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NATIONAL RENEWABLE ENERGY LABORATORY

Energy Storage: What's the Next Big Thing?

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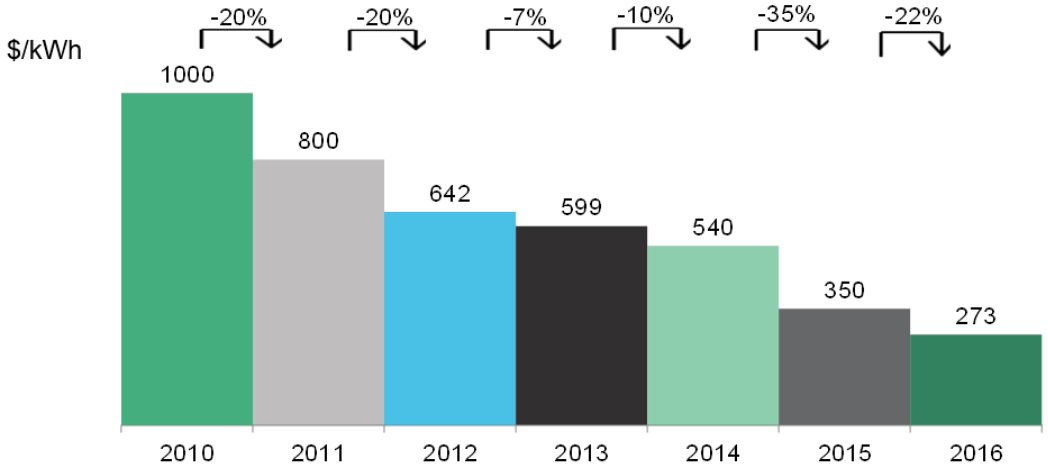
Storage

- Its becoming difficult to ignore the dramatic cost reductions.
- But what are the market opportunities?
- How big are they?

BNEF lithium-ion battery price survey, 2010-16 ($/kWh)

[Source: Bloomberg New Energy Finance, Lithium-ion Battery Costs and Market (July 2017)



Applications of Utility-Scale Energy Storage

Application	Description	Timescale of Operation
Load Leveling/ Arbitrage	Purchasing low-cost off-peak energy and selling it during periods of high prices	Hours
Firm Capacity	Provide reliable capacity to meet peak system demand	4 + Hours
Operating Reserves		
Regulation	Fast response to random, unpredictable variations in demand	15 minutes to 1 hour
Contingency Spinning	Fast response to respond to a contingency such as a generator failure	30 minutes to 2 hours
Replacement/ Supplemental	Units brought on-line to replace spinning units	Hours
Ramping/Load Following	Follow longer term (hourly) changes in electricity demand	30 minutes to hours
T&D Replacement and Deferral	Reduce loading on T&D system during peak times	Hours
Black-Start	Units brought online to start system after a system-wide failure (blackout)	Hours

Value Capture?

- The concept of stacked services is well documented
- But so are the challenges
- Depending on location, these values are captured by 1-4 different entities under different regulatory framework
- What are the likely market applications that can achieve significant market share from a limited number of revenue streams?

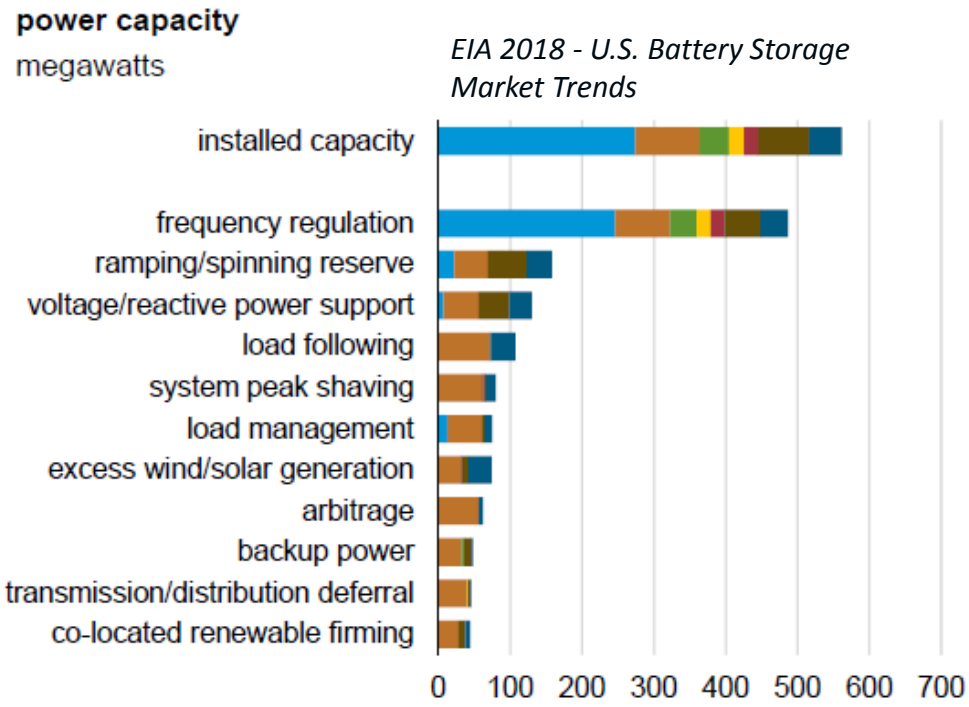
Applications of Utility-Scale Energy Storage

Application	Valued in A Single Restructured Market?
Load Leveling/ Arbitrage	Yes
Firm Capacity	Via scarcity pricing, combined scarcity plus capacity markets, or through resource adequacy payments
Regulation Reserves	Yes
Contingency Spinning Reserves	Yes
Replacement/Supplemental/ Non-Spinning	Yes but values are very low
Primary Frequency Response / Inertia	No. Early-stage proposals
Ramping/Load Following	No. Proposed in several markets
Transmission Replacement and Deferral	Only partially via congestion prices
All Distribution Specific Applications	No. Will likely remain cost of service through regulated entities
Renewable Integration	Captured through other services

Frequency Regulation?

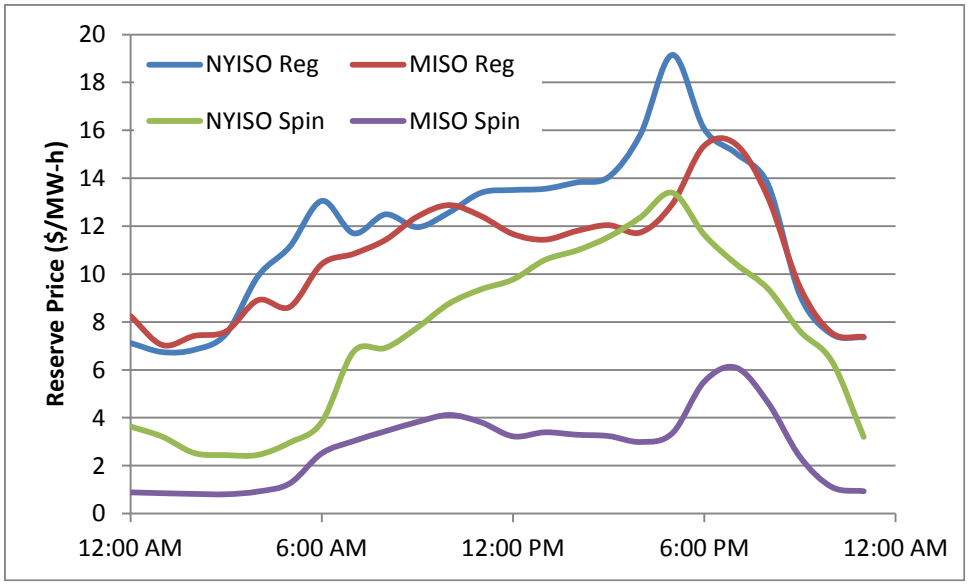
- Total market for regulating reserves in all RTO/ISO markets is ~2.5 GW
- Already have ~500 MW of battery storage providing FR
- Several hundred MW that are capable of providing FR (and probably is)

EIA 2018 - U.S. Battery Storage Market Trends

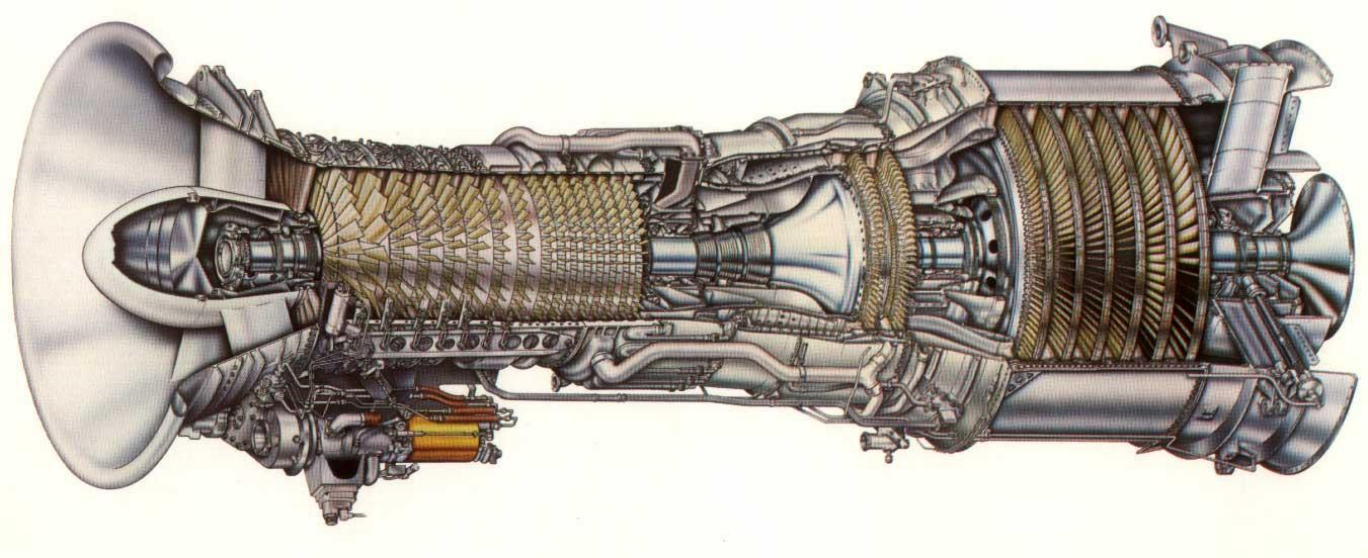


Other Ancillary Services

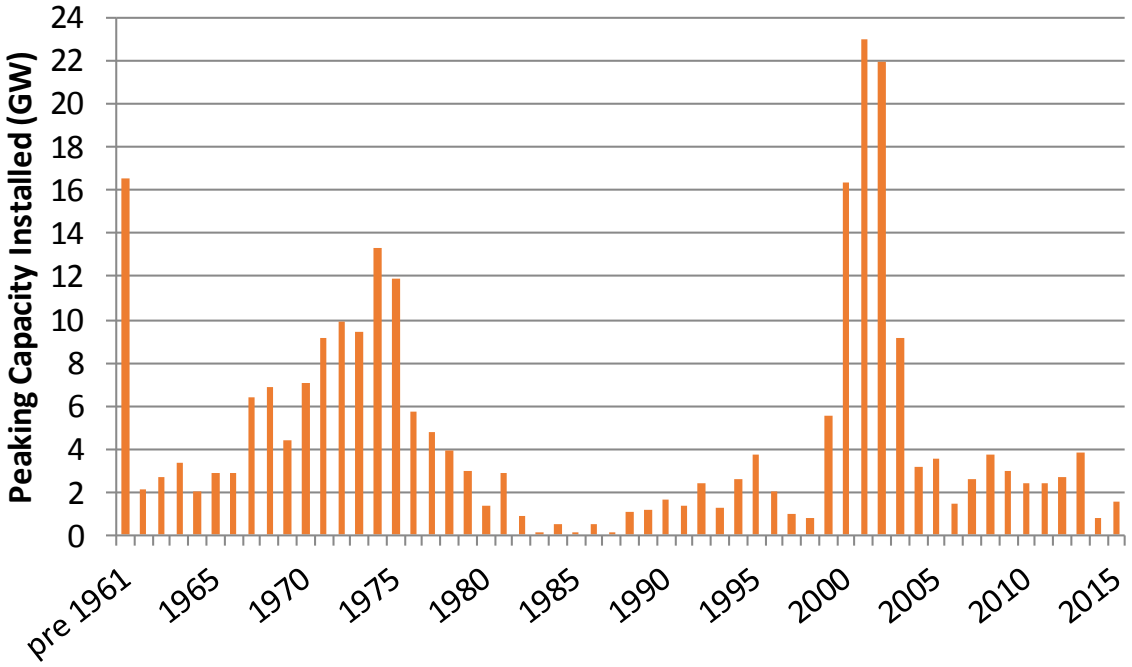
- Perhaps, but much lower prices for spinning reserves
  - Non-spin is basically worthless
- Increased competition from DR



The Next Big Thing?



U.S. Peaking Capacity



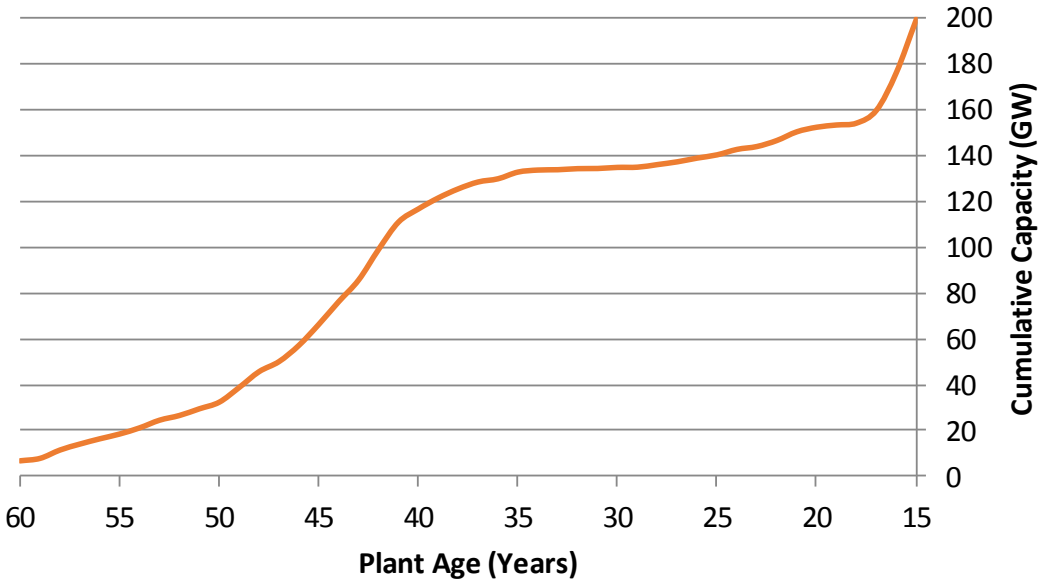
Installation dates of U.S. peaking capacity
(non CHP CT, IC, oil/gas steam)

Data from EIA 860

U.S. Peaking Capacity

Age of retirement for U.S. peaking capacity (EIA-860)

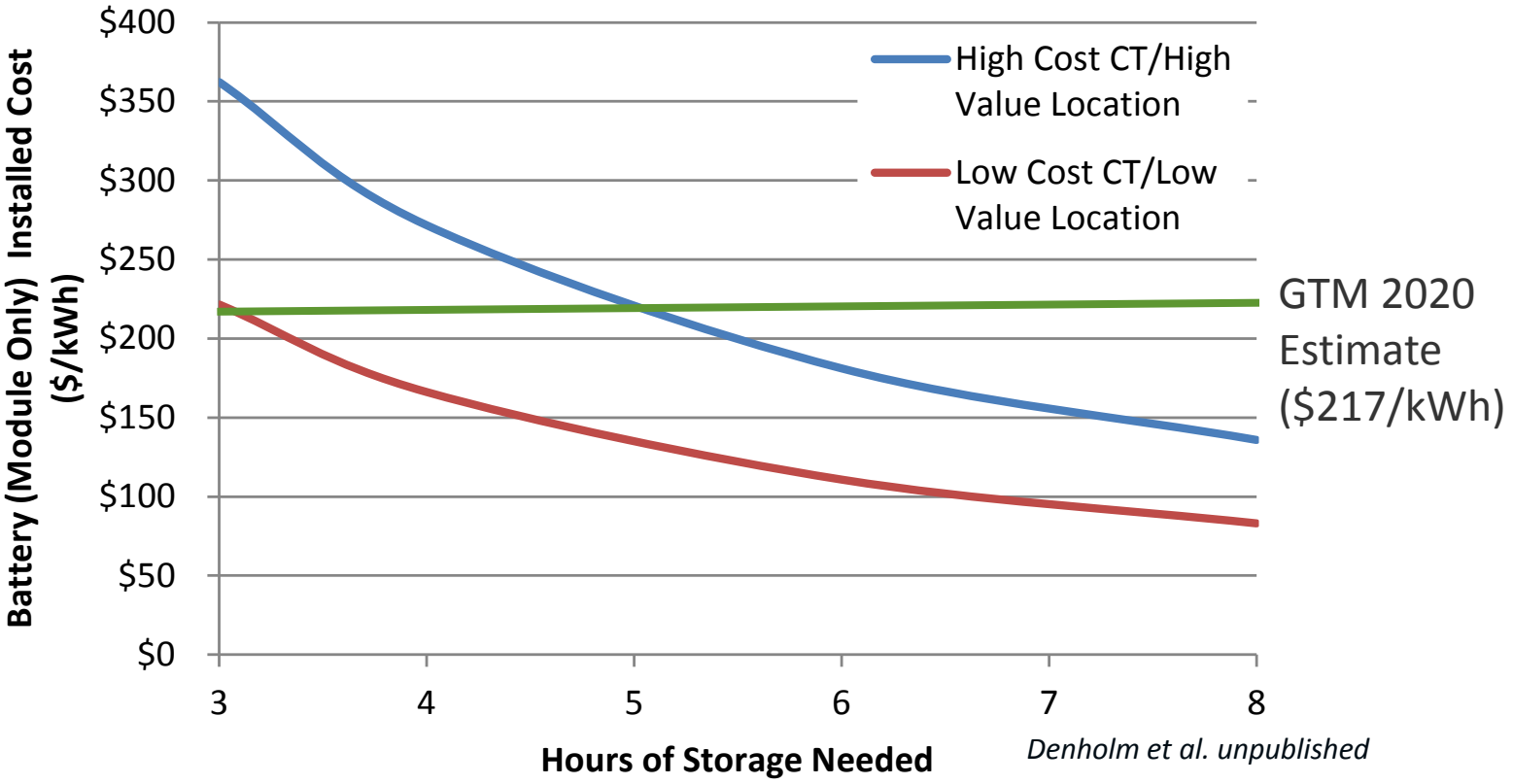
Significant peaking capacity now over 40 years old. Over the next 20 years, we would expect about 152 GW of peaking capacity to retire



How to Compare Costs

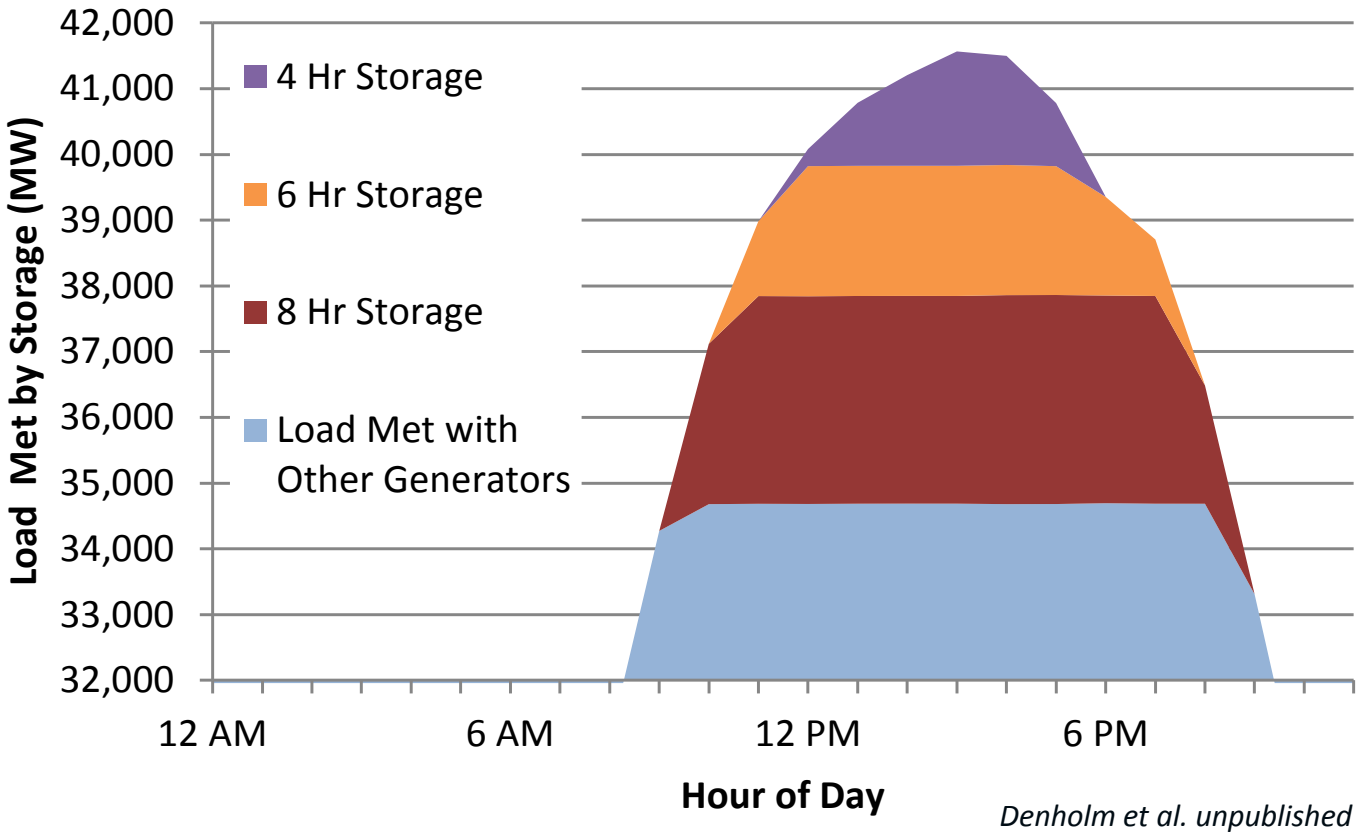
- Difficult for storage to compete purely on capital cost
- CT: $700/kW (frame) - $1200/kW (aeroderivative)
- Translates to $75 to $200/kWh for battery module if we assume $400/kW BOS
  - Assumes 4-hour duration
  - And before accounting for limited lifetime
- But storage provides other values that can be captured in an energy market

So How Cheap Does Storage Have to Be?



We are nearing a tipping point for 4-hour storage providing capacity services – but how big is this market?

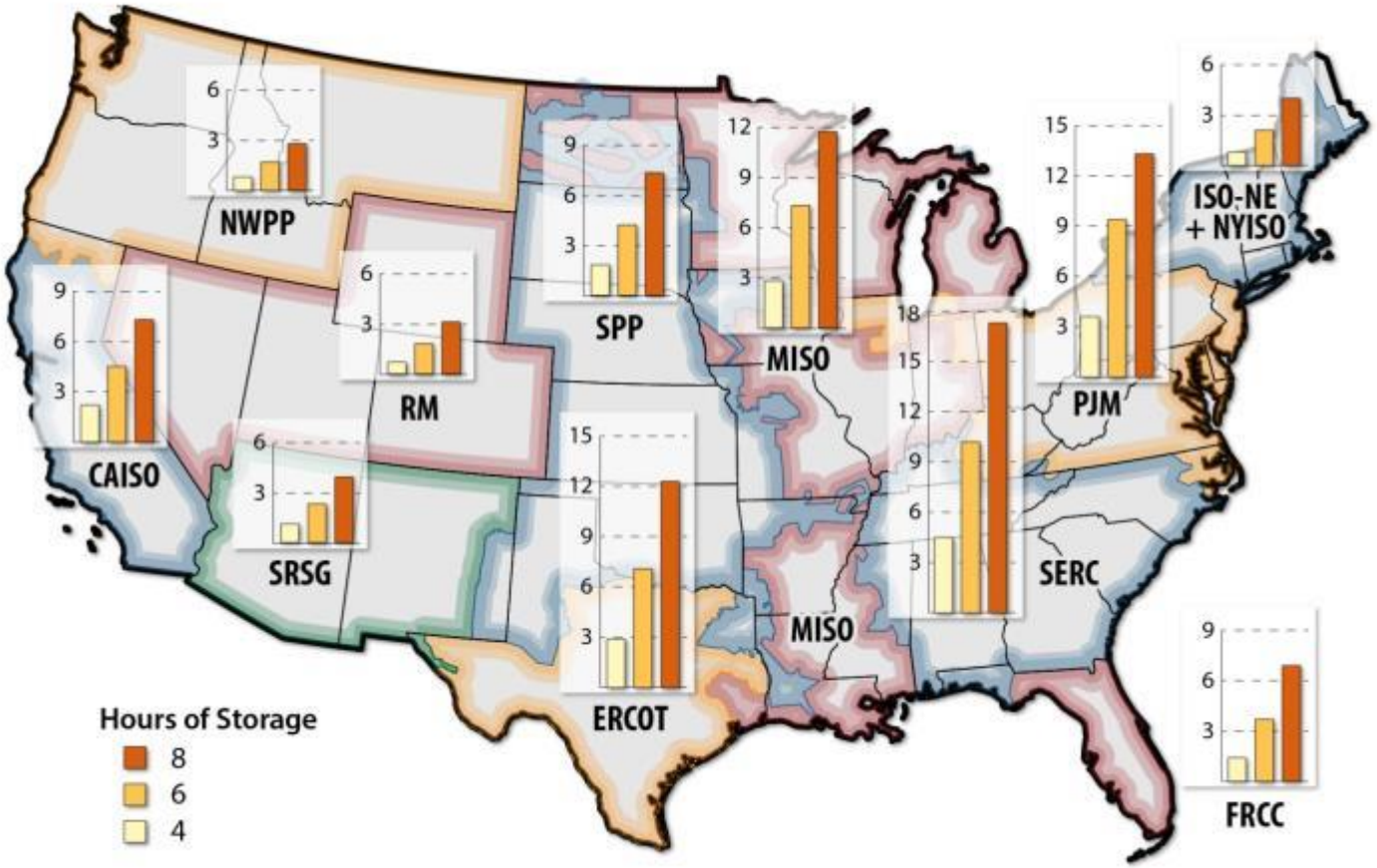
But How Big Is the Market?



Denholm et al. unpublished

CAISO and MISO allows 4-hour storage to provide resource adequacy. But only a limited market size due to "widening" of net demand peak.

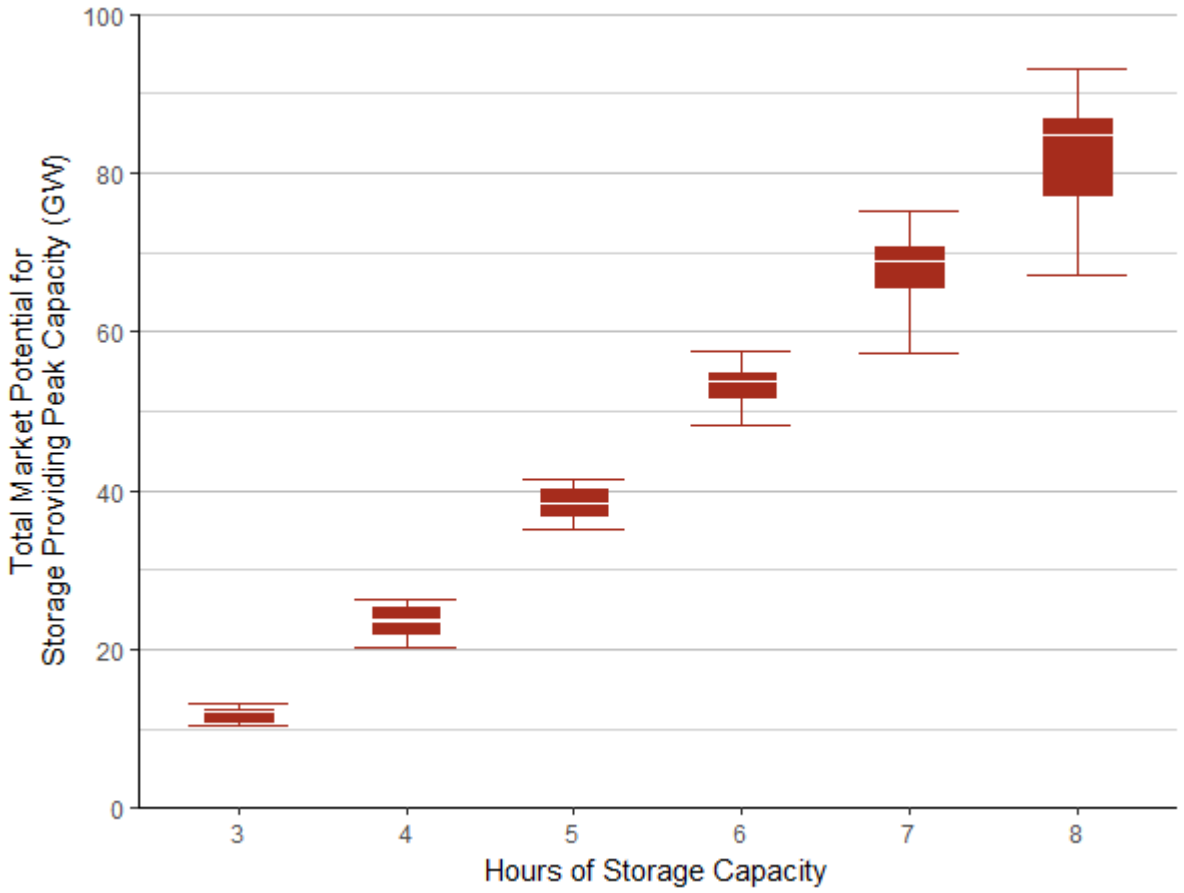
Market Potential?



Denholm et al. unpublished

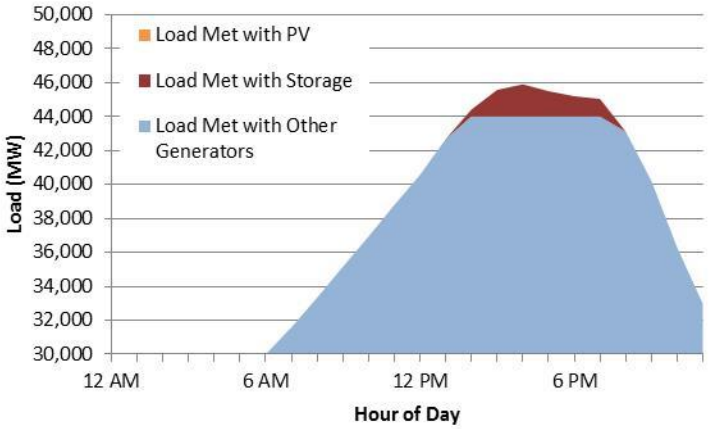
Total market potential for energy storage as a peaking capacity in the U.S.

Total U.S. Market Potential for Storage as Peaking Capacity

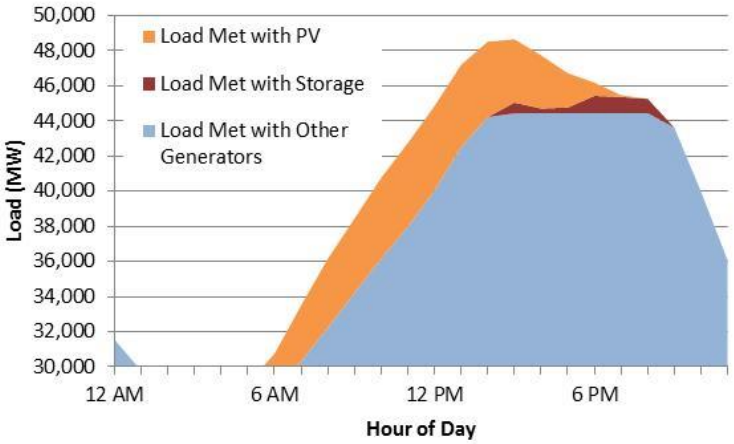


Total market potential for energy storage as a peaking capacity in the U.S.

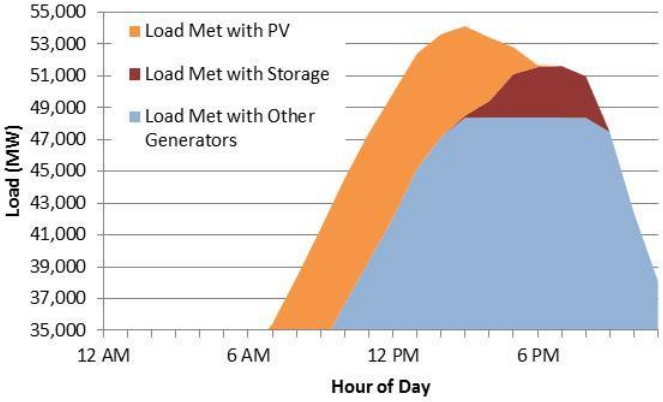
How Do Renewables Affect This?



Zero PV



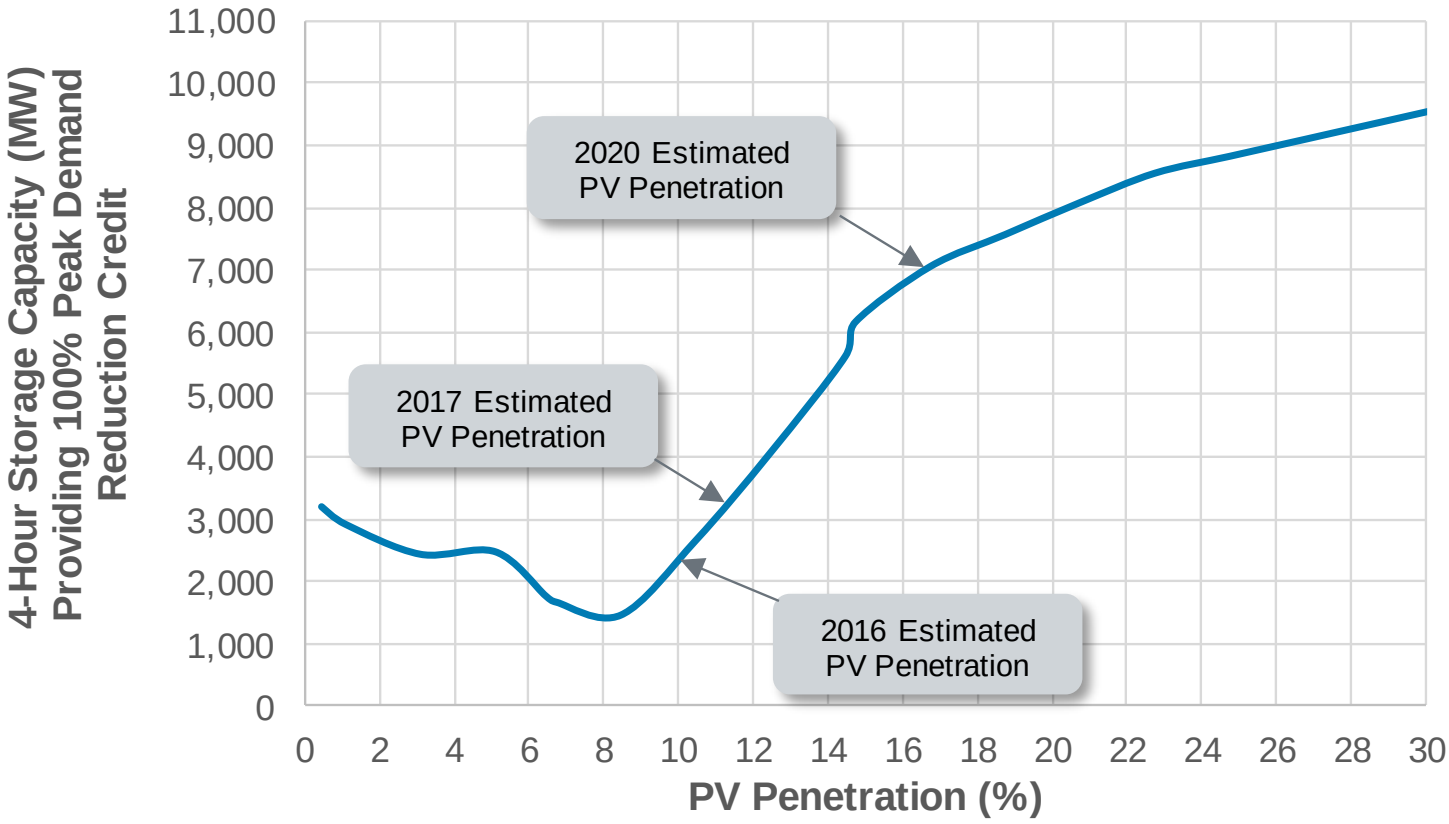
5% PV



10% PV

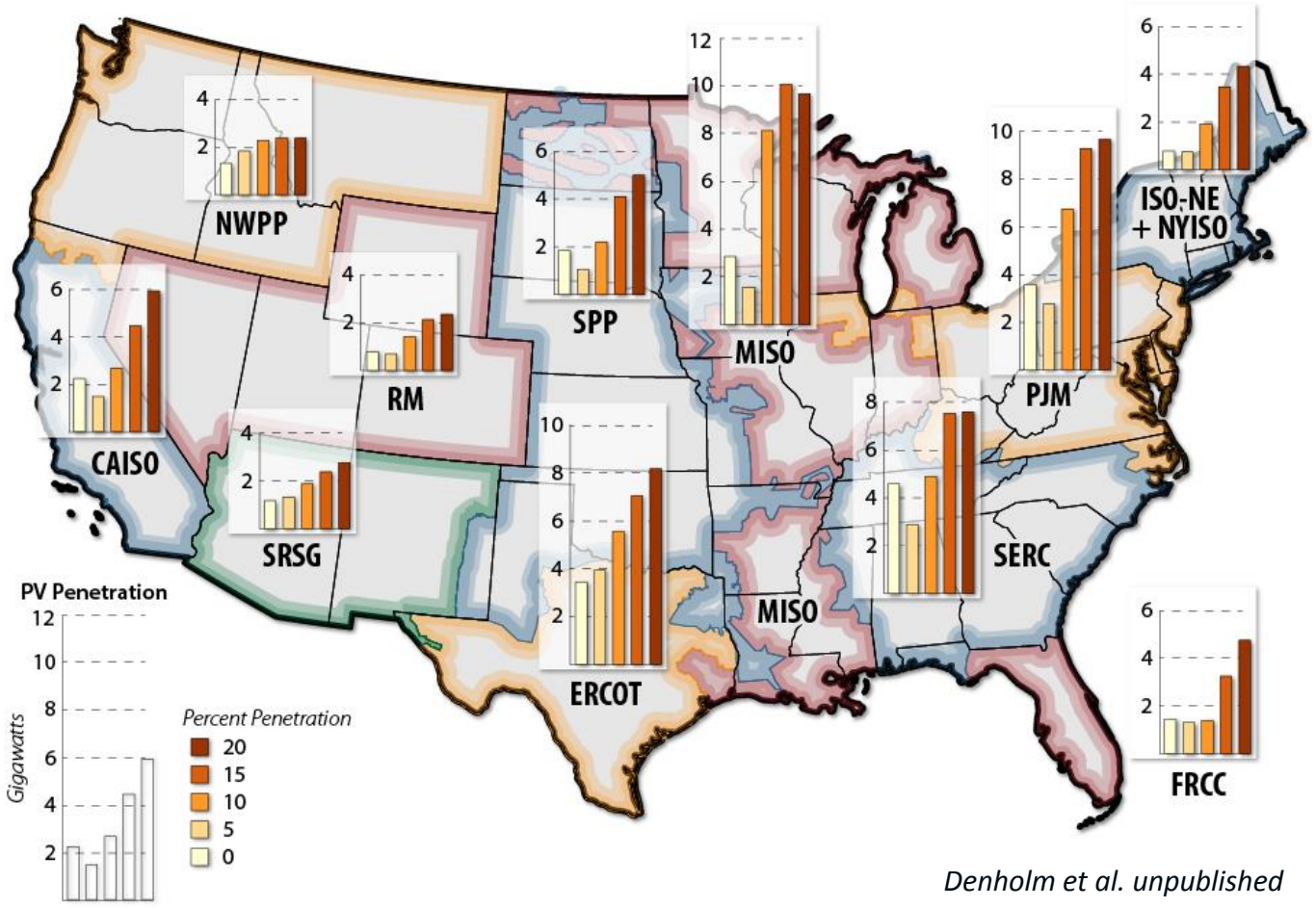
With increased PV penetration, the capacity credit of PV decreases while the capacity credit of storage increases

Impact of PV in California on Potential



Denholm and Margolis 2017

Increase in 4-hour storage technical potential



Denholm et al. unpublished

Preliminary, non-bankable results

Conclusions / Opinions

1. When properly scheduled, long-duration (several hours of capacity) batteries provide an alternative to combustion turbines for meeting peak capacity requirements
2. We are at or close to a tipping point for storage as peaker alternative
3. This market is 10s of GWs for 4-hour storage and could be >100 GW for 8 hour storage after considering growth in PV
4. MANY CAVEATS
   - Current markets long on capacity, still need to address missing money in energy-only markets, etc.

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