ECEN 460
Power System Operation and Control
Spring 2025

Lecture 1: Overview

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TEXAS A&M UNIVERSITY

Welcome and Course Mechanics

- In Spring 2025 ECEN 460 is offered with lectures in Zach 241 on Mondays and Wednesdays from 5:45 to 7 pm
  - There are also six two hour lab sections meeting in Zach 326, with 16 students each: 501 on Wed 8 to 950 am, 502 Fri 11:10 to 1pm, 503 Fri 1:30 to 3:20 pm, 504 Friday 4:10 to 6pm, 505 Wed 11:10 to 1 pm, and 506 Wed 1:30 to 3:20 pm
- The course has a public website as well as a private Canvas website
  - We'll post all material on Canvas; all should be able to login to Canvas at canvas.tamu.edu (also from lms.tamu.edu)
  - Slides will be available on Canvas before each lecture, with often updated slides posted after the lecture
  - Much of the material will be on the public website, included the ppts of the lectures

Syllabus Material

- The syllabus is posted in several locations, including Canvas, Howdy and on the public website
- The public website is
  - overbye.engr.tamu.edu/course-2/ecen460sp25/
    - Slides from the last time I taught the class (2017) are at overbye.engr.tamu.edu/course-2/ecen460fa2017/
- Canvas access (TAMU students only) is lms.tamu.edu
- The assumed background is knowledge of TAMU ECEN 214 material with 340 helpful
- Course staff is Prof. Tom Overbye and three TAs: Nicole Logiudice (lead) (502 and 505), Lyric Haylow (501, 506), and Brian Lee (503, 504)
  - Contact information is on the syllabus (TAMU only)

Syllabus Material, cont.

- The course will have homework (seldom graded), a project, labs, and two in class exams
  - Final grade is based 30% from the first exam, 30% from the second exam, 25% from the lab, and 15% homework and the project
  - Your two lowest lab scores will be dropped, but this does not apply to lab 11 (associated with the project)
  - In class exams are on March 5 and April 23; final exam date is Thursday May 1 from 7:30 to 9:30 am; there will not be a final exam, but the final project is due on May 1.
  - All grading in the course is based on a percentage, with final grades determined based on this percentage. If your final average falls within the below ranges you are guaranteed to receive at least the letter grad indicated: A: 90-100; B: 80-89; C: 70-79; D: 60-69; F: 59 or lower
- Last day of class for 460 is Monday April 28

Course Text and Slides

- The course text is Glover, Overbye, Birchfield and Sarma, *Power System Analysis and Design 7th Edition*, Cengage Learning, 2023 (ISBN-13: 978-0357676189)
- Much of the Course Material will be presented via PowerPoint Slides
- Prior to each lecture the draft slides will be available in Canvas
- After each lecture an updated version of the slides will be posted in Canvas
  - Usually modified based on the number of slides we actually covered
- Student questions are greatly encouraged!

Course Topics

- Introduction and review of phasors & three-phase
- Transmission line and transformer modeling
- Models for generators, and loads
- Power flow analysis and control
- Economic system operation, optimal power flow, power markets
- Power system stability, oscillations and control
- Renewable generation including weather impacts modelings
- Transients
- Emerging topics

Contrasting ECEN 459 and 460

- ECEN 459 (Power System Faculty Analysis and Projection) is not required for ECEN 460; they are two independent, complimentary courses that cover different aspects of electric power system analysis and design
- ECEN 459, last taught in Fall 2024 by Dr. Butler-Purry, covers mostly detailed modeling of transmission lines, transformers, faults (both symmetric and unsymmetric), and power system protection
  - Book chapters 1-5, 8, 10 and 11
- ECEN 460 uses some of the models developed in 459 without going into the details of their derivation
- The overlap is mostly associated with three-phase system modeling, per unit, and a little bit on the formation of the bus admittance matrix

About Me: Professional

- Received BSEE, MSEE, and Ph.D. from UW-Madison
- Worked for eight years as engineer for Madison Gas & Electric
- Was at UIUC from 1991 to 2016, doing teaching and doing research in the area of electric power systems
- Joined TAMU in January 2017; Taught many power systems classes over last 34 years, including 460 material at least 12 times
- Developed commercial power system analysis package, known now as PowerWorld Simulator. This package has been sold to about 1000 different corporate entities worldwide
- DOE investigator for 8/14/2003 blackout
- Member US National Academy of Engineering; now Section 6 Chair

About Me: TAMU Research Group

TAMU Energy and Power Group Fall 2024 Dinner

Held at Dr. Davis's house in September

About Me: Nonprofessional

- Married to Jo; and have three children: Tim (now with Megan), Hannah (now with Will) and Amanda
- We homeschooled our kids with Tim now a 2023 TAMU alumni (PhD) working for ARL, Hannah doing a PhD at UCSB in communications, and Amanda also at UCSB doing a Master's in Environmental Data Science
- Jo is a counselor (LPC), we attend Grace Bible Church in College Station and teach 4th graders class (Creekside)
- I am the faculty advisor for Christian Engineering Leaders; I also like swimming, watching football

Announcements

- Please read Chapters 1, 2
- Labs will start next week (January 22 or 24)
- Of course, no class next Monday (January 20) because of the campus holiday

ECEN 460 Motivation: A Vision for a Long-Term Sustainable Electric Future

- Electric grids worldwide 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 impact of artificial intelligence is a big unknown (both its application and high electricity use)
- Our electric energy future should be quite bright
- However, there are lots of concerns with this transition, particularly in dealing with electric grid resilience
  - The result is there are lots of great engineering challenges, and lots of need for new engineers to enter the field!
- The goal of 460 is to help develop future electric power engineers
  - Its focus on design and operation of large-scale electric grids will help even if you do not get a job directly in the power engineering field

Power System Examples

- Electric utility: can range from quite small, such as an island, to one covering half the continent
  - there are four major interconnected ac power systems in North American, each operating at 60 Hz ac; 50 Hz is used in some other countries.
- Microgrids can power smaller areas (like a campus) and can be optionally connected to the main grid
- Airplanes and Spaceships: reduction in weight is primary consideration; frequency is 400 Hz.
- Ships and submarines
- Automobiles: dc 12 V standard; 360-376 V for electric
- Battery operated portable systems

Electric Grid Overview

- Generation – source of electric energy
  - Coal had provided over half of the U.S. electric energy, but now natural gas leads, with renewable sources rapidly growing
- Load – consumes electric energy
  - Consumers are in complete control of the switch; utilities must supply enough power to meet load
- Transmission and Distribution – the wires that carry the power from generation to load
  - Operating at voltages up to 765 kV (kilovolt), with 500 kV, 345 kV, 230 kV 161 kV and 138 kV common

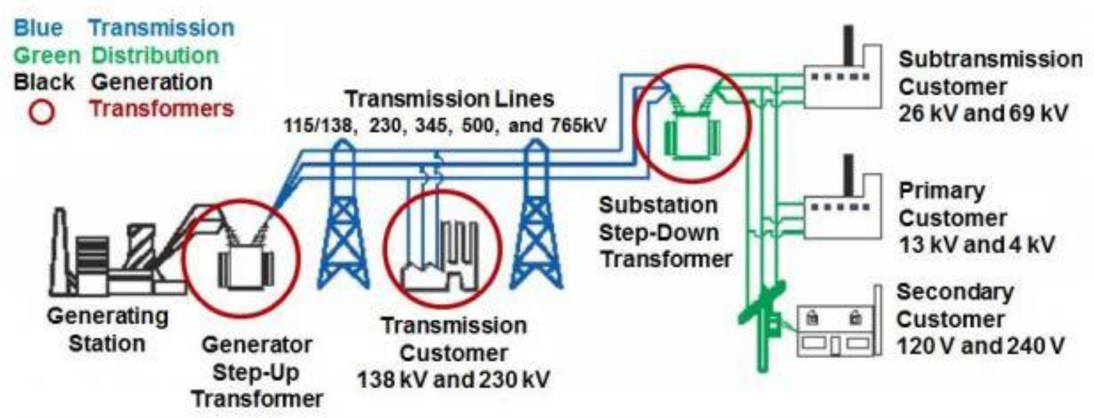


Image source is US DOE, www.energy.gov/indianenergy/articles/united-states-electricity-industry-primer

Power and Energy

- Power is the instantaneous transfer of energy; expressed in watts (W), kW, MW, GW
  - US installed generation capacity is about 1000 GW
- Energy is the integration of power over time; expressed in units of joules (J = 1 W-sec), kWh (3.6 x 10^6 J), or btu (1055 J; 1 Mbtu = 0.292 MWh)
- U.S. electric energy consumption is about 4350 billion kWh (about 13,000 kWh per person; 1.4 kW continuous per person on average)
- For many people the word “energy” has better connotations compared to power; in 2008 the IEEE Power Engineering Society (PES) changed its name to the IEEE Power and Energy Society (PES)

Electric Power Engineering: A Great Career!

- A good definition of power engineering is provided by the IEEE PES field of interest:
  - "to develop standards and empower development of technology, software, and best practices in all areas of electric power and energy including generation, transmission, distribution and utilization to provide a reliable, resilient, safe, cost-effective and sustainable AC and DC electricity supply system to the end-user"
- A nice aspect of electric power engineering is its breadth ("all areas") since the focus is on providing reliable, resilient, safe cost effective, and sustainable electricity to people
- Since electricity touches most aspects of human society, electric power engineering does as well

Three-Phase Systems

- Essentially all large-scale electric grids are three-phase
  - Three wires, with the same voltage magnitude and a phase shift of 120 degrees
- Usually the high voltage electric grid is "balanced,"
  - This means that it can be very well modeled as an equivalent single-phase system
  - The three-phase lines are often shown with a single line, what is known as a oneline

Synchronous Electric Grids

- Much of the electricity in the developed world is supplied by large-scale, 60 or 50 Hz synchronous electric grids
  - Such grids can provide improved reliability, larger electricity markets and often economics of scale
  - However, they add planning complexities
  - Power can be transferred between synchronous grids by first converting it to dc, with HVDC lines one example
- Islands, and other parts of the world are supplied by smaller electric grids

Large-Scale Electric Grid Interconnections

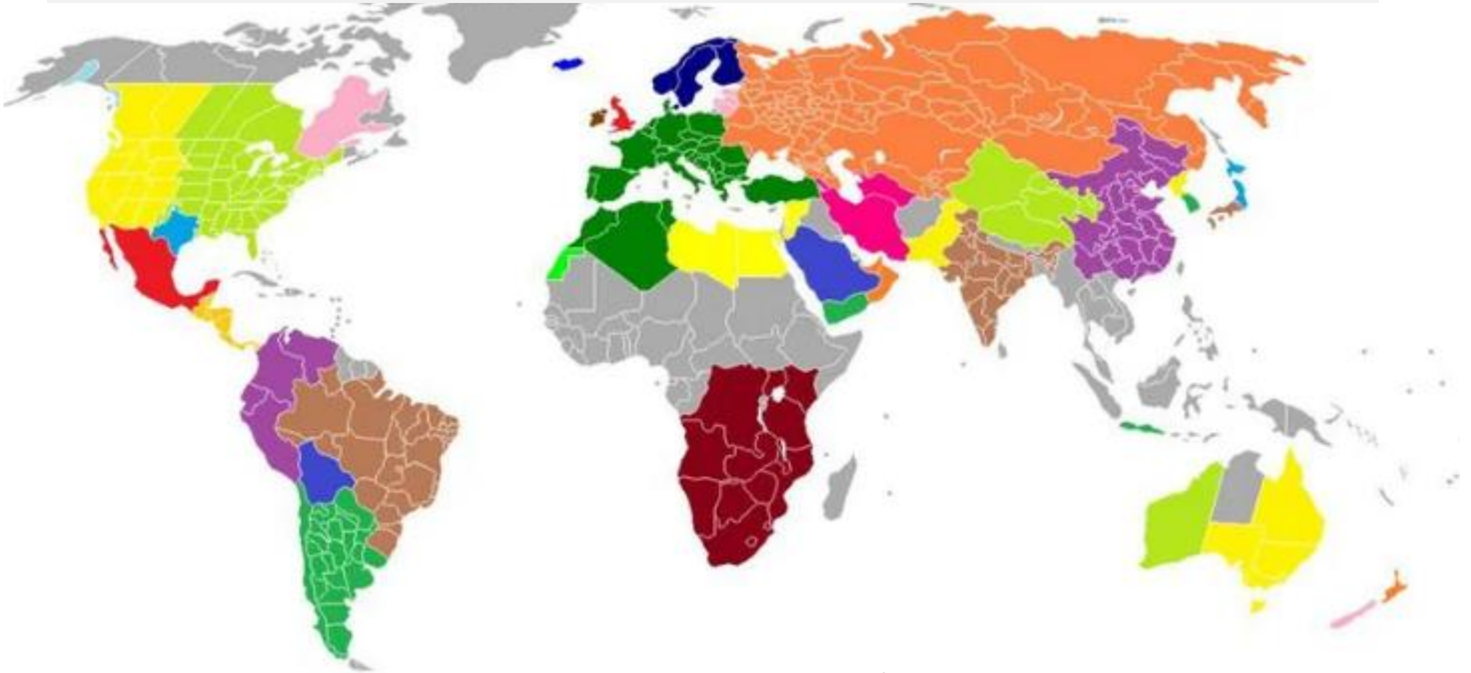
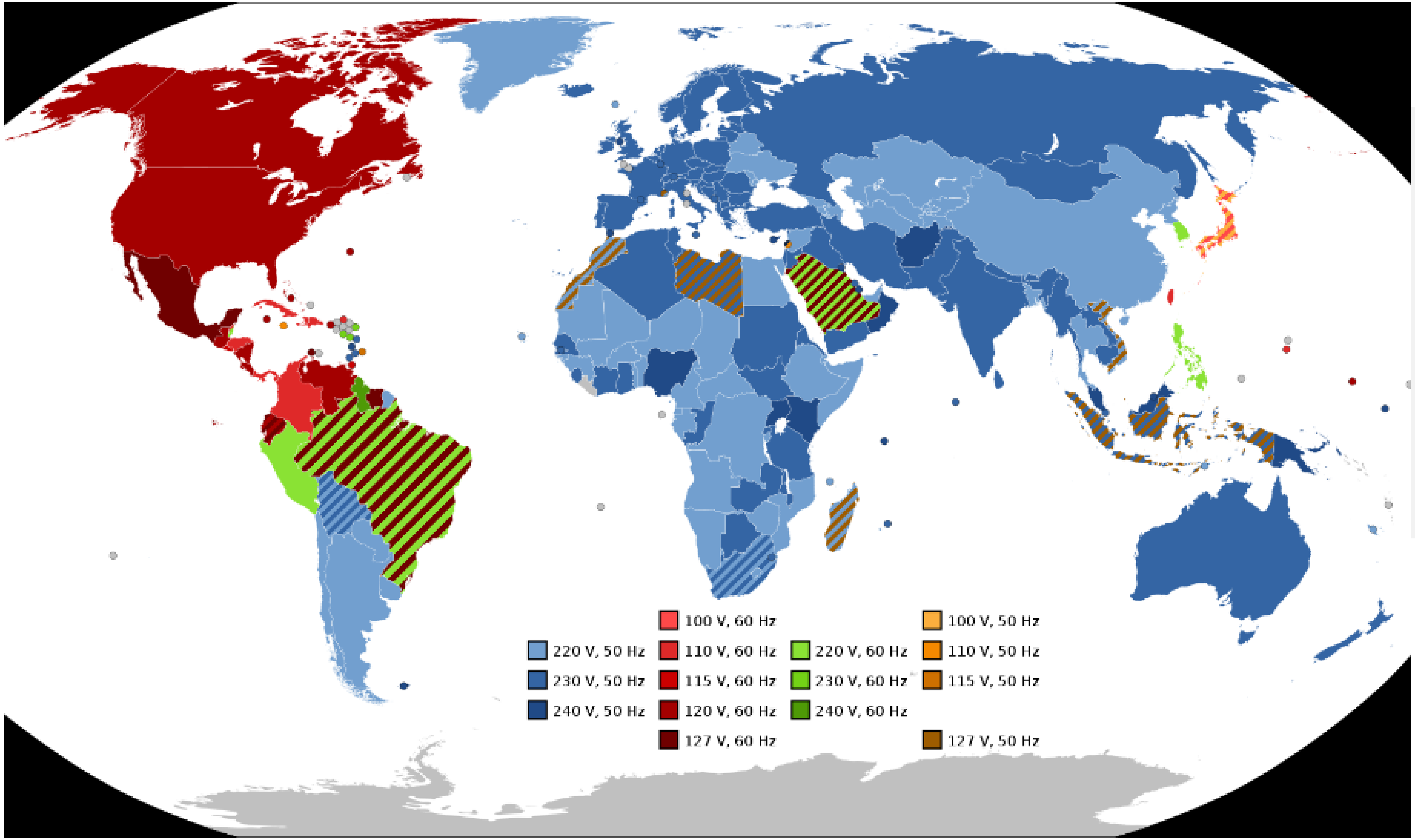


Image Source: i.redd.it/krkhdfslrjh61.jpg

Electric Frequencies and Residential Voltages Worldwide



In the US the supplied residential voltage should be 120 V, with a 5% range allowed

Image Source: en.wikipedia.org/wiki/Mains_electricity_by_country#/media/File:World_Map_of_Mains_Voltages_and_Frequencies,_Detailed.svg

North America Interconnections

The term US includes all 50 states and other areas like DC and Puerto Rico; the continental US includes only the parts of the US in North America (49 states plus DC), the contiguous US (or CONUS) is the 48 connected states plus DC; OCONUS is everything outside of CONUS

All Three US Grids Are 60 Hz, But Are Not Usually At the Same Value

- Images show the frequency during the 2022 Super Bowl (2/13/22)

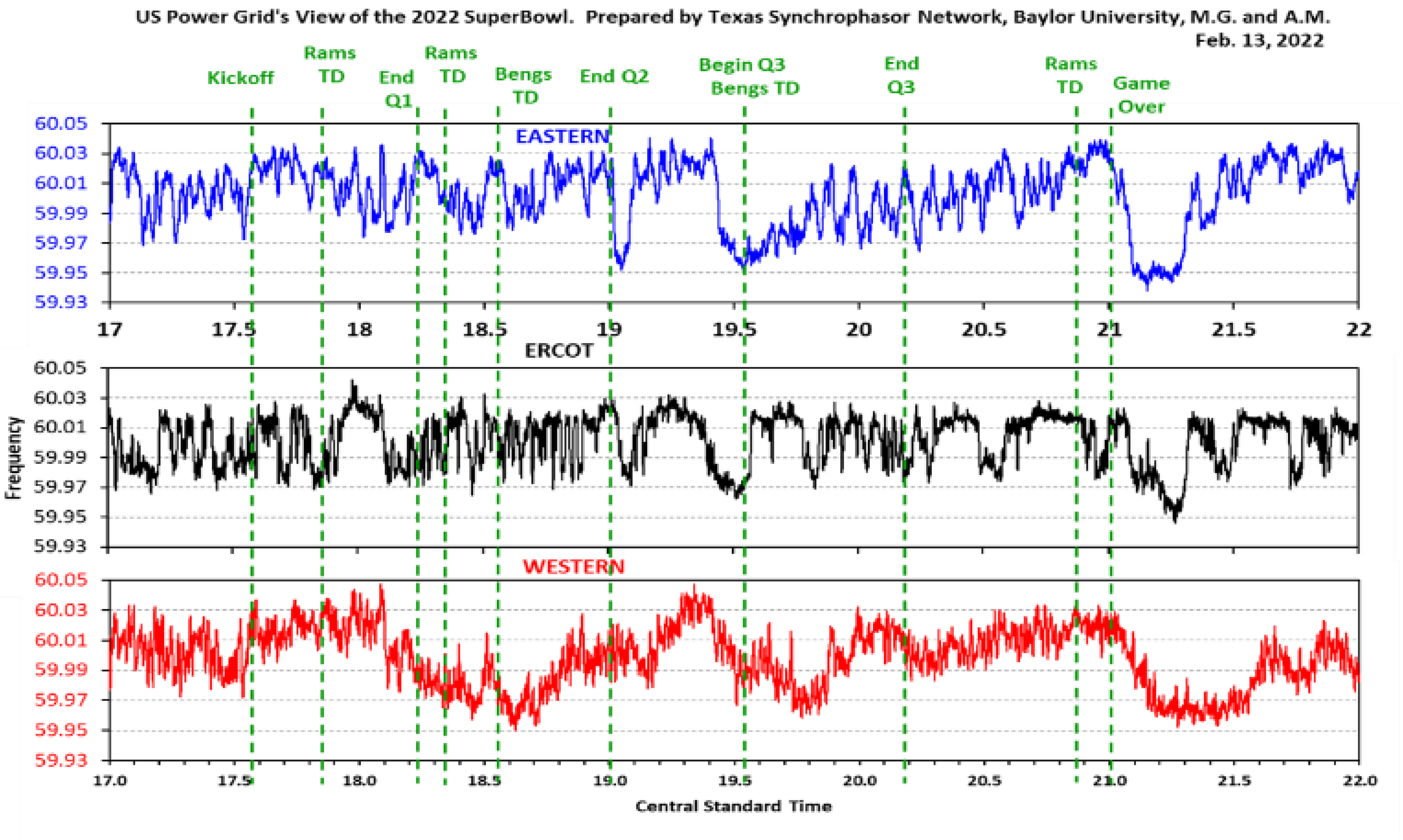
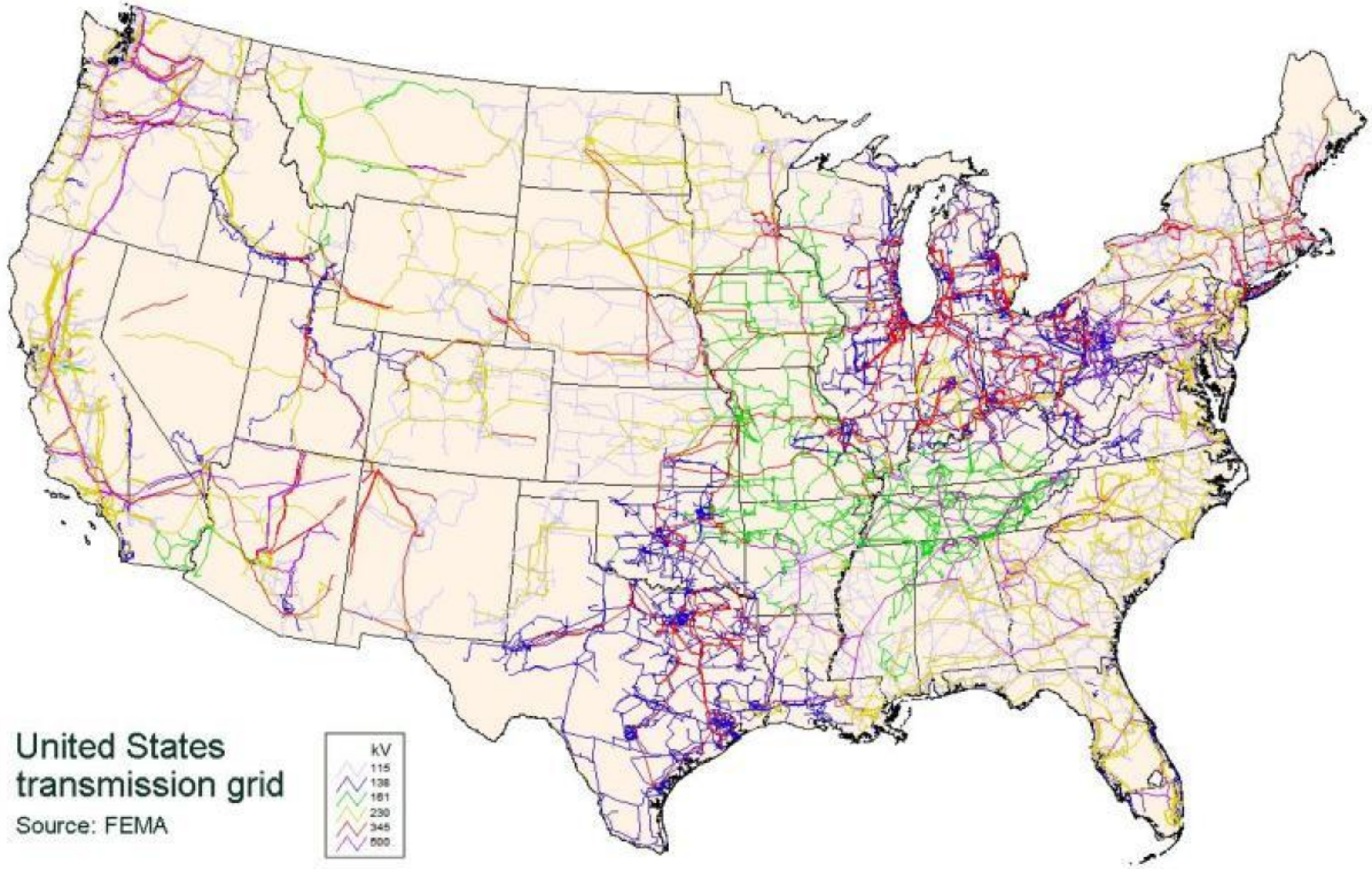


Image from Prof. Mack Grady of Baylor University

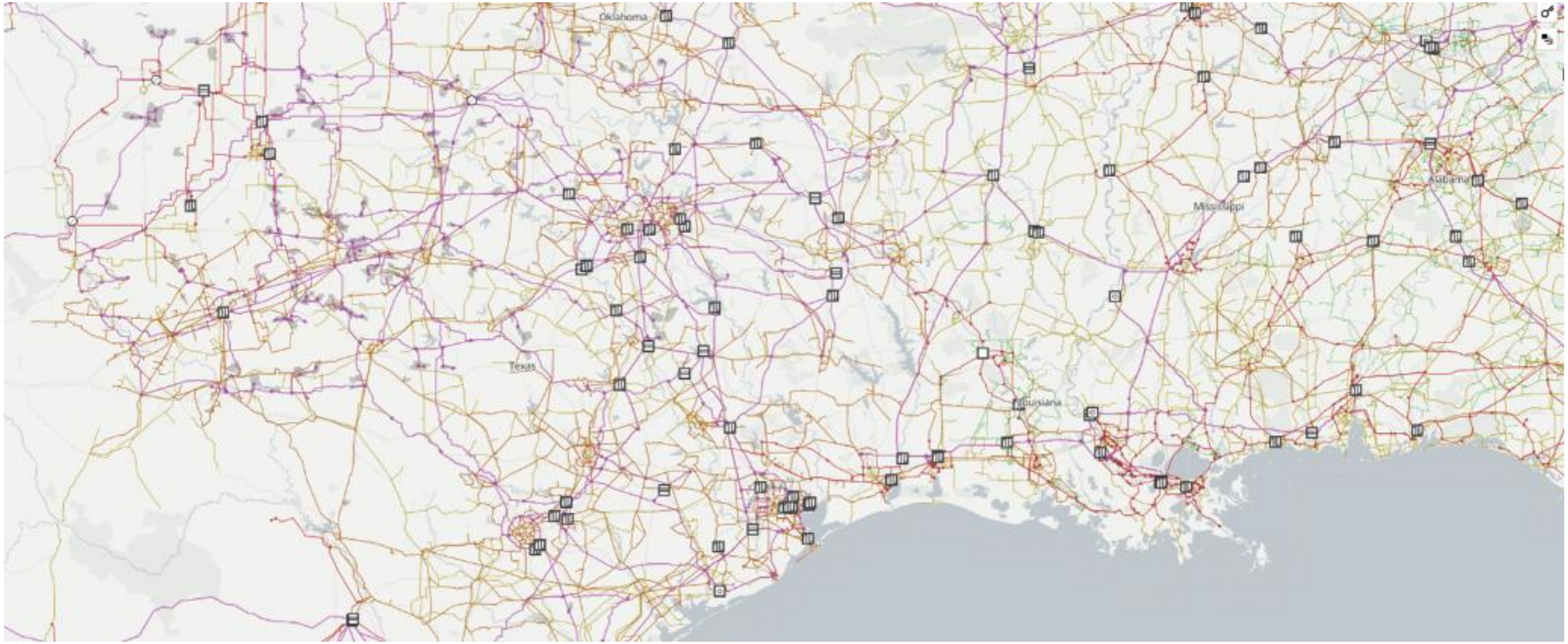
CONUS Transmission Grid



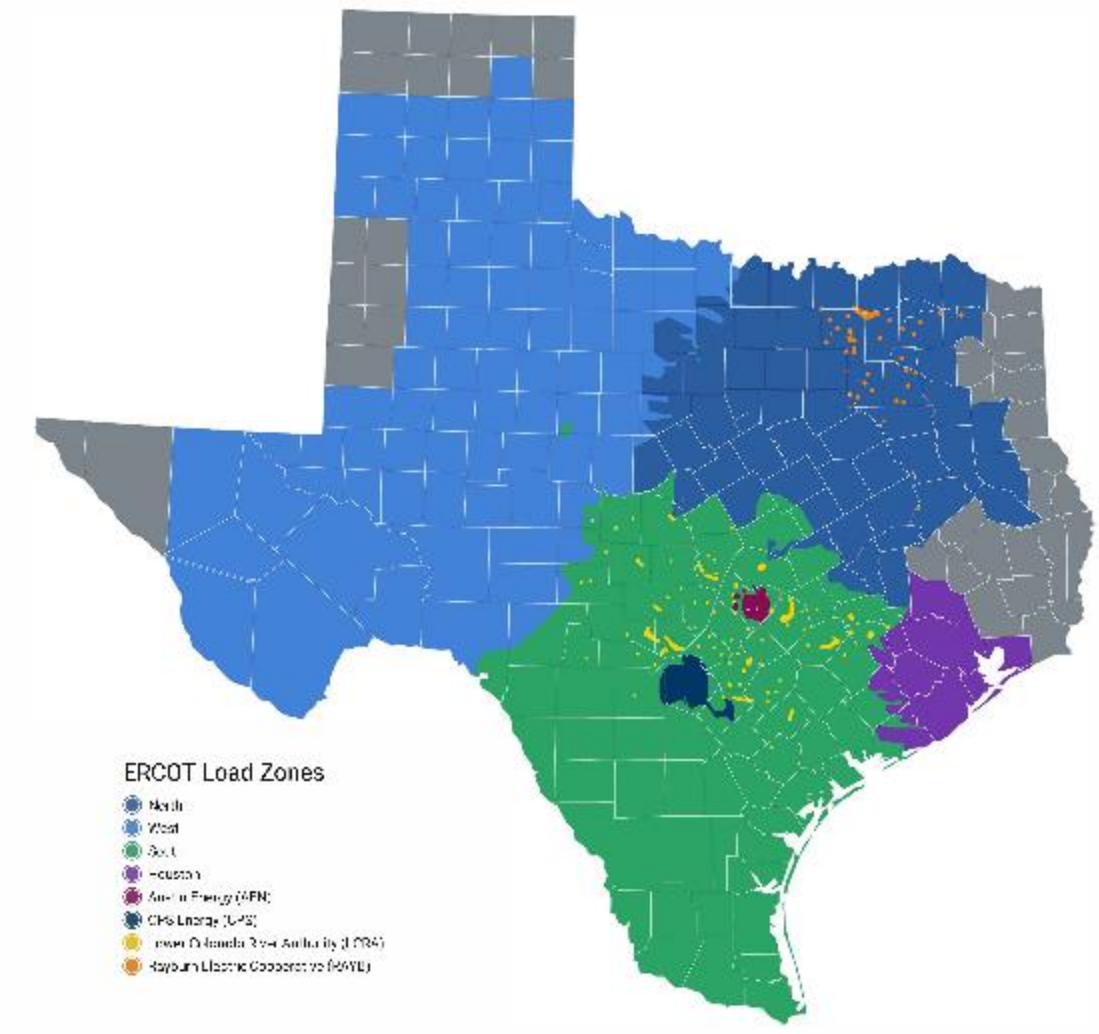
The CONUS Grid is interconnected with Canada and parts of Mexico

A Nice Visualization of Worldwide Electric Grids

The website **openinframap.org** visualizes the worldwide electric grid information contained in the OpenStreetMap database



Electric Interconnections in Texas

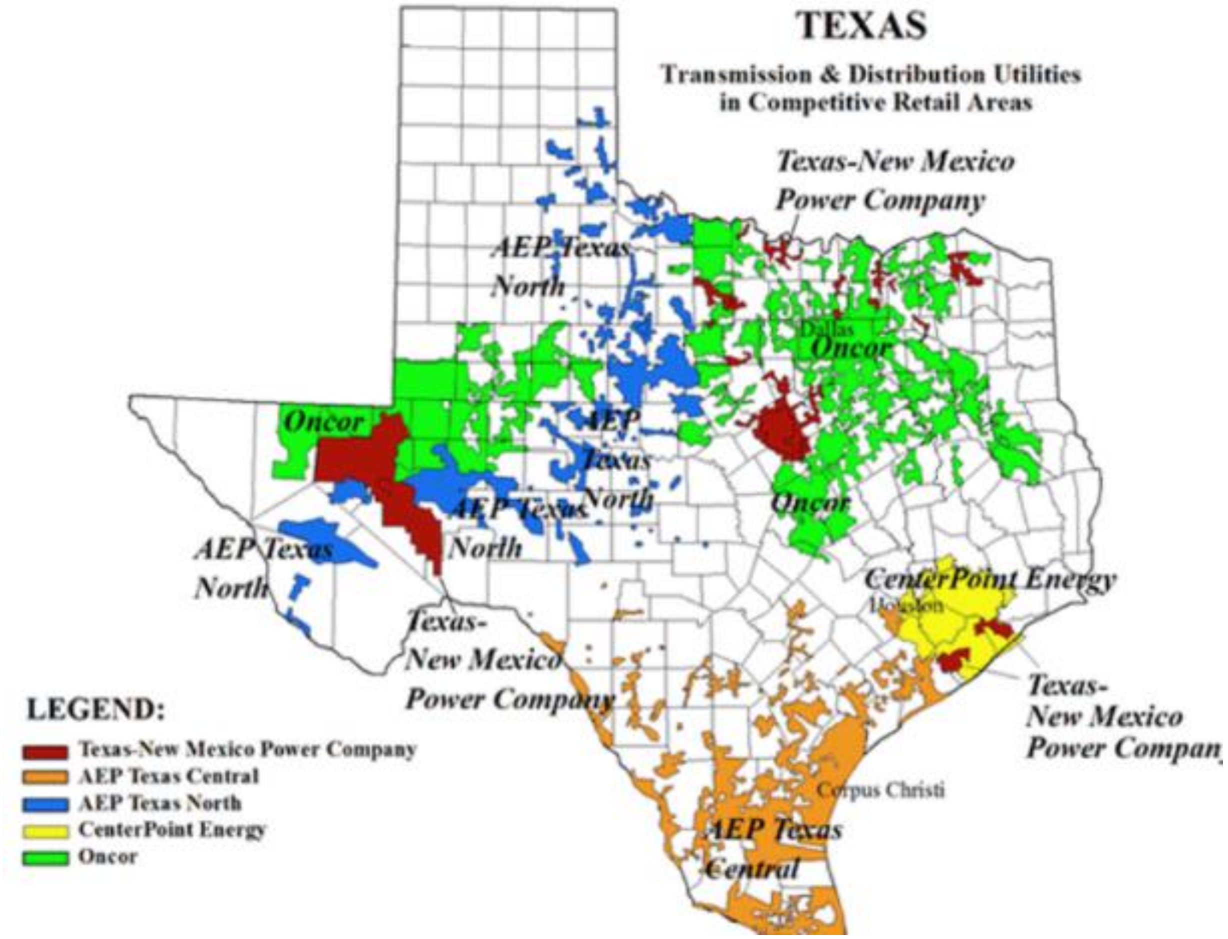


Source: www.ercot.com/news/mediakit/maps

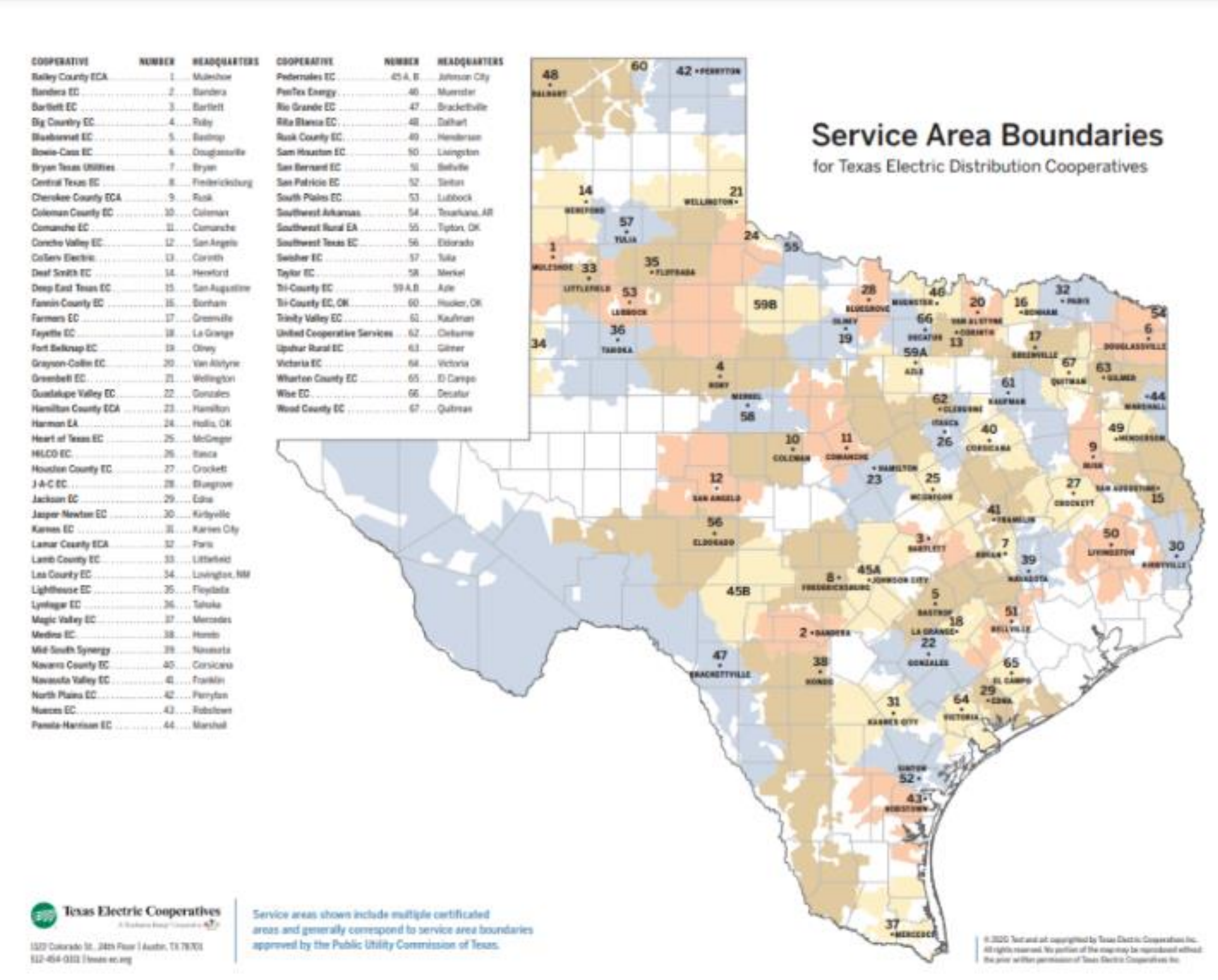
El Paso is in the Western Interconnect (WECC) and parts of North and East Texas are in the Eastern Interconnect (EI) (with the boundaries in the image just approximate)

Lubbock Power and Light customers joined ERCOT in May 2021

Electric Utilities in Texas (IOUs and Municipals)



Electric Utilities in Texas (Coops)



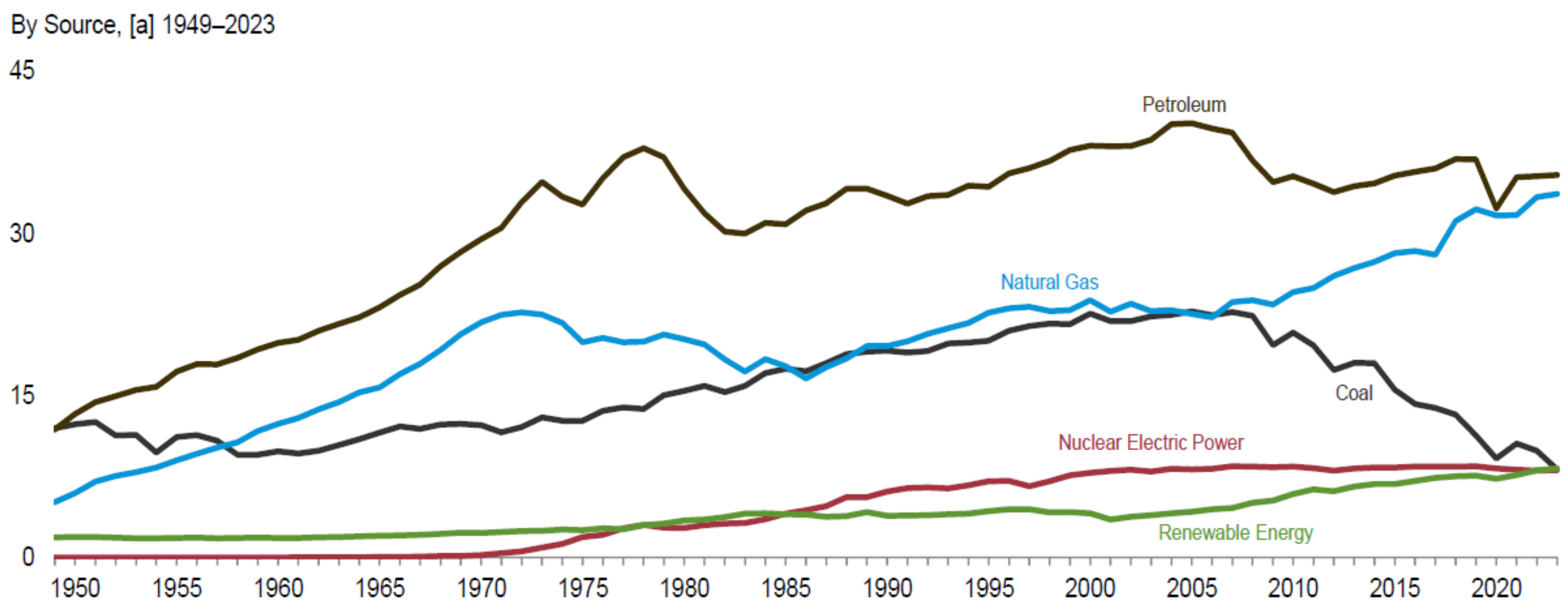
Electric Systems in an Energy Context

- Class focuses on electric power systems, but we first need to put the electric system in context of the total energy delivery system
- Electricity is used primarily as a means for energy transportation
  - Use other sources of energy to create it, and it is usually converted into another form of energy when used
- About 40% of US energy is transported in electric form
- Concerns about need to reduce CO2 emissions and potential fossil fuel depletion are main drivers for change in world energy infrastructure

Looking at the 2023 Energy Pie: Where the USA Got Its Energy

- The below graph shows the total US energy consumption by source, with one 1 Quad = a quadrillion btu; the total in 2023 was 93.7 quad, which hasn't changed substantially in more than 20 years (2005 was 98 quad)

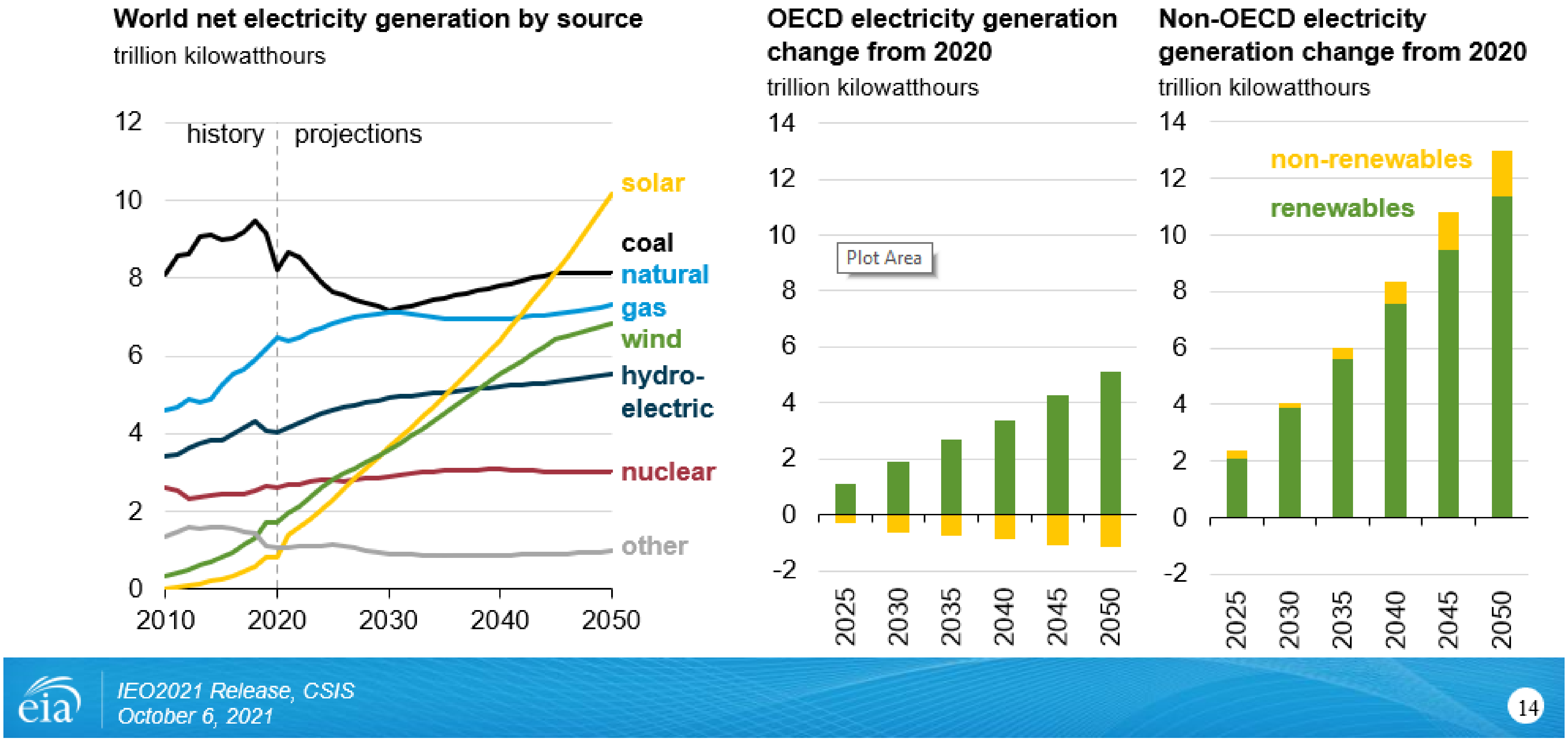
Figure 1.3 Primary Energy Consumption
(Quadrillion Btu)



EIA is the US Energy Information Administration, which is a semi-independent agency under the US Department of Energy (DOE)

Source: EIA Monthly Energy Review, December 2024

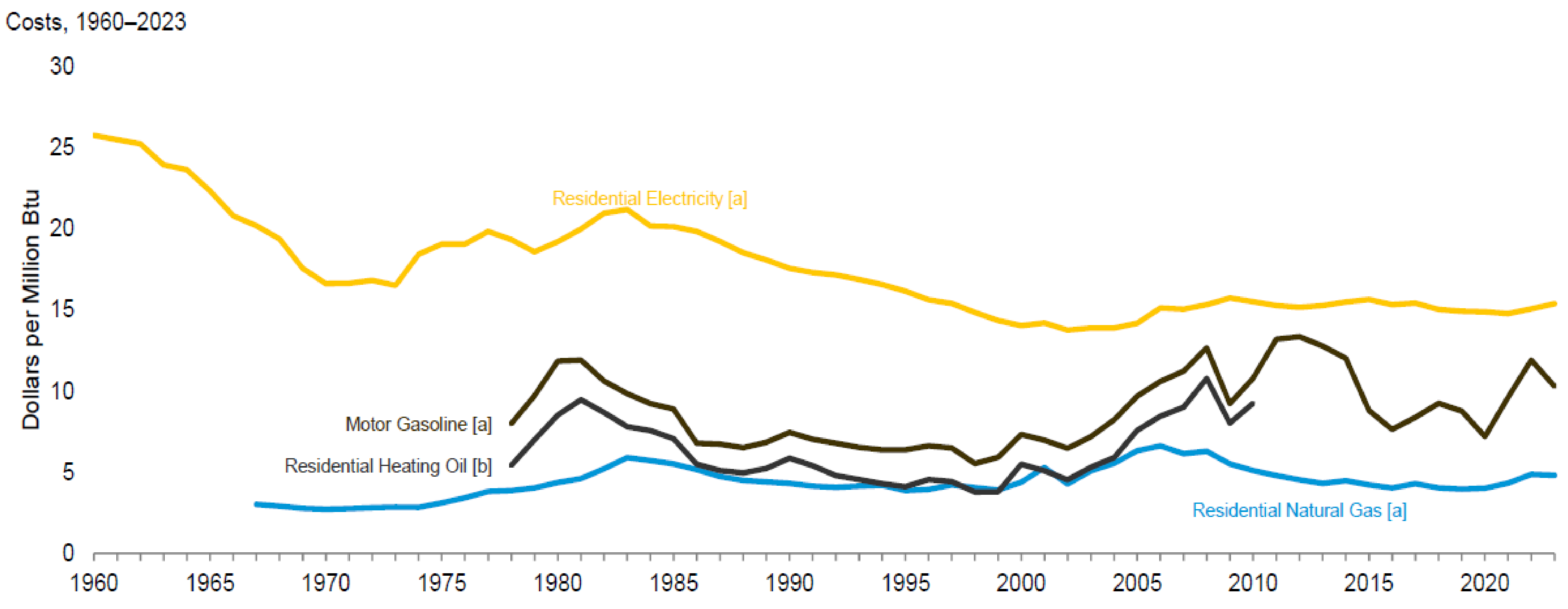
The World: Electricity Consumption by Source



Cost of Energy to the End Users

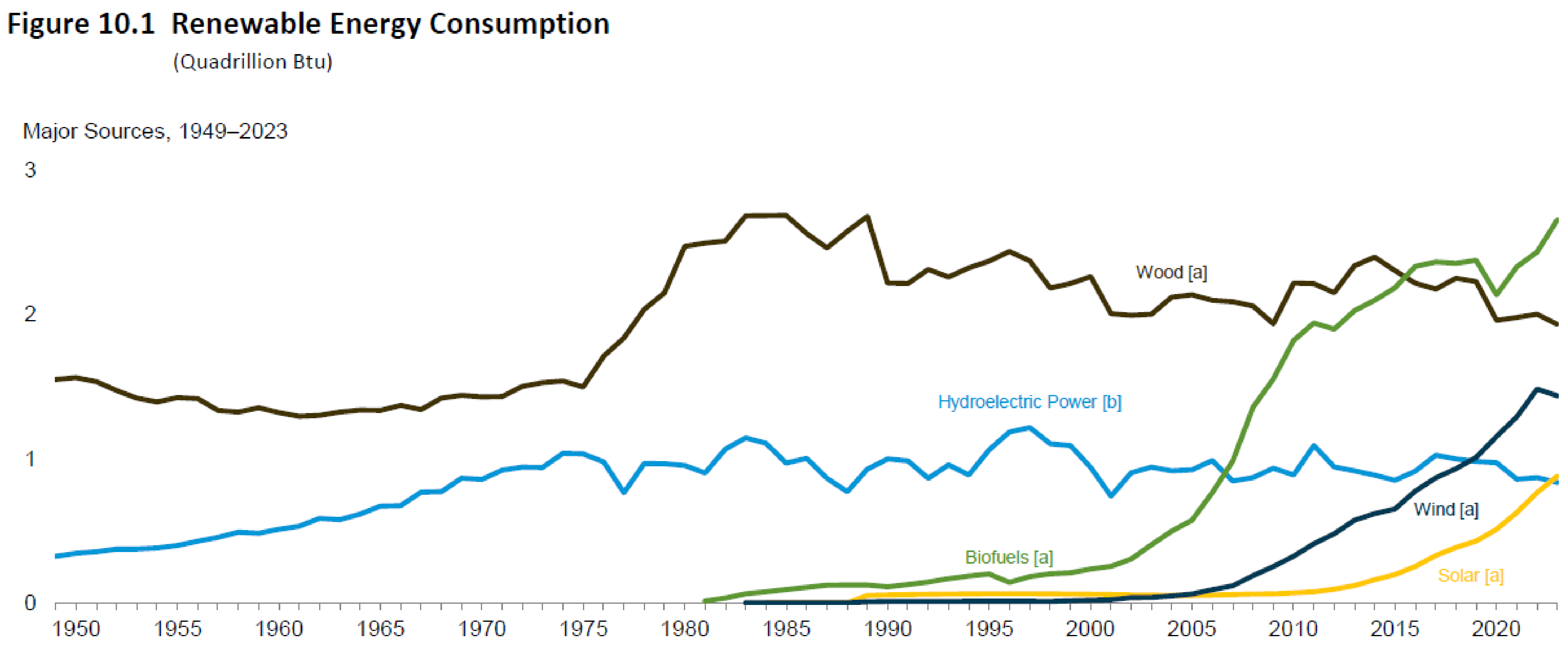
- Overall energy prices have stayed relatively constant over the last 20 years
  - When comparing costs over time the way to remove the impact of inflation is to use dollars adjusted for inflation (constant or real dollars) as opposed to current dollars

Figure 1.6 Cost of Fuels to End Users In Real (1982-1984) Dollars



US Renewable Energy Consumption

- Most of the renewable energy is transported in the form of electricity, with biofuels (e.g., ethanol and biodiesel) the major exceptions

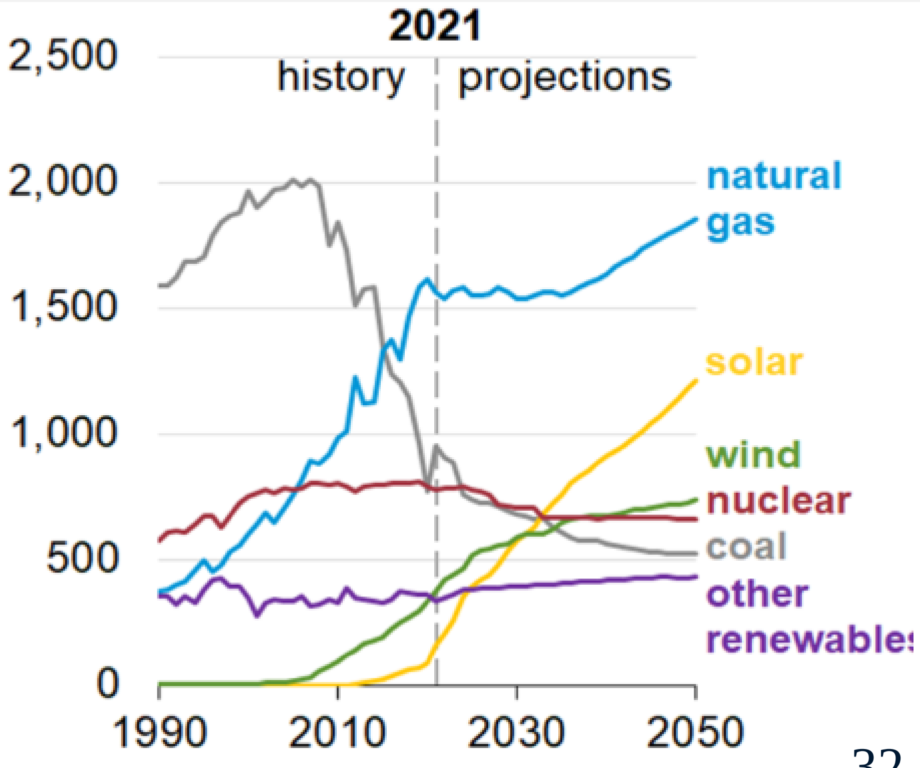


Source: EIA Monthly Energy Review, December 2024

US Electricity Generation

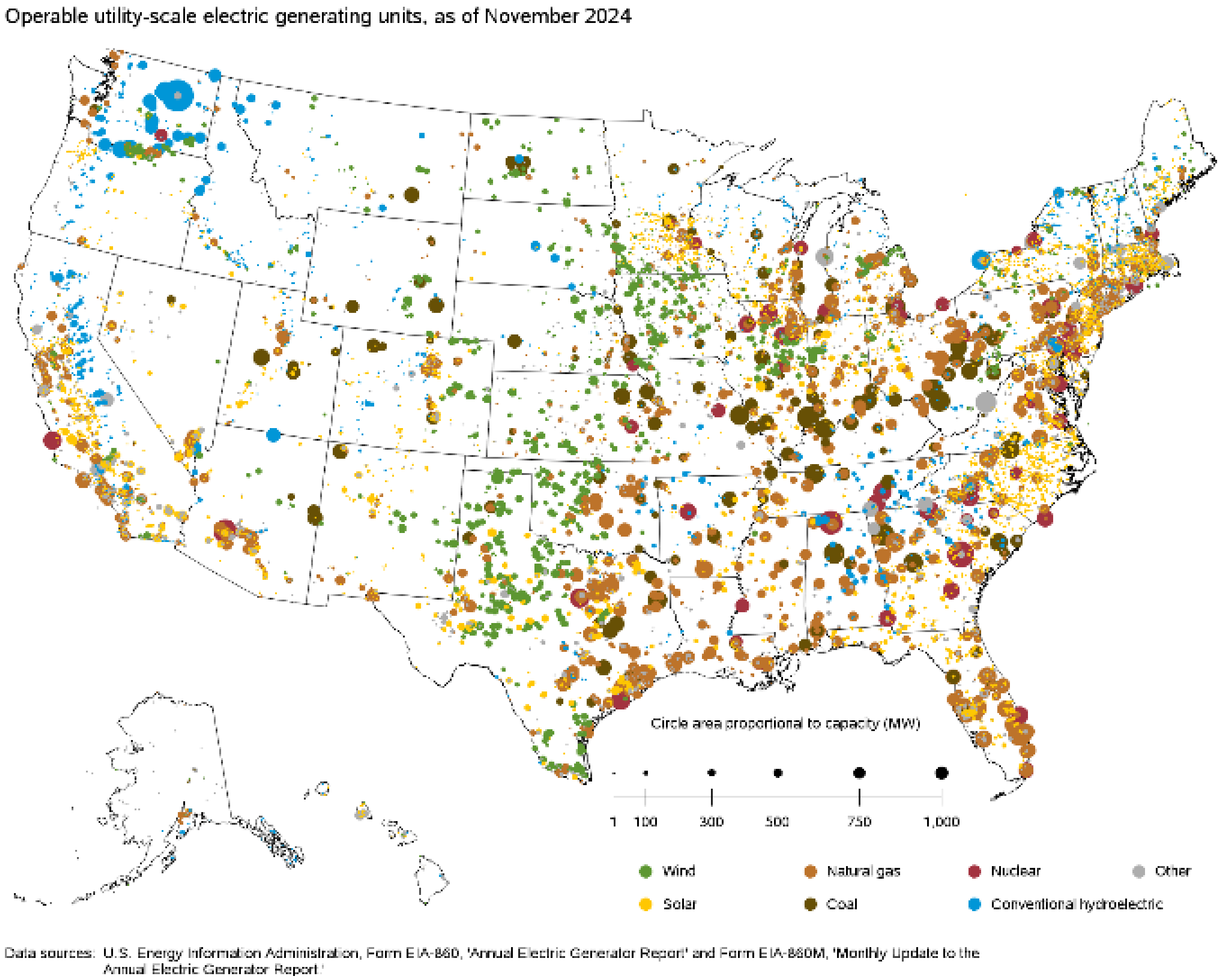
- Natural Gas (42.5%) and nuclear (18.3%) are most common sources, followed by coal (15.8%), wind (10.4), solar (6.3) and hydro (5.6%)
  - Wood is 0.8%, geothermal 0.4%
  - Coal was at least 50% of the total up to 2007
- New construction mostly wind, solar and natural gas (with wind and solar energy costs now quite low)
- When looking at predictions keep in mind the Yogi Berra quote, "It's tough to make predictions, especially about the future"

US Generator Capacity Additions



Sources are by energy (not capacity), source US EIA, August 2024

US Generation (November 2024) by Fuel Type



The sources variety substantially by state

Image Source: www.eia.gov/electricity/data/eia860m/