



Electric Grid and Markets 101

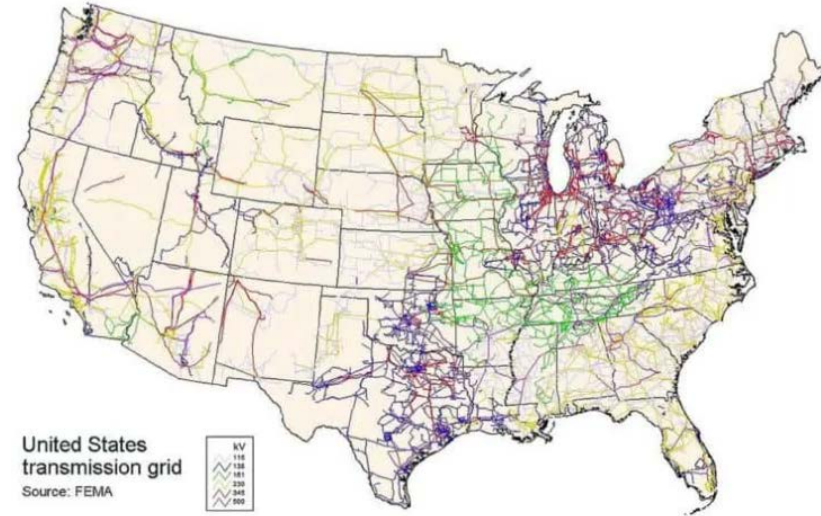
Luke Lavin

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National Renewable Energy Laboratory

The Amazing Continental-Scale Power Grid

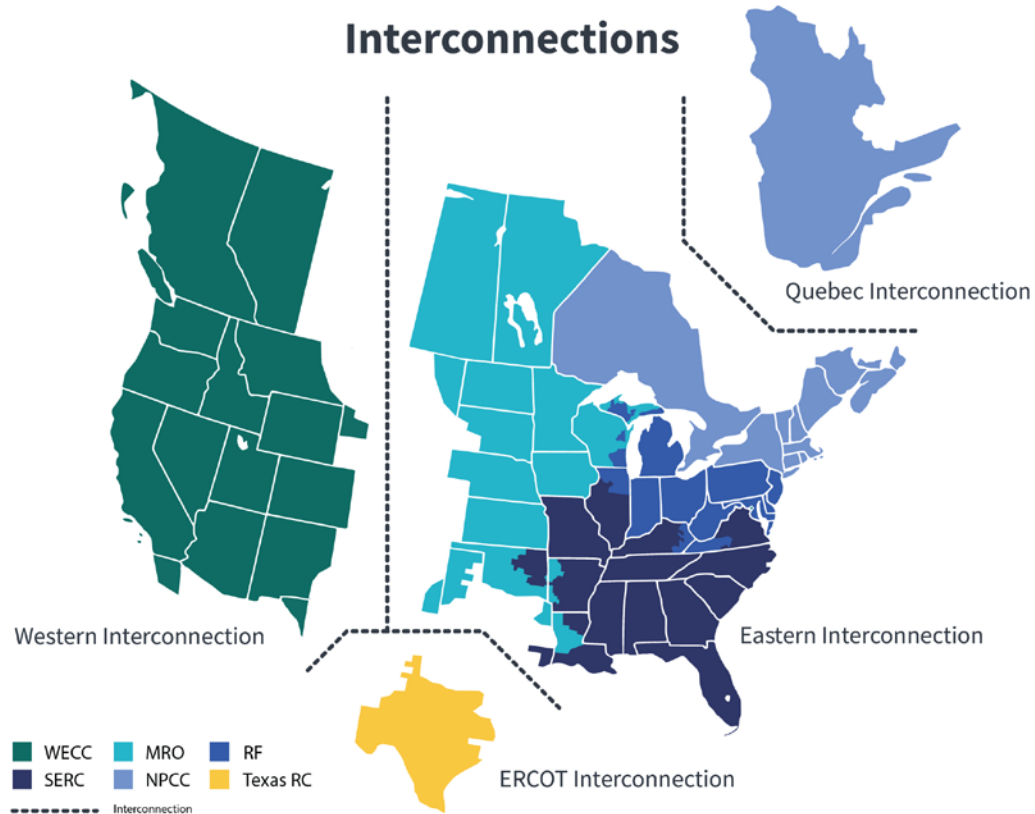
Often referred to as the largest, most complex “machine “ in the world – the North American Power Grid:

- 400 million customers
- Over a TW of generation capacity
- About 500,000 miles of transmission lines
- Over 6 million miles of distribution lines



Source: FEMA; available publicly via Wikimedia commons at https://commons.wikimedia.org/wiki/File:UnitedStatesPower_Grid.jpg

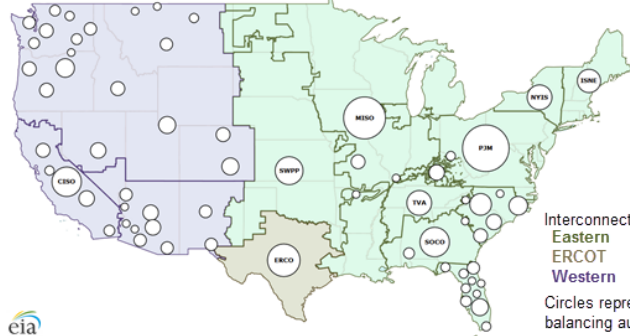
Really, it's three grids in the United States



Source: Federal Energy Regulatory Commission Reliability explainer; available <https://www.ferc.gov/reliability-explainer>

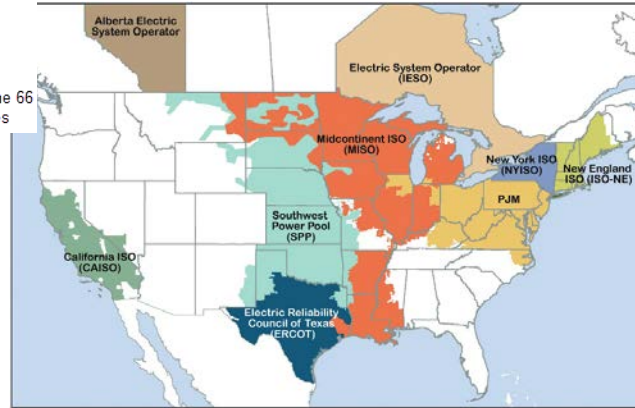
But from a regulatory standpoint, it's hundreds-to-thousands!

U.S. electric power regions



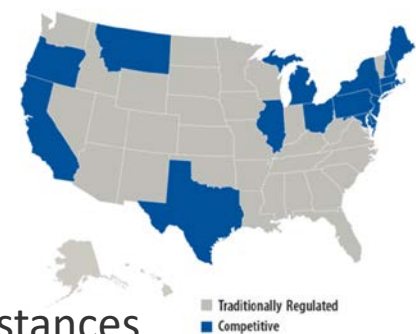
Interconnections
Eastern
ERCOT
Western
Circles represent the 66
balancing authorities

Balancing authorities generally handle reliability



States have jurisdiction over retail bills (the ones you get at home!)

Retail Electric Power Markets



Wholesale markets coordinate transmission, dispatch, pricing

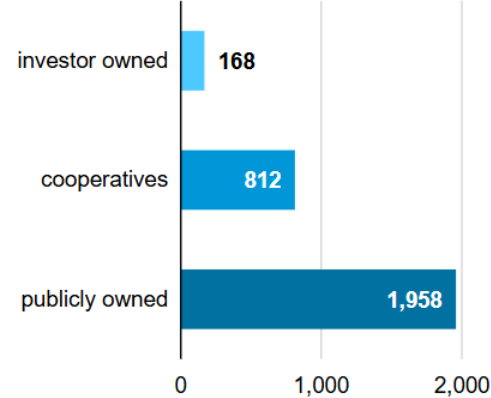
Sources: U.S. Energy Information Administration (<https://www.eia.gov/energyexplained/electricity/delivery-to-consumers.php>), Wikimedia commons (https://commons.wikimedia.org/wiki/File:Rto_map.gif), U.S. EPA (<https://www.epa.gov/green-power-markets/us-electricity-grid-markets>)

**There are exceptions to “general” rules in... pretty much all circumstances

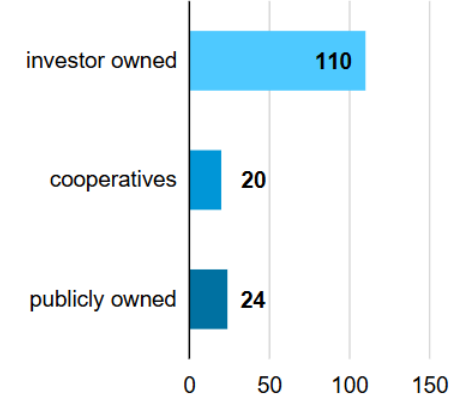
Generally, you have three types of entities that invest in infrastructure and bill customers

U.S. electric utilities by ownership type (2017)

number of companies



million customers



Source: U.S. Energy Information Administration, *Annual Electric Power Industry Report*

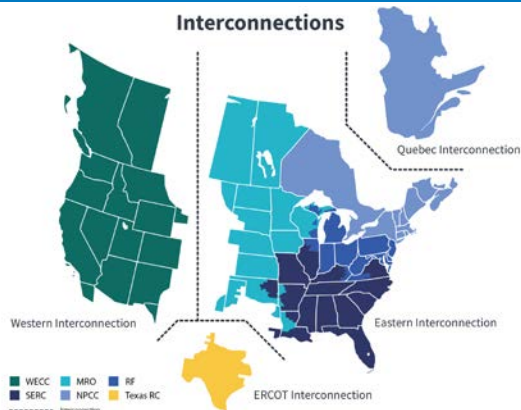
Counties served by U.S. utilities, by type of ownership (2017)



Source: EIA, <https://www.eia.gov/todayinenergy/detail.php?id=40913>

Major point (1): For me, it helps to think of physics/engineering and regulation/finance as *related* but **distinct** concepts in electricity

Sources: Federal Energy Regulatory Commission Reliability explainer; available <https://www.ferc.gov/reliability-explainer>; NREL SEAMS study; available <https://www.nrel.gov/analysis/seams.html>; Southwest Power Pool; available <https://www.spp.org/western-services/rto-expansion/>



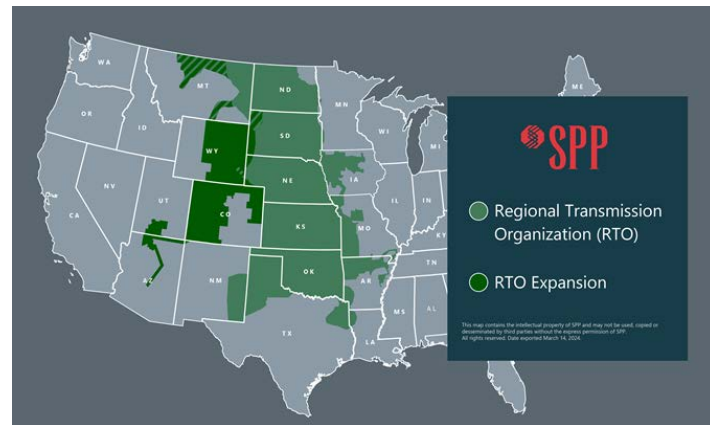
Engineering and physics of moving power across interconnection “seams” (NREL, 2021)



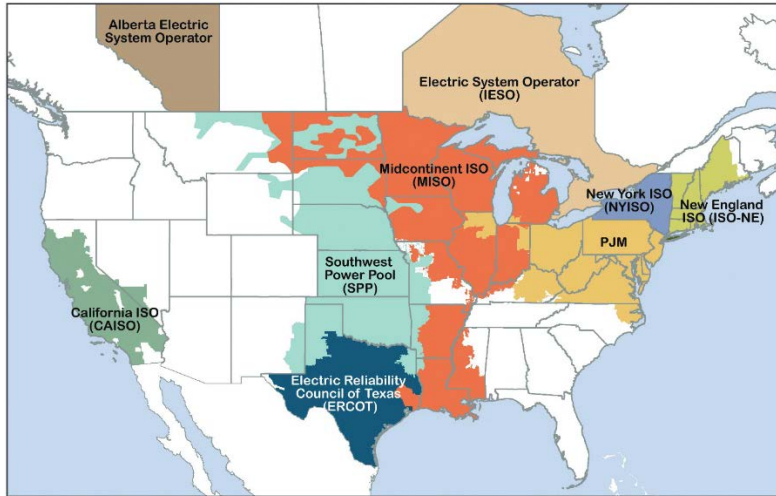
Helps motivate transmission expansion?



need not be a constraint on regulation and markets where incentives say otherwise



Major point (2): And, to draw a mental line between the wholesale and retail regulatory levels of the grid

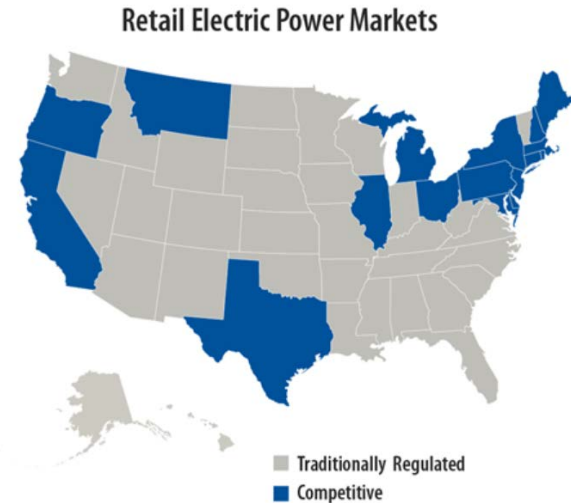


Wholesale

- The big stuff
- Often inter-state
- Large FERC-regulated market regions
- Buy and sell big generation contracts

Sources: Wikimedia commons

(https://commons.wikimedia.org/wiki/File:Rto_map.gif), U.S. EPA
(<https://www.epa.gov/green-power-markets/us-electricity-grid-markets>)



Retail

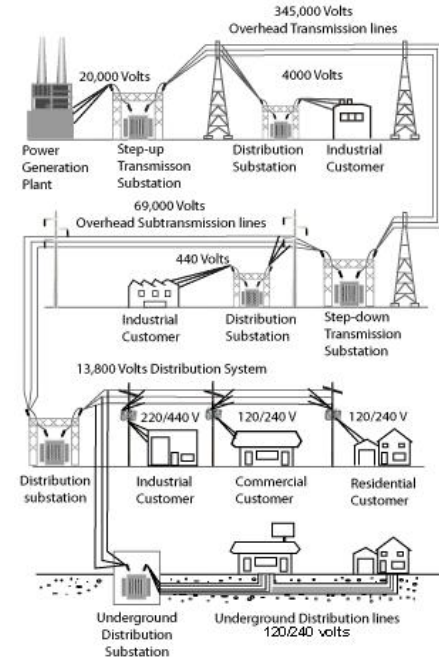
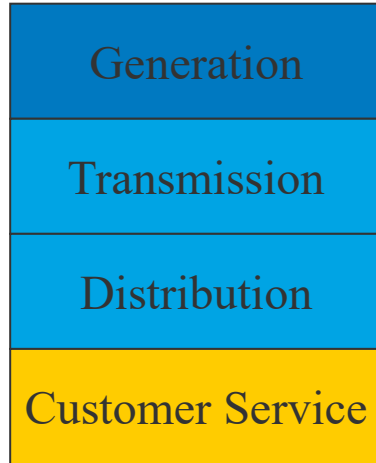
- Customer electricity bills
- Often state-regulated (depends on utility structure)
- Much of bill is transmission, distribution, and other charges, *not* just generation
- Can procure generation on behalf of customers (“green” tariffs, etc.)

Regulation of electricity grew out of the legacy “natural monopoly” concept

- Regulated vertical monopolies were the norm in power for much of history
- “Cost plus”: make your money back plus a profit for your trouble
- Consolidated planning and operations

Conceptually: Leave this to the engineers and we’ll avoid costly redundancies and safety issues!

Single Entity!

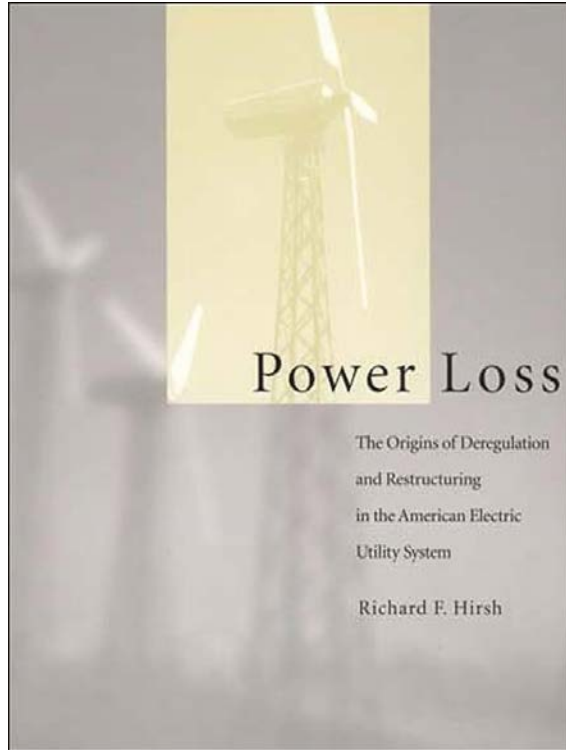


Remind me, what's a natural monopoly?

- A “natural monopoly” typically has high start-up costs or powerful economies of scale, resulting in significant barriers to entry for potential competitors
- Natural monopolies can arise when one firm is much more efficient than multiple firms in providing the good or service to the market
- A good example of this is in the business of electricity transmission, where once a grid is set up to deliver electric power to all of the homes in a community, putting in a second, redundant grid may be higher cost and/or lower safety!

More recently: incomplete “deregulation” ... often called “restructuring”

If you ever have a lot of time, this is a pretty complete book on the topic!



- “Deregulate” sectors like generation that can be (more easily made) competitive
- Should wires still be a monopoly?
- Add independent entities on top to coordinate operations, and fair/open access transmission and markets

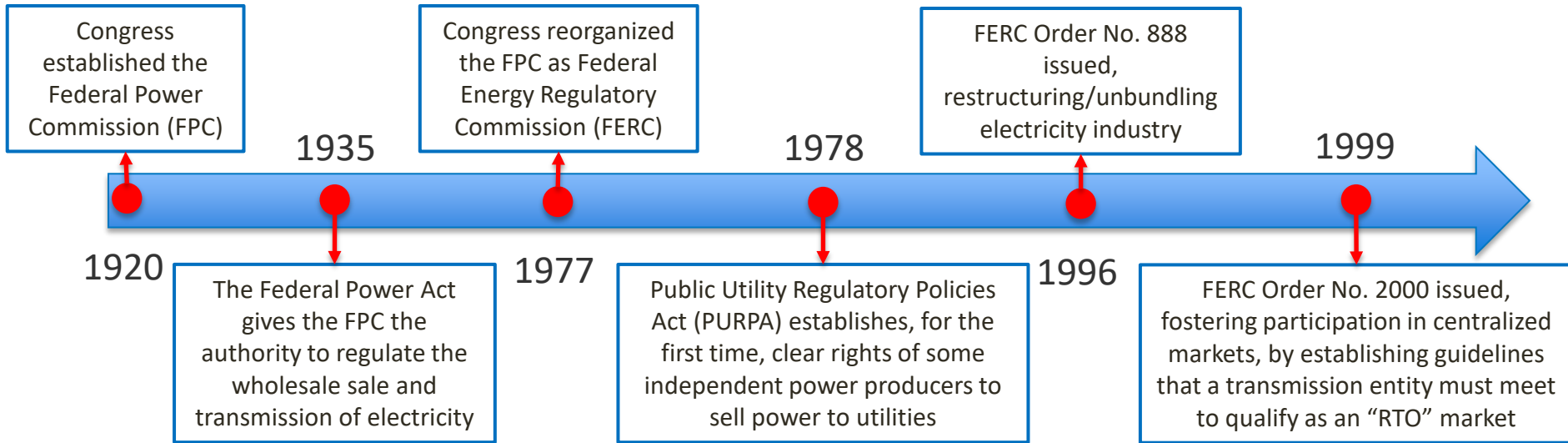
Generation

Transmission

Distribution

Customer Service

Milestones of US Electricity Industry Regulation



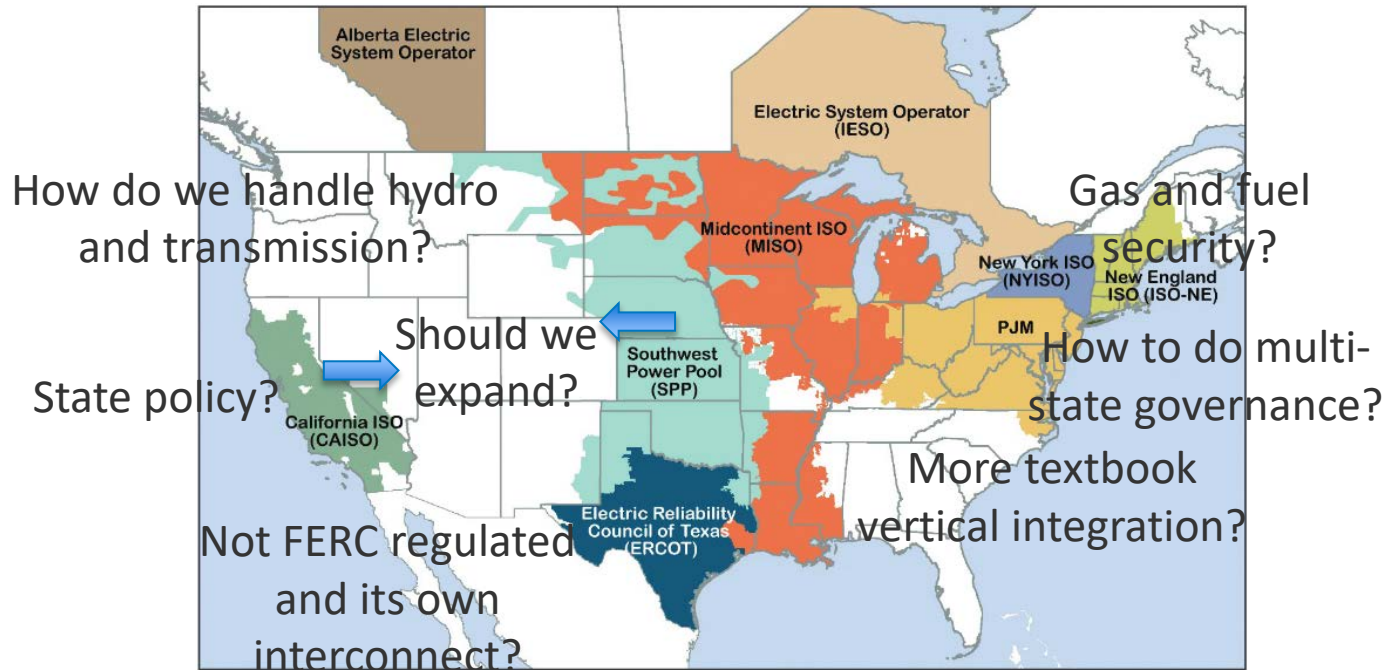
- FERC regulate interstate transmission rates & services, and wholesale market electric rates and services.
- State Public Utilities Commission (PUC) regulate distribution and retail rates paid by end-use customers.

What's up with “restructured”
(wholesale) markets today?

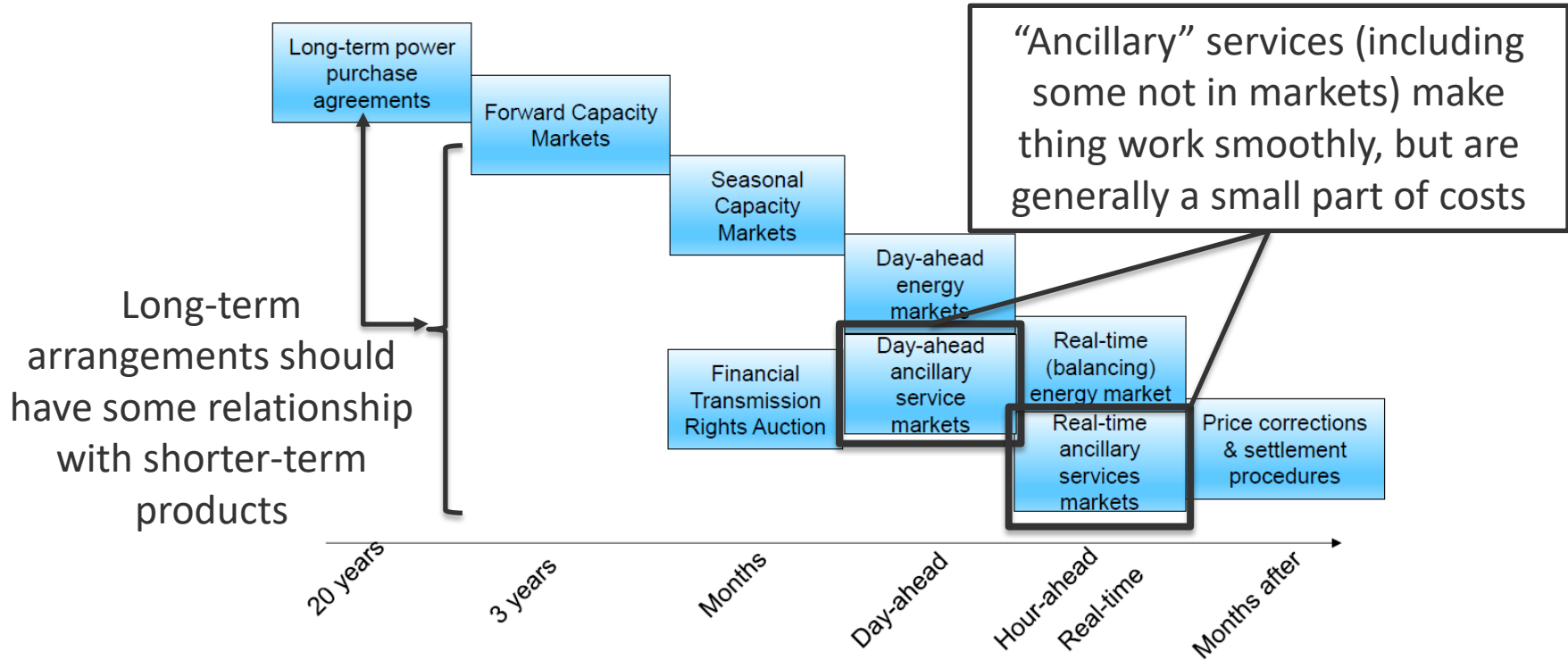
Incomplete process, and every Independent System Operator (ISO) has its own detailed rules

Generally: a ISO creates consistent rules for wholesale operations and markets in its footprint

Challenge: ISOs differ, not everywhere has one, and coordinating across ISOs

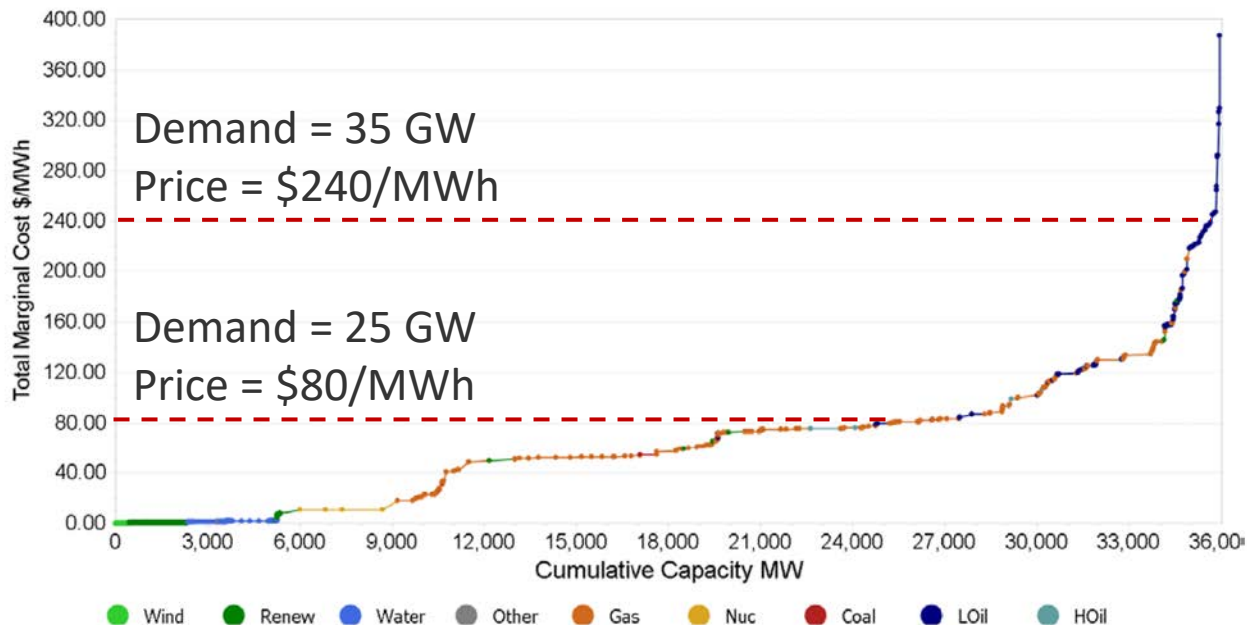


Lots of products have emerged to balance physics of grid with markets



The standard electricity market feature you're most likely to hear about is merit-order dispatch

Figure 2-6: Market Supply Curve for NYISO (Illustrative)

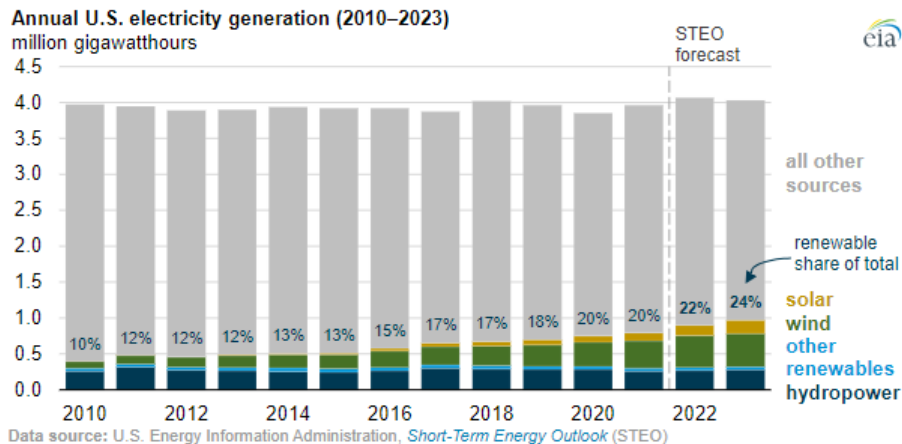


Source: Hitachi Energy, Velocity Suite¹¹⁴

If competition is working, can't we cost-effectively integrate new generation?

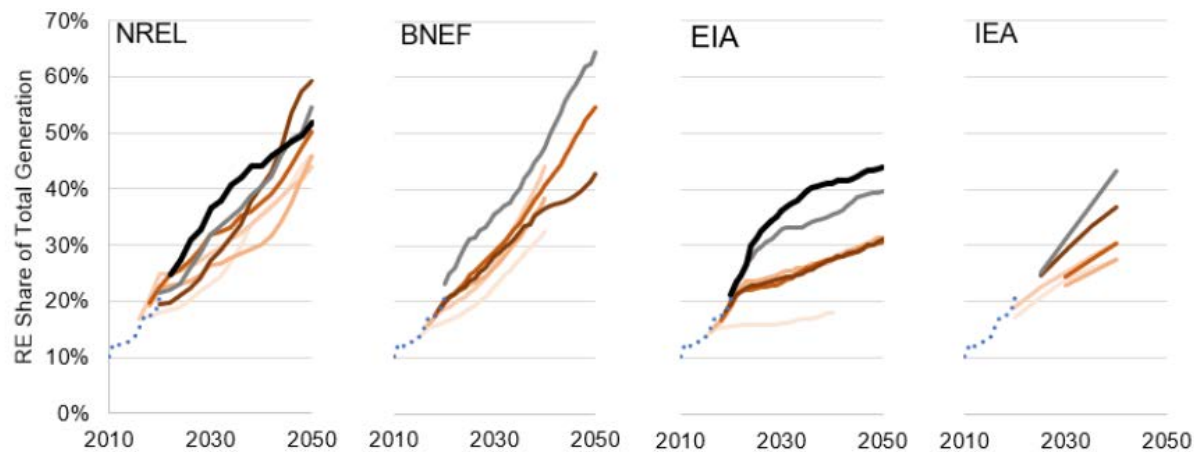
Renewable energy made up **21%** of US electricity generation in 2023, and is expected to reach **30%** by 2026

EIA AEO 2022, Reference Scenario



EIA "Today in Energy" 8/16/22

Projection Year: **2015** **2016** **2017** **2018** **2019** **2020** **2021**

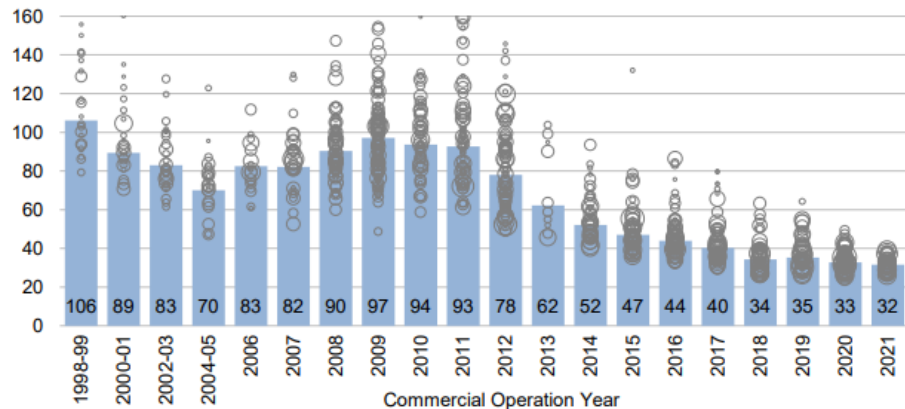


2021 Standard Scenarios Report, Cole et al, NREL

Declining costs, increasing adoption & competition

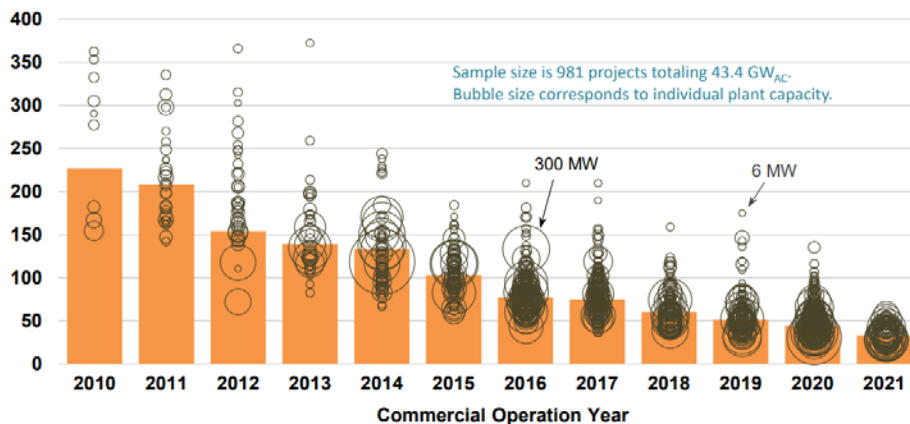
WIND

Average and Project-level LCOE (2021 \$/MWh)



Note: Size of bubble reflects project capacity.

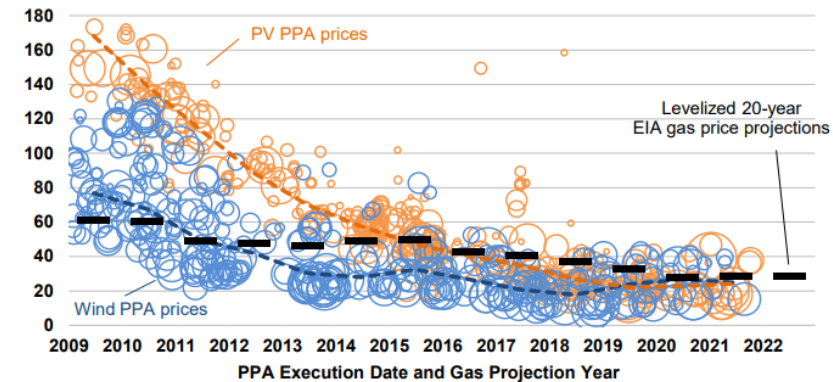
Generation-Weighted Average and Project-Level LCOE (2021 \$/MWh)



SOLAR

Sources: Lawrence Berkeley National Laboratory Land Based Wind Technologies Market Report (2022) and Utility Scale Solar 2022 report
available: <https://emp.lbl.gov/wind-technologies-market-report/> and <https://emp.lbl.gov/utility-scale-solar>

Levelized PPA and Gas Price (2021 \$/MWh)

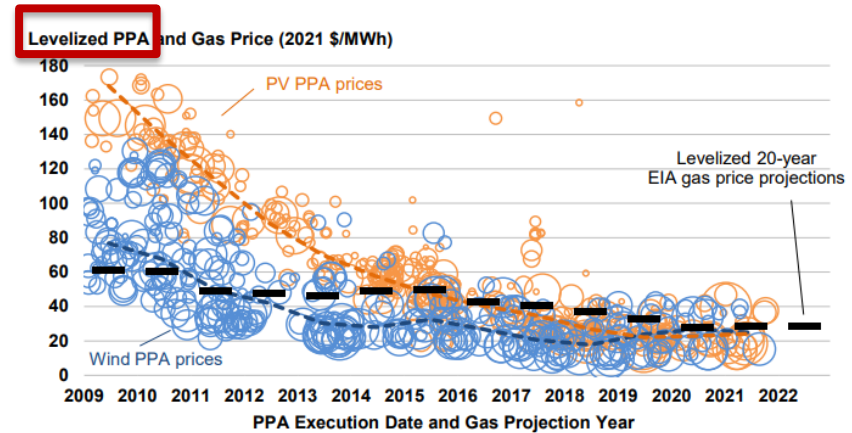


Much more data is available at <https://emp.lbl.gov/data>

If we have great markets, what's up with "power purchase agreements?"

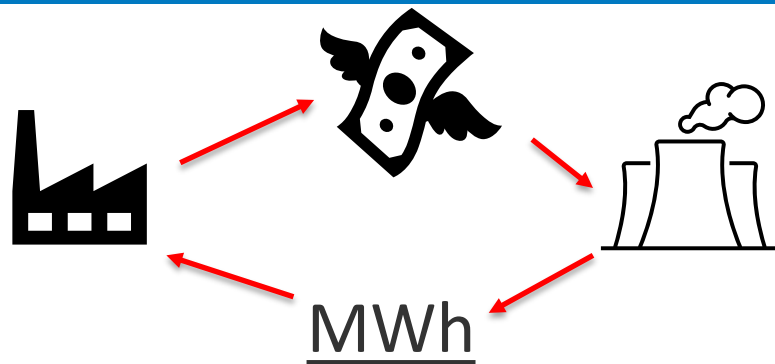
An incomplete list of reasons...

- ✓ Long-term arrangement helps secure financing
- ✓ Standardized approaches to buying/selling power
- ✓ Meet state or other jurisdiction policy goals
- ✓ Don't have to deal with complexity, leave volatility to others
- ✓ Lots of flavors: Corporate, virtual, contract-for-differences, etc.

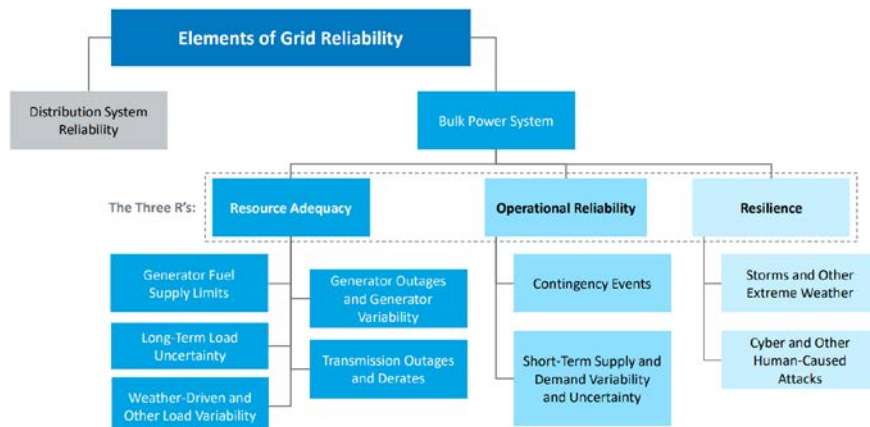


Much more data is available at <https://emp.lbl.gov/data>

Contractual arrangements help secure financing, but don't obviate physics!



Details matter, but PPA is \$ for *energy*... reliability requires much more!



Transmission is critical to making this all work, and is its own regulated market

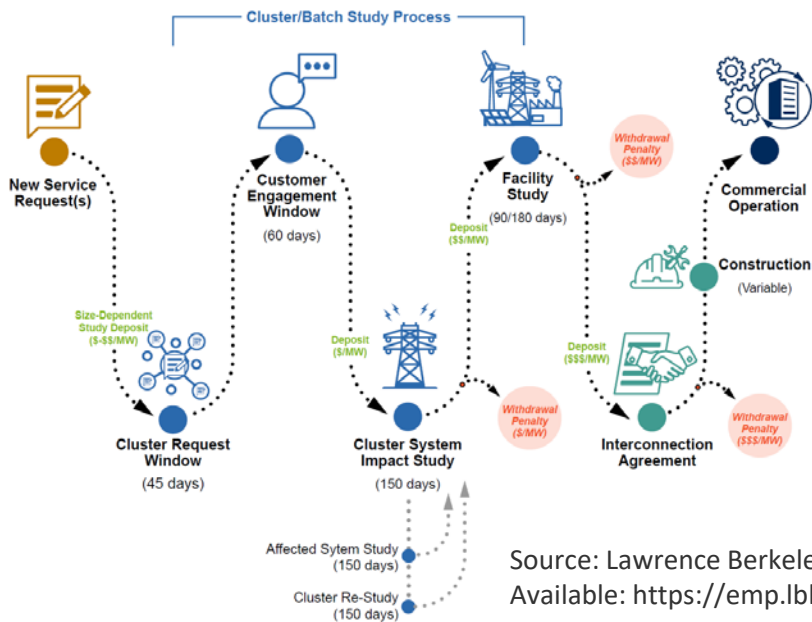
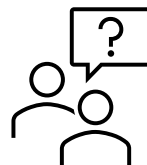
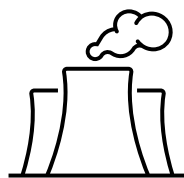
“FERC requires that public utilities that own transmission lines used in interstate commerce offer transmission service on a nondiscriminatory basis to all eligible customers. The rates and terms of service are published in each utility’s Open Access Transmission Tariff (OATT).”

BUT...

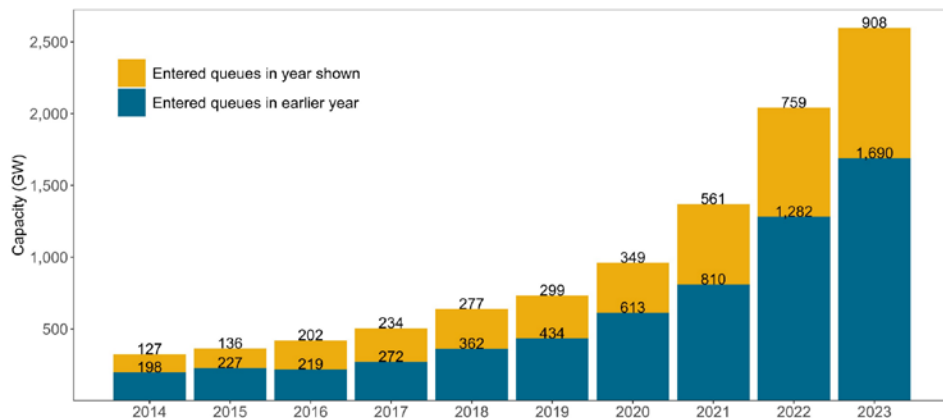
- ⊗ Not all regions are FERC-jurisdictional
- ⊗ What is the market for trading transmission rights?
- ⊗ How are transmission costs allocated to customers?
- ⊗ What about building new transmission?

... you can assume each region has its own terminology and variation on the general rules of the road

Generators wait in line to make sure they'll have interconnection agreement for transmission access



**Total (cumulative) active capacity in queues is now nearly 2,600 GW (2.6 TW);
New (annual) capacity entering the queues has increased every year since 2014**



Source: Lawrence Berkeley National Laboratory, "Queued Up" (2024)

Available: https://emp.lbl.gov/sites/default/files/2024-04/Queued%20Up%202024%20Edition_1.pdf NREL | 21

And regulatory and economic frictions mean we have a lot less transmission than many studies think desirable

“Approximately \$1.60 to \$1.80 is saved for every dollar spent on transmission”

“total transmission system of the contiguous United States expands to 2.1 to 2.6 times the size of the 2020 system by 2050 and interregional transmission grows 1.9 to 3.5 times” – *Department of Energy National Transmission Planning Study (2024)*

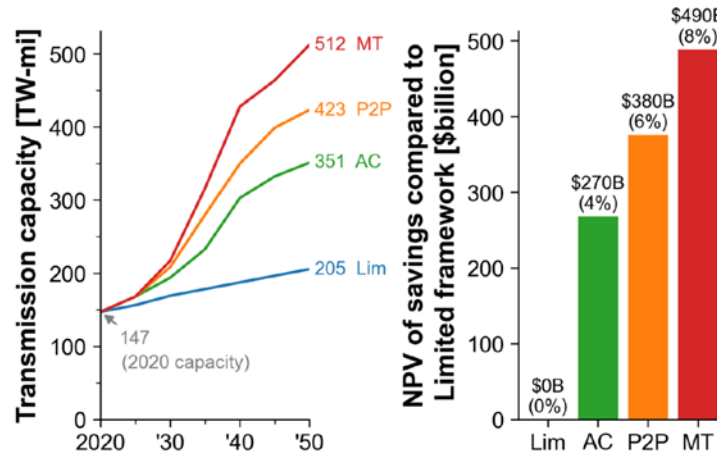
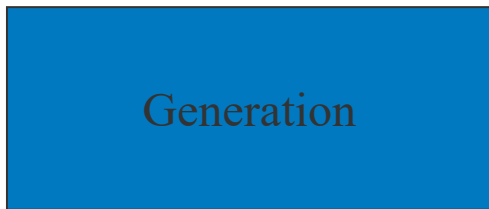


Figure ES-4. (Left) Total transmission expansion through 2050 and (right) cost savings of the accelerated transmission frameworks (AC, P2P, and MT) compared to the Limited framework with 90% by 2035 emissions reductions and Mid-Demand

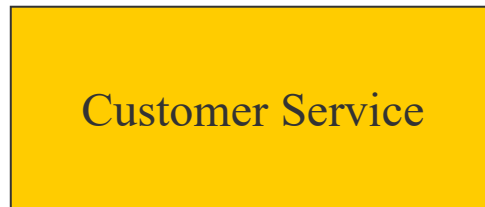
Source: U.S. Department of Energy National Transmission Planning Study <https://www.energy.gov/gdo/national-transmission-planning-study>

Where does this leave these four layers today?

Market-based processes
for investment in many
regions!



Becoming constrained and will eventually
affect generation and reliability



We really didn't talk about
this, and can ignore when
contracting for generation

They see the bill at the
end of all this... mostly the
province of utilities

In summary...

- There is a relationship between grid physics and regulation, but...
- Hundreds-to-thousands of entities are involved in that regulation
- Many areas – especially “restructured” ones – have *wholesale* markets with well-defined rules for generation investment and operations while respecting reliability needs
- Transmission access is a growing barrier to generation investment and contracting

Questions please!



Thank you

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