

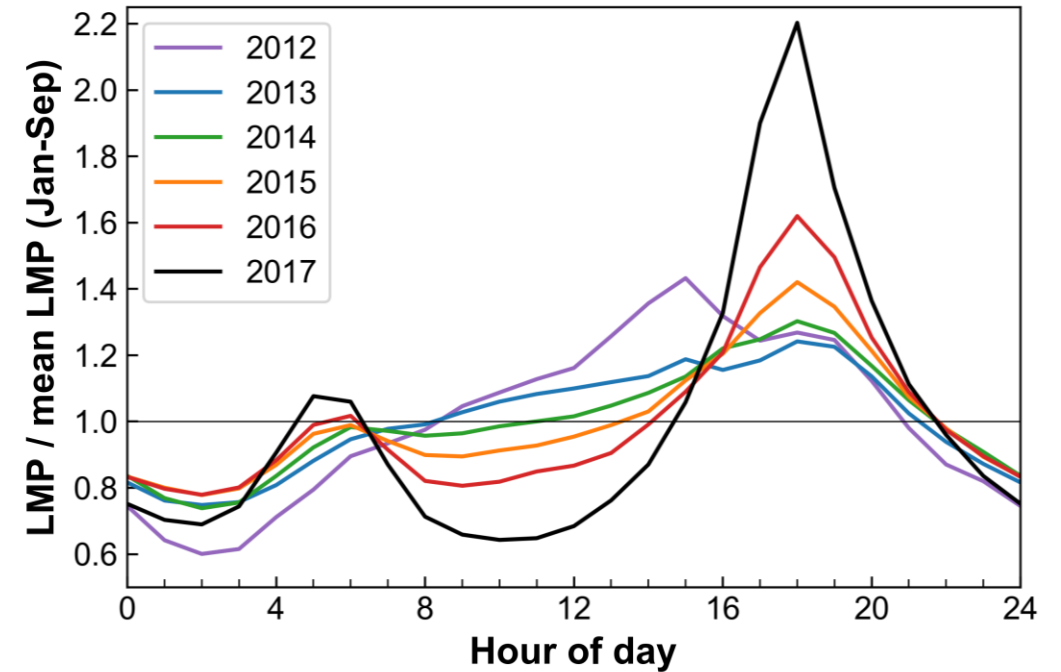
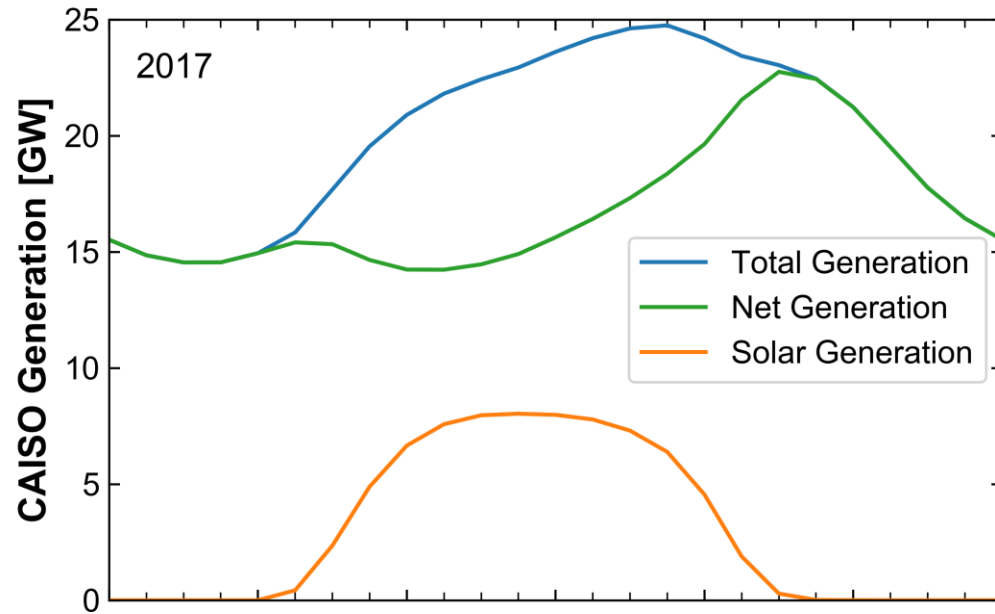
# Power in Transition – The Changing Market Landscape

Francis O' Sullivan

July 14<sup>th</sup>, 2018

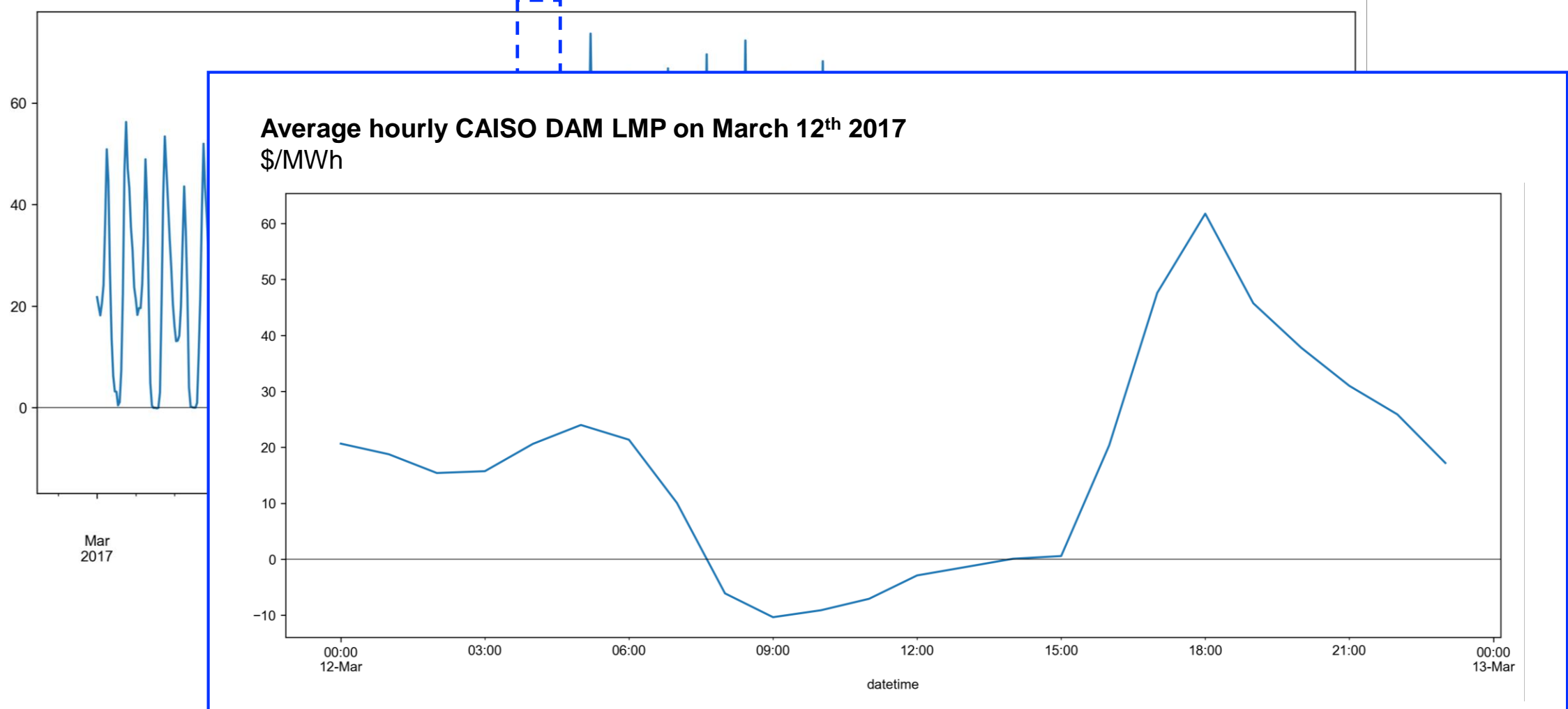


# As the role played by renewables transitions from marginal to meaningful, the bulk power system is beginning to face new challenges



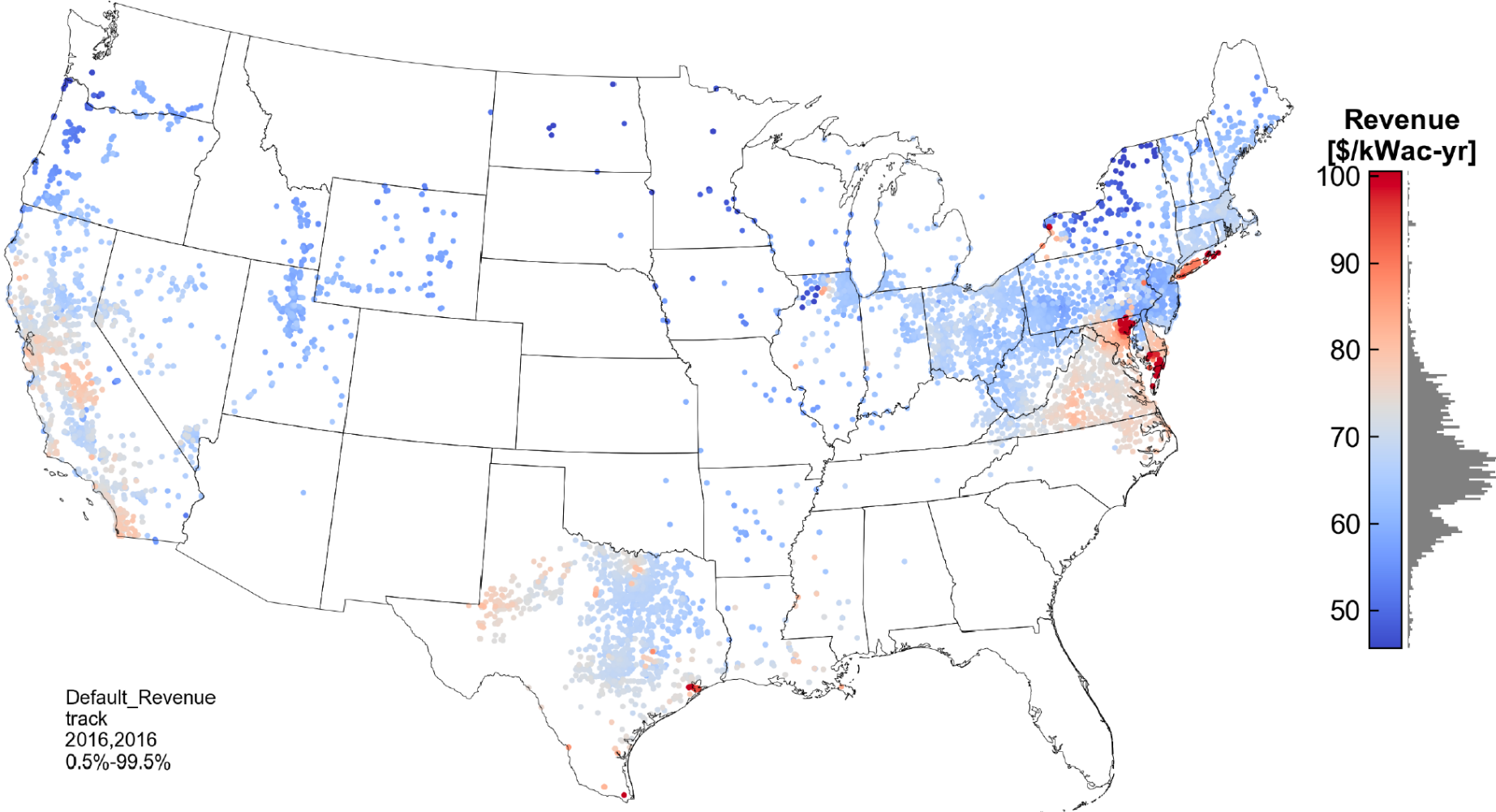
# Growing instances of negative power prices raise issues regarding how fit-for-purpose existing wholesale electricity market structures are

Average hourly CAISO DAM LMP in March 2017  
\$/MWh



# The dynamics in the value of renewables generation as penetration grows means that project economics are becoming more complicated

Modeled yearly revenue for U.S. solar PV generation capacity based on 2016 DAM LMPs  
\$/kWac-yr



Source: P. Brown, F. O'Sullivan, CAISO

# Increased system flexibility is a key enabler of an efficient, reliable and resilient future power system

**Transmission capacity**



**Flexible dispatchable generation**



**Energy storage**

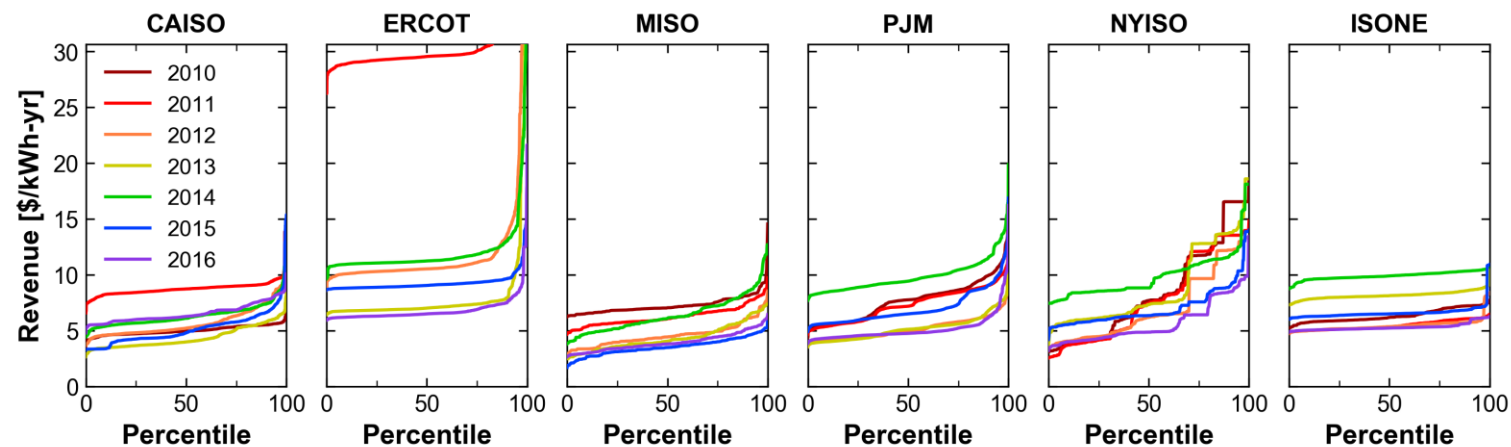
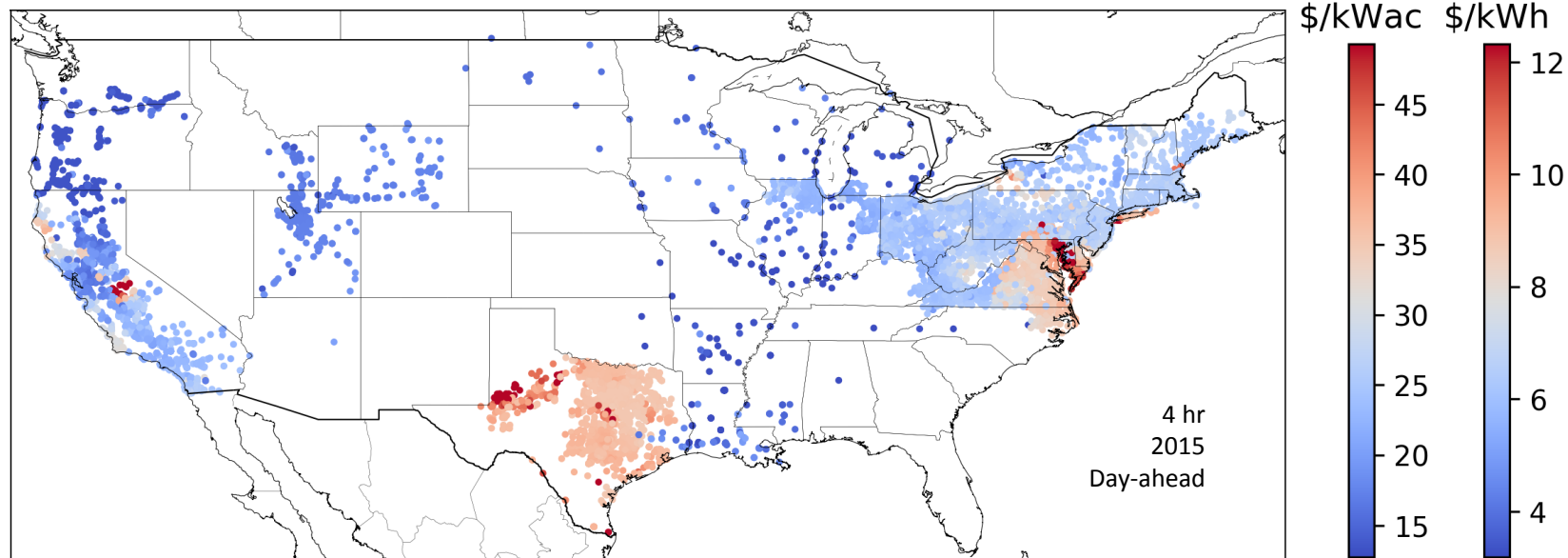


**Active demand management**



# Earning a return from energy arbitrage is very challenging with today's storage economics – Opportunities do exist, but the market is very dynamic

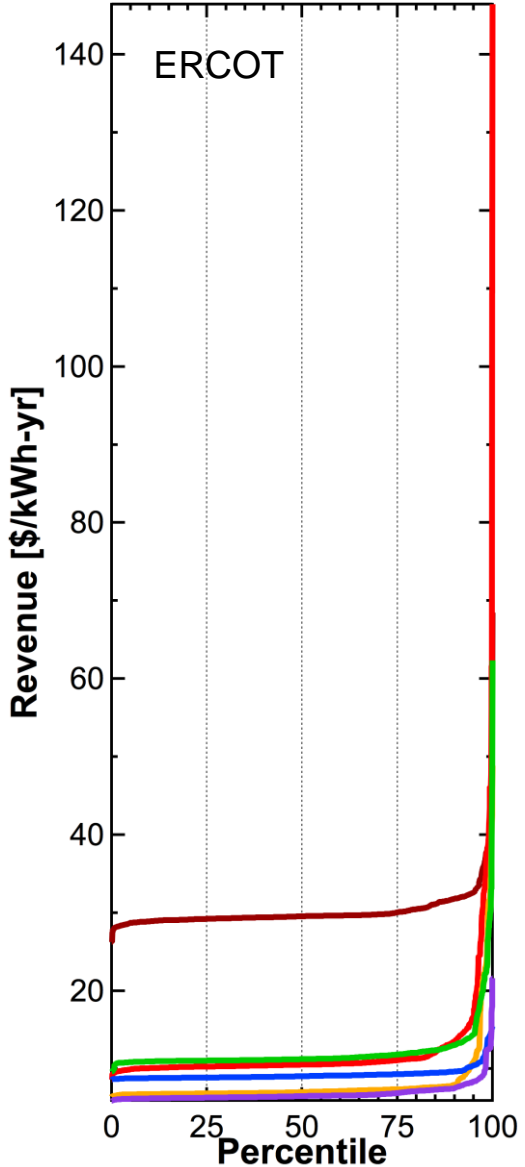
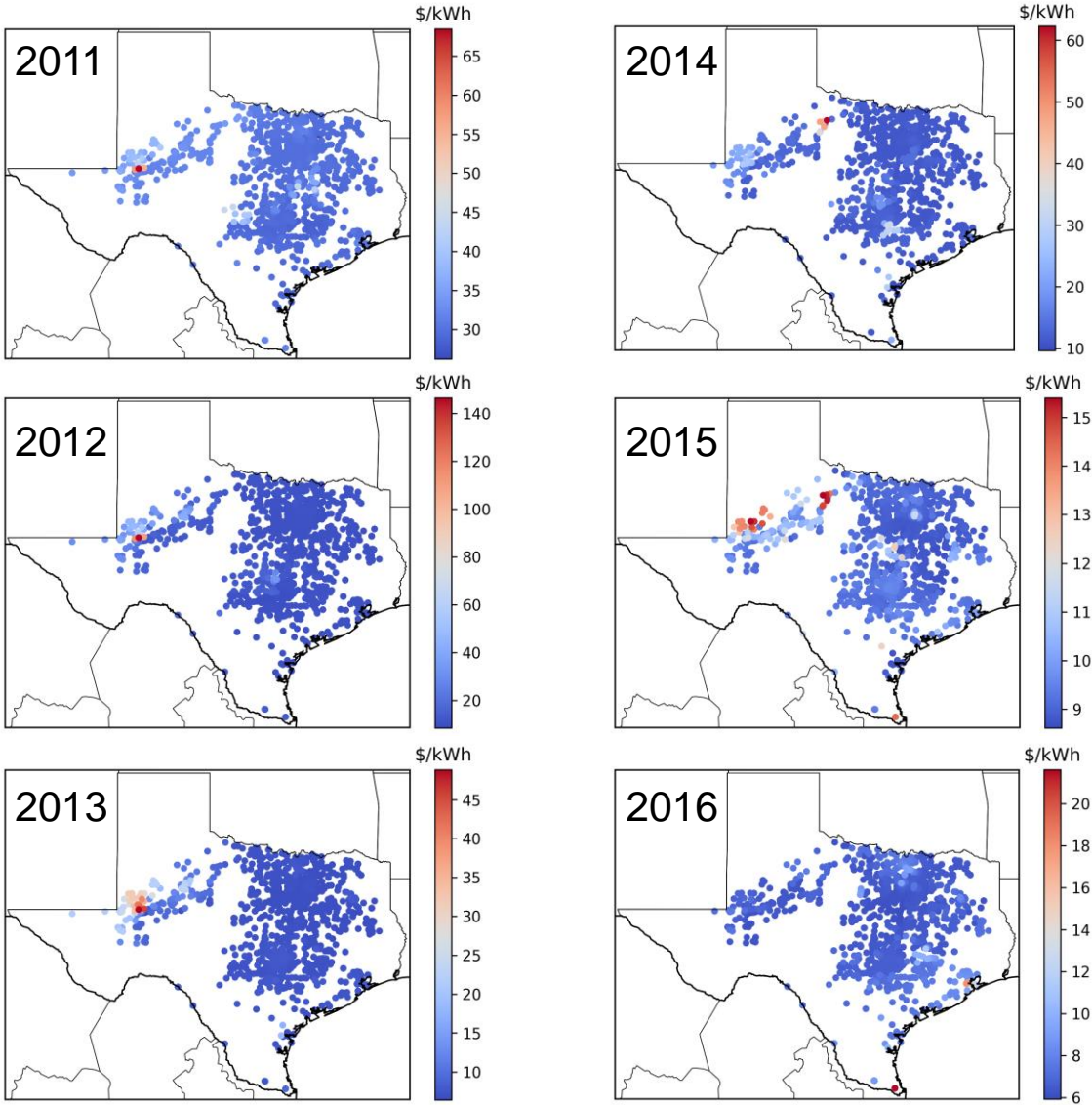
Assessment of energy arbitrage value across U.S. ISOs



Source: MIT Analysis, P. Brown

# ERCOT offers an interesting example of how storage economics are sensitive to market volatility and transmission infrastructure

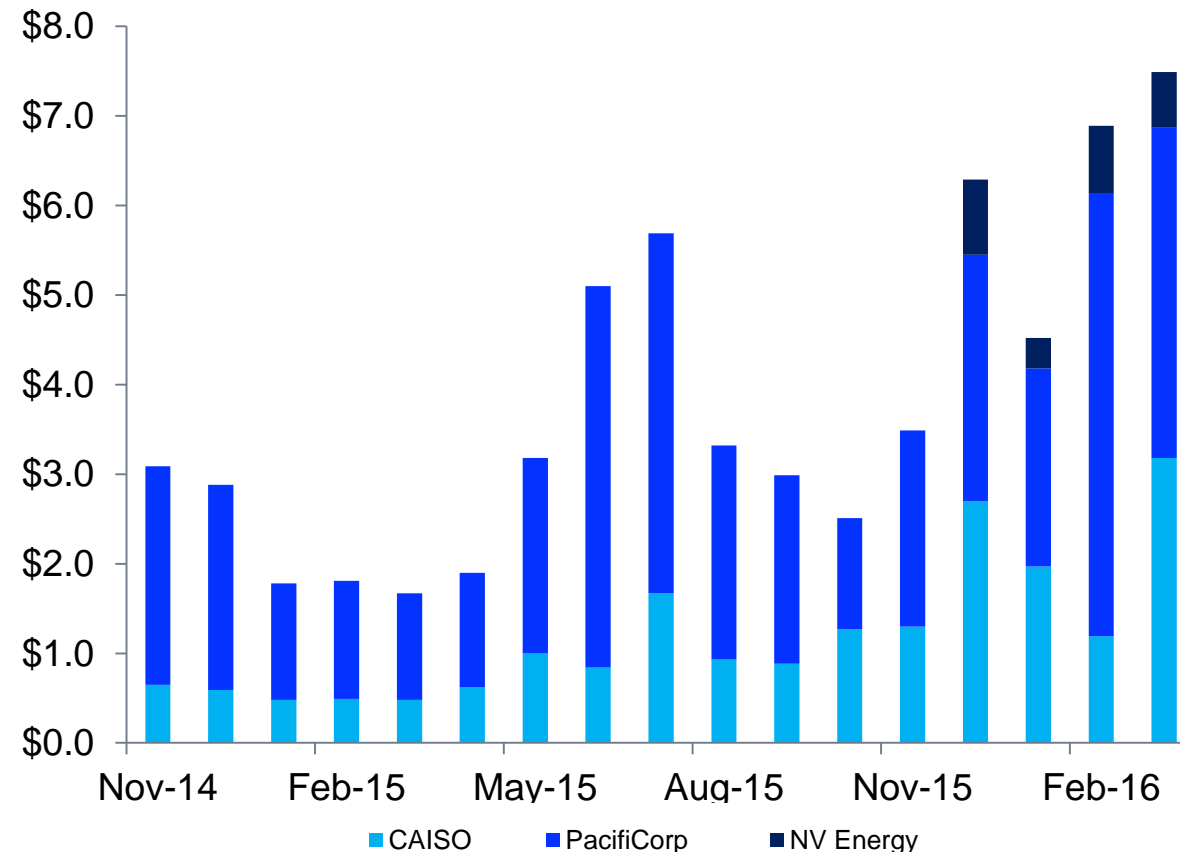
Yearly revenue  
\$/kWh-yr



Source: MIT Analysis, P. Brown

# Some of the challenges of large-scale renewables penetration can be mitigated through market design – The EIM is a small but important example of how thoughtful reform can yield value

**Cost savings arising from EIM integration Q4 '14 to Q1 '16**  
\$ Millions

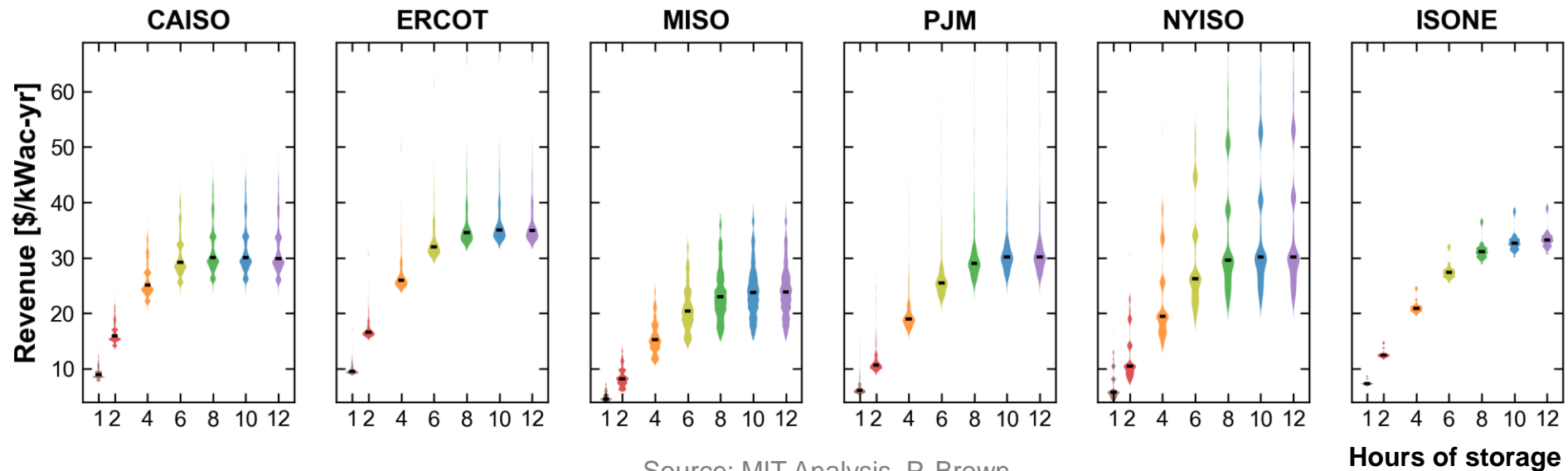
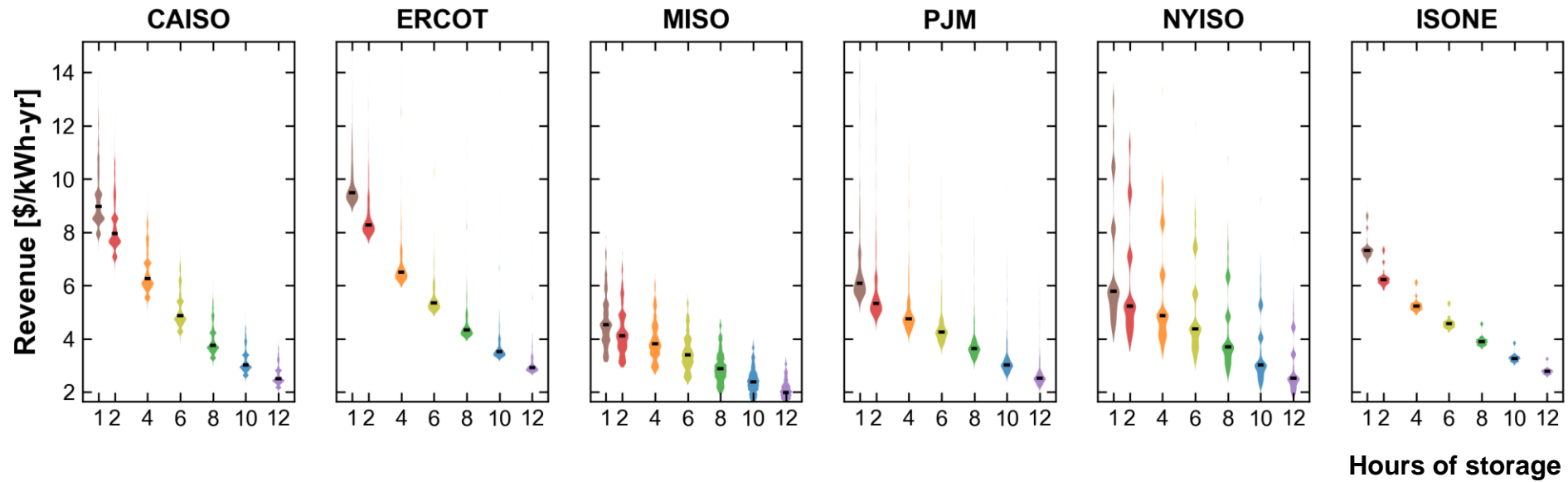


**The Energy Imbalance Market** – A first step towards greater market integration in the Western U.S.

- CAISO’s development of the EIM is aiding the optimization of the real-time dispatch and reducing costs appreciably among 5 participants
  - Estimated \$330M in real-time dispatch savings since November '14
- Aiding California in meeting its renewable energy targets by reducing renewables curtailment
  - Reduced Q1 '17 CA renewables curtailment by 66GWhs
- Demonstrating the value of greater western integration in a manner designed to best integrate high levels of variable resources



# Unsurprisingly, the returns offered by a battery diminish as storage duration increases – From a commercial perspective there is a sweet spot



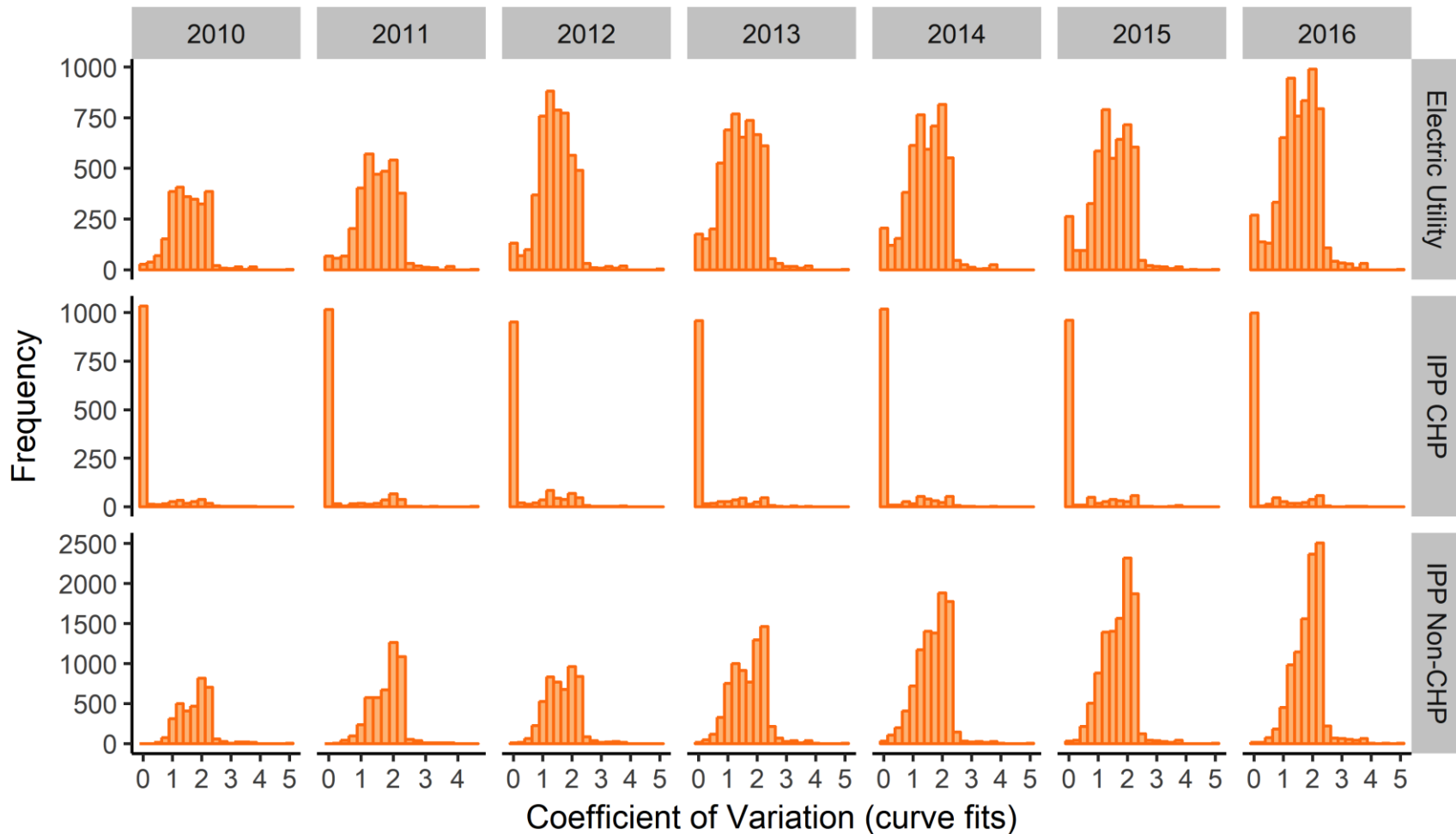
Source: MIT Analysis, P. Brown

# Supplementary Materials

# An important short-term consequence of these changes in the power system is that fact that gas units are being operated more dynamically – Merchant assets in particular have seen a significant change in they are being dispatched

## Assessment of the coefficient of variation of CCGT gas plant dispatch in CAISO

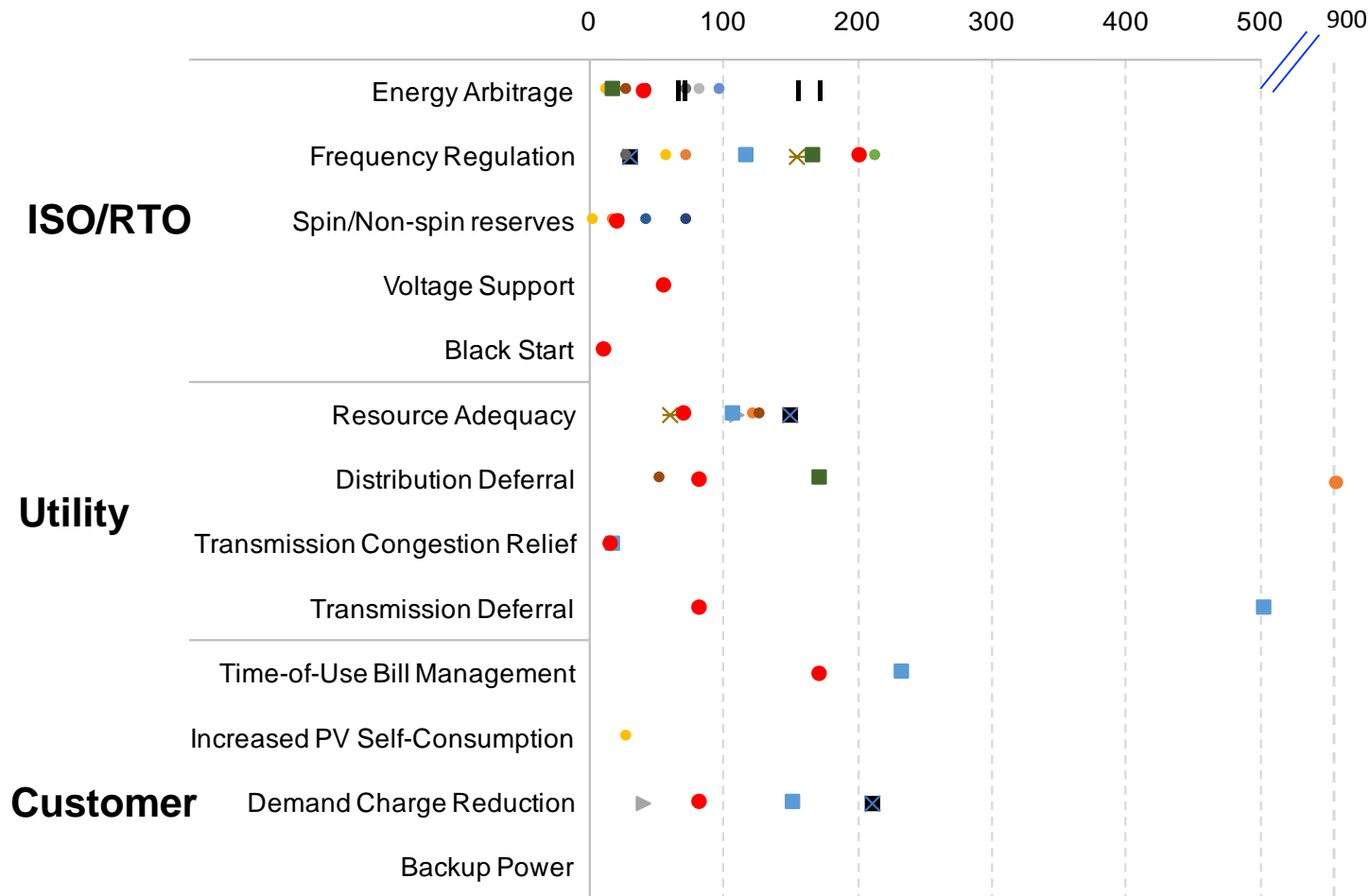
Daily  $\sigma/\mu$



**As solar penetration has risen in CA, the intra-day operation of merchant CCGTs in particular has become much more dynamic**

# Battery storage is one exciting new option for supporting the system's changing needs, but complex barriers remain to monetization

## Service Value \$/kWh-year



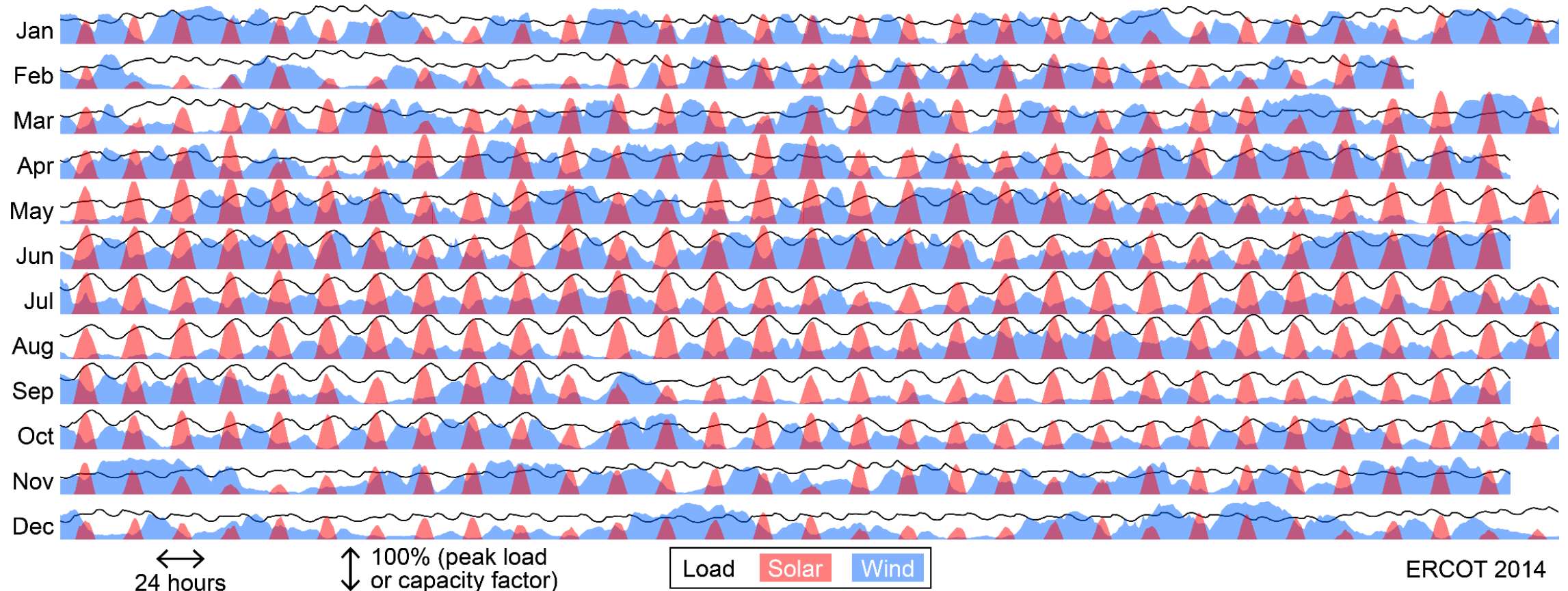
**Stacking storage services enhances the return on investment**

**Possibility of 2-3X increase in asset value**

**Market and regulatory barriers are extensive**

# Tomorrow's power system is going to be much more reliant upon intermittent resources and the operational challenges these bring

Daily variability of wind and solar resource in Texas relative to load in 2014



# How we think about the future of the system is being altered dramatically by new technologies, new business models and changing customer behavior

