Renewable energy and electricity market design

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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

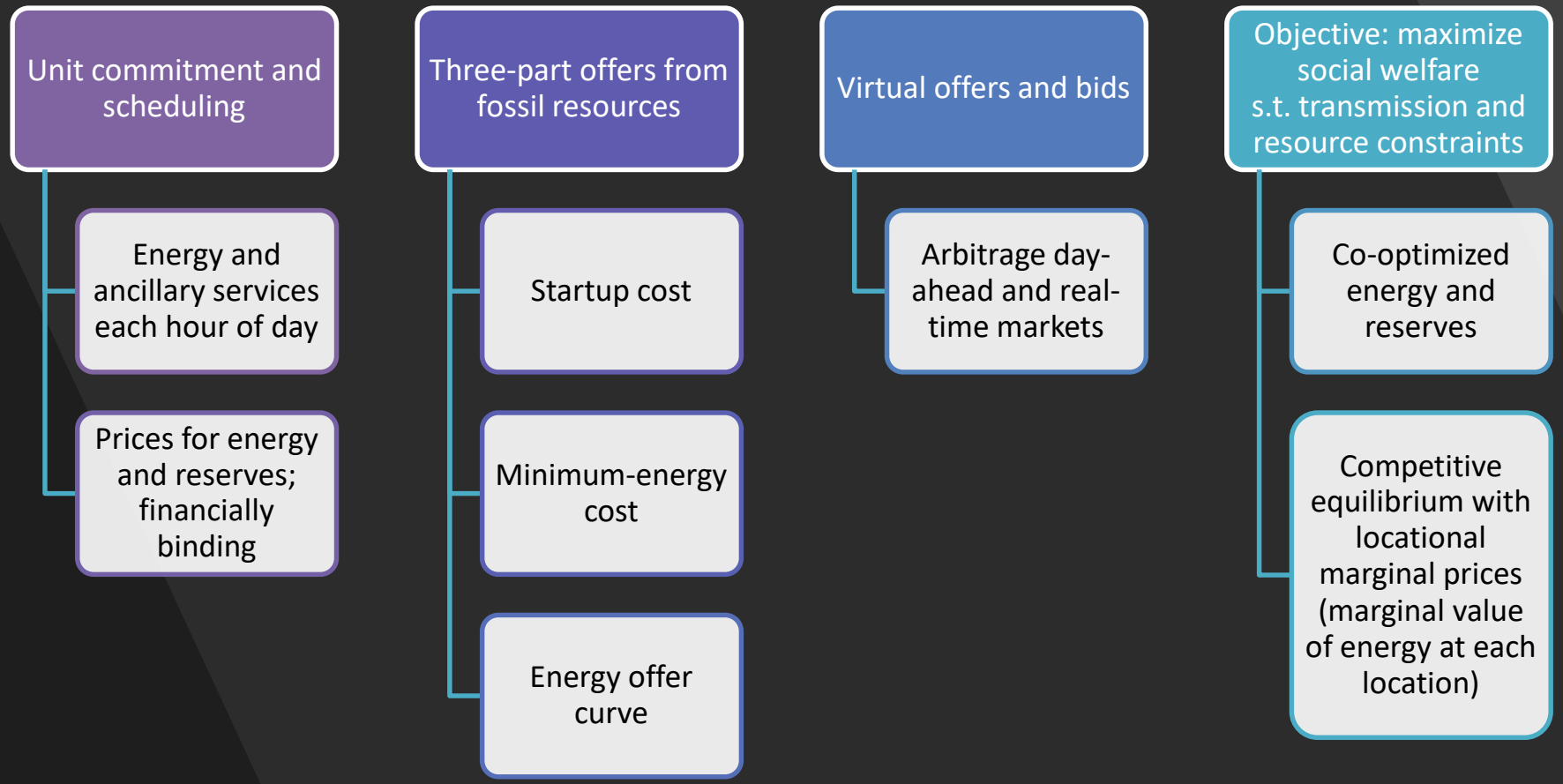
Challenges of electricity markets

- 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

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)

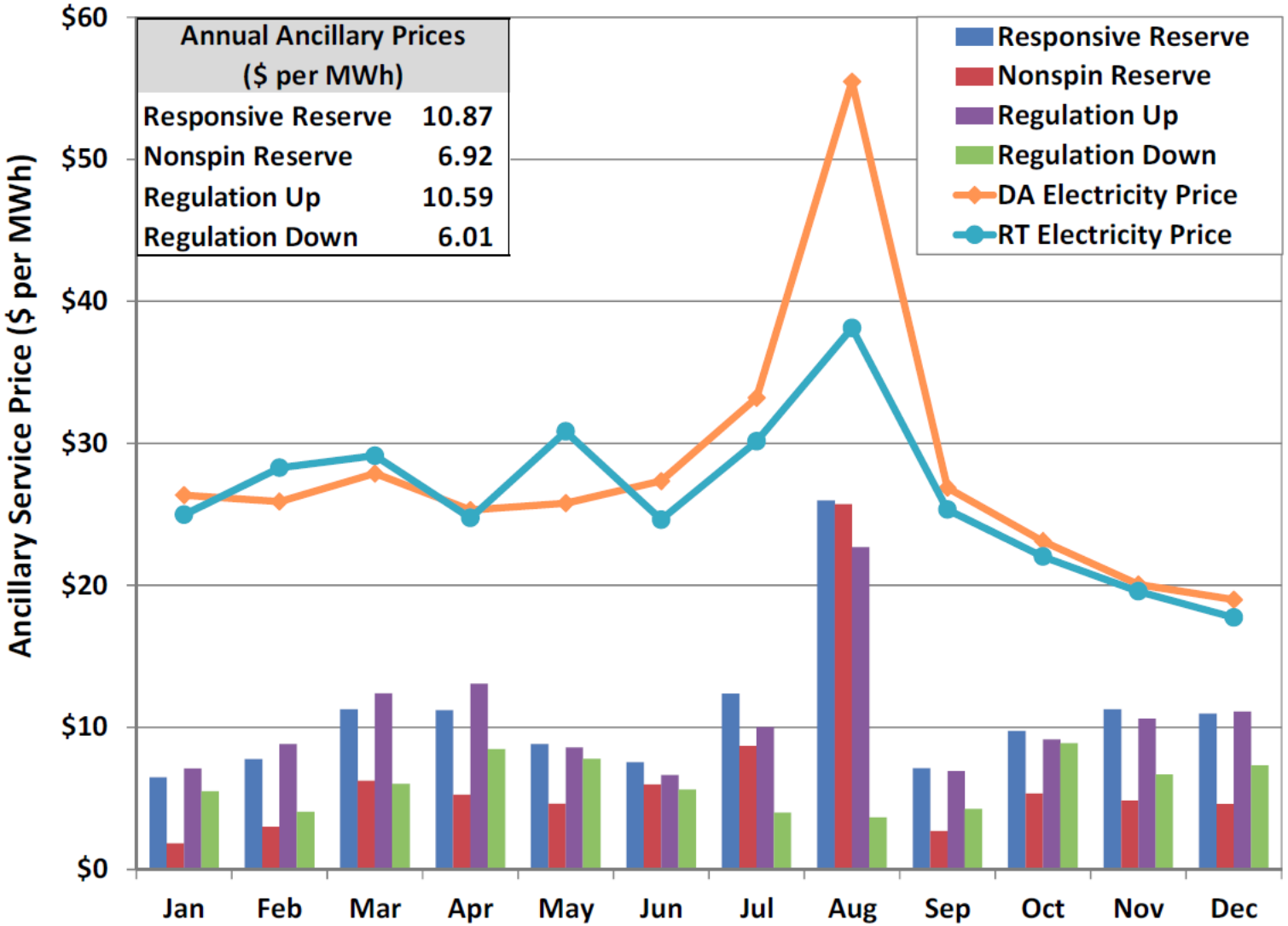
Ancillary services

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

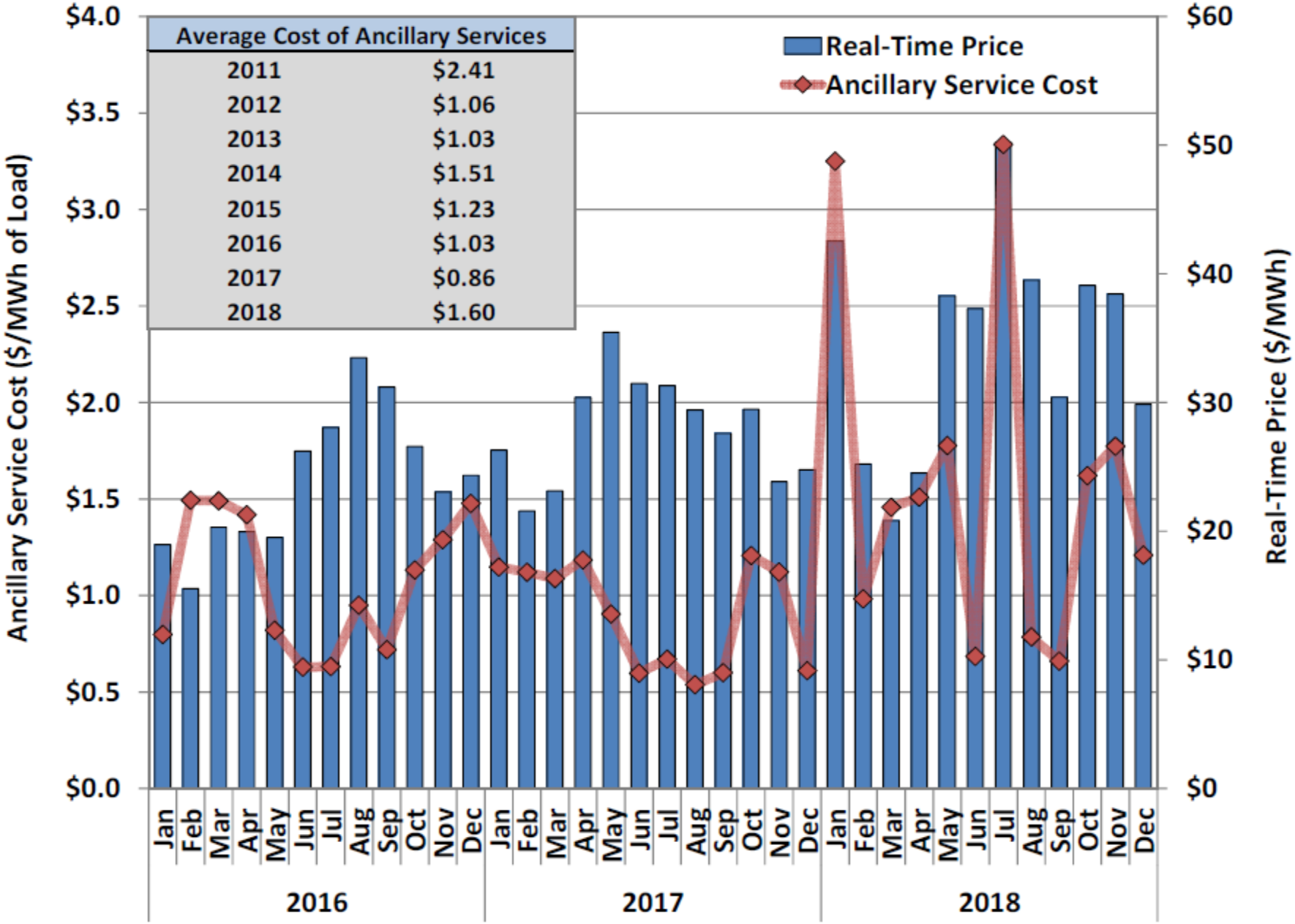
Ancillary Service Prices



Source: Potomac Economics

Figure 37: Ancillary Service Costs per MWh of Load

Average Cost of Ancillary Services	
2011	$2.41
2012	$1.06
2013	$1.03
2014	$1.51
2015	$1.23
2016	$1.03
2017	$0.86
2018	$1.60



Source: Potomac Economics

Real-time market

Security constrained economic dispatch

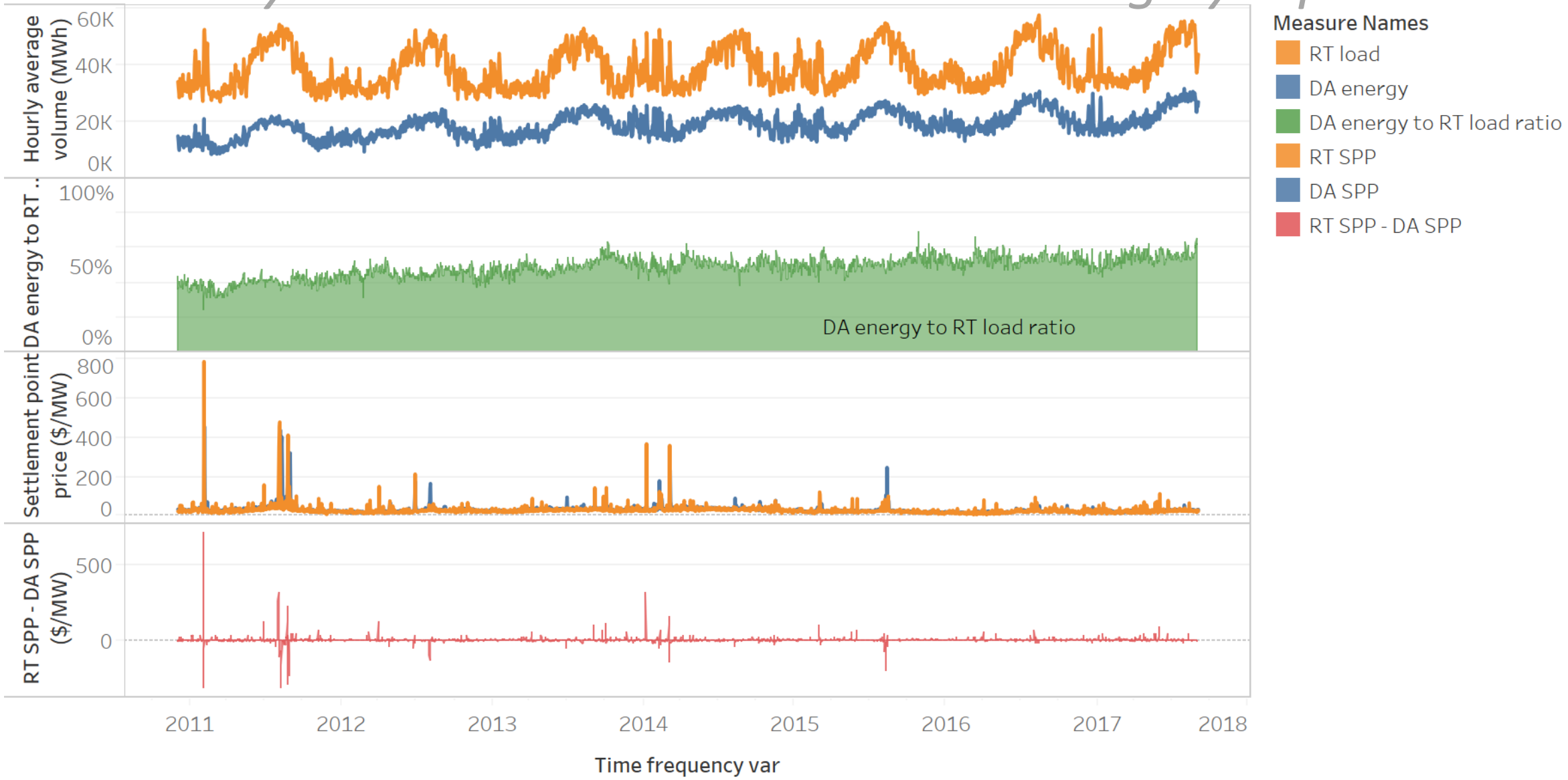
Determines optimal dispatch and prices every five minutes

Financially and physically binding

Allows efficient settlement from forward positions

DA vs RT

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

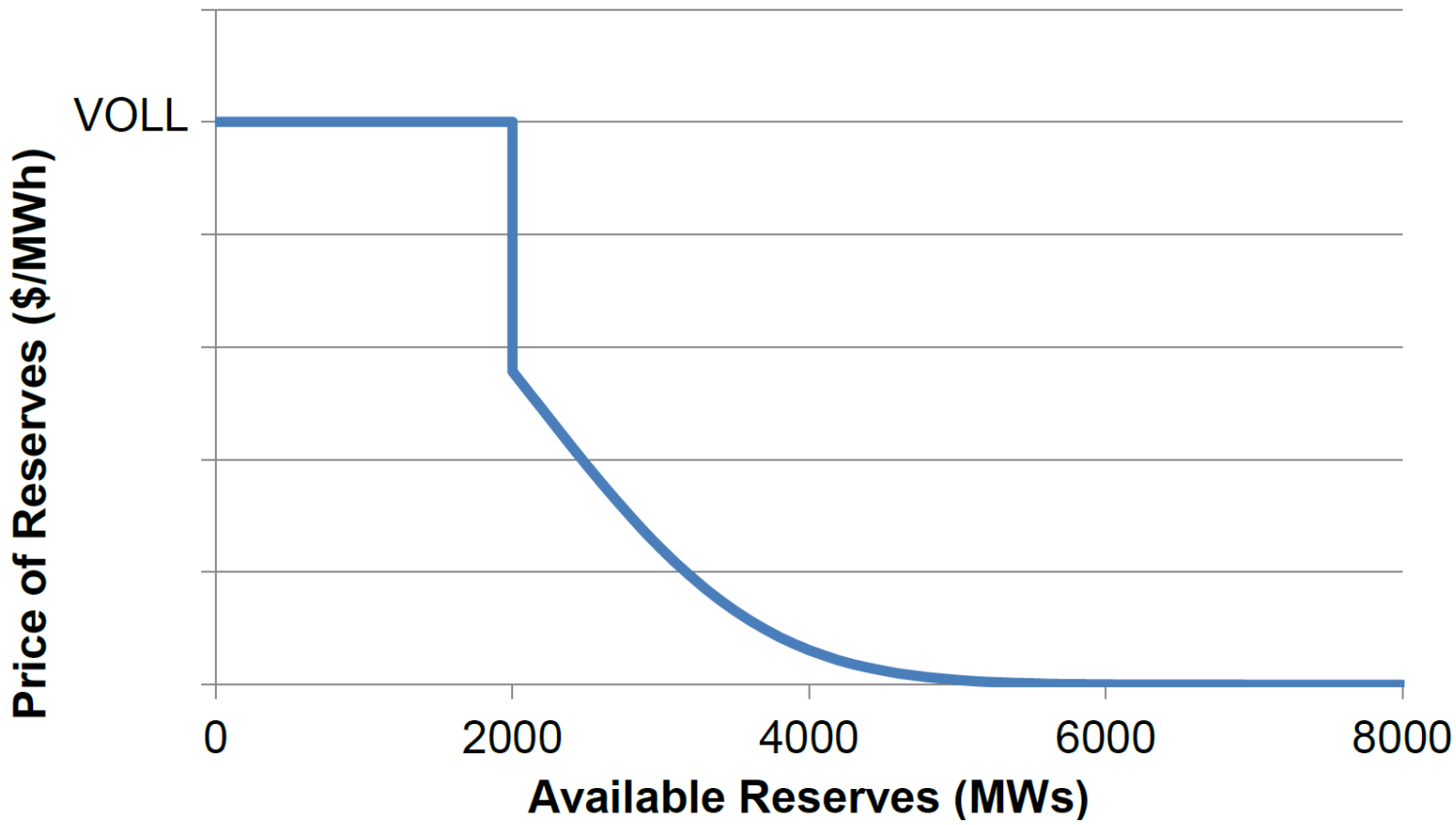
Tatton Substation

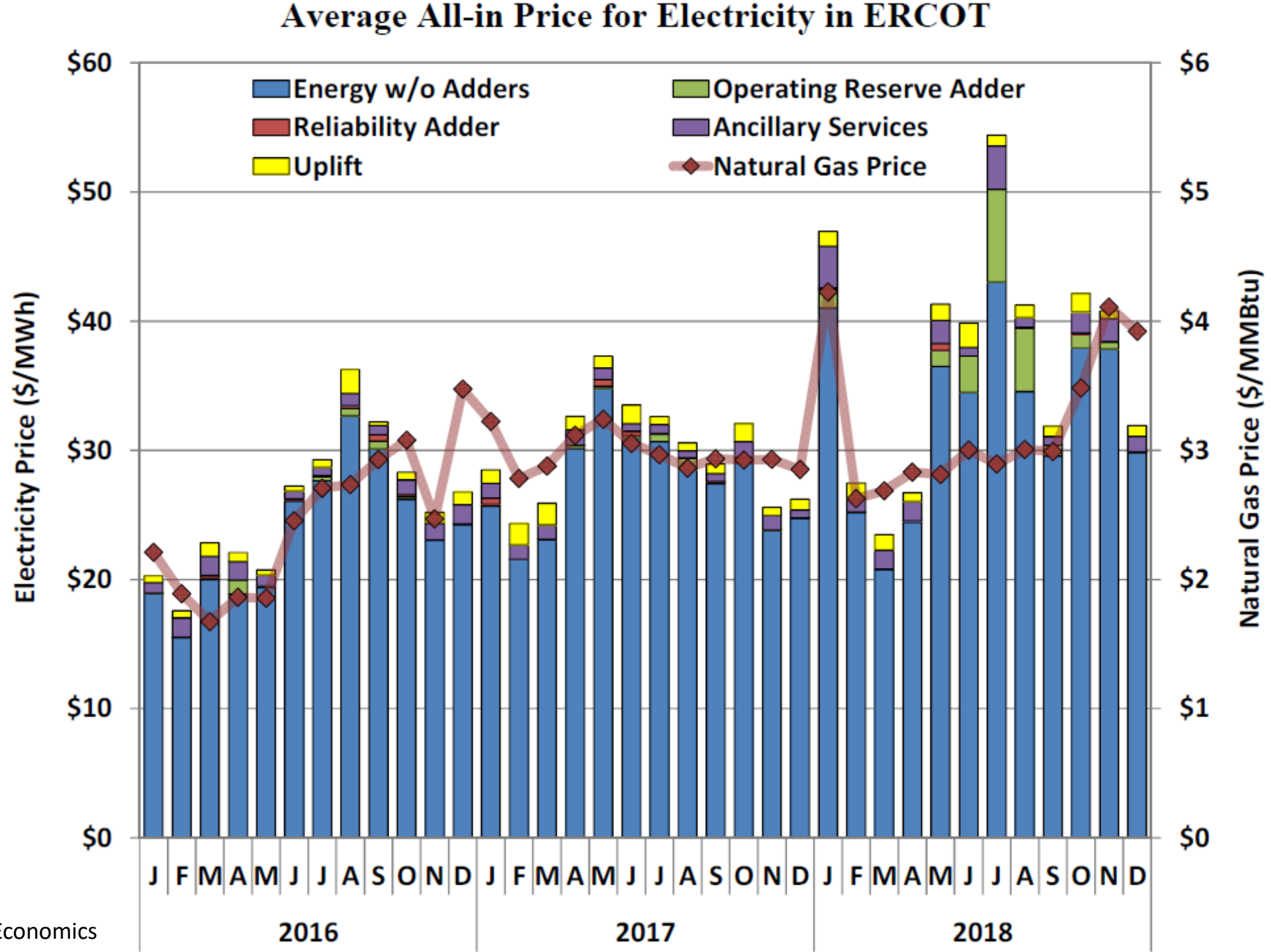
- **52 inches** of rainfall in southeast Texas
- Harvey made landfall **multiple times**
  - **Category 4** near Port Aransas, Texas
  - **Tropical storm** in Cameron, Louisiana
- More than **42,000** lightning strikes
- Record number of tornado warnings in southeast Texas

Shortage 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 when start shedding load
- Load's implicit preference for reliability given by operating reserve demand curve

Operating reserve demand curve



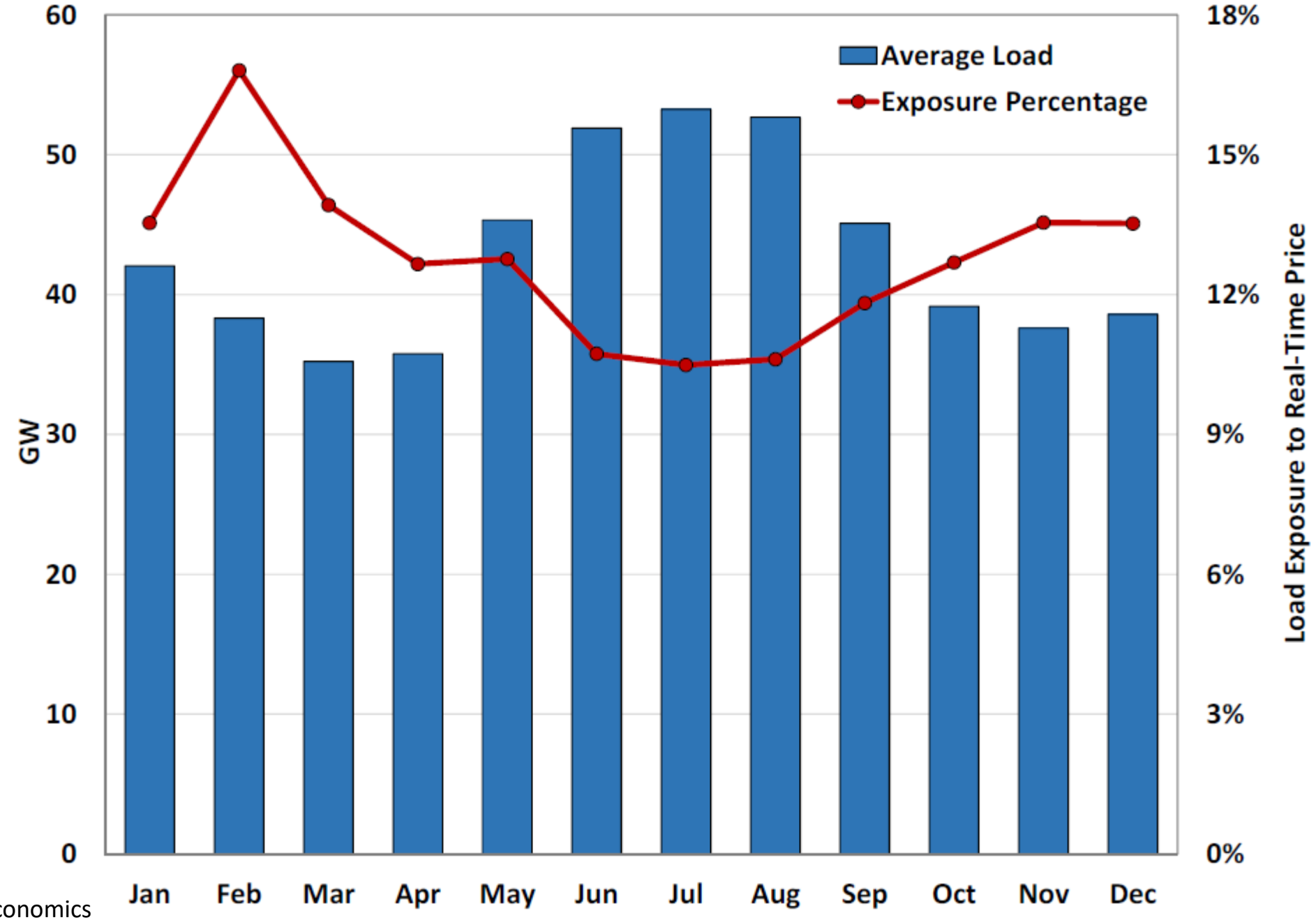


Source: Potomac Economics

Forward contracts

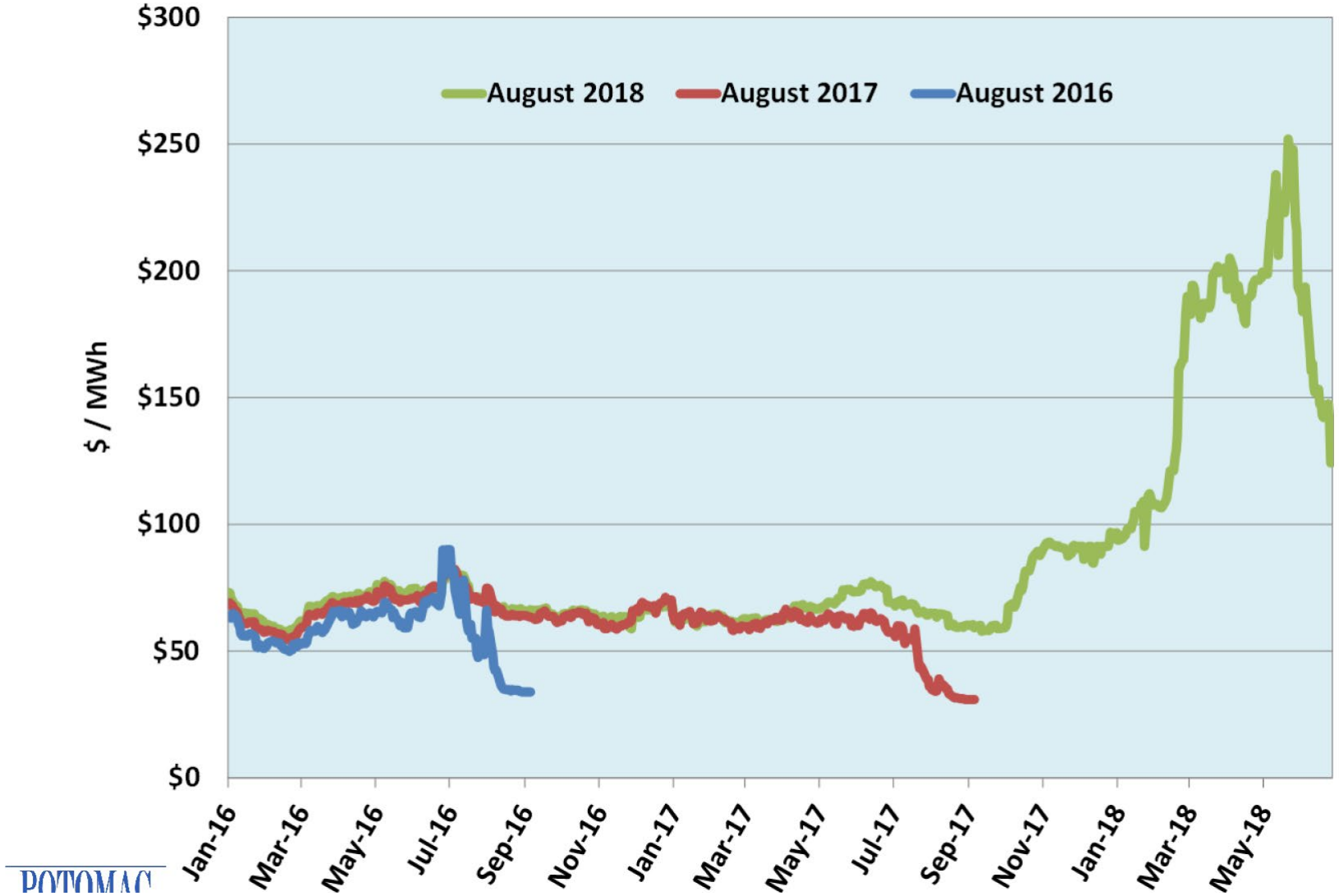
- Forward contracts are essential to manage risk
  - California energy crisis 2000-2001
  - Forward provides hedge for load
  - Generator + fuel contract provides physical hedge for supply
- Shortage pricing motivates forward contracts
- Forward contracting improves bidding incentives

Figure 24: Monthly Load Exposure



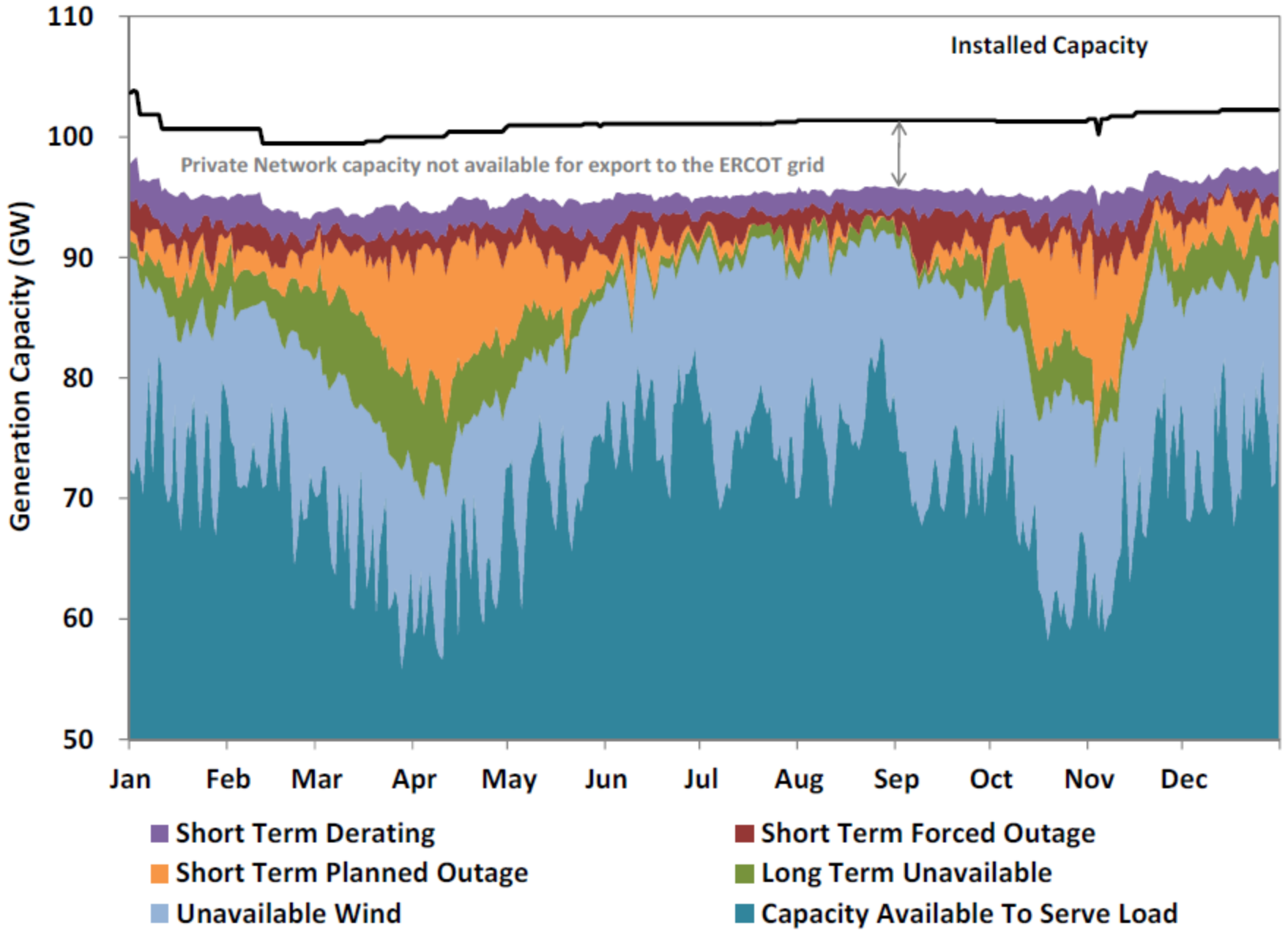
Source: Potomac Economics

August Forward Prices



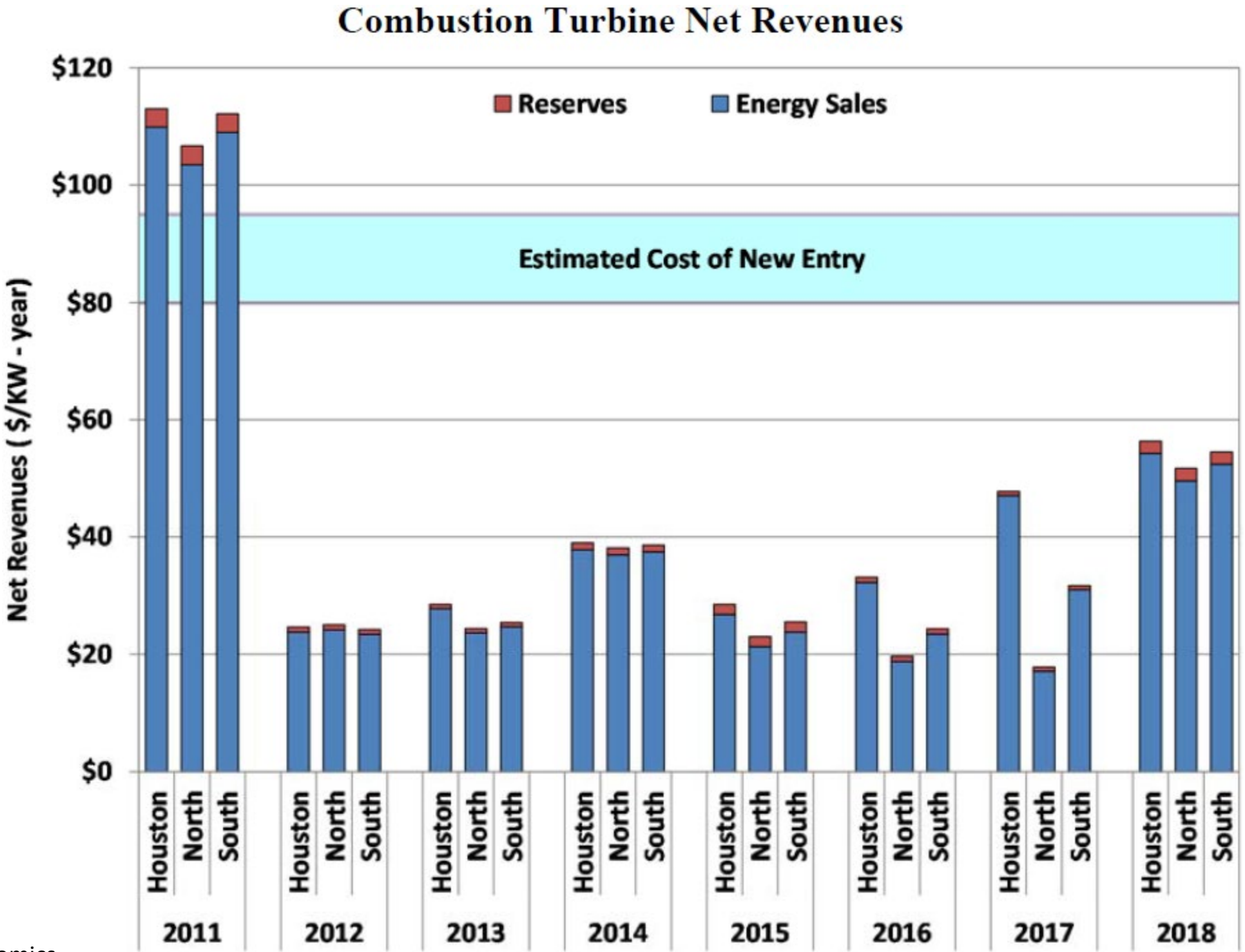
Source: Potomac Economics

Figure 95: Reductions in Installed Capacity



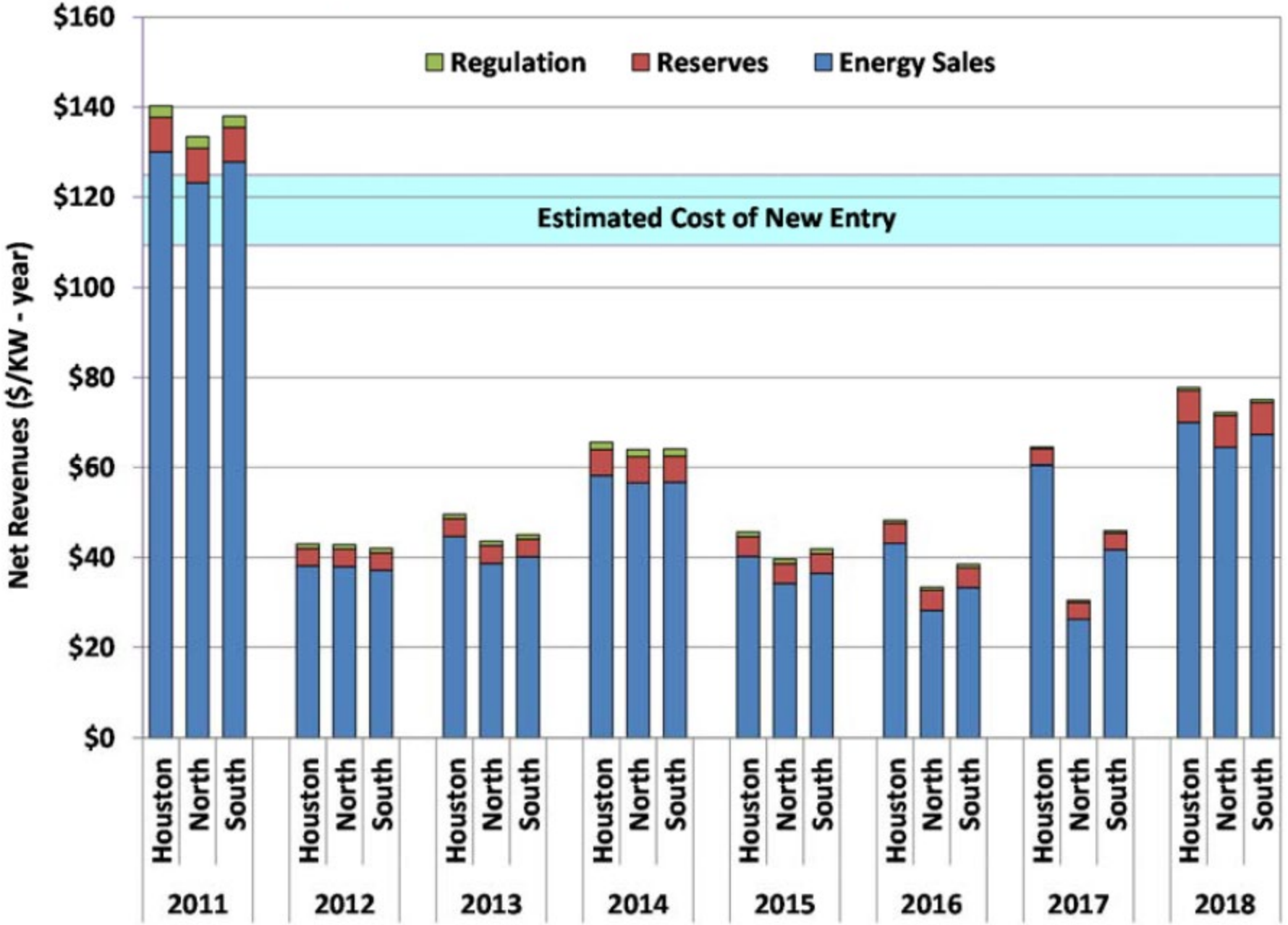
Source: Potomac Economics

Investment



Source: Potomac Economics

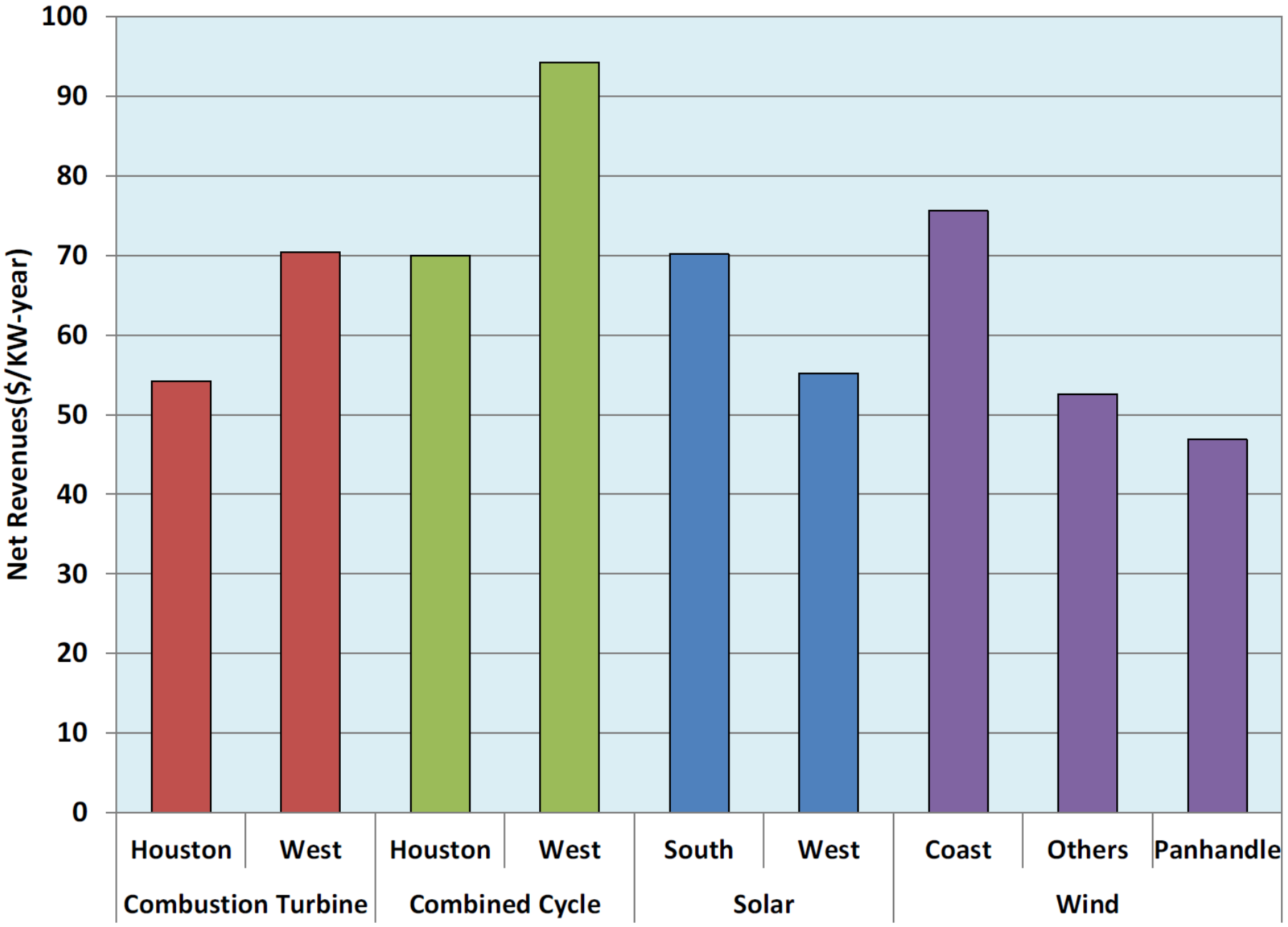
Figure 86: Combined Cycle Net Revenues



Source: Potomac Economics

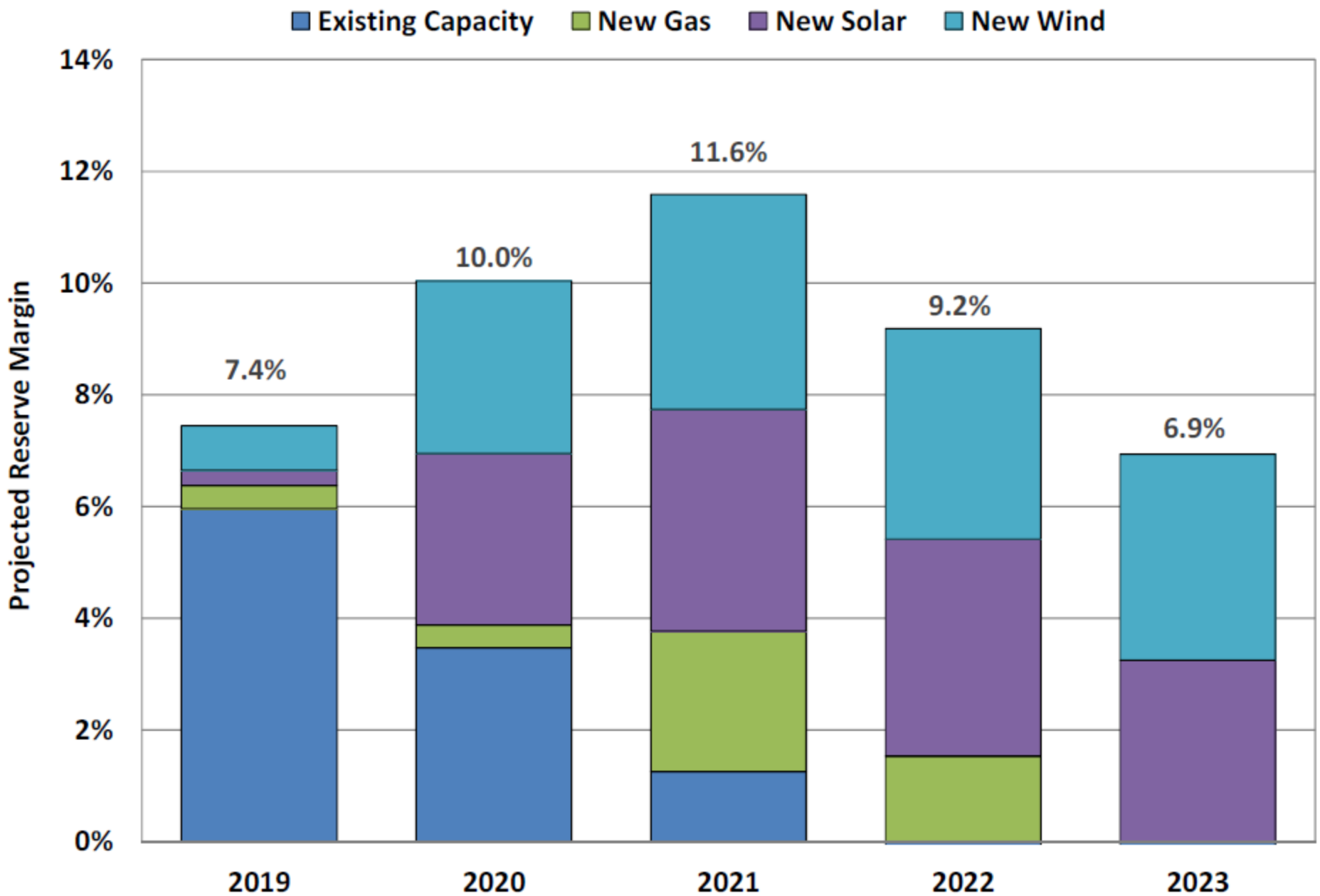
Energy Net Revenues

- West Zone using Waha gas price
- Revenues based on generation nodes



Source: Potomac Economics

Projected Planning Reserve Margins

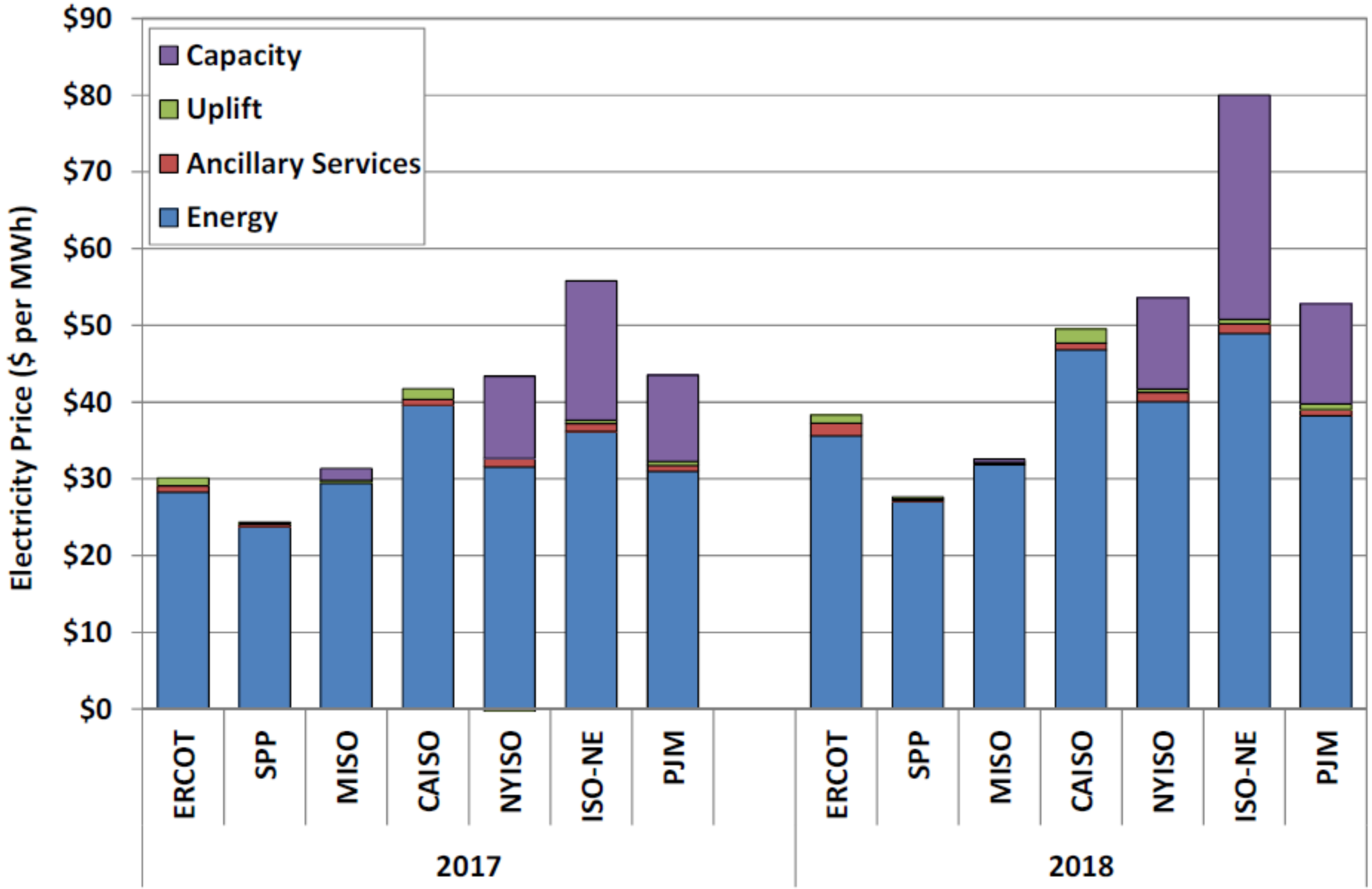


Source: ERCOT Capacity, Demand and Reserves Report, December 2018 with Gibbons Creek capacity removed

Capacity market

- ERCOT is “energy only”; many others have a capacity market (PJM, ISO-NE, …)
- Good capacity markets rely on shortage 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 shortage
  - Strong performance obligation
    - Financial obligation to provide energy during shortage
    - Provides hedge to load from shortage prices
  - Coordinated investment to ensure adequate resources

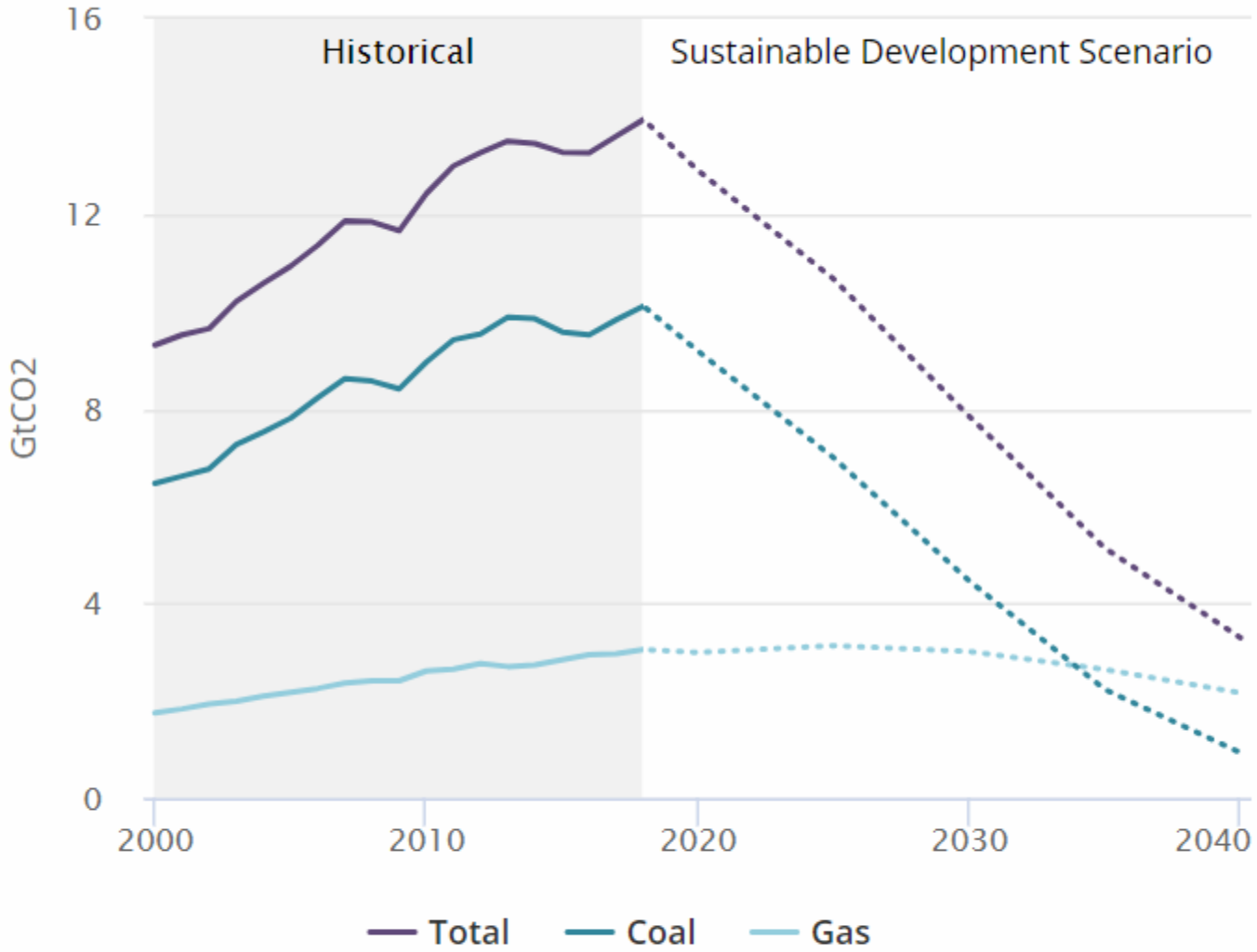
Figure 7: Comparison of All-in Prices Across Markets



Source: Potomac Economics

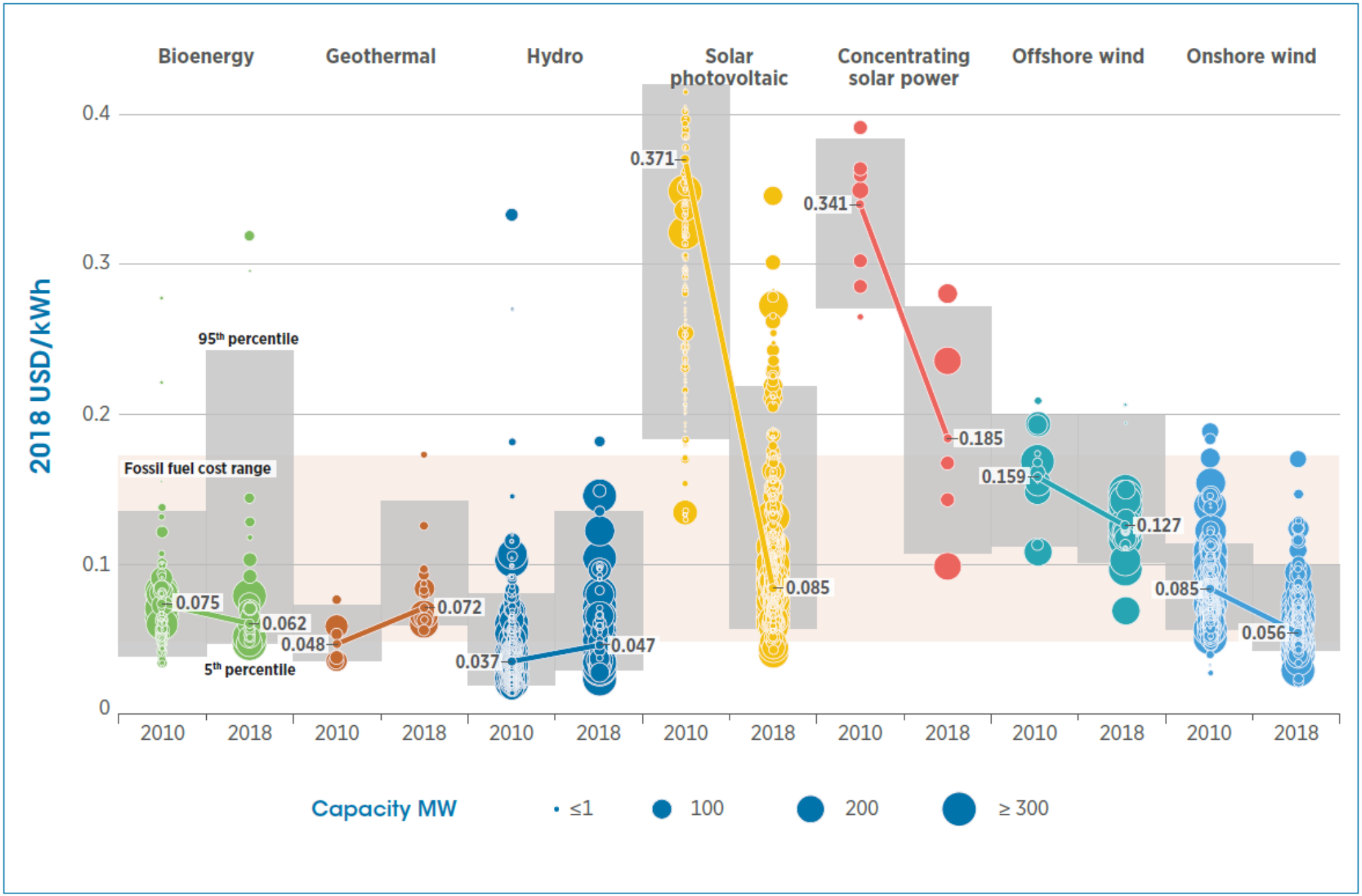
Transformation to renewables

Power sector CO2 emissions



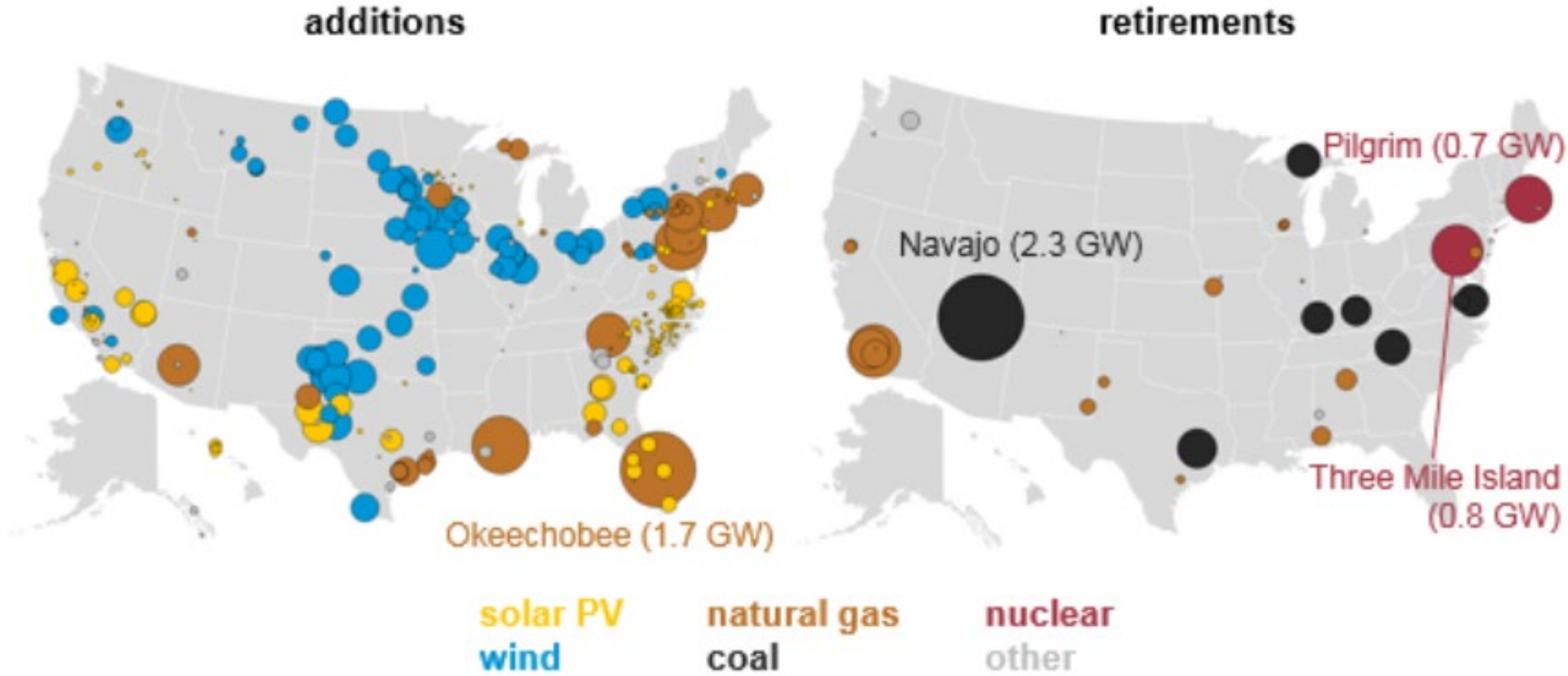
Last updated **Tuesday, May 28, 2019**

Figure S.1 Global LCOE of utility-scale renewable power generation technologies, 2010–2018



Source: IRENA

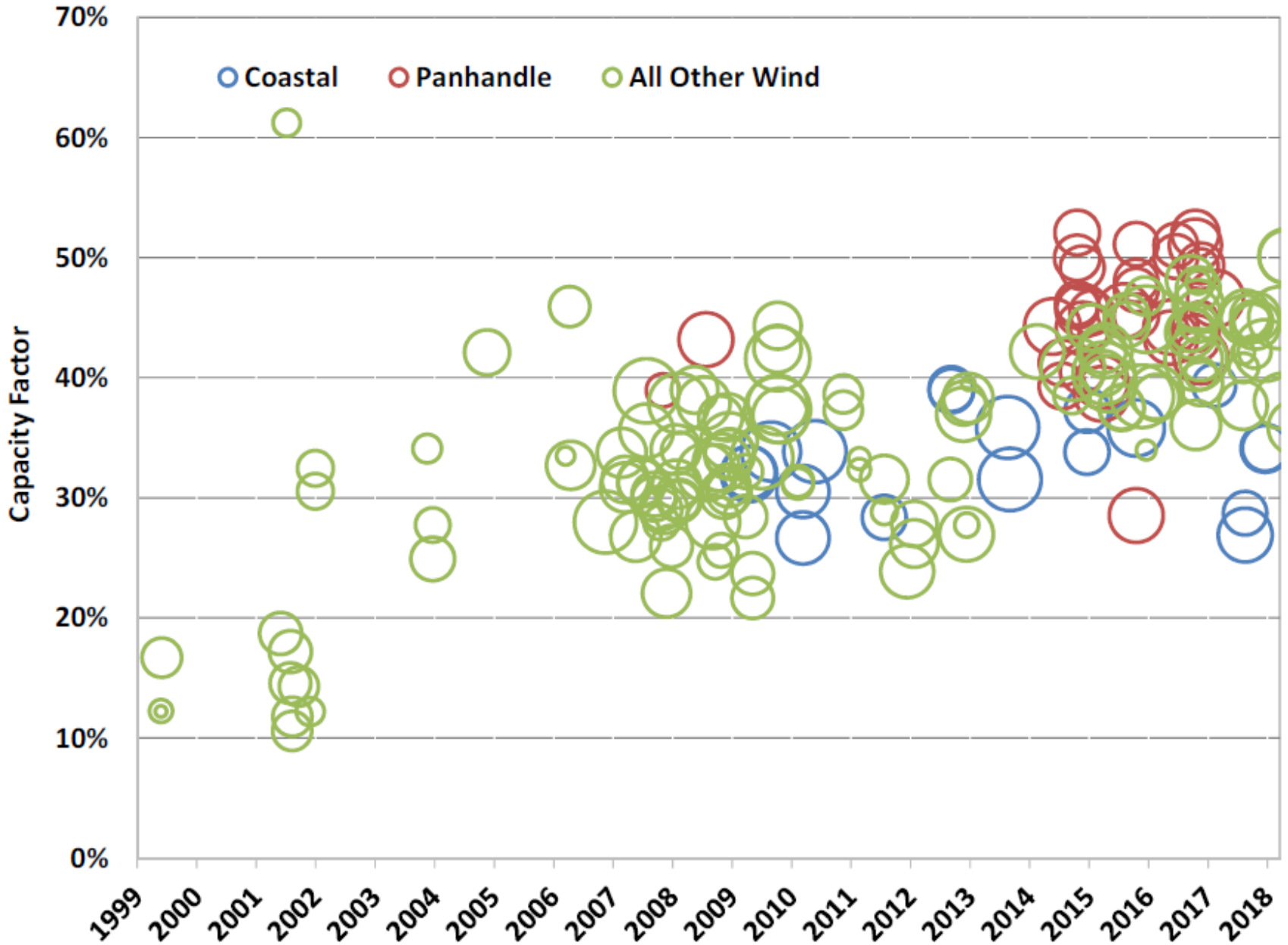
U.S. electric capacity additions and retirements, 2019
gigawatts (GW)



Source: U.S. Energy Information Administration, *Preliminary Monthly Electric Generator Inventory*

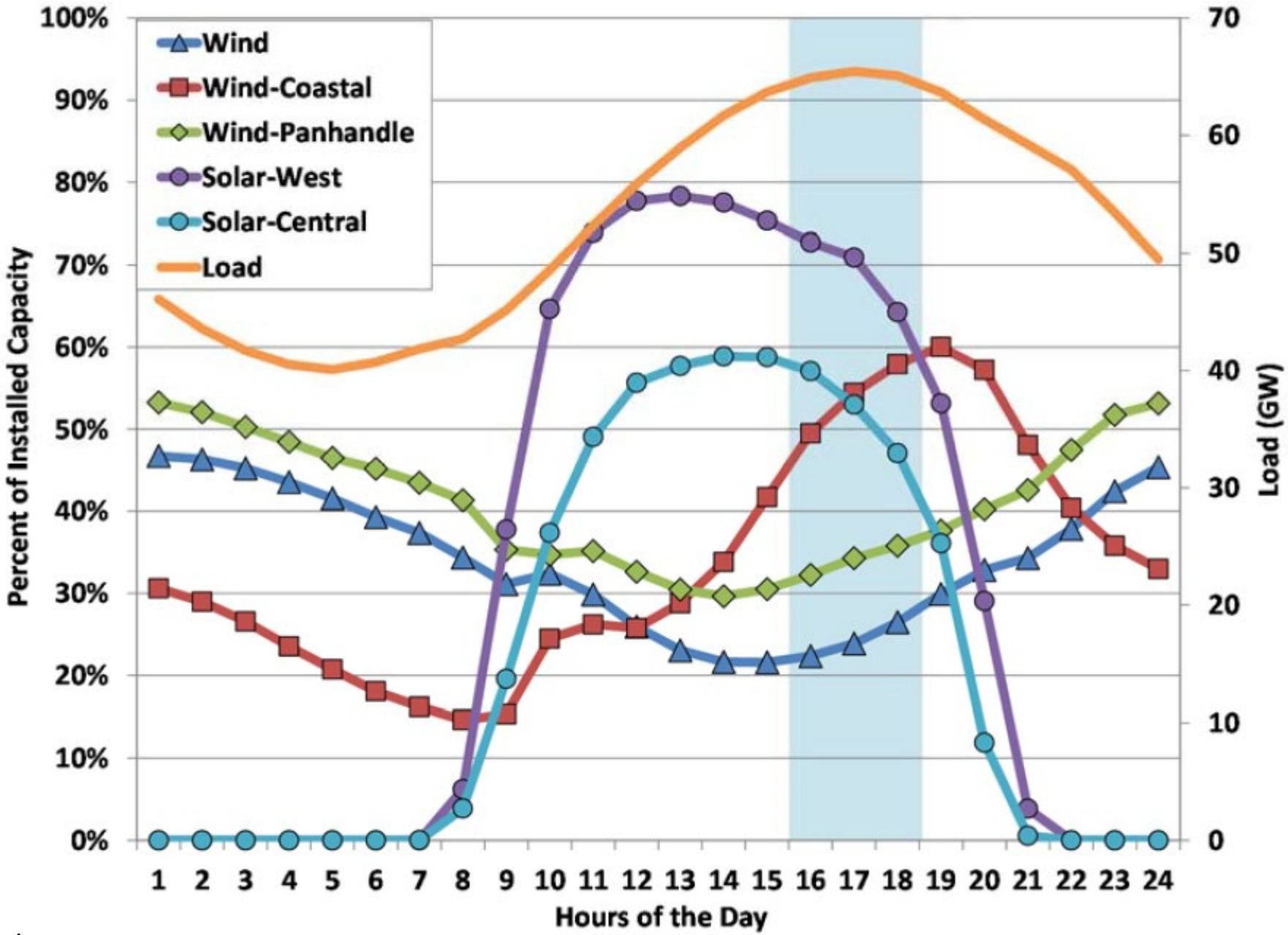
- Last year 60% of new capacity in US is wind and solar
- Coal hasn’t been built in years
- Intermittent supply, zero marginal cost, no inertia
  - More uncertainty, worse price formation, faster response needed
  - Also best sites not where load is; transmission issues
- Today’s design easily handles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

Figure 71: Wind Generator Capacity Factor by Year Installed



Source: Potomac Economics

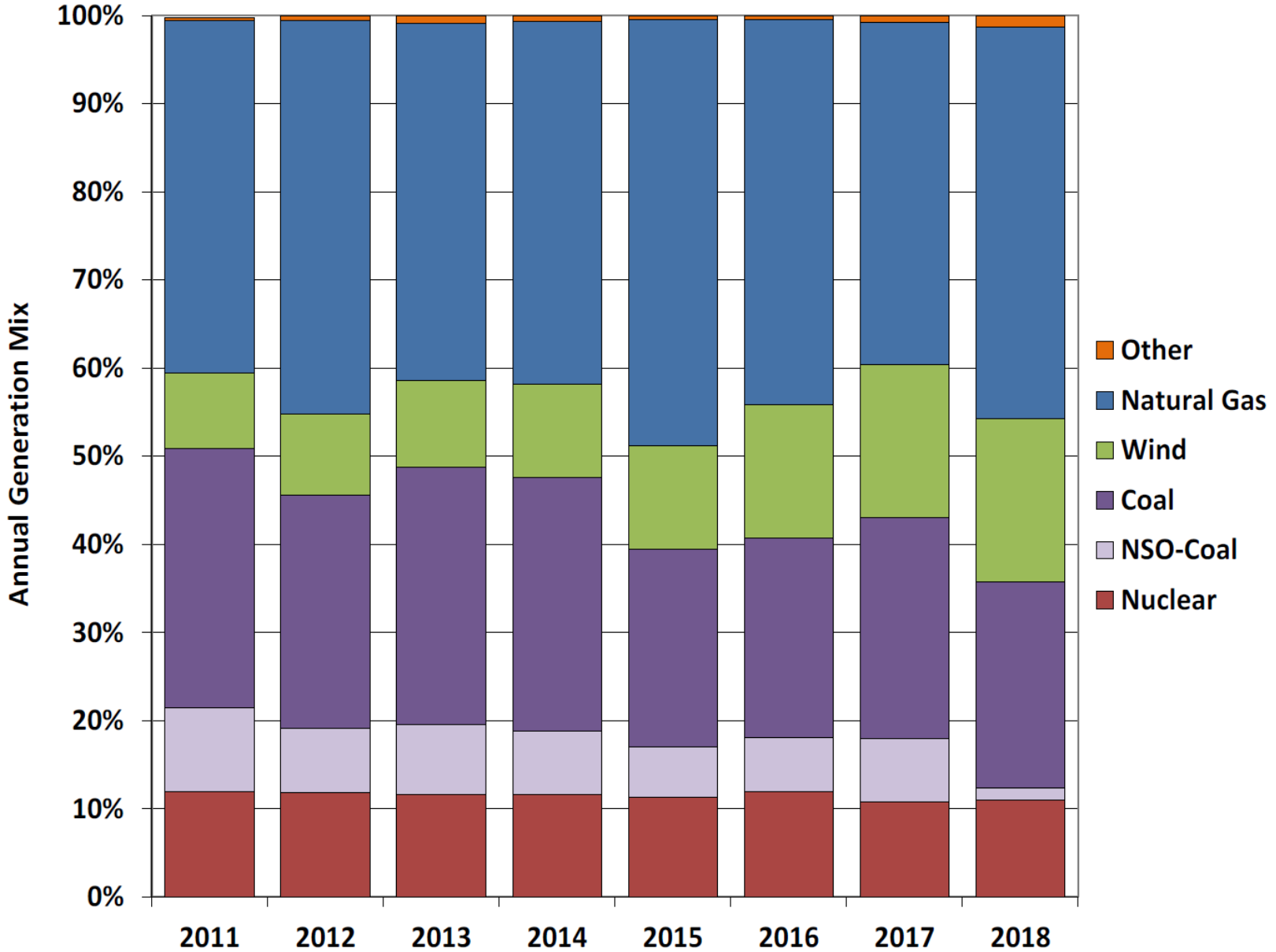
Figure 75: Summer Renewable Production



Source: Potomac Economics

Annual Generation Mix

Other:	1%
Gas:	44%
Wind:	19%
Coal:	25%
Nuclear:	11%



Source: Potomac Economics

Solution looking forward

- But what if >80% renewable
- Core design still works well
- *More flexibility needed*
  - *Demand response* (smart homes)
  - *Battery storage*

Need to encourage technology-neutral solutions!

Greater need for flexibility ⇒ efficient price signals increasingly important

- Nodal pricing
  - Price reflects scarcity at time and location
  - Pretending no congestion does not work
    - German redispatch cost of €1.5 billion in 2018
    - Wrong price signal; poor location incentives
- Shortage pricing
  - Motivate those to provide flexibility

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

Carbon dividend (pending US legislation)

- Carbon price, increasing each year until goal met
- Revenue rebated back to citizens
- Replaces inefficient regulations
- Carbon border adjustments for reciprocity

Widely supported (4-1 overall)

Good basis for climate club e.g. US, Europe, and China

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