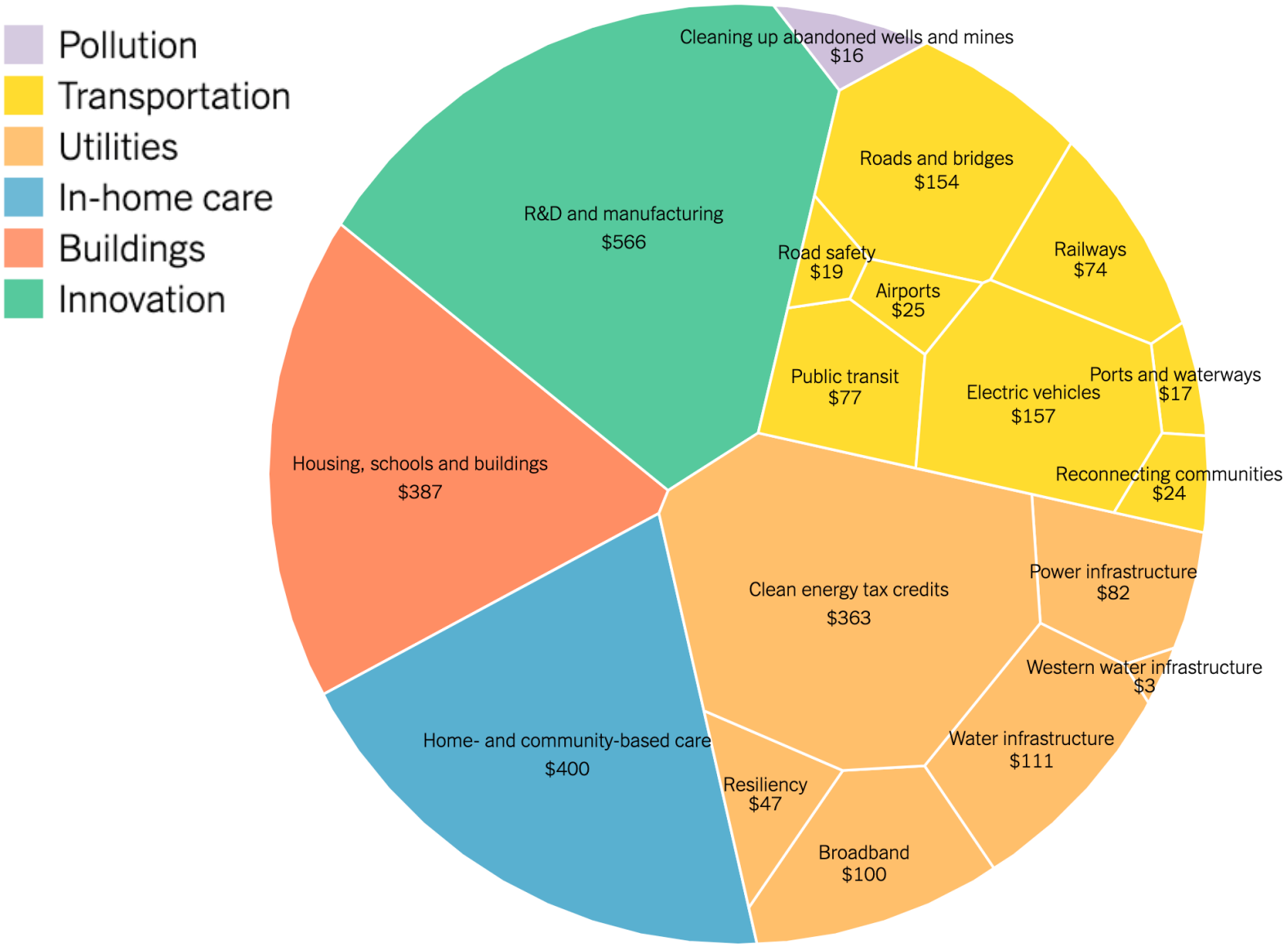
BIDEN ADMINISTRATION'S CLIMATES GOALS

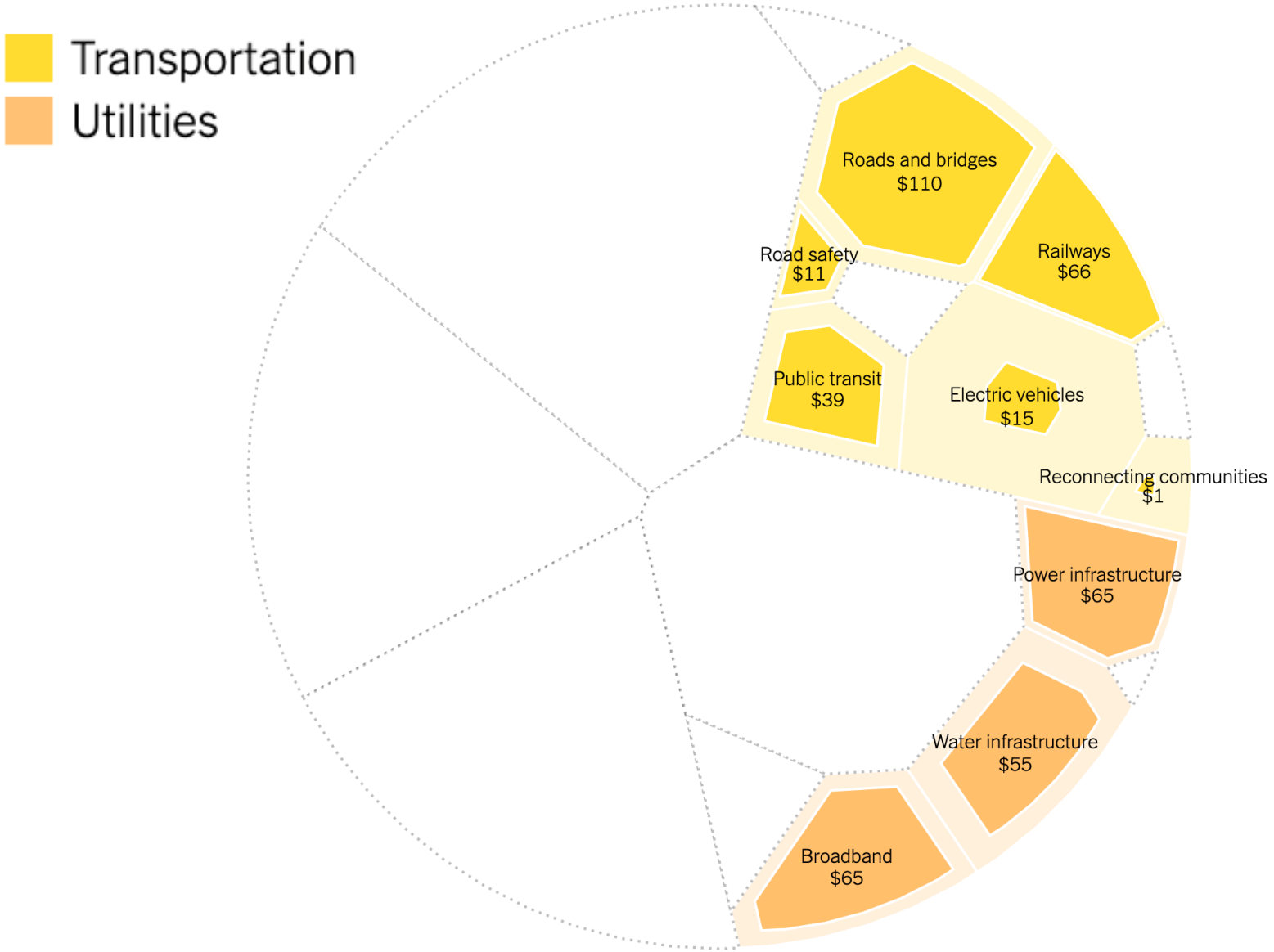
sector	goal for the year		
	2030	2035	2050
US economy 	*GHG* emission reduction by 50 %		net–zero *C*
transportation  	set up of 500,000 *EV* chargers	electrification of the transportation sector; growth of *US EV* manufacturing	
buildings 		*C* footprint reduction by 50 %	
power & energy  	80 % zero *C*	*C*–free electricity	

THE ORIGINAL BIDEN PLAN: 2.6 *TRILLION $*



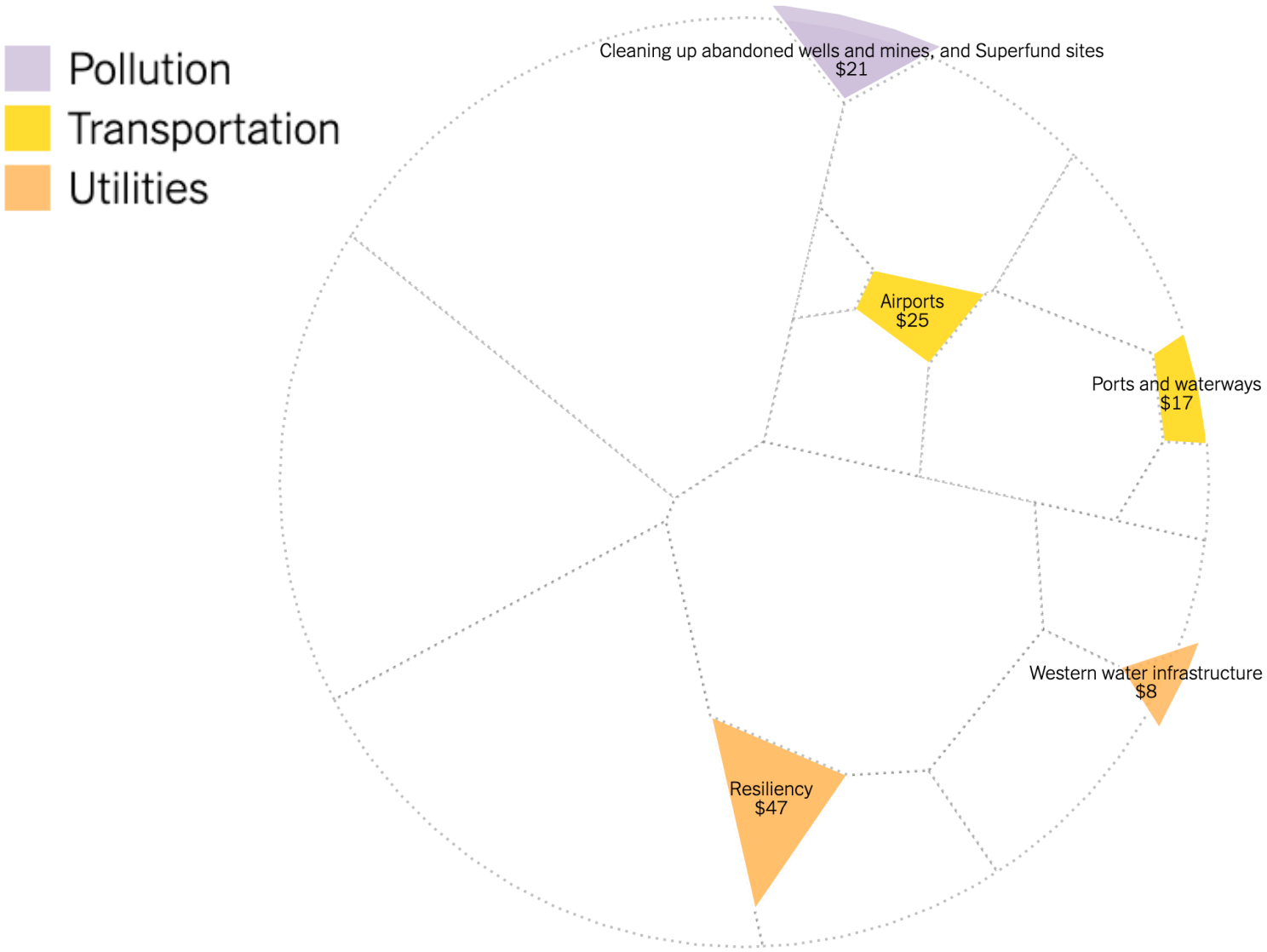
Source: NY Times online; avalible online at https://www.nytimes.com/interactive/2021/07/28/upshot/infrastructure-breakdown.html?action=click&module=RelatedLinks&pgtype=Article

THE ELIMINATED AND THE SHRUNK PARTS OF THE BIDEN PLAN



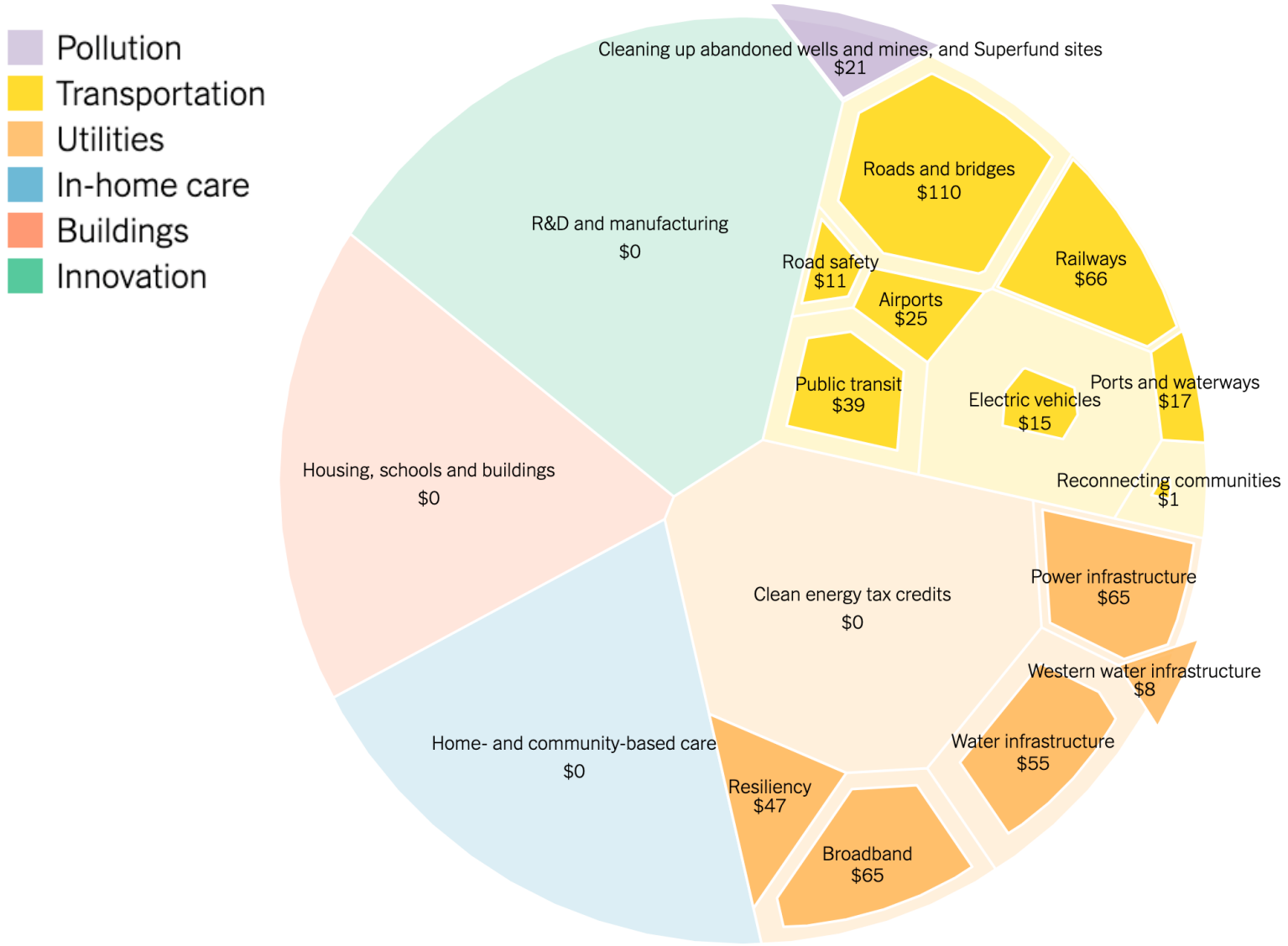
Source: NY Times online; avalible online at https://www.nytimes.com/interactive/2021/07/28/upshot/infrastructure-breakdown.html?action=click&module=RelatedLinks&pgtype=Article

THE PARTS THAT REMAINED UNCHANGED OR INCREASED



Source: NY Times online; avalible online at https://www.nytimes.com/interactive/2021/07/28/upshot/infrastructure-breakdown.html?action=click&module=RelatedLinks&pgtype=Article

THE SENATE BIPARTISAN PLAN: 550 *BILLION $*

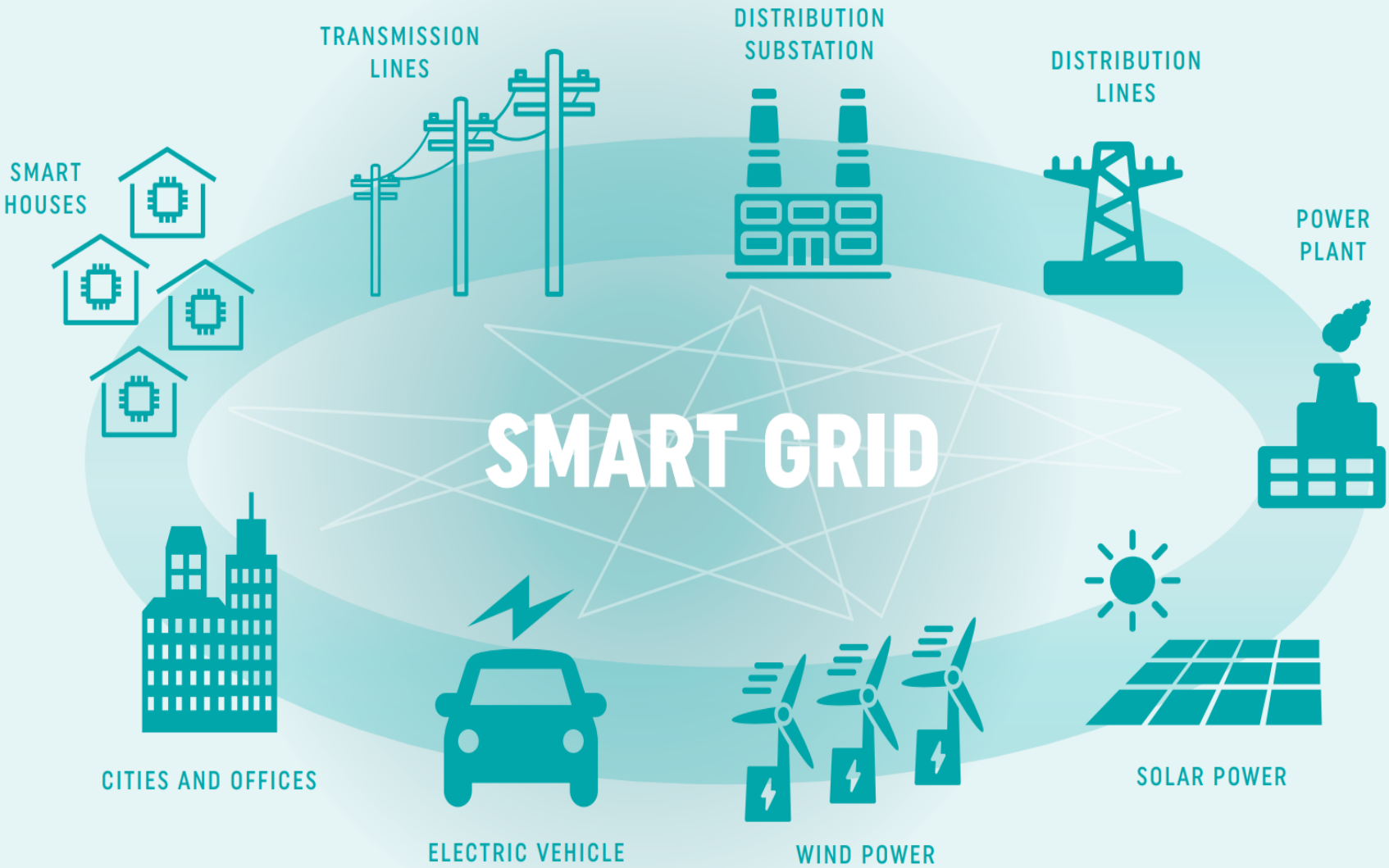


Source: NY Times online; avalible online at https://www.nytimes.com/interactive/2021/07/28/upshot/infrastructure-breakdown.html?action=click&module=RelatedLinks&pgtype=Article

THE CHANGING ENVIRONMENT

- There is a huge, global interest in the *integration of renewable resources* into the grid, along with that of *demand response and storage resources*, to displace costly and polluting fossil–fuel–fired generation
- The integration progress drives the creation of sustainable paths to meet each nation's energy needs, veering it towards energy independence
- The context within which this progress unrolls is the *restructured, competitive electricity industry* and the effective exploitation of *Smart Grid* implementation advances throughout the world

THE EVOLVING SMART GRID



Source: ZPryme, 2020, available at https://zpryme.com/insights/spatial-data-at-the-core-of-grid-modernization/

RENEWABLE ENERGY RESOURCES

- We focus on *technical/economic/environmental issues* in renewable energy deployment to understand their role in meeting the future electricity needs of the growing global population
- We provide an update on the status of renewable energy developments around the world
- The course provides a solid basis to *exploit the opportunities and address the challenges* to implement deeper penetrations of renewable resources

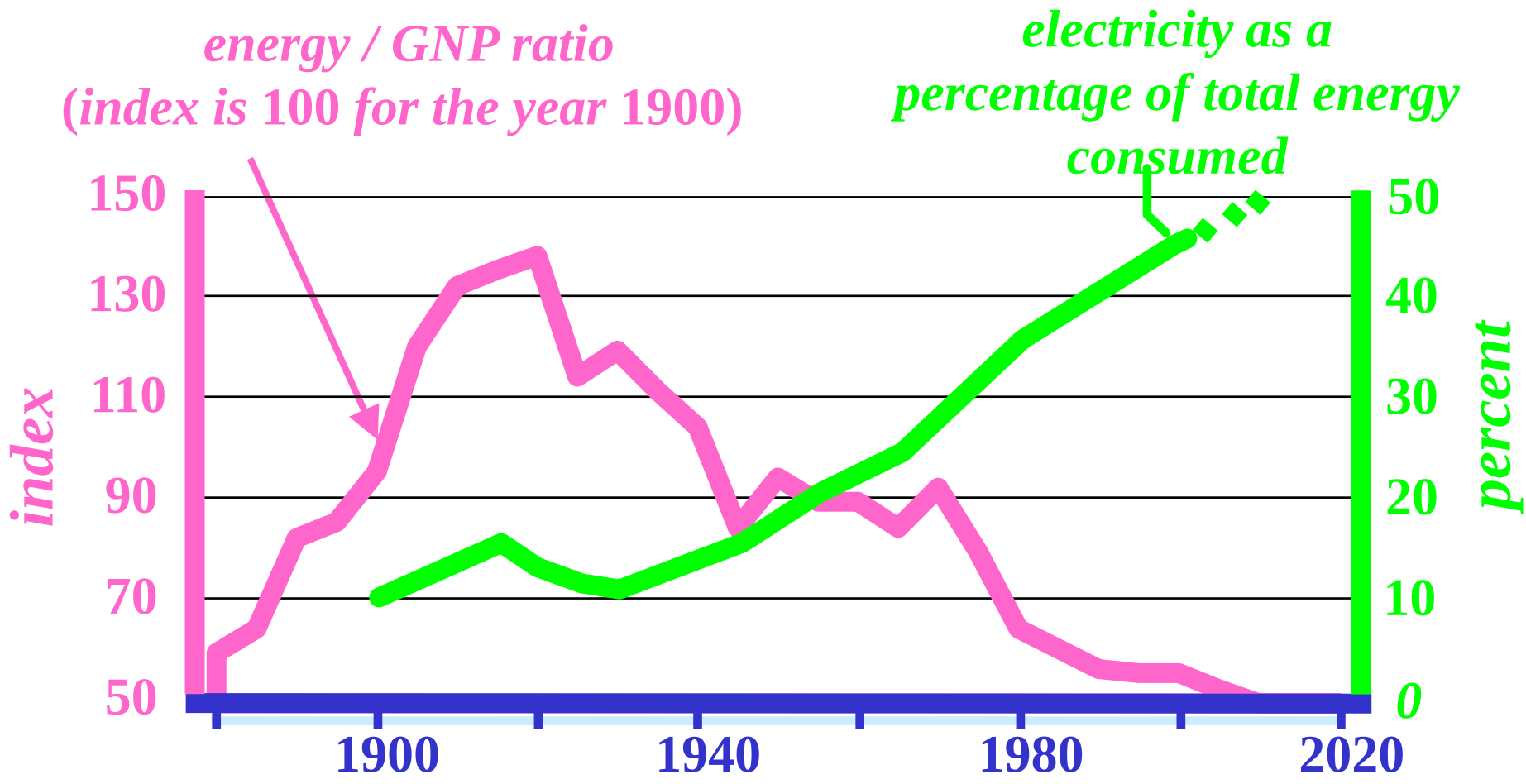
OVERVIEW TOPIC OUTLINE

- The importance of electricity
- Overview of the *US* electricity industry
- The nature of electric demand
- The developments in energy supply
- An overview of renewables
- Salient characteristics of wind and solar power
- Renewable resource investment picture
- Modernization of the grid

CRITICAL IMPORTANCE OF ELECTRICITY

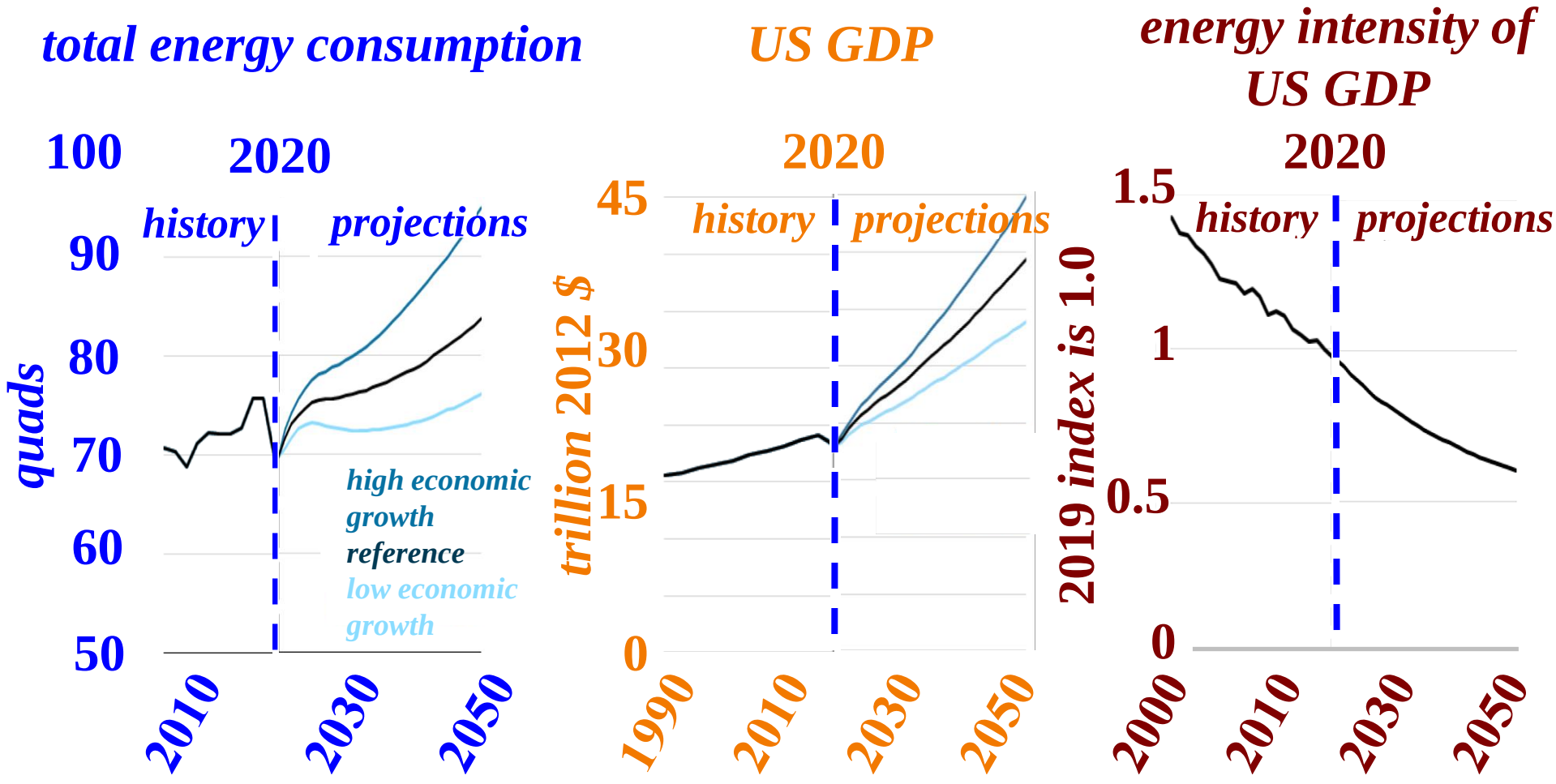
- Energy is the *lifeblood* of modern society
- The importance of electricity is on the rise
- Efficient and environmentally sensitive electricity services are key requirements for the nation's global competitiveness
- The *US* power industry valued above *$ 2.3 trillion* is among the world's largest industrial sectors; 2020 retail sales revenues dipped below *400 billion $*

US ENERGY CONSUMPTION AND ELECTRICITY USE



electricity will continue to substitute for less efficient and less productive energy forms

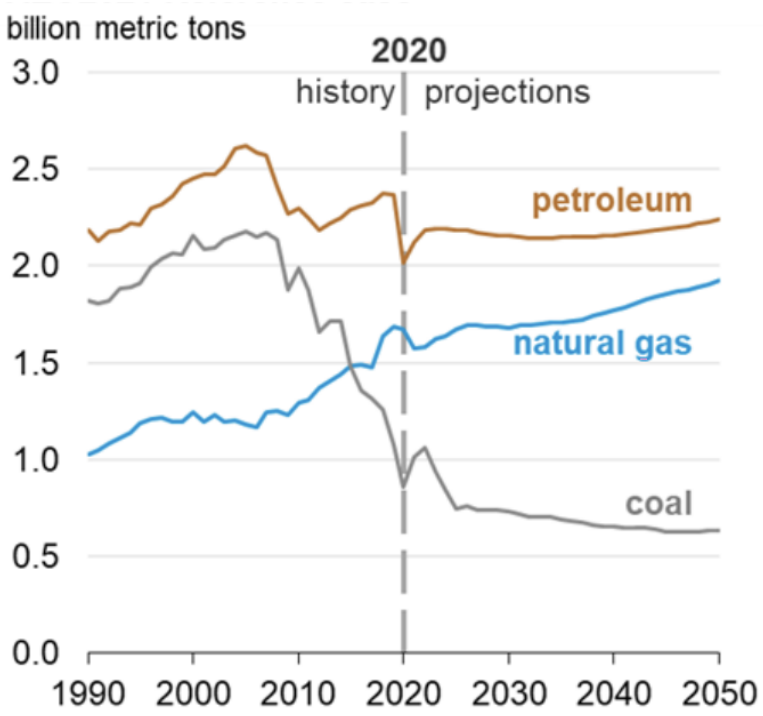
US ENERGY CONSUMPTION AND *GDP*

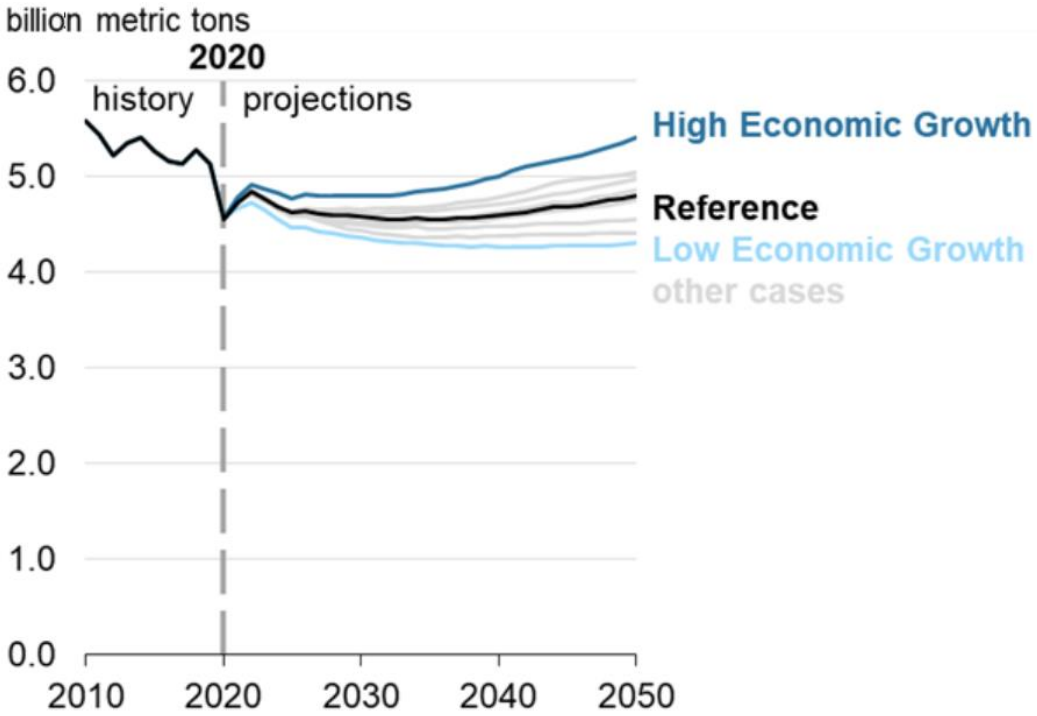


Source: EIA February 20, 2019; available at https://www.eia.gov/outlooks/aeo/pdf/AEO_Narrative_2021.pdf

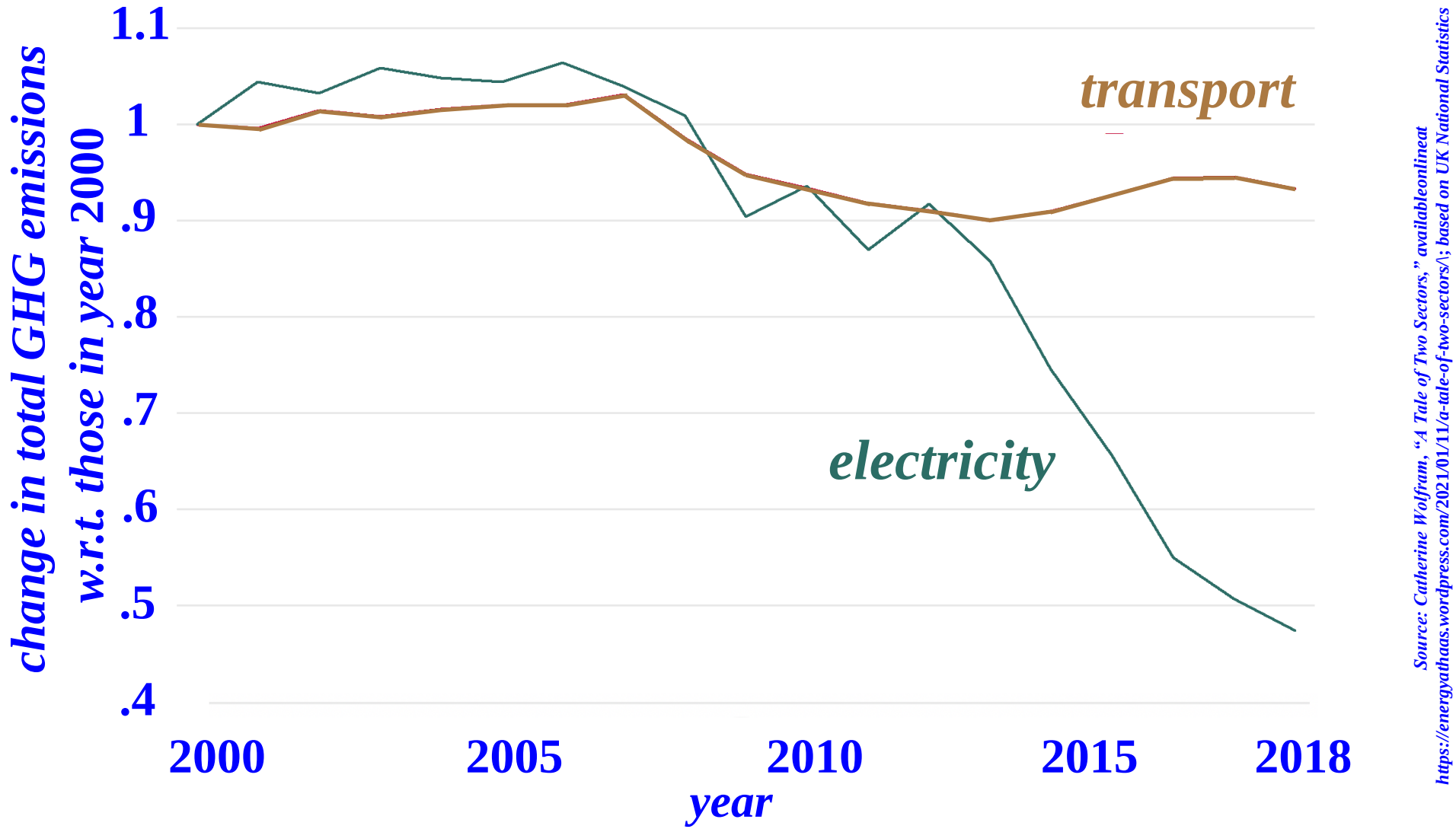
GLOBAL CO_2 EMISSIONS FROM FOSSIL FUELS

Source: EIA February 2021: available at https://www.eia.gov/outlooks/aeo/pdf/AEO_Narrative_2021.pdf



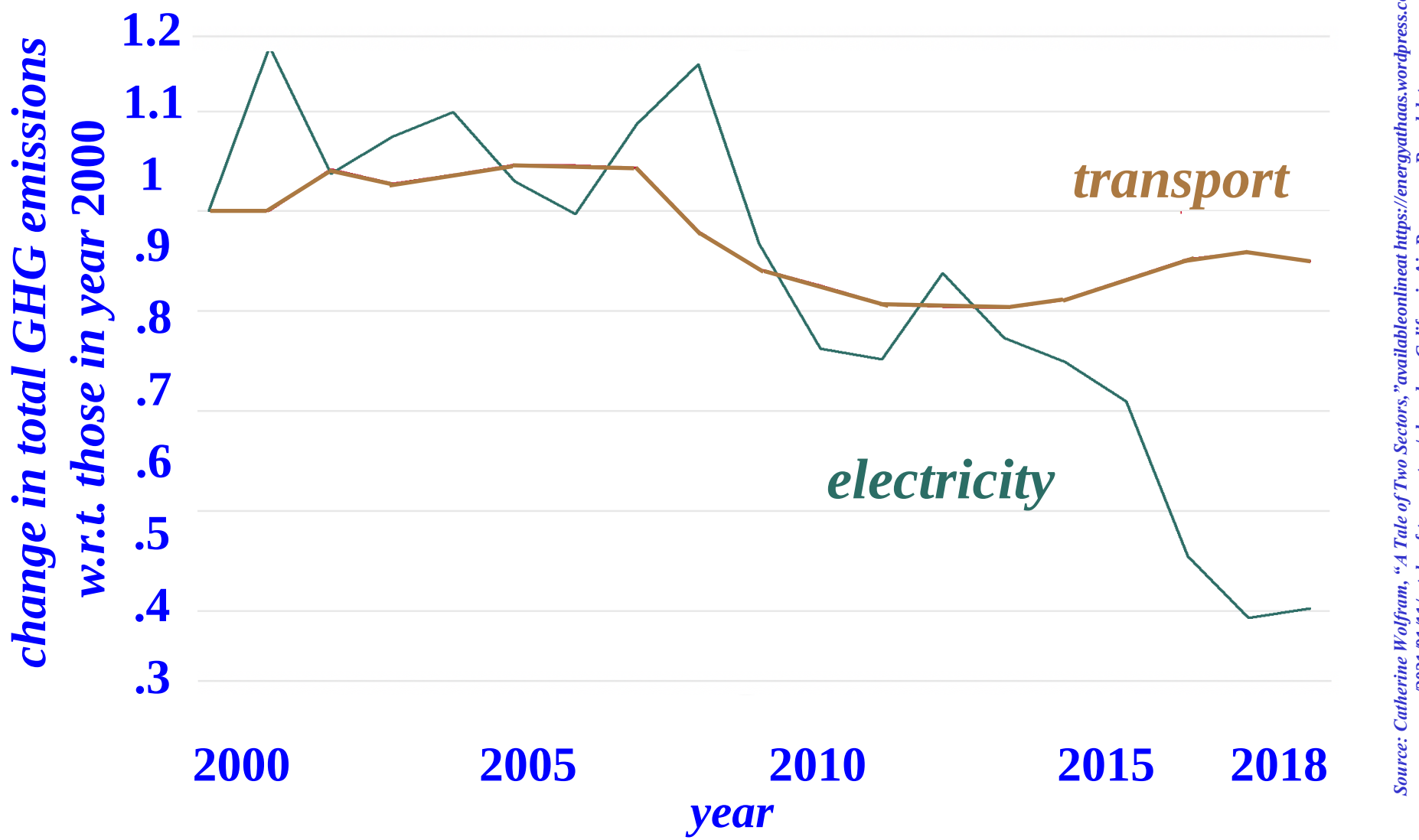


CHANGES IN TOTAL *UK GHG* EMISSIONS



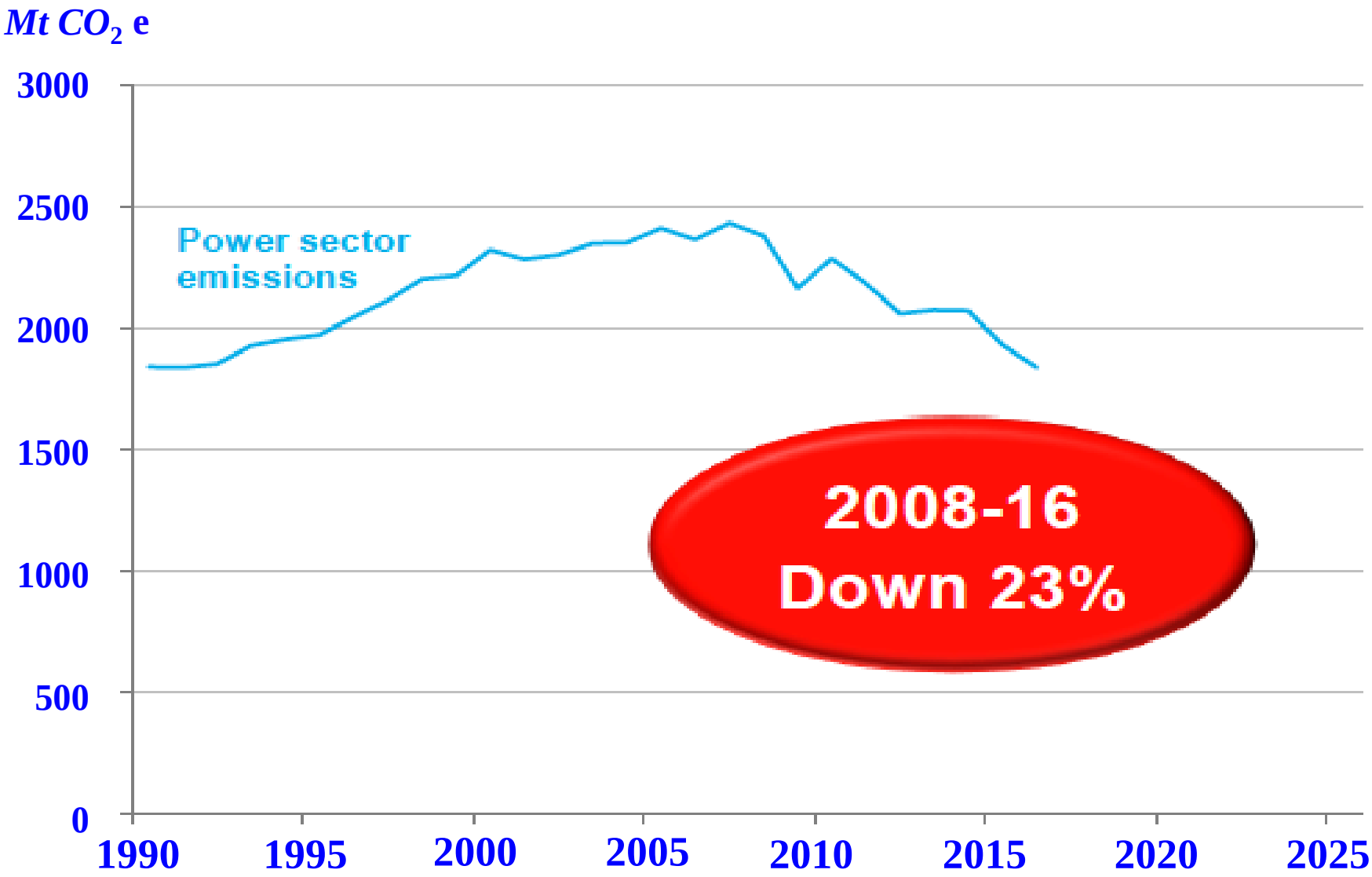
Source: Catherine Wolfram, "A Tale of Two Sectors," availableonlineat https://energyathaas.wordpress.com/2021/01/11/a-tale-of-two-sectors/\; based on UK National Statistics

CHANGES IN TOTAL *GHG* EMISSIONS IN *CA*



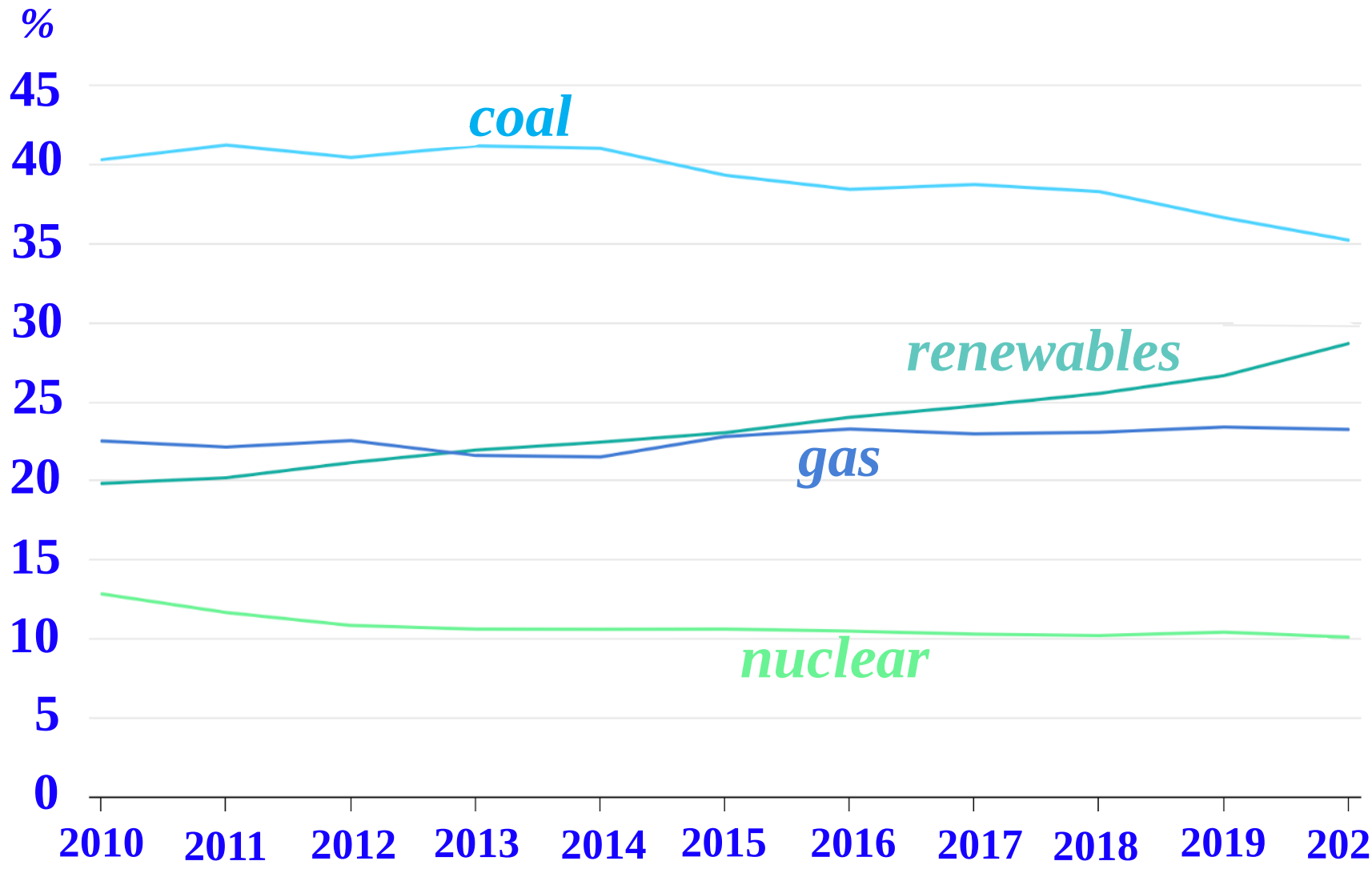
Source: Catherine Wolfram, "A Tale of Two Sectors," availableonlineat https://energyathaas.wordpress.com /2021/01/11/a-tale-of-two-sectors/; based on California Air Resources Board data

US CO_2 POWER SECTOR EMISSIONS



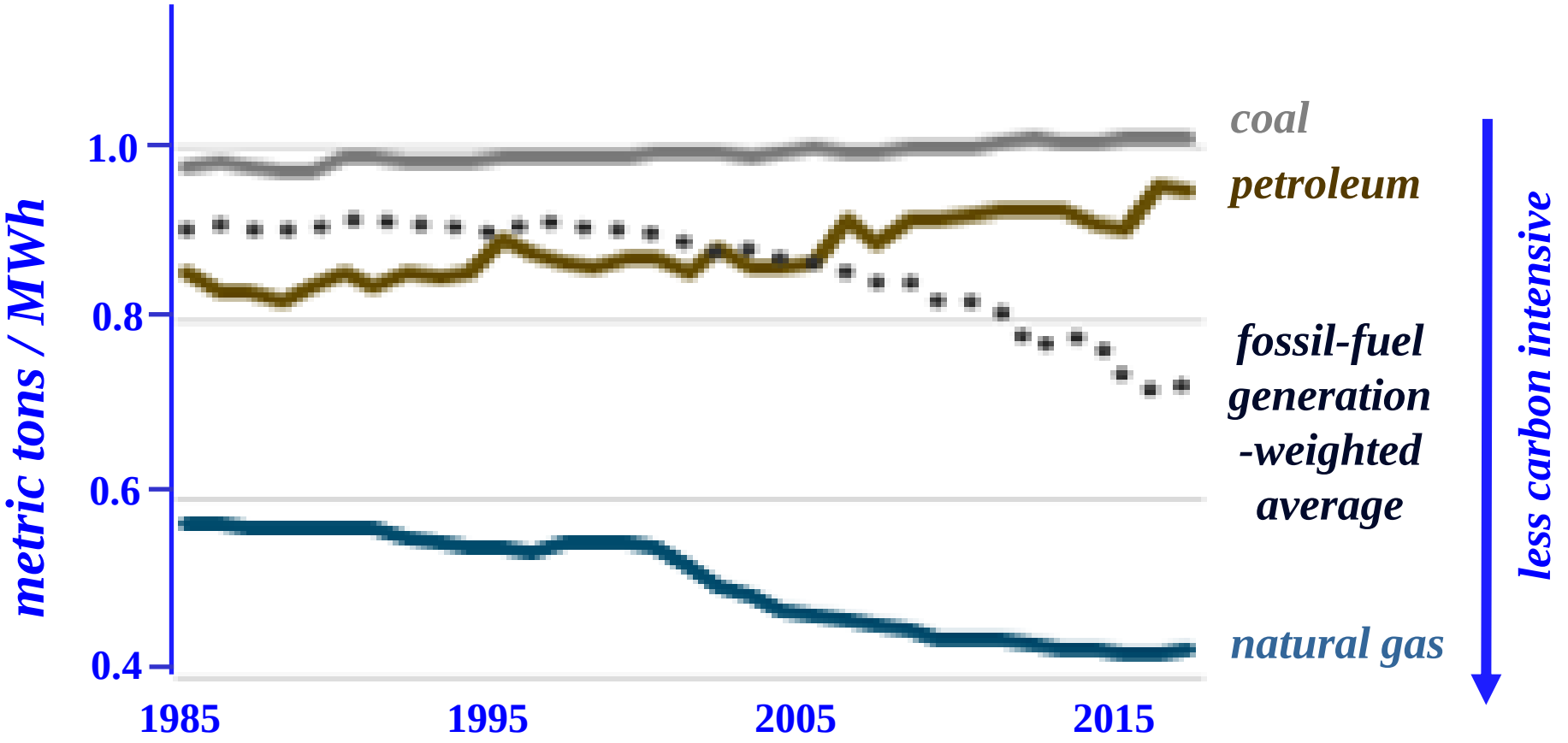
Source: Bloomberg New Energy Finance

GLOBAL ELECTRICITY GENERATION RESOURCE MIX: 2010 – 2020



Source: International Energy Agency, Key Electricity Trends 2020, published in April 2021; available online at https://www.iea.org/articles/global-energy-review-co2-emissions-in-2020

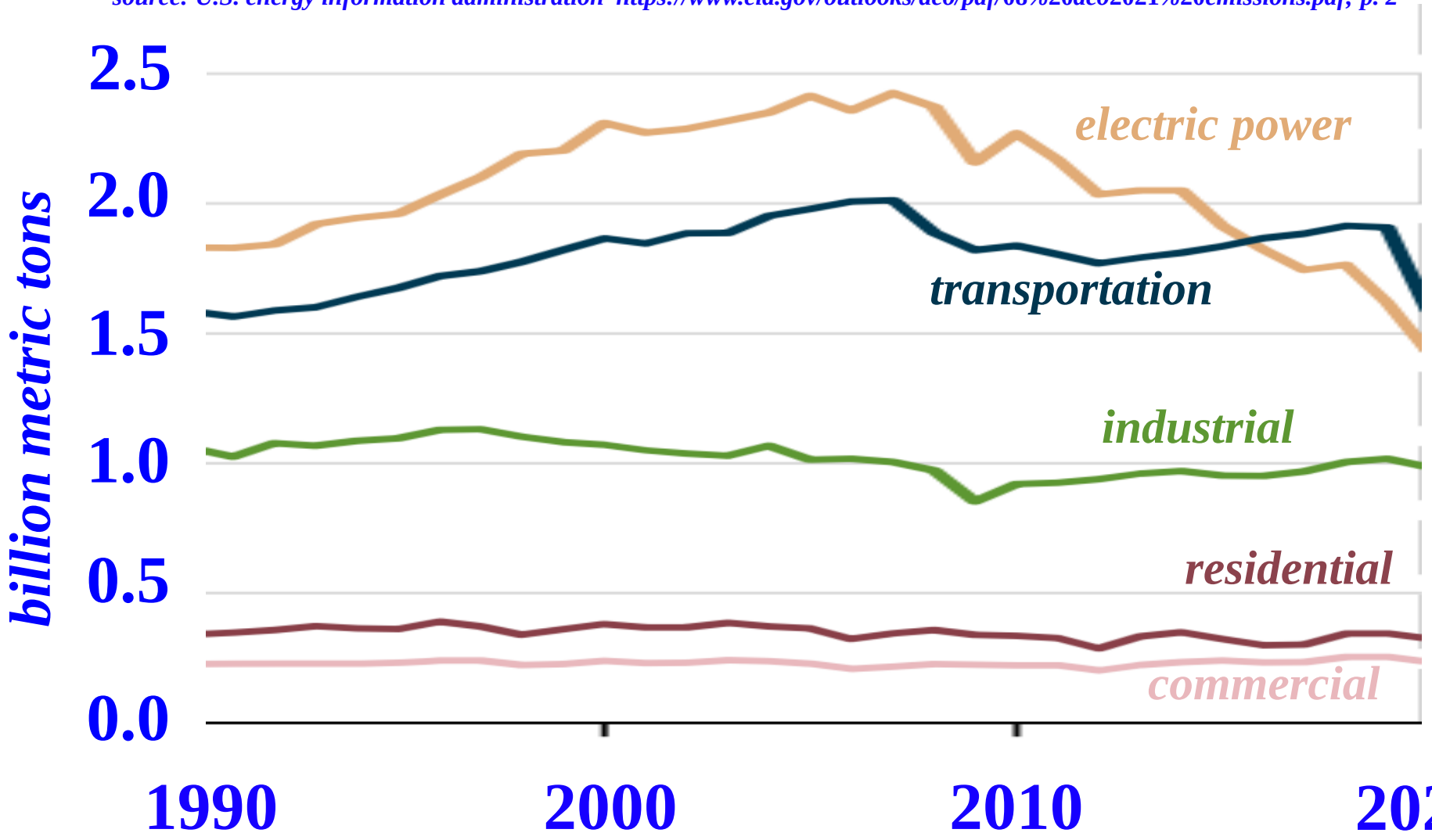
US FOSSIL – FIRED GENERATION CO_2 EMISSIONS



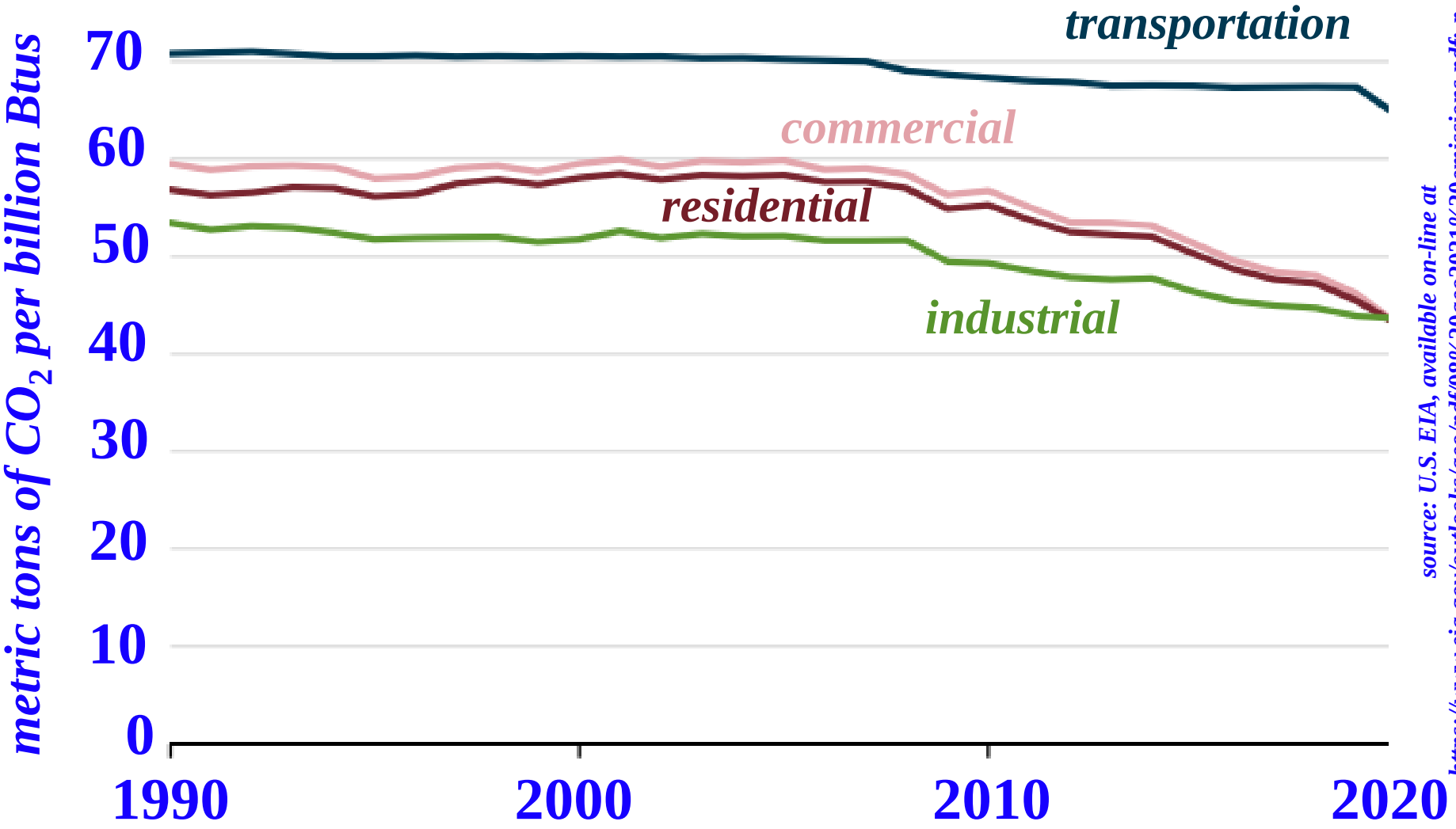
Source: EIA, Monthly Energy Review data published in Today in Energy May 29, 2018; available online at https://www.eia.gov/todayinenergy/detail.php?id=33543

US ENERGY – RELATED CO_2 EMISSIONS BY SECTORS: 1990 – 2020

source: U.S. energy information administration https://www.eia.gov/outlooks/aeo/pdf/08%20aeo2021%20emissions.pdf; p. 2

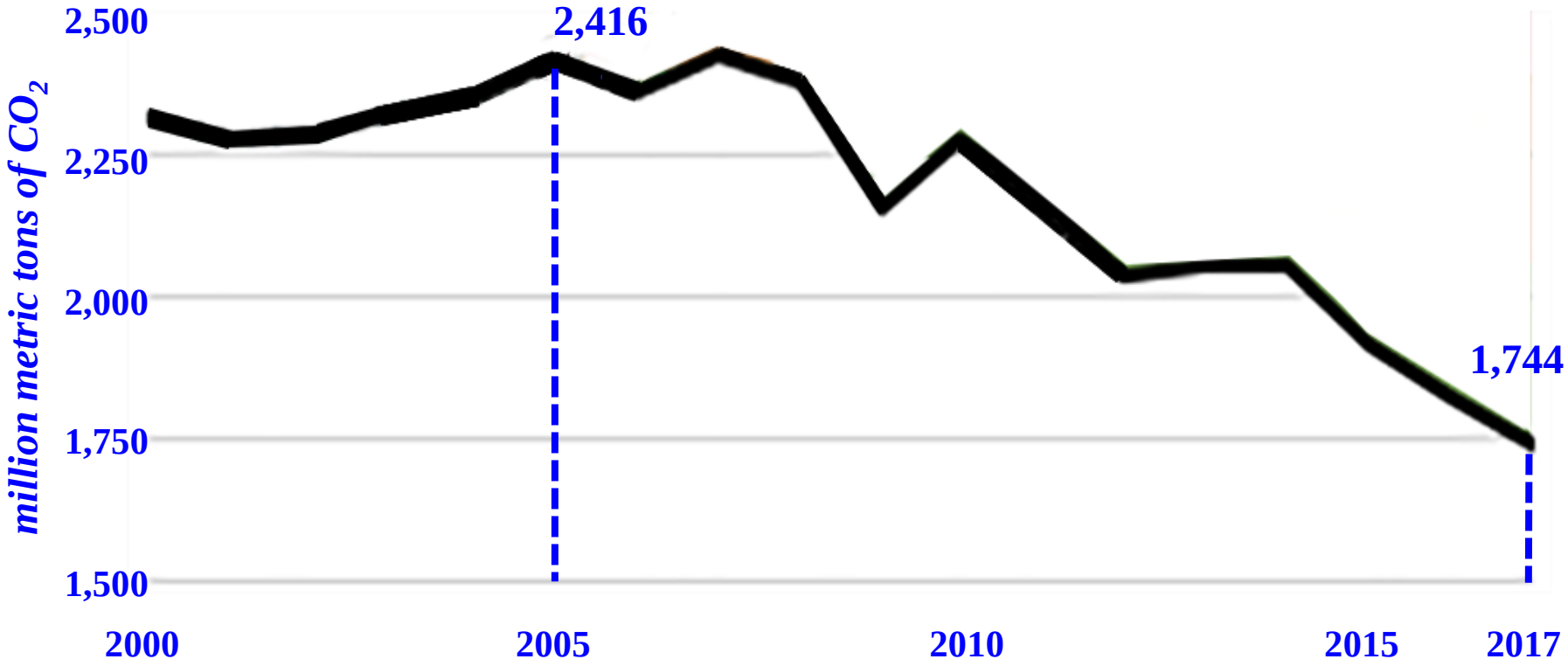


US CO_2 INTENSITY BY END–USE SECTOR: 1990 – 2020



source: U.S. EIA, available on-line at https://www.eia.gov/outlooks/aeo/pdf/08%20aeo2021%20emissions.pdf; p. 4

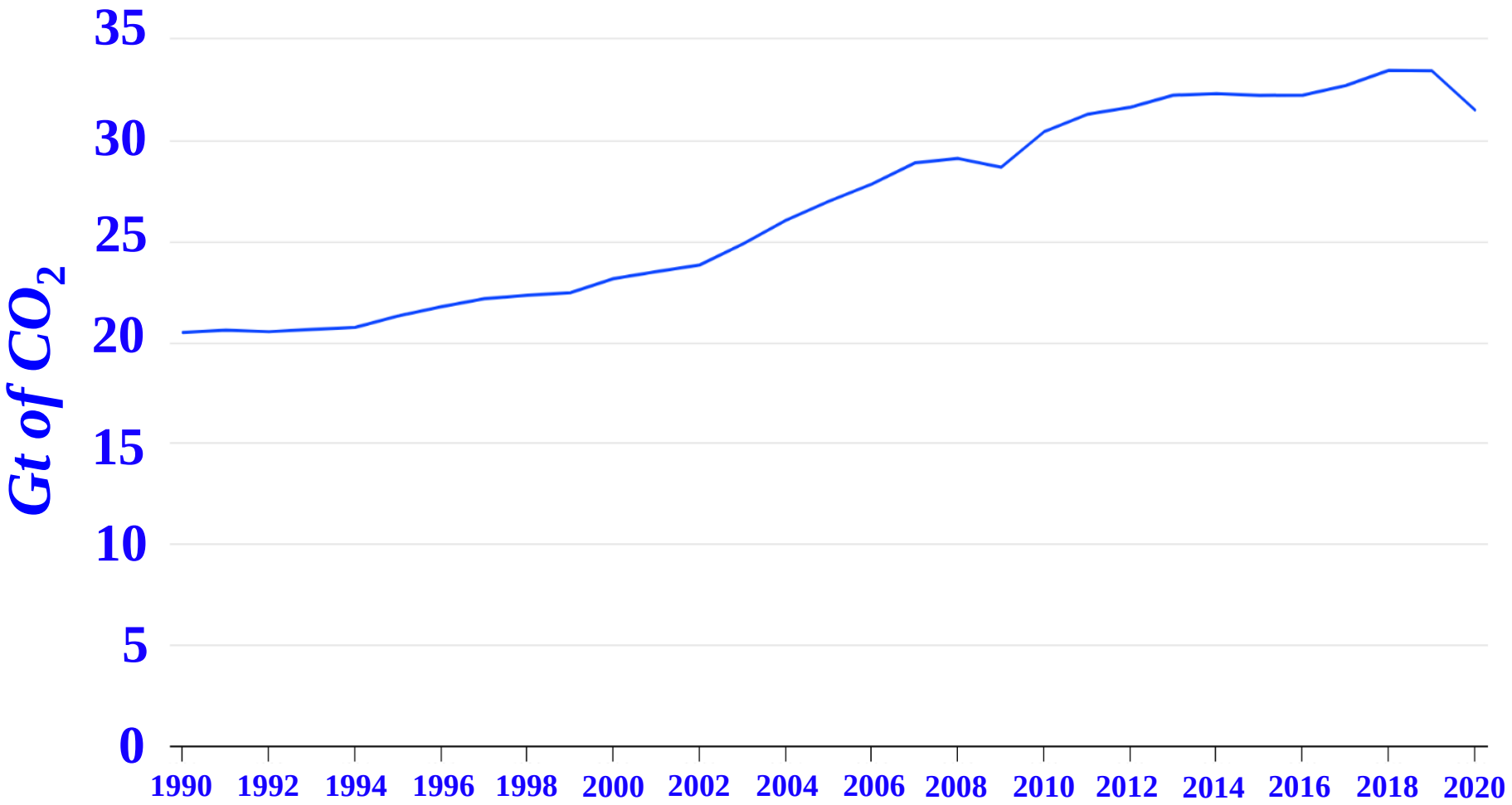
US CO_2 EMISSION REDUCTIONS IN POWER GENERATION: 2005 – 2017



Source: EIA, Today in Energy, December 21, 2018; available online at https://www.eia.gov/todayinenergy/detail.php?id=37392

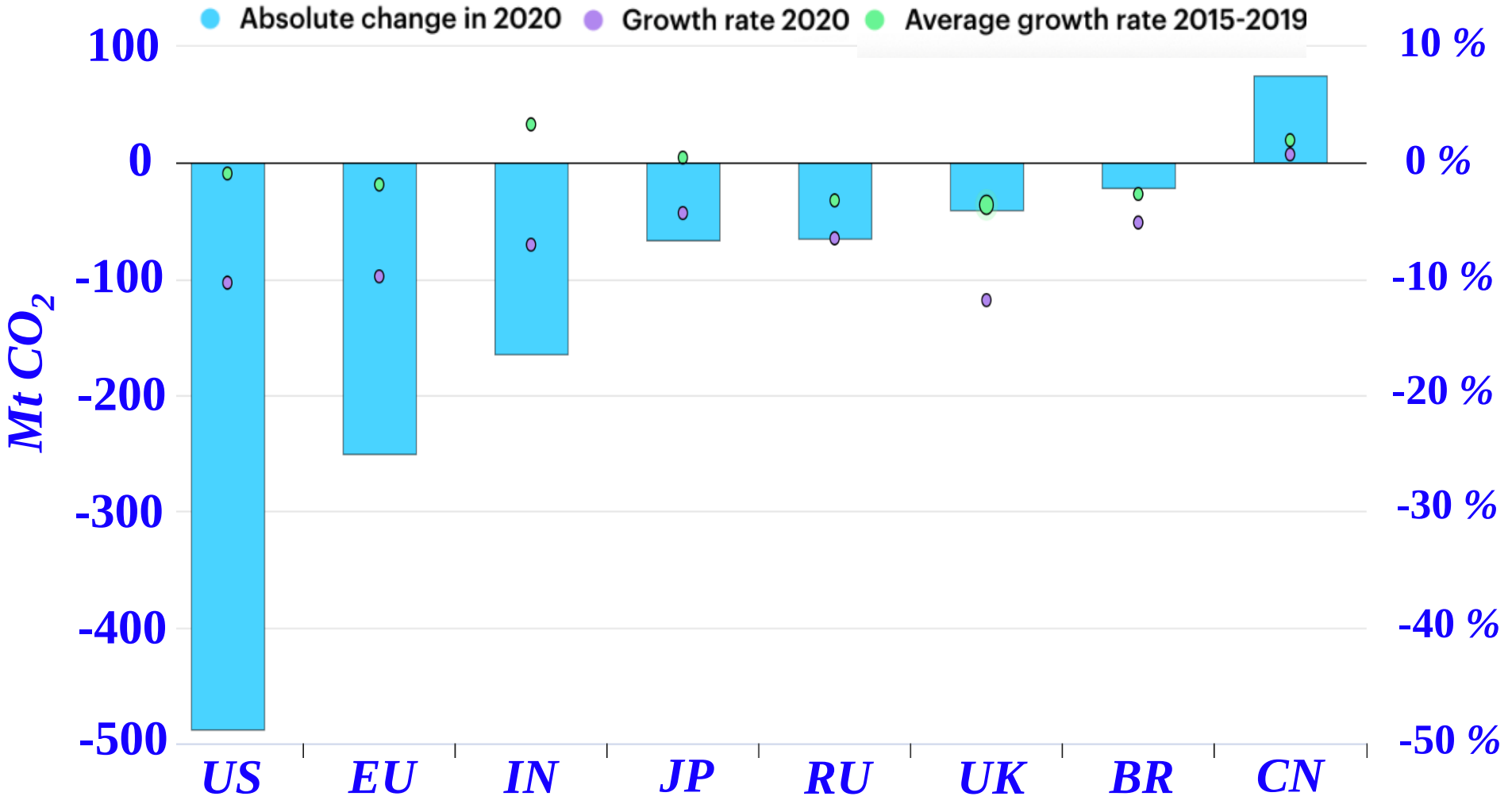
GLOBAL ENERGY–RELATED CO_2 EMISSIONS: 1990 – 2020

Source: International Energy Agency, Key Electricity Trends 2020, published in April 2021; available online at https://www.iea.org/data-and-statistics/charts/yearly-solar-production-in-oecd-countries-2010-2020

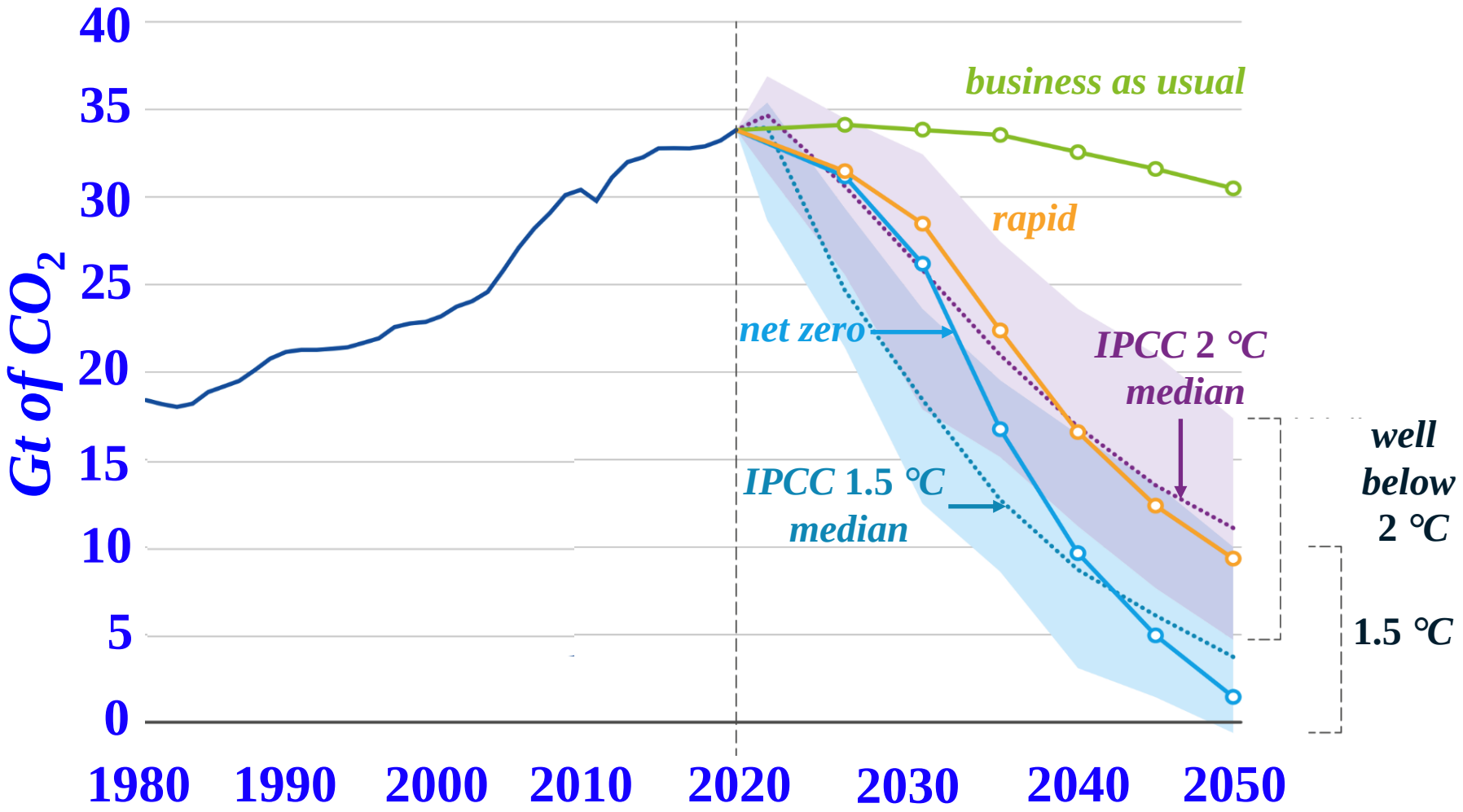


CO_2 EMISSION CHANGES IN 2020

Source: International Energy Agency, Key Electricity Trends 2020, published in April 2021; available online at https://www.iea.org/data-and-statistics/charts/yearly-solar-production-in-oecd-countries-2010-2020



GLOBAL CO_2 EMISSIONS FROM FOSSIL FUELS



Source: BP, Energy Outlook 2020. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2020.pdf

THE WORLD ECONOMIES RELY ON ABUNDANT AND AFFORDABLE ELECTRICITY

ELECTRICITY AND ENERGY

- While the main focus of the ECE 333 course is on green resources, we need to also understand both the energy context, together with the policy and market contexts, within which such resources are planned and operated
- Energy obtained from various sources is converted into electricity; electric energy is not used in

ELECTRICITY AND ENERGY

that form but is converted into other energy forms, such as light, sound and mechanical energy

- As more energy consumed is electricity, the focus on the environmental impacts is driving the changes underway in the electricity infrastructure, given the global drive to effectively address the impacts of *climate change*

IMPACTS OF ELECTRICITY

- **The National Academy of Engineering, the *US*'s most prestigious collection of outstanding engineers, named *electrification* – the *development of the vast networks of electricity that power the world*– the *most important* of the 20 engineering achievements that have had the *greatest* impact on the quality of life in the 20^{th} century**

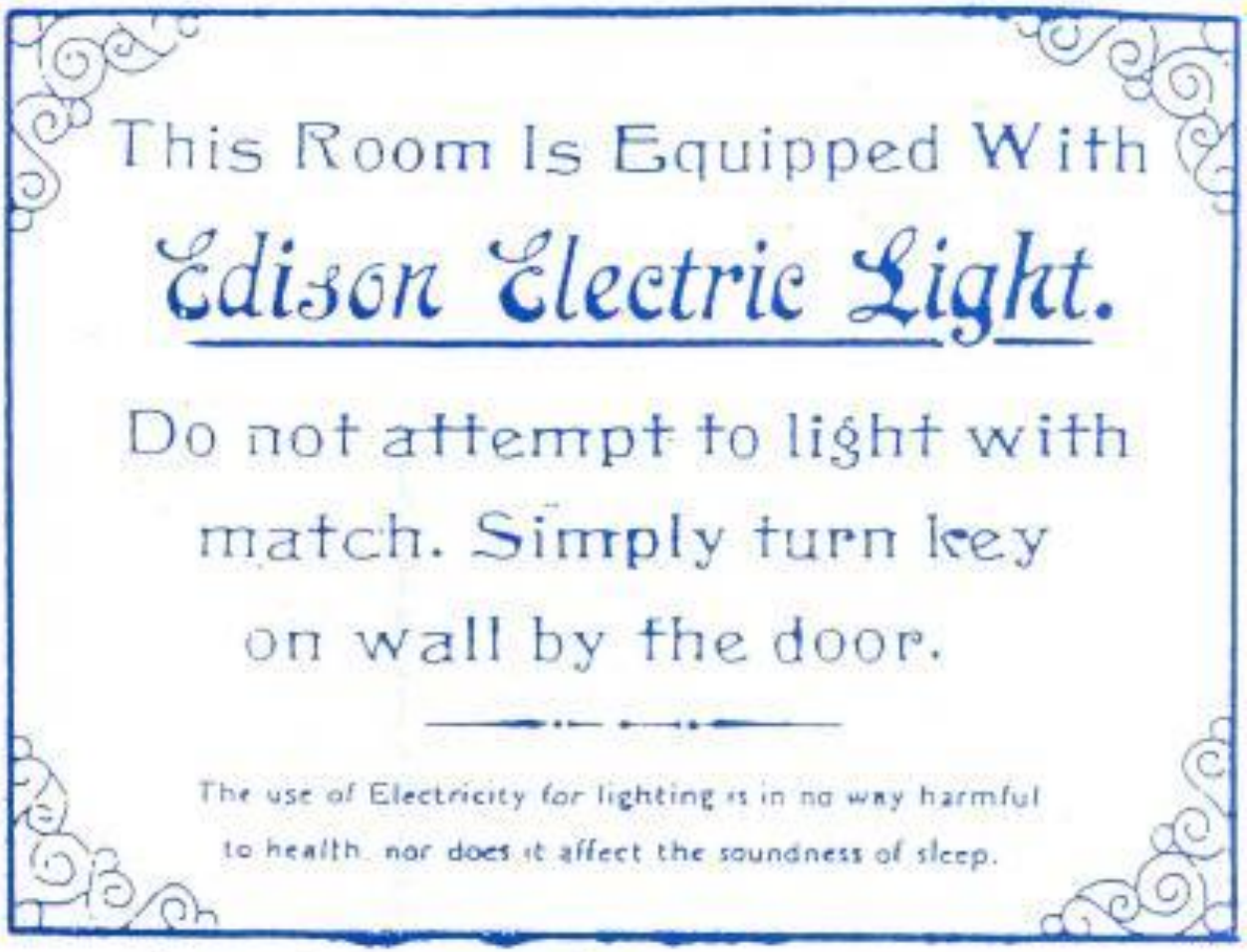
IMPACTS OF ELECTRICITY

- Electricity ranked ahead of the automobile, airplane, safe and abundant water, electronics, computers and space exploration
- The widespread electrification implemented in the twentieth century gave us energy for our cities, factories, farms and homes, forever changing the lives of people forever

THE BEGINNINGS

- Commercial use of electricity began in the late 1870's with the development of arc lamps for street lighting and lighthouse illumination
- The first complete electric power system, comprising a generator, cable, fuse, meter and loads, is often considered to be *Edison's Pearl Street Station* in New York in 1882
  - DC system with a DC generator supply
  - 59 customers within a 1 – mile radius area

1882 EDISON POSTER ON ELECTRIC LIGHTING



Issued during the introduction of electricity supply to New York in 1882.

THE BEGINNINGS

- Actually, George Roe had founded in 1879 an electric company in San Francisco, which later became part of today's *PG&E*
  - this was the first entity in the nation to offer central station electric service to the public
  - two brush arc–light dynamos supplied 21 lights that served from sundown to midnight – Sundays and holidays excluded – for a flat rate of *$* 10 per lamp per week – 1882 *$*

MAJOR DEVELOPMENTS

- Frank Sprague developed *electrical motors* in 1884; within a short time, he incorporated them into the electricity system
- The major limitations of *DC* systems became apparent by 1886:
  - inability to deliver long–distance power
  - high voltages for longer distance transmis–sion were needed to reduce the delivery losses, but, considerably lower voltages for generation and consumption were required

MAJOR DEVELOPMENTS

- Gaulard and Gibbs developed the *transformer* and AC transmission, the forerunners of the *AC* transmission systems in use today
- George Westinghouse immediately bought *US* rights to the Gaulard and Gibbs technology
- In 1889, the *first AC transmission line in North America* – a single phase 4–*kV*, 21–*km* line – was put into operation to link Willamette Falls to Portland

MAJOR DEVELOPMENTS

- A key and important development was Nikola Tesla's invention of induction motors and polyphase systems
  - Westinghouse purchased the rights to Tesla's inventions on AC motors, generators, transformers and transmission systems
  - Westinghouse was the key driver of the construction of the basis of today's AC grid

MAJOR DEVELOPMENTS

- *AC* won out over *DC* because
  - the ease of transformation of voltage levels thereby providing the flexibility to use diffe–rent voltage levels for generation/transmis–sion and consumption
  - the increased simplicity of *AC* over *DC* generators
  - the decreased complexity and lower costs of *AC* over *DC* motors
- *AC* replaced *DC* over a very brief time period

MAJOR DEVELOPMENTS

- In 1893, the first three–phase transmission line in North America went into service – a 2.3–kV, 12–km line in *Southern California*

- *Niagara Falls* was connected to *Buffalo* – a 30–km distance – using *AC* since *DC* was *not practical*

TECHNOLOGY DEVELOPMENTS

- The push to transmit larger amounts of power over larger distances led to higher voltages
  - early systems: 12, 44 and 66 kV (RMS line–to–line)
  - 1922: 165 kV
  - 1923: 220 kV
  - 1935: 287 kV
  - 1953: 330 kV
  - 1965: 500 kV
  - 1966: 735 kV (*Hydro Quebec*)
  - 1969: 765 kV (*American Electric Power*)

TECHNOLOGY DEVELOPMENTS

- Standardization of voltage levels led to voltage classifications
  - 115, 138, 161 and 230 *kV* are *high voltage* (*HV*)
  - 345, 500 and 765 *kV* are *extra high voltage* (*EHV*)
- The development of mercury arc valves in the early 1950's made *HVDC* economical in specific cases for the transmission of larger blocks of power over longer distances

TECHNOLOGY DEVELOPMENTS

- Eventually, the various frequencies in use – 25, 50, 60, 125 and 133 *Hz* – became standardized to 60 *Hz* in North America; there are many parts of the world where the frequency is 50 *Hz* today
- *DC* became economic over *AC* for distances that exceed
  - 500 *km* for overhead lines
  - 50 *km* for underground/submarine cables

INDUSTRY STRUCTURE

- Brutal and inefficient competition was rife in the early days of electricity; for example,
  - 24 central station power companies were established in Chicago between 1887 and 1893
  - exhaustive duplication and fierce competition led to very high costs

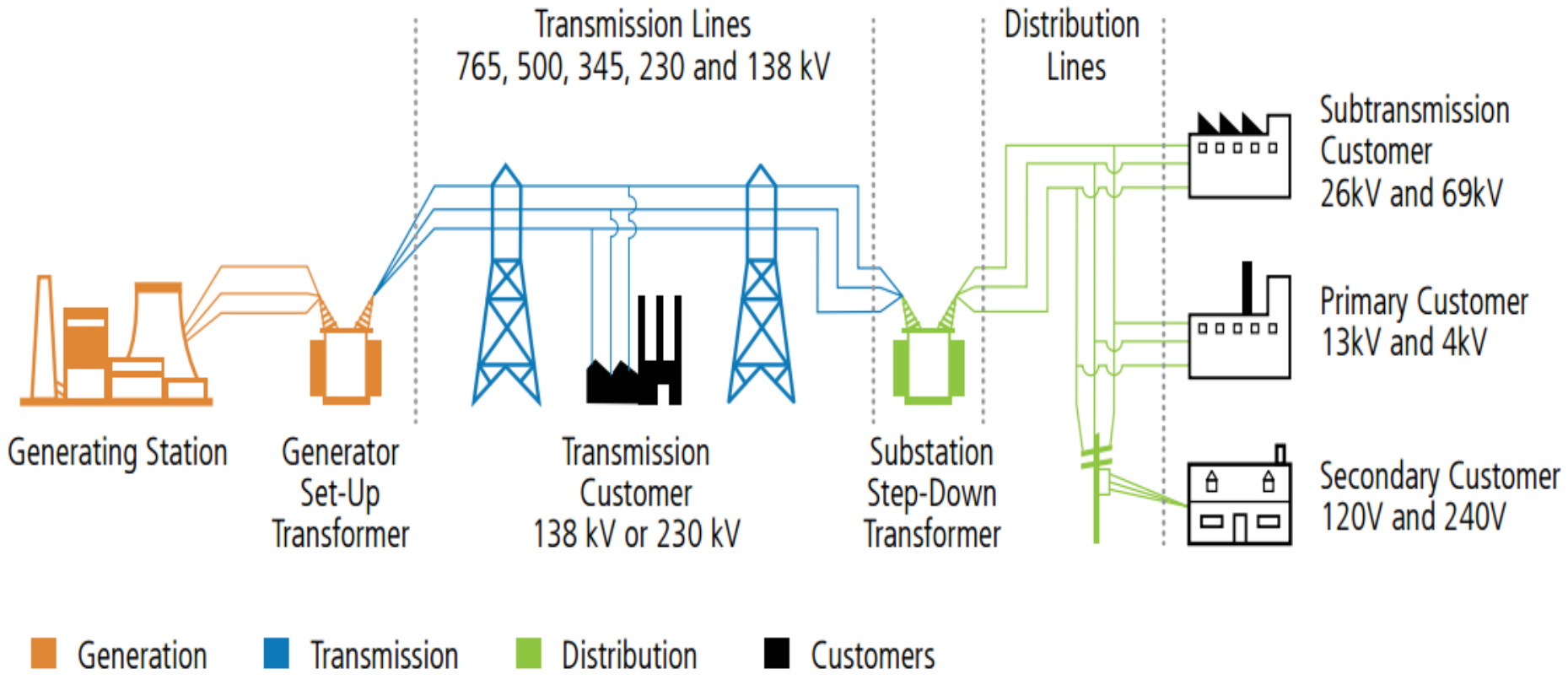
INDUSTRY STRUCTURE

- Samuel Insull built a monopoly over all central station production in Chicago and is considered the father of the regulated monopoly concept:

  "exclusive franchises should be coupled with the conditions of public control, requiring all charges for services to be based on a cost plus a reasonable profit"

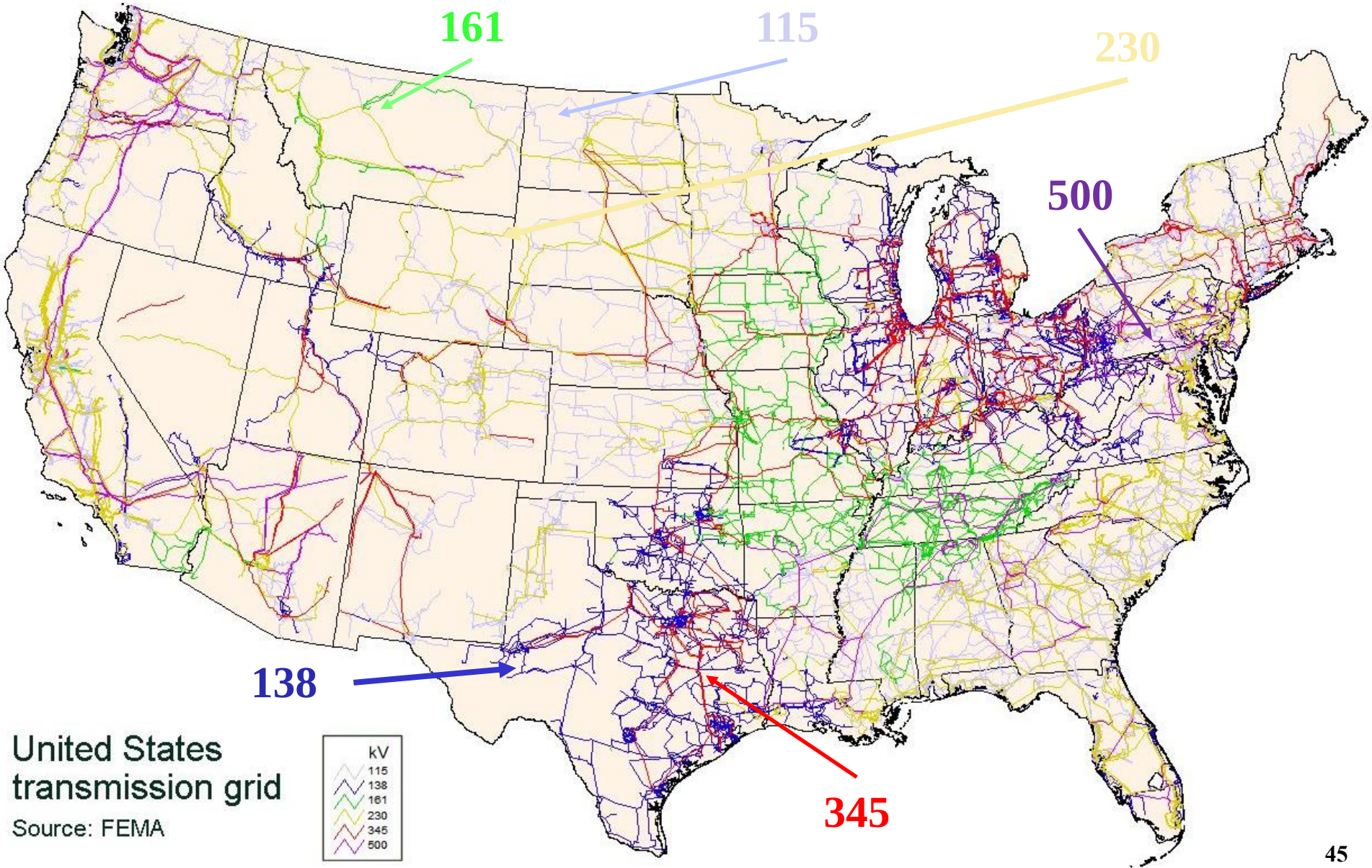
- In 1907, New York and Wisconsin set up their regulatory commissions to regulate electricity

THE ELECTRIC POWER GRID

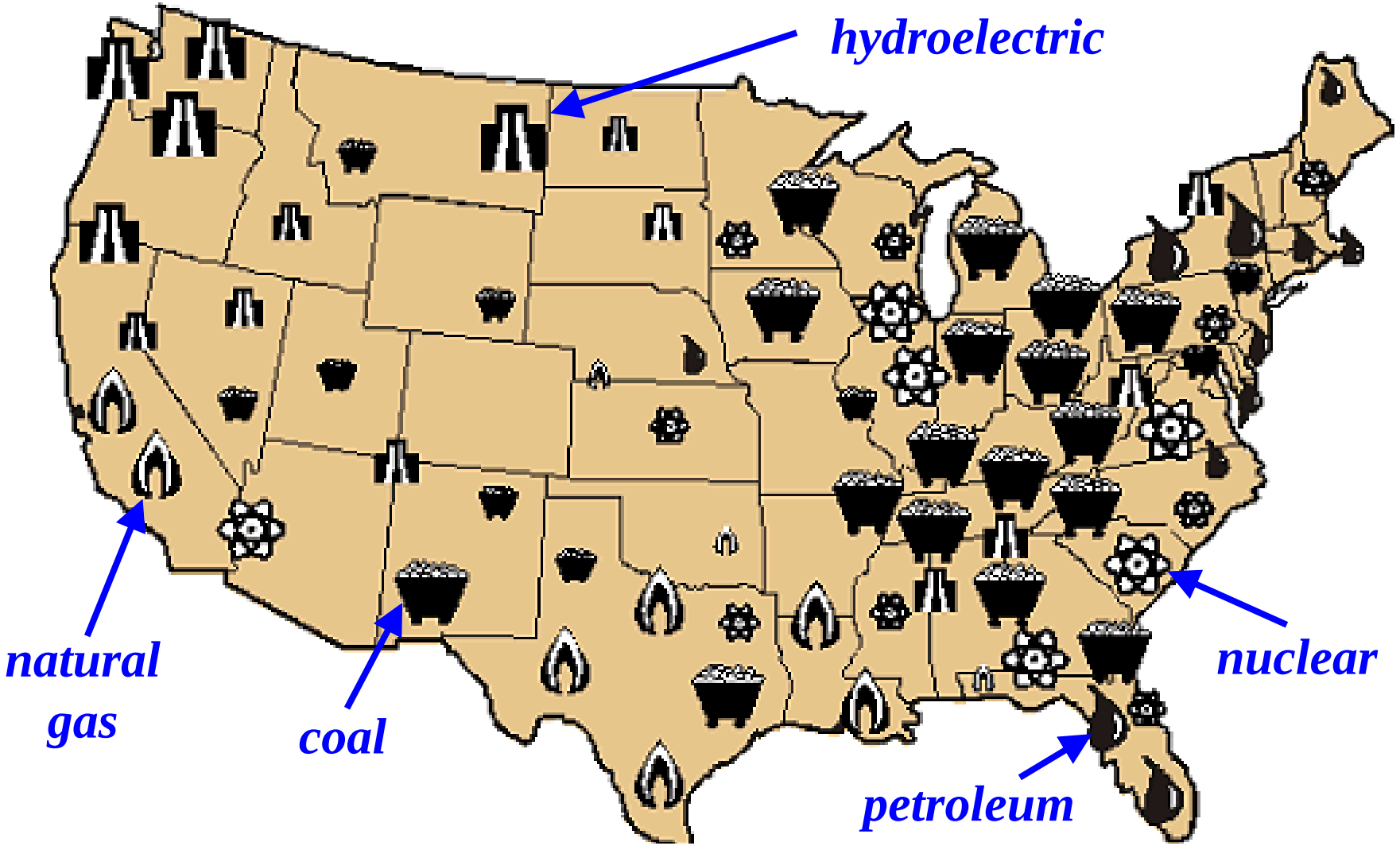


Source: EIA (2010-2013) http://www.eia.gov/electricity/monthly/current_year/february2014.pdf; pg 134; Issued April 2015

THE *US* TRANSMISSION GRID

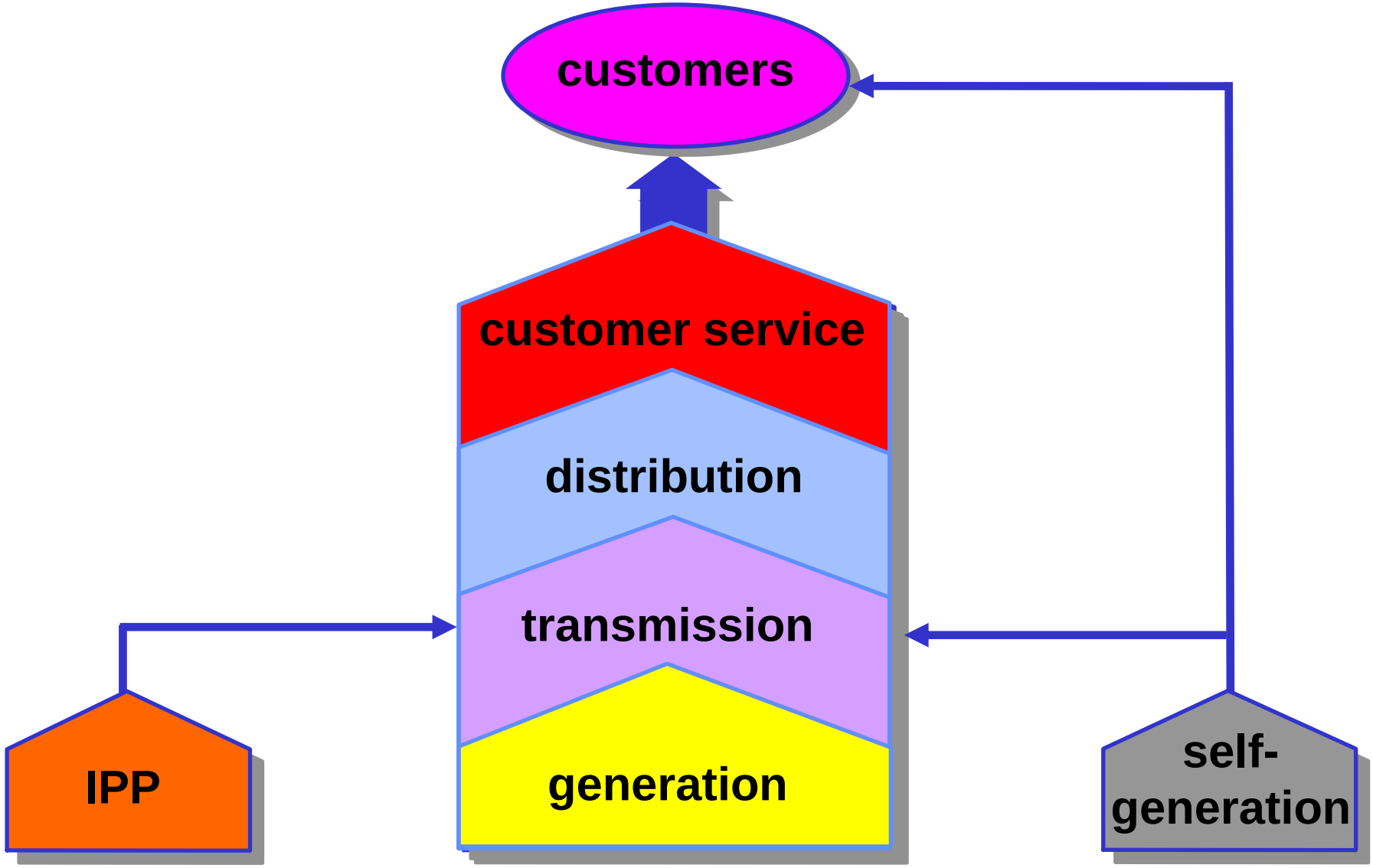


US CONVENTIONAL ELECTRICITY GENERATION SOURCES



Source: The Changing Structure of the Electric Power Industry 2000: An Update (EIA, 2000)

THE VERTICALLY INTEGRATED UTILITY INDUSTRY STRUCTURE



COMPETITION IN THE GENERATION MARKET

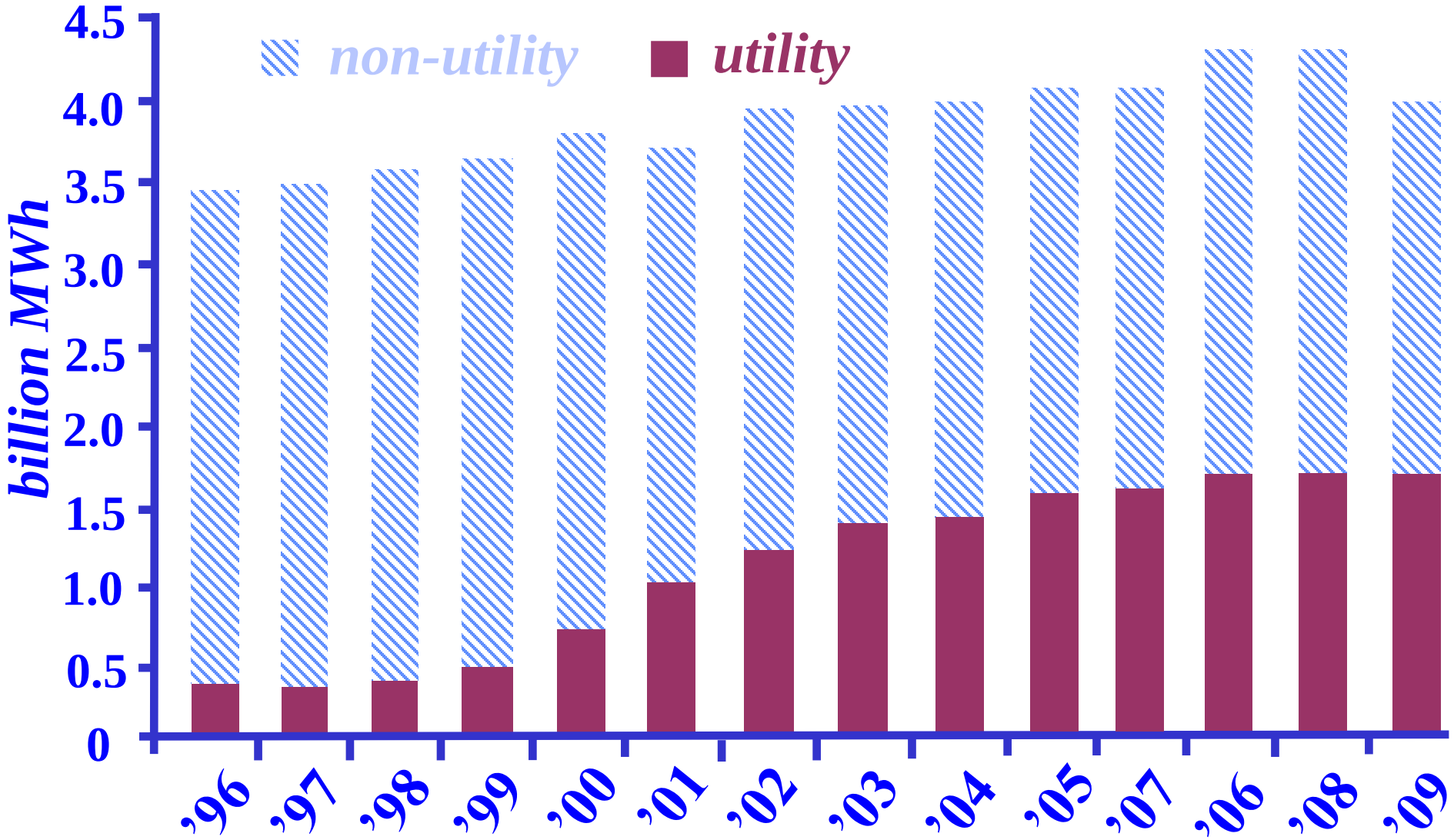
- The 1978 Public Utility Regulatory Policies Act (*PURPA*) unleashes competition through the introduction of qualifying facilities (*QFs*)
- *PURPA* mandates each investor–owned utility to purchase power at *avoided cost* from *QF*s located in its service territory
- *PURPA* implementation was left to individual states resulting in non–uniform implementations

COMPETITION IN THE GENERATION MARKET

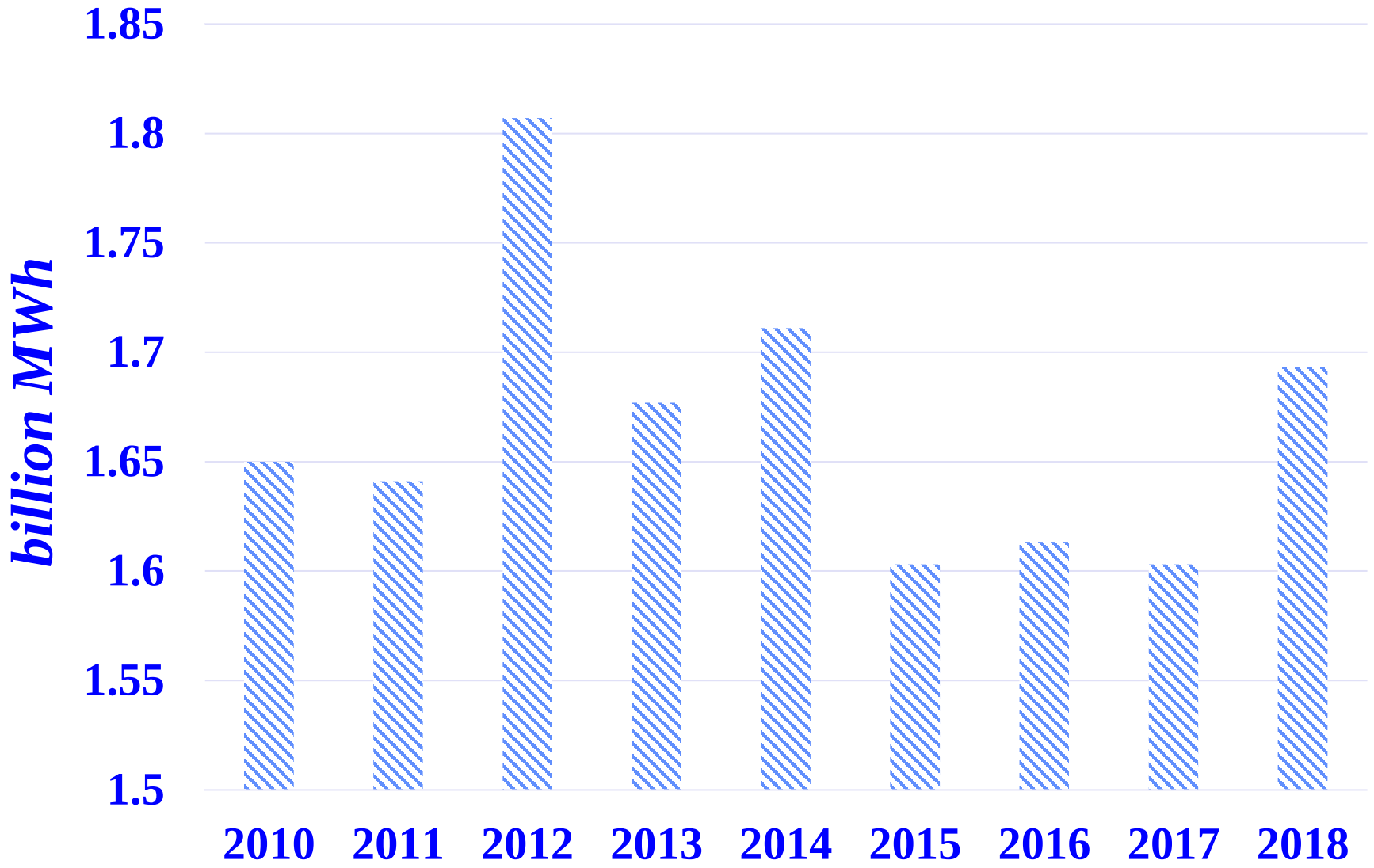
- Today, the once fledgling private power entities constitute a *multibillion-dollar* industry whose role in the electricity business is *critically important*
- We refer to all the new players such as *QF*s and the various independent power producers (*IPP*s) as non-utility generators (*NUG*s) and their output as non-utility generation (*NUG*)
- The majority of the new energy generation added in recent years in *US* comes from the *NUG* sector

GROWING IMPACT OF *NUG* ENERGY

Source: http://www.eia.doe.gov/cneaf/electricity/epm/table1_1.html; Issued 2010

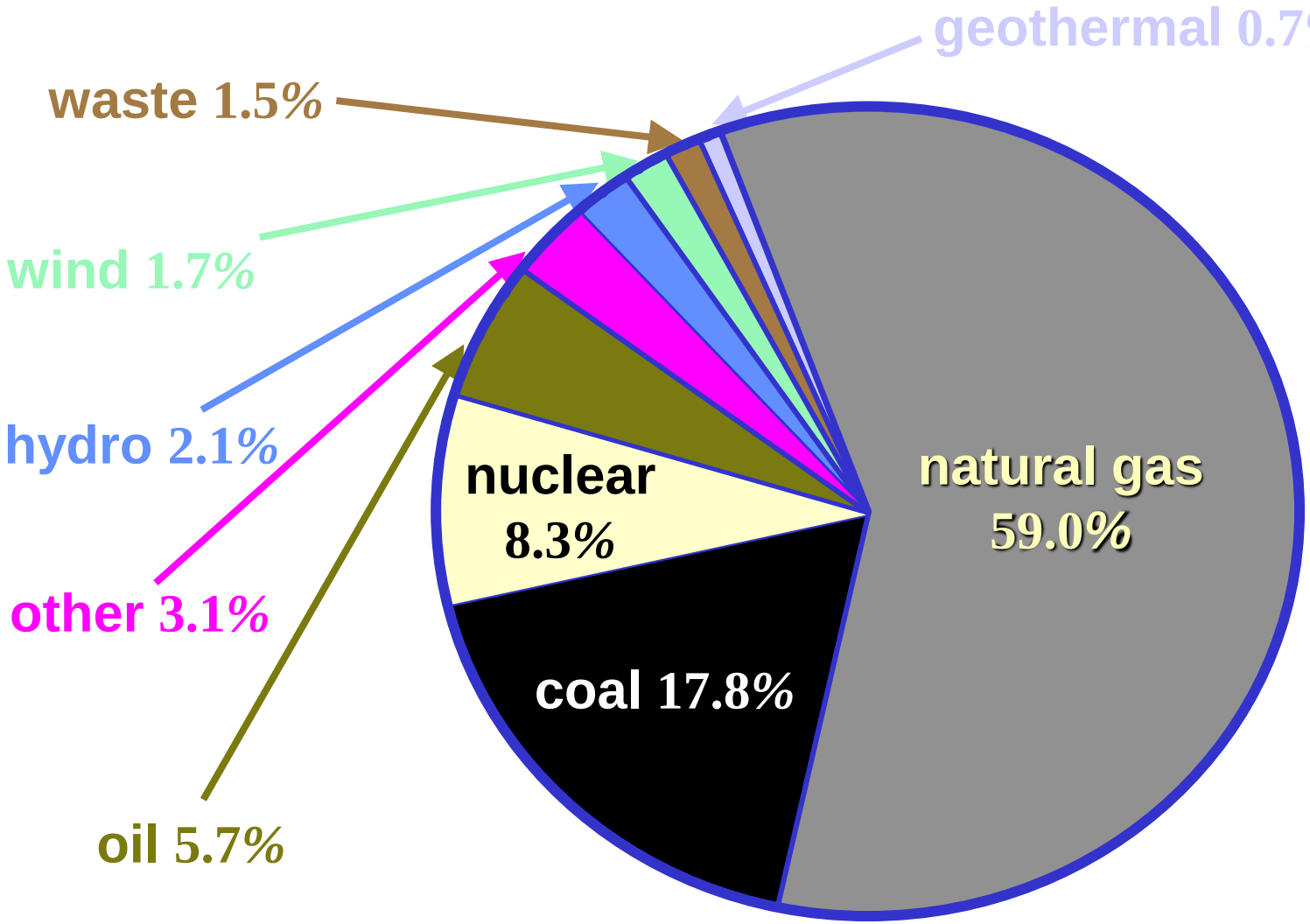


NUG ENERGY



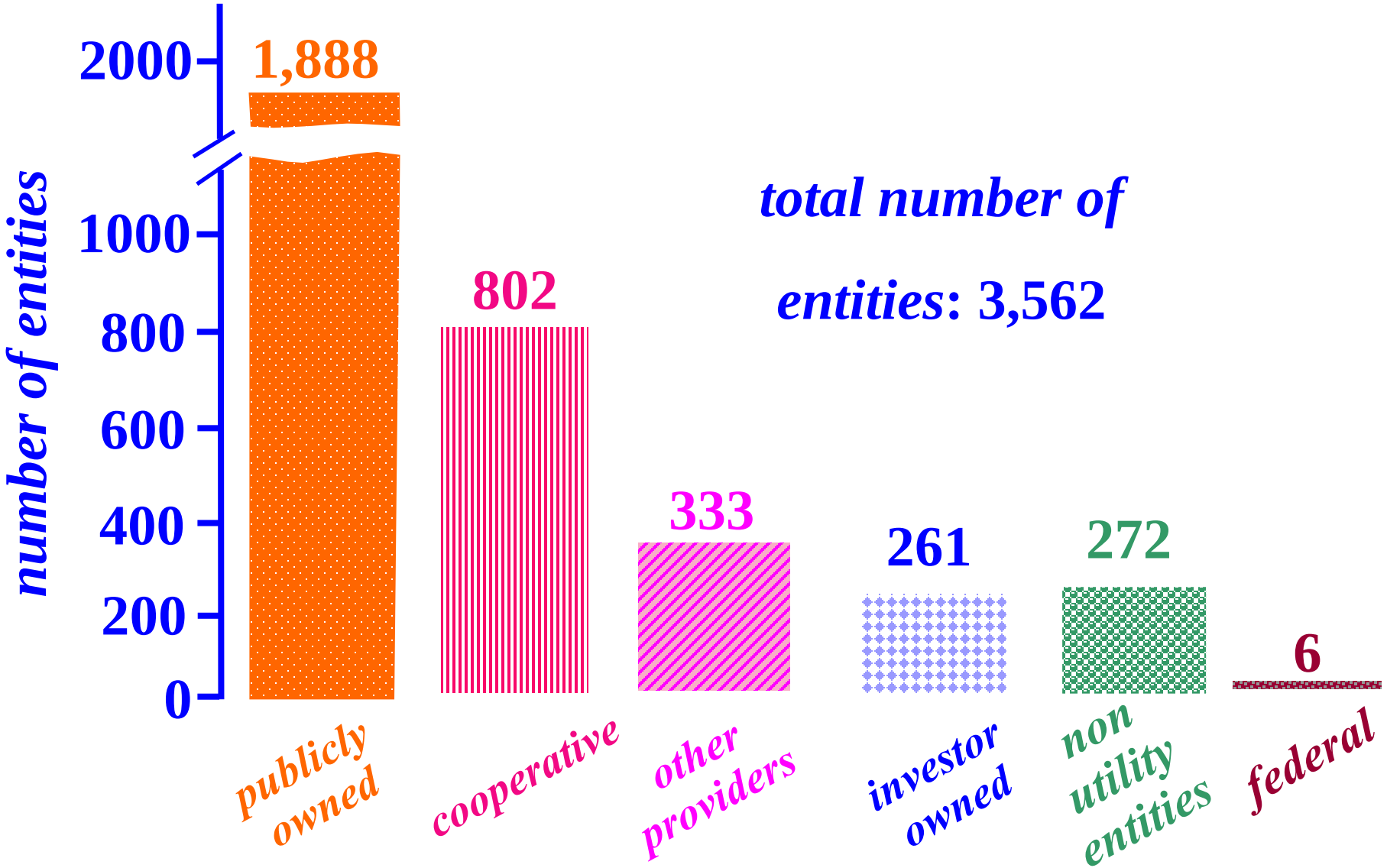
Source: https://www.eia.gov/electricity/data.cfm#generation; Issued Mar 2019

ENERGY SOURCES OF *PURPA* – BASED *NUG* CAPACITY BY 1993



Source: 1993 Capacity and Generation of Non-Utility Sources of Energy, Edison Electric Institute

DIVERSITY OF THE *US* ELECTRICITY INDUSTRY



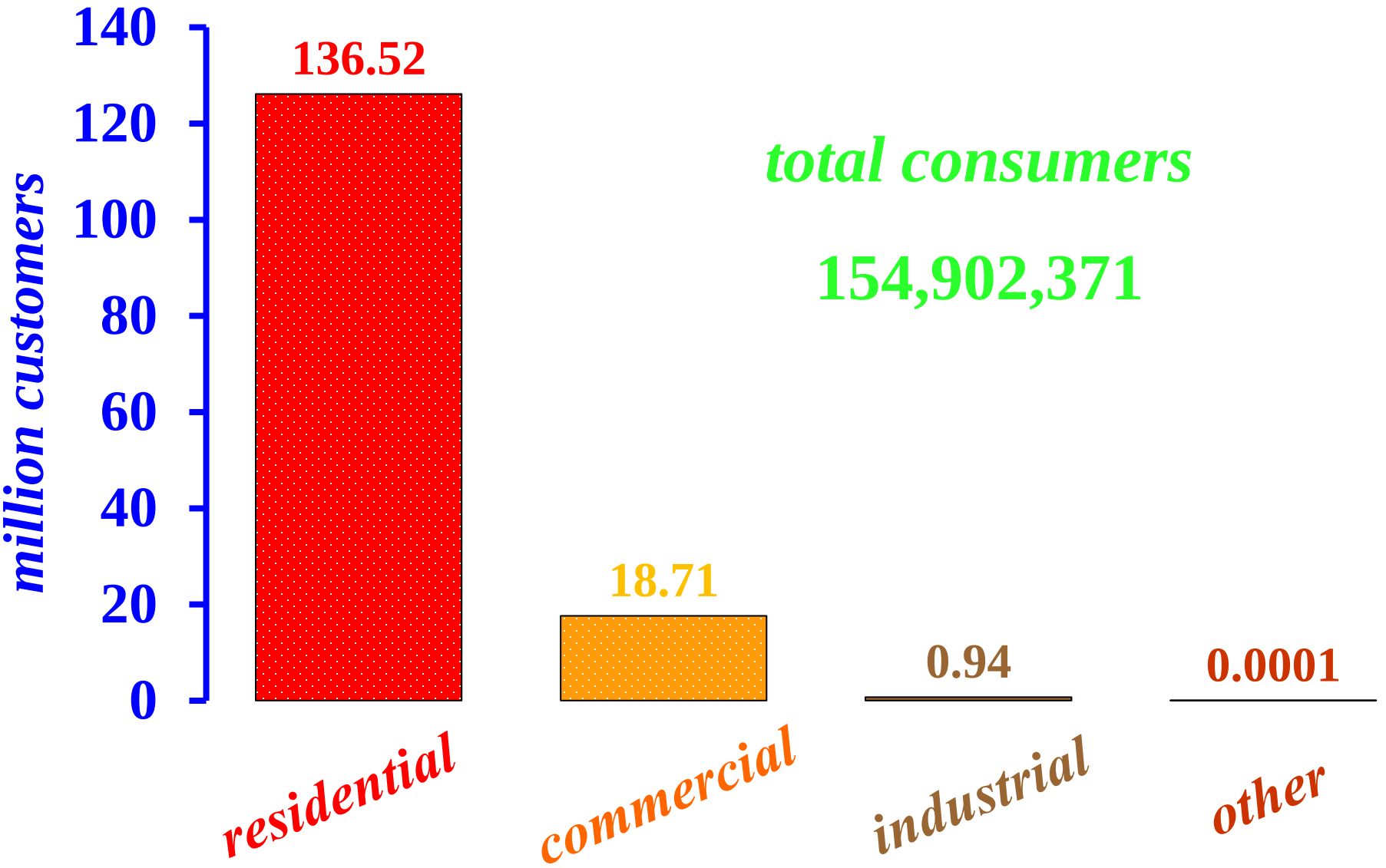
THE *US* ELECTRICITY INDUSTRY

- The 802 rural electric coops stem from the *New Deal* years – a result of the drive to supply electricity to everyone and everywhere
- The 333 "other providers" include 70 "delivery providers" and 263 "energy providers" – entities that sell energy services, but not delivery
- The 6 federal power marketing agencies (*FPMA*s) include *Bonneville Power*, *WAPA* and *TVA*

THE *US* ELECTRICITY INDUSTRY

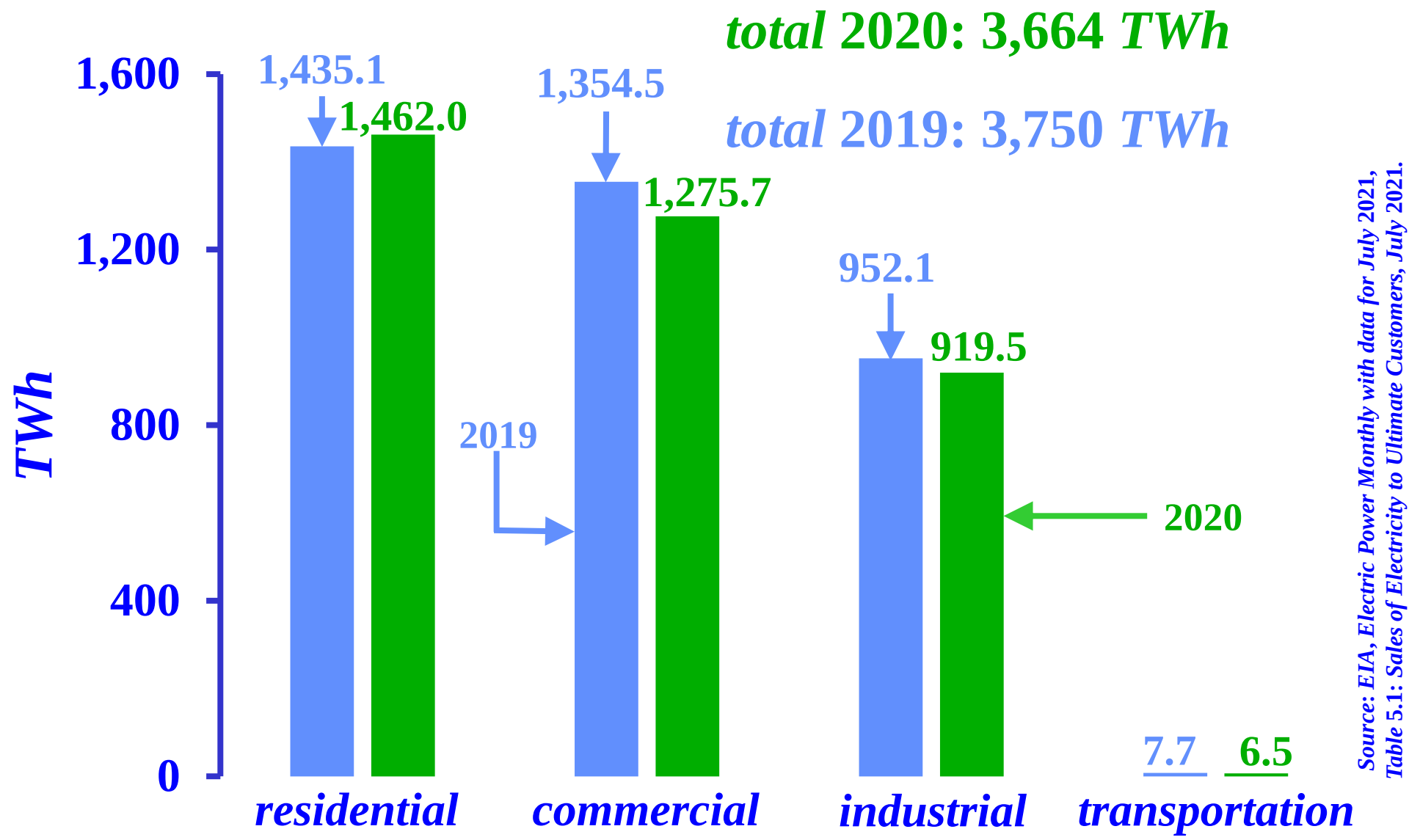
- The 261 investor–owned utility companies (*IOU*s) represent the predominant part of the industry because nearly three fifths of all electricity sales come from these entities
- The 1,888 publicly–owned electric utilities are the most numerous members of the industry: they represent non-profit, customer-owned government agencies at the local and state levels
- The 272 non–utility companies are, typically, not state–regulated entities

2020 *US* ELECTRICITY CUSTOMERS

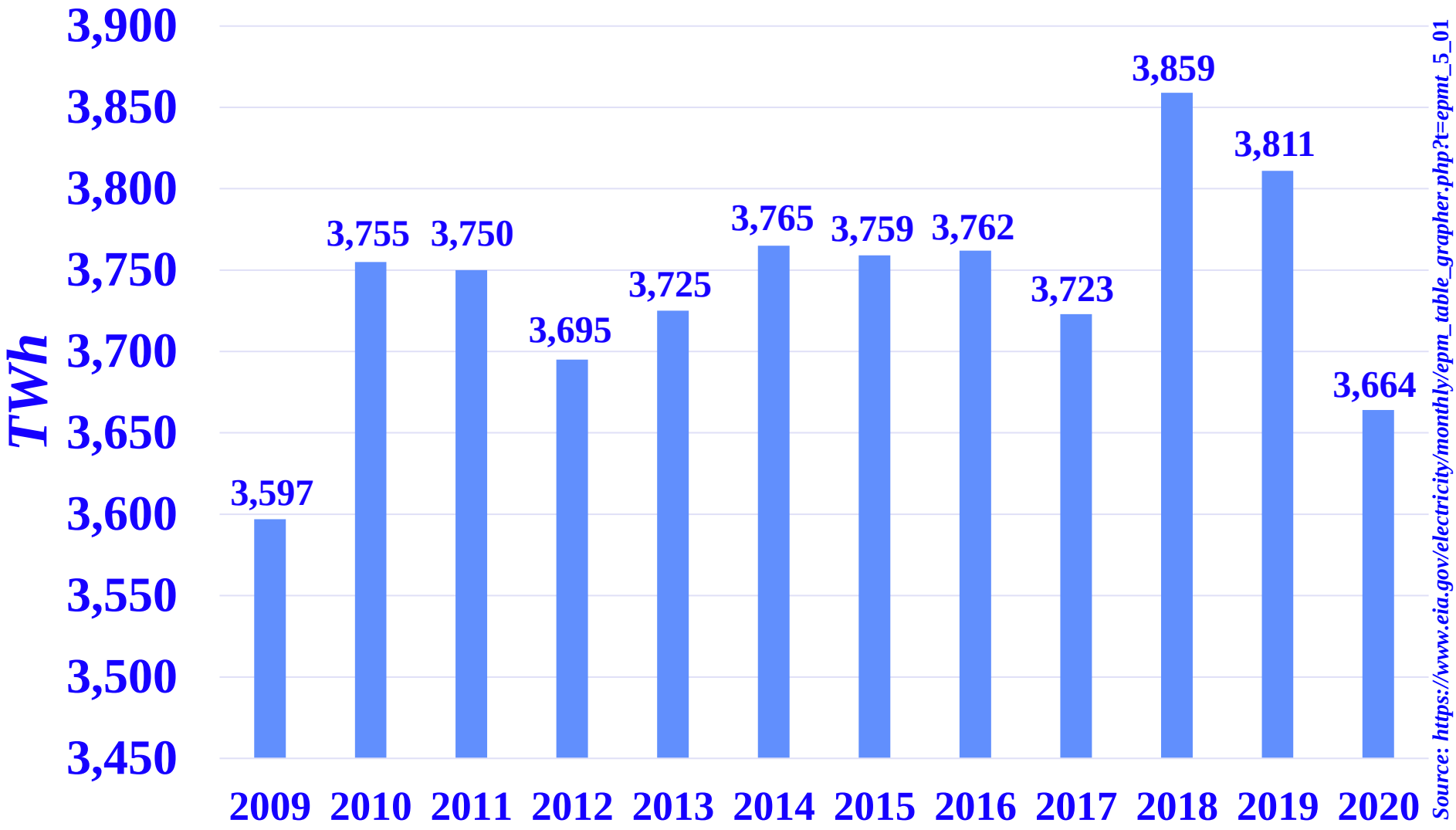


952,149

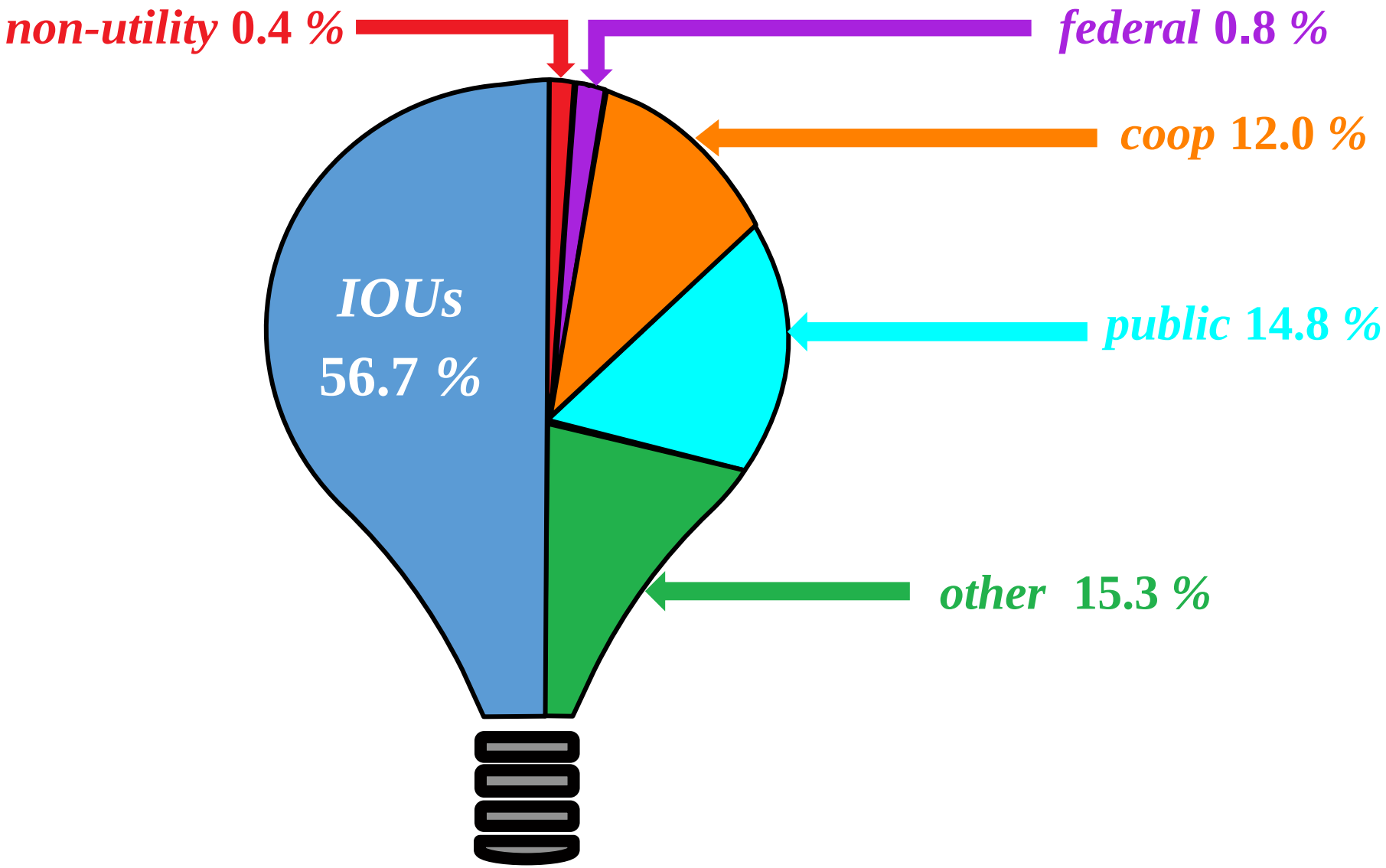
RETAIL ELECTRICITY SALES TO END–USE SECTOR CUSTOMERS



US ELECTRICITY CONSUMPTION: 2009 – 2020



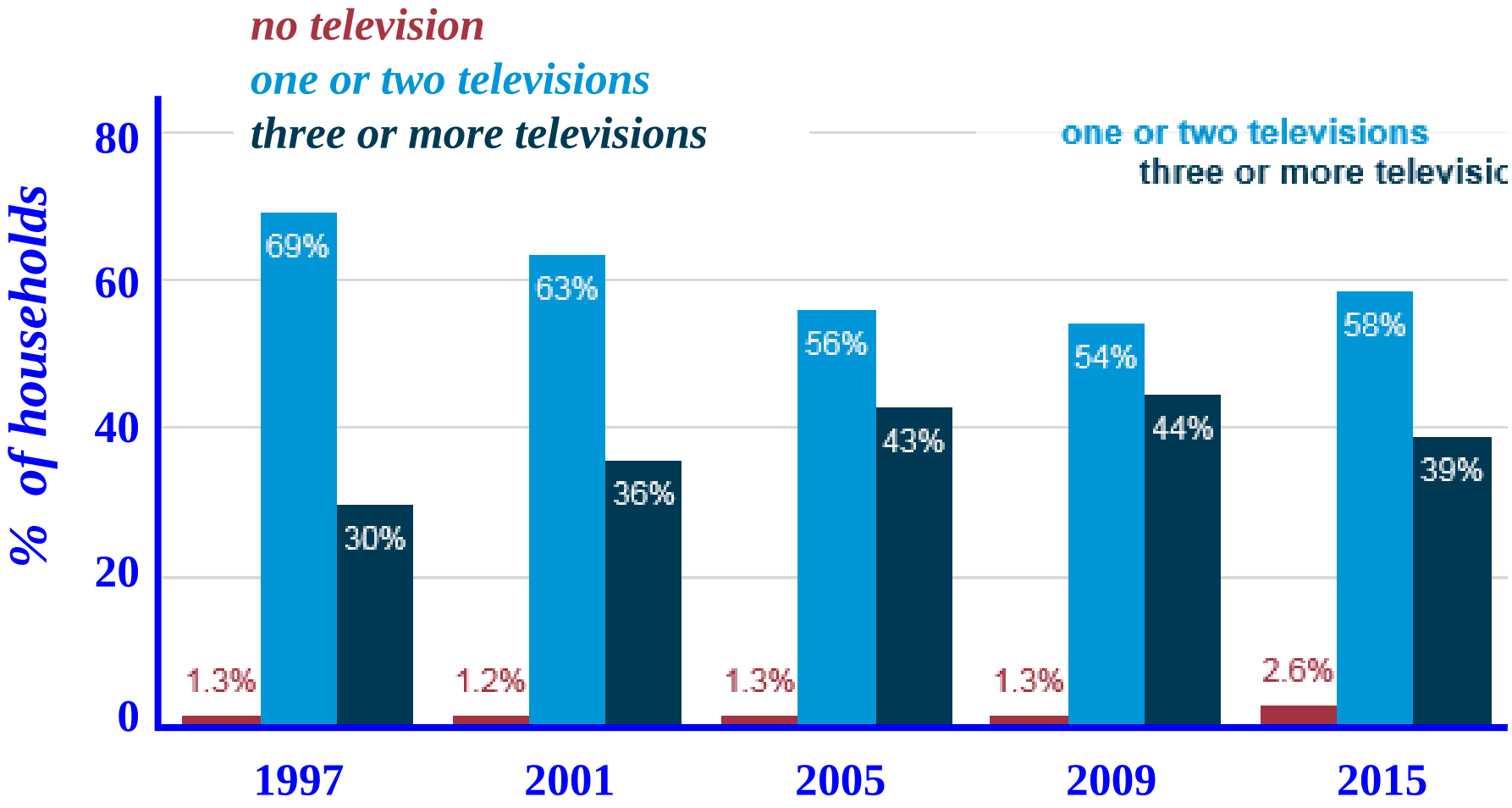
PERCENT OF CUSTOMERS SERVED BY ELECTRICITY PROVIDERS



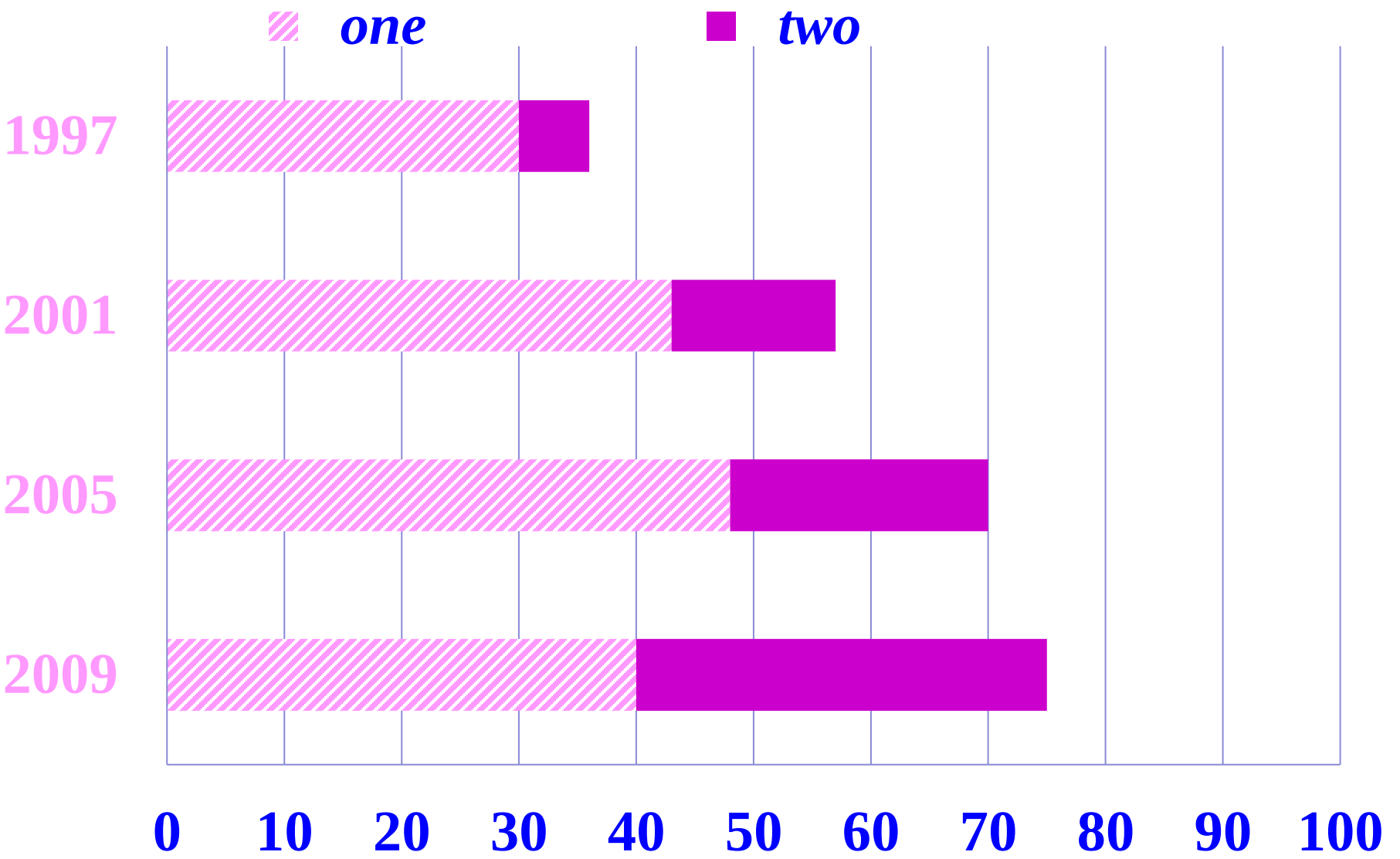
Source: Table 9 at http://www.eia.gov/electricity/state/unitedstates/

TV POPULATION IN *US* HOMES

Source: U.S. Energy Information Administration, Residential Energy Consumption Surveys, December 22, 2017, https://www.eia.gov/todayinenergy/detail.php?id=31692

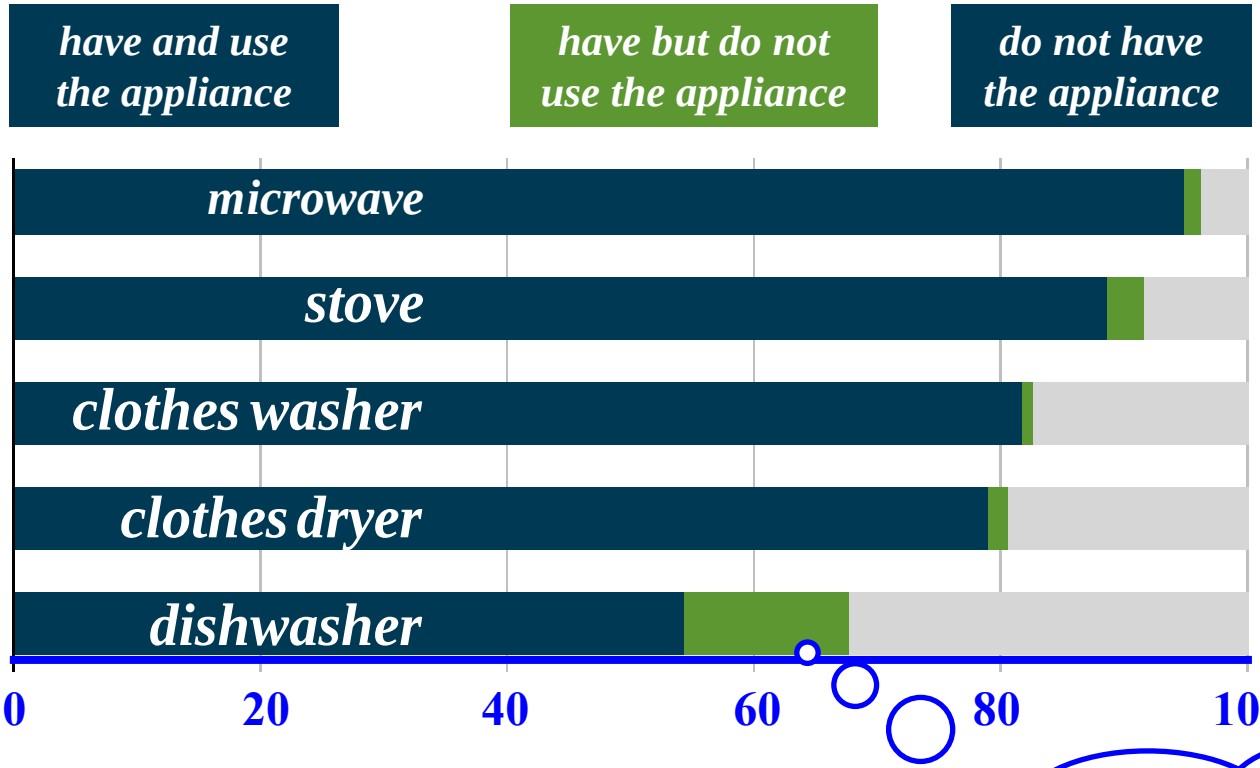


RISING NUMBER OF COMPUTERS IN HOUSEHOLDS



Source : EIA, http://www.eia.doe.gov/consumption/residential/; Issued January 2009

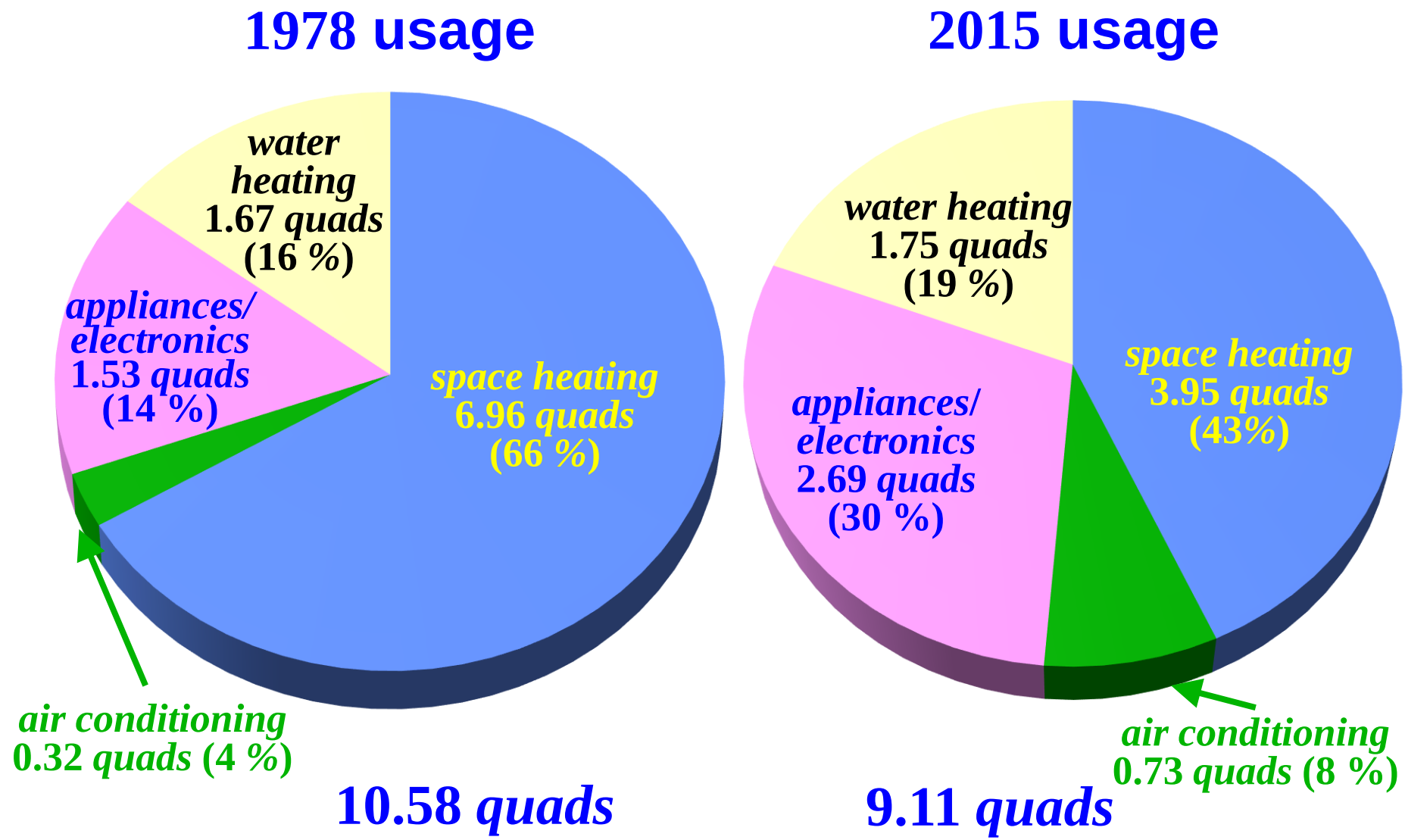
PRESENCE AND UTILIZATION OF MAJOR APPLIANCES IN *US* HOMES



Source: EIA June 19, 2017; https://www.eia.gov/todayinenergy/detail.php?id=31692

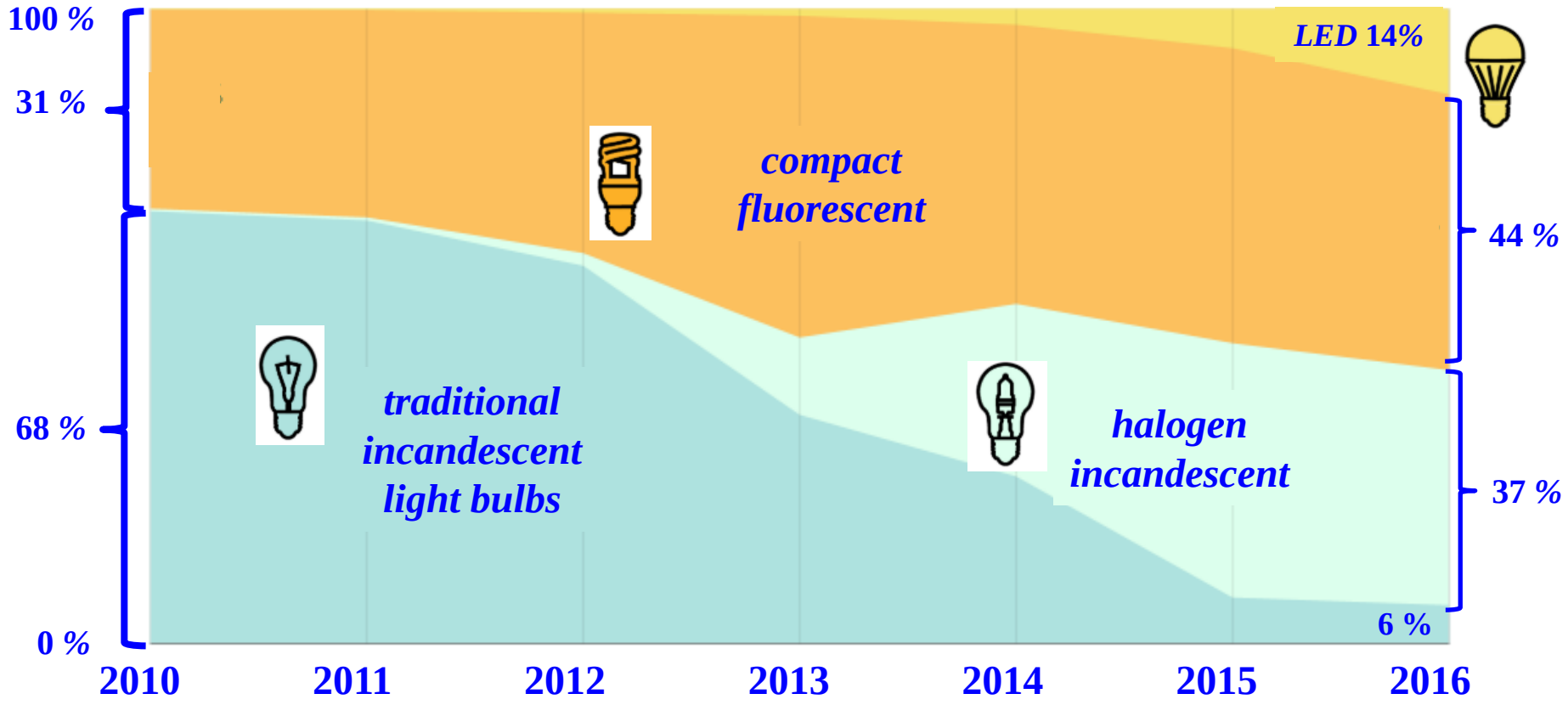
dishwashers are among the least-used appliances in American homes

TOTAL RESIDENTIAL ENERGY USE



Source : EIA, https://www.eia.gov/consumption/residential/data/2015/c&e/pdf/ce3.1.pdf; issued May, 2018

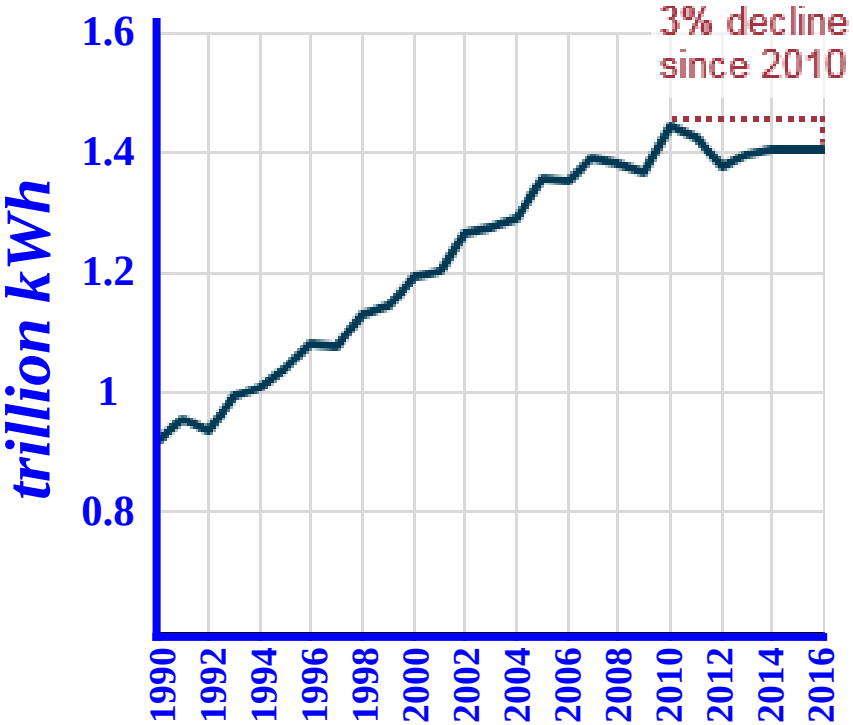
THE DECLINING SALES OF INCANDESCENT LIGHT BULBS IN *US* HOMES



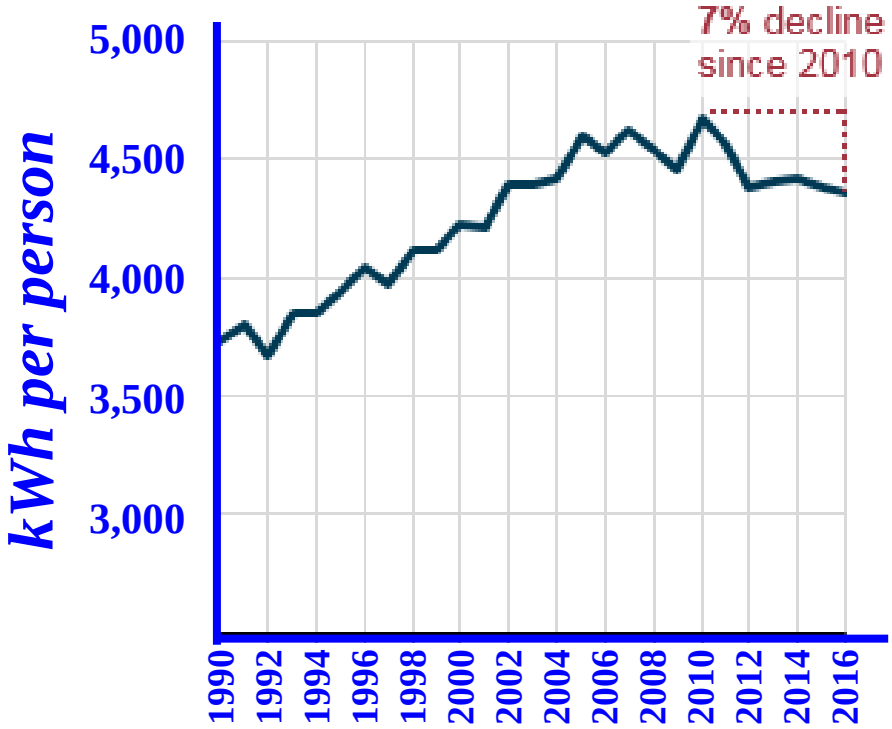
Source: N. Popovich, "The Energy Saver Above Your Head," New York Times, March 13, 2019; available online at: https://www.nytimes.com/interactive/2019/03/08/climate/light-bulb-efficiency.html

US ANNUAL RESIDENTIAL ELECTRICITY SALES

total annual residential electricity sales



per capita residential electricity sales



Source: EIA July 26, 2017, https://www.eia.gov/todayinenergy/detail.php?id=32212

ELECTRICITY CONSUMPTION FACTS

- Since 2007, the annual *US* electricity consumption became rather stagnant, with a small growth in 2018; the COVID-19 pandemic reduced again sales
- *Per capita* consumption has fallen even more dramatically, reaching levels not seen since 2001
- The trend toward *miniaturization* drives the decline in consumption: laptops use less electricity than desktops; tablets use less than laptops; and, smartphones use less than tablets

ELECTRICITY CONSUMPTION FACTS

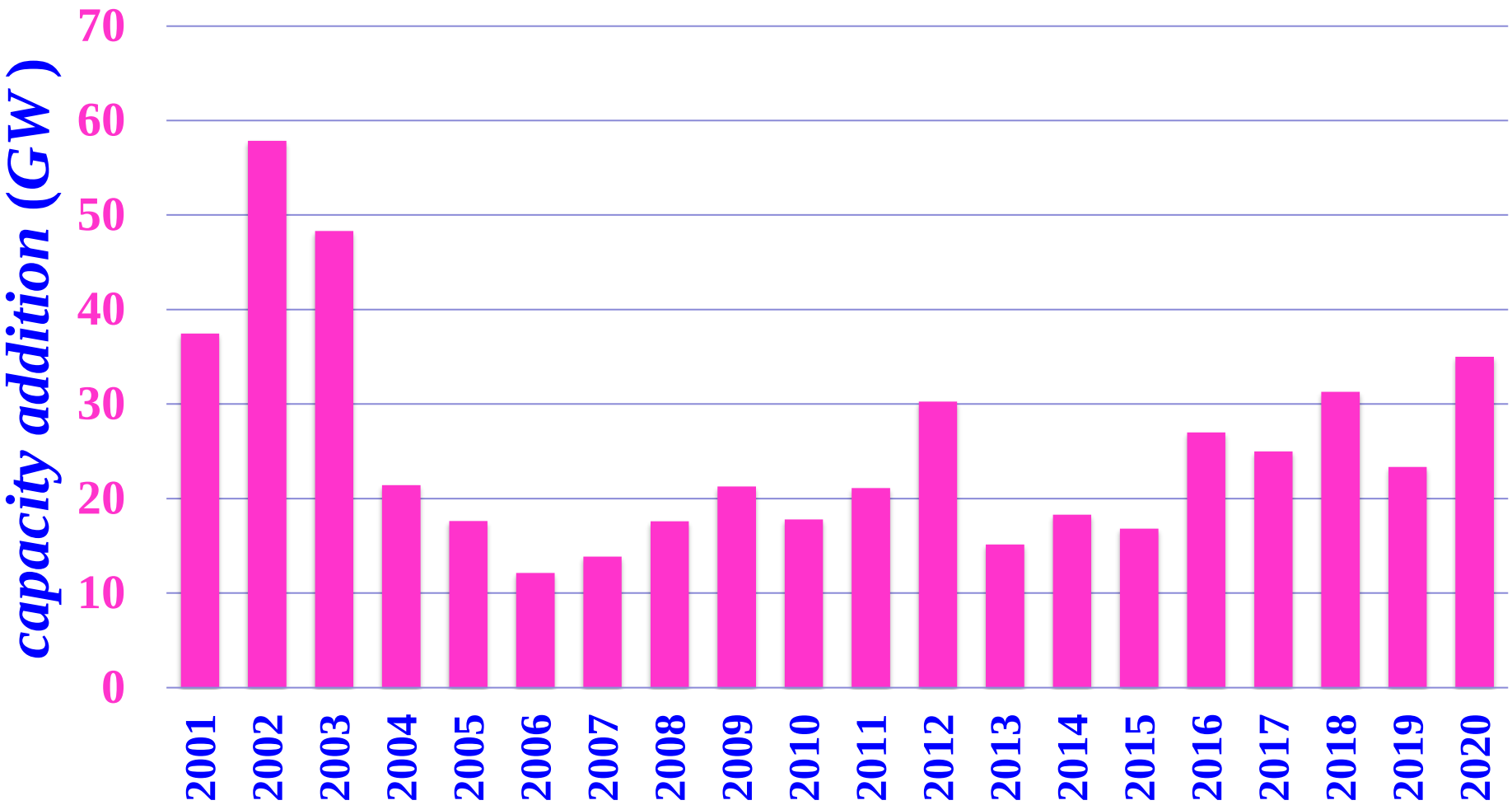
- *Electric Power Research Institute* states that today's *iPad* consumes less than 1/20 of the electricity used by a desktop computer

- Today's flat-screen *TV*s use 80 % less energy than the monster cathode–ray sets of decades ago

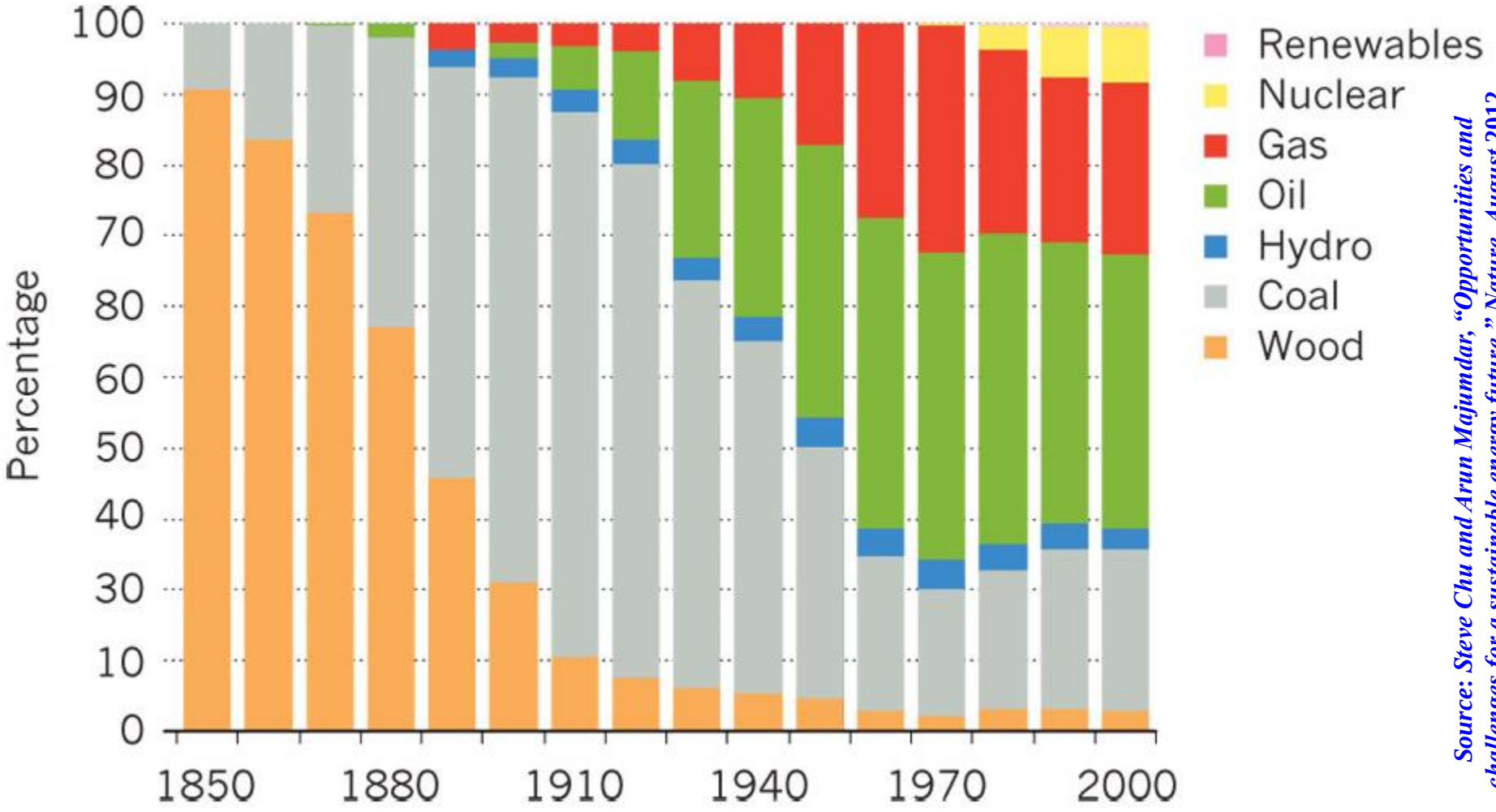
Source: http://www.realdailybuzz.com/rdb.nsf/DocView?Open& UNID=a9fdc7660ffb166e85257c5800517841 January, 2014

2001 – 2020 GENERATION CAPACITY ADDITIONS

Source: *EEI,* https://www.eei.org/resourcesandmedia/Pages/IndustryData.aspx; *issued July* 2021



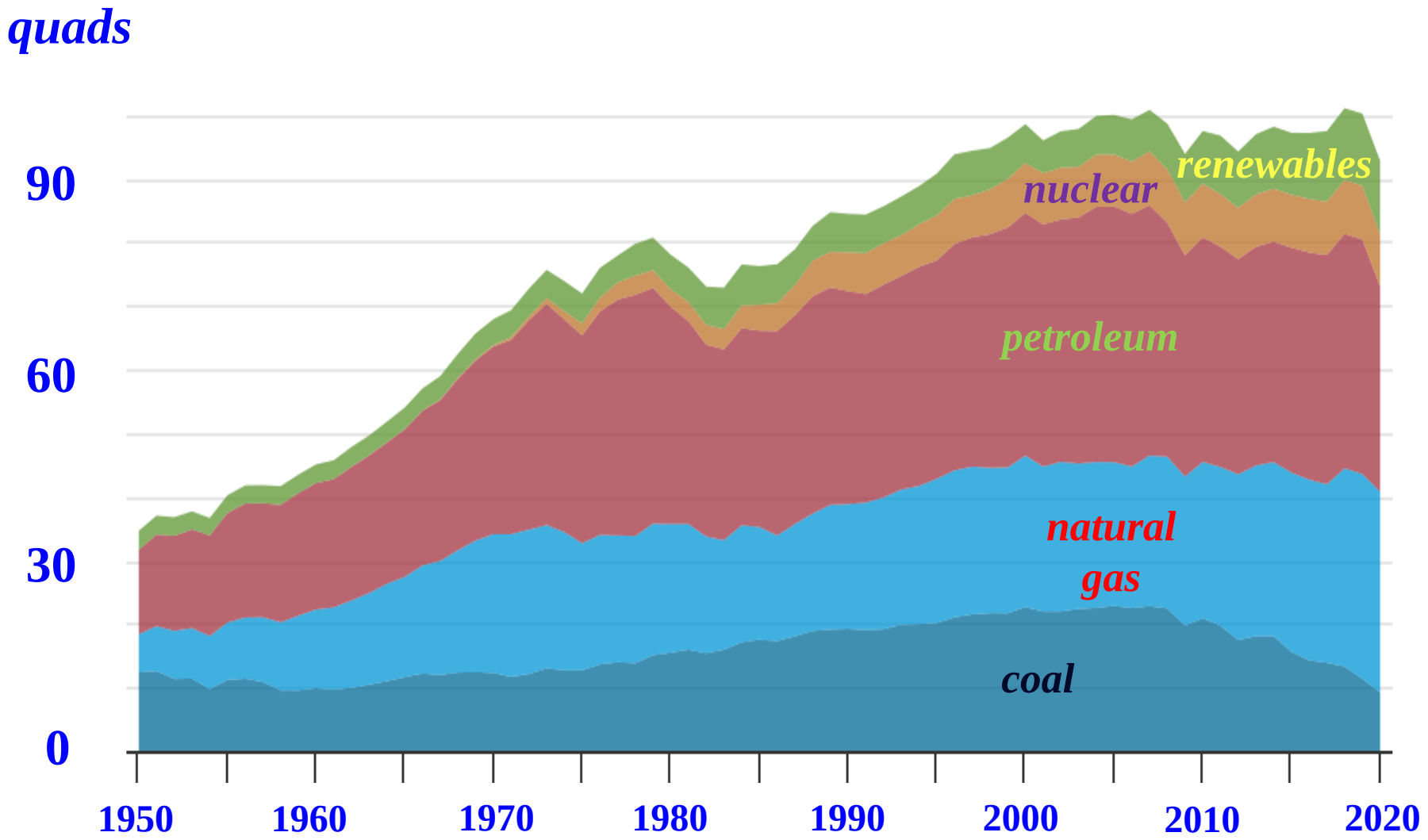
EVOLUTION OF THE MAIN SOURCES OF *US* ENERGY CONSUMPTION



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

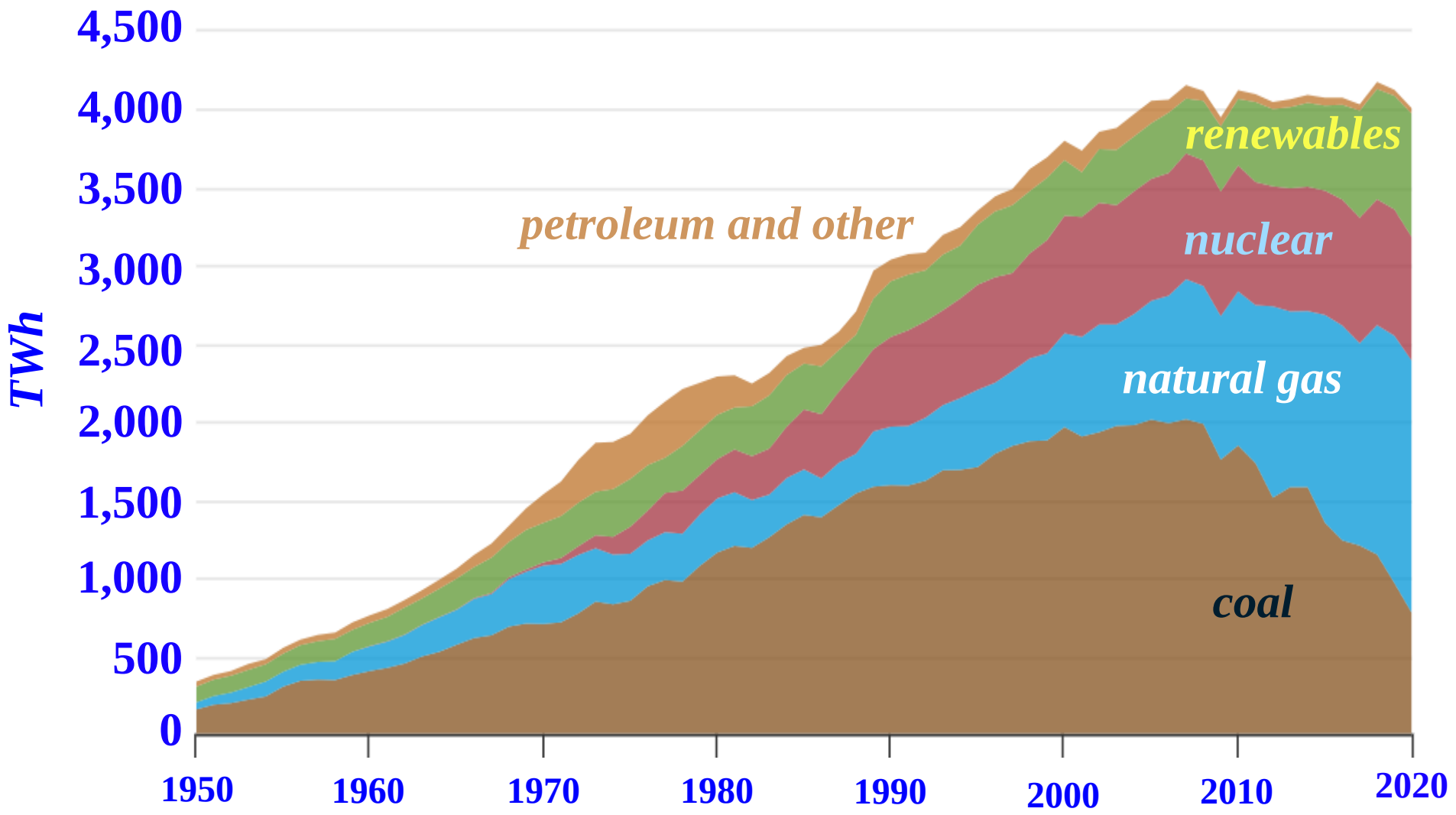
MAJOR SOURCES OF *US* ENERGY CONSUMPTION: 1950 – 2020

Source: EIA, U.S. Energy Facts Explained; available online at https://www.eia.gov/energyexplained/us-energy-facts/

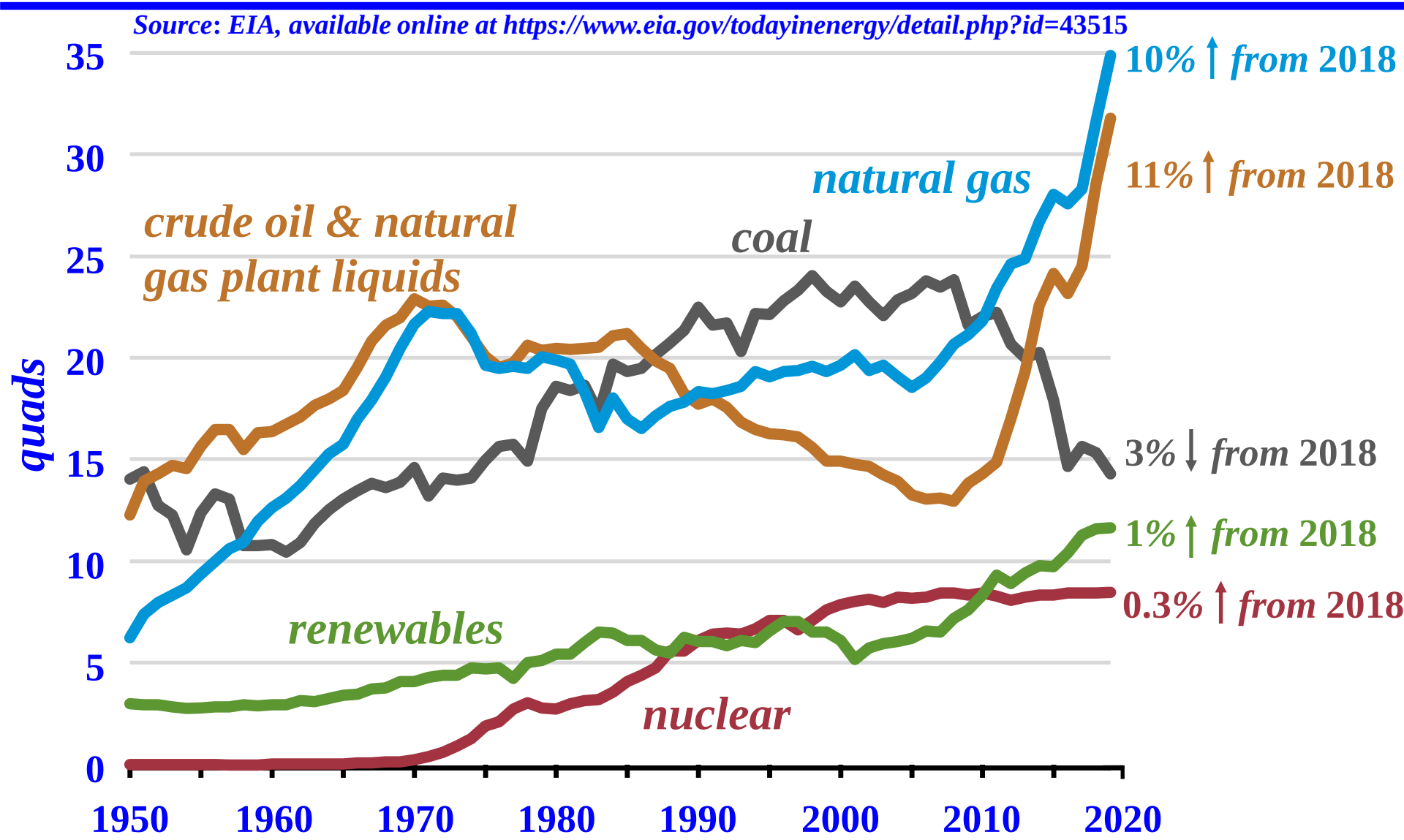


US ELECTRICITY GENERATION SOURCES: 1950 – 2020

Source: EIA, U.S. energy facts explained; available online at https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php

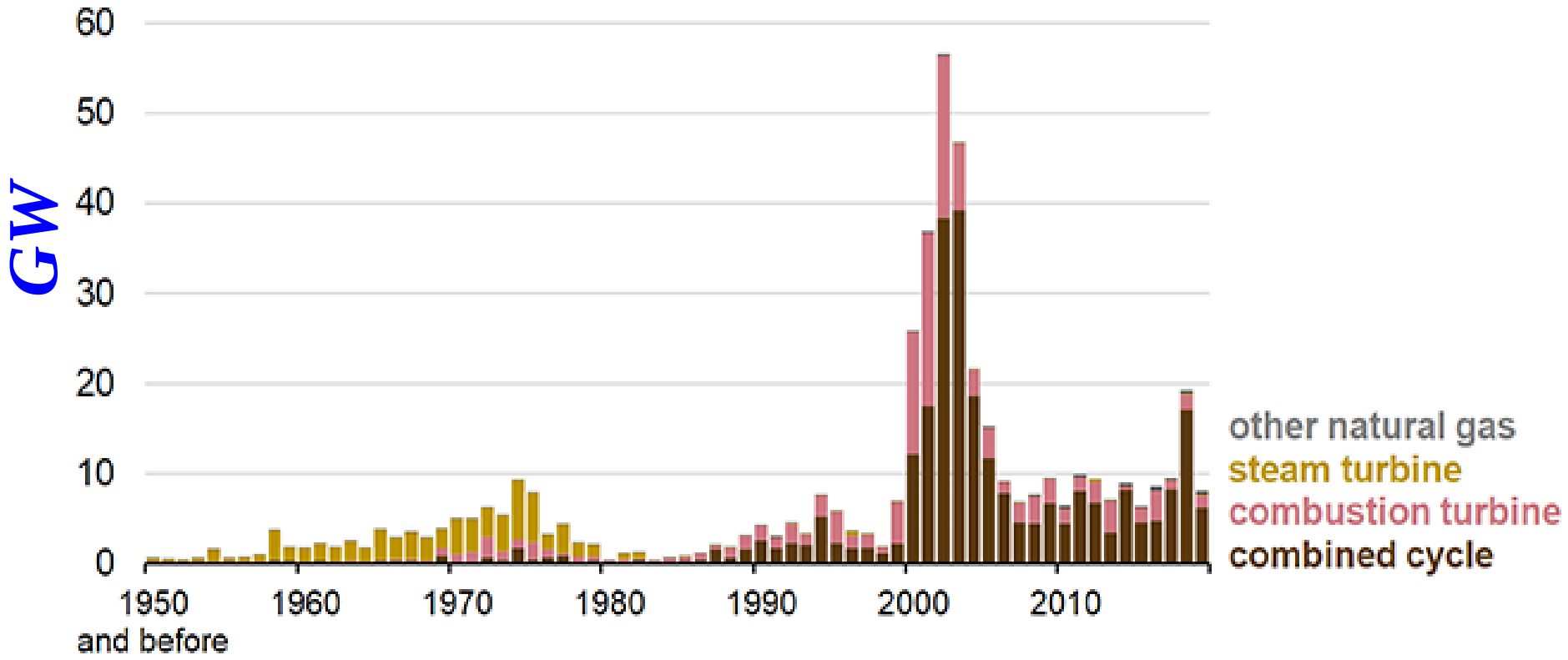


PRIMARY ENERGY PRODUCTION SOURCES: 1950 – 2019

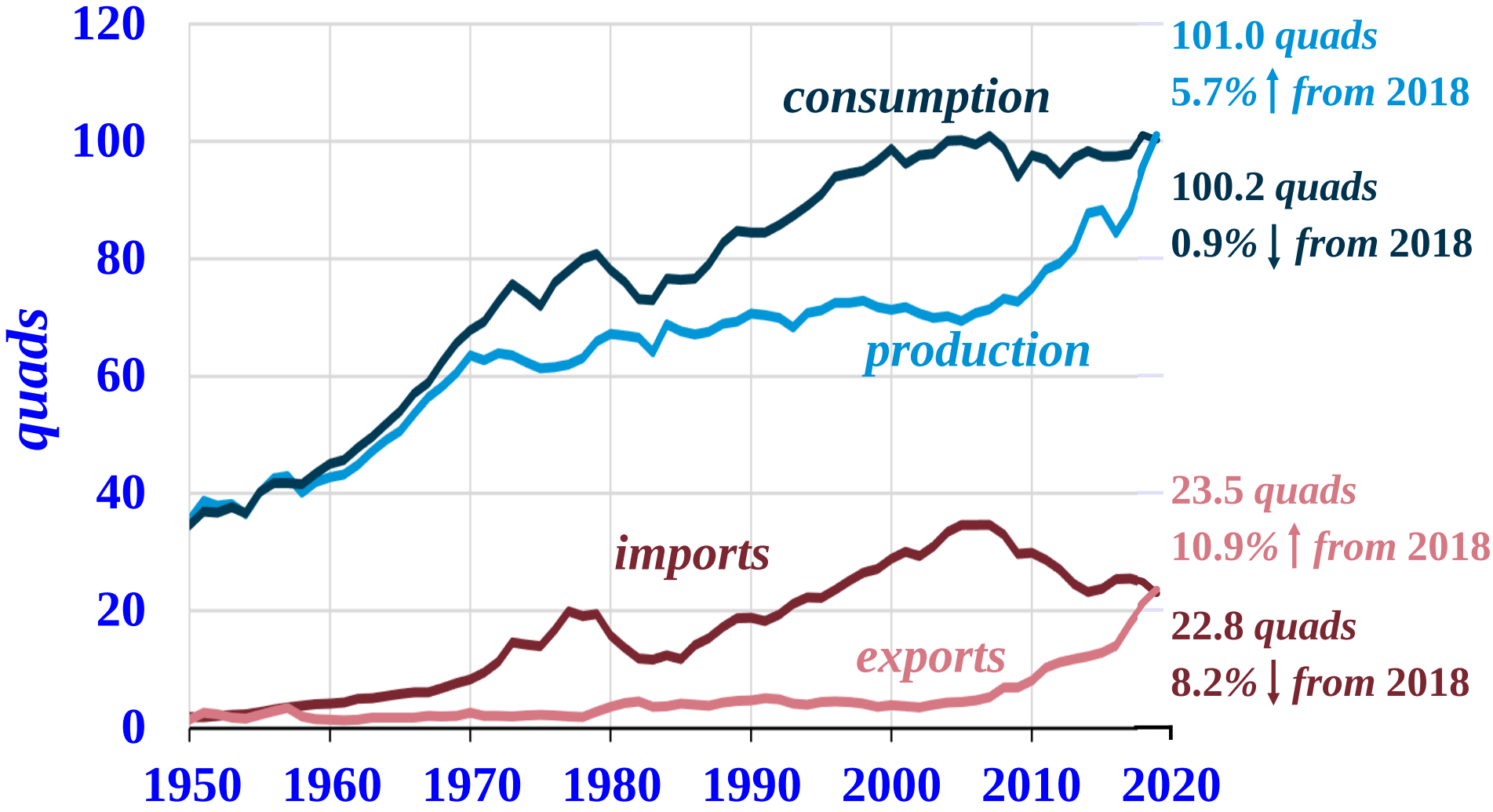


US RESOURCE MIX EVOLUTION SOURCES: 1950 – 2019

Source: EIA, Form EIA-860 detailed data with previous form data, September 15, 2020; available online at https://www.eia.gov/electricity/data/eia860/

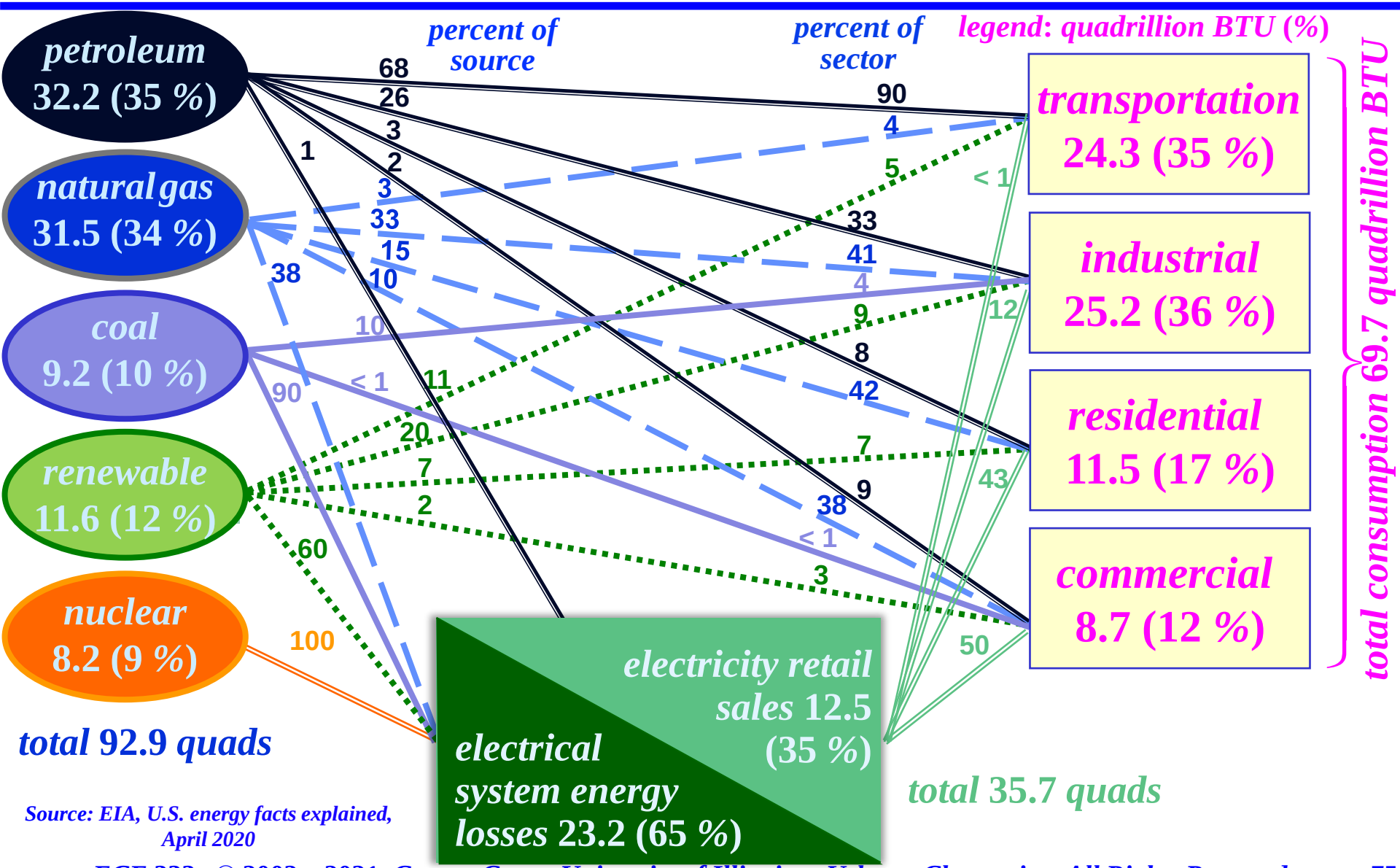


US ENERGY PRODUCTION, EXPORTS, IMPORTS AND CONSUMPTION TRENDS



Source: EIA, Monthly Energy Review data in Today in Energy, April 28, 2020; available online at https://www.eia.gov/todayinenergy/detail.php?id=43515

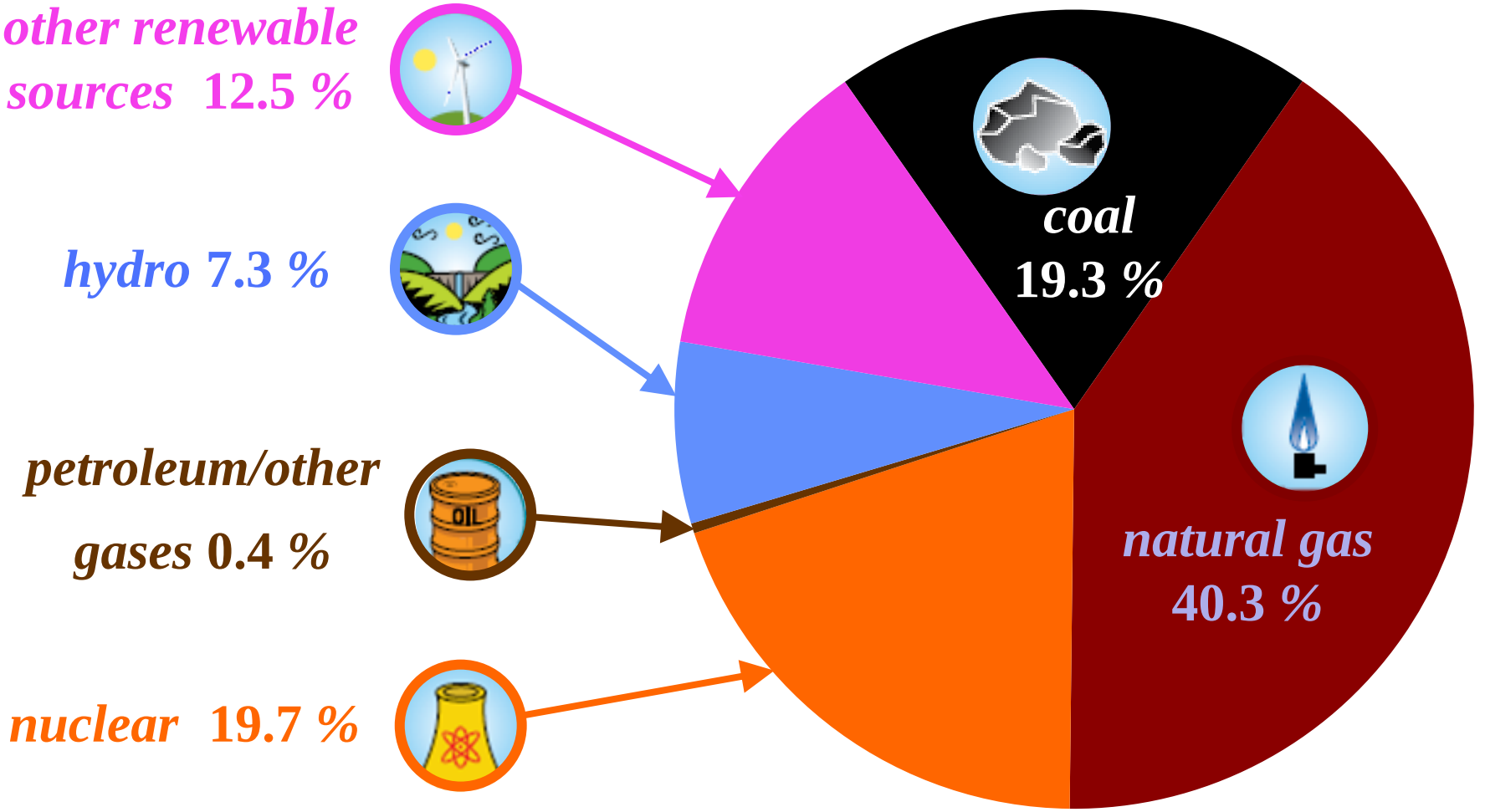
US ENERGY CONSUMPTION IN 2020



Source: EIA, U.S. energy facts explained, April 2020

2020 *US* GENERATION BY SOURCE

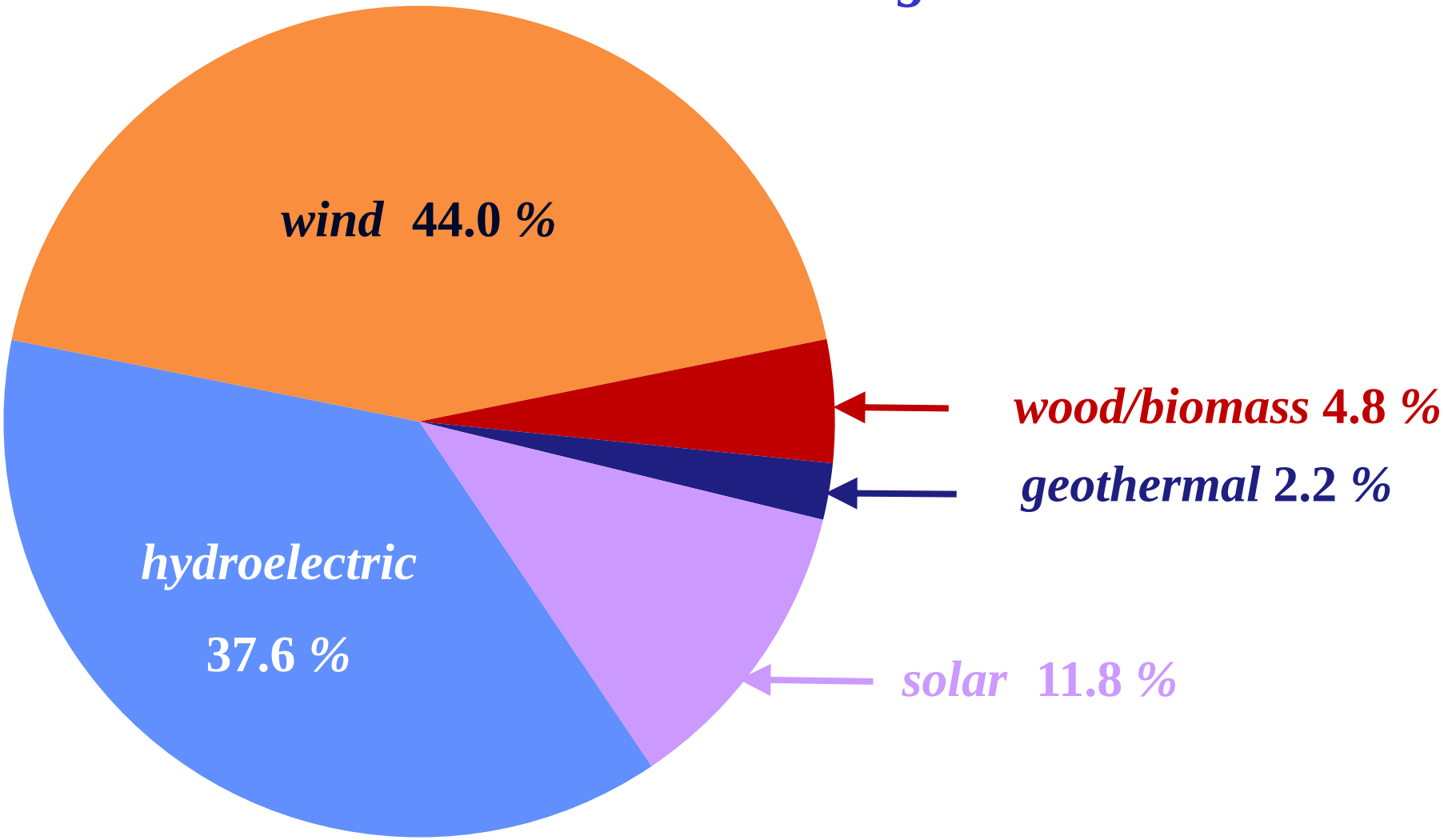
total generation = 4,009 TWh



Source: EIA, June 2021, https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

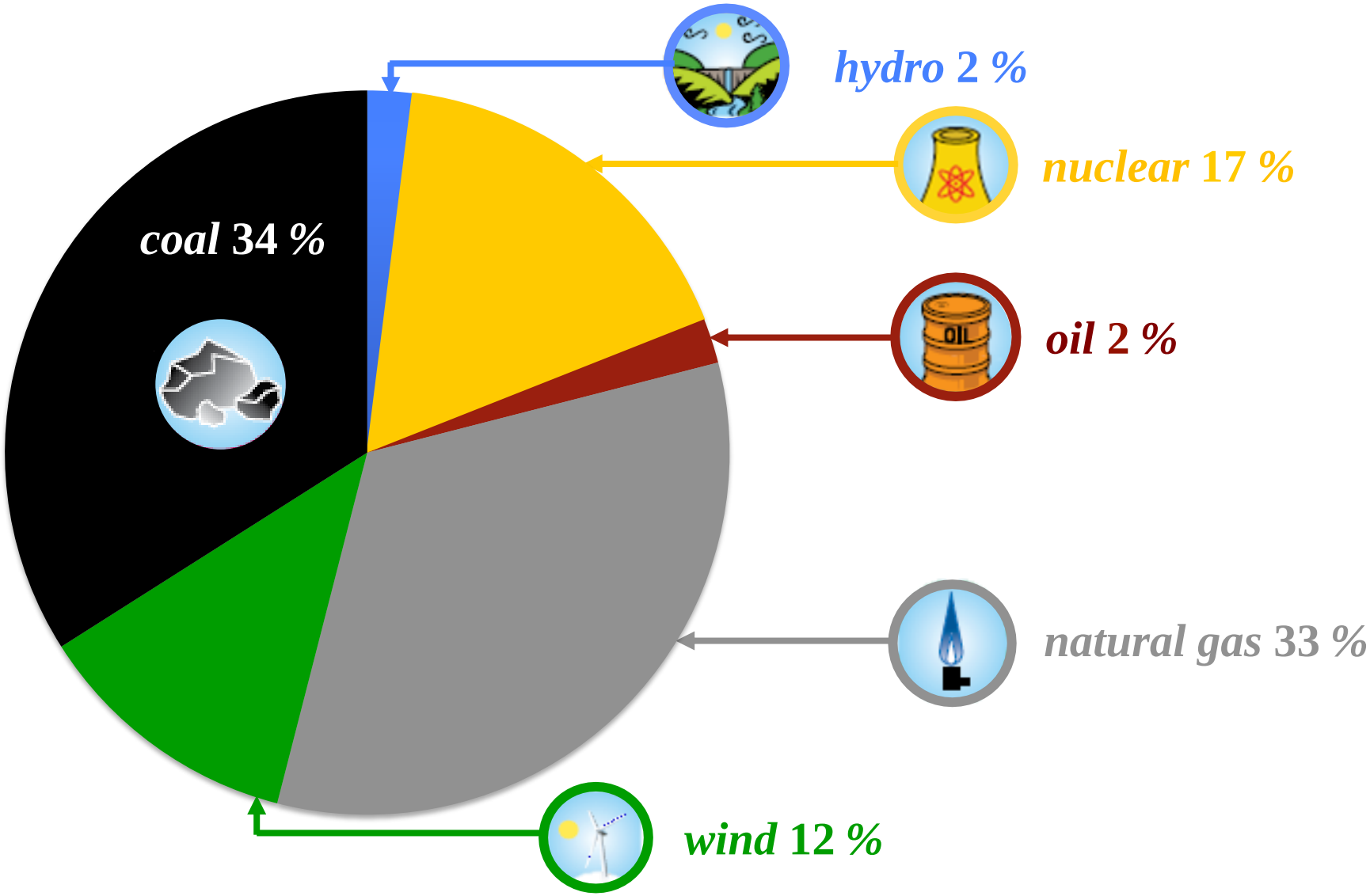
2020 NET GENERATION OF RENEWABLE ENERGY SOURCES

total renewable generation = 792 TWh



Source: EIA, June 2021, https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

AMEREN ILLINOIS ENERGY SOURCES OF ELECTRICITY SUPPLIED IN 2020



Source: Ameren IP, data for the 12 months ending April 2021; available at https://www.ameren.com//media/illinois-site/files/electricchoice/sourcesofsupply/aic_32850_environmentaldisclosurestatement_0421.pdf?la=en-us-il&hash=5D3D5BEF9E13B6EDF5BCCD23785A1E37B350951D1

2020 *AMEREN ILLINOIS POWER* AVERAGE ELECTRICITY EMISSIONS / WASTE

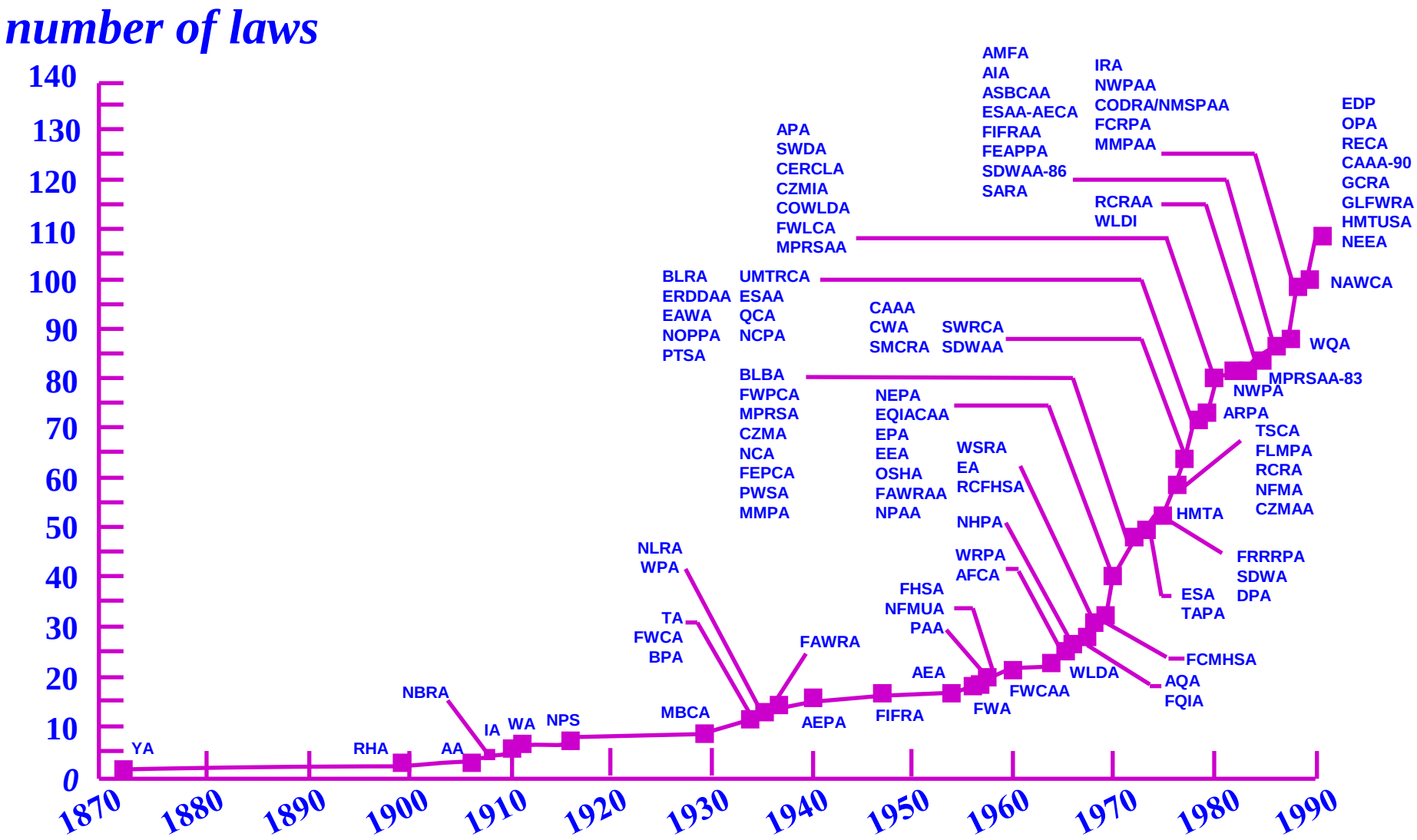
Source: Ameren IP, data for the 12 months ending April 2021; available at https://www.ameren.com/-/media/illinois-site/files/electricchoice/sources-of-supply/aic_32850_environmentaldisclosurestatement_0421.pdf?la=en-us-il&hash=5D3D5BEF9E13B6EDF5BCCD23785A1E37B35095D1

output	*average amount per MWh*
carbon dioxide	1,075 *lb*
nitrogen oxides	0.42 *lb*
sulfur dioxide	0.68 *lb*
high–level nuclear waste	0.0010 *lb*
low–level nuclear waste	0.0002 ft^3

ENVIRONMENTAL ASPECTS

- The electricity industry is the most highly visible stationary source of pollution
- In big picture terms, before 2016, the *US* electric power industry was responsible for about
  - 3/4 of SO_X emissions
  - 1/3 of CO_2 and NO_X emissions
  - 1/4 of particulate matter and toxic heavy metals emissions

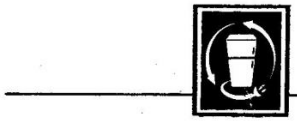
US LAWS ON ENVIRONMENTAL PROTECTION



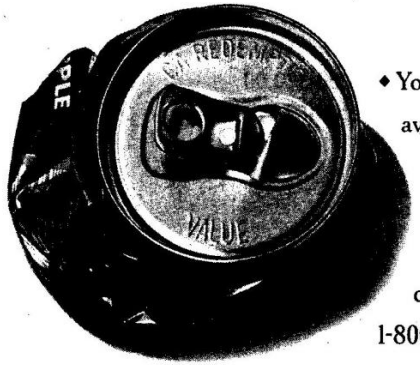
ACRONYM SOUP

- *NIMBY* : *Not In My Back Yard*
- *NOOS* : *Not on Our Street*
- *LULU* : *Locally Undesirable Land Use*
- *NOPE* : *Not on Planet Earth*
- *NIMTOO* : *Not in My Term of Office*
- *SLAPP* : *Strategic Lawsuits Against Public Participants*
- *CAVE* : *Citizens Against Virtually Everything*
- *BANANA* : *Build Absolutely Nothing Anywhere Near Anyone*

ENERGY EFFICIENCY



WE'LL PAY YOU IF WE CAN DO THIS TO YOUR SPARE REFRIGERATOR.

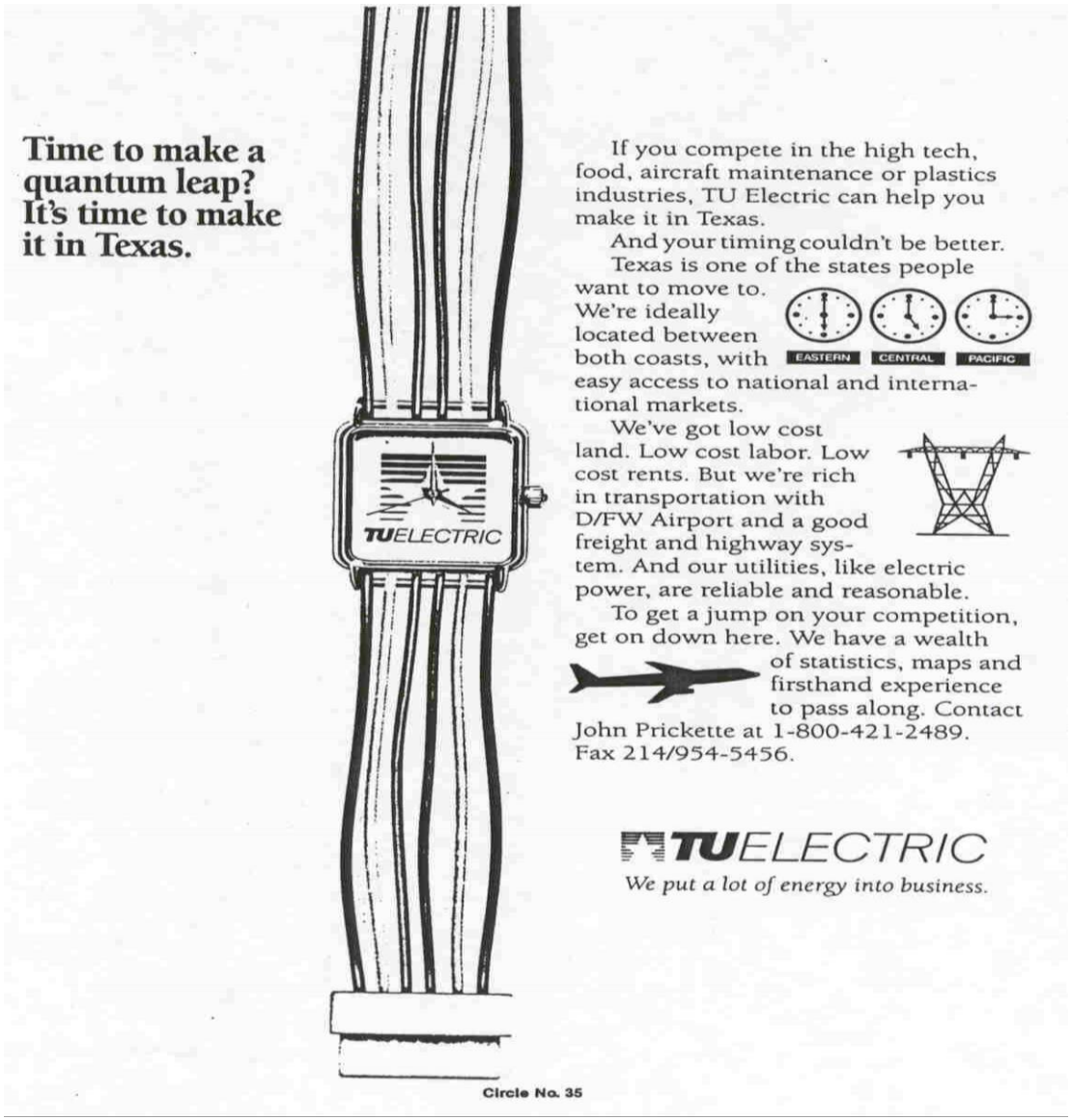


◆ You'd flatten your spare refrigerator yourself, if you realized how wasteful it is. An average one devours a whopping $150 a year in energy costs. ◆ If you let us recycle it, not only will you get rid of an old energy guzzler, you'll get a $50 savings bond from Edison or DWP. ◆ To qualify, it must be in working order and used as a second refrigerator for the last six months. ◆ So for your $50 savings bond, call Edison or DWP at 1-800-234-9722. Or use our TDD accessible number 1-800-234-9710. It pays to recycle your spare refrigerator.

Southern California Edison

Los Angeles Department of Water and Power

ECONOMIC DEVELOPMENT



THE ENERGY UNIT PREFIX

prefix	*symbol*	*value*	*exponent value*
kilo	*k*	*thousand*	10^{3}
Mega	*M*	*million*	10^{6}
Giga	*G*	*billion*	10^{9}
Tera	*T*	*trillion*	10^{12}
Peta	*P*	*quadrillion*	10^{15}
Exa	*E*	*quintillion*	10^{18}

ENERGY AND POWER UNITS

- Energy is expressed in a wide variety of units:
  - *Joules*
  - *quads*
  - *Watt-hours*
  - *Btus*
  - *calories*
- Fuel supply are expressed in *barrels*, *tons oil equivalent* (*toe*), *Btus*, *calories* or *cubic feet* for gas and *acre feet* for water
- In round numbers
  - the *US* annually consumes 100 *quads* of energy
  - the *US* installed electric generation capacity is about 1,200 *GW*
  - the *Champaign* electrical load is about 300 *MW*