U.S. DEPARTMENT OF ENERGY

Office of Electricity Delivery & Energy Reliability

DOE Staff Report on Electricity Markets and Reliability

Travis Fisher

Senior Advisor, Office of Electricity Delivery & Energy Reliability

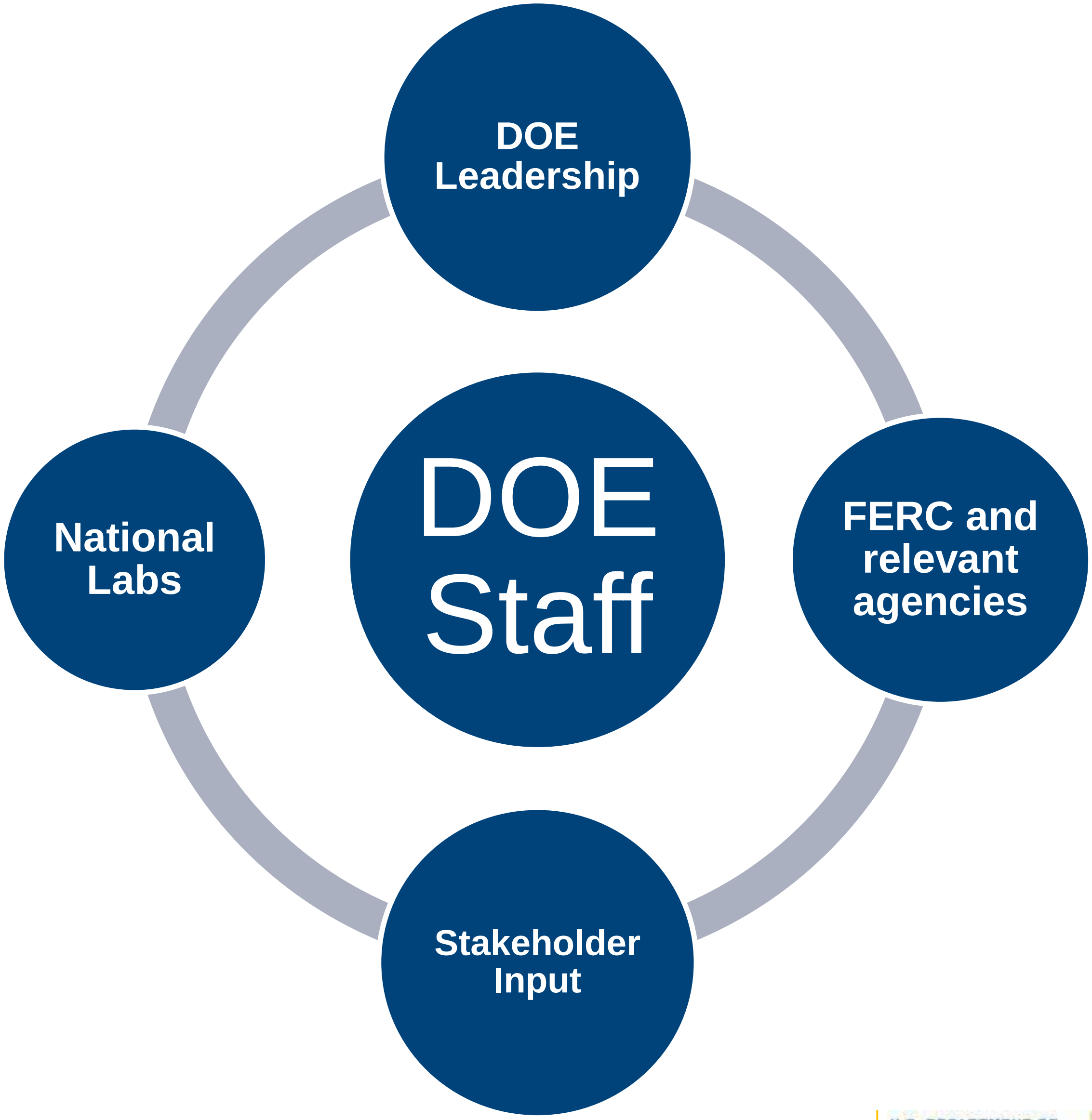
September 14, 2017

Secretary Perry requested a grid study in April 2017

The memo asked staff to examine:

- The evolution of wholesale electricity markets
- Compensation for resilience in wholesale energy and capacity markets
- Premature baseload power plant retirements

Process and report framework



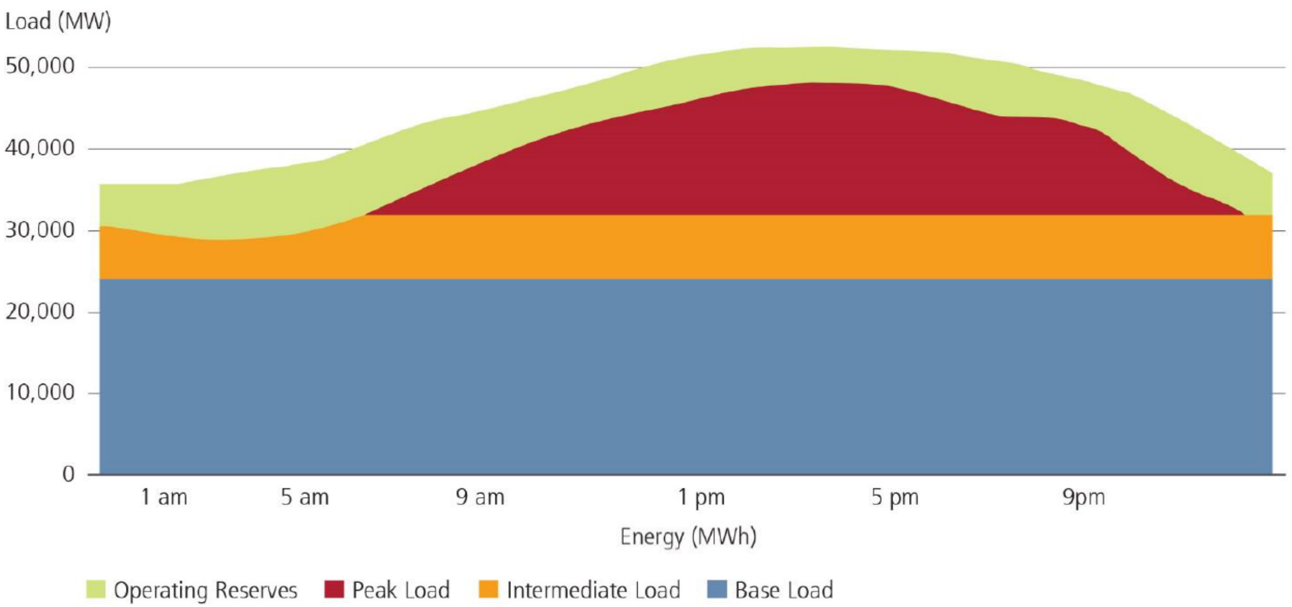
Study scope: 2002-2017

EIA data from this period captures several important trends:

- Merchant generation competing in centrally-organized markets beginning in the mid-2000s
- The shale revolution and a significant increase in natural gas supply
- The drop in electricity demand in 2008 following the recession and subsequent flat demand growth
- Higher variable renewable energy (VRE) penetration beginning to impact grid operations in certain areas
- The expanded participation of demand response in wholesale markets starting around 2010

Key definitions

Figure 1.2. Schematic of Typical Daily Load Curve Showing Base Load[13]



- **Baseload power plants**: *defined by their operation*
  - High, sustained output levels
  - High capacity factors
  - Limited cycling or ramping
- **Premature retirement**: *subjective term*

Key findings

Power Plant Retirements

- A combination of market and policy forces has accelerated the closure of a significant number of traditional baseload power plants:
  - Low natural gas prices
  - Low electricity demand growth
  - Environmental regulations
  - Increased VRE penetration

Reliability and Resilience

- Bulk power system reliability is adequate today despite significant VRE growth, but long-term concerns about baseload retirements merit further study
- Markets recognize and compensate reliability, but more work is needed to better understand resilience across a variety of grid and market scenarios
- Growing interdependence on natural gas

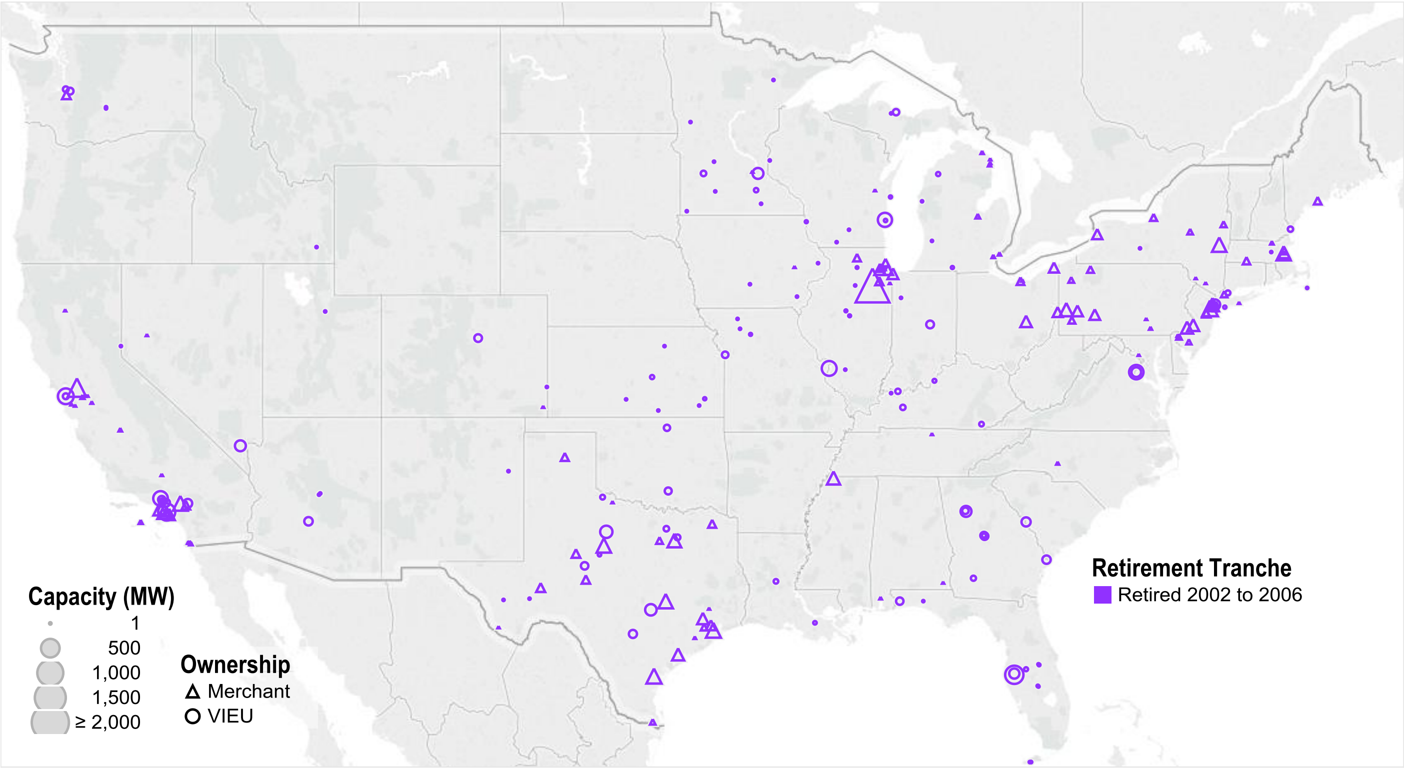
Key findings

Wholesale Markets and Affordability

- Changing circumstances are challenging electricity markets
  - The “missing money” problem
  - Negative pricing in certain areas
- Markets do not currently value all attributes of electricity provision
  - Examples: jobs, local economic development, national security

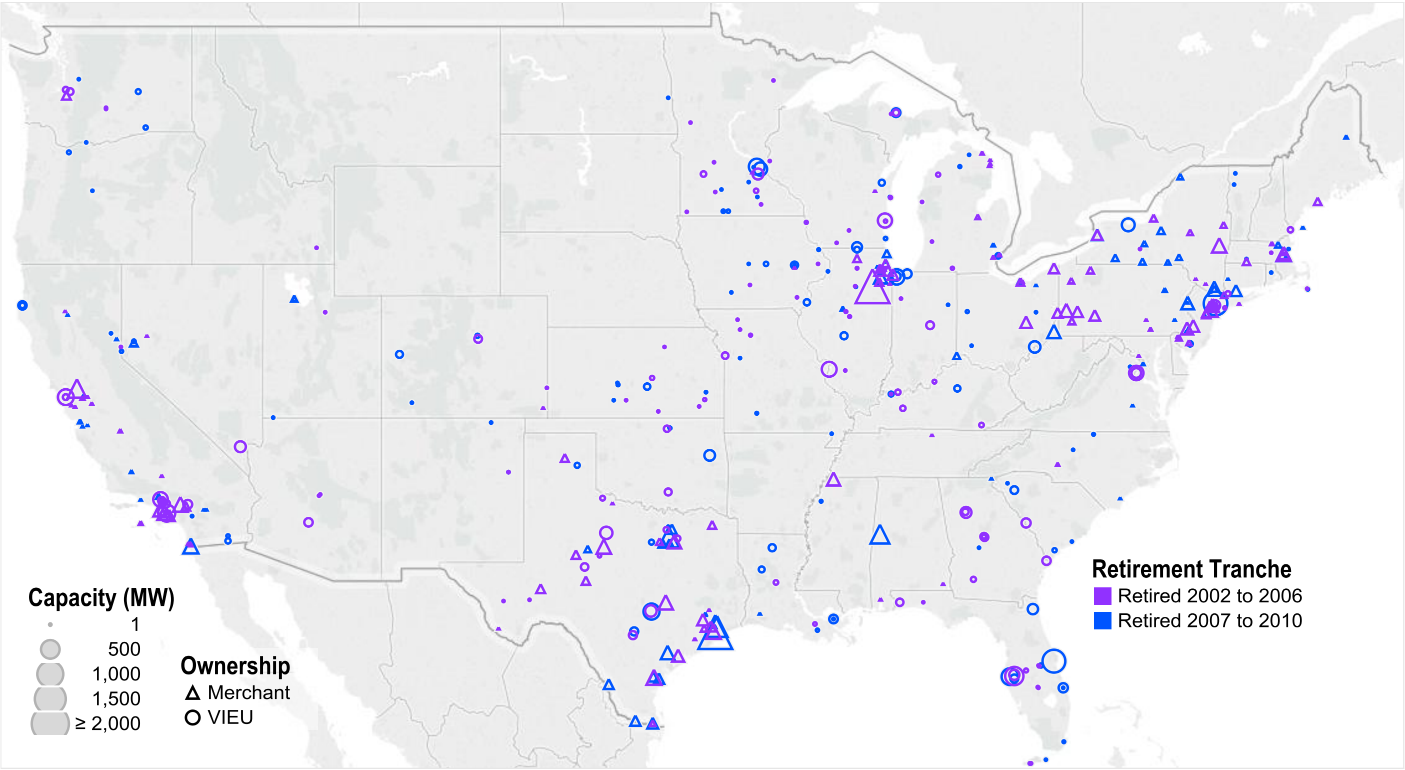
Power Plant Retirements

Retirement tranches by size, ownership



- 2002-2006: restructuring. Majority of retirements are smaller, older merchant plants

Retirement tranches by size, ownership



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- **2007-2010: economic recession, shale gas, *Mass v. EPA*, strong utility-scale wind growth**

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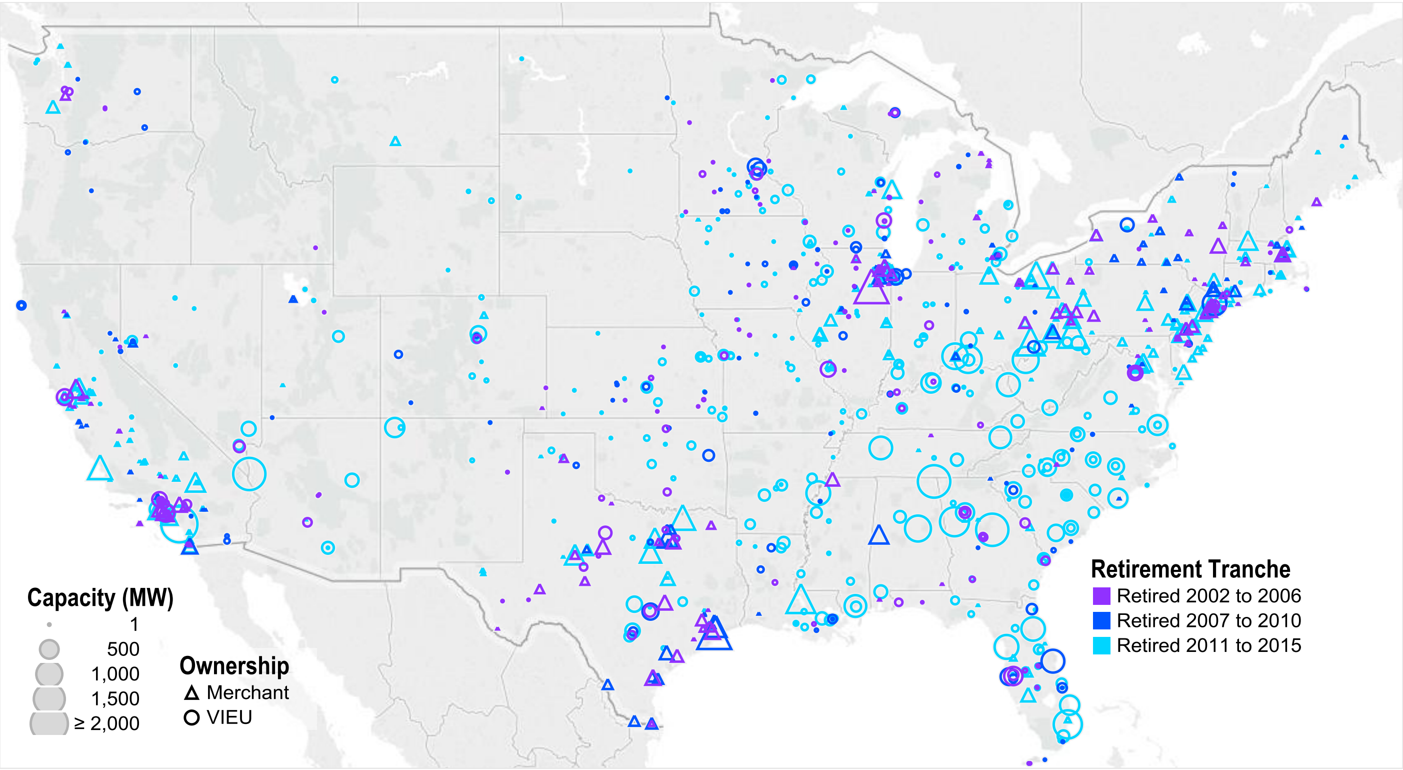
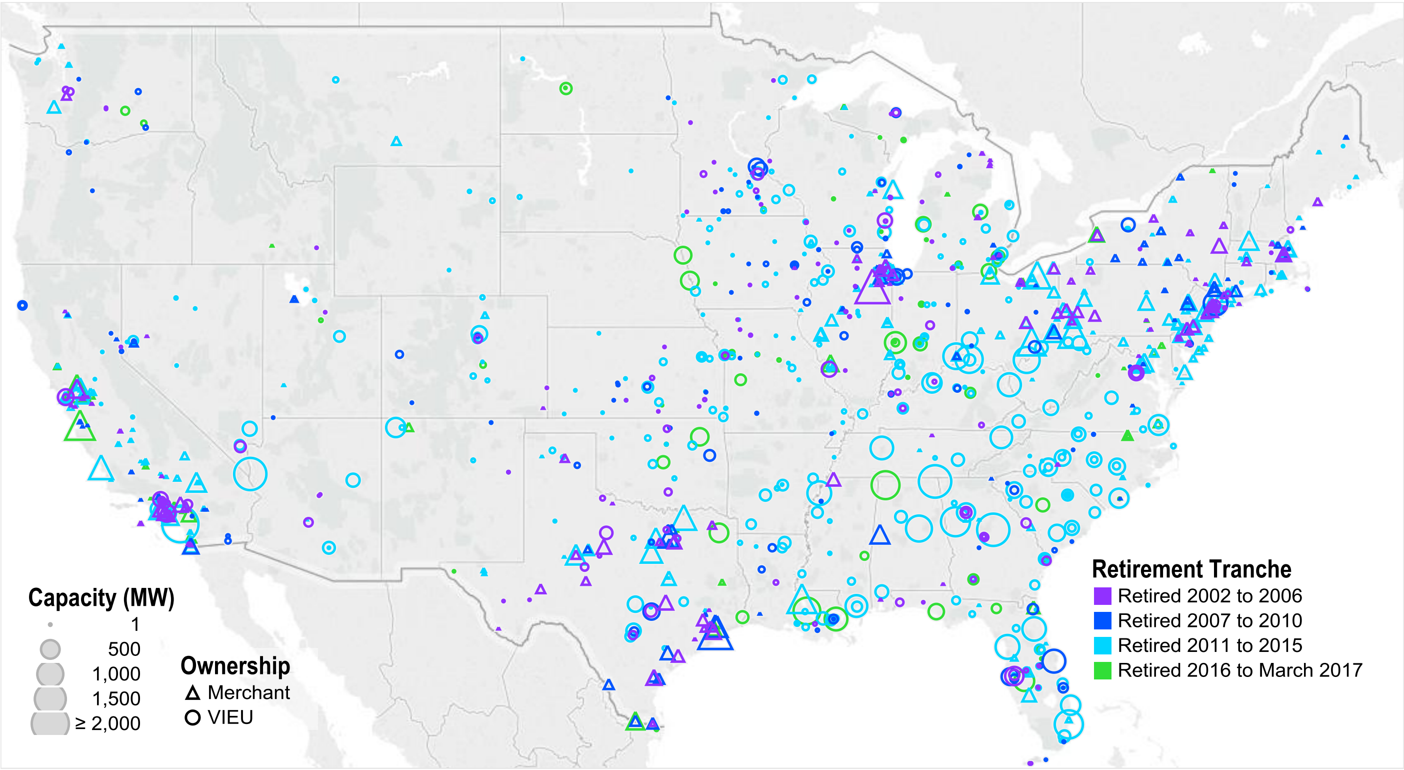


- 2002-2006: restructuring. Majority of retirements are smaller, older merchant plants
- 2007-2010: economic recession, shale gas, *Mass v. EPA*, strong utility-scale wind growth
- **2011-2015: sustained low electricity demand and NG prices, MATS deadline, CPP finalized**

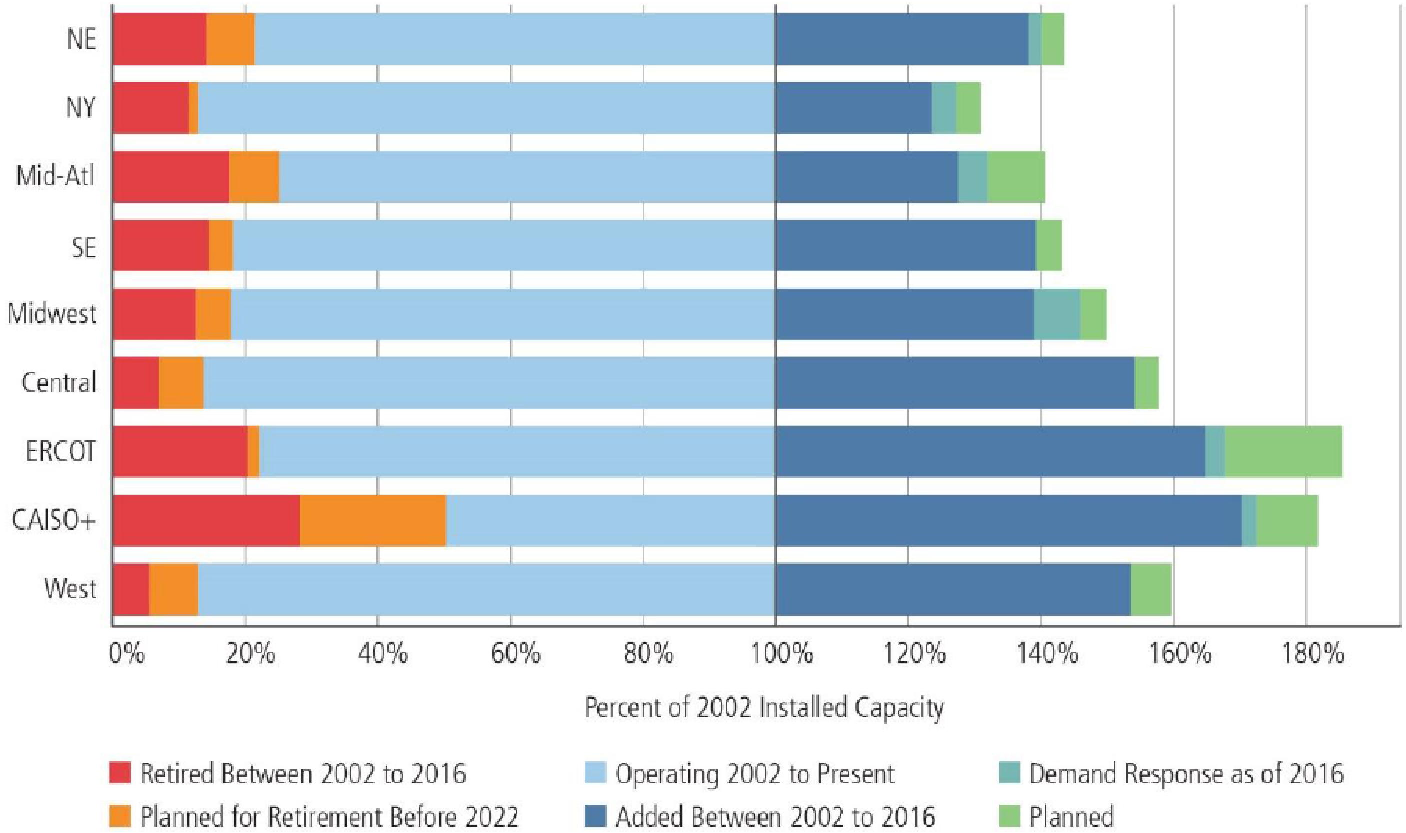
Retirement tranches by size, ownership



- 2002-2006: restructuring. Majority of retirements are smaller, older merchant plants
- 2007-2010: economic recession, shale gas, *Mass v. EPA*, strong utility-scale wind growth
- 2011-2015: sustained low electricity demand and NG prices, MATS deadline, CPP finalized
- **2016 onward: where do we go from here?**

Retirements and additions by region

Figure 3.5. Operating Generation Capacity, Additions, Retirements, and Announced Retirements by Region for All Generation Types, January 2002–December 2022[29]

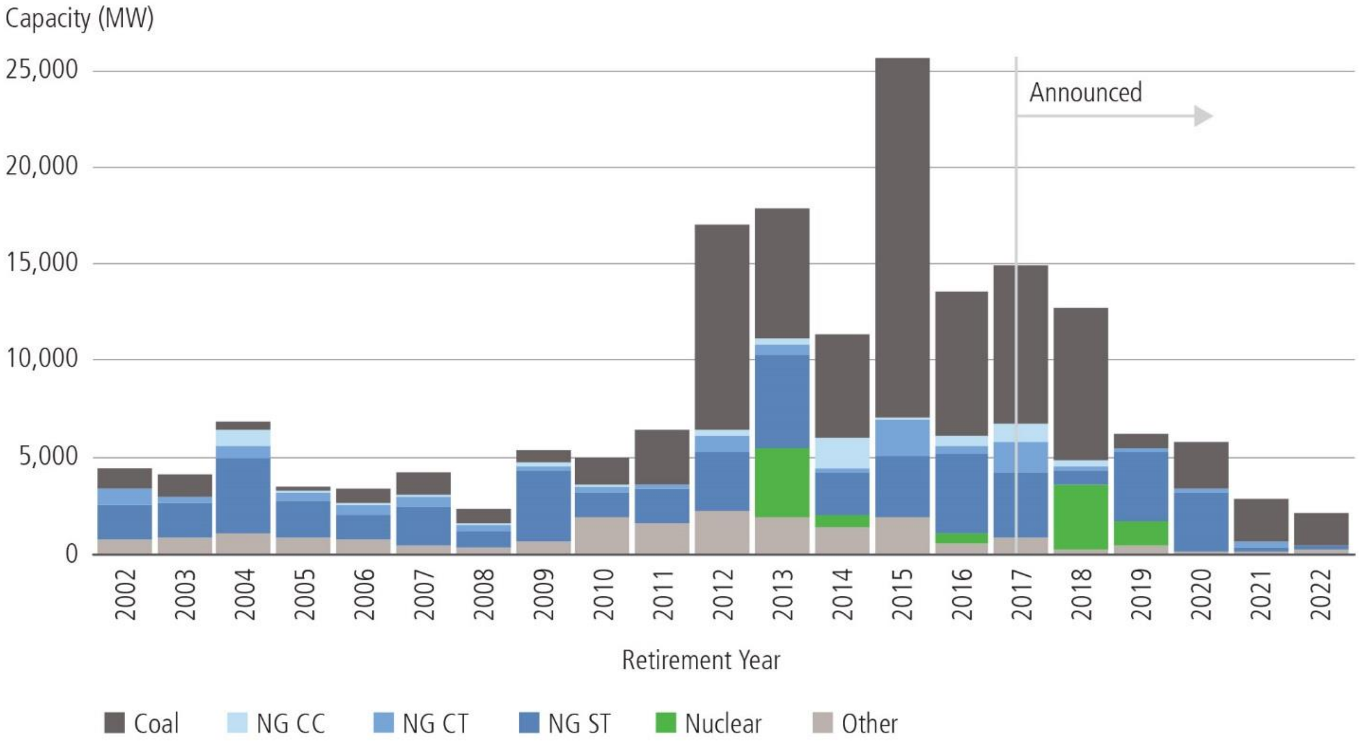


Overall, retirements since 2002 have been no greater than 20% of the 2002 installed base (except CAISO)

Retirements by fuel type

Coal, total retirements peaked in 2015

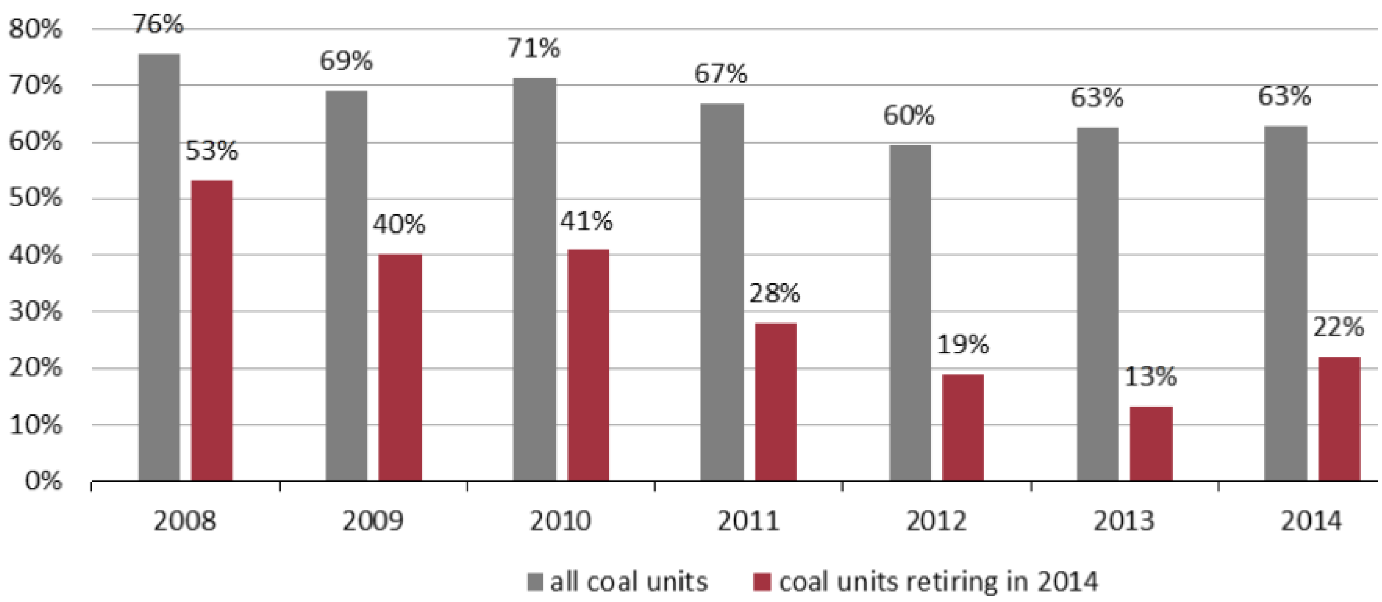
- MATS deadline
- Clean Power Plan finalization



Retirements: Coal

- **Net retirement of 36,000 MW or 12% of 2002 coal fleet**
- **Coal plants that retired recently did not operate as baseload**
  - Retired plants were smaller, older, had higher heat rates, and therefore were dispatched less often and ran at lower capacity factors

Figure 3.23. Average Coal Plant Capacity Factors, 2008–2014[148]



Source: EIA Form 860 and Form 923

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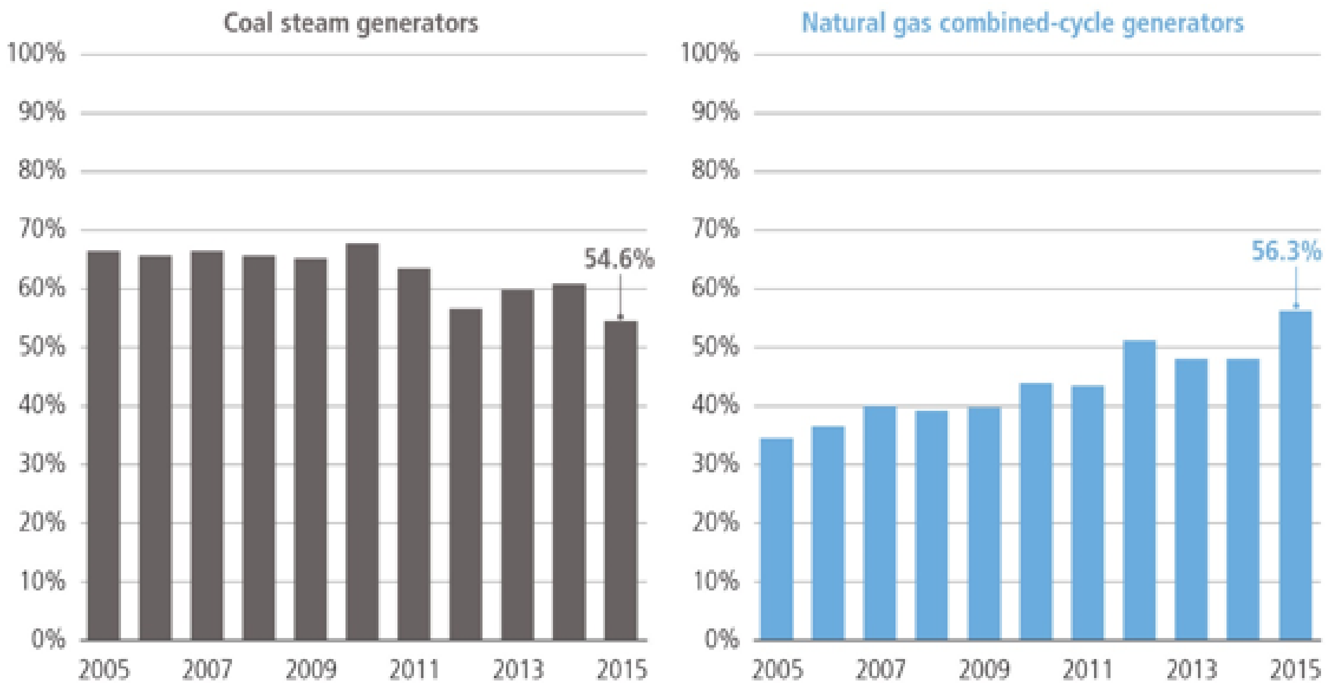
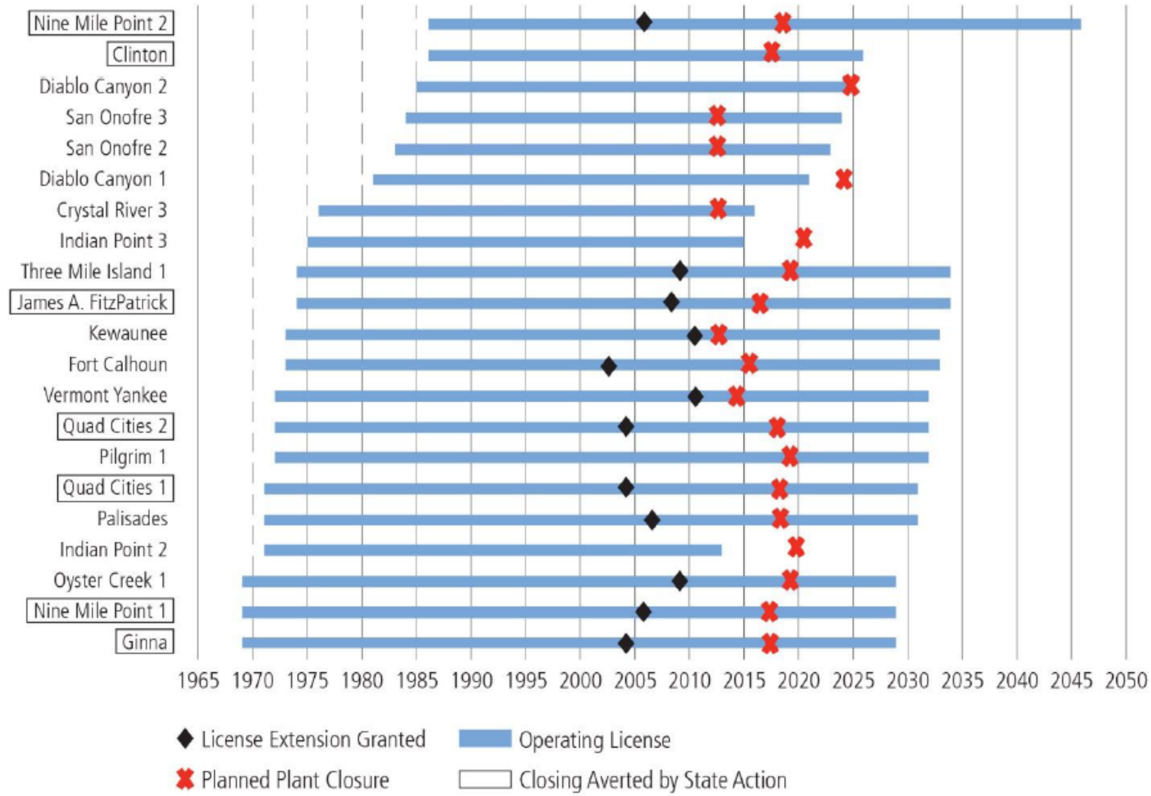
Figure 5.7. Annual Average Capacity Factors of Coal and Natural Gas Generators



Retirements: Nuclear

Figure 3.15. Nuclear Plant Retirements Compared to NRC Plant Operating License Terms[84] [85] [86]



- **Between 2002-2016, 4.6 GW or 4.7% of the total nuclear fleet announced retirement**
- **BNEF estimates that 34 of the total 60 plants are operating in the red**
- **Many plants closing well before their operating licenses expire**

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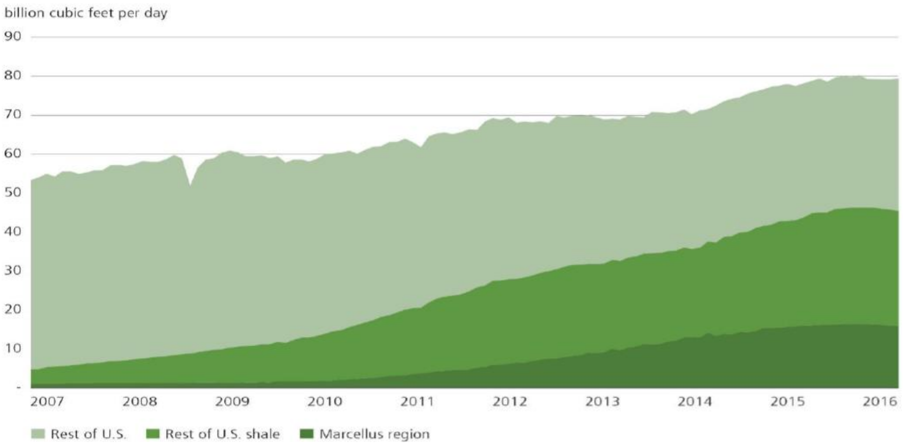
Retirements: Key drivers

1. **Advantaged economics of natural gas-fired generation**
   - Shale gas development has significantly expanded the availability of natural gas and lowered its cost
2. **Low growth in electricity demand**
   - Electricity demand historically had risen with economic growth (real GDP), but the two began decoupling around 2000
3. **Environmental regulations**
   - A suite of regulations affecting the electricity generation sector had implementation deadlines between 2011 and 2021, stemming from statutes enacted between 1970 and 1990
4. **Dispatch of VRE has negatively impacted baseload plant economics**
   - Total VRE generation consistently reaches new record levels

Retirements: Natural gas supply

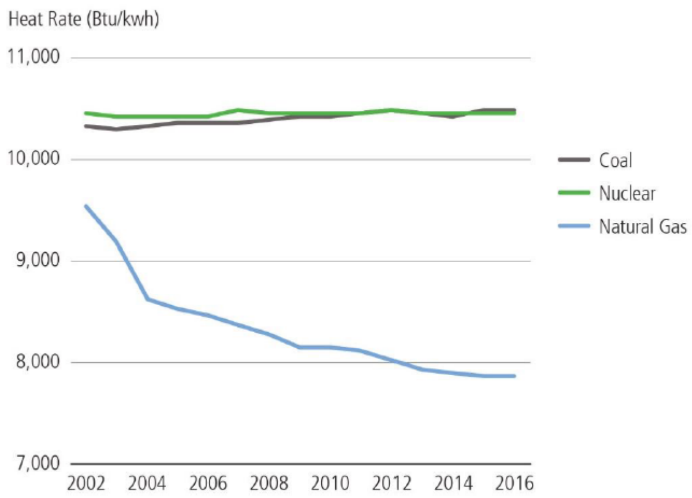
Conventional and Shale Natural Gas Production, 2007–2016



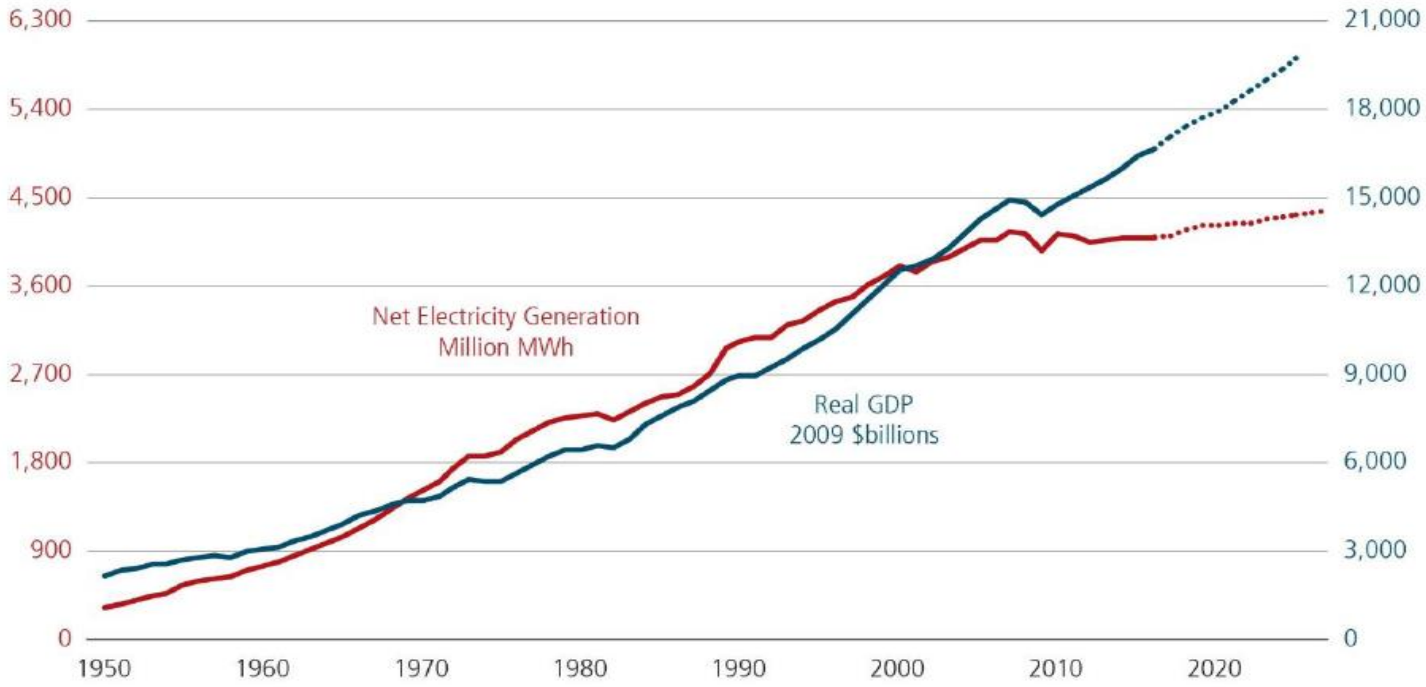
Shale gas development has significantly expanded availability and lowered costs

And natural gas plants have had increasingly more favorable heat rates than coal and nuclear

Figure 3.20. Heat Rates for Coal, Nuclear, and Natural Gas, 2002–2016[117]

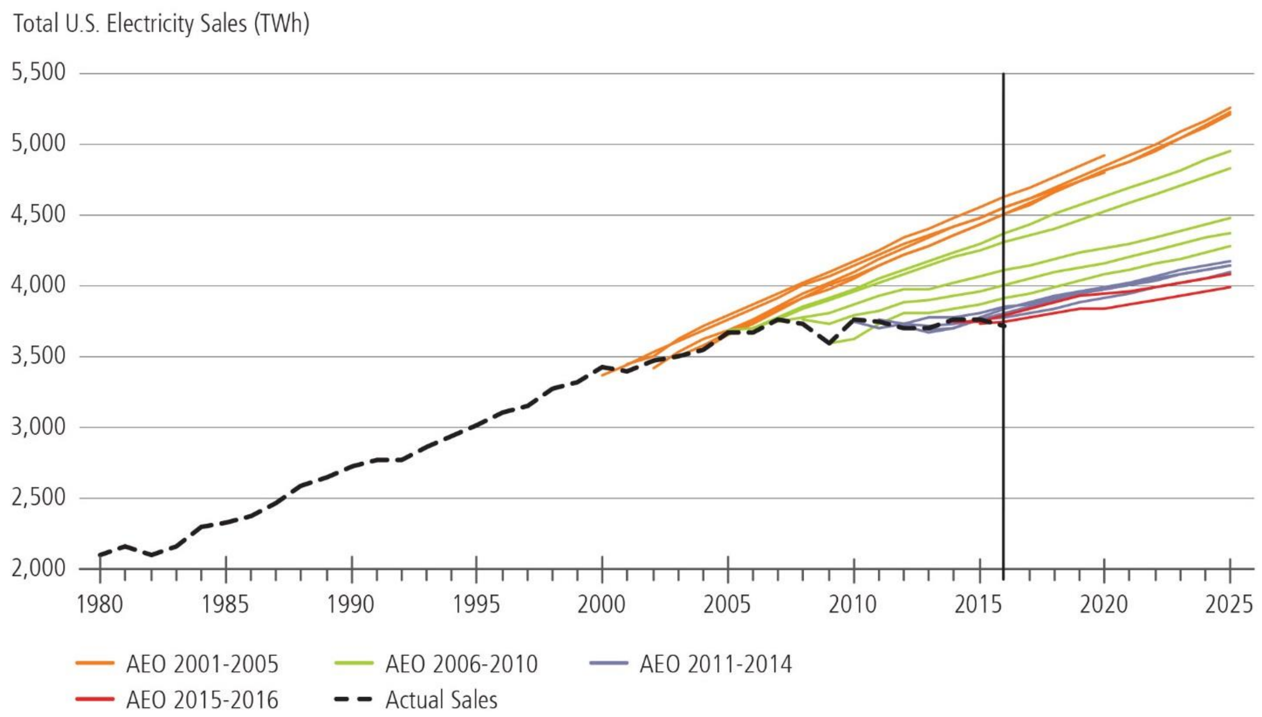


Retirements: Demand and economic growth decoupling



Demand growth has stalled since 2005, despite economic recovery after the recession

Retirements: Lower demand than expected

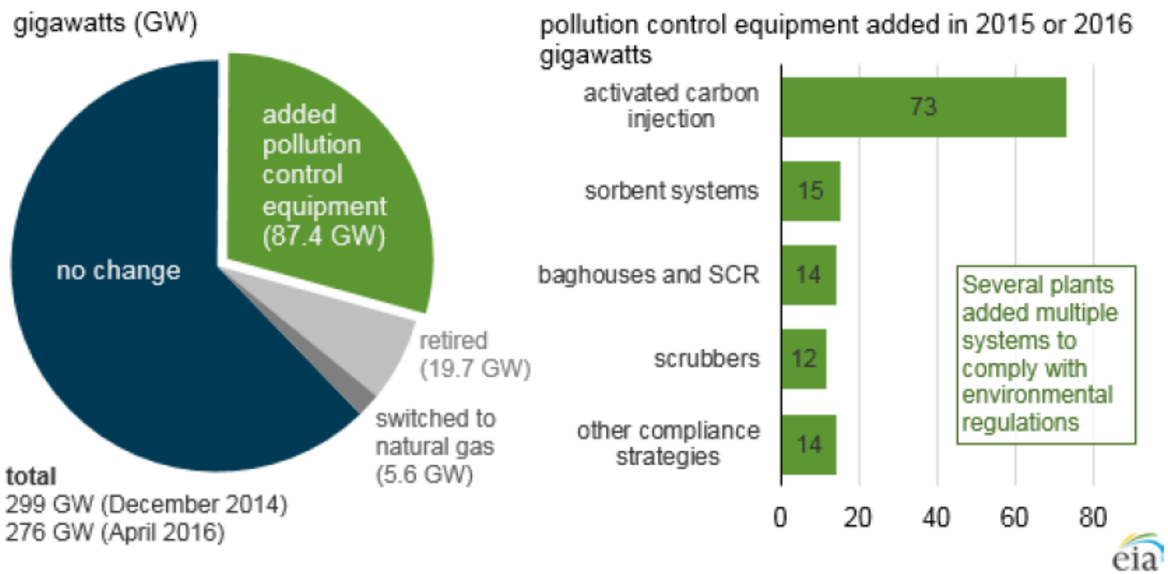


Changing policy and market conditions have made it challenging to accurately forecast electricity demand

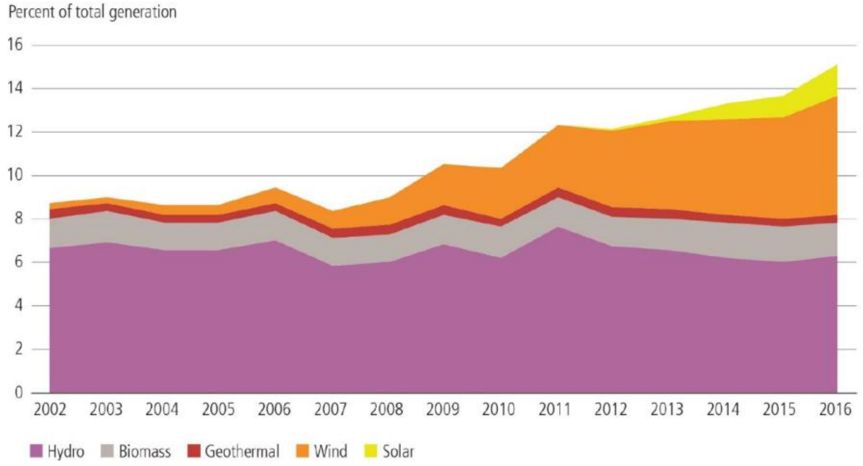
Retirements: Environmental regulations

- Reported planned retirements suggest that approximately 27,000 MW or 8.5 percent of 2011 coal-fired capacity was rendered uneconomic under the combination of regulatory compliance costs, low demand growth, and low natural gas prices
- Difficult to tease out relative impact of regulations on retirements in isolation

Figure 3.22. Changes in U.S. Coal Capacity, December 2014–April 2016[141]



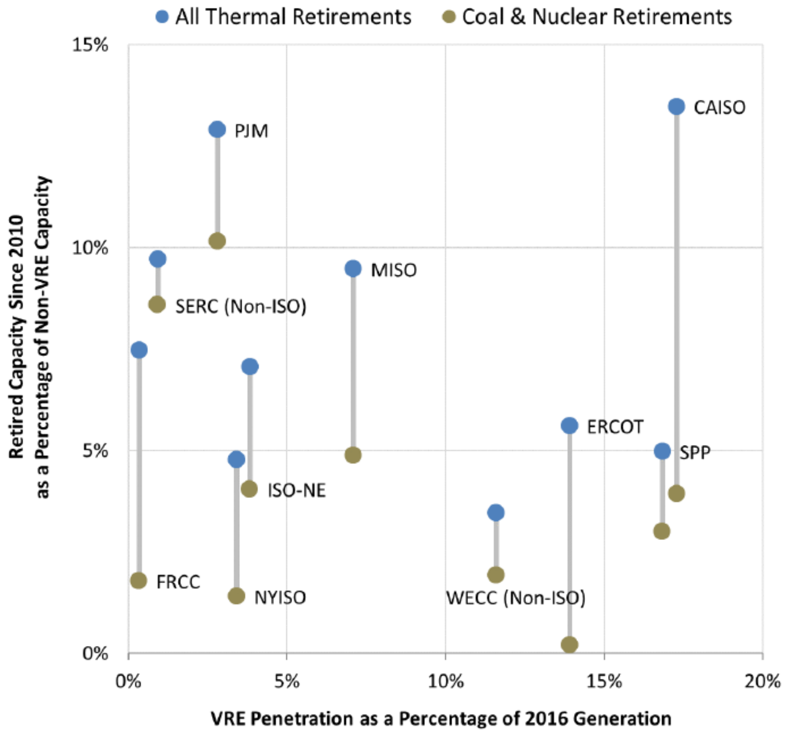
Retirements: VRE penetration



VRE penetration is steadily rising…

… but according to LBNL research, existing data do not suggest a correlation between VRE penetration and thermal plant retirements

Figure 3.28. VRE Penetration as a Percentage of 2016 Generation versus Retired Capacity since 2010 as a Percentage of Non-VRE Capacity[176]



Reliability and Resilience

Reliability: Key findings

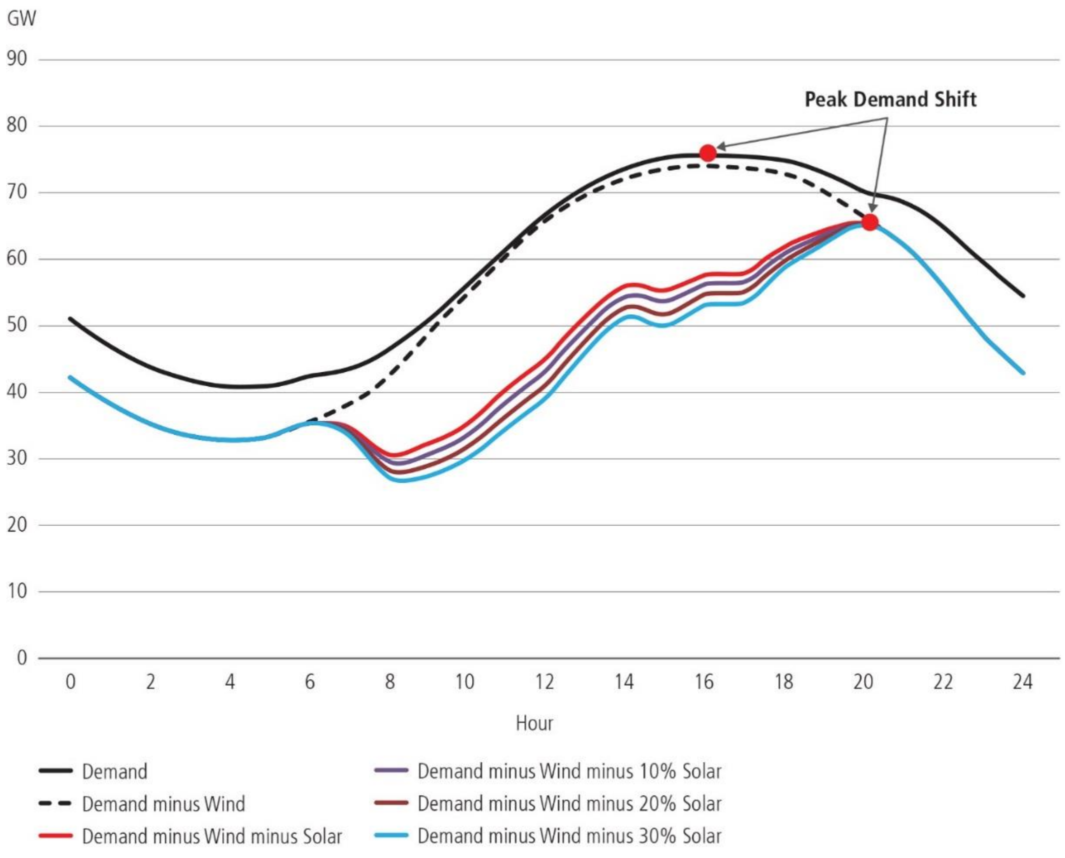
1. A diverse portfolio of generation resources and well-planned transmission investments are critical to meeting regional reliability and resilience objectives
2. Integrating VRE is about managing its effects on grid operations and planning (variability, uncertainty, location specificity, non-synchronous generation, and low capacity factor)
3. There are tradeoffs between multiple desirable attributes for the electric grid. A more reliable and resilient system may be more costly than the least-cost system

Reliability: NERC's perspective

<u>NERC CEO Gerry Cauley to DOE</u>*:*

- *As conventional resources prematurely retire, sufficient amounts of* ***essential reliability services****, such as frequency and voltage support, ramping capability, etc., must be replaced based on the configuration and needs of the system*
- *Resource* ***flexibility*** *is needed to supplement and offset the variable characteristics of solar and wind generation*
- *Maintaining fuel diversity and security provides best assurance for resilience. Premature retirements of* ***fuel secure baseload generating stations*** *reduces resilience to fuel supply disruptions*
- *Because the system was designed with large, central-station generation as the primary source of electricity, significant amounts of* ***new transmission*** *may be needed to support renewable resources located far from load centers*

Reliability: Changing "net load" shapes



- RTOs/ISOs are integrating growing levels of VRE, which shift the time of peak load
- They also introduce more hourly and intra-hourly variability

Reliability: NERC's perspective

Figure 4.2. Five-Year Average Reserve Margins across Different Regions (2018–2022)[231]

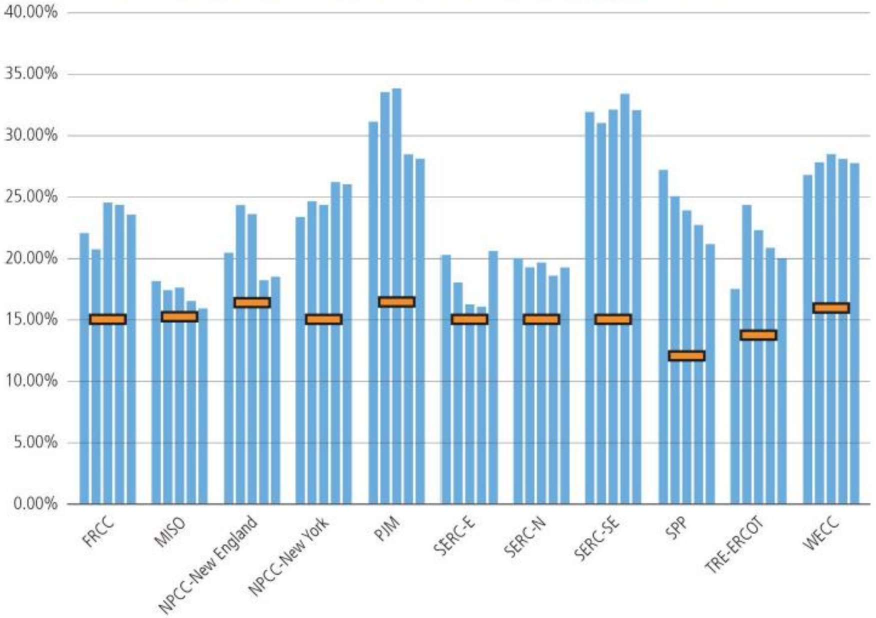
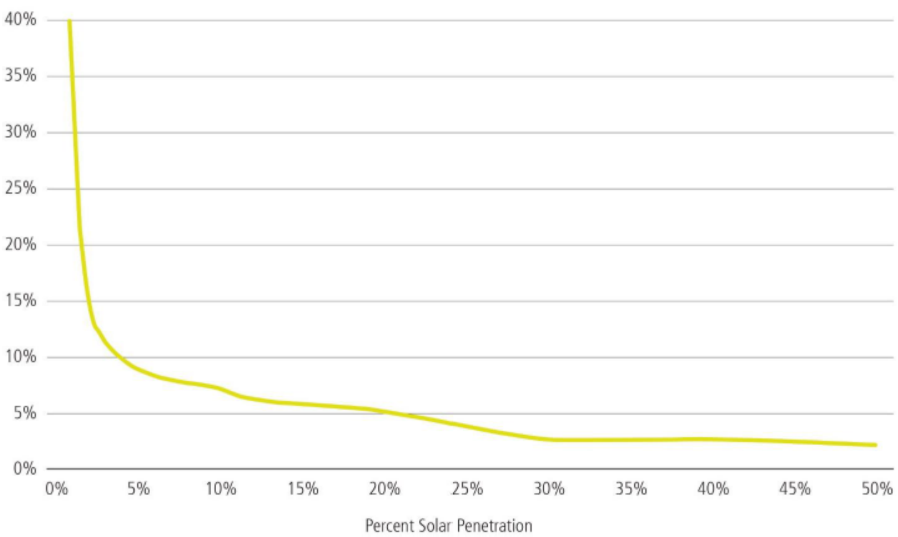


Figure 4.3. Historical Solar On-Peak Capacity Factors in ERCOT[232]



- **NERC: reliability is adequate**
  - Long-term resource adequacy is good – most (but not all) planning margins are flush
  - Emerging emphasis on capacity value of VRE
- **Need more analysis on changing needs for ERS in a future with increasing VRE levels and decreasing rotating mass-based inertia**
  - E.g. what's the capability of storage and DR to provide synthetic inertia or primary frequency response?

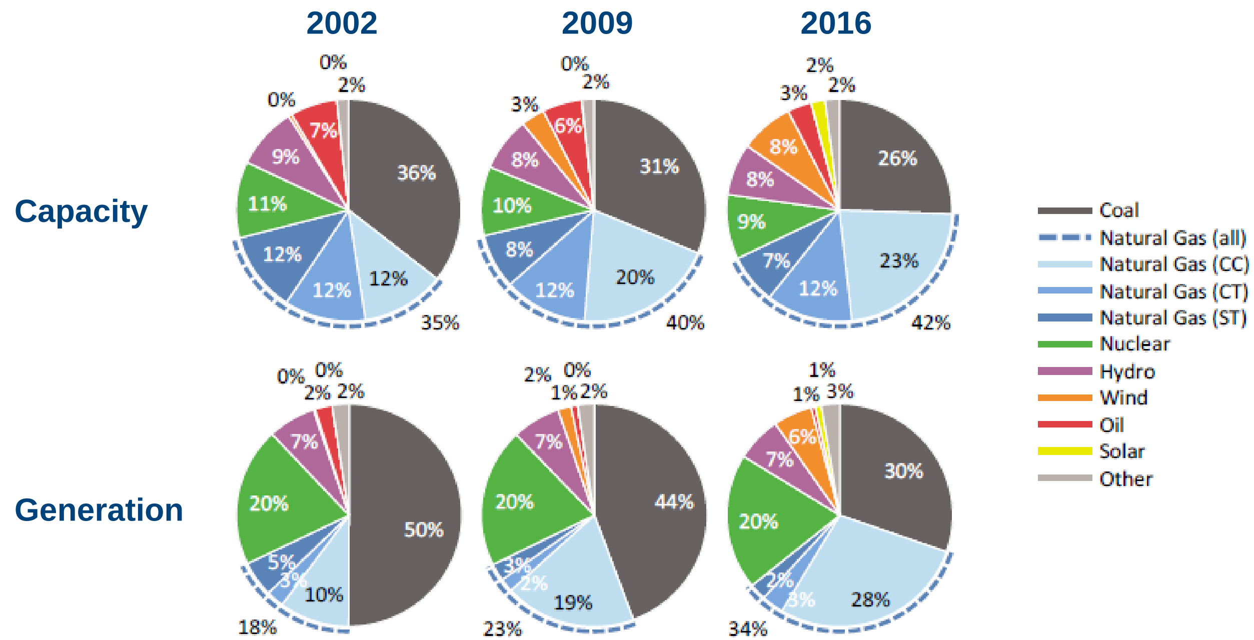
Reliability: PJM's perspective

● = Exhibits Attribute
◓ = Partially Exhibits Attribute
○ = Does Not Exhibit Attribute

Resource Type	Essential Reliability Services (Frequency, Voltage, Ramp Capability)					Fuel Assurance		Flexibility			Other		
	Frequency Response (Inertia & Primary)	Voltage Control	Ramp										
			Regulation	Contingency Reserve	Load Following	Not Fuel Limited (> 72 hours at Eco. Max Output)	On-site Fuel Inventory	Cycle	Short Min. Run Time (< 2 hrs.)/ Multiple Starts Per Day	Startup/ Notification Time < 30 Minutes	Black Start Capable	No Environmental Restrictions (That Would Limit Run Hours)	Equivalent Availability Factor
Hydro	●	●	●	●	●	○	◓	●	●	●	●	◓	●
Natural Gas - Combustion Turbine	●	●	◓	●	◓	●	○	●	●	●	●	◓	◓
Oil -Steam	●	●	●	●	●	●	●	●	○	○	○	○	◓
Coal - Steam	●	●	●	●	●	●	●	◓	○	○	○	◓	◓
Natural Gas - Steam	●	●	●	●	●	●	○	●	○	○	●	◓	◓
Oil/ Diesel - Combustion Turbine	●	●	○	●	○	○	●	●	●	●	●	○	◓
Nuclear	◓	●	○	○	◓	●	●	○	○	○	○	◓	●
Battery/ Storage	◓	◓	●	●	○	○	○	●	●	●	◓	●	●
Demand Response	○	○	◓	◓	◓	◓	◓	●	●	◓	○	●	●
Solar	◓	◓	○	○	◓	○	○	●	●	●	○	●	●
Wind	◓	◓	○	○	◓	○	○	●	●	●	○	◓	●

- PJM: first step is to determine how different resources can provide different types and levels of ERS
- More work is needed to fully define, value, procure, and compensate ERS

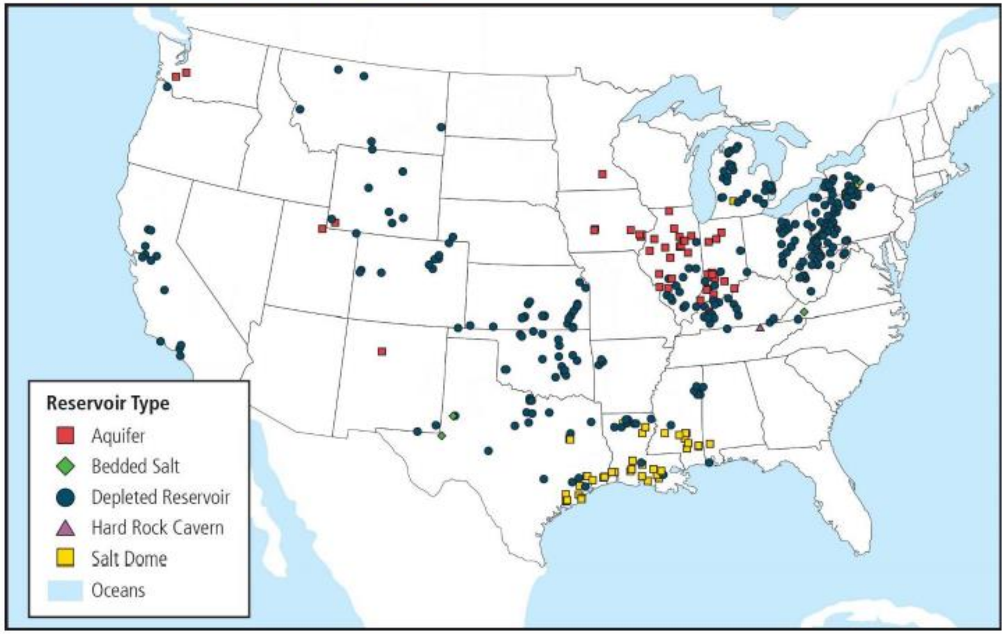
Reliability vs. Resilience



- Greater diversity doesn't always mean greater system reliability or resilience
- PJM simulation: when subjected to a polar vortex event, only 34 of the 98 portfolios which were classified as desirable in terms of *reliability* were also *resilient*

Resilience: Growing natural gas interdependence

Figure 4.18. Natural Gas Storage Facilities[322]



- **NERC letter:** *Growing reliance on natural gas continues to raise reliability concerns regarding the ability of both gas and electric infrastructures to maintain the BPS reliability at acceptable levels*
  - *Insufficient progress has been made reconciling the planning approaches and operating practices (scheduling situation awareness, information sharing) between these two inter-linked sectors*
  - *Planning approaches, operational coordination, and regulatory partnerships are needed to assure fuel deliverability, availability, security (physical and cyber), and resilience to potential disruptions*

Resilience: Withstanding and recovering from extreme weather events

Polar Vortex (Jan 2014)

- Fuel-gelling in natural gas generators in the Northeast
- Frozen gas fields and compressors in Texas
- Frozen conveyer belts and coal piles

Superstorm Sandy (Oct 2012)

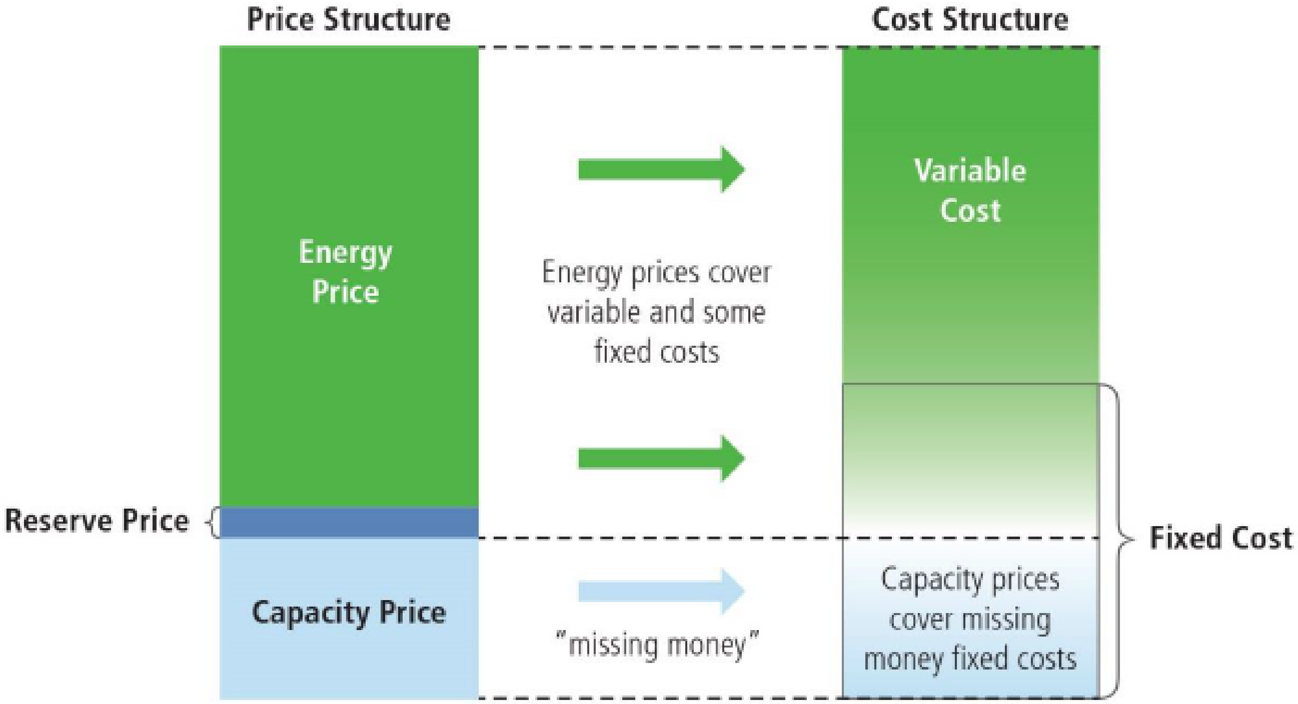
- Three nuclear reactors shut down
- Two key natural gas compressor stations downed in northern New Jersey

Hurricane Irma (as of 9/13/17): 3,515,268 customer outages in Florida (35% of total state customers)

Wholesale Electricity Markets

Missing money

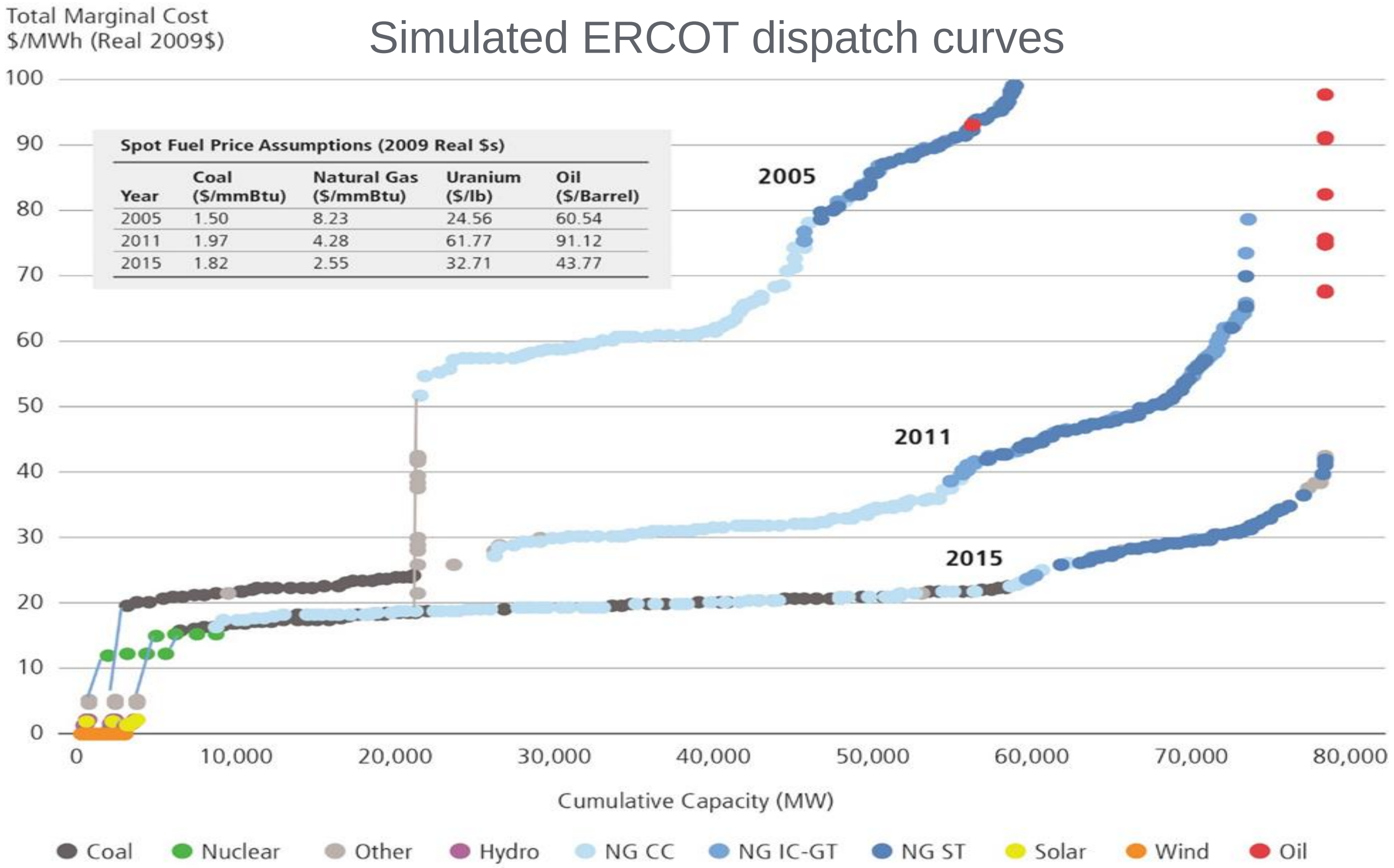
Figure 5.4. How Market Prices Allow Resource Costs to be Recovered in a Centrally-organized Wholesale Market[384]



- Increased penetration of zero-marginal cost VRE (and other factors) has lowered energy market prices
- Centrally-organized markets have turned to capacity markets and shortage pricing to help generators recover their variable + fixed costs, with mixed results

Wholesale Markets: Changing dispatch

Simulated ERCOT dispatch curves



Spot Fuel Price Assumptions (2009 Real $s)

Year	Coal ($/mmBtu)	Natural Gas ($/mmBtu)	Uranium ($/lb)	Oil ($/Barrel)
2005	1.50	8.23	24.56	60.54
2011	1.97	4.28	61.77	91.12
2015	1.82	2.55	32.71	43.77

Low-cost natural gas + subsidized VRE significantly flatten supply curves

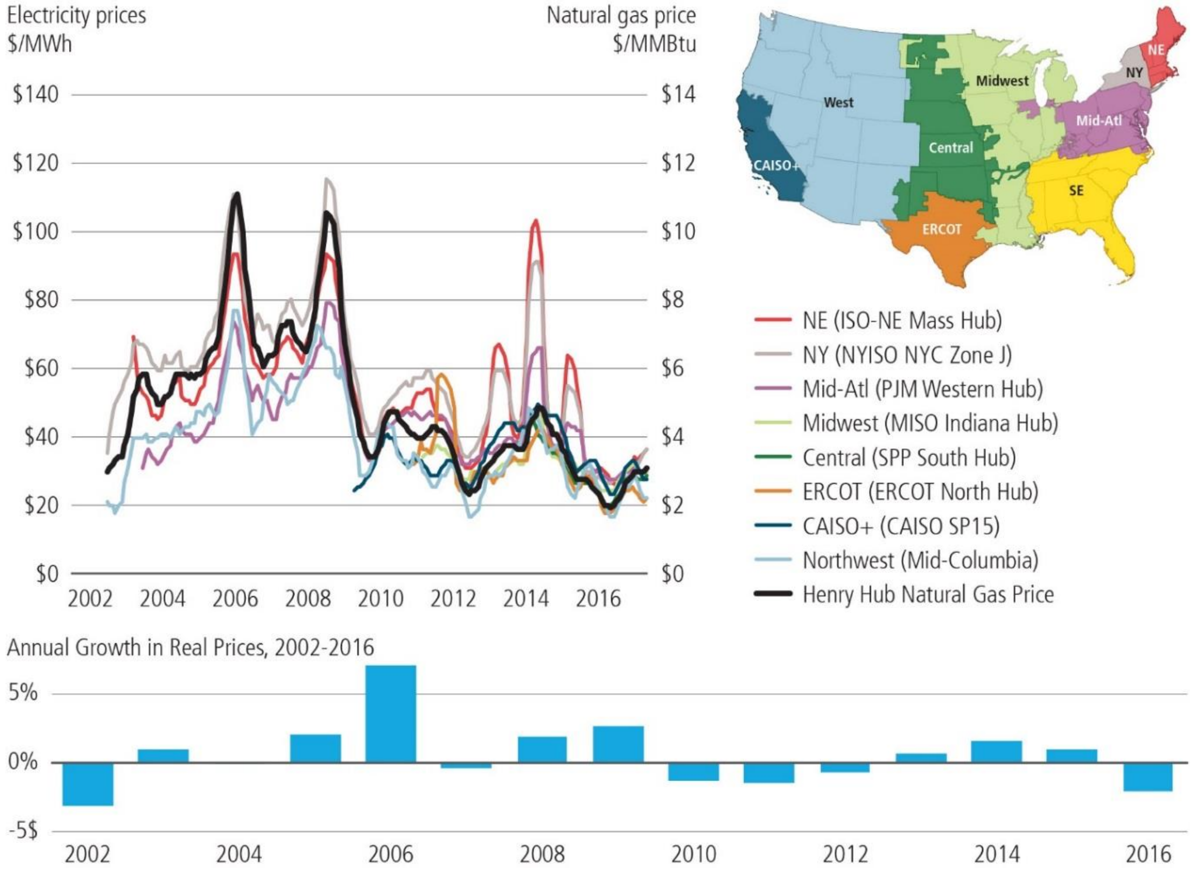
Wholesale Markets: Negative pricing

- According to analysis from LBNL, negative pricing events have historically been rare at many major pricing hubs (less than two percent of total hours in real-time markets in 2016)
- However, more frequent negative pricing has been observed in CAISO, and in constrained hubs that feature a relatively large amount of VRE and/or nuclear generation
- In addition, PJM has observed that "prices go negative at nuclear units buses in approximately 2,176 hours – representing 14 percent of off-peak hours"

William Hogan and Susan Pope on negative pricing in ERCOT:
Prior to the increase in wind and other intermittent capacity in the ISOs, negative prices sometimes occurred in the middle of the night, as load dropped and generators needed for operation the following day were pinned at their minimum loads. ***In contrast, the increasing incidence of negative prices in ERCOT is caused by the incentive of the owners of wind generation capacity receiving the PTC to continue to produce even when the locational price is negative****.*

Affordability

Affordability



- **Wholesale-retail disconnect**
- **Limited work done to-date on the affordability of the BPS as a system or portfolio**

Policy Recommendations & Further Research Areas

Key policy recommendations

Department of Energy

- Support industry efforts and focus R&D to enhance system resilience (for example, OE awards)
- Accelerate and reduce costs for re/licensing and permitting
- Facilitate programs for workforce development
- Prioritize energy dominance and EO 13783
- Increase coordination of electric and natural gas industries

Federal Energy Regulatory Commission (FERC)

- Expedite efforts to reform energy price formation
- Value new/existing essential reliability services

Environmental Protection Agency (EPA)

- Allow coal-fired power plants to improve efficiency and reliability without triggering new regulatory approvals and associated costs

Nuclear Regulatory Commission (NRC)

- Revisit nuclear safety rules
- Ensure safety without unnecessarily adding costs

Further research areas

Market Structure and Pricing	Reliability and Resilience	Cost and Affordability	Regulatory
Study mechanisms to enable equitable, value- based remuneration for desired grid attributes	Develop policy metrics and tools for evaluating system-wide provision of these attributes	Estimate system-wide costs of different generation mixes and sensitivities to fuel price fluctuations	Explore potential to utilize existing authorities to ensure system reliability and resilience
Evaluate ongoing capacity market reforms	Examine ways to improve power generator fuel delivery data collection	Update analysis of subsidies and support for electricity production	Explore costs and benefits of states applying cost-of-service regulation to at-risk plants

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Read the report here.

Provide your own review or input on the study here.

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