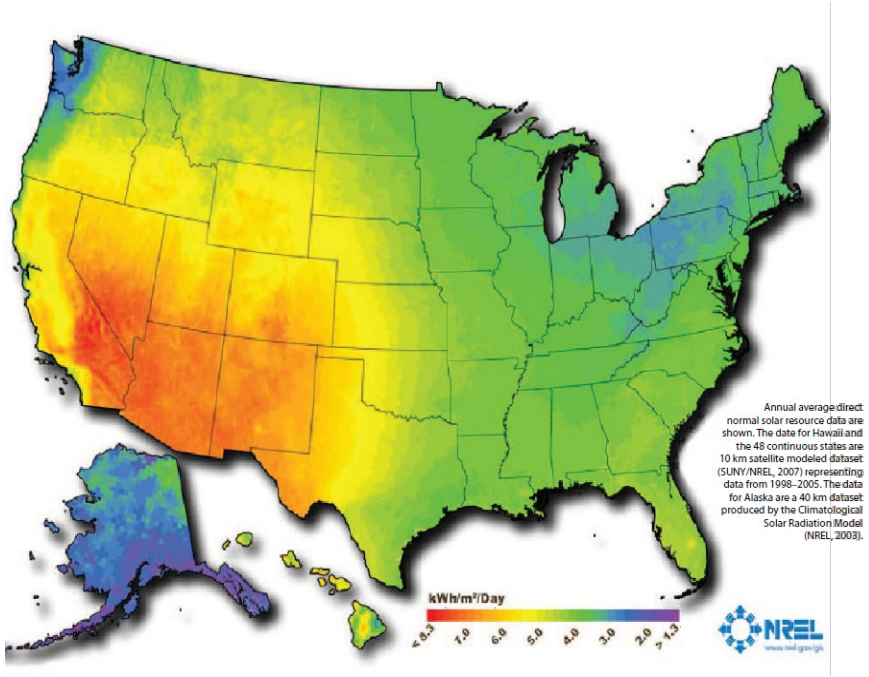
Challenges for Grid Reliability



Source: CAISO



Source: U. Tamrakar, D. Shrestha, M. Maharjan, B. Bhattarai, T. Hansen, and R. Tonkoski, "Virtual Inertia: Current Trends and Future Directions," Applied Sciences, vol. 7, no. 7, p. 654, Jun. 2017.



High Variability And Uncertainty

Large amount of generated renewable energy is not coincident with the peak load creating large ramps

Zero Inertia Grid

Inverter-dominated power systems have low or no inertia creating large frequency fluctuation after disturbances.

Transmission Infrastructure

Most attractive resources for wind and solar are located far from load center requiring enormous transmission expansion.

Electric Grid Infrastructure Needs

Adaptation to Accommodate High Renewables, Electrification and Climate Change

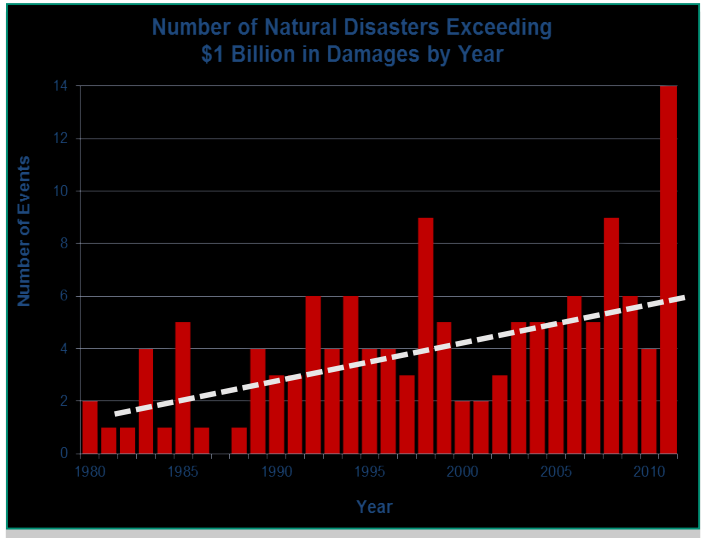
- Flexibility, G-T-D Coordination, Market Design

Handle Increased Resilience

- Weather, Natural disasters, Cyber, Physical attacks

Smarter Grid

- Sensors, Analytics, Automation, IOT, Demand Side Participation



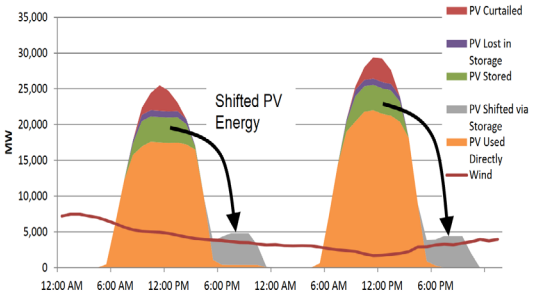
Role of Energy Storage in the Grid

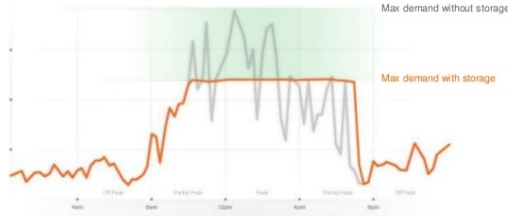
Energy storage is a key resource for grid operators.

- Provides flexibility, resiliency and reliability
- Improve power quality
- Improve the efficiency of existing generation fleet
- Facilitates demand management
- Supports large scale renewable integration; T&D upgrade deferrals
- Provides alternative to "locational marginal price"
- Multiple grid services and value streams

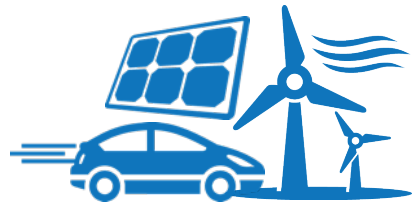
Key metrics: MW, MWHr, cost, scale, cycles, safety and performance

Mitigate $79B/yr in commercial losses from outages





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.

Energy Storage in the Grid Today

Grid-Scale Energy Storage < 0.1% of U.S. Generation Capacity

US installed energy storage capacity of 32 GW represents ~15 min ride through

BESS reached 2GW in installed capacity in 2018, rest is mostly Pumped Hydro.

1.6 GW Raccoon Mountain PHS

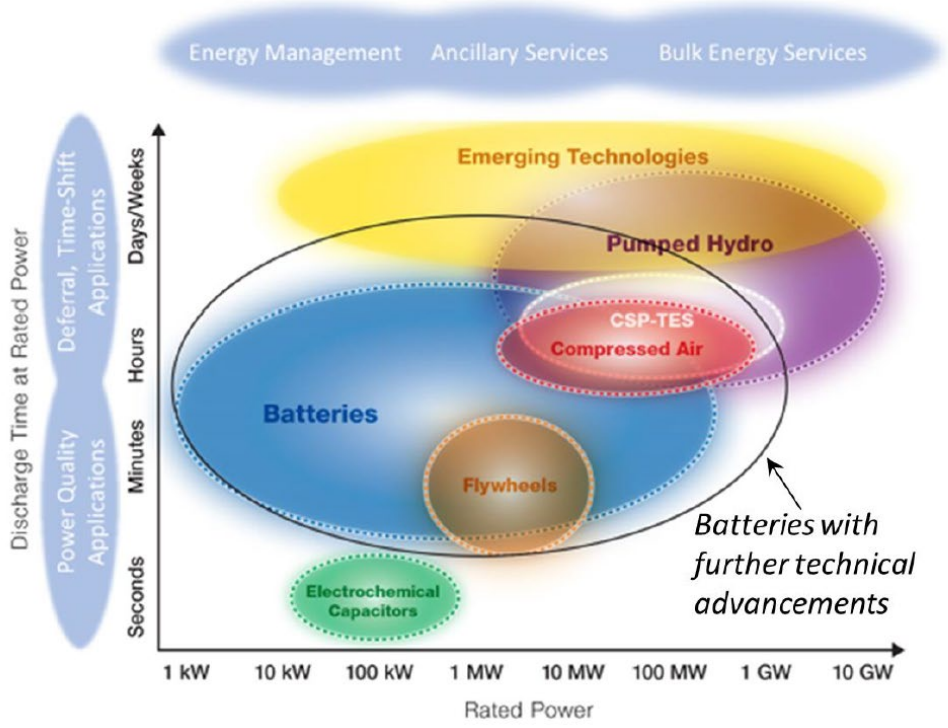
100 MWh BESS Plant - Tesla

Wood Mackenzie P&R / ESA | U.S. energy storage monitor 2018 YIR and Q132

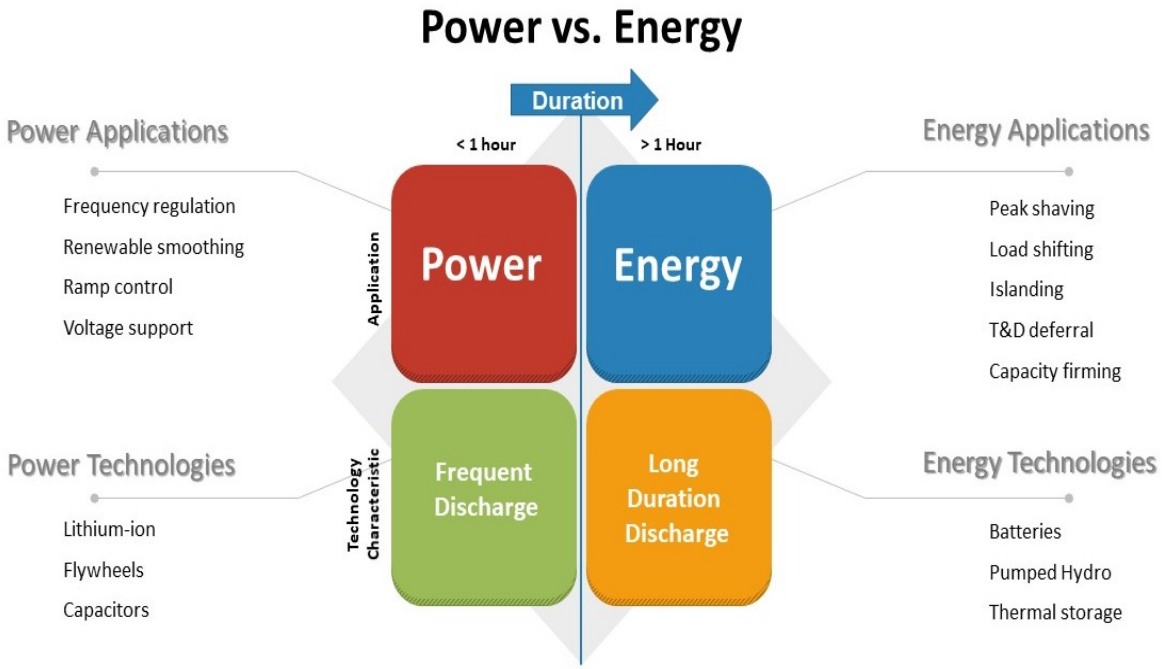
Compared to the need, the scale of energy storage deployments is insignificant.
With a 1 TW US electric grid, even 1 hr of energy storage means 1 TWh

DOE Global Energy Storage Database, 2018

Range of Technologies and Applications



Source: Potential Benefits of High-Power High-Capacity Batteries, DOE Report, Jan 2020



Source: Energy Storage Primer, IEEE Power and Energy Society, 2020

Range of battery technologies for short duration energy storage, seconds to days

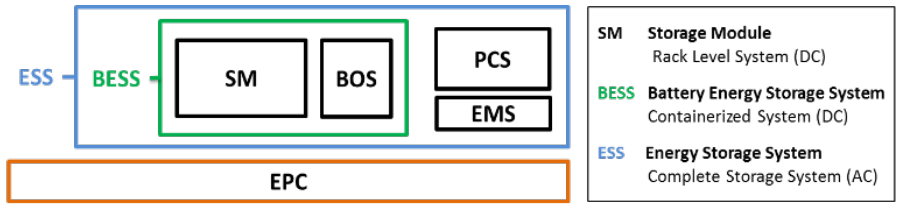
Pumped hydro and CAES for hours to day long energy storage

No ready solutions for real long duration and seasonal storage needs

"Energy" applications: slower times scale, large amounts of energy

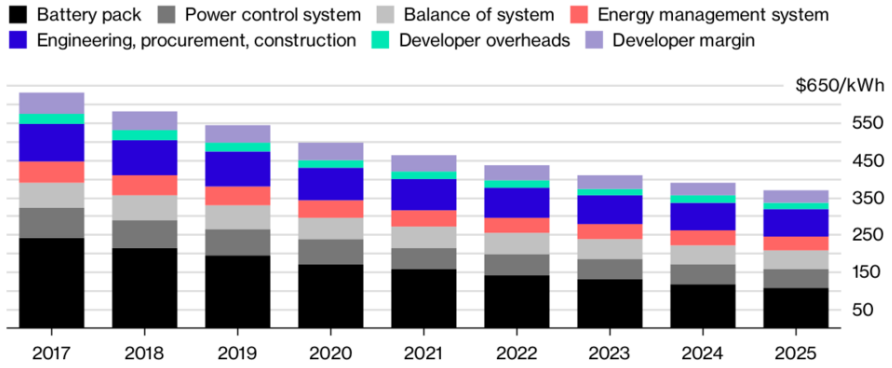
"Power" applications: faster time scale, real-time control of the electric grid

Battery Energy Storage is not just about Batteries …



Storage Module (SM)	Balance of System (BOS)	Power Conversion System (PCS)	Energy Management System (EMS)	Engineering Procurement & Construction (EPC)
Racking Frame / Cabinet	Container	Bi-directional Inverter	Application Library	Project Management
Local Protection (Breakers)	Electrical Distribution & Control	Electrical Protection	Economic Optimization	Engineering Studies / Permitting
Rack Management System	Fire Suppression	Connection to Transformer	Distributed Asset Integration	Site Preparation / Construction
Battery Management System	HVAC / Thermal Management		Data Logging	Foundation / Mounting
Battery Module			Communication	Commissioning

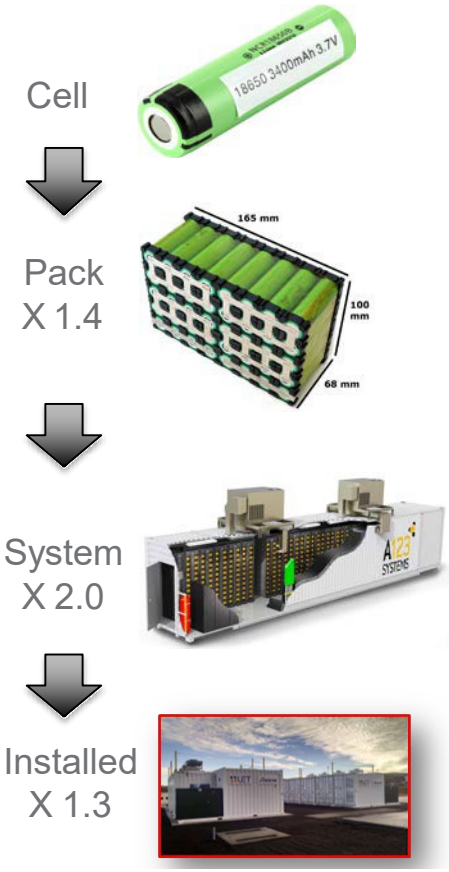
Source: R. Baxter, I. Gyuk, R.H. Byrne, B.R. Chalamala, IEEE Electrification, Aug 2018



Note: Benchmark numbers for a 1MW/1MWh project
Source: Bloomberg New Energy Finance (BNEF)

Bloomberg

Cell to Battery to a Storage System
> Doubling in cost, $250/kWh battery leads to $500-$700/kWh at the System level



Integration costs are significant
Big savings now are not in the cells, but in the systems and integration. . .

Battery Energy Storage Technologies

Market drivers

- Consumer electronics, mobile devices and EVs – primarily Li-ion batteries
- Grid energy storage – growing market, currently modest size. Range of technologies

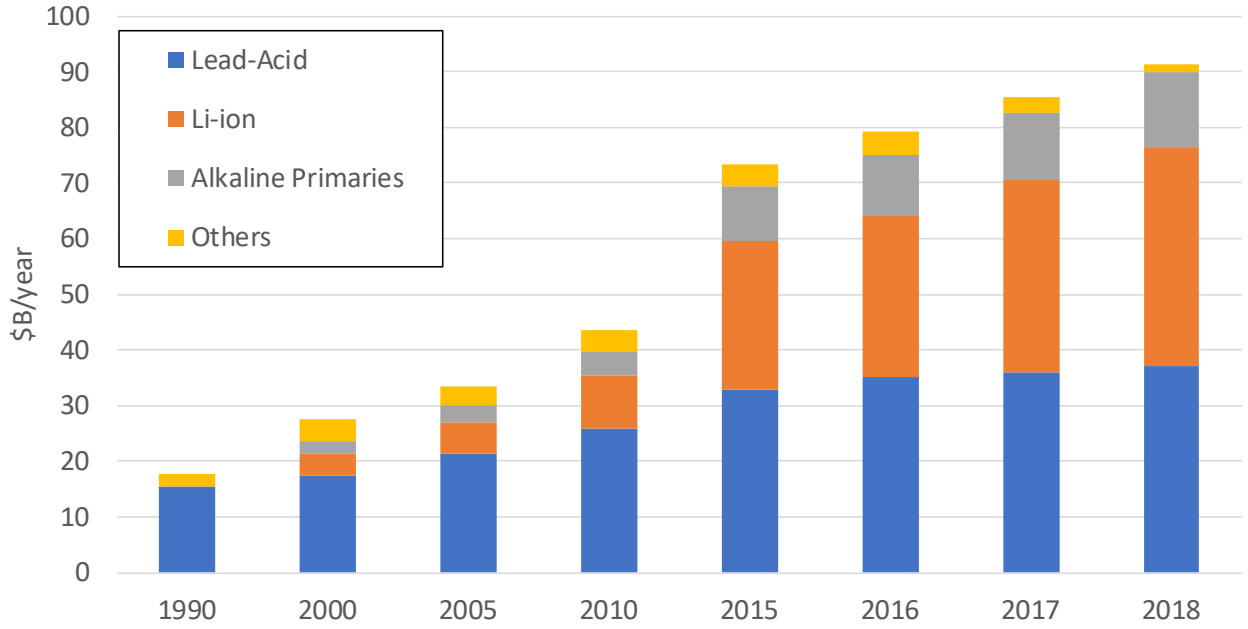
Traditional Batteries
e.g. Lead-acid, Ni-Cd, Ni-MH, Zn-MnO_2

Lithium Batteries
e.g. Li-ion, Li-polymer, Li-metal, Li-S

High-temperature Batteries
e.g. Na-S, Na-$NiCl_2$

Flow Batteries
e.g. Vanadium redox, Zn-Br

Global Battery Sales



- Lead-Acid: 350 GWh production capacity, $38B/yr
- Li-ion: over 300 GWh and growing capacity, $40B/yr
- Primary cells: $13B/yr

Source: S. Banerjee, DOE ESGC South/Southwest Workshop, June 2020

Battery Energy Storage - Design and Application Aspects

Cell Architecture
- Cell format
  - Cylindrical, Prismatic
  - Bipolar
  - Flow Cell

Cell Chemistry
- Aqueous
- Non-aqueous

Thermal management
- Heating
- Cooling

Safety
- Abuse resistance
- Flammability
- Toxicity
- Containment

Plant Models
- Modularized

Power vs. Energy
- High-power, short-duration discharge
- High-energy, long-duration discharge
- Fast Charging

Modularity and Scalability
- kW to MW (Power Scaling)
- kWh to MWh (Energy Scaling)
- Module stacking and Containerization

Cycle Life
- Electrical
- Thermal

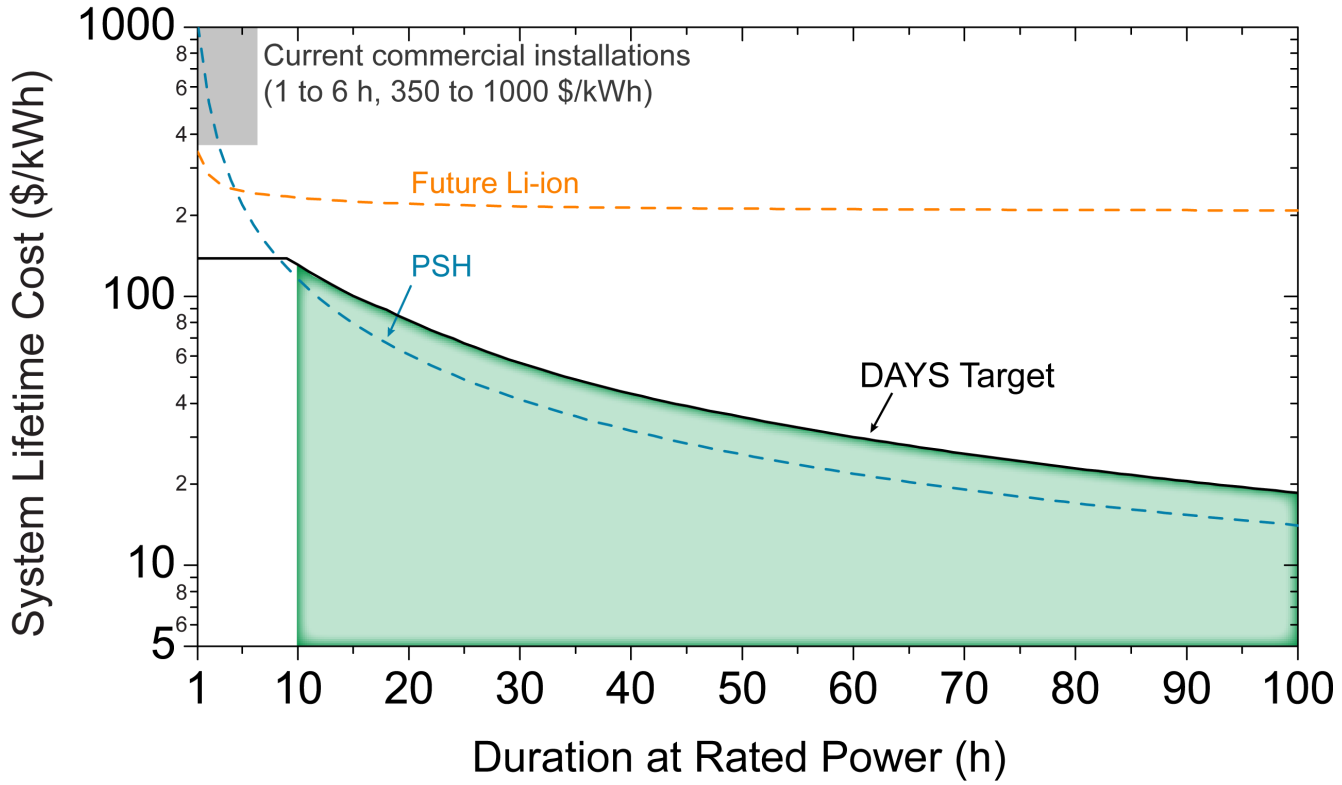
Operational Aspects
- Round-trip efficiency
- Auxiliary power consumption
- O&M Costs

Long Duration Energy Storage – Major Gap

Majority of current battery energy storage today are for applications that require ~ 4 hours at rated power. Requirement for 10 hours coming up quickly.

No ready solutions for longer duration storage, days to seasonal .

Longer duration energy storage economic requirements are significantly different from battery storage.
Projects have to be larger to justify lower system costs



Reference: Albertus et al., Joule *4*, 21-32, January 15, 2020.

Grid Energy Storage - Gaps?

Technology - Need further improvements in cost and performance

- Lower cost, longer duration energy storage is a major gap
- Technologies that can scale from microgrids to large transmission applications
- Further improvements in safety and reliability

Energy storage is new for the electric utility industry

- Markets and Operations – Business Models and Operational Tools
- Analytics – Economics and Planning tools
- Appropriate Regulatory Policy – Business Models, Asset Classification

Industry needs cycles of learning - manufacturing scale through deployments

- Project finance - bankable, warrantees, Performance guarantees, risk management
- Standardization- equipment, permitting, construction processes

ENERGY STORAGE R&D AT SANDIA

BATTERY MATERIALS

Large portfolio of R&D projects related to advanced materials, new battery chemistries, electrolyte materials, and membranes.

CELL & MODULE LEVEL SAFETY

Evaluate safety and performance of electrical energy storage systems down to the module and cell level.

POWER CONVERSION SYSTEMS

Research and development regarding reliability and performance of power electronics and power conversion systems.

SYSTEMS ANALYSIS

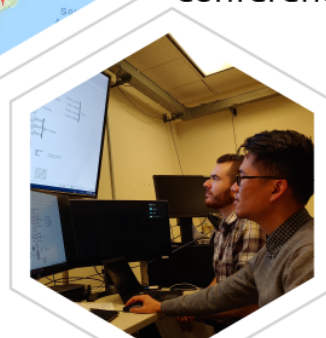
Test laboratories evaluate and optimize performance of megawatt-hour class energy storage systems in grid-tied applications.

DEMONSTRATION PROJECTS

Work with industry to develop, install, commission, and operate electrical energy storage systems.

STRATEGIC OUTREACH

Maintain the ESS website and DOE Global Energy Storage Database, organize the annual Peer Review meeting, and host webinars and conferences.



GRID ANALYTICS

Analytical tools model electric grids and microgrids, perform system optimization, plan efficient utilization and optimization of DER on the grid, and understand ROI of energy storage.

Wide ranging R&D covering energy storage technologies with applications in the grid, transportation, and stationary storage

Acknowledgements

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Dr. Imre Gyuk, Program Manager