NAVIGANT

ENERGY

Energy Storage Industry Overview

Prepared for:

aee®

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DISPUTES & INVESTIGATIONS • ECONOMICS • FINANCIAL ADVISORY • MANAGEMENT CONSULTING

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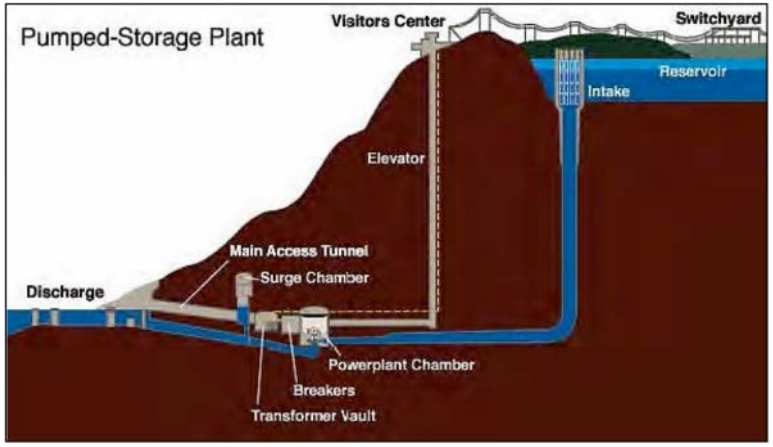
Background

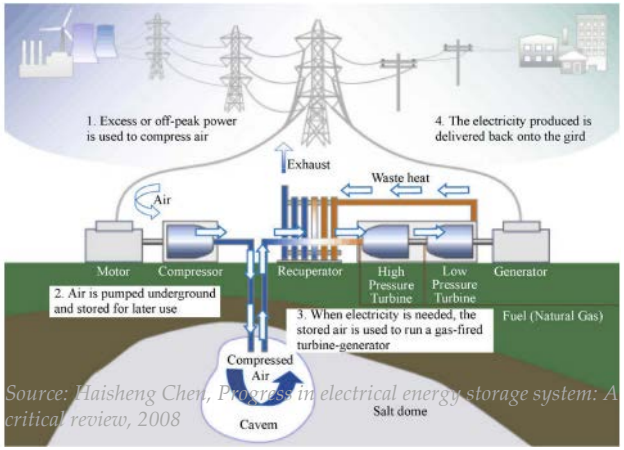
Until recently, grid scale electric energy storage has been either pumped hydro, compressed air energy storage, or lead acid batteries.

- 1836 Daniell lead acid battery becomes the first commercial battery
- 1890's Pumped storage used in Italy and Switzerland
- 1929 First U.S. pumped hydro storage system at Rocky River, New Milford, CT
- 1978 First compressed air energy storage (CAES) plant in Huntorf, Germany
- 1970's Lead acid batteries begin to be used for reactive power
- 1991 First U.S. CAES plant in McIntosh, Alabama
- 2000's Increased use of batteries in grid scale pilots

Pumped Storage Cutaway Diagram



CAES



Source: Haisheng Chen, Progress in electrical energy storage system: A critical review, 2008

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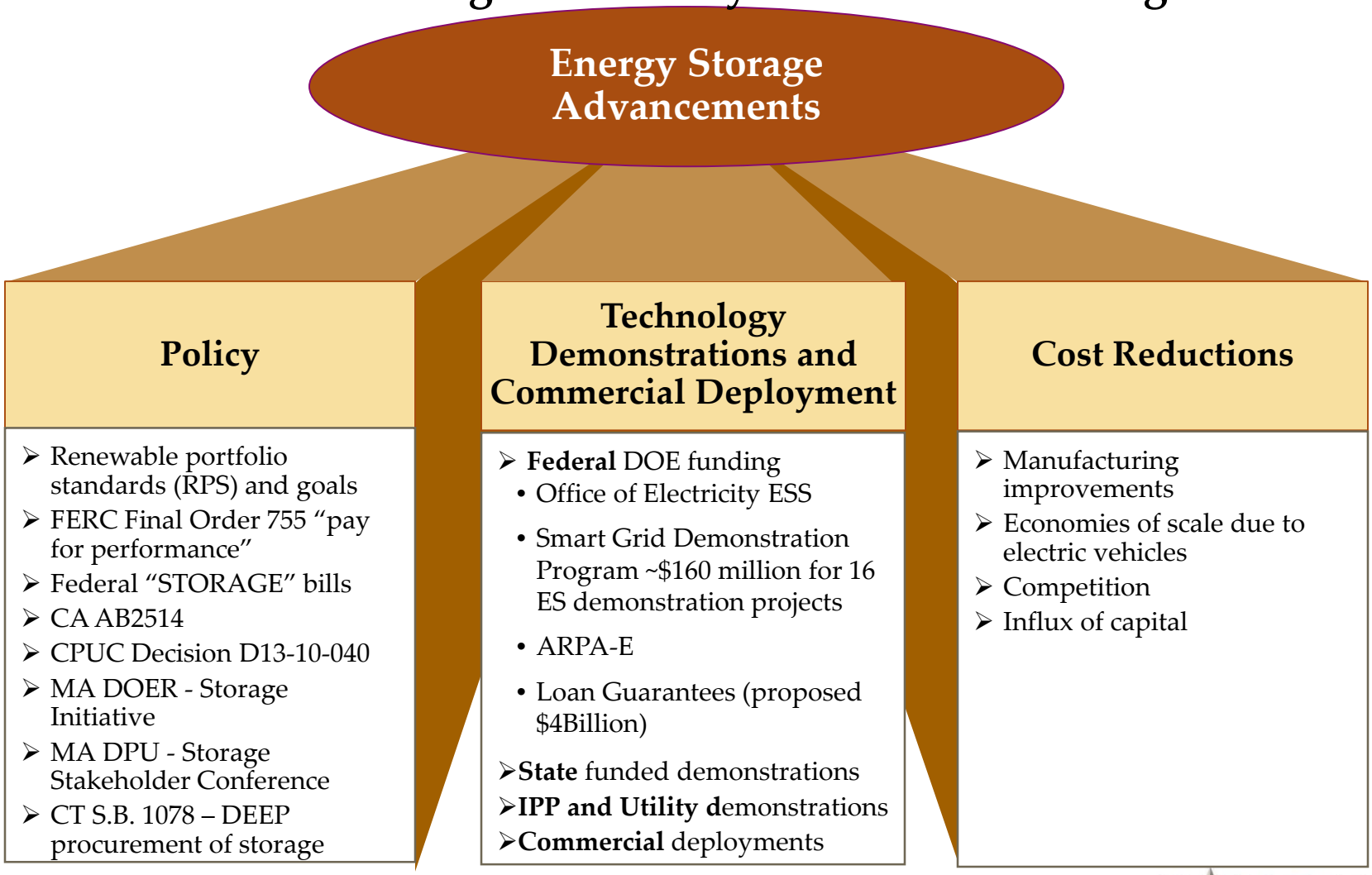
Background

While energy storage has been around for a century, recent advancements are causing the industry to re-examine storage.



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Technologies

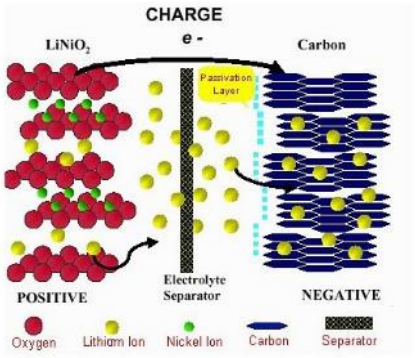
Electrical energy is generally stored through mechanical, chemical, thermal or electro-chemical means.

Mechanical

Source: Beacon Power

- Pumped Hydro Storage (PHS)
- Compressed Air Energy Storage (CAES)
- Flywheel

Batteries



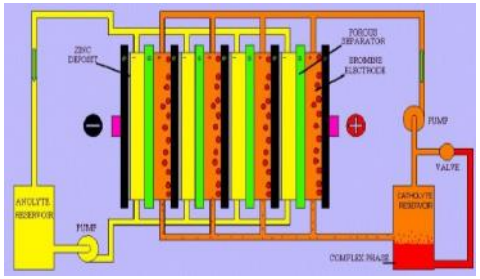
Source: SAFT

- Lead Acid
- Advanced Lead Acid
- Zinc Air
- Sodium Sulfur
- Sodium Metal Halide
- Sodium Ion
- Other

Lithium-

- Iron Phosphate
- Manganese Oxide
- Titanate
- Cobalt
- Nickel Cobalt Aluminum
- Nickel Manganese Cobalt

Flow Batteries



Source: www.ZBBenergy.com

- Zinc Bromine
- Vanadium Redox
- Iron Chromium
- Other

Other

Source: www.smartgrid.gov

Thermal

- Ice Based
- Thermal Molten Salt

Power To Gas

- Hydrogen
- Synthetic Natural Gas

Capacitors

- electric double-layer capacitors, or "supercapacitors" or "ultracapacitors"

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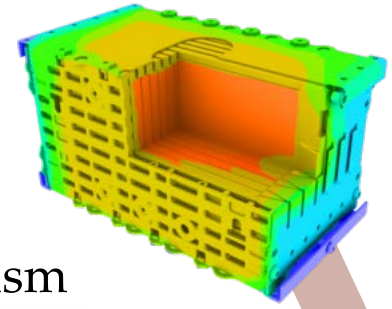
A typical storage system contains a storage technology, thermal management system, power conversion system and software & controls.

Energy Storage System Components

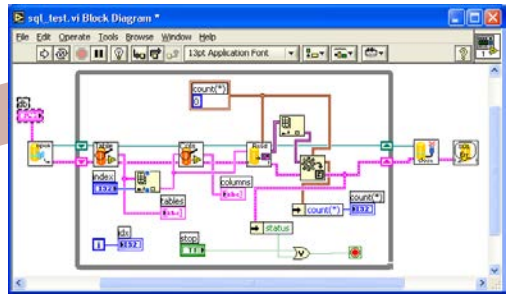
Thermal Management



Power Conversion

Storage Mechanism

Software & Controls



Energy Storage System

Image Source: REneweconomy, AVL, Energy Storage Report, Free-SQL

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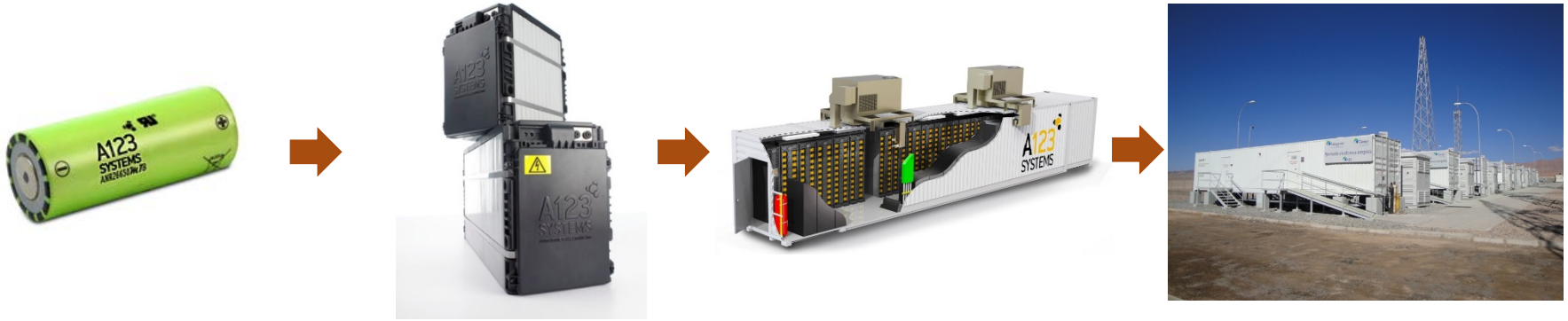
Technologies

For a battery system, the software & controls, and thermal management are often integrated across the modules, packs and system.

Representative Battery Storage System



Cells
- High Power
- High Energy
- Chemistry

Modules
- Internal Cooling
- Sensors, monitoring, balancing
- Communication

Packs
- Battery Management
- Wiring & racking
- Relays, fuses, etc.

System
- Power Conversion System
- Software &Controls
- Thermal Management Systems

Image Source: A123 Systems

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Applications and Benefits

Navigant's energy storage valuation framework categorizes applications as: load leveling, grid operational support, and grid stabilization.

Load Leveling (Generating power off peak and using it on peak)

- Renewable Energy Shifting
- Wholesale Market & Cost Optimization (e.g., arbitrage)
- Retail Market (e.g., time of use rates, demand charge management)
- Asset Management

Grid Operational Support (Matching supply to demand)

- Load Following
- Operating Reserves
- Frequency Regulation
- Renewable Energy Firming
- Black Start

Grid Stabilization (Improving reliability)

- Renewable Energy Ramping
- Renewable Energy Smoothing
- Backup Power
- Power Quality

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Applications and Benefits

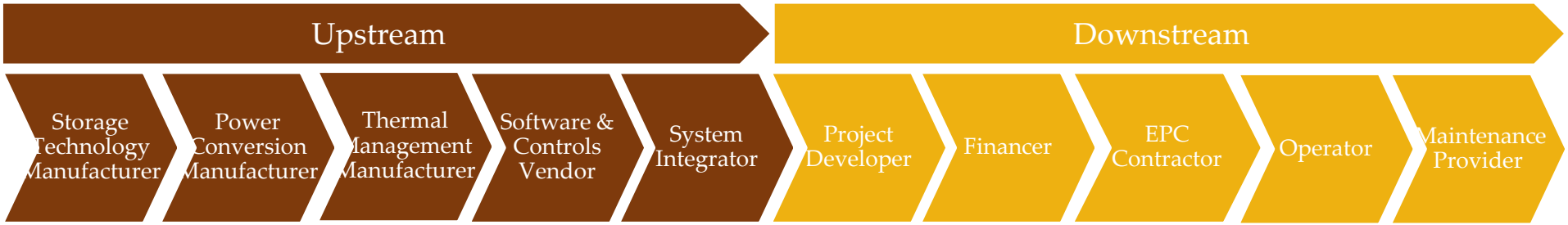
Depending on the application, energy storage will provide a combination of economic, reliability, and environmental benefits.

	Economic										Reliability		Environmental		
	Market Revenue			Asset Utilization					Efficiency	Cost	Interruptions		Air		Water
Applications	Arbitrage Revenue	Capacity Revenue	Ancillary Service Revenue	Optimized Generator Operation	Reduced Congestion Cost	Deferred Generation Capacity Investments	Deferred Transmission Capacity Investments	Deferred Distribution Capacity Investments	Reduced Electricity Losses	Reduced Electricity Cost	Reduced Outages	Improved Power Quality	Reduced CO_2 Emissions	Reduced SO_X, NO_X, and Particulate Emissions	Reduced Water Use
Load Leveling															
Renewable Energy Shifting	X			X	X	X	X	X	X	X			X	X	X
Wholesale Market Arbitrage & Cost Optimization	X			X	X	X	X	X	X	X			X	X	X
Retail Market				X	X	X	X	X	X	X			X	X	X
Asset Management				X	X	X	X	X	X	X			X	X	
Grid Operational Support															
Operating Reserves			X	X		X							X	X	X
Load Following				X		X							X	X	X
Frequency Regulation			X	X		X							X	X	X
Renewable Energy Capacity Firming		X													
Black Start			X			X									
Grid Stabilization															
Renewable Energy Ramping				X		X							X	X	X
Renewable Energy Smoothing				X									X	X	X
Backup Power											X				
Power Quality												X			

Key Players and Deployment

The value chain includes technology manufacturers, system integrators, project developers, owners/operators, and financing organizations.

Energy Storage Value Chain



Typical Upstream Activities:

- Component manufacturing and testing
- Software and controls algorithm development
- Component and system level modelling, design, and testing

Typical Downstream Activities:

- Site selection and permitting
- Arranging project level finance
- Contracting with storage system end user
- Site preparation, installation and commissioning
- Operation
- Ongoing maintenance

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Key Players and Deployment

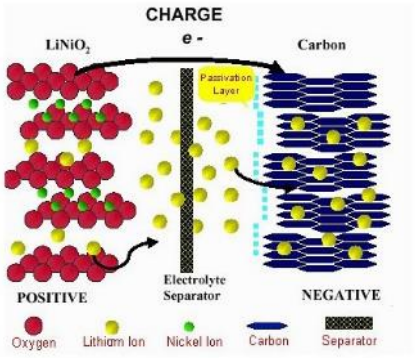
Technology manufacturers will often perform all the functions across the value chain.

Mechanical

Source: Beacon Power

- CAES
  - Dresser Rand
  - MAN Turbo
  - GCX Energy
  - Hydrostor
  - Highview
  - APEX, RWE, etc.
- Flywheel
  - Beacon Power
  - Temporal Power
  - PowerThru
  - Vycon Energy

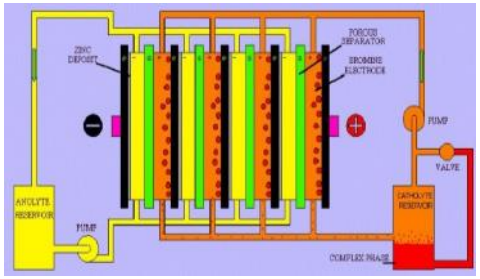
Batteries



Source: SAFT

- Lithium Ion
  - Saft
  - Toshiba
  - AltairNano
  - Electrovaya
  - Dow Kokam
  - LG Chem
  - BYD
- Sodium Metal Halide
  - Fiamm
  - GE
- Sodium Sulfur
  - NGK
- Lead Acid
  - East Penn (Ecoult)
  - Exide
  - EnerSys
  - Axion
  - Trojan
  - Atraverda
- Zinc Air
  - Eos Energy
  - ViZn
- Other
  - Ambri
  - Aquion

Flow Batteries



Source: www.ZBBenergy.com

- Zinc Bromide
  - ZBB
  - Primus Power
  - RedFlow
- Vanadium Redox
  - Prudent Energy
  - UniEnergy Techn.
  - Imergy
  - Gildemeister
  - Sumitomo
  - Vionx
- Other
  - Enervault
  - Enstorage

Other

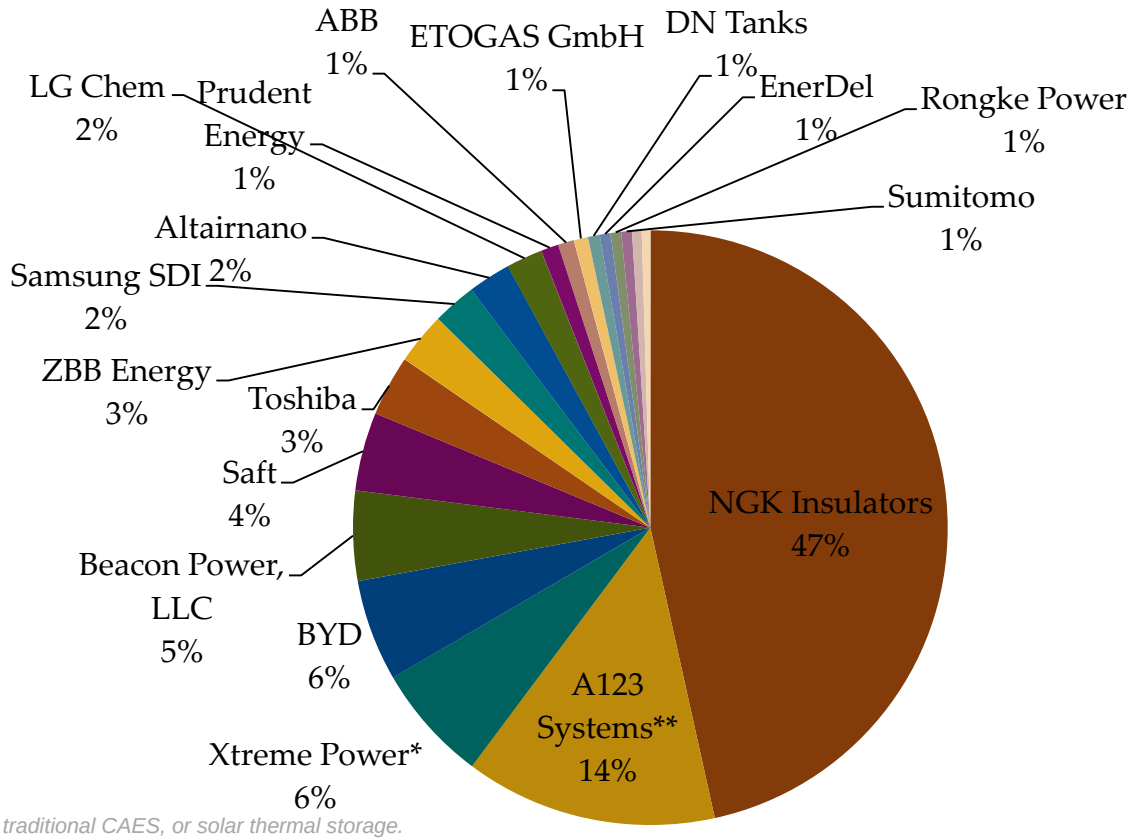
Source: www.smartgrid.gov

- Thermal
  - Ice Energy
  - Calmac
- Power To Gas
  - Hydrogenics
  - ITM Power
  - ETOGAS
  - Sunfire
- Ultracaps
  - Ionova
  - Maxwell

Key Players and Deployment

The following technology manufacturers have supplied energy storage systems for deployment globally.

Deployed Capacity Market Share by Top 20 Technology Vendors* World Markets: 1Q 2015



(Source: Navigant Research)

**Note: Does not include PHS, traditional CAES, or solar thermal storage.*

***NEC acquired the grid storage business from A123 Systems and is now a systems integrator*

****Younicos acquired Xtreme Power and is now a systems integrator.*

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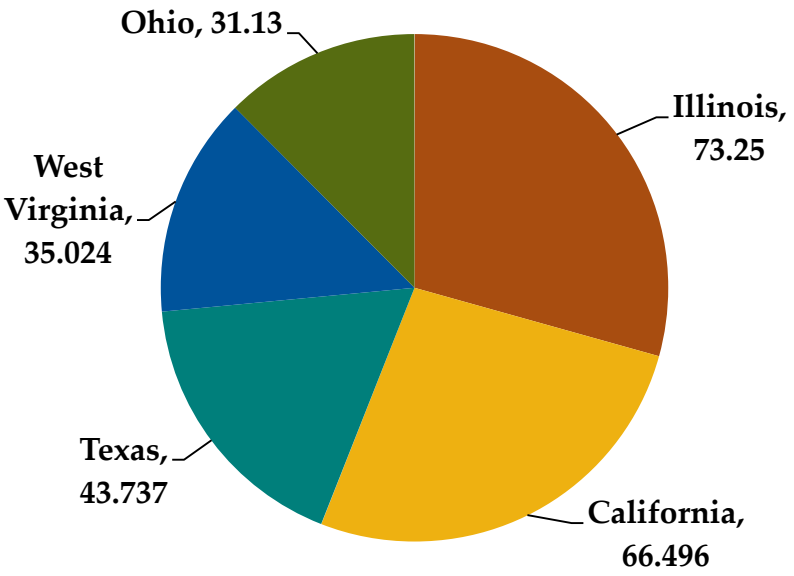
Key Players and Deployment

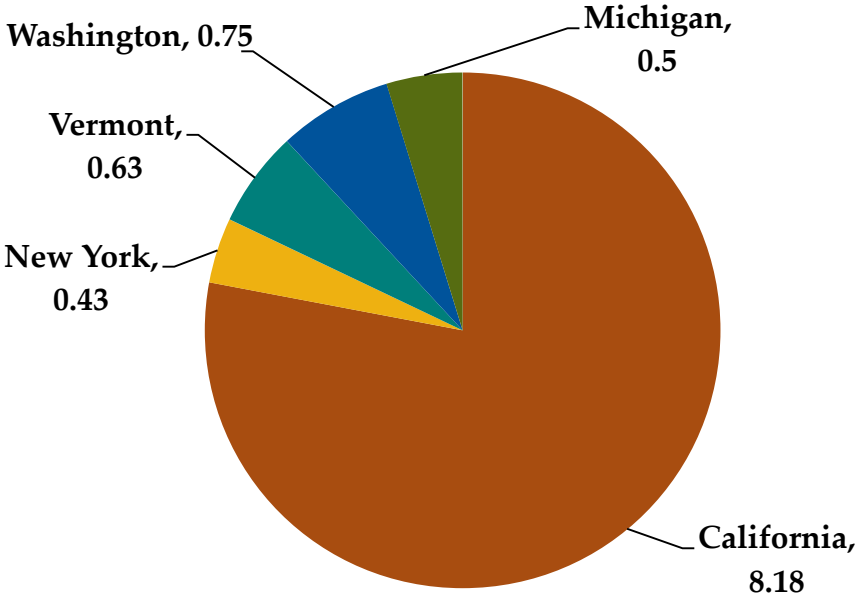
California and Texas lead the US in grid scale energy storage which is larger than the total deployed capacity of behind the meter storage.

FTM Storage, Q1 2015 Capacity (MW)



Top 5 States (250 MW)

BTM Storage, Q1 2015 Capacity (MW)



Top 5 States (10 MW)

Source: Navigant Research

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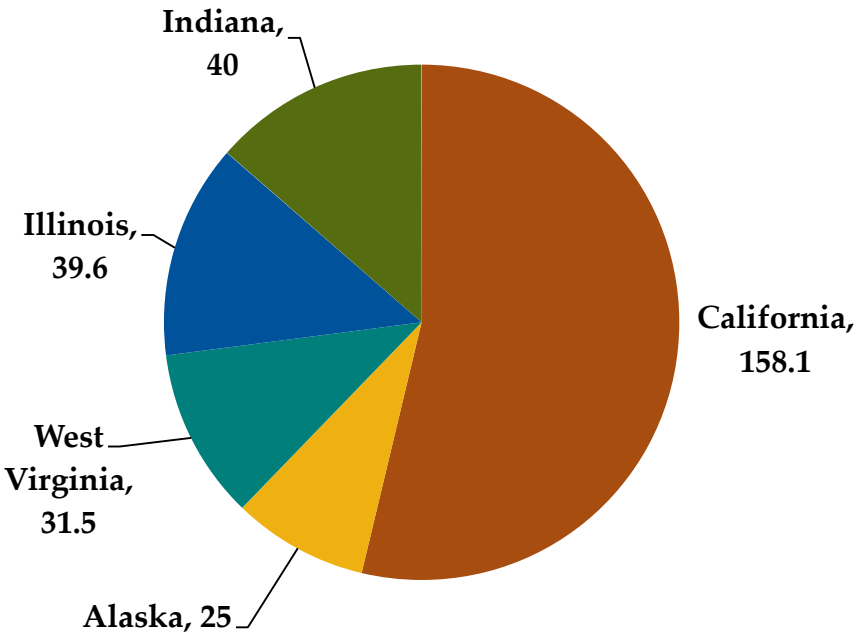
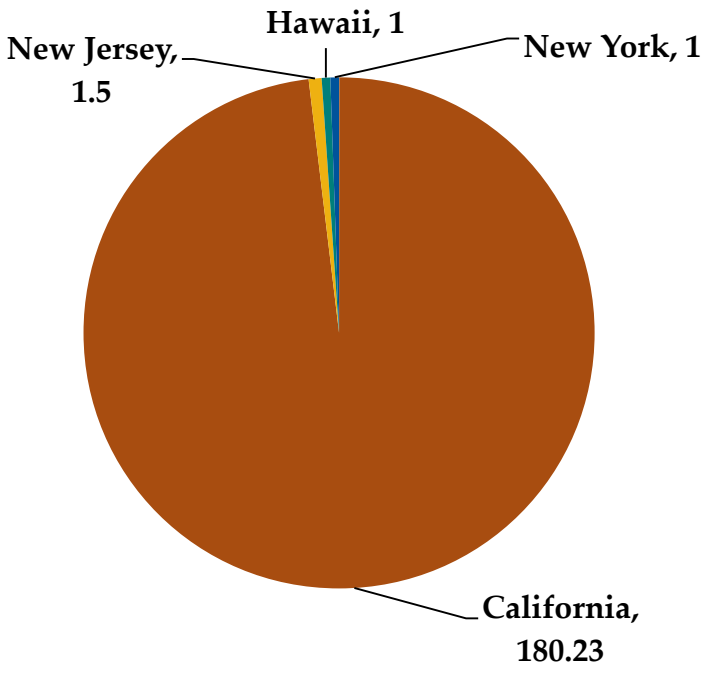
Key Players and Deployment

US grid scale pipeline is driven by policy in CA and frequency regulation elsewhere.

FTM Storage, Q1 2015
Capacity (MW)



BTM Storage, Q1 2015
Capacity (MW)



Source: Navigant Research

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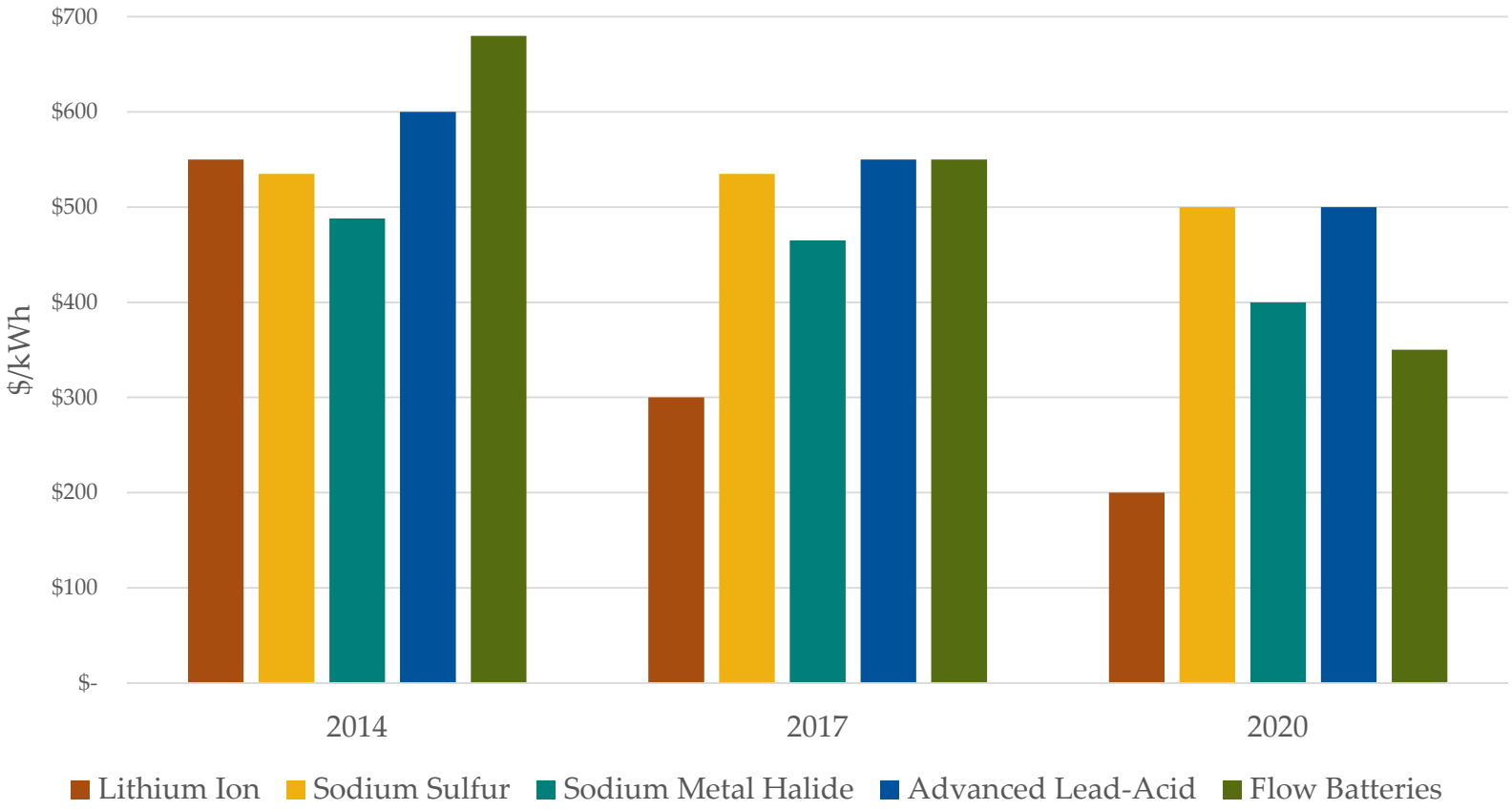
Cost reductions are expected across all technologies, with the largest percentage reductions expected for Li ion and flow batteries.

Lowest Cell Price for Utility Applications 2014, 2017, 2020



Source: Navigant Research

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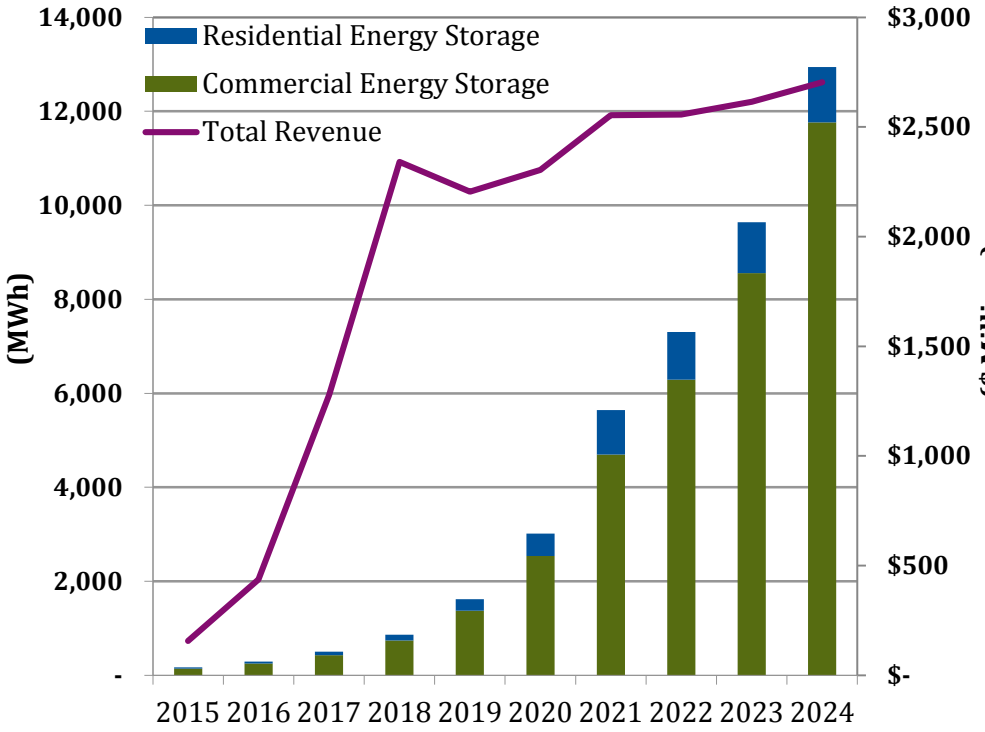
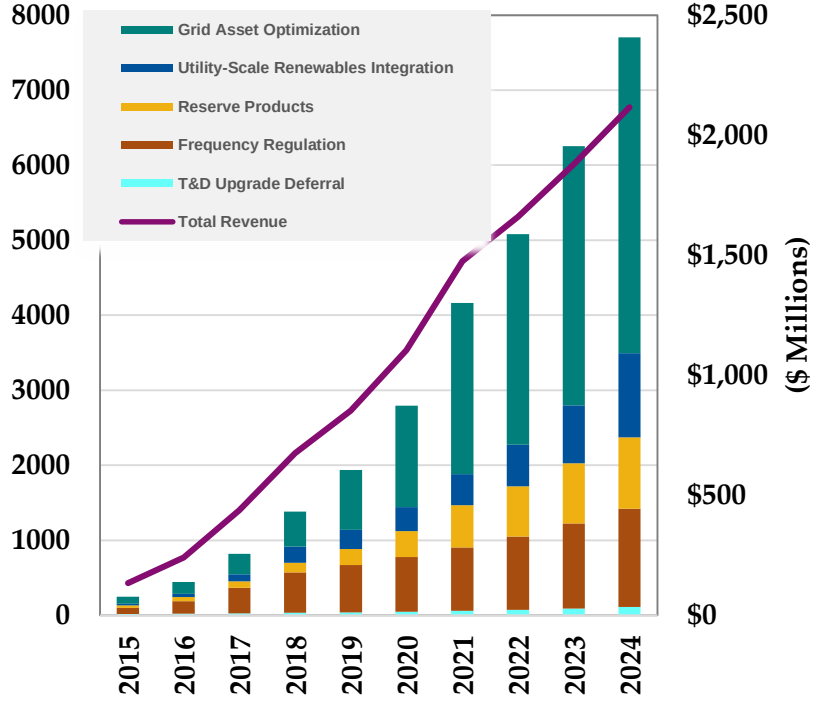
TOU pricing will drive BTM growth, while FTM growth will be dominated by applications to defer T&D expenditures.

Behind the meter battery energy capacity (MWh) and revenue ($M) by application)



Front the meter battery energy capacity (MWh) and revenue ($M) by application



Source: Navigant Research

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Key CONTACTS

Colette Lamontagne
Director
Burlington, MA
781-270-8340
colette.lamontagne@navigant.com

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