ECE 333

Green Electric Energy Systems

Lecture 1

Introduction

Professor Andrew Stillwell

Department of Electrical and Computer Engineering

ECE 333 Class Info

- Lecture Time and Location
  - Tuesday/Thursday 9:30 – 10:50 am
  - ECEB 1015
- Course website: http://courses.engr.illinois.edu/ece333/

Teaching Staff

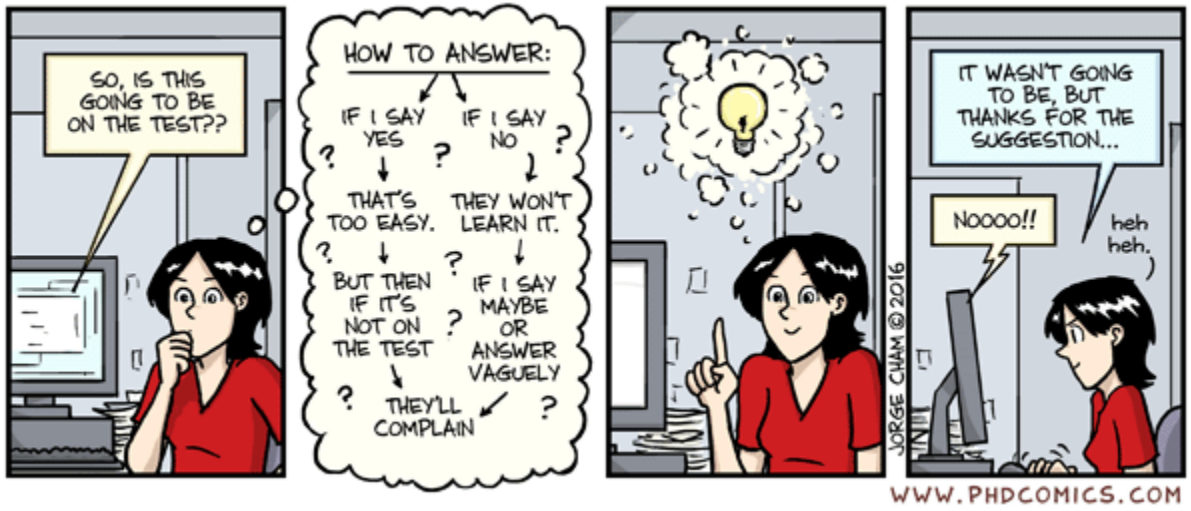
- Professor Andrew Stillwell
  - Office hours:
    - Tuesdays, 2:00-3:00pm in ECEB 4054
- TA: Theodore Mamalis
  - Office hours:
    - Wednesdays TBD. Will be posted on the website

Green Electric Energy Systems

- Course covers electric energy sources that are sustainable (won't diminish over time), excluding large-scale hydro
  - Focused primarily on the electric aspects of the sources
  - Focus on Wind and Solar energy
  - Course does **NOT** cover nuclear
  - Course does **NOT** cover biological resources (at least not in-depth)
  - Course is technical. This is **NOT** a survey course!
- Course prerequisite is ECE 205 or ECE 210

Spring 2019 Course Syllabus

- Topics (see syllabus on website)
  - General Introduction; Why Green Electric Energy?
  - Power Grid Basics
  - Wind Energy Conversion
  - The Solar Resource
  - Solar Energy Conversion



Spring 2019 Course Syllabus

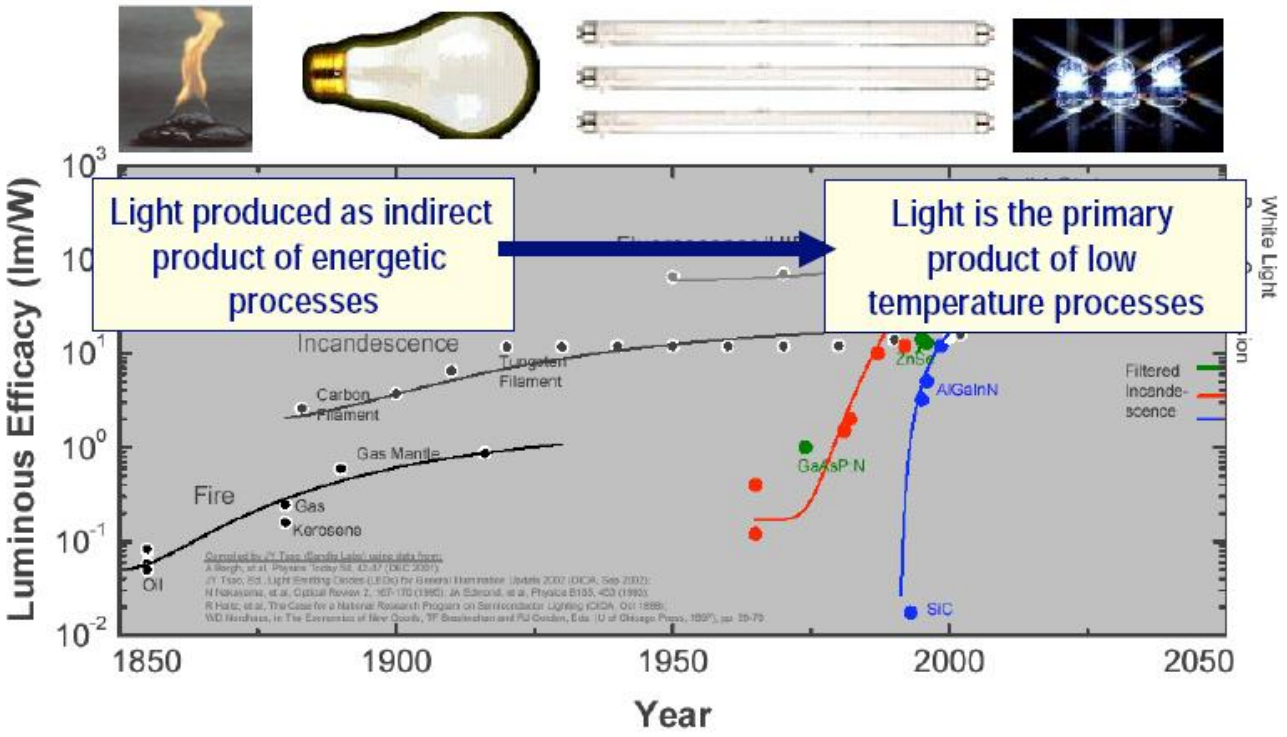
- Weekly HW (15% of final grade)
  - ~10 HWs
  - Drop lowest score
  - Due at beginning of class on Thursday
- 2 Exams (25% each)
  - In-class, closed book 1 sheet of notes
- Final Exam (30%)
- Participation worth (5%)
  - In class discussion
  - Office hours
  - Attendance
- Extra credit opportunities
  - EOH participation
  - Visiting lectures

With Energy, What Do We Want?

- To feel green?
- To use less energy?
- To have a higher standard of living?
- To decrease our carbon dioxide emissions now? In the future?
- To have more renewable energy?
- To have less expensive energy?
- To have jobs?
- To have it “Not in My Backyard (NIMBY)”

Engineers Have Long Been "Green"

- 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

Notation - Power

- Power: Instantaneous consumption of energy
- Power Units

  Watts = voltage x current for dc (W)

  kW – 1×10^3 Watt

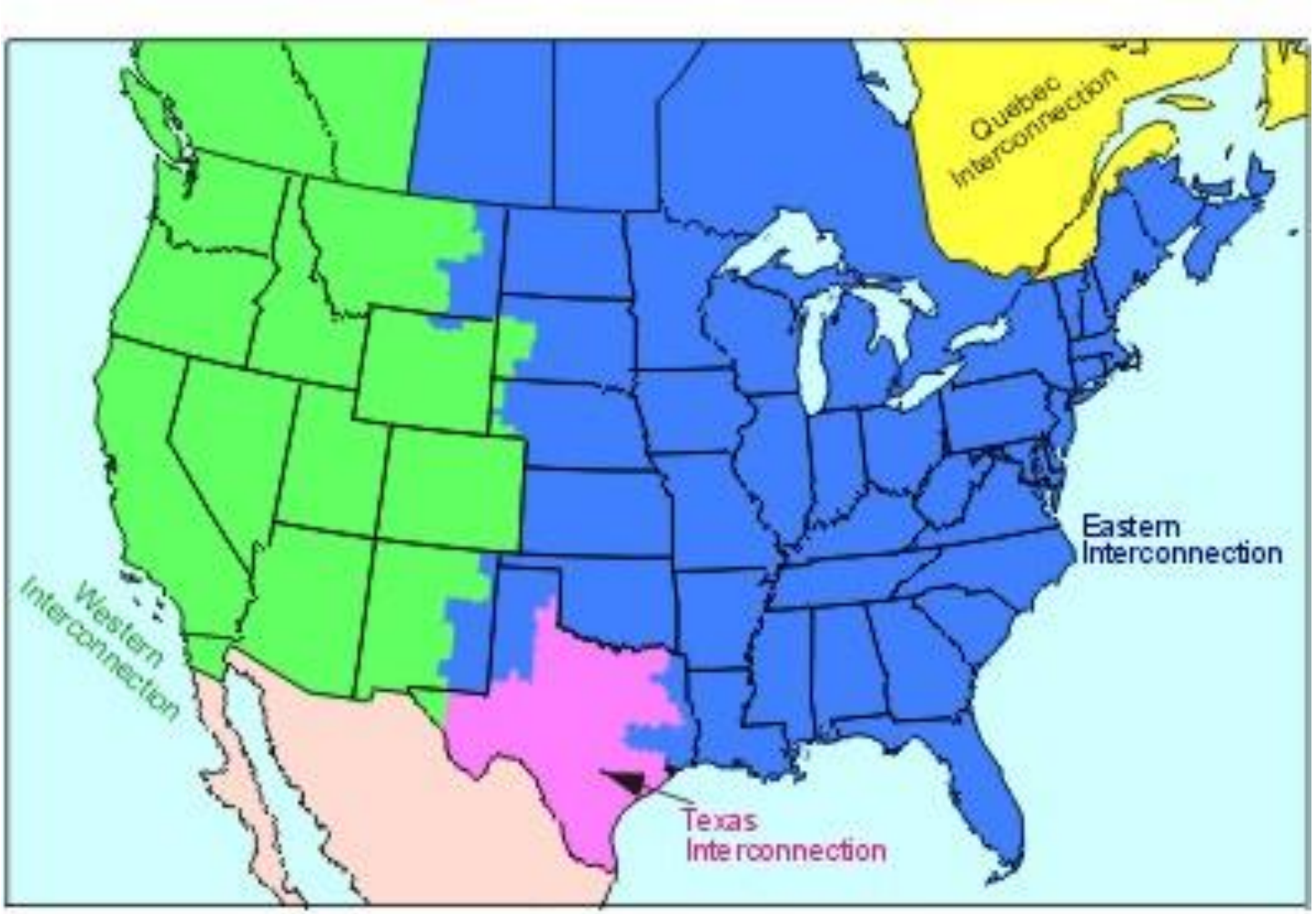
  MW – 1×10^6 Watt

  GW – 1×10^9 Watt
- Installed U.S. generation capacity is about 1000 GW (about 3 kW per person)
- Maximum load of Champaign/Urbana about 300 MW

Notation - Energy

- Energy: Integration of power over time; energy is what people really want from a power system
- Energy Units
  - Joule = 1 Watt-second (J)
  - kWh = Kilowatt-hour (3.6×10^6 J)
  - Btu = 1055 J; 1 MBtu=0.292 MWh; 1 MWh=3.4 Mbtu
  - quad = 10^{15} Btu
  - One gallon of gas has about 0.125 MBtu (36.5 kWh); one gallon ethanol as about 0.084 Mbtu (2/3 that of gas)
- U.S. annually consumes ~100 quads of energy

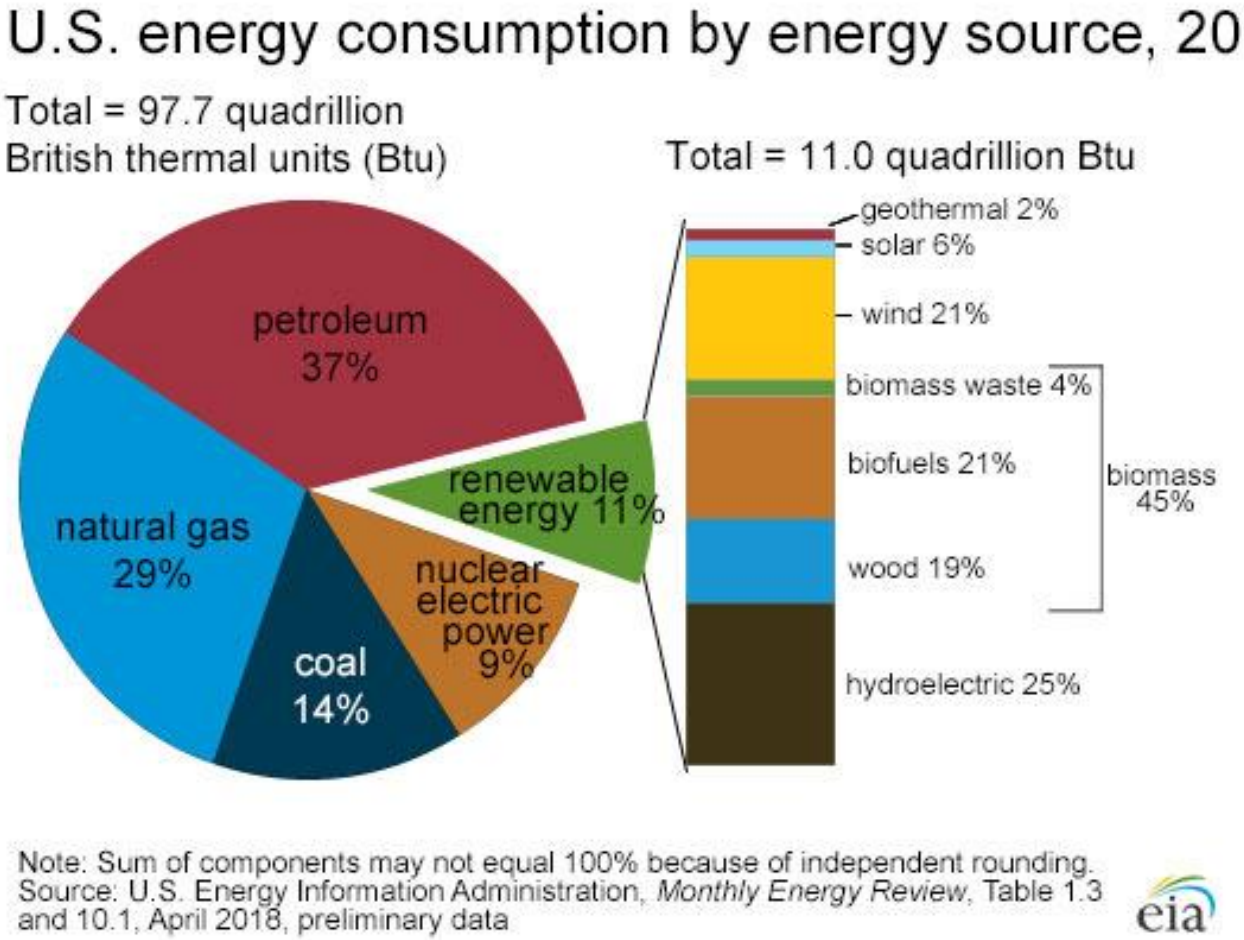
North America Interconnections



Electric Systems in Energy Context

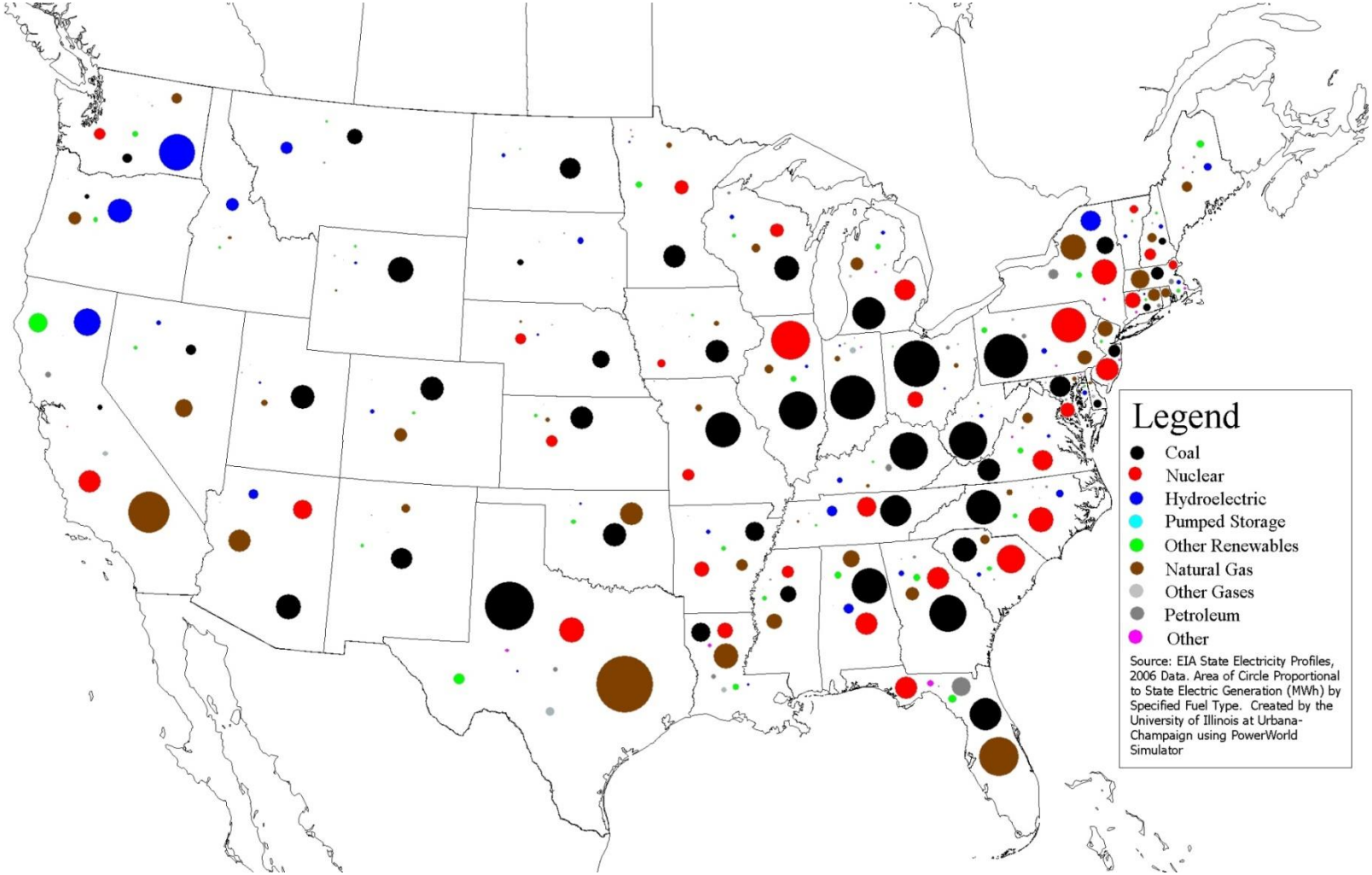
- Class focuses on renewable electric systems, but we first need to put them in the context of the total energy delivery system
- Electricity is used primarily as a means for **energy transportation**
  - Use other sources of energy to create it, and it is usually converted into another form of energy when used
- 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



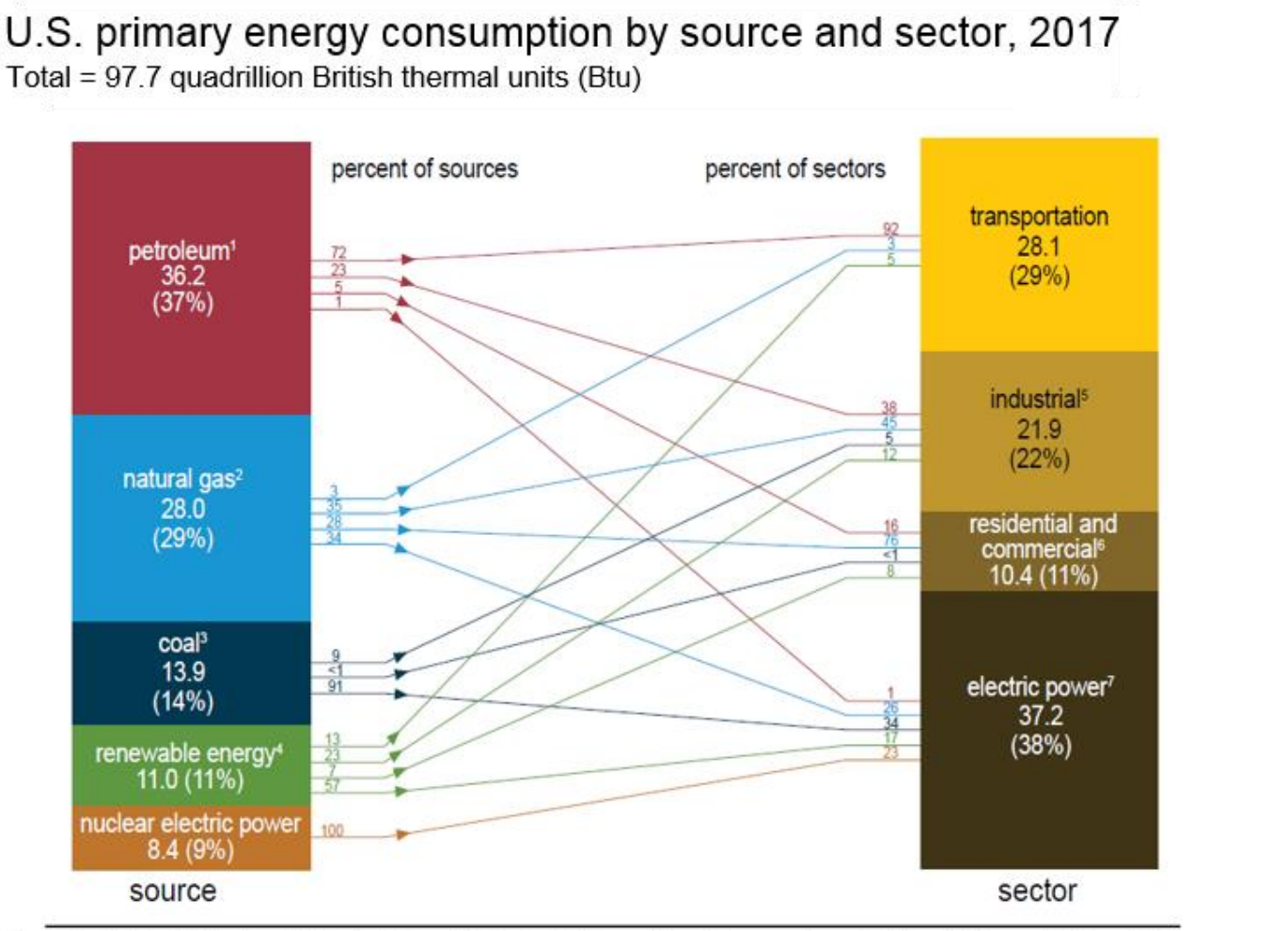
About 80% Fossil Fuels

Electric Generation by Fuel/State



Source: 2006 EIA Data, Slide by Kate Davis

2017 U.S. Energy Use



[1] Does not include biofuels that have been blended with petroleum—biofuels are included in "Renewable Energy."
[2] Excludes supplemental gaseous fuels.
[3] Includes -0.03 quadrillion Btu of coal coke net imports.
[4] Conventional hydroelectric power, geothermal, solar, wind, and biomass.
[5] Includes industrial combined-heat-and-power (CHP) and industrial electricity-only plants.
[6] Includes commercial combined-heat-and-power (CHP) and commercial electricity-only plants.
[7] Electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes 0.17 quadrillion Btu of electricity net imports not shown under "source."

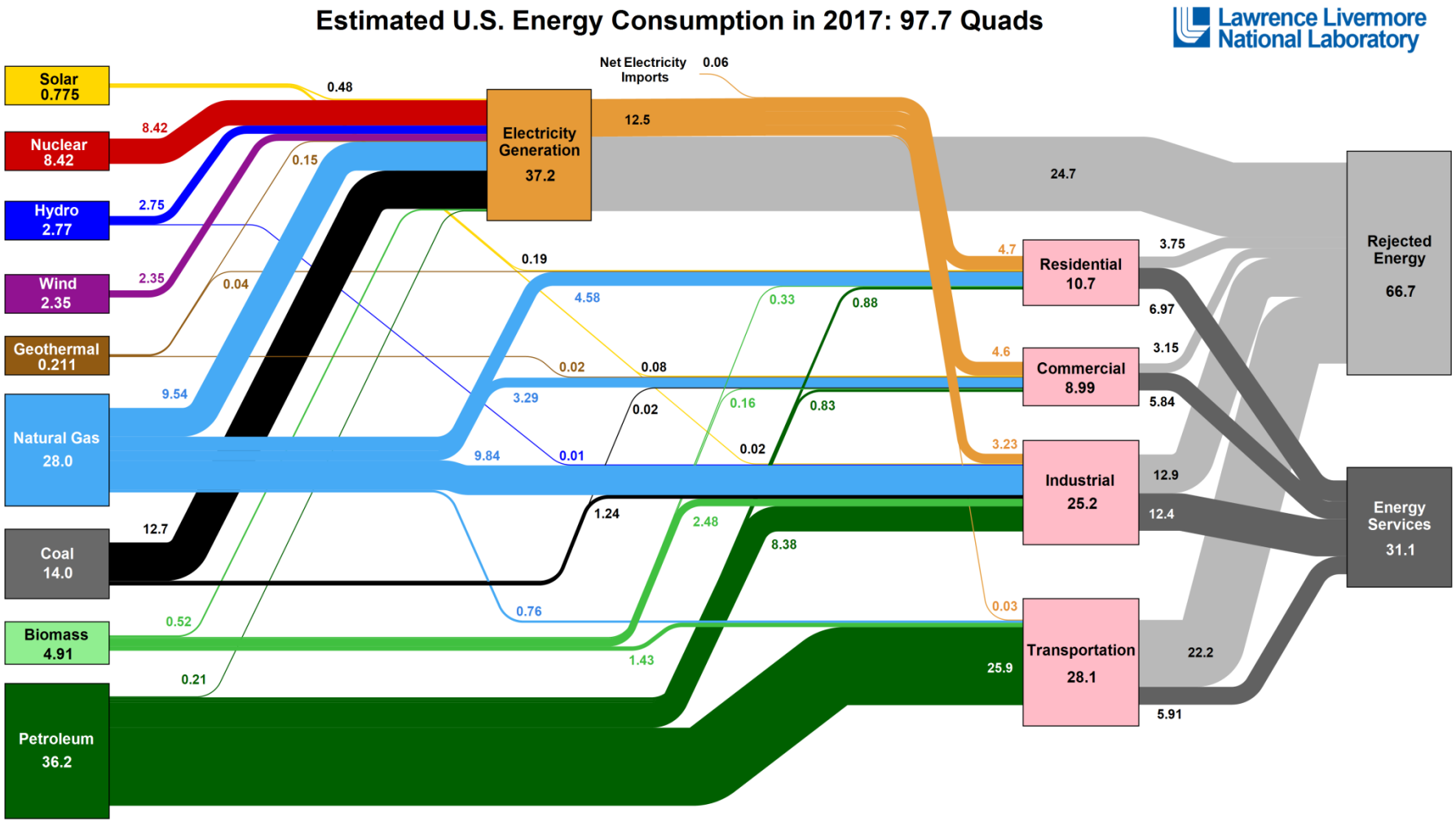
Notes: • Primary energy is energy in the form that it is accounted for in a statistical energy balance, before any transformation to secondary or tertiary forms of energy occurs (for example, coal is used to generate electricity). • The source total may not equal the sector total because of differences in the heat contents of total, end-use, and electric power sector consumption of natural gas. • Data are preliminary. • Values are derived from source data prior to rounding. • Sum of components may not equal total due to independent rounding.

Sources: U.S. Energy Information Administration, *Monthly Energy Review* (April 2018), Tables 1.3, 1.4a, 1.4b, and 2.1-2.6.

eia

https://www.eia.gov/energyexplained/?page=us_energy_home

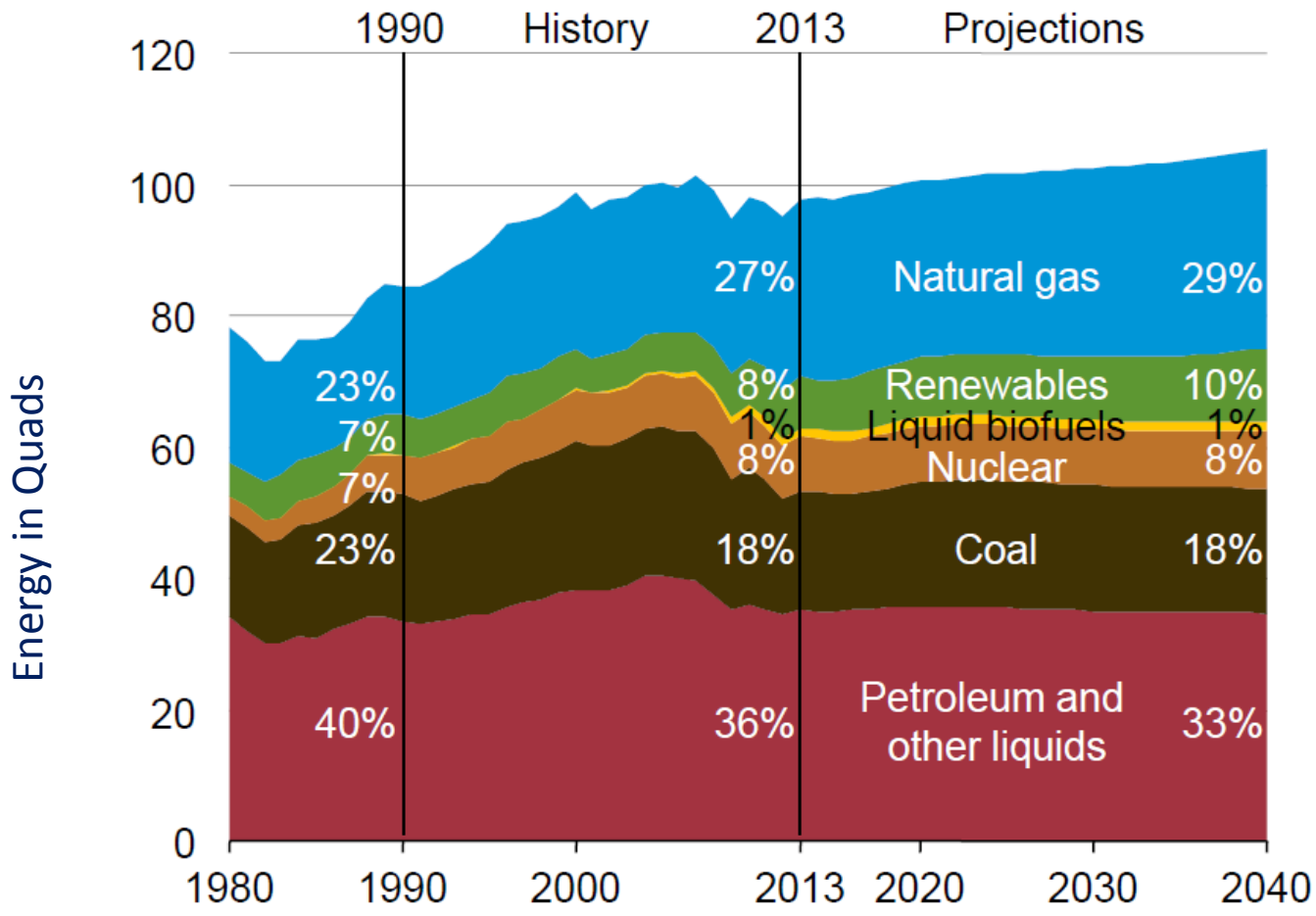
2017 U.S. Energy Use



Source: LLNL April, 2018. Data is based on DOE/EIA MER (2017). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. This chart was revised in 2017 to reflect changes made in mid-2016 to the Energy Information Administration's analysis methodology and reporting. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector, and 49% for the industrial sector which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

https://flowcharts.llnl.gov/content/assets/images/charts/Energy/Energy_2017_United-States.png

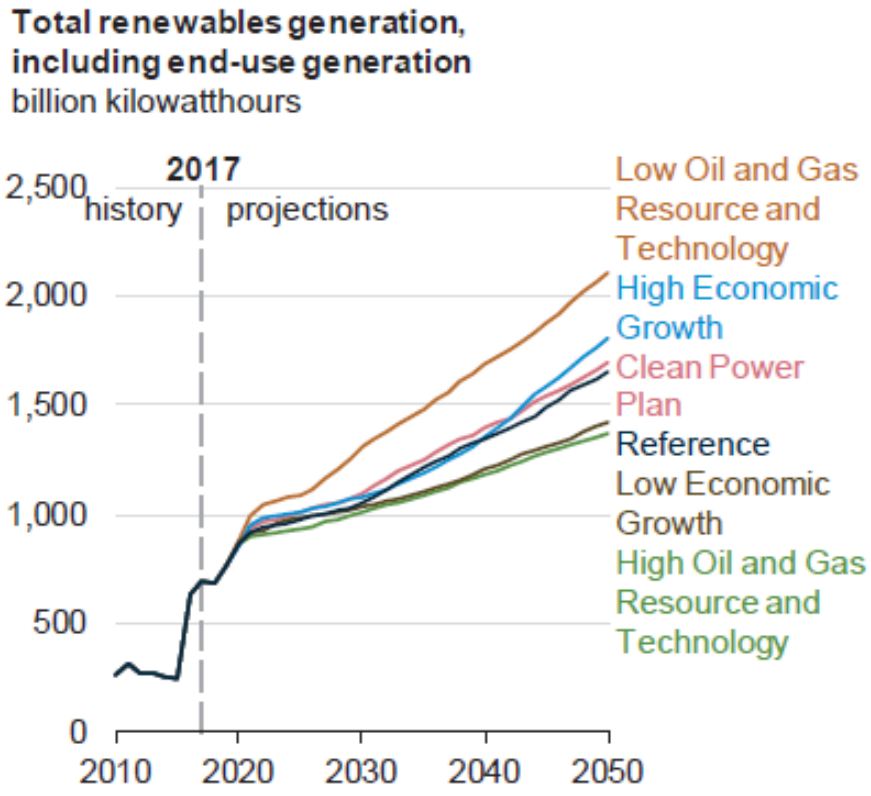
Historical and Projected US Energy Consumption

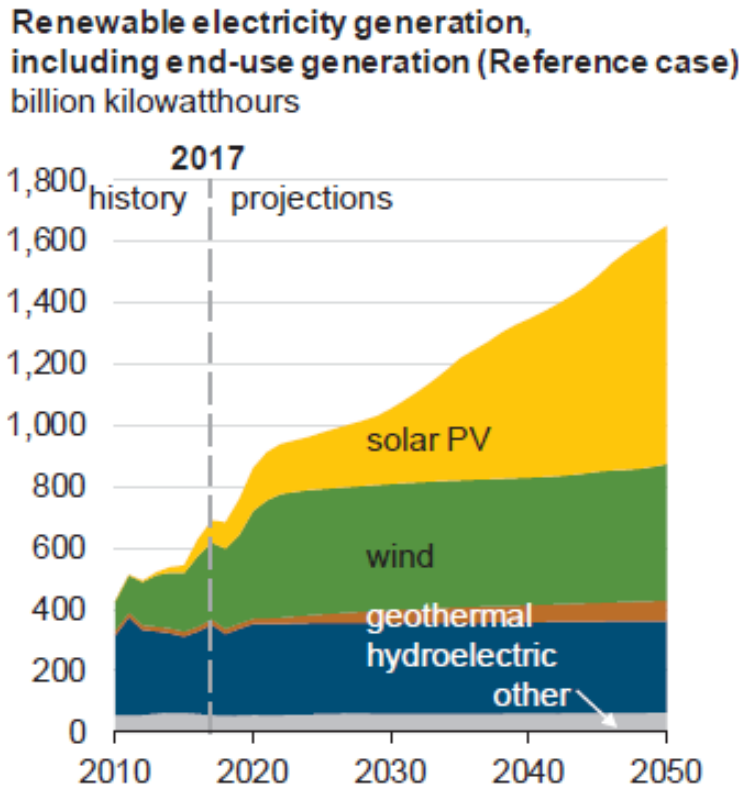


Source: EIA Annual Energy Outlook, 2015, Figure 18

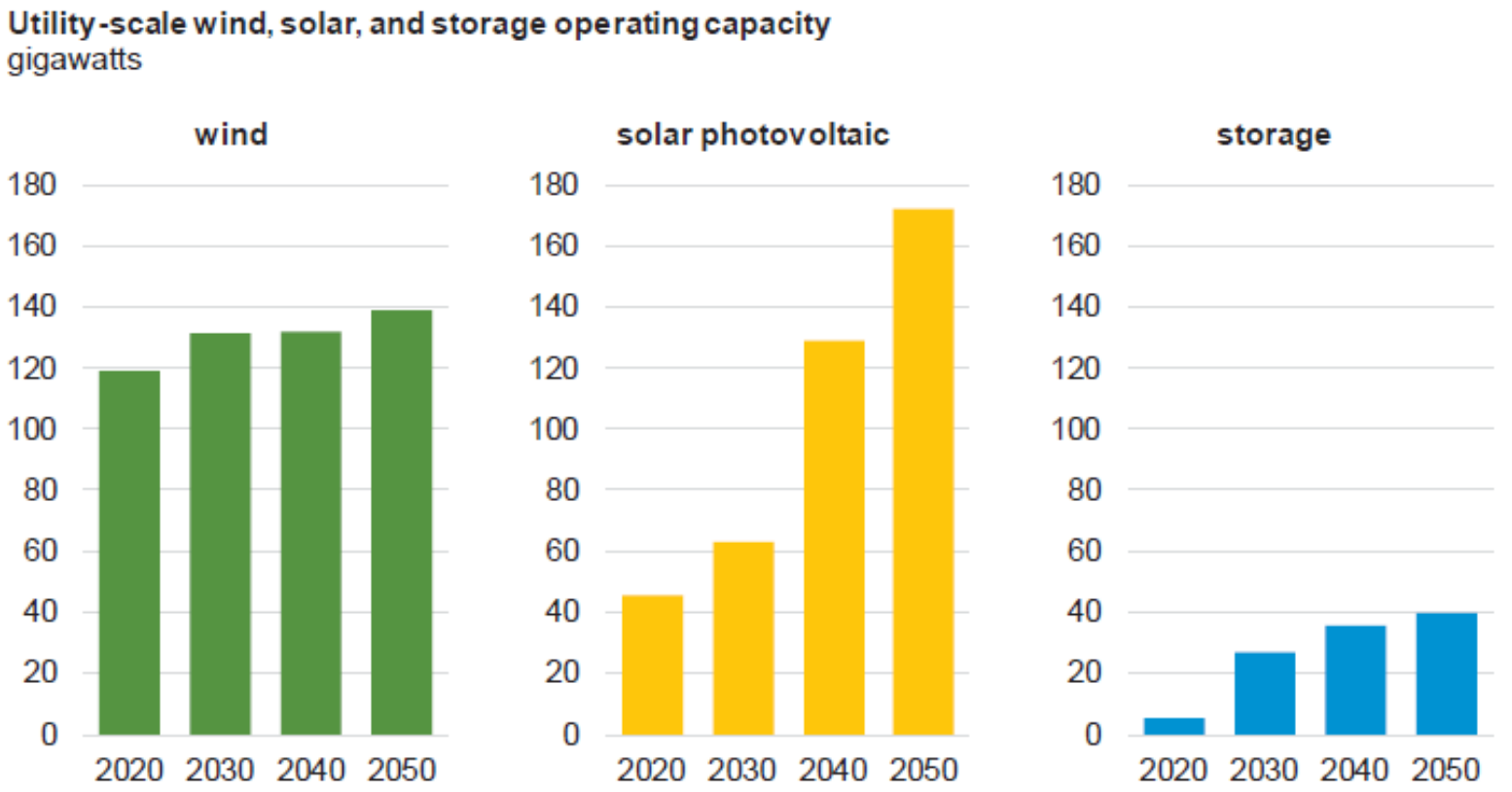
Data says we will still be 80% Fossil in 2040!!

Renewable Energy Generation

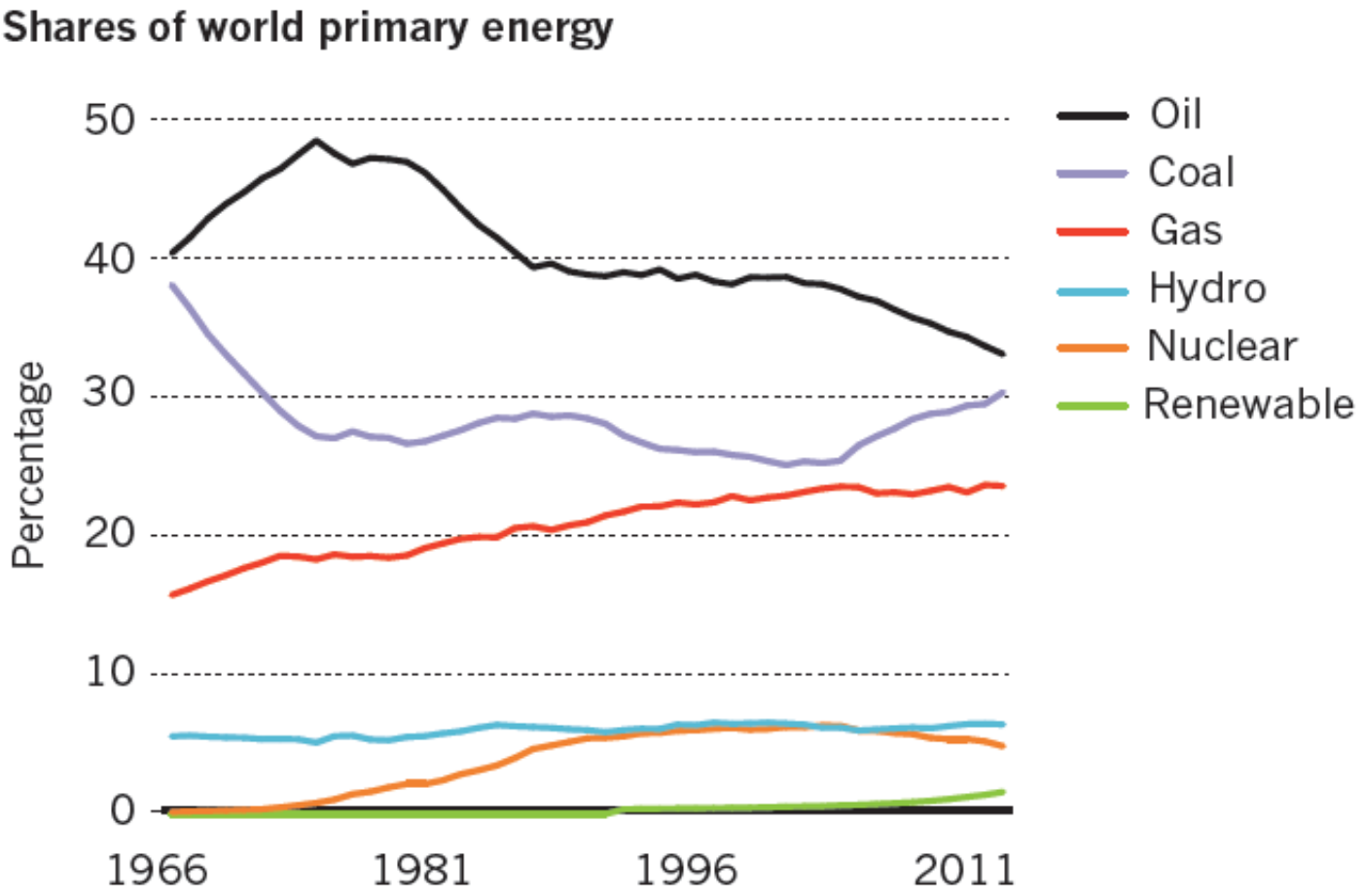




Projected Growth in US Renewables



The World



Source: Steve Chu and Arun Majumdar, "Opportunities and challenges for a sustainable energy future," *Nature*, August 2012

The World: Top Energy Users (in Quad), 2012 Data

- China – 105.9
- USA – 95.1
- Europe – 81.5
- Russia – 31.5
- India – 23.9
- Japan – 20.3
- Africa – 17.3
- Canada – 13.4
- Brazil – 12.1

- World total was about 524 Quad in 2012;
- Average per 100 Million people is about 7.18.
- If world used US average total consumption would be about 2177 quad!

Source: US DOE EIA

Per Capita Energy Consumption in MBtu per Year (2011 data)

Source http://www.eia.gov

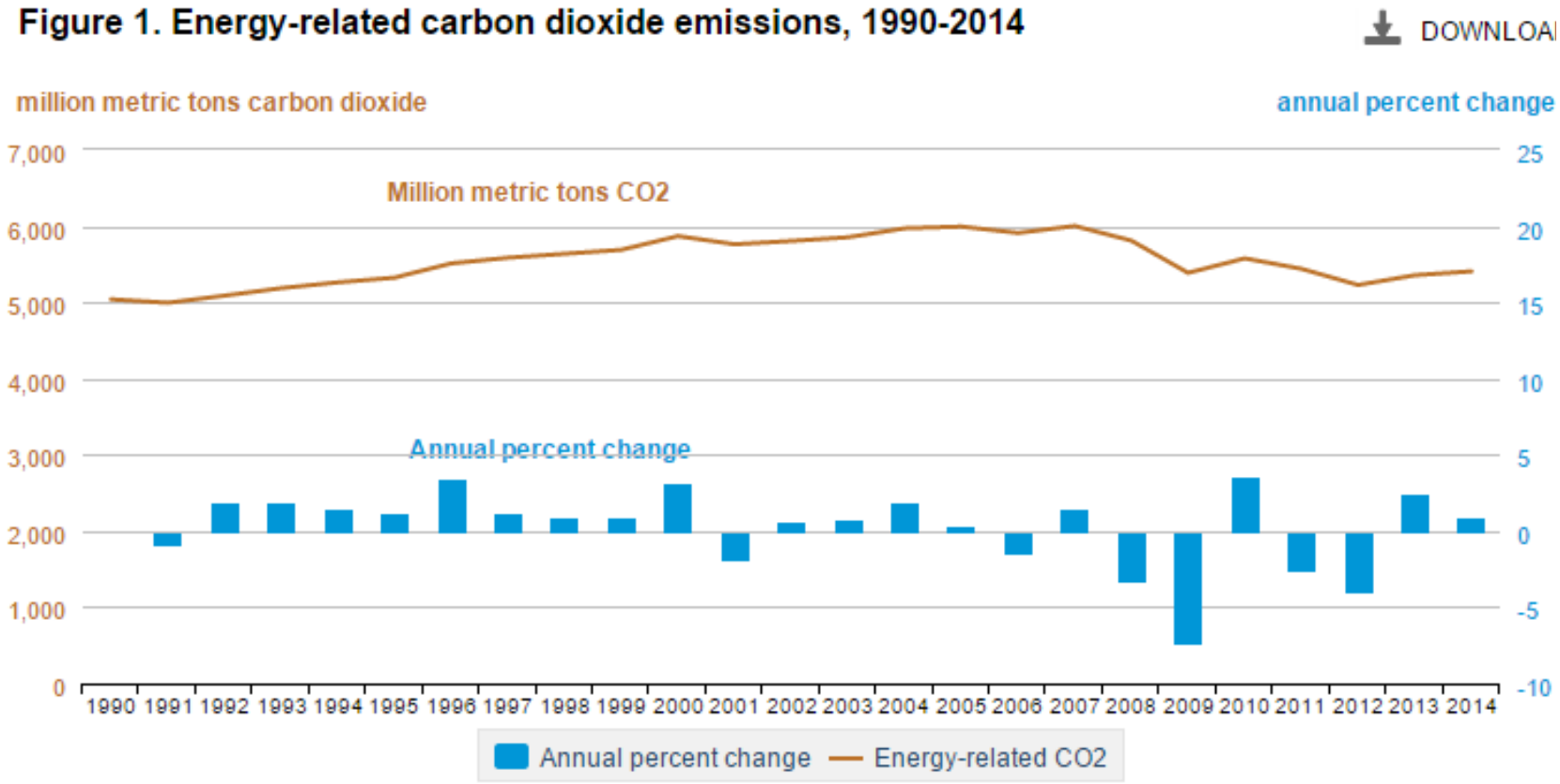
Iceland:	688	Norway:	387
Kuwait:	577	Canada:	394
USA:	313	Australia:	276.9
Russia:	213	France:	166
Japan:	164	Germany:	165
UK:	134	S. Africa:	115
China:	78	Brazil:	60
Indonesia:	17.9	India:	20
Pakistan:	14.2	Nigeria:	5
Malawi:	1.9	Afghanistan:	4.1

World Population Trends

Country	2005	2015	2025	%
Japan	127.5	126.9	123.3	-3.3
Germany	82.4	80.8	79.2	-3.9
Indonesia	220.2	255.9	276.7	25.6
USA	295.7	322.3	351.3	18.8
China	1306	1361	1394	6.7
India	1094	1251	1396	27.6
World	6473	7250	7984	23.3

Source: www.census.gov/ipc/www/idb/summaries.html; values in millions; percent change from 2005 to 2025

USA Energy-Related CO_2 Emissions are Down to mid 1990's levels

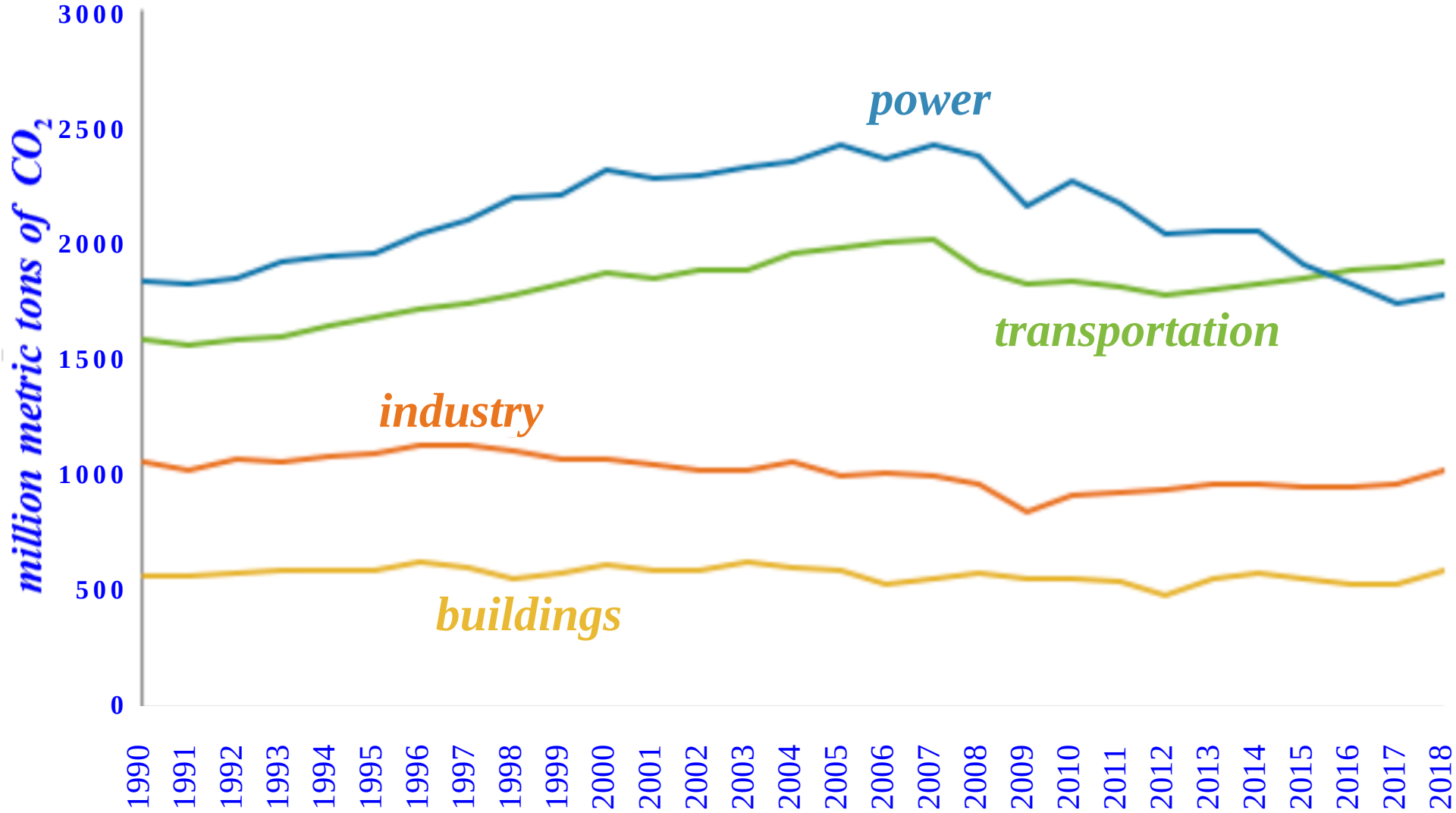


Source: U.S. Energy Information Administration, *October 2015 Monthly Energy Review*, Table 12.1 Carbon dioxide emissions from energy consumption by source.

Part of the reason for the decrease is due to low natural gas prices, which has caused greatly increased natural gas generation and less coal generation.

US CO_2 EMISSIONS: 1990 – 2018

***Source*:** *Rhodium Group report http://rhg.com/notes/preliminary-2018-us-emissions*

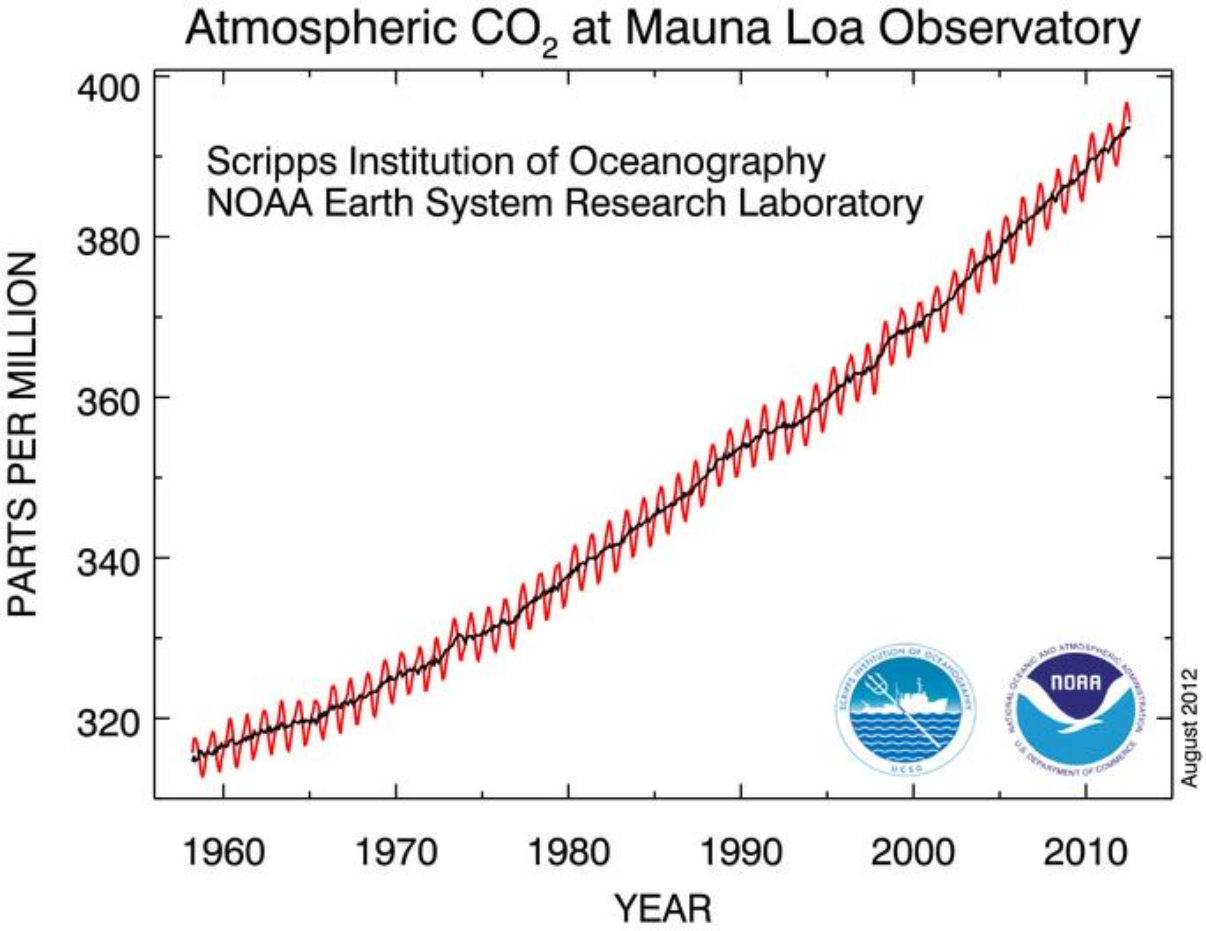


Worldwide CO_2 Emissions

- Worldwide CO_2 emissions continue to (mostly) climb, from 23.7 billion metric tons in 2000 to 29.8 in 2010 (with a max of 30.3 in 2009).
- Country comparisons between 2000 and 2010 (billion metric tons)

Country	2000	2010
USA	5861	5427
China	2850	7204
India	1002	1622
Russia	1499	1448
Japan	1201	1104
Germany	854	762

Global Warming: What is Known is CO_2 in Air is Rising

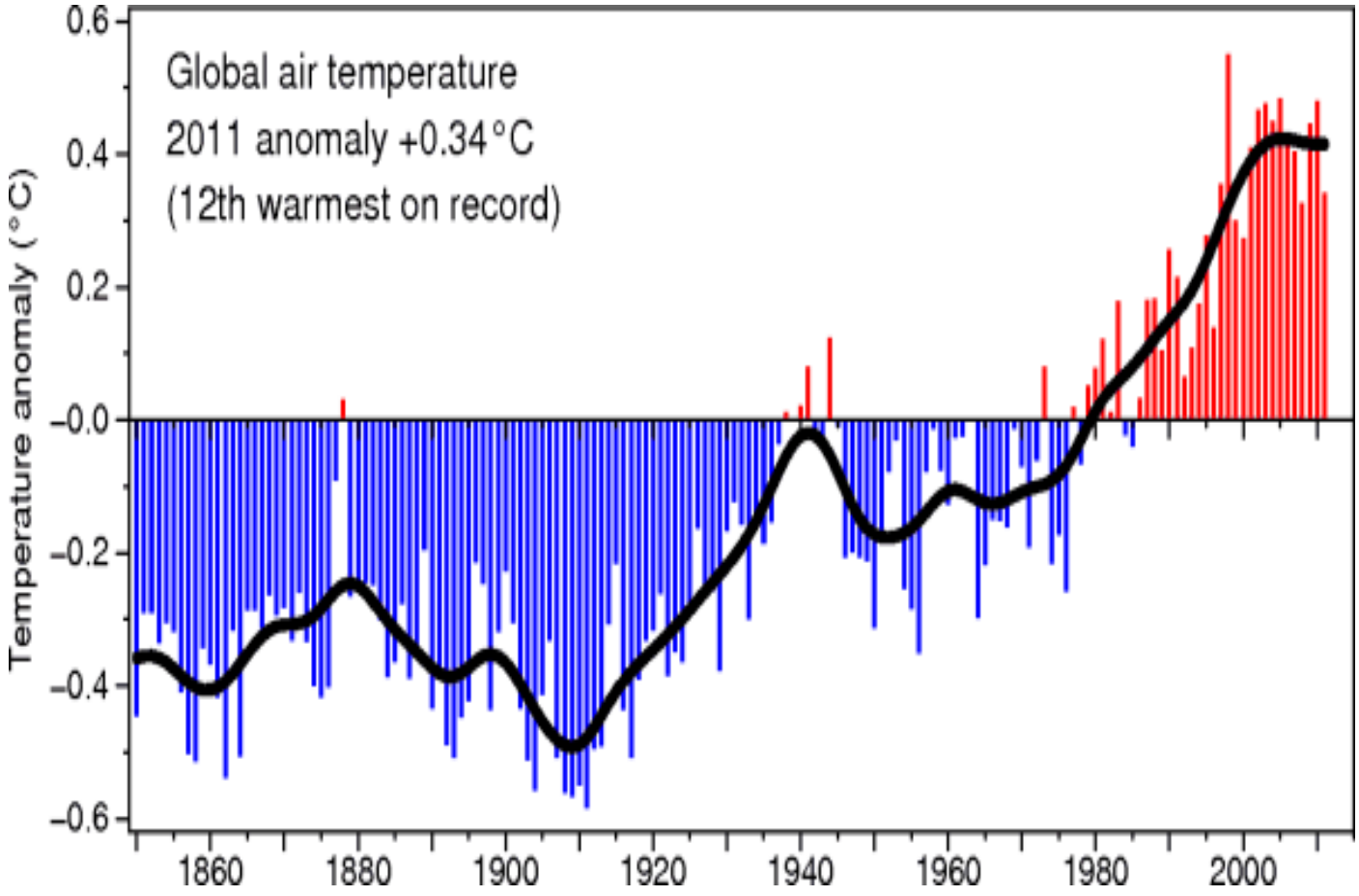


Value was about 280 ppm in 1800, 394 in 2012

Rate of increase is about 2 ppm per year

Source: http://www.esrl.noaa.gov/gmd/ccgg/trends/

As is Worldwide Temperature (Over Last 150 Years)



Source: http://www.cru.uea.ac.uk/cru/info/warming /

Illinois Renewables Portfolio Standard (25% by 2025)

- Illinois Power Agency Act, enacted August 2007
  - Requires large, investor-owned electric utilities (EUs) and alternative retail electric supplies (ARES) to source 25% of eligible retail electricity sales from renewable energy by 2025. ("25% by 2025")
  - Electric co-ops and municipal utilities are exempt
- Eligible Renewables
  - Solar thermal electric and photovoltaic (PV)
  - Wind (All)
  - Biomass and landfill gas
  - Hydroelectric
  - Anaerobic digestion

State of Illinois Green Energy

- In December 2016, IL enacted S.B. 2814 (the Future Energy Jobs Act)
  - 75% of renewable must be from wind and PV combined
  - IL currently ranked 34th in solar capacity (amount of available solar energy hitting the surface)
  - Projected to grow to 1856 MW in the next 5 years, which will rank us 11th in solar production
  - Goal is to get to 3,000 MW by 2030

Wrap-up

- Power vs Energy
  - US installed capacity (Power) is 1000 GW
  - US annual energy usage is 100 quad
- Fossil fuels still supply ~80% of energy in US
- US CO_2 emissions are decreasing, worldwide emissions are increasing

Thursday

- Power Grid History