The Future of ERCOT and the US Electric Grid

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Overview

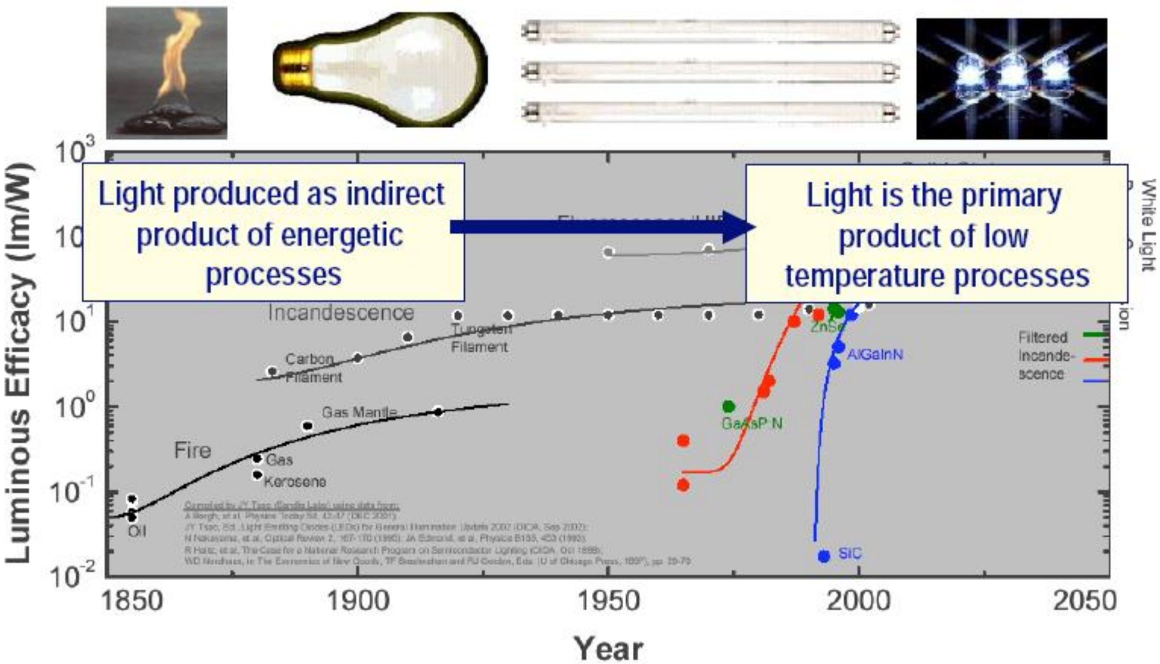
- Electric grids are in a time of rapid transition with lots of positive developments including the addition of large amounts of renewable generation and the electrification of transportation
  - The result is there are lots of good engineering challenges!
- Our electric energy future should be quite bright
- However, there are lots of concerns with this transition, particularly in dealing with electric grid resilience
- This presentation looks at what is likely in store for us here in Texas

A Little Bit of Electric Grid Background

- Years back what people wanted from electric grids was fairly straightforward
  - Is it reliable and is it inexpensive
  - Up until the 1970's both trends were positive with electric rates decreasing and reliability improving
- Over the last 50 years things have gotten more complicated
  - Low cost continues to be a desire
  - Desires for reliability have greatly increased
  - There are now many more desires, particularly associated with electricity being "green", and citing facilities is now much more difficult (NIMBY – Not in My Backyard)

The Good News: We're Getting More Energy Efficient!

With lighting over the last 150 years we've increased efficiencies by about a factor of 1000. From 0.05 lumens/watt for a candle, to 15 for an incandescent bulb, to > 130 for an LED.



Source: http://www.ornl.gov/sci/cmsinn/talks/3_kung.pdf

High efficiency gains have occurred in many other areas such as refrigeration and certainly computation

A Little Bit of Terminology

- With electric grids we talk about power, energy, frequency, and voltage
- Power is the instantaneous consumption (or production) of energy
  - Watts (W), kW (a thousand W), MW (a million W), GW (a billion W)
  - The electric load in Texas varies, but its maximum is about 85 GW, or about 2.8 kW per person
  - A horsepower is about 746 W
  - Electric power is used to produce something useful, such as lighting (e.g., 100 W incandescent bulb; now a 10 W LED bulb can provide about the same amount of light)

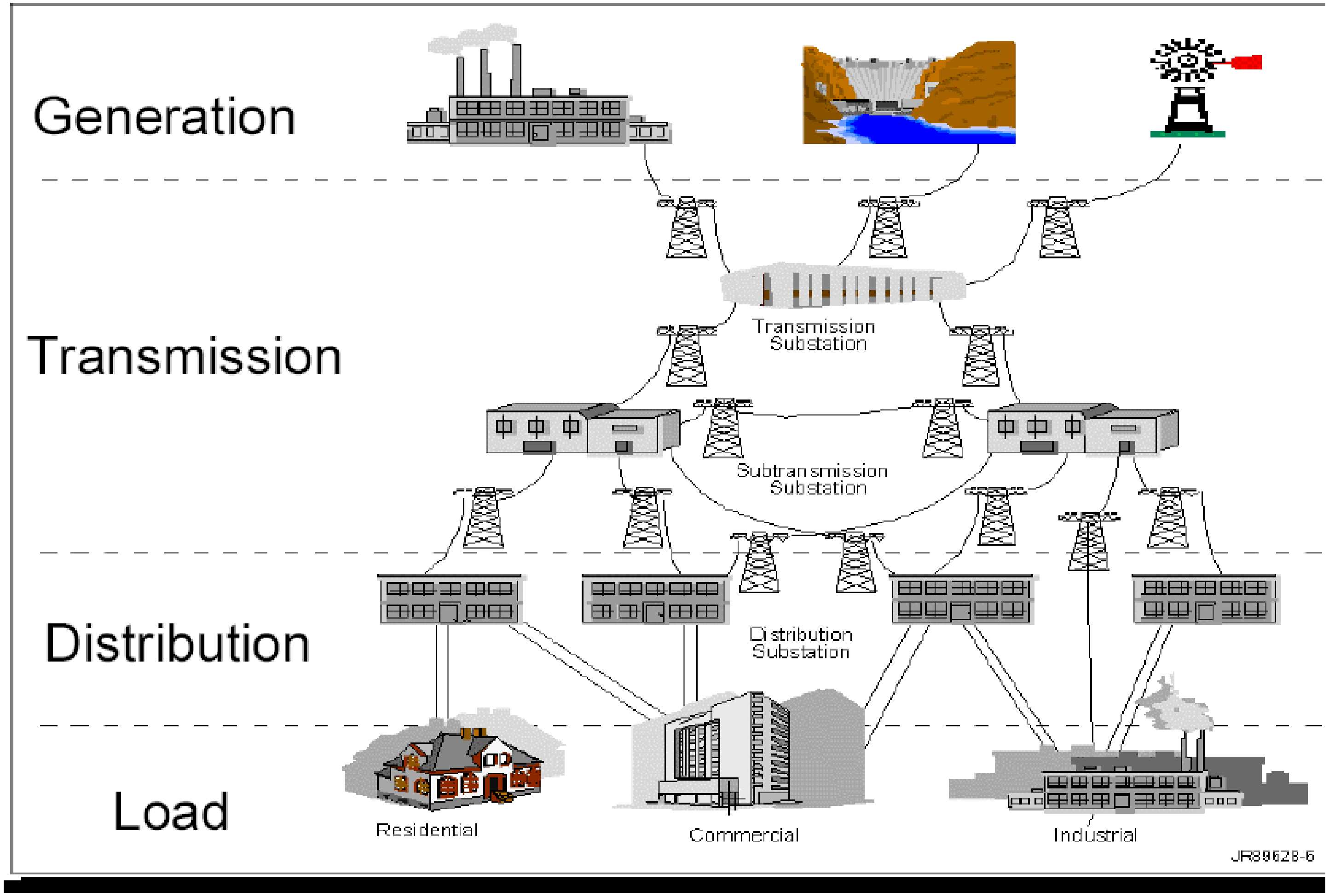
A Little Bit of Terminology, cont.

- Energy: The integration (summation) of power over time; the capacity to do work; it is what people really want
- With the electric grid the common energy units are
  - Joule (J) is 1 watt for one second
  - kWh is 1000 watts for one hour (3.6 million Joules)
  - MWh is 1000 kWh
  - BTU is 1055 J;
  - MBtu is 1 million BTUs; one gallon of gasoline has 0.125 MBtu or about 36.5 kWh
- Electric grids provide very high quality (easily useable) energy

Last Terminology Slide

- Frequency and voltage are how we supply electricity
  - Direct current (DC) or alternating current (AC); most electric grids are 60 or 50 Hertz (Hz) AC
  - Electricity is supplied with a voltage; an advantage of AC grids is they can use transformers to easily convert voltages
  - Common supply voltages are 120 or 240 volts (V); kV is a 1000 volts
  - Power is equal to voltage times current
  - Higher voltages are used for longer distance power transmission with 345 kV the highest voltage in Texas; 765 kV is the highest voltage in the US

Electric Grid Overview



Interconnected Electric Grids

- When operating at the same frequency (either 50 or 60 Hz), electric grids can be connected into interconnects

World Electric Interconnects

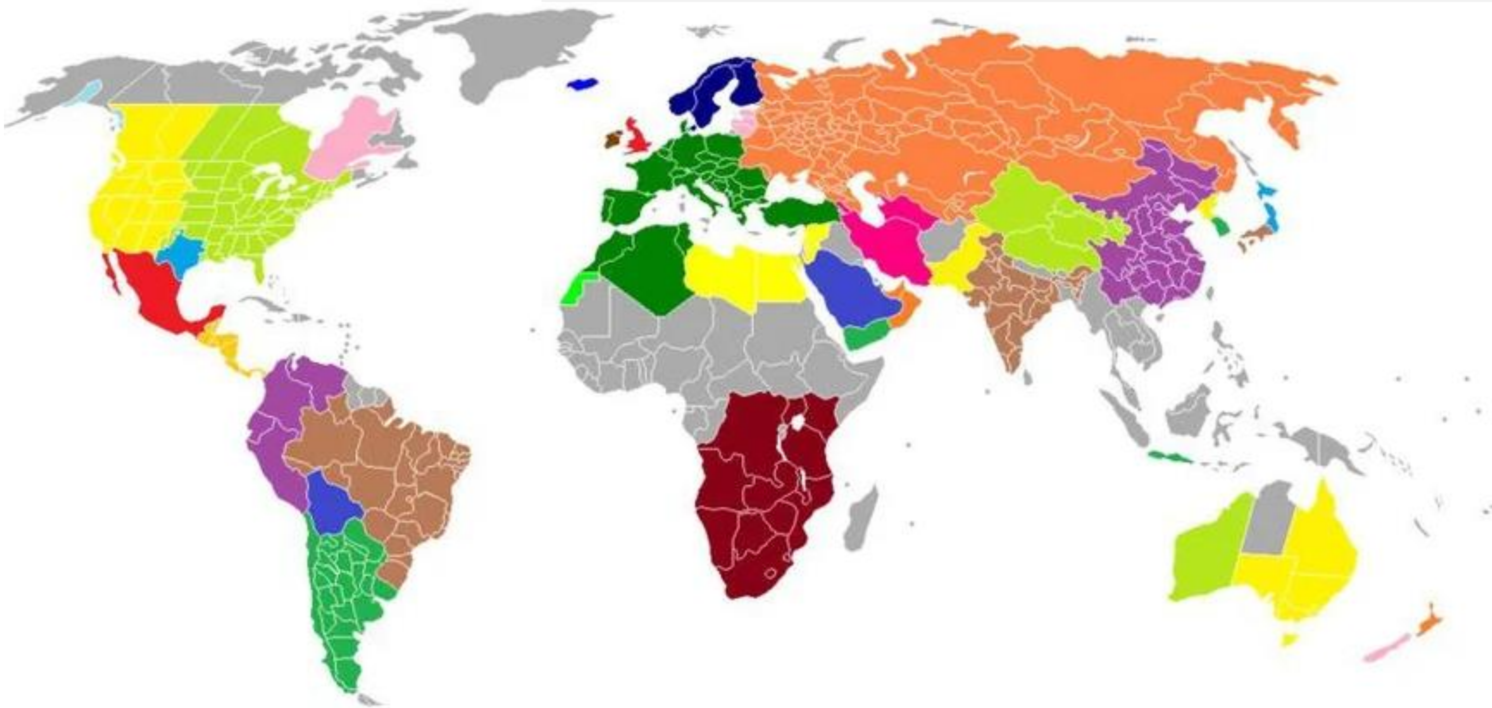
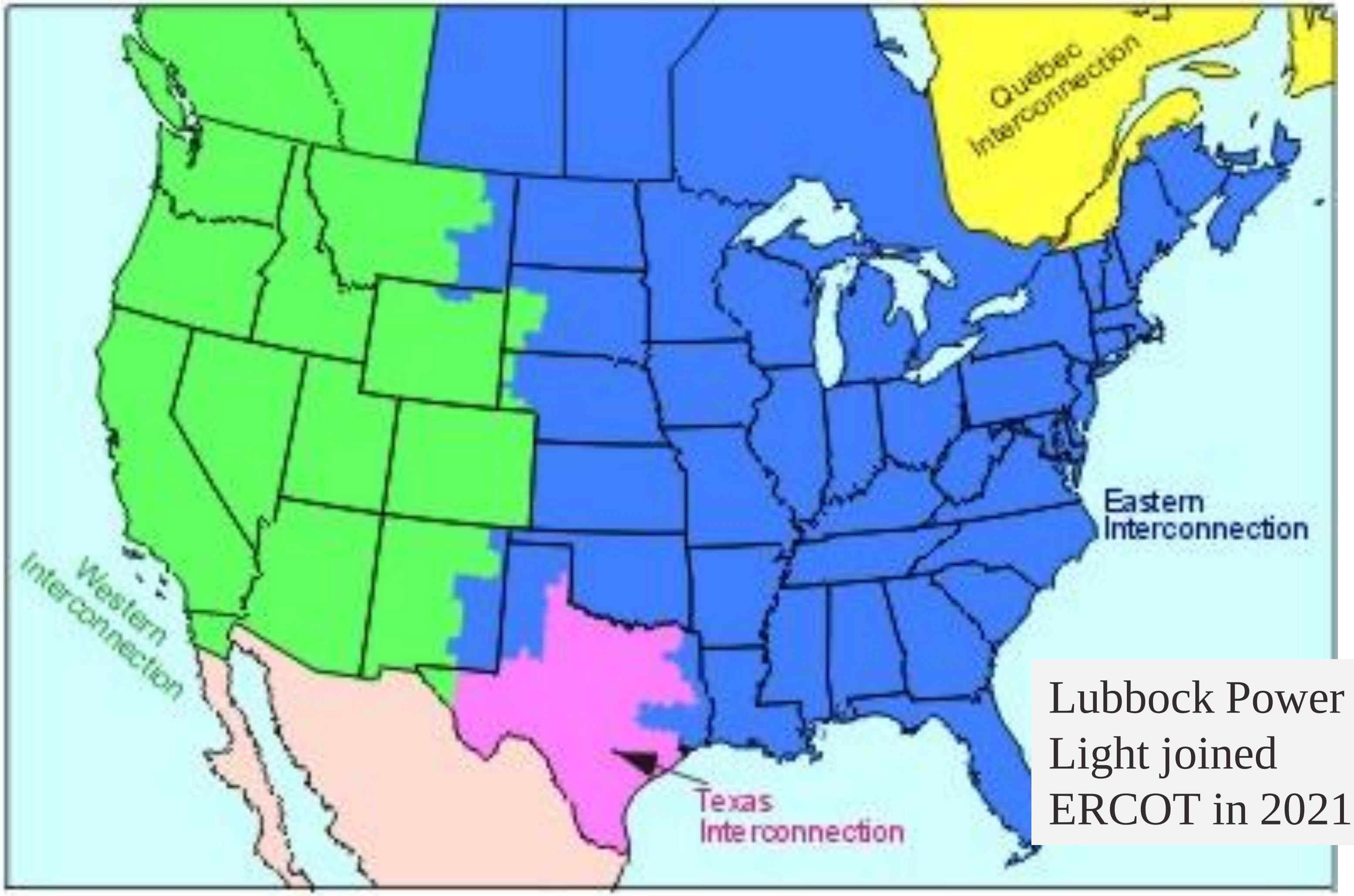


Image Source: i.redd.it/krkhdfslrjh61.jpg

North America Grid Interconnections



Lubbock Power and Light joined ERCOT in 2021

Interconnects Always Have Slightly Different Frequencies (USA 2/13/22)

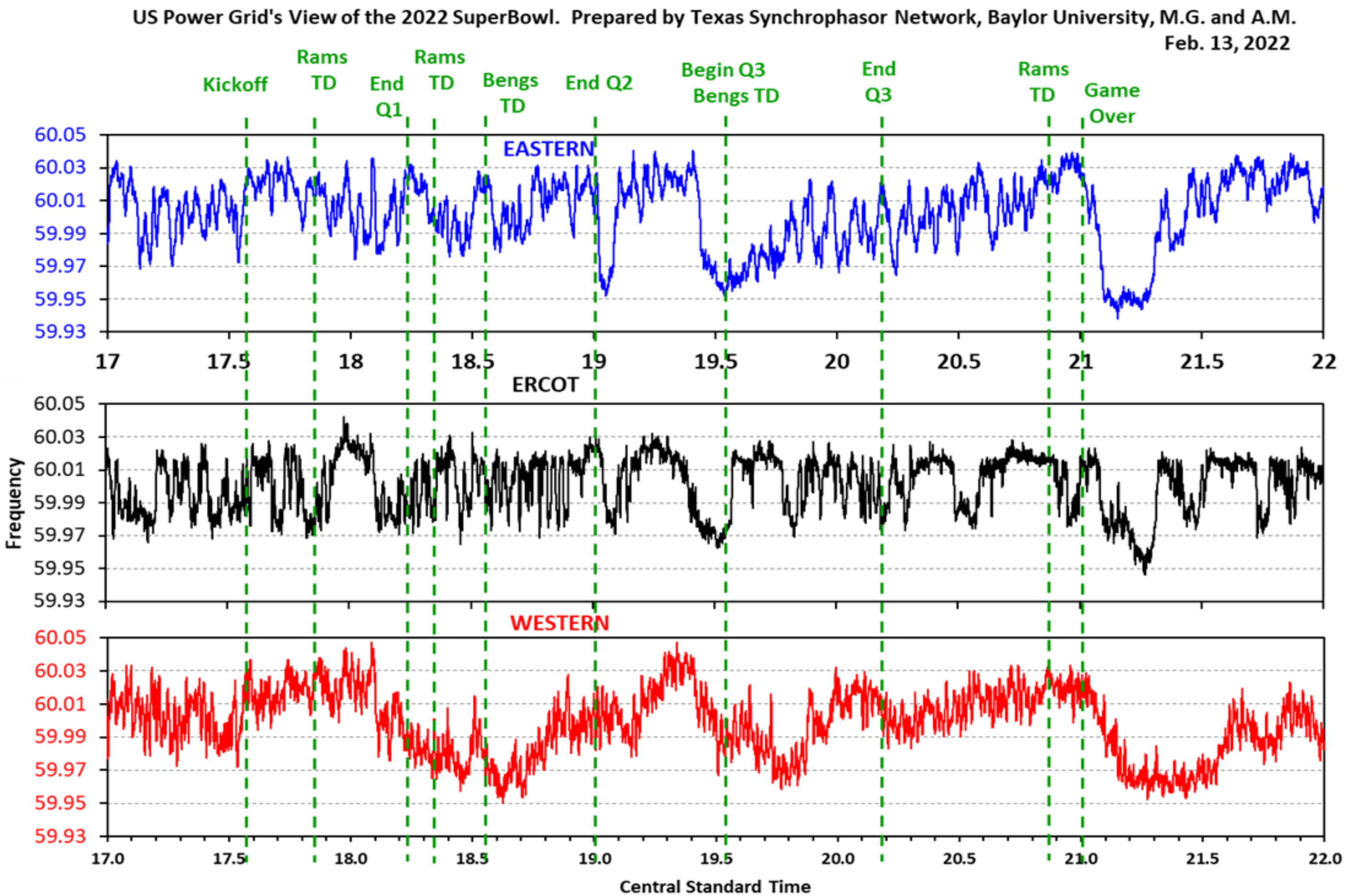
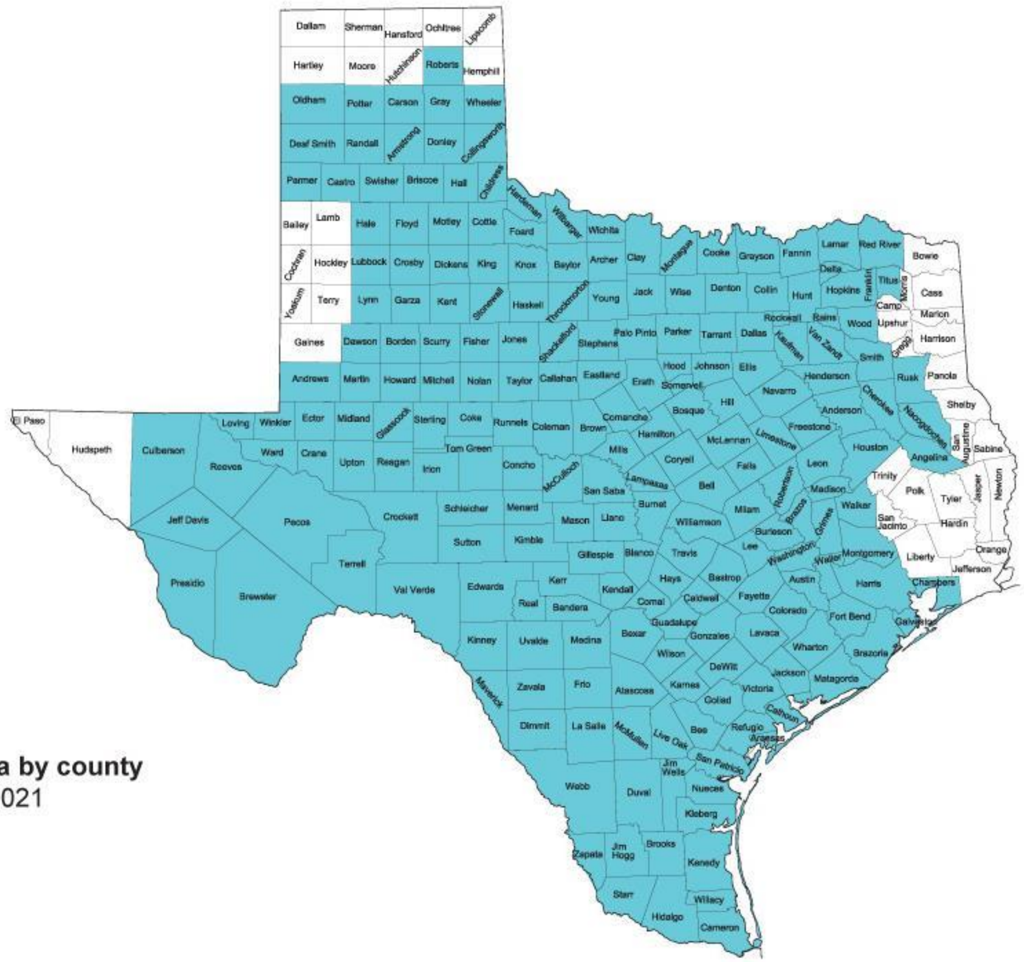


Image from Prof. Mack Grady of Baylor University

Most of Texas Has Its Own Grid (ERCOT)



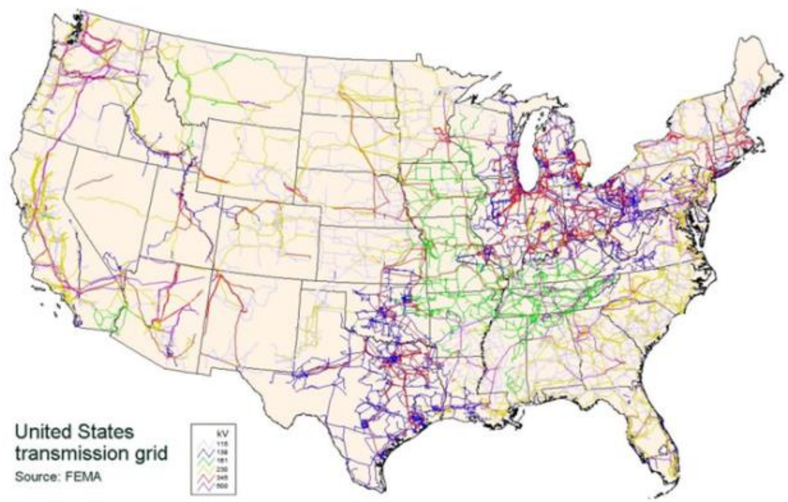
ERCOT area by county
as of June 2021

El Paso is in the Western Interconnect (WECC) and parts of North and East Texas are in the Eastern Interconnect (EI) (with the boundaries not always by county)

Source: www.ercot.com/news/mediakit/maps

Important Electric Grid Considerations

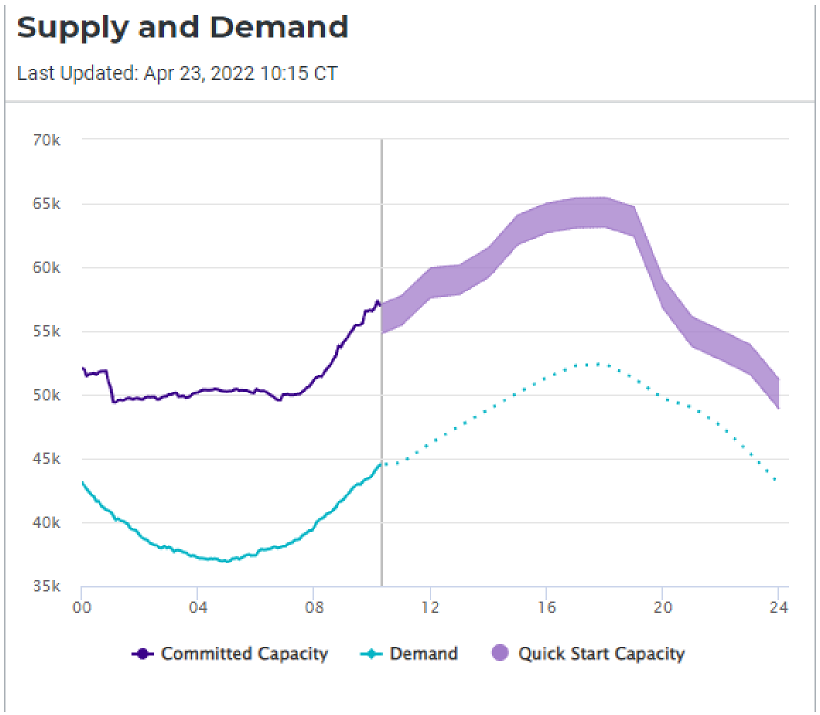
- Electricity cannot be economically stored
  - In an interconnect generation must be continually adjusted to match changes in electric load and losses
- Electric power flows on high voltage transmission lines cannot usually be directly controlled
  - Control is mostly indirect, by changing generation



- Customers have been in control of their load
- Transmission system has finite limits; often operated close to its limit for economic reasons

The Electric Load is Constantly Changing

- This is a result of millions of decisions made by individual users and automatic control systems



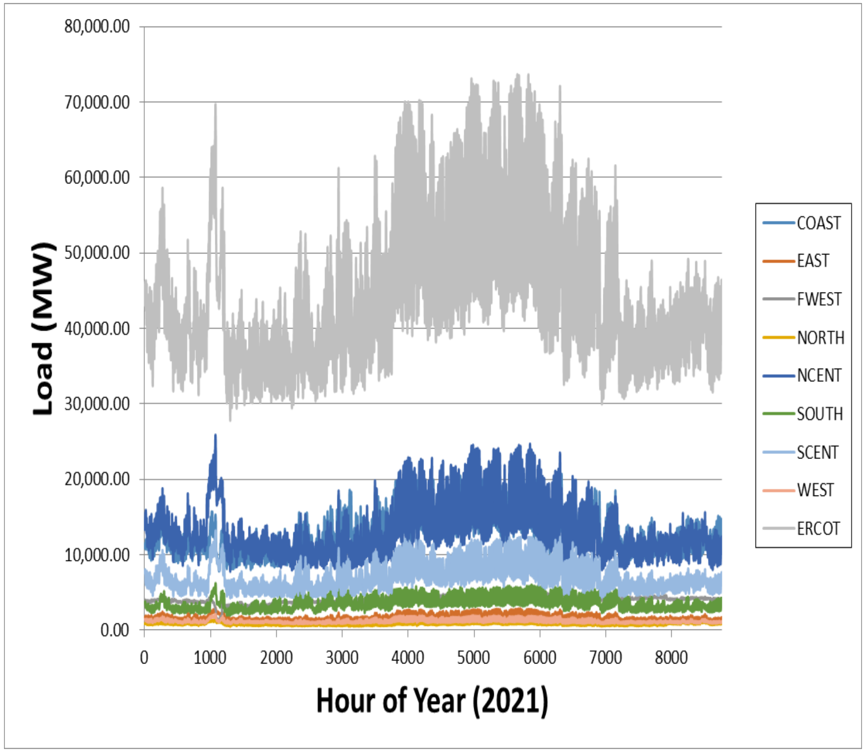


Image source: www.ercot.com/gridmktinfo/dashboards

Interconnect Frequency Control

- Each interconnect has its own frequency, a value that is usually very close to 60 Hz
- If there is too much generation then the frequency rises, if there is too little then it falls
- The frequency is controlled on the order of seconds using a process known as automatic generation control (AGC)
- Power can only be transferred between interconnects by using high voltage DC (HVDC) transmission

Interconnect Advantages and Disadvantages

- Within an interconnect power can be transferred long distances (many hundreds of miles) with low losses (maybe a total of 3 to 5% in the transmission system)
  - This allows for large power markets
- When a problem arises (such as a lost generator) all the other generators in the interconnect can help
- A disadvantage is the disturbances can rapidly propagate through an interconnect
- Another issue is with multi-state interconnects there is additional regulation

Why is ERCOT Separate

- ERCOT operates asynchronous from the rest of North America, but has high voltage dc (HVDC) ties with the Eastern Interconnect and Mexico
- The advantage is ERCOT avoids some federal regulation. The legal basis for this is complex, based on the US Constitution, the Federal Power Act, the 5/4/76 midnight connection, other legislation, court rulings, and FERC decisions

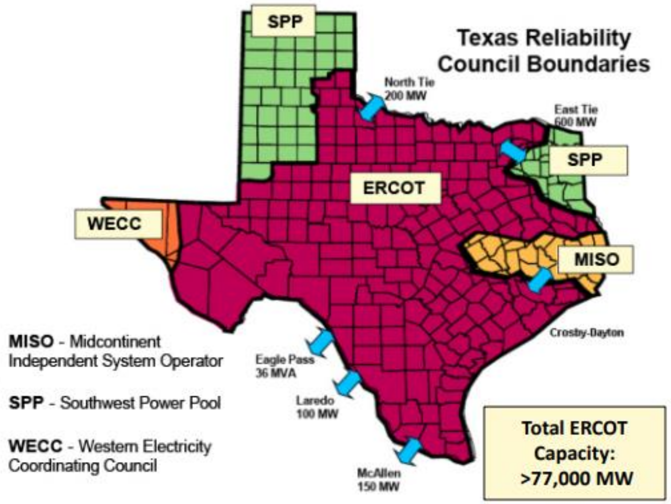
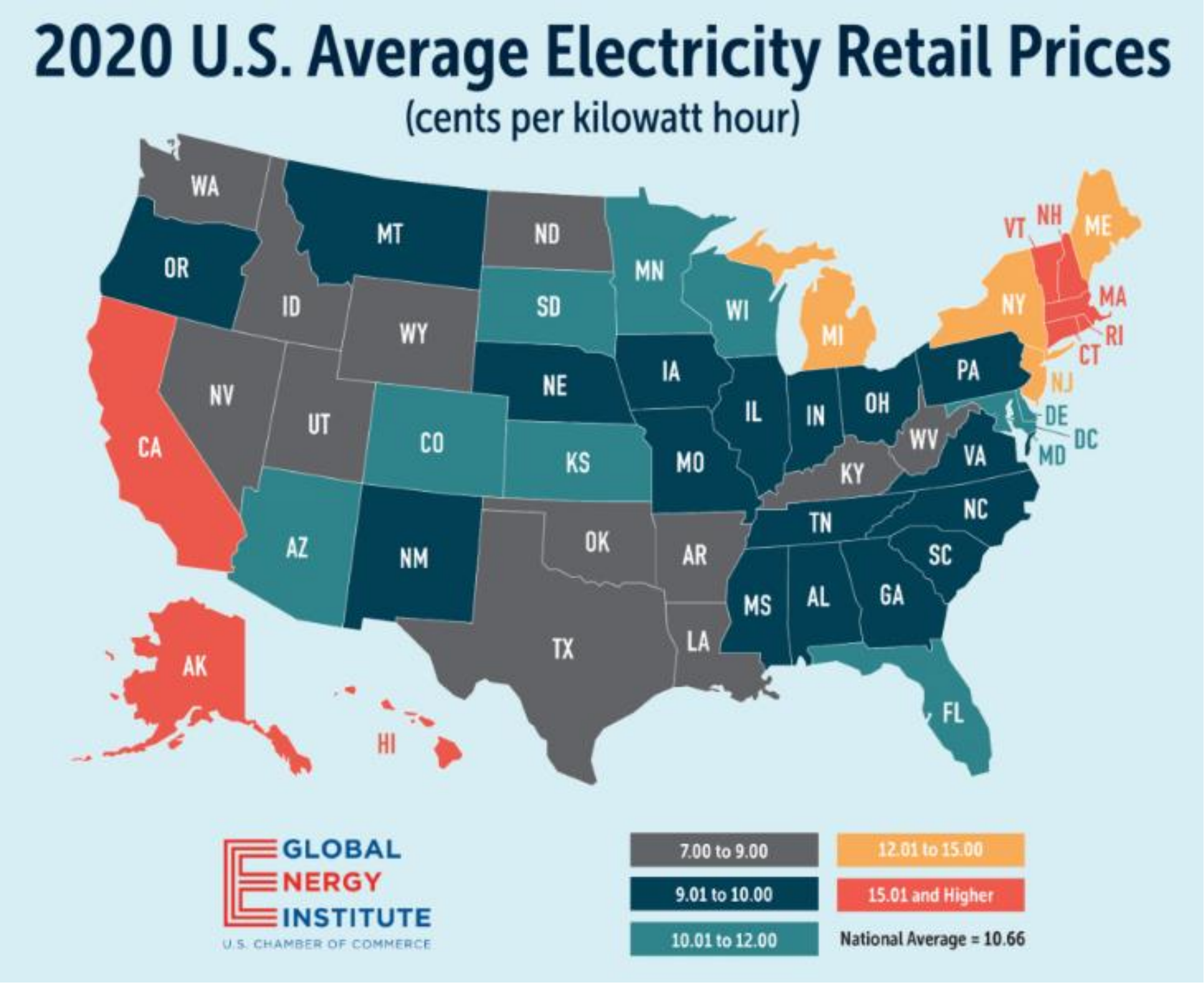


Image Source: aect.net/documents/2017/AECT%20LSB%20012617.pdf

High Voltage Direct Current (HVDC) Transmission

- HVDC is sometimes used to transmit electricity either within an interconnect or between interconnects (back-to-back HVDC)
  - Within an interconnect, HVDC is usually used for long distance transfer, or in underground or undersea cables
- HVDC avoids issues with reactive power, but incurs the costs associated with the rectification (ac to dc) and inversion (dc to ac)
- HVDC power flow can be quickly controlled (milliseconds)

State Variation in Electricity Retail Prices

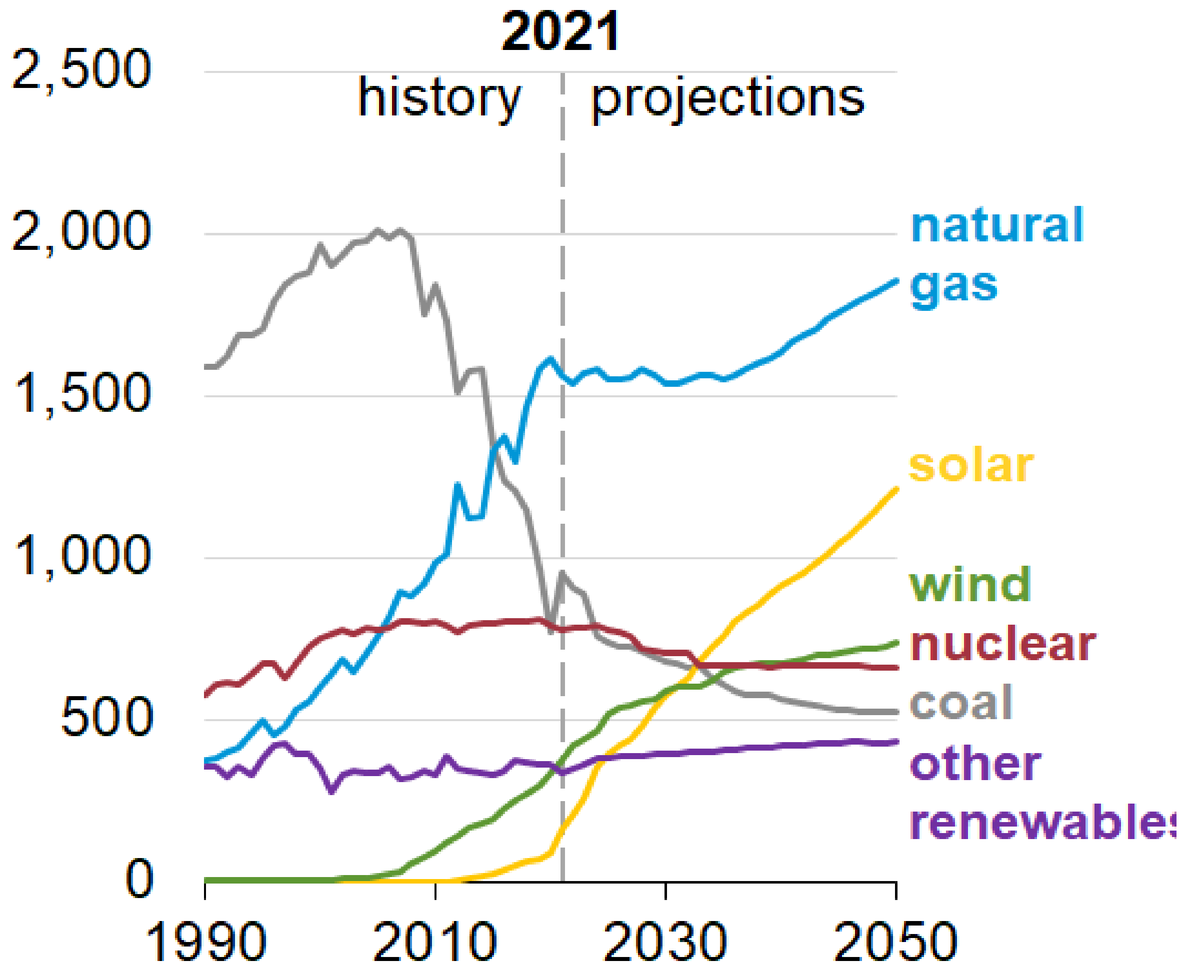


Texas is 8.58 whereas California is 18.15 (cents per kWh)

In 2020 for industrial prices Texas was the third lowest (at 5.07); US average was 6.67 with OK at 4.61 and LA at 4.88; CA was 14.27 (cents per kWh)

The data source is ultimately the US EIA

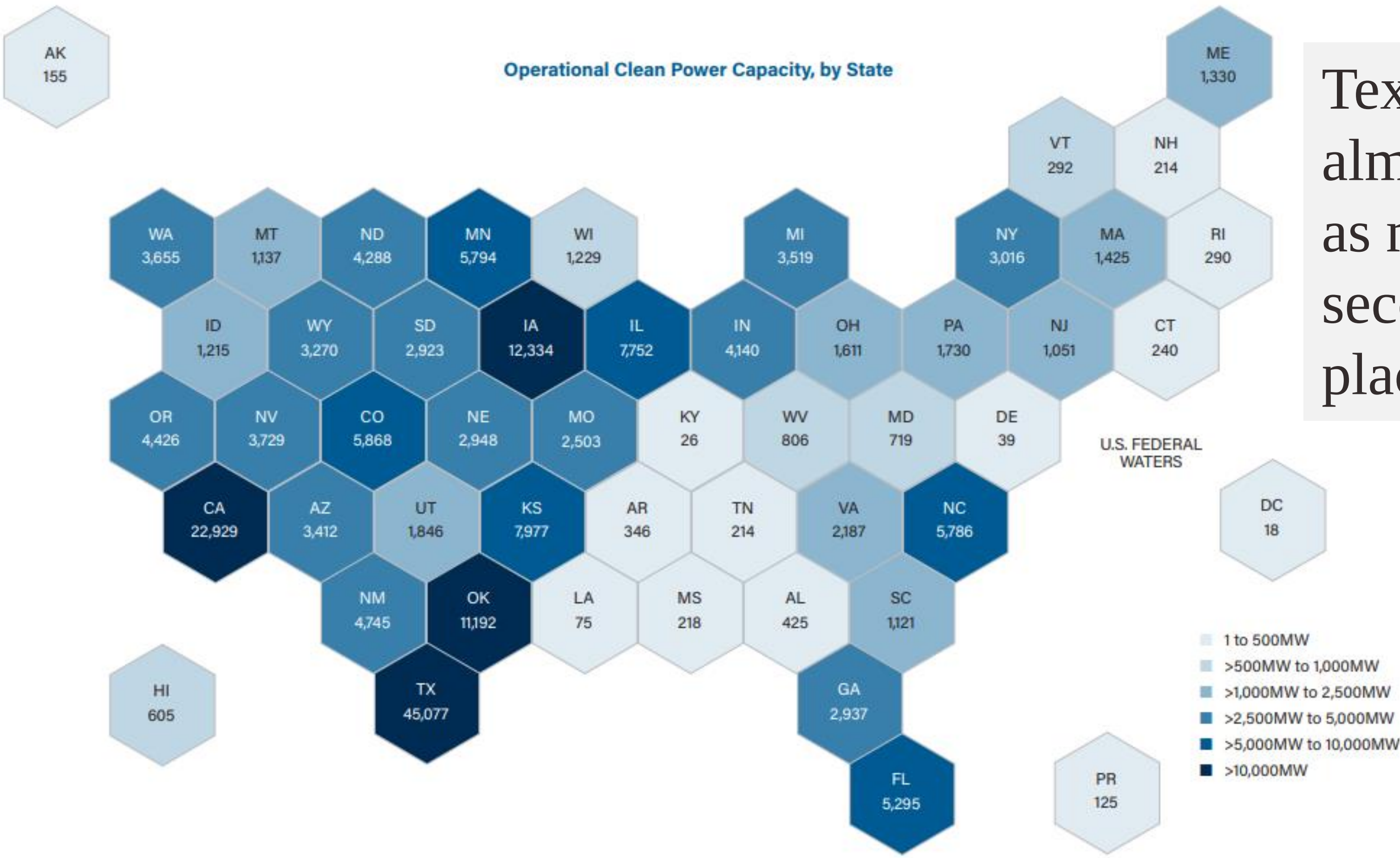
Changing Sources of US Electricity Generation



The future values, of course, involve many assumptions

Image source: EIA AEO2022

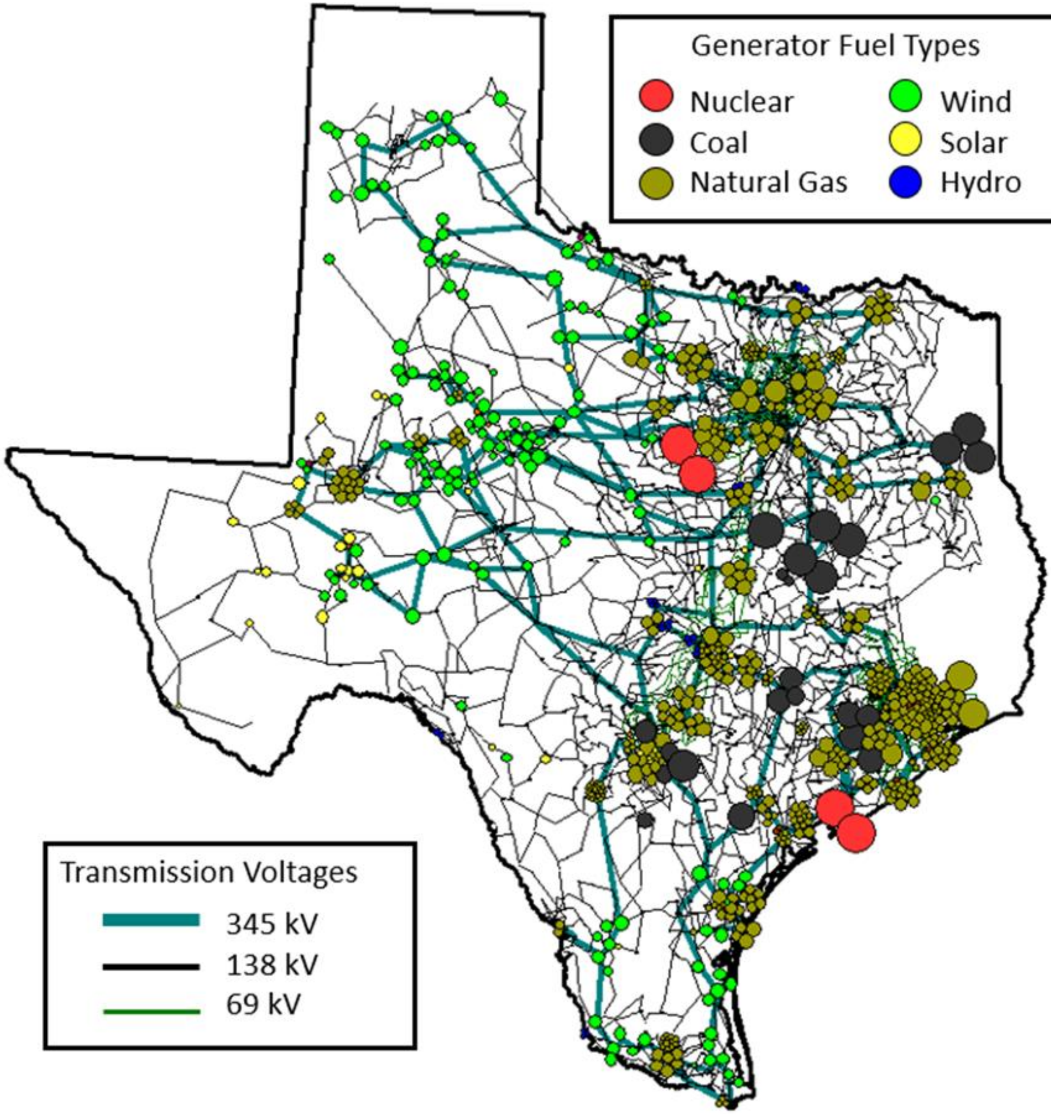
Texas is the Leader in Wind and Solar Generation (End of 2021 Data)



Texas has almost twice as much second place CA

Source: Clean Power Quarterly, 2021 Q4 edition

ERCOT Electric Generation



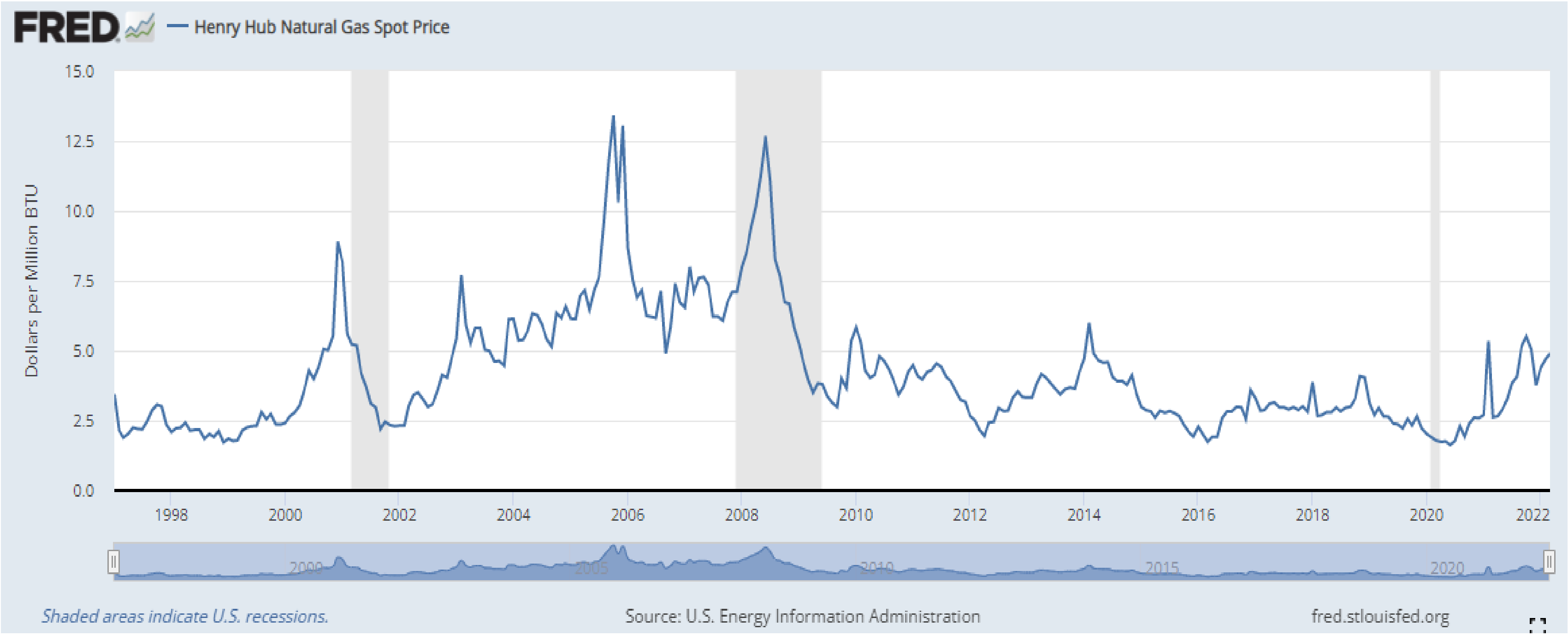
In ERCOT we sometimes gets more than half our electric energy from wind!

This is a synthetic grid model with generation matching the actual grid and a statistically similar transmission grid

Generator Costs

- Electric generating technologies involve a tradeoff between fixed costs (costs to build them) and operating costs
  - Nuclear and solar high fixed costs, but low operating costs (though cost of solar has decreased substantially recently)
  - Natural gas/oil have low fixed costs but can have higher operating costs (dependent upon fuel prices)
  - Coal, wind, hydro are in between
  - – Losses in electric transmission are about 3-5% in the transmission system and 10-15% in the distribution system
- There is a strong coupling between electricity and natural gas prices

Natural Gas Prices 1997 to 2022



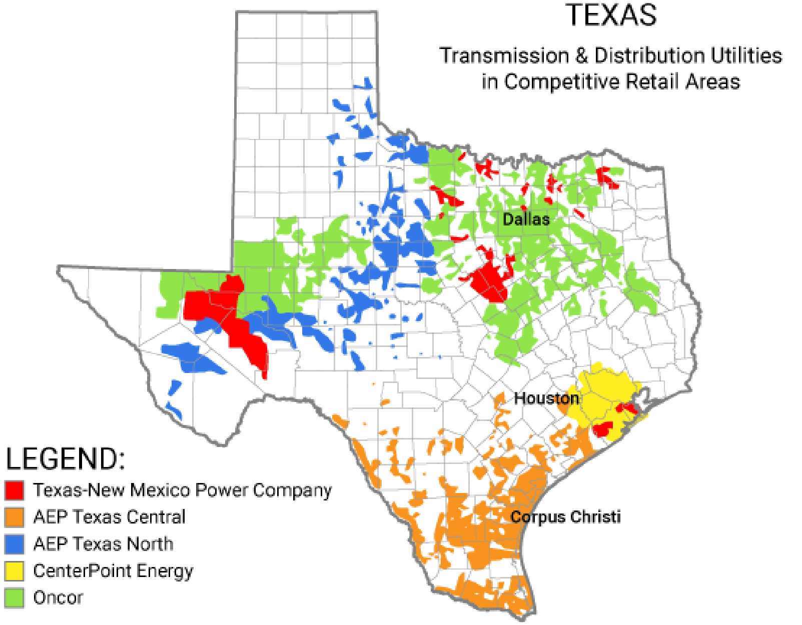
April 2022 values have been higher, reaching close to $8/MBtu

Marginal cost for natural gas fired electricity price in $/MWh is about 7-10 times the gas price in $/MBtu; Henry Hub is located in Erath, LA

Source: fred.stlouisfed.org/series/MHHNGSP

Types of Electric Utilities

- There are three major types of electric utilities
  - Investor owned utilities (IOUs; most of electric load)
  - Municipals (CPS is largest, then Austin)
  - Rural cooperatives



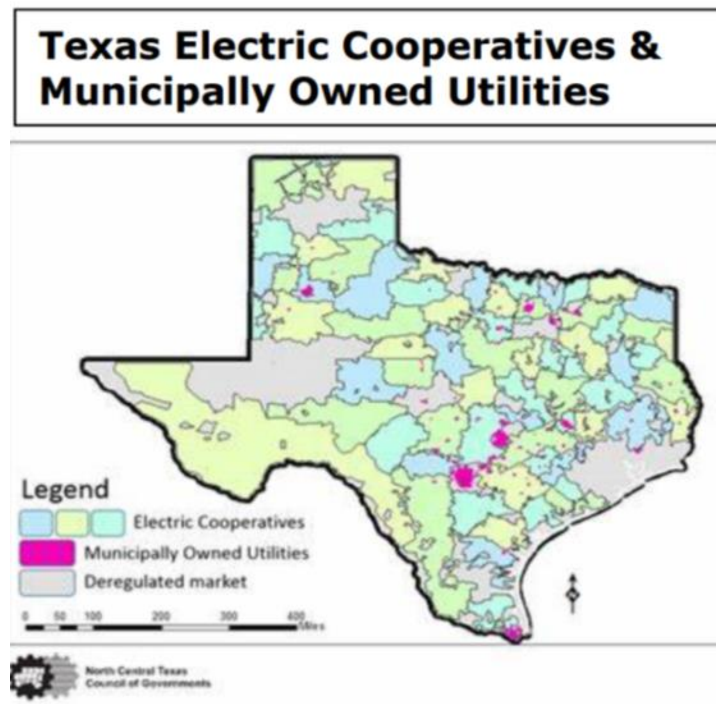
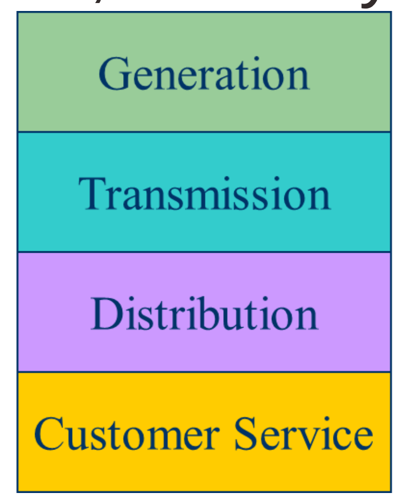


Image sources are Direct Energy and CPS Energy

Electricity Markets

- Up until the1990’s most electric utilities operated as vertical monopolies and each had an exclusive franchise, customers did not have choice, and they primarily bought and sold electricity with their neighbors through bi-lateral transactions



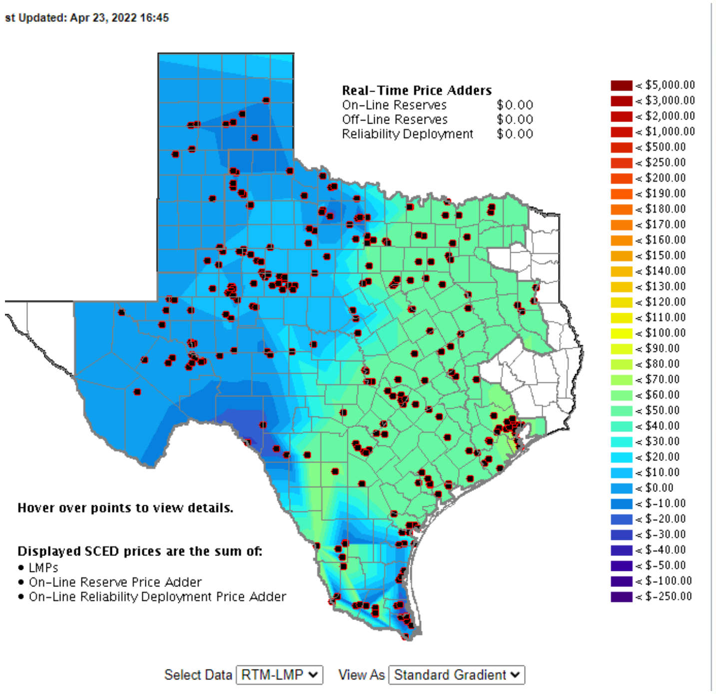
- Over the last few decades large electricity markets have developed offering a variety of products
  - The US Federal Energy Regulatory Agency (FERC) regulates most US markets but not ERCOT since it is just in Texas

North American Electricity Markets

ISO stands for independent system operator whereas RTO is regional transmission organization. ERCOT is an ISO (since 1996) but is not a FERC regulated RTO

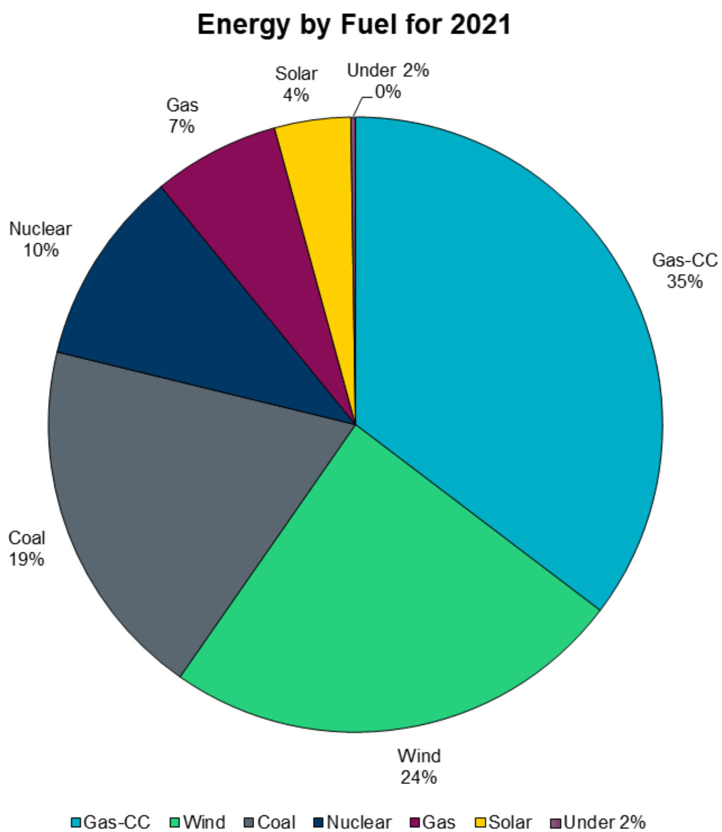
The ERCOT Market

- Like all other electricity markets, ERCOT has a day-ahead market (DAM) and a real-time market (RTM) for electric energy
- The price of electricity can vary across ERCOT because of congestion (to prevent line overloads); the prices are known as the locational marginal costs (LMPs)
- Loads pay the LMP ($/MWh) and generators get paid the LMP; now capped at $5000 / MWh



ERCOT Generation and Its Availability

2021 for ERCOT



Varying generation capacity in 2020

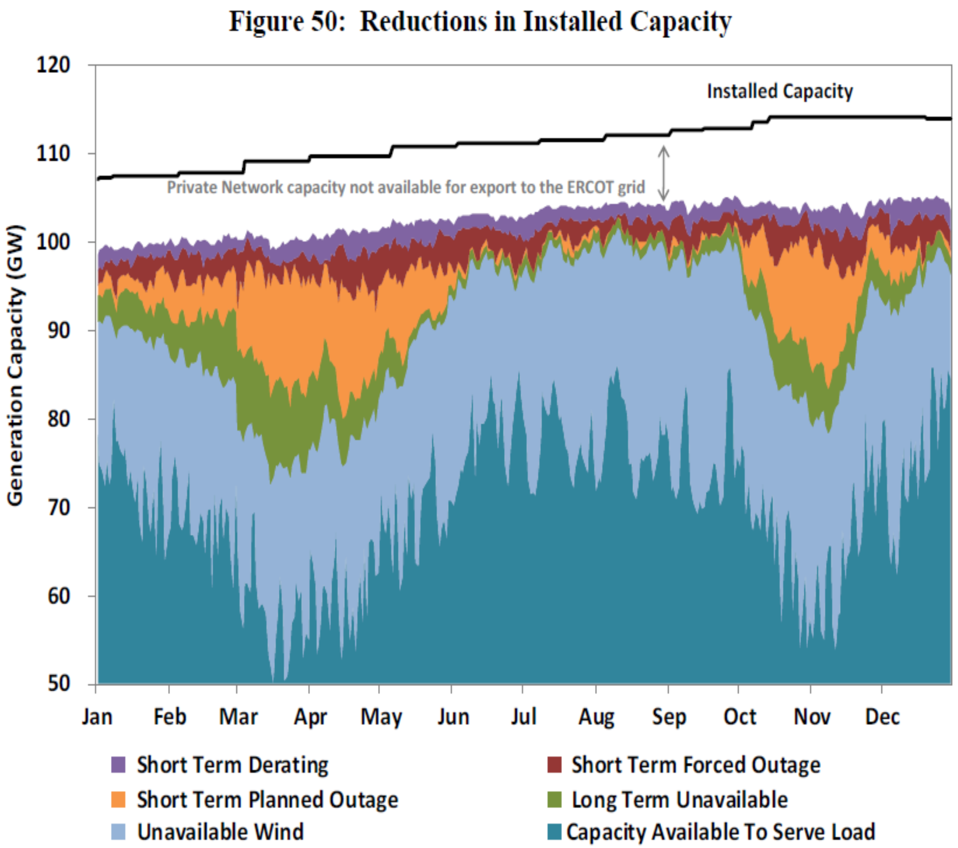


Image sources: ERCOT and ERCOT 2020 State of the Market Report

Quick Summary of Winter Storm Uri, February 2021

- Unfortunately electric grids often make the news for all the wrong reasons!
- Starting on Feb 14, 2021 statewide Texas had temperatures much below avg., though not record cold
- This stressed many infrastructures including the ERCOT electric grid

Figure 2: Severe Cold Weather Conditions – February 15, 2021

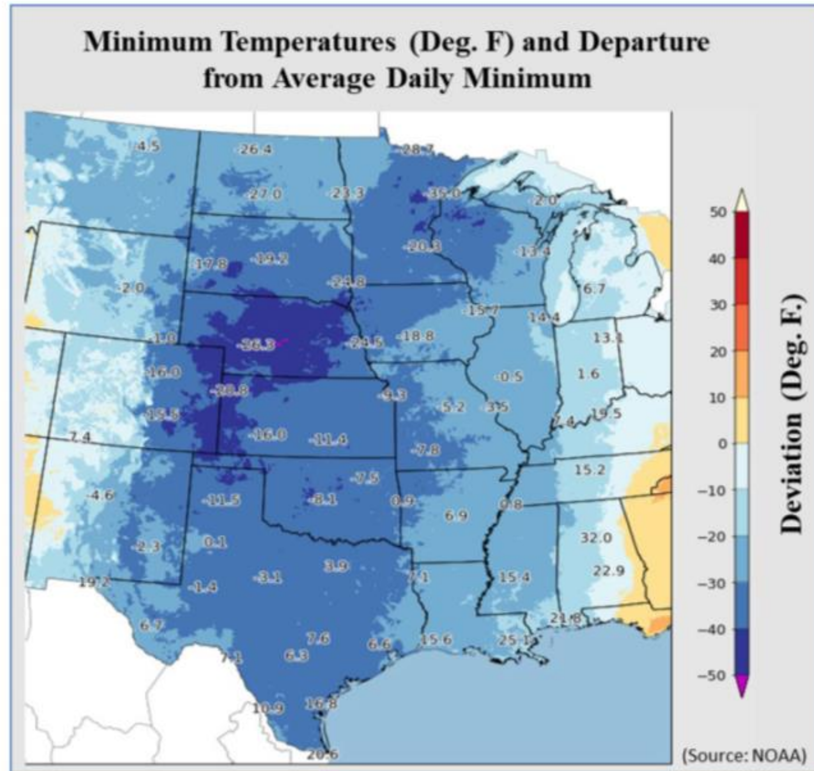


Image source: FERC/NERC Feb 2021 Winter Storm report

Uri Impacts in a Nutshell

- It was unusually cold across the region, Texas has a high percentage of electric heat load so the load was going up, and a large number of generators were unavailable because of the cold
- There was a generation shortage across the region, and because of limited power import capability ERCOT needed to go to load shedding
- Prices went quite high!

Figure 4: Location and Fuel Type of Unplanned Generation Outages and Derates During the Event (Outaged Capacity in MW)

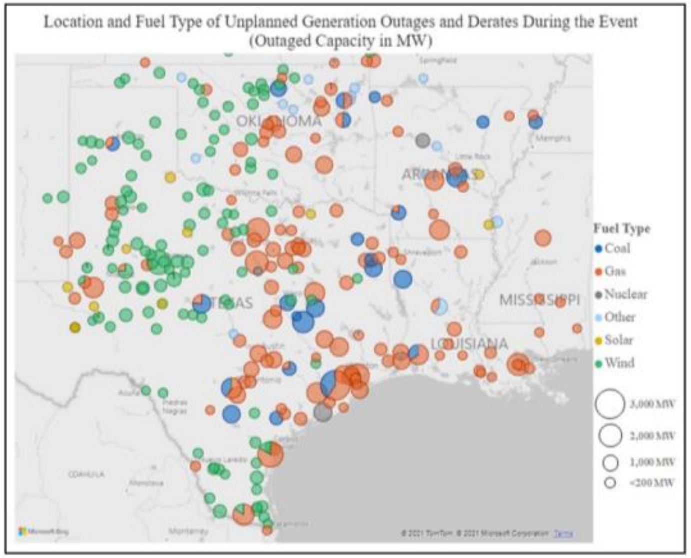


Image source: FERC/NERC Feb 2021 Winter Storm report

ERCOT Frequency, Feb 15, 2021

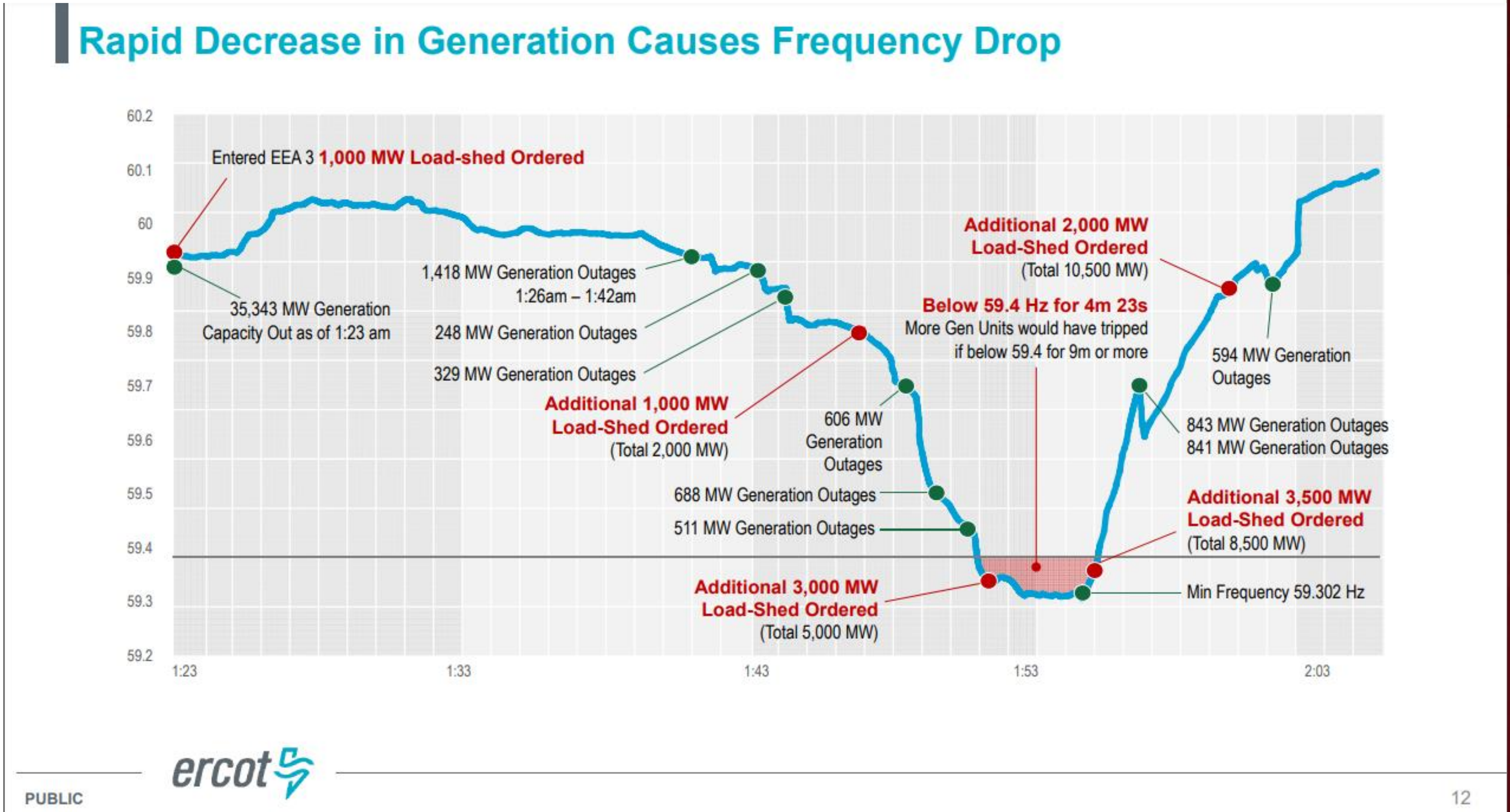
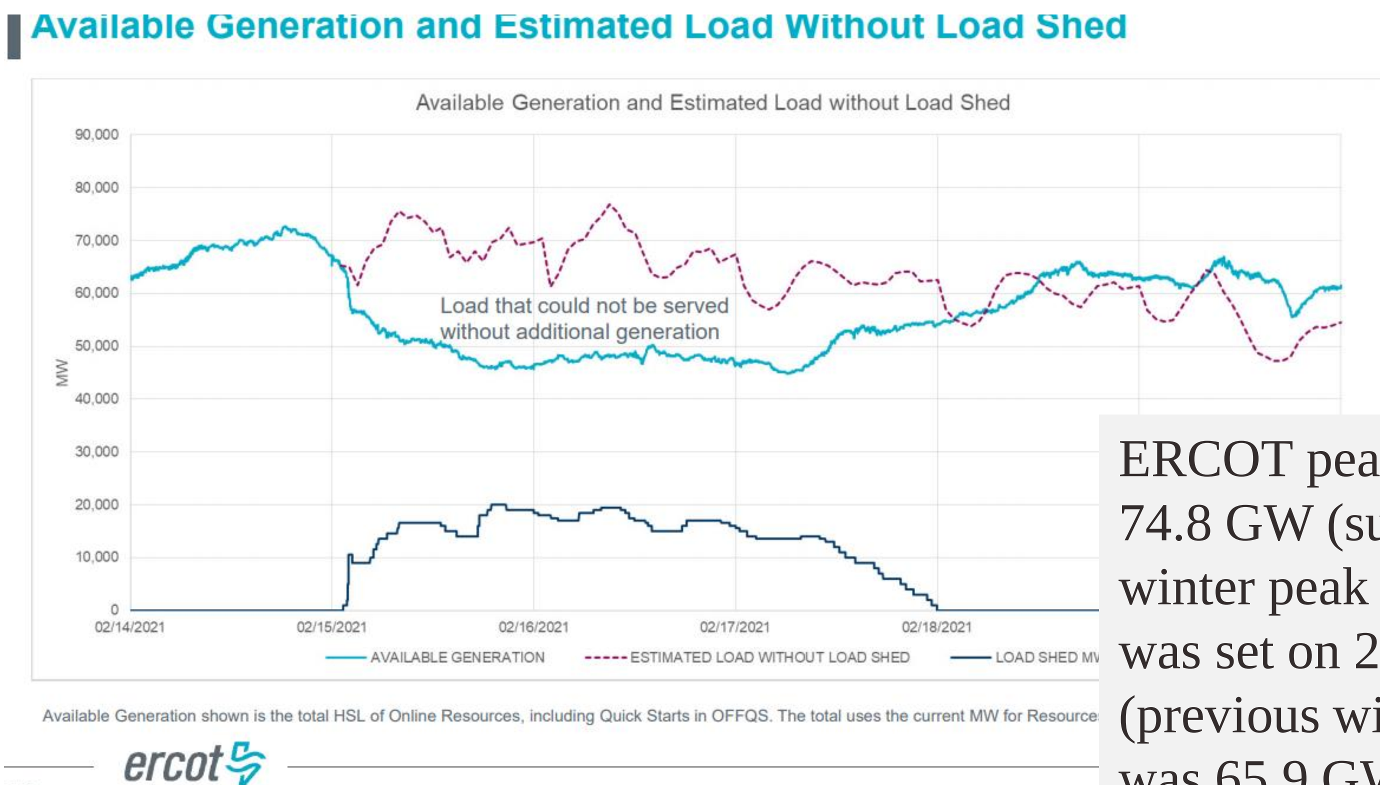


Image source: ERCOT Presentation by Bill Magness, February 25, 2021

ERCOT Load Shed and Rotating Blackouts

- The vast majority of the lost load was due to load shed and then rotating blackouts

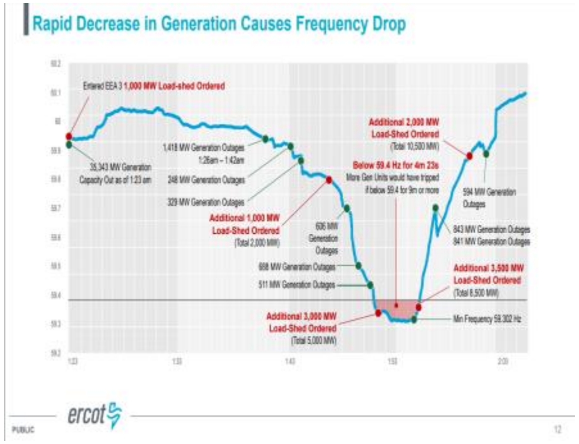


ERCOT peak load is 74.8 GW (summer); winter peak of 69.2 GW was set on 2/14/21 (previous winter peak was 65.9 GW)

Image source: ERCOT Presentation by Bill Magness, February 25, 2021

How can Grids Cascade?

- ERCOT reported that they were minutes away from a catastrophic blackout that would have taken down the entire grid, requiring many days to restore
- Grids can cascade due to a number of different reasons with many related to the transmission grid flows and voltages
- For ERCOT the situation was the prolonged (minutes) low frequency would have result in generators tripping due to under frequency resulting in a cascading collapse in the frequency and hence the entire system

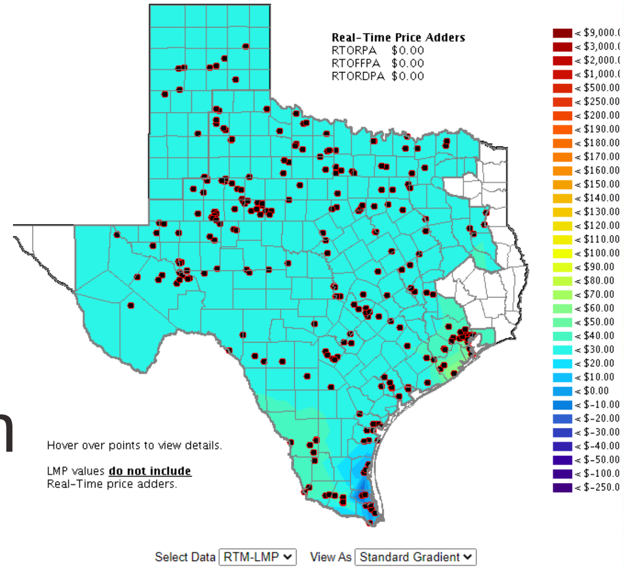


Winterizing Wind Turbines

- In general wind turbines can operate in quite low temperatures
- However, most of the wind turbines in Texas were not configured with the systems needed to deal with low temperatures
  - They mostly were not available because of turbine blade icing and low temperature limit shutdowns
- Wind turbines can be winterized with systems such as heated blades or coatings; packages can also be installed to protect the gearbox and motors, such as adding heating to the nacelle

Why Were Electric Prices High?

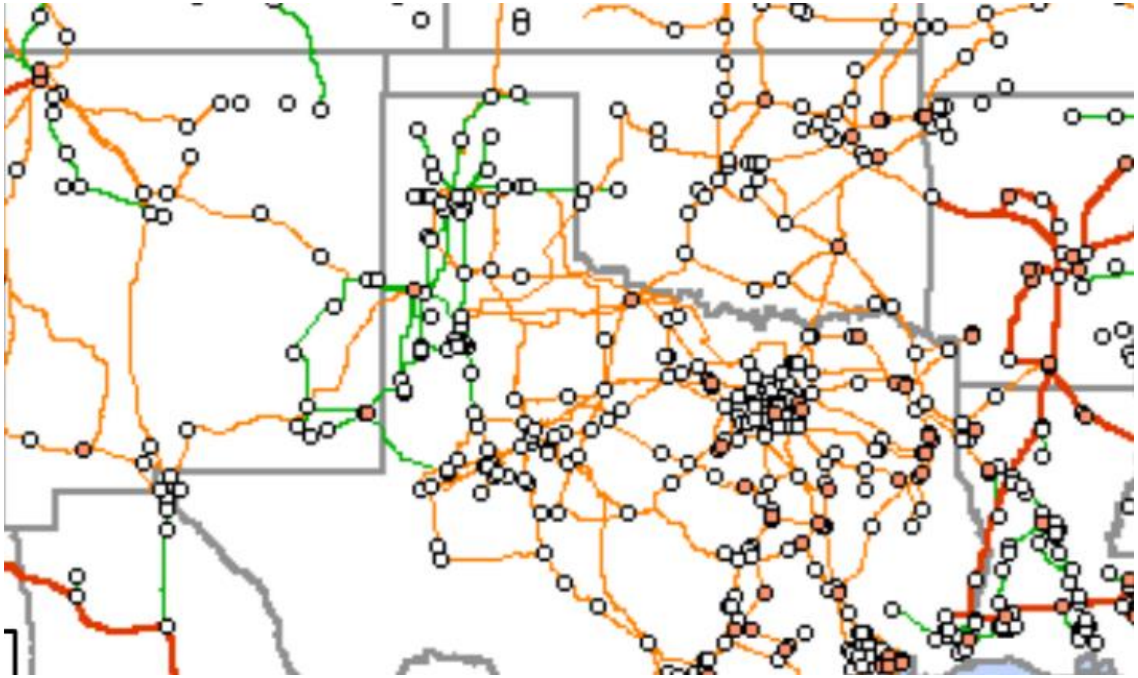
- In ERCOT, like much of the rest of the country, electricity is priced using a locational marginal price (LMP) market, that has both day-ahead and real-time markets
  - The price of electric varies by location and time of day



- Usually the price is relatively low say $30/MWh (or $0.03 by kWh)
- It had been capped at $9000/MWh but this has been lowered to $5000/MWh
- Operating for days at price was considered unlikely!

Should ERCOT Increase its Power Transfer Capacity?

- This can be done by either constructing more HVDC lines or doing a full AC interconnection with the East
  - Technically an AC interconnection would be relatively straightforward so it is more of a public policy question



Orange is 345 kV, Red is 500 kV; a few connections could provide perhaps several GWs of capacity

Public Source Map: www.nerc.com/comm/CIPC/Agendas%20Highlights%20and%20Minutes%202013/2015%20December%20Compiled%20Presentations.pdf

Southern Cross HVDC Transmission Project

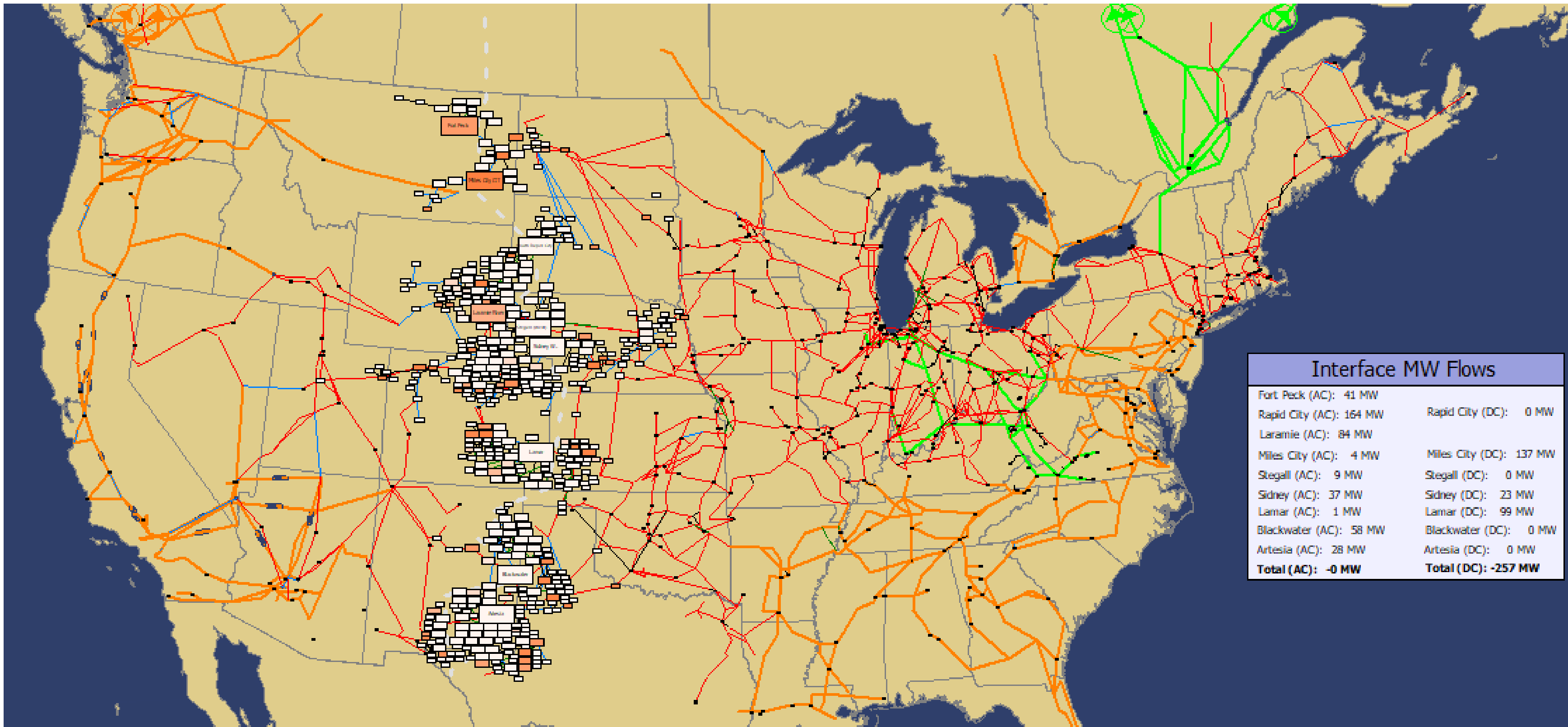
- The Texas Public Utility Commission has approved an application to build a 38 mile, 345 kV ac transmission line to connect to a 400 mile long, 500 kV HVDC between the Mississippi/Alabama and the Louisiana/Texas borders
  - As planned it would have a capacity of 2000 MW
  - It could be operational in 2022 with a cost that might be more than $1 billion
  - Up-to-date information on the project is available at www.ercot.com/mktrules/puctDirectives/southernCross

Image source: southerncrosstransmission.com; the website says it is being updated and not available

Joining the East and West Grids

- In 2020 we did a research project for SPP looking at an ac interconnection of the East and West grids
  - This did not include ERCOT, but did include parts of Texas
- There are nine locations where the grids are close and could be tied together
- The study required lots of dynamic simulations using quite detailed full system models (transient stability level, 110,000 buses)
- The result was there are no show stoppers to doing this, and there could be good benefits!

East-West Combined Grid



The study included Canada but we did not consider any ac interconnections between the grids in Canada; the grids were connected at nine points from Montana to New Mexico

Broadening to Electric Grid Resiliency

- The ability of electric grids to resiliently respond to high impact, low frequency events is an important but often overlooked aspect of operation, design and research
  - There is always a tradeoff between risk and mitigation cost
- A good reference is the free 2017 report from the US National Academies titled, “Enhancing the Resilience of the Nation’s Electricity System”
  - It does mention the threat of cold weather, and specifically mentions the February 2011 Texas cold snap

Some Electric Grid Risks (National Academies 2017 Report)

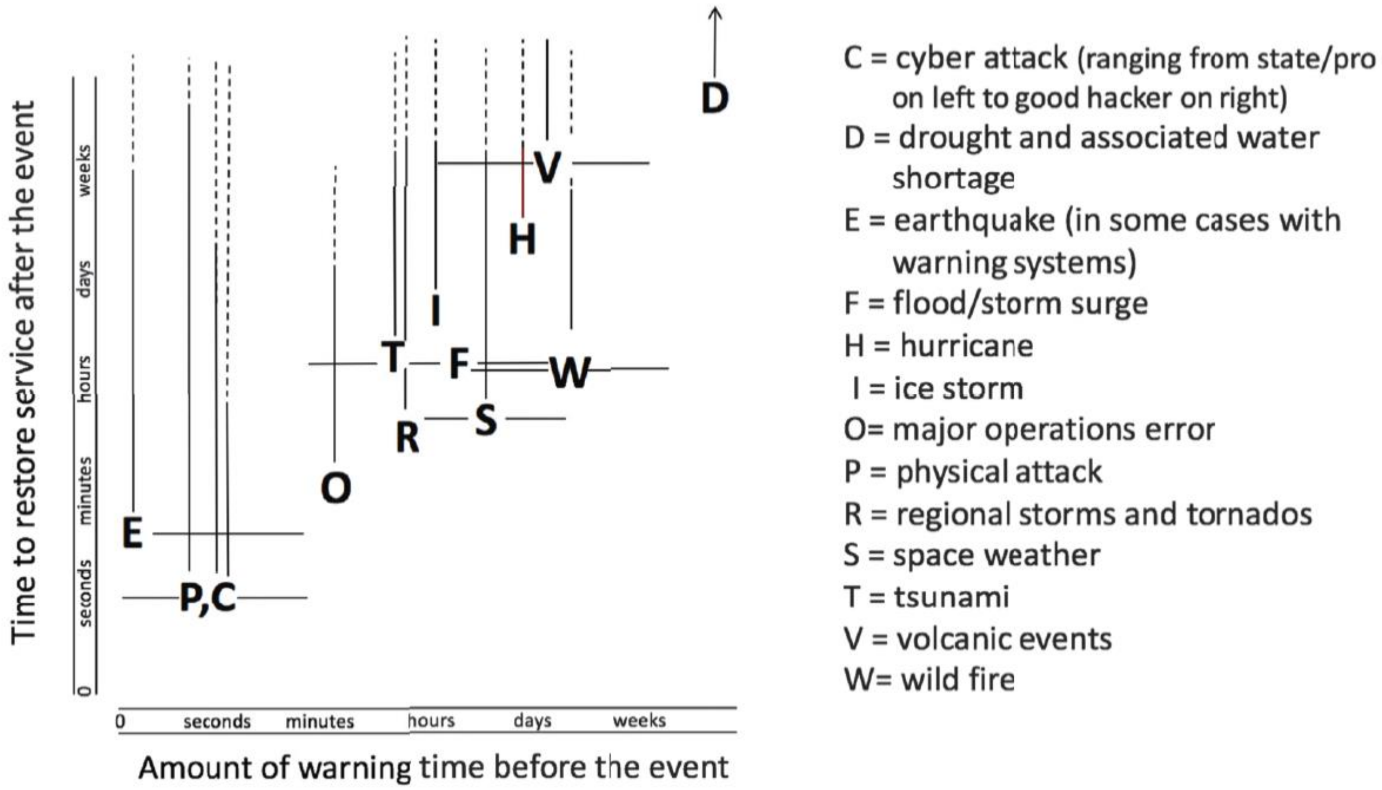
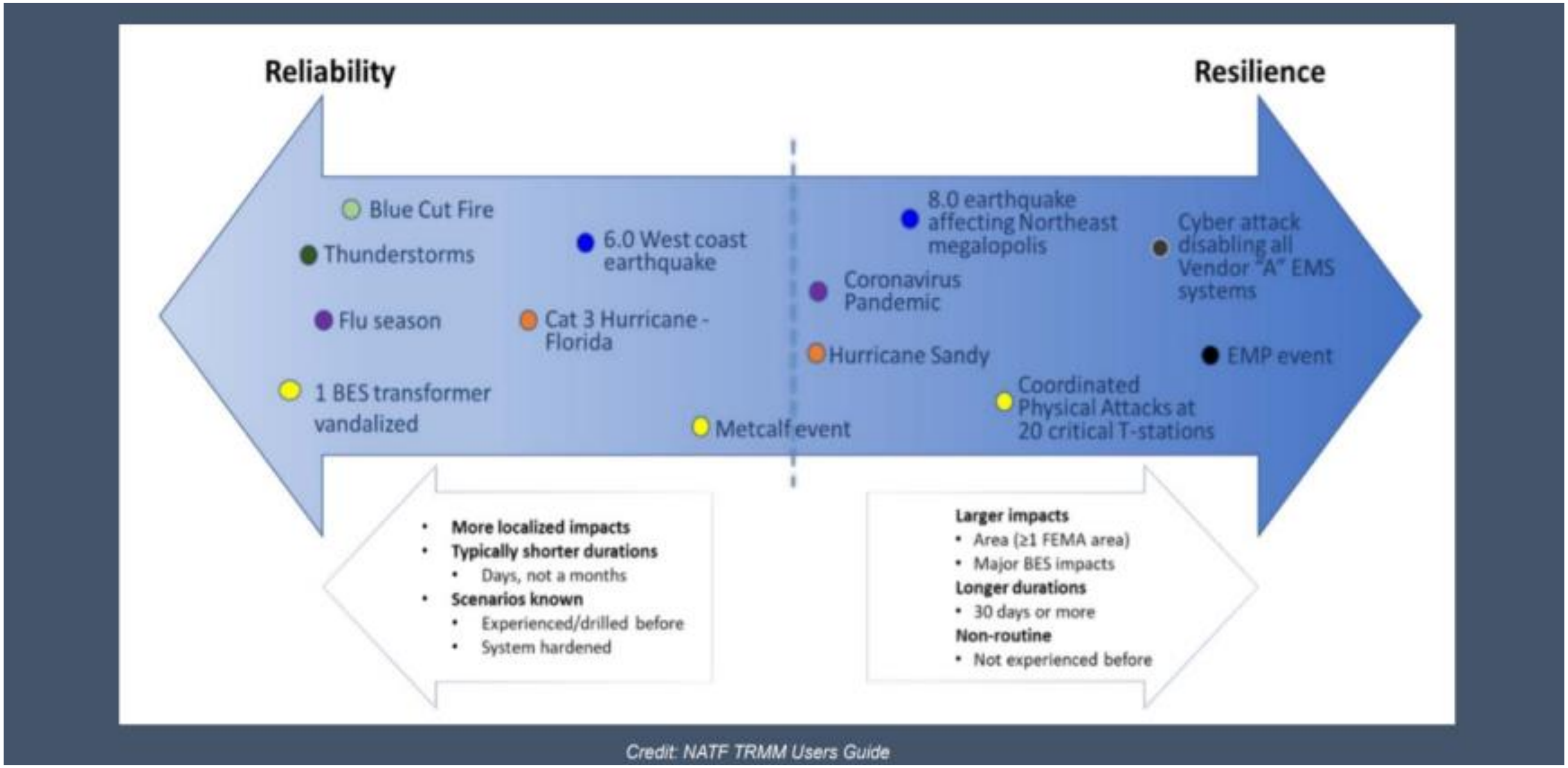


FIGURE 3.1 Mapping of events that can cause disruption of power systems. The horizontal placement provides some indication of how much warning time there may be before the event. The vertical axis provides some indication of how long it may take to recover after the event. Lines provide a representation

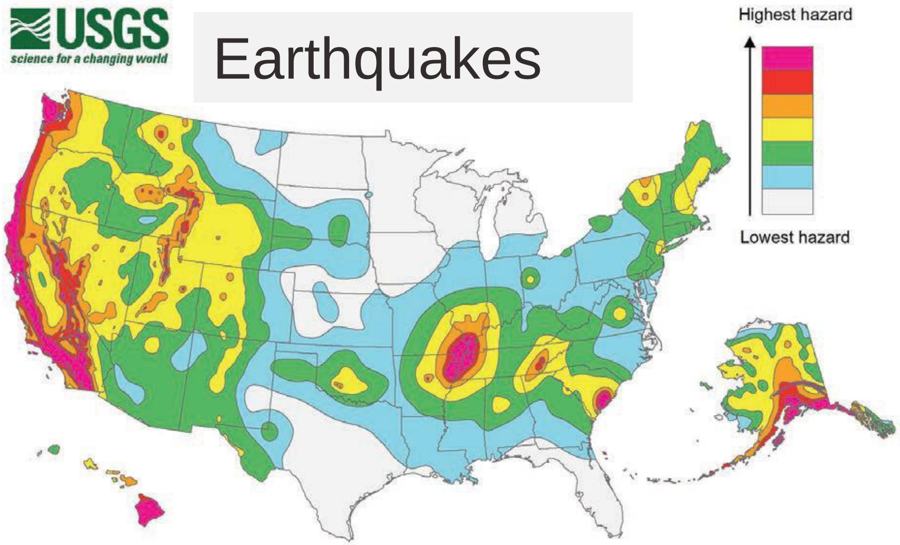
Electric Grid
Reliability – Resilience Continuum



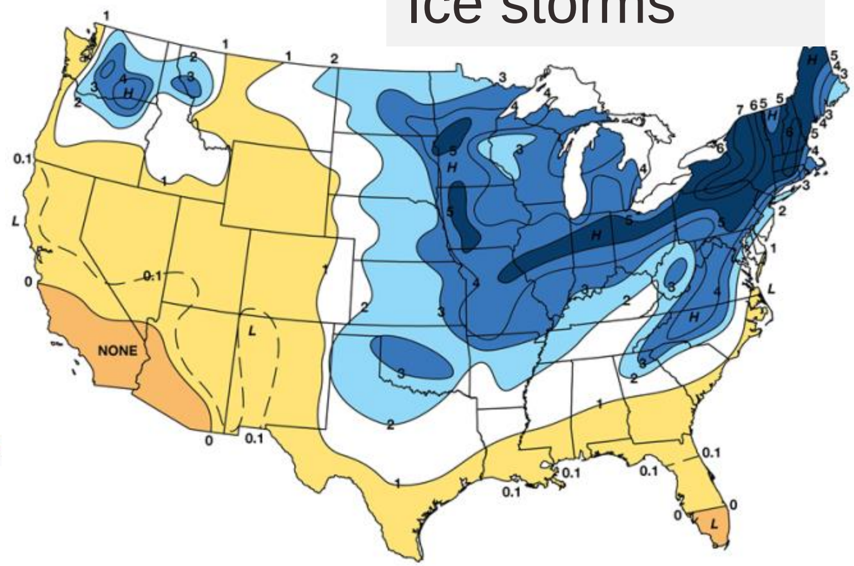
Slide is from the 53rd North American Power Symposium keynote address by Dan Smith of Lower Colorado River Authority, November 2021; credit NATF

Some Electric Grid Risks

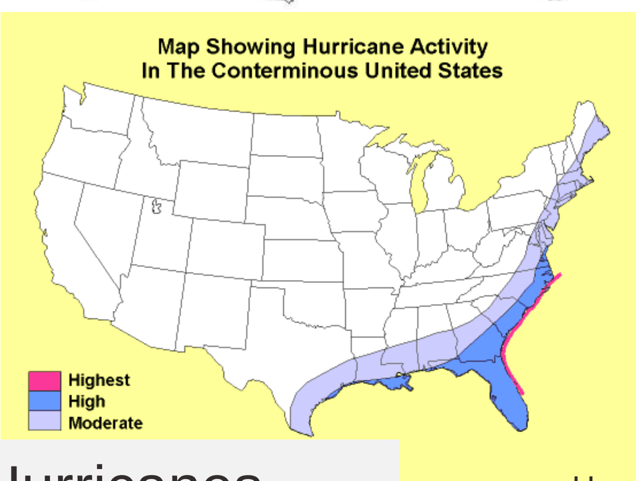
Earthquakes



Ice storms



The average annual number of days with freezing rain, based on 1948-2000 data. *From Changnon and Karl, 2003.*



Hurricanes

And many more! But all need to be considered from a risk/benefit perspective

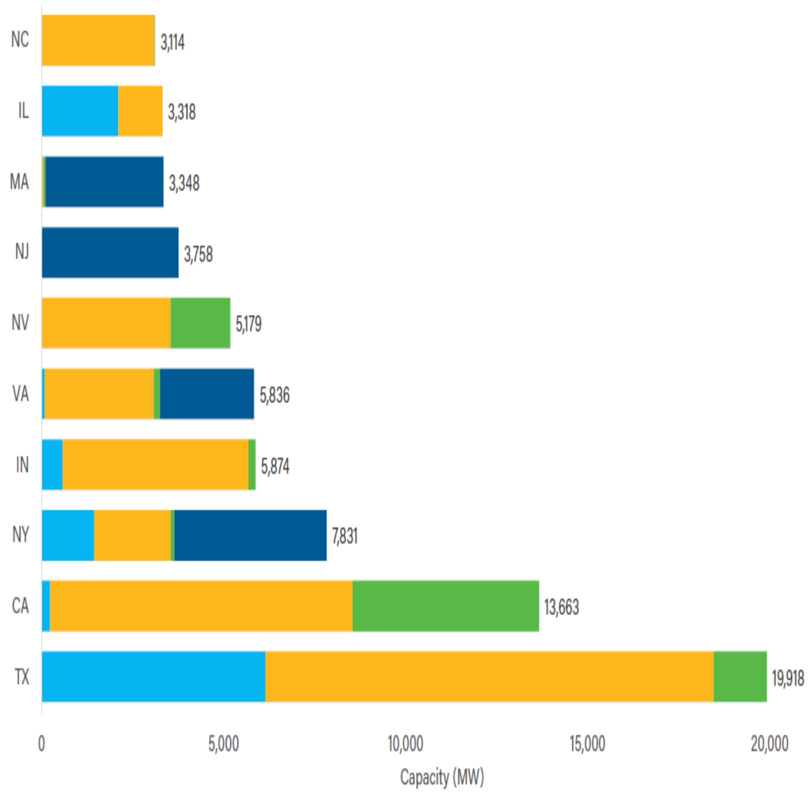
Hurricane risk image source: USGS

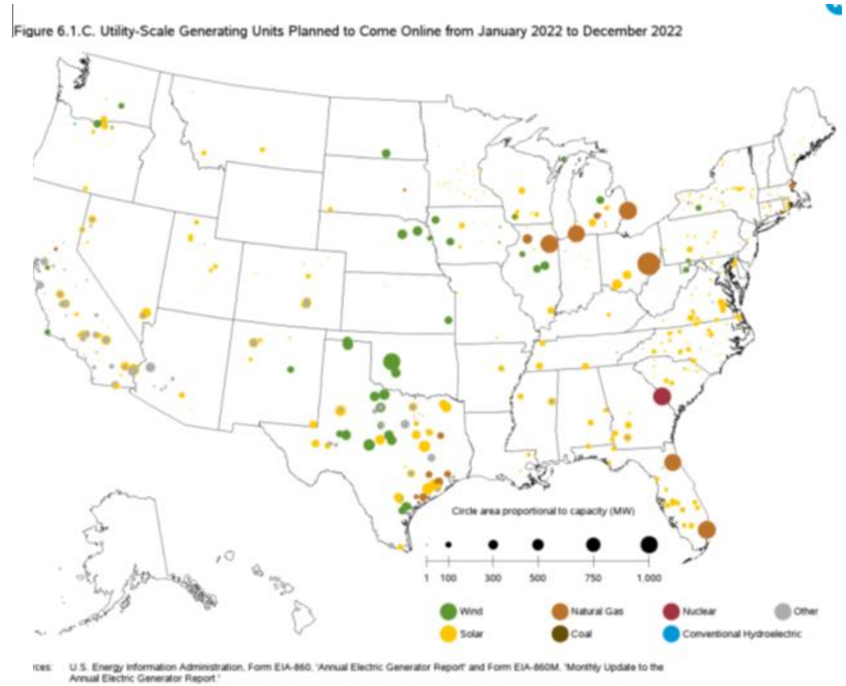
Some Thoughts on the Future Grid

- Overall I think the future is bright, with the key challenge the need to focus on enhancing grid resiliency to severe events
  - The ERCOT grid is strong, with good capacity. Changes has a result of Uri should help with generation reliability
- The electric load is likely to increase with one major driver being the electrification of transportation; cryptocurrency (bitcoin) miners could also significantly increase the load
  - The Texas population is also growing
- New generation will mostly be wind and solar, with storage helping to address intermittency issues

Generator Additions in the Pipeline

- Graph on left shows new renewable generation by state; image on right shows 2022 additions





Other good references are at www.ercot.com/gridinfo/planning

Image sources: Clean Power Quarterly and EIA Electricity Monthly

Some Thoughts on the Future Grid, cont.

- Some of the opportunities and challenges are particularly acute in Texas
  - We're a large, geographically diverse state with (mostly) our own electric grid
  - Having our own grid has given us many advantages and should continual to do so, but it does require having exceptional electric grid expertise within the state
- My major concerns are associated with our resiliency to high-impact, low-frequency (HILF) events
- Future grid changes need to be considered from a cost-benefit point of view
  - we can't prevent all blackouts, but we need to mitigate the effects of severe HILF events

Some Thoughts on the Future Grid, cont.

- The future is uncertain, but we know we'll need a strong and resilient electric grid
- So we need to do the research and develop to "future proof" our electric grid
  - So regardless of what the future holds we'll be prepared
  - We need to simulate a variety of futures to determine hidden modes of failure before they occur
  - Electric grid analysis tools need to be designed to handle severe events, allowing events to be simulated and appropriate mitigation plans to be developed
    - What would we do if "?" Example, if temperatures in College Station went to -3°F (like in 1949)?

Thank you and Questions