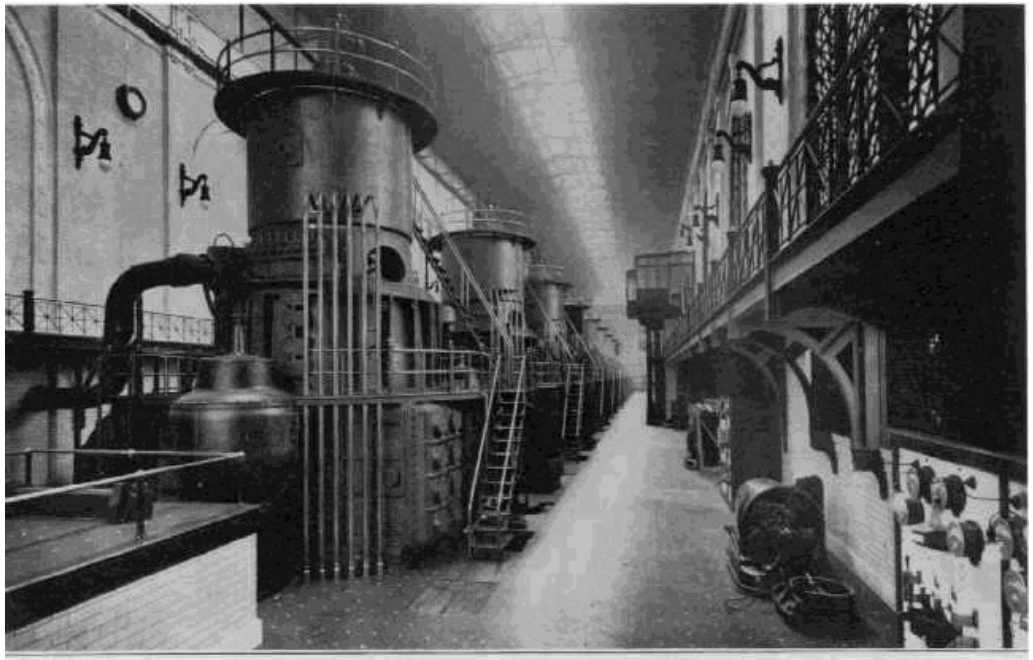
Electricity markets material

GEOS 24705 / ENST 24705 / ENSC21100

History of electricity sector

Electric sector history – from individual private companies



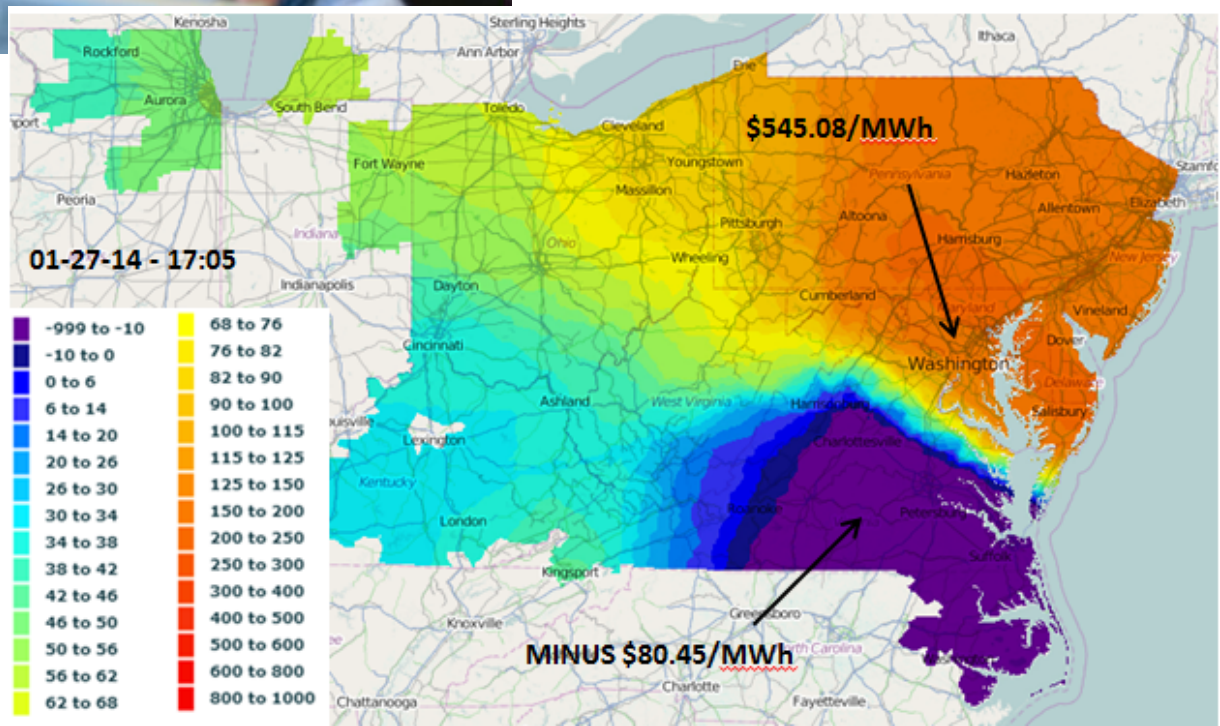
STEAM TURBINE GENERATING PLANT, FISK STREET STATION, COMMONWEALTH EDISON COMPANY, CHICAGO

Fisk Street power station, Chicago, 1903
Commonwealth Edison Chicago
first turbine-driven electricity in U.S.
(vertical turbines, AC power)

Edison Illuminating Co., Detroit, ~1900
(Detroit Historical Society)

Electric sector history - ... to organized, regulated markets

PJM control room, 2016



Locational marginal price, PJM, 5 PM Jan 27, 2014

Electric sector shift over time:

from individual private companies to organized regulated markets

1. **UNIFYING AND CENTRALIZING THE GRID**
2. **INTRODUCING MARKET FORCES**
3. **DECENTRALIZING GENERATION**

Electrical grid: major regulatory shifts

1. **UNIFYING AND CENTRALIZING THE GRID: shift from disconnected organizations and transmission to unified transmission** (3 grid regions), gradually more centralized authority

- 1920: First regulation under Federal Power Act (then repeatedly amended over time).
- 1965: blackout led to more communication between utilities on voluntary basis to ensure reliability
- 1977: Federal Electricity Regulatory Commission (FERC) established to regulate rates (+ license hydro), under authority of Federal Power Act
- 2005: Voluntary reliability council (NERC) replaced by an "Electric Reliability Organization" with actual enforcement authority

1965 blackout was wakeup call for need for grid management

New York City went dark, people were stuck in high-rises, crime spiked

Then 2nd blackout in 1977 contributed to sense of system (and city) in decay

FINAL DAILY NEWS

BLACKOUT!

LIGHTNING HITS CON ED SYSTEM

NEW YORK POST

METRO TODAY'S RACING

FRIDAY, JULY 15, 1977 · 25 CENTS

24 HOURS OF TERROR

- Several thousand looters and arsonists ran wild in parts of four boroughs during yesterday's blackout. It was the worst outbreak of rioting in the city's history and more than 3400 were arrested. Page 3.
- The blackout started because lightning struck three times — not in the same place, but close enough to trigger a crisis. It lasted 24 hours because of the enormous technical problems involved in restoring service. Pages 4 and 13.
- The blackout and the violence that went with it will cost uncounted millions of dollars. New York's disaster adds up to most expensive man-made one the nation has ever seen. Page 17.
- Con Edison is under heavy criticism on many levels as both the state and federal government begin investigations of why the second big blackout happened. Page 5.
- Inspectors fanned out through the city today in a massive sweep of stores and restaurants to guard against the sale of food spoiled after refrigerators and freezers were knocked out. Page 7.
- It was a time for heroes and well as villains. Some of the greatest benefactors were those involved in the life-and-death drama of the hospital emergency wards. Page 5.

8-page pullout picture section inside

BLACKOUT SPECIAL

headlines, 1977 blackout

The New York Times

POWER FAILURE BLACKS OUT NEW YORK; THOUSANDS TRAPPED IN THE SUBWAYS; LOOTERS AND VANDALS HIT SOME AREAS

State Troopers Sent Into City As Crime Rises

Lightning Apparently to Blame – Some Suburbs Affected

Lightning Bolt Now It Struck

1965: bad relay setting caused line out of Niagara power station to shut down, overloads cascaded. Blackouts for 30M people: CT, MA, NH, NJ, NY, RI, PA, VT, + Ontario.

1977: lightning hit substation and lines, took out some breakers and power lines. Overloads cascaded, shutting down more lines. Blackout over New York City only, lasted all night.

Electrical grid: major regulatory shifts

2. INTRODUCING MARKET FORCES: Transition from vertically integrated regional monopolies (one utility owns generation, transmission, distribution) to competitive systems

- 1992 Energy Policy Act: FERC can order a company to carry power for someone else
- FERC orders through 1996 encourage formation of Regional Transmission Organizations (RTOs)
- Most places now have competitive generation: utility or load-serving entity buys from multiple independent generators, with a market for power and hourly pricing
- Possibly in the works: market system on retail side too (requires hourly pricing and so "smart meters")
- Still problematic: competitive distribution

Electrical grid: major regulatory shifts

3. DECENTRALIZING GENERATION: Encouragement of distributed power:

- Energy Policy Act of 2005 requires net metering – *residential producers must be allowed to sell excess power back to the grid (typical at retail but that is not fixed by law)*
- Small (2-10 MW) operators can sell at market rate by Federal law
- Demand-side management, or DSM (pay for "negawatt" generation) is now an option in some markets, areas

Now multiple entities involved in electricity system

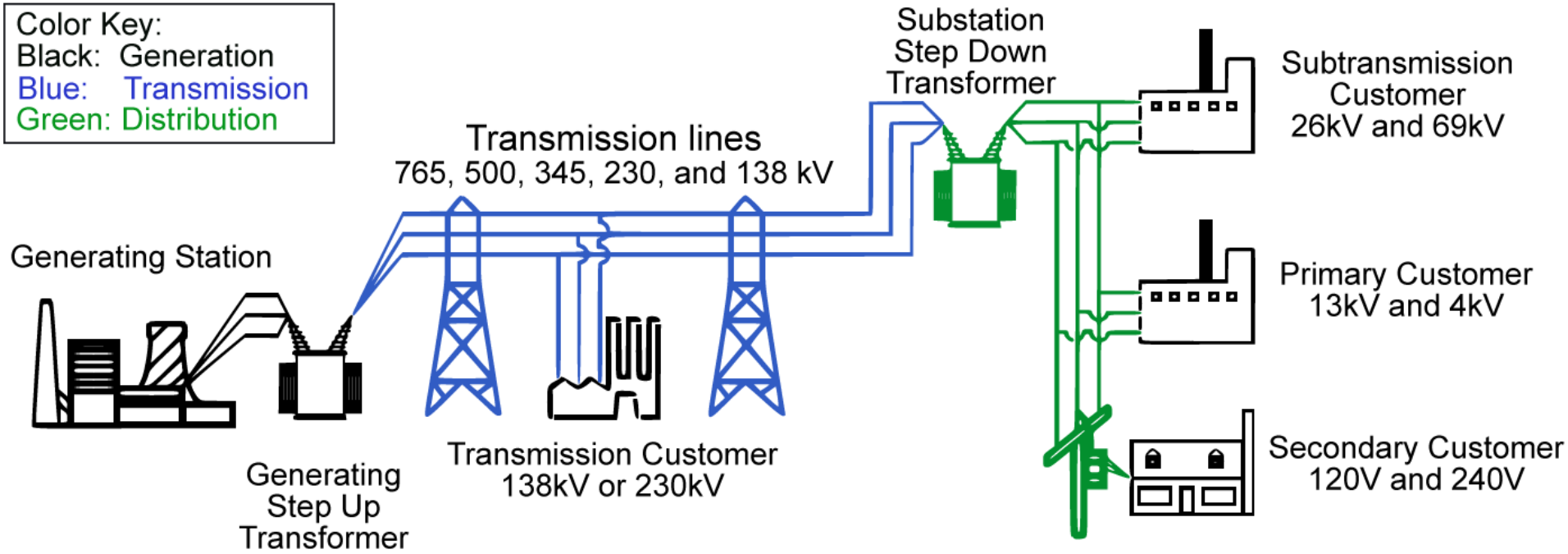


Image: Wikipedia

For most of 20th century, one entity owned all components in chain

Now typically owned by 2 or 3 diff. entities, managed by another, and market can be managed by outside broker – up to 5 players in game

- Generator
- Transmitter (long-dist. wires)
- Grid operator (wires operator)
- Utility for distribution (local wires)
- Load-serving entity (seller to consumer)

Present ownership and operation

Summary of ownership in the new deregulated elect. industry

Utilities are "wires" companies. They own the distribution and transmission lines, repair the lines, process billing, and take payment from retail customers.

RTOs are managers: (for most people, though not everywhere): They manage the market (buy and sell, set clearing prices), and exercise minute-by-minute control of generation and congestion management (call to get plants turned on or off)

Anyone can be a generator: in market system, power production is open to all

Definition: **Regional Transmission Organization**

"An entity that is independent from all generation and power marketing interests and has exclusive responsibility for grid operations, short-term reliability, and transmission service within a region."

Regional Transmission Organizations

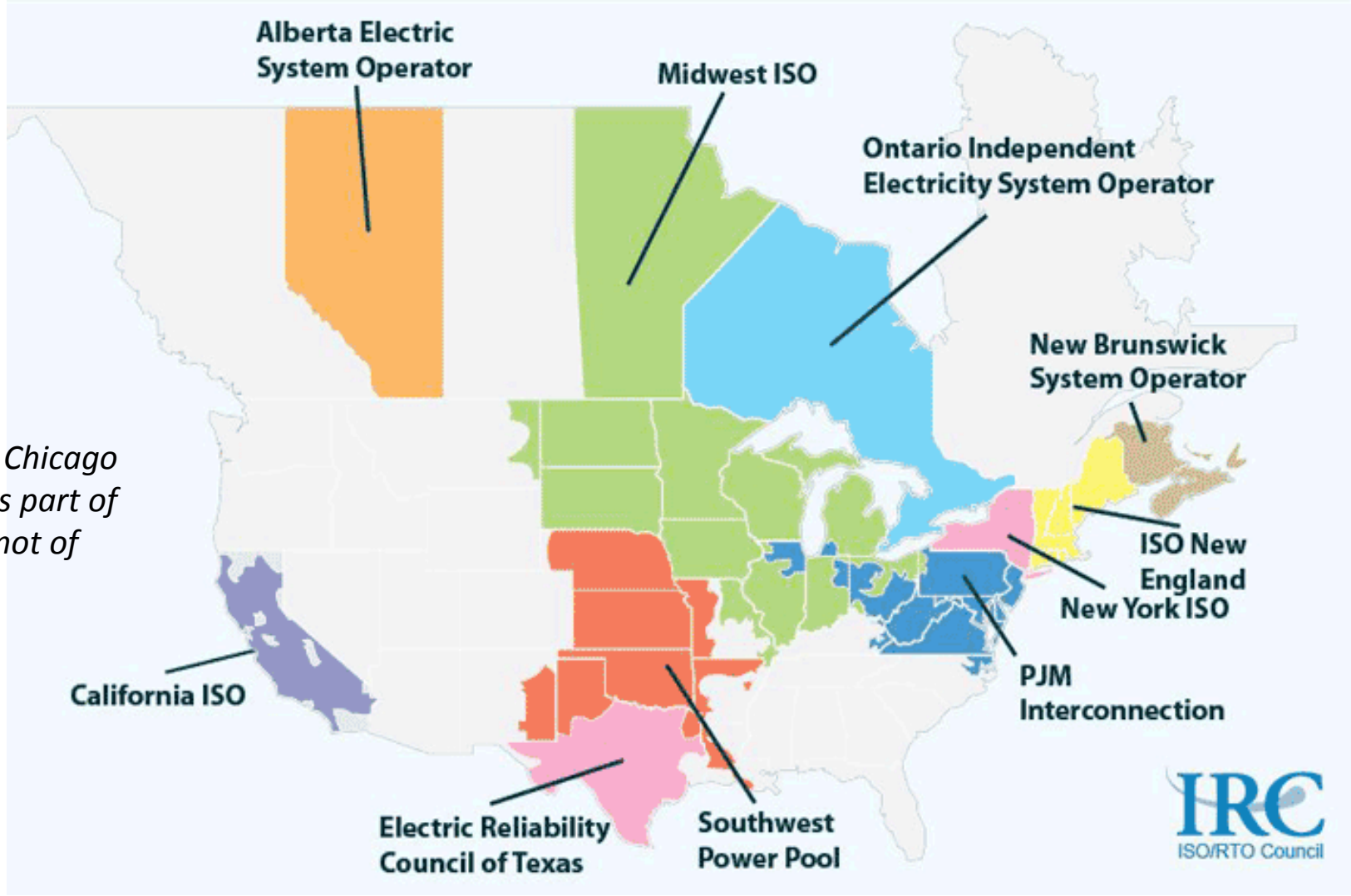
An RTO is an entity created to balance generation across a regional footprint regardless of ownership of generation ….invented to promote competition and hopefully efficiency. "Independent system operators" (ISOs) are similar to RTOs but often cover smaller geographic areas.

RTOs eliminate the need for generators to contract with separate utilities to sell and transmit power, and prevent integrated utilities to favor their own generation and block transmission of competitors. The goal is to create a transparent market to incentivize more optimal building and dispatching of generation.

In Europe analogous entities operating across countries are called "transmission system operators" (TSOs)

About 60% of U.S. electricity is now managed by RTOs and ISOs

RTOs as of 2010 (ISO/RTO Council)



Note: Chicago area is part of PJM, not of MISO

RTO exceptions:

Arizona: from electricity standpoint is essentially a colony of California – its generation not managed by RTO, but independent generators make long-term contracts with California, sell into California markets.

Texas: The only state where a single agency regulates both the generation/transmission side (wholesale prices) and demand side (retail rates). Texas is its own RTO, full state-wide authority. Makes planning much easier to have one central power.

SE U.S. is traditional utility ownership and operation on big scales (e.g. TVA, The Southern Company) so no need for RTOs. Note that the SE U.S. is the site of many recent over-budget projects that were ultimately canceled.

Rocky Mtn. corridor doesn't have much transmission

Ownership: high-voltage transmission

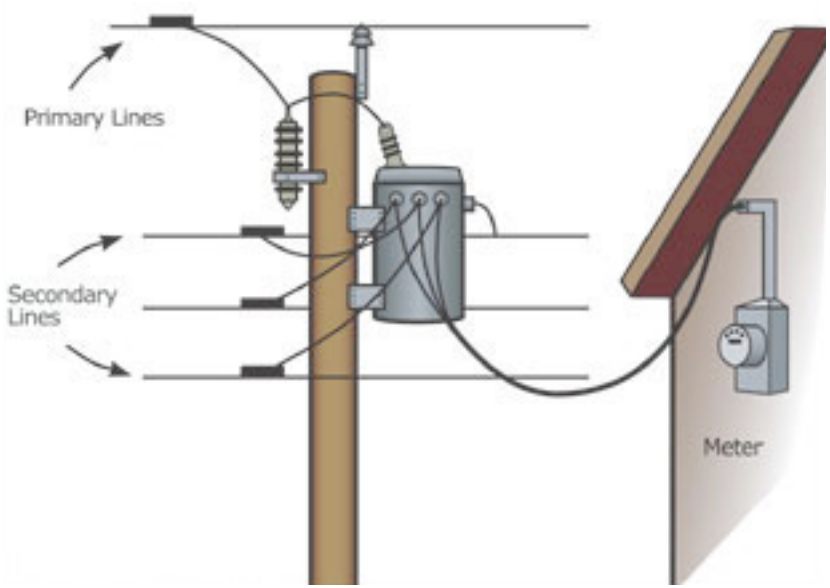
Generally owned by utilities but managed by RTOs (regional transmission organizations). The RTOs are are themselves owned by groups of utilities.

Ownership: distribution

Owned by utilities: 3170 total in U.S. (75% of customers are served by 239 investor-owned; the remainder are public, co-op, Federal)

The primary job of utilities (like ComEd) is to maintain a distribution network and to sell power to residential, commercial, and industrial customers.

Many utilities still generate much of the power they carry, but some generate none. The businesses of generating and selling are becoming decoupled. You can even bypass the utility for your electricity purchase and ONLY pay them for the distribution service. Very analogous to phone system after deregulation.



Ownership: generation

Generation can be owned by utilities but also by independent power producers who sell on the open market

Example: Exelon, who own Dresden nuclear generating station, is not a utility. It is mostly a power company that owns power plants and sells their output to utilities or RTOs.

Exelon *owns* ComEd. The utility is a subsidiary of Exelon, not the other way around. When the lights go out, the guys (or gals) who come fix it will wear ComEd hardhats, not Exelon hardhats.

How is electricity sold?

3 markets for electricity generation

For electrical power itself

- Day-ahead market: payment made under contract to provide power if needed at market-clearing price
- Real-time market: emergency purchases of power as needed minute by minute at pre-set rates

For electrical capacity

- Capacity markets payments made to all generators in RTO simply for existing to provide backup (ca. 2% of elect. price)

Who pays, and to who?

RTO: Every day the RTO buys all the power that will be used and sells all that power.

Each day the RTO forecasts power demand for next day. Each day the generators all send in "bids" stating how much they'll be willing to sell their power for. The RTO then buys all the power it thinks will be needed, at the ***marginal price***. I.e. everyone gets the price of the highest-priced seller whose power is bought.

But, the RTO doesn't actually write a check to those generators til the power is used. If power isn't needed after all, no $ change hands. Only if power is generated does the RTO writes a check to generators.

The RTO then turns around and sells all that power to utilities, who then sell it to their customers. The utilities write a check to the RTO.

Who pays, and to who?

RTO: Every day the RTO buys all the power that will be used and sells all that power.

Utilities: The utilities pay the RTO.

Utilities can also make "bilateral contracts" with particular generators, to lock in that power for the utility at a given price. If so, the utility then pays the generator just the difference between the market price and the contract price. This is a hedging strategy to minimize risk.

Who pays, and to who?

RTO: Every day the RTO buys all the power that will be used and sells all that power.

Utilities: The utilities pay the RTO.

Generators: Sell to RTOs. Also get $ from contracts with utilities.

Generators can also sell directly to customers IF on private land and if the distribution network can be bypassed.

And , generators are also paid not for power but simply for existing, to provide power if necessary. ("Capacity" market)

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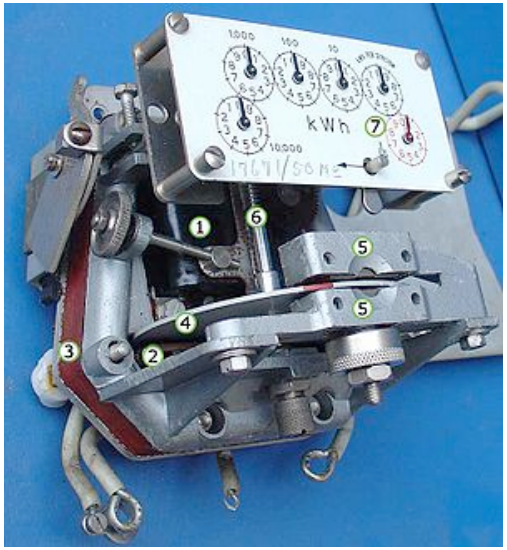
Residential power customers: pay $ to the utilities



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Residential power customers: pay $ to the utilities

Transmission owners: receive payment from the RTO, but just for recovering costs – fixed return on investment. (Need permission to build, though).

Note: If transmission owners are also generators they have insufficient incentive to build more transmission, since get more money for generation if it must be local because of congestion. (Even 15% return w/ no risk from building transmission won't outweigh the profit from generation).

Who sets the amounts that people pay?

In the old days

The utilities owned everything, and would charge customers enough to recover their costs. The state utilities commission would approve the rates.

Nowadays

Generator price set by the day-ahead (and real-time) markets: Sets the hourly price that generators receive for power or for capacity.

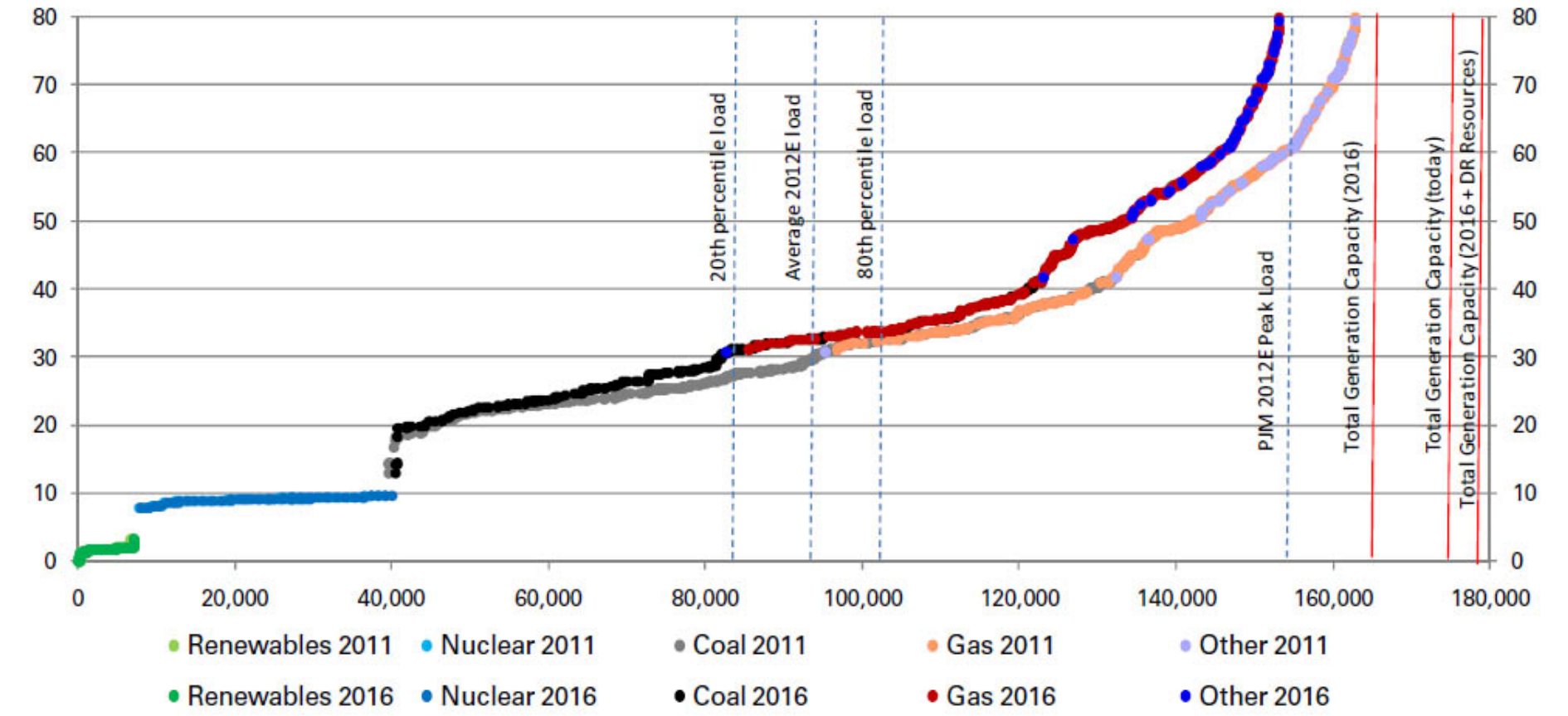
Wholesale price set by market and by FERC: FERC sets the markup that the RTO can charge over market, and sets the fees paid for transmission.

Retail price set by state utilities commissions: The PUC sets the rates that the utilities can charge their customers. At present these are flat rates – no hourly charges – but that may change.

Day-ahead market: hourly prices set to match expected demand

- Generators bid in at the "marginal cost" at which they would sell electricity
- RTOs assemble the "stack" of bids, forecast the next day's demand, and set price
- All generators whose bids are "taken" get the same price

Figure 19: PJM Supply Curve – 2011 vs. DB 2016E ($/MWh and MWs of Capacity)

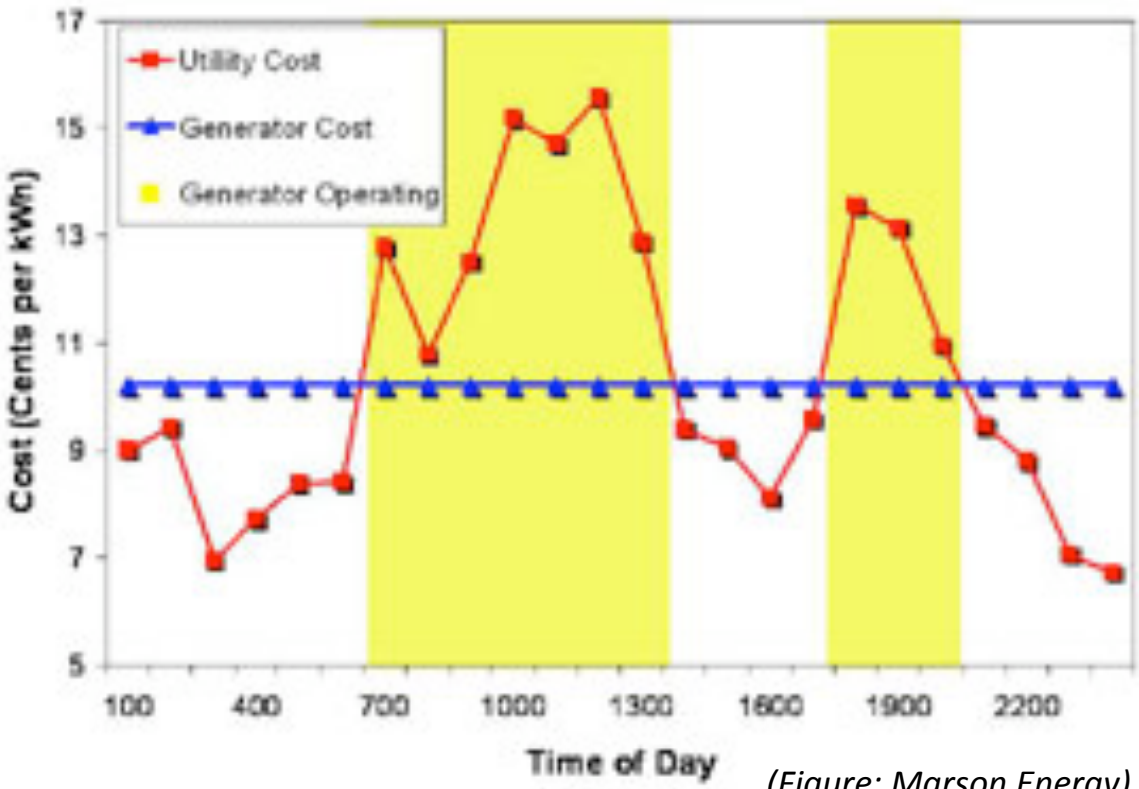


*Source: Deutsche Bank; Energy Velocity; PJM. *2012 load estimates are from Energy Velocity.*

Marginal price differences are fundamental to market

Generators are turned on when their bid is below market-clearing price

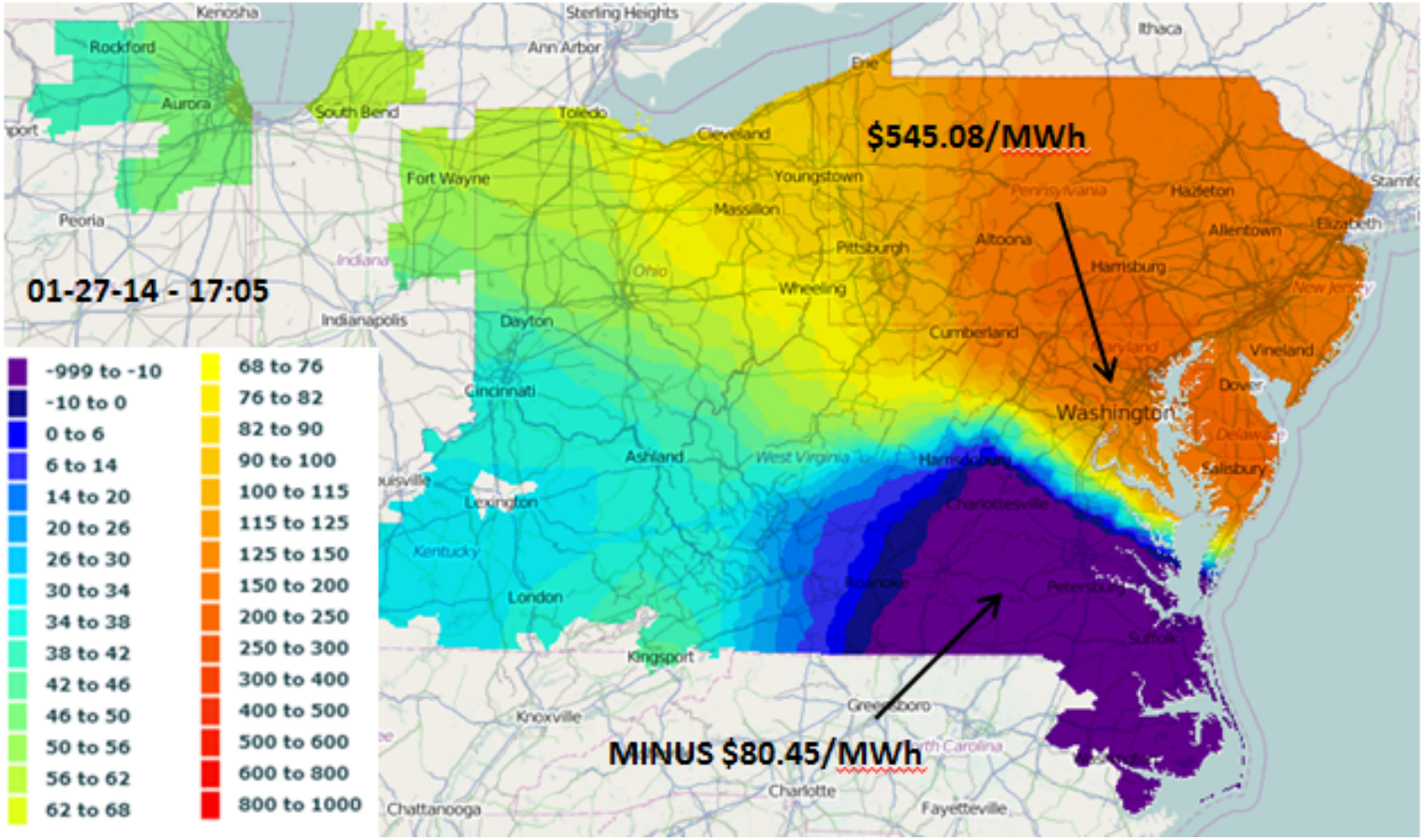
Generators bid their marginal cost…then each generator receives the market-clearing price when it is turned on. All get the same price.



(Figure: Marson Energy)

Note: the market system does not *guarantee* that the user will get a lower price than in the old monopoly system. The user now pays the **marginal** cost of electricity generation rather than the average **total** cost. But the theory is that the system will lead to incentives to build the appropriate generation units and ultimately lower costs, and that seems to be mostly working in practice.

Market is then adjusted by location to avoid congestion on lines



Example: locational marginal price, PJM, 5 PM Jan 27, 2014

clearing price is now different in different parts of PJM

frigid winter temperatures and gas shortages drive demand and high prices... more power flows, then transmission constraints cause negative prices over large area. Peak price (not clearly shown) is nearly 100 x normal ($2.6/kWh), allows expensive local generation.

Diurnal cycle requires mix of generators

demand typ. peaks mid-day, expensive peakers turn on only during max load

Typical: Baseload power stays on all the time. High-marginal-cost power is purchased only during mid-day when demand is highest.

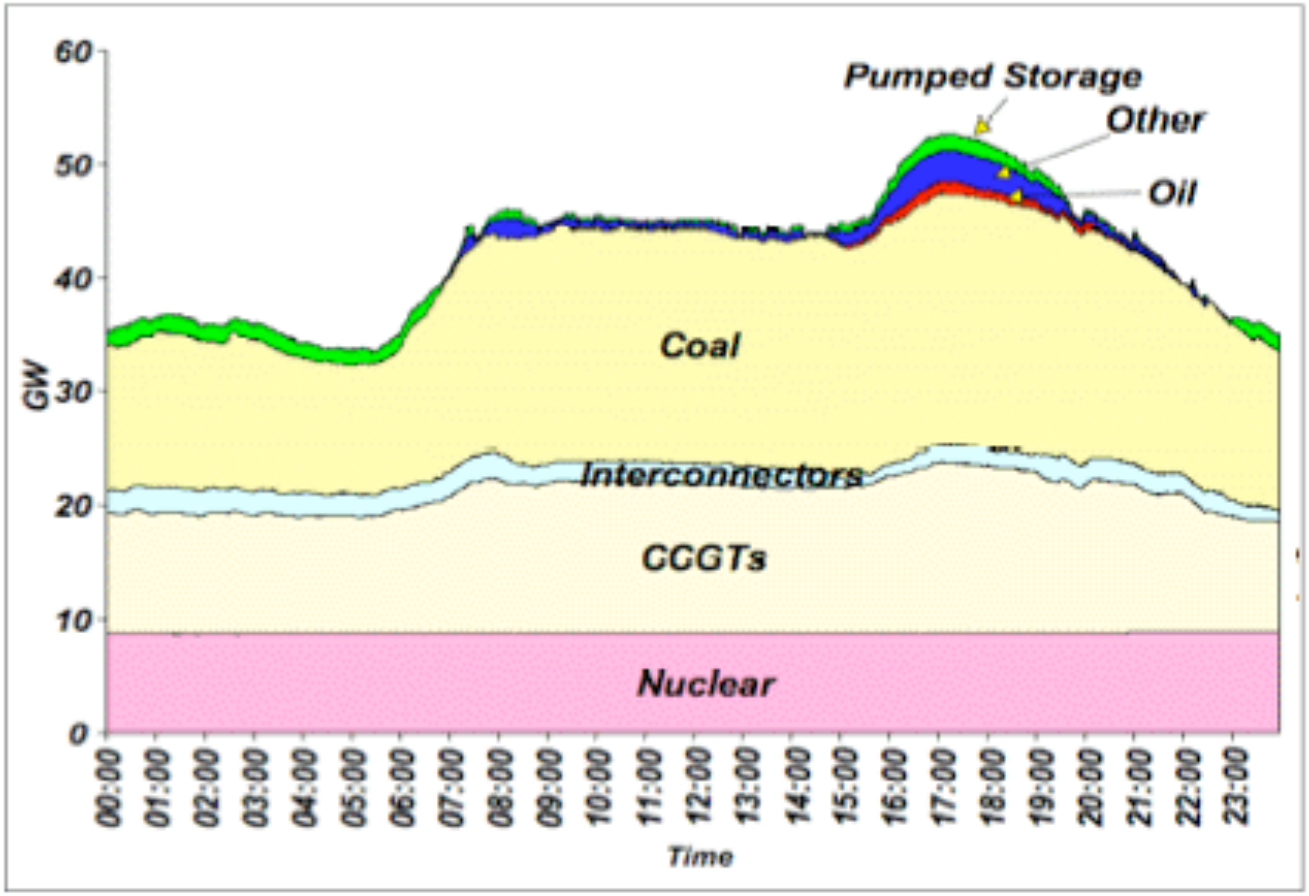


Figure 11: Generation source for a typical daily demand profile. ***Courtesy of NGC 2007***

(CCGT: Combined Cycle Gas Turbines).

(figure from the U.K.?)

Electricity market used to work well, partly by coincidence:

key feature: peakers were always more expensive than baseload

In all previous history, the expensive marginal cost generation is fast to turn on and off, so can be used as peakers when demand is high

Generation Type	Response time
Pumped Storage	10 seconds
Gas Turbines	2 minutes
Combined Cycle Gas Turbine	6 hours
Oil Fired	8 hours
Small Coal	12 hours
Large Coal	24 hours
Nuclear	48 hours

Table 4: Typical Response Times of various forms of Power Generation (National Grid Company, 2007).

Issue: now the marginal generation is often coal, which is slow to dispatch

Electricity strategies driven by the ordinary diurnal cycle

When demand is too high

Peakers: buy high cost but fast turn-on generation that can come on just for the peak energy demand period. (*Big complications now that relative costs are flipped.)*

Peak-shaving: buy electricity when it's cheap and store it, then sell it back to the grid when it's expensive

Demand-side management, contracted: agreements with customers requiring them to turn off if demand is too high

Demand-side management, incentives: introduce time-variable pricing for customers to incentivize less use at peak periods.

When demand is too low

Load-dumping or curtailment: turn off renewables, or for baseload power that can't turn off, just have to dump it

Current issues upending electricity markets

- Market is profoundly changed by cheap natural gas
  - *the more expensive power is no longer the more dispatchable - can't just take the low bids in the supply stack*
  - *if coal plants become un-economical, shut down, then stack shifts – low capacity means high demand causes price spikes*

- Gas and must-take renewables lower wholesale prices
  - *renewables bid in a $0 since their marginal cost is zero*
  - *some renewables also bypass the market because get side contracts (power purchase agreements, PPAs)*
  - *marginal price is no longer sufficient to incentivize new builds*

- Renewables are changing the diurnal cycle
  - *in CA, HI solar power means no longer have peak in middle of day, instead have dramatic rise in 'net' demand in evening when sun sets*

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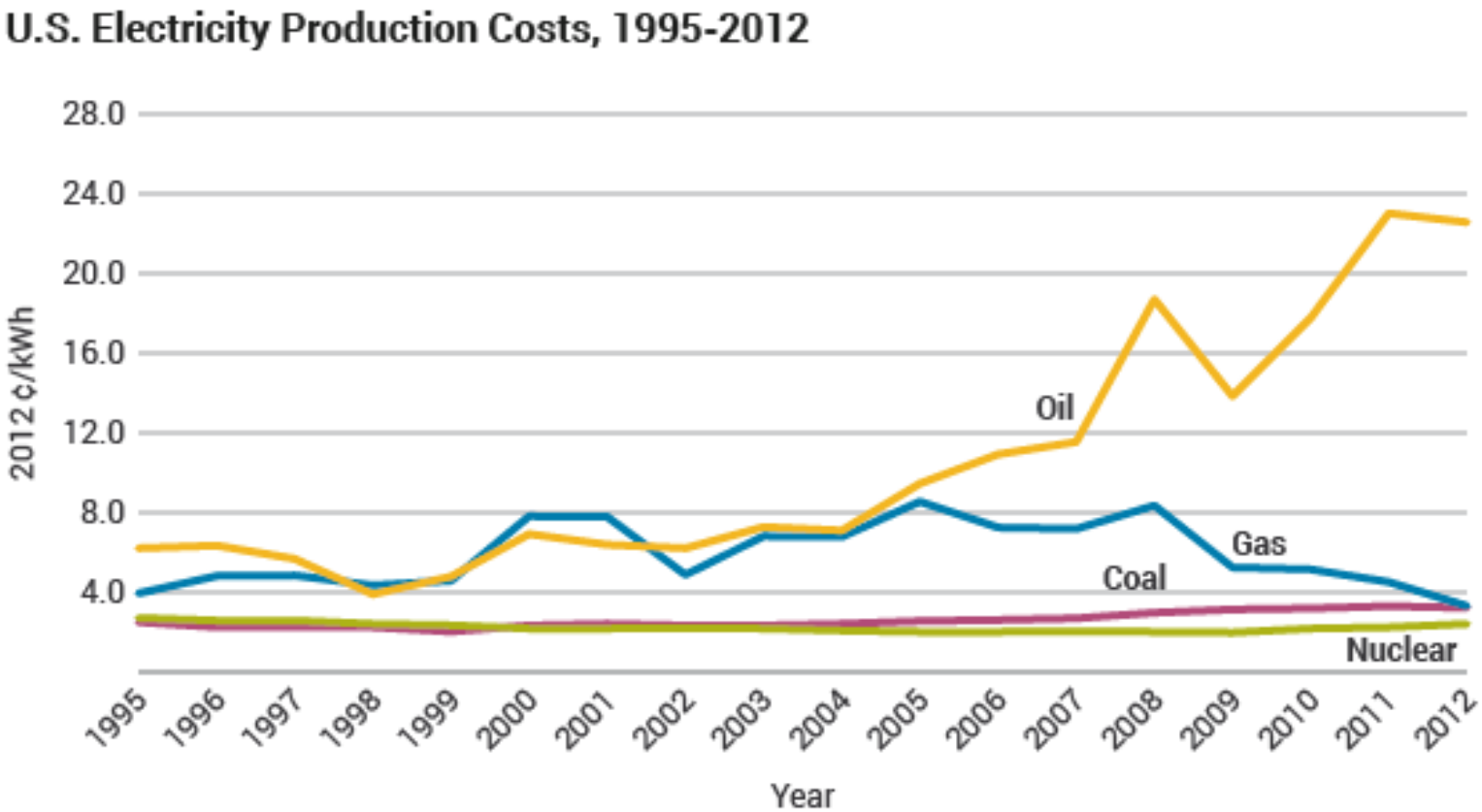
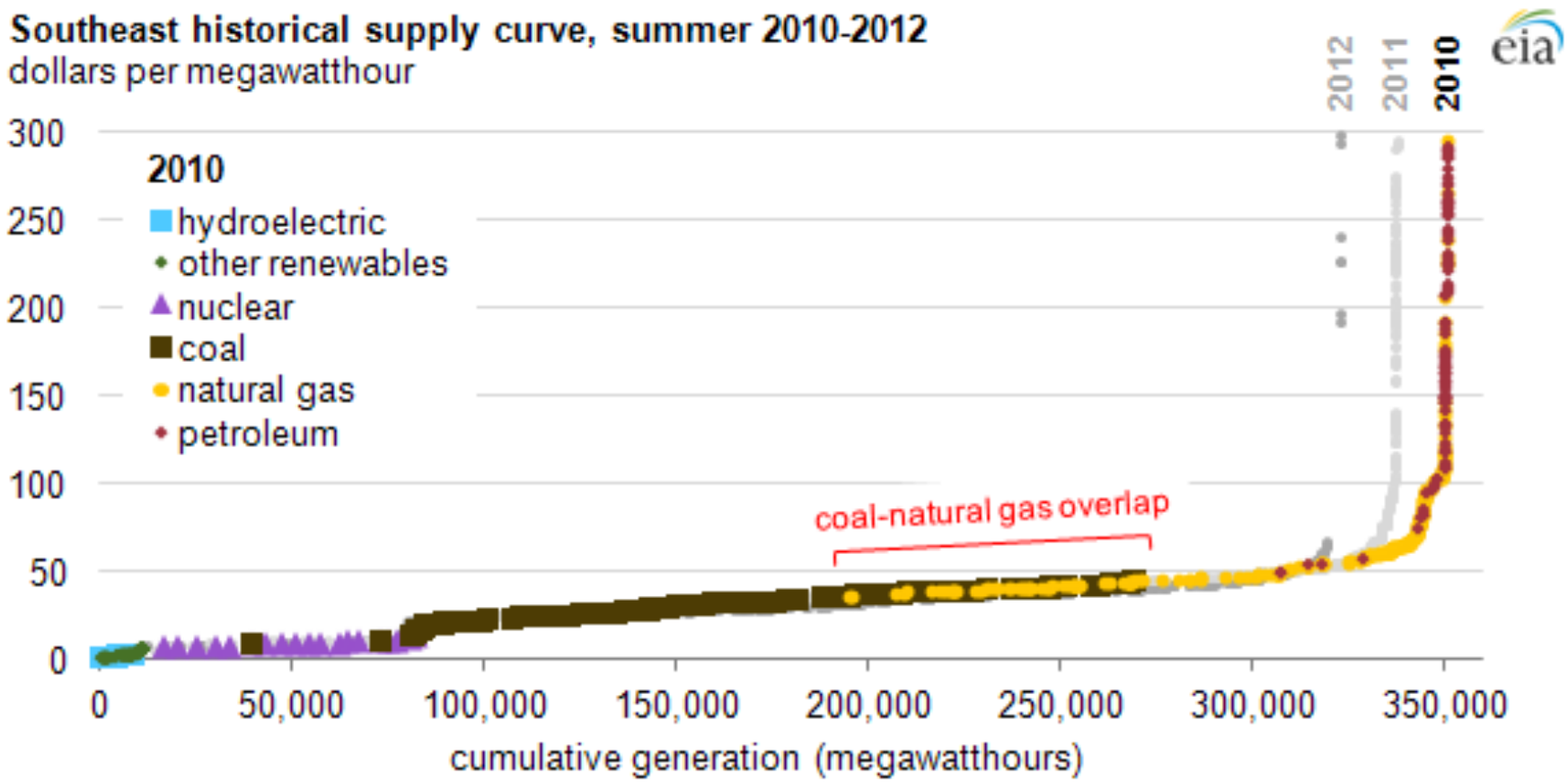
Generation cost: baseload used to be cheaper than peakers, but gas generation cost falls sharply starting ~ 2007 (fracking)



Production costs = operation & maintenance + fuel. (excludes indirect costs and capital)
Source: Ventyx Velocity Suite / NEI, May 2013

now cheaper than electricity from less flexible coal plants...

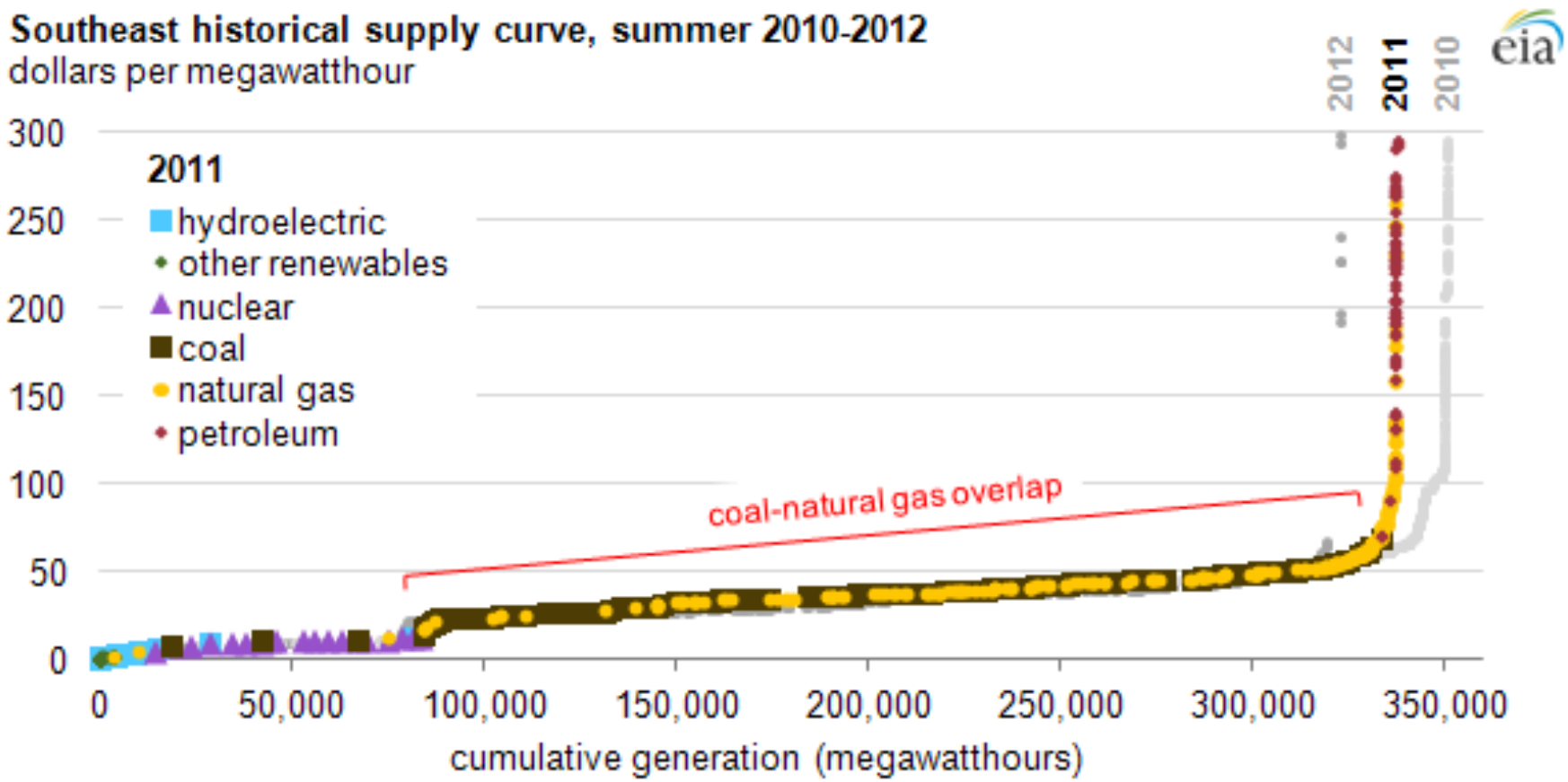
Electricity market - lowering gas prices shifts the supply stack



2010: *some gas generation starts to become as cheap as coal (plants move down the stack so they would be "taken" earlier)*

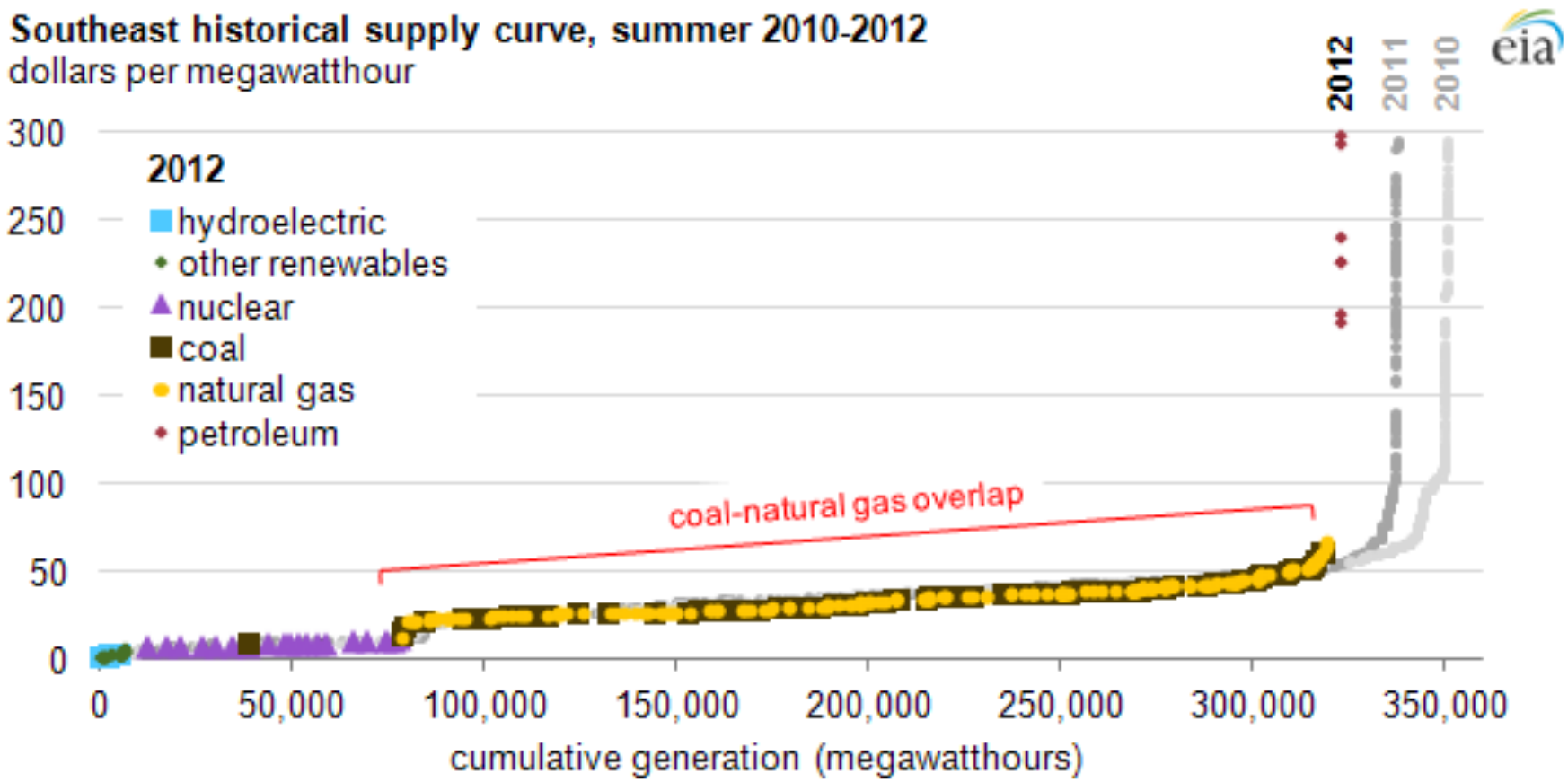
from https://www.eia.gov/todayinenergy/detail.php?id=9090#tabs_SpotPriceSlider-3

Electricity market - lowering gas prices shifts the supply stack



2011: *gas-coal overlap increases. Effect on prices during normal demand is very small. But, some coal plants shut down, reducing the total generation capacity, so peak prices would spike*

Electricity market - lowering gas prices shifts the supply stack



2012: *overlap progresses. During normal demand periods, wholesale price is now lower. More coal plants shut down, reducing capacity.*

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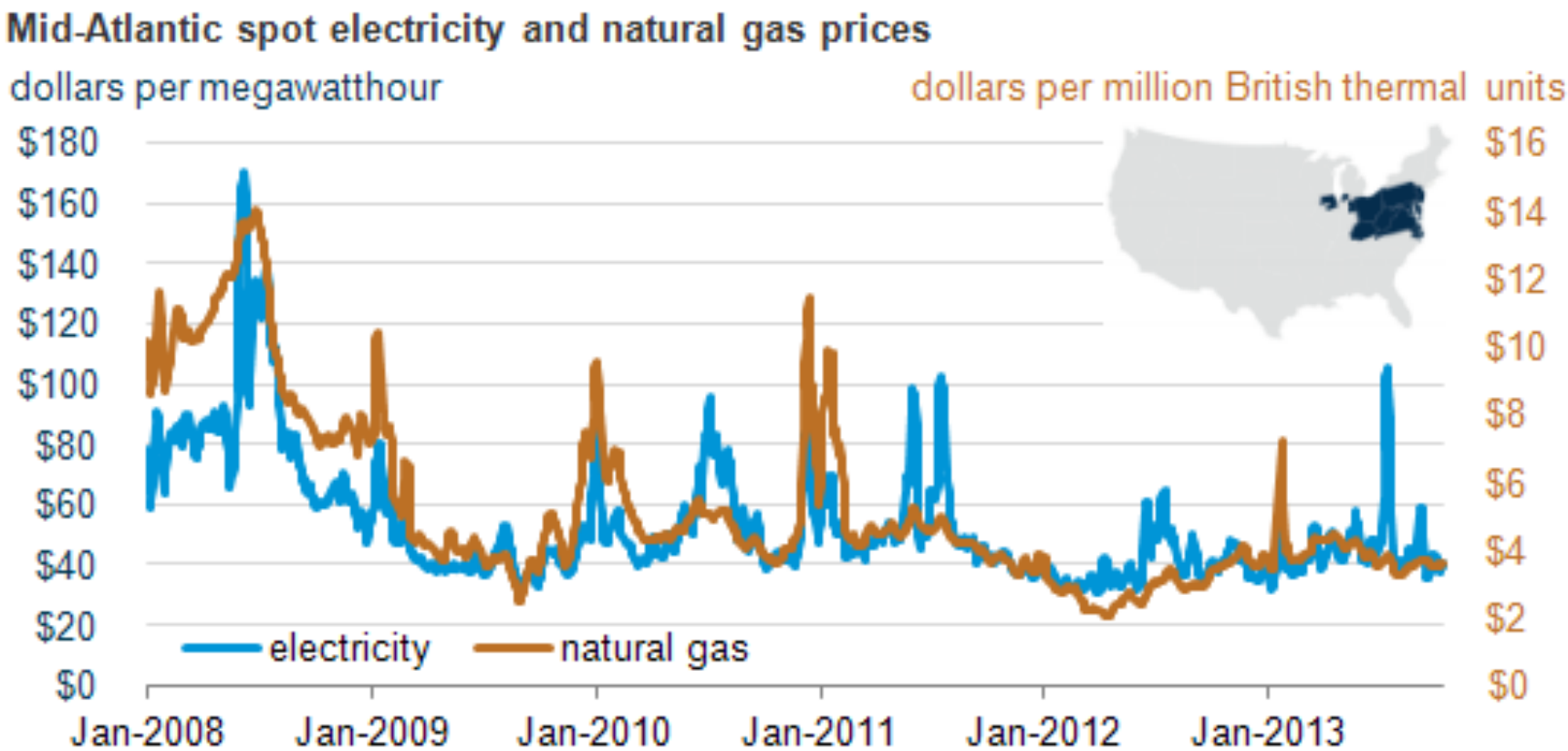
Low natural gas prices have lowered mean wholesale rate

low prices are bad for renewables, make it harder to compete

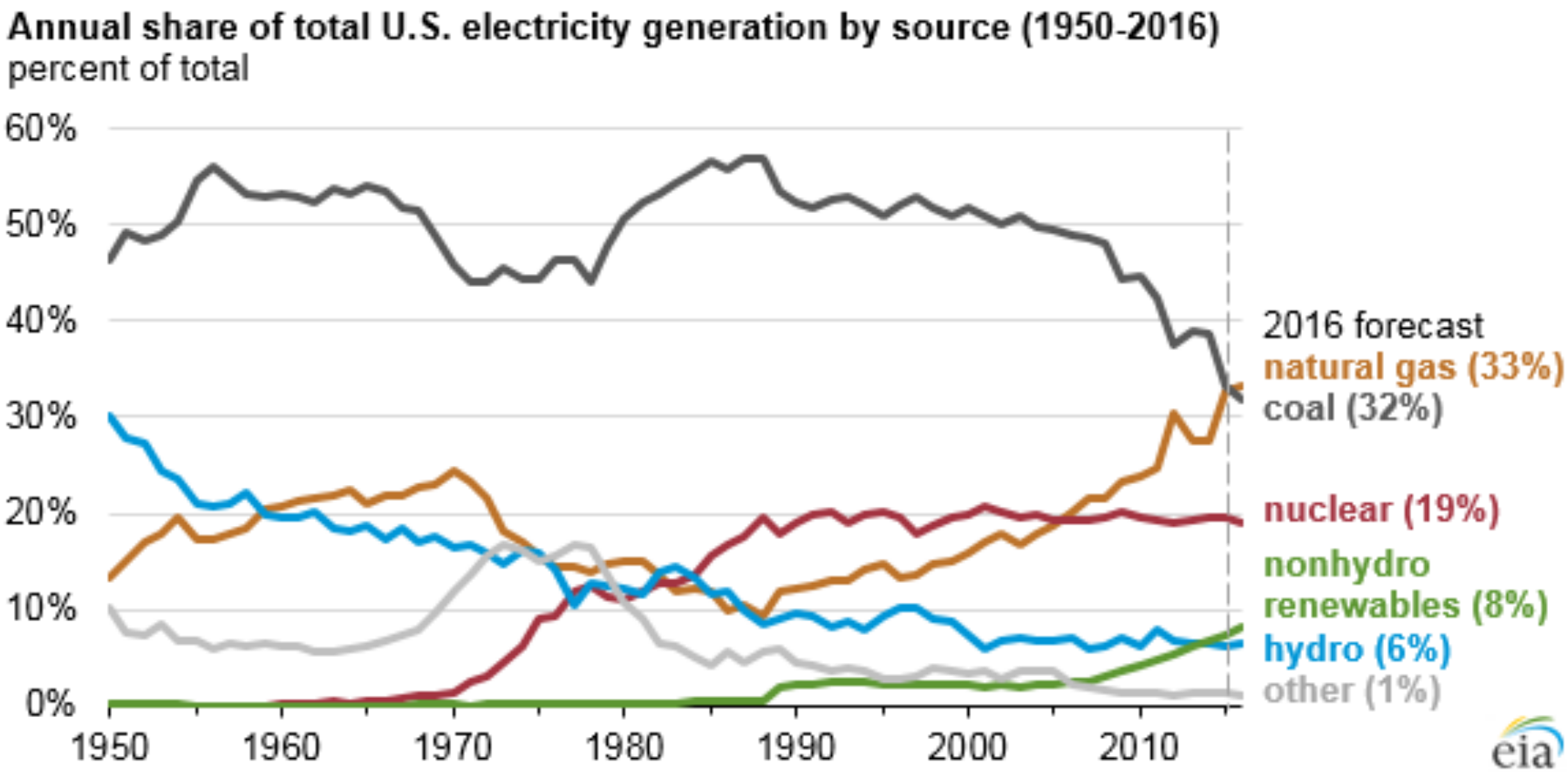
renewables demand long-term contracts, nuclear and coal demand subsidies



Gas and wholesale electricity prices peaked ~2008 when gas was scarce – then fracking causes both prices to fall by about half. Enormous change to economic landscape of electric sector.

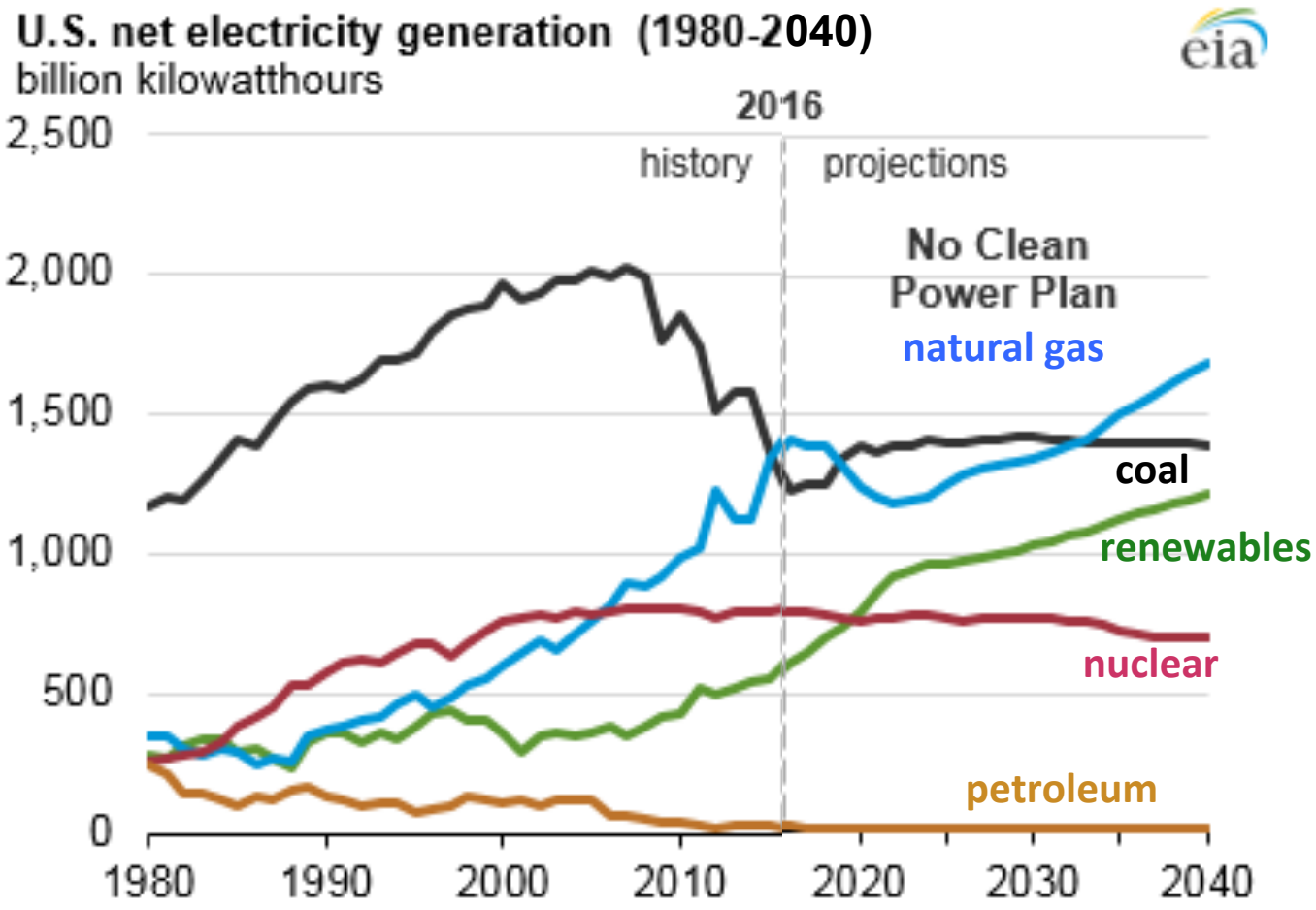
Market response: less coal generation, more gas generation

Coal decrease is unprecedented in last century



Coal decrease is in absolute as well as relative terms

decline in coal projected to be permanent, even without policy



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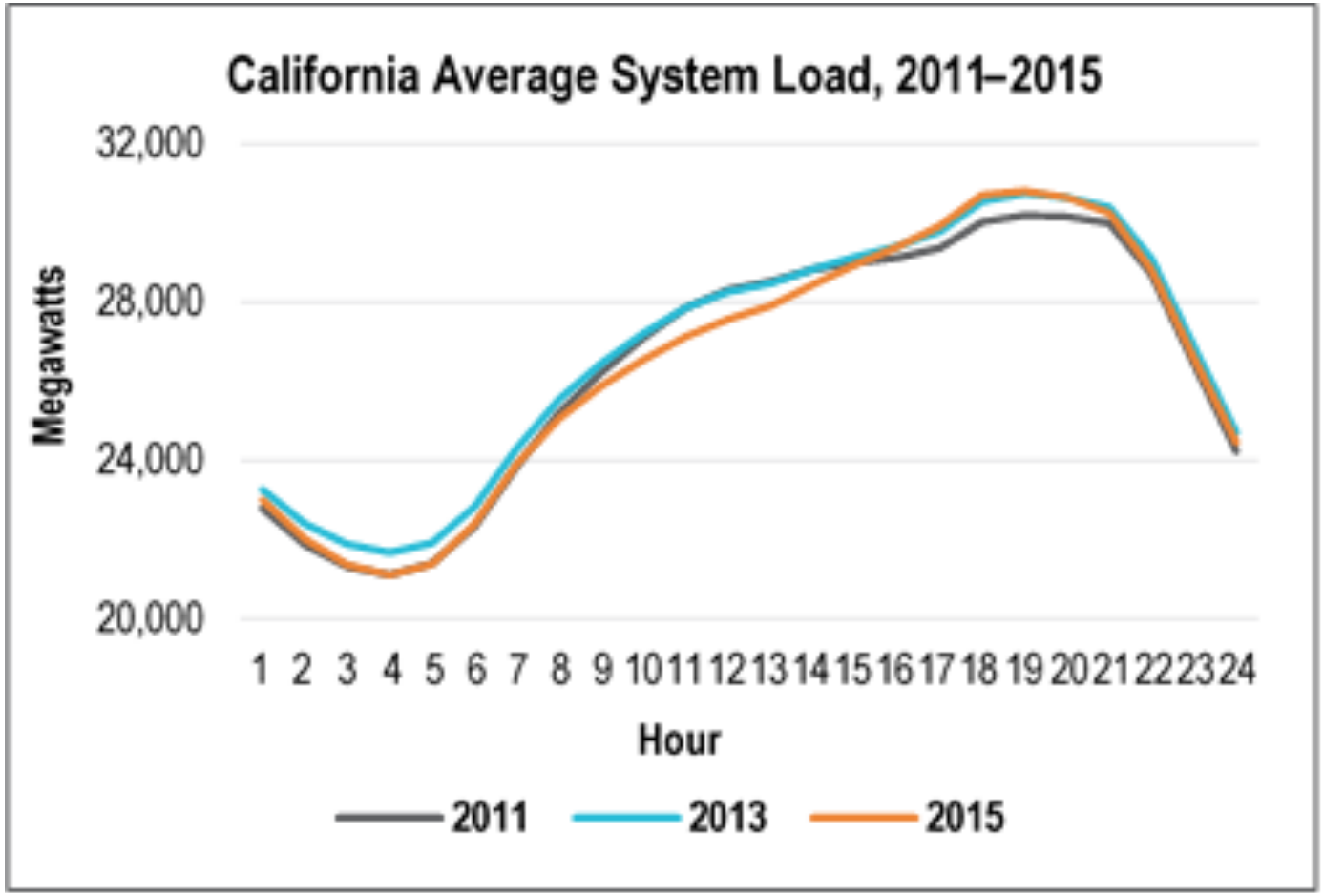
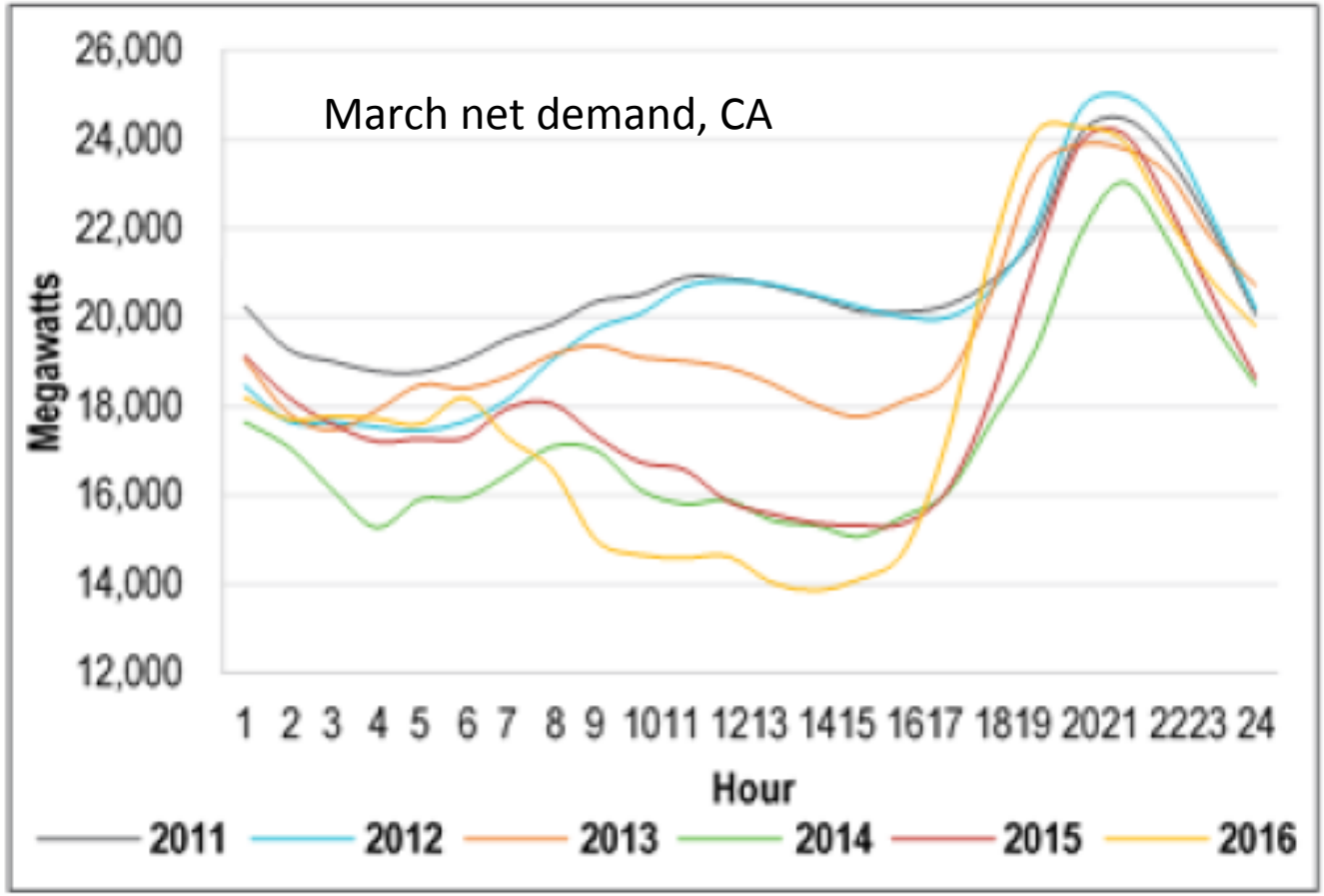
California has a normal cycle of total demand

Figure shows demand for utility-provided electricity, which is highest in the afternoon, as it is in nearly all regions.



...but demand *net of renewables* shows different shape

In California, build-up of utility-scale solar power means cycle of **net demand** (demand minus non-dispatch) is changing. Evening rise in net demand is now too fast to meet – can't turn on plants fast enough. This is the famous "duck curve".

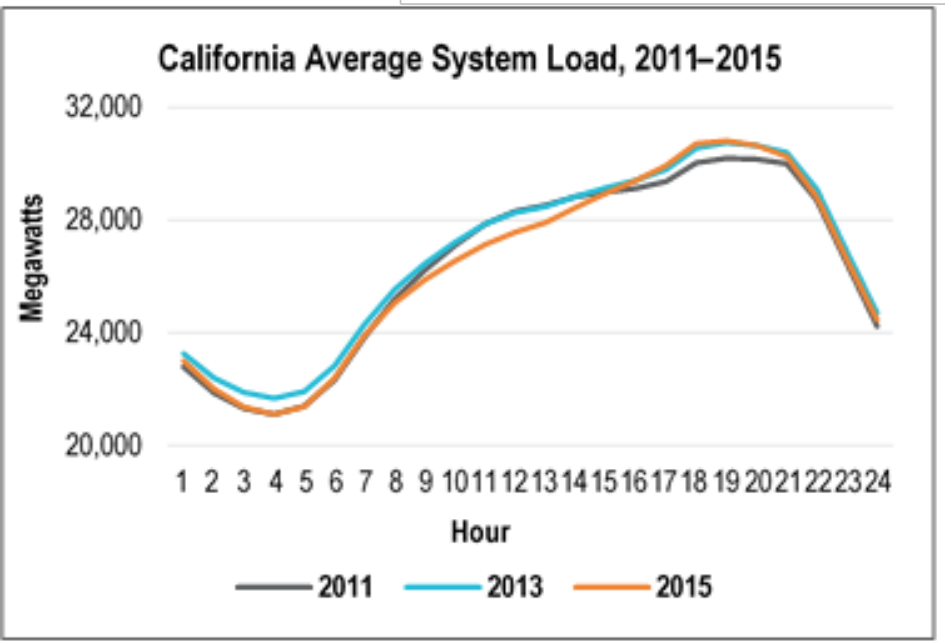


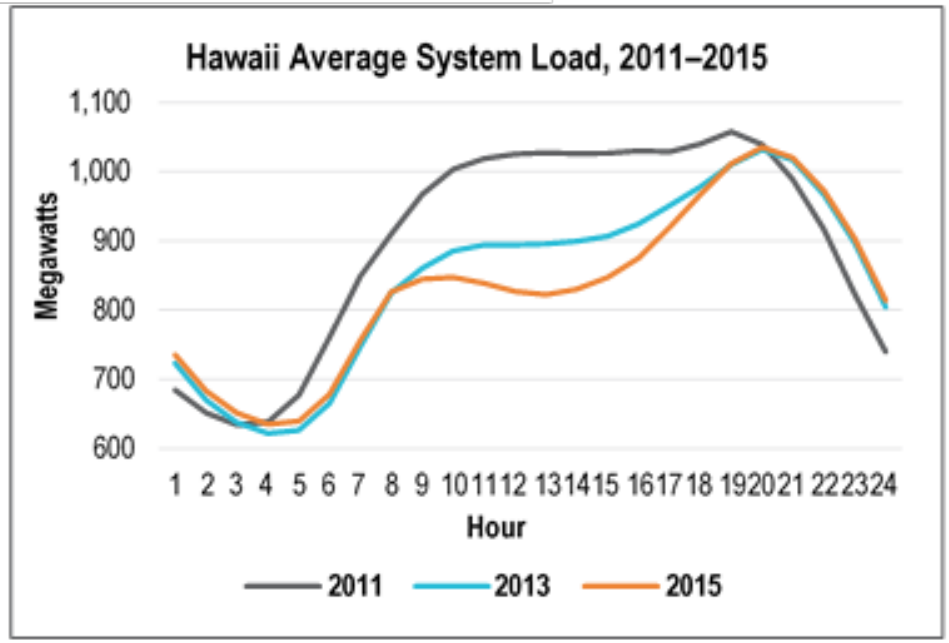
Electricity prices used to peak mid-day, but now can go ***negative*** mid-day.

Hawaii is more extreme – even *total* demand is warped

Massive residential solar installations (HI is most expensive electricity state) mean "duck" curve appears even in HI ***total*** grid demand. Households just don't want power from utilities during the day when their solar is running.

Figure 7: California and Hawaii Average System Load, 2011–2015





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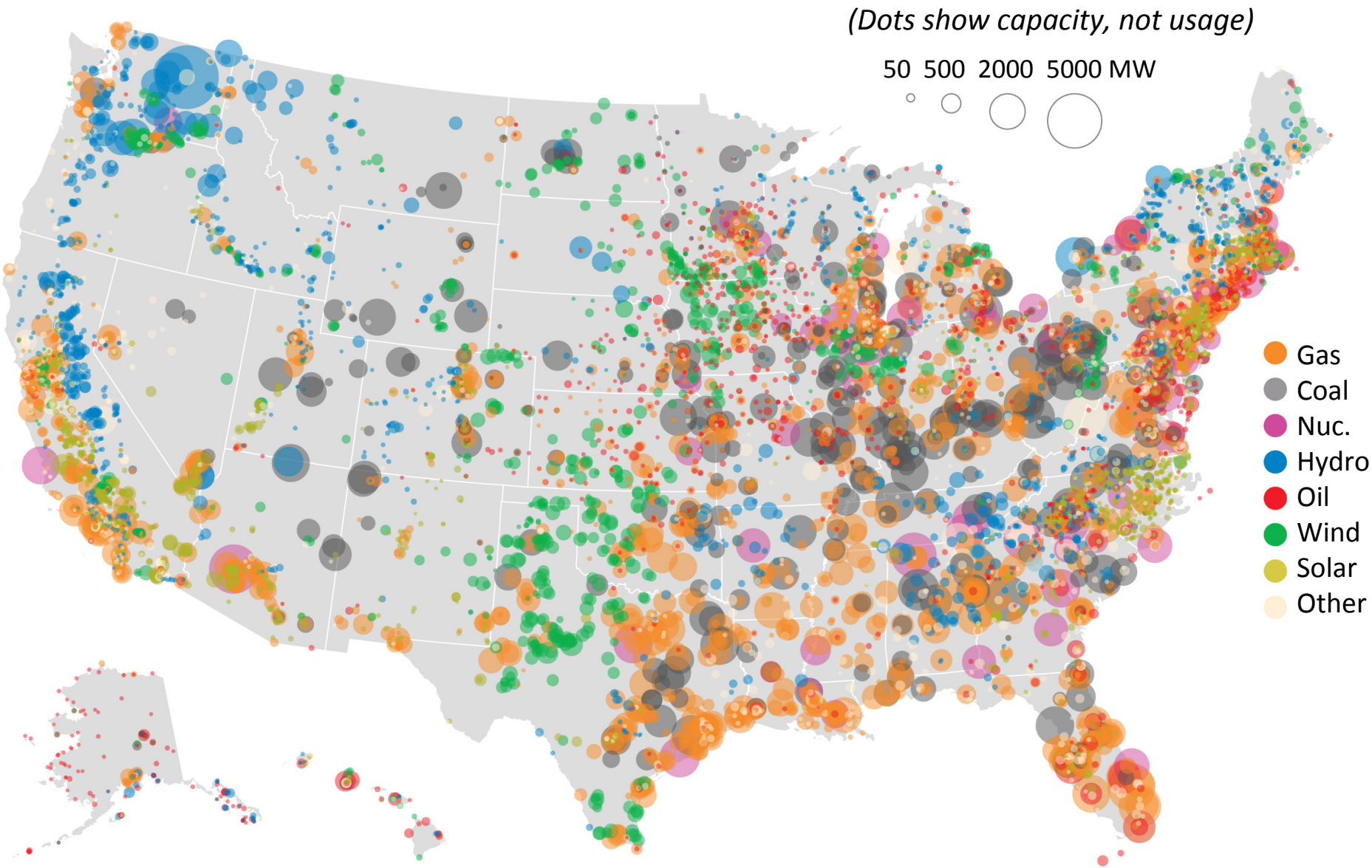
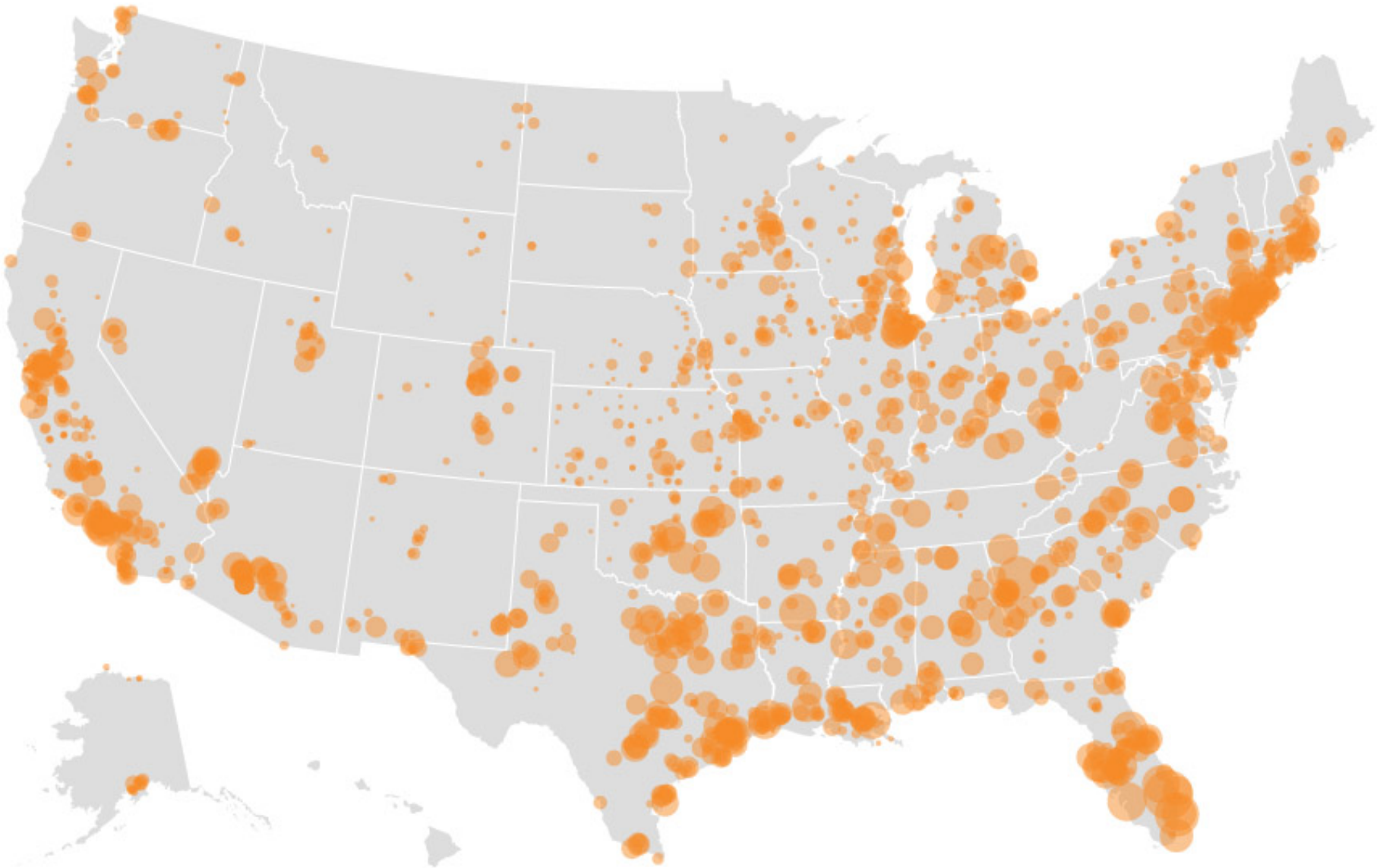
For context: regional differences in electricity generation

Strong regional differences in primary power for electricity



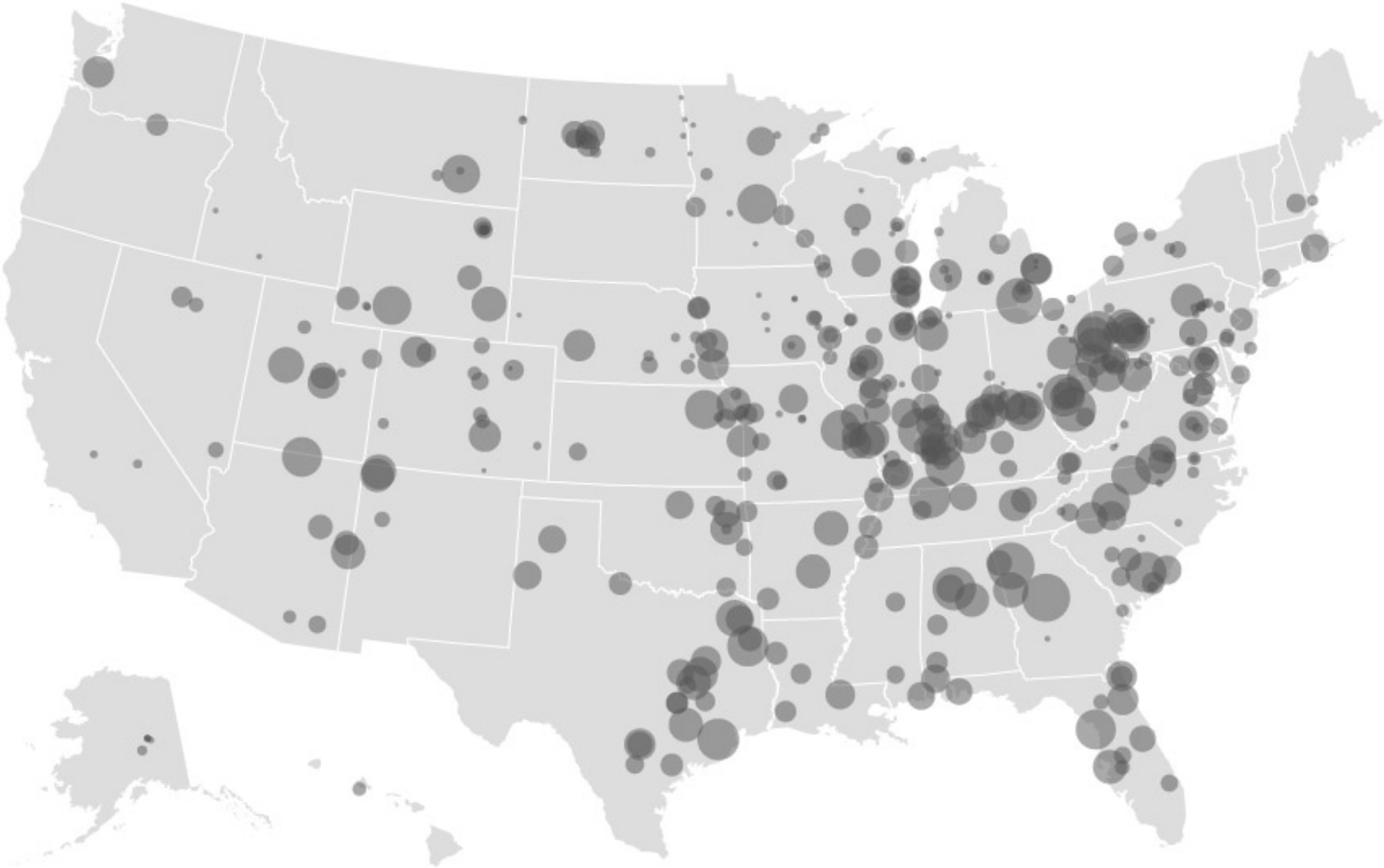
https://www.washingtonpost.com/graphics/national/power-plants/

Primary power for electricity: natural gas (34%)



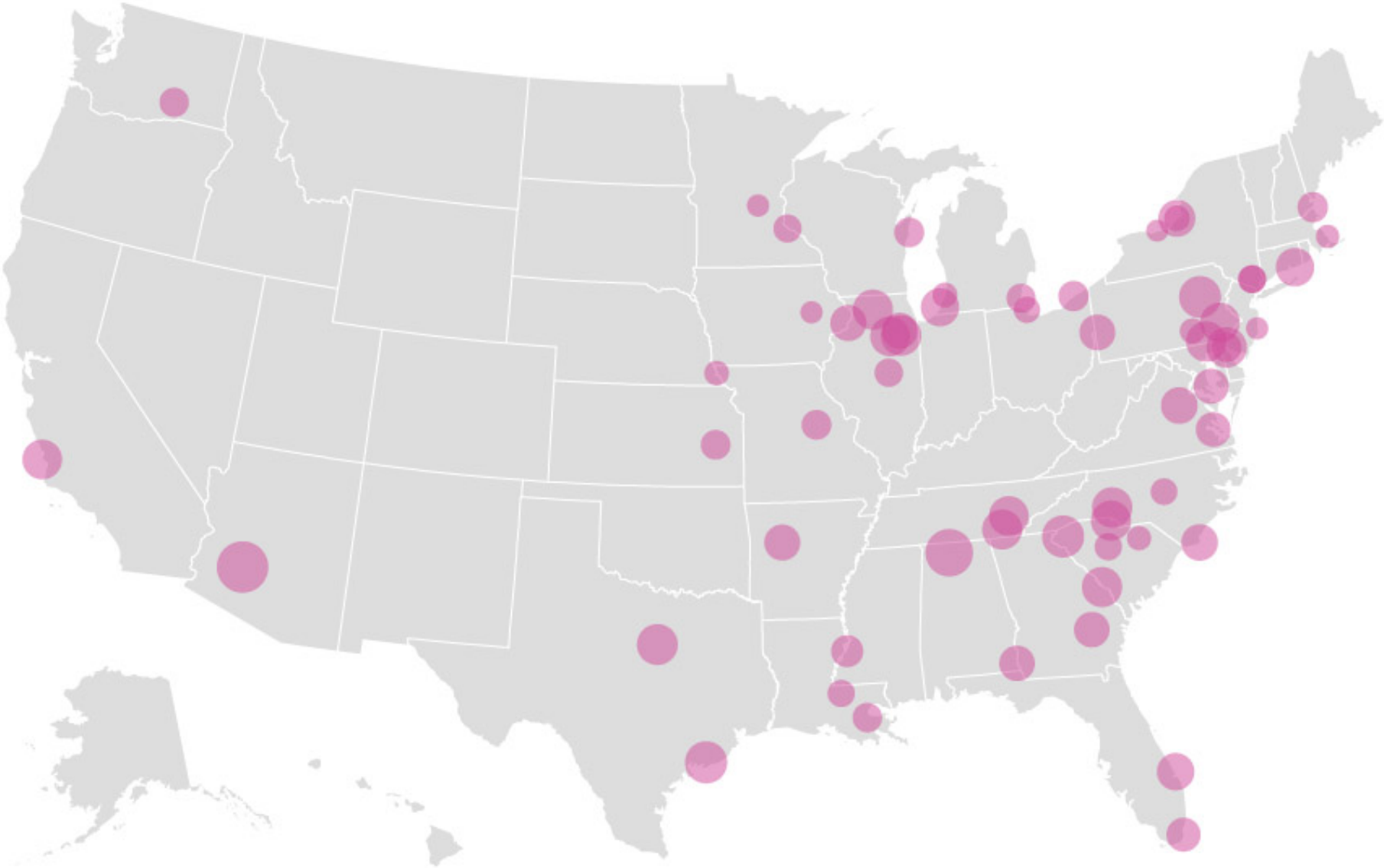
https://www.washingtonpost.com/graphics/national/power-plants/

Primary power for electricity: coal (30%)



https://www.washingtonpost.com/graphics/national/power-plants/

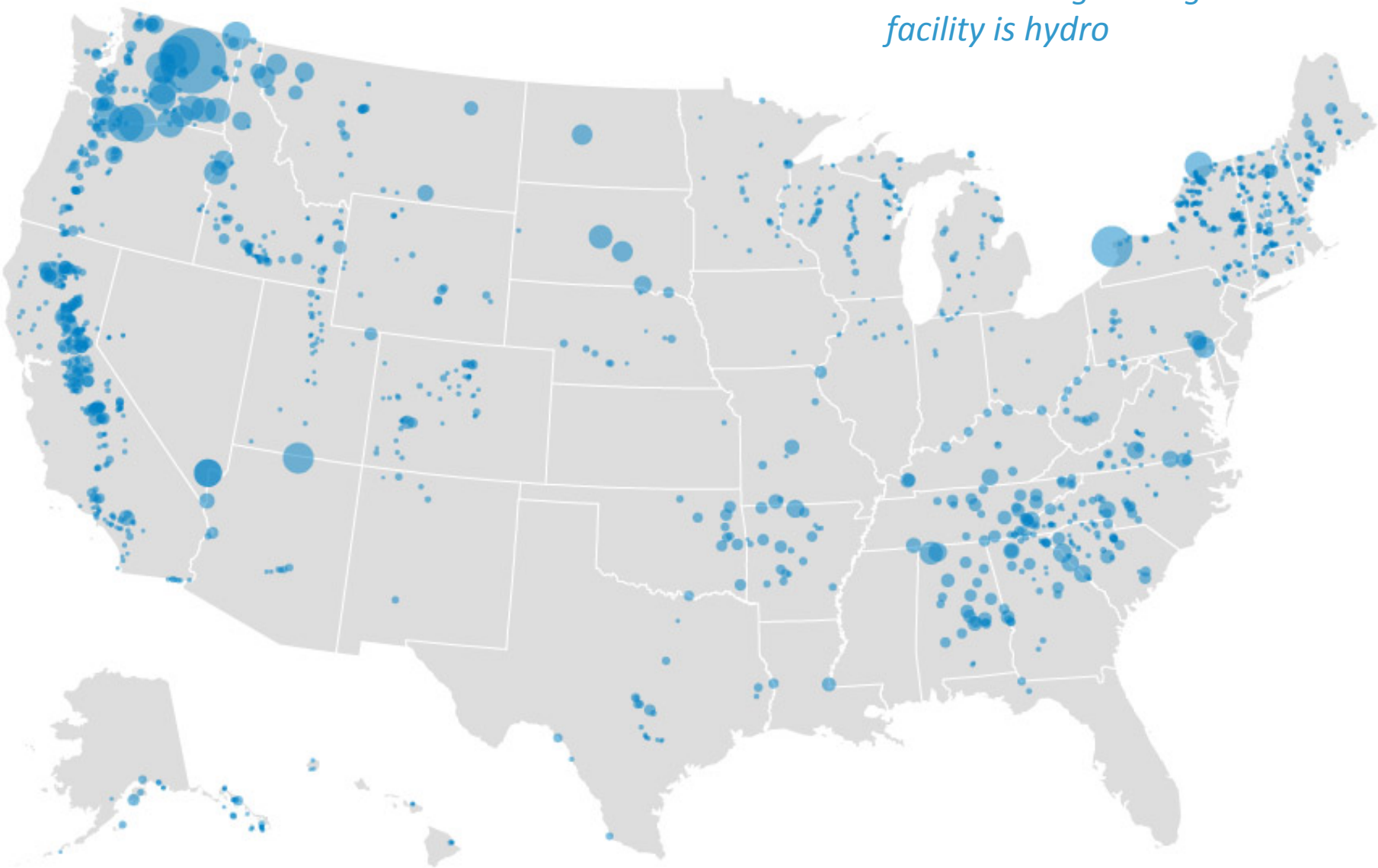
Primary power for electricity: nuclear (20%)



https://www.washingtonpost.com/graphics/national/power-plants/

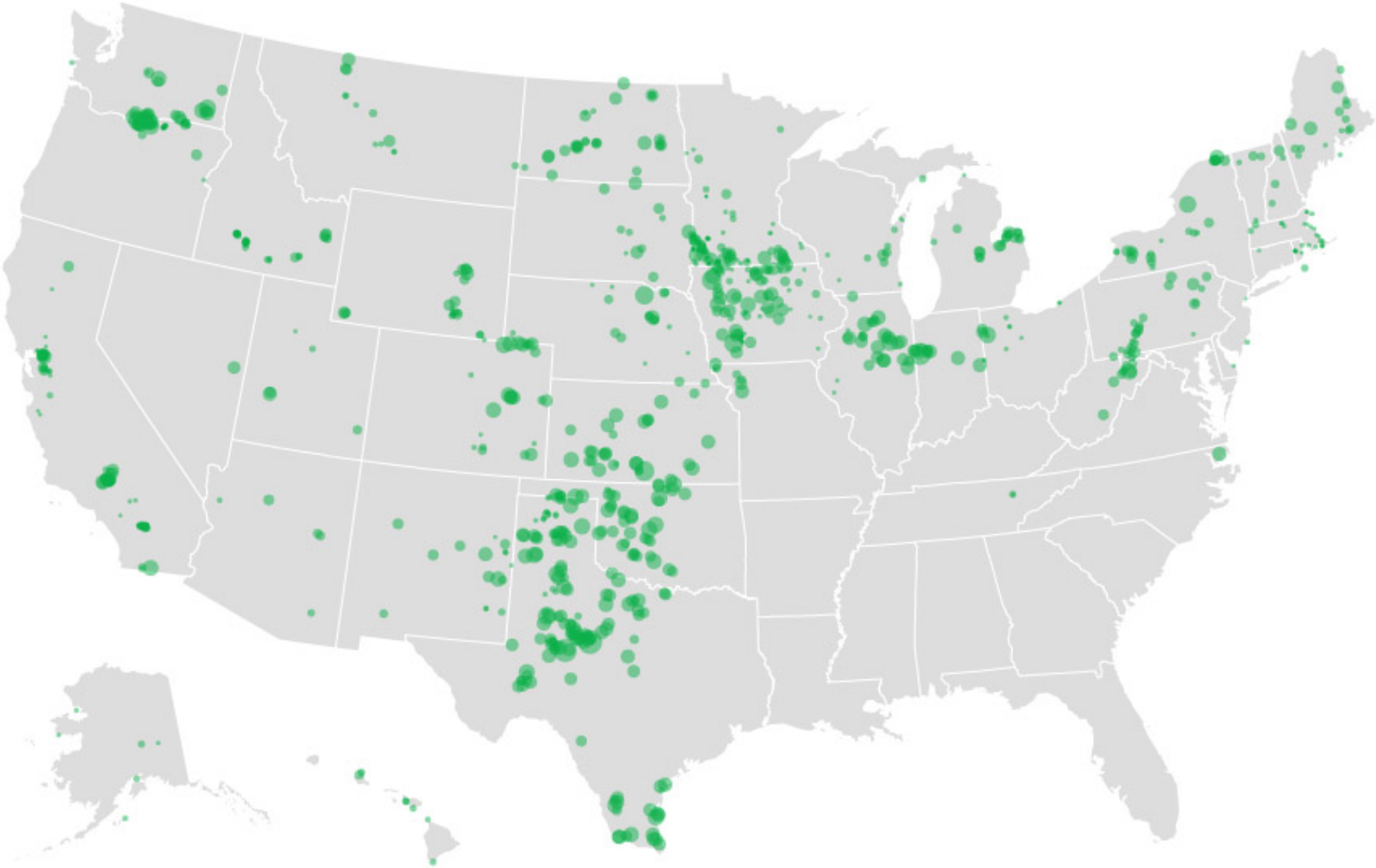
Primary power for electricity: hydro (7%)

note that largest single facility is hydro



https://www.washingtonpost.com/graphics/national/power-plants/

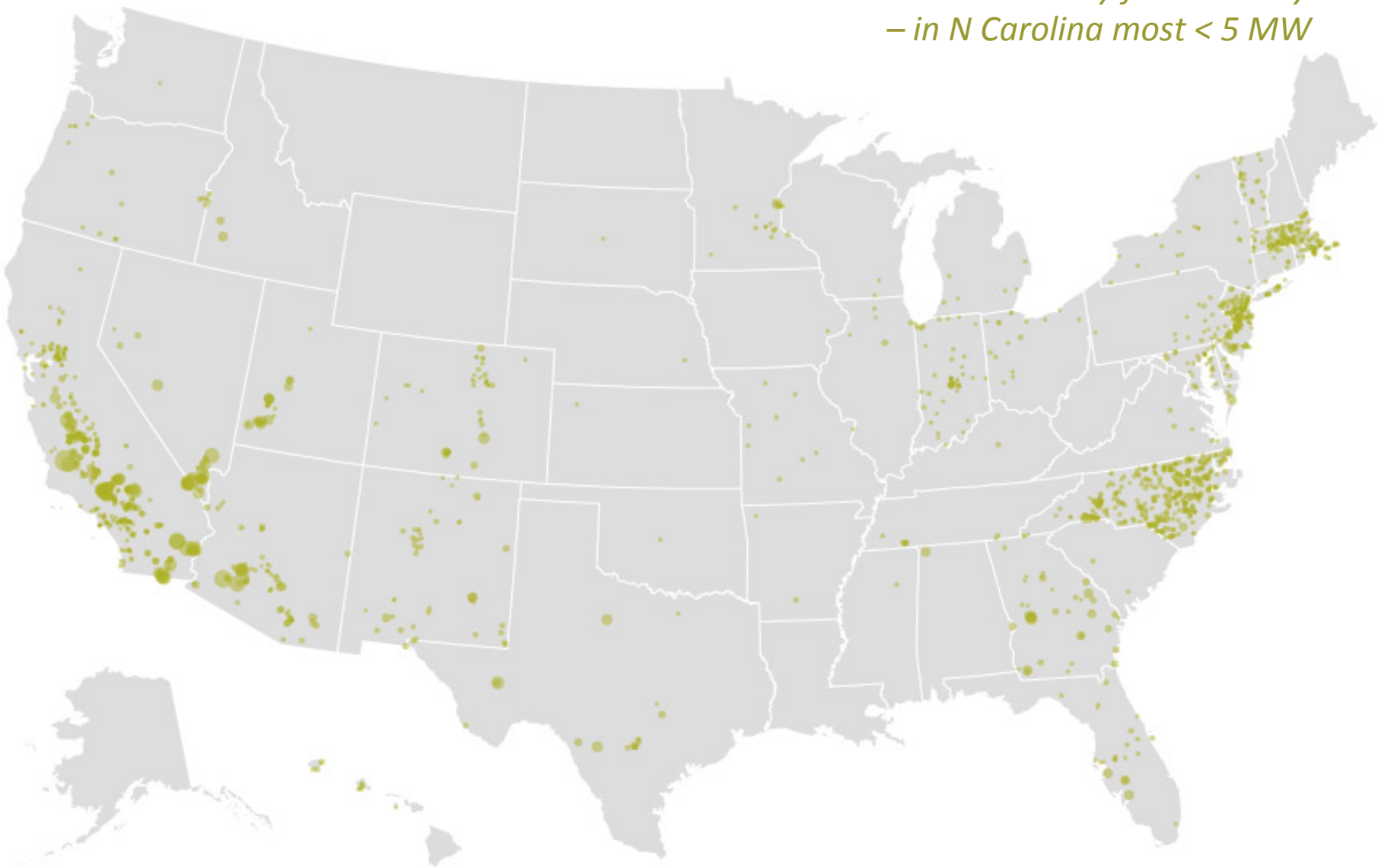
Primary power for electricity: wind (6%)



https://www.washingtonpost.com/graphics/national/power-plants/

Primary power for electricity: solar *(utility-scale, 1%)*

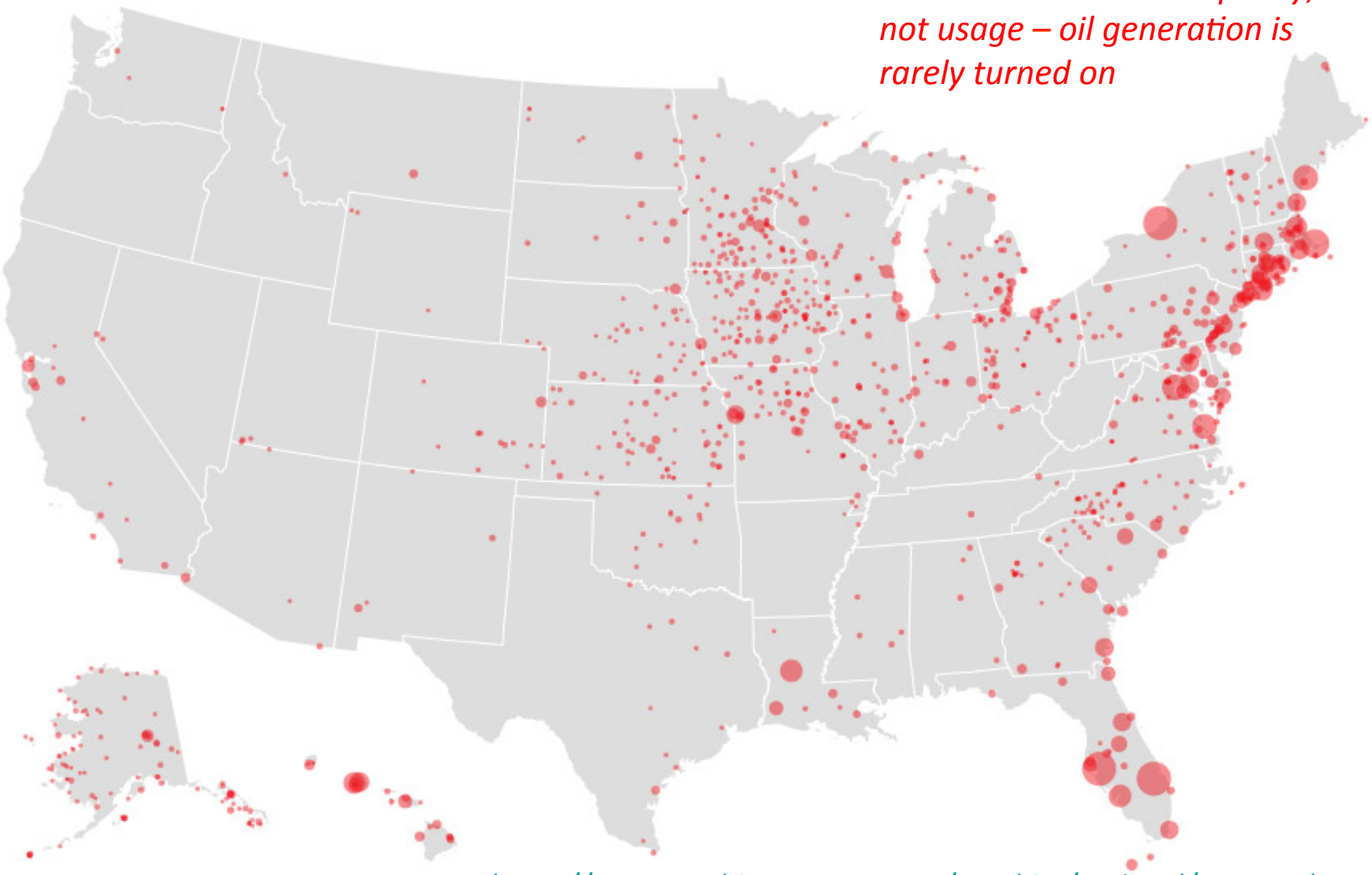
note that many facilities tiny – in N Carolina most < 5 MW



https://www.washingtonpost.com/graphics/national/power-plants/

Primary power for electricity: oil (< 1%)

note that this shows capacity, not usage – oil generation is rarely turned on



https://www.washingtonpost.com/graphics/national/power-plants/

Topics to think / ask more about

Electrical grid organization and management:

things to perhaps ask about in lab

- **Dispatching:** who decides what power plants turn on? what happens if you need more power minute by minute?
- **Investing**: how would you evaluate whether to build a given power plant? What are business strategies for generators?
- **Transmission congestion:** why does it happen? What is the response? how is a "locational marginal price" implemented?
- **Blackouts:** why do they happen? how do they propagate?
- **RTOs/ISOs:** how do they communicate? Which generators sell to which markets and why?
- **Market manipulation:** if DOJ is involved, why? What nefarious things have companies done? How can manipulation be prevented?

Electrical grid organization and management:

big new interesting issues

- **Renewables:** how will grid operators and markets handle varying and non-dispatchable renewals? how to respond to sudden changes in net demand?
- **Reliability:** who will pay for back-up / reliability? How will reliable generators be rewarded?
- **Gas vs. coal price changes:** what happens to the market when coal becomes the marginal cost generation – the expensive thing you want only at peak – but takes hours to turn on?
- **Flattened diurnal cycles:** how will markets be organized when there is no peak to drive prices higher?
- **Transmission:** how do we incentive building needed transmission that would ultimately lower costs?
- **Retail integration**: how do we handle demand-side management that brings retail customers into the electricity market?