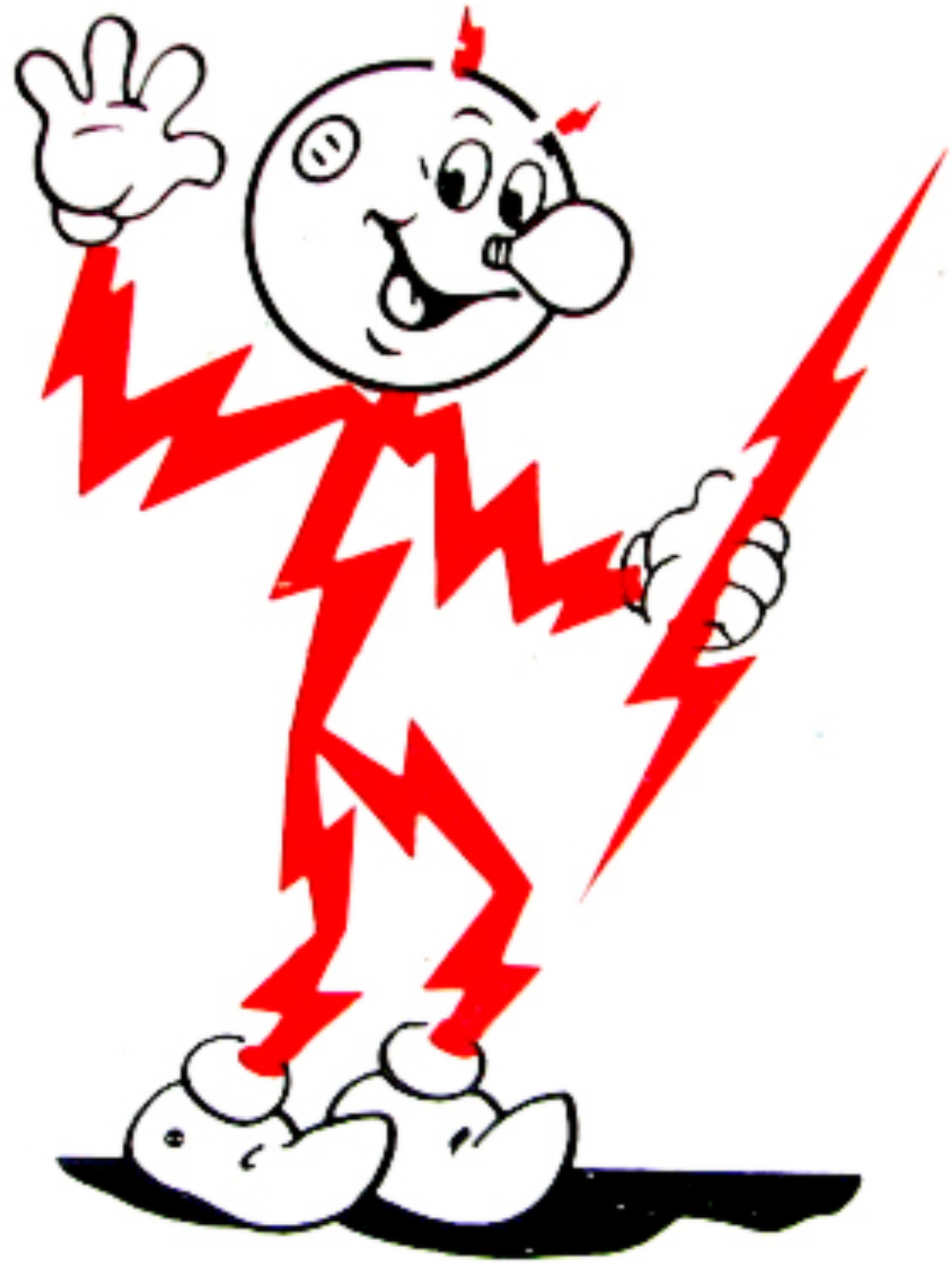


### 3 Earth's carbon battery



*Fission is in Fashion*

Fossil fuel timeline

Limits to extracting energy

Role of investment

Coal, then oil, and gas

Developing nations' coal use

CO<sub>2</sub> in the atmosphere

Energy from burning carbon is the basis of civilization. We need to put in place a different source of reliable, economic energy before removing the old.



**How the World Really Works by Vaclav Smil — what powers our economies**

# Carbon battery charging

## Coal

300,000,000 BC

50,000 tons/year

## Gas

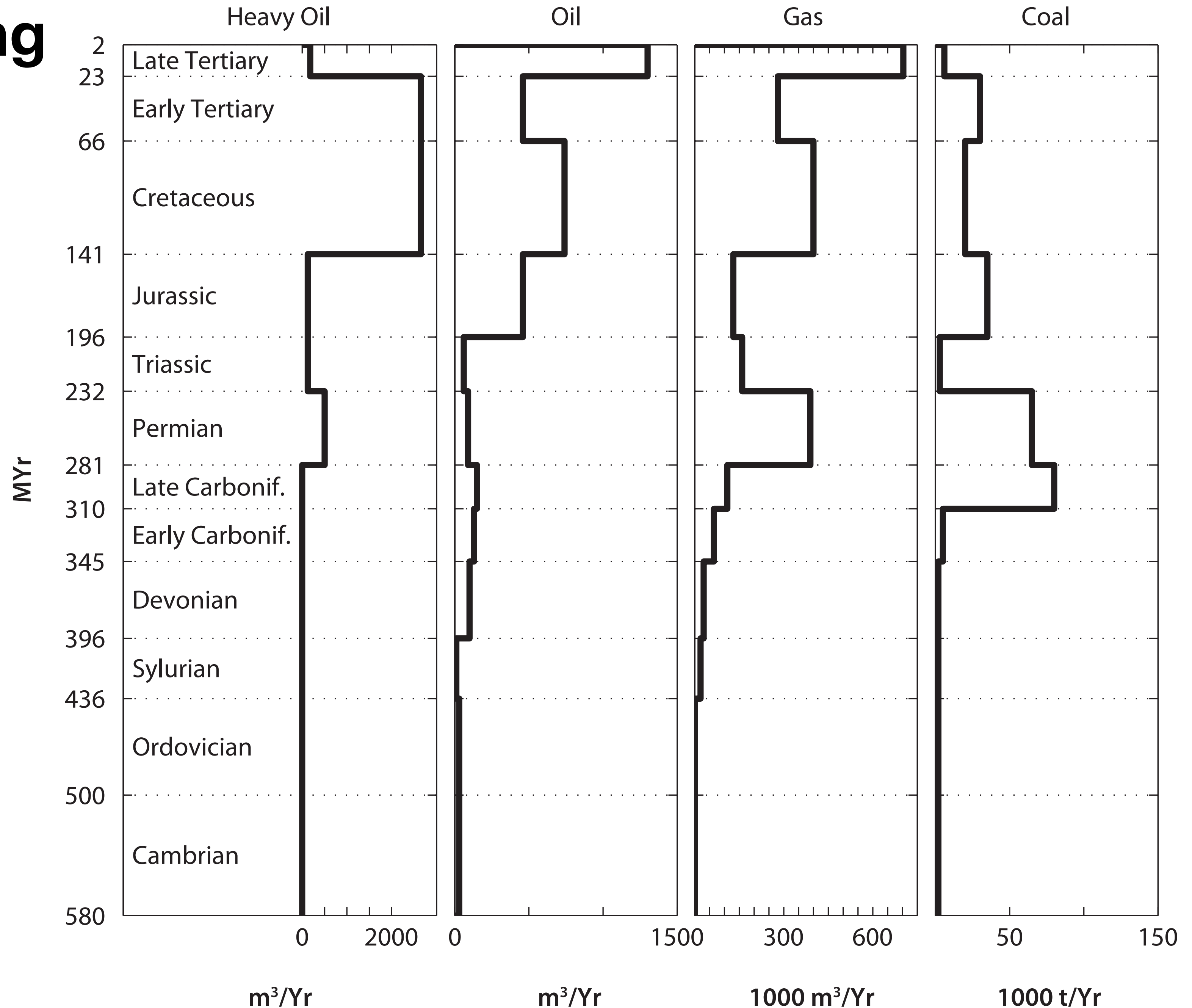
200,000,000 BC

300 tons/year

## Oil

100,000,000 BC

500 tons/year



# Annual discharge of world carbon battery

130,000 TWh (heat)

~ 468 EJ

~ 40 billion tons of oil or coal

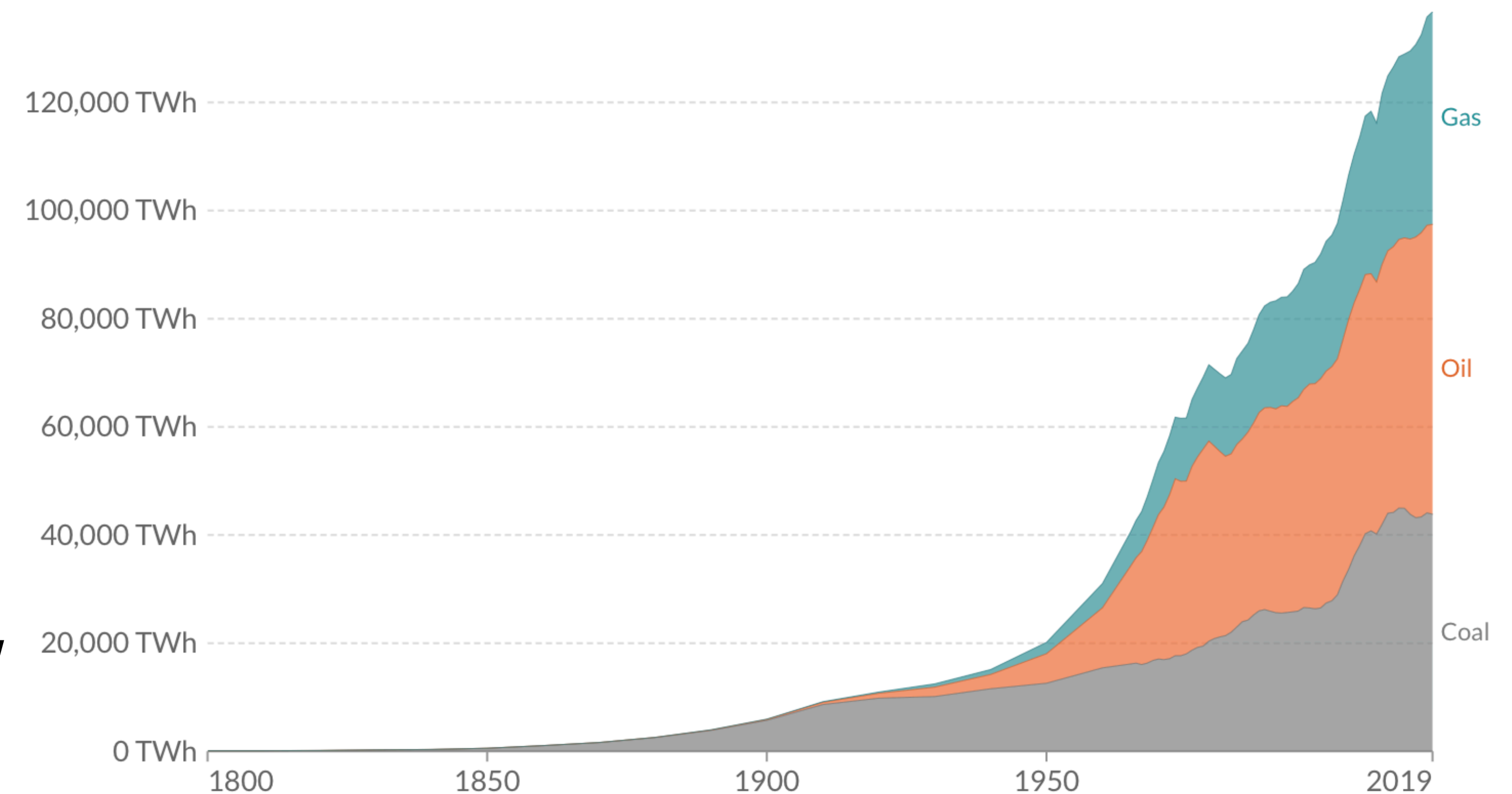
~ 3 cubic miles of oil

Discharge rate: 15,000 GW  
3 million x charge rate

## Global fossil fuel consumption

Global primary energy consumption by fossil fuel source, measured in terawatt-hours (TWh).

Relative



Source: Vaclav Smil (2017). Energy Transitions: Global and National Perspective & BP Statistical Review of World Energy  
OurWorldInData.org/fossil-fuels/ • CC BY

1 TWh is the energy of 123,000 t-coal.

# King Hubbert, for Shell, 1956

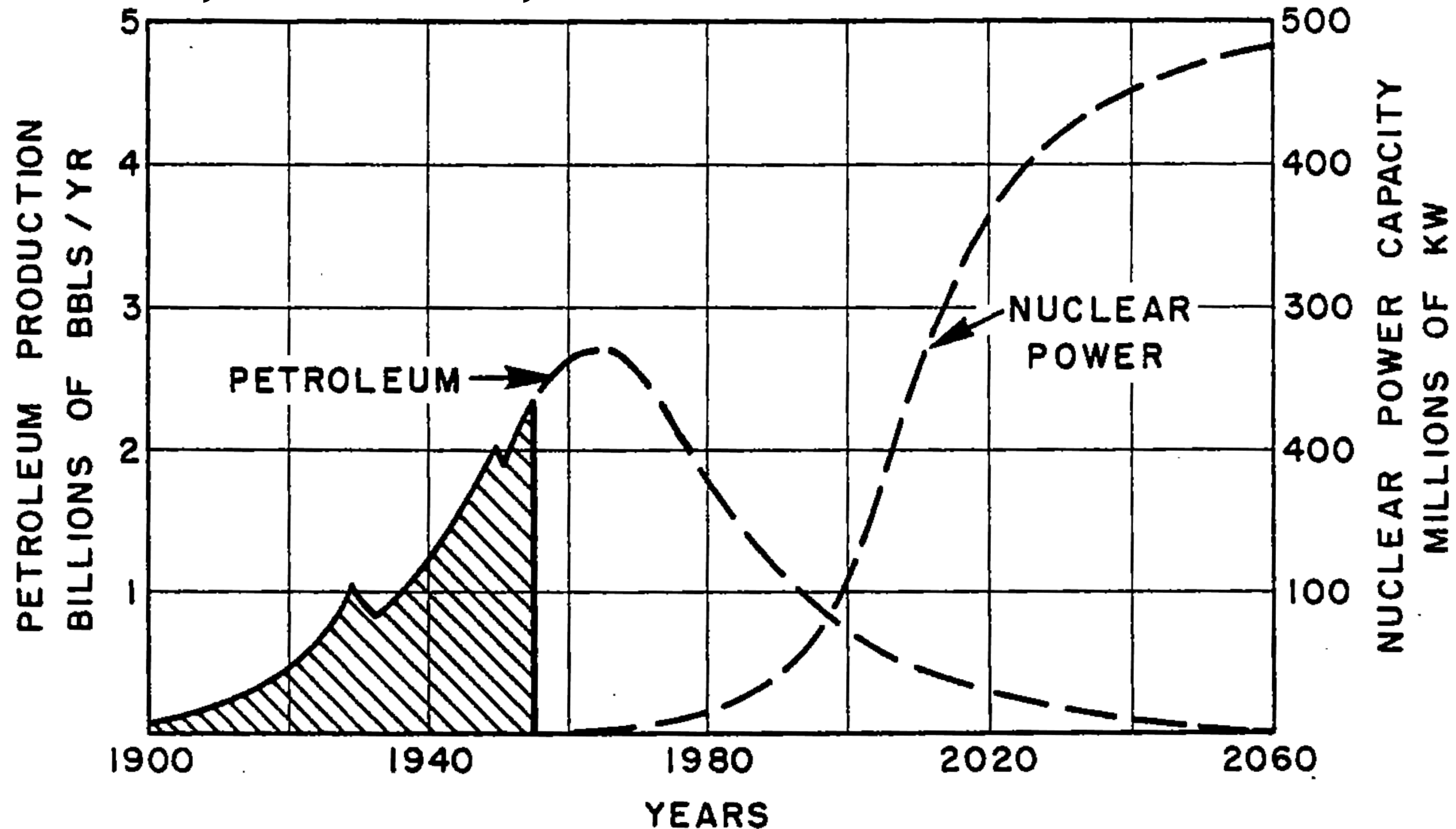
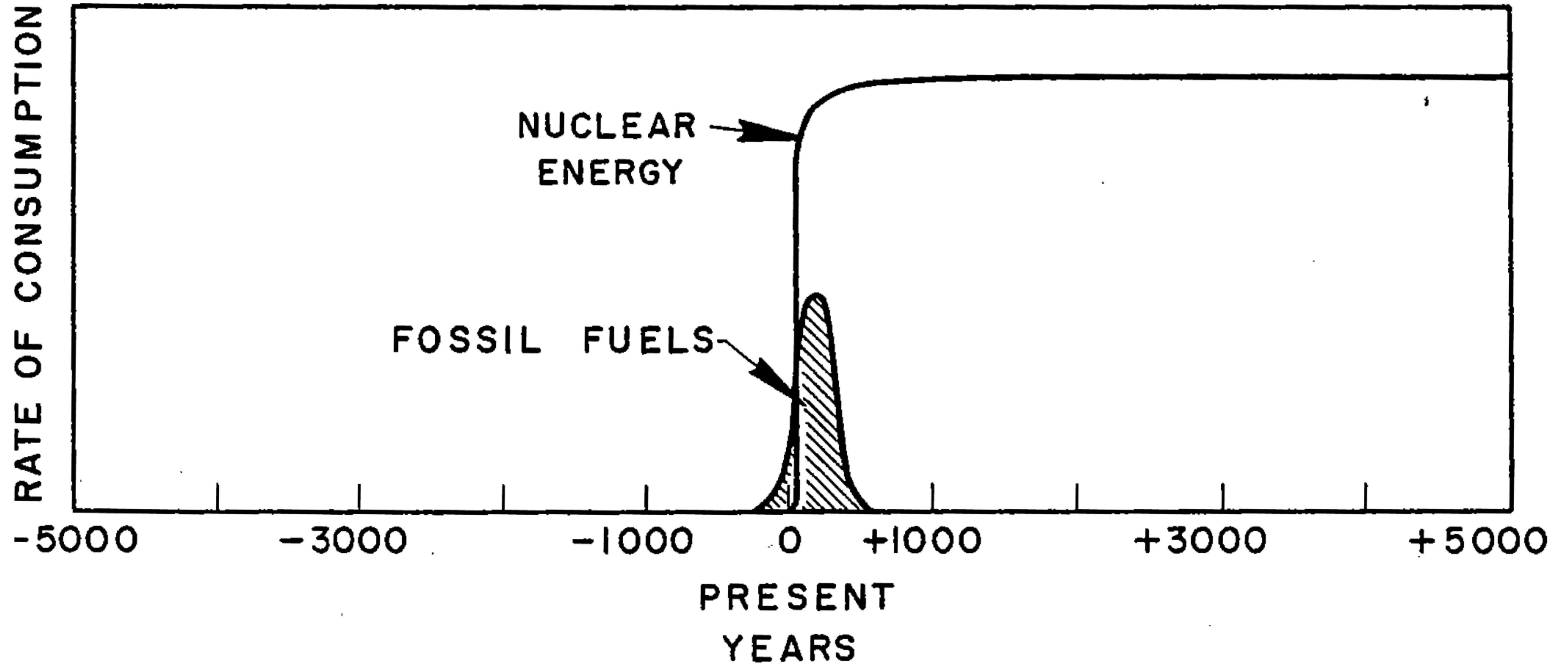
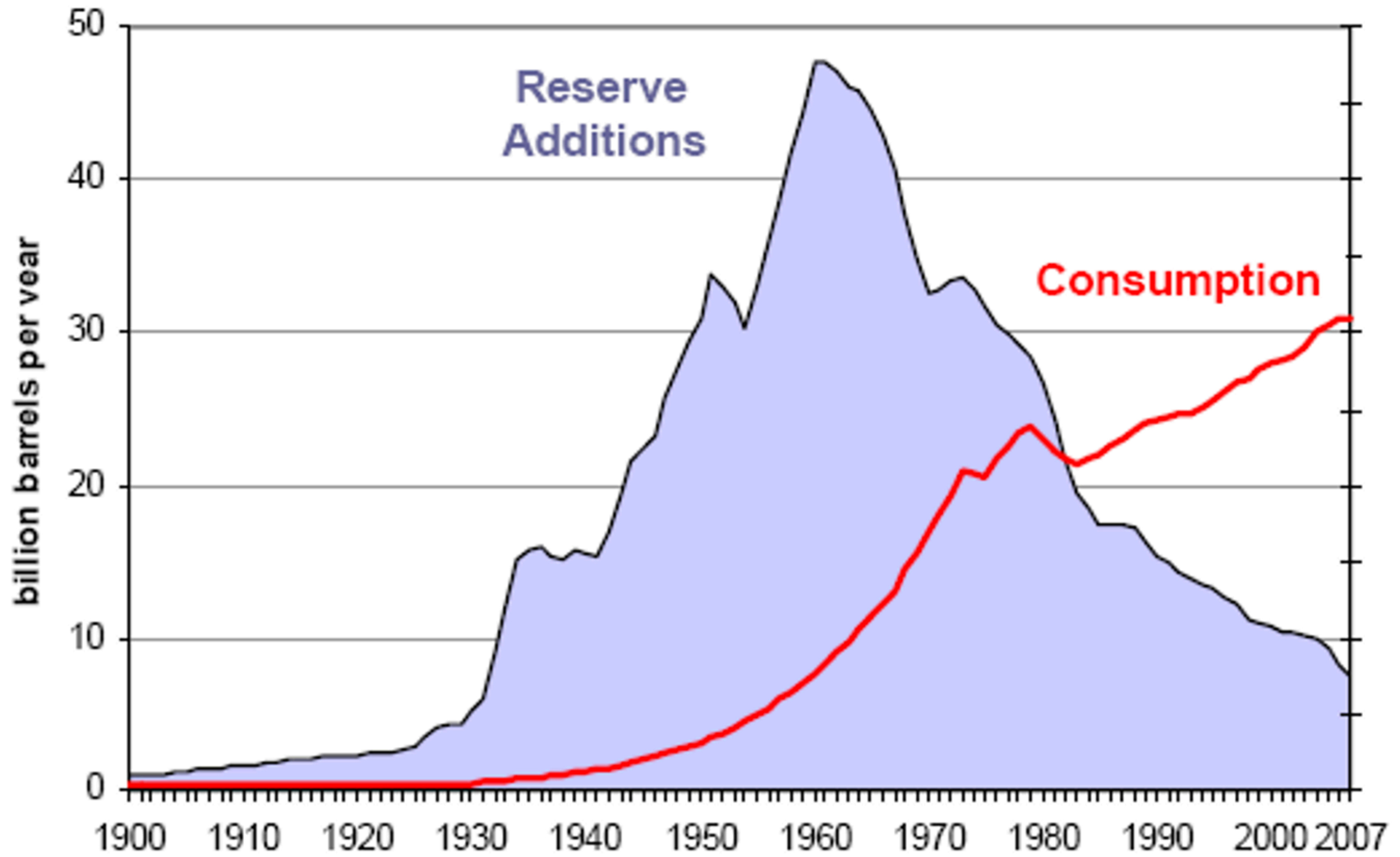


Figure 29 - Concurrent decline of petroleum production and rise of production of nuclear power in the United States. Growth rate of 10 percent per year for nuclear power is assumed; actual rate may be twice this amount.

# King Hubbert on peak oil



# Peak oil



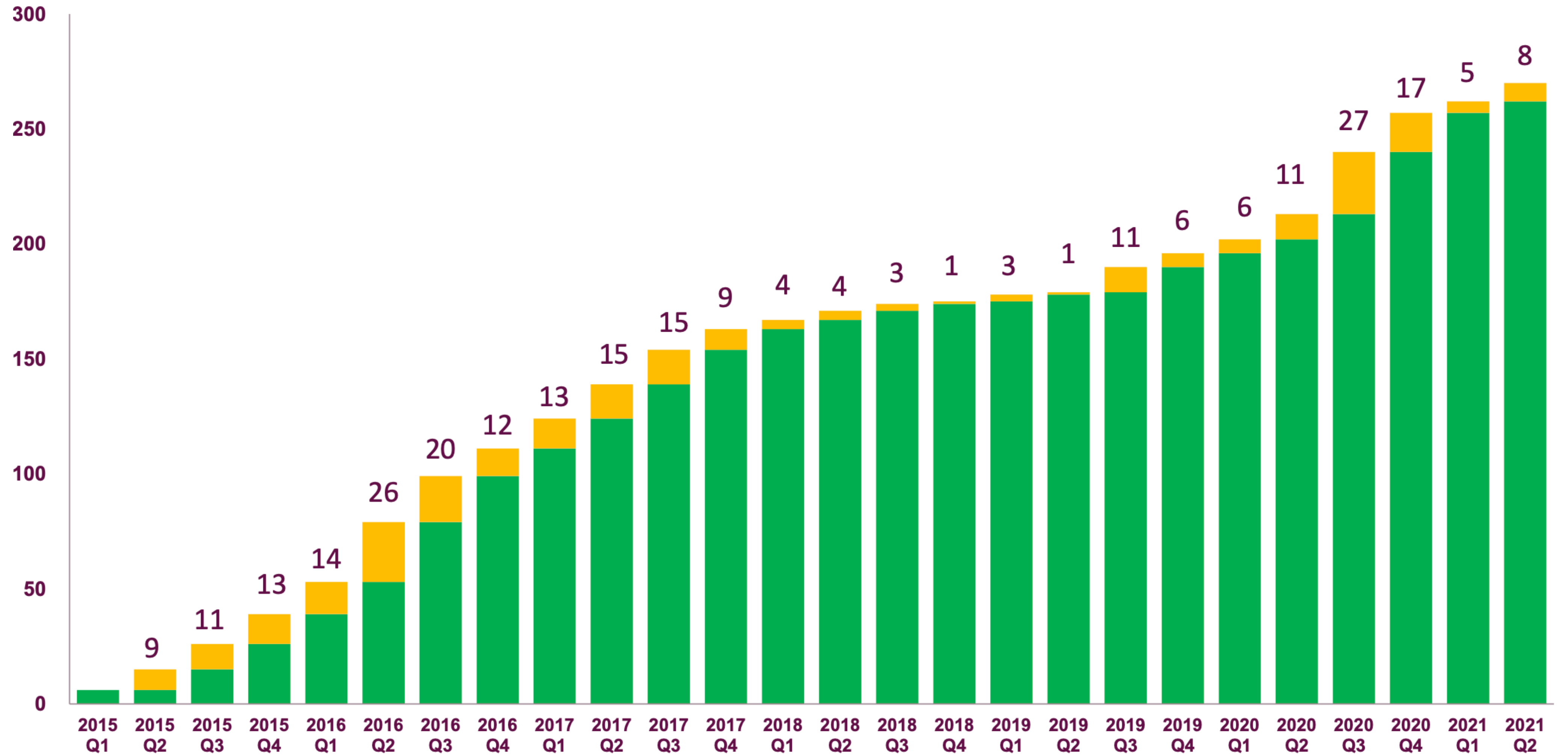
Source: Bezdek, 2008

# Penwell, TX, 2020





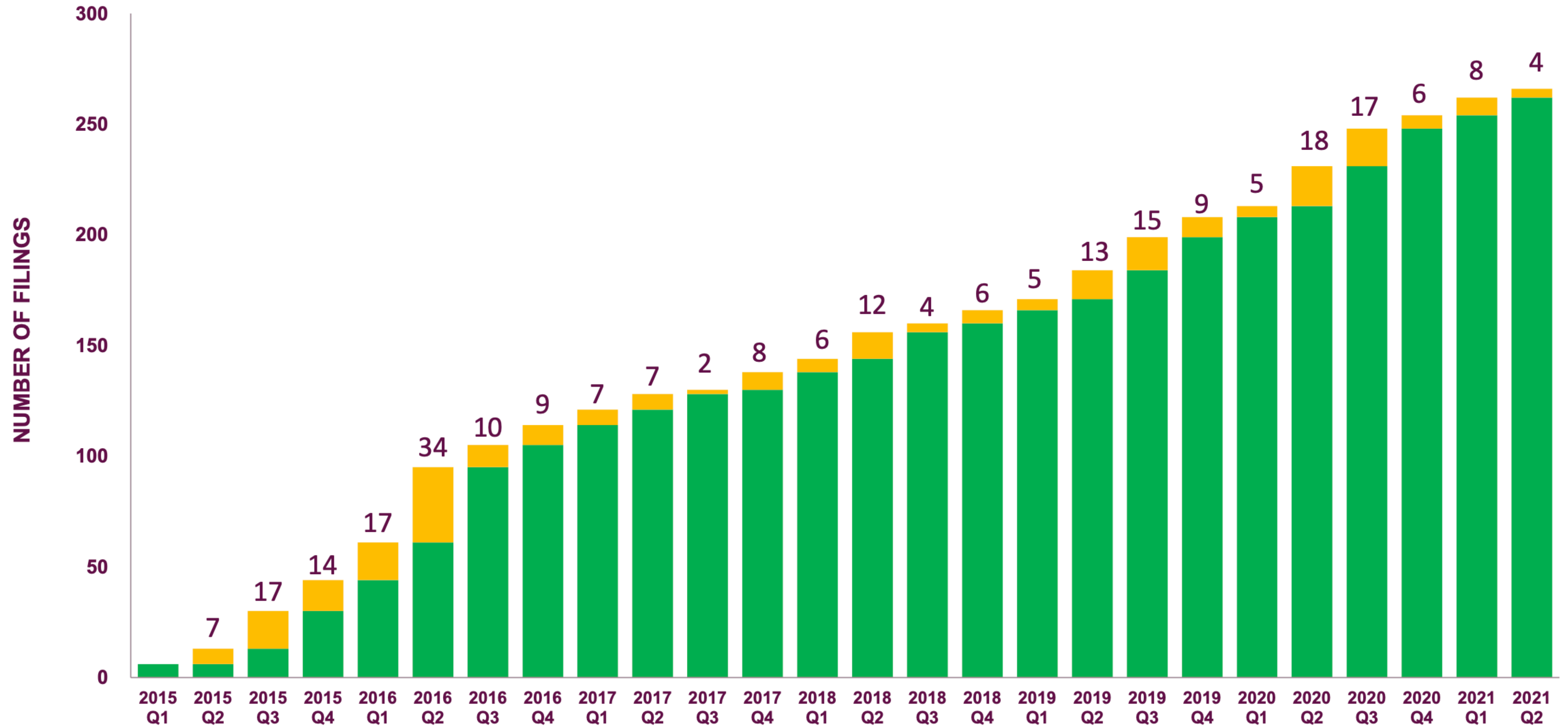
# Oilfield services bankruptcies: \$117 billion, 2015-2021



HAYNES BOONE OILFIELD SERVICES BANKRUPTCY TRACKER©

- Cumulative bankruptcies
- New bankruptcies since the previous quarter

# Explorer and producer bankruptcies: \$177 billion, 2015-2021



HAYNES BOONE OIL PATCH BANKRUPTCY MONITOR©

- Cumulative bankruptcies
- New bankruptcies since the previous quarter

# Oil Frackers Brace for End of the U.S. Shale Boom

**WSJ**

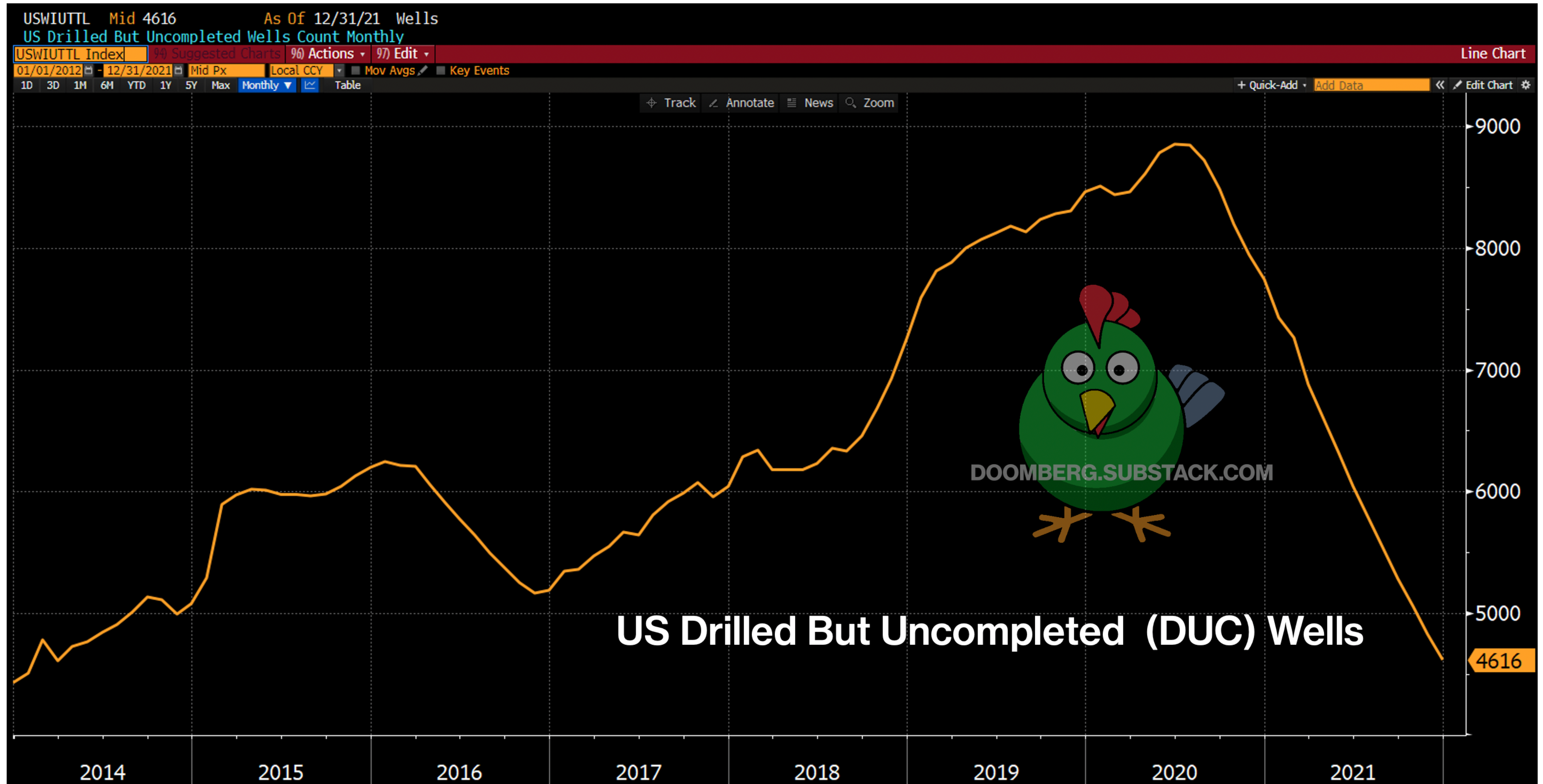
**Feb 3, 2020**

“despite the highest oil prices in years”

“pressured companies to slow production growth and return cash to shareholders rather than pump it back into drilling”

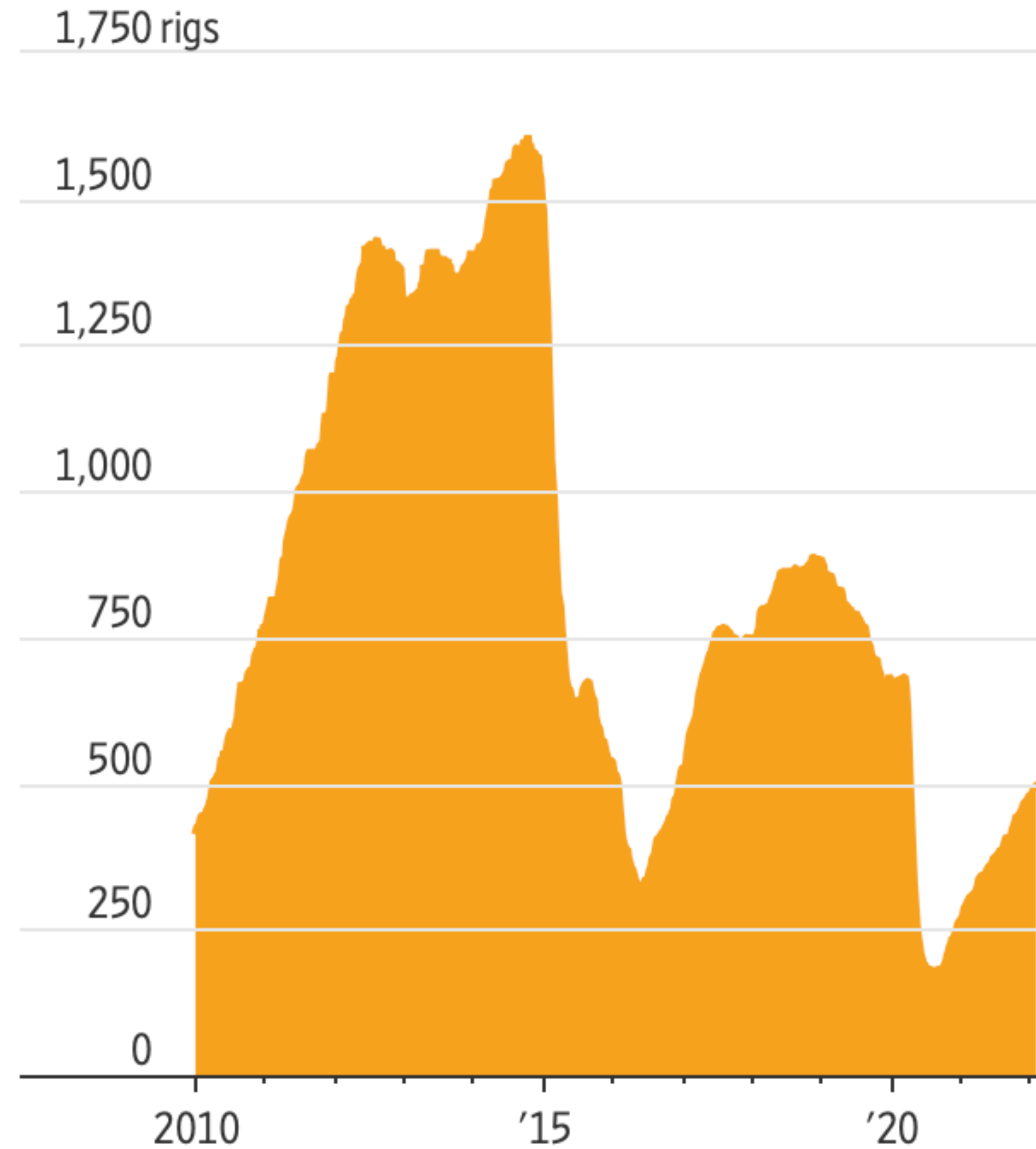


# US drilled but uncompleted oil wells

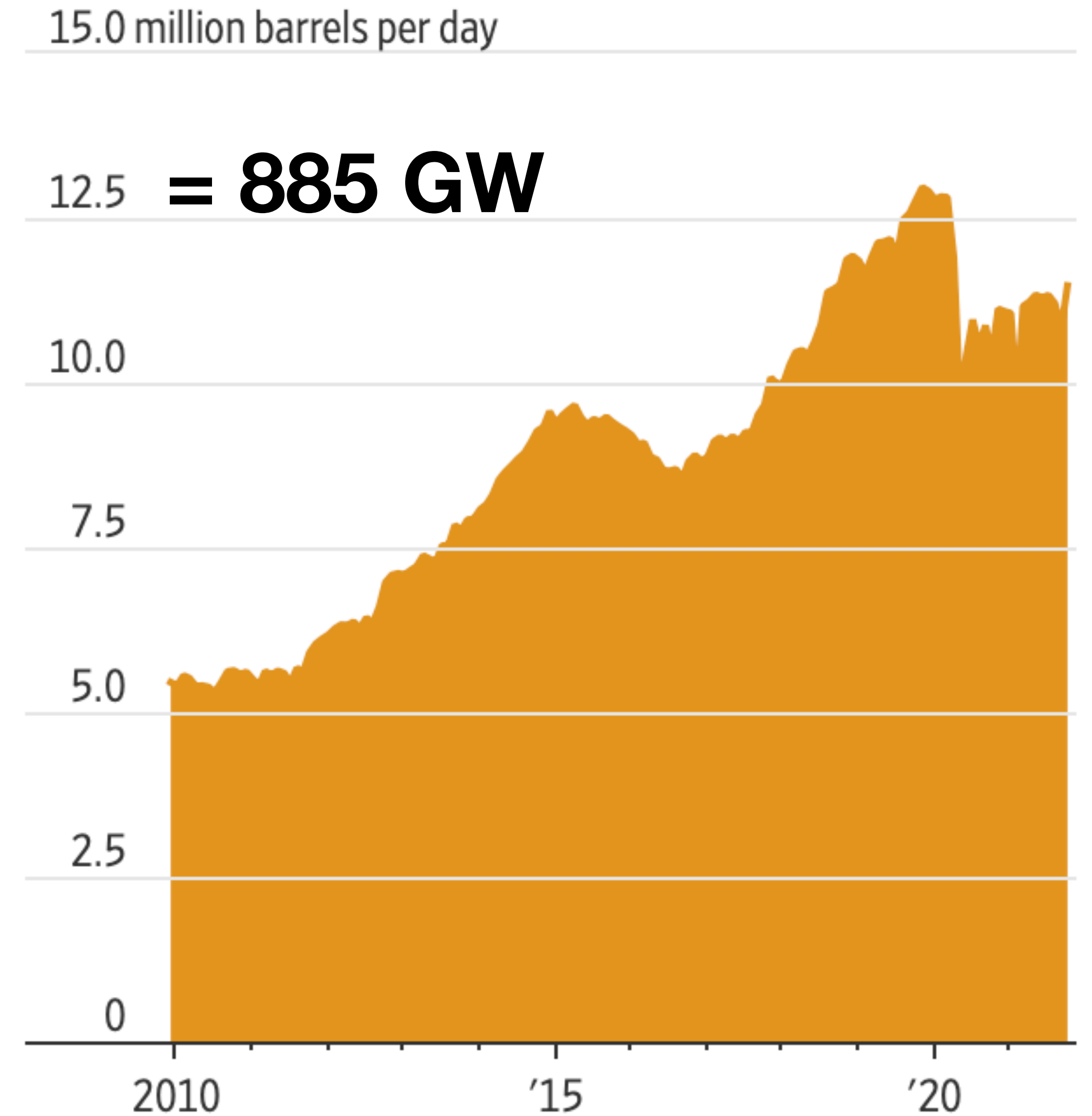


# Pump, baby, pump.

## Active U.S. oil-drilling rigs

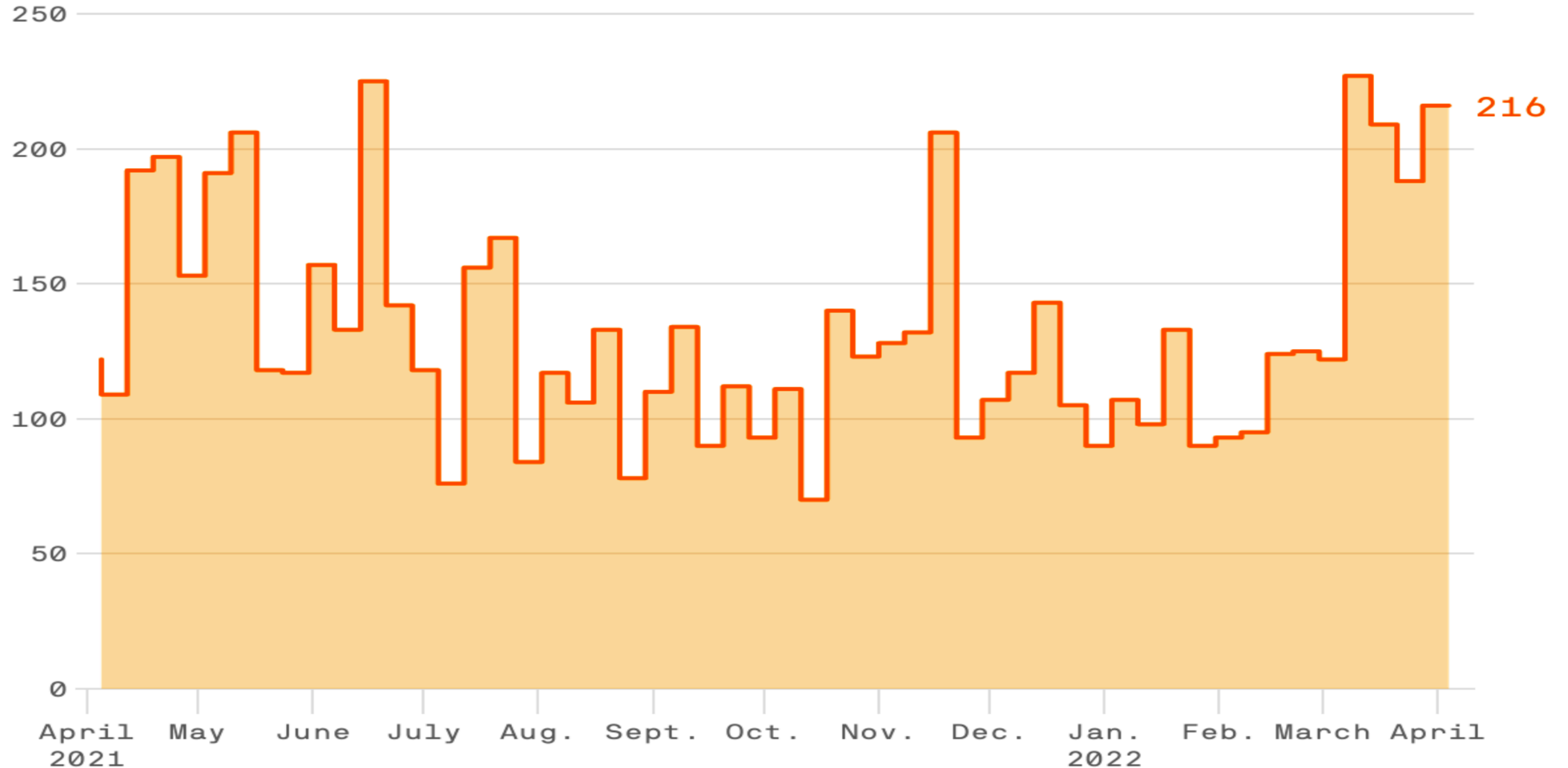


## U.S. oil production



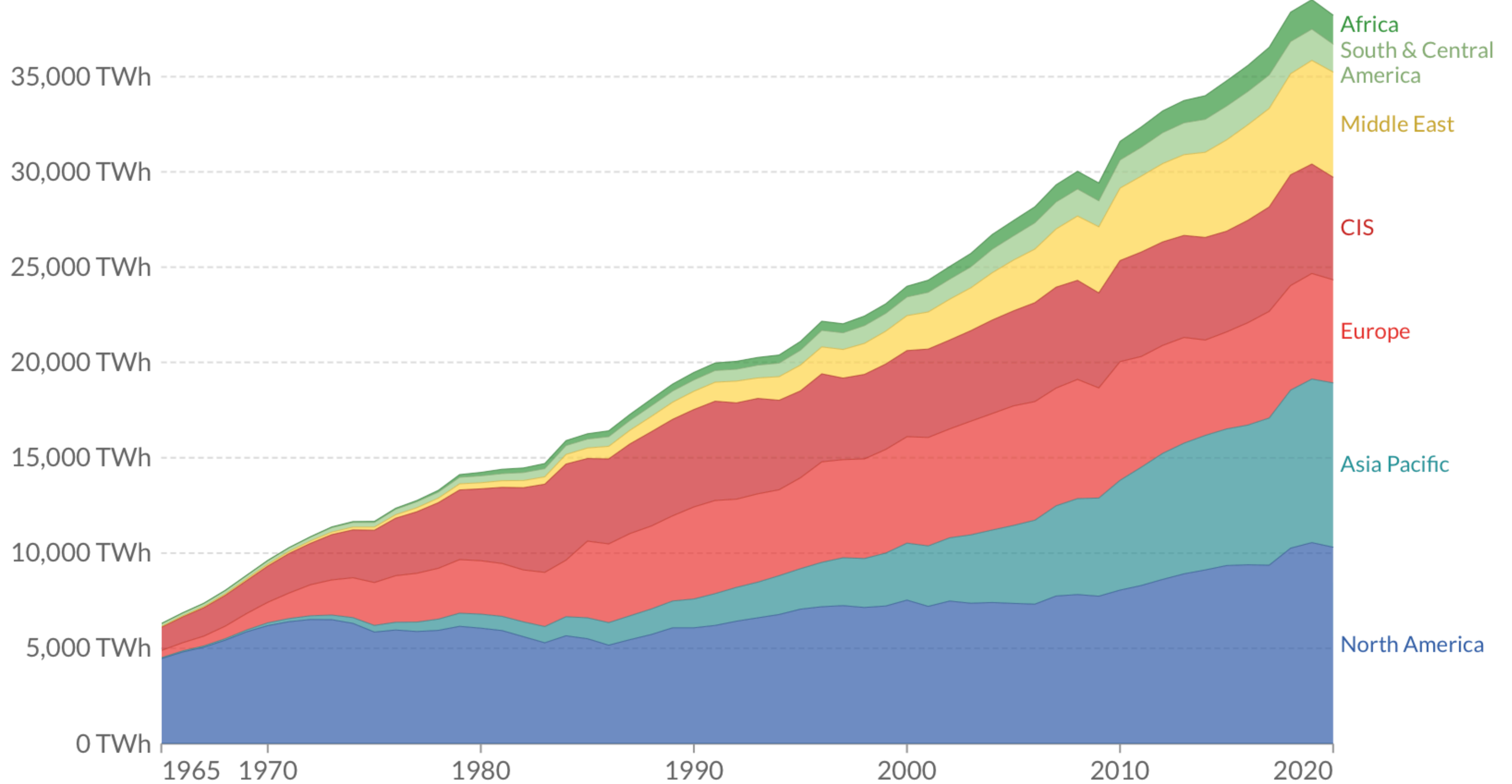
# April 2022 ! Permian Basin permits approved, by week

Horizontal permits; April 4, 2021, to April 4, 2022



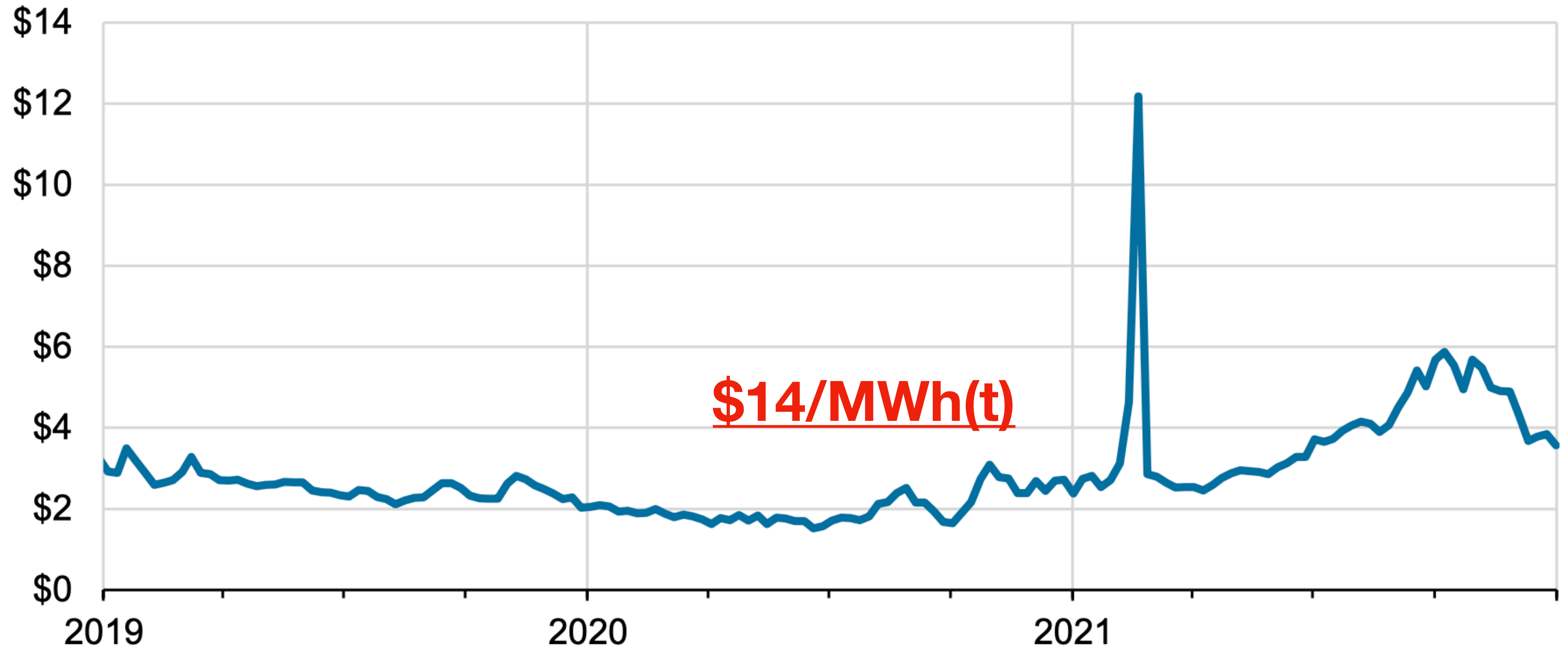
# Gas consumption by region (2020)

**4,400 GW total**



# US natural gas prices doubled to \$4/MMBTU at end 2021.

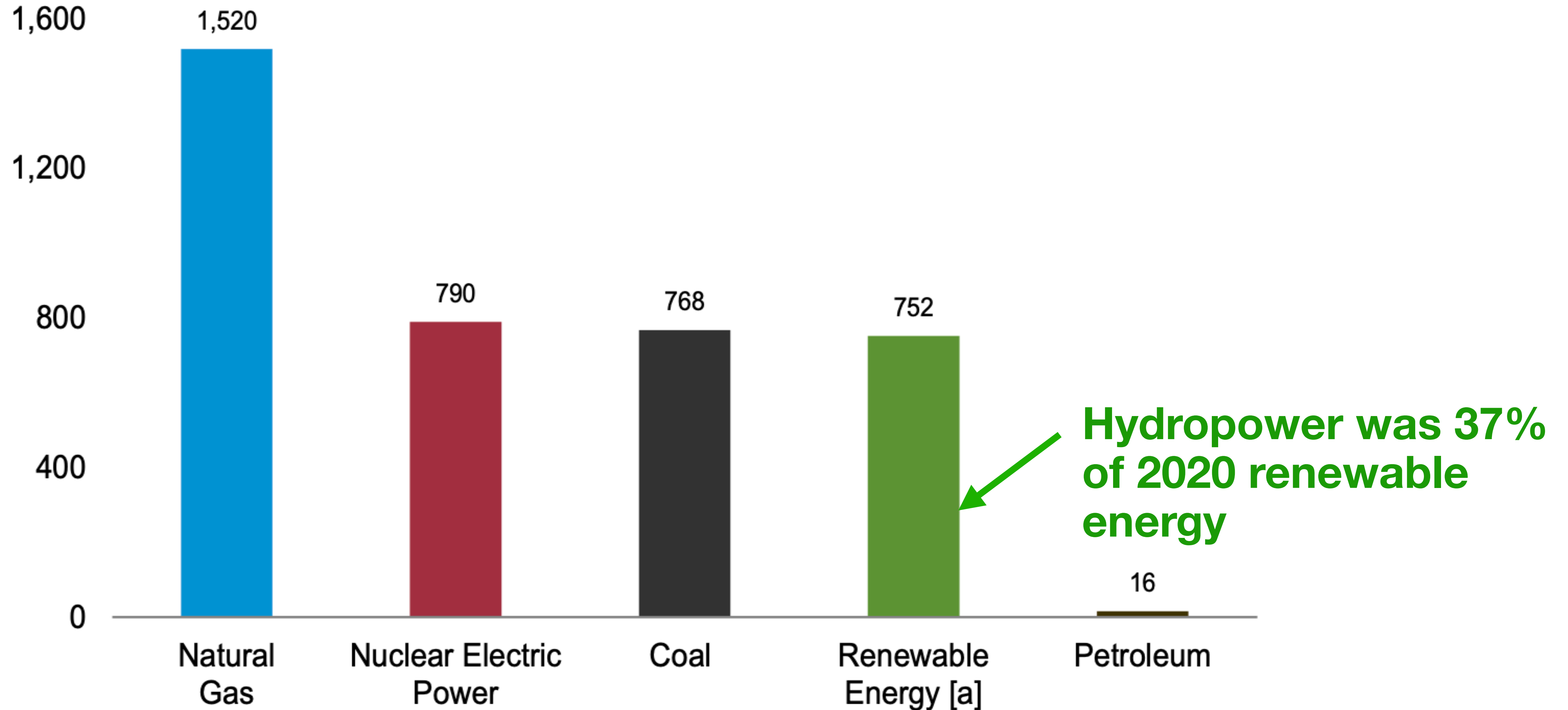
Weekly average Henry Hub natural gas spot price (Jan 2019–Dec 2021)  
dollars per million British thermal units (\$/MMBtu)



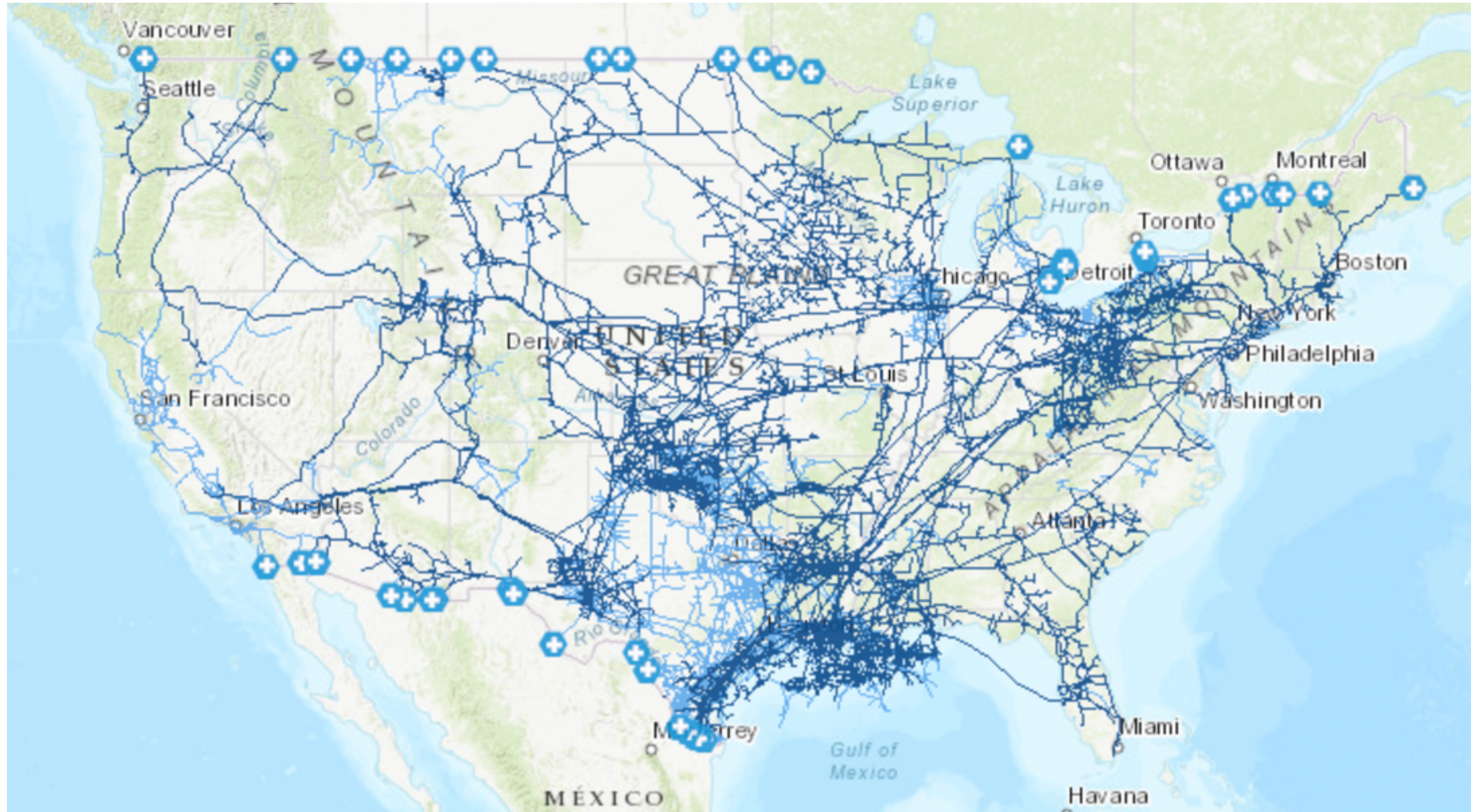


# Natural gas is the largest source of energy for US electricity.

Electric Power Sector, Major Sources, 2020



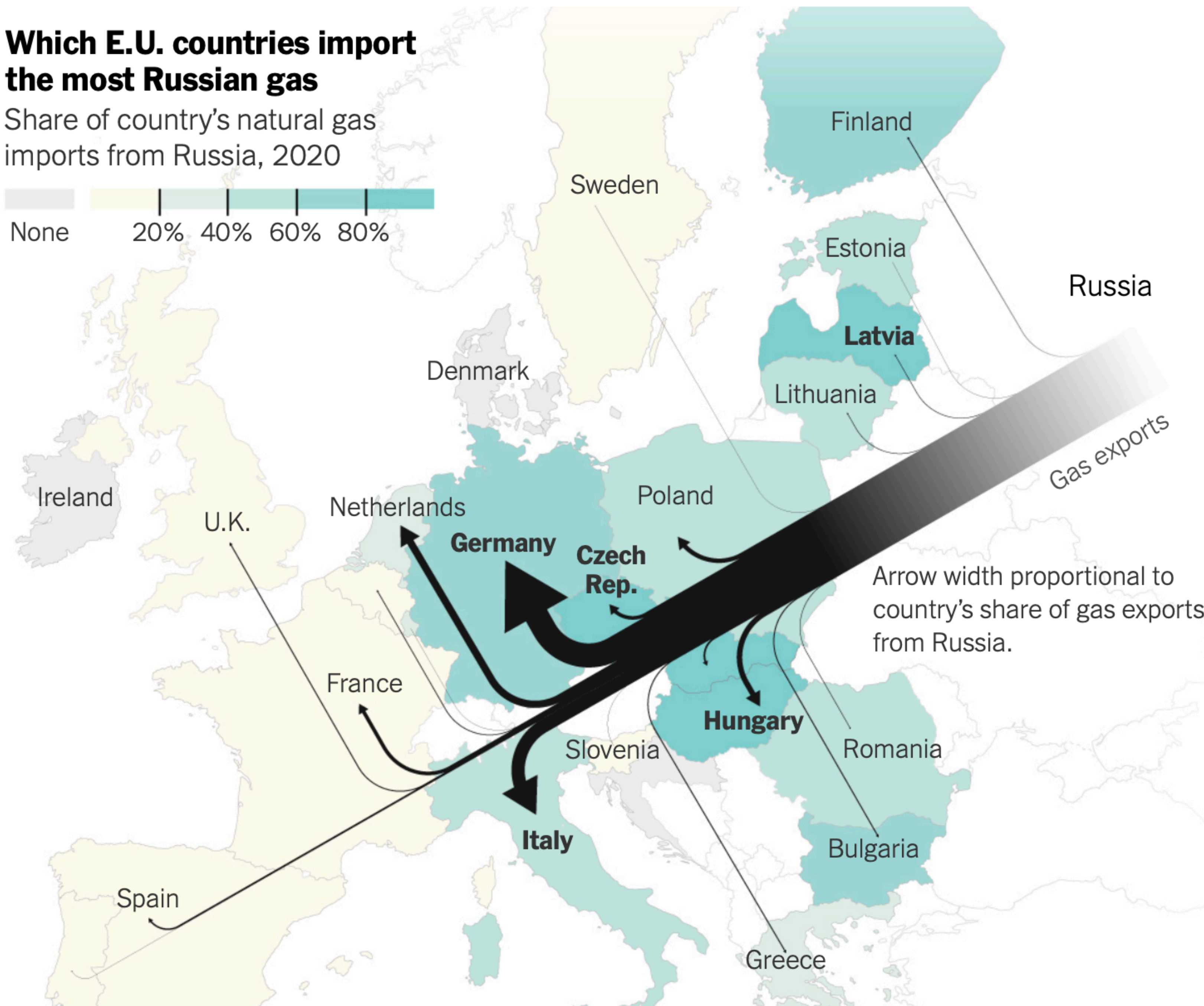
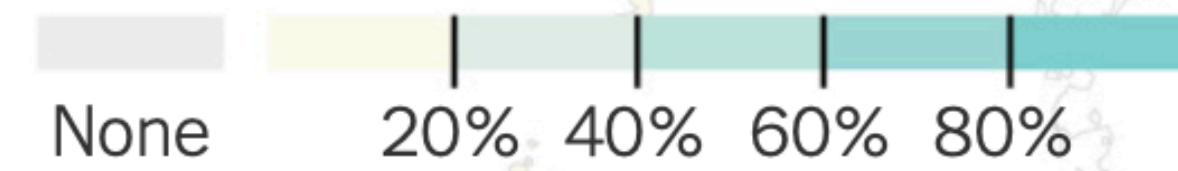
# US pipelines supply natural gas for electricity and heating.



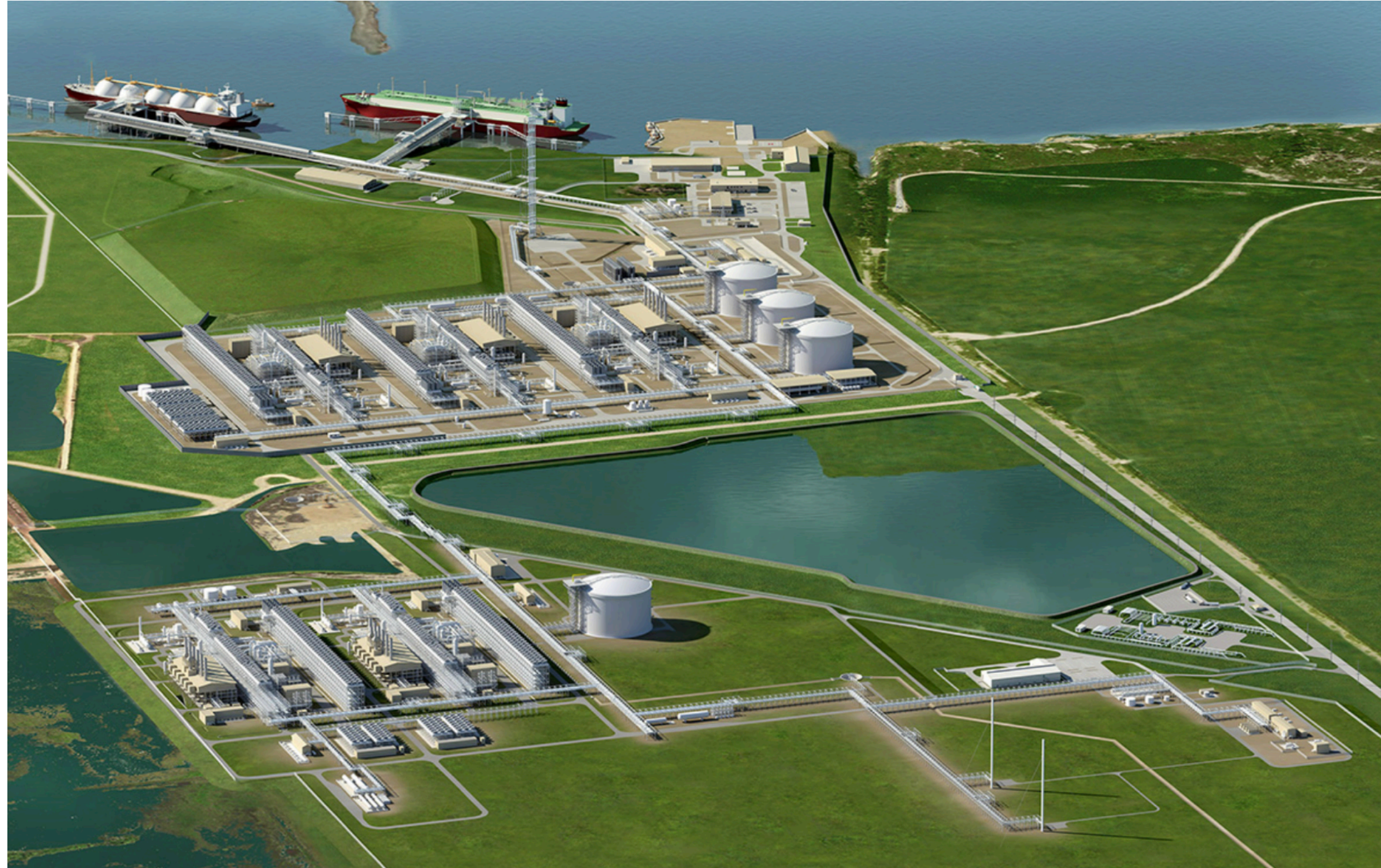
# Russia dominates natural gas supplies to Europe.

## Which E.U. countries import the most Russian gas

Share of country's natural gas imports from Russia, 2020



# Liquefied Natural Gas liquefaction and transport



Sabine Pass, liquefaction train #4  
\$2 to 4 billion each



Typical \$200 million LNG tankship  
LNG liquid at  $-160^{\circ}\text{C}$

LNG from tankship may be stored, regassified, transferred to pipelines by \$500 million floating storage and regasification unit (FSRU).



# World LNG energy: 366 Mt/year, 486 GW, 11% total gas

## LNG Flows in December 2021

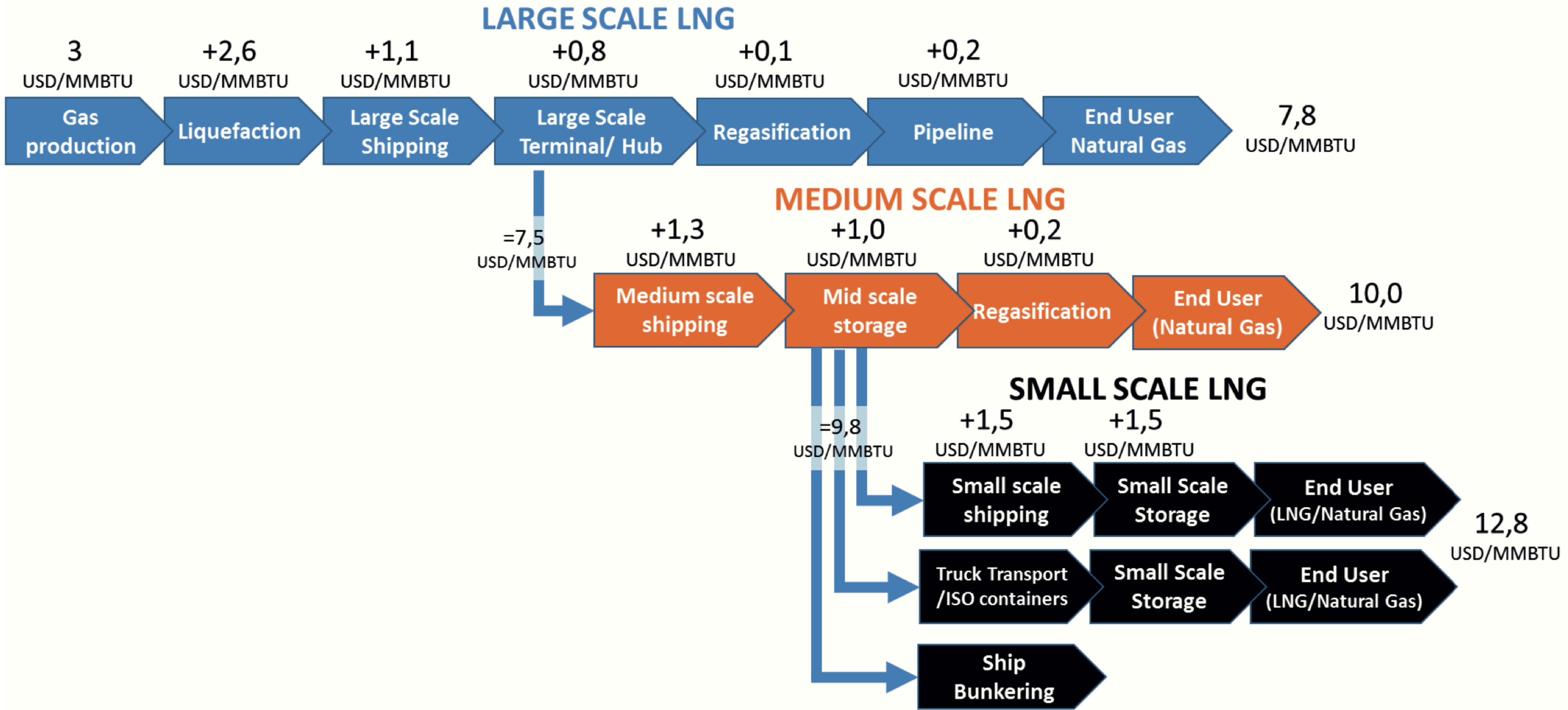
*in million tons of LNG*

From / To	Asia	Europe	Americas	Total
Qatar	5.67	1.05	0.09	<b>6.80</b>
United States	1.91	4.17	0.73	<b>6.80</b>
Africa	1.14	2.73	0.14	<b>4.01</b>
Russia (West)	0.37	1.44	0.00	<b>1.81</b>
Australia	7.14	0.00	0.00	<b>7.14</b>
Rest of Asia	5.90	0.03	0.07	<b>5.97</b>
Russia (East)	1.03	0.00	0.00	<b>1.03</b>
Rest of World	1.14	0.46	0.49	<b>2.14</b>
<b>World</b>	<b>24.30</b>	<b>9.88</b>	<b>1.52</b>	<b>35.70</b>

Source: Kpler LNG Service (data accessed January 23, 2021). The numbers refer to exported

**Europe total natural gas 488 GW; 135 GW from LNG**

# LNG liquefaction, transport, regasification adds 5 cents/kWh(e)



# Gas turbine, 34% work/heat efficiency: \$700/kW capital cost

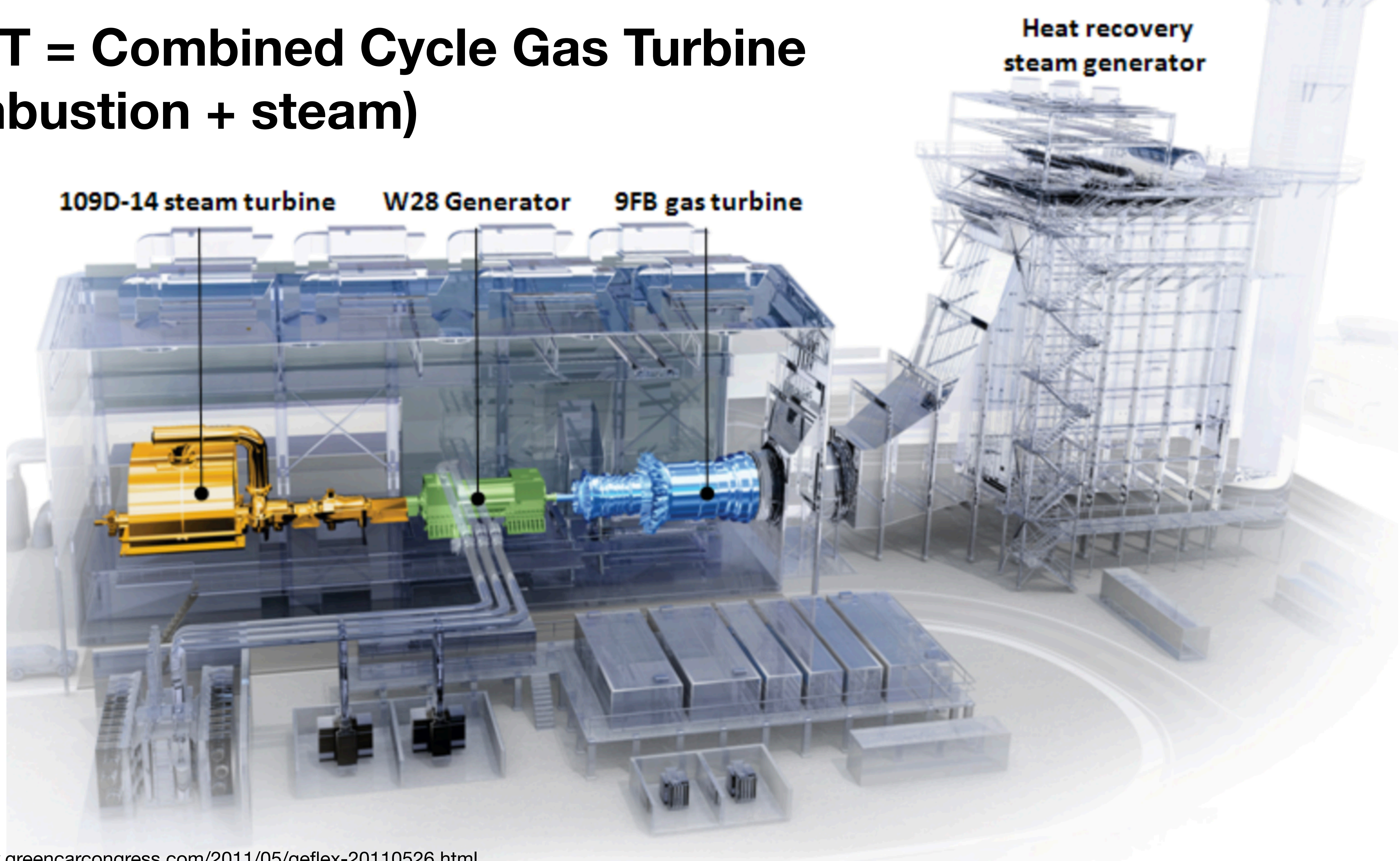




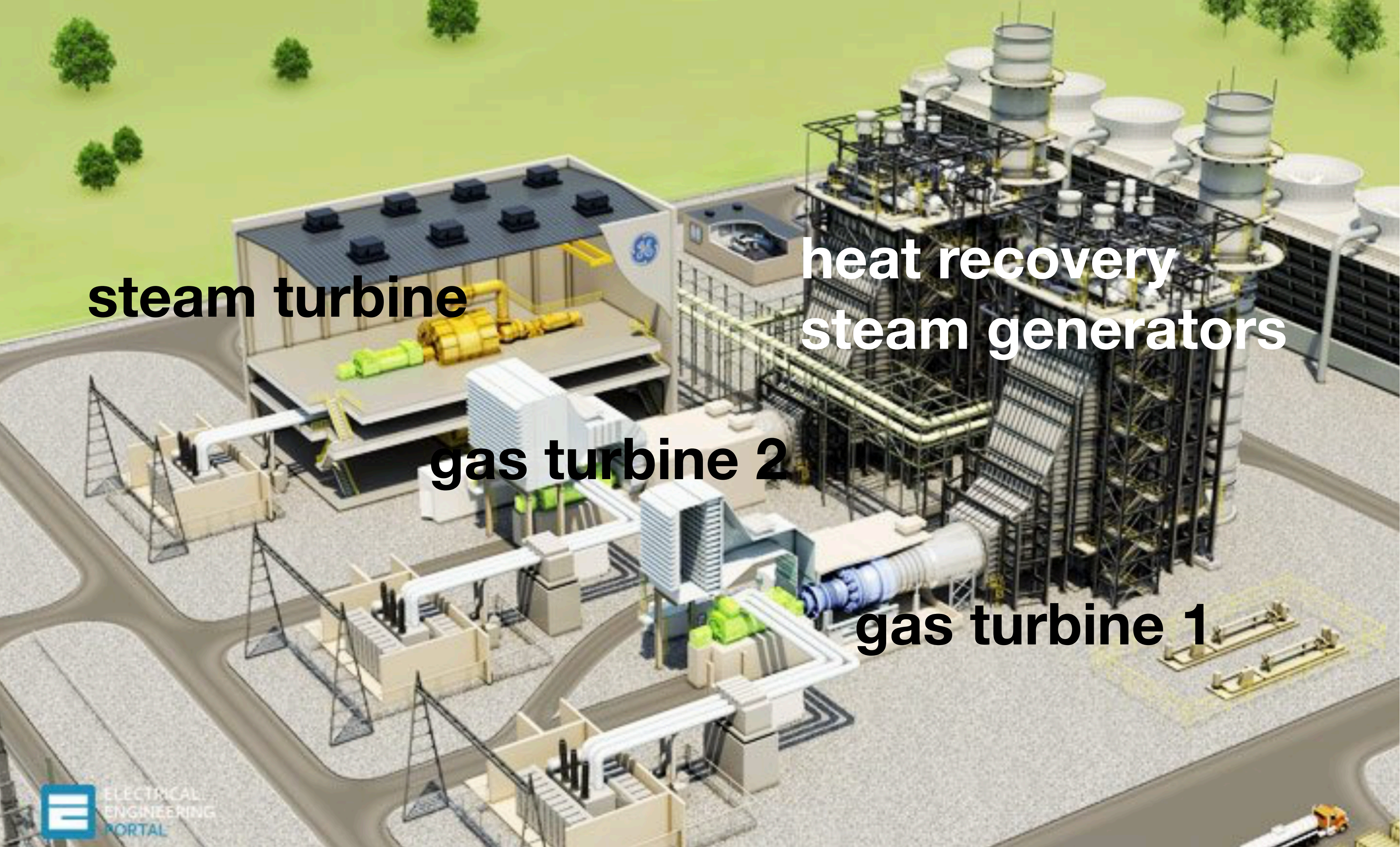
# CCGT = Combined Cycle Gas Turbine (combustion + steam) CCGT gas + steam turbines, 53% efficiency: \$1100/kW



# CCGT = Combined Cycle Gas Turbine (combustion + steam)



# CCGT plant, 53% efficiency: \$1100/kW

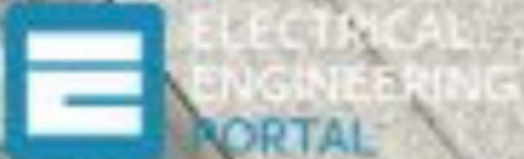


**steam turbine**

**heat recovery  
steam generators**

**gas turbine 2**

**gas turbine 1**



# Latest GE 9HA gas turbine

GE's 9HA high efficiency, air-cooled gas turbine is one of the industry leaders among H-class offerings, and now the 9HA gas turbine is at the heart of the world's most efficient combined-cycle power plant.

**448-571 MW**

simple-cycle output

**>64%**

combined-cycle  
efficiency

**28 years**

of H-class experience

**50%**

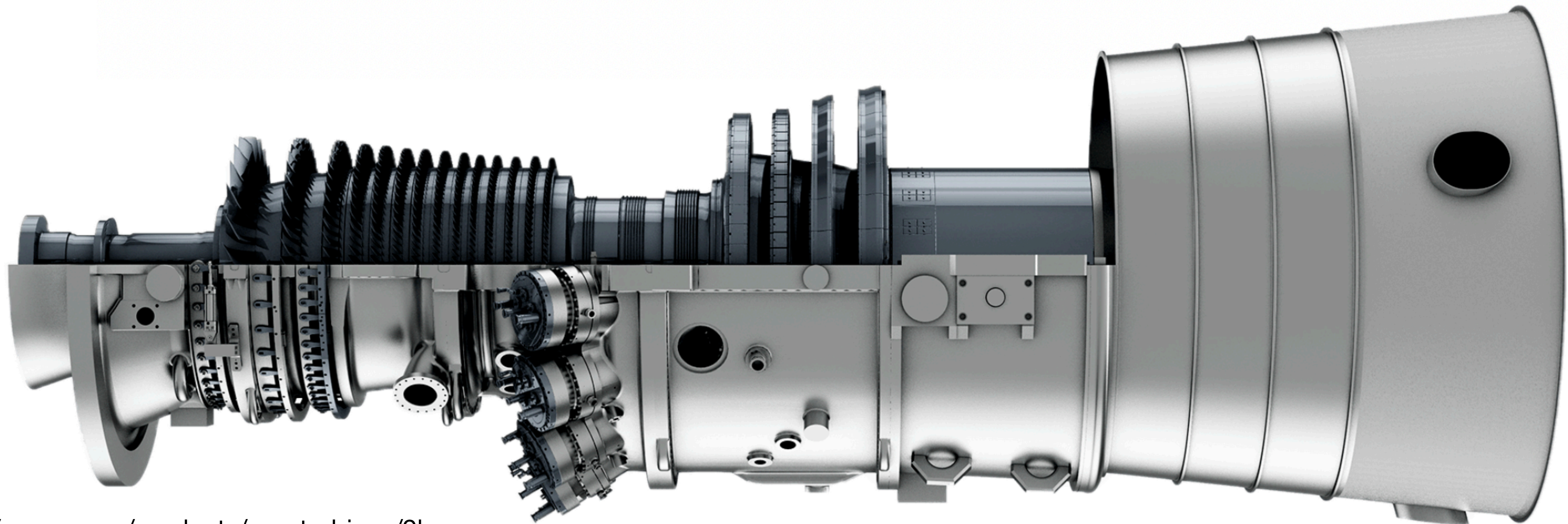
hydrogen (H<sub>2</sub>) capable

**<30 min.**

full combined-cycle  
plant load

[View specifications >](#)

[Watch video ▶](#)



# GE video ad shows 125 years of gas turbine engineering.

Enhanced 4-stage

air-cooled hot gas path

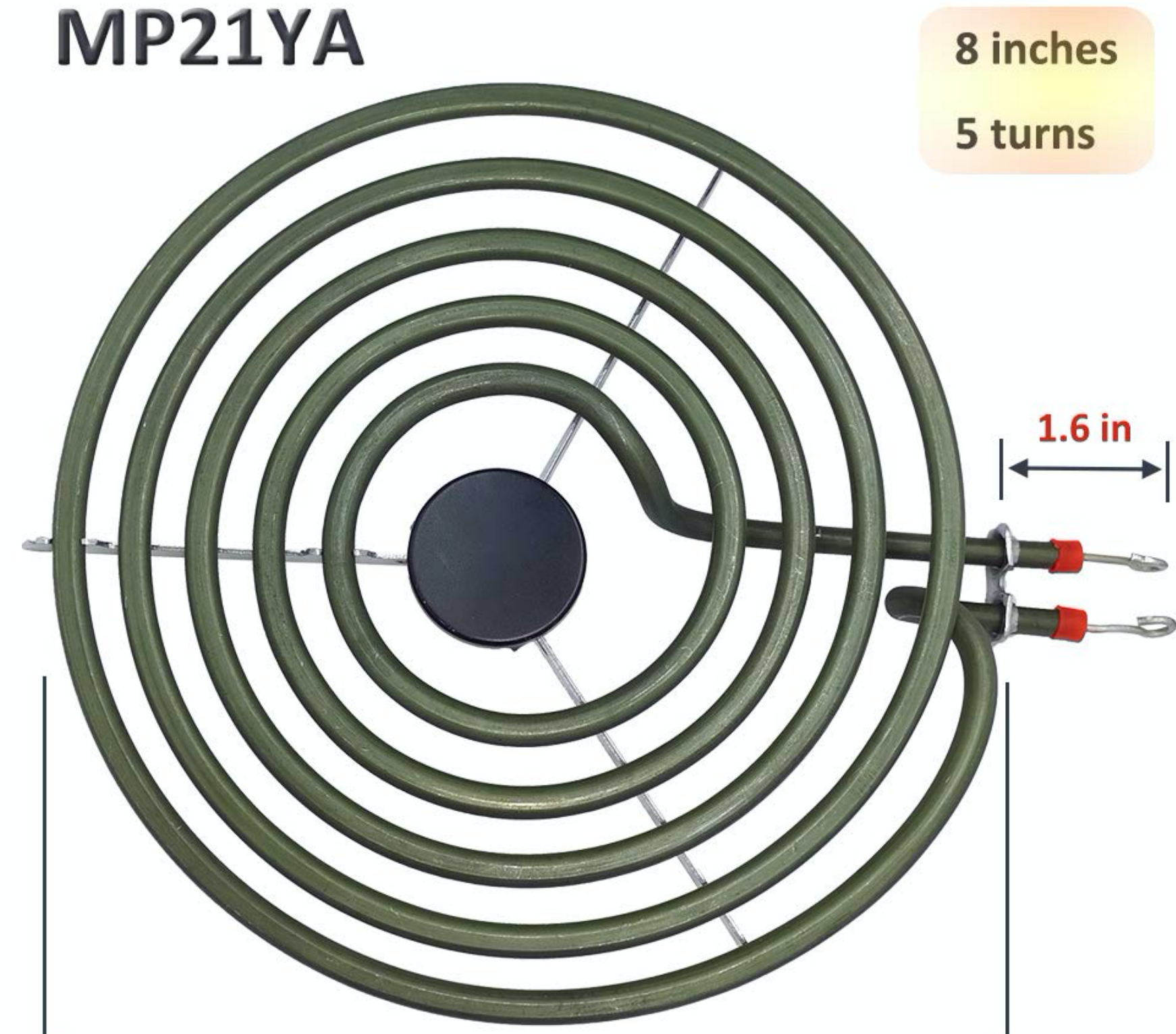


# Banning home gas stoves burns more gas.



Power company distributes  
**2 kW(t) natural gas**  
to make 2 kW(t) of heat

MP21YA



Power company burns  
**~ 4.5 kW(t) natural gas**  
to generate 2 kW(e) of electricity  
to make 2 kW(t) of heat

# Banning home gas stoves burns more gas.

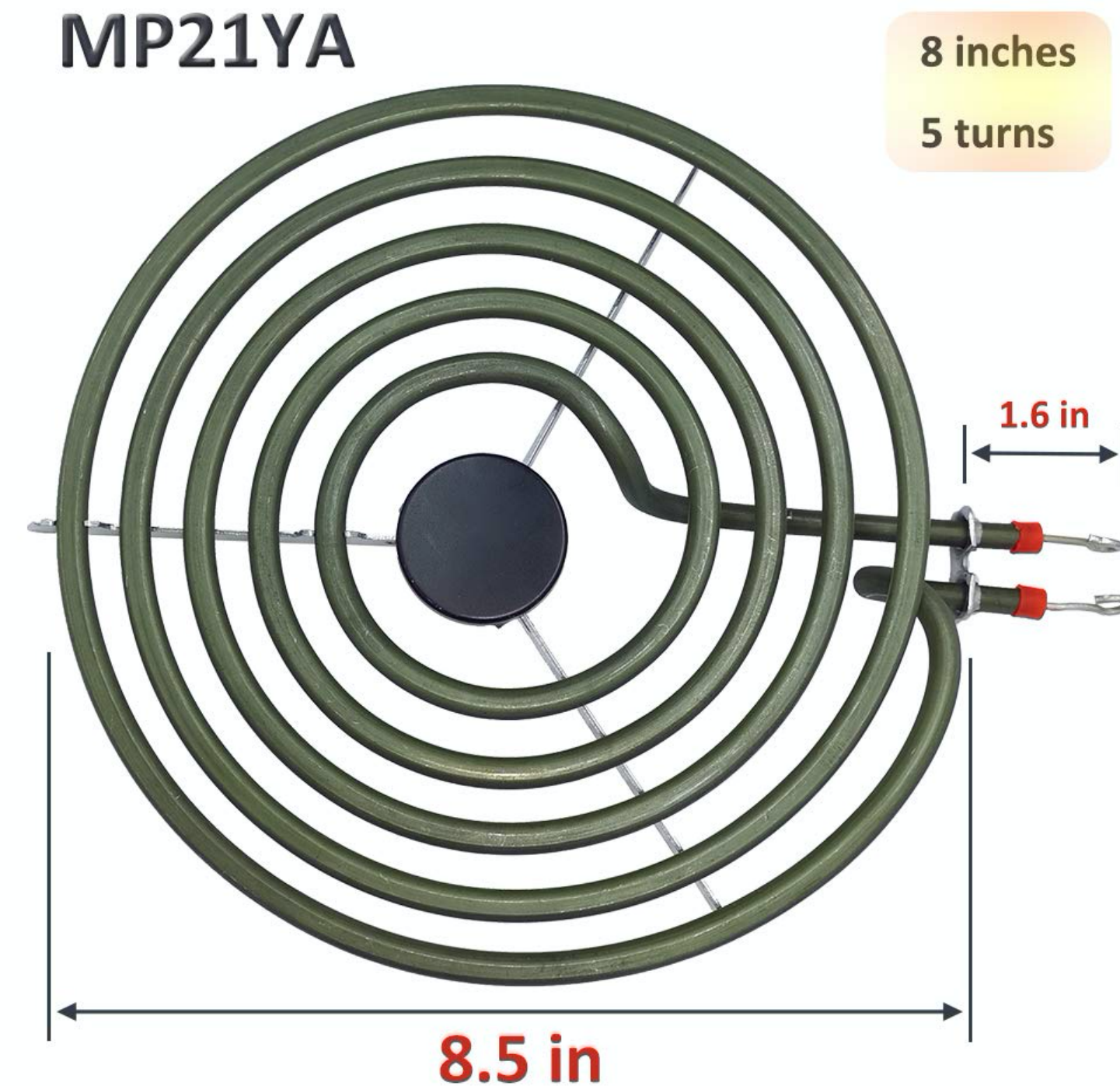
BUT, fission, wind, or solar power would cause no CO2 emissions.

STILL, natural gas is the largest, *increasing* energy source for the US grid.

Solar power not available for evening meal cooking.

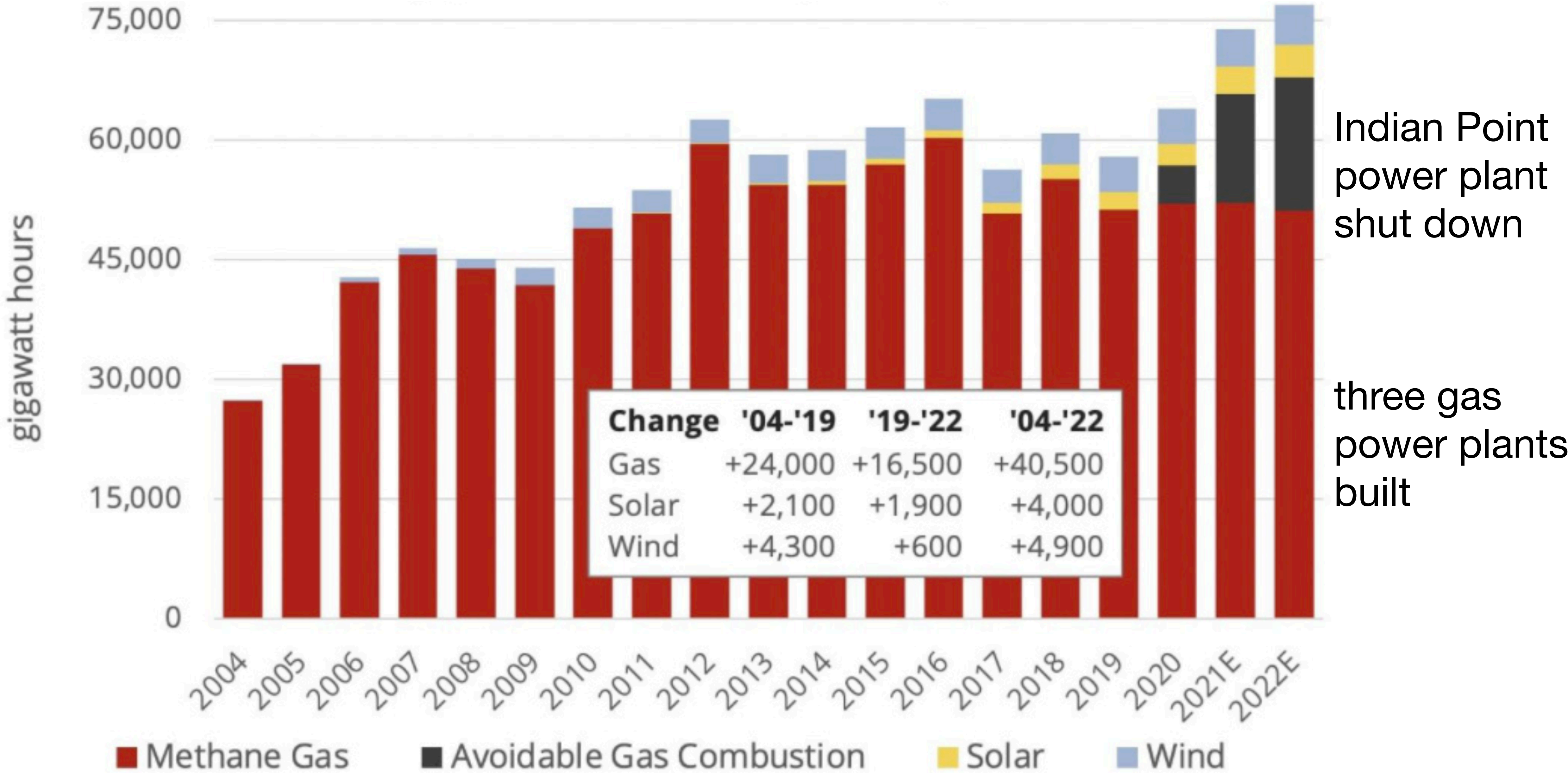
Wind does not speed up when you turn the stove on.

Dipatchable power on demand is needed.



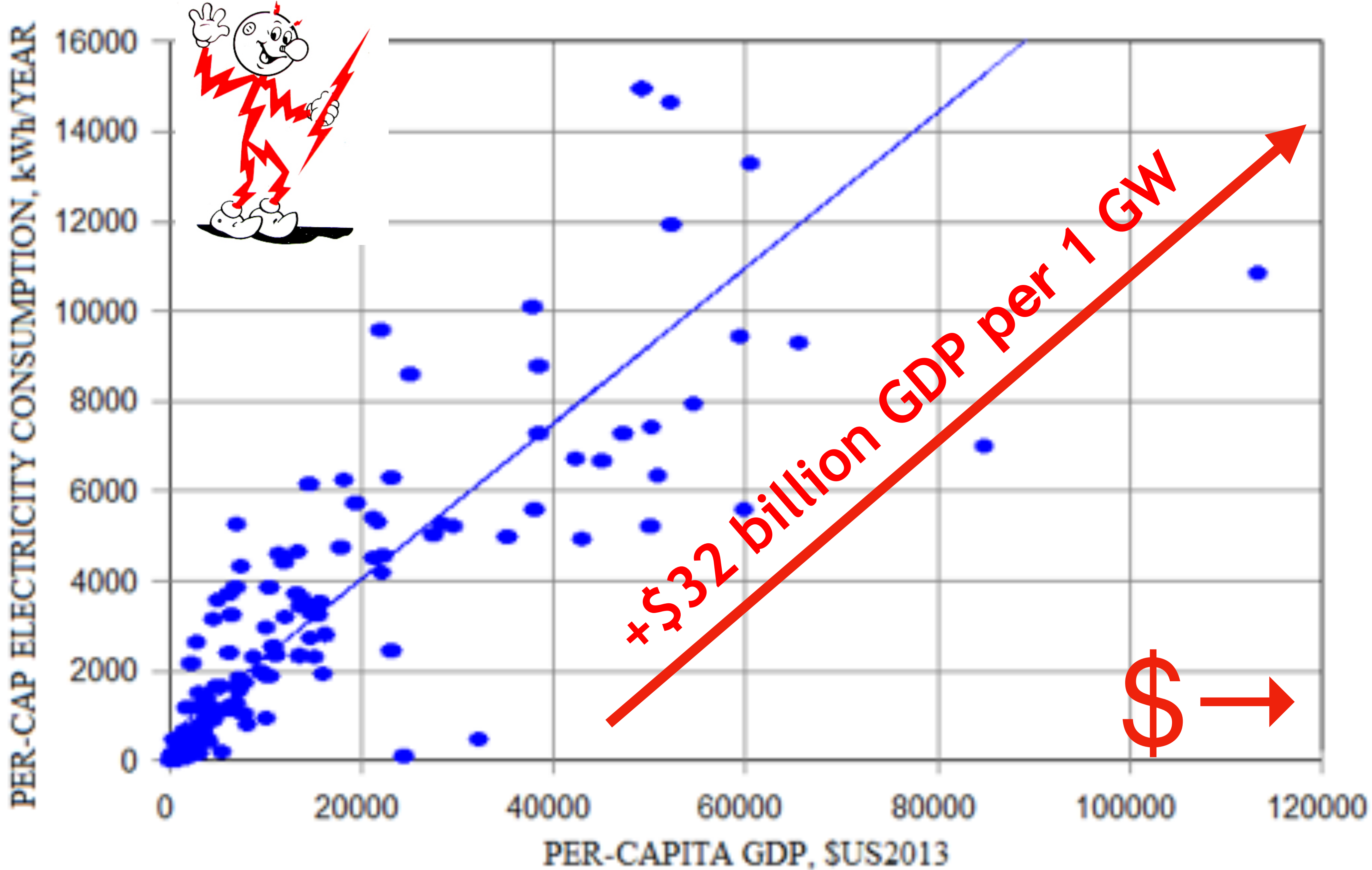
Power company burns  
~ **4.5 kW(t) natural gas**  
to generate 2 kW(e) of electricity  
to make 2 kW(t) of heat

# New York electricity generation: more gas, less uranium



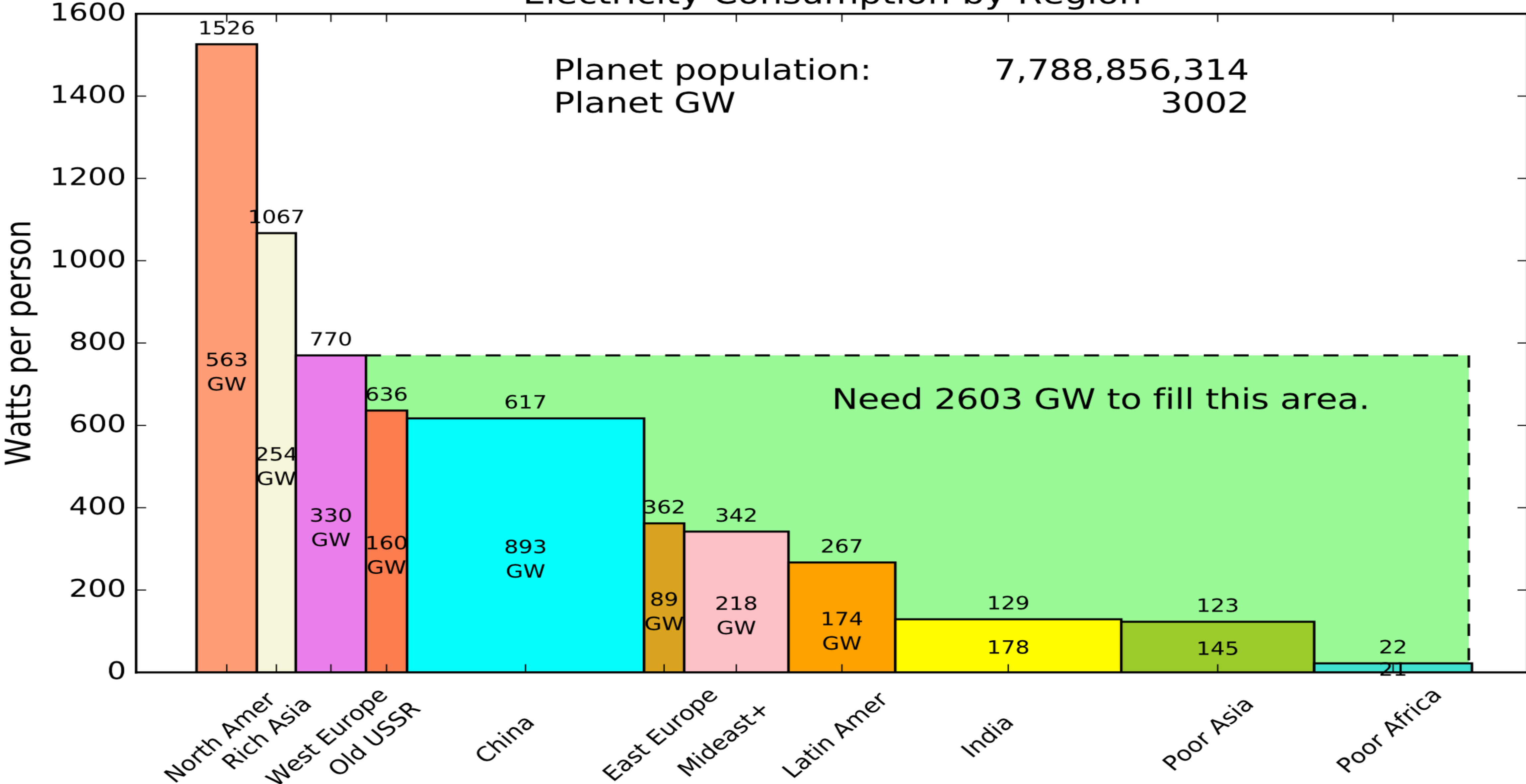


# Nations' GDPs are propotionate to electric power.



# 3,000 GW global electricity use may grow by 2,600 GW.

Electricity Consumption by Region





**Developing nations now build coal-fired power plants.**

**Reliable, 24x7, affordable**

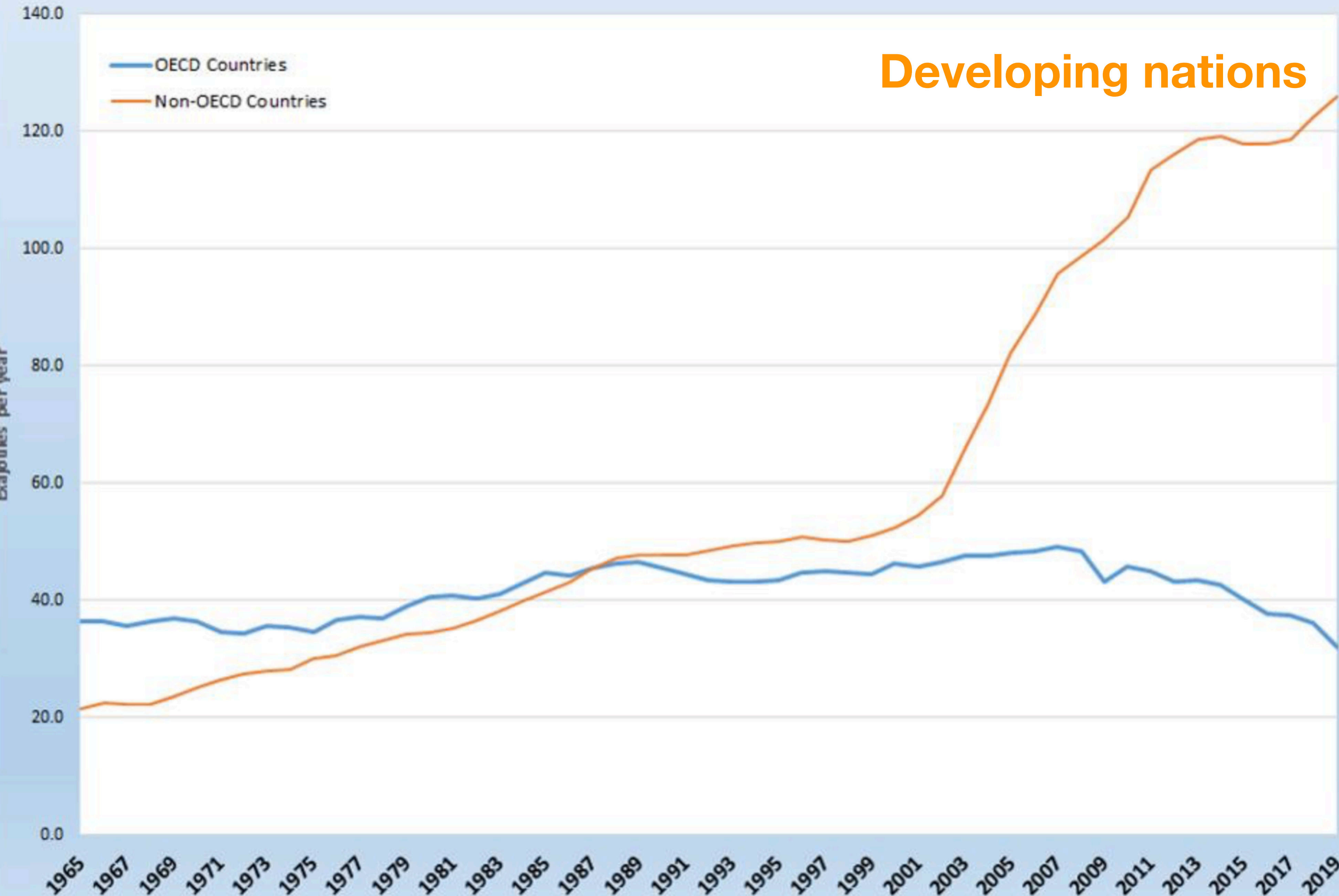
# 574 GW of new power plants will be coal fired, the economic choice of developing nations.

Coal power capacity in development and operating by country (megawatts).

Country	Pre-construction	Construction	All Active Development	Shelved	Operating
China	69,950	128,650	198,600	278,125	973,609
India	57,800	36,158	93,958	87,716	220,670
Vietnam	32,610	9,705	42,315	5,200	17,387
Turkey	36,666	800	37,466	24,554	18,826
Indonesia	15,225	11,466	26,691	16,240	29,047
Bangladesh	18,724	2,640	21,364	10,150	525
Japan	6,584	8,724	15,308	2,000	45,568
South Africa	7,840	6,352	14,192	3,050	42,281
Egypt	13,240	0	13,240	2,000	0
Philippines	9,728	2,890	12,618	3,650	8,273
Pakistan	6,773	3,300	10,073	3,995	3,110
Qatar	0	0	0	0	0
Jordan	0	0	0	30	0
<b>Total</b>	<b>338,571</b>	<b>235,633</b>	<b>574,204</b>	<b>483,160</b>	<b>2,015,280</b>

----- <http://endcoal.org/wp-content/uploads/2017/03/BoomBust2017-English-Final.pdf> -----

# Coal Consumption 1965-2019



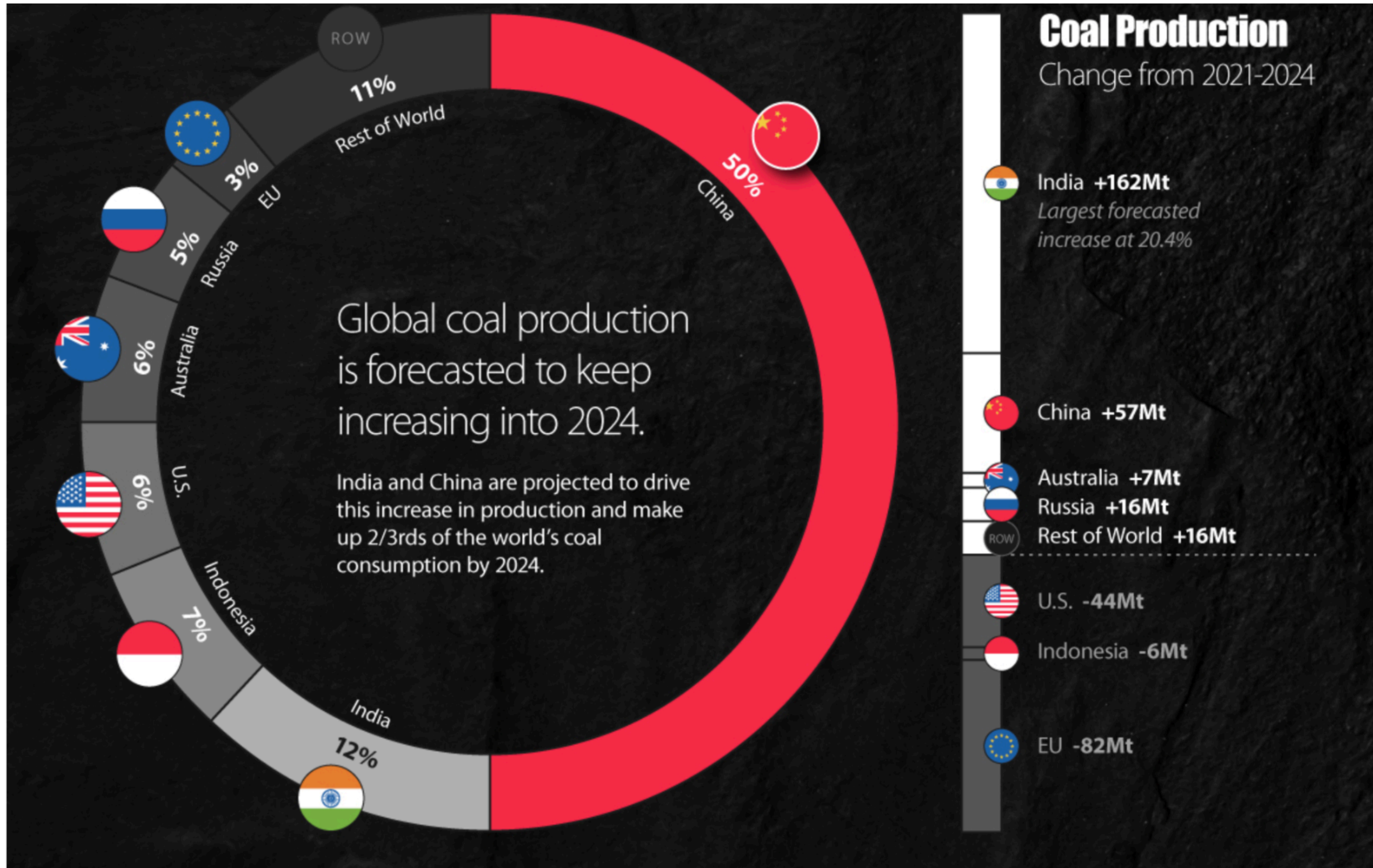
**Developing nations**

**building  
574 GW of new  
coal-fired  
power plants**

**will add**

**+4 Gt CO<sub>2</sub>/yr**

# The 2021-2024 future of global coal production: +114 Mt/yr



China  
U.S.  
India  
Russia  
Australia

did not join the COP26 pledge to reduce coal production.

**Why?**

# Today's carbon cycle

(Gt carbon units)

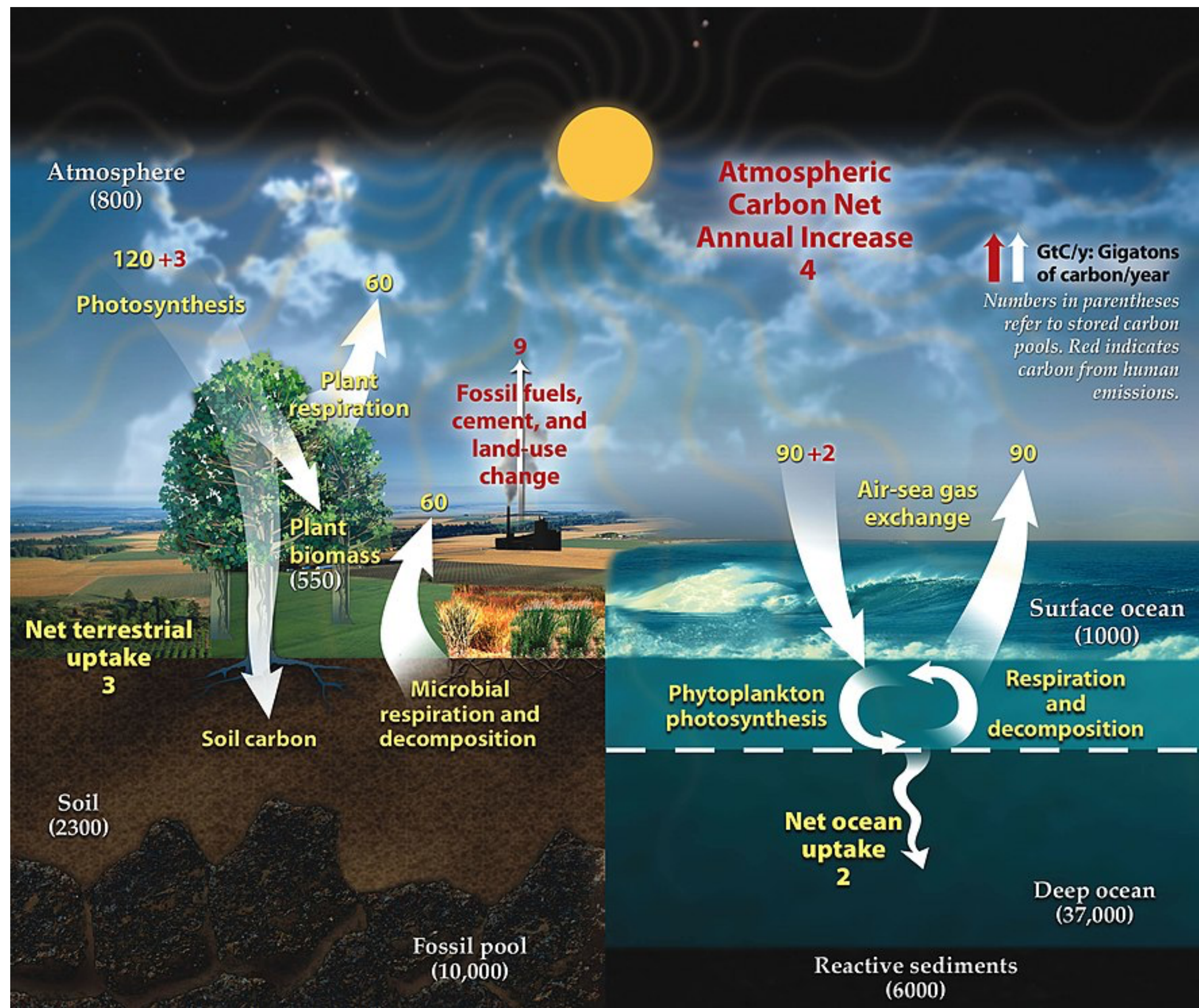
$$3+9+2 \text{ Gt-C} = 14 \text{ Gt-C}$$

$$= 51 \text{ Gt-CO}_2$$

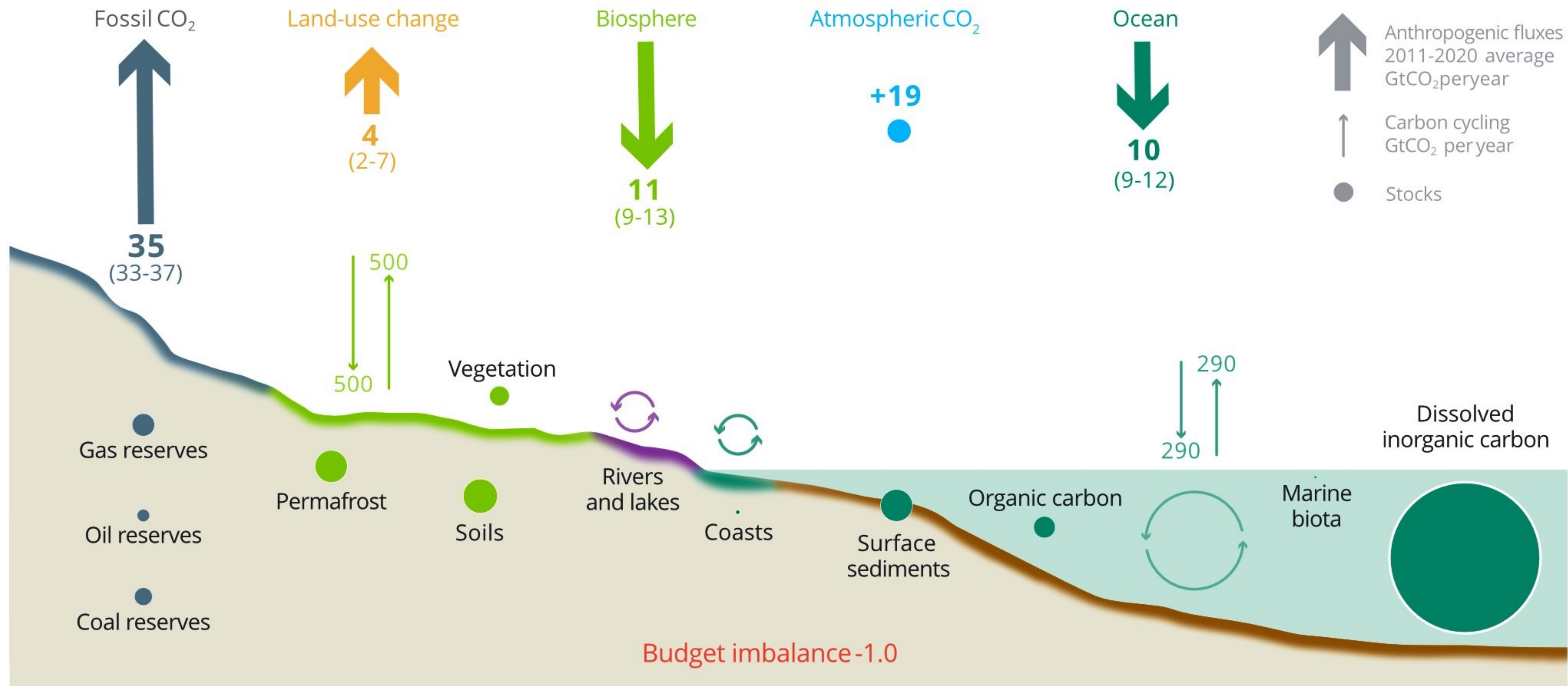
red = human effect

t = metric tonne =  
1000 kg = 1 Mg

(Mt ambiguous)

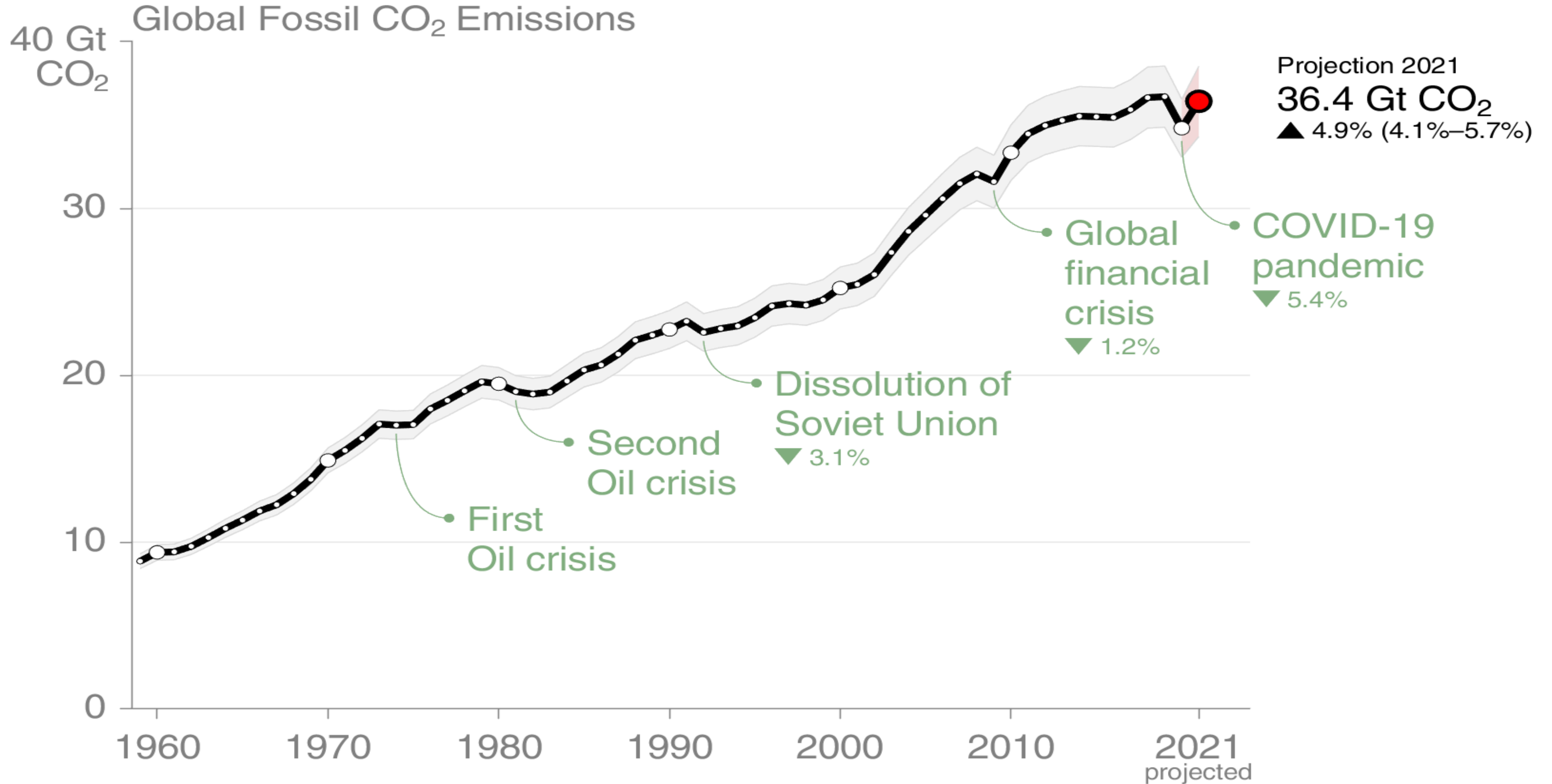


# Today's carbon cycle (Gt CO<sub>2</sub> units)

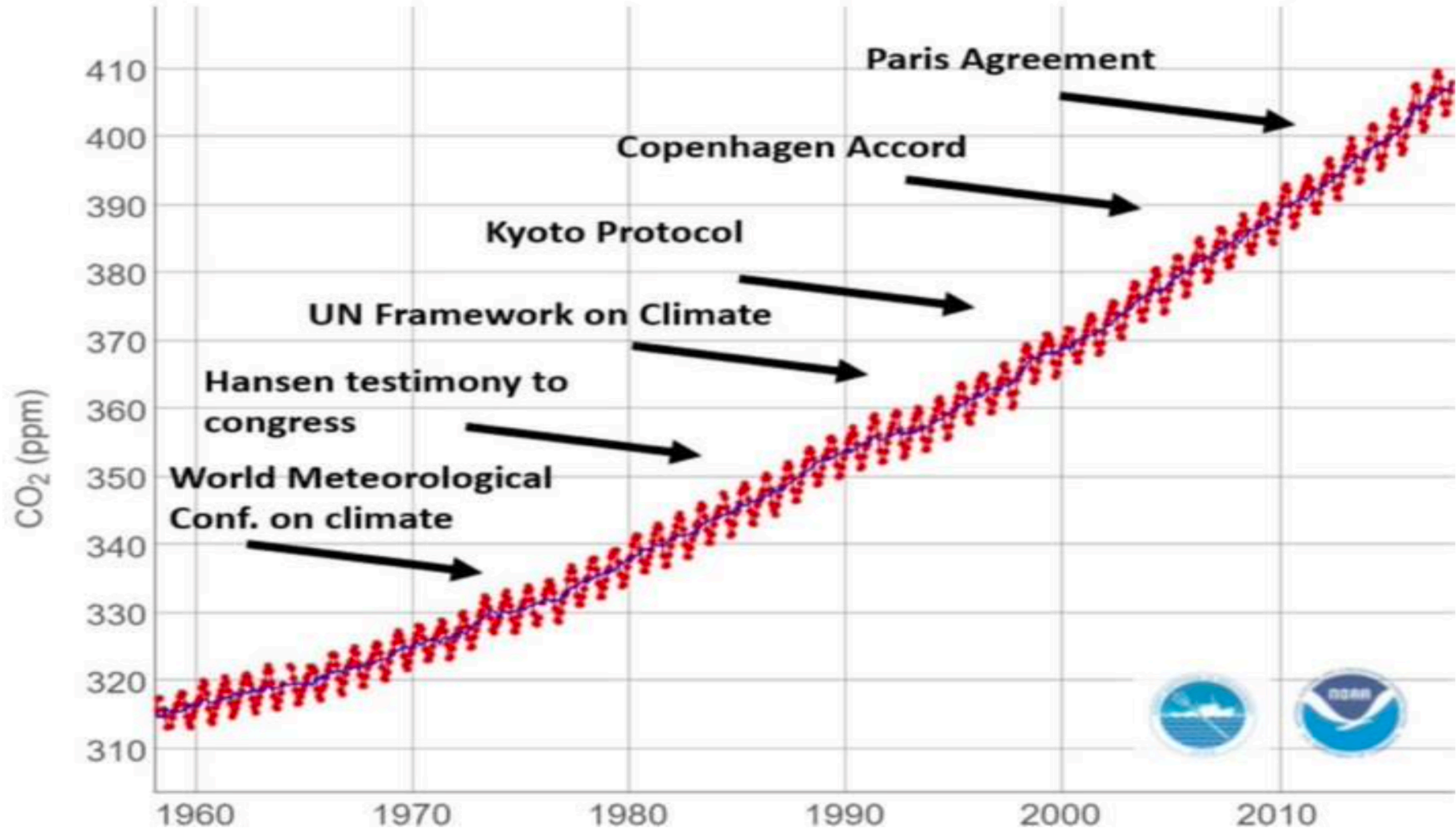




# Annual additions to atmospheric CO2 continue to increase.

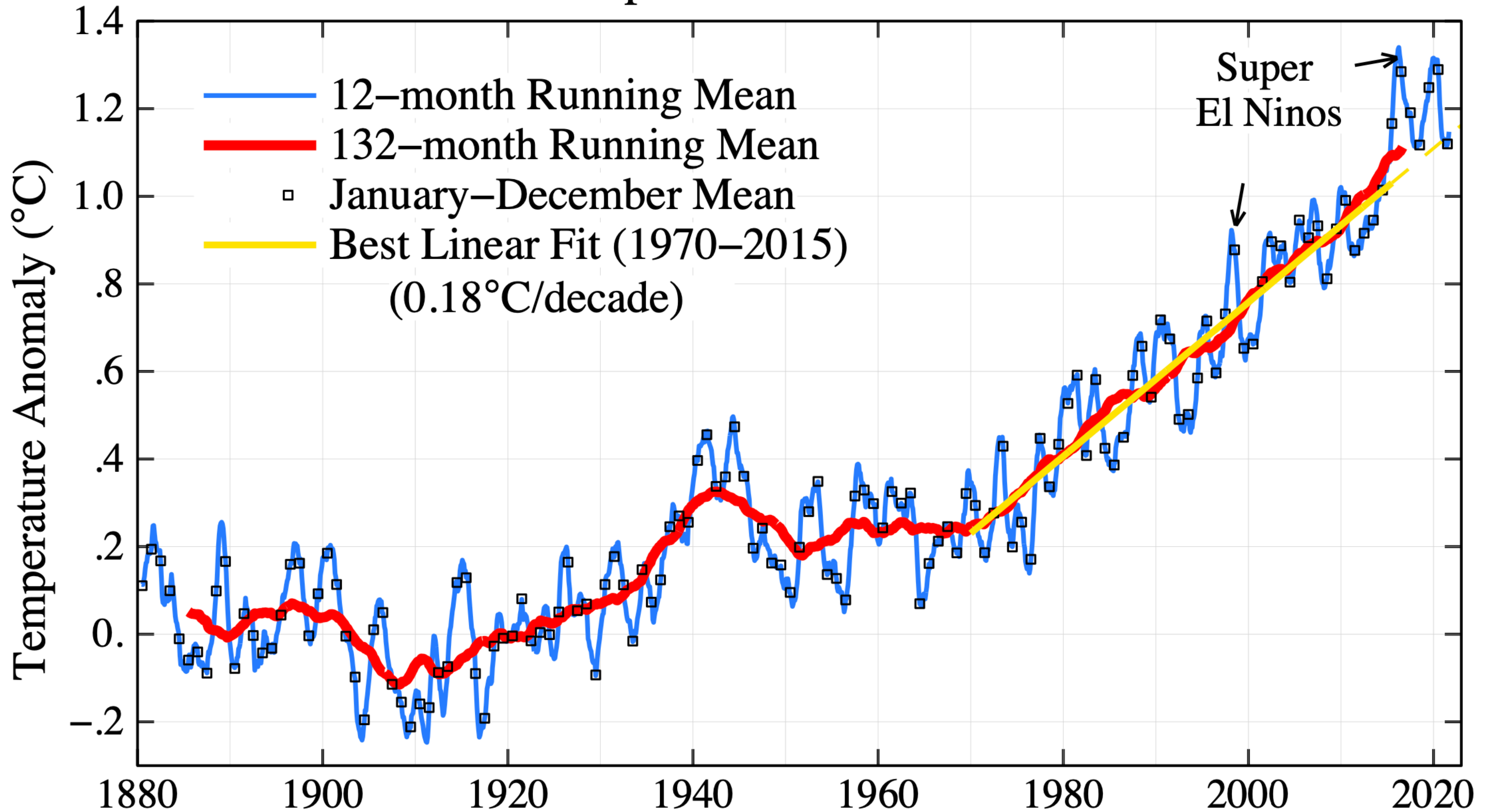


# Governments have no effect measured CO2 in the air.

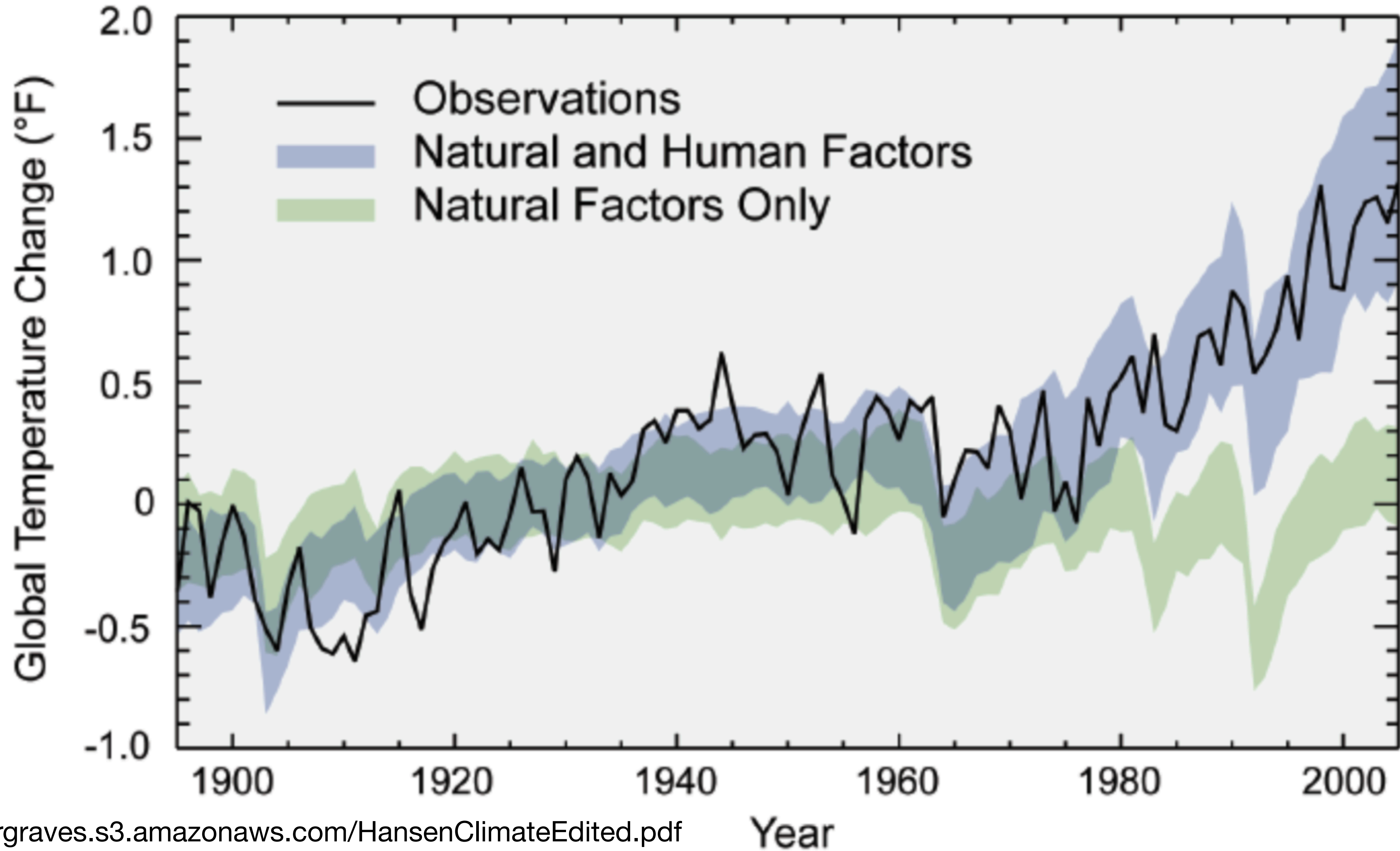


# Climate is changing, rapidly.

## Global Surface Temperature Relative to 1880–1920 Mean

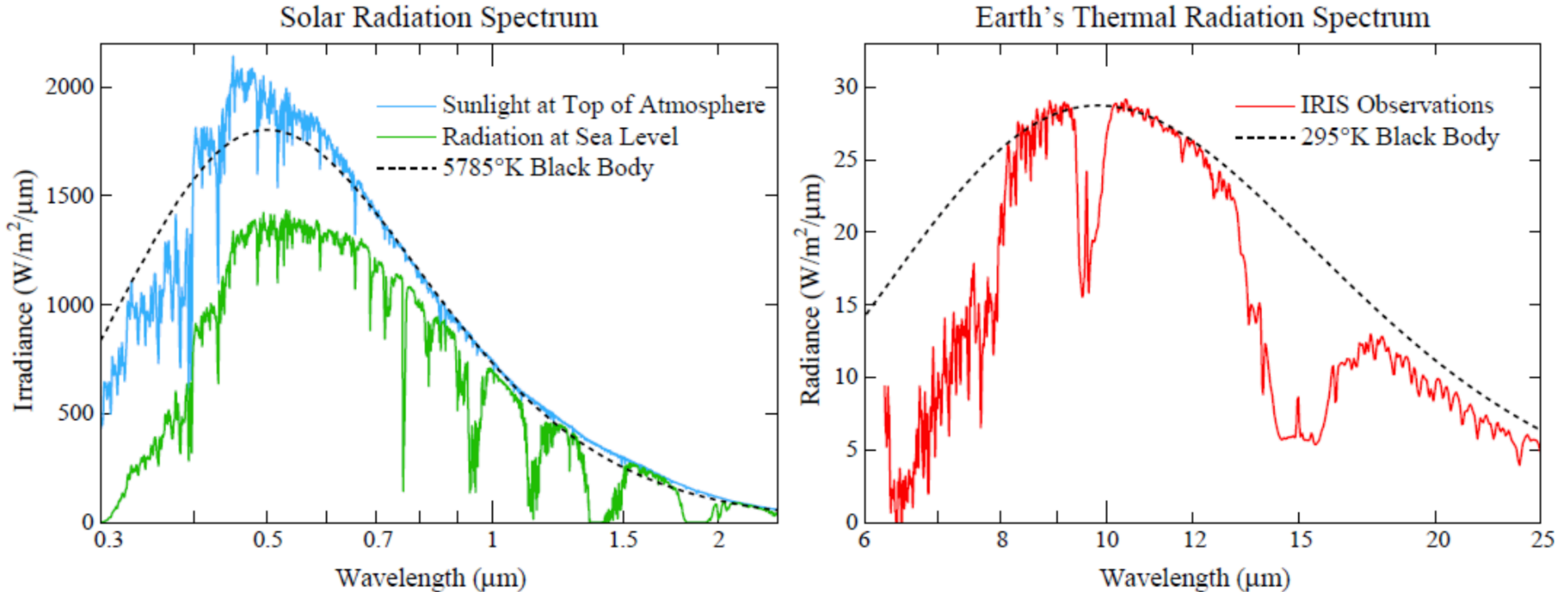


# Warming has risen out of the range of natural variability.



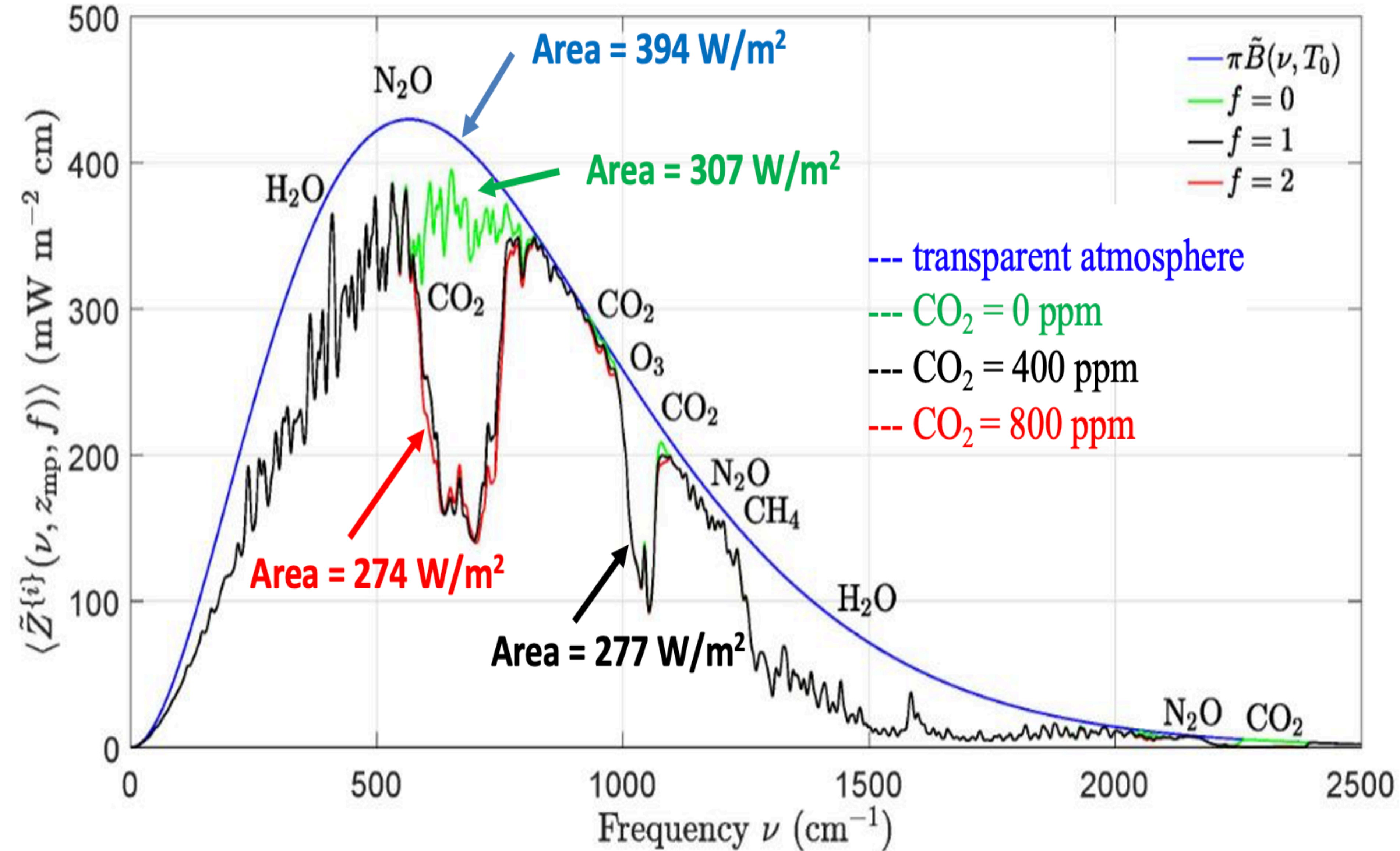
# Incoming visible radiation

# Outgoing infrared radiation



**Fig. 31.1. Sunlight reaching Earth and reaching the ground for clear sky conditions (left). Thermal (heat) radiation to space measured from a satellite over the Sahara desert (right).**

# Princeton Prof William Happer: more CO2 is ineffectual.



Green zero CO2

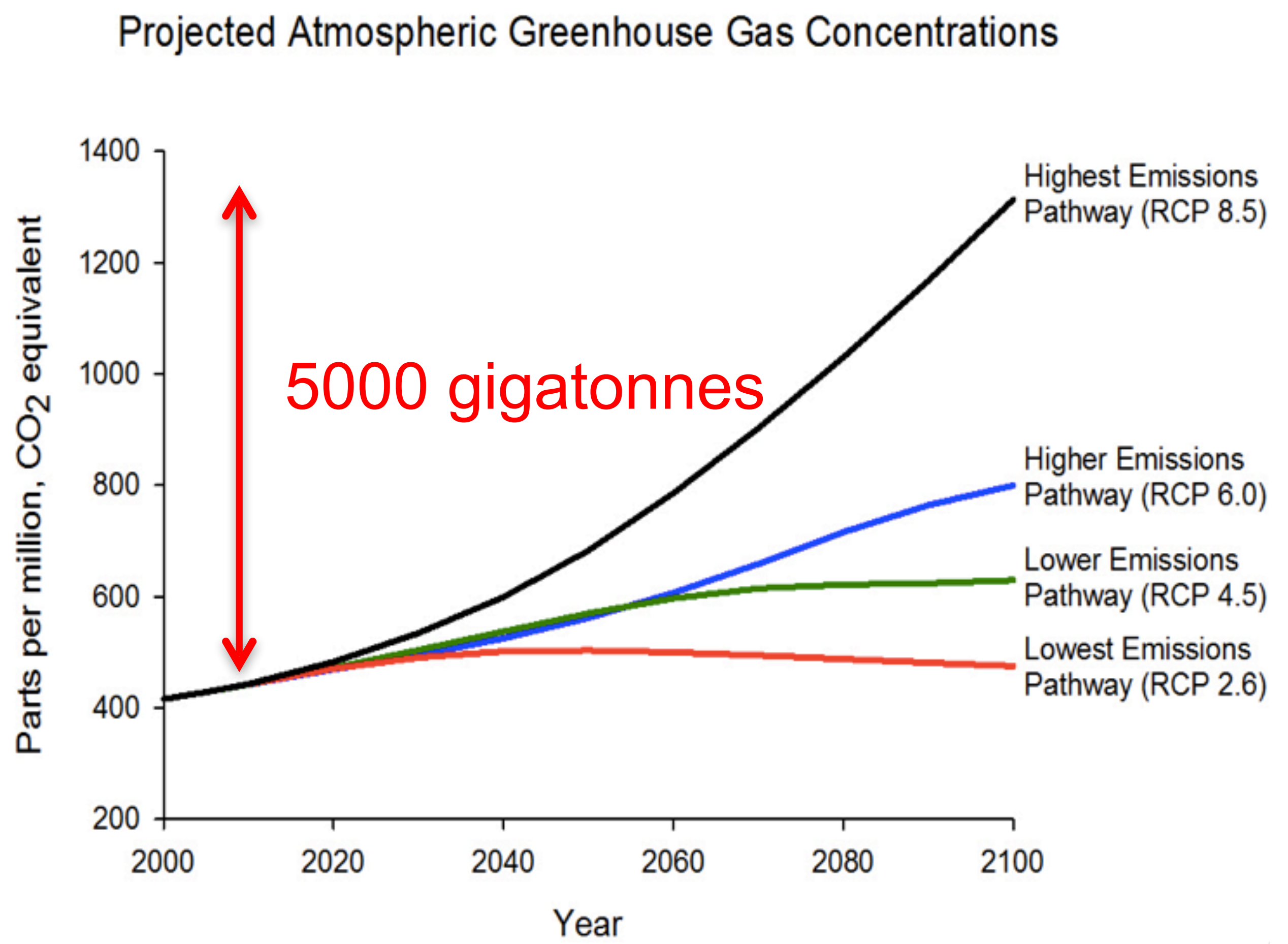
Black 400 ppm CO2

Red 800 ppm CO2

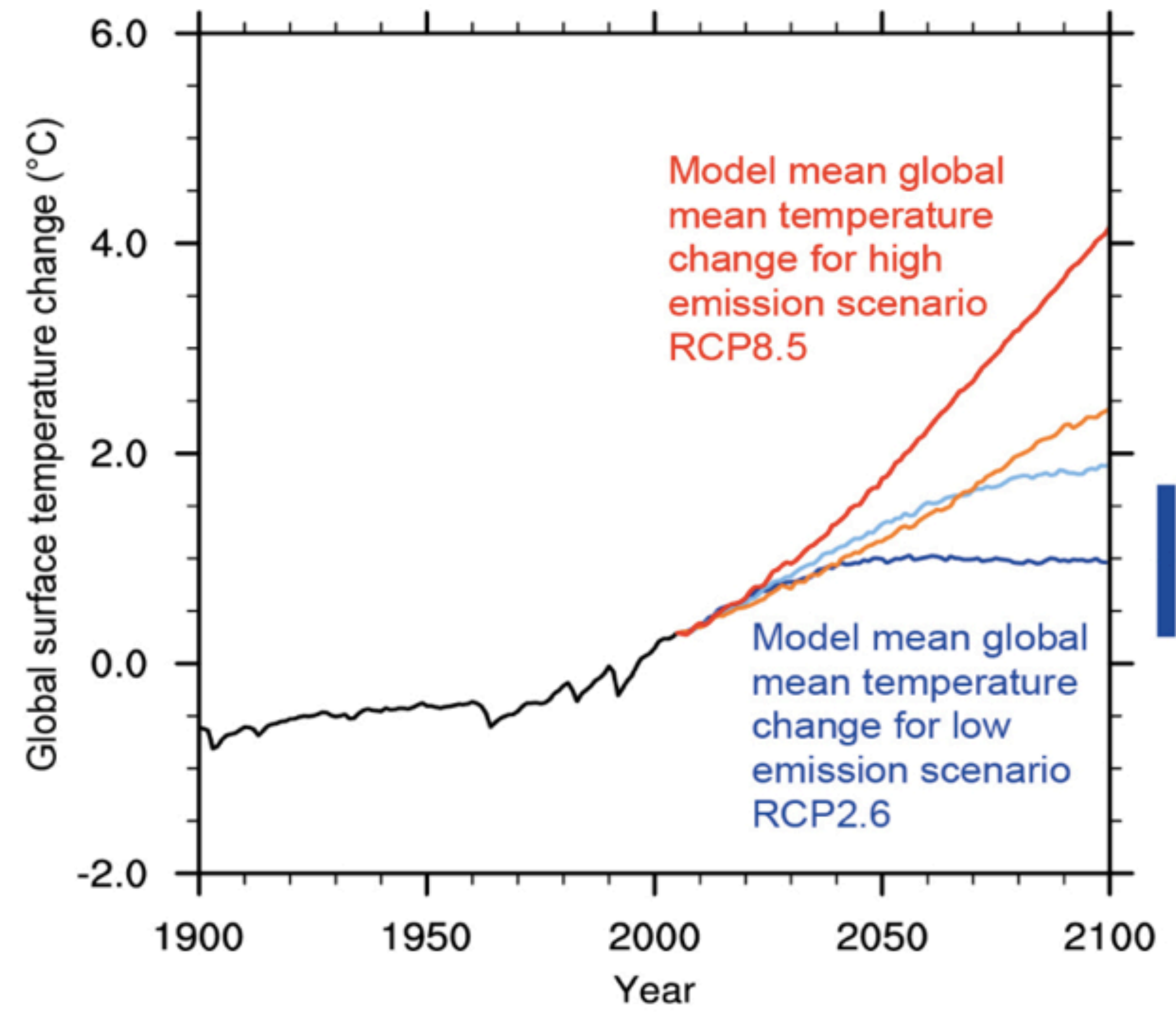
Happer: Doubling the concentration of CO2 (from 400 to 800 ppm) would cause a forcing increase (the area between the black and red lines) of 2.97 W per m2.

Surface temp 60°F;  
16°F w/o greenhouse gases

# As CO<sub>2</sub> emissions accumulate, temperatures rise: IPCC



*CO<sub>2</sub> in atmosphere, ppm*

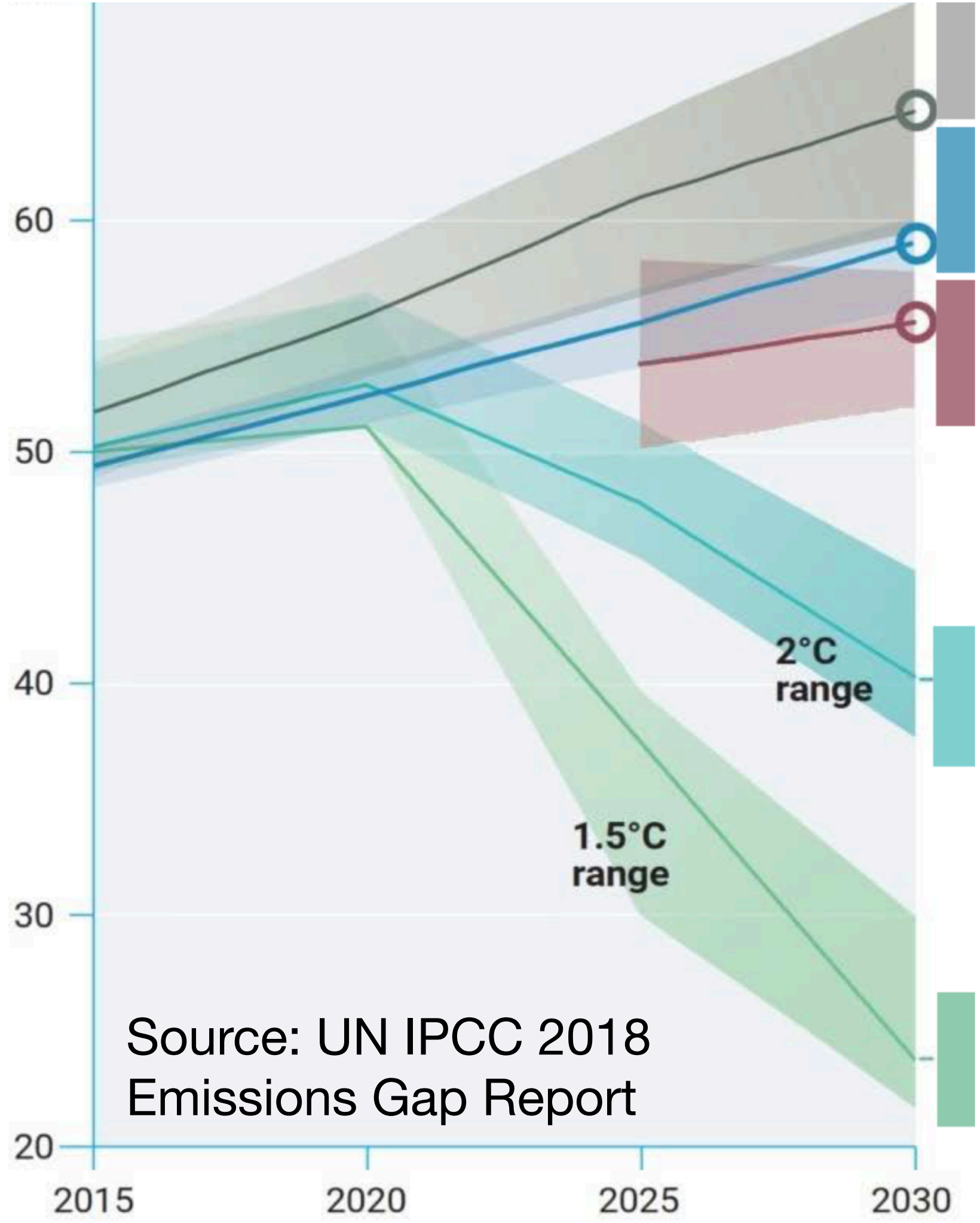


*Temperature rise, °C*

**Business As Usual: adding 1000 ppm (5000 Gt) will add 4°C**

# CO2 reductions pledged at Paris are 10X too small.

Gigatons/year CO<sub>2</sub> added to atmosphere

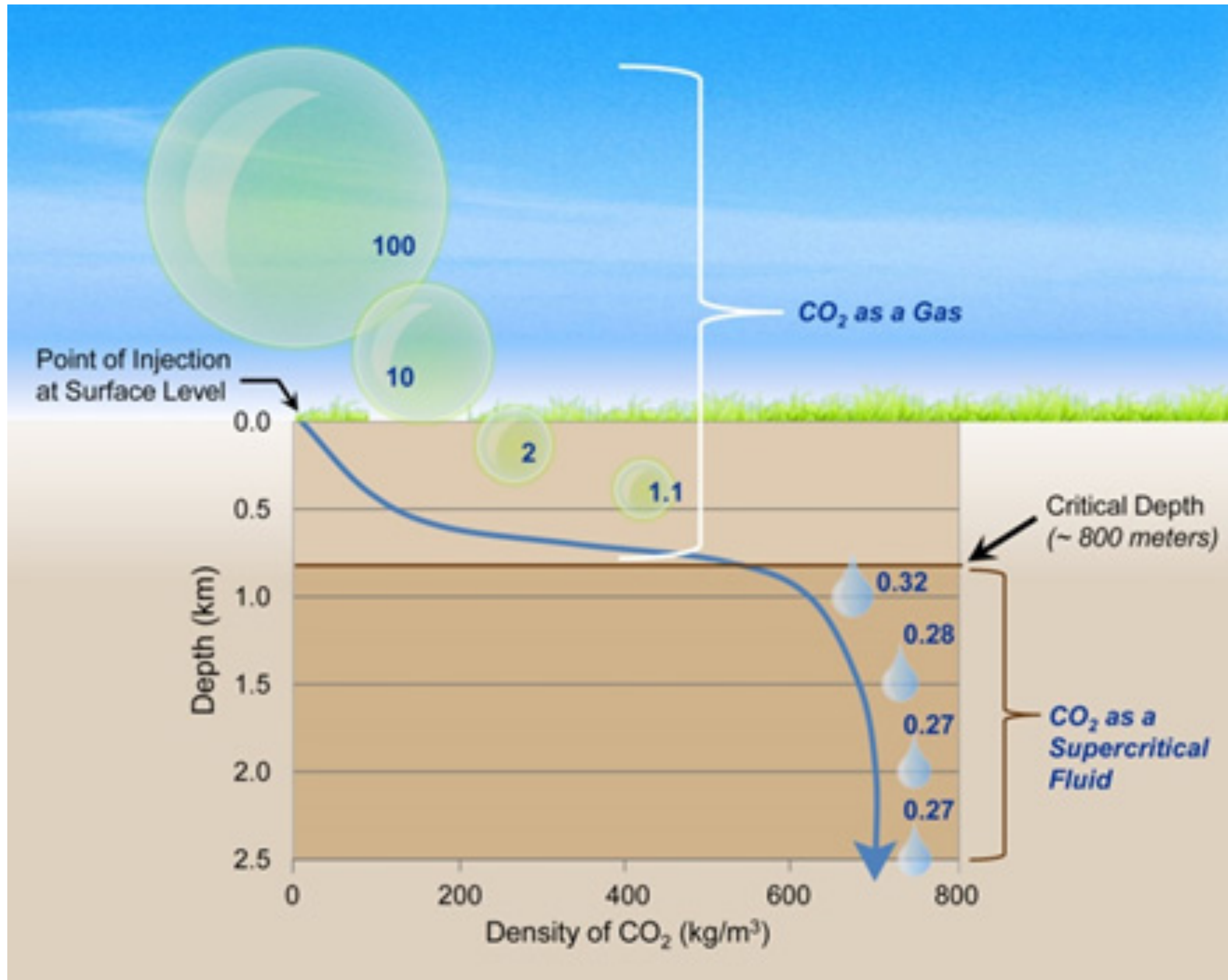


**65 Gt** Business as usual  
**59 Gt** Cancun policy  
**56 Gt** Paris pledges  
**40 Gt** 2°C warming  
**24 Gt** 1.5°C warming

Source: UN IPCC 2018 Emissions Gap Report



# US DOE promotes carbon capture and storage.



CO<sub>2</sub> is a supercritical liquid 1 km underground at 32°C.

Buoyant liquid CO<sub>2</sub> may be trapped beneath geological formations.

CCS demo projects in Norway and Canada store > 1 Mt-CO<sub>2</sub>/year.

A 1-GW coal power plant emits 6 Mt-CO<sub>2</sub>/year.

# CCS, carbon capture and storage, is not feasible.



\$1 billion total

Goal: 33% capture  
from 240 MW boiler

81 mile pipeline to  
oil field to sell CO<sub>2</sub>  
for injection to push  
up more oil

Uses 45 MW natural  
gas power, halving  
CO<sub>2</sub> savings

Petra Nova CO<sub>2</sub> capture at NRG coal plant, Texas,  
killed in 2020. DOE, \$195M grantor, still optimistic.

# Offsets? Planting trees can't absorb enough CO<sub>2</sub>.



Global forests cover  
4 billion hectares.

Add a billion ha more?

- **Mature** forests emit as much CO<sub>2</sub> as they absorb, as trees die and rot or burn.
- **New** forest growth absorbs 8 tons/hectare per year, until maturity @ ~ 100 years.
- Increasing forests by planting 1 billion more hectares of trees (2X the Amazon basin) would absorb only 8 Gt/year, for ~ 100 years.
- Manmade world CO<sub>2</sub> emissions are ~ 50 Gt per year.

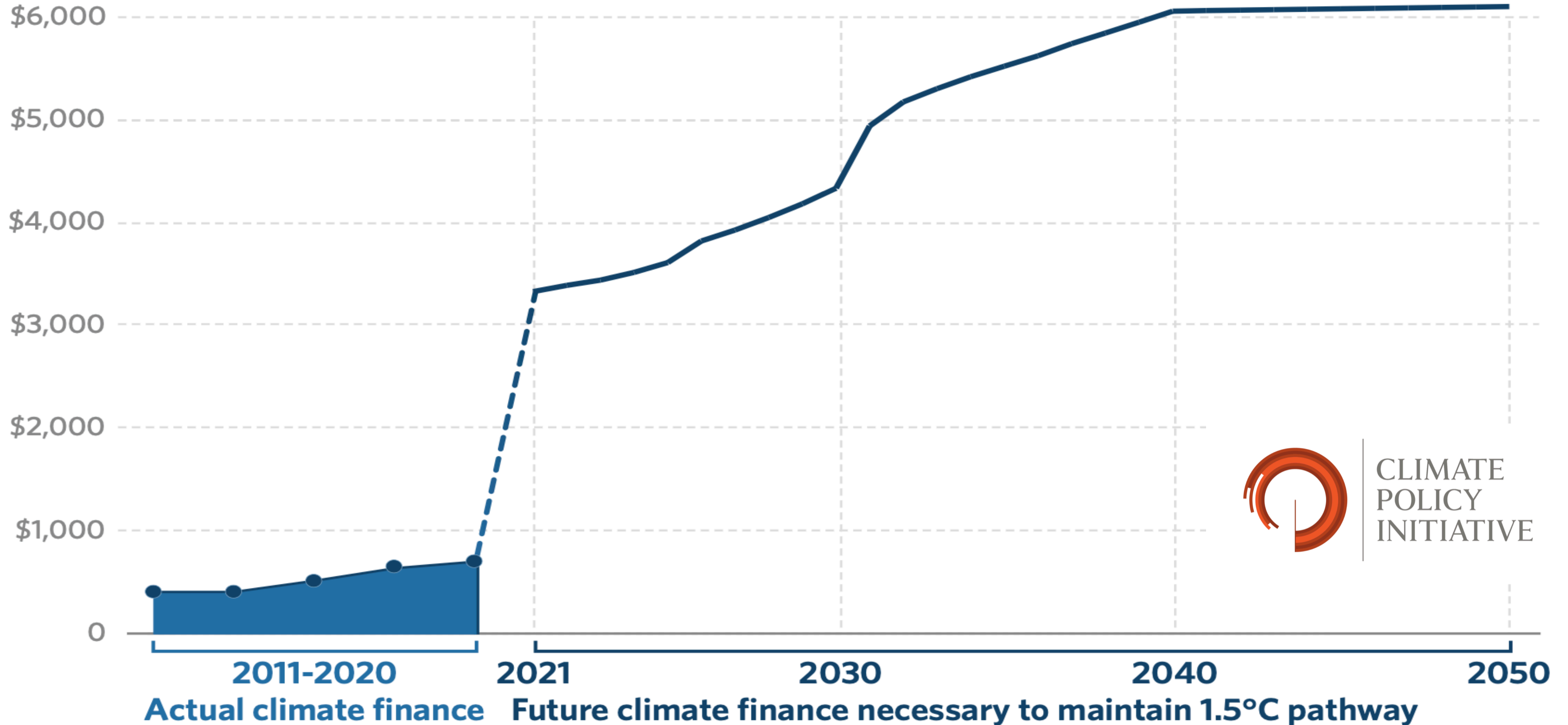
# Adaptation can reduce harm from climate change.



More than half of the Netherlands lies beneath sea level.

# \$6 trillion per year on “climate finance”?

(USD billion)



# Global average electric power = 3,000 GigaWatts

## One fission power plant can supply 1 GW, or so can...



Based on a representative silicon model panel size of 320 watts.

**3,125,000 solar panels, if sunny**



Based on the average utility-scale wind turbine size of 2.43 MW installed in 2018. ([Source](#))

**412 wind turbines, if windy**

**NATIONAL**

**SUICIDE**

**PREVENTION**

**LIFELINE**

**1-800-273-TALK (8255)**

[suicidepreventionlifeline.org](http://suicidepreventionlifeline.org)

**Economic suicide?**

**Don't end reliable,  
cheap power before  
getting a substitute!**

**Vaclav Smil:**

**Energy from burning carbon  
is the basis of civilization.**

### 3 Earth's carbon battery



*Fission is in Fashion*

Fossil fuel timeline

Limits to extracting energy

Role of investment

Coal, then oil, and gas

Developing nations' coal use

CO<sub>2</sub> in the atmosphere