ECEN 615
Methods of Electric Power Systems Analysis

Lecture 1: Power Systems Overview

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TEXAS A&M UNIVERSITY

Syllabus

ECEN 615 – Methods of Electric Power Systems Analysis
Fall 2018 TR 2:20 -3:35pm ETB 1037

Instructor: Prof. Tom Overbye, 308C WEB, overbye@tamu.edu
Office Hours (tentative): Mondays 1-3 pm
Instructor Website: overbye.engr.tamu.edu
Course Website: https://overbye.engr.tamu.edu/course-2/ecen615fa2018/
Prerequististies: ECEN 460 or consent of instructor
Text: A. J. Wood, B. F.Wollenberg, G. B. Sheble, *Power Generation, Operation and Control,* Third Edition, Wiley, 2013, ISBN-13: 978-0471790556
TA: Iyke Idehen, iidehen@tamu.edu
TA Office Hours: Wednesday 4-6pm (tentative)

Evaluation:

	Midterm Exam	30%
	Final exam	40%
	Homework and project	30%

Tentative Dates for Midterm: Thursday, October 18, In Class

Comprehensive Final Exam: Wednesday, December 13, 1 to 3 pm

Notesheets for Exams: All exams are closed-book, closed-notes. You may bring in one notesheet (8.5" by 11"), and may use standard calculators.

Grading

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

Slides will be posted before each lecture on the website

Course Topics

- Introduction to Power Systems
- Overview of Power System Modeling and Operation
- Power Flow
- Sparse Matrices in Power System Analysis
- Sensitivity Analysis and Equivalents
- Power System Data Analytics and Visualization
- Optimal Power Flow and Power Markets
- Power System State Estimation
- Black start Analysis

Announcements

- Start reading chapters 1 to 3 from the book (more background material)
- Download the 42 bus educational version of PowerWorld Simulator at

  https://www.powerworld.com/gloveroverbyesarma

About Me: Professional

- Received BSEE, MSEE, and Ph.D. all from University of Wisconsin at Madison (83, 88, 91)
- Worked for eight years as engineer for an electric utility (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 27 years
- Developed commercial power system analysis package, known now as PowerWorld Simulator. This package has been sold to about 600 different corporate entities worldwide
- DOE investigator for 8/14/2003 blackout
- Member US National Academy of Engineering

About Me: TAMU Research Group Spring and Summer 2018

About Me: Nonprofessional

- Married to Jo
- Have three children: Tim, Hannah and Amanda
- We homeschooled our kids with Tim now starting an ME PhD at TAMU, Hannah a senior at UIUC in psychology, and Amanda a sophomore at Belmont in environmental sciences
- Jo is finishing a master's in counseling, we attend Grace Bible Church in College Station (and teach the 3rd and 4th graders sometimes); I also like swimming, biking and watching football (Aggies and Packers!)

About TA Iyke Idehen

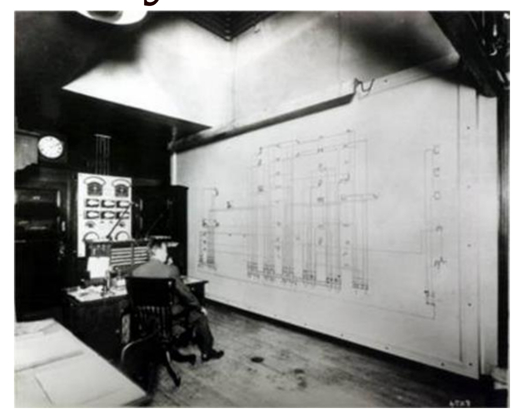
- Fifth year graduate student
  - BSc (ECE, University of Benin, Nigeria)
  - MSc (EE, Tuskegee University, Alabama)
  - Spent 2.3 years at UIUC, now at TAMU
  - Research Area
    - Power Systems and Control
    - Data Analytics, Visualization
    - Large-Scale Systems
  - Advisor: Prof. Tom Overbye
  - Hobbies & Interests: Soccer, Music, Travel
  - Former Co-chair, TPEC 2018

Hollywood, 2014

Co-Chair, Texas Power and Energy Conference (TPEC) 2018

ECEN 615 Motivation: A Vision for an Long-Term Sustainable Electric Future

- In 2000 the US National Academy of Engineering (NAE) named Electrification (the vast networks of electricity that power the developed world) as the top engineering technology of the 20th century
  - Beating automobiles (2), airplanes (3), water (4), electronics (5)
  - Electricity has changed the world!

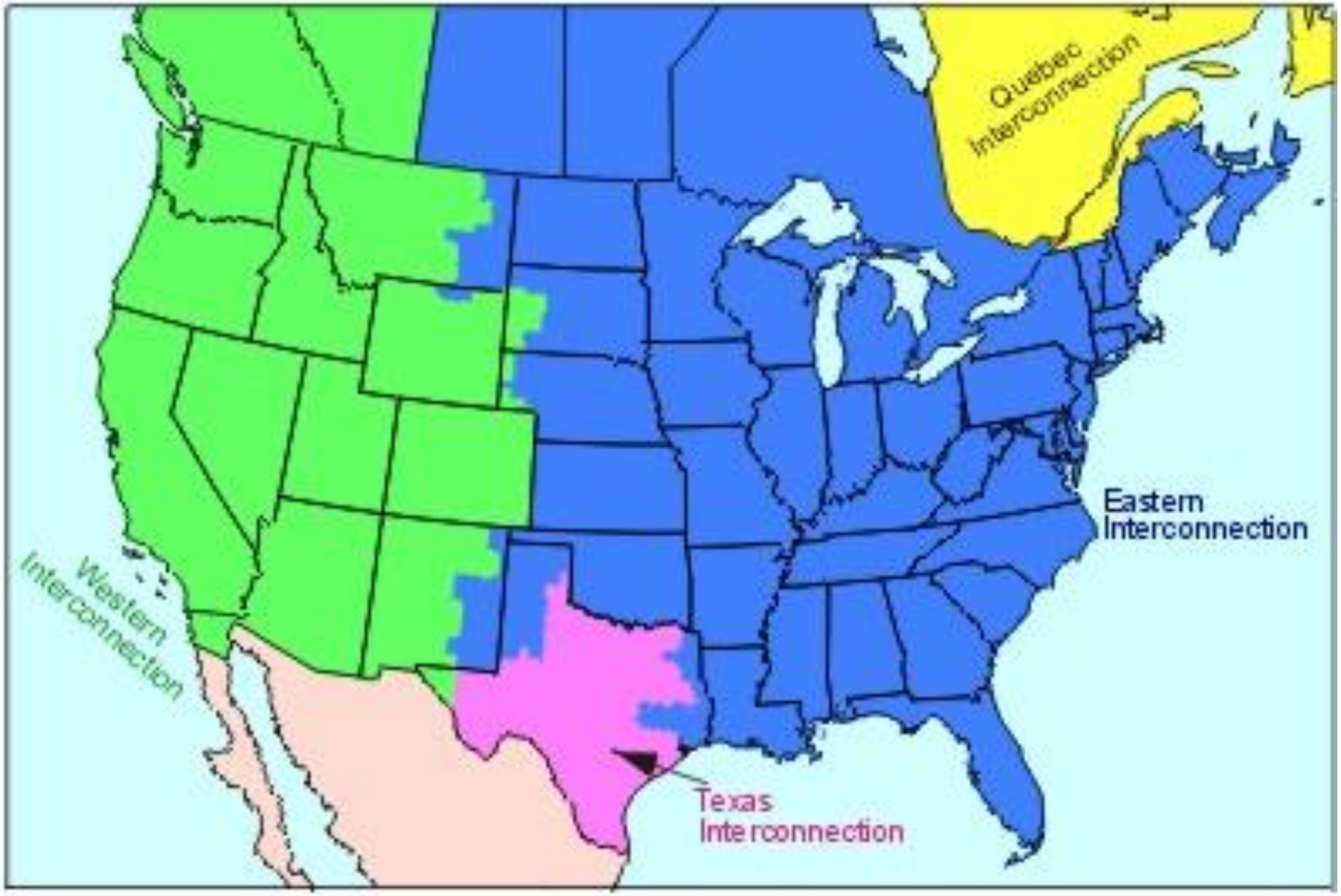


- For the 21th century the winner could be “Development of a sustainable and resilient electric infrastructure for the entire world”

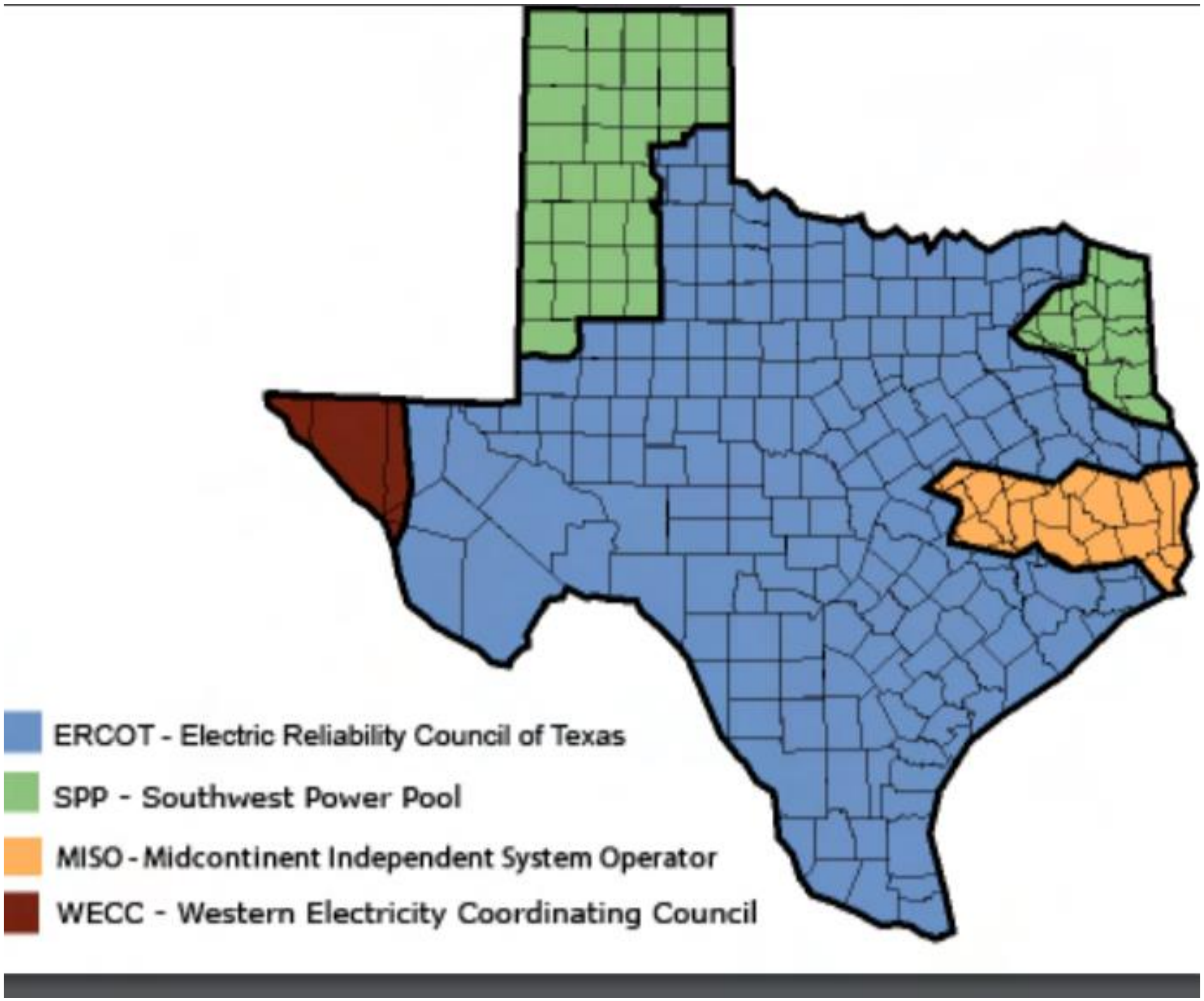
Power System Examples

- 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

North America Interconnections



Electric Interconnections in Texas

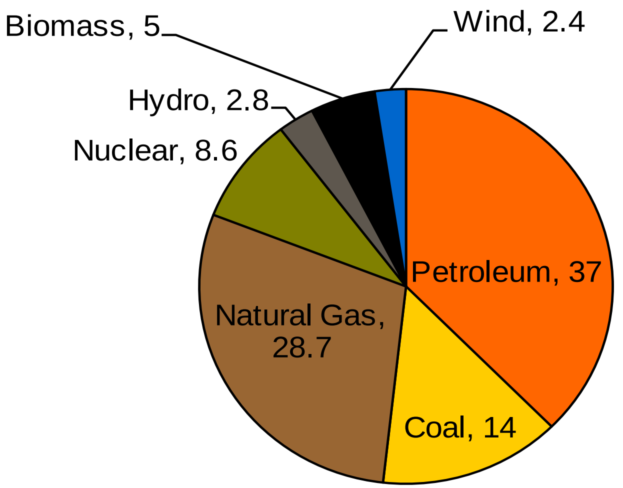


Source: www.puc.texas.gov/industry/maps/maps/ERCOT.pdf

Electric Systems in 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 fossil fuel depletion are becoming main drivers for change in world energy infrastructure

Looking at the 2017 Energy Pie: Where the USA Got Its Energy



About 40% of our energy is consumed in the form of electricity, a percentage that is gradually increasing. The vast majority on the non-fossil fuel energy is electric!

In 2017 we got about 2.4% of our energy from wind and 0.8% from solar (PV and solar thermal), 2.8% from hydro

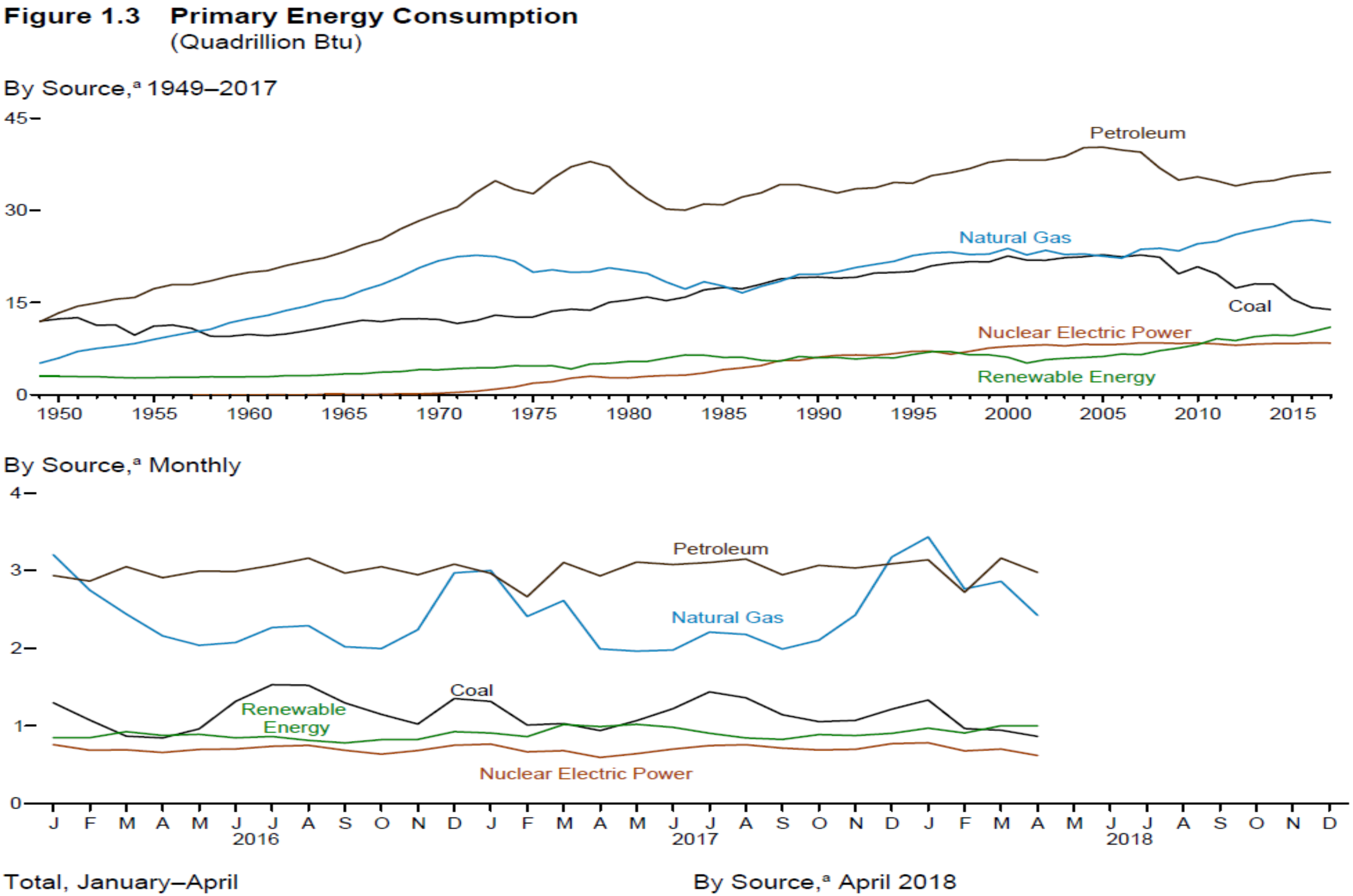
About 80% Fossil Fuels (89% in 1980 and 85% in 2000)

Total of 97.7 Quad; 1 Quad = 293 billion kWh (actual), 1 Quad = 98 billion kWh (used, taking into account efficiency)

EIA is US DOE Energy Information Administration

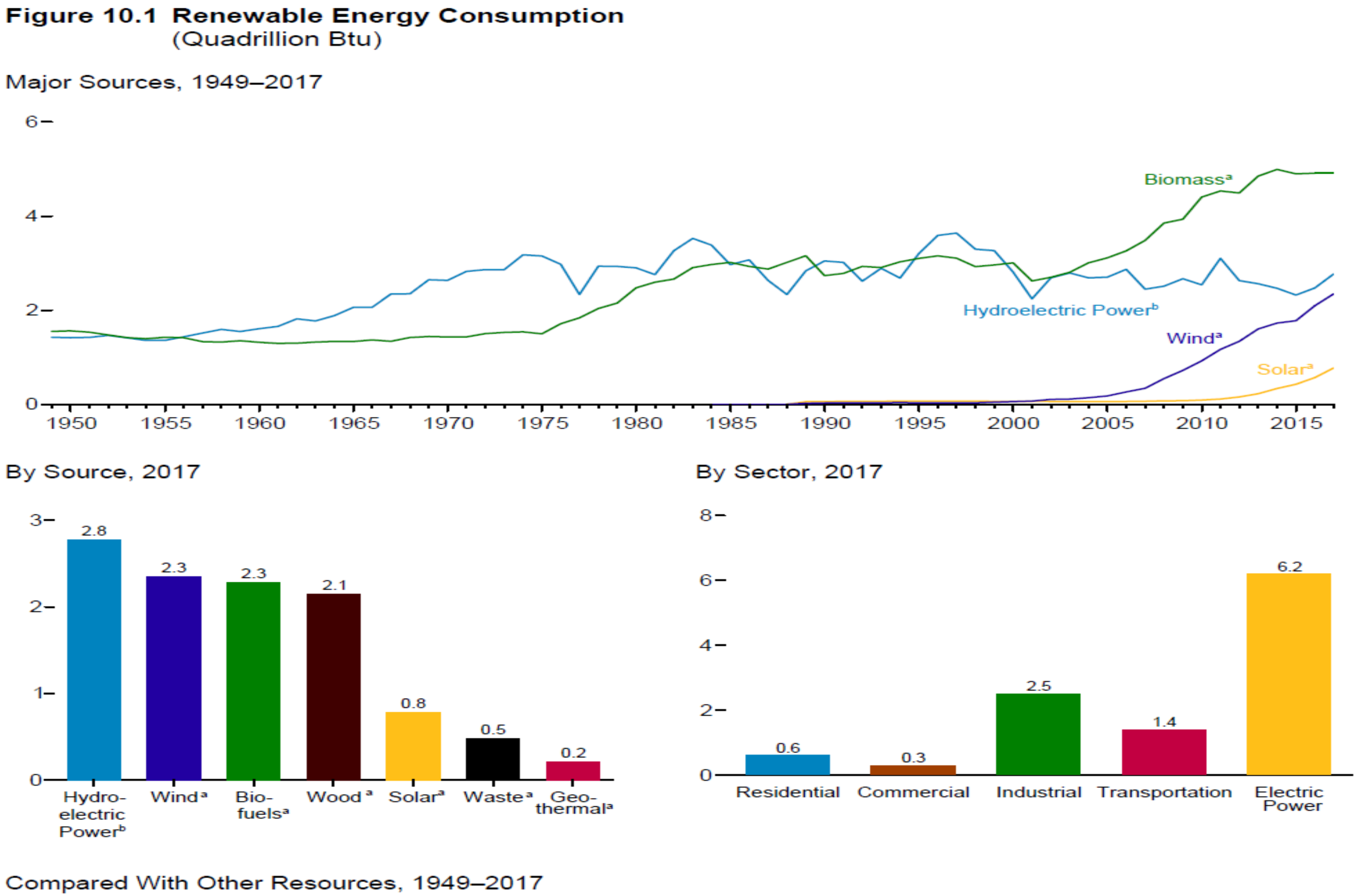
Source: EIA Monthly Energy Review, July 2018

US Historical Energy Usage



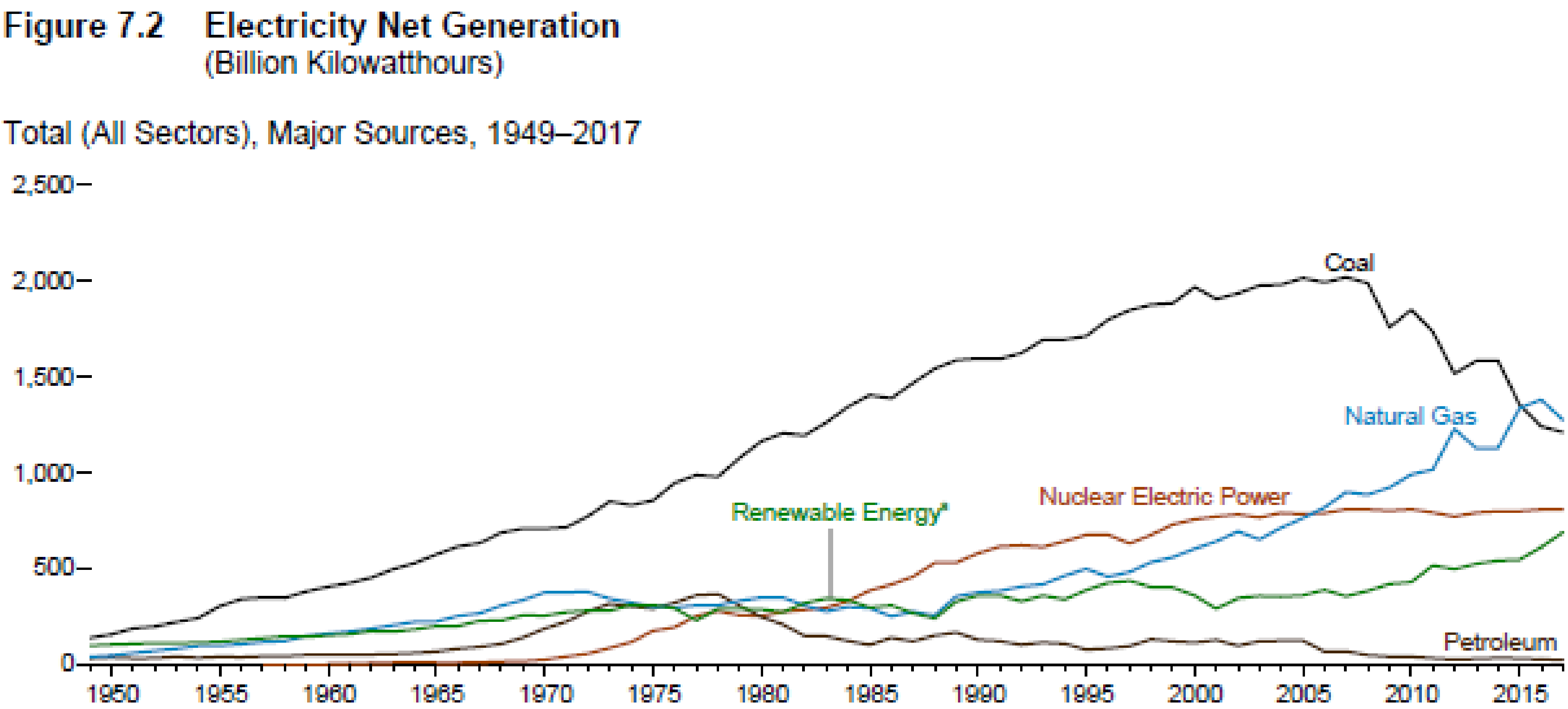
Source: EIA Monthly Energy Review, July 2018

Renewable Energy Consumption



Source: EIA Monthly Energy Review, July 2018

US Electricity Generation

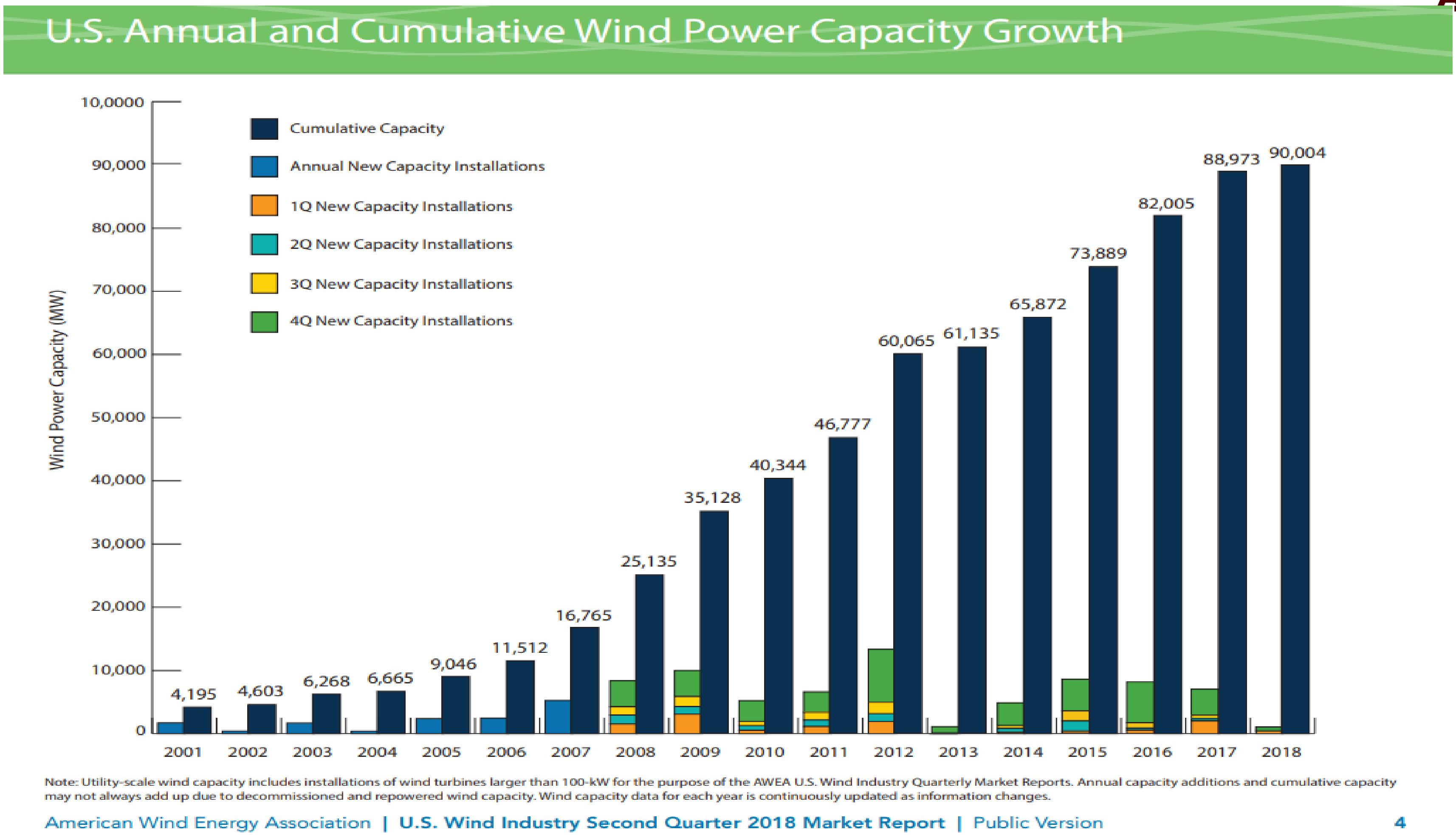


In 2017 the major sources were coal (31%), natural gas (30.5%), nuclear (20.9%), hydro (7.7), wind (6.7%), and solar (2.0)

Wind and solar are rapidly growing (12% and 40% growth in 2017)

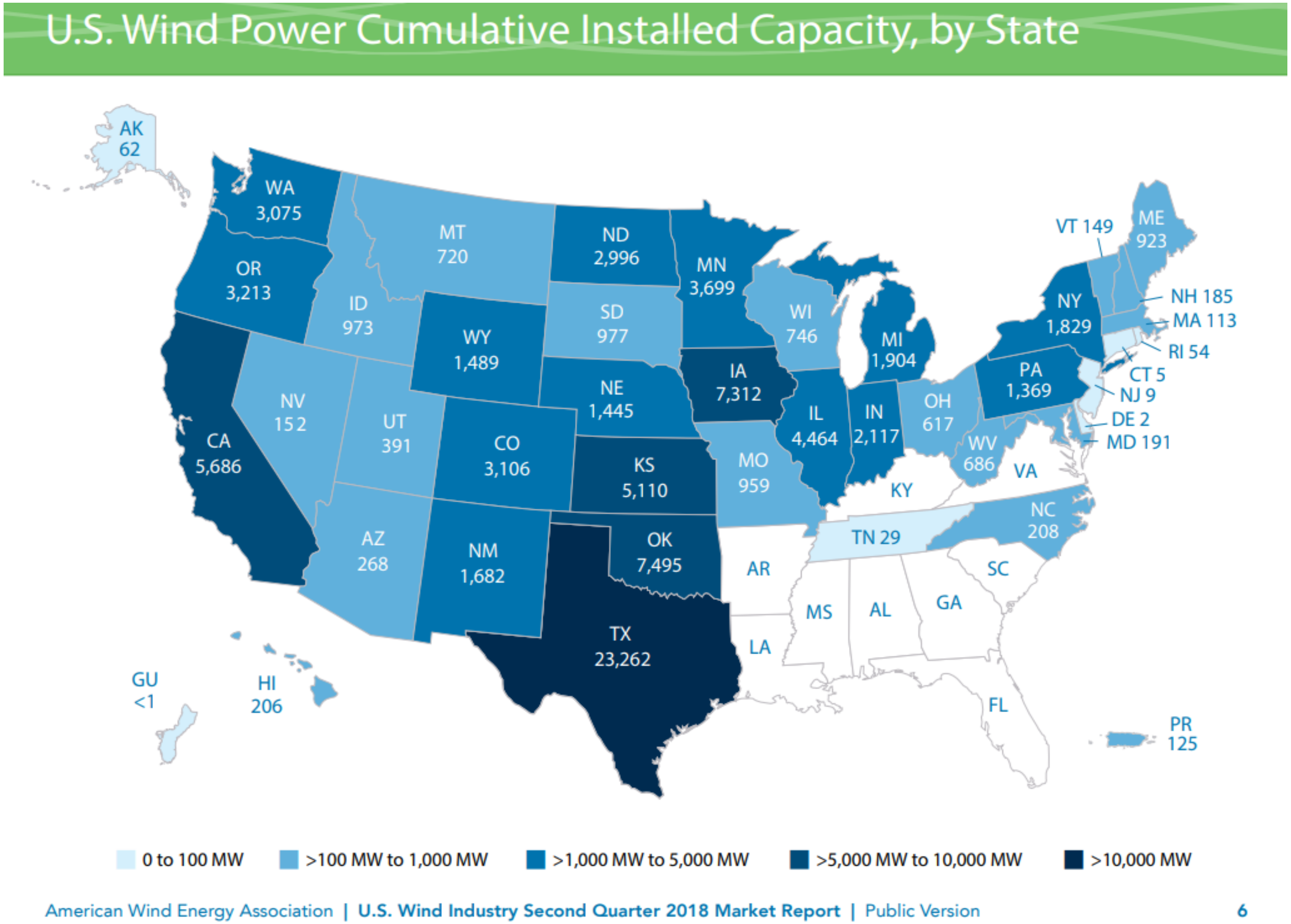
Source: EIA Monthly Energy Review, July 2018

Growth in US Wind Power Capacity



Source: AWEA Wind Power Outlook Second Quarter, 2018

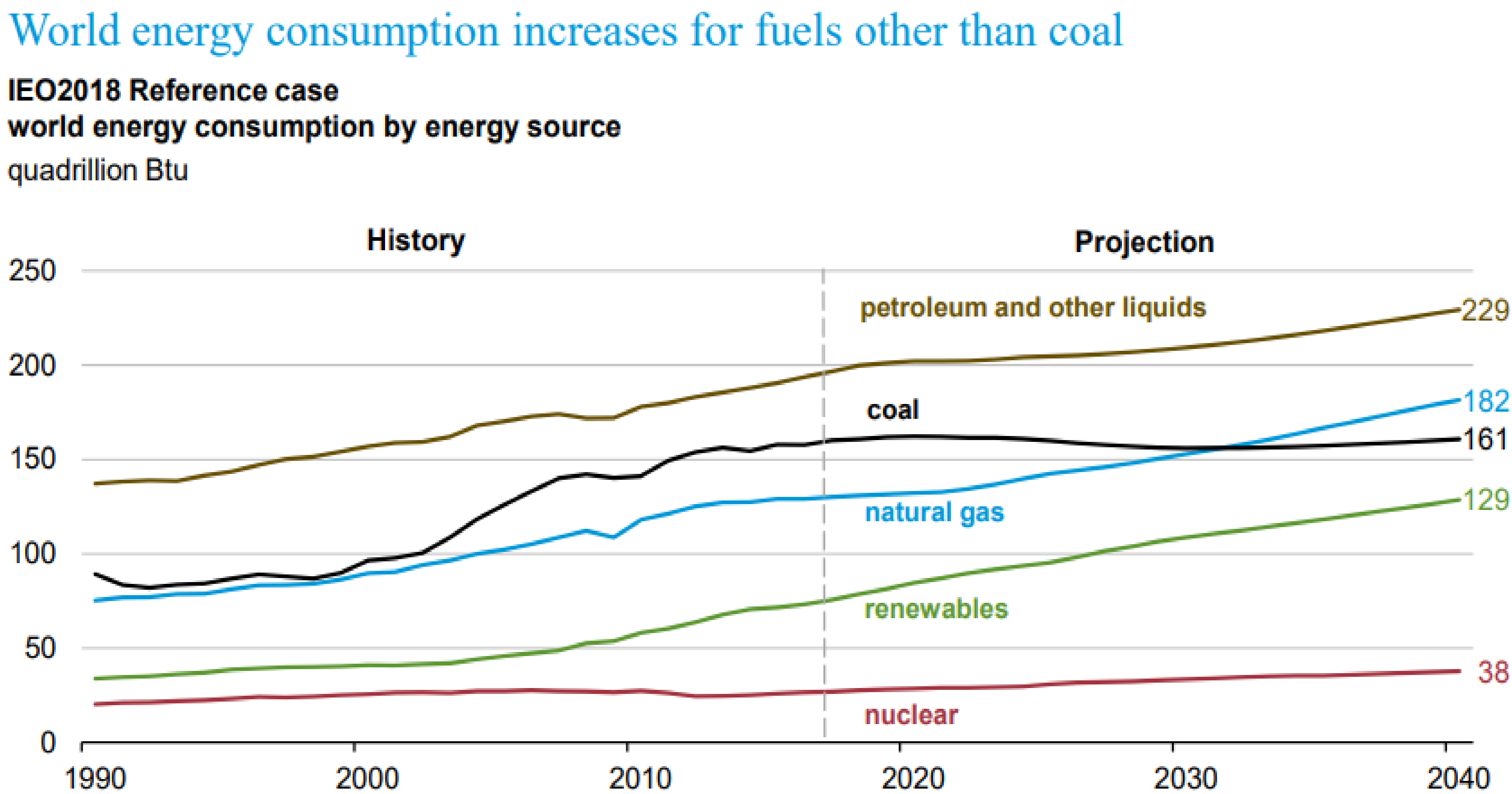
Wind Capacity Installations by State



Texas is number one!

Source: AWEA Wind Power Outlook Second Quarter, 2018

The World



Source: EIA, International Energy Outlook 2018

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 ultimate cost of electricity

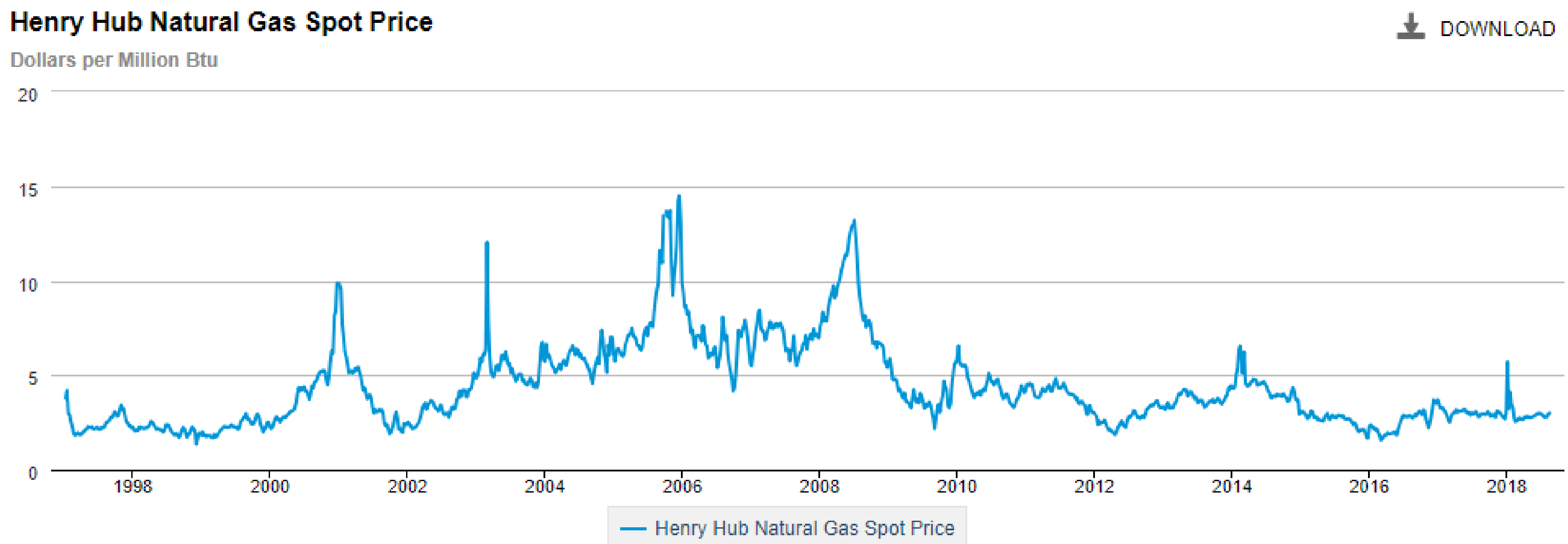
Estimated Energy Costs for New Generation

Table 1b. Estimated levelized cost of electricity (unweighted average) for new generation resources entering service in 2022 (2017 $/MWh)

Plant type	Capacity factor (%)	Levelized capital cost	Levelized fixed O&M	Levelized variable O&M	Levelized transmission cost	Total system LCOE	Levelized tax credit[1]	Total LCOE including tax credit
Dispatchable technologies								
Coal with 30% CCS[2]	85	84.0	9.5	35.6	1.1	130.1	NA	130.1
Coal with 90% CCS[2]	85	68.5	11.0	38.5	1.1	119.1	NA	119.1
Conventional CC	87	12.6	1.5	34.9	1.1	50.1	NA	50.1
Advanced CC	87	14.4	1.3	32.2	1.1	49.0	NA	49.0
Advanced CC with CCS	87	26.9	4.4	42.5	1.1	74.9	NA	74.9
Conventional CT	30	37.2	6.7	51.6	3.2	98.7	NA	98.7
Advanced CT	30	23.6	2.6	55.7	3.2	85.1	NA	85.1
Advanced nuclear	90	69.4	12.9	9.3	1.0	92.6	NA	92.6
Geothermal	90	30.1	13.2	0.0	1.3	44.6	-3.0	41.6
Biomass	83	39.2	15.4	39.6	1.1	95.3	NA	95.3
Non-dispatchable technologies								
Wind, onshore	41	43.1	13.4	0.0	2.5	59.1	-11.1	48.0
Wind, offshore	45	115.8	19.9	0.0	2.3	138.0	-20.8	117.1
Solar PV[3]	29	51.2	8.7	0.0	3.3	63.2	-13.3	49.9
Solar thermal	25	128.4	32.6	0.0	4.1	165.1	-38.5	126.6
Hydroelectric[4]	64	48.2	9.8	1.8	1.9	61.7	NA	61.7

Source: www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf (March 2018)

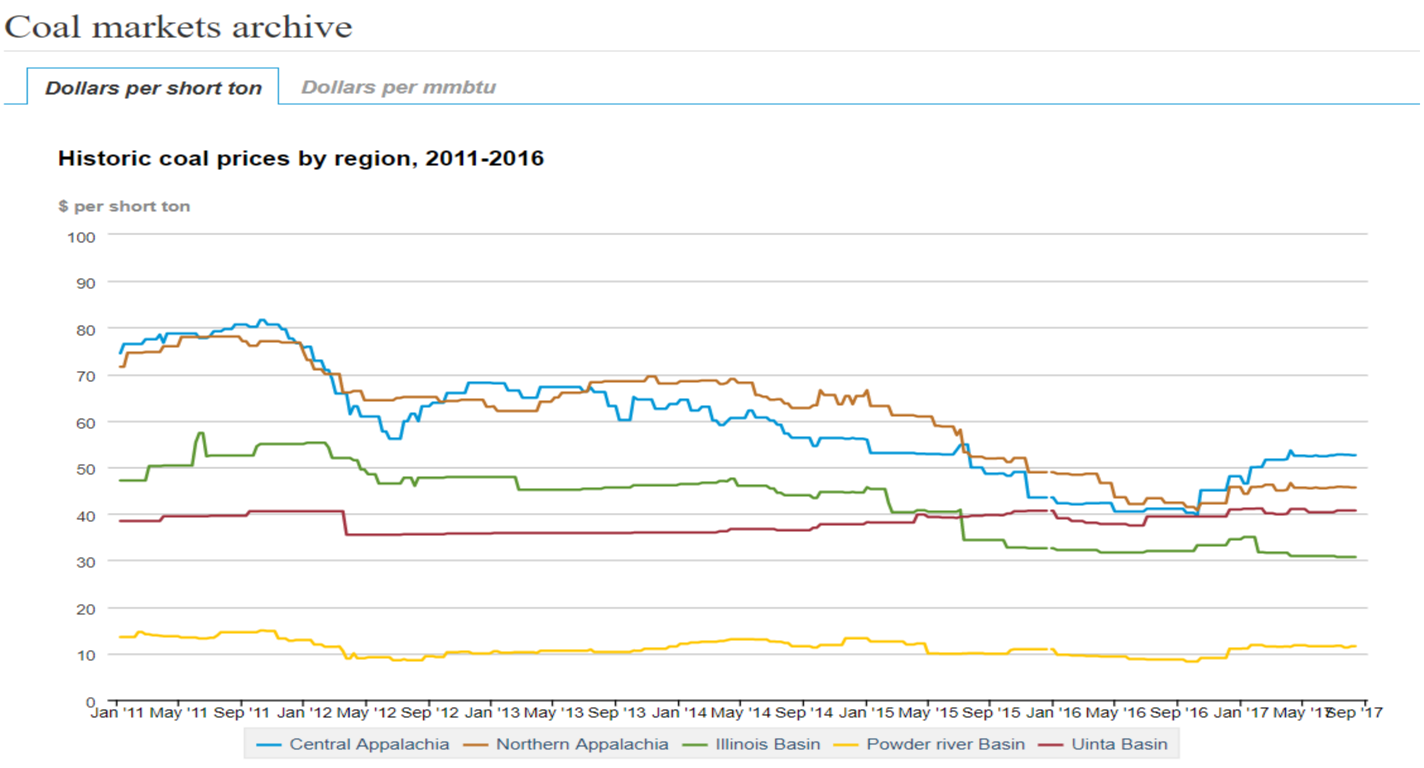
Natural Gas Prices 1997 to 2018



Marginal cost for natural gas fired electricity price in $/MWh is about 7-10 times gas price

Source: http://www.eia.gov/dnav/ng/hist/rngwhhdW.htm

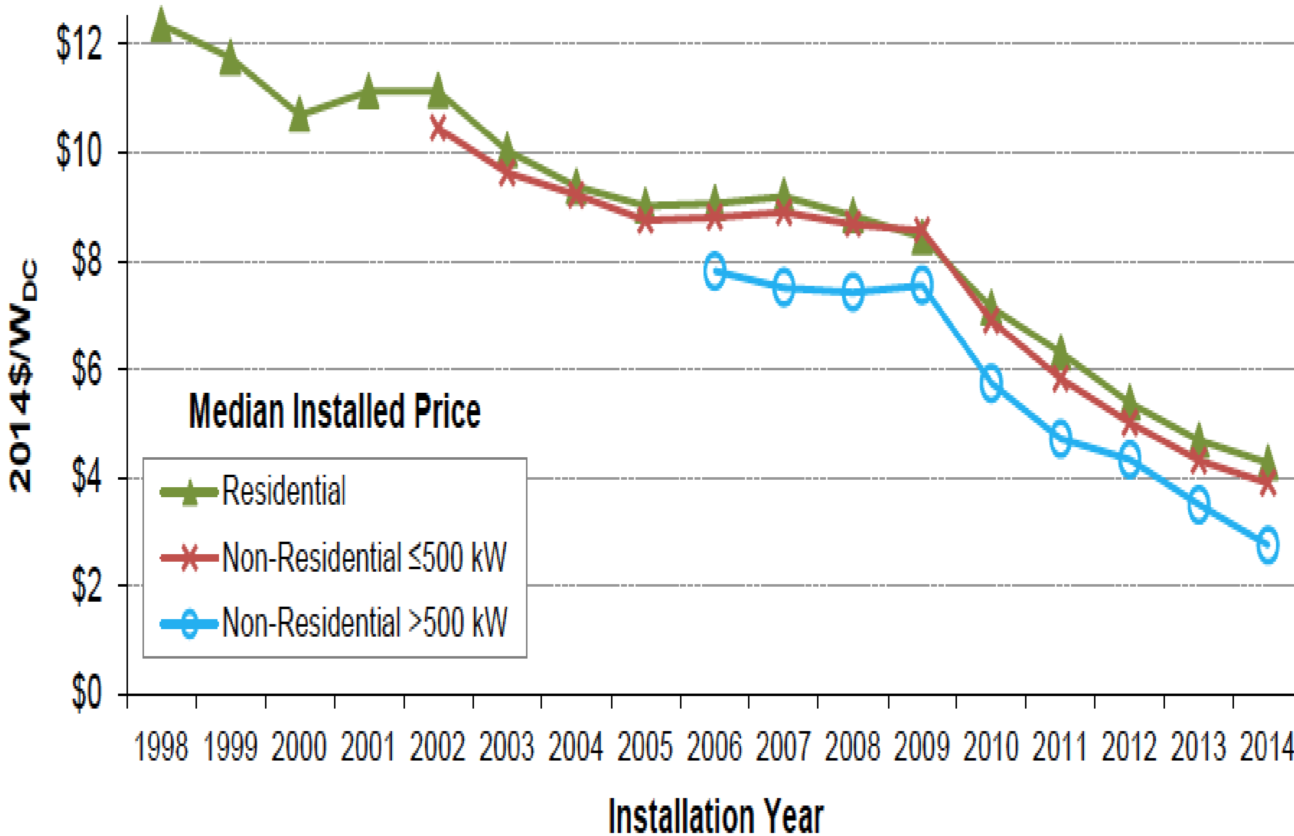
Coal Prices had Fallen But Are Now Back to Values from Five Years Ago

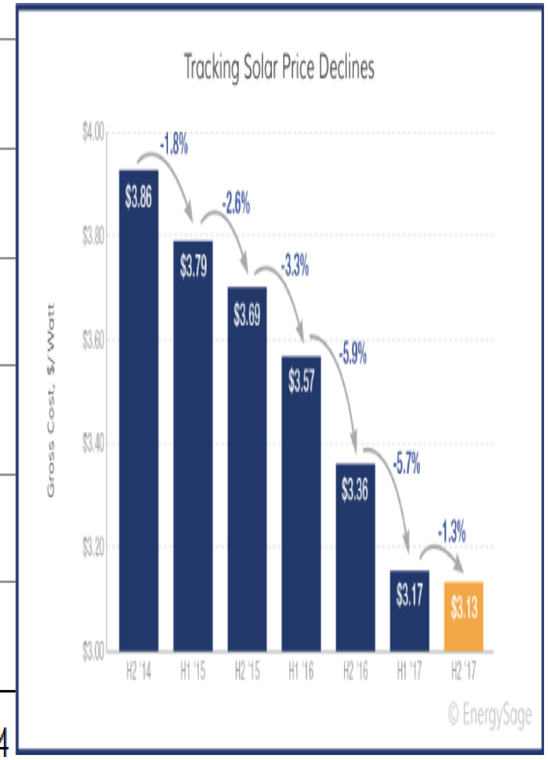


BTU content per pound varies between about 8000 and 15,000 Btu/lb, giving costs of around $1 to 2/Mbtu

Source: eia.gov/coal

Solar PV Prices





Note: Median installed prices are shown only if 20 or more observations are available for a given year and customer segment.

Images: http://cleantechnica.com/2015/08/13/us-solar-pv-cost-fell-50-5-years-government-report/screen-shot-2015-08-12-at-12-33-53-pm/ and https://news.energysage.com/how-much-does-the-average-solar-panel-installation-cost-in-the-u-s/

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

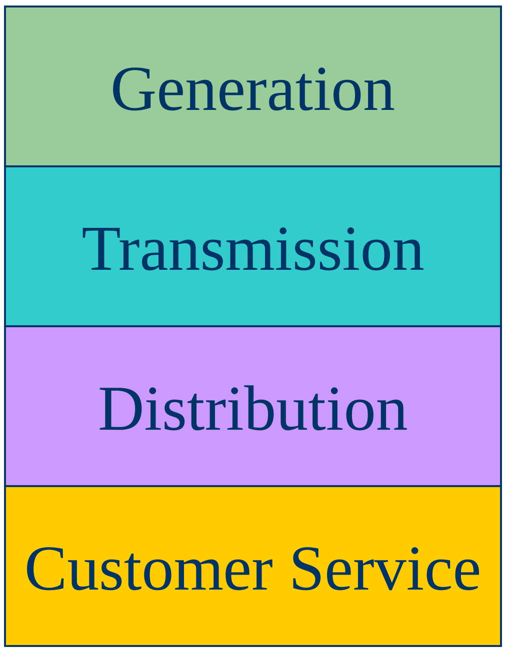
- 1896 – ac lines deliver electricity from hydro generation at Niagara Falls to Buffalo, 20 miles away; also 30kV line in Germany
- Early 1900's – Private utilities supply all customers in area (city); recognized as a natural monopoly; states step in to begin regulation
- By 1920's – Large interstate holding companies control most electricity systems

History, cont'd

- 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
- Frequency standardized in the 1930's

Vertical Monopolies

- Within a particular geographic market, the electric utility had an exclusive franchise



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

It was a “cost plus” business

Vertical Monopolies

- Within its service territory each utility was the only game in town
- Neighboring utilities functioned more as colleagues than competitors
- Utilities gradually interconnected their systems so by 1970 transmission lines crisscrossed North America, with voltages up to 765 kV
- Economies of scale keep resulted in decreasing rates, so most every one was happy

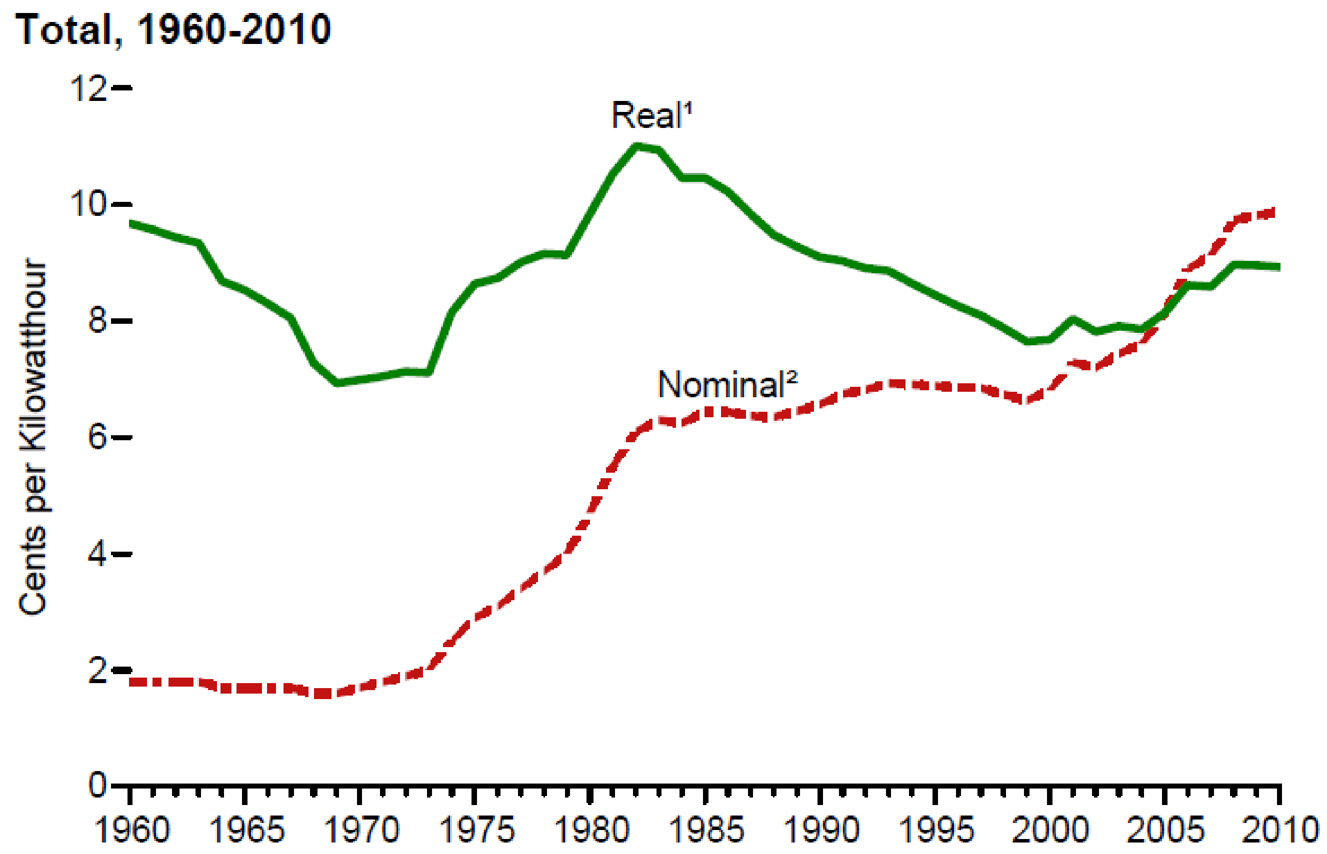
History, cont'd -- 1970's

- 1970's brought inflation, increased fossil-fuel prices, calls for conservation and growing environmental concerns
- Increasing rates replaced decreasing ones
- As a result, U.S. Congress passed Public Utilities Regulator Policies Act (PURPA) in 1978, which mandated utilities must purchase power from independent generators located in their service territory (modified 2005)
- PURPA introduced some competition

History, cont'd – 1990's & 2000's

- Major opening of industry to competition occurred as a result of National Energy Policy Act of 1992
- This act mandated that utilities provide "nondiscriminatory" access to the high voltage transmission
- Goal was to set up true competition in generation
- Result over the last few years has been a dramatic restructuring of electric utility industry (for better or worse!)
- Energy Bill 2005 repealed PUHCA; modified PURPA

Electricity Prices, 1960-2010

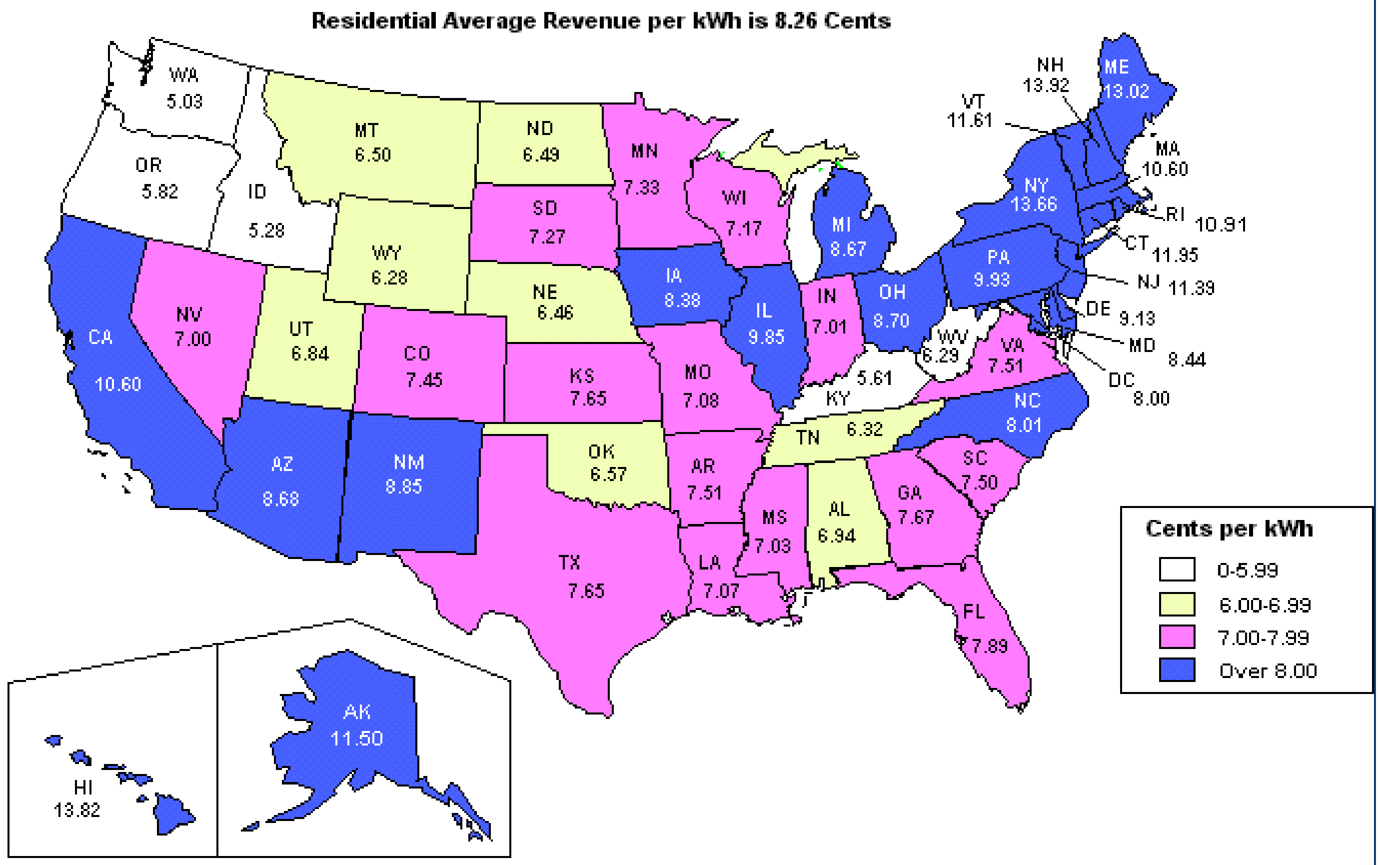


Source: EIA, Annual Energy Review, 2010, Figure 8.10

Utility Restructuring

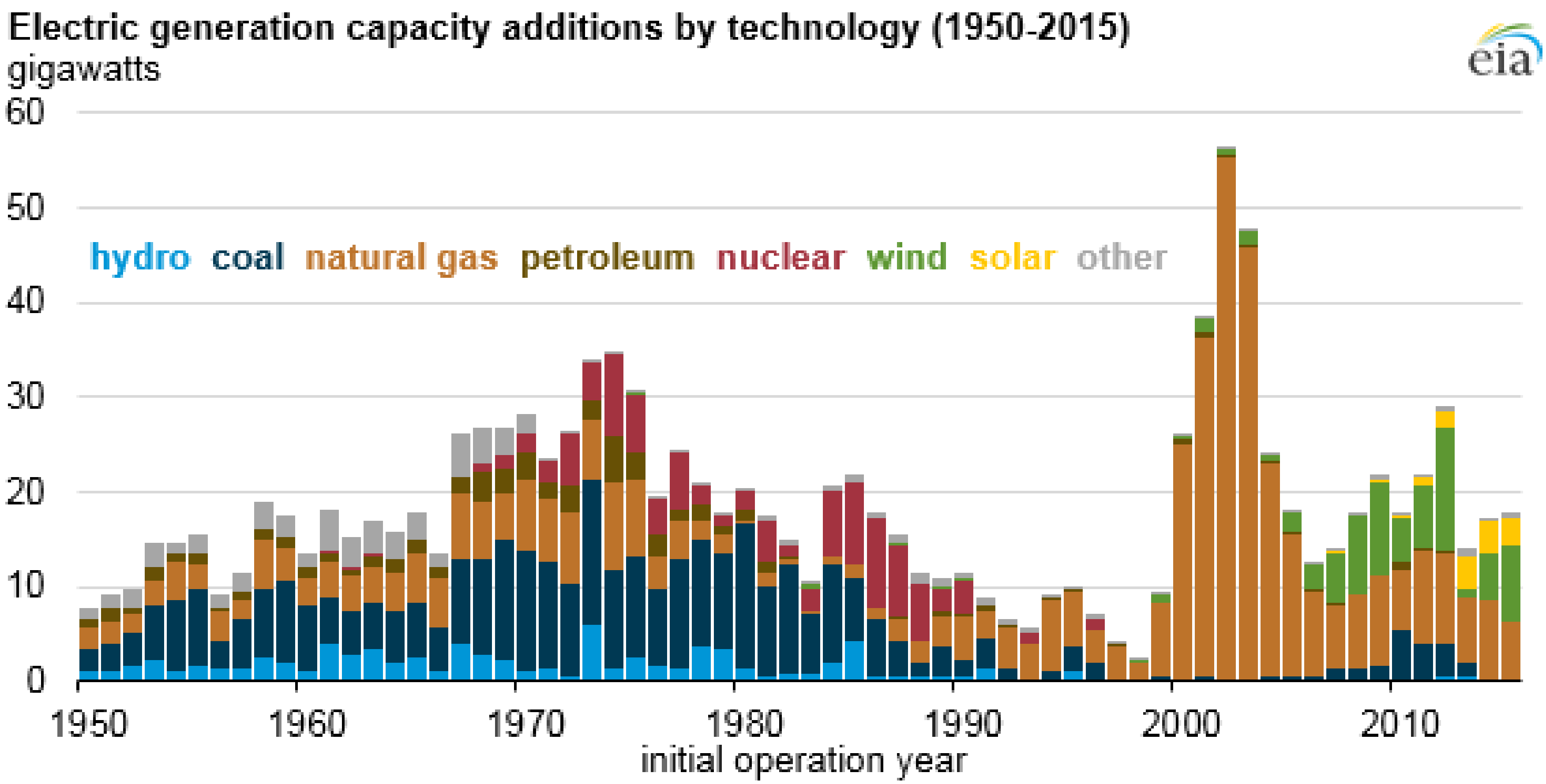
- Driven by significant regional variations in electric rates
- Goal of competition is to reduce rates through the introduction of competition
- Eventual goal is to allow consumers to choose their electricity supplier

State Variation in Electric Rates



KWh = Kilowatthour.
Note: The average revenue per kilowatthour of electricity sold is calculated by dividing revenue by sales.
Source: Energy information Administration, Form EIA-861, "Annual Electric Utility Report."

The Rise of Natural Gas Generation



Source: US EIA, 2016

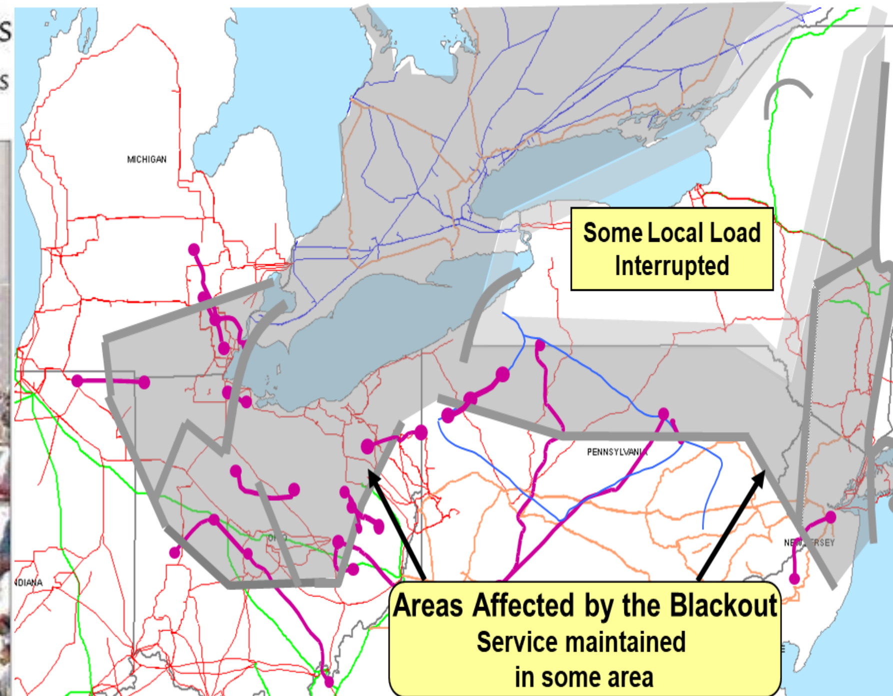
August 14th, 2003 Blackout

Blackout misery

50 million affected in Northeast and beyond as power grid fails

Transportation Many 'wait it out,' by air and land ■ 4A | **Scenes** Moms in labor, cars stuck in car washes ■ 5A | **Impact** Offices close, ATMs idle, cellphones jam ■ 1B

Brooklyn Bridge: Thousands of commuters in New York took to their feet Thursday evening after a major power outage hit the city and much of the Northeast.



Above image from energy.gov, August 14, 2003 Blackout Final Report