Lecture 14: Modern Climate Change Drivers I

Today's Learning Outcomes

1. Be able to explain the reason for the strong positive correlation between income and carbon emissions

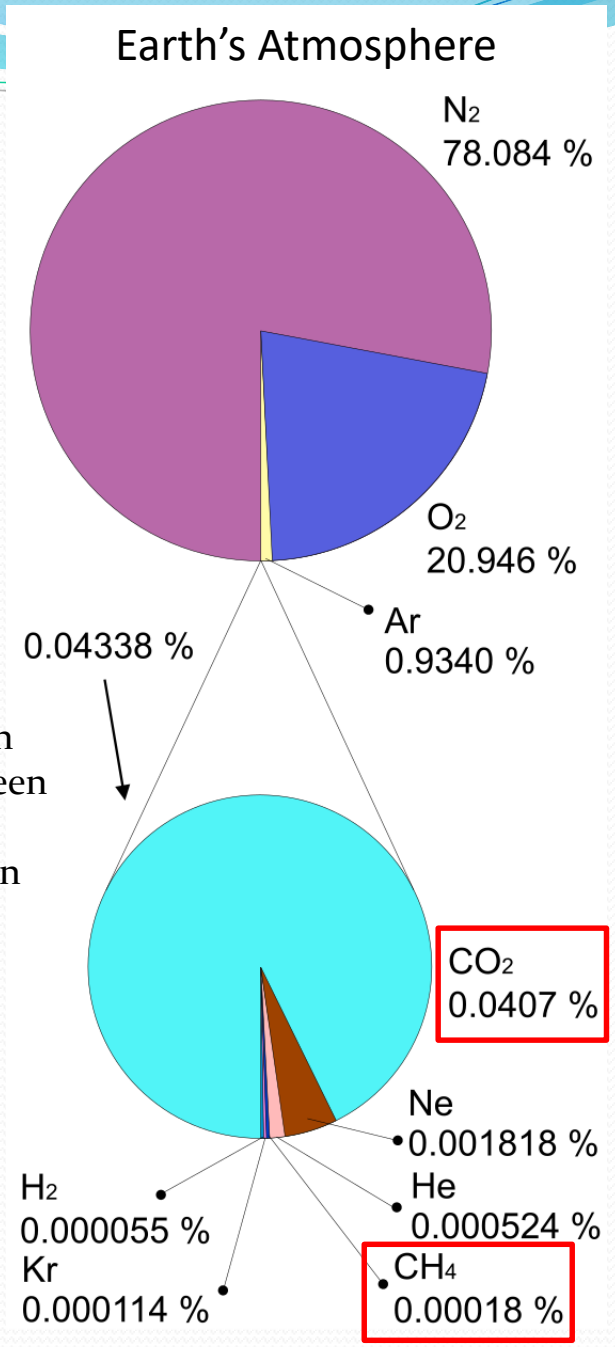
2. Know the difference between total, per capita, and cumulative GHG emissions

3. Know the main driver in the reduction of greenhouse gas emissions in the United States over the past decade

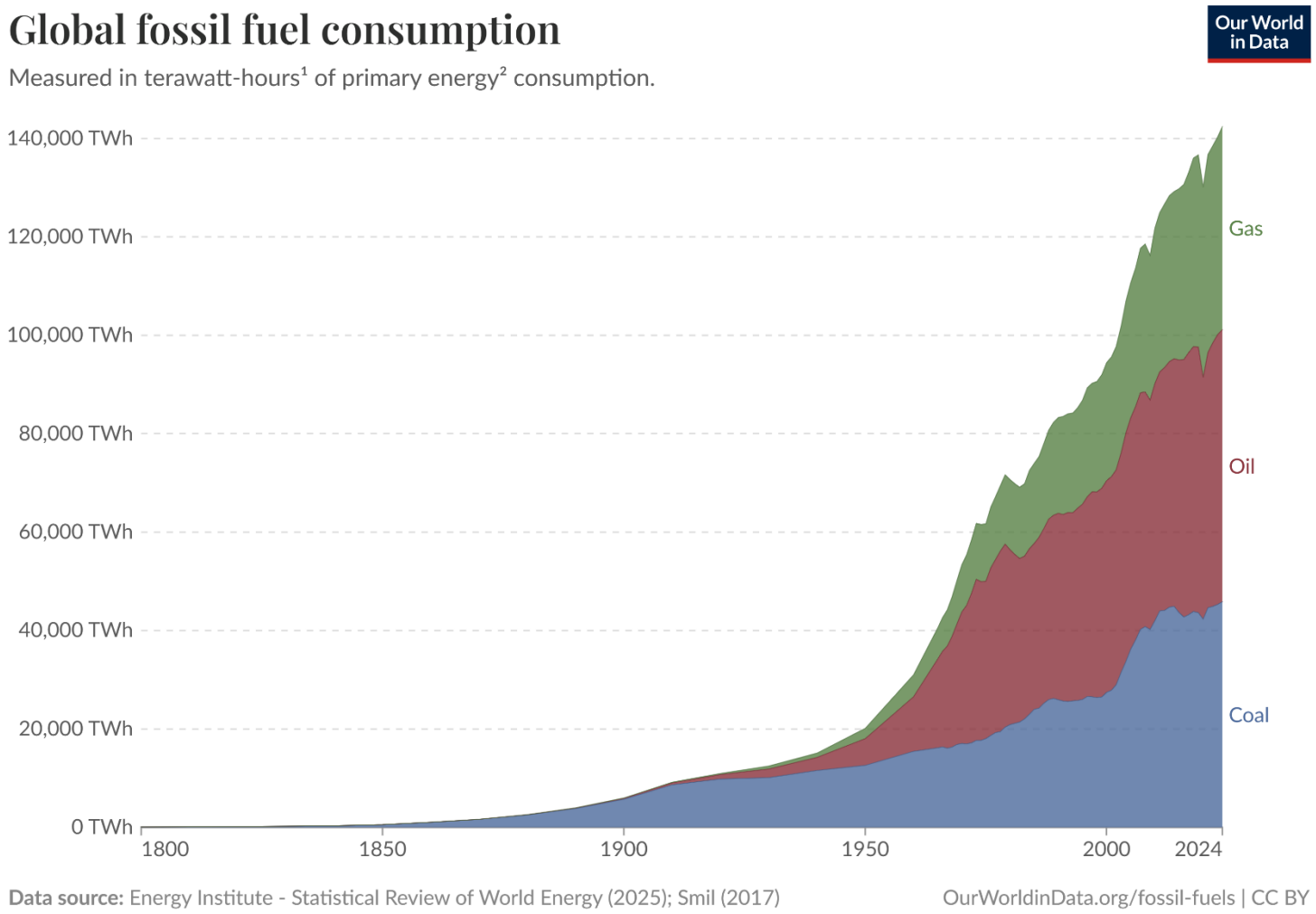
GHGs on Earth Today

- Water Vapor ($H_2O_{(g)}$)
- Carbon dioxide (CO_2)
- Methane (CH_4)
- N_2O (Nitrous oxide)
- Ozone (O_3)
- Fluorinated gases

Water vapor not included in this image, but varies between 0-4% making it the most abundant greenhouse gas on Earth

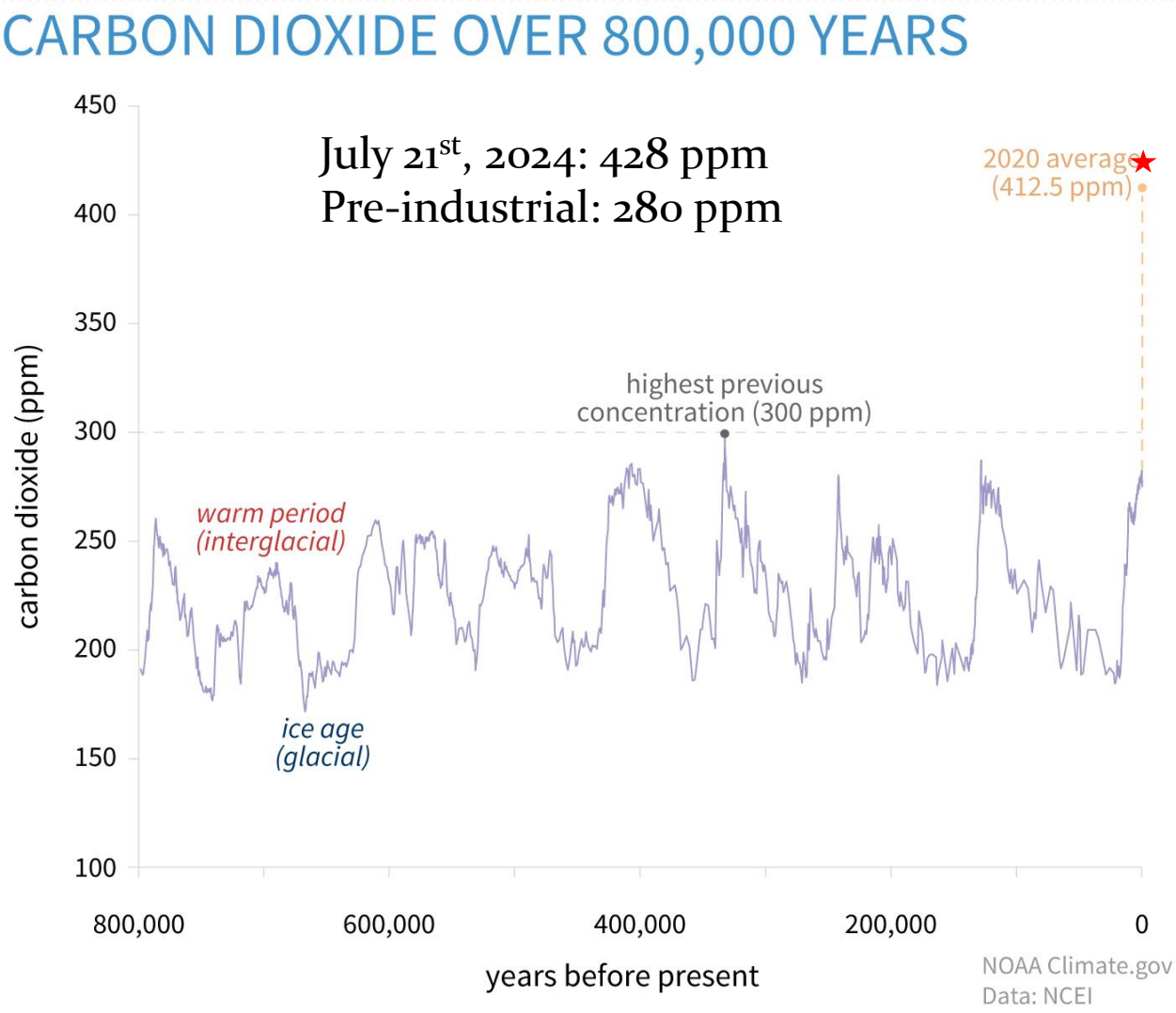


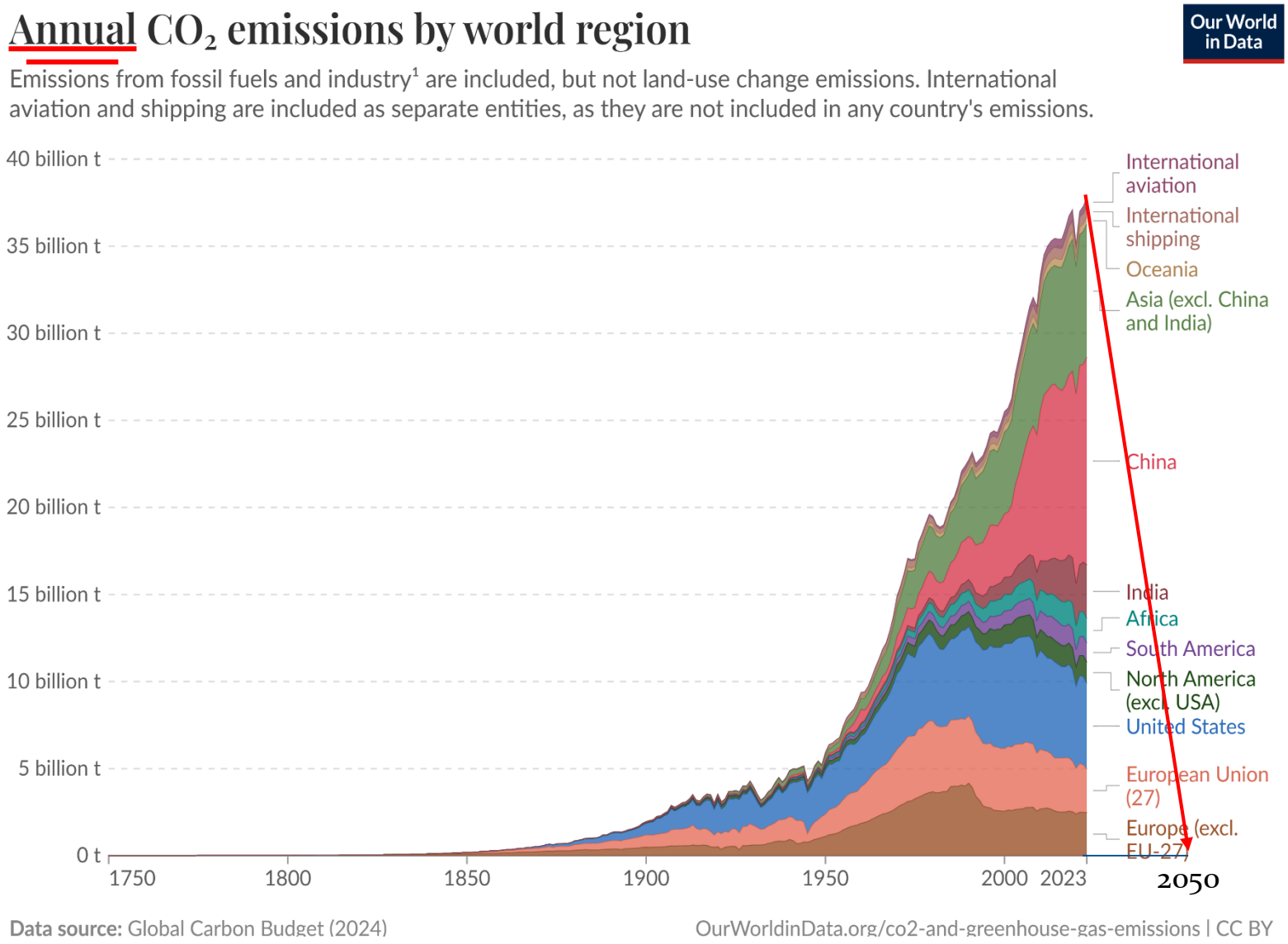
Fossil Fuel Consumption (global)



1. **Watt-hour** A watt-hour is the energy delivered by one watt of power for one hour. Since one watt is equivalent to one joule per second, a

Historical CO_2 Atmosphere Levels

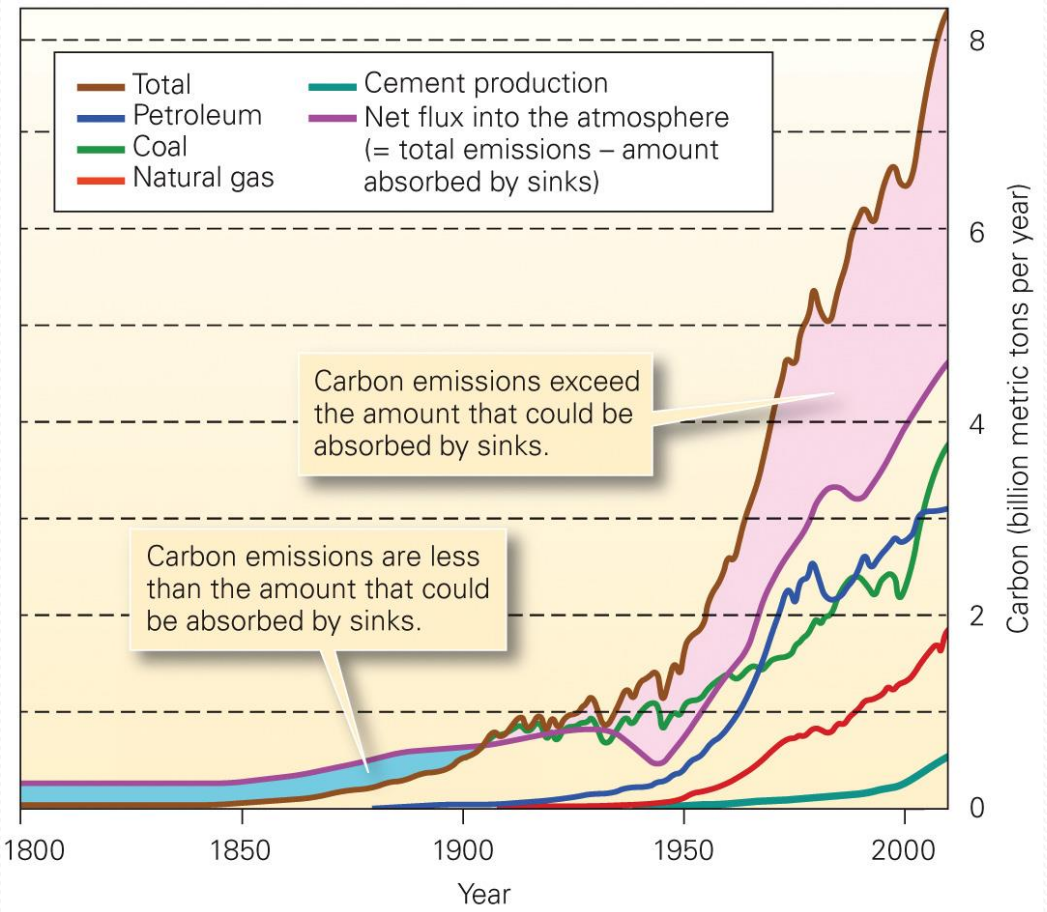




- CO_2 emissions are currently accelerating
  - Climate talks are mostly about reducing this value to net zero by 2050

Overwhelmed Earth

- Earth had the capacity to absorb some amount of CO_2 before it went into the atmosphere
- Tipping point was around 1900
- We are both increasing carbon fluxes to the atmosphere and decreasing carbon fluxes out of the atmosphere



Why the Accelerating Emissions?

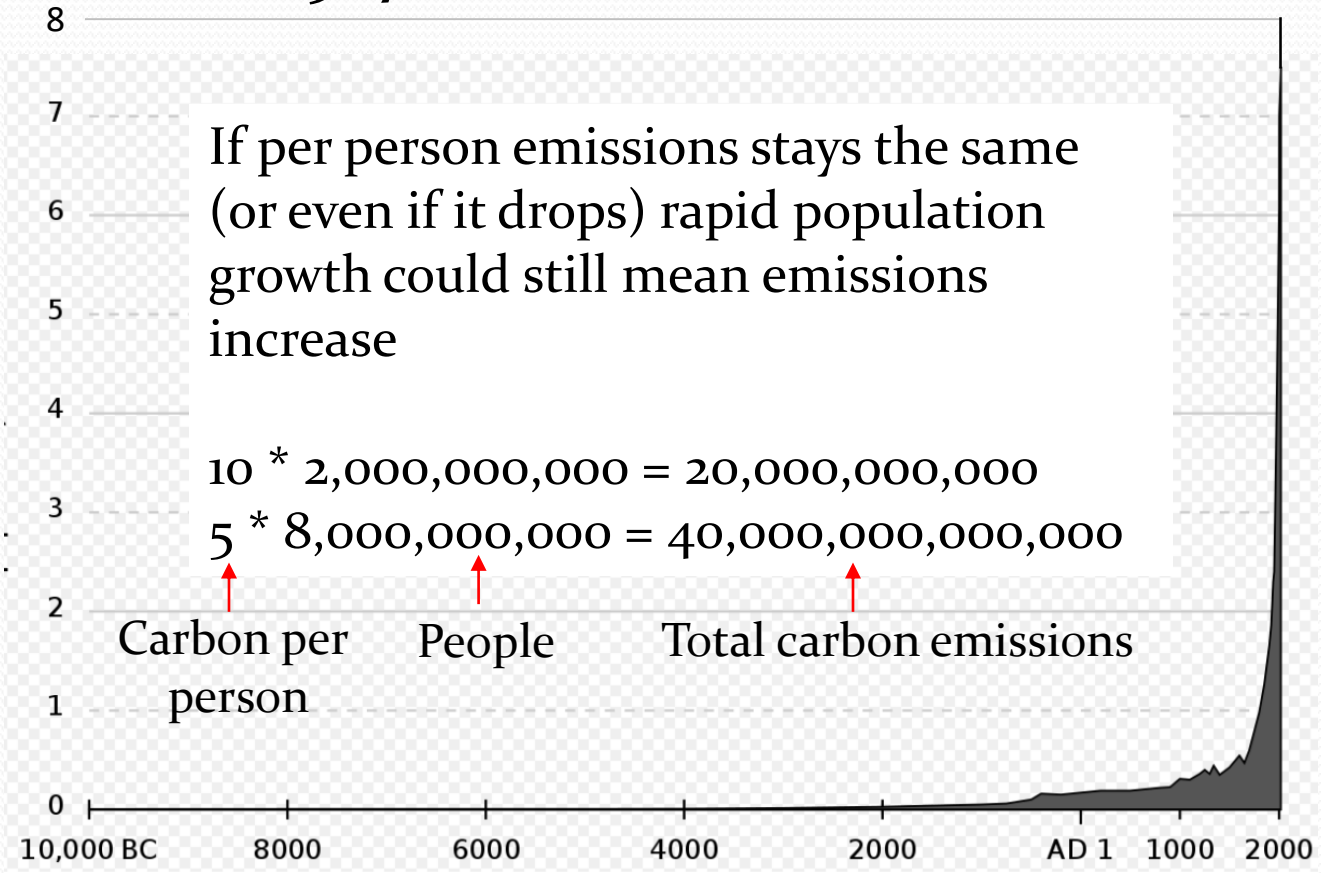
- Two main factors….

1) Population Growth

2) Correlation of
GHG Emissions & Wealth

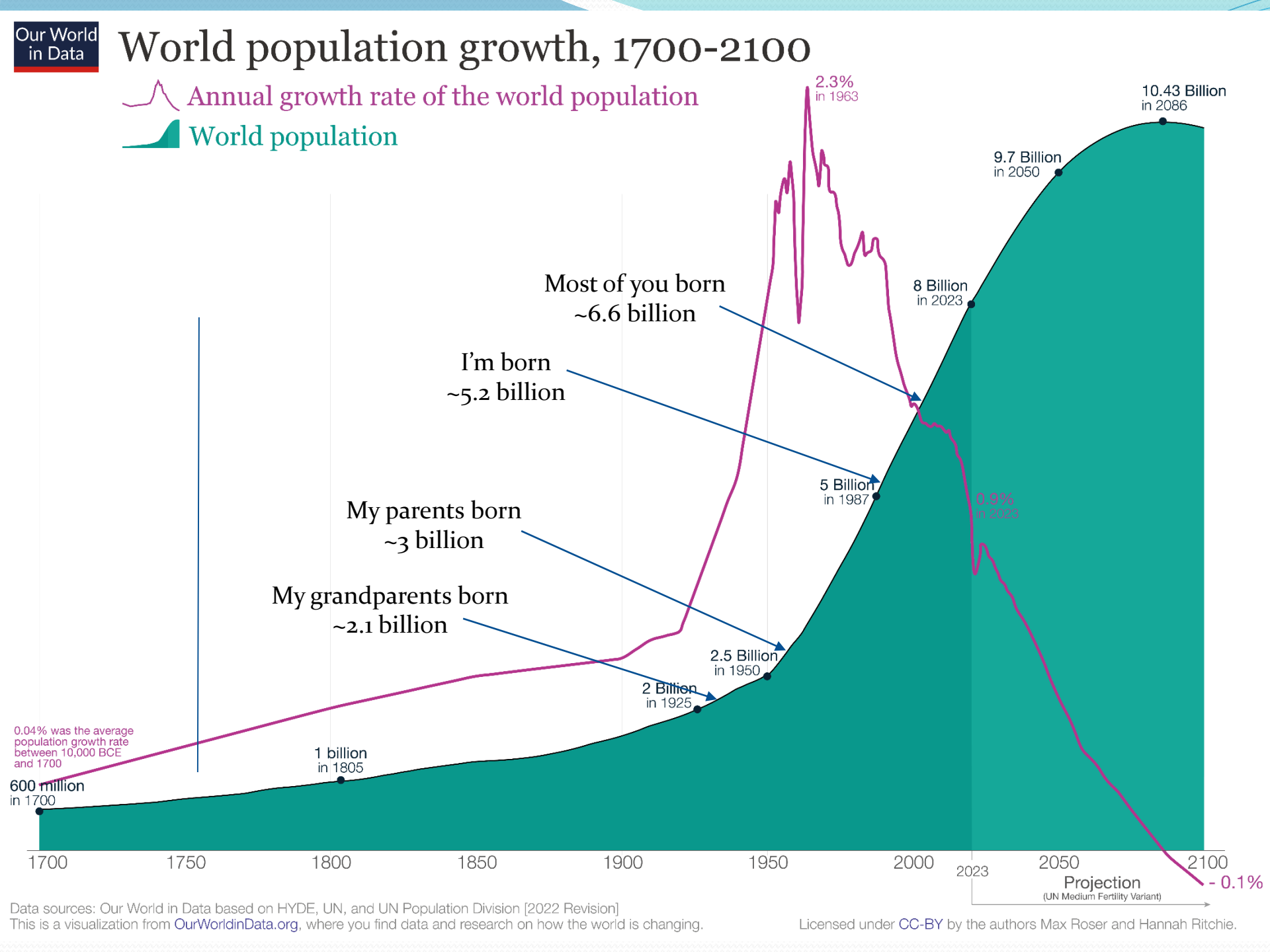
Human Population Growth

- Human population was <1 billion until ~1800, <2 billion until ~1927



Our World in Data

World population growth, 1700-2100

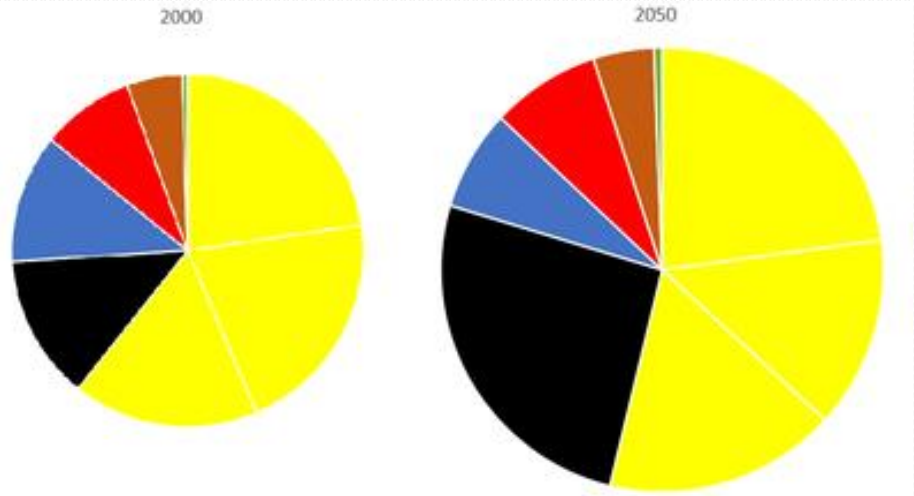


Data sources: Our World in Data based on HYDE, UN, and UN Population Division [2022 Revision]
This is a visualization from OurWorldinData.org, where you find data and research on how the world is changing.

Projected Population Growth

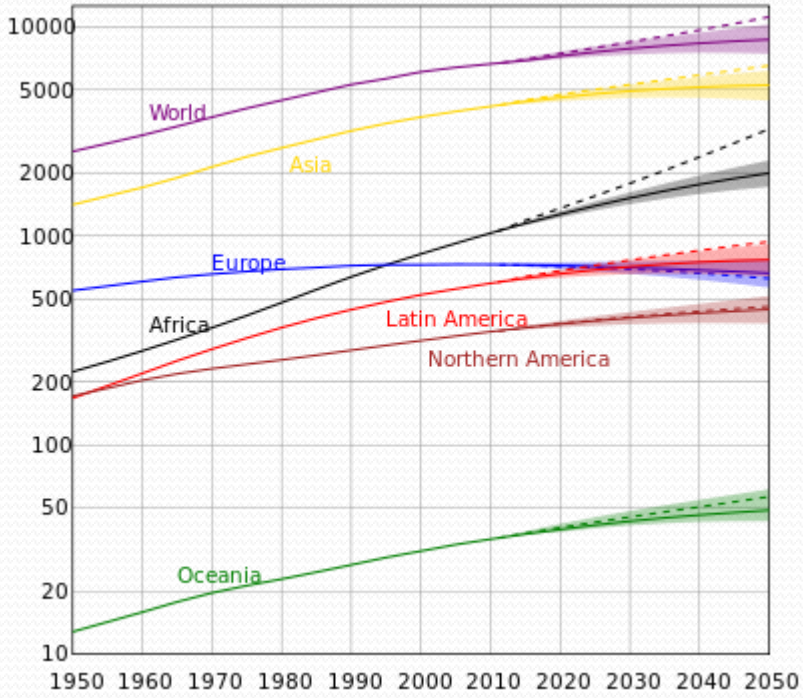
- Current world population is ~8.2 billion

- United Nations projects that it will reach 9.7 by 2050



UN estimates (as of 2017) for world population by continent in 2000 and in 2050 (pie chart size to scale).[1]

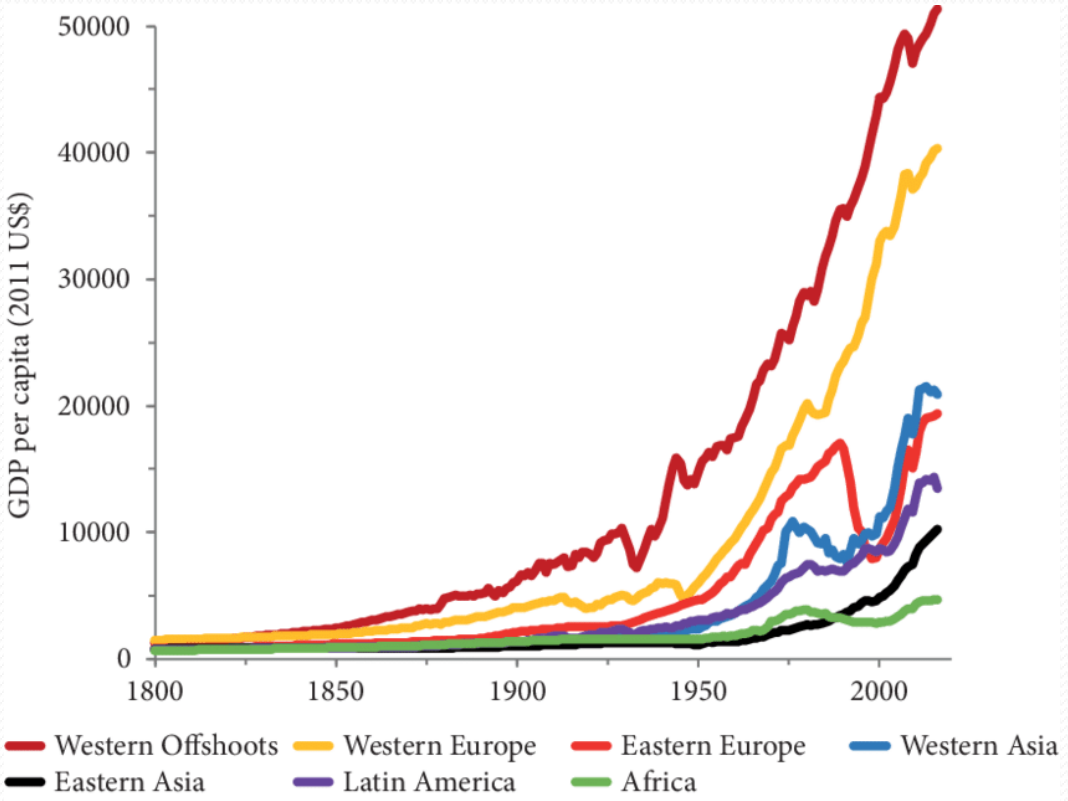
Asia Africa Europe Latin America Northern America Oceania



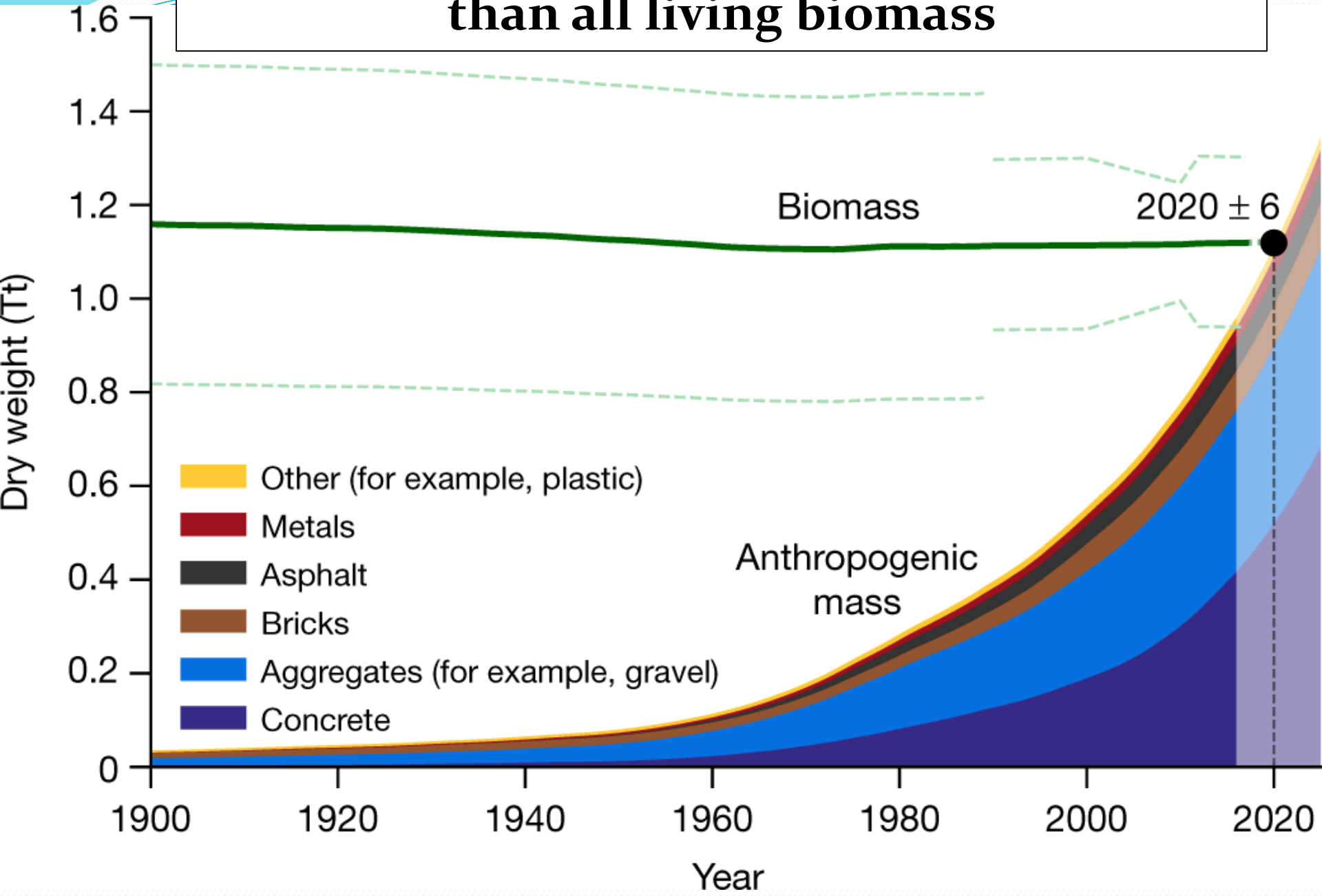
With Population Has Come Wealth

- Technological advances have allowed us to extract more materials faster, raise standards of living, and provide access to more resources

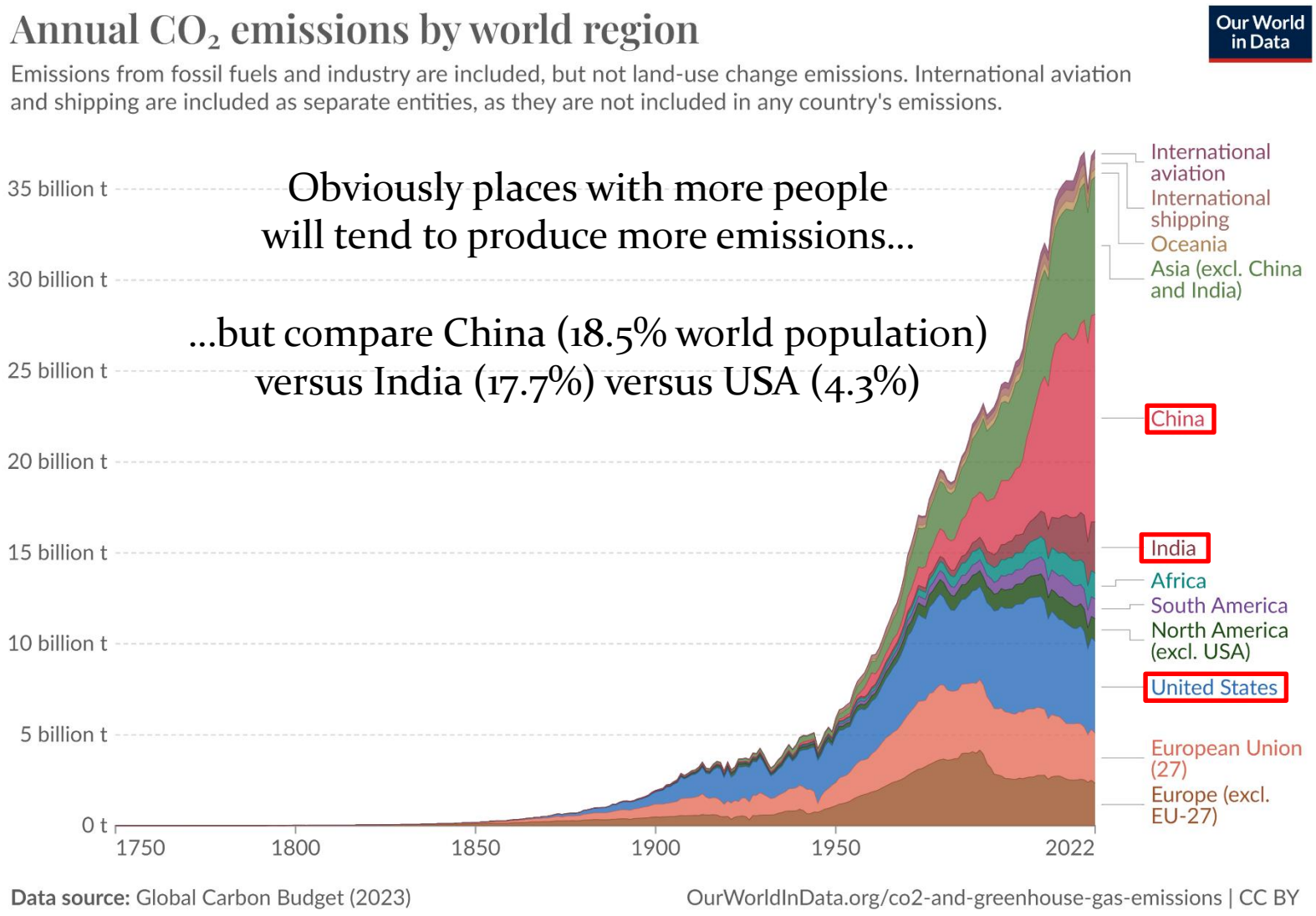
- Also means increasing ability to affect the global environment



There is now more human-made material than all living biomass



Distribution of Emissions



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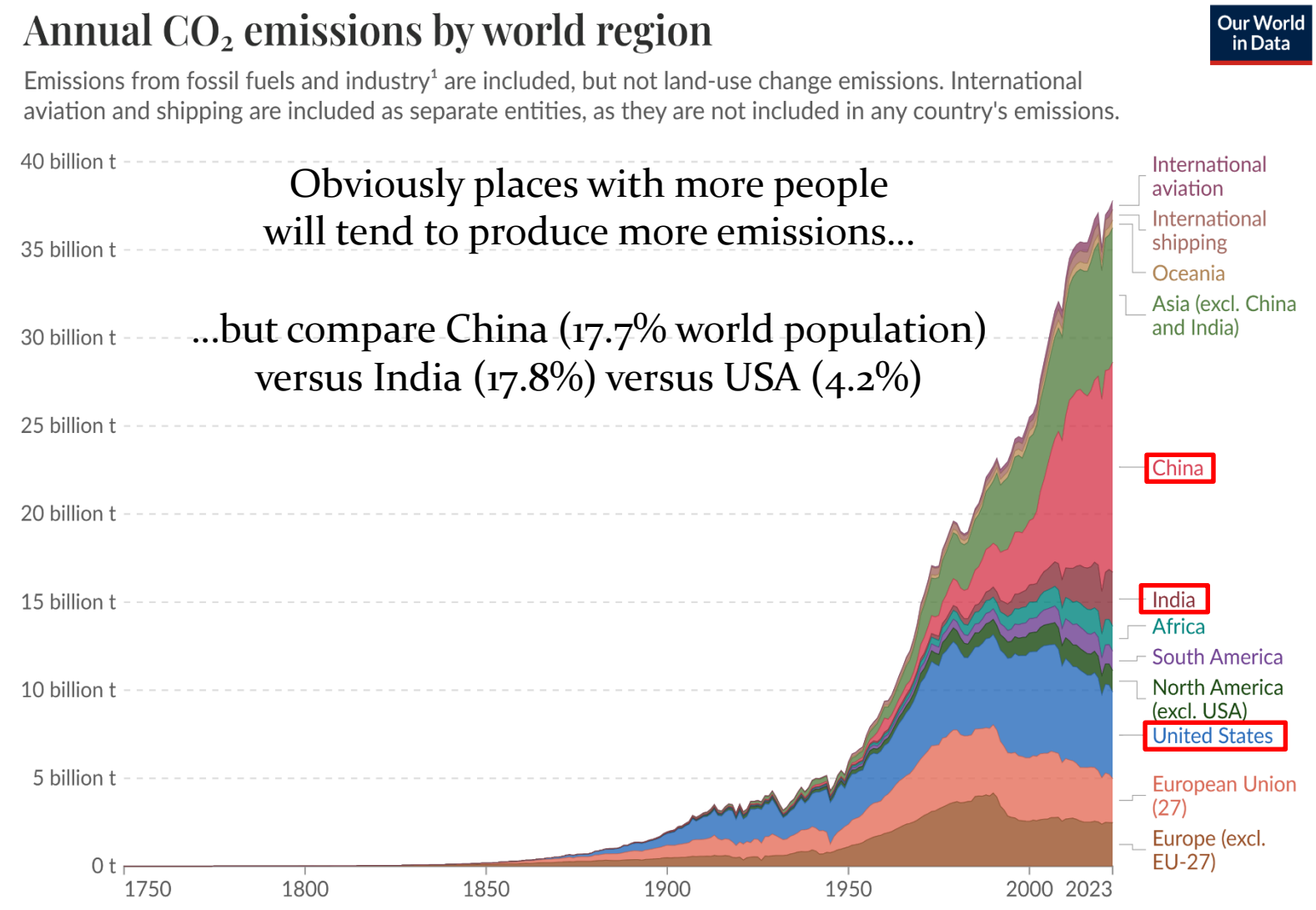
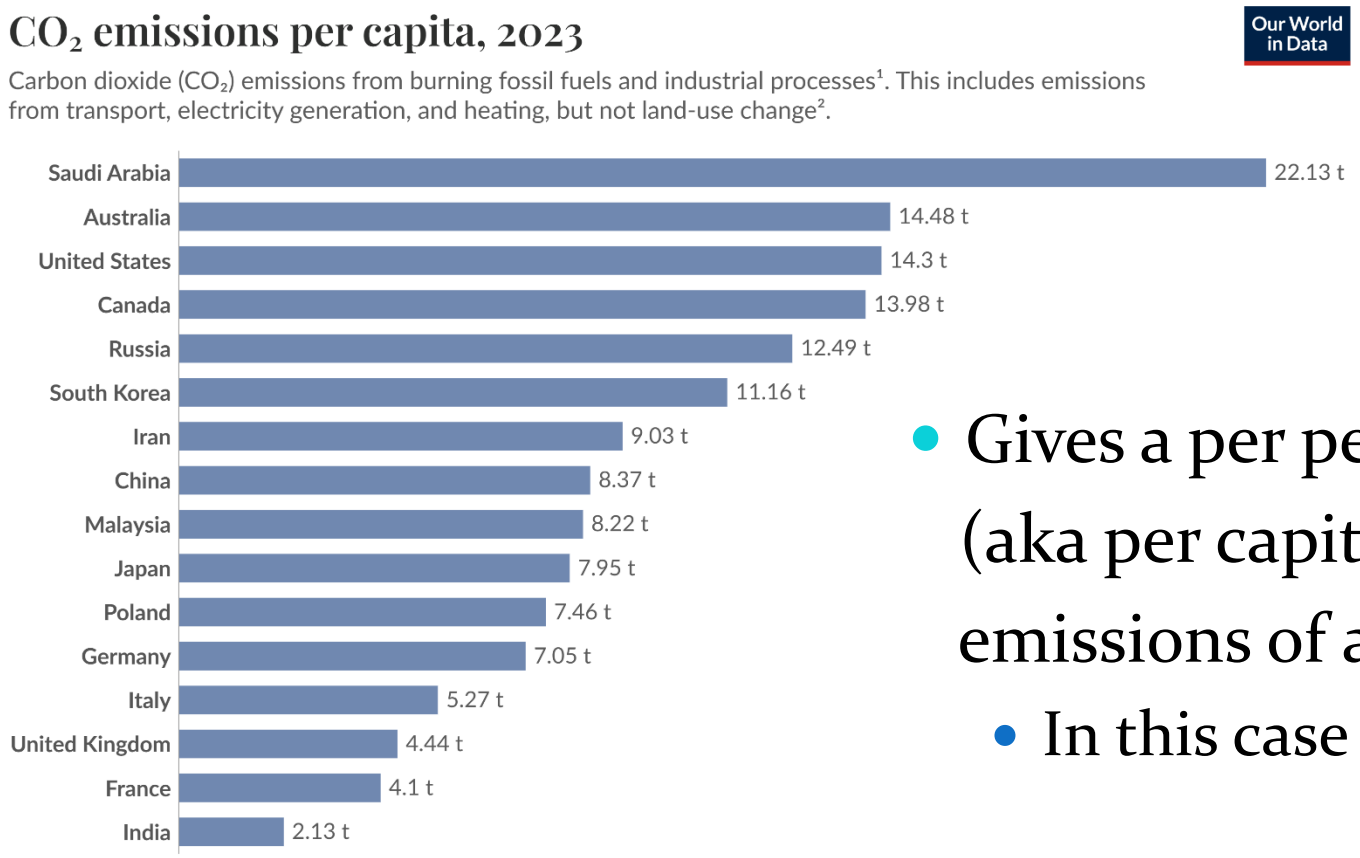


Per Capita Emissions

- Better comparison of a nation's emissions is to divide by population



- Gives a per person (aka per capita) <u>average</u> emissions of a population
  - In this case within a country

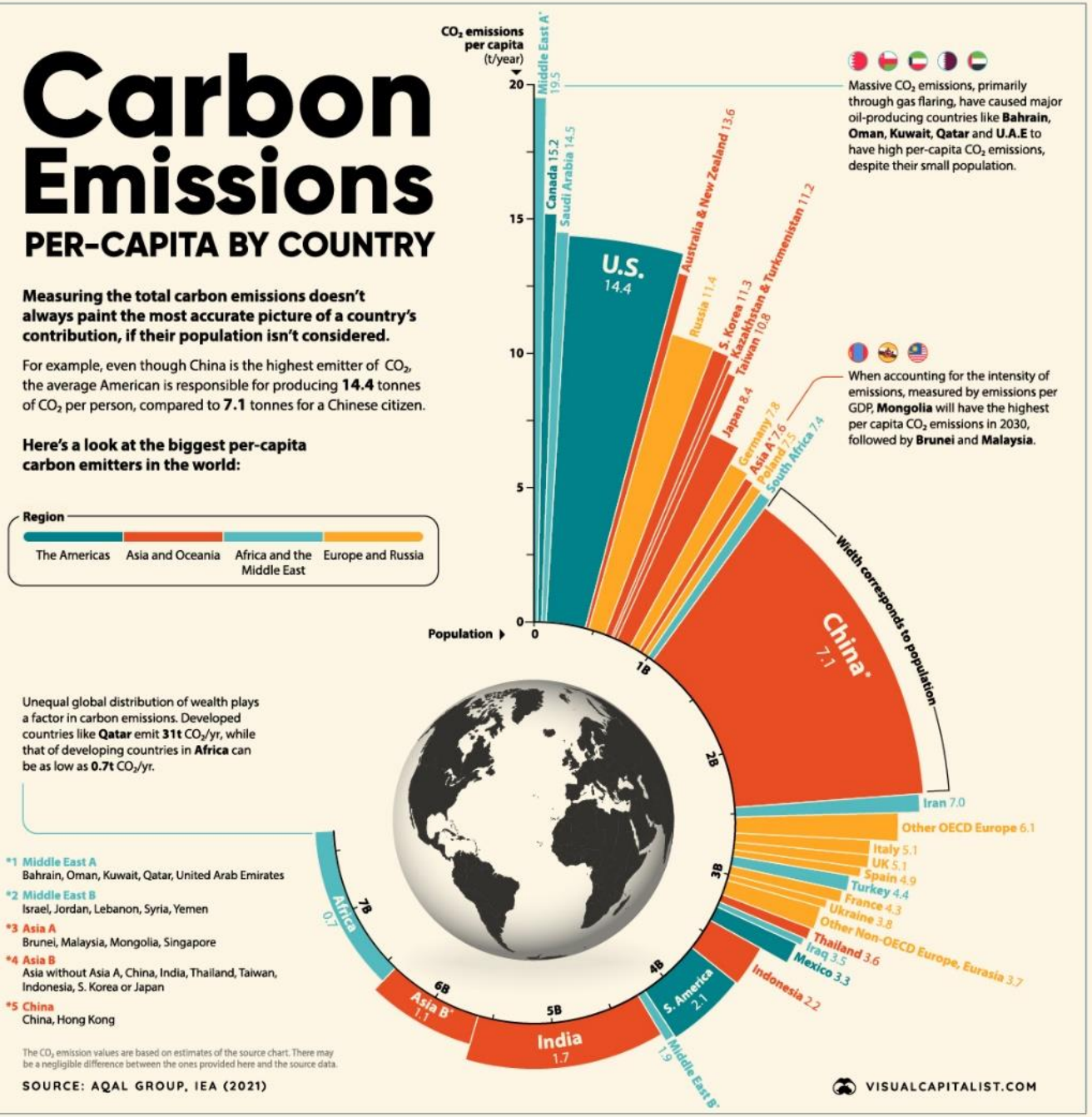
Carbon Emissions

PER-CAPITA BY COUNTRY

Measuring the total carbon emissions doesn't always paint the most accurate picture of a country's contribution, if their population isn't considered.

For example, even though China is the highest emitter of CO_2, the average American is responsible for producing **14.4** tonnes of CO_2 per person, compared to **7.1** tonnes for a Chinese citizen.

Here's a look at the biggest per-capita carbon emitters in the world:



Region

The Americas | Asia and Oceania | Africa and the Middle East | Europe and Russia

Unequal global distribution of wealth plays a factor in carbon emissions. Developed countries like **Qatar** emit **31t** CO_2/yr, while that of developing countries in **Africa** can be as low as **0.7t** CO_2/yr.

*1 Middle East A
Bahrain, Oman, Kuwait, Qatar, United Arab Emirates

*2 Middle East B
Israel, Jordan, Lebanon, Syria, Yemen

*3 Asia A
Brunei, Malaysia, Mongolia, Singapore

*4 Asia B
Asia without Asia A, China, India, Thailand, Taiwan, Indonesia, S. Korea or Japan

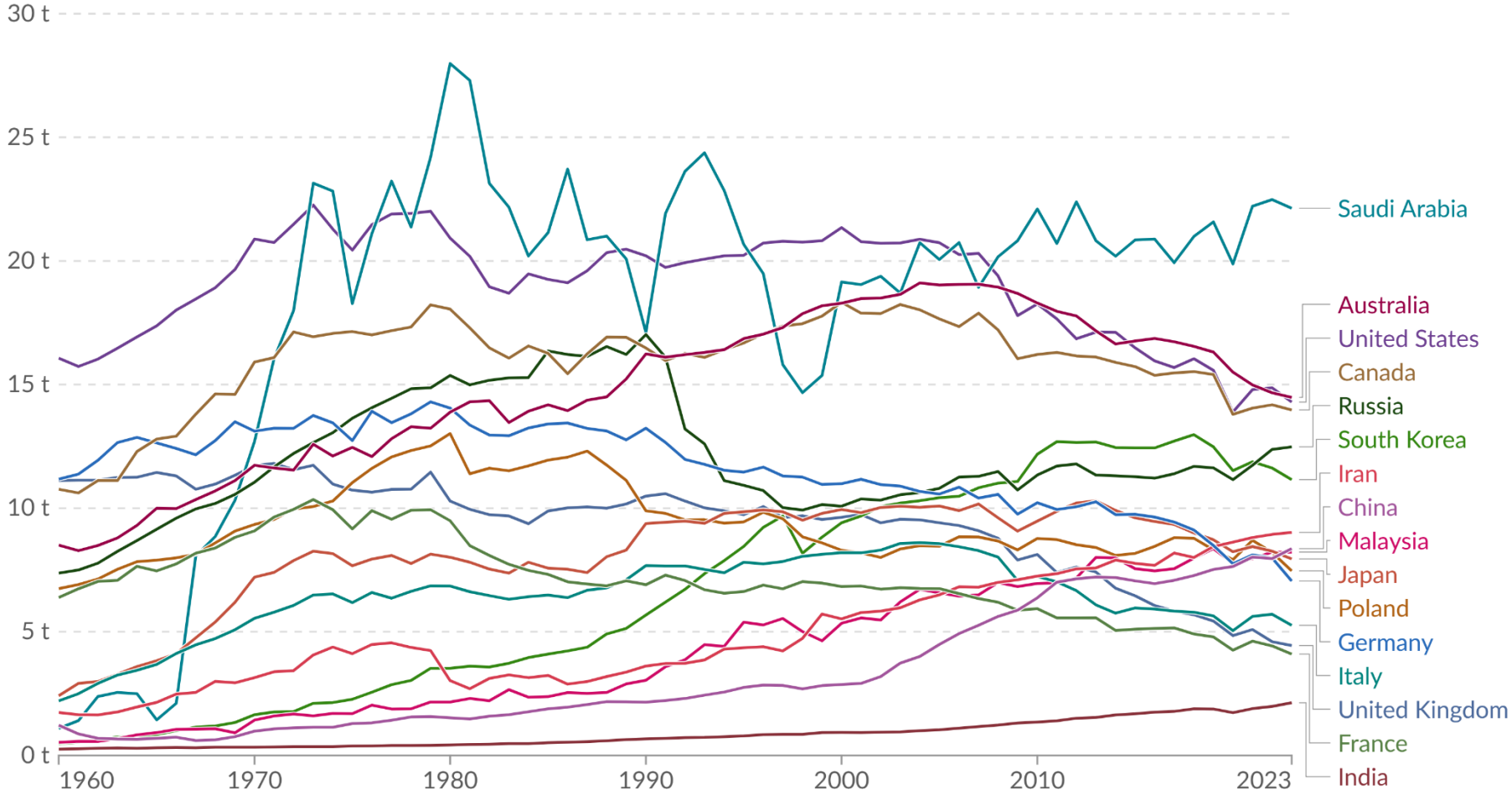
*5 China
China, Hong Kong

The CO_2 emission values are based on estimates of the source chart. There may be a negligible difference between the ones provided here and the source data.

SOURCE: AQAL GROUP, IEA (2021)

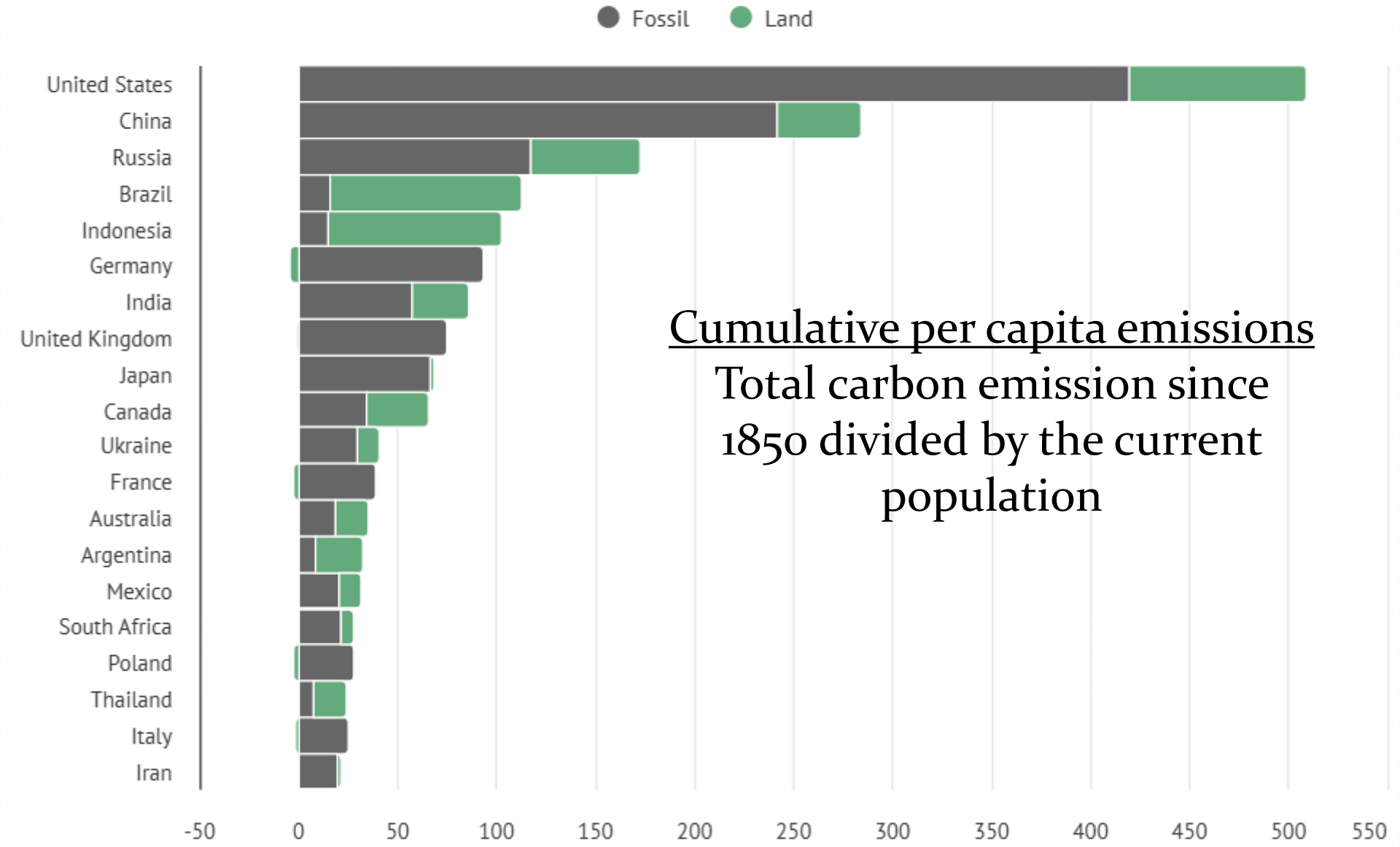
VISUALCAPITALIST.COM

Per Capita CO_2 Emissions per year by Country



The countries with the largest cumulative emissions 1850-2021

Billions of tonnes of CO2 from fossil fuels, cement, land use and forestry



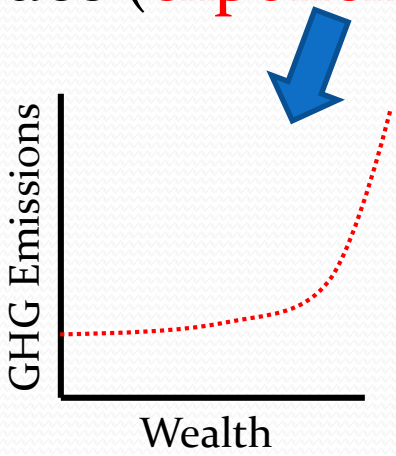
Cumulative per capita emissions

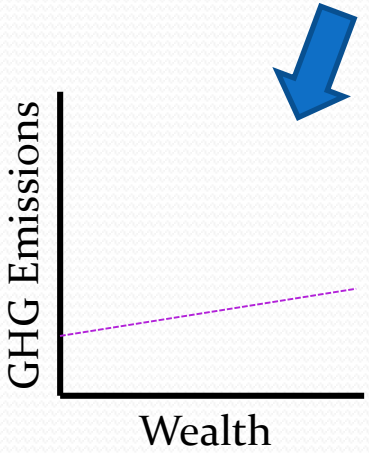
Total carbon emission since 1850 divided by the current population

Wealth Correlates with Emissions

- Looking by country shows that population matters but that more developed nations (i.e. wealthy) tend to have high per capita emissions

- The more money you have the more emissions you tend to produce (exponential, rather than linear increase)





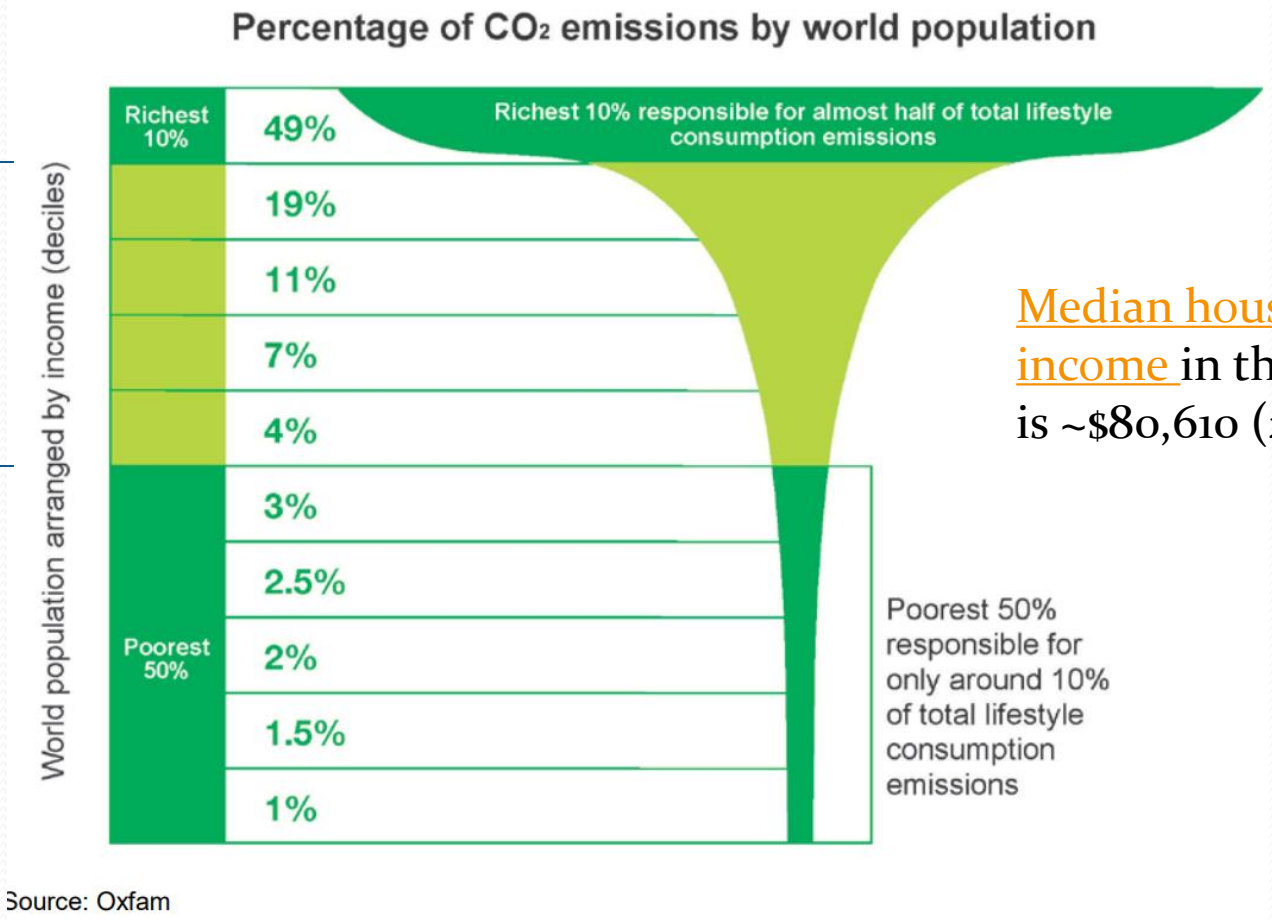
GHG Emissions & Income

>$93,000

<$93,000

>$9,700

<$9,700



Median household income in the US is ~$80,610 (2023)

How the billionaire space race could be one giant leap for pollution

One rocket launch produces up to 300 tons of carbon dioxide into the upper atmosphere where it can remain for years

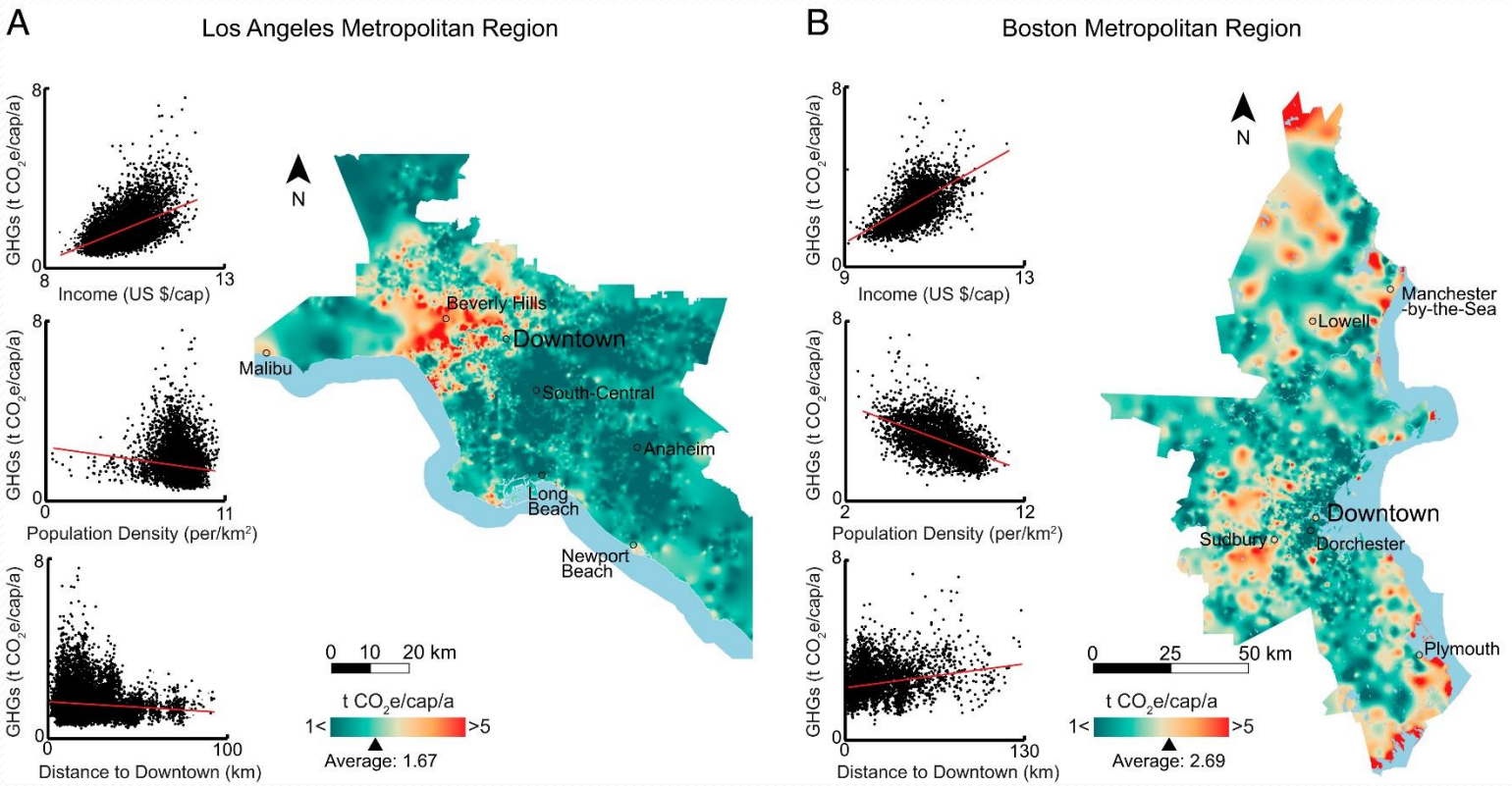
My projected lifetime carbon emissions is ~837 tons

A SpaceX Falcon 9 rocket launches at Cape Canaveral in Florida. Photograph: Joe Marino/UPI/Rex/Shutterstock

Last week Virgin Galactic took Richard Branson past the edge of space, roughly 86 km up - part of a new space race with the Amazon billionaire Jeff Bezos, who aims to make a similar journey on Tuesday.

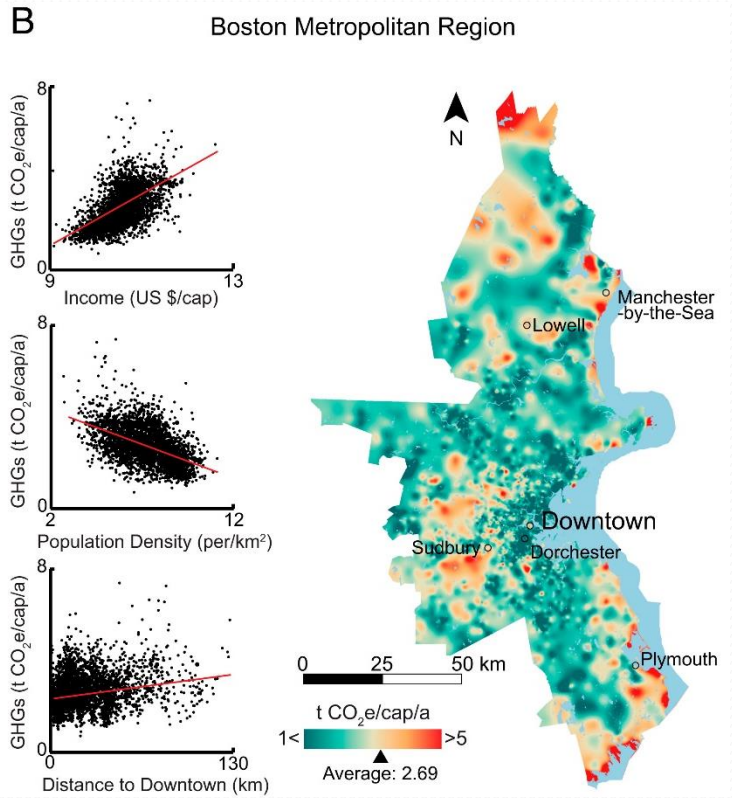
Wealth Correlates with Emissions

- This correlation is extremely robust and holds up as you zoom in within a country as well

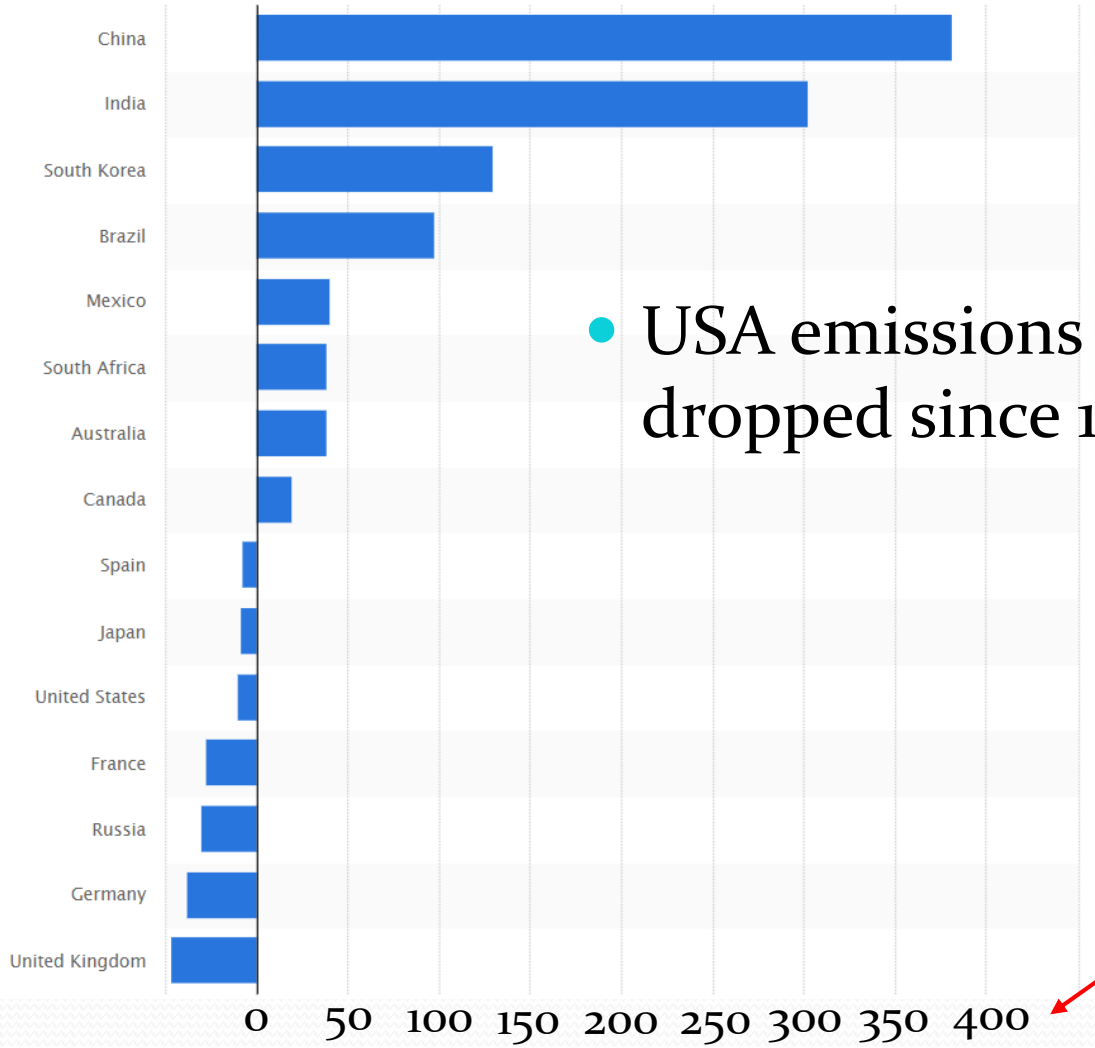


Causes of Income Correlation in USA

- Stereotype of "success" in USA culture is owning your own home in the suburbs, travel, gadgets
- Further commute to work
- Larger homes need energy to heat and large grass lawns (lower land sink)
- Luxury of air travel, vacations, & energy-hungry devices



Change in Emissions Relative to 1990



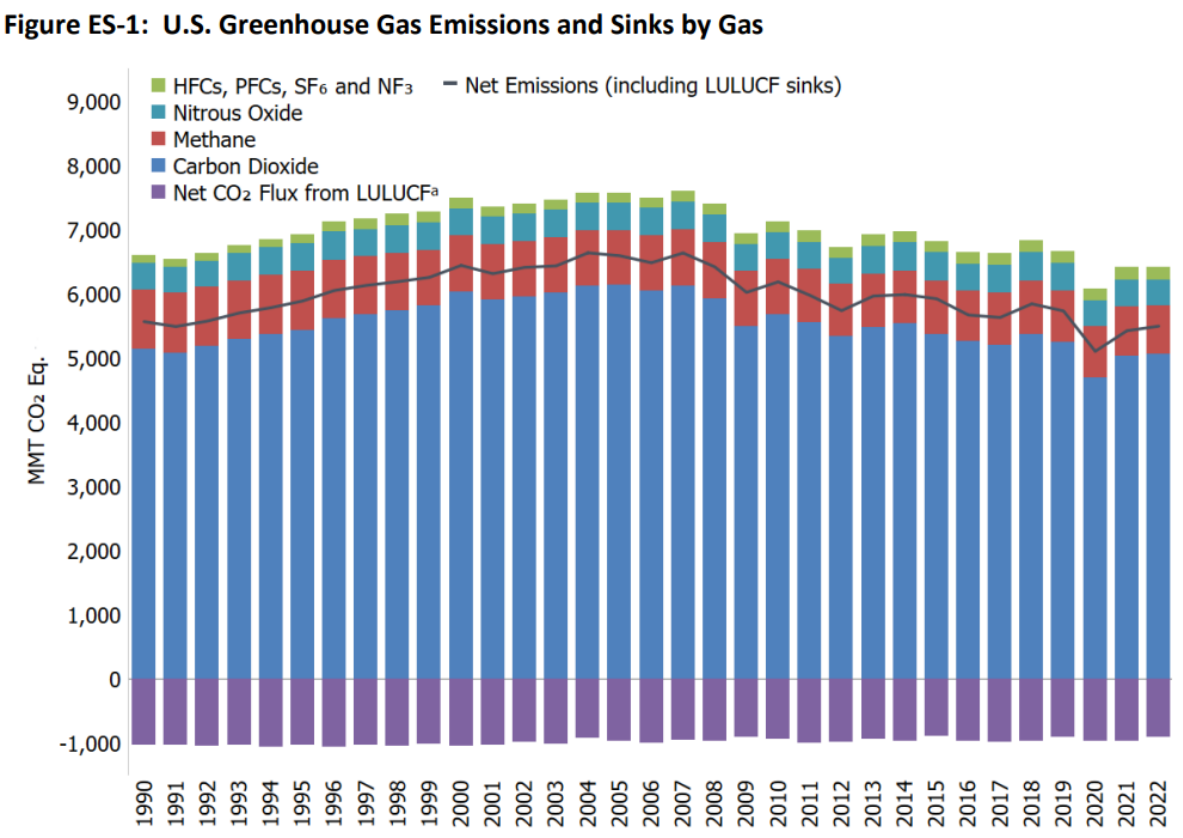
- USA emissions total has actually dropped since 1990 (first IPCC report)

Percent Change in carbon emissions in 2020 relative to 1990

USA GHG Emissions

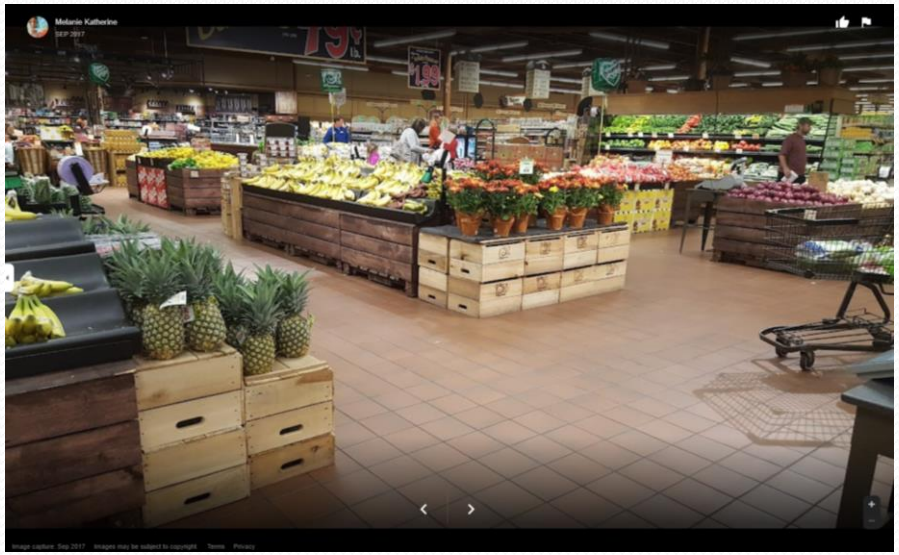
- USA greenhouse gas emissions peaked 2004-2007
  - 2020 was weird (COVID), but overall trend is going down

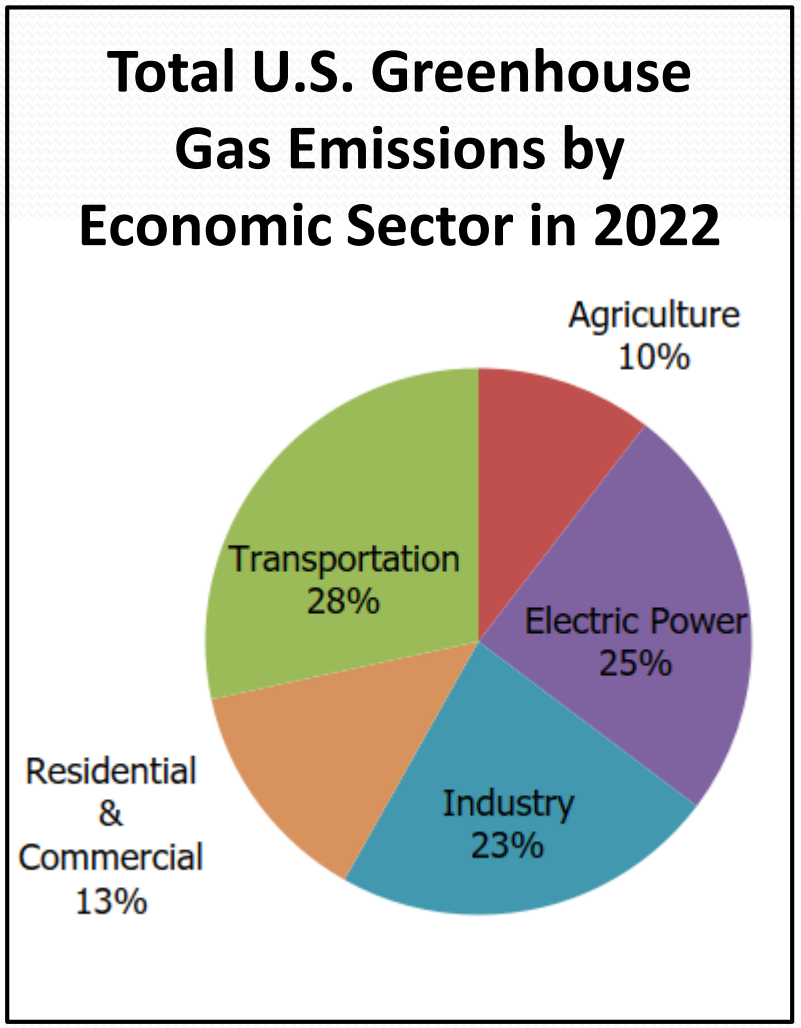
Figure ES-1: U.S. Greenhouse Gas Emissions and Sinks by Gas



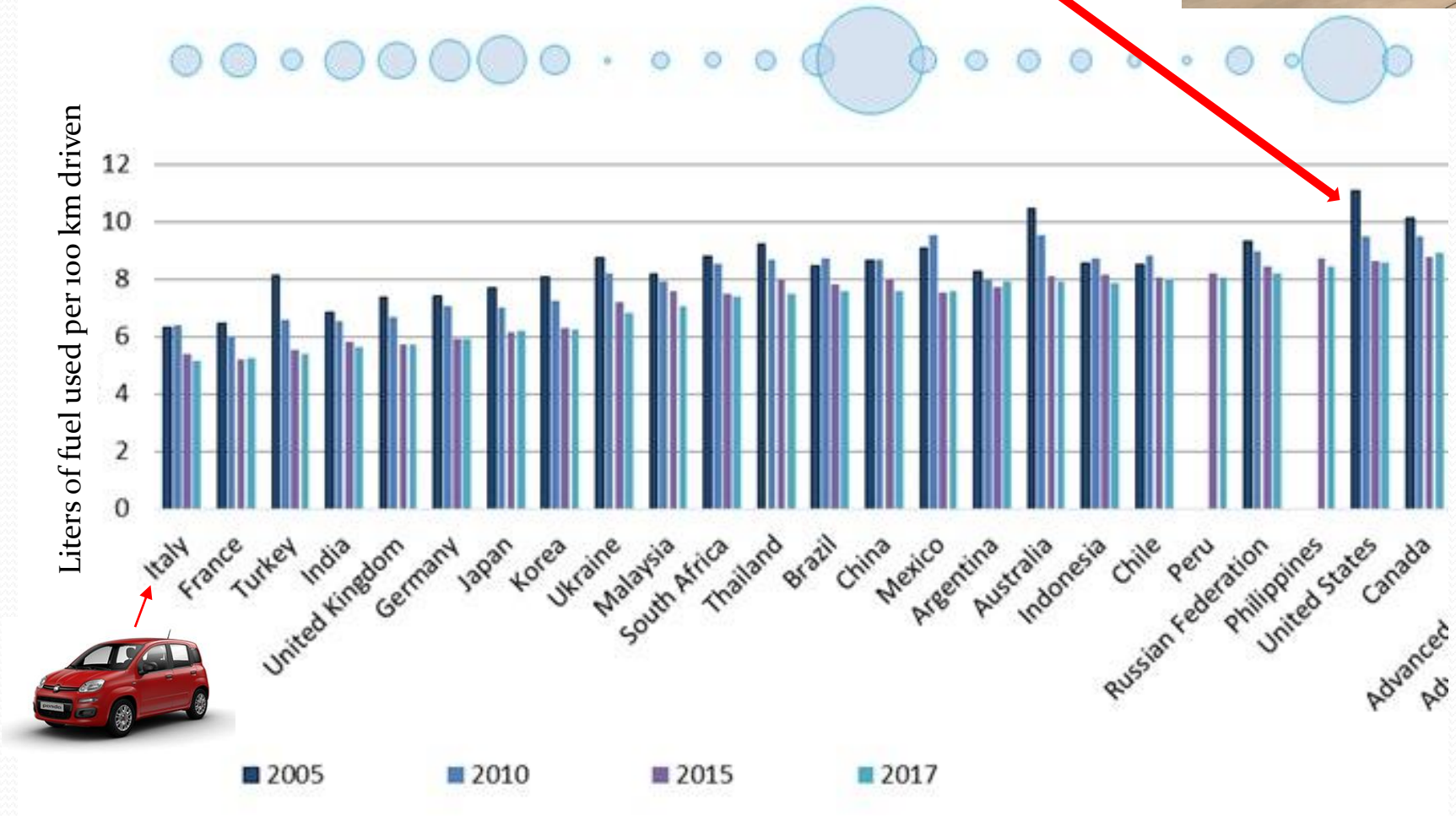
USA Emissions by Sector

- Transport – the United States is a huge country with lots of goods available on a whim
  - Pineapples year-round!!!



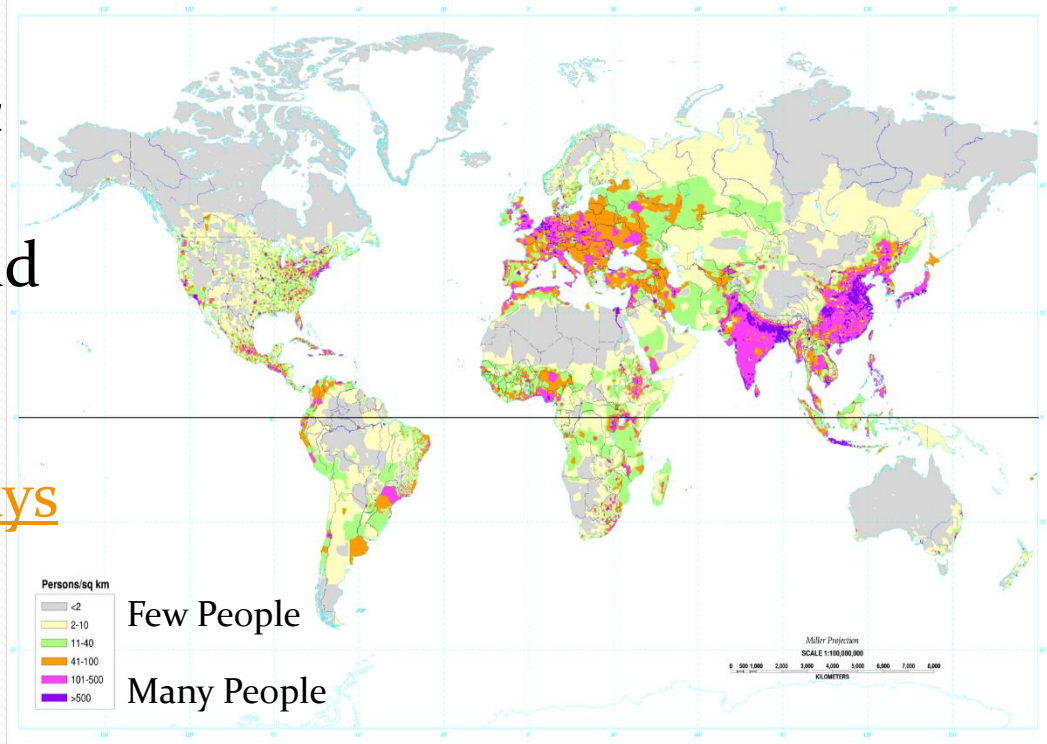


We drive large, heavy cars in America

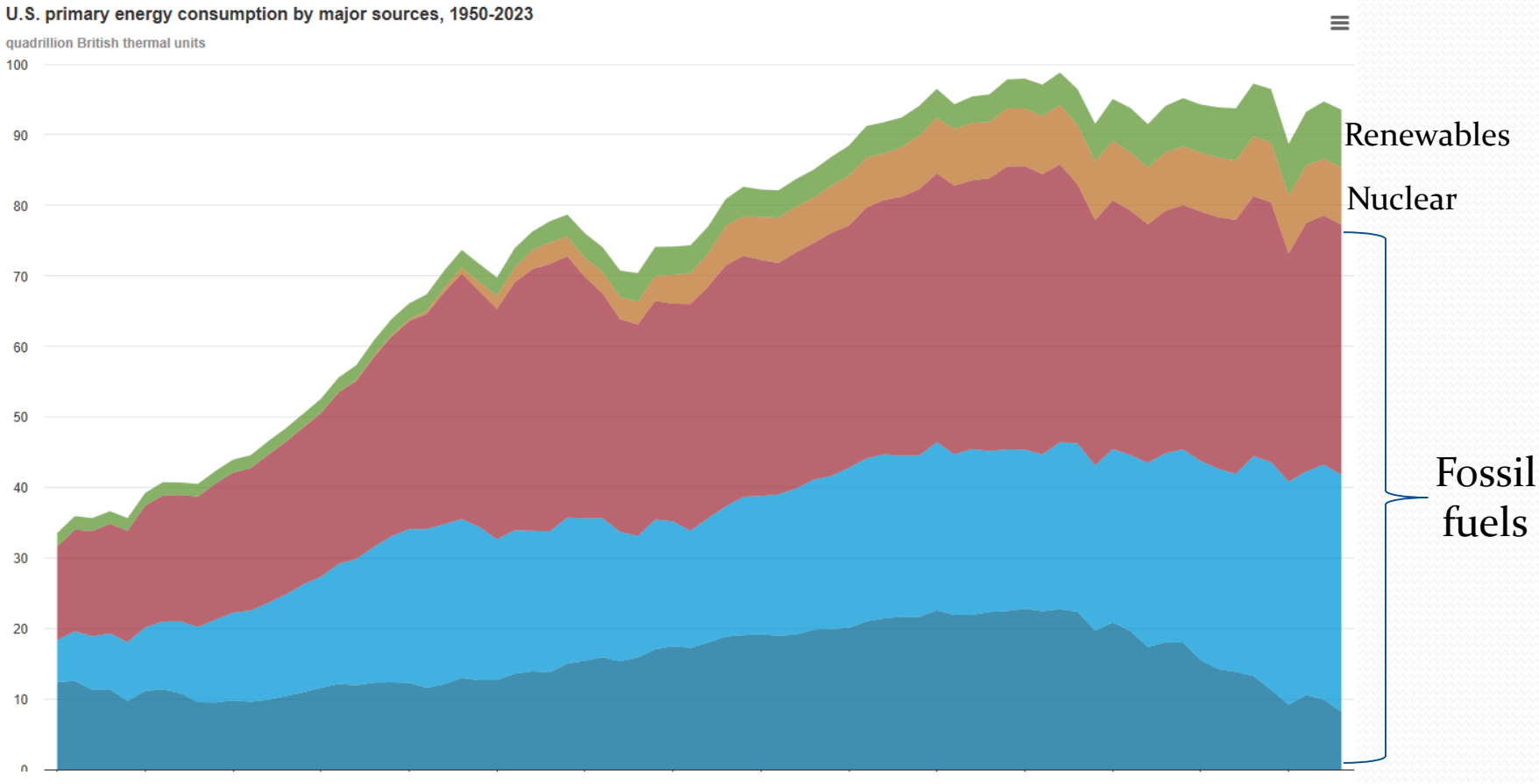


Population density is low in the USA

- We are spread out, and thus need to drive/fly farther to get places
  - Cars are a necessity for many people
- This also makes public transportation MUCH more expensive to build
  - And we have a particularly tainted history with highways and public transit



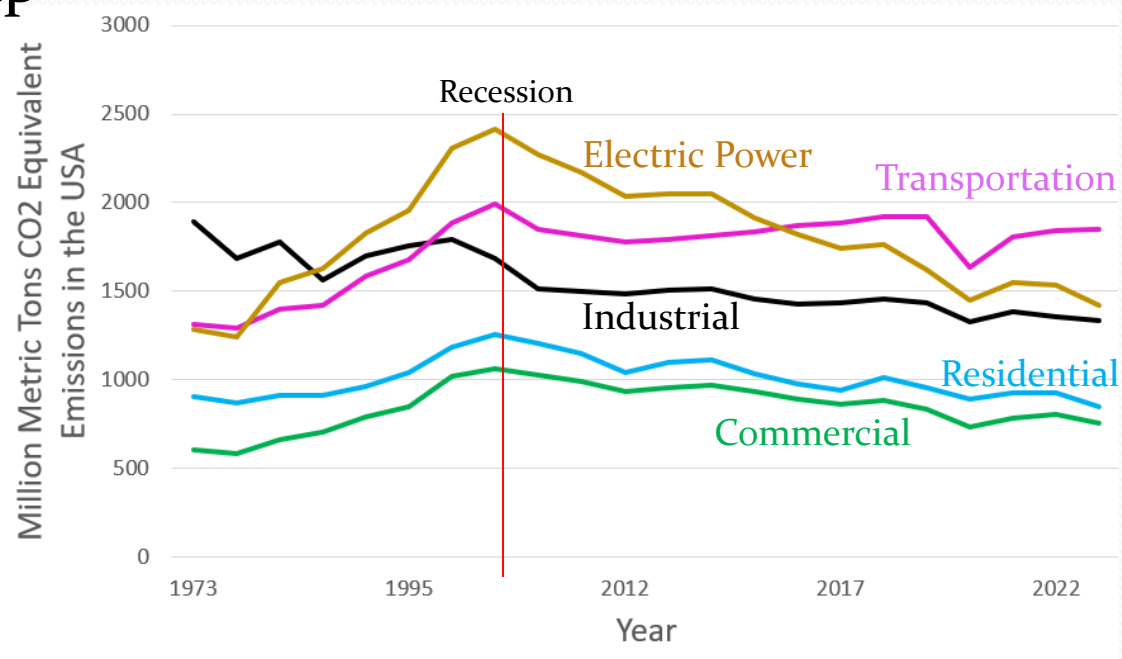
Fossil fuels are 82% of US energy



No amount of “green living” personally is going to save us

GHG Emissions by Sector Over Time

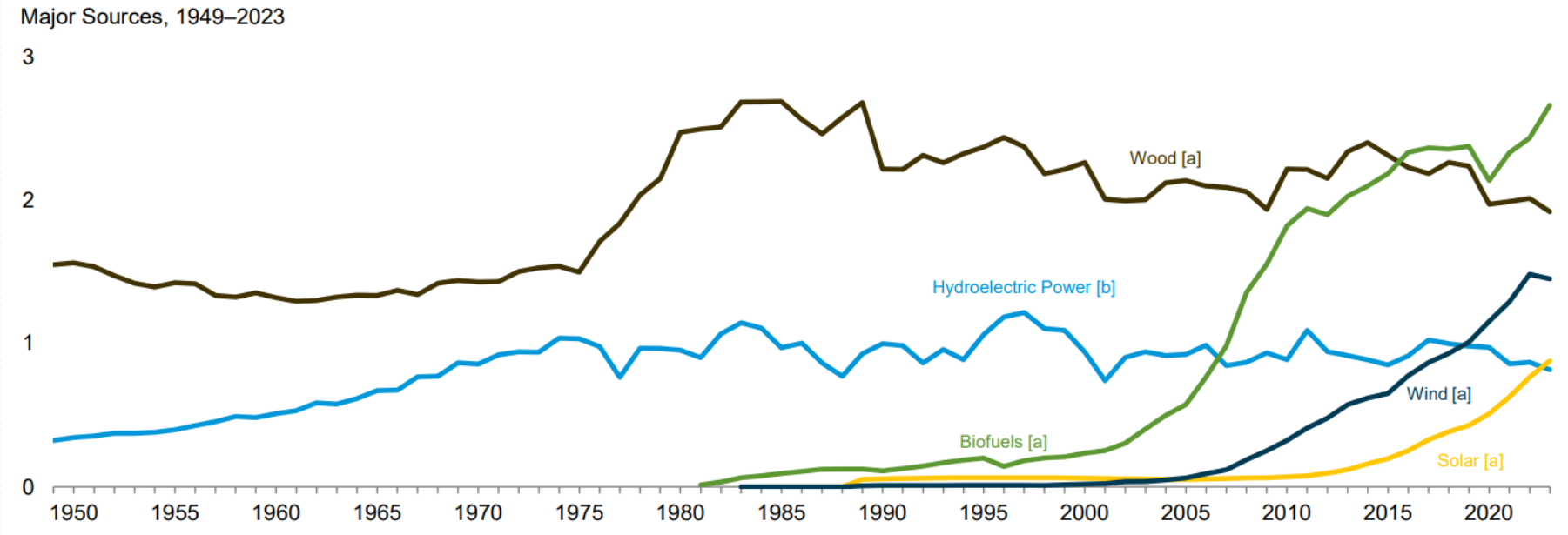
- Residential/commercial and industrial use of energy have very slowly declining for ~40 years
  - But both have grown in size so major per capita decline!
- Transportation emissions peaked ~2007 (recession) but has been creeping back up
- Electric power use has dropped substantially
  - 41% reduction from a peak in the mid-2000s



Why Electric Power Emissions Drop?

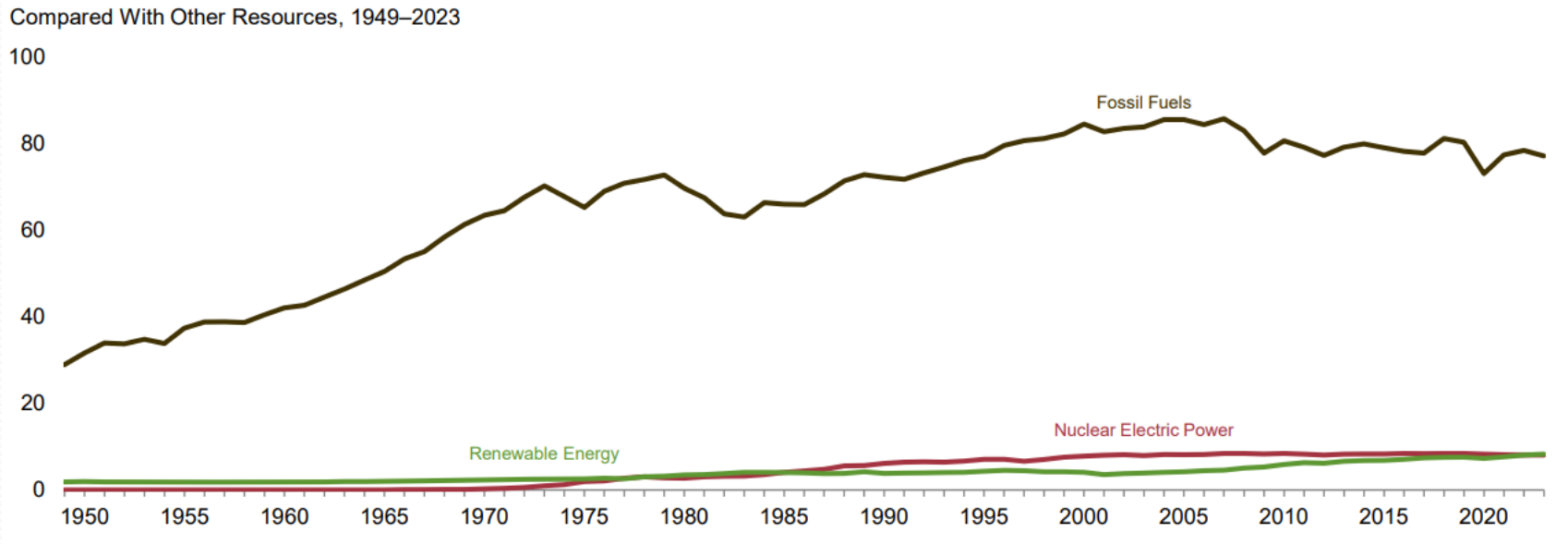
- Moderate expansion of renewable energy sources
  - Particularly wind and solar, but not nearly enough to explain the drop

Figure 10.1 Renewable Energy Consumption
(Quadrillion Btu)

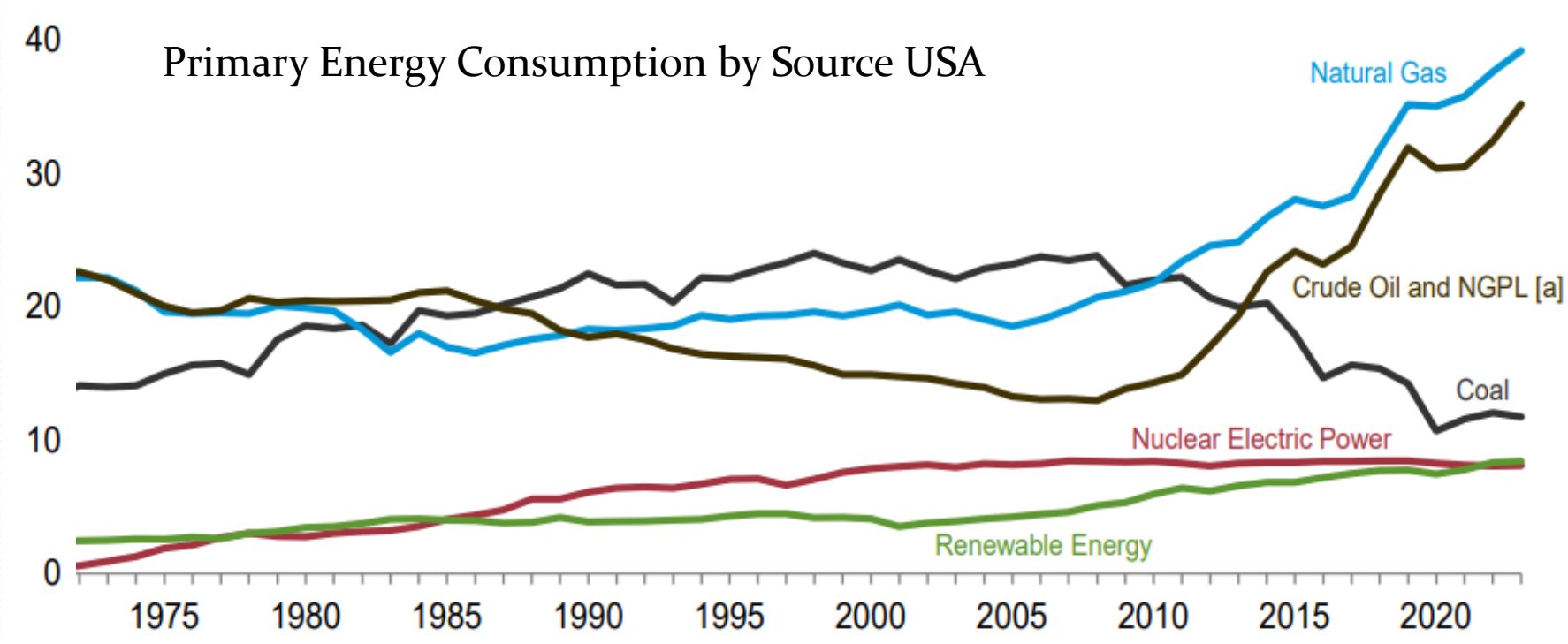


Why Electric Power Emissions Drop?

- Moderate expansion of renewable energy sources
  - Particularly wind and solar, but not nearly enough to explain the drop
  - Alternative energies still a drop n the bucket of total energy consumption



The biggest reason emissions from electricity have decreased… less coal, more natural gas

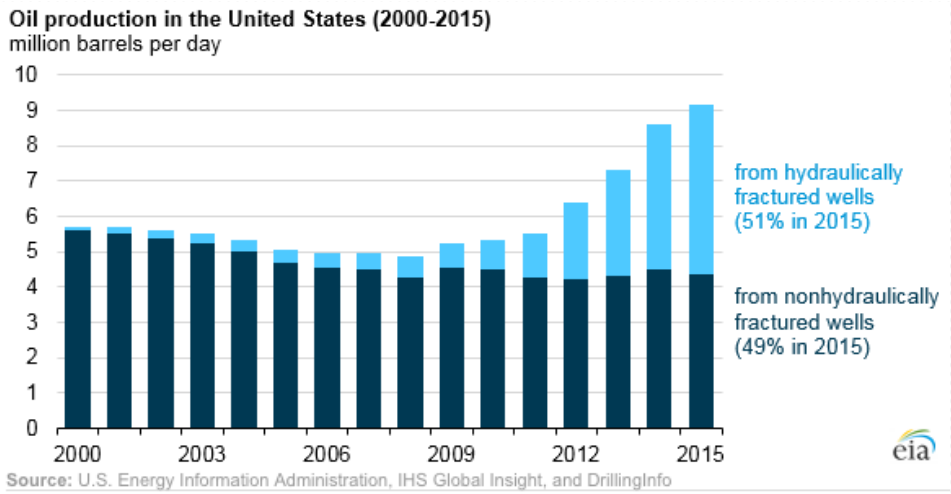


Data Centers & Energy Use

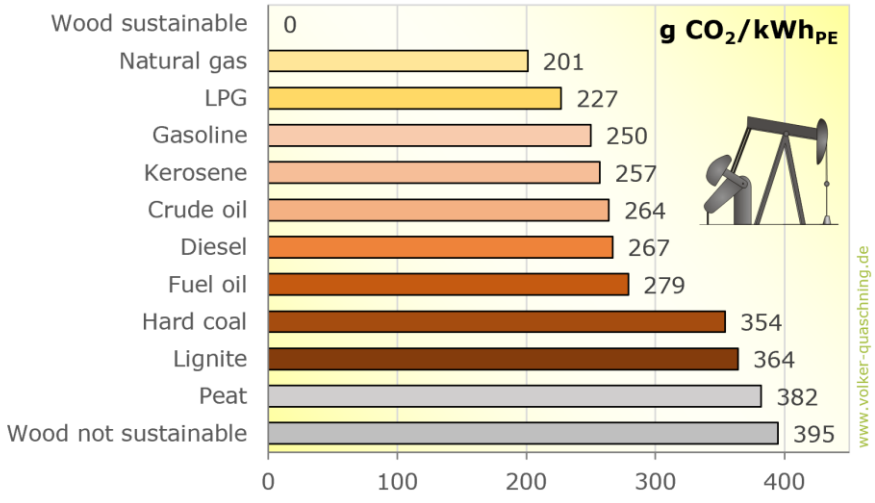
- Generative AI models require enormous amounts of processing power to train and run
  - Infographic article
- Massive expansion of data centers being built or planned and straining the existing energy grid
  - Reopening or extending coal plants
- 4.4% of all USA energy went to data centers in 2023, expected to be 6.7-12% by 2028

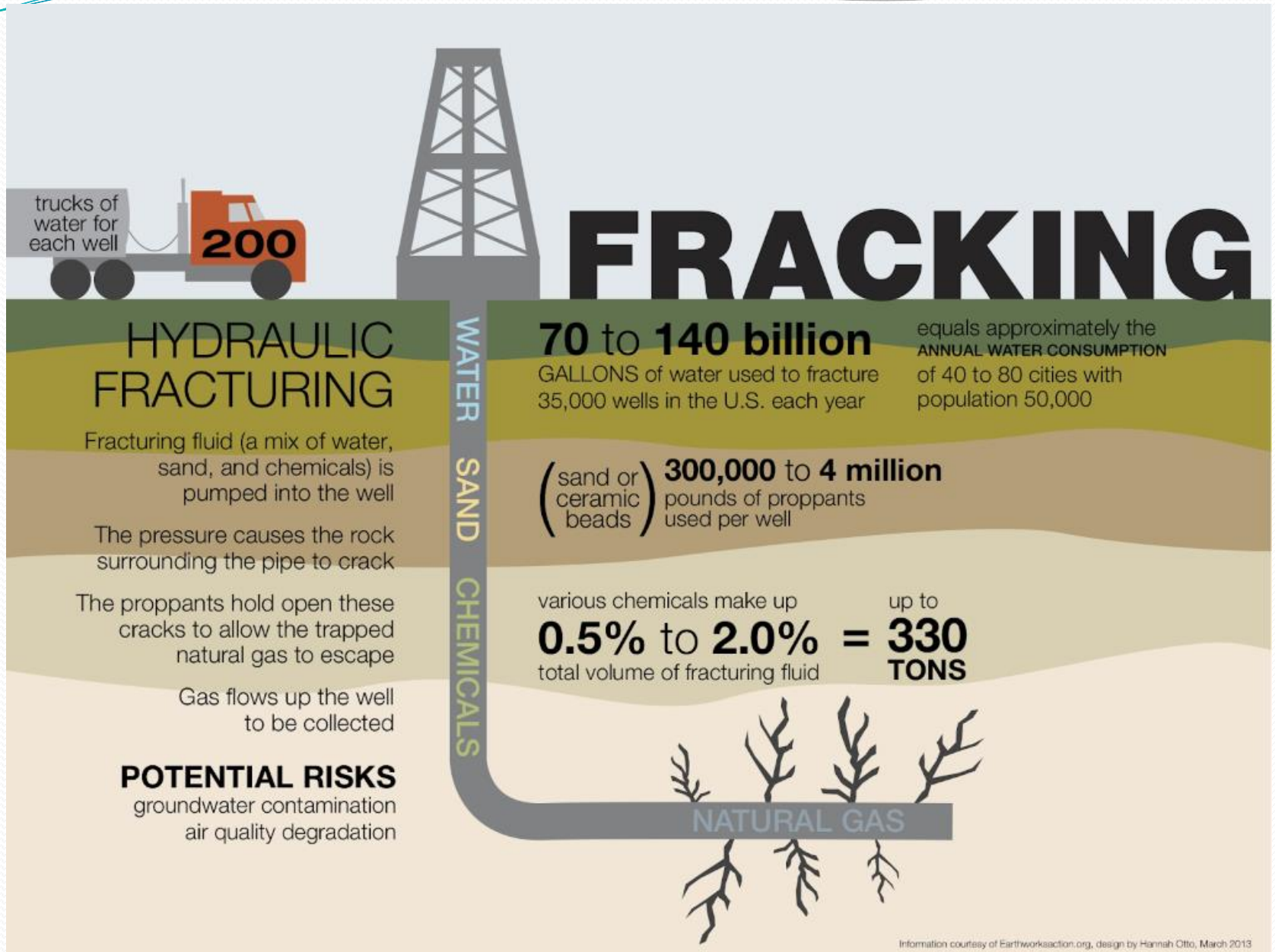
GHG Emissions by Energy Source

- Coal 1.5x GHG emissions compared to natural gas
  - Swap driven by increased cost of coal and gas glut from hydraulic fracturing (light blue in left chart)



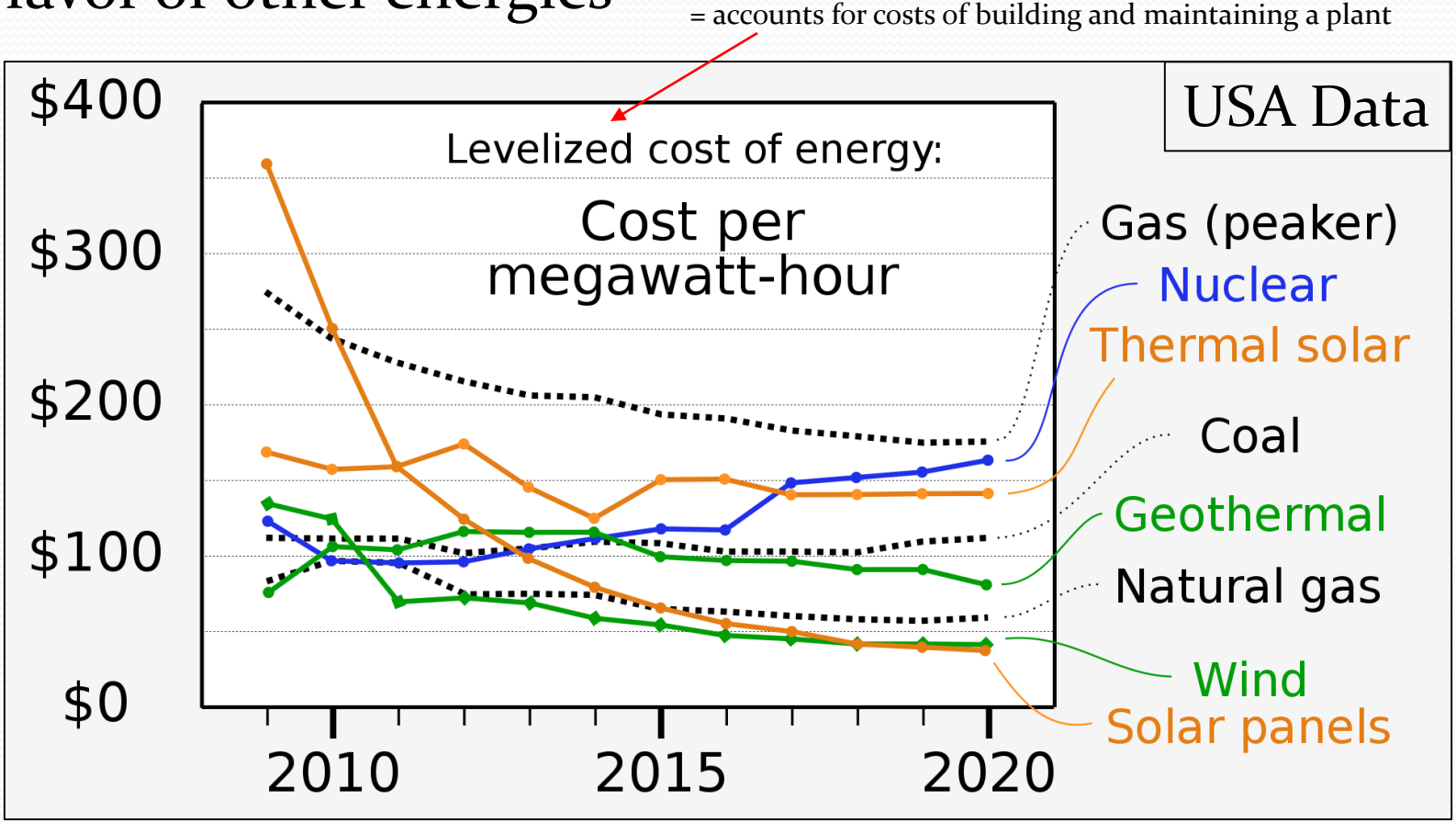
Amount of CO_2 produced per kWh of electricity produced




trucks of water for each well
200
FRACKING
HYDRAULIC FRACTURING
Fracturing fluid (a mix of water, sand, and chemicals) is pumped into the well
The pressure causes the rock surrounding the pipe to crack
The proppants hold open these cracks to allow the trapped natural gas to escape
Gas flows up the well to be collected
POTENTIAL RISKS
groundwater contamination
air quality degradation
WATER
SAND
CHEMICALS
70 to 140 billion
GALLONS of water used to fracture 35,000 wells in the U.S. each year
equals approximately the ANNUAL WATER CONSUMPTION of 40 to 80 cities with population 50,000
(sand or ceramic beads) 300,000 to 4 million pounds of proppants used per well
various chemicals make up 0.5% to 2.0% total volume of fracturing fluid
= up to 330 TONS
NATURAL GAS
Information courtesy of Earthworksaction.org, design by Hannah Otto, March 2013

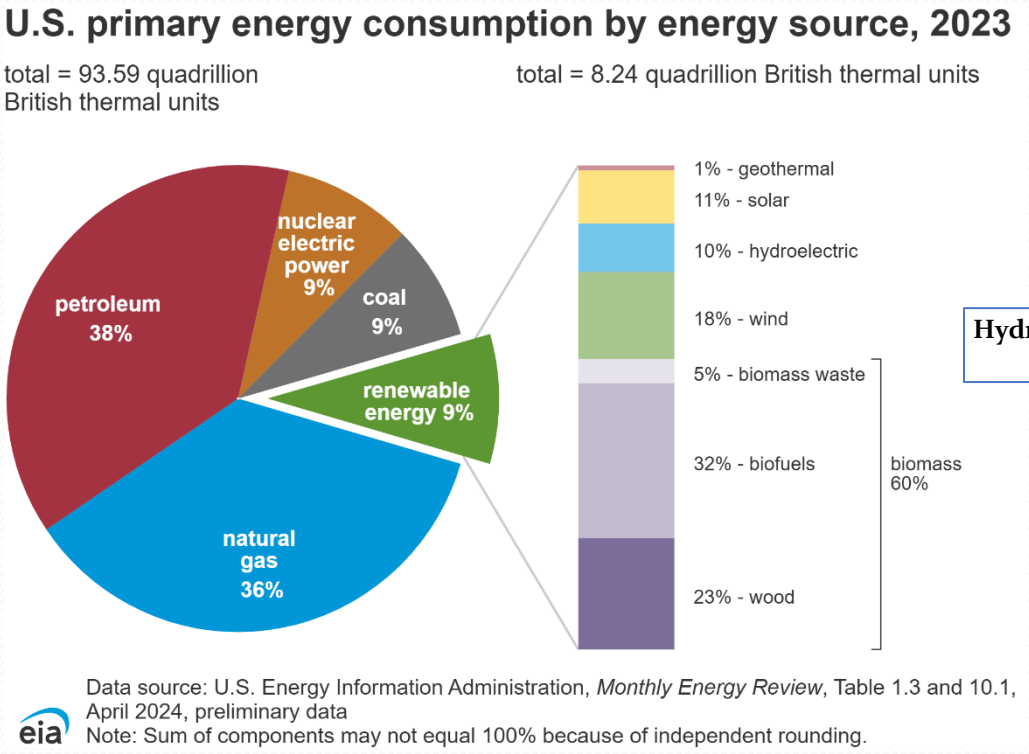
Economic Downfall of Coal (USA)

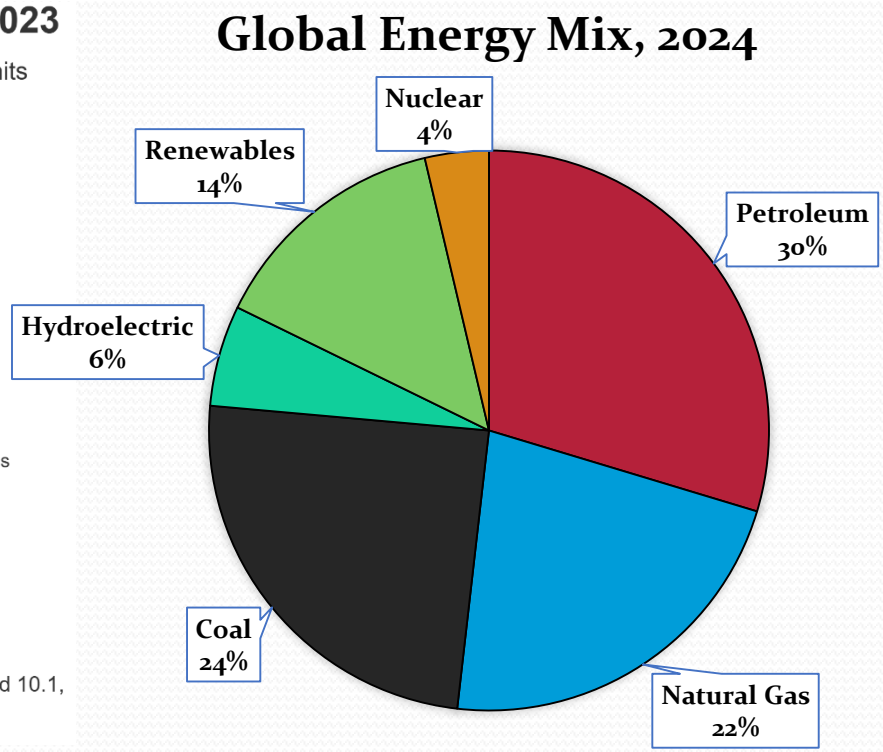
- Coal is just more expensive so being phased out in favor of other energies



Coal Is Not Dead Yet

- Coal still economically attractive in large parts of the world
  - China , India, Germany, Australia, etc.





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