7 July 2017

NCPA 2017 Energy Storage Updates

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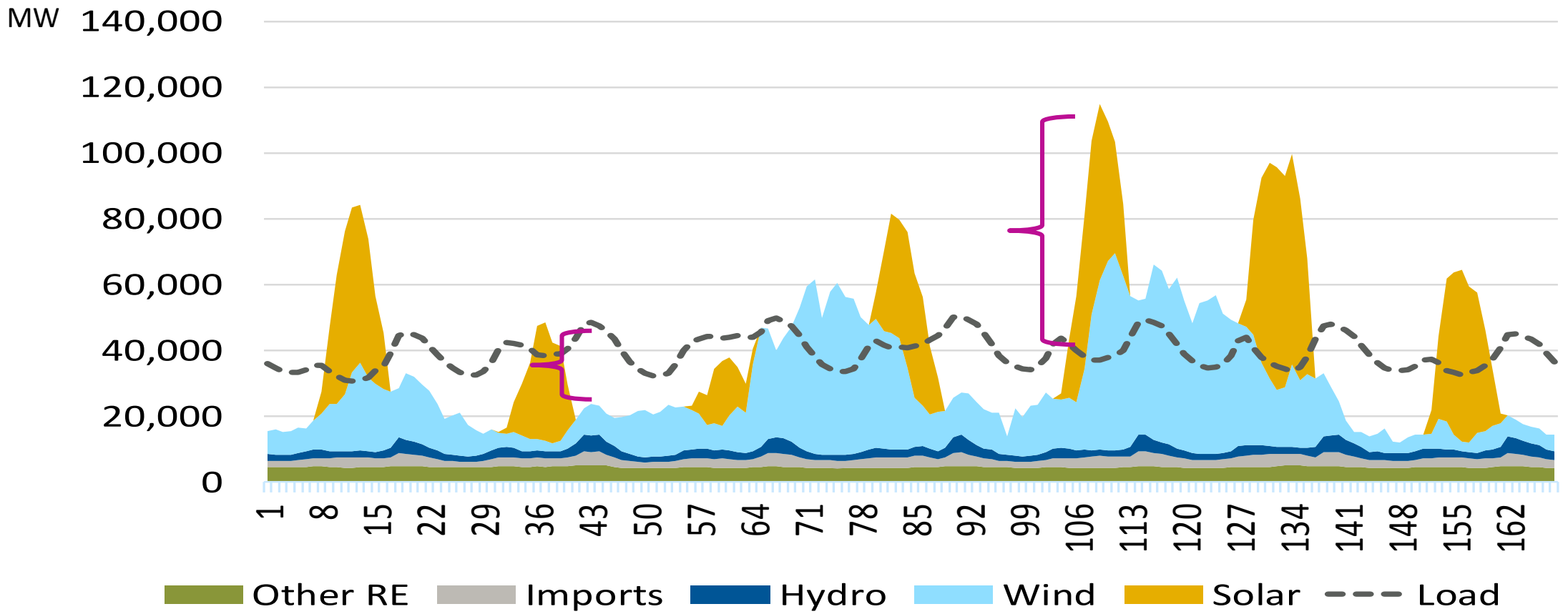
BLACK & VEATCH

Putting Storage into Perspective



Source: B&V SCPPA 100 Renewables Part 2

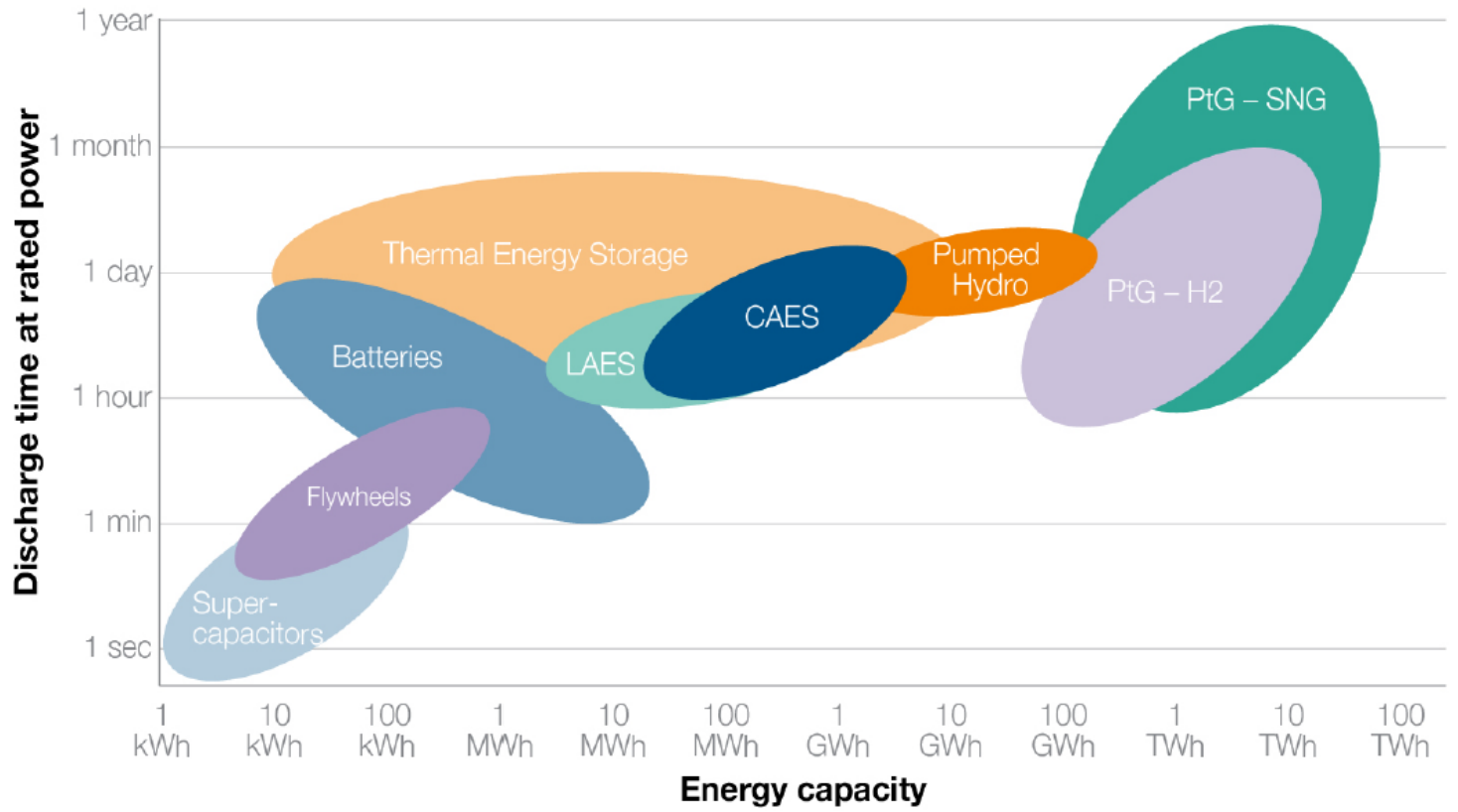
Typical Winter Week (Jan 3)

Agenda

- Energy Storage Technology Overviews
- Battery Sizing for Different Applications
- Battery Storage Cost Trends
- Approaches to Evaluating Cost/Benefit of Energy Storage
- Energy Storage Market Happenings

Energy Storage Technology Overviews

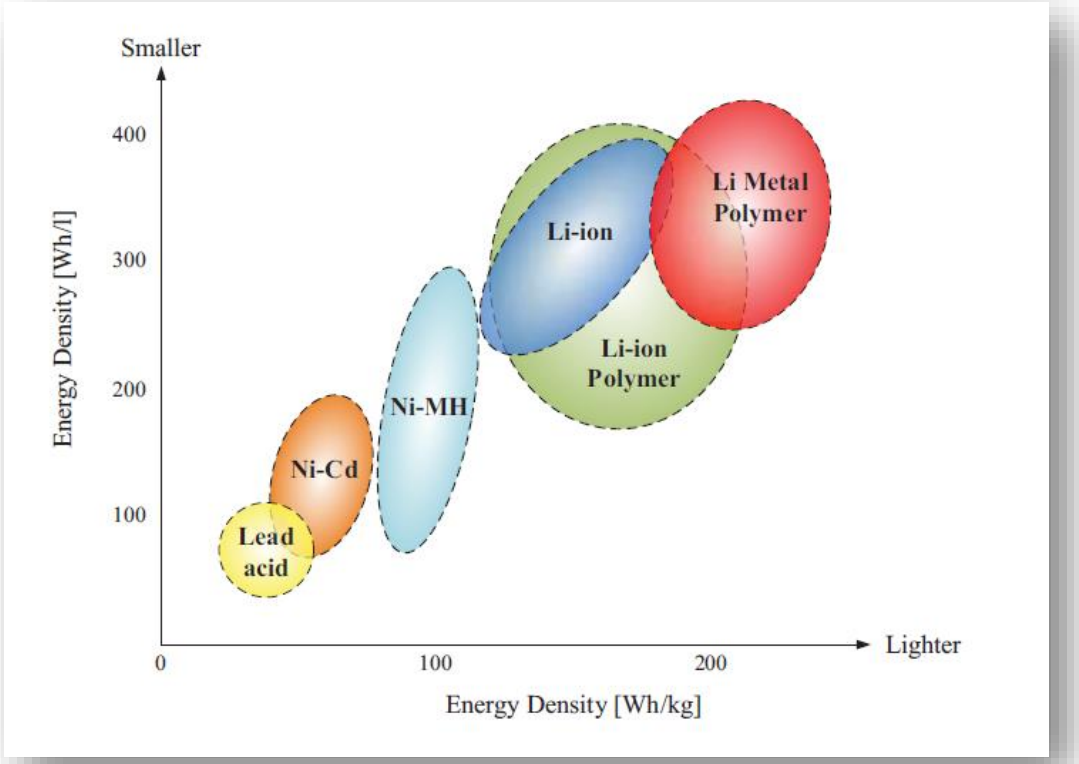
Technology Sizes and Durations



Source: PwC, 2015, following Sterner et al. 2014

There are many ways to store energy

Battery Storage Characteristics



- Lithium-based batteries offer the highest storage capacities
  - Per unit volume
  - Per unit weight

Source: IEEE

Lithium ion chemistries are the current “best available”

Technology:
Cell > Module > Battery > Rack > Container
(1 W) (50 W) (1 kW) (50 kw) (1 MW)

W

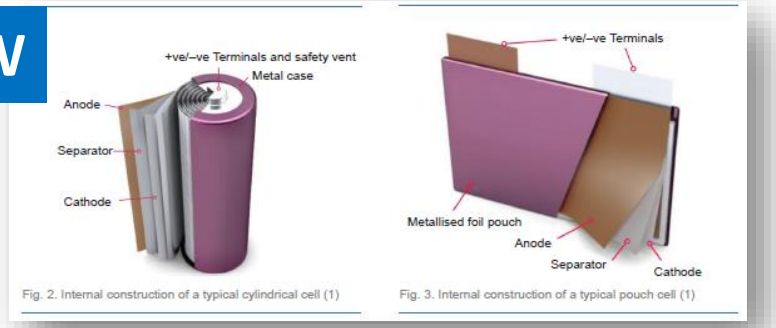


Fig. 2. Internal construction of a typical cylindrical cell (1)
Fig. 3. Internal construction of a typical pouch cell (1)

kW

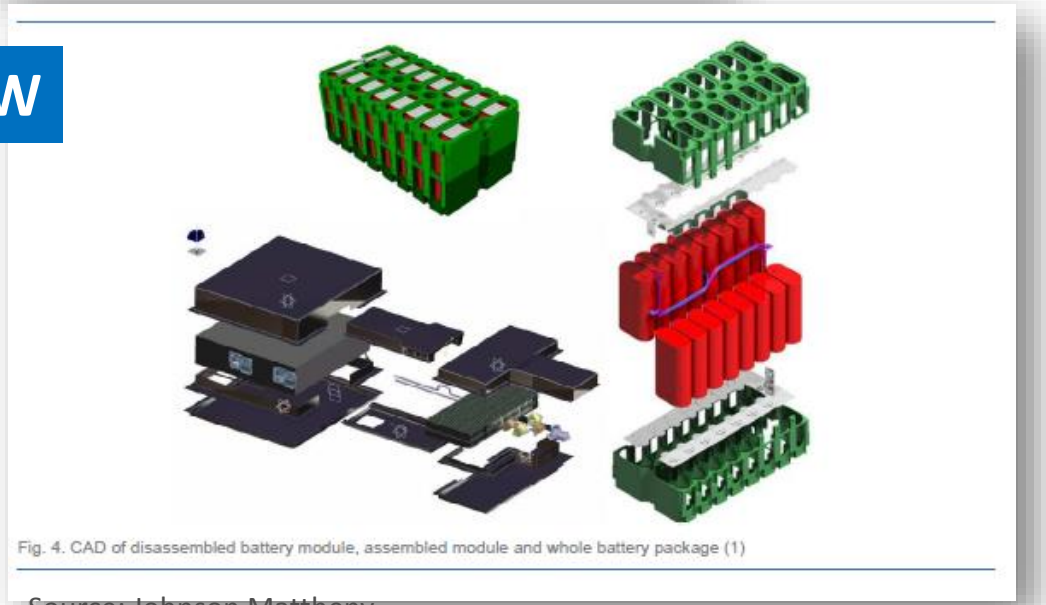
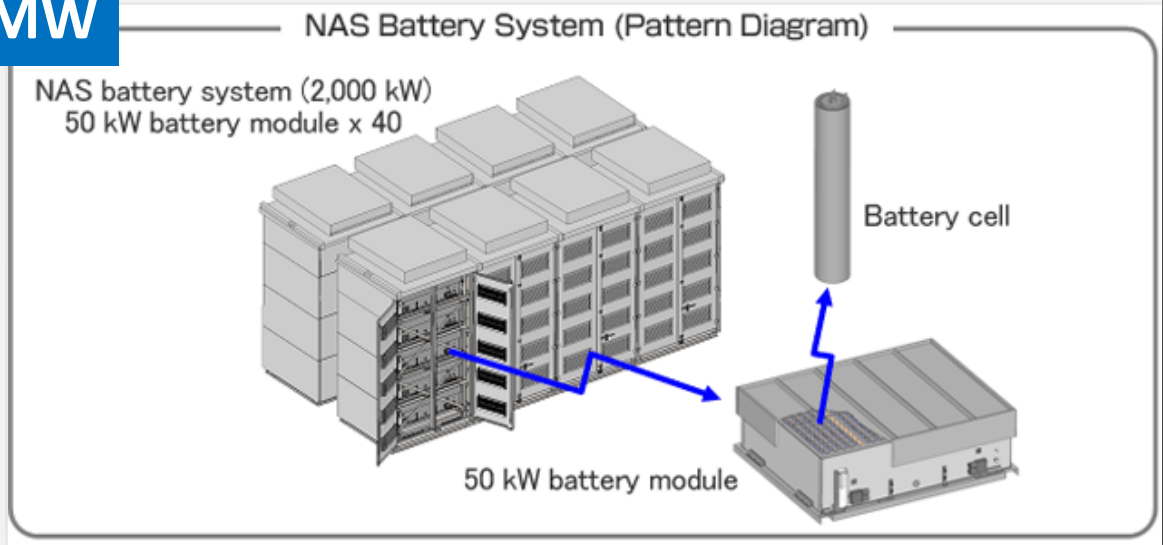


Fig. 4. CAD of disassembled battery module, assembled module and whole battery package (1)

Source: Johnson Mattheny

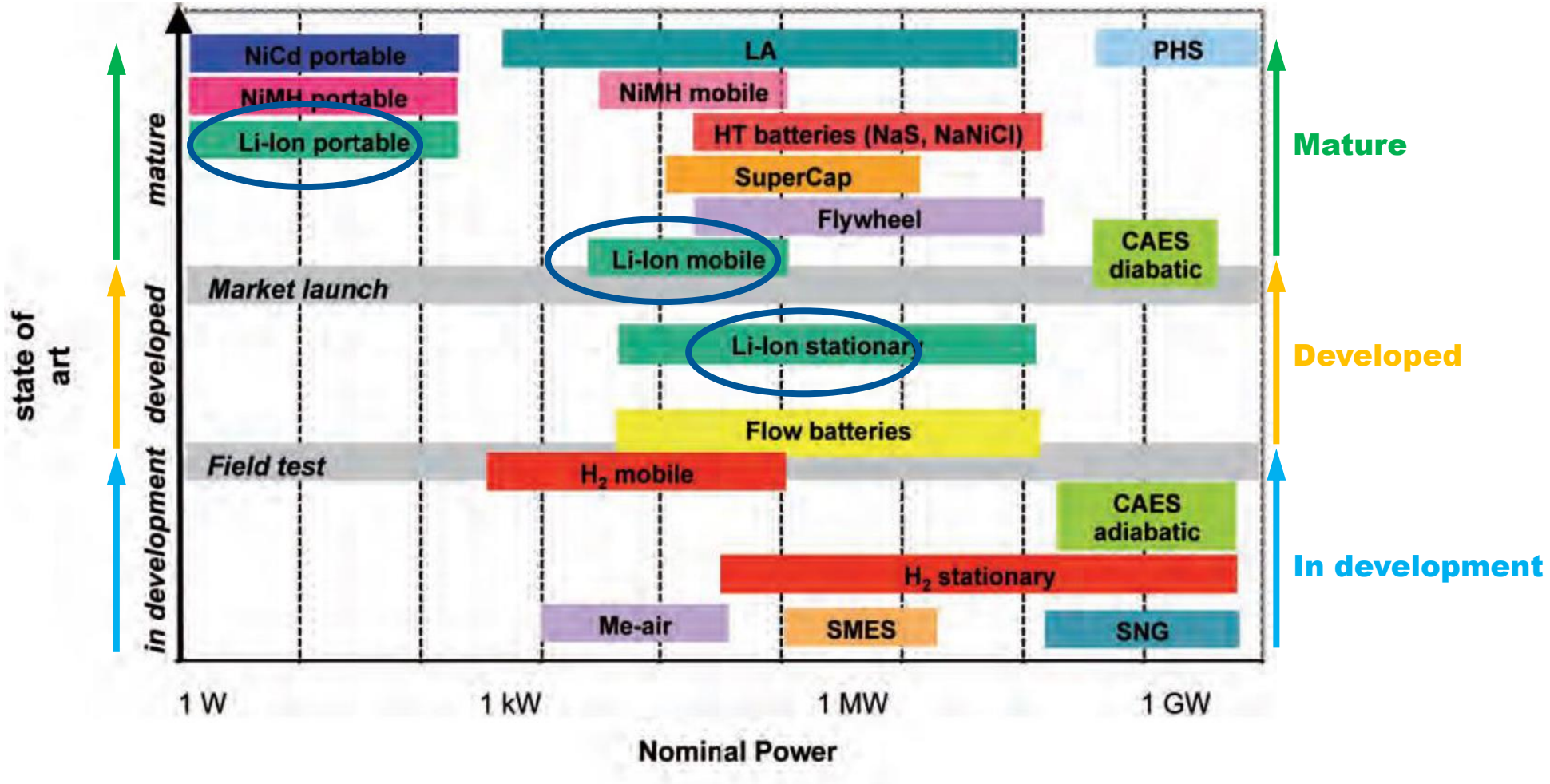
MW



Source: NGK

Batteries scale as individual elements (e.g., transistors)

Storage Technologies Are at Various Stages of Development and Maturity

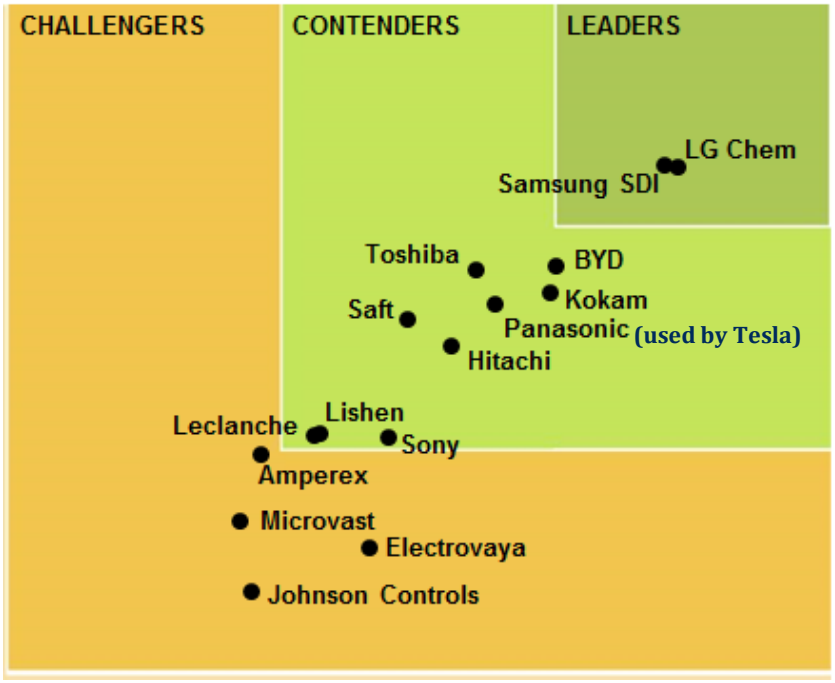


Source: Fraunhofer

Maturity versus size for different technologies

Battery Technology Trends

- Lithium ion, the most common choice
  - >97% of deployments in 2016
- Leading lithium-ion suppliers remain similar to prior year
  - LG Chem, Samsung SDI, BYD Tesla (Panasonic) emerging
  - Other “fast followers”
- Other technologies on the radar
  - Sodium Sulfur, NaS (NGK), Zinc Air (Eos)
  - Flow Batteries: Vanadium, Zinc chemistries (Sumitomo, ViZn)
  - CAES, LAES

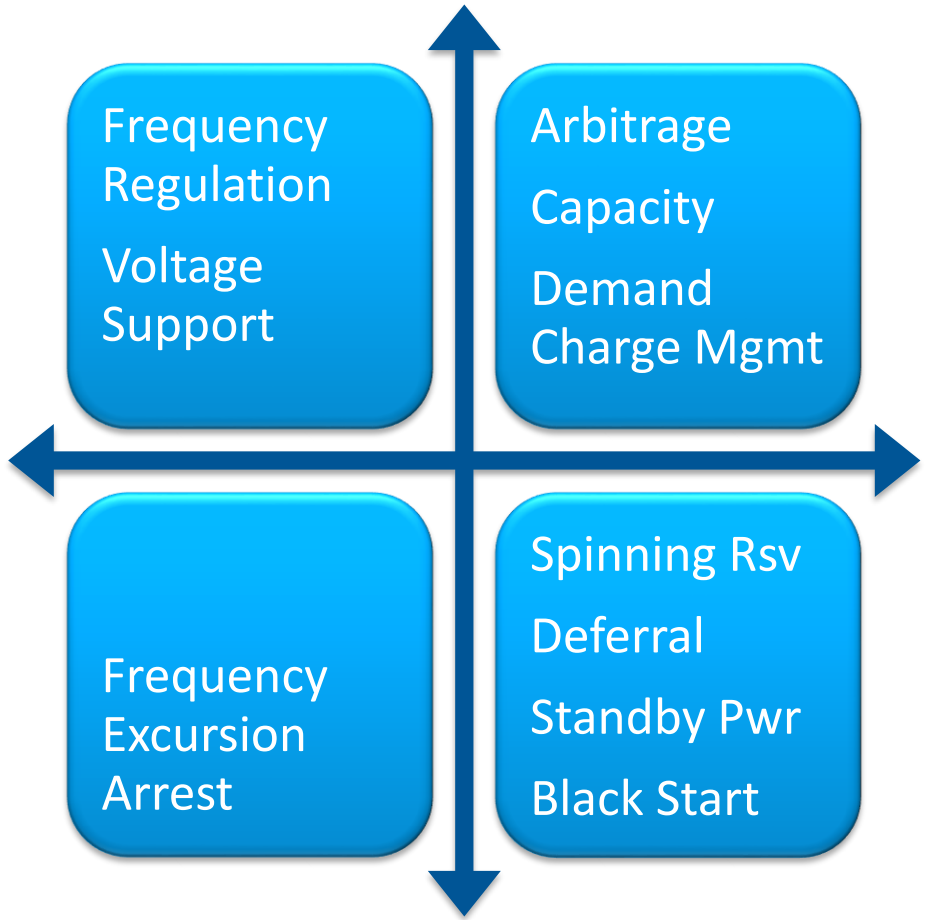


Source: Navigant Research Leaderboard Report: Li-Ion Grid Storage (June 2015)

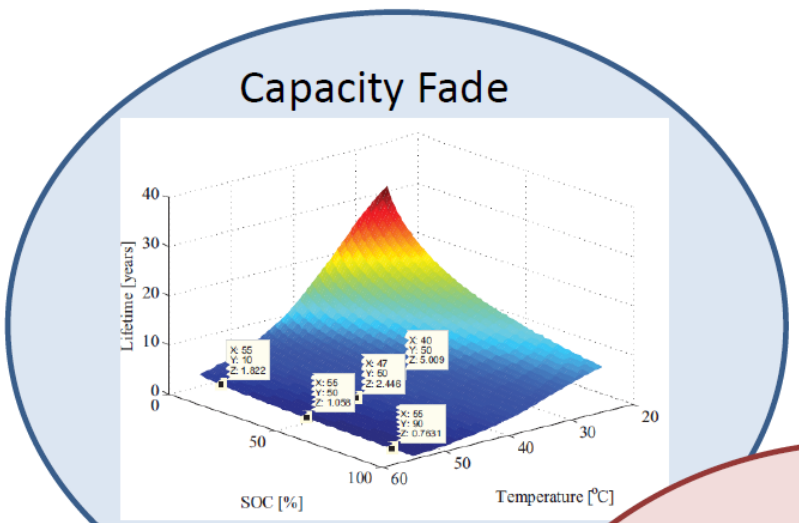
Li-ion for grid is now, flow batteries may be the future

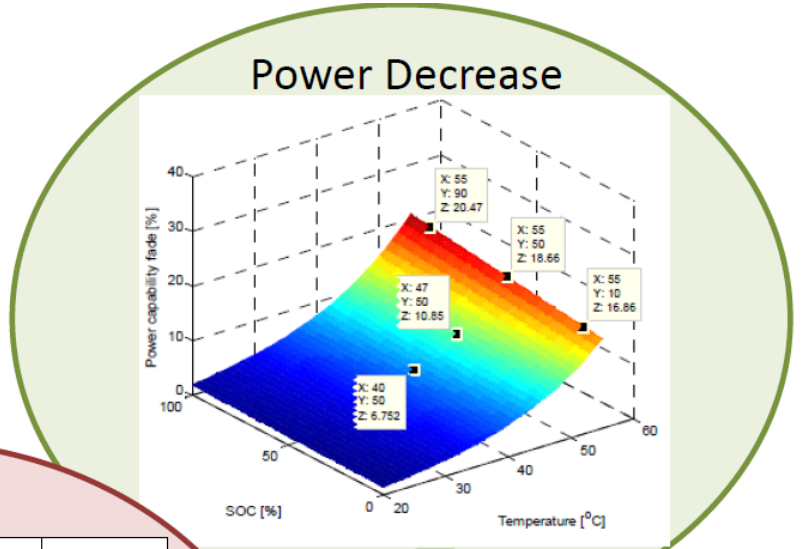
Battery Sizing and Design for Different Applications

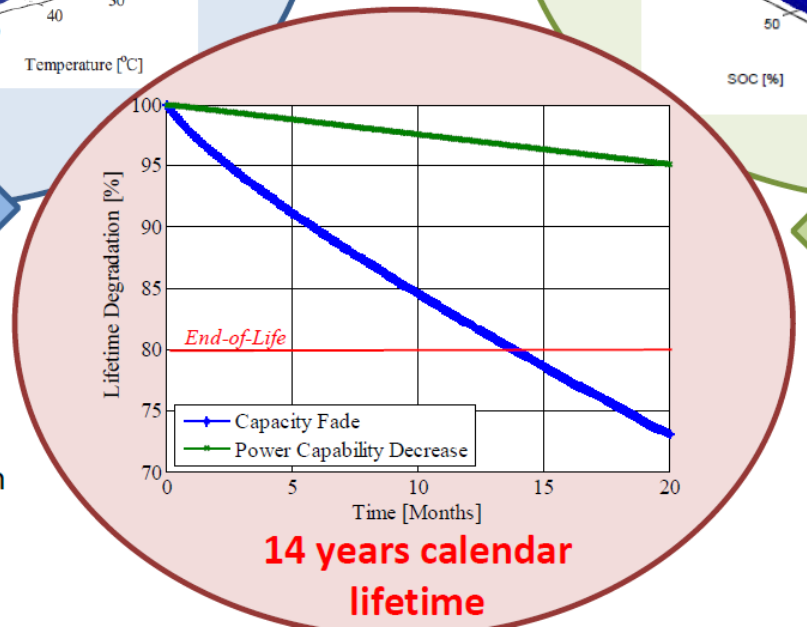
Use Cases vs. Storage Type



Lifetime Estimation at Different Conditions







- Dependence on storage time:

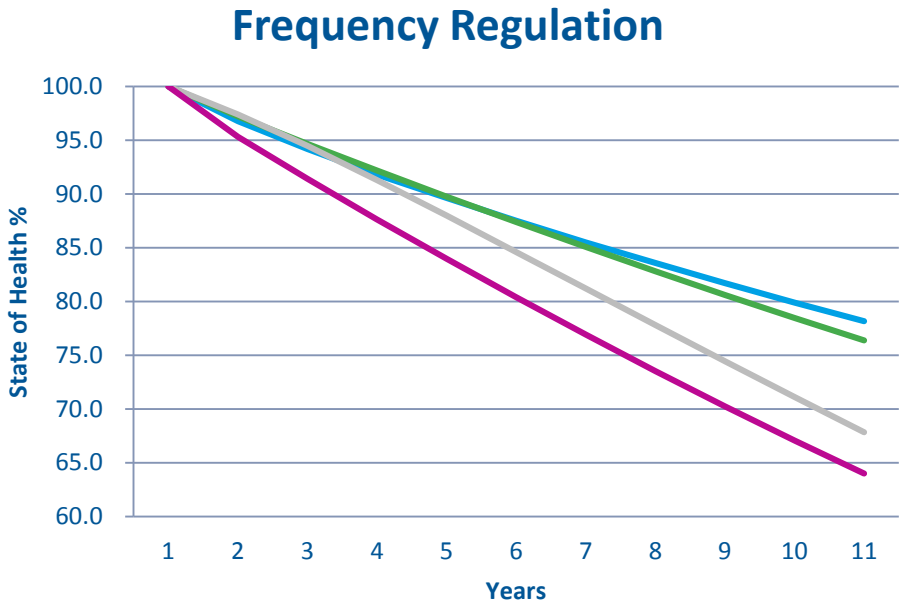
$$C_{fade}(t)[\%] = a_T \cdot t^{0.8}$$

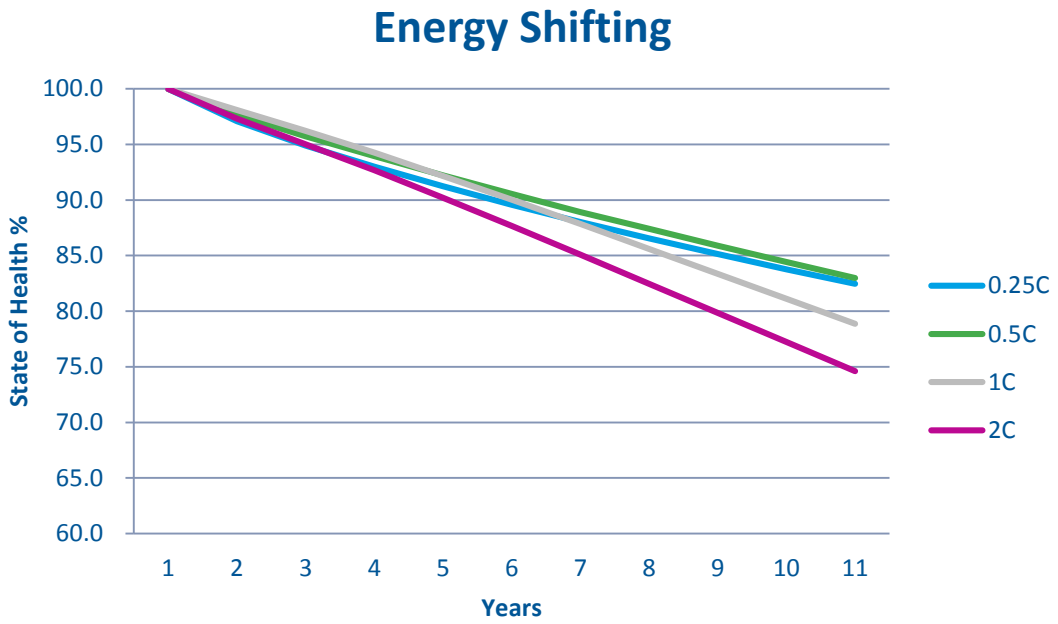
- Exponential dependence on storage temperature and idling SOC;

- Linear dependence on storage time;
- Exponential dependence on storage temperature;
- Linear dependence on idling SOC.

Source: Stroe (2014)

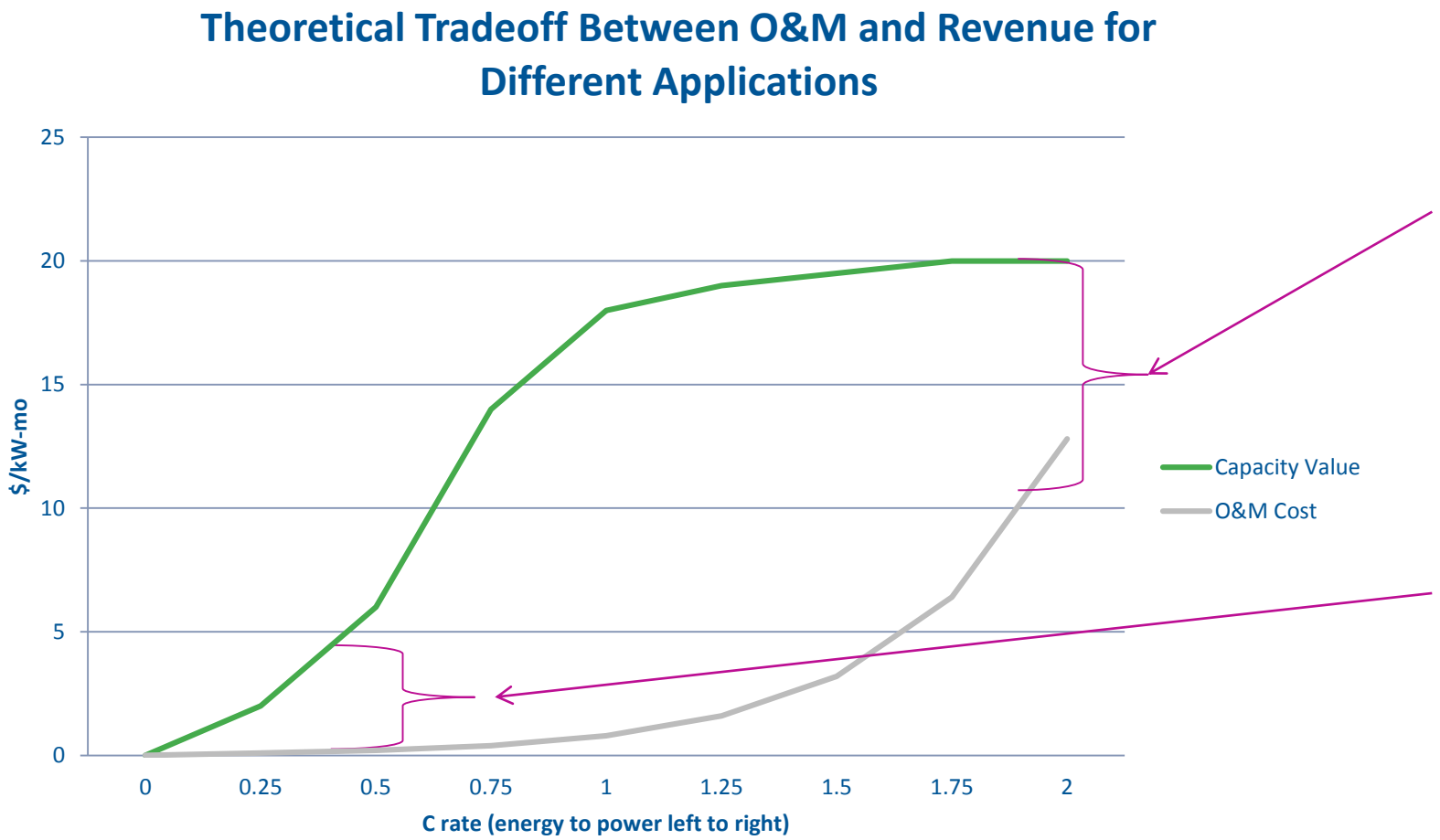
Use Cases VS Battery Performance

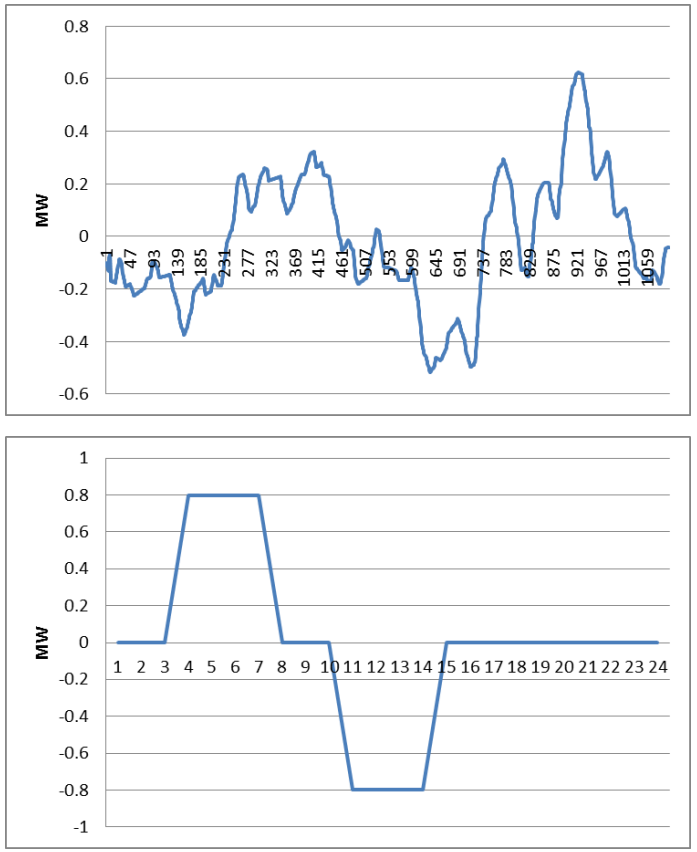




Battery life will depend on how batteries are used, which can also influence O&M costs and replacement schedules

Sizing Batteries and Choosing Applications: 'It Depends'





Understanding O&M and degradation of batteries will better inform the owner as to what applications and applicable sizing make the most sense

DC vs AC Coupling

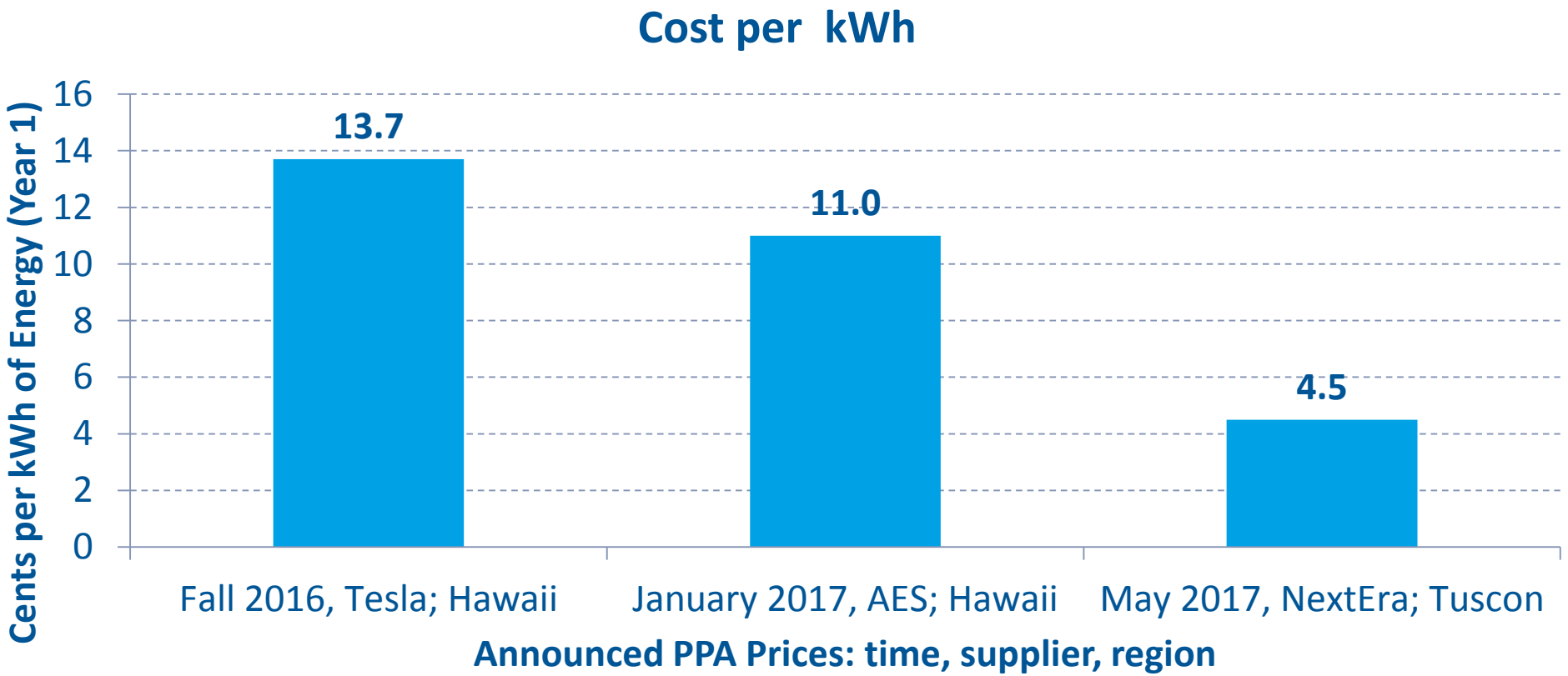
- Drivers:
  - ITC Extension and solar + storage inclusion
  - New inverter topologies
  - Interest in retrofitting plants for unused DC power

	DC-COUPLED	AC-COUPLED	HYBRID
CAPACITY FIRMING	✓	✓	✓
ENERGY TIME SHIFTING	✓	✓	✓
CLIPPING RECAPTURE	✓		
CURTAILMENT RECAPTURE	✓	✓	✓
LOW VOLTAGE HARVEST	✓		
RAMP RATE CONTROL	✓	✓	✓
PV TO GRID EFFICIENCY	HIGH	MEDIUM	MEDIUM
PV TO BATTERY EFFICIENCY	HIGH	LOW	MEDIUM
BATTERY TO GRID EFFICIENCY	MEDIUM	MEDIUM	MEDIUM
EASE OF MICROGRID INTEGRATION	MEDIUM	MEDIUM	HIGH
EASE OF RETROFIT OF EXISTING PV	HIGH	HIGH	LOW
COST	MEDIUM	LOW	HIGH

Source: Dynapower

Battery Storage Cost Trends

Recent Developments in PPA prices for Solar PV + Energy Storage



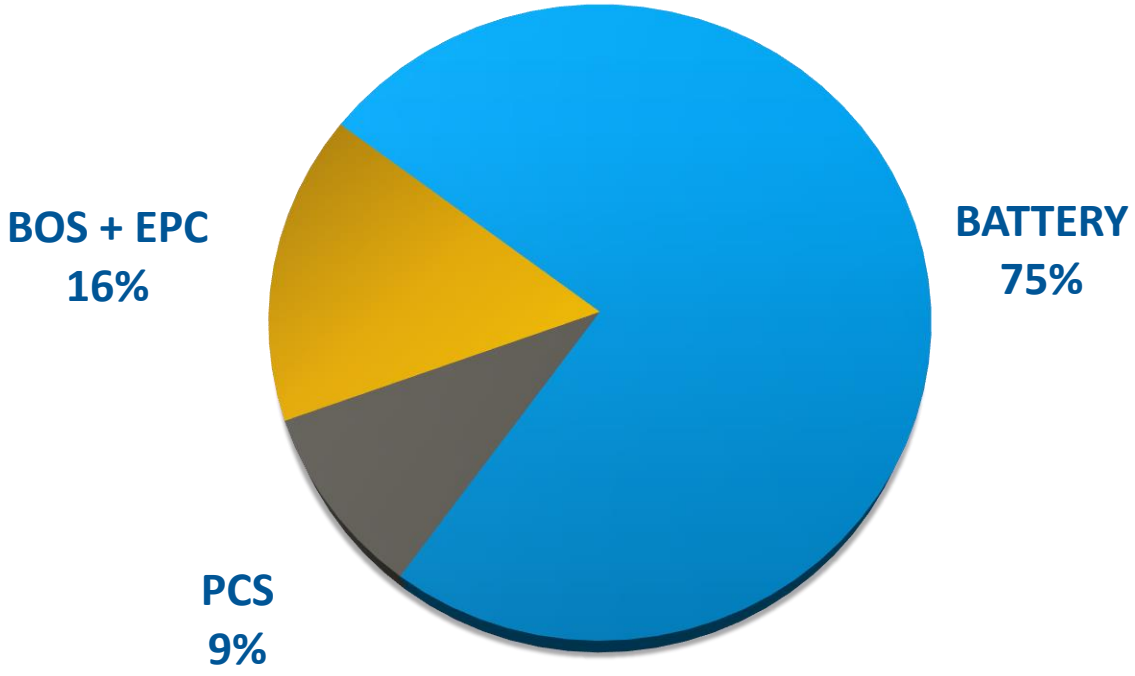
The latest PPA rate is said to be $0.09/kWh without available subsidies and tax incentives

Installed Cost by Application (SAMPLE Li Ion Projects)

ENERGY

5 MW / 20 MW-hr

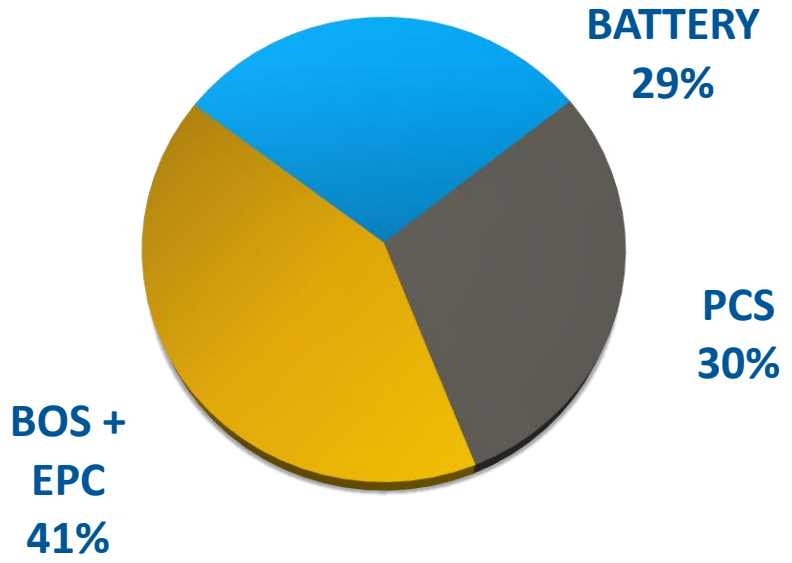
~ $ 1500/kW ~$ 480/kW-hr



POWER

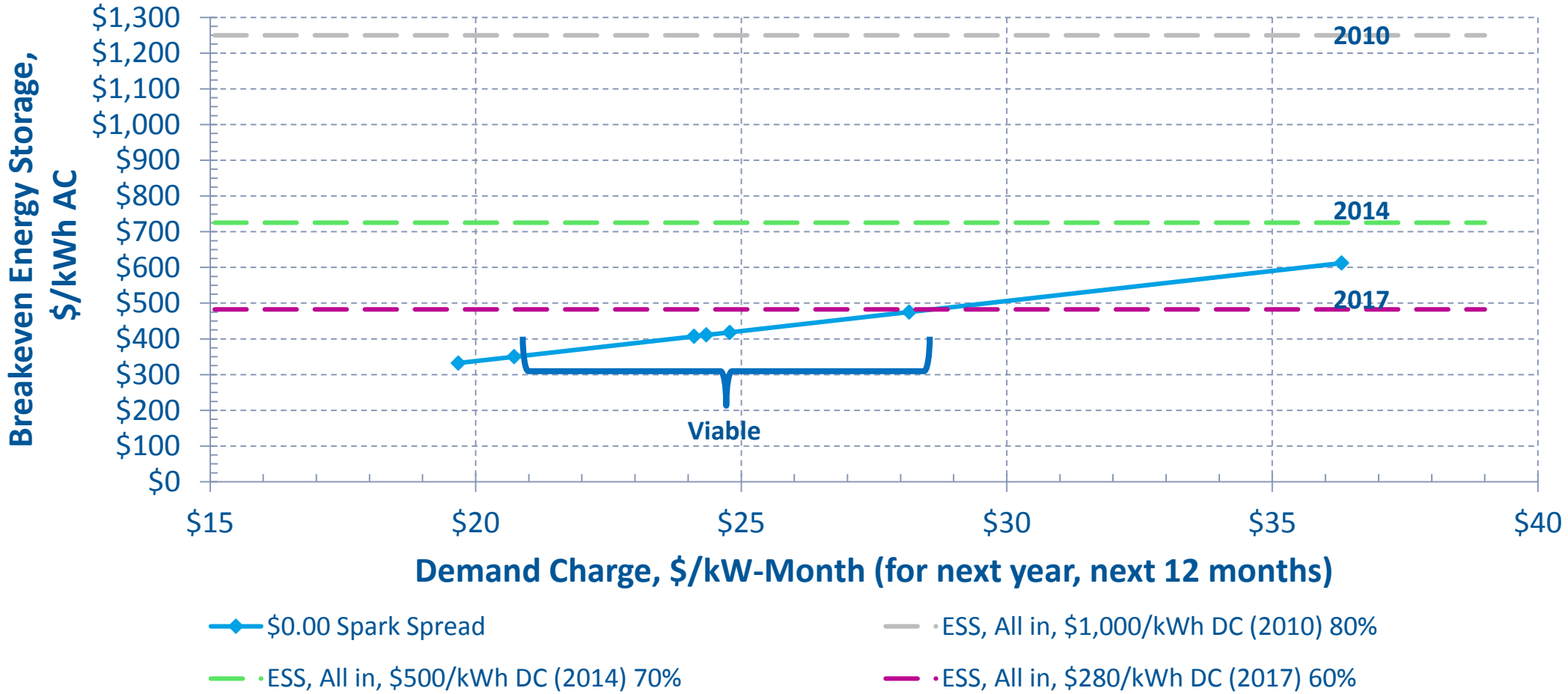
10 MW / 5 MW-hr

~ $ 480 /kW ~$ 950/kW-hr



Battery storage duration(size) drives total project cost

Of all Use Cases “Peak Shaving” is Closest to Economic Viability in USA



Ref: Moody’s Energy Storage Technology Economics (1/2017)
Ref: Bloomberg (12/2016)

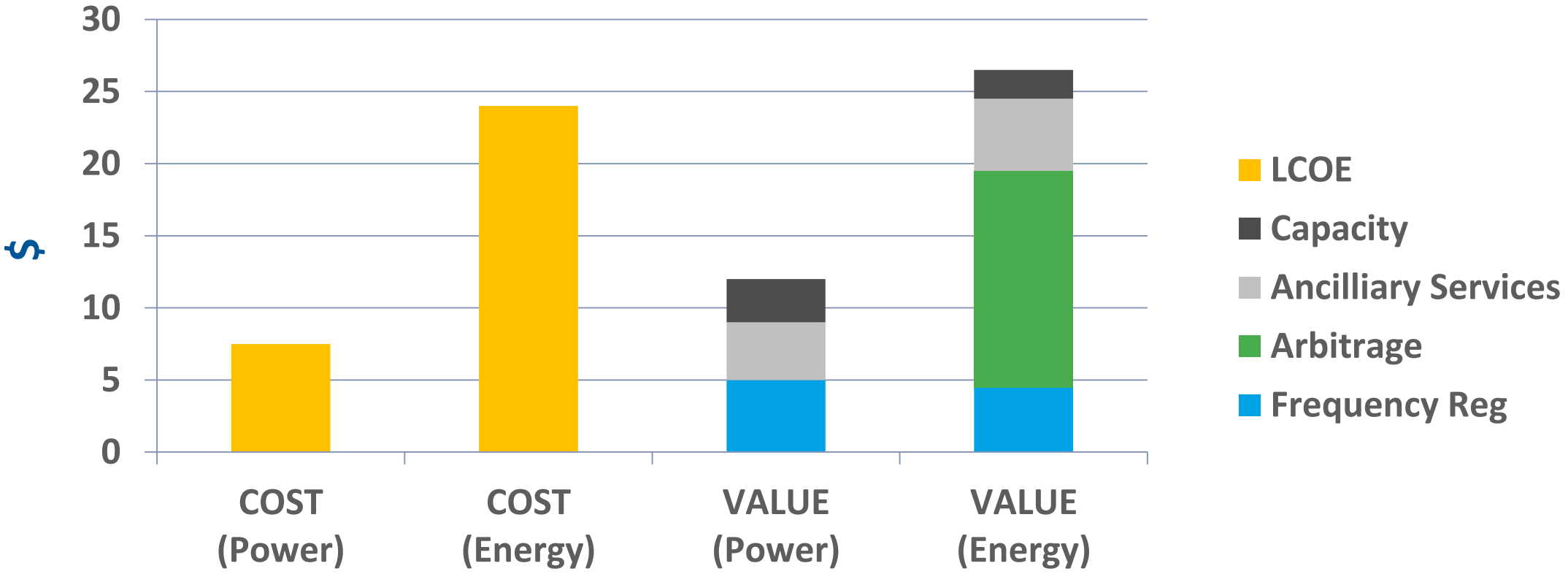
Of all Use Cases “Peak Shaving” is Closest to Economic Viability

US Utility	US State	Demand Charge ($/kW-Month)			Breakeven Installed Cost ($/kWh)
		Lo	Med	Hi	
ConEd Rate1	NY			28.16	475
ConEd Rate2	NY			36.30	612
HECO	HI		24.34		411
PG&E	CA		24.11		407
PSE&G	NJ	19.67			332
SoCal Ed	CA		24.78		418
UIC	CT	20.72			350

Ref: Moody’s Energy Storage

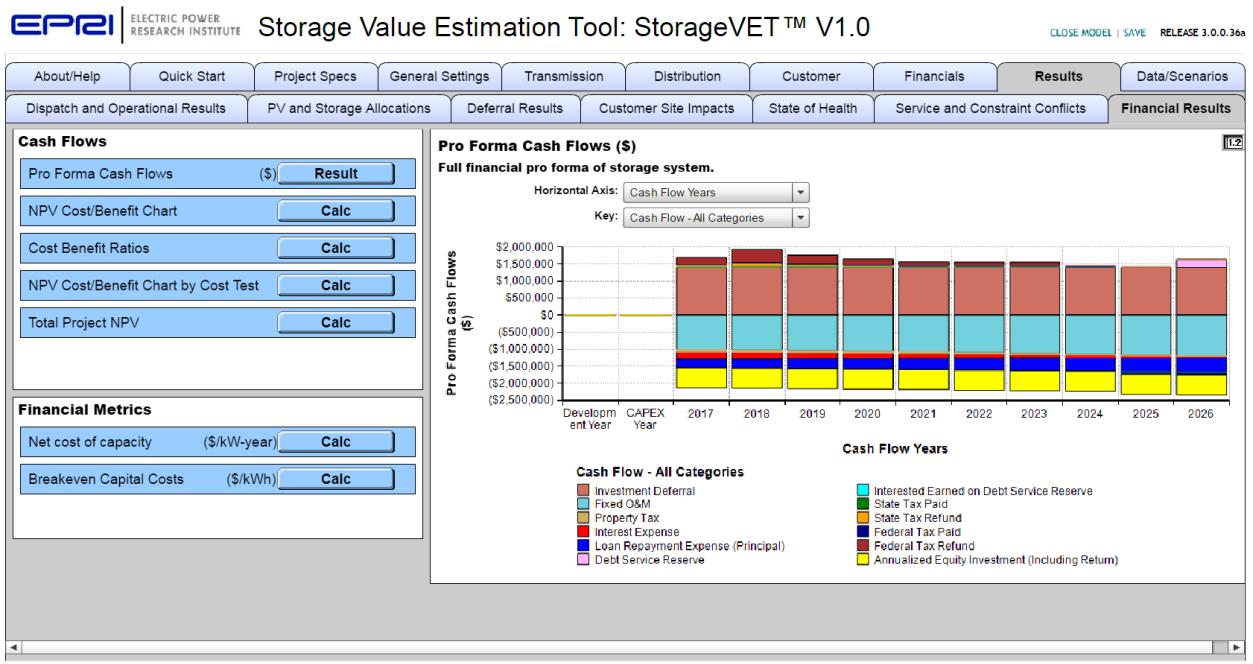
Approaches to Evaluating Cost/Benefit of Energy Storage

Importance of “Stacking” Benefits



Multiple value streams may be required for attractive ROI

Cost Benefit Analysis Using StorageVET™



- Have worked or are working with CA POUs to define use cases and value multiple storage applications
- IRPs are one way to look at storage, but they do not usually capture value at the distribution and customer level
- EPRI tool re-released this year to assist utilities (especially in CA) model and value storage portfolios

Understanding storage value means grappling with optimization and tradeoffs between different sets of applications

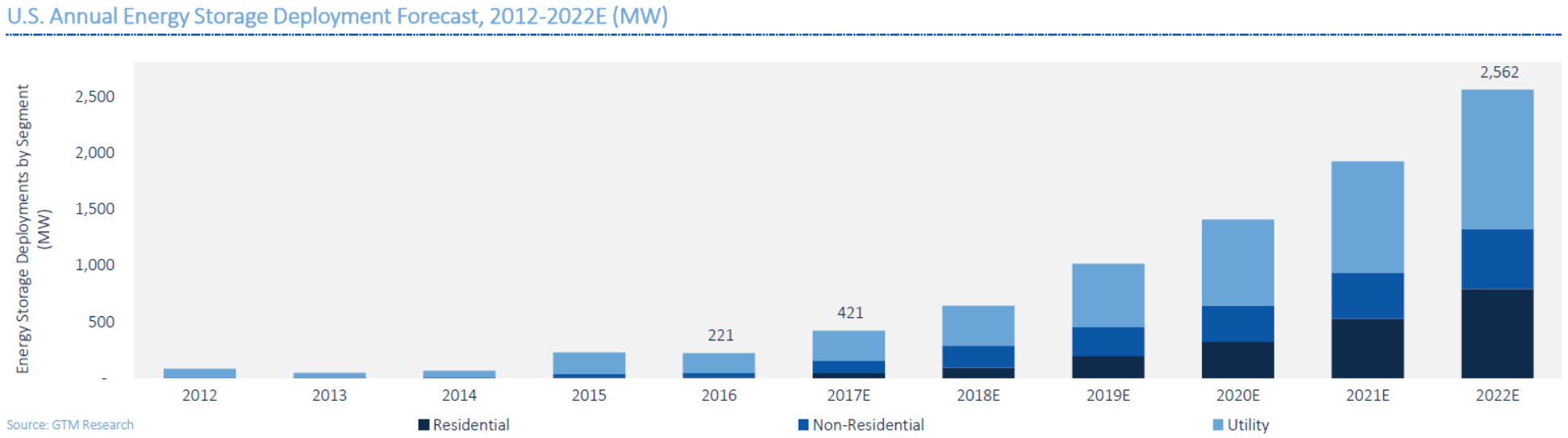
Energy Storage Market Happenings

Black & Veatch Trends Based on Recent Project Experience

- ITC compliance with distributed solar + storage projects (CA and HI)
  - Software logic and controls is a major concern to meet the minimum “charge from renewables” requirement
- Solar + Storage design considerations
  - DC vs AC tied with new and retrofit builds: increasing production (dc) versus simpler connection (ac)
- Island Grid “Energy Storage Optimization” (650 MW Grid)
  - Problem Statement: sudden loss of generation from renewables (~ 40 MW) caused instability currently mitigated by instantaneous load shedding of 20 MW (blackouts)
    - An equivalent amount of 20 MW energy storage would accomplish the same effect,
      - at a cost of $10-15 M
    - Detailed, transient power flow analysis concluded that 5 MW of energy storage together with more appropriately control of spinning reserve would mitigate the instability as well
  - *The hybrid solution, optimally sized storage with improved control of conventional assets, solved the problem for well under $10 M*

Discussion

- Will storage be procured through utility or customer models?
- Has storage impacted the traditional IRP process? If so, how?
- What are areas that you plan on using storage for in the near future?



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7/5/2017

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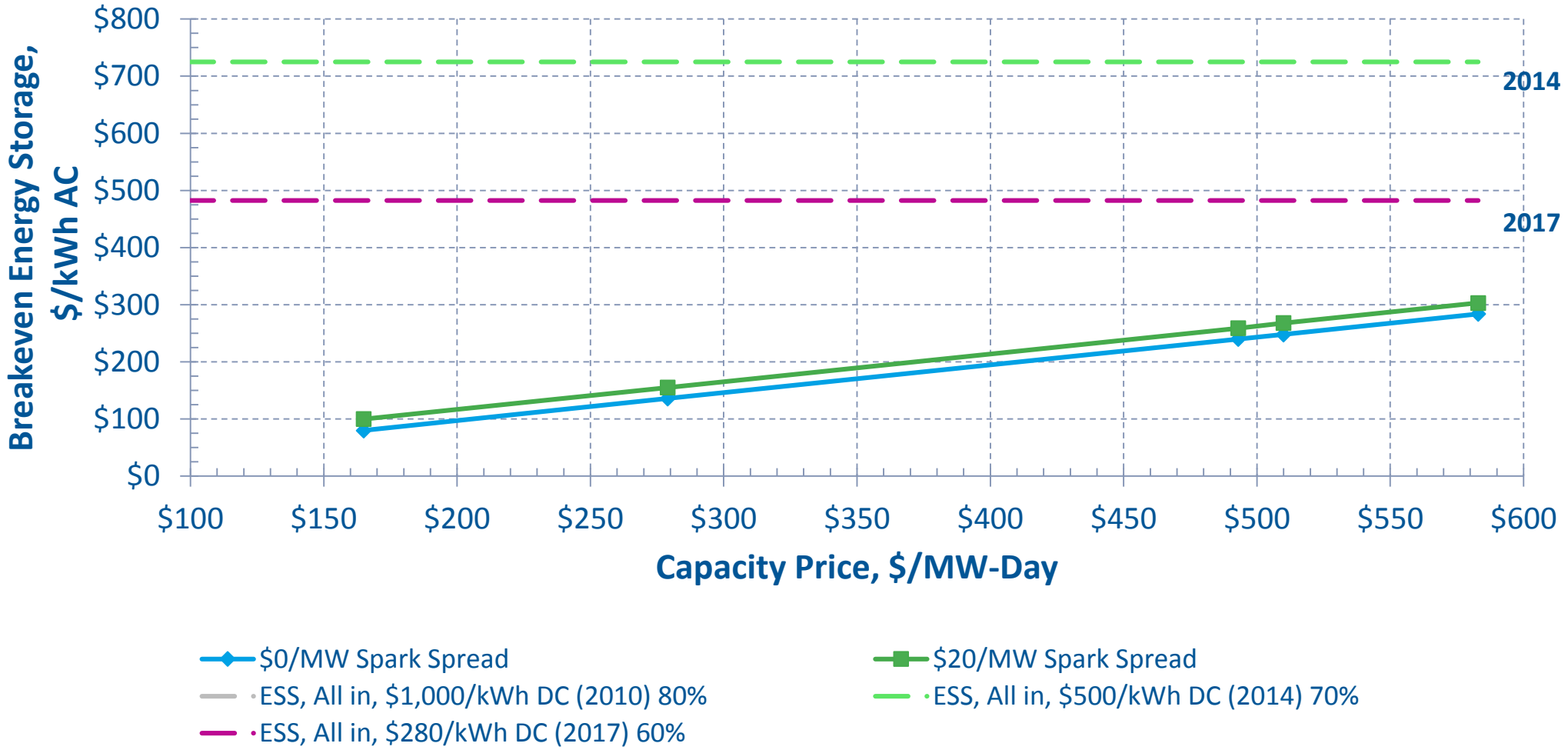
Next Use Case is “Capacity Market”



Ref: Moody’s Energy Storage Technology Economics (1/2017)
Ref: Bloomberg (12/2016)

How Low Will Storage Have to Go to Be Competitive?

US Region	Capacity Price $/MW-day			Breakeven Installed Cost ($/kWh) @ Spark Spread	
	Lo	Med	Hi	@ $0.00/MW	@ $20/MWh
NYC			510	248	268
NYISO-Zone G-J	279			136	155
NE-ISO			583	284	303
California		493		240	259
PJM-RTO	165			80	100

Ref: Moody's Energy Storage Technology Economics (2017)