

Advanced Storage and the Changing Power System

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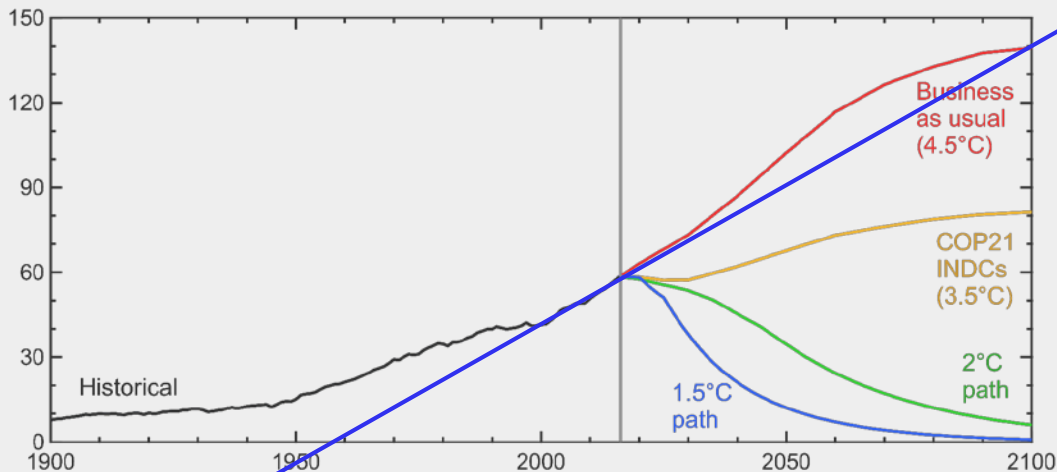
November 7th, 2017



Meaningful action to address climate change centers on the rapid near-term decarbonization of the power sector

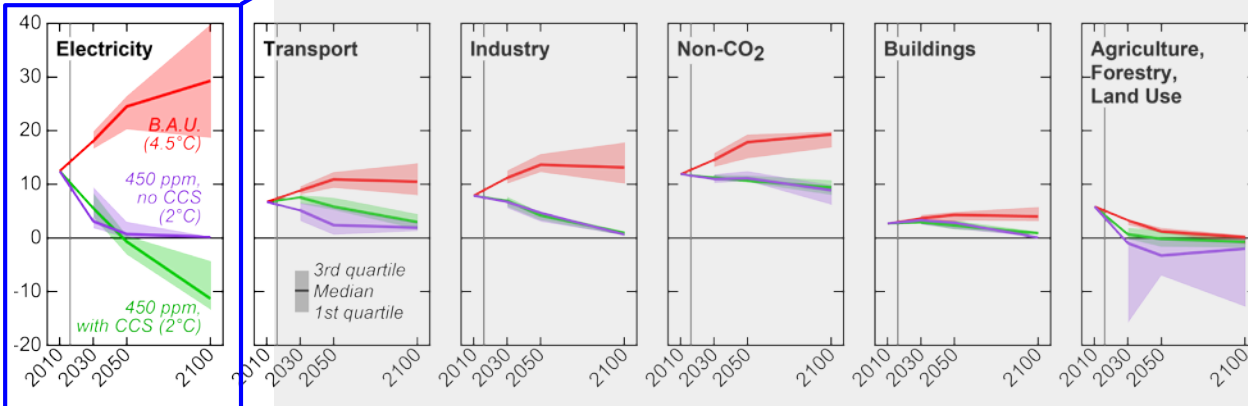
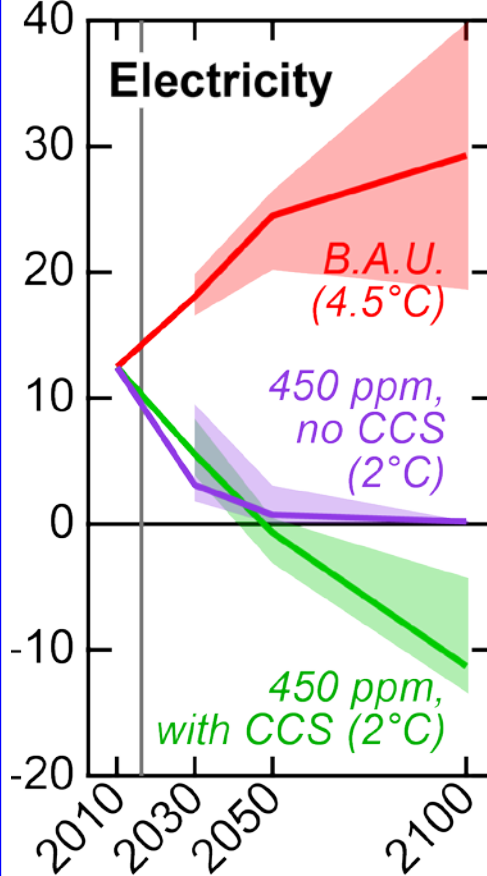
Total global CO₂(eq) emissions

Gt/year



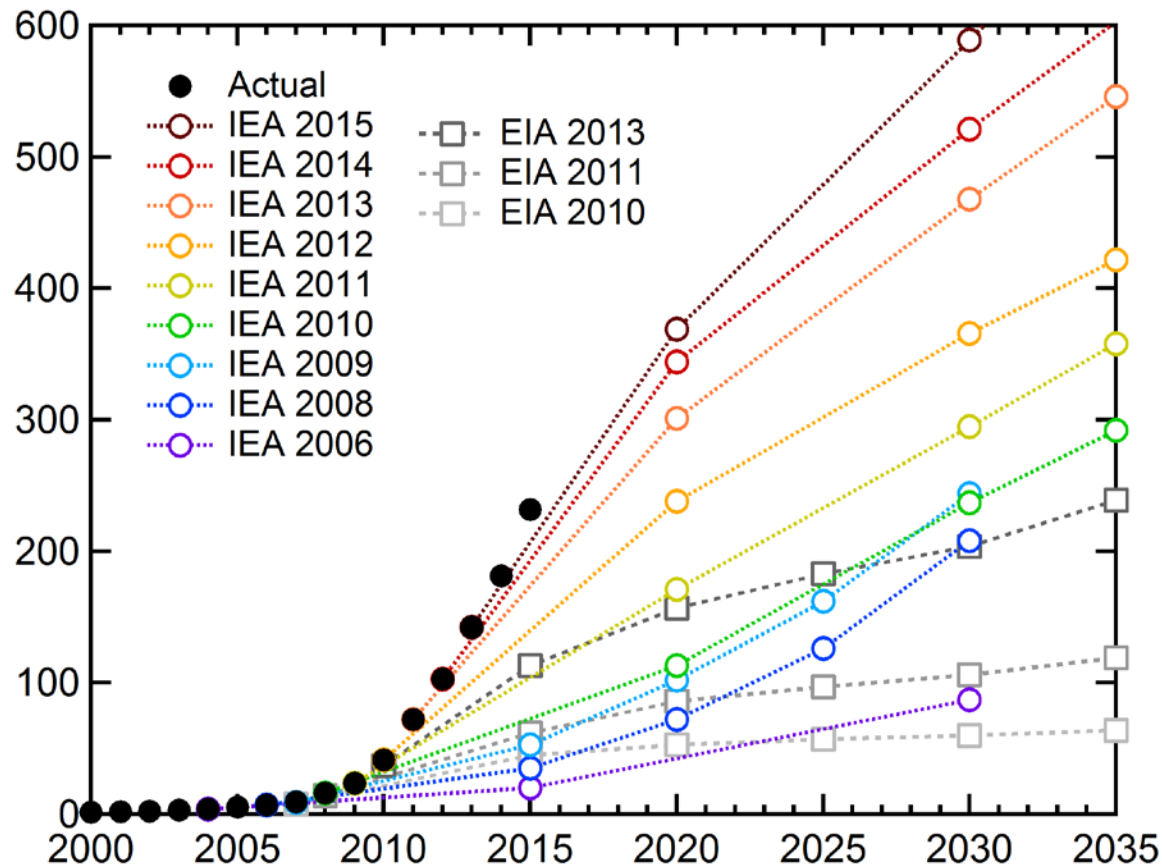
CO₂(eq) emissions

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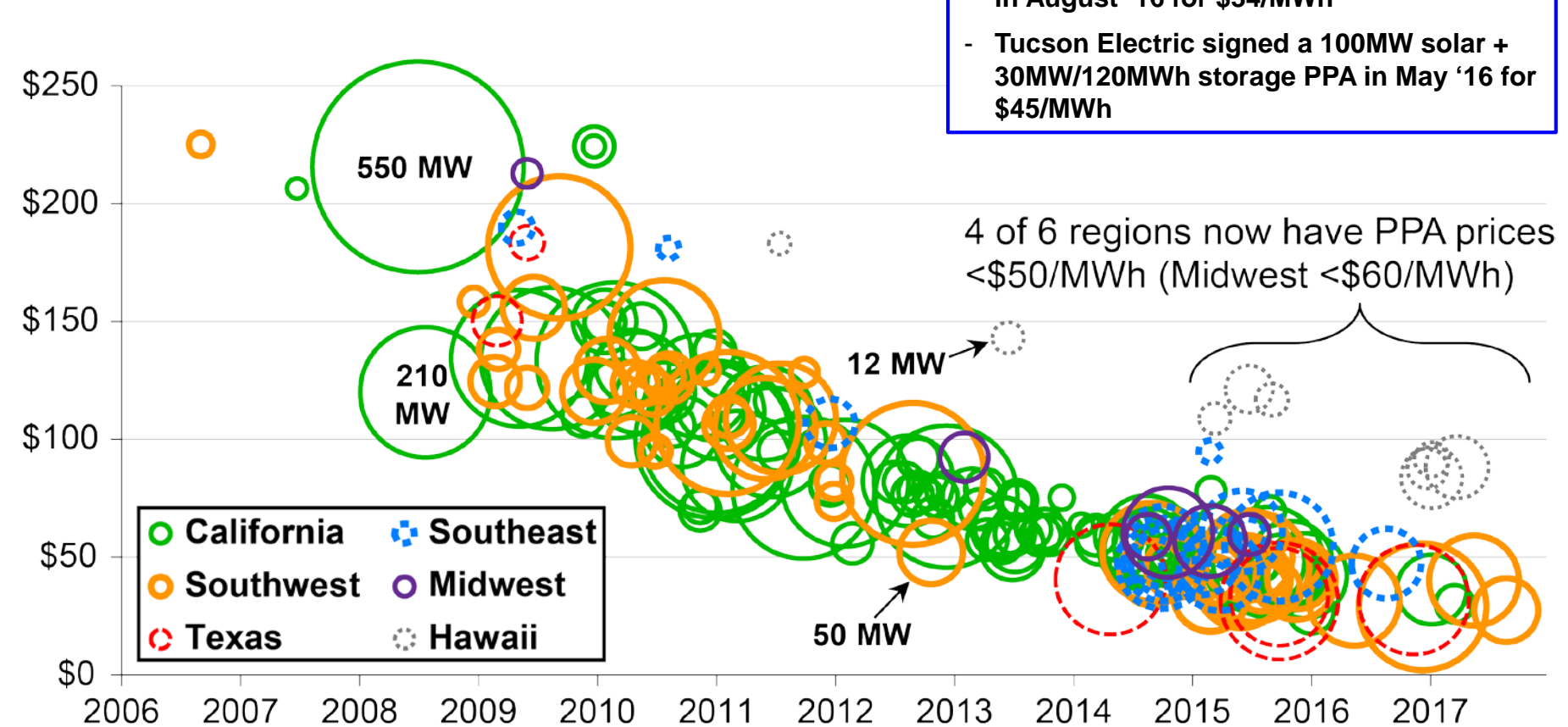
The relatively good news is that progress in terms of the deployment of low-carbon technologies has been doing better than projected

Actual vs. predicted cumulative solar deployment GW of Capacity



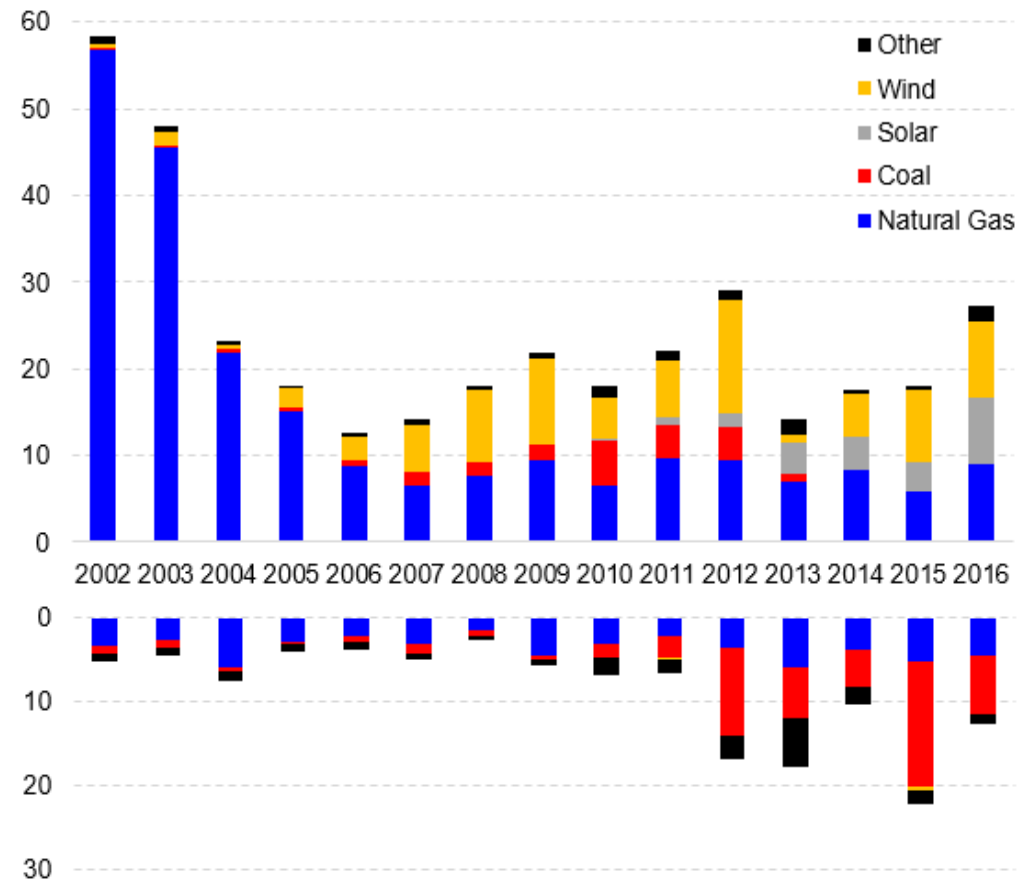
Gains in the competitiveness of key technologies like utility-scale PV over the past half decade have been striking

U.S. Utility-scale solar PPA prices evolution since 2006
\$/MWh

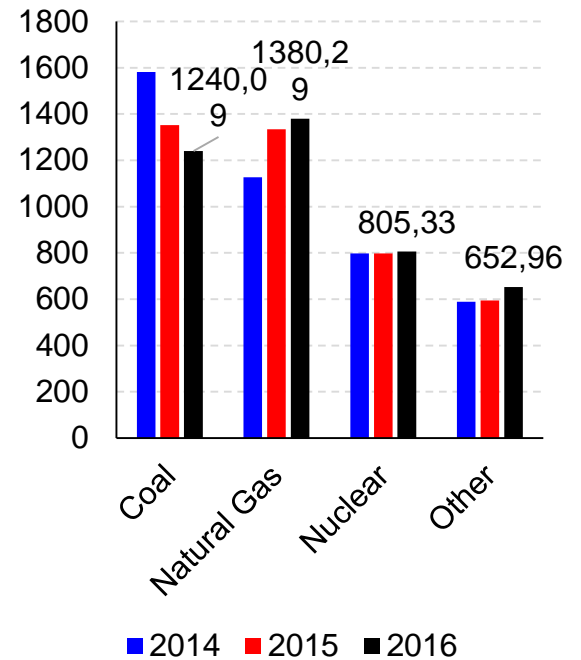


Today's changing capacity mix in the U.S. reveals a rebalancing of the system away from coal and towards gas and renewables

Utility-scale electric capacity additions and retirements in U.S.
GW



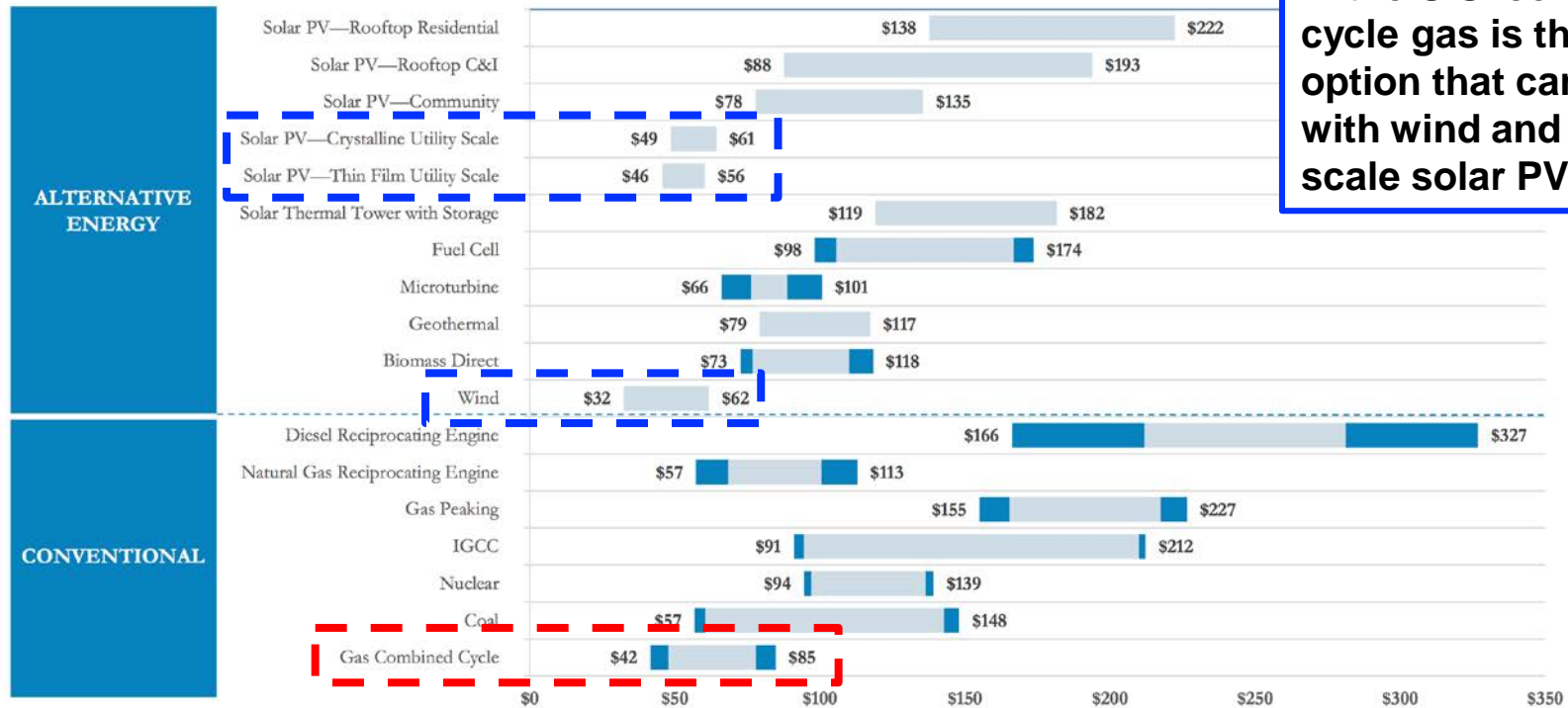
Net Generation
TWh



In fact today, on an LCOE basis only combined cycle gas can compete with wind and utility-scale solar in the U.S. market

Unsubsidized U.S. energy technology LCOEs including fuel sensitivity

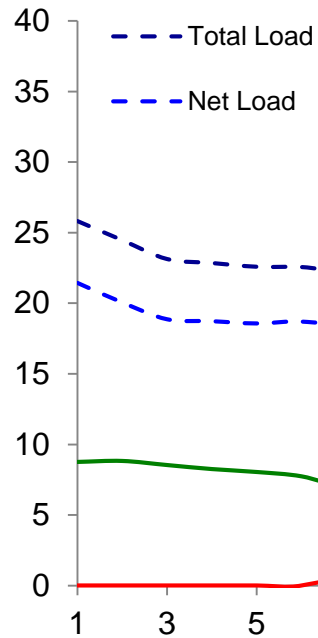
\$/MWh



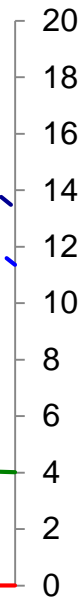
In the U.S. combined cycle gas is the only option that can compete with wind and utility-scale solar PV

Now that the economics of renewables are becoming more compelling, the harder issues of large-scale integration must be addressed

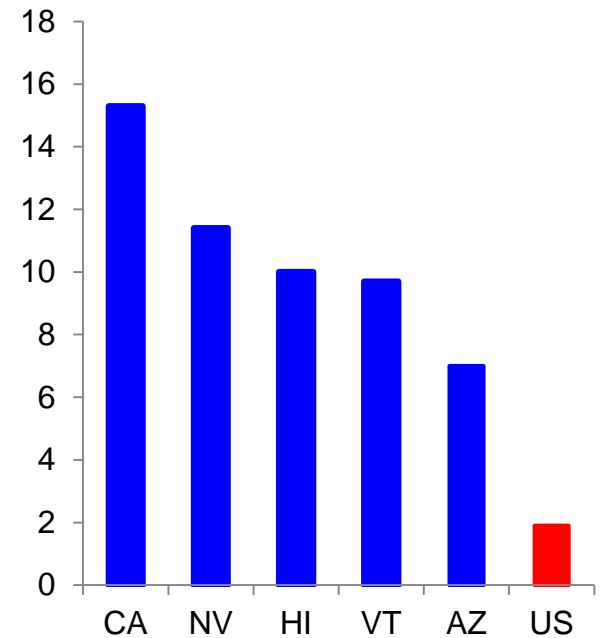
CA system load
GW



PV & other non-hydro renewables
GW

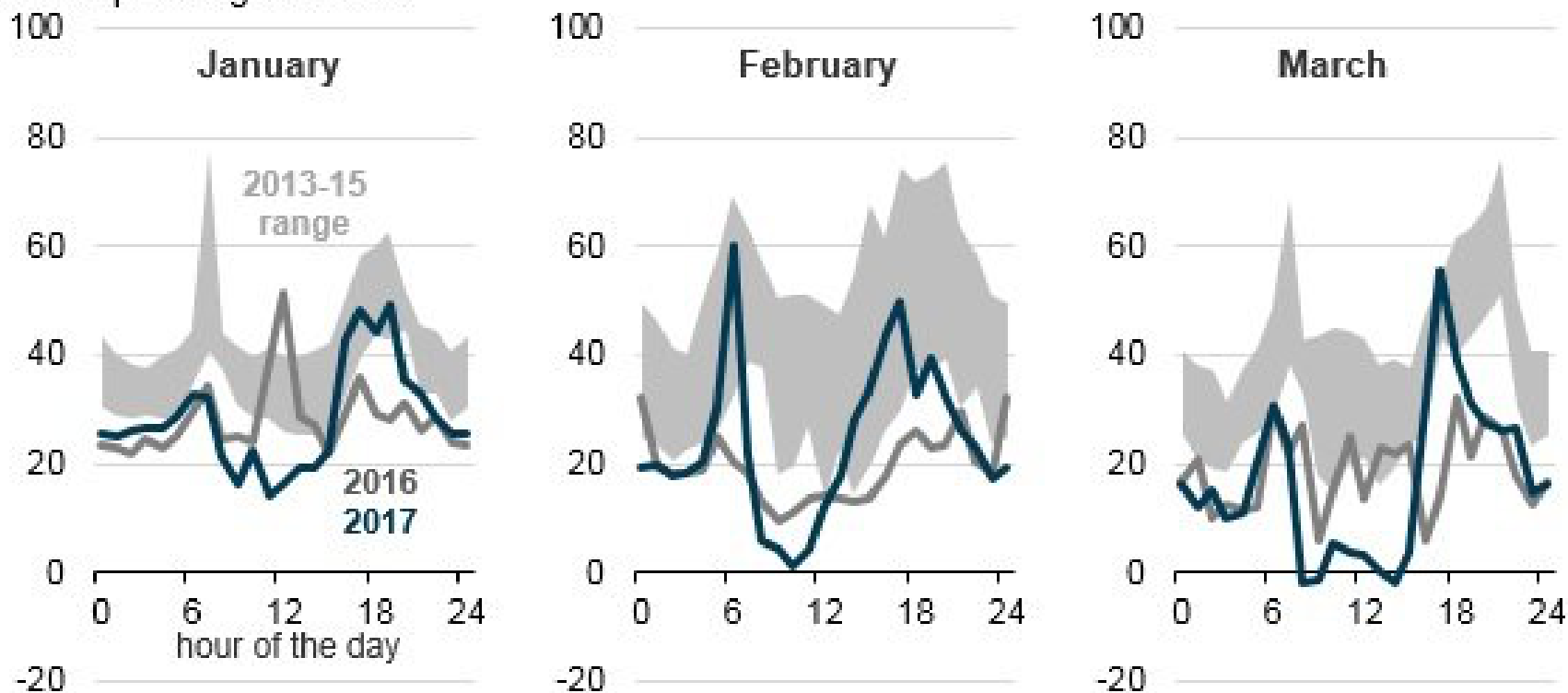


Solar as % of total generation
Percent (Jan 2017 to May 2017)



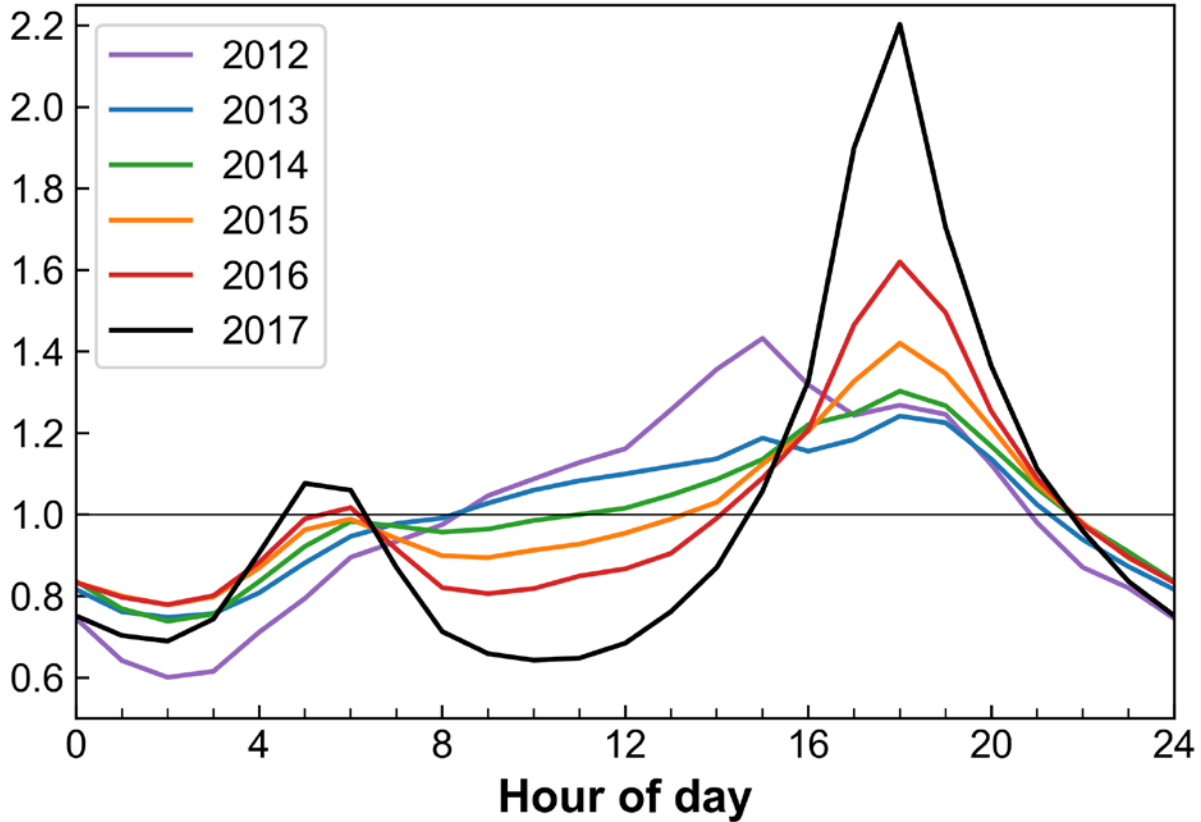
Solar PV generation is now pushing power prices in CA into negative territory on a regular basis

California Independent System Operator average hourly real-time price
dollars per megawatt-hour



Even at today's relatively modest penetration levels, solar has profoundly altered intra-day pricing in CA

Average hourly price normalized to RTC price
CAISO LMPs



Sources: P. Brown, MIT Analysis, CAISO

Dealing with today's new net-load profile is of course a problem for which a broad range of solutions exist

Transmission capacity and market redesign



Flexible dispatchable generation



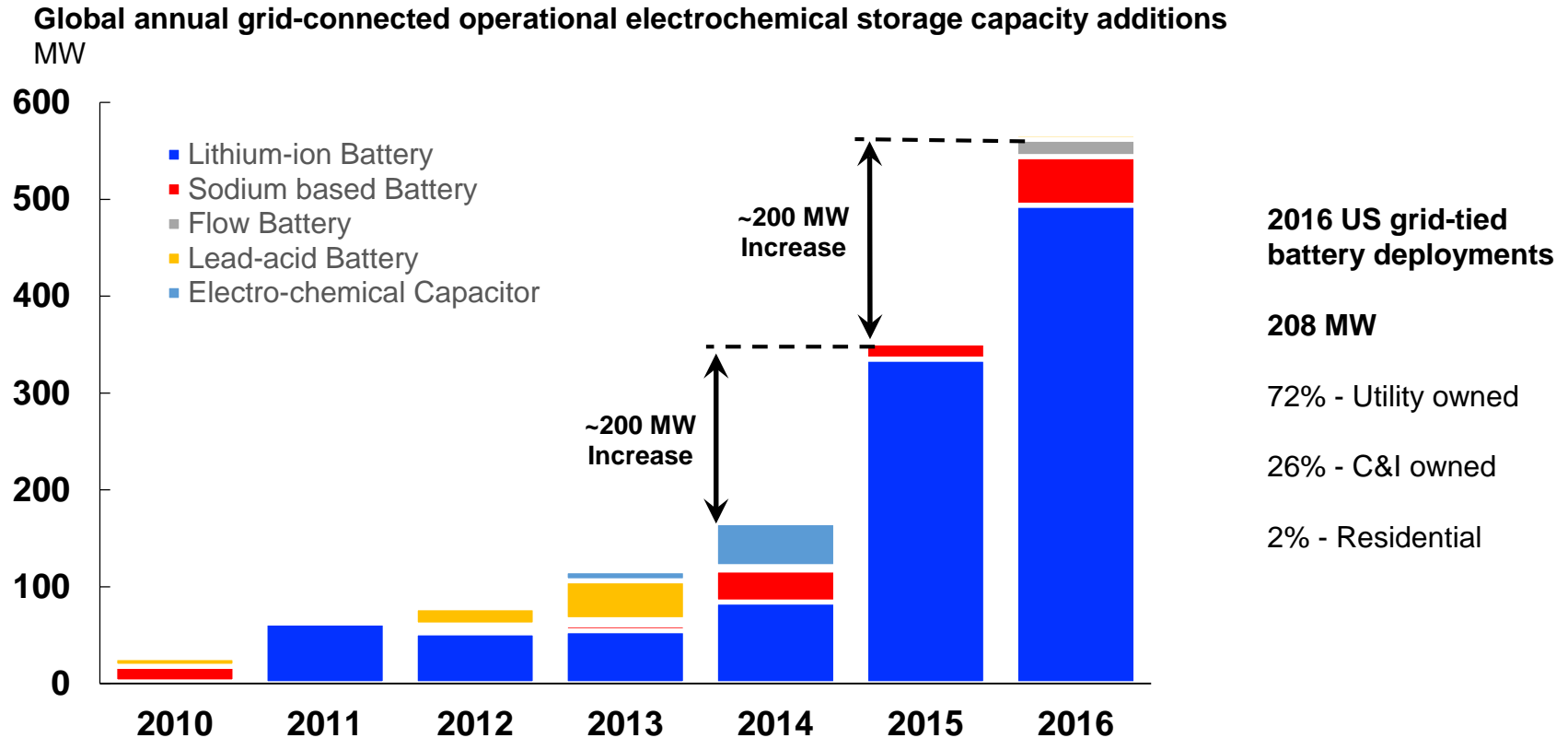
Energy storage



Active demand management

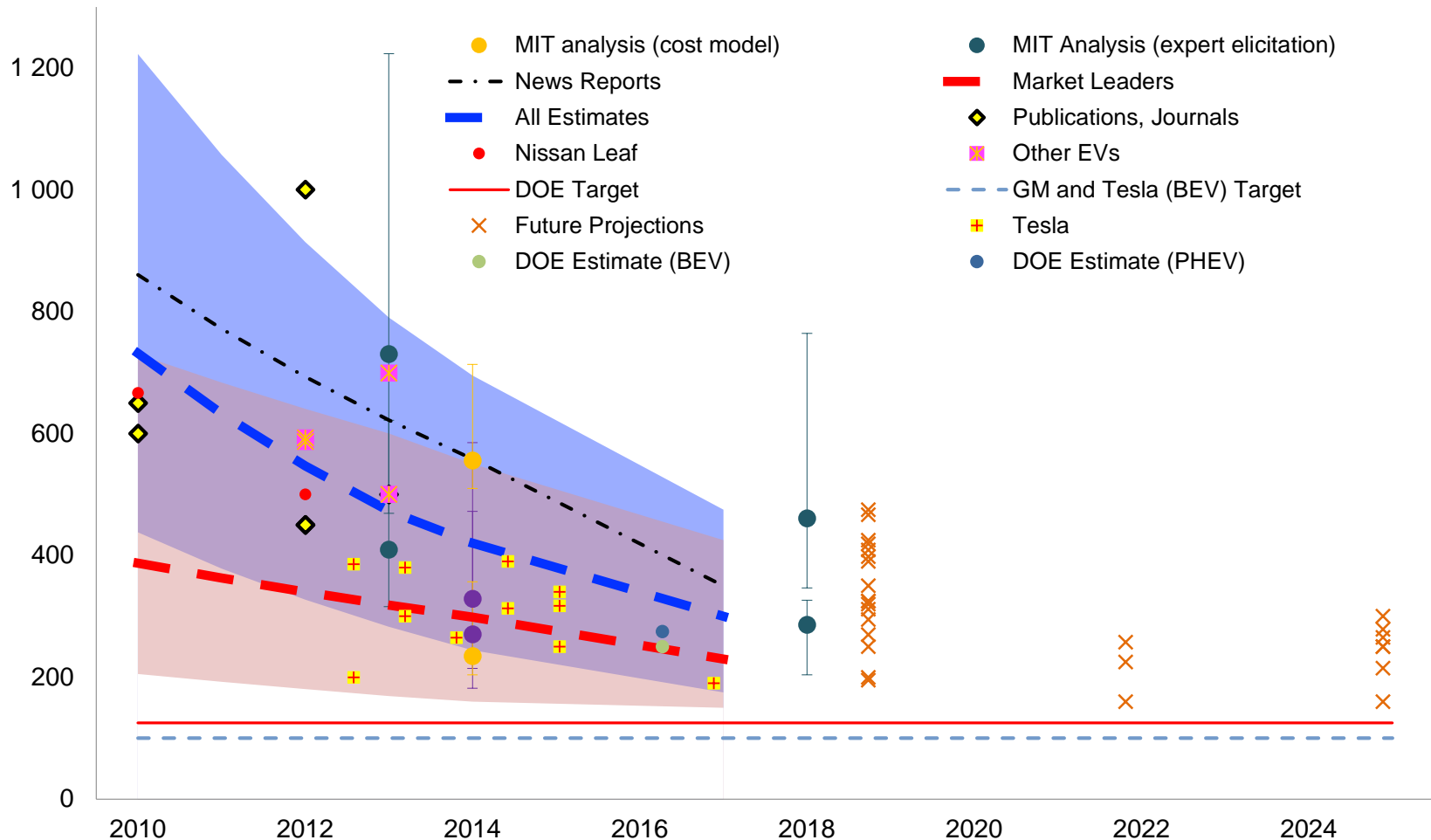


In terms of contemporary electrochemical storage deployments, Li-ion based chemistries are now utterly dominant



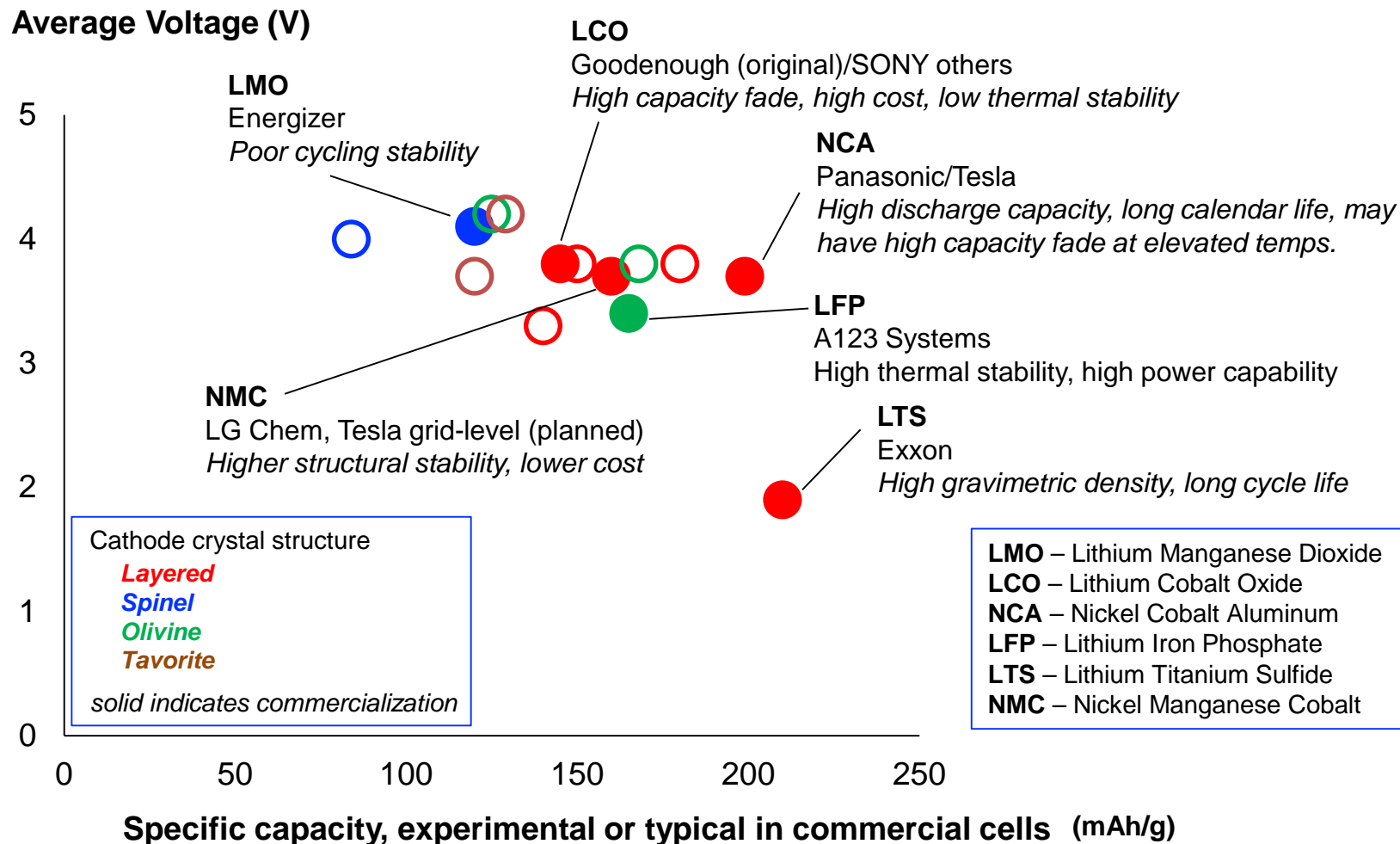
Li-Ion's march down the cost curve is well documented (hyped even), but opacity remains regarding the technology's real economic potential

Cost (\$) per kWh



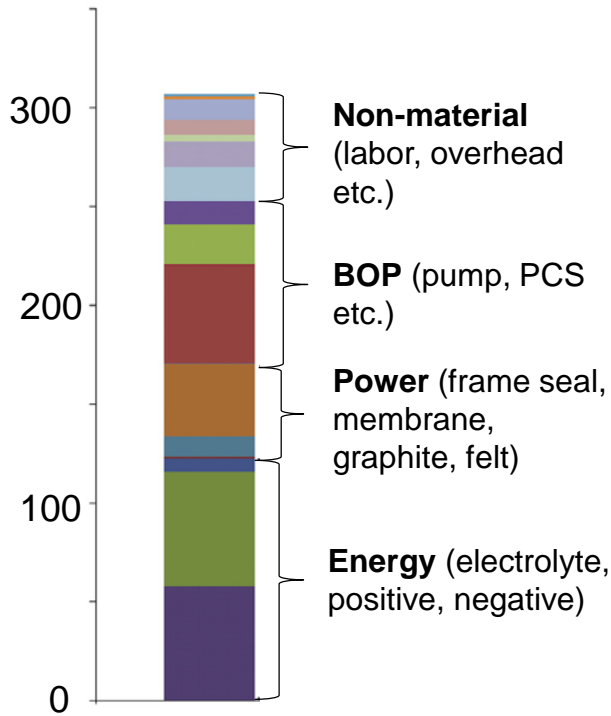
Source: Sakti et al. 2015 Journal of Power Sources; Sakti et al. 2017 Energy Policy; Ciez et al. 2017 Journal of Power Sources; Nykvist and Nilsson 2015 Nature Climate Change; IEA, 2017; MIT Analysis

Different market players are focused on different Li-ion chemistries with varying performance attributes



Flow batteries continue to garner attention and some concepts seem to offer the potential for very low-cost energy batteries

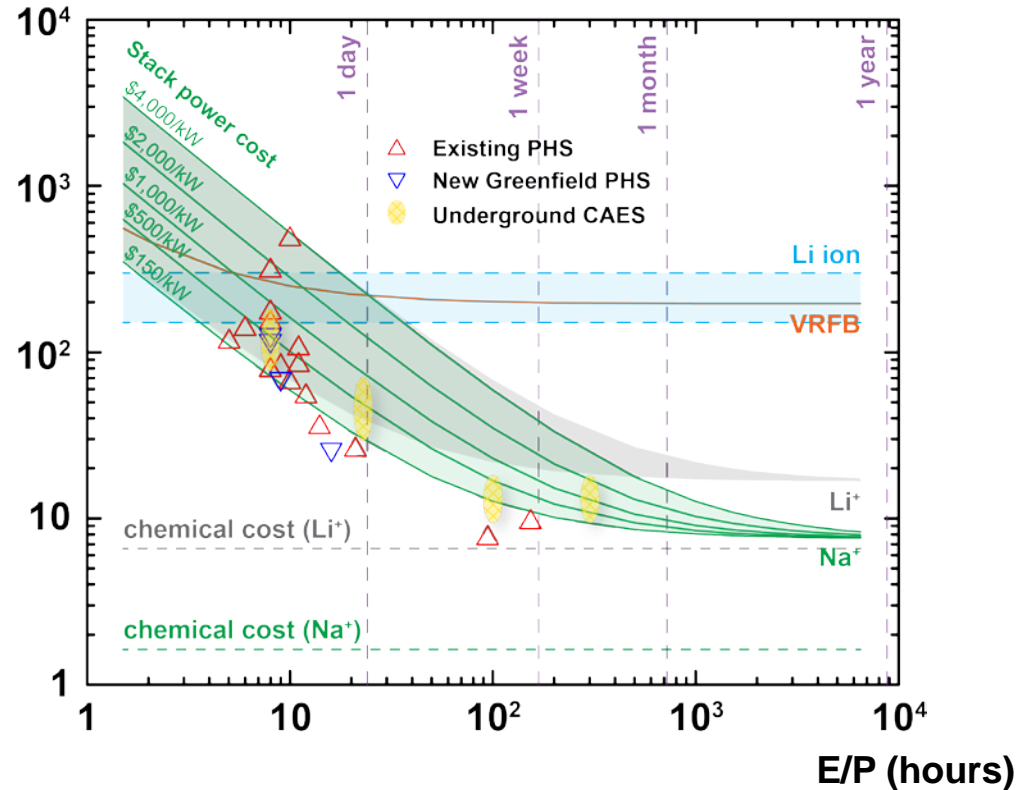
Cost (\$) per kWh



Vanadium Redox Flow Battery (VRFB) Stack, at scale

Could cost ~\$300/kWh at ~400MW per annum deployment

Cost (\$) per kWh

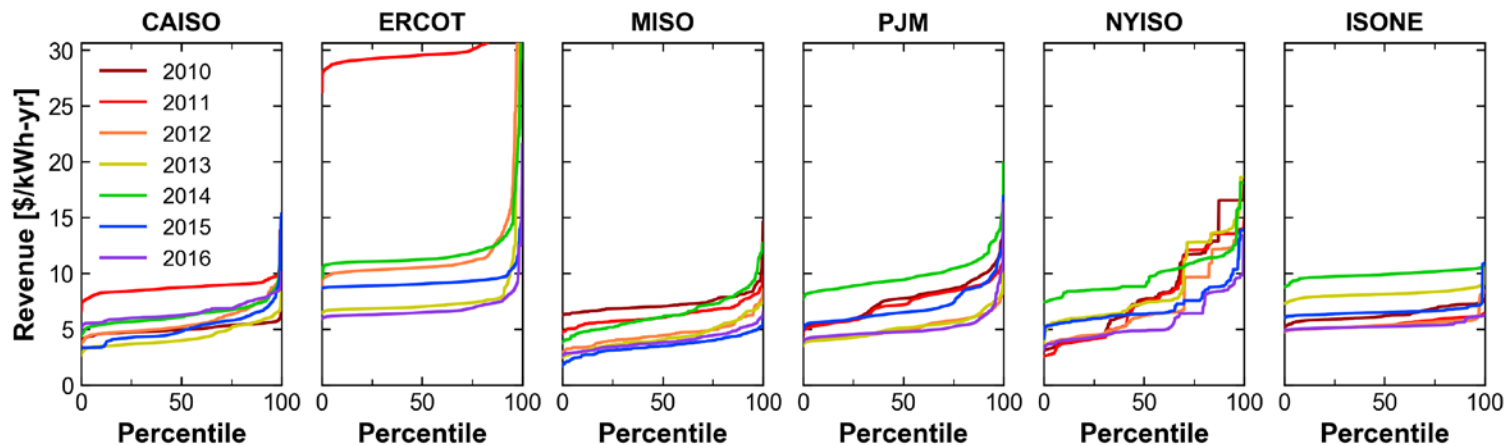
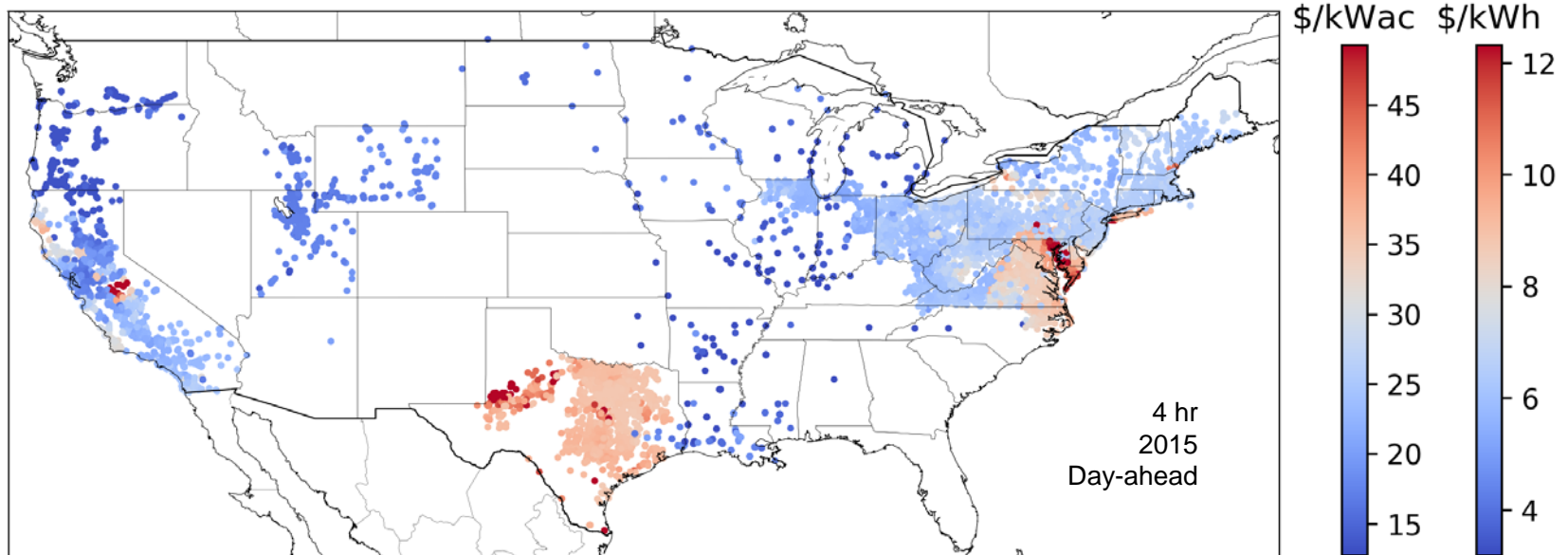


Aqueous-sulfur Flow Battery, at scale (MIT)

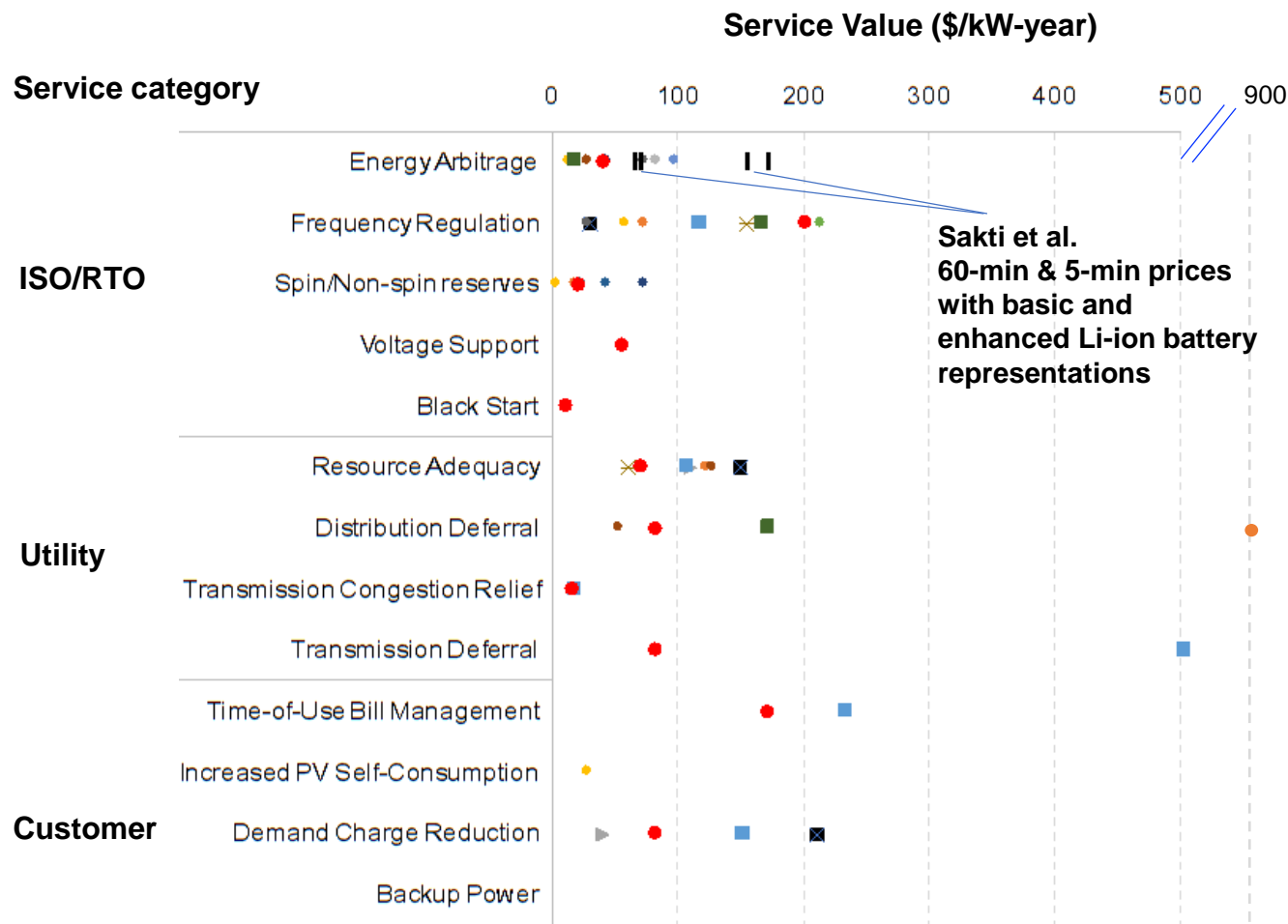
Claims cost competitiveness with pumped-hydro and compressed air with 500X the energy density of pumped-hydro

Leveraging storage to take advantage of price arbitrage has of course been widely cited as key to supporting high-levels of renewables

Assessment of energy arbitrage value across U.S. ISOs



Beyond arbitrage, storage can deliver a plethora of other (sometimes valuable) services, but monetization is challenging

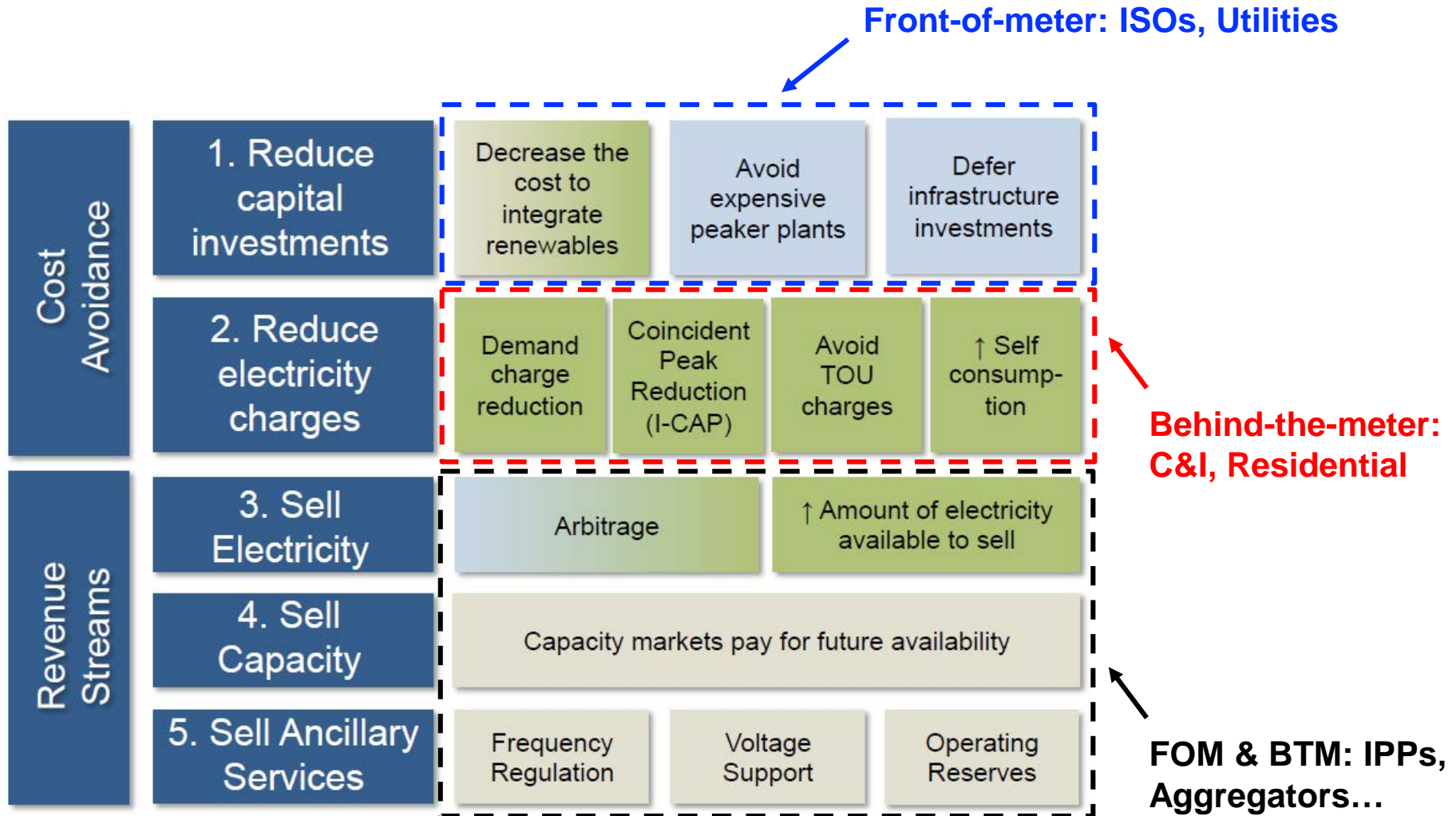


Stacking services enhances the return on investment from the energy storage system.

Existing studies show a 2-3x increase in value compared to individual use cases

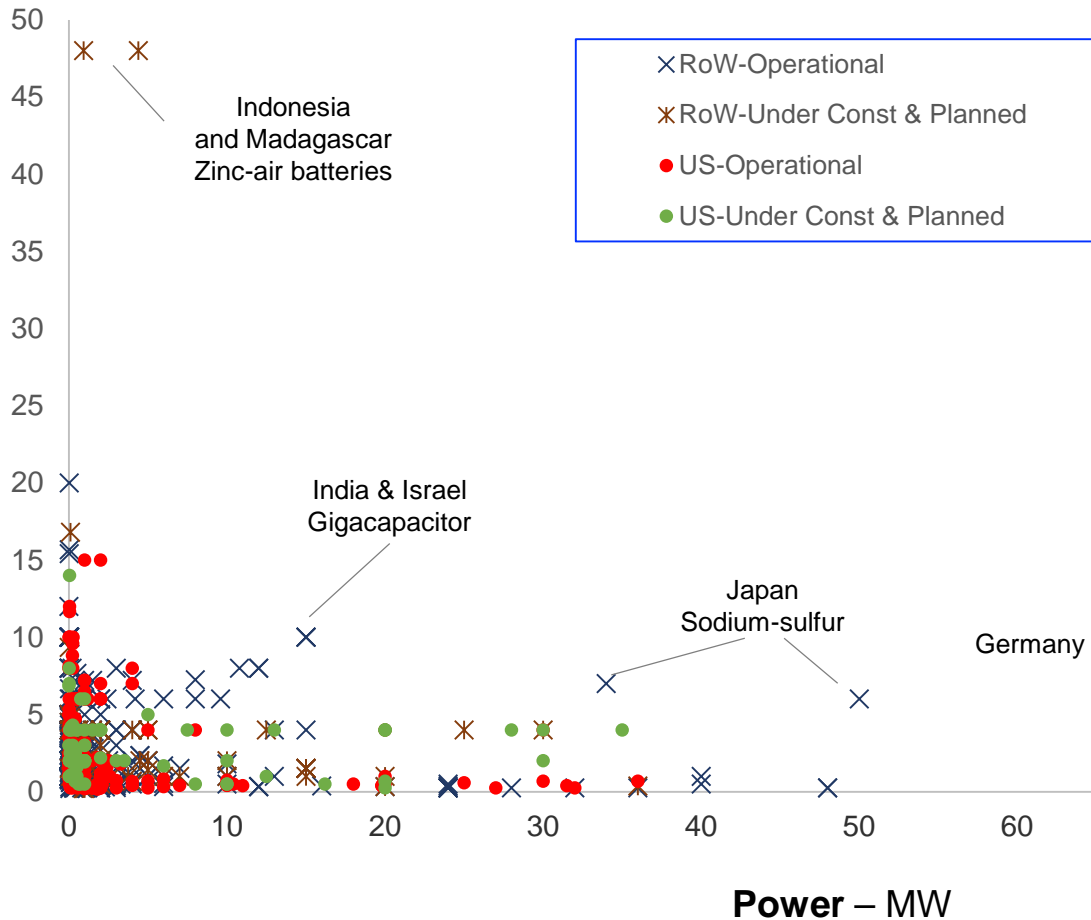
Beyond the technical challenge of providing stacked services, in many markets the regulations explicitly preclude it

Today's regulatory framework in many states makes its difficult or impossible to fully leverage a storage asset's economic potential

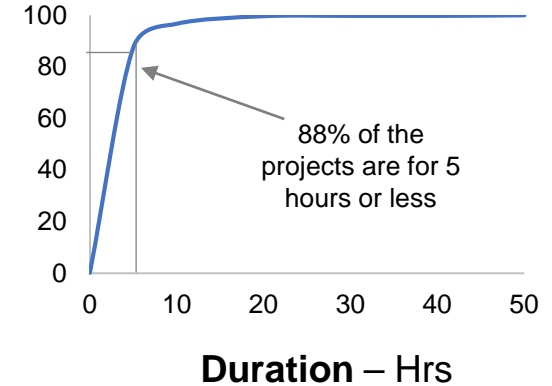


Today's storage deployments are near universally "power" orientated, and targeting ancillary services and demand management applications

Duration – Hrs

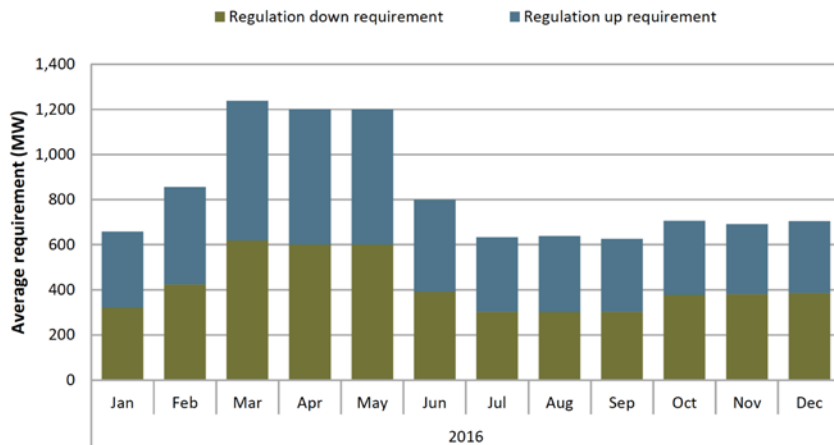


% of projects

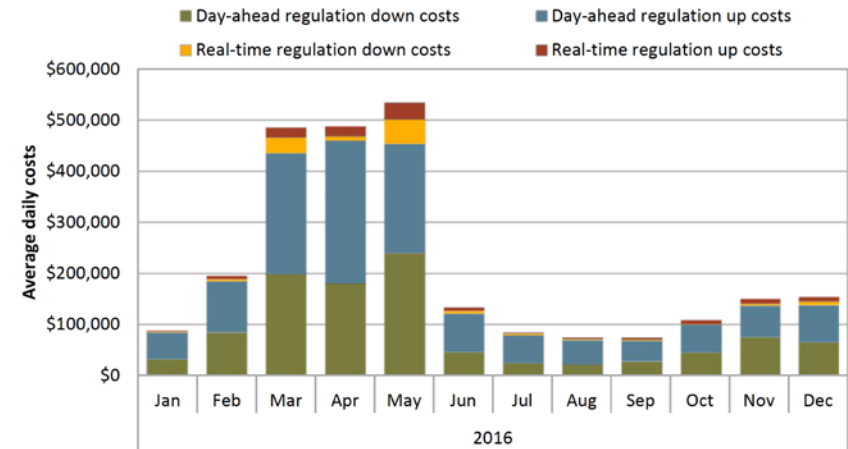


Battery deployment for regulation on renewables heavy systems is an attractive use case but market size is very limited

2016 CAISO daily frequency regulation requirements
MW

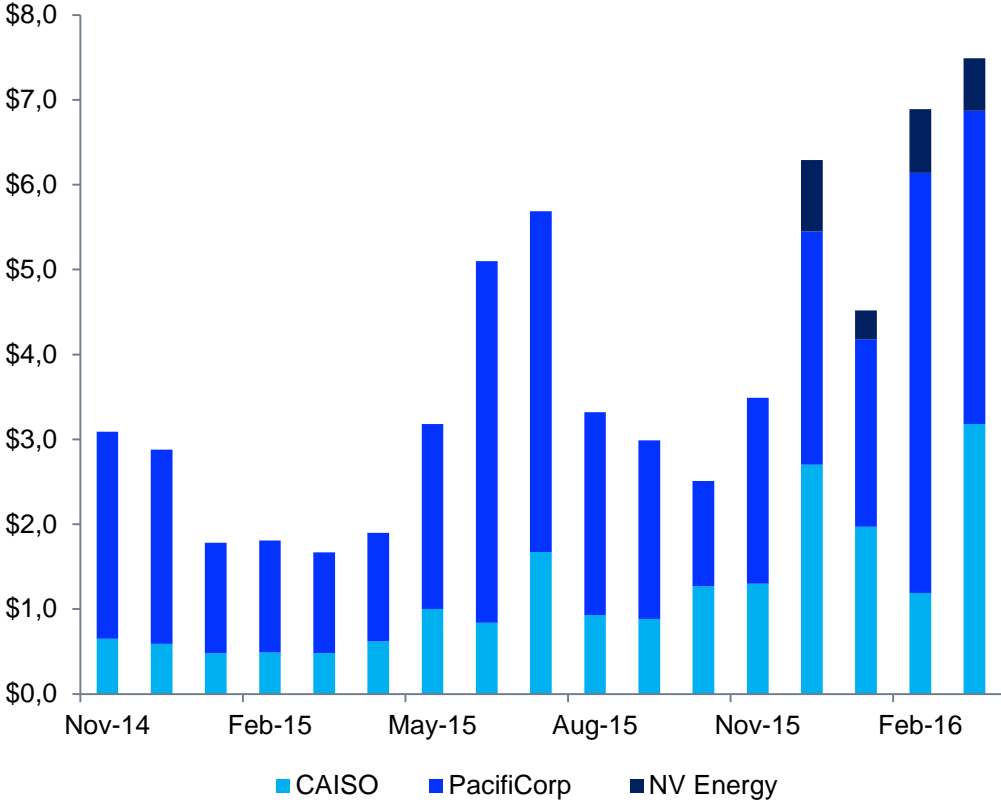


2016 CAISO daily frequency regulation costs
MW



An important aspect in the evolving U.S. storage market is how the power markets themselves change

Cost savings arising from EIM integration
\$ Millions

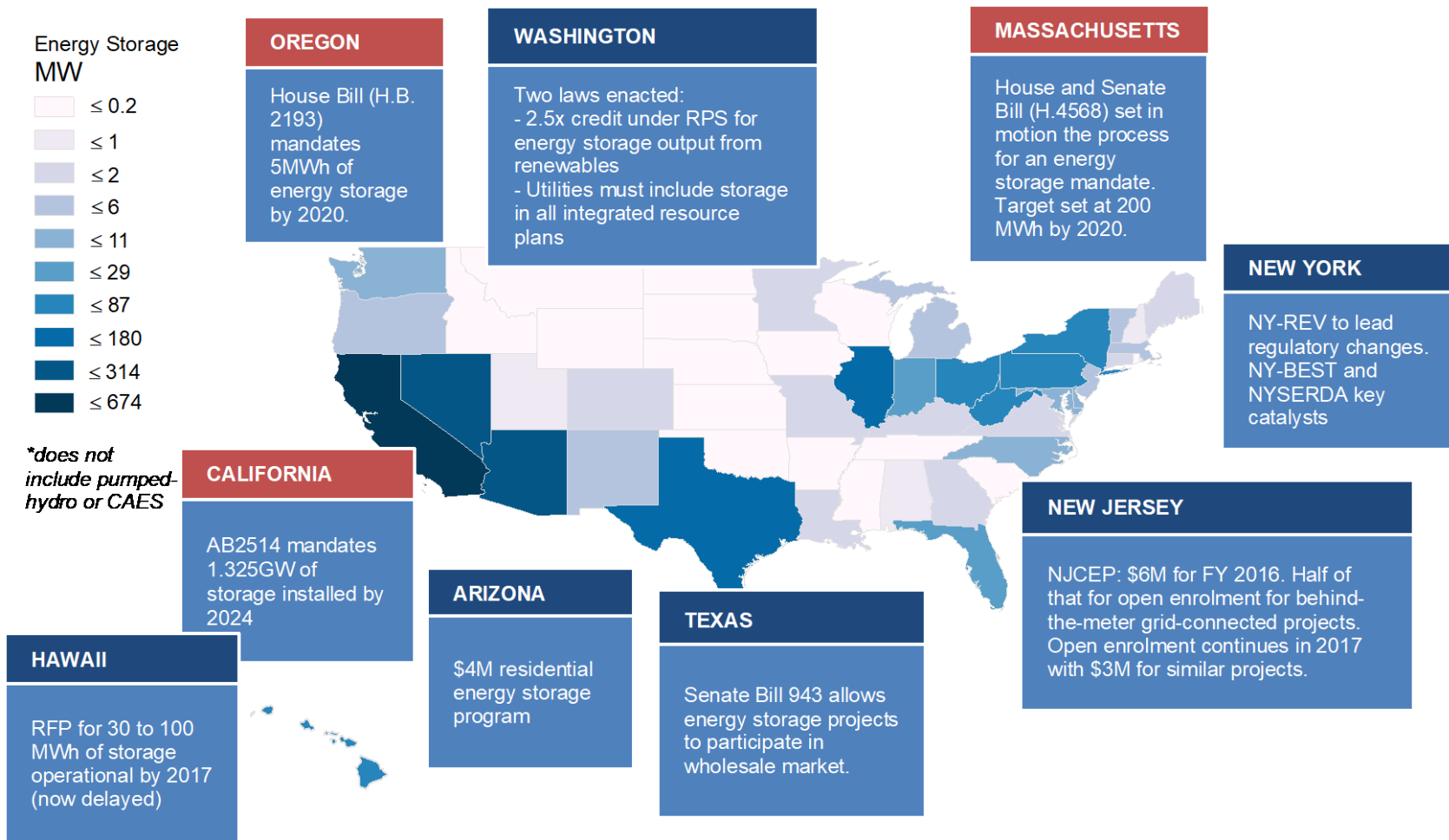


The Energy Imbalance Market – A first step towards greater market integration in the Western U.S.

- CAISO’s development of the EIM is aiding the optimization of the real-time dispatch and reducing costs appreciably
 - Estimated \$120M in real-time dispatch savings since November ’14
- Aiding California in meeting its renewable energy targets by reducing renewables curtailment
 - Reduced Q4 ’16 CA renewables curtailment by 24GWhs
- Acting as a stepping stone to much greater western integration in a manner designed to best integrate high levels of variable resources

Source: MIT Analysis, CAISO, F. O’Sullivan, P. Brown

In addition to the restructured markets, the medium-term future for storage will also be heavily shaped by state-level actions



The commercial models driving today's storage deployment across U.S. markets vary greatly, with state-level regulation playing a key role



Advanced Microgrid Solutions

- Politically, very well connected in CA, their main market
- Focused on securing large-scale utility contracts
- Deployment is via a distributed C&I base
- Dual purpose battery application model

- Initial focus on storage+charging for C&I customers
- Pivoted to storage+solar with a shared savings business model
- Has balance sheet strength given Engie ownership
- Sales force being integrated with Engie



- A focus on product standardization for C&I demand charge management
- Very strong software focus with capabilities in aggregation
- Business model leverages SPVs for asset financing
- Tesla is a key supplier... and competitor

- Vertically integrated
- Expanding development activity with the integration of SolarCity
- Preference for system sales rather than long-term contracting
- Diversified market focus, residential BTM, C&I BTM, Utility BTM & FTM



Some concluding remarks