Institute for Sustainable Energy

The Hype and Reality of Electrical Energy Storage

Brett A. Perlman

Senior Fellow

Agenda for today

- **Promise of Energy Storage**
- Current Energy Storage Market Size
- Energy Storage Technology Overview
- Business cases for energy storage and the importance of regulatory incentives
- Competitive landscape
- What's next?

Brett A. Perlman Bio and Research Interests

Current Activities:

- Non-Resident Fellow, BU Institute for Sustainable Energy. Fellow, Harvard Advanced Leadership Initiative.
- President, Vector Advisors. Current activities on providing management consulting services to energy clients
- Board of Directors, Just Energy. NYSE/TSX traded retailer of gas and electricity in 17 deregulated North American markets, UK and Germany

Professional Background:

- Commissioner, Public Utility Commission of Texas (1999 to 2003): Responsible for the successful restructuring of Texas' $17 billion electric utility industry and $4 billion telecommunications industry.
- Management consultant: Houston office of McKinsey & Company, with focus on developing business strategy for telecommunications and electric utility clients

Education:

- MPA, Harvard Kennedy School
- JD, University of Texas Law School
- BA, Northwestern University

- Energy Storage
  - Project Acorn: Working with Mike Aziz (Harvard SEAS) on organic flow battery technology
- Energy Technology Commercialization
  - Materials Translational Initiative: Working with Ramana Nanda (HBS) and Sadas Shankar (Harvard SEAS) on new business model to commercialize energy tech.
- Electricity Market Structures
  - HBS Case Study (2017): Mexican Power Market with HBS Prof. Dick Vietor
  - Upcoming Summit on North American Energy Security with former Mexican Deputy Energy Secretary and MIT Fellow Lourdes Melgar

ALMOST 150 years after photovoltaic cells and wind turbines were invented, they still generate only 7% of the world's electricity.

Yet something remarkable is happening. From being peripheral to the energy system just over a decade ago, they are now growing faster than any other energy source and their falling costs are making them competitive with fossil fuels.

Yet green energy has a dirty secret.

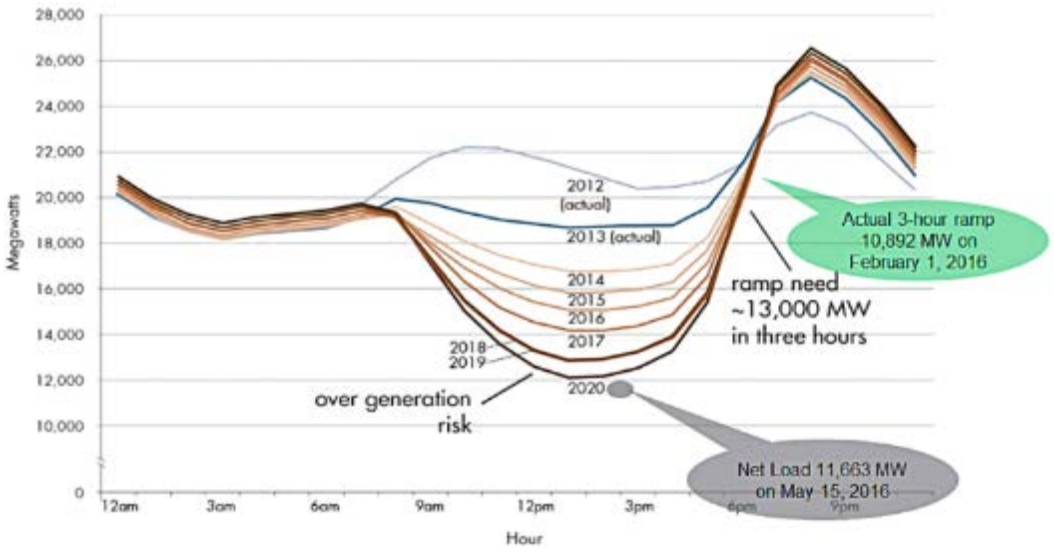
The more it is deployed, the more it lowers the price of power from any source. That makes it hard to manage the transition to a carbon-free future, during which many generating technologies, clean and dirty, need to remain profitable if the lights are to stay on.

The good news is that new technology can help fix the problem. Digitalisation, smart meters and batteries are enabling companies and households to smooth out their demand — by doing some energy-intensive work at night, for example.

The bigger task is to redesign power markets to reflect the new need for flexible supply and demand.

Vision for Role of Energy Storage

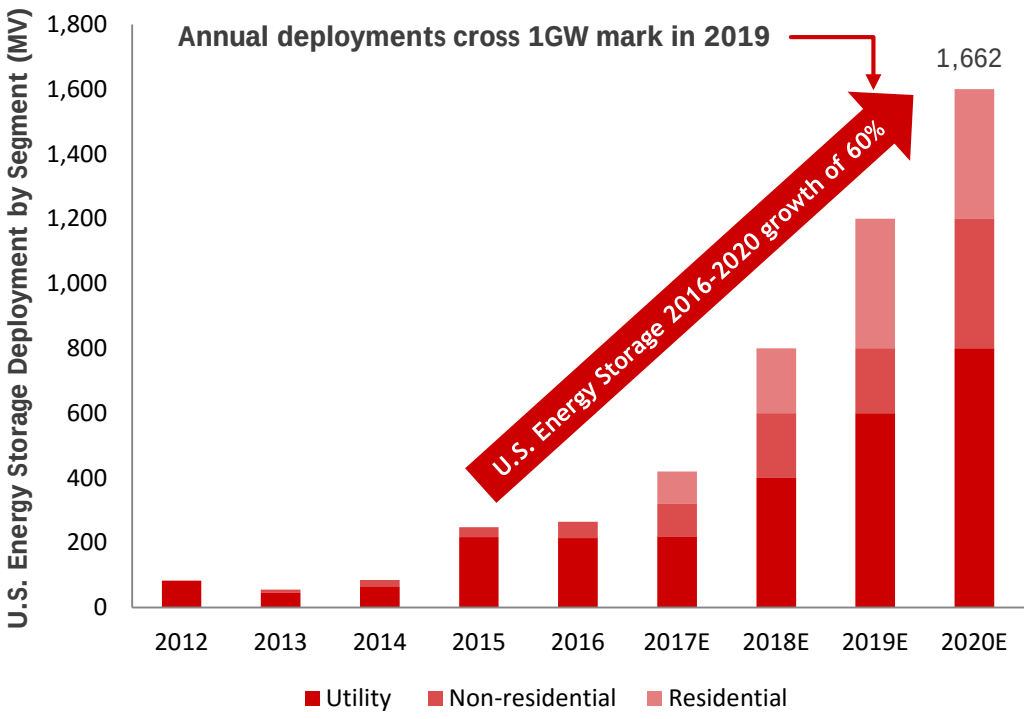
California ISO's "Duck Curve," caused by high renewables penetration and GHG reduction goals….



…. is creating the need for more flexible resources, and perhaps a role for energy storage

- Calif. GHG and renewable policies…
  - 50 percent of electricity from renewable sources by 2030
  - GHG reductions to 1990 levels
  - 1.5 MM zero emission vehicles by 2025
- Creating grid reliability issues..
  - Overgeneration during peaks
  - Steep, sharp ramping after peaks
  - Frequency issues since renewables aren't dispatchable
- … driving the need for flexible resources, such as energy storage
  - Could soak up "excess" on-peak renewables
  - Provide rapid dispatch to meet ramping requirements and frequency issue

Much Hype Around Energy Storage



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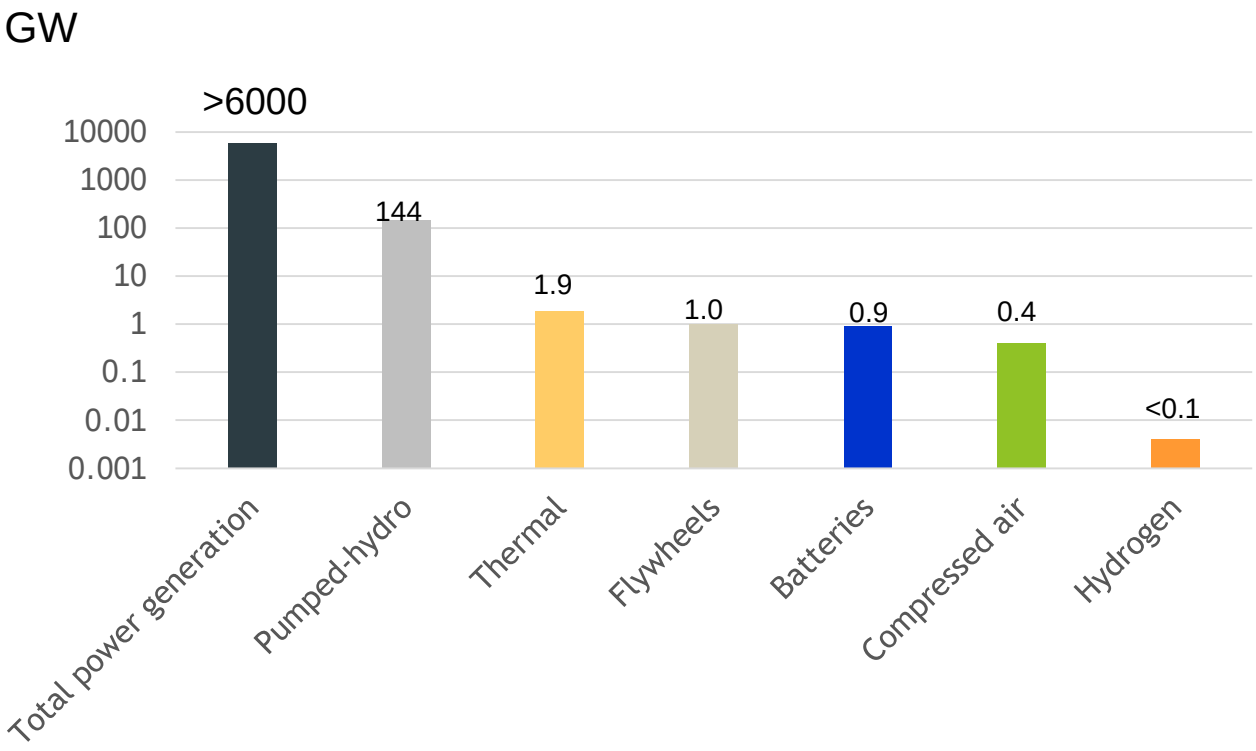
Global Installed Generation and Storage Base: January 2016



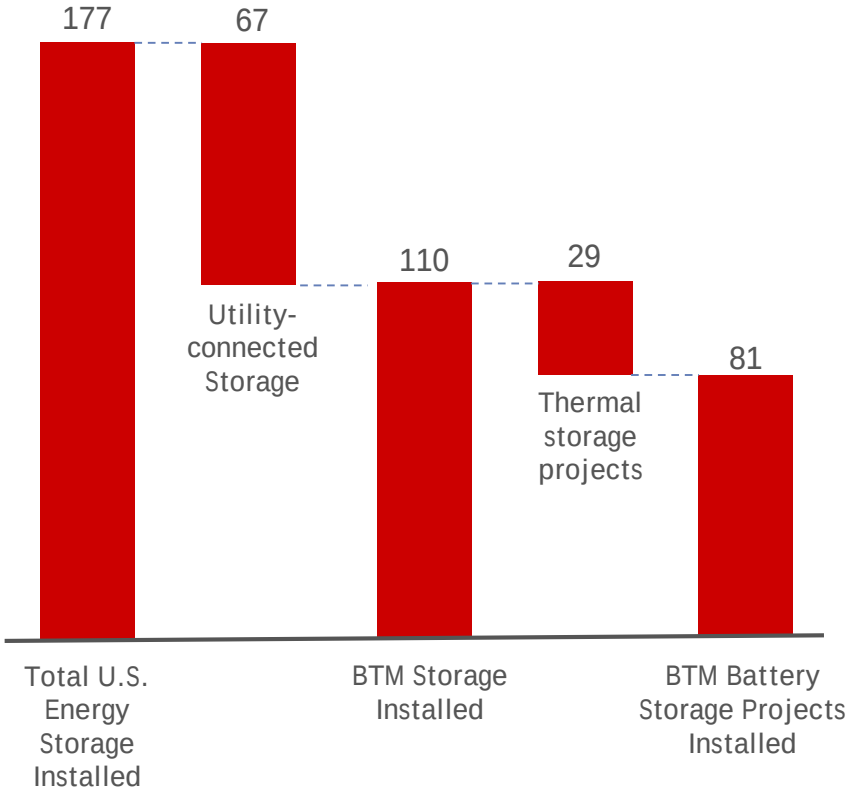
Storage < 2% of power generation capacity

Pumped-hydro represents 99% of storage

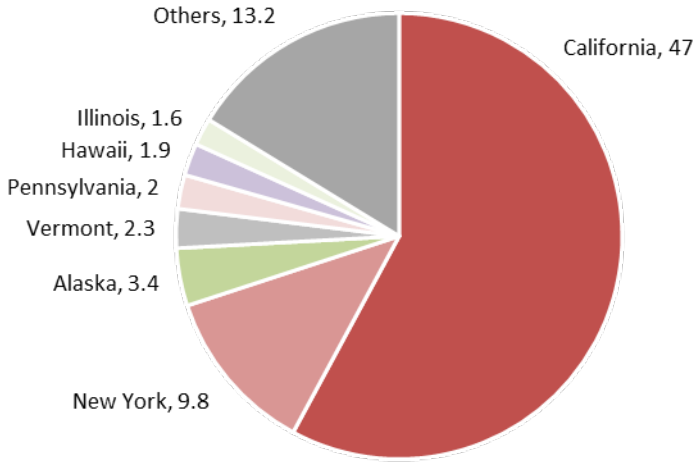
Source: "The Future of the Electric Grid and the Role of Energy Storage" Electric Power Research Institute, May 24, 2016

Energy storage heavily focused in California due to regulatory incentives

US Energy Storage Capacity – Q3, 2016 (MW)



BTM Battery Storage by State



Total= 81 MW

Source: Enovation Partners analysis from variety of sources (primarily SGIP data for California projects and DOE Global Energy Storage Database for other states)

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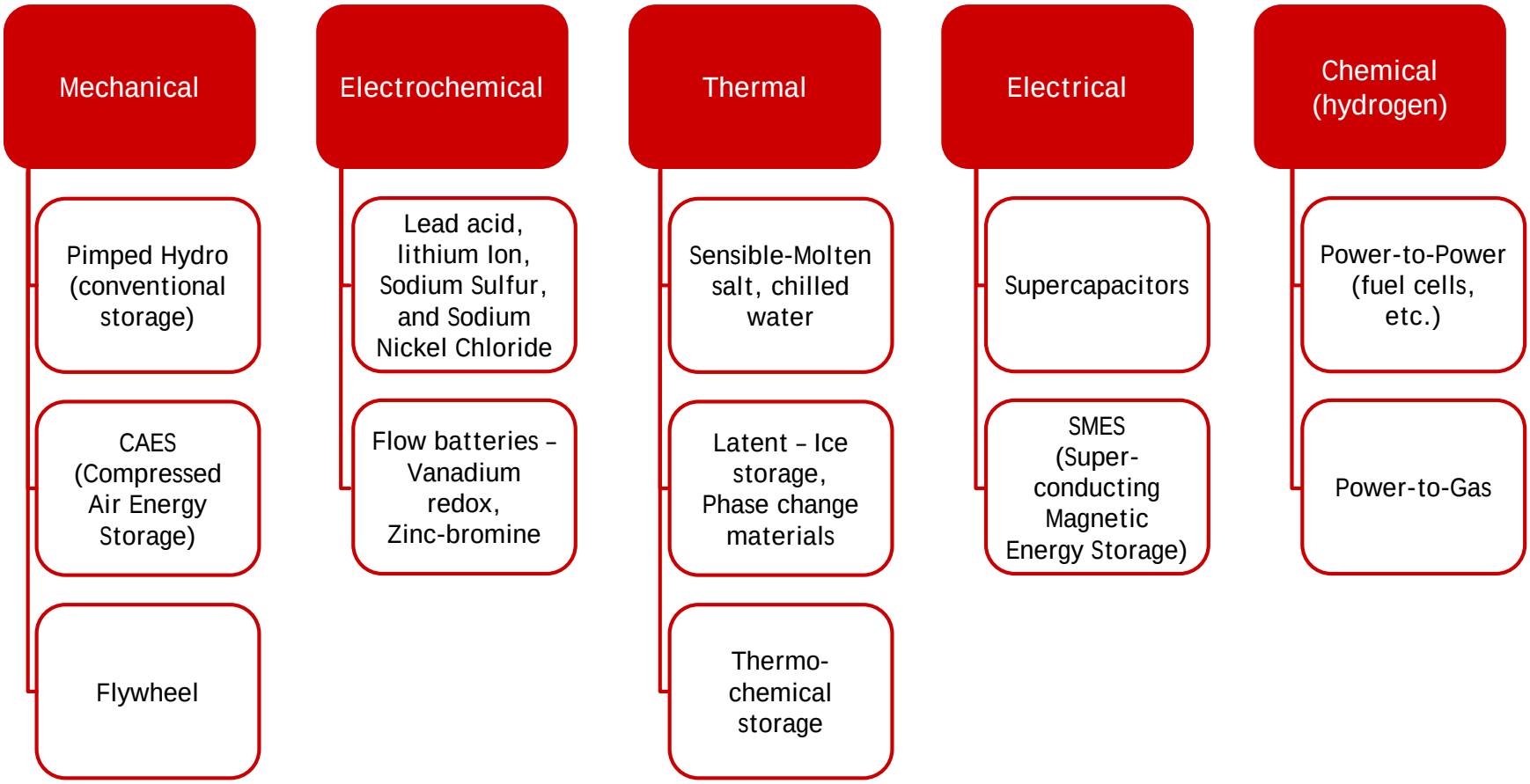
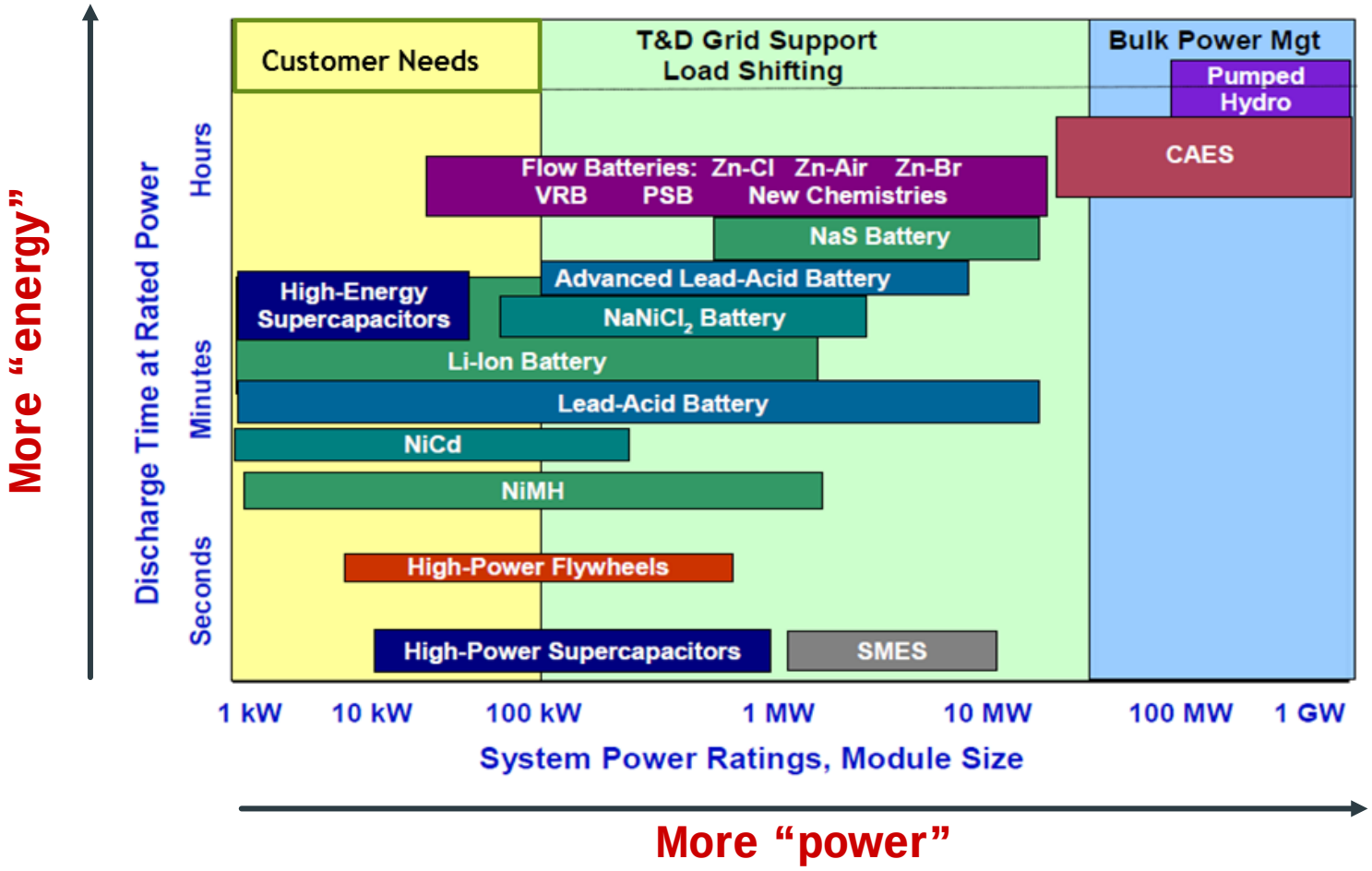
Advanced Energy Storage Technologies



Different Storage Technologies for Different Applications



Source: Environmental and Energy Study Institute, Issue Brief, August 2013
Data source: Sandia National Laboratories

Comparison of Alternative Battery Chemistries for Grid Storage

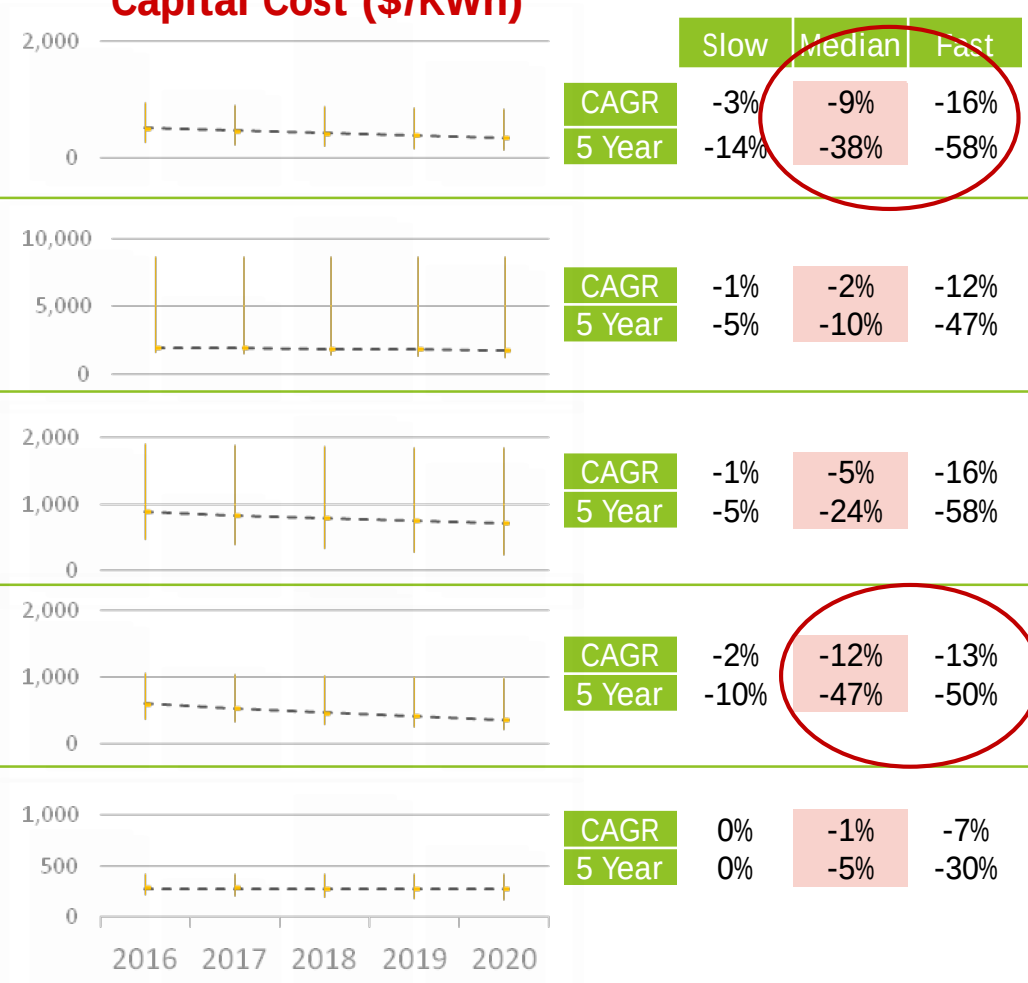
	Flywheels	Lead Acid Batteries	Li-ion Batteries	Trad, Flow Batteries
Cost	●	●	◒	◒
Energy Density	●	○	●	○
Energy Capacity	○	○	◒	◒
Installation	○	○	◒	◒
Cyce Life	●	○	○	●
Depth of Discharge	◒	○	●	●
O&M	◒	○	◒	◒
Response	●	◒	◒	●
Environment	●	○	○	◒

● Good ◒ Medium ○ Poor

Source: "Beyond Four Hours", ESS white paper, 2016

Continued Dramatic Cost Declines In Storage Over the Next 5 Years

Capital Cost ($/KWh)



	Slow	Median	Fast
Flow Battery			
CAGR	-3%	-9%	-16%
5 Year	-14%	-38%	-58%
Flywheel			
CAGR	-1%	-2%	-12%
5 Year	-5%	-10%	-47%
Lead			
CAGR	-1%	-5%	-16%
5 Year	-5%	-24%	-58%
Lithium			
CAGR	-2%	-12%	-13%
5 Year	-10%	-47%	-50%
Zinc			
CAGR	0%	-1%	-7%
5 Year	0%	-5%	-30%

Technology Trends and Opportunities

Flow Battery
- Designing out high cost materials, and scale
- Improved manufacturing and design will improve performance – Size/thickness reduces current flow
- Integration time for manufacturing

Flywheel
- Reducing required high cost materials
- Improving control and response time to increase usable range of operation
- Improvements in operation sustainability – ability to remove heat, higher efficiency motor/generator

Lead
- Improvements in competitive cost position from increases in capability / performance
- Material additives such as carbon is increasing the usable energy and capability envelope
- Design changes to reduce lead requirement

Lithium
- Scale manufacturing lowering cost (Gigafactory)
- Design improvements reducing needed materials
- Chemistry improvements increasing capability of battery, increases usable energy and range of operation

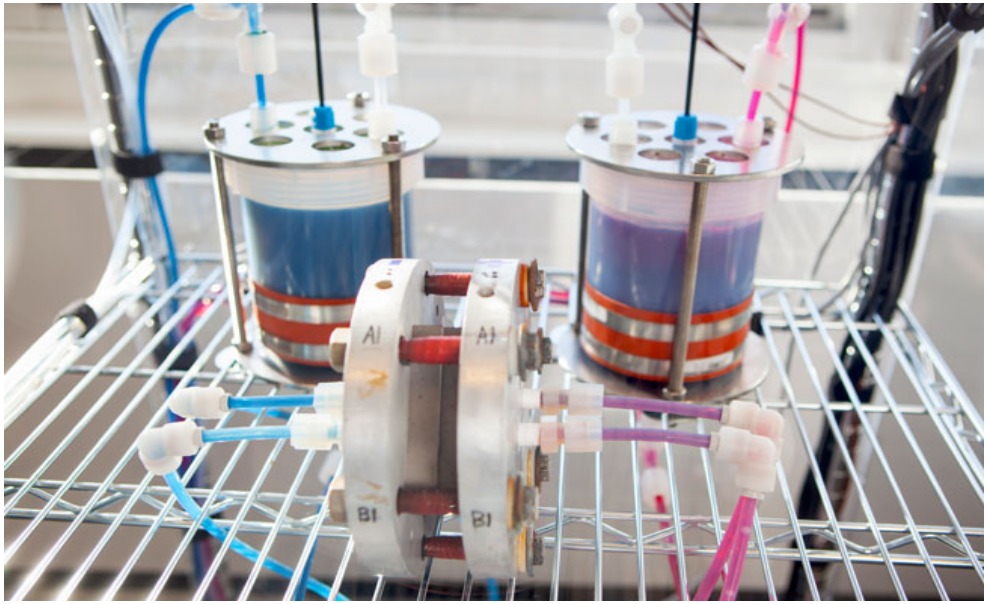
Zinc
- Cost reduction depends on manufacturing at scale
- Design improvement to reduce high cost sub-components
- Chemistry improvements will increase lifespan and range of operation

Source: Enovation Partners, Lazard LCOS survey

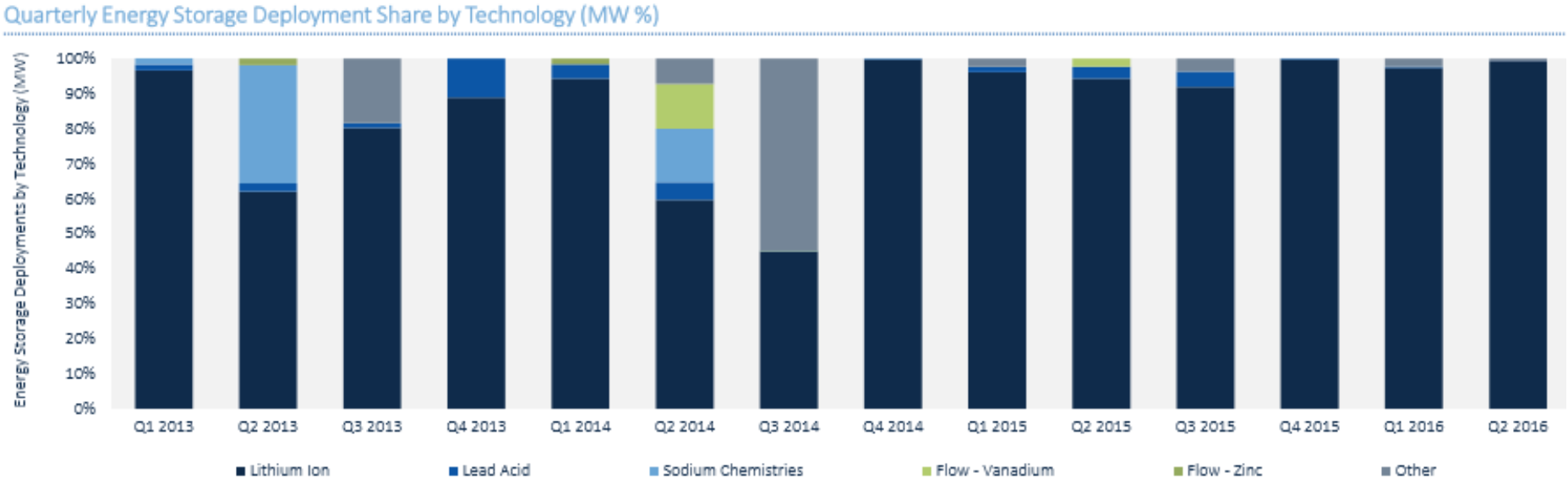
Project Acorn – Aziz Energy Group
Aqueous, Organic, Neutral pH Flow Battery

- Market-driven approach to engineer a storage system that meets market needs
  - 3rd iteration of an aqueous flow battery using organic active materials
- Low Cost
  - Chemicals become a small fraction of system cost
  - New chemistry enables use of cheaper ion exchange membranes

- Good performance
  - High capacity
  - Long cycle lifetimes
- Safe & environmentally friendly
  - Aqueous
  - Neutral pH



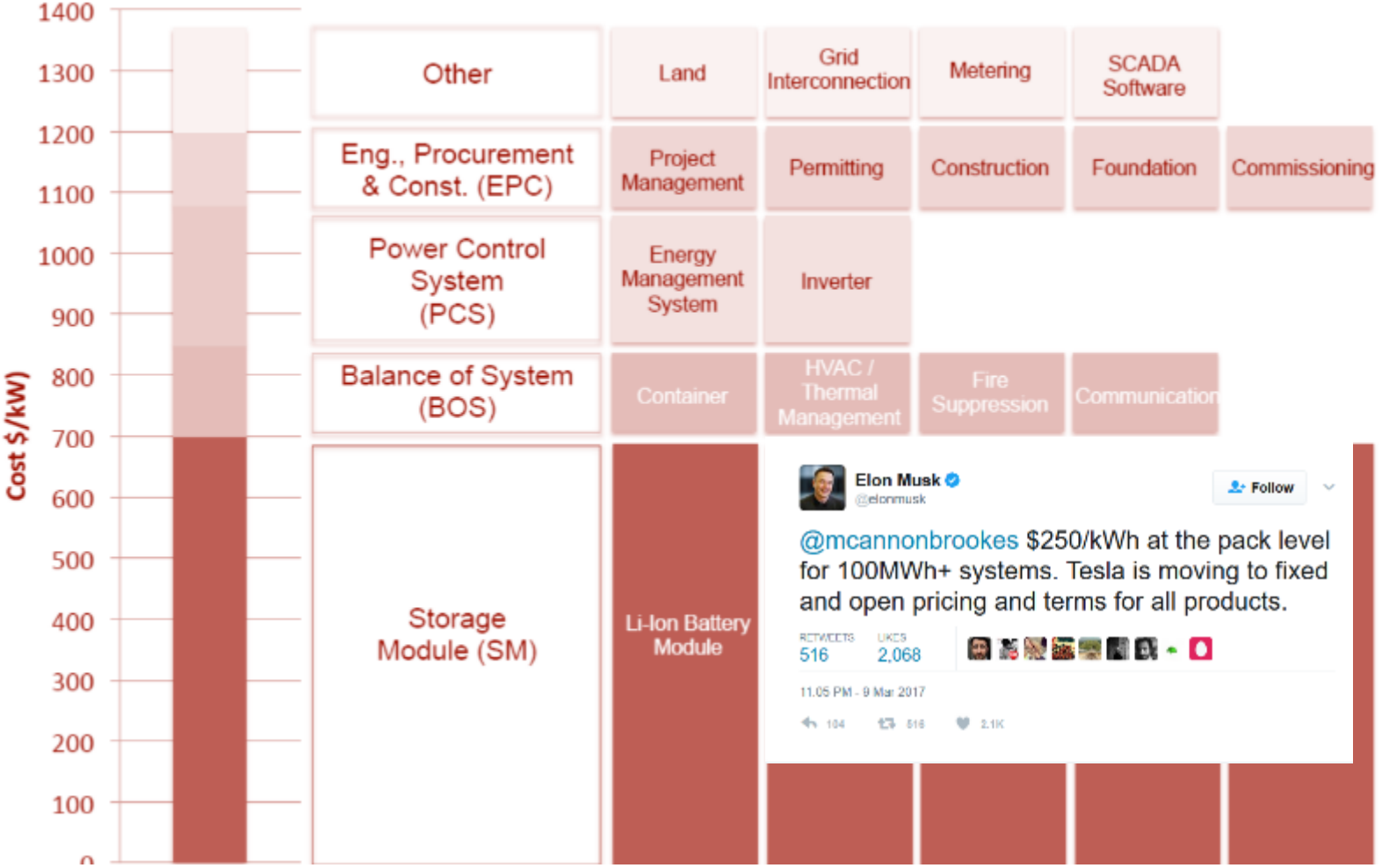
Li-Ion Batteries Dominating Recent Additions to Grid



Source: GTM Research/ESA, US Energy Storage Monitor (3Q 2016)

Will LION Rule the Energy Storage Market?

$1370/kw or $685/kWh*



* Assumes a 2 hour system

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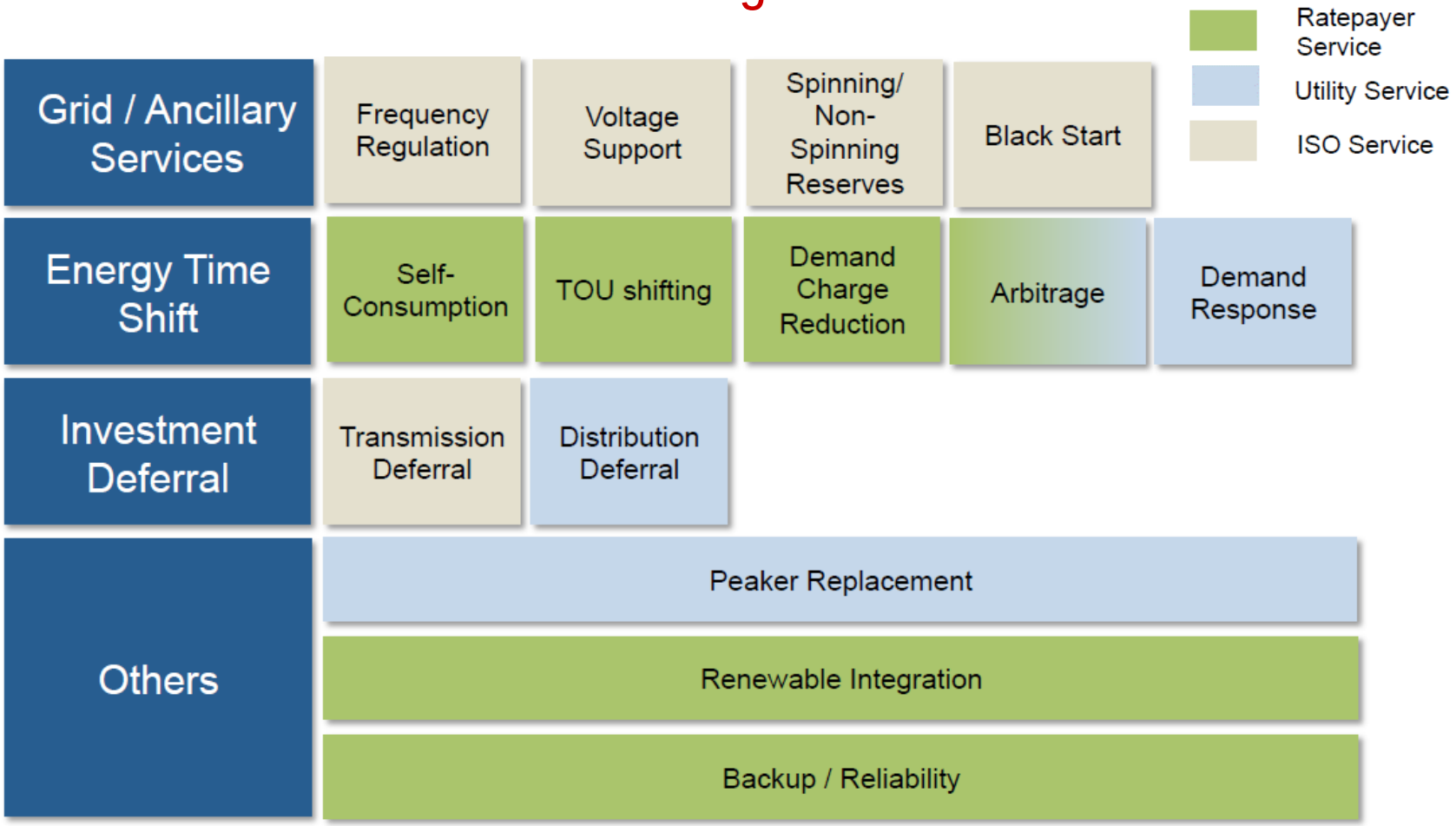
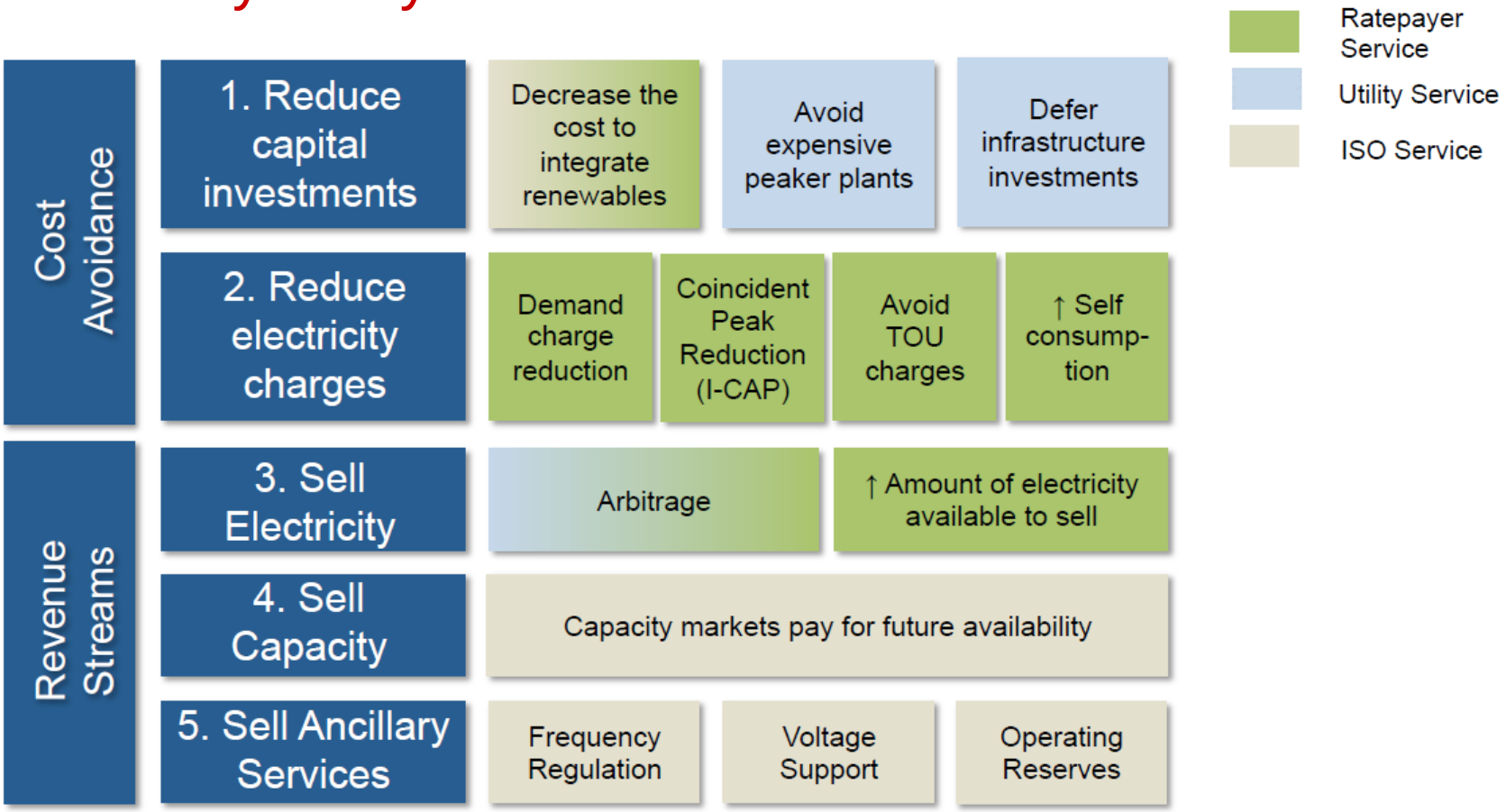
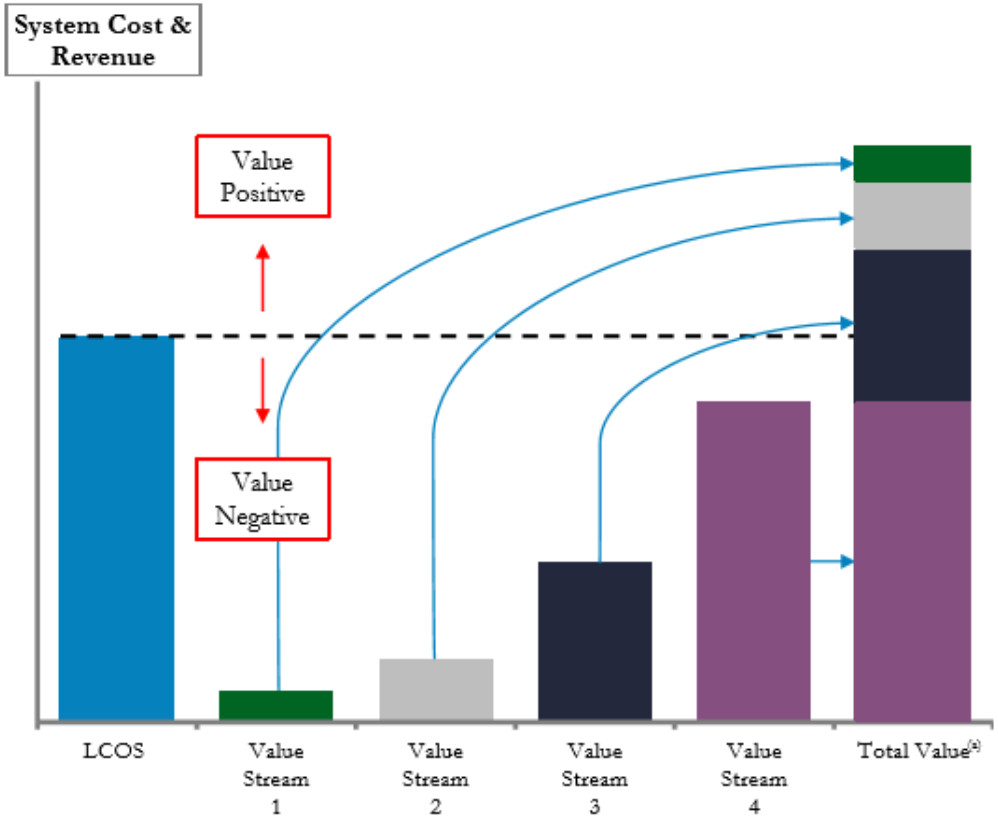
Lots of "Use-Cases" for Storage…



...But only 5 ways to monetize



Grid Storage Costs Often Greater Than Any One Value Stream



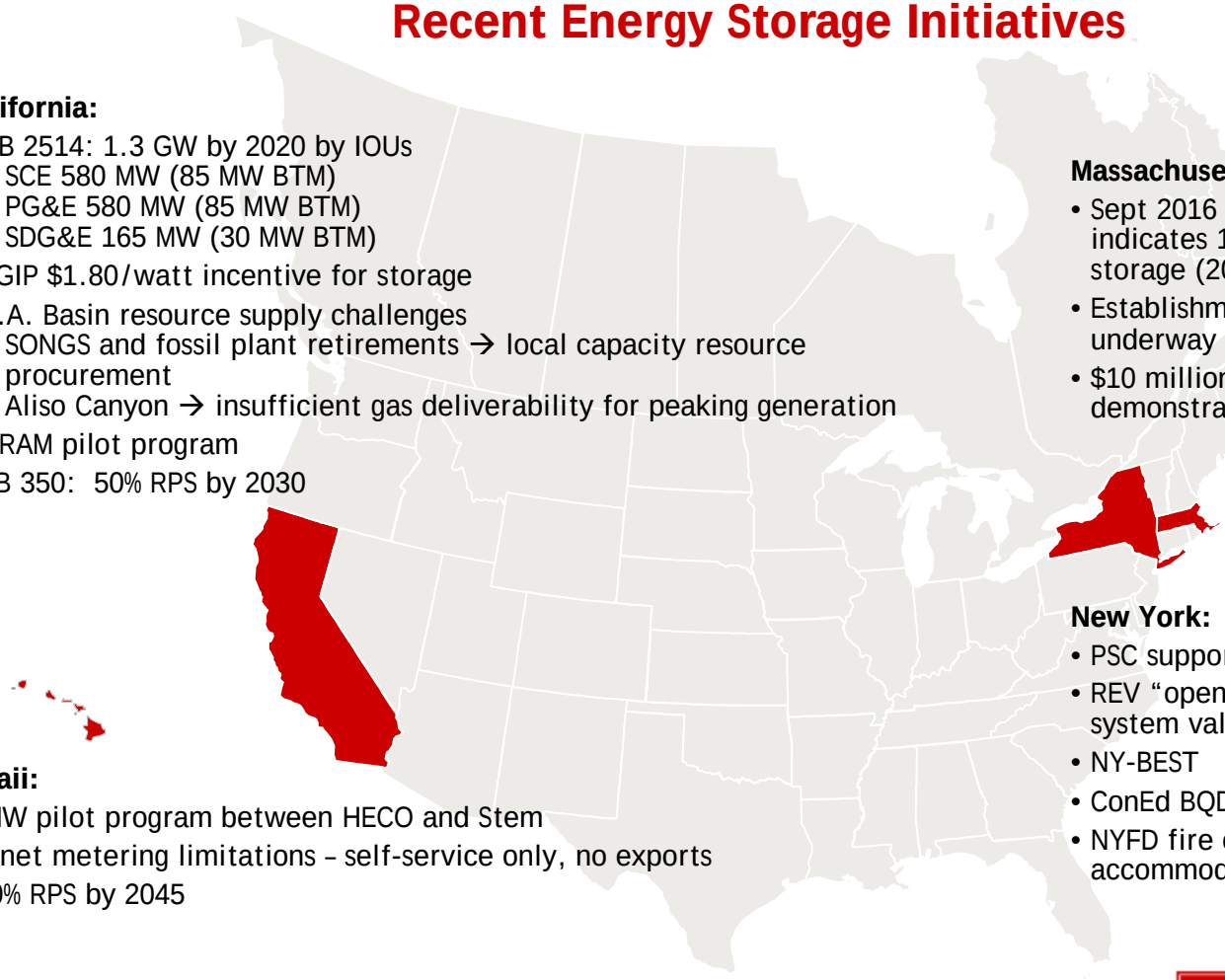
"Stacking" of value streams generally required for economic viability at current storage costs

(a) Presented here as the simple sum of all available value streams. Due to operational and other factors, such "stacked" value would likely differ from the simple sum of all value streams in practice.

Source: Lazard "Levelized Cost of Storage V2.0", December 2016

Regulatory support for Energy Storage will be key to market growth, though probably insufficient for the development of a sustainably viable market

Recent Energy Storage Initiatives



California:

- AB 2514: 1.3 GW by 2020 by IOUs
  - SCE 580 MW (85 MW BTM)
  - PG&E 580 MW (85 MW BTM)
  - SDG&E 165 MW (30 MW BTM)
- SGIP $1.80/watt incentive for storage
- L.A. Basin resource supply challenges
  - SONGS and fossil plant retirements → local capacity resource procurement
  - Aliso Canyon → insufficient gas deliverability for peaking generation
- DRAM pilot program
- SB 350: 50% RPS by 2030

Massachusetts:

- Sept 2016 "State of Charge" report indicates 1.8 GW of economically-viable storage (200 MW BTM)
- Establishment of storage mandates underway
- $10 million grant funding in demonstration projects

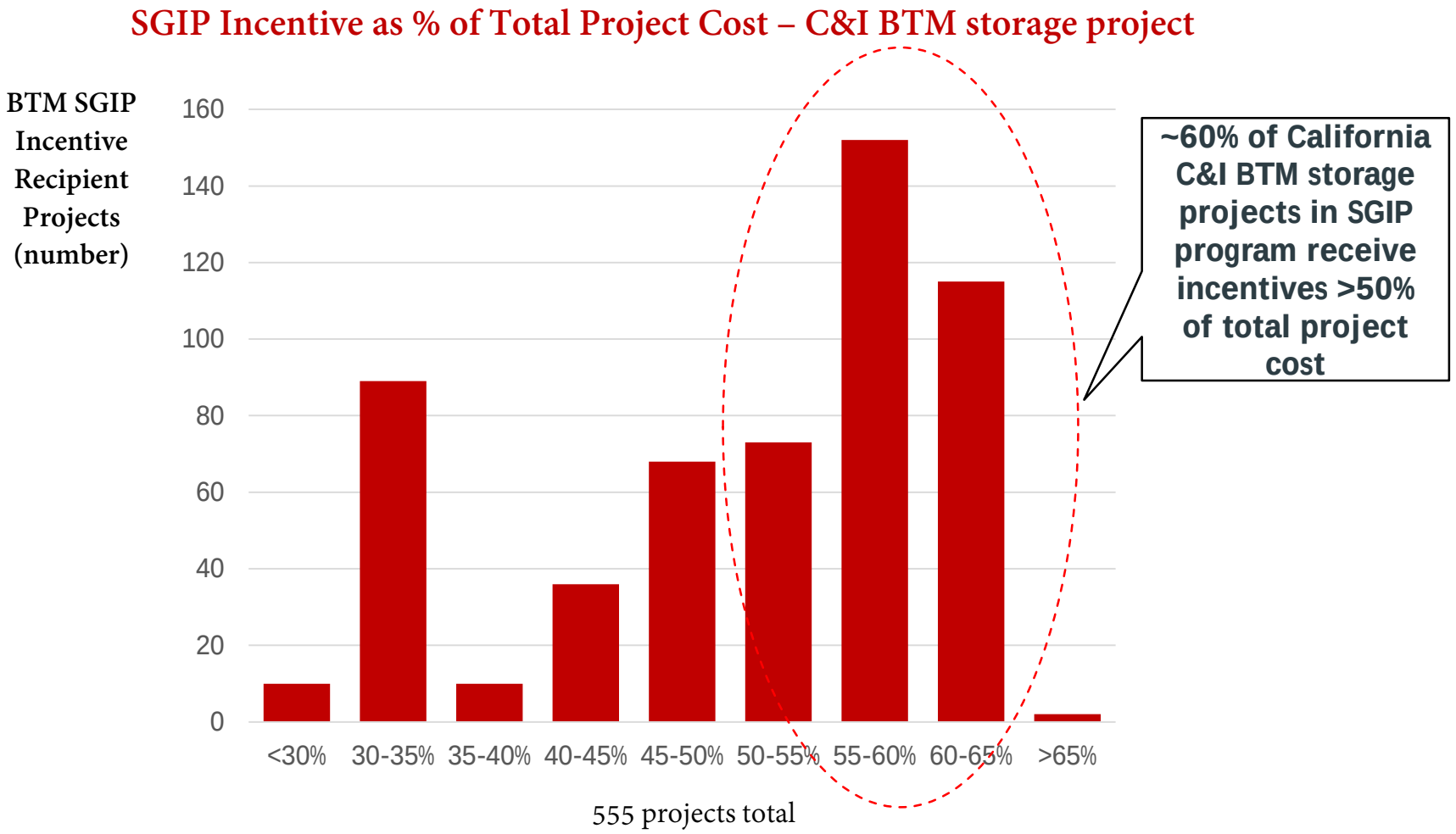
New York:

- PSC supporting DER integration
- REV "opening markets to enhance system value"
- NY-BEST
- ConEd BQDM program
- NYFD fire code revision to accommodate Li-ion batteries

Hawaii:

- 1 MW pilot program between HECO and Stem
- PV net metering limitations – self-service only, no exports
- 100% RPS by 2045

Incentives critical for storage economics



Source: EP analysis of California SGIP data (Dec. 26, 2016)

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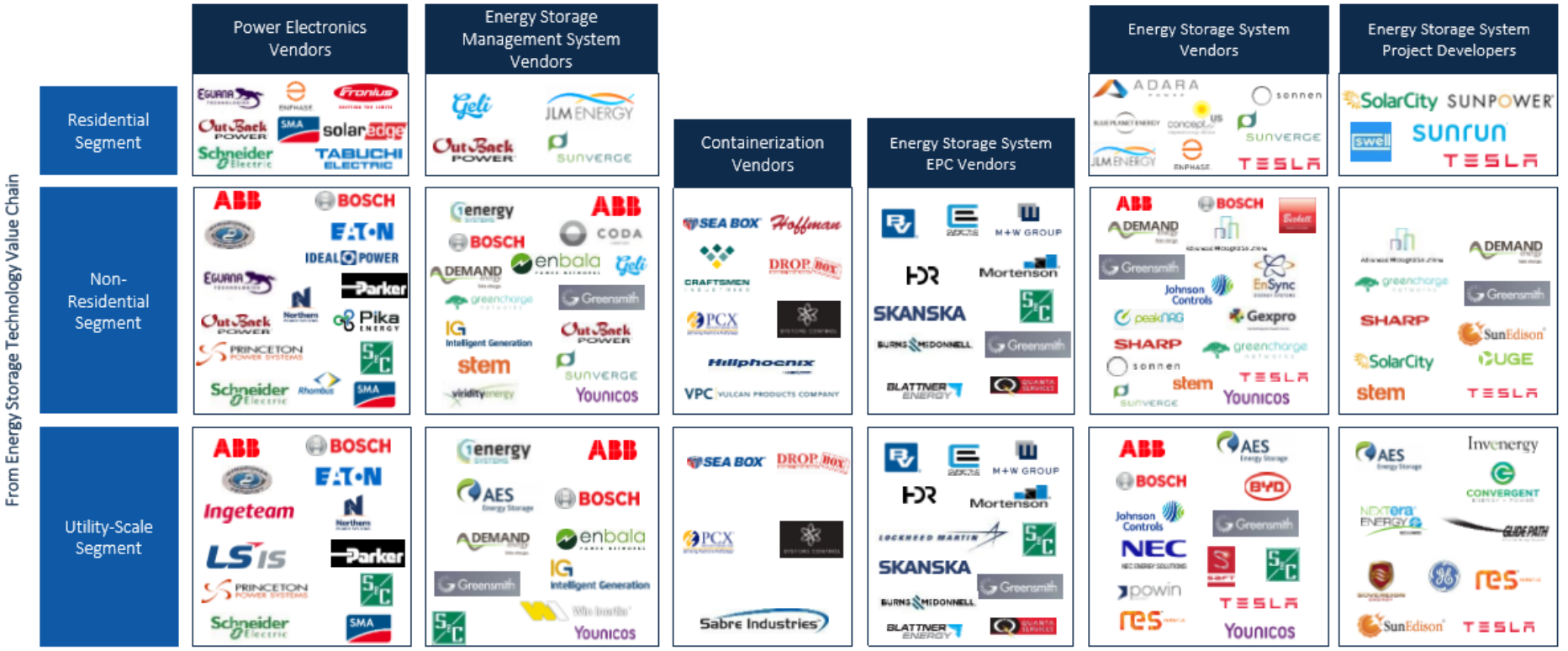
Companies in Overall Stationary Energy Storage Ecosystem



Source: GTM Research

Four integrators are currently key players in energy storage markets

Integrator	Overview
Advanced Microgrid Solutions	• Politically well-connected in California, their primary market (especially SoCal) • Strategy: secure contract for large volumes of storage w/utility (e.g., SCE), then fulfill via BTM deployments with C&I customers • Half of each deployed BTM system is contracted to utility, half to customer • Relatively few projects completed, strengthening internal fulfillment capabilities after bankruptcy of SunEdison (former channel partner) • Strong reliance on Tesla as battery supplier
GreenCharge	• Started by bundling storage with EV charging for C&I, now heavily focused on bundling storage with PV • Key differentiating factor: shared savings contract in which GCN keeps 60-75% of savings • Balance sheet strength: 80% owned by Engie • Integrating sales force with Engie, likely will increasingly focus on Engie customers
stem	• Standardized small-scale product line, focused exclusively on C&I customers • Migrating from hardware orientation to greater depth in software; probable leader in storage fleet aggregation and utility interface • Equipment usually sold to SPV, which then leases system to customer • Significant capital resources, especially project finance ($350 million) • Potentially facing increasing competition from key supplier (Tesla)
TESLA ENERGY SolarCity	• Originally a battery supplier to other project developers, now becoming more active in development via acquisition of Solar City • Vertically-integrated: battery, inverter, software, sales, installation, service • Preference for selling equipment rather than long-term contract • Diversified: residential BTM, C&I BTM, utility BTM, utility IFM

Source Enovation Partners

Conclusions

- To date, very little energy storage has been deployed on electricity grids worldwide, due to unfavorable economics
- The relatively few storage deployments (outside of pumped hydro) to date have been mainly in the U.S. and have been both grid-focused and customer-focused
- Although different technologies may be most attractive for the various market segments of grid-based energy storage, lithium-ion batteries are now dominating grid energy storage markets, and this dominance is expected to continue
- As costs have declined, energy storage has gotten closer to viability in an increasing number of applications on the grid, each with different required performance/operational characteristics
- Significant cost reductions in energy storage systems are generally anticipated, and consequently market growth is expected to be robust (>30% CAGR)
- In addition to cost, the complexity of the marketplace – the dearth of fully-integrated providers and the need to "stack" value streams – is also a constraint to growth
- There is a large and growing "eco-system" of companies interested in the energy storage market