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Opportunities for Grid Energy Storage

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Sandia National Laboratories

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U.S. Electricity Generation Mix

- 2016 U.S. utility-scale electricity generation (EIA)
  - Natural gas = 33.8%
  - Coal = 30.4%
  - Nuclear = 19.7%
  - Renewables (total) = 14.9%
    - Hydropower = 6.5%
    - Wind = 5.6%
    - Biomass = 1.5%
    - Solar = 0.9%
    - Geothermal = 0.4%
  - Petroleum = 0.6%
  - Other gases = 0.3%
  - Other nonrenewable sources = 0.3%
  - Pumped storage hydroelectricity = -0.2%

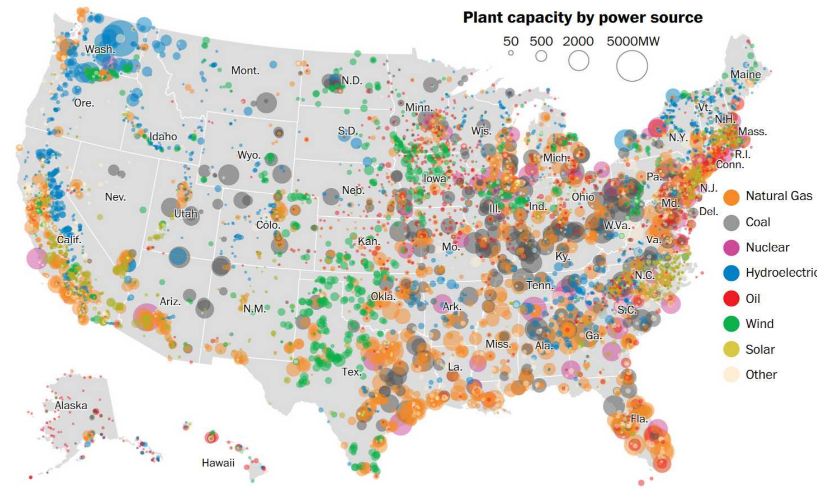
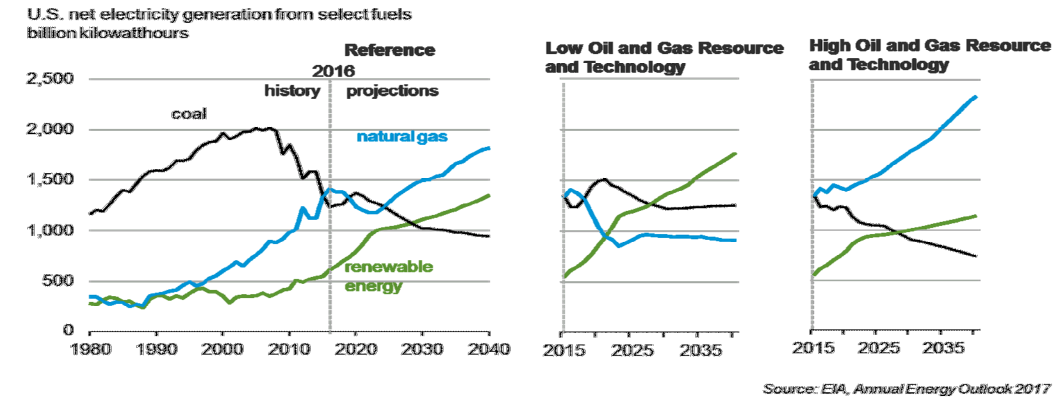
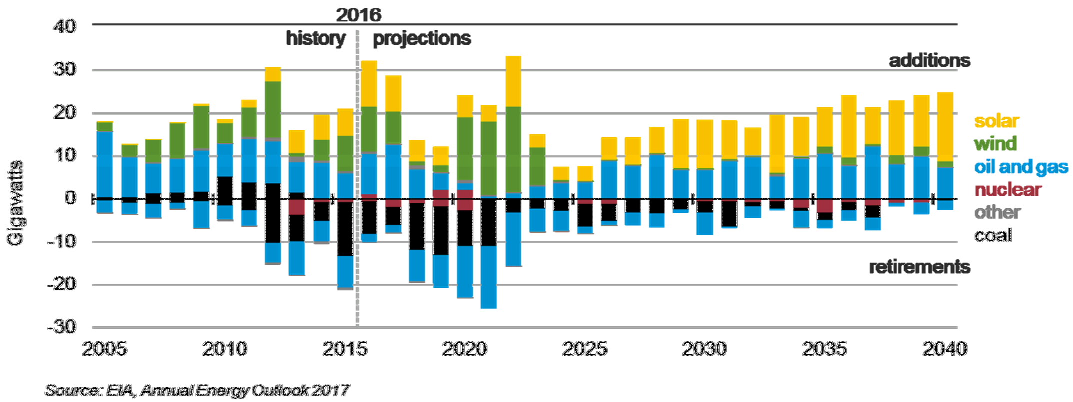


Image credit: Washington Post

Capacity Additions and Retirements

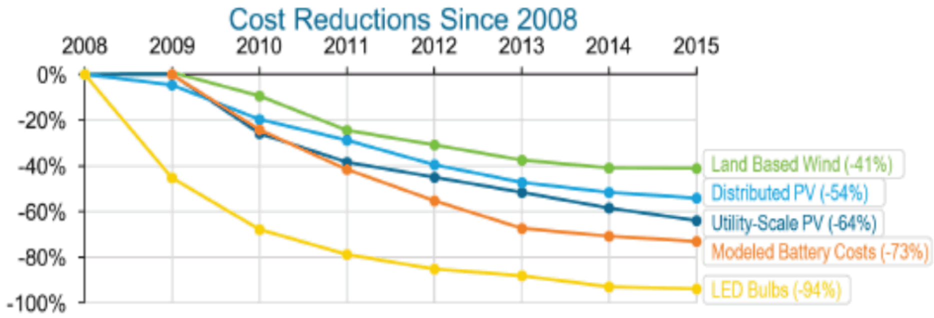




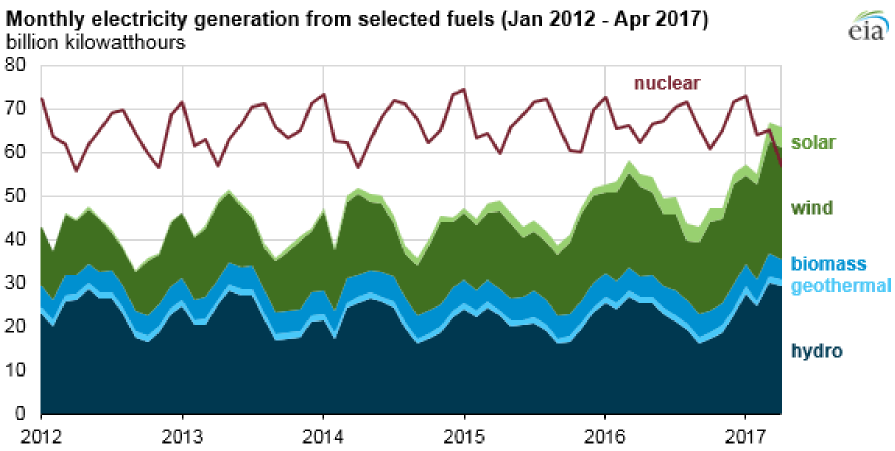
- Natural gas resource availability affects prices and plays a critical role in determining the generation mix:
  - Coal-fired unit retirements primarily driven by low natural gas prices

Renewable Energy Growth

- Reductions in solar and wind capital costs and clean energy tax credits sustaining rapid renewable growth:
  - Cost reductions primarily due to high volume manufacturing and large scale deployments



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



- Utility-scale renewables generation in the US surpassed nuclear generation in April 2017
- In California by 2021, solar, storage and wind capacity additions will exceed natural gas (GTM Research)

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Drivers for Grid Modernization

- Economic drivers:
  - Aging electric power system exacts substantial costs due to outages and inefficient energy technologies.
- Environmental drivers:
  - Increasing frequency and severity of extreme weather (drought, storms, etc.) affect the ability to generate power and stress the resiliency of electric power grid.
- Security drivers:
  - Physical: damage to infrastructure by malicious actors or natural hazards increasing risk to critical assets
  - Cyber: disruption of energy production/energy flow and damage to equipment caused by cyber threats/attacks.
- Competitiveness drivers:
  - Increasing competition worldwide in energy sector as countries are moving toward clean energy technologies
  - Improving competitiveness domestically and globally requires steep cost reduction by technology/manufacturing advances, and competitive energy market

Image credit: AP

Image credit: T&DWorld

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Development Trends

- Renewable integration
- Energy storage integration
- Microgrids
- Smart Metering
- Internet of things
- Big data
- New technologies/resources (cost reduction)
- Cyber/physical security (networked resources)
- Operation/market structure/policy (aggregators, brokers, retail markets)

Image credit: energystoragedirect.com.au

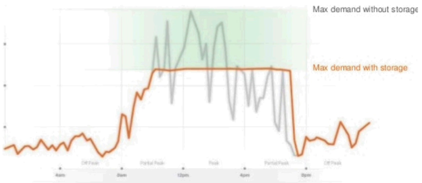
Grid Research & Development Needs

Electric systems	Traditional Grid	Development Trends and Needs	Future Grid
Generation	• Large centralized power plants • Dispatchable generation • Mechanically coupled • Minimal DER	• Growing role of DER • Energy storage • New planning tools to handle RE • Control coordination • NG replacing coal plants	• Hybrid control architectures • Bidirectional power flows and stochastic loads • Power electronic centric infrastructure across the grid
Transmission	• SCADA for status visibility • Operator-based controls • Aging infrastructure. Low peaking capacity utilization. • Threats/vulnerabilities not well defined	• VDC transmission • Growing dc loads • Improving EMS • Integrated planning tools • Growing security awareness • Increasing role of storage	• Wide-spread PMU deployment • Coordinated sensing and control infrastructure • System-wide dynamic power flow management • Resilient and self healing
Distribution	• Minimal to non-existent sensing and automation • Radial design and one-way power flows • Aging distribution infrastructure	• Deployment of ADMS • FACT/inverter enabled voltage regulation • Early adoption of storage in distribution systems	• Truly bi-directional power flows and large scale DG • Pervasive sensing and communications • Local, autonomous coordination • Asynchronous networks
Consumption	• Regional, location and customer specific rate structure • Uniformly high reliability • Predictable behavior based on historical needs and weather • Reliable, yet inflexible	• Customer-determined reliability/power quality • Real time pricing, time of use rates, demand charges • Improved utility communications • Behind-the-meter storage	• Autonomous microgrids • Advanced EMS • Widespread DERs and transactive energy • Pervasive sensor environment
Operation/Market structure	• Vertically integrated utilities, wholesale markets	• Market reform to compensate for services provided	• Diversity of energy products and services

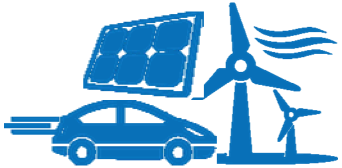
The Need for Energy Storage

Mitigate $79B/yr in commercial losses from outages

Reduce $2T in required T&D upgrades



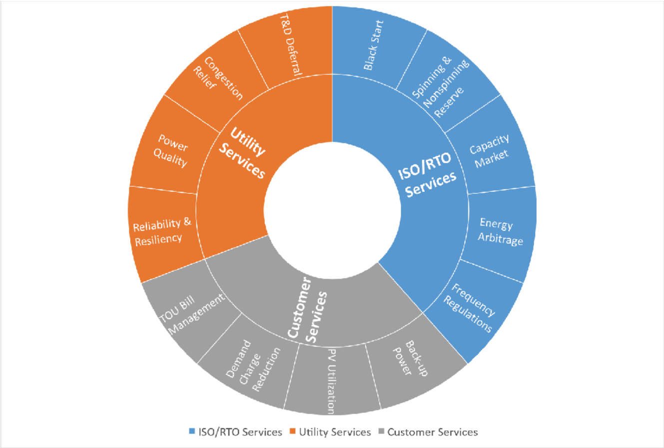
Reduce commercial and industrial electrical bills through demand charge management. 7.5 million U.S. customers are enrolled in dynamic pricing (EIA 2015)

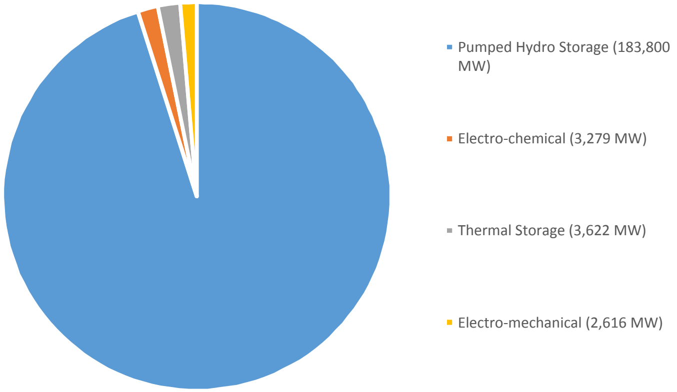


Balance the variability of 825 GW of new renewable generation while improving grid reliability and efficiency.

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

Energy Storage Deployments

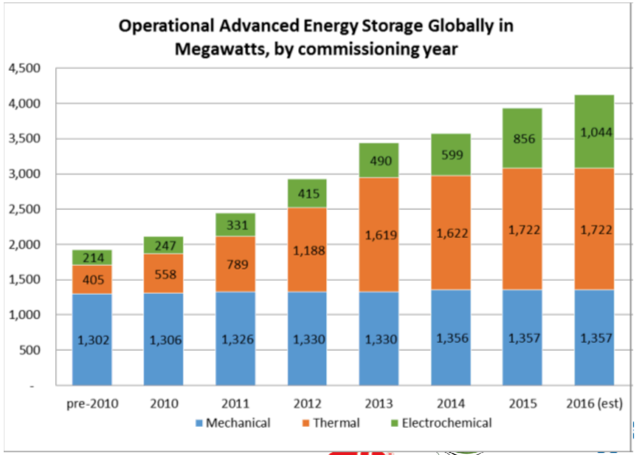




DOE ESS Database http://www.energystorageexchange.org/

Applications of large scale energy storage

- Renewable integration
- Grid resiliency
- Transmission & Distribution upgrade deferral
- Power quality, e.g., UPS application, microgrids, etc.
- Improved efficiency of nonrenewable sources
- Off-grid applications



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Example – Peak Shaving in NYISO

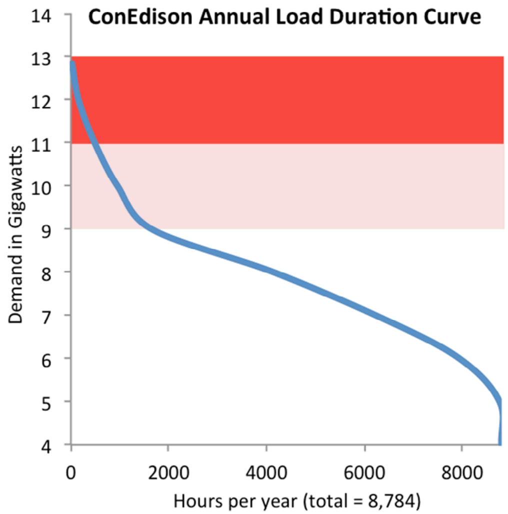


Table I-1: NYCA Energy and Demand Forecasts Net of Energy Saving Impacts

2017 Long Term Forecast[1] - 2017 to 2027

Energy - GWh				Summer Peak Demand - MW				Winter Peak Demand - MW			
Year	Low[3]	Baseline[4]	High[3]	Year	Low[3]	Baseline[4,5]	High[3]	Year	Low[3]	Baseline[4]	High[3]
2016		159,169		2016		33,225		2016-17		24,416	
2017	156,755	158,632	160,504	2017	29,980	33,178	35,487	2017-18	22,693	24,365	25,989
2018	156,128	157,996	159,859	2018	29,891	33,078	35,375	2018-19	22,628	24,294	25,913
2019	155,546	157,405	159,258	2019	29,854	33,035	35,326	2019-20	22,546	24,207	25,821
2020	154,903	156,752	158,598	2020	29,817	32,993	35,279	2020-21	22,439	24,090	25,696
2021	154,017	155,855	157,689	2021	29,832	33,009	35,297	2021-22	22,394	24,043	25,645
2022	153,613	155,444	157,271	2022	29,856	33,034	35,323	2022-23	22,375	24,023	25,624
2023	153,468	155,298	157,124	2023	29,911	33,096	35,388	2023-24	22,361	24,008	25,607
2024	153,306	155,135	156,959	2024	29,962	33,152	35,448	2024-25	22,362	24,007	25,606
2025	153,182	155,009	156,832	2025	30,034	33,232	35,533	2025-26	22,356	24,001	25,600
2026	153,094	154,920	156,743	2026	30,118	33,324	35,629	2026-27	22,356	24,001	25,599
2027	153,143	154,971	156,795	2027	30,185	33,398	35,707	2027-28	22,356	24,000	25,599

Average Annual Growth - Percent

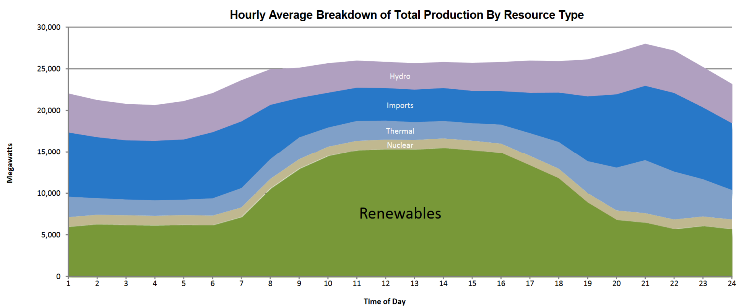
Period	Low	Baseline	High	Period	Low	Baseline	High	Period	Low	Baseline	High
2017-27	-0.23%	-0.23%	-0.23%	2017-27	0.07%	0.07%	0.06%	2017-27	-0.15%	-0.15%	-0.15%
2017-22	-0.40%	-0.41%	-0.41%	2017-22	-0.08%	-0.09%	-0.09%	2017-22	-0.28%	-0.28%	-0.28%
2022-27	-0.06%	-0.06%	-0.06%	2022-27	0.22%	0.22%	0.22%	2022-27	-0.02%	-0.02%	-0.02%

Source: ConEdison, NYISO

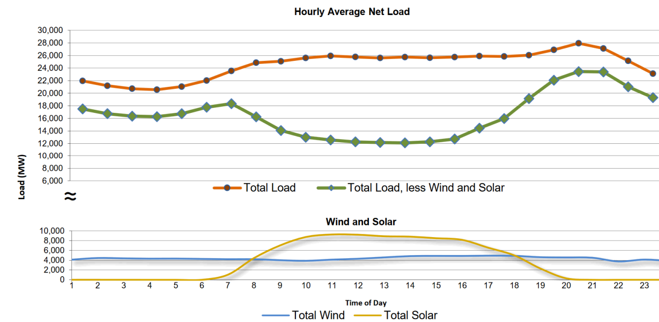
- Top 15% (~5GW) of total demand runs 7 days/yr, <2% of the time
  - Cutting top 100 hours saves $1.7B
  - Opportunity for energy storage: at least 500 GWh

Example – High RE Penetration

CAISO – Production in May 16, 2017

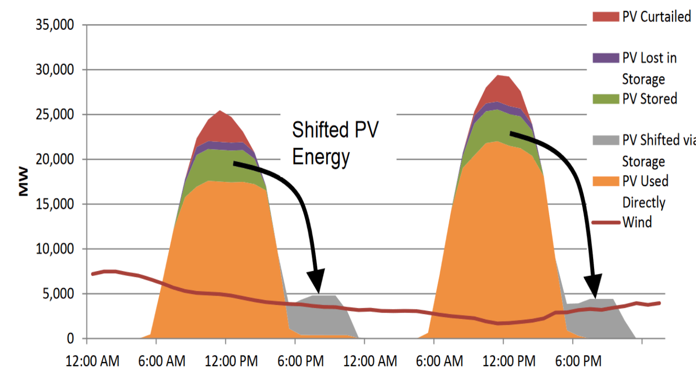


CAISO – Demand in May 16, 2017



Source: CAISO

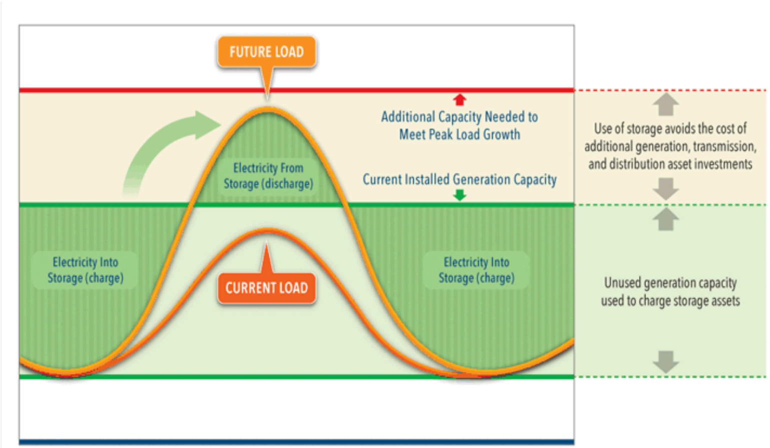
- In May 16, 2017, RE penetration in CAISO reached 42%
  - Ramp rate support needed: 12GW in 4 hours
  - Opportunity for energy storage in ramp support + peak shaving : at least 50 GWh



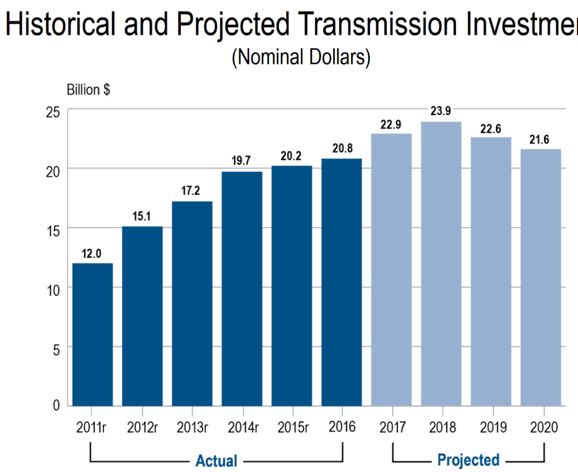
(b) Dispatch of solar energy

Source: NREL

Example – T&D Deferral



Source: NRStor Inc



Source: Edison Electric Institute

- According to a new report from Navigant Research, global installed energy storage power capacity for T&D deferral is expected to grow from 332 MW in 2017 to over 14 GW in 2026.

Example – Substation Resilience

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

AES Gener Los Andes Substation, Atacama Desert, Chile
Source: AES Energy Storage

- Big opportunity for ESS in substation resilience
  - Imagine: US mandates 1MW ESS for each of the 66,000 substations

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 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.

Source: Kauai Island Utility Cooperative

Source: UtilityDrive

Recent Deployments – Aliso Canyon

SDG&E 30 MW/120 MWh Li-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).

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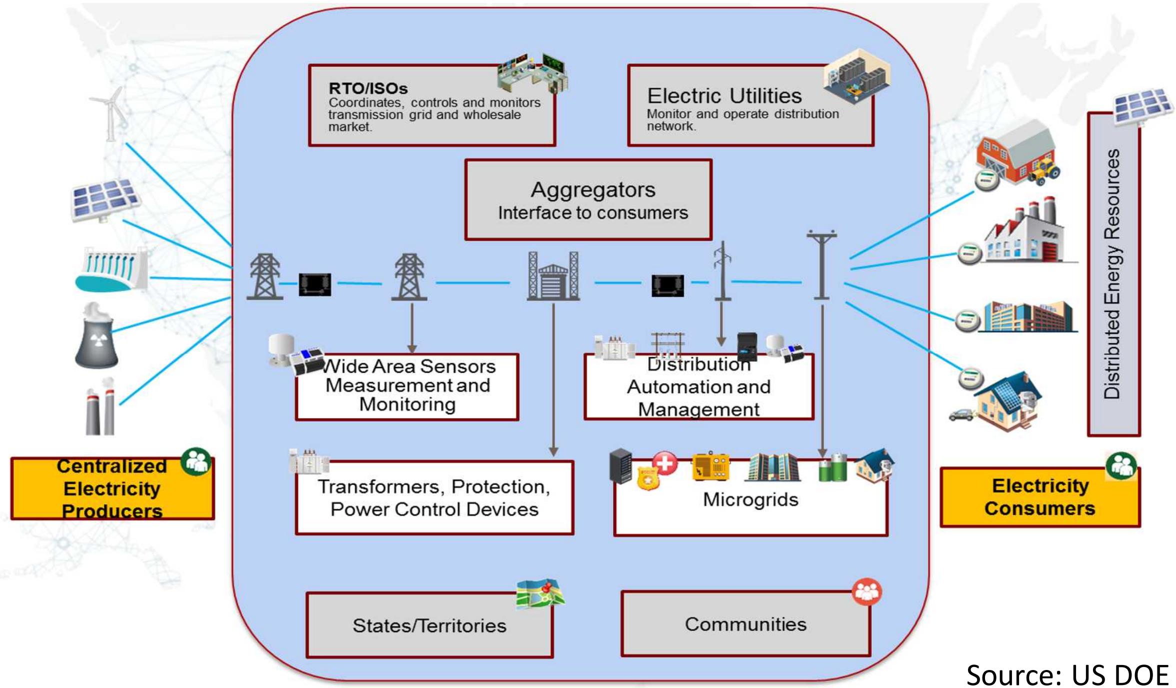
Hybrid Grid Architecture



Source: US DOE

- Throughout these changes in the next 20-30 years, a hybrid grid architecture will emerge: mix of resources, entities, architectures
- There are opportunities for ESS at every level.

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
- 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 in Technology and Implementation

- Technology gaps
  - Existing storage solutions are expensive for most applications
  - Deep discharge and longer cycle life
  - Safe and reliable chemistry
  - Scalable technologies to cover all markets/applications
- Implementation
  - Performance data
  - Validation of storage
  - Organizational adaptability of new technologies

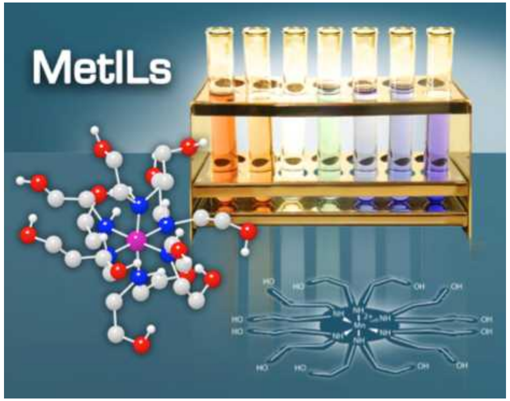
Sandia Grid Energy Storage R&D

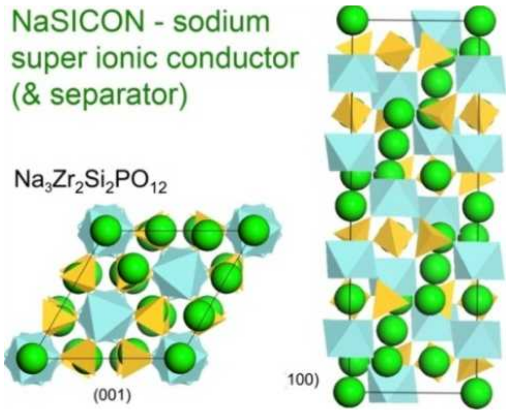
- Strategic goal - Solving critical problems to make energy storage safe, reliable, and cost effective across all markets.
  - Advancing new battery chemistries through technology development and commercialization
  - Optimization at the interface between power electronics and electrochemistry
  - Excellence 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



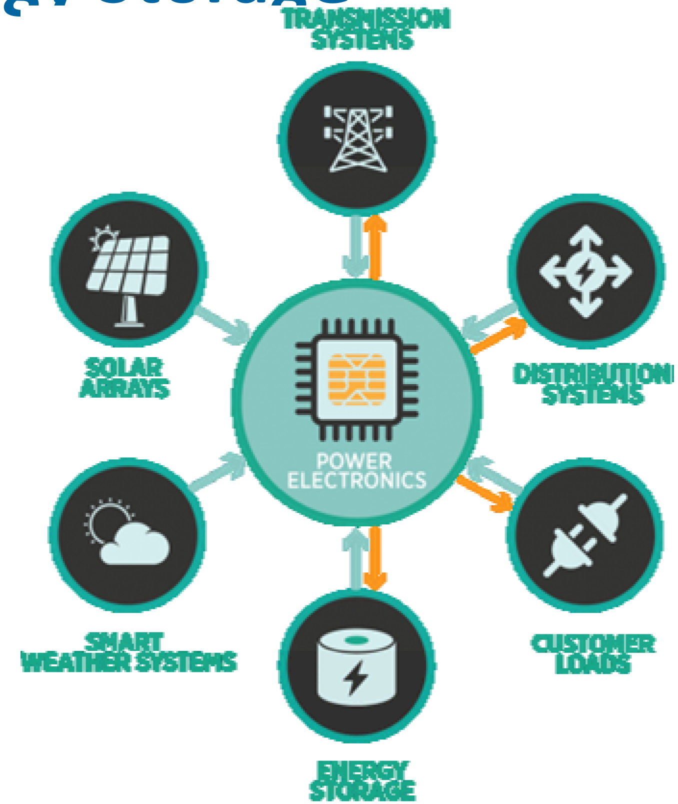


Power Electronics for Energy Storage

Power Electronics is an enabling technology. It synthesizes, processes, converts, conditions and controls the power flow.

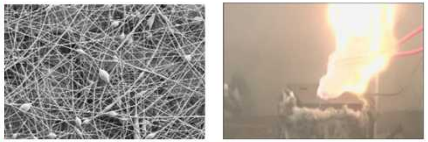
Key Projects

- High-temperature iron-nitride transformer for high frequency converters
- Development of advanced gate oxide for wide band gap devices
- High energy dielectrics for scalable capacitors
- SiC and GaN-based power inverters
- Monolithic SiC-based semiconductor switches



Source: US Department of Energy

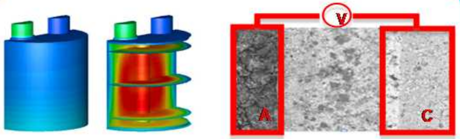
Energy Storage Systems Safety



Materials R&D to date:
- Non-flammable electrolytes
- Electrolyte salts
- Coated active materials
- Thermally stable materials

Materials R&D needs:
- Viable flow batteries
- Aqueous electrolyte batteries
- High specific heat suppressants
- Vent gas composition

Testing
- Electrical, thermal, mechanical abuse testing
- Failure propagation testing on batteries/systems
- Suppressants and delivery with systems and environments
- Large scale thermal and fire testing (TTC)



Simulations and Modeling
- Multi-scale models for understanding thermal runaway
- Validating failure propagation models
- Fire Dynamic Simulations (FDS) to predict the size, scope, and consequences of battery fires

Procedures, Policy, and Regulation
- UL 1973-13 Batteries for Use in Stationary Applications
- ANSI/UL 9540-P (ESS Safety)
- UL 1974 (Repurposing)
- IEEE 1635-12 (Ventilation and thermal management)

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)

Recent DOE 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

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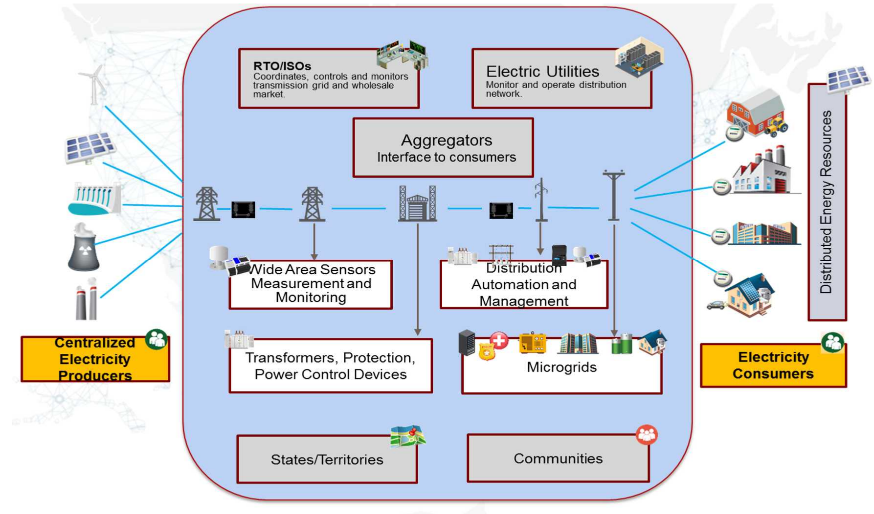
Summary

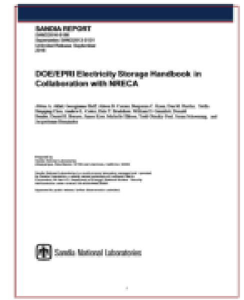


Growing number of opportunities for ESS

- Large scale renewables integration
- Behind the meter applications
- Communities move off-grid
- Aggregators interface multiple entities
- Generation in both transmission and distribution networks
- Interfacing electric vehicles to the grid
- Distributing/shifting/shaving generation and load
- Resilience in transmission and distribution
- Taking advantage of changing market structures to save money

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



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