Renewables and electricity market design

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11 May 2018

Goal of electricity markets:
Reliable electricity at least cost

Short-run efficiency

Least-cost operation of existing resources

Long-run efficiency

Right quantity and mix of resources

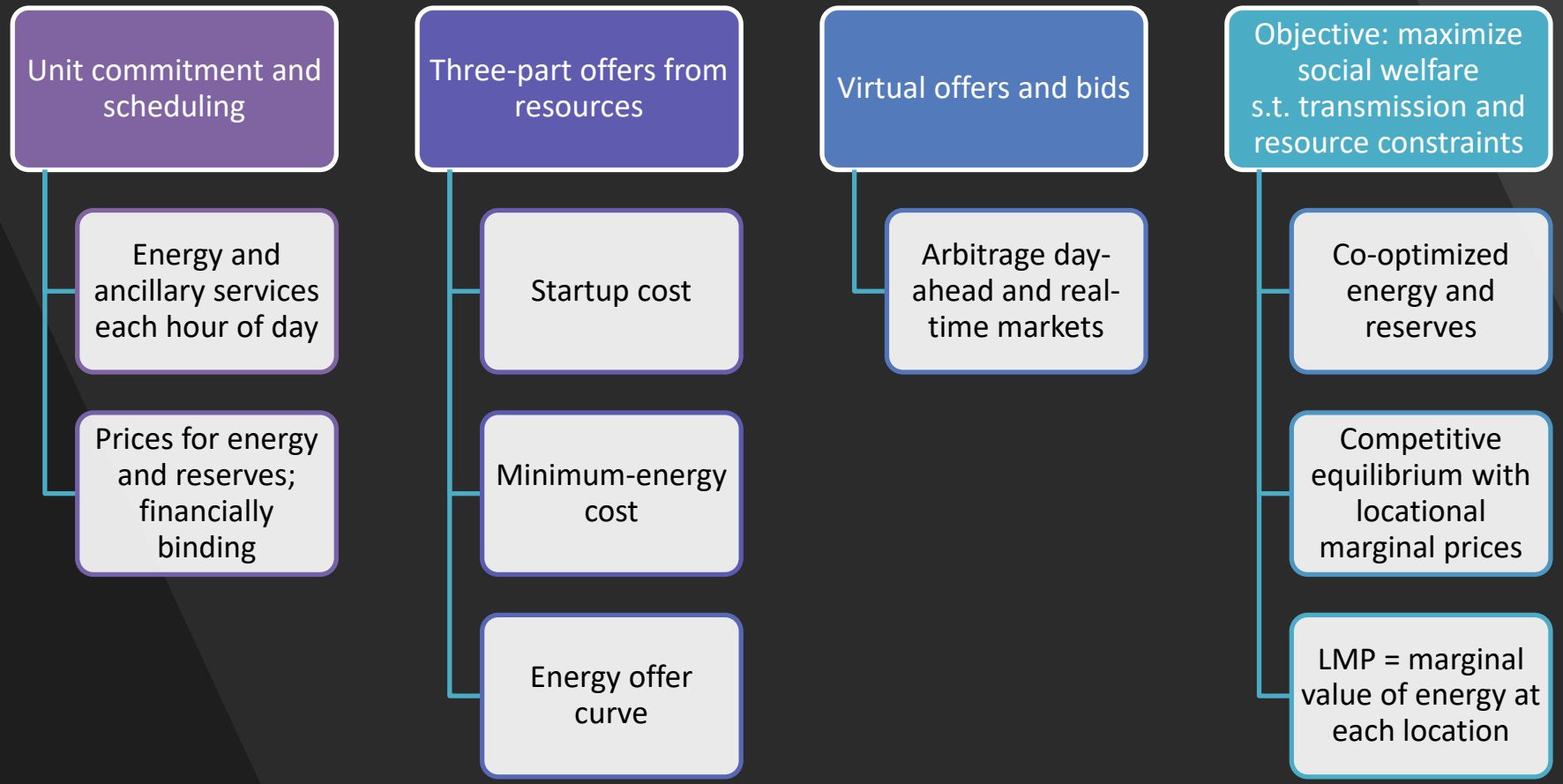
Challenges of electricity markets

- Must balance supply and demand *at every instant*
- Physical constraints of network and resources
- Shocks in supply
  - Transmission line or generator outage
  - Intermittent resources: wind and solar
- Absence of demand response
- Climate policy

A successful market design

- Get the spot market right
  - Day ahead
    - Scheduling and unit commitment
  - Real time
    - Bid-based security constrained economic dispatch
- Forward trade to manage risk and support long-run investment

Day-ahead market



Day-ahead market

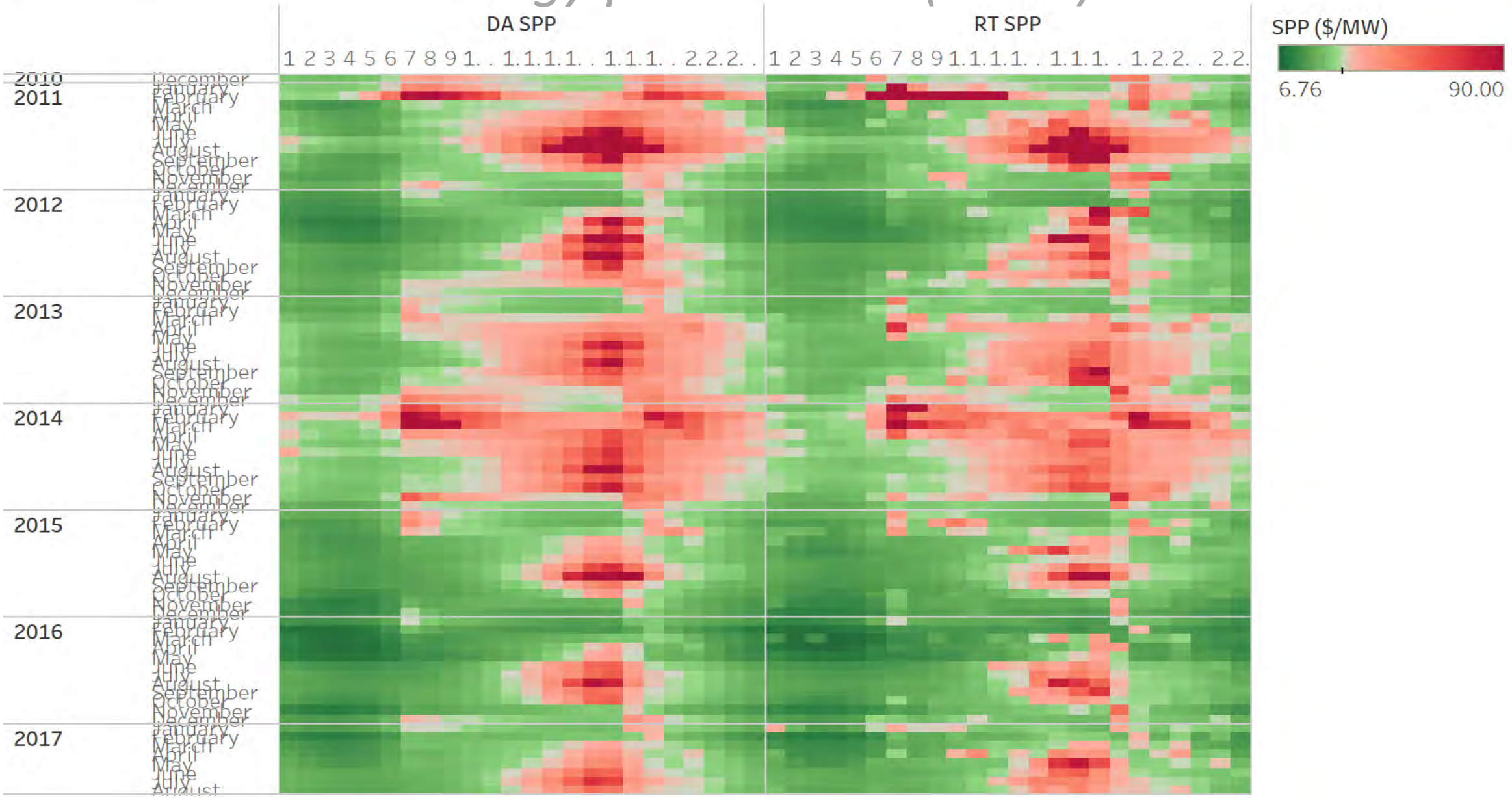
Handling non-convexities, such as startup and minimum energy costs

- If total cost of unit not covered by energy & reserve revenue, then unit gets make-whole payment for shortfall
- Make-whole payments small in practice
- LMPs are approximate supporting prices

Procompetitive

- Allows small generators to optimally schedule
- Allows small participants to hedge real-time risk

Energy price ERCOT (Texas)

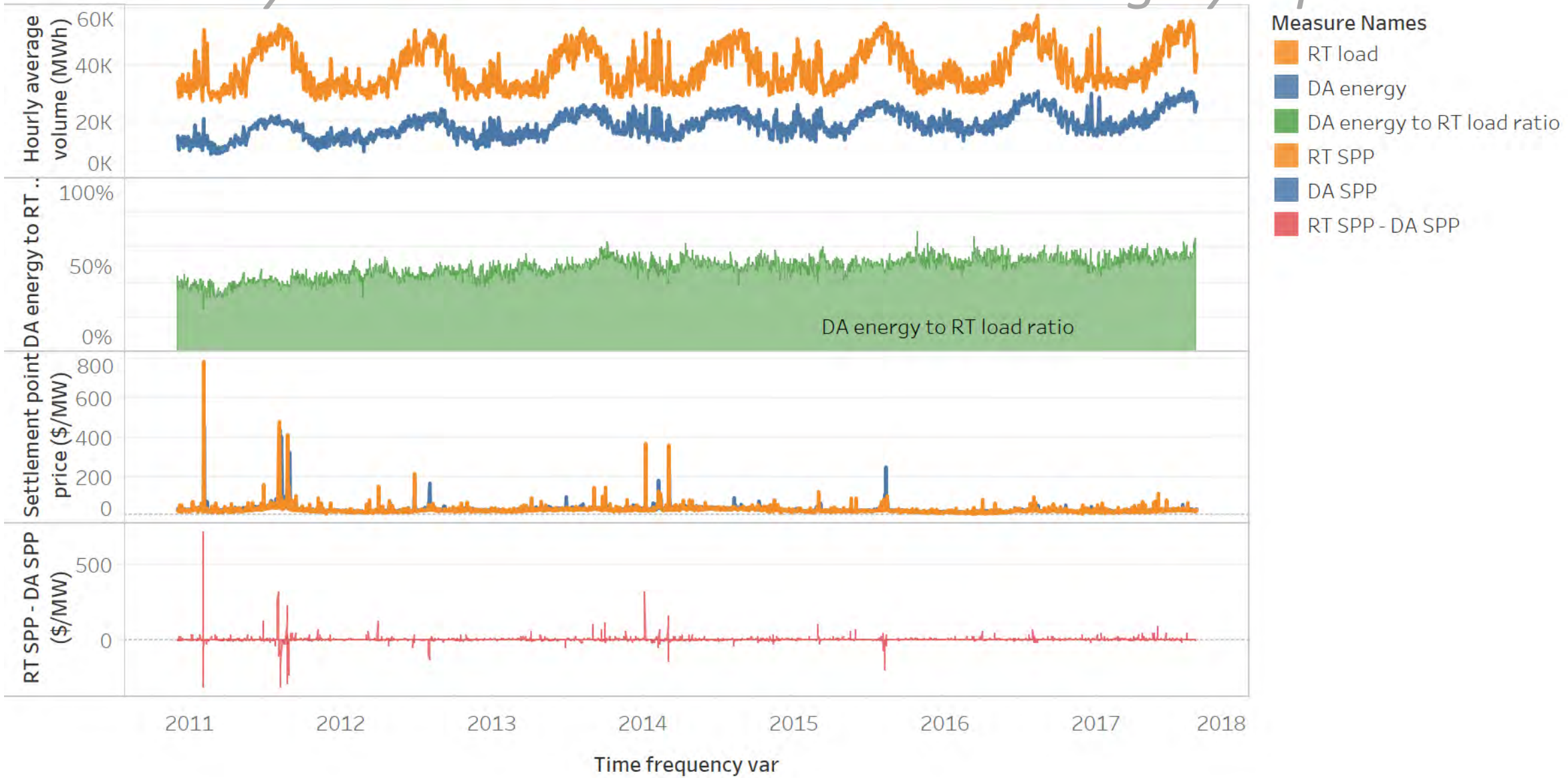


DA SPP and RT SPP (color) broken down by Hour vs. Date Year and Date Month. The view is filtered on Hour, which keeps 24 of 25 members.

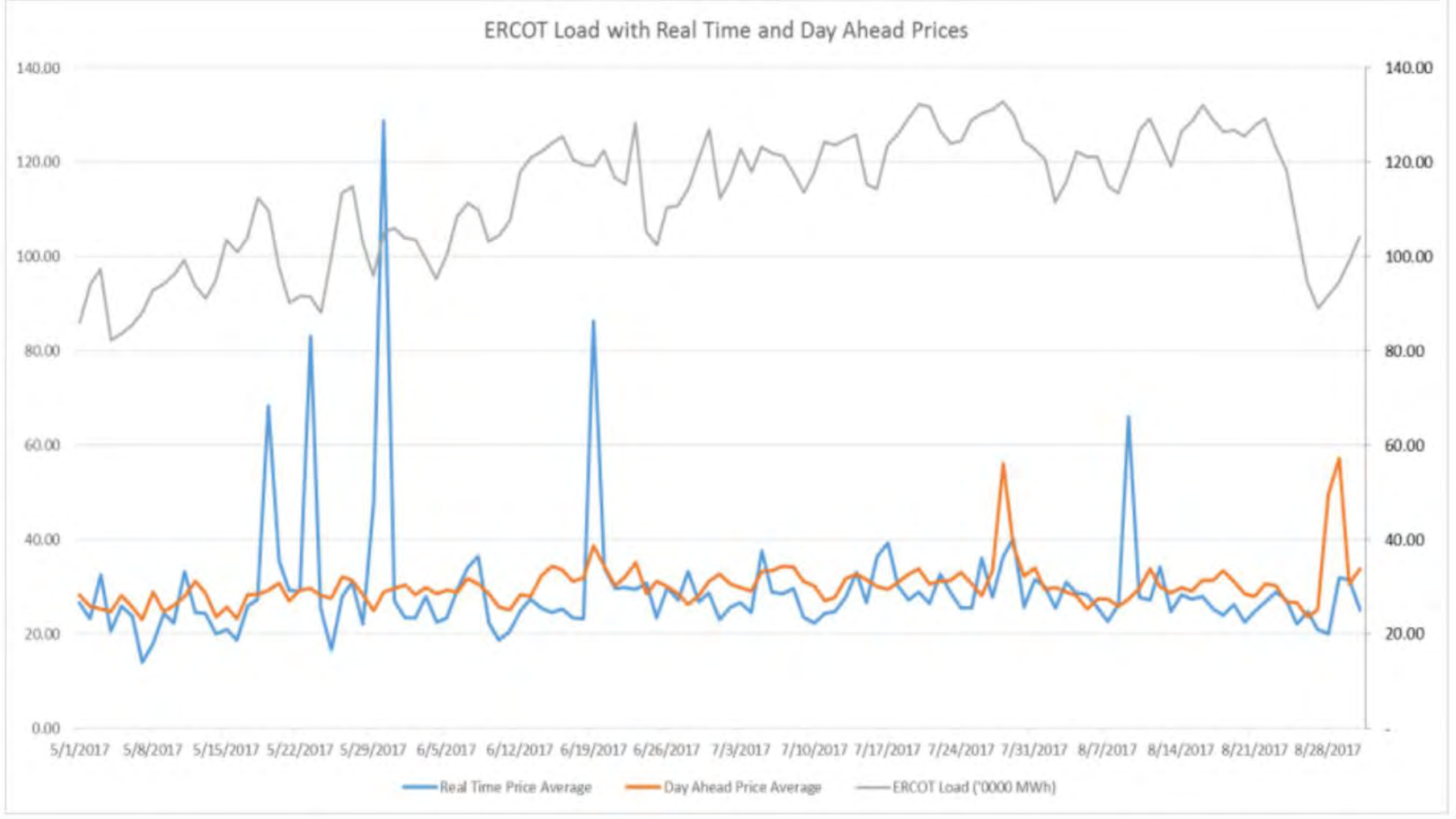
Energy price spikes

The trends of RT SPP, DA SPP, sum of Number of Records and sum of Number of Records for Time frequency var. For pane Average of Rt Spp: Color shows details about RT SPP and DA SPP. For pane Average of Da Spp: Color shows details about RT SPP and DA SPP. For pane Sum of Number of Records (2): Color shows details about DA SPP spike. For pane Sum of Number of Records: Color shows details about RT SPP spike.

Day-ahead and real-time markets highly liquid



The trends of DA energy, RT load , DA energy to RT load ratio, DA SPP, RT SPP and RT SPP - DA SPP for Time frequency var. Color shows details about DA energy, RT load , DA energy to RT load ratio, DA SPP, RT SPP and RT SPP - DA SPP. The marks are labeled by DA energy, RT load , DA energy to RT load ratio, DA SPP, RT SPP and RT SPP - DA SPP.


ERCOT Load with Real Time and Day Ahead Prices
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
5/1/2017
5/8/2017
5/15/2017
5/22/2017
5/29/2017
6/5/2017
6/12/2017
6/19/2017
6/26/2017
7/3/2017
7/10/2017
7/17/2017
7/24/2017
7/31/2017
8/7/2017
8/14/2017
8/21/2017
8/28/2017
Real Time Price Average
Day Ahead Price Average
ERCOT Load ('0000 MWh)

Transmission Damage

STP-to-Whitepoint 345-kV transmission structures

Tatton Substation

- **52 inches** of rainfall in southeast Texas
- Harvey made landfall **multiple times**
  - **Category 4** near Port Aransas, Texas
  - **Tropical storm** in Cameron, Louisiana
- More than **42,000** lightning strikes
- Record number of tornado warnings in southeast Texas

Operating plan and adjustment period

- Generator submits operating plan for each resource
  - Online/offline, constraints
- Until 60 minutes before operating hour, plan can be adjusted
- System operator may commit additional resources for reliability, but these have a high offer floor ($1500/MWh)

Real-time market

Security constrained economic dispatch

Determines optimal dispatch and prices every five minutes

Financially and physically binding

Allows efficient settlement from forward positions

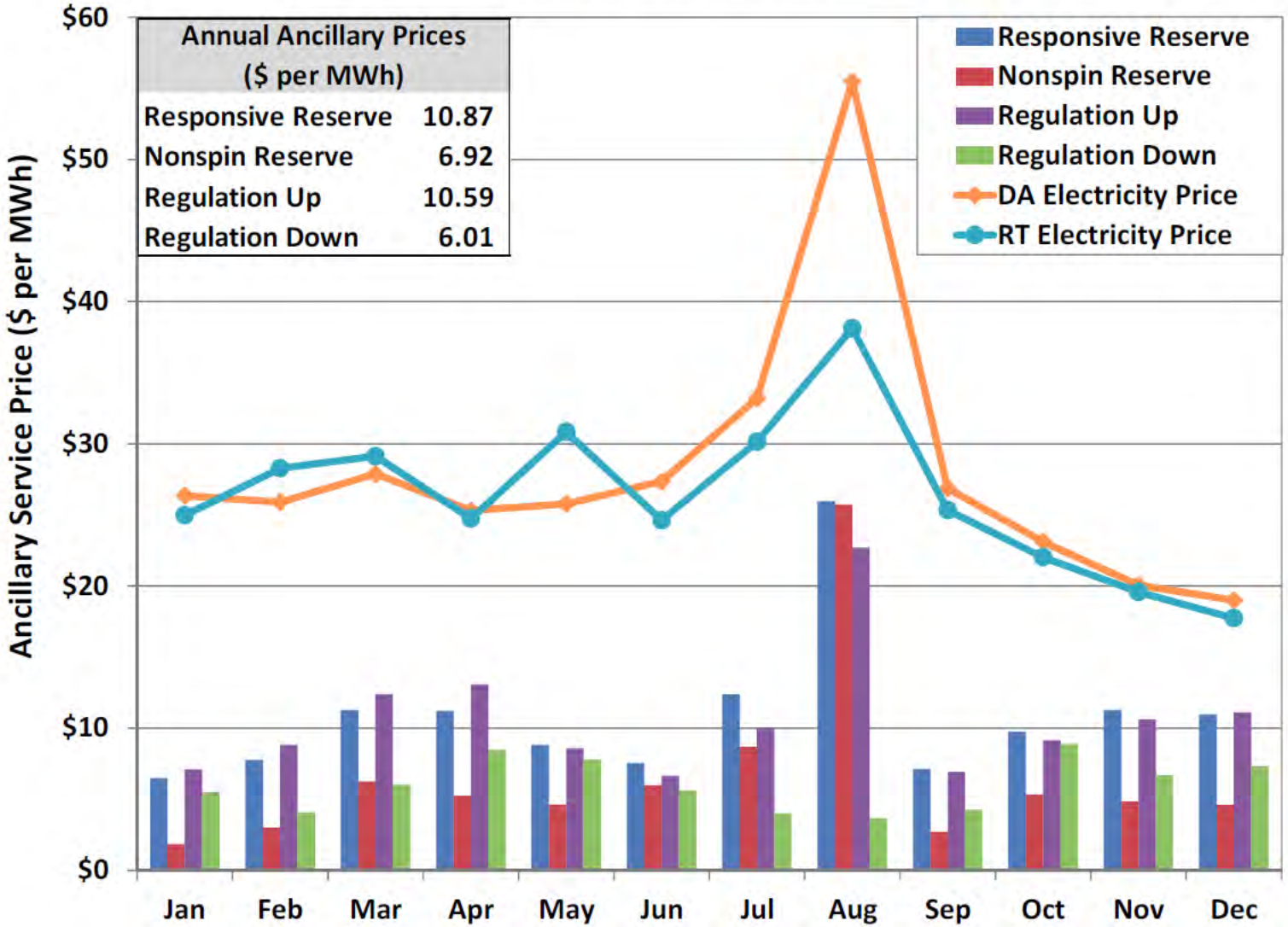
Ancillary services

Address supply/demand uncertainty:

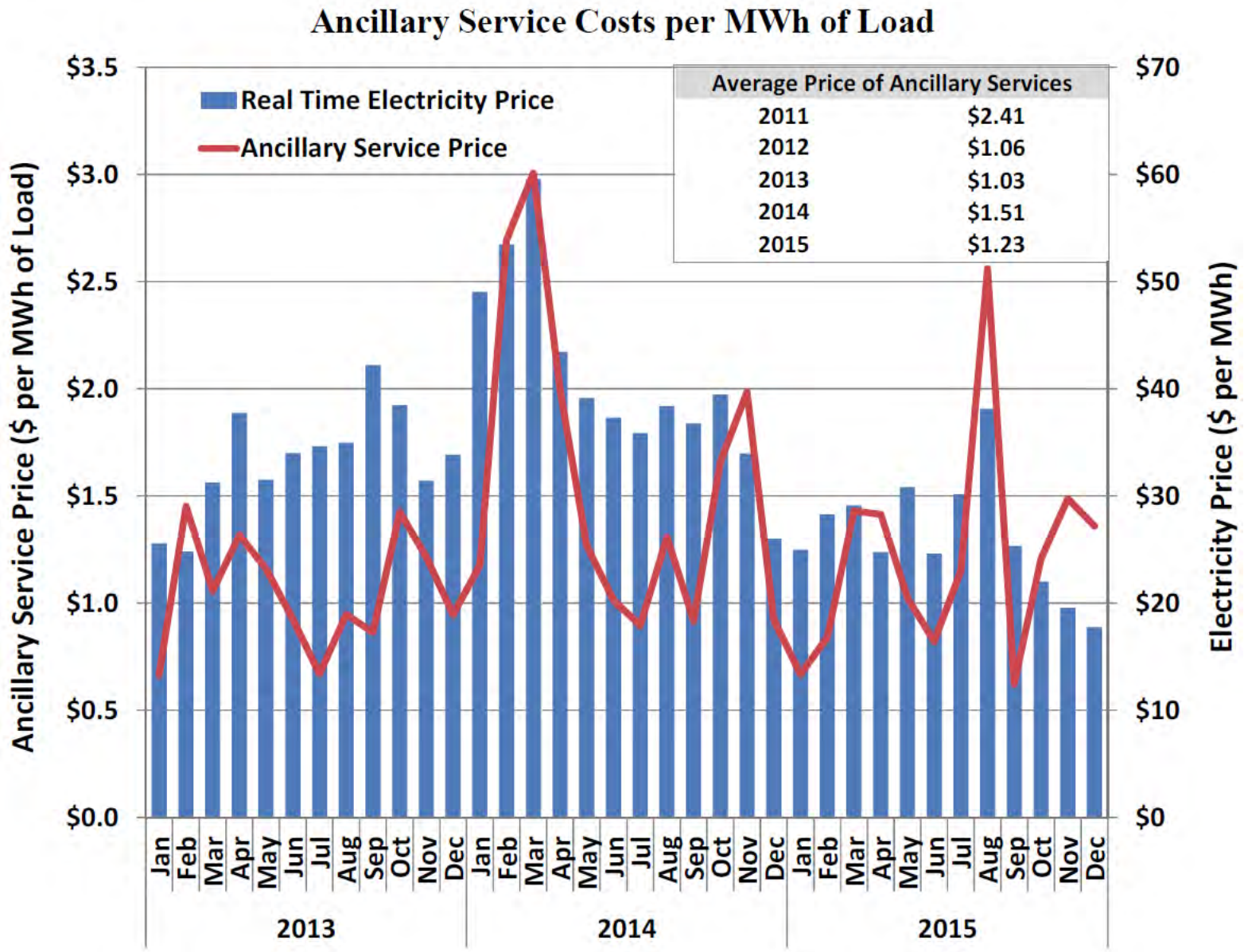
- Regulation: online, responds in second
  - Reg up, Reg down to maintain frequency of 60 Hz
- Responsive reserve: online, 10min response
- Non-spinning reserve: offline, 30min response

Need for reserves depends on market;
products and quantities reviewed periodically

Ancillary Service Prices



Source: Potomac Economics

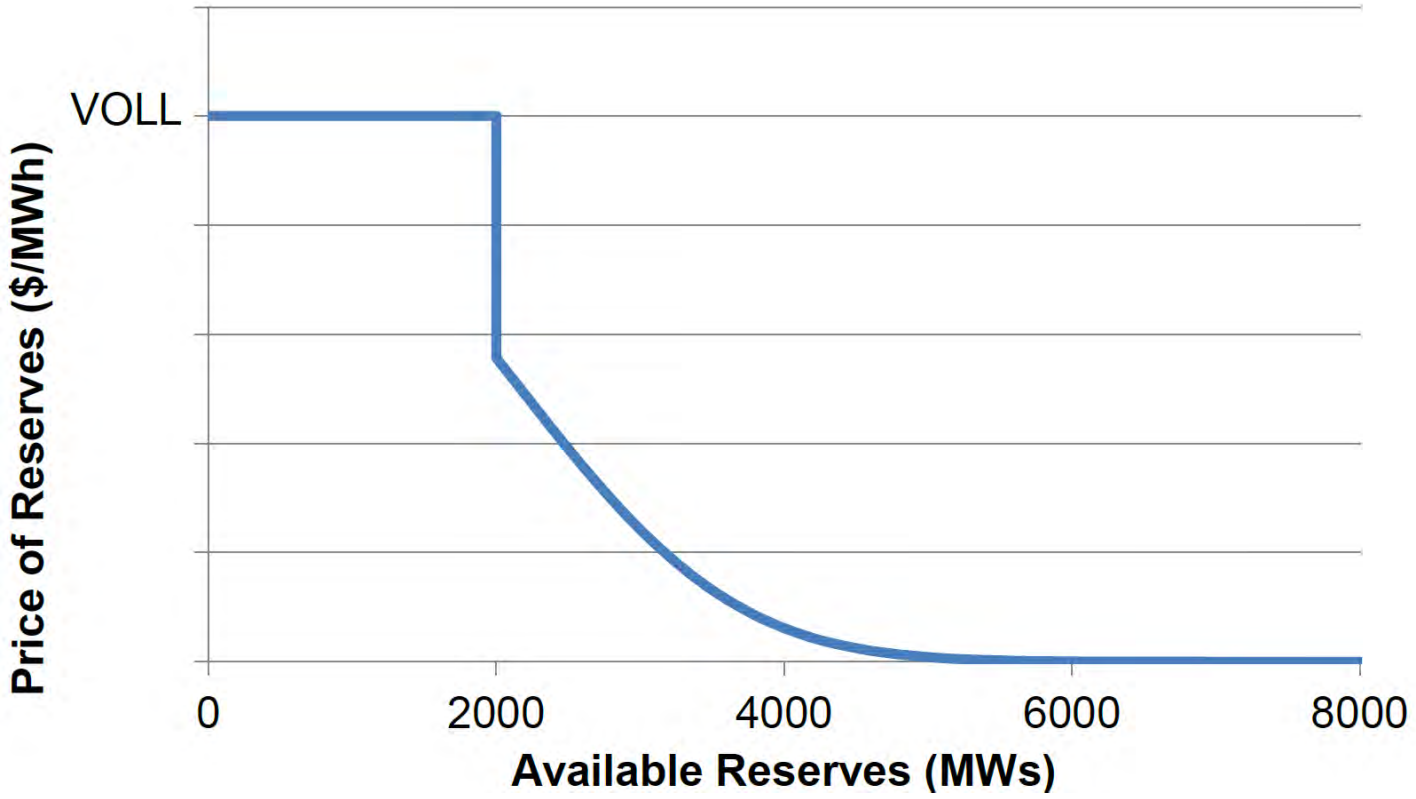


Source: Potomac Economics

Scarcity pricing

- Reserves have value in avoiding load shedding
- Marginal value of reserves depends on
  - Value of Lost Load, e.g. $9000/MWh
  - Probability of Lost Load, e.g. 1 in extreme scarcity
- Load's implicit preference for reliability given by operating reserve demand curve

Operating reserve demand curve



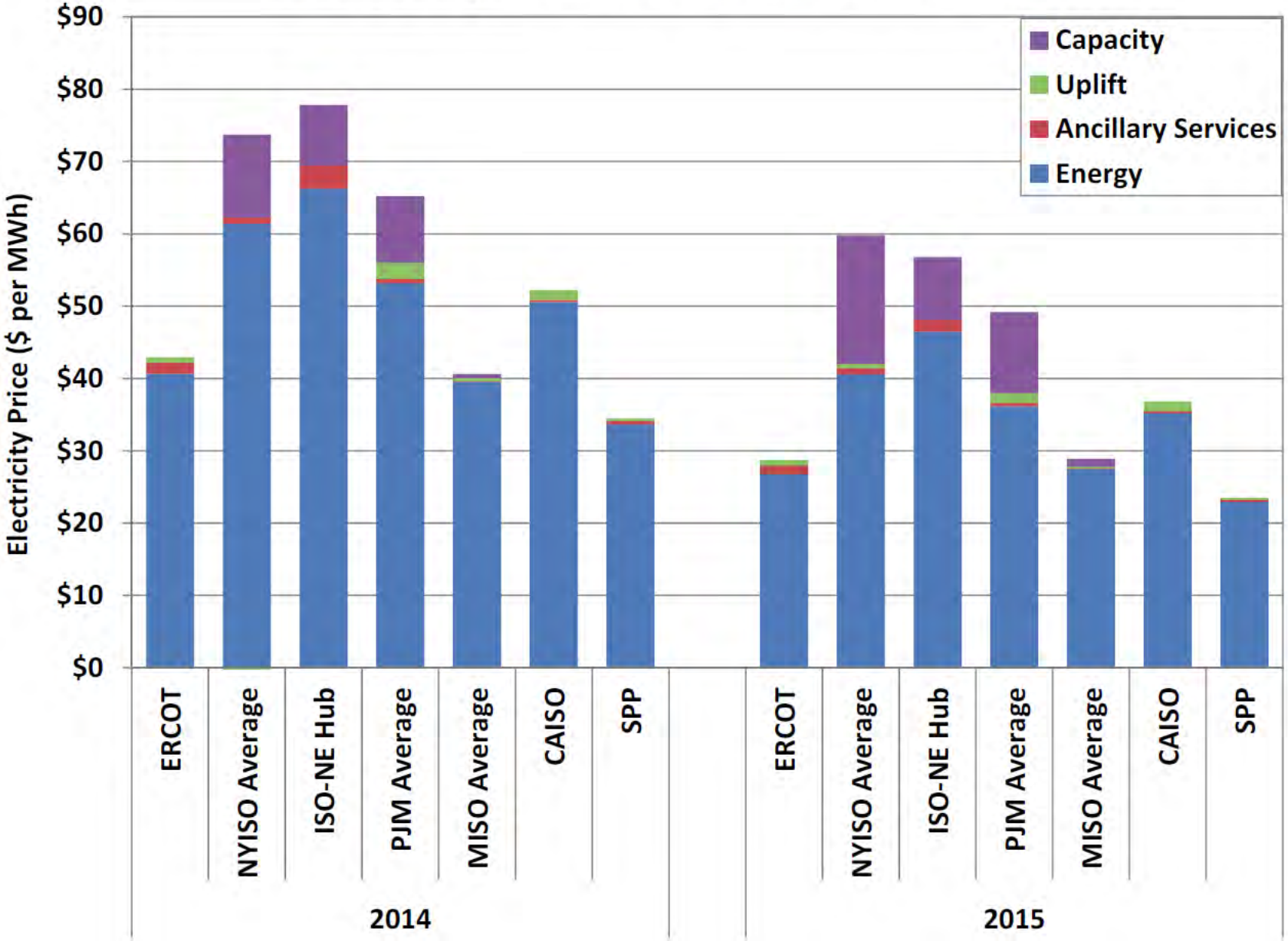
Forward contracts

- Forward contracts are essential to manage risk
  - California energy crisis 2000-2001
  - Forward provides hedge for load
  - Generator + fuel contract provides physical hedge for supply
- Scarcity pricing motivates forward contracts
- Forward contracting improves bidding incentives
- Congestion revenue rights are forwards in congestion rents

Capacity market

- ERCOT is “energy only”; some others have a capacity market (PJM, ISO-NE, …)
- Good capacity markets rely on scarcity pricing, just like energy only market
- Buy enough in advance
  - Conducted several years in advance, so new entry can compete before costs are sunk
  - Product is ability to deliver energy during scarcity
  - Strong performance obligation
    - Financial obligation to provide energy during scarcity
    - Provides hedge to load from scarcity prices
  - Coordinated investment to ensure adequate resources

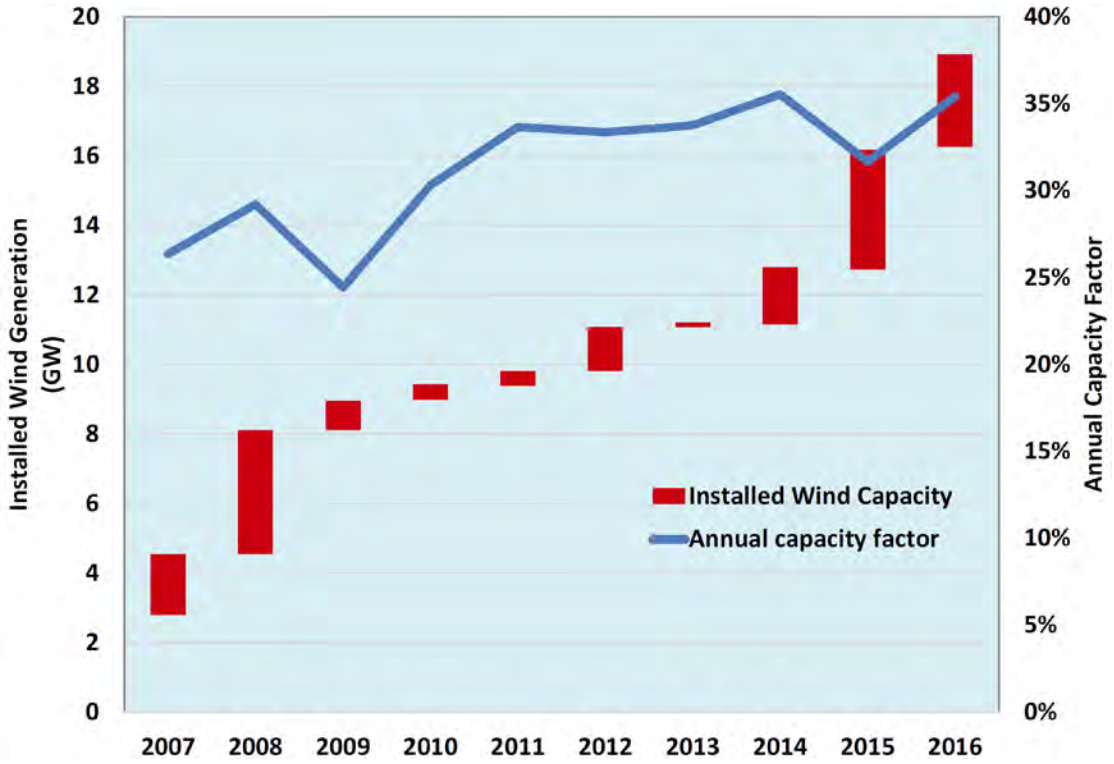
Figure 5: Comparison of All-in Prices Across Markets



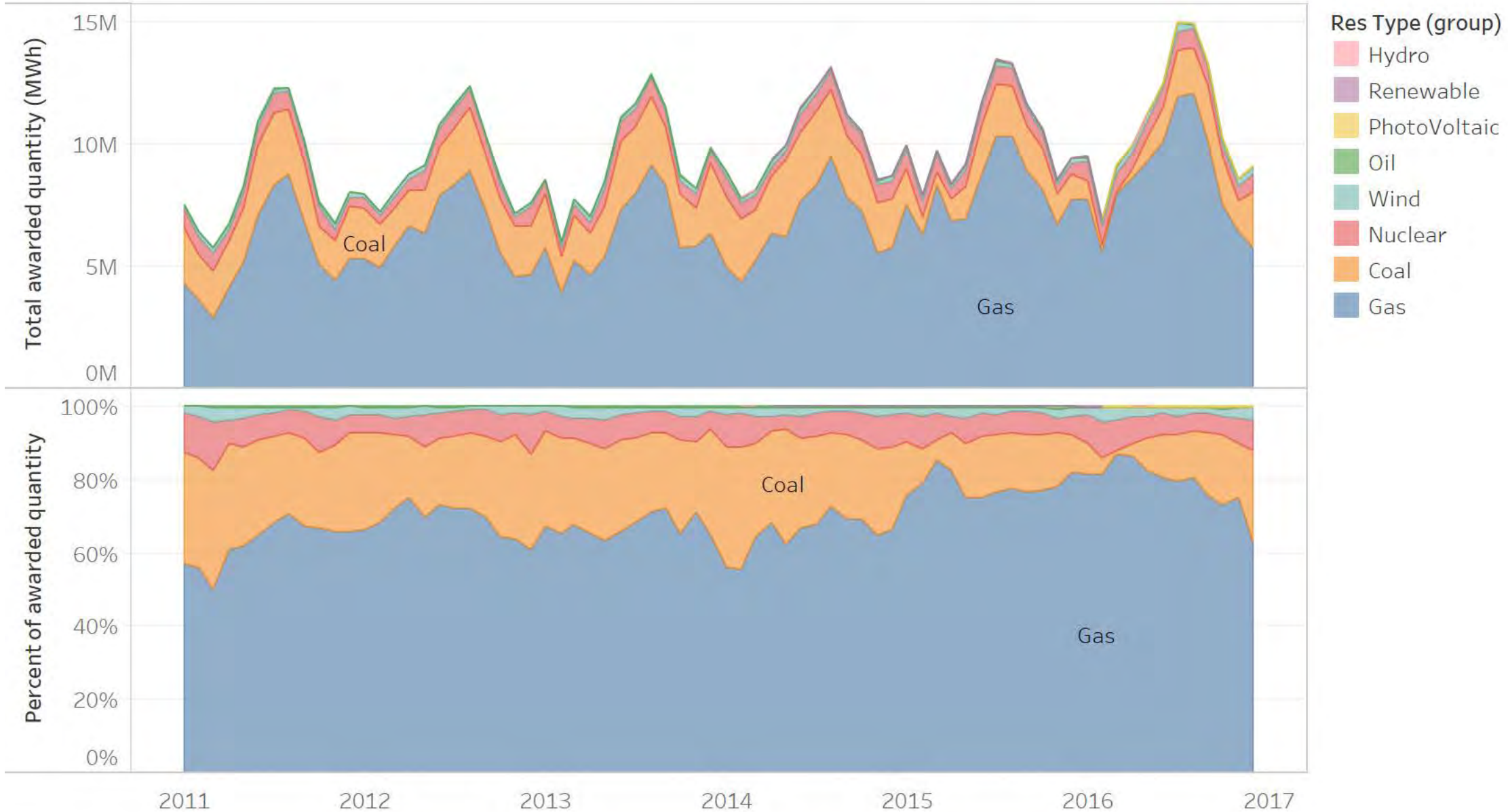
Source: Potomac Economics

Transformation to renewables

- Last year 60% of new capacity in US is wind and solar
- Coal hasn't been built in years
- Intermittent supply, zero marginal cost, no inertia
  - More uncertainty, worse price formation, faster response needed
  - Also best sites not where load is; transmission issues
- Today's design easily handles moderate share of wind


Installed Wind Generation (GW)
Annual Capacity Factor
20
18
16
14
12
10
8
6
4
2
0
40%
35%
30%
25%
20%
15%
10%
5%
0%
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Installed Wind Capacity
Annual capacity factor

TPO: mix



The plots of sum of Awarded Qty and % of Total Awarded Qty for Date Month. Color shows details about Res Type (group). The marks are labeled by Res Type (group). The data is filtered on Date Year, which excludes 2010 and 2017.

Solution looking forward

- But what if >80% renewable
- Core design still works well
- *Battery storage* and more *demand response* (smart homes) will complement wind, solar
  - Flexible, smooth prices

Need to encourage technology-neutral solutions!

Enable demand response with good *default retail contract*

- Each customer has smart meter
- System operator estimates demand of customer
- System operator buys forward estimated demand
- Real-time deviations settled at real-time price
- Customer can opt out of default

Incoherent and unstable climate policy

- Policy built on myriad of changing subsidies and emission restrictions makes planning difficult
- Uncertainty harms investment
- Policy based on carbon price would greatly reduce uncertainty
- Carbon price is a critical input in investment and retirement decision

Conclusion

- Electricity good example of the power of market design
  - Highly efficient spot market
  - Supporting extensive forward contracting
  - Competitive retail market to foster demand response
- Good governance remains important to make sure market design continues to improve and addresses new challenges like the transition to renewables