ECEN 615
Methods of Electric Power Systems Analysis

Lecture 1: Power Systems Overview

Prof. Tom Overbye
Dept. of Electrical and Computer Engineering
Texas A&M University
overbye@tamu.edu

TEXAS A&M UNIVERSITY

Syllabus

ECEN 615 – Methods of Electric Power Systems Analysis
Fall 2019 TR 12:45 - 2pm ETB 1037

Instructor: Prof. Tom Overbye, 308C WEB, overbye@tamu.edu
Office Hours: Mondays 1-3 pm or by appointment
Instructor Website: overbye.engr.tamu.edu
Course Website: https://overbye.engr.tamu.edu/course-2/ecen615fa2019/
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: Yijing Liu, yiji21@tamu.edu
TA Office Hours: Wednesday 10 to noon in 308N WEB

Evaluation:	Exam 1	30%
	Exam 2	30%
	Homework, projects	40%

Tentative Date for Exam 1: Tueday, October 8, In Class

Tentative Date for Exam 2: Thursday, November 21, In Class

Notesheets for Exams: All exams are closed-book, closed-notes. You may bring in one notesheet (8.5" by 11"), and may use 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
- High Impact, Low Frequency Events

Announcements

- Start reading chapters 1 to 3 from the book (more background material)
- Download the 42 bus educational versions of PowerWorld Simulator and PowerWorld DS 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 28 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 2019

About Me: Nonprofessional

- Married to Jo
- Have three children: Tim, Hannah and Amanda
- We homeschooled our kids with Tim now a PhD student at TAMU, Hannah working at Stanford, and Amanda a junior at Belmont in environmental sciences
- Jo just finished a master's in counseling, we attend Grace Bible Church in College Station (and teach the 3^{rd} and 4^{th} graders sometimes); I am the faculty advisor for Christian Engineering Leaders; I also like swimming, biking and watching football (Aggies and Packers!)

About TA Yijing Liu

- Third year graduate student
  - BSc (EE, University of Electronic Science and Technology of China, China)
  - Research assistant since Fall, 2017
  - PhD Research Area
    - Power Systems Transient Stability Analysis
    - Power Systems Protection
  - Advisor: Prof. Tom Overbye
  - Hobbies: Movie, cooking, travelling
  - Award: Thomas W. Powell ’62 and Powell Industries Inc. Fellowship

Cancun, Mexico, 2018

The control room at the A&M Center for Infrastructure Renewal (CIR)

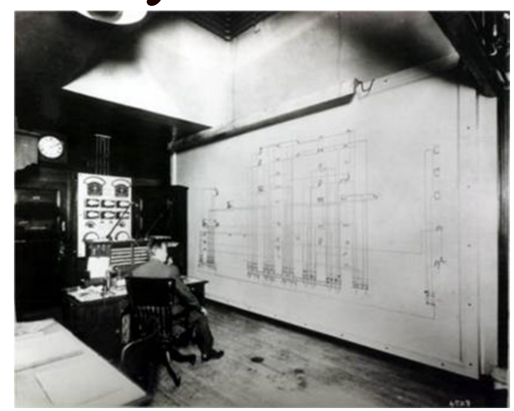
Electric Grid Control Room at CIR

TAMU ECE Energy and Power Group Picnic: September 27, 2019

This picture is from our event last spring. If you would like to join us this year, RSVP to Alex Bello (zandra23@ece.tamu.edu)

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

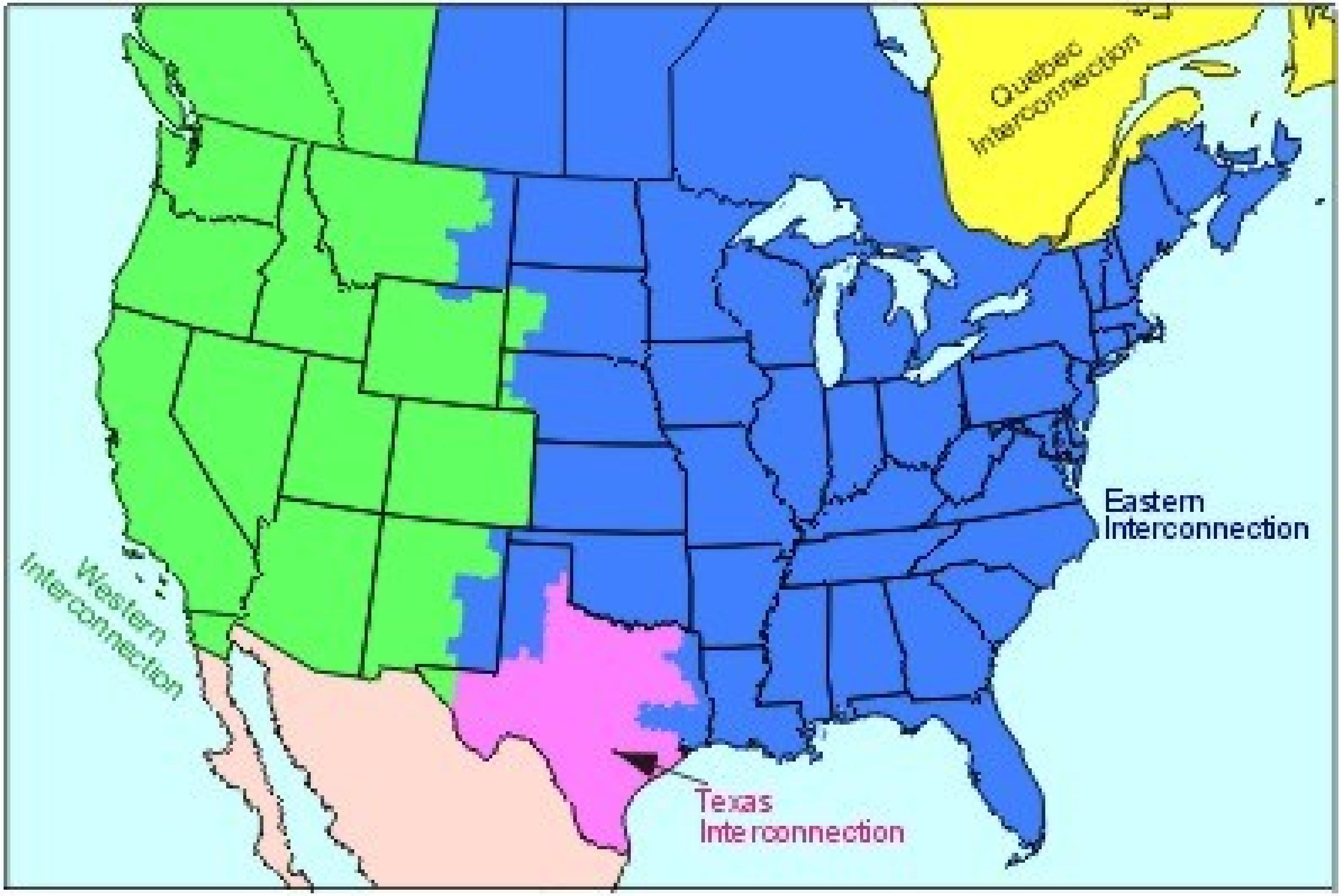
- In 2000 the US National Academy of Engineering (NAE) named Electrification (the vast networks of electricity that power the developed world) as the top engineering technology of the 20th century
  - Beating automobiles (2), airplanes (3), water (4), electronics (5)
  - Electricity has changed the world!
- For the 21th century the winner could be "Development of a sustainable and resilient electric infrastructure for the entire world"



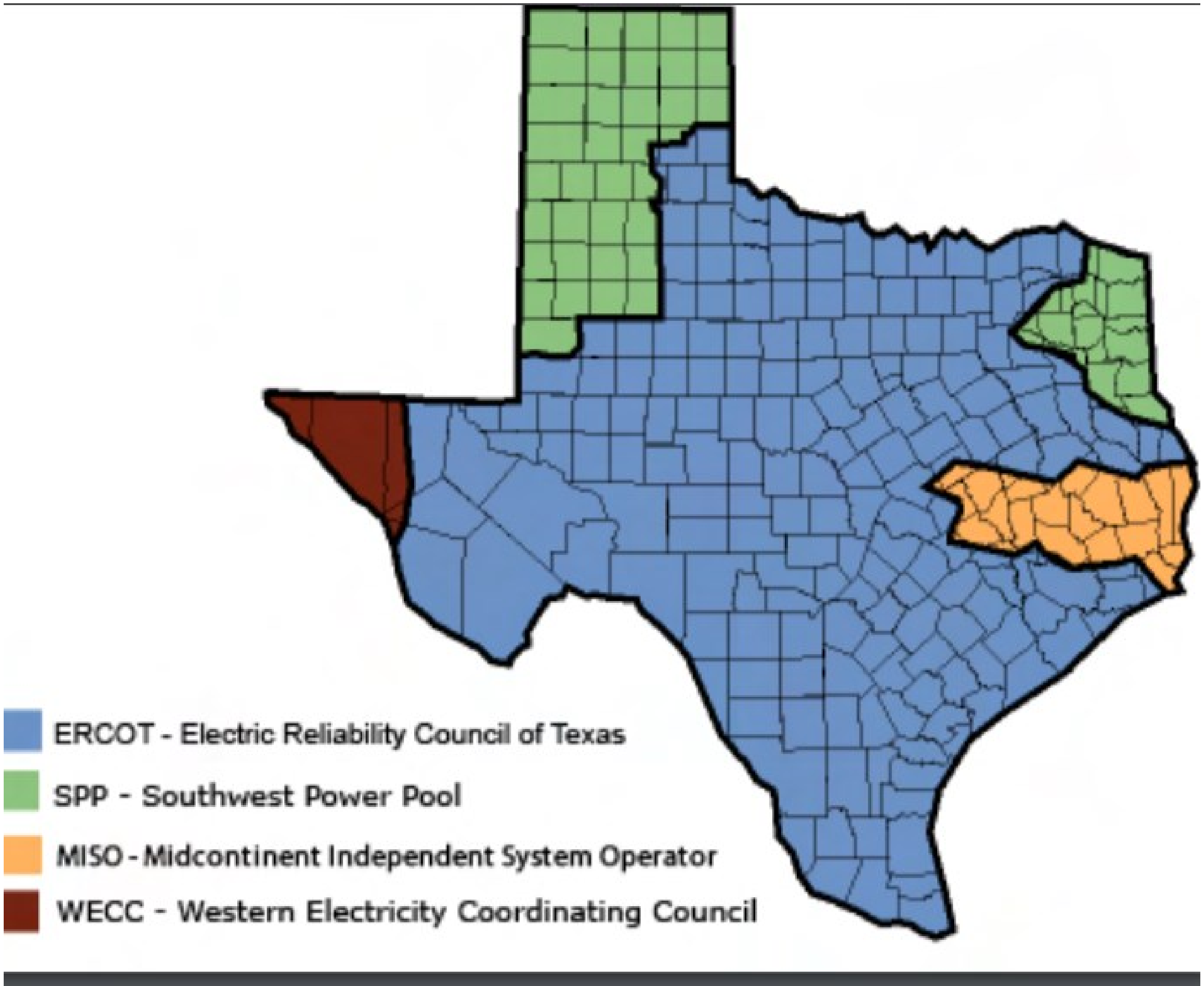
Power System Examples

- 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

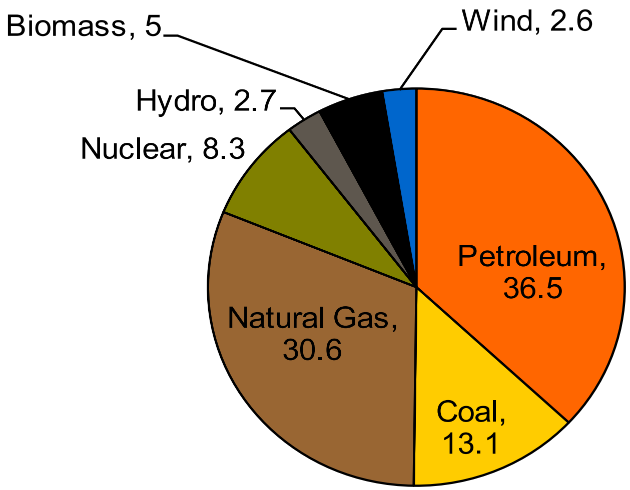


Source: www.puc.texas.gov/industry/maps/maps/ERCOT.pdf

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 CO_2 emissions and fossil fuel depletion are becoming main drivers for change in world energy infrastructure

Looking at the 2018 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 2018 we got about 2.5% of our energy from wind and 0.94% from solar (PV and solar thermal), 2.7% from hydro

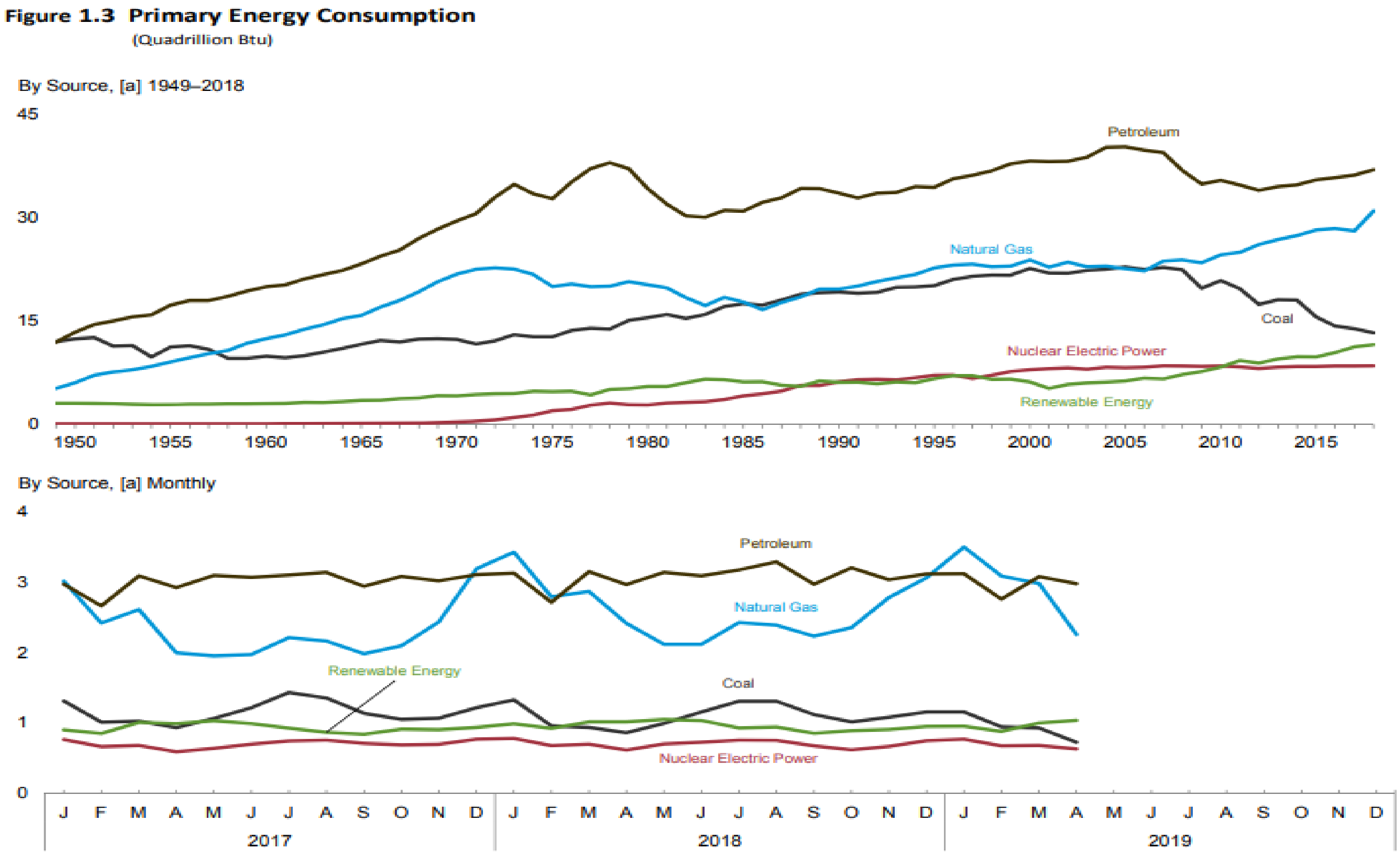
About 80% Fossil Fuels (89% in 1980 and 85% in 2000)

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

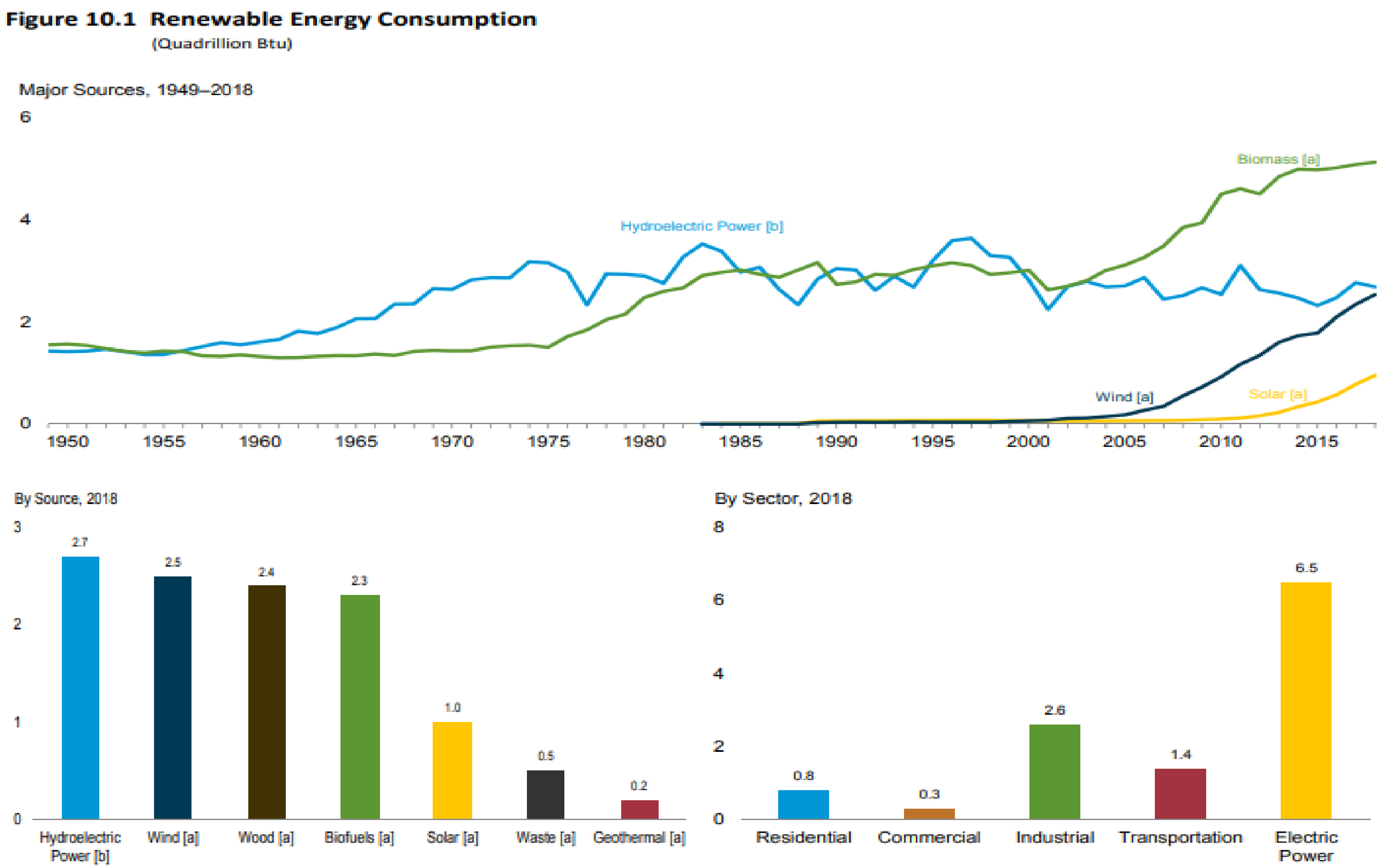
Source: EIA Monthly Energy Review, July 2019

US Historical Energy Usage



Source: EIA Monthly Energy Review, July 2019

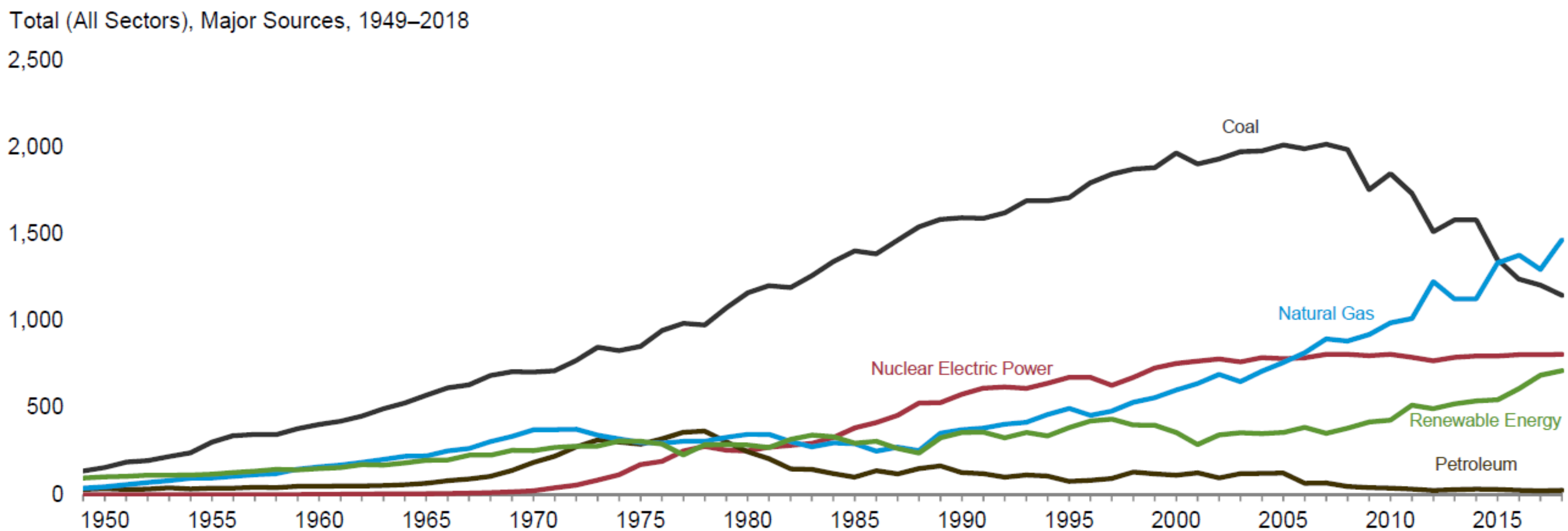
Renewable Energy Consumption



Source: EIA Monthly Energy Review, July 2019

US Electricity Generation

Figure 7.2 Electricity Net Generation
(Billion Kilowatthours)

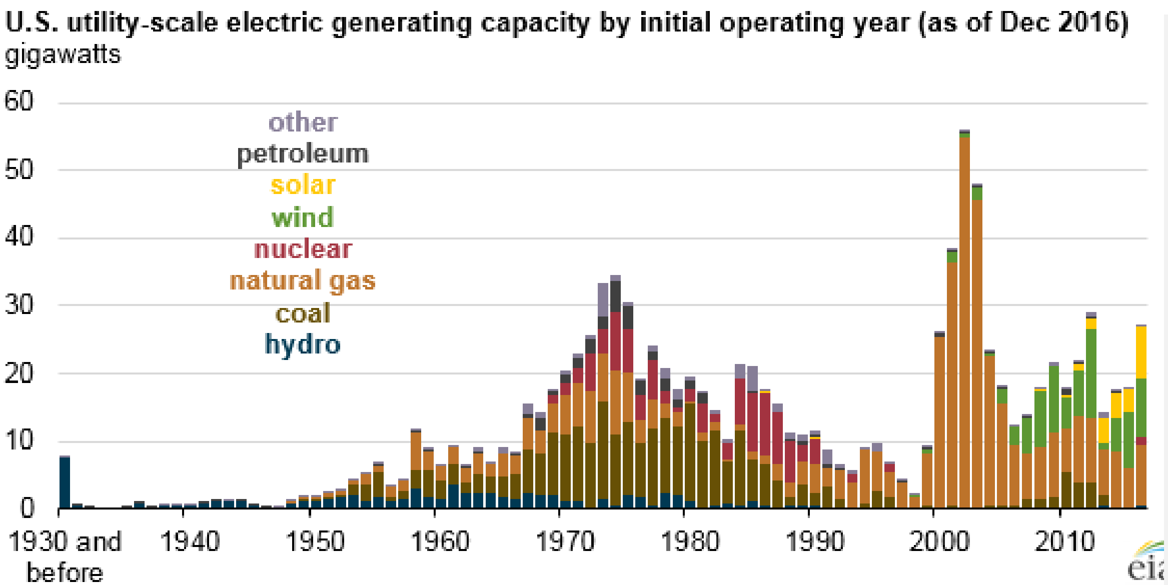


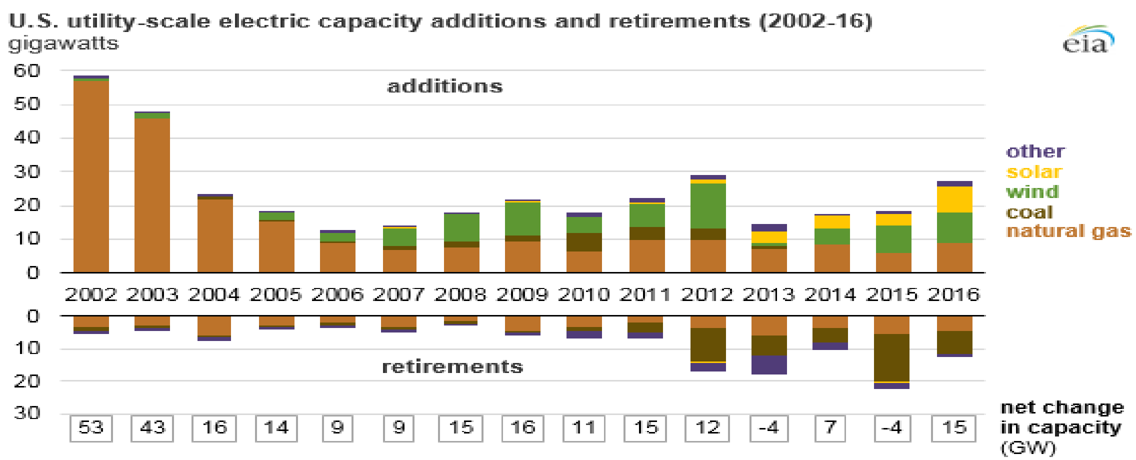
In 2018 the major sources were natural gas (35.5%), coal (26.8%), nuclear (19.2%), hydro (6.8%), wind (6.4%), and solar (2.3%)

Wind and solar are rapidly growing (11% and 25% growth in 2018) though the growth is slowing (solar was a over 100% from 2012-13)

Source: EIA Monthly Energy Review, July 2019

US Generator Capacity Additions



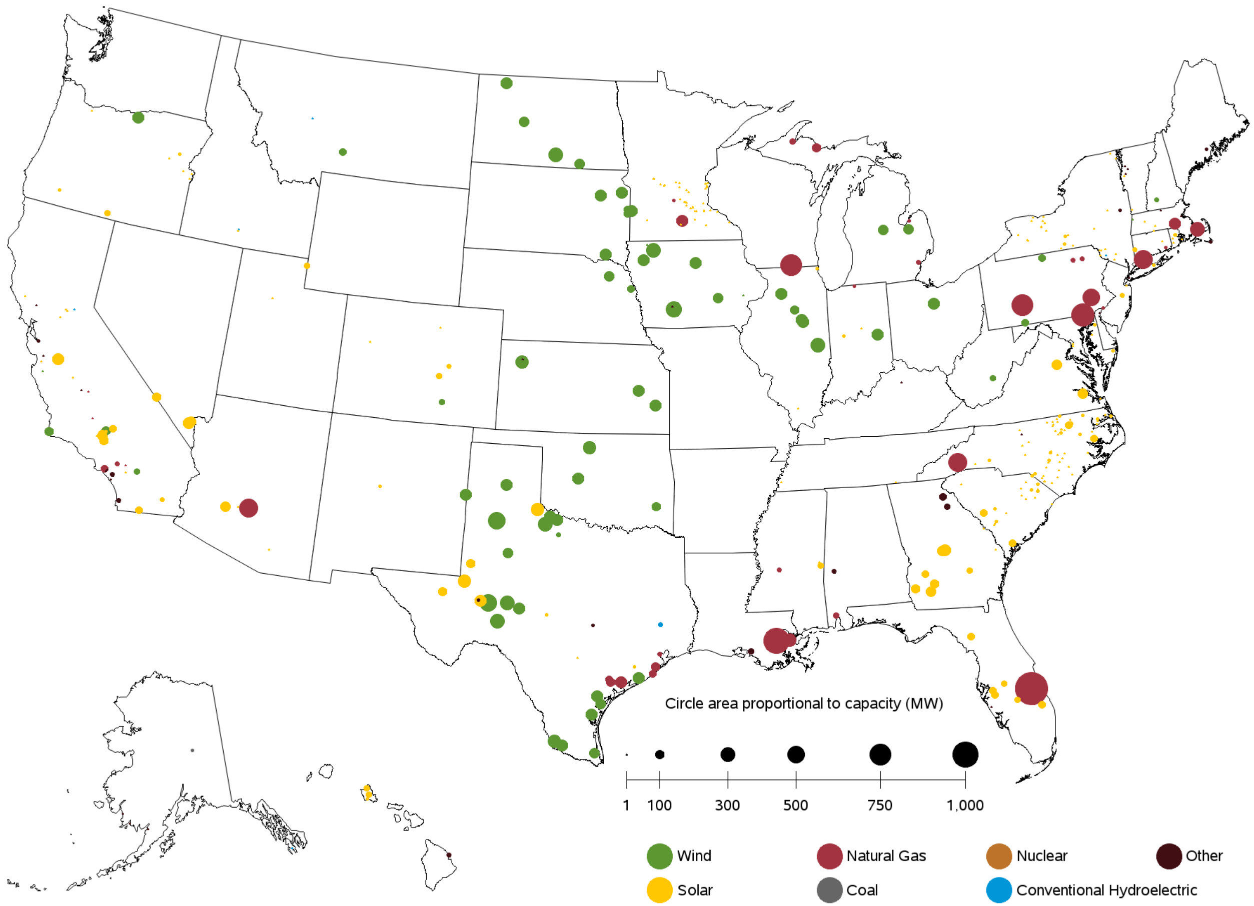


Natural gas and wind generation additions in the last decade dwarfed all other technologies, but with solar rapidly growing. The gas generation, and low natural gas prices were partially responsible for the recent decrease in carbon dioxide emissions.

Sources: www.eia.gov/todayinenergy/detail.php?id=25432

New Generation March 2019 to Feb 2020

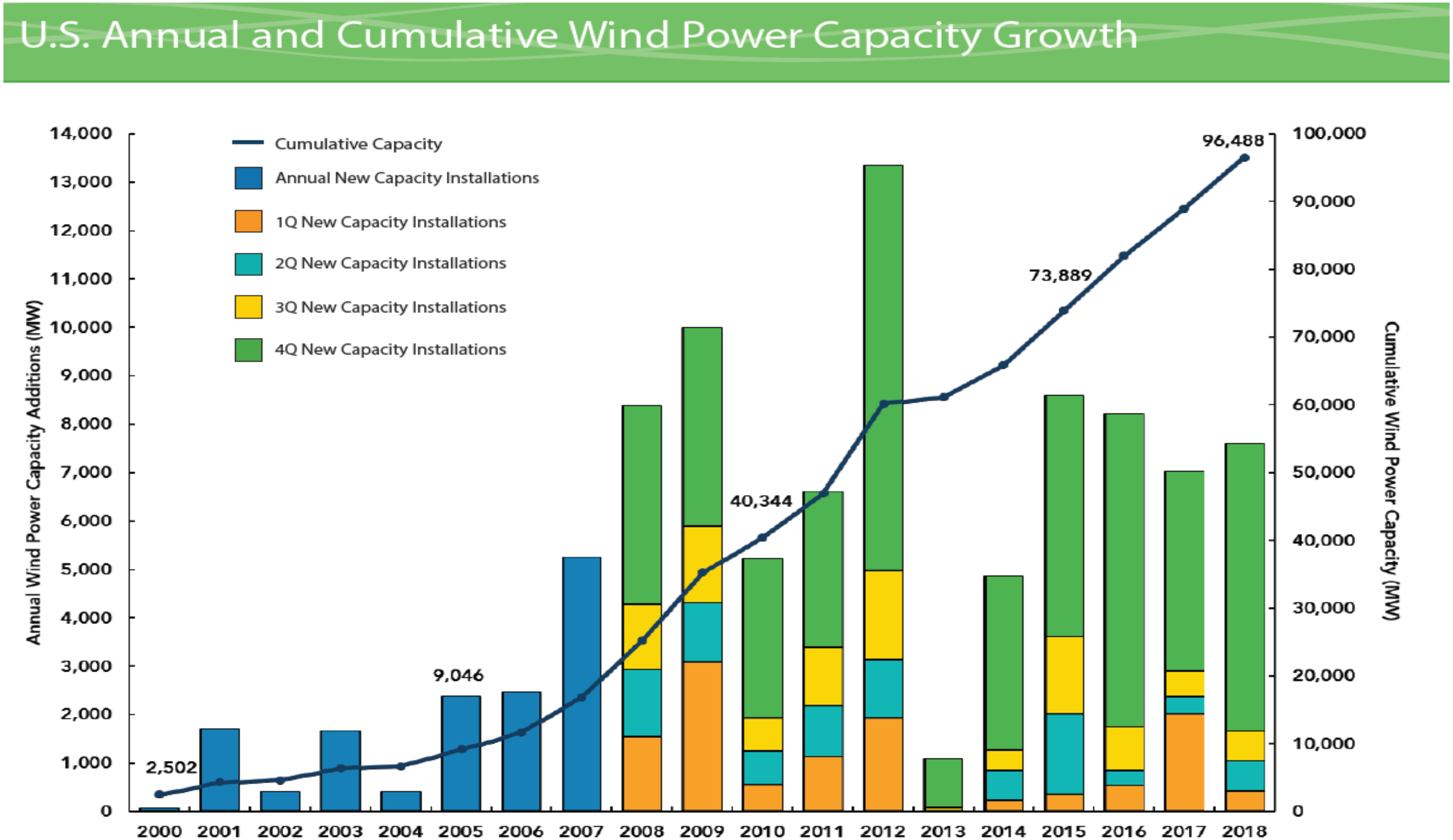
Figure 6.1.C. Utility-Scale Generating Units Planned to Come Online from March 2019 to February 2020



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.'

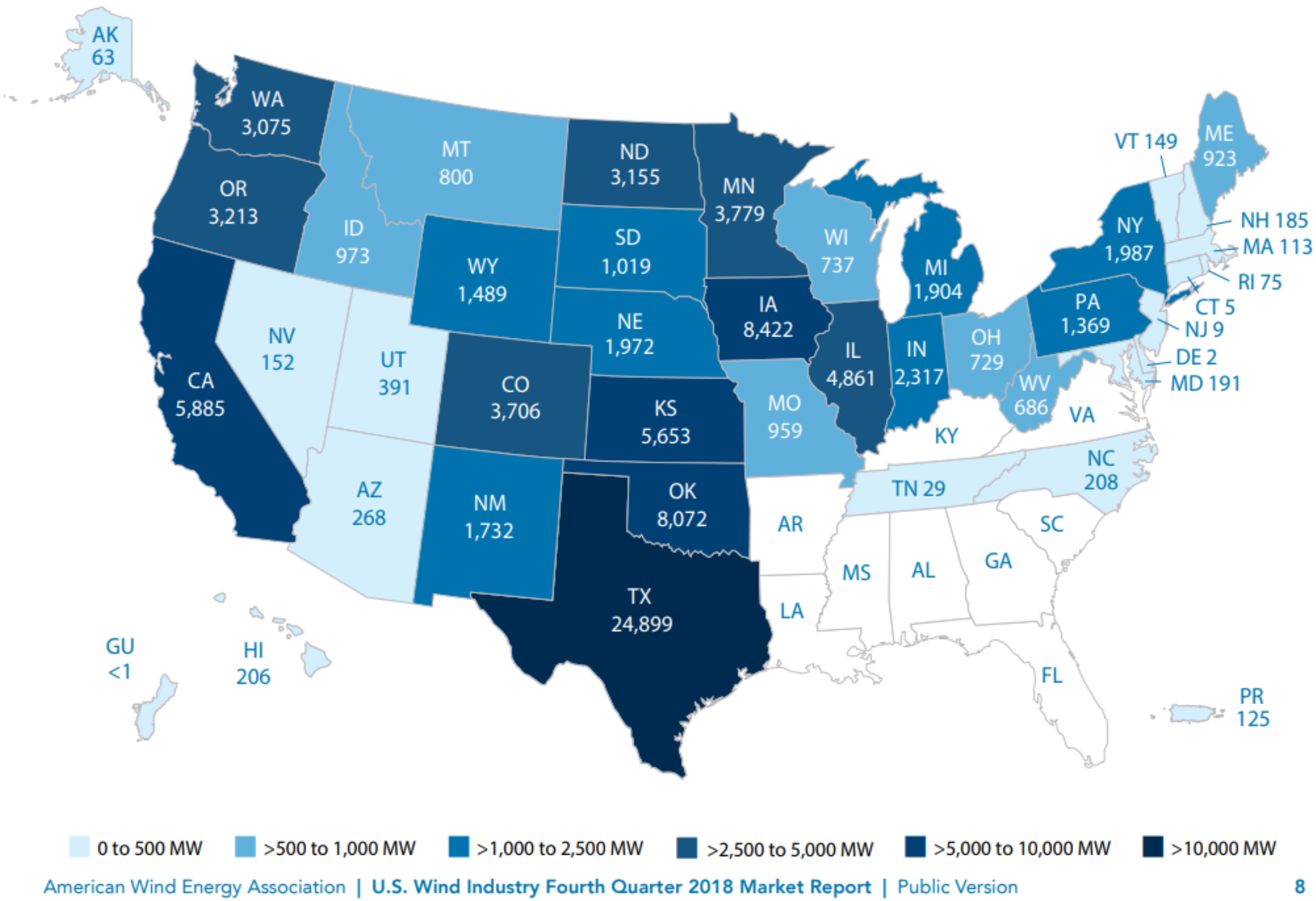
Sources: EIA Electricity Monthly, April 2019

Growth in US Wind Power Capacity



Source: AWEA Wind Power Outlook Fourth Quarter, 2018

Wind Capacity Installations by State

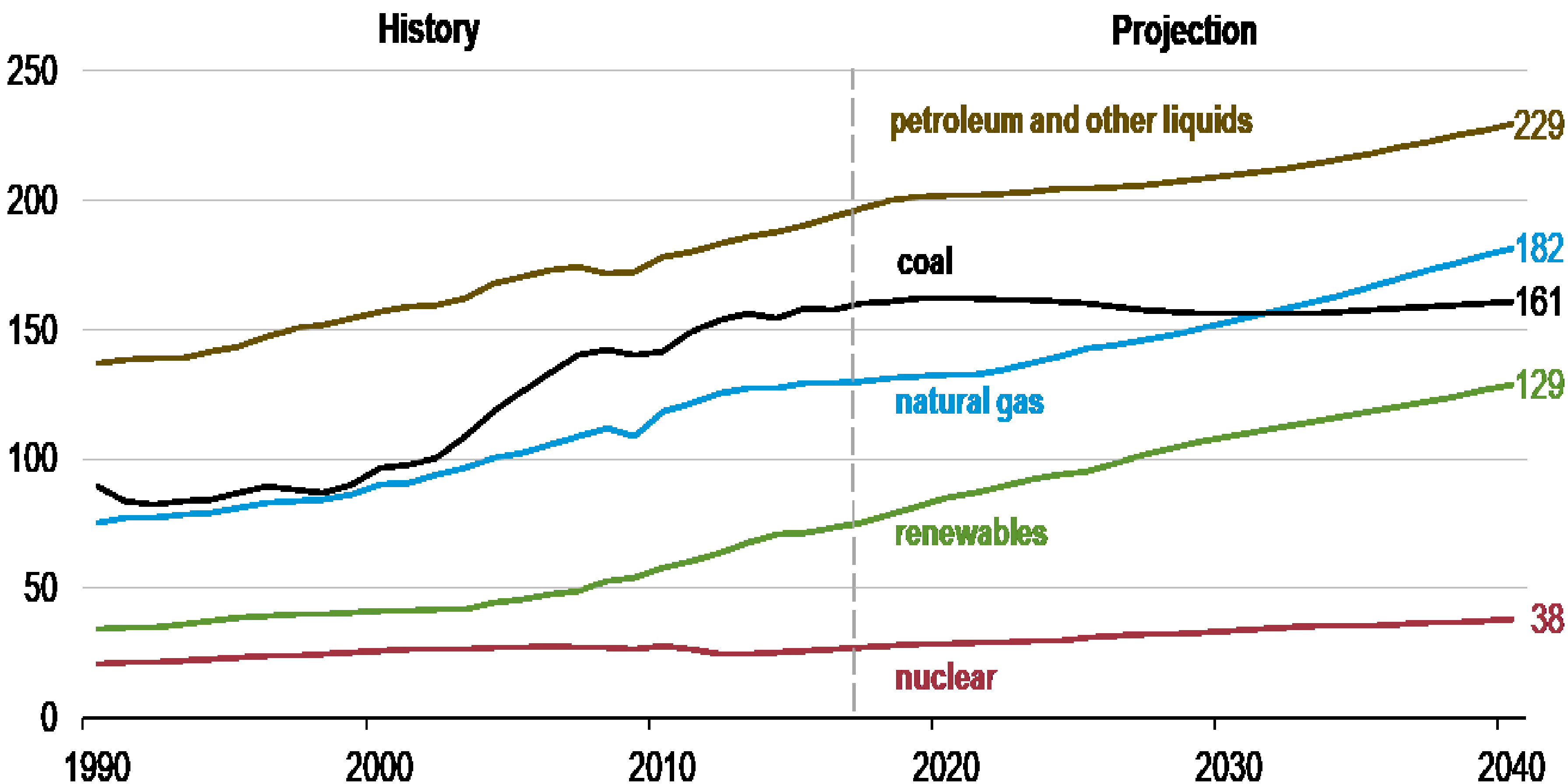


Texas is number one!

Total capacity at end of 2017 was 89 GW and 96.5 at the end of 2018

Source: AWEA Wind Power Outlook Fourth Quarter, 2018

The World: Energy Consumption by Source



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

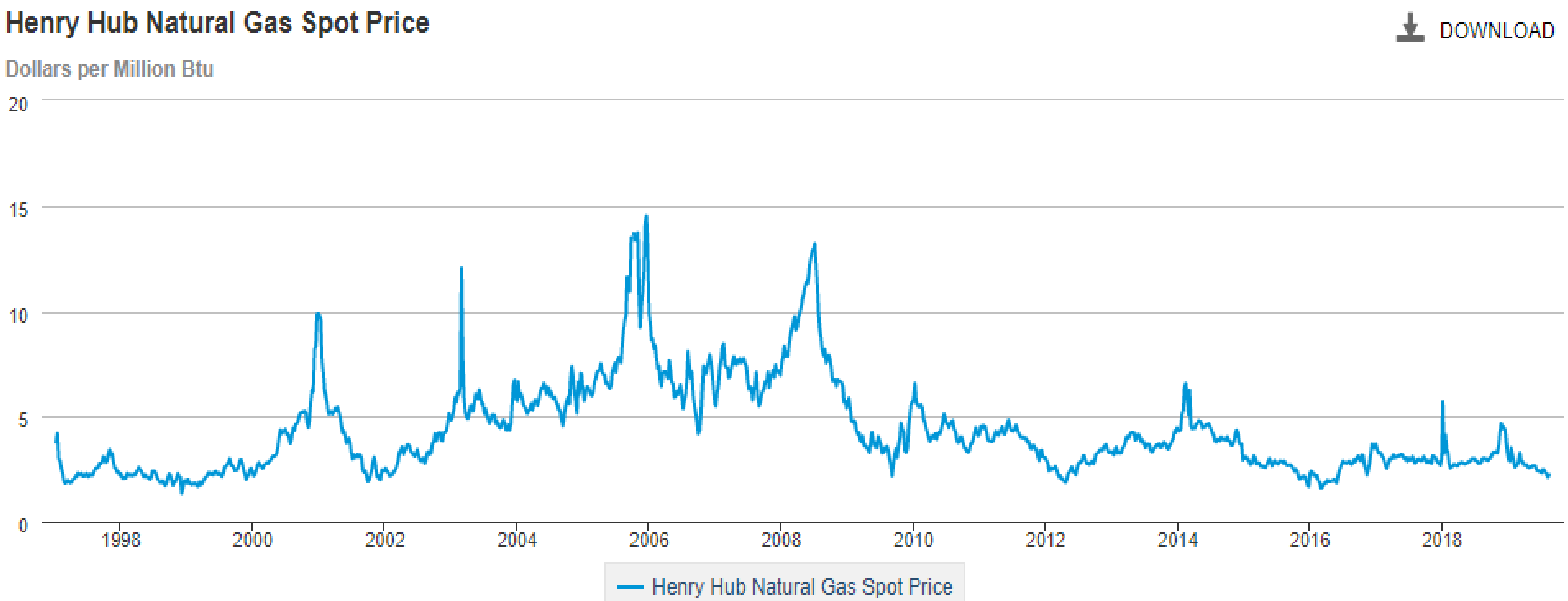
Estimated Energy Costs for New Generation

Table 1b. Estimated levelized cost of electricity (unweighted average) for new generation resources entering service in 2023 (2018 $/MWh)

Plant type	Capacity factor (%)	Levelized capital cost	Levelized fixed O&M	Levelized variable O&M	Levelized transmis-sion cost	Total system LCOE	Levelized tax credit[1]	Total LCOE including tax credit
Dispatchable technologies								
Coal with 30% CCS[2]	85	61.3	9.7	32.2	1.1	104.3	NA	104.3
Coal with 90% CCS[2]	85	50.2	11.2	36.0	1.1	98.6	NA	98.6
Conventional CC	87	9.3	1.5	34.4	1.1	46.3	NA	46.3
Advanced CC	87	7.3	1.4	31.5	1.1	41.2	NA	41.2
Advanced CC with CCS	87	19.4	4.5	42.5	1.1	67.5	NA	67.5
Conventional CT	30	28.7	6.9	50.5	3.2	89.3	NA	89.3
Advanced CT	30	17.6	2.7	54.2	3.2	77.7	NA	77.7
Advanced nuclear	90	53.8	13.1	9.5	1.0	77.5	NA	77.5
Geothermal	90	26.7	12.9	0.0	1.4	41.0	-2.7	38.3
Biomass	83	36.3	15.7	39.0	1.2	92.2	NA	92.2
Non-dispatchable technologies								
Wind, onshore	41	39.8	13.7	0.0	2.5	55.9	-6.1	49.8
Wind, offshore	45	107.7	20.3	0.0	2.3	130.4	-12.9	117.5
Solar PV[3]	29	47.8	8.9	0.0	3.4	60.0	-14.3	45.7
Solar thermal	25	119.6	33.3	0.0	4.2	157.1	-35.9	121.2
Hydroelectric[4]	75	29.9	6.2	1.4	1.6	39.1	NA	39.1

Source: www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf (February 2019)

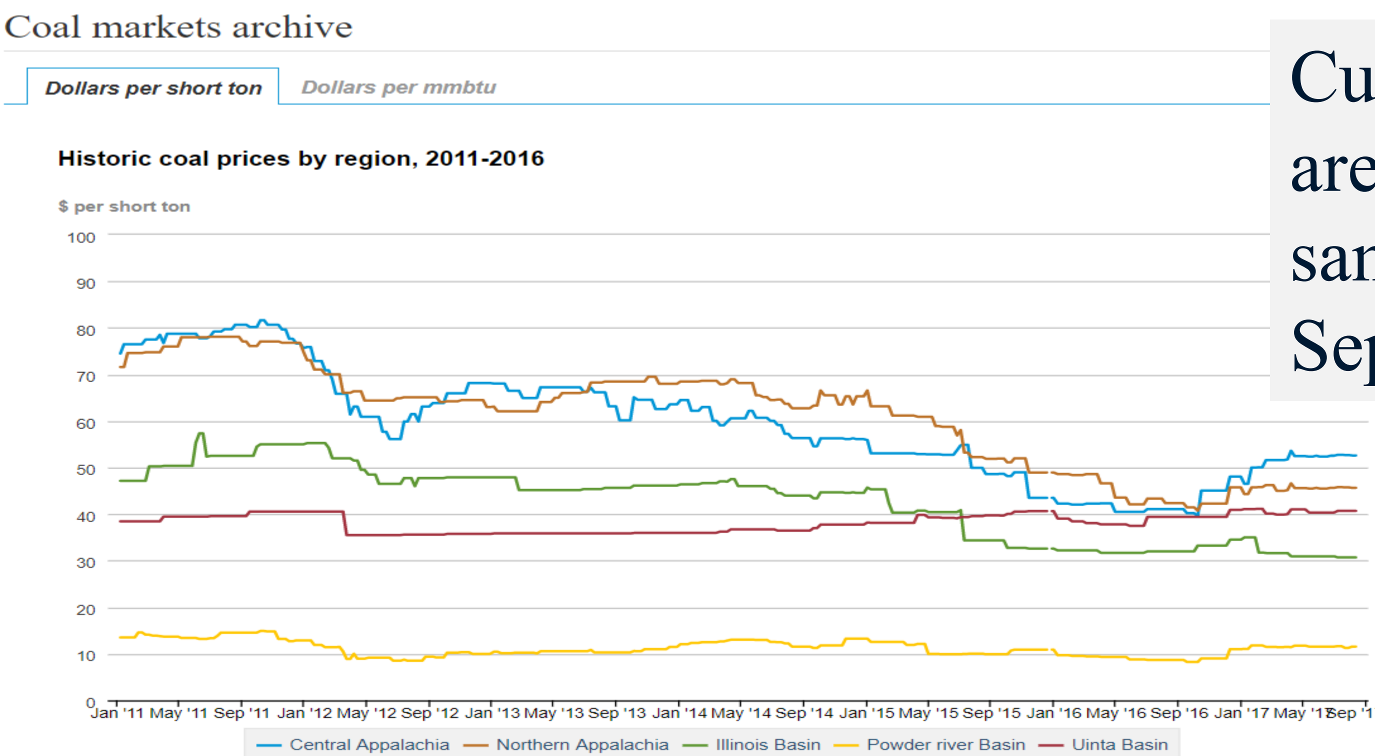
Natural Gas Prices 1997 to 2018



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.

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

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

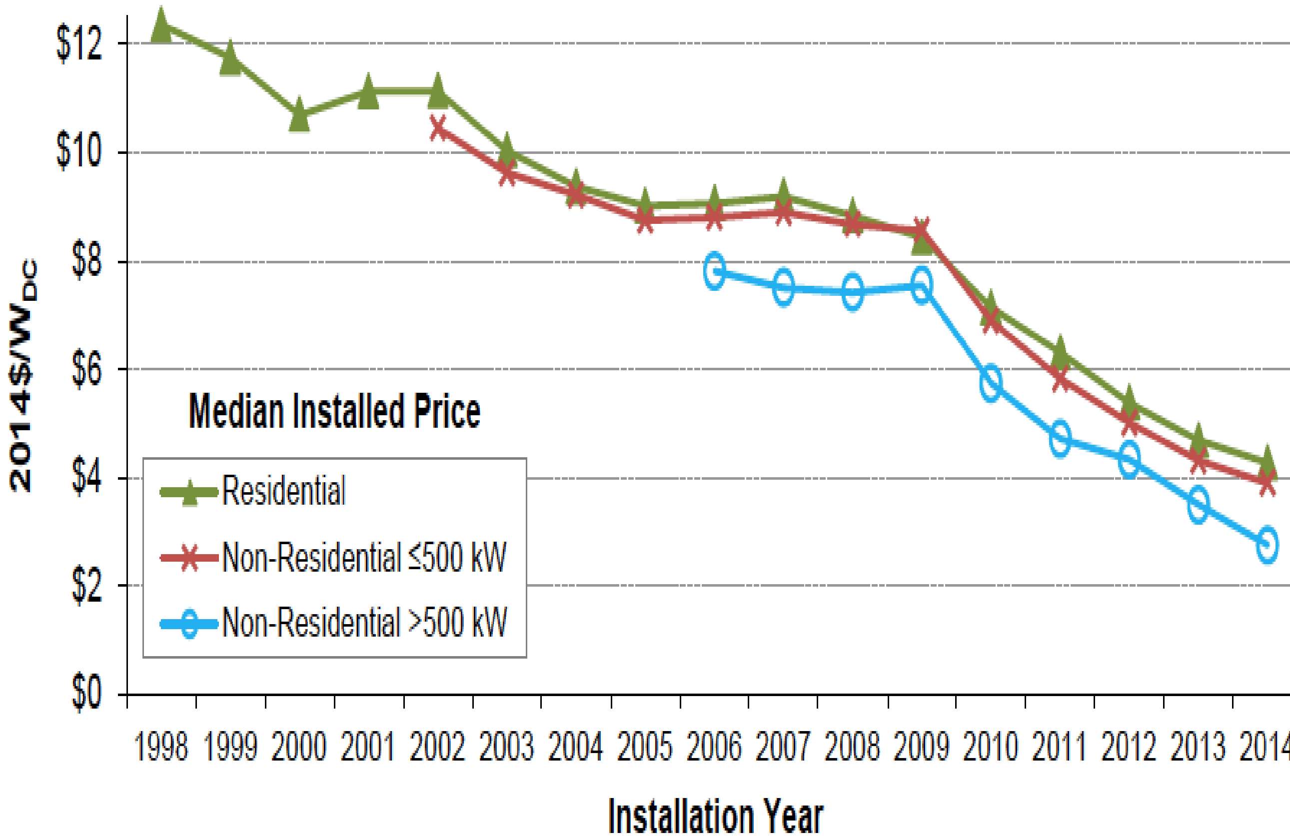


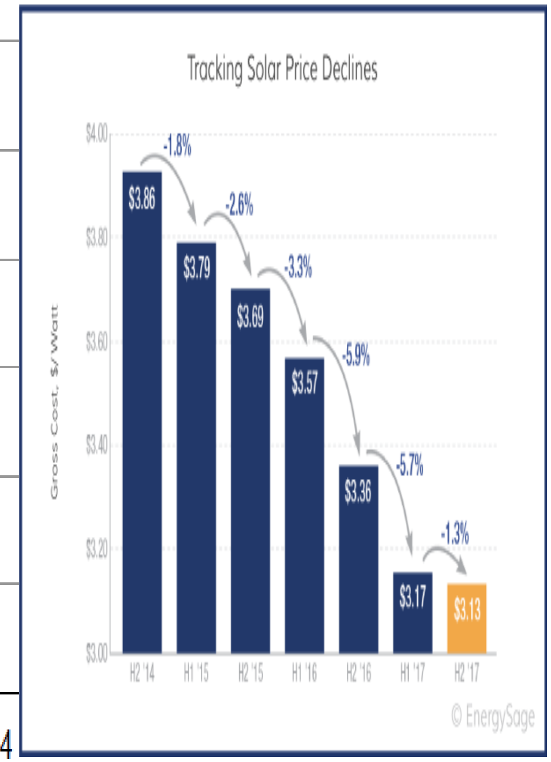
Current prices are about the same as in Sept. 2017

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/

Average Cost of Solar Systems, 2019

Average cost of solar panels based on system size

SYSTEM SIZE	AVERAGE SOLAR PANEL SYSTEM COST (BEFORE TAX CREDITS)	AVERAGE SOLAR PANEL SYSTEM COST (AFTER TAX CREDITS)
2 kW	$5,960	$4,172
3 kW	$8,940	$6,258
4 kW	$11,920	$8,344
5 kW	$14,900	$10,430
6 kW	$17,880	$12,516
7 kW	$20,860	$14,602
8 kW	$23,840	$16,688
10 kW	$29,800	$20,860
12 kW	$35,760	$25,032
15 kW	$44,700	$31,290
20 kW	$59,600	$41,720
25 kW	$74,500	$52,150

For the cost for a 10 kW system is $2.98 per watt before the tax credit and $ 20.86 after

These prices reflect the cost of a solar energy system both *before AND after* deducting the federal solar tax credit (known as the ITC), which reduces your solar system cost by 30 percent. Some states, local governments, and utilities also offer rebates and other tax incentives that can further reduce the solar system costs in your quotes from solar installers.

Source 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