ECEN 615
Methods of Electric Power Systems Analysis

Lecture 2: Power Systems Overview

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Announcements

- Start reading Chapters 1 to 3 from the book (mostly background material)
- Exam 1 is moved to Oct 13 (Oct 10 and 11 are fall break)
- We'll be using PowerWorld Simulator fairly extensively in this class, both the educational and professional versions
- Download the free 42 bus educational versions of PowerWorld Simulator at https://www.powerworld.com/gloverovebyesarma

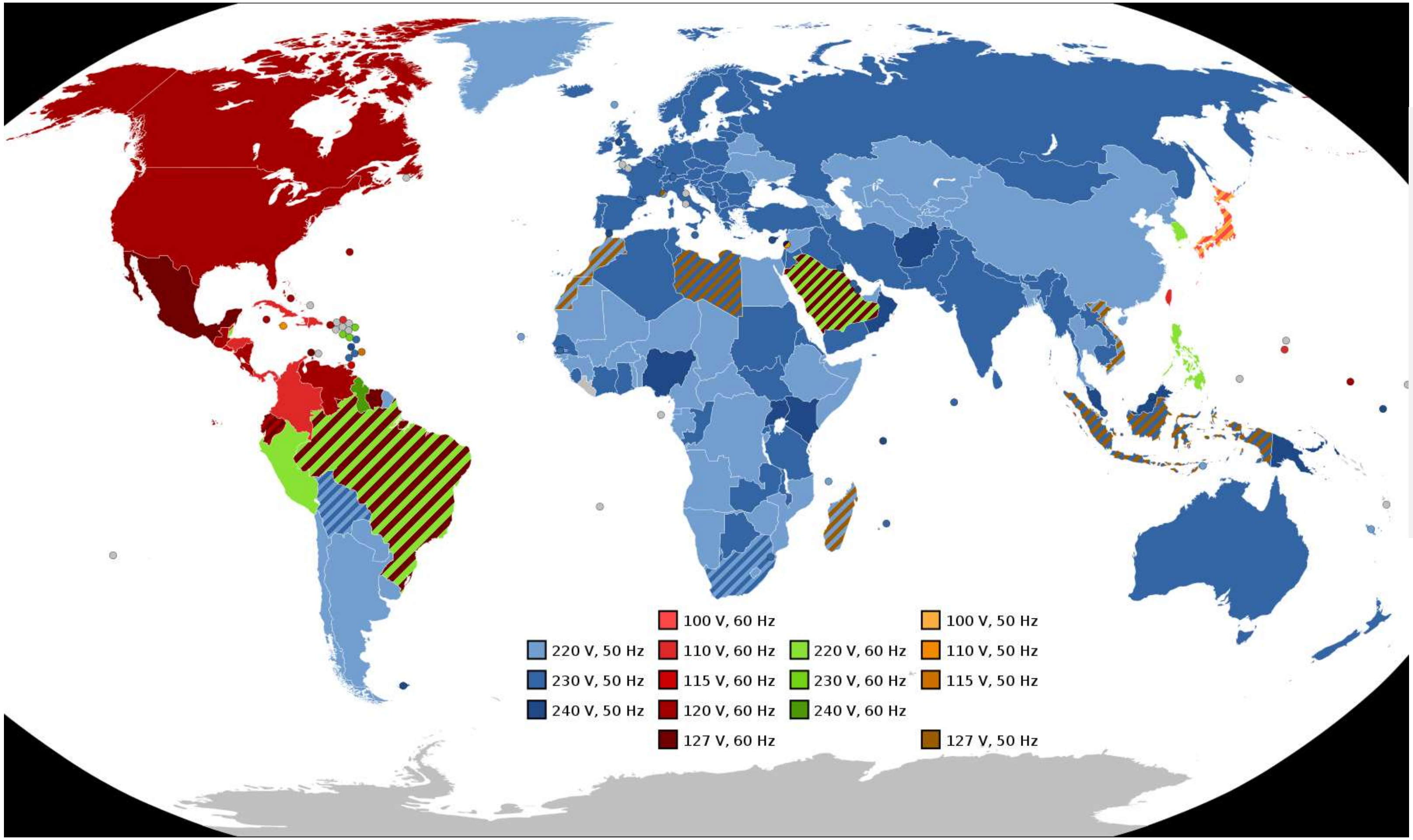
The Technical Literature

- As a graduate student you should get in the habit of reading many technical papers, including all the ones mentioned in these notes
- Papers are divided into 1) journal papers and 2) conference papers, with journal papers usually undergoing more review and of high quality
  - There are LOTs of exceptions
- Key journals in our area are from IEEE Power and Energy Society (PES); PSCC is a top conference
- I read papers by looking at 1) title, 2) abstract, 3) summary, 4) results, 5) intro, 6) the rest; many papers never make it beyond step 1 or 2.
- You should also be reading a variety of books, not use ones directly in the electric power area

Learning to Write Well

- Writing is a key skill for engineers, especially for students with advanced degrees
  - If you write poorly people will ignore your work!
- If you are not currently a good technical writer, use your time at TAMU to learn how to write well!!
- There are lots of good resources available to help you improve your writing. Books I've found helpful are
  - Zinsser, "On Writing Well: The Classic Guide to Writing Nonfiction"
  - Strunk and White, "The Elements of Style"
  - Alred, Oliu, Brusaw, "The Handbook of Technical Writing"
- TAMU Writing Center, writingcenter.tamu.edu/

Electric Frequencies and Residential Voltages Worldwide

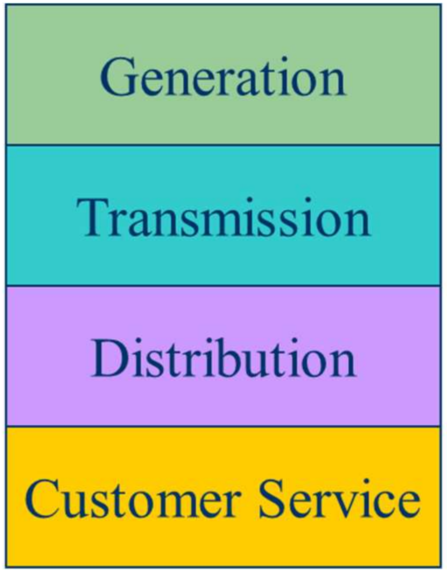


In the US the supplied residential voltage should be 120 V, with a 5% range allowed

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

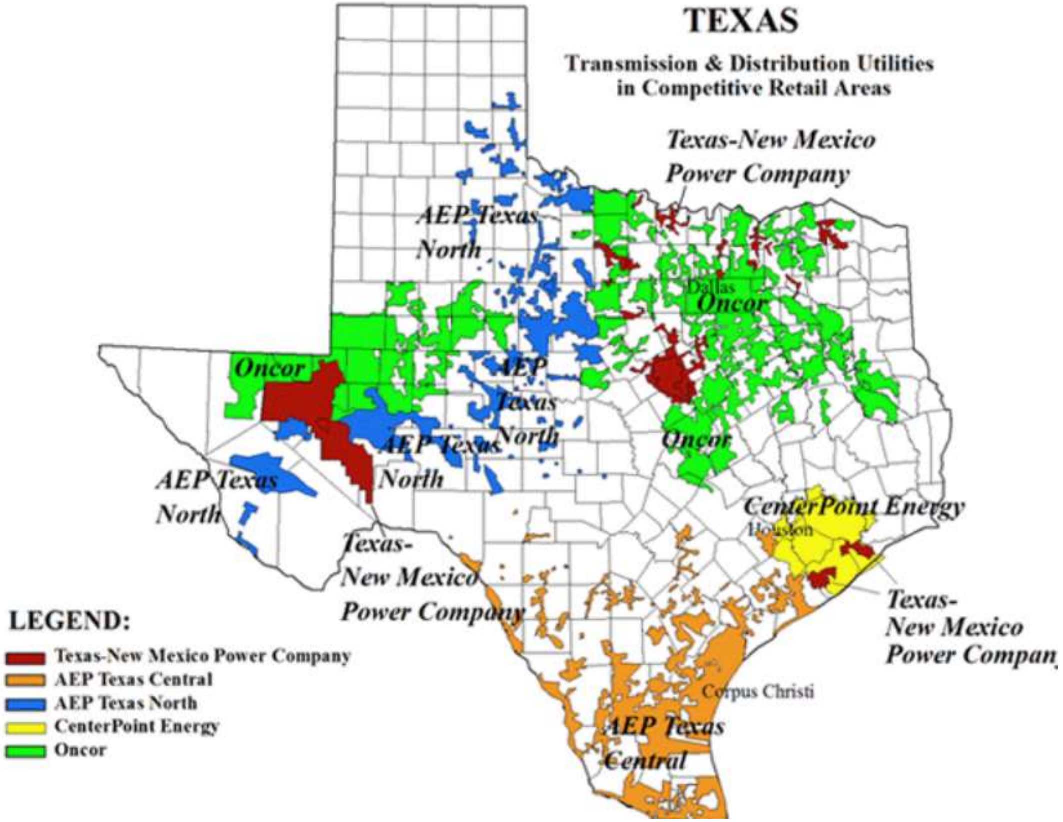
Historical Electric Utility Organization

- Traditionally electric utilities were vertical monopolies; within a particular geographic market, they had an exclusive franchise
  - This has changed in many places around the country



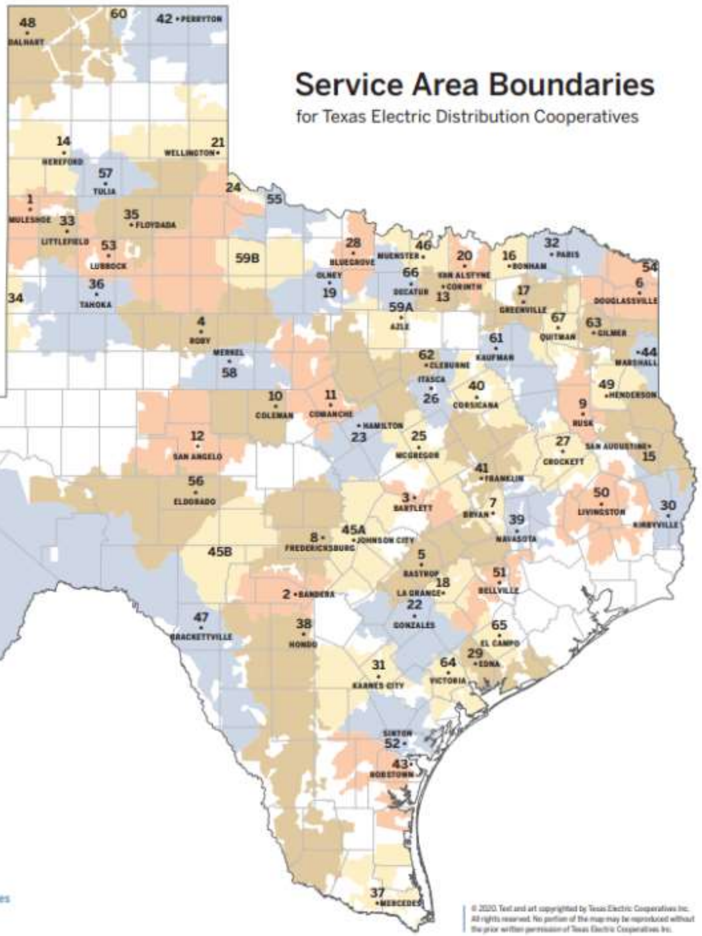
In return for this exclusive franchise, the utility had the obligation to serve all existing and future customers at rates determined jointly by utility and regulators.

Electric Utilities in Texas (IOUs and Municipals)



Electric Utilities in Texas (Coops)

COOPERATIVE	NUMBER	HEADQUARTERS
Bailey County ECA	1	Muleshoe
Bandera EC	2	Bandera
Bartlett EC	3	Bartlett
Big Country EC	4	Roby
Bluebonnet EC	5	Bastrop
Bowie-Cass EC	6	Douglassville
Bryan Texas Utilities	7	Bryan
Central Texas EC	8	Fredericksburg
Cherokee County ECA	9	Rusk
Coleman County EC	10	Coleman
Comanche EC	11	Comanche
Concho Valley EC	12	San Angelo
CoServ Electric	13	Corinth
Deaf Smith EC	14	Hereford
Deep East Texas EC	15	San Augustine
Fannin County EC	16	Bonham
Farmers EC	17	Greenville
Fayette EC	18	La Grange
Fort Belknap EC	19	Olney
Grayson-Collin EC	20	Van Alstyne
Greenbelt EC	21	Wellington
Guadalupe Valley EC	22	Gonzales
Hamilton County ECA	23	Hamilton
Harmon EA	24	Hollis, OK
Heart of Texas EC	25	McGregor
HILCO EC	26	Itasca
Houston County EC	27	Crockett
J-A-C EC	28	Bluegrove
Jackson EC	29	Edna
Jasper-Newton EC	30	Kirbyville
Karnes EC	31	Karnes City
Lamar County ECA	32	Paris
Lamb County EC	33	Littlefield
Lea County EC	34	Lovington, NM
Lighthouse EC	35	Floydada
Lyntegar EC	36	Tahoka
Magic Valley EC	37	Mercedes
Medina EC	38	Hondo
Mid-South Synergy	39	Navasota
Navarro County EC	40	Corsicana
Navasota Valley EC	41	Franklin
North Plains EC	42	Perryton
Nueces EC	43	Robstown
Panola-Harrison EC	44	Marshall
Pedernales EC	45 A, B	Johnson City
PenTex Energy	46	Muenster
Rio Grande EC	47	Brackettville
Rita Blanca EC	48	Dalhart
Rusk County EC	49	Henderson
Sam Houston EC	50	Livingston
San Bernard EC	51	Bellville
San Patricio EC	52	Sinton
South Plains EC	53	Lubbock
Southwest Arkansas	54	Texarkana, AR
Southwest Rural EA	55	Tipton, OK
Southwest Texas EC	56	Eldorado
Swisher EC	57	Tulia
Taylor EC	58	Merkel
Tri-County EC	59 A,B	Azle
Tri-County EC, OK	60	Hooker, OK
Trinity Valley EC	61	Kaufman
United Cooperative Services	62	Cleburne
Upshur Rural EC	63	Gilmer
Victoria EC	64	Victoria
Wharton County EC	65	El Campo
Wise EC	66	Decatur
Wood County EC	67	Quitman



Texas Electric Cooperatives

1122 Colorado St., 24th Floor | Austin, TX 78701
512-454-0311 | texas-ec.org

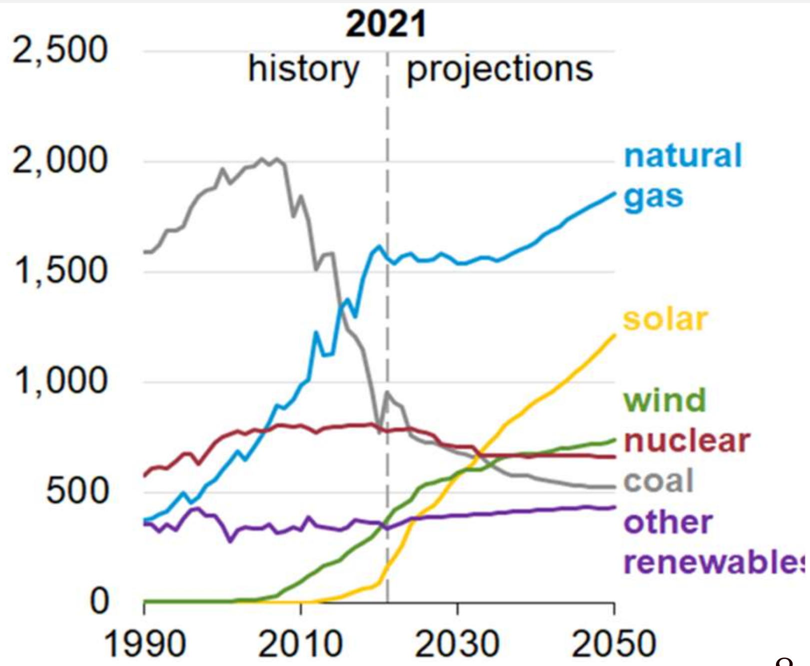
Service areas shown include multiple certificated areas and generally correspond to service area boundaries approved by the Public Utility Commission of Texas.

Generation

- Natural Gas (38.4%) and coal (21.3%) are most common sources, followed by nuclear (18.6%), wind (9.7), hydro (6.4%), solar (4.2%)
  - Wood is 0.9%, 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)

US Generator Capacity Additions



Sources are by energy (not capacity), 4/2021-3/2022; source US EIA

US Generation (July 2021) by Fuel Type

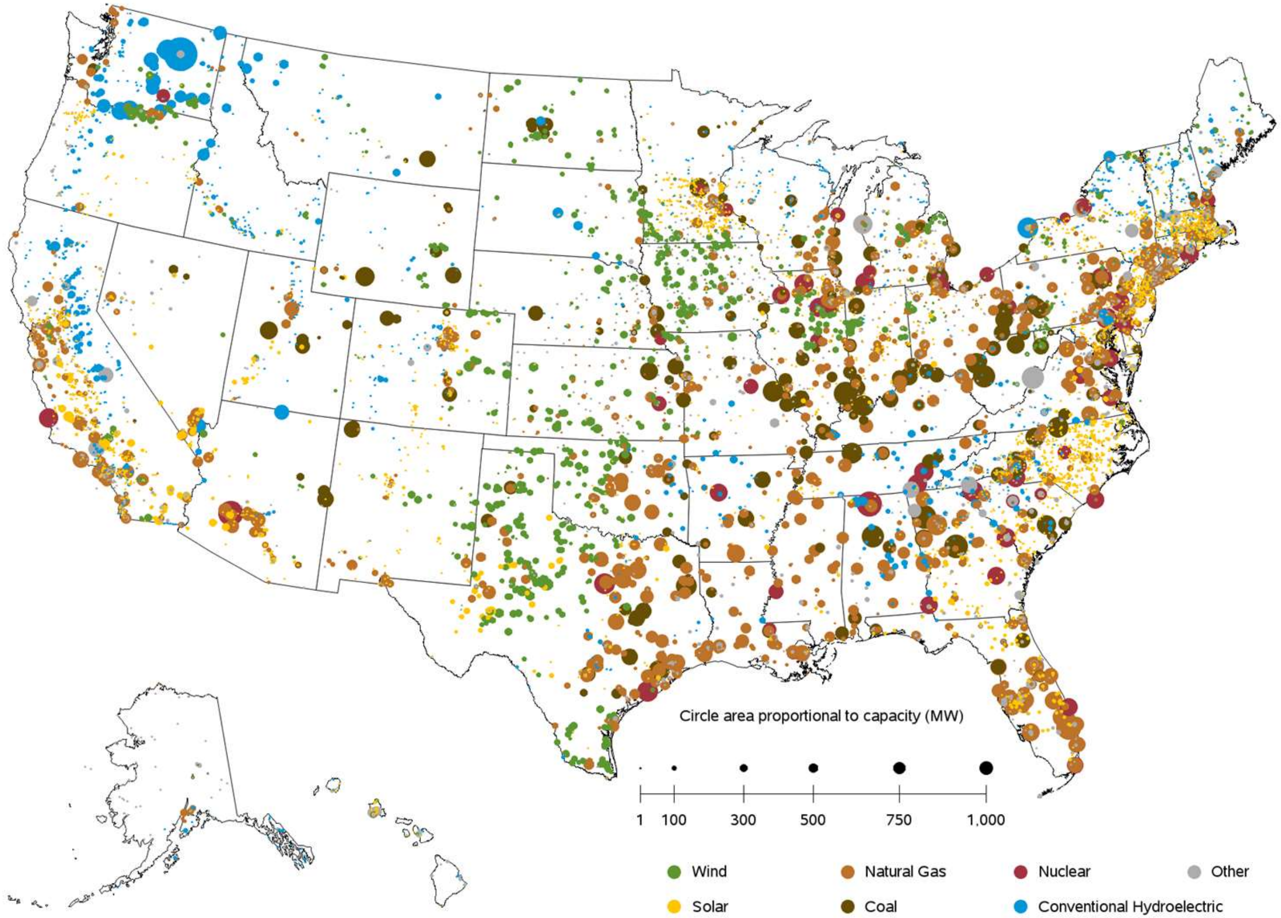
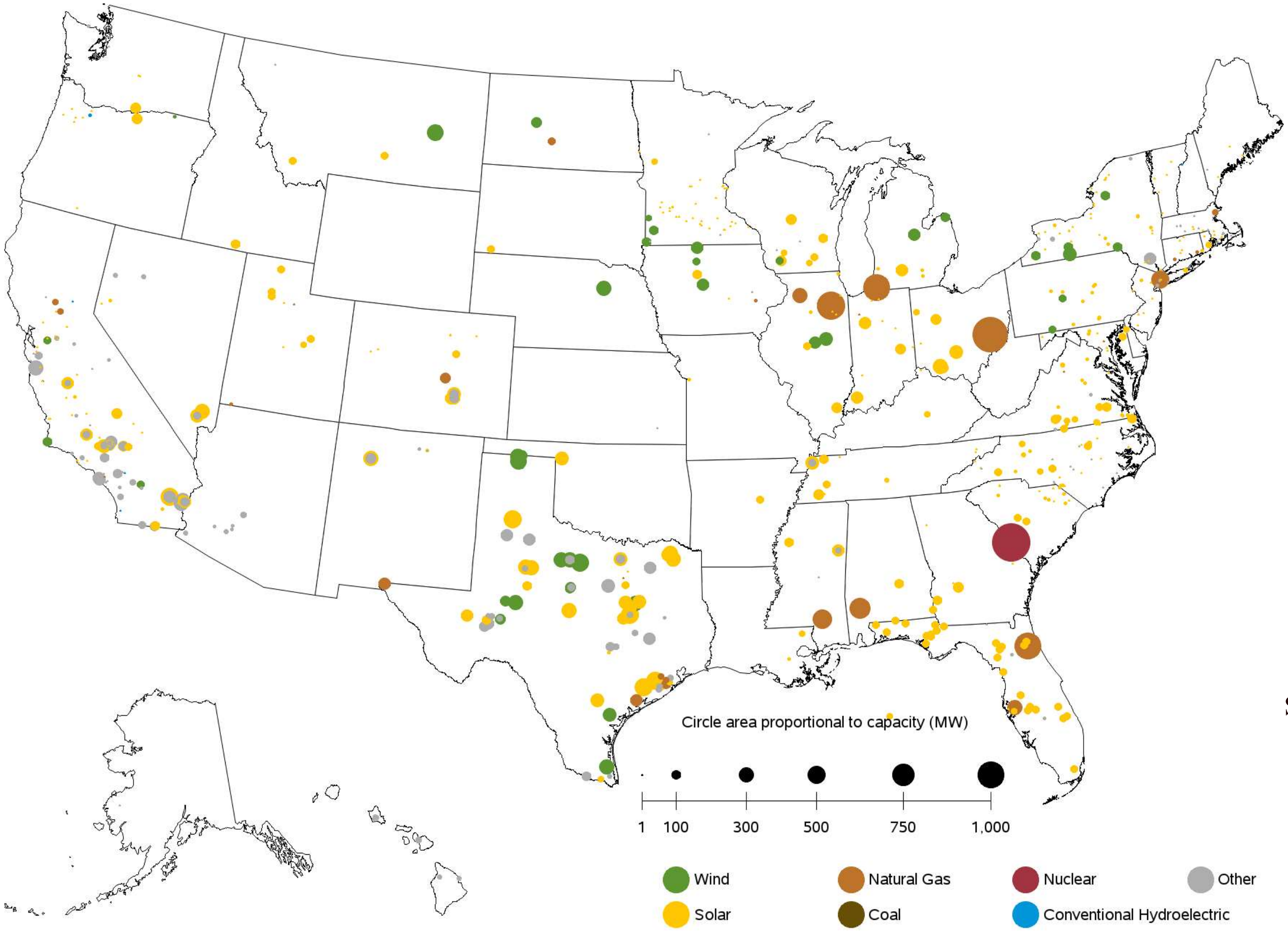


Image Source: www.eia.gov/electricity/data/eia860m/

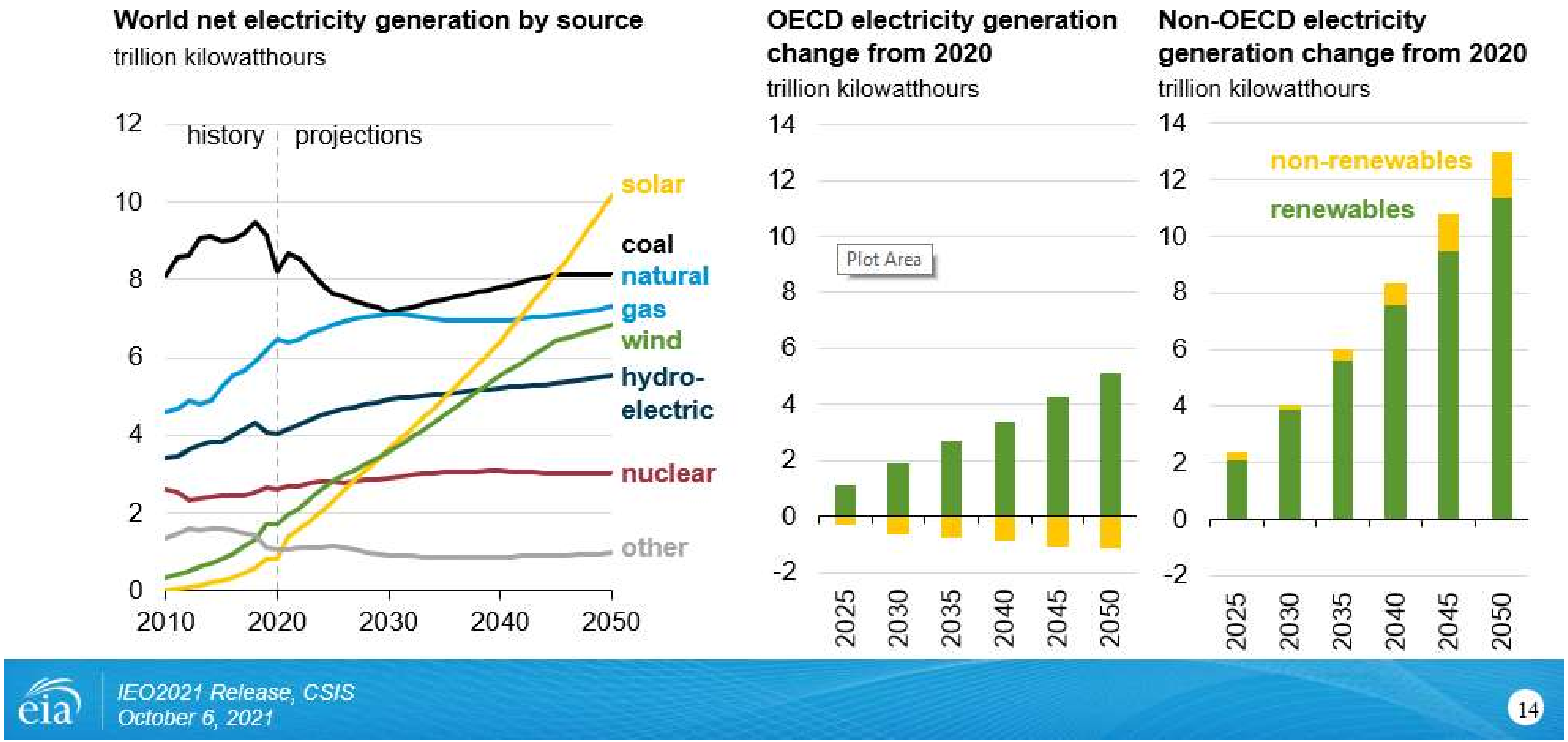
Planned New Generation July 2022 to June 2023



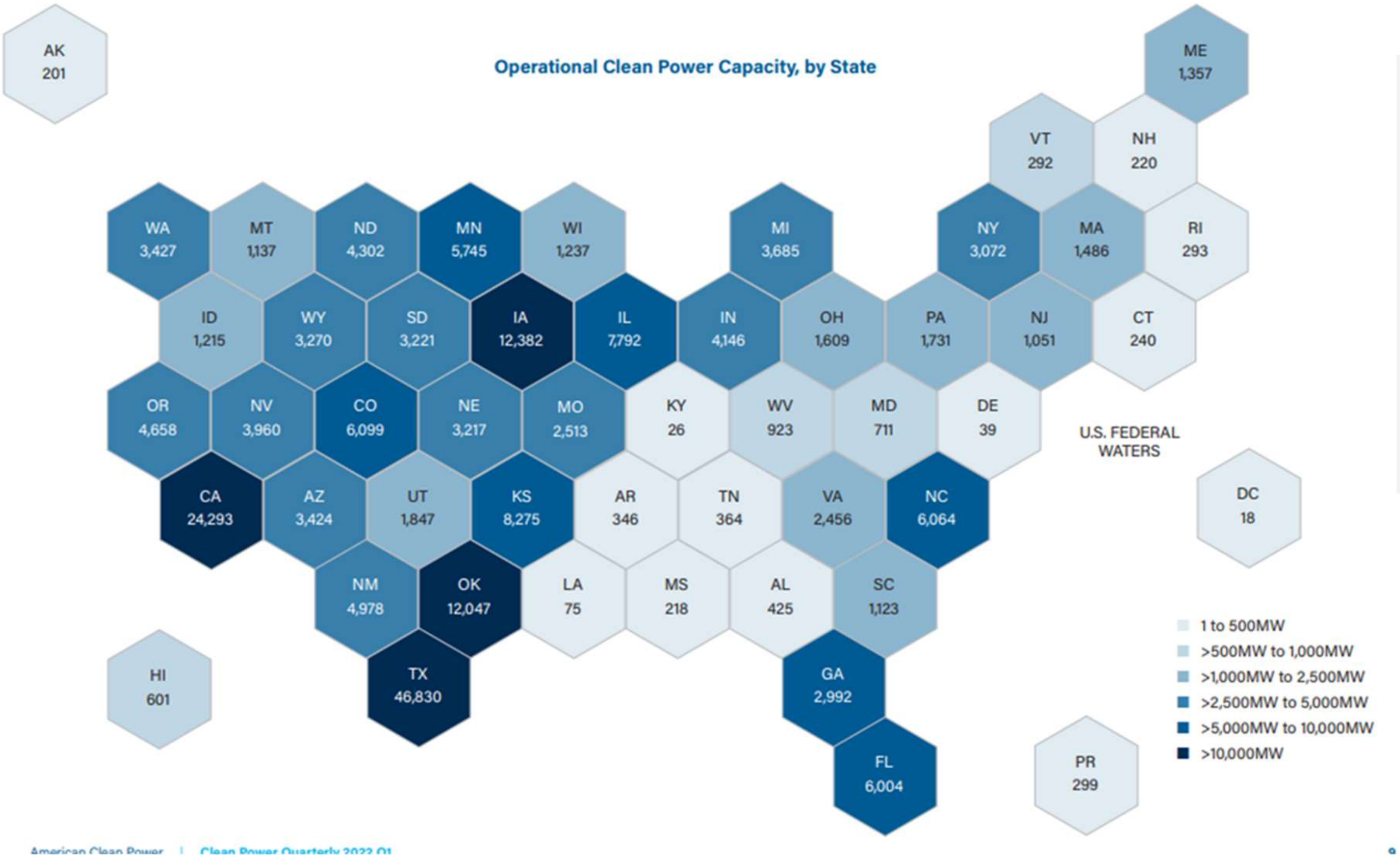
Sources: EIA Electricity Monthly

Sources: U.S. Energy Information Administration, Form EIA-860, 'Annual Electric Generator Report' and Form EIA-860M, 'Monthly Update to the Annual Electric Generator Report.'

The World: Electricity Consumption by Source



US Wind and Solar Capacity by State

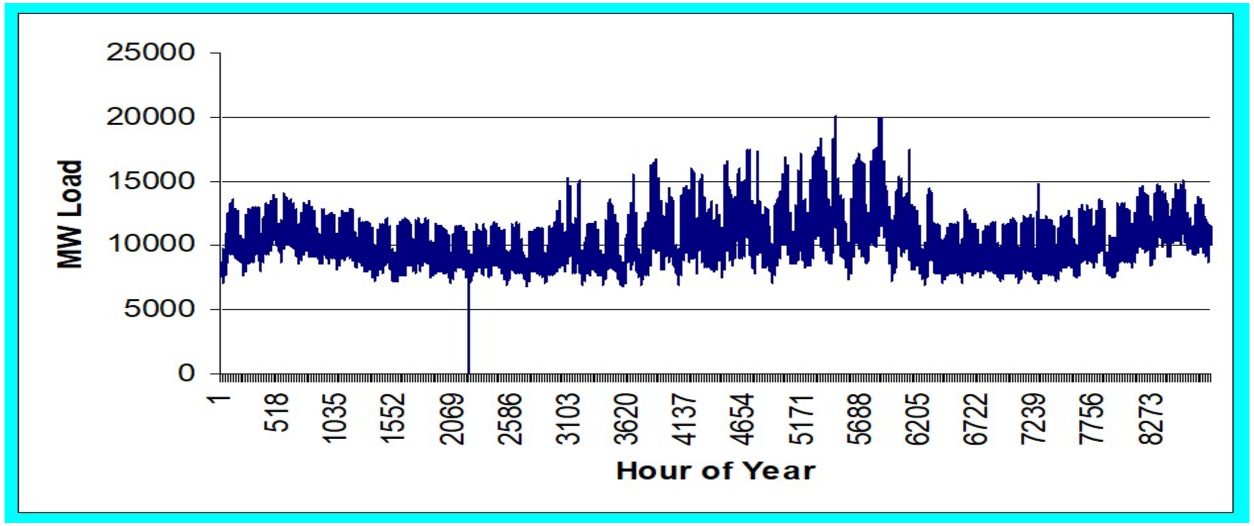


Total US capacity at the end of 2021 was about 139 GW of wind and 63 GW of solar (compared to a total US capacity of about 1000 GW)

Source: Clean Power Quarterly, 1st Quarter 2022

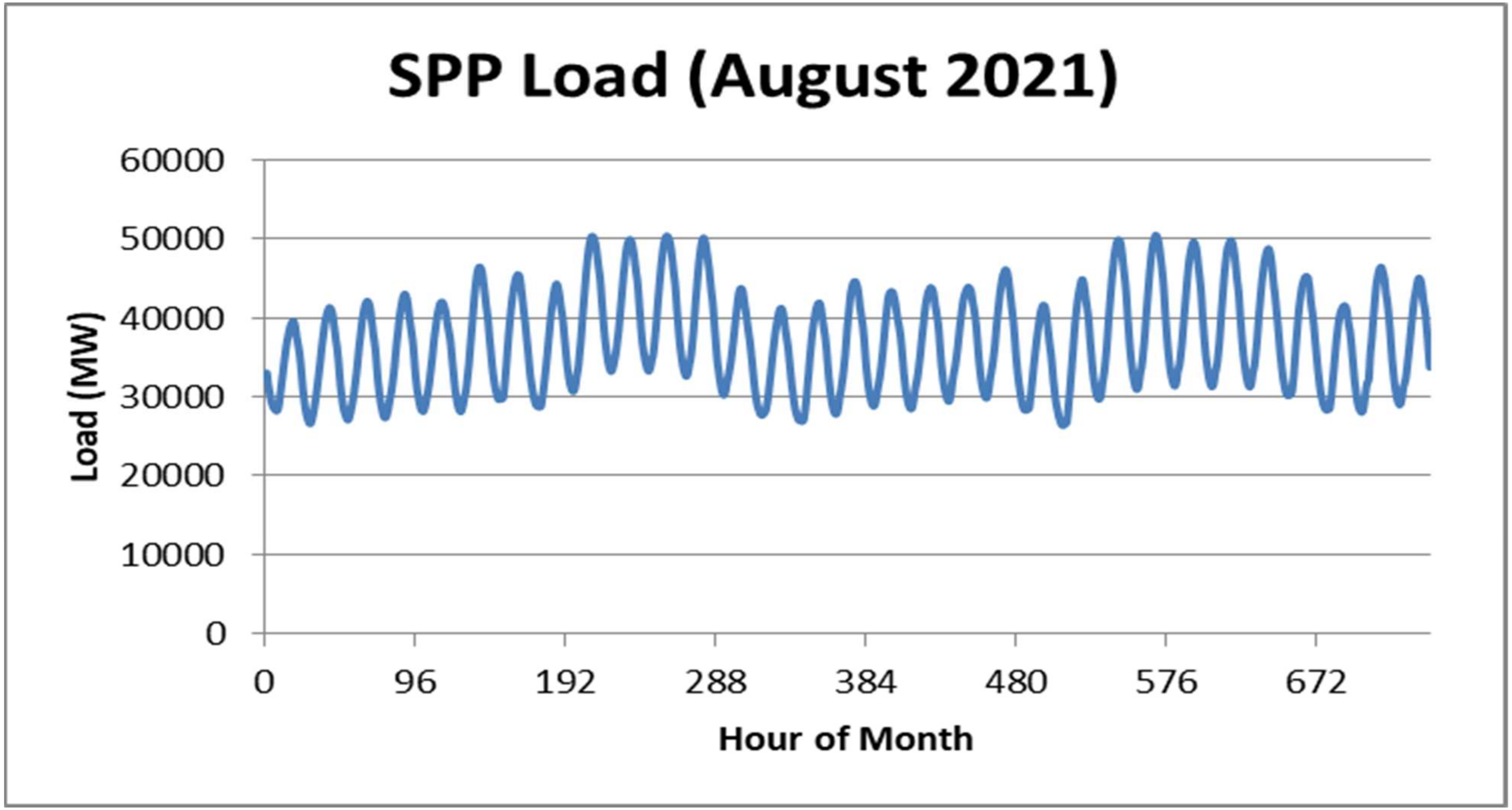
Loads

- Can range in size from less than one watt to 10's of MW.
- Loads are usually aggregated.
- The aggregate load changes with time, with strong daily, weekly and seasonal cycles.



ComEd Yearly Load

Example: Southwest Power Pool Monthly Load



SPP Load Data Source: marketplace.spp.org

Load Models

- Ultimate goal is to supply loads with electricity at constant frequency and voltage
- Electrical characteristics of individual loads matter, but usually they can only be estimated
  - actual loads are constantly changing, consisting of a large number of individual devices
  - only limited network observability of load characteristics
- Aggregate models are typically used for analysis
- Two common models
  - constant power: $S_i = P_i + jQ_i$
  - constant impedance: $S_i = |V|^2 / Z_i$

The ZIP model combines constant impedance, current and power (P)

Transmission and Distribution

- Goal is to move electric power from generation to load with low losses.
- Less losses at higher voltages (S=VI* and I^2R losses), but more difficult to insulate.
- Typical high voltage transmission voltages are 765, 500, 345, 230, 161, 138 and 69 kV.
- Lower voltage lines are used for distribution (12.4 or 13.8 kV).
- Typical losses are about 3 to 5% in transmission and 10 to 15% in the distribution system.

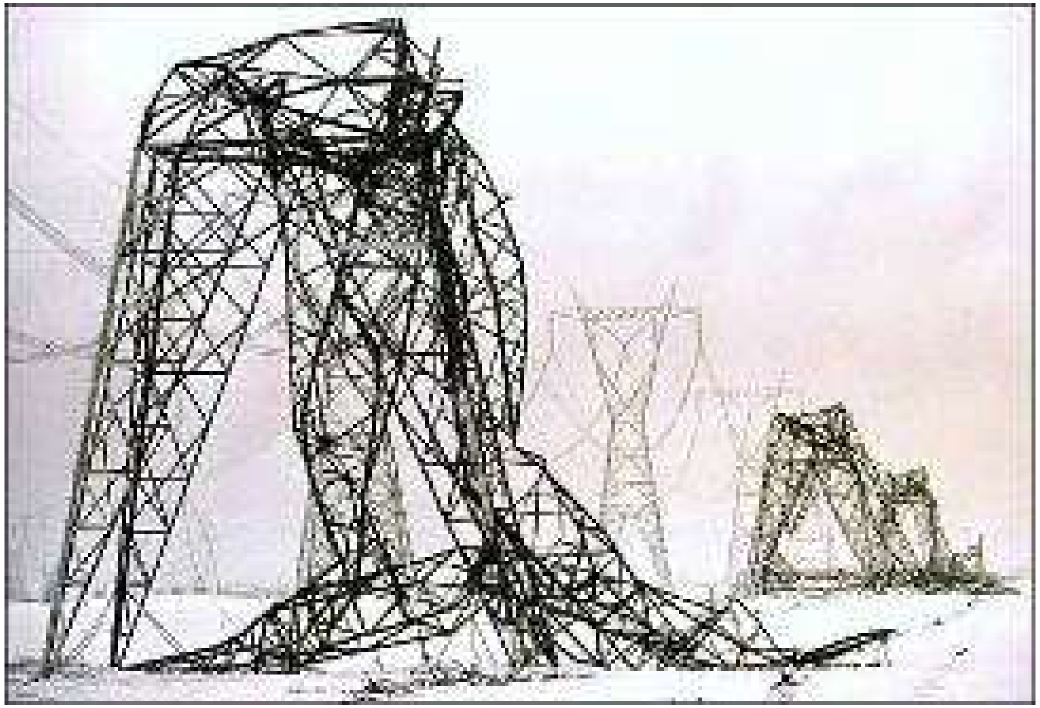
Transmission & Distribution

- Transmission
  - networked connections
  - power can be supplied from multiple sources
  - typically higher voltages, above 100 kV
  - mostly overhead, with some underground in urban areas
  - Often source of large-scale blackouts
- Distribution
  - radial connections
  - power moves in one direction only
  - typically lower voltages, below 100 kV
  - the source of most black-outs, but these are local
  - Most new construction is underground, especially in suburban and urban locations

Three Phase Transmission Line

Transmission Lines and the Elements

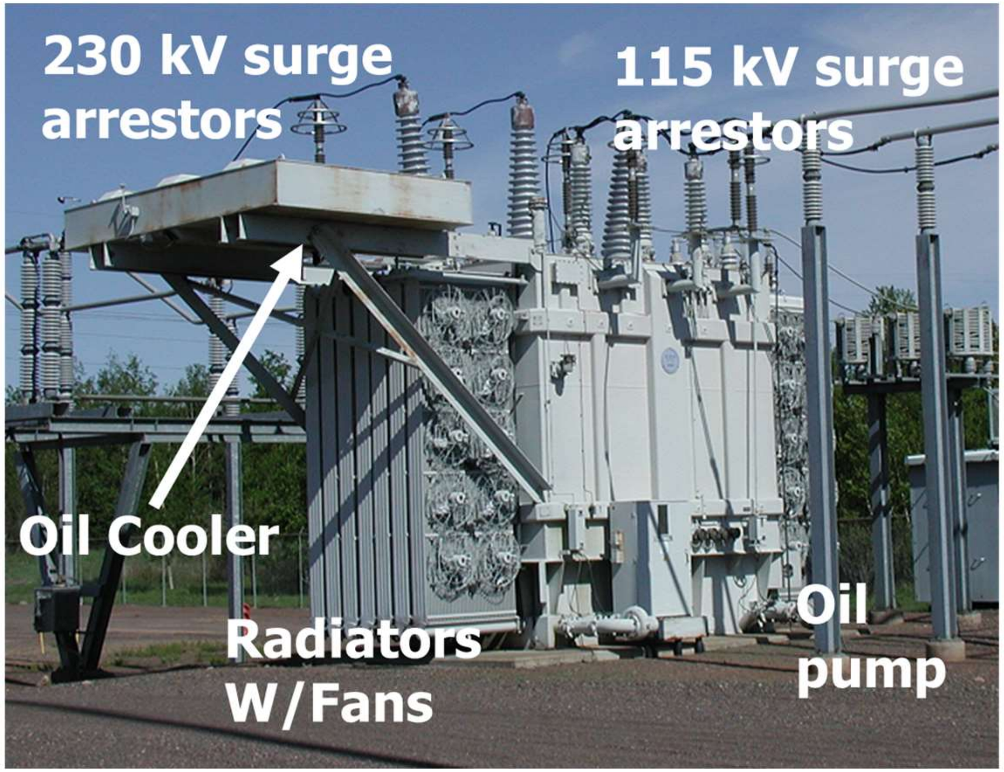
Hurricane Ike in Beaumont, Tx



Quebec Ice Storm

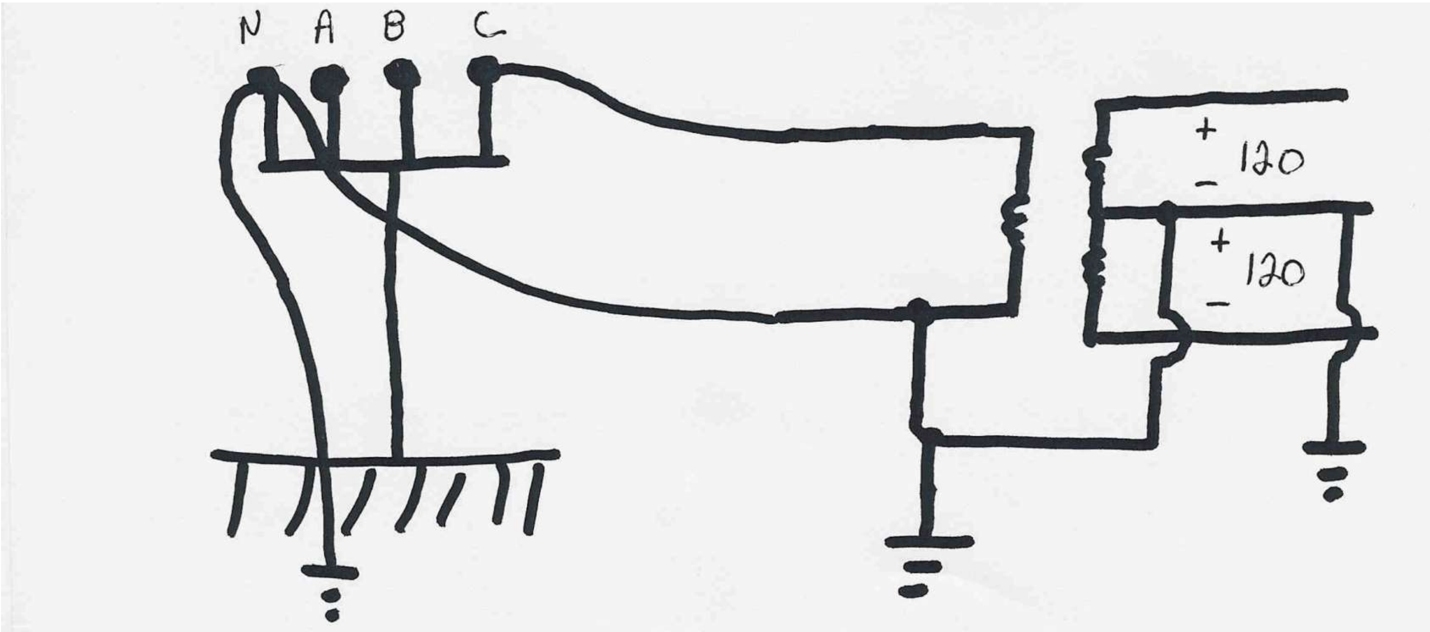
Transformers

- Transformers provide an easily means for changing ac voltage levels
  - Power flow through transformers is bi-directional
- Heating is a major concern that can quickly lead to loss of transformer life (and occasionally explosions!)
- High voltage transformers (say 230 kV and up) are large, heavy, and difficult to replace



Residential Distribution Transformers

- Residential single phase electric service uses a center tapped transformer to provide 240/120 volt service; a separate ground is used for safety



Per Unit Calculations

- A key problem in analyzing power systems is the large number of transformers.
  - It would be very difficult to continually have to refer impedances to the different sides of the transformers
- This problem is avoided by a normalization of all variables.
- This normalization is known as per unit analysis

$$\text{quantity in per unit} = \frac{\text{actual quantity}}{\text{base value of quantity}}$$

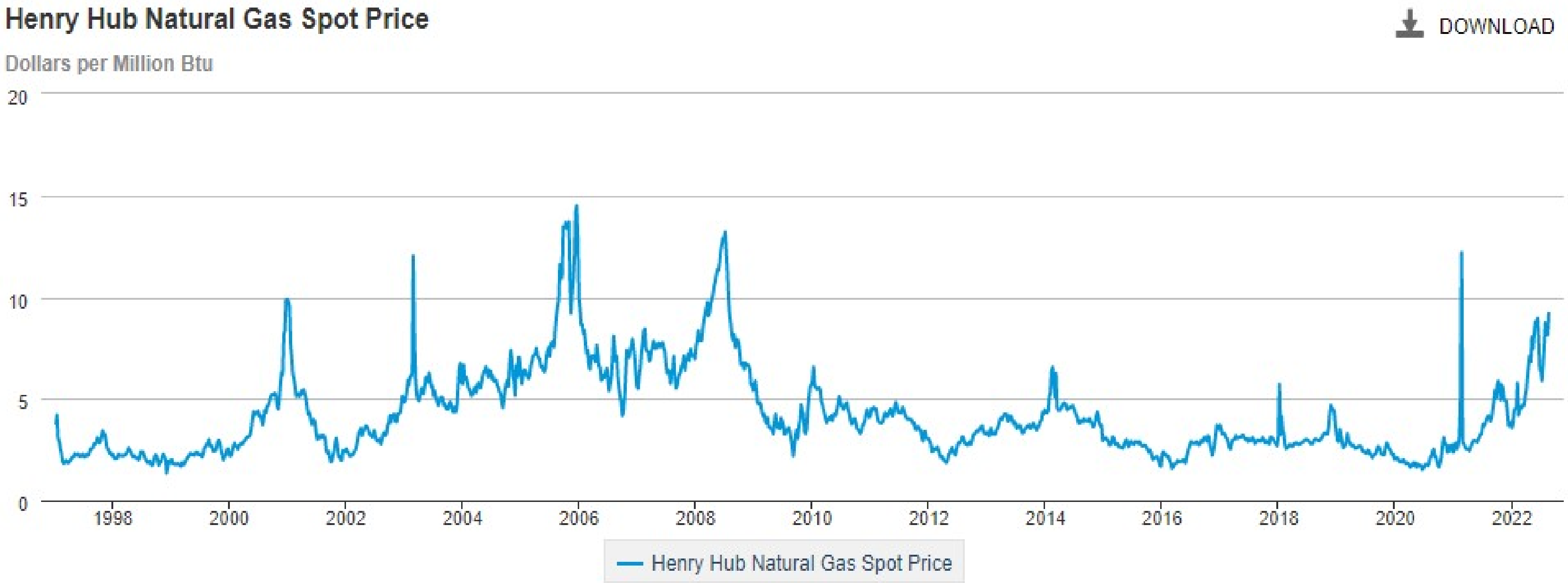
This is covered in ECEN 460; slides from 2017 are available on my website at overbye.engr.tamu.edu/course-2/

Components Join Together at a Bus

Energy Economics

- 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
- Also the units capacity factor is important to determining the ultimate cost of electricity

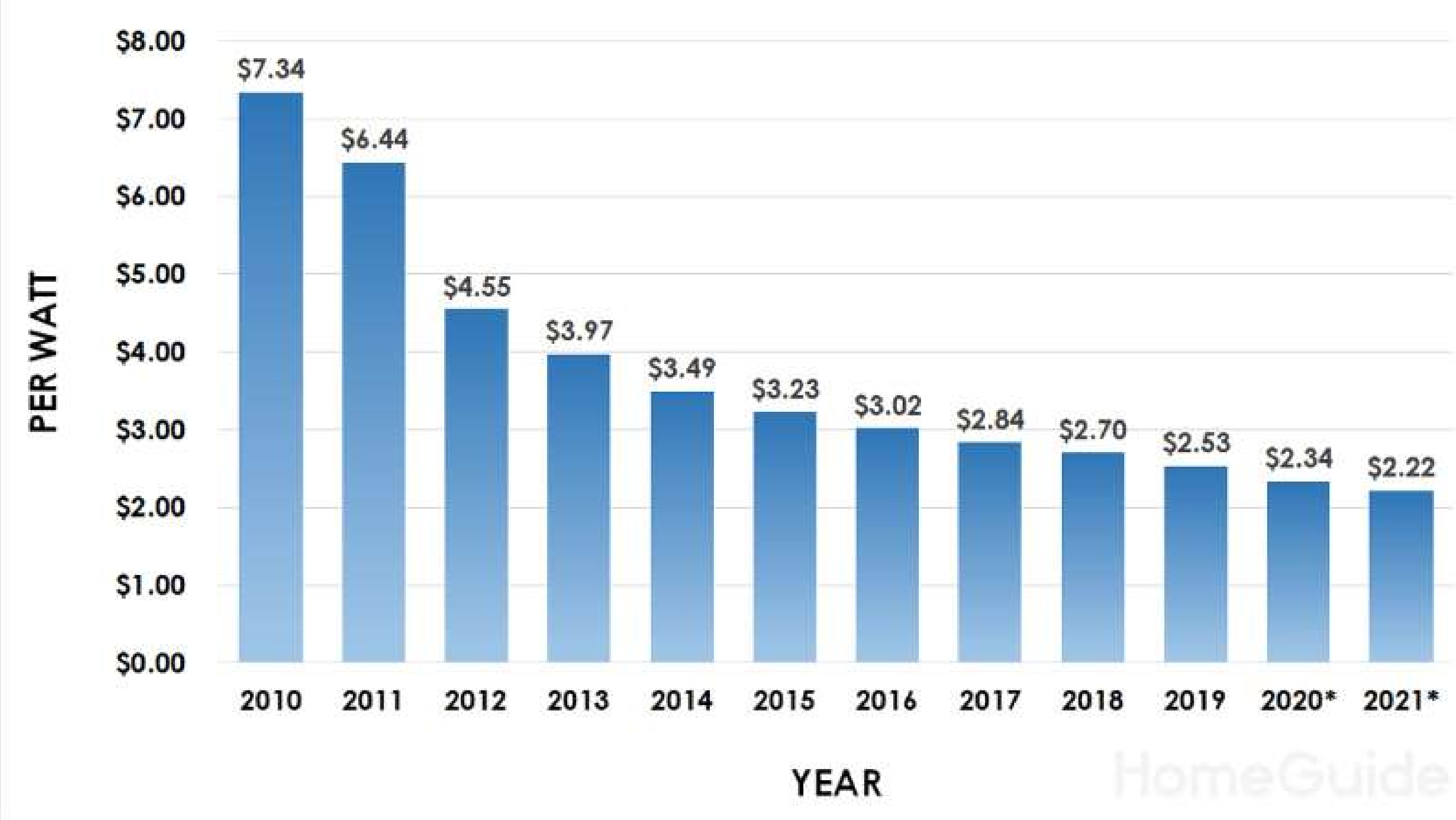
Natural Gas Prices 1997 to 2022



Marginal cost for natural gas fired electricity price in $/MWh is about 7-10 times gas price; Henry Hub is a gas pipeline located in Erath, Louisiana.

https://www.eia.gov/dnav/ng/hist/rngwhhdW.htm

Average Cost of Small Residential Solar



This does not include tax credits; individual prices do vary of course.

Image source: homeguide.com/costs/solar-panel-cost

Economies of Scale with Renewable Generation

- Large-scale electric grids developed because of the economies of scale with generation
  - It made more sense economically to have large generators further from the load rather than everyone having a generator at their house
- This has partially changed with renewable generation, but perhaps less than people realize
  - Larger-scale wind is much more cost effective than smaller turbines
- With solar the issue is more complicated
  - Utility scale solar tends to be much less expensive (see right image)

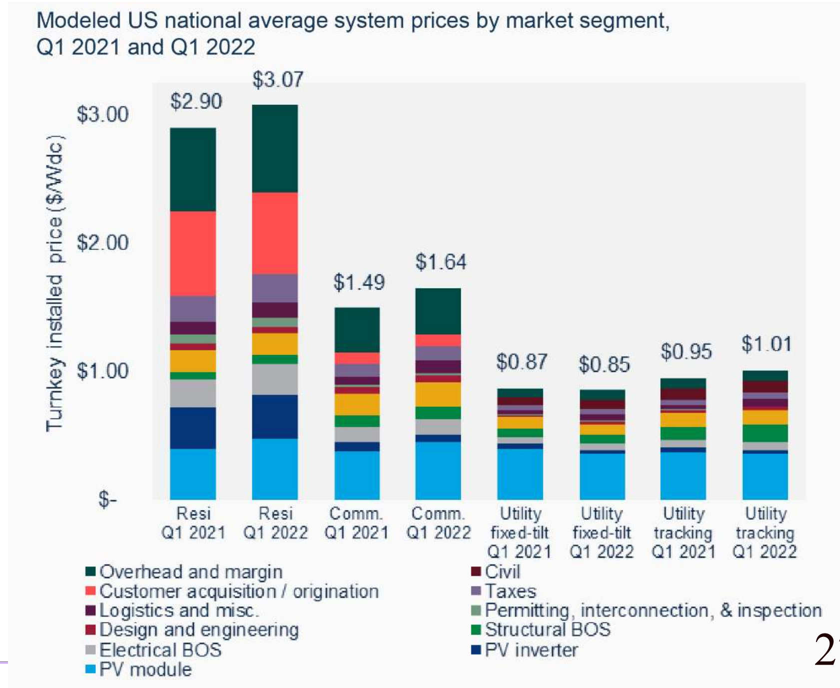
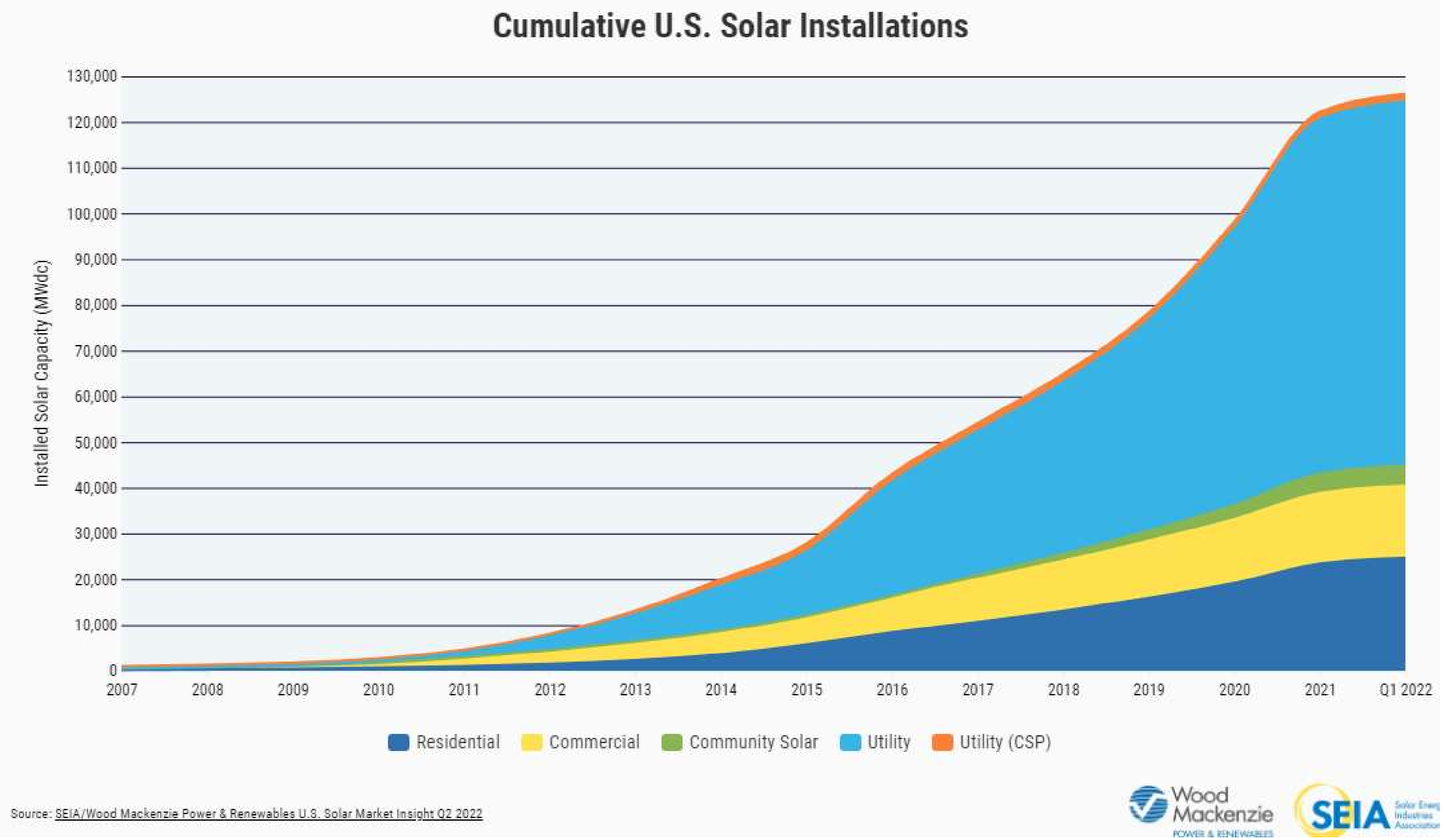


Image source: www.seia.org/research-resources/solar-market-insight-report-2022-q2

Solar Economies of Scale: Installations by Type



This rapid growth
solar is causing modifications to some of the techniques that we'll be talking about in 615

Image source: ww.seia.org/solar-industry-research-data

Brief History of Electric Power

- First real practical uses of electricity began with the telegraph (1860's) and then arc lighting in the 1870's
- Early 1880's – Edison introduced Pearl Street dc system in Manhattan supplying 59 customers
- 1884 – Sprague produces practical dc motor
- 1885 – invention of transformer
- Mid 1880's – Westinghouse/Tesla introduce rival ac system
- Late 1880's – Tesla invents ac induction motor
- 1893 – Three-phase transmission line at 2.3 kV

History, cont'd

- 1896 – ac lines deliver electricity from hydro generation at Niagara Falls to Buffalo, 20 miles away; also 30kV line in Germany
- Early 1900's – Private utilities supply all customers in area (city); recognized as a natural monopoly; states step in to begin regulation
- By 1920's – Large interstate holding companies control most electricity systems
- 1935 – Congress passes Public Utility Holding Company Act to establish national regulation, breaking up large interstate utilities (repealed 2005)
  - This gave rise to electric utilities that only operated in one state
- 1935/6 – Rural Electrification Act brought electricity to rural areas
- 1930's – Electric utilities established as vertical monopolies