Our Burning Economy, Siren Song, and Fission Promise

Basics, Energy, Power, Carbon

Osher @ Dartmouth

Robert Hargraves

Jan 4, 2023

Humans harnessed fire 1.8 million years ago.

The final confrontation with the Environmental Anti Fire Party

Cooking with heat energy.

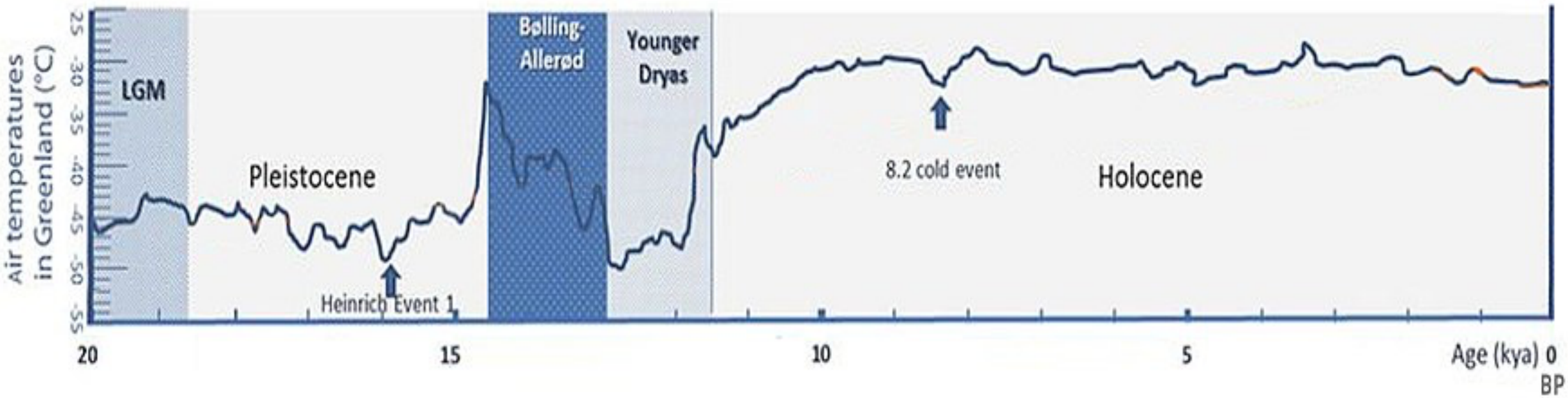
Cooking food saved time and energy. Primates still spend half their day chewing raw food.

By switching to cooked, softer, more energetically rich food homo erectus was able to **devote time to more productive activities**, making tools, farming, and interacting socially

Reduced kinetic energy demands for metabolism permitted **evolution of the human's large brain**, which consumes a quarter of the body's energy.

Fossil records show evolution to larger brains and smaller guts, jaws, and teeth.

Climate warming in 10,000 BC enabled agriculture.



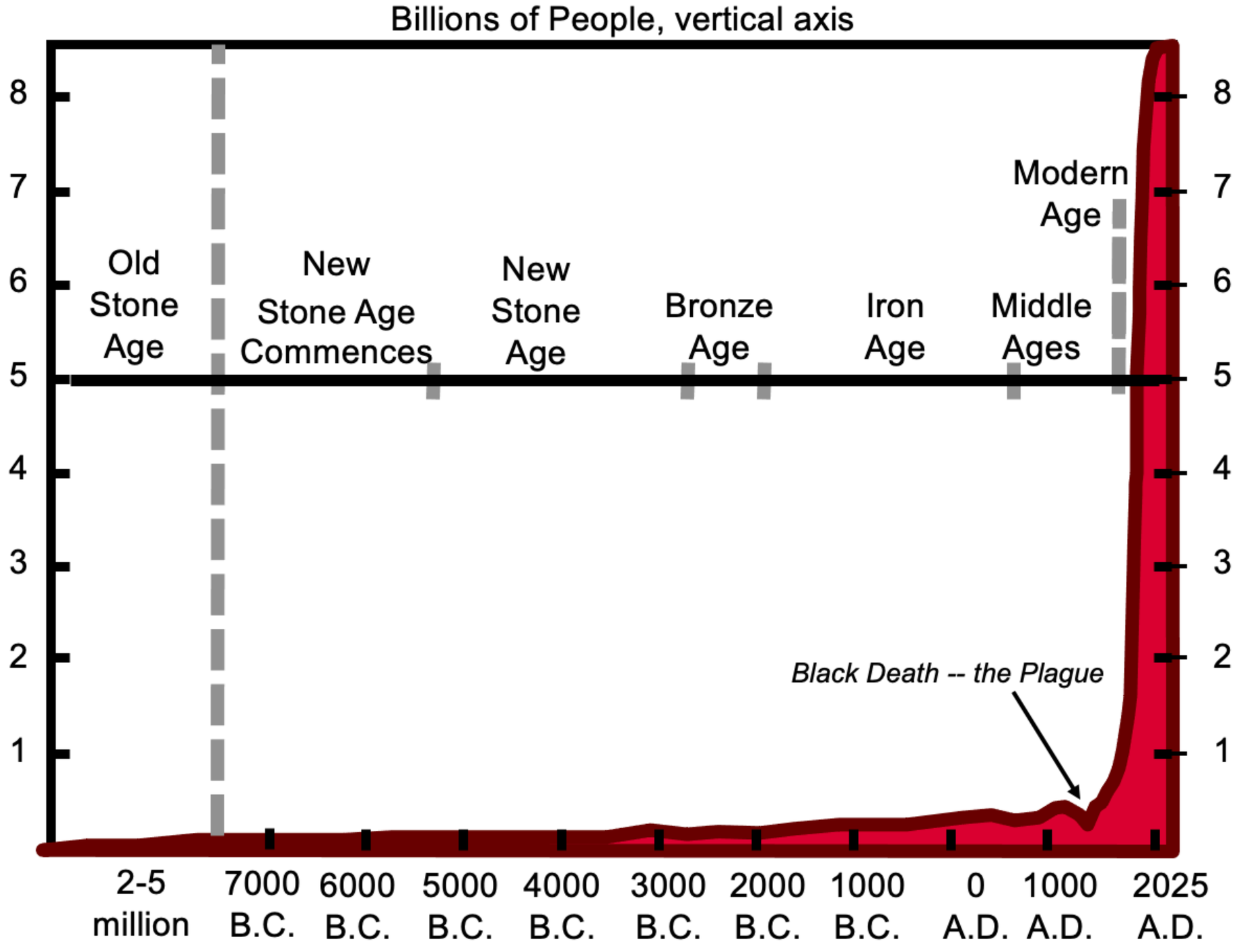
Earlier stone age roving bands subsisted on hunting animals and gathering food.

Productive agriculture of cereals enabled storage of food and free time to make tools, build shelters, develop writing, and advance civilization.

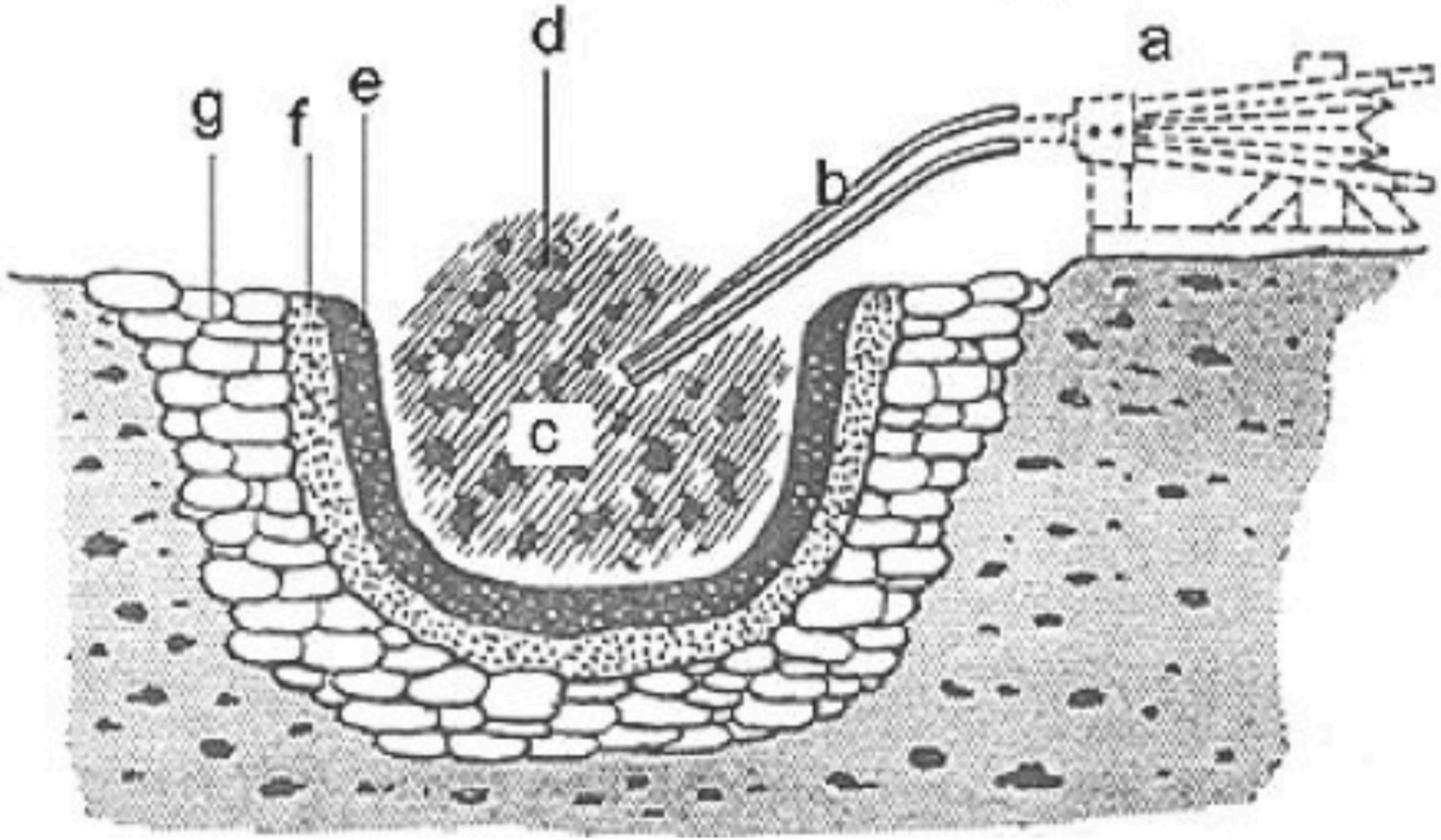
Stored food was **wealth**.

https://en.wikipedia.org/wiki/Neolithic_Revolution#Social_change

What's the value of energy to civilization?



Bronze Age 3000 BC
1100°C furnace for melting copper and tin



a-Smile

b-nozzle

c-charcoal (wood?)

d-fine "grind" of copper and tin ore

e-lining of clay

f-priming with pen

g-stone lining

https://www.researchgate.net/publication/233731071_The_investigation_of_microstructure_and_hardness_of_archaeological_alloys/figures?lo=1

Iron Age 1200 BC; 1250-1535°C heat needed.

Killick A well-preserved tall (2.2 m) natural draft iron smelting furnace in the Kasungu National Park, Malawi

https://www.researchgate.net/publication/298801110_A_global_perspective_on_the_pyrotechnologies_of_Sub-Saharan_Africa/figures?lo=1

Iron ore is plentiful, inexpensive.

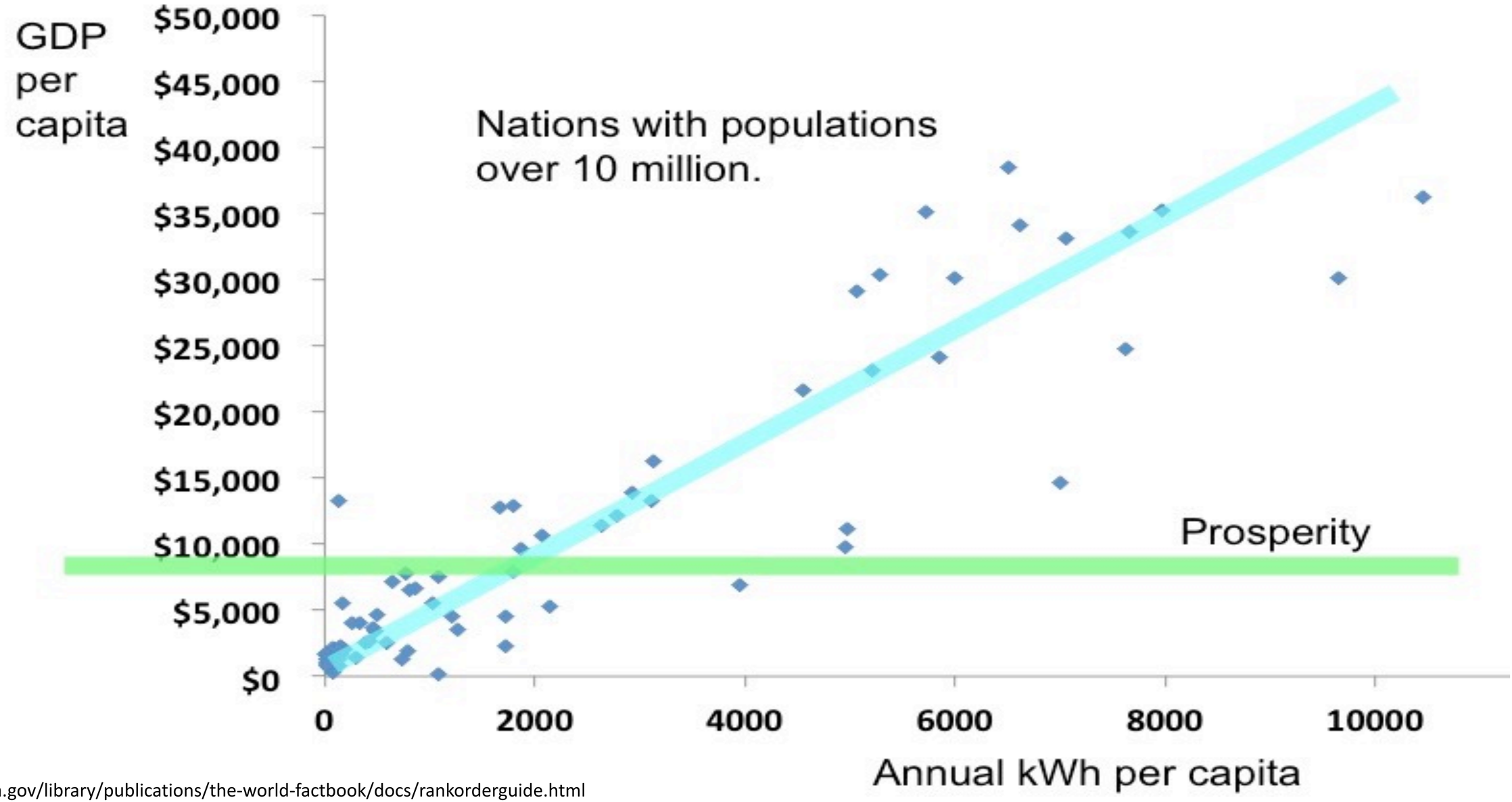
1250°C to reduce iron ore to iron bits that could be pounded together, **forged**, to form “wrought iron”.

African hardwood fuel burns hotter, as does charcoal.

1535°C to melt iron to form “cast iron”.

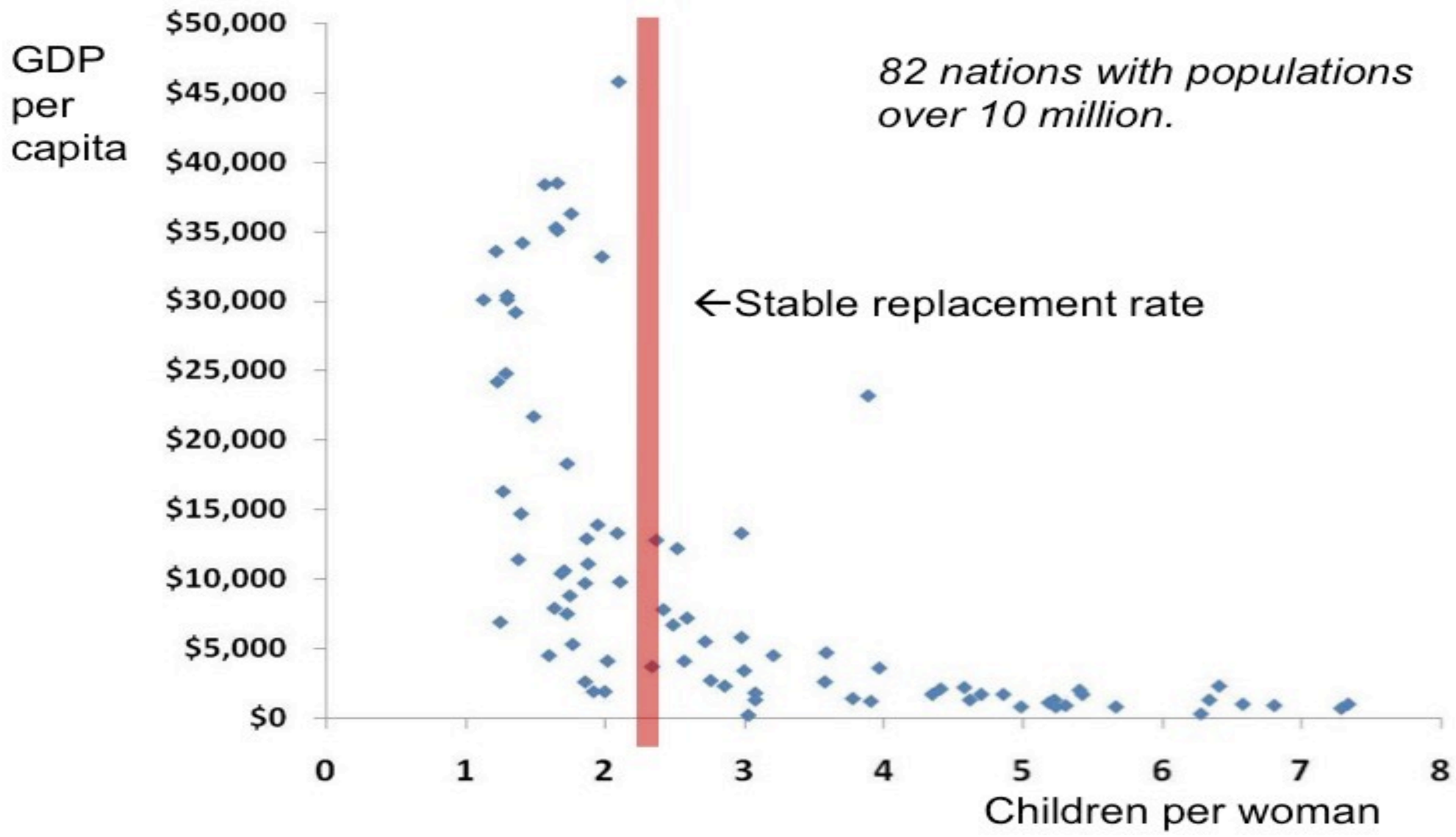
Adding carbon lowers iron melting point to 1150°C, but iron is brittle.

Nations achieve prosperity with electricity over ~250 watts per person.

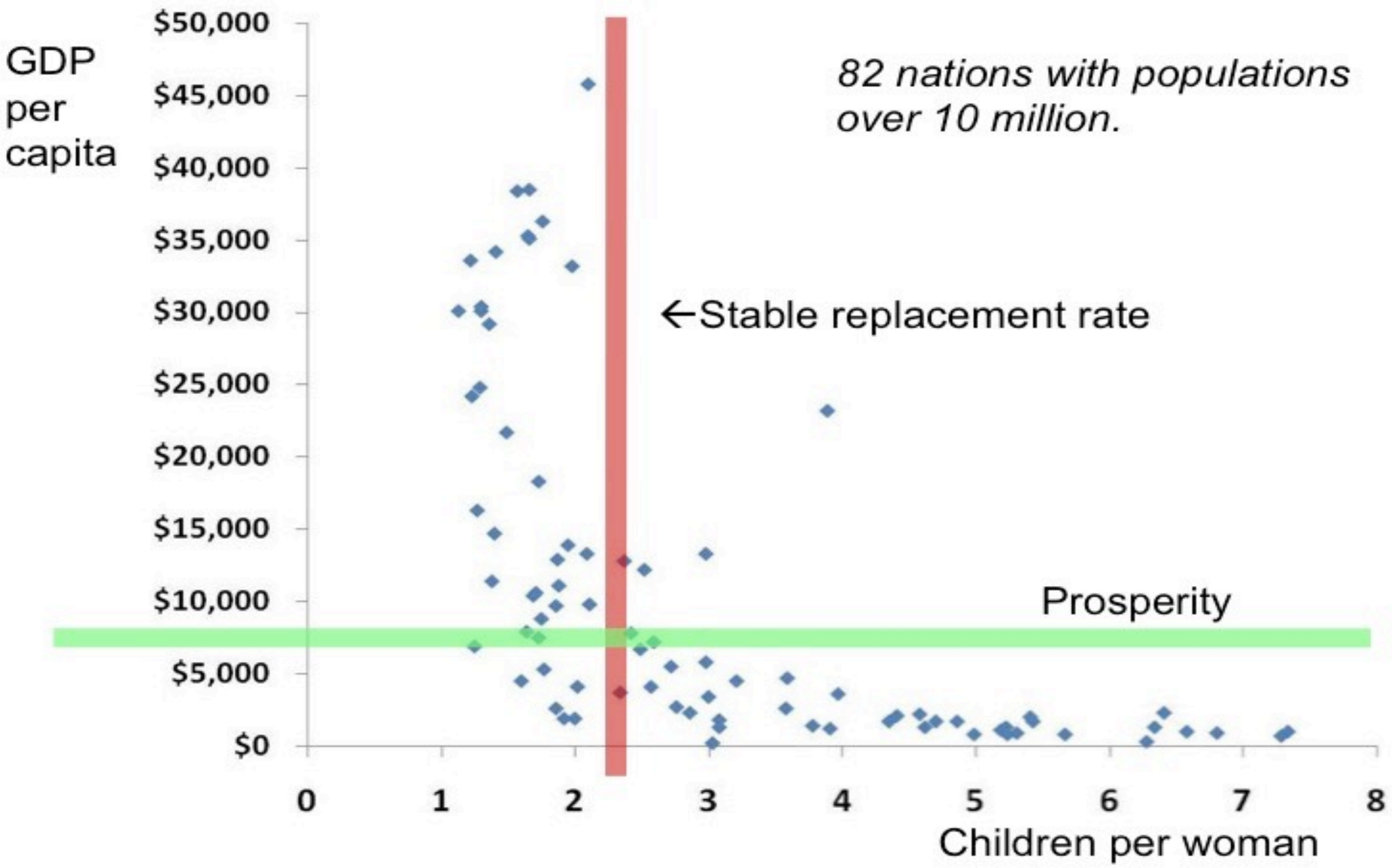


https://www.cia.gov/library/publications/the-world-factbook/docs/rankorderguide.html

Prosperous people have fewer children.



Fewer birthed people, with adequate energy, compete for finite world resources.



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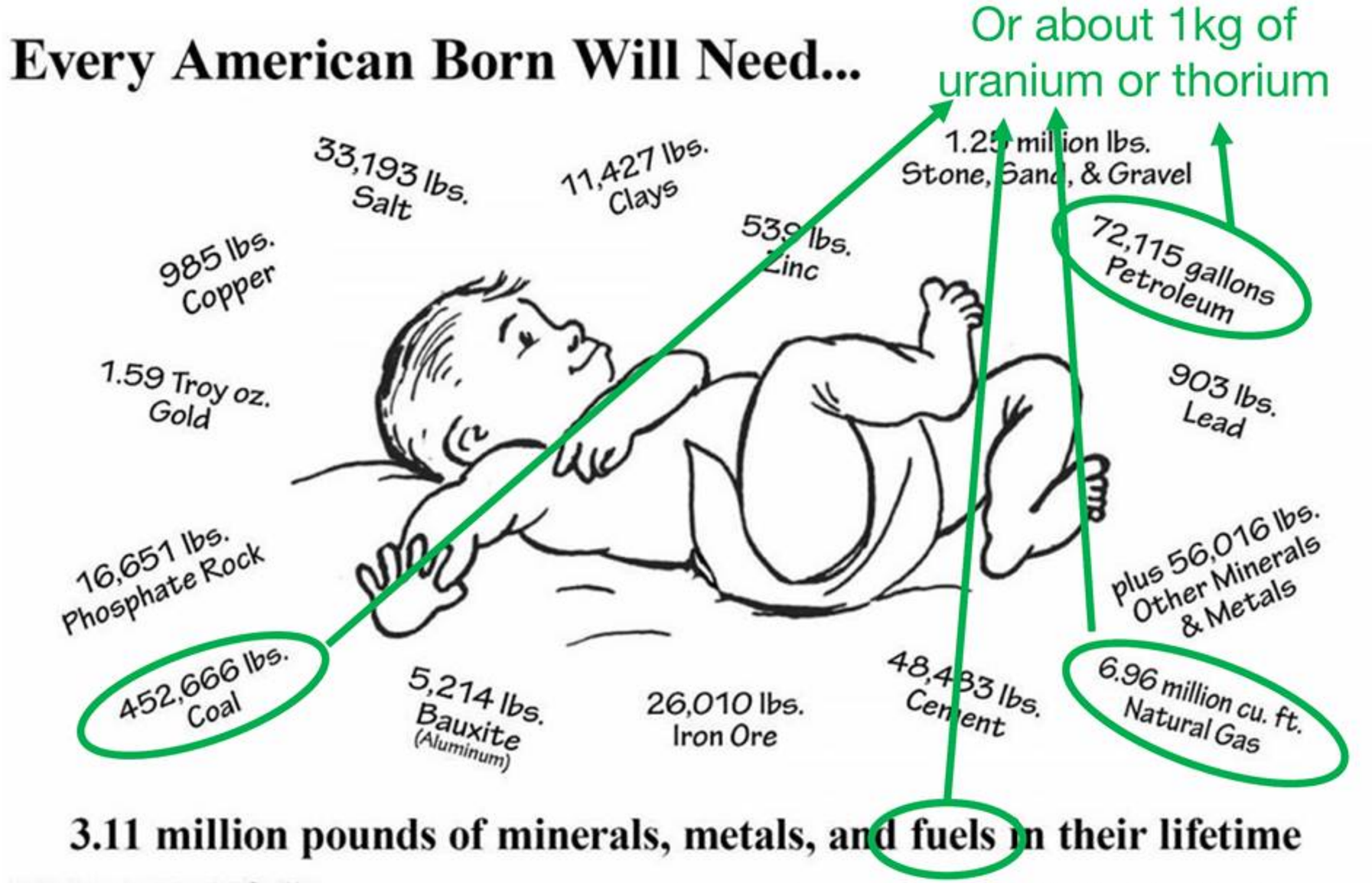


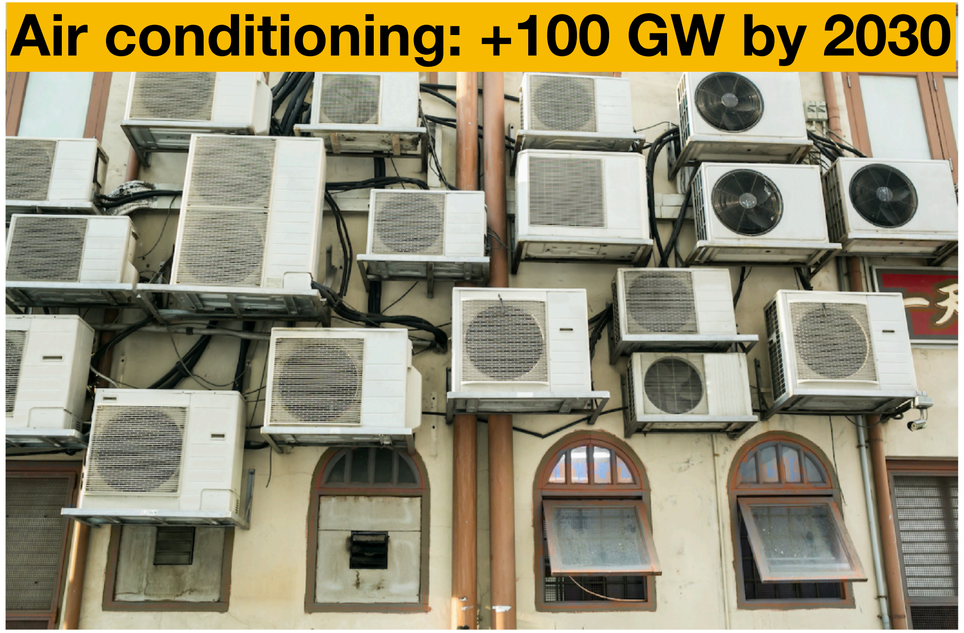
Connecting a billion poor to power by 2030: **+100 GW** (at only 100 W/person)

Connecting one billion powerless people with just 100 watts of power — a tenth of US and EU average electricity use.

2030 GW growth +42 +62 +100 +300 +100 ....

By 2030, 122 million more electric vehicles travel 12,000 miles per year at 4 miles/kWh.

Desalination of 87 million cubic meters of water per year is growing at 8% annually, demanding 3 kWh per cubic meter.



Data centers, the internet, and consumer electronics will demand 300 GW more by 2030.

Basics of energy and power. *Critical knowledge!*

Distinguish **heat energy** from **useful energy.**

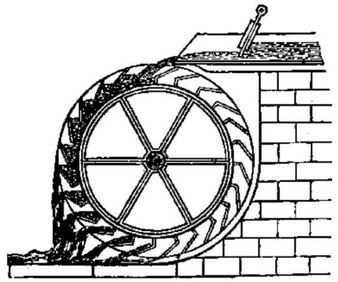
Useful energy includes electricity, kinetic energy, gravitational potential energy, to do **work** (force x distance)

Power is energy **flow** (energy per unit time)

Distinguish **heat power** from **useful power**.

Kinetic energy is a form of ***useful energy***.

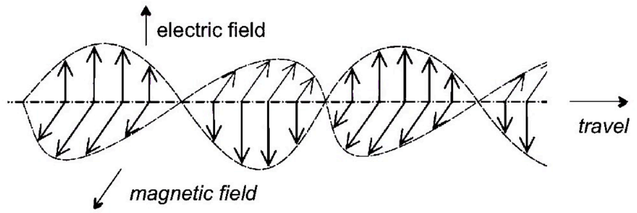
Kinetic energy: mass x velocity squared / 2



Gravitational energy: height x mass x g

Work: force (newtons) x distance (meters)

Electric energy is one form of ***useful energy***.



Electric energy: amps x volts x time

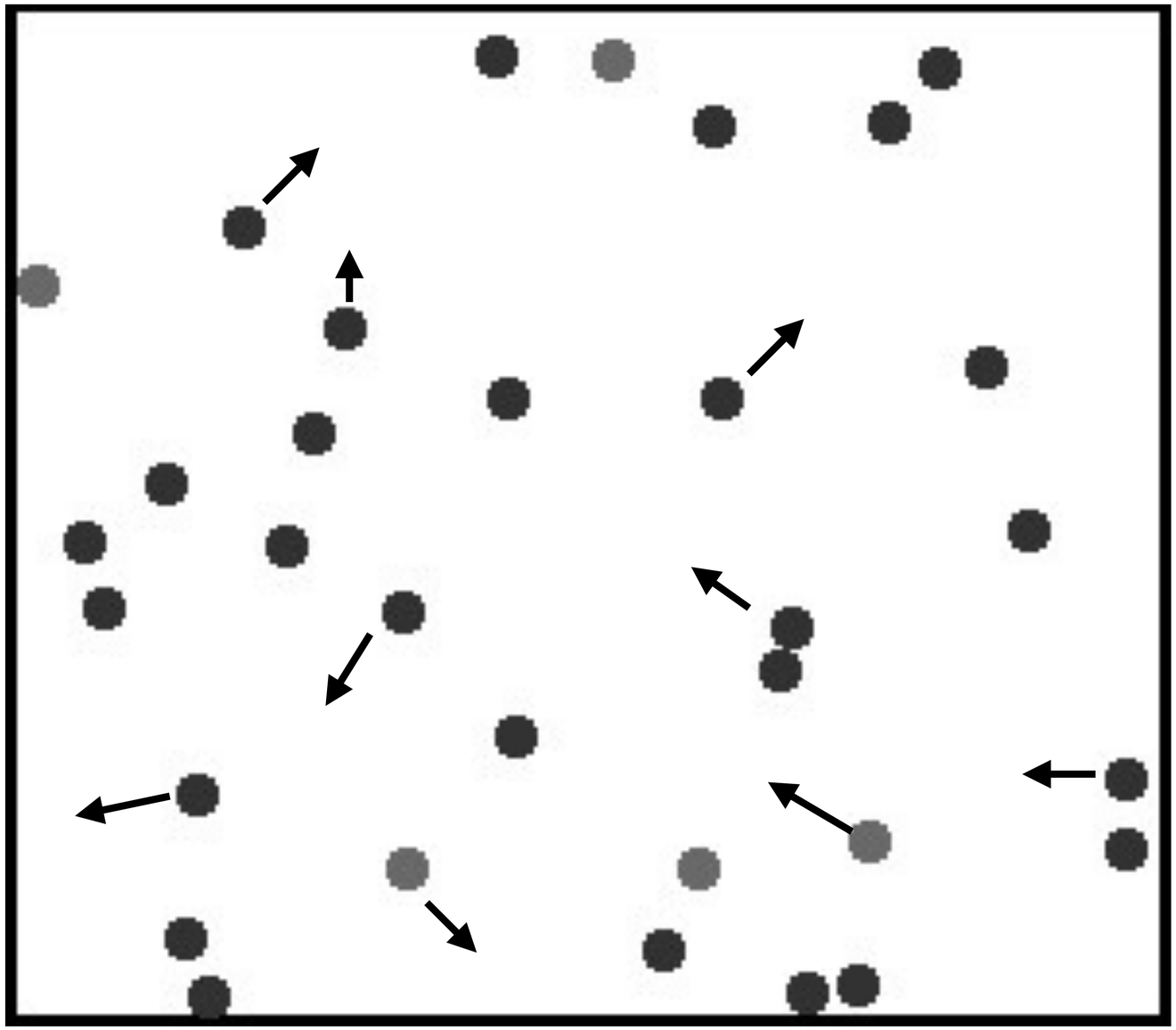
1 watt-sec = 1 amp x 1 volt x 1 sec

Joule = 1 watt-sec

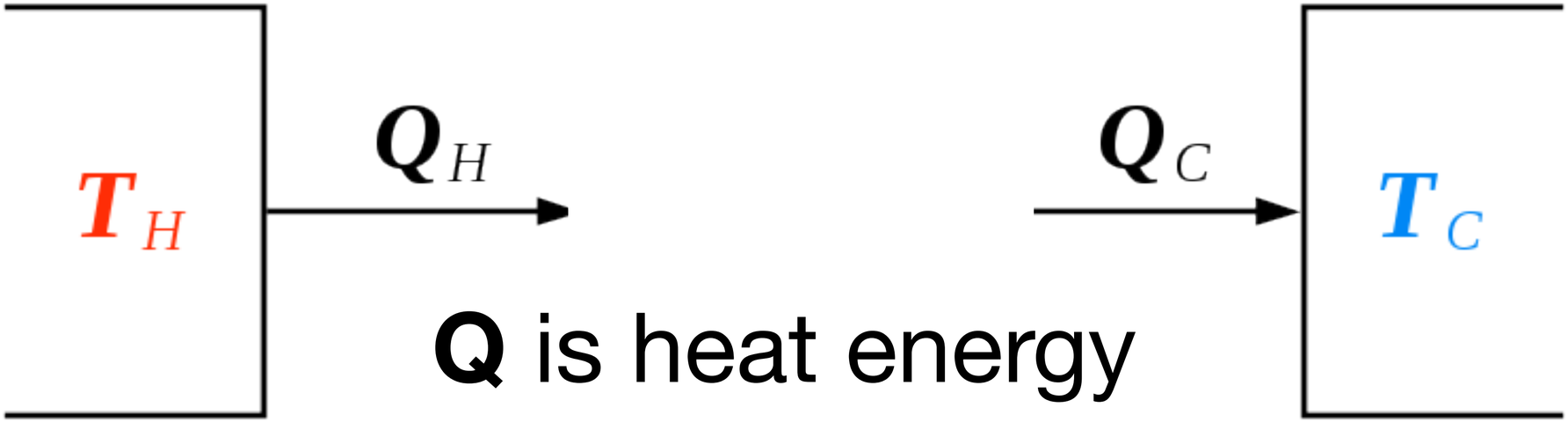
60 x 60 watt-sec = 1 watt hour, 1 Wh

1 joule/sec = 1 watt (**power** measure)

Heat **energy is the kinetic energy of many molecules.**



Heat flows from ***hot*** to cold.

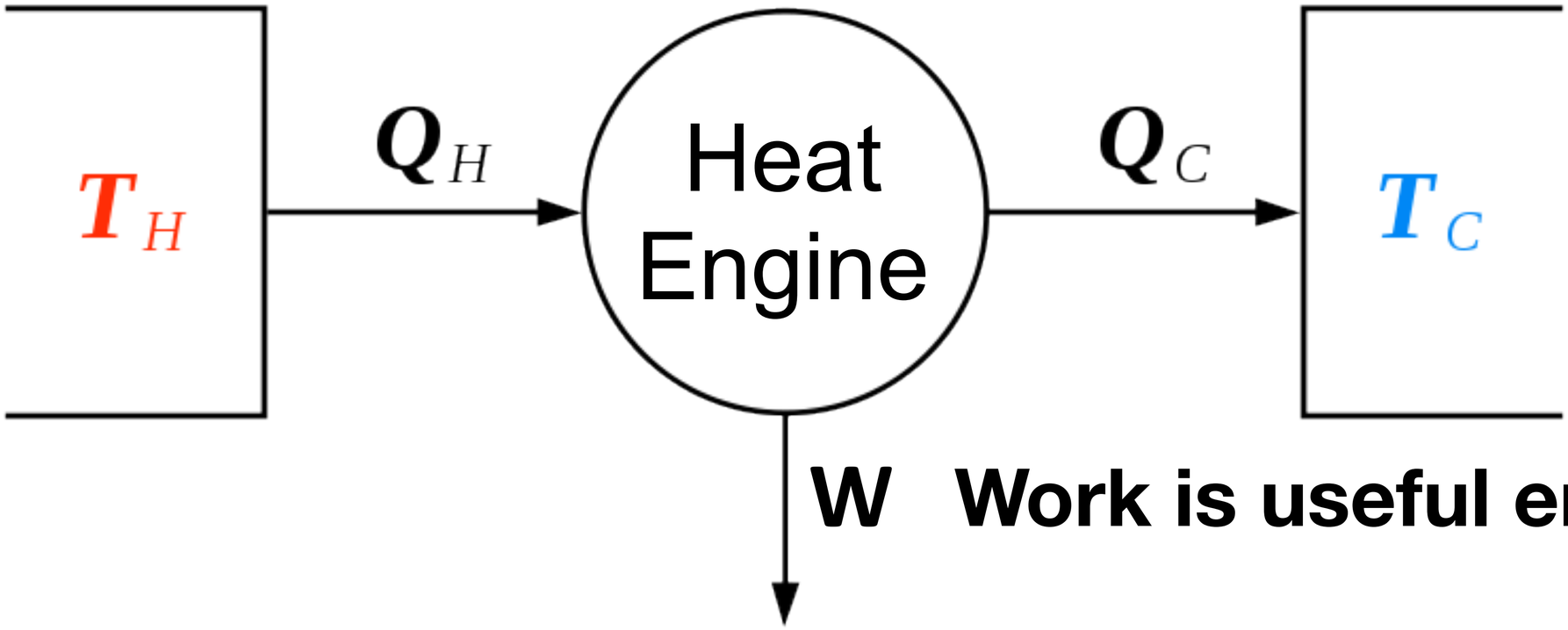


Q is heat energy

Hot heat source

Cold heat sink

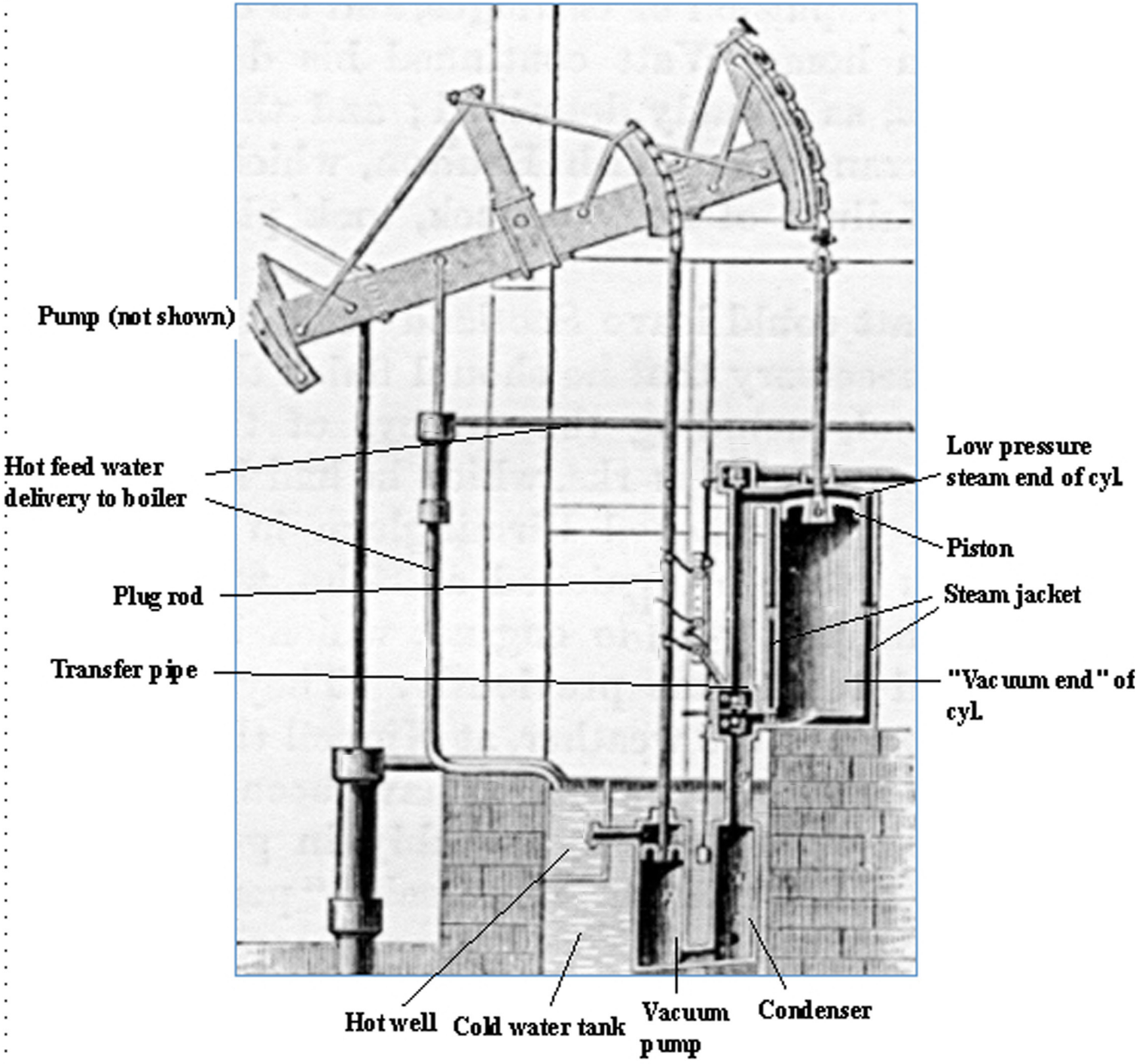
Work, **useful energy, can be extracted from the *flow* of *heat* from *hot* to cold.**



"**Exergy**" is a term for the extractable, useful energy.

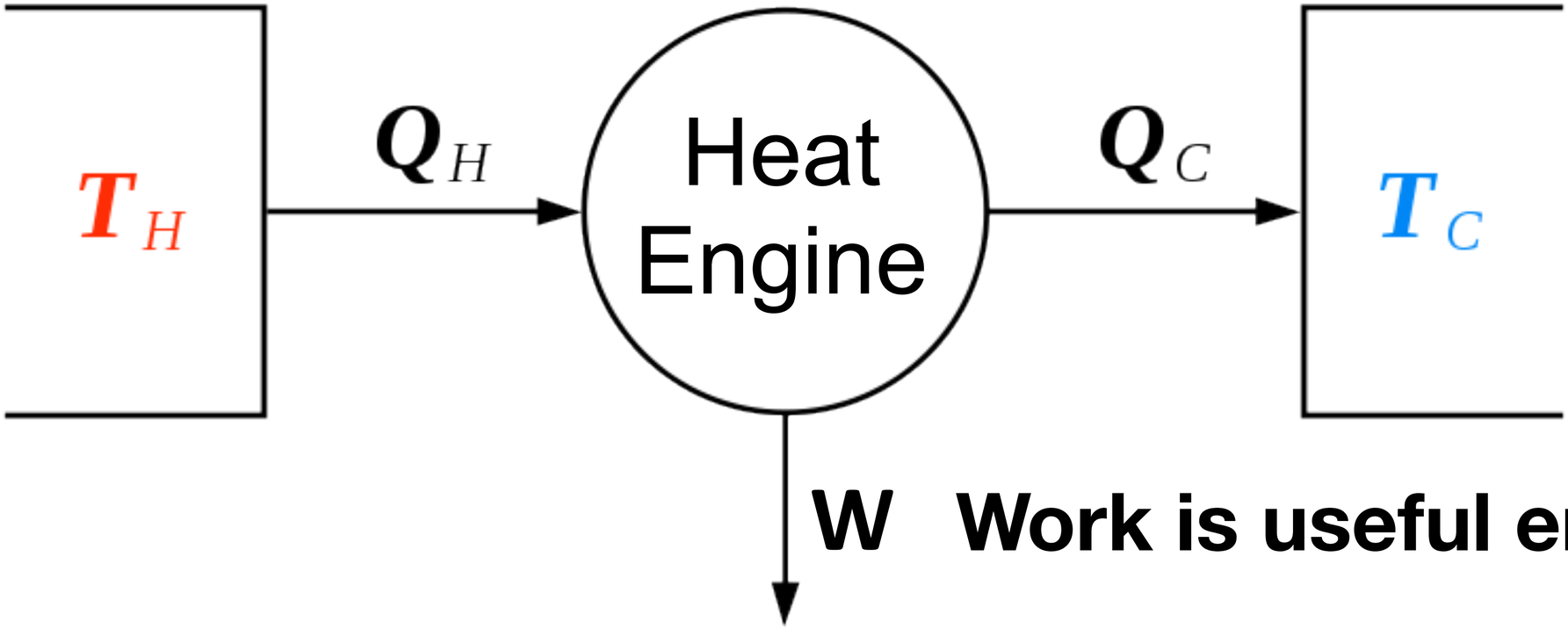
1763-1775 James Watt developed the steam engine.

- Pumped water from coal mines.
- Powered industrial revolution.
- Patented, but not paid for.



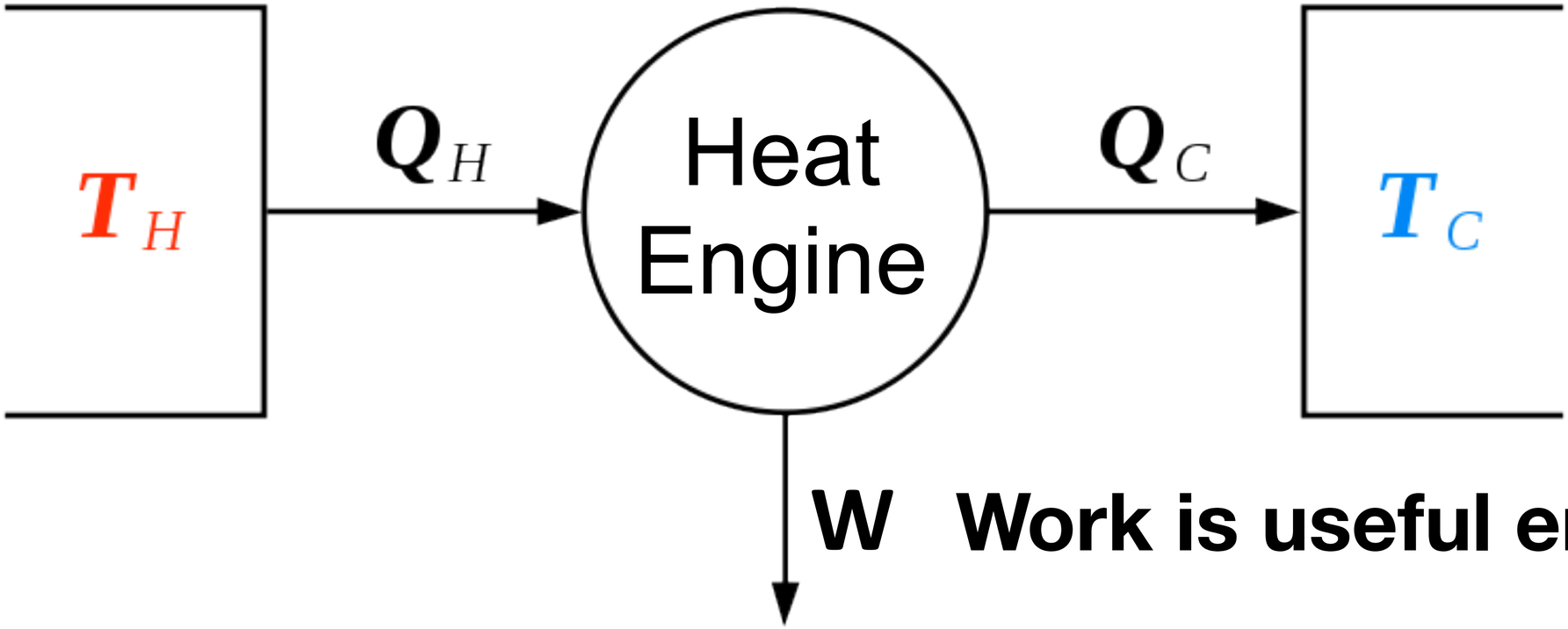
https://en.wikipedia.org/wiki/James_Watt

Work, **energy, can be extracted from the *flow* of *heat* from *hot* to cold.**



Typical conversion efficiency is 33%.

Work, **useful energy, can be extracted from the *flow* of *heat* from *hot* to cold.**

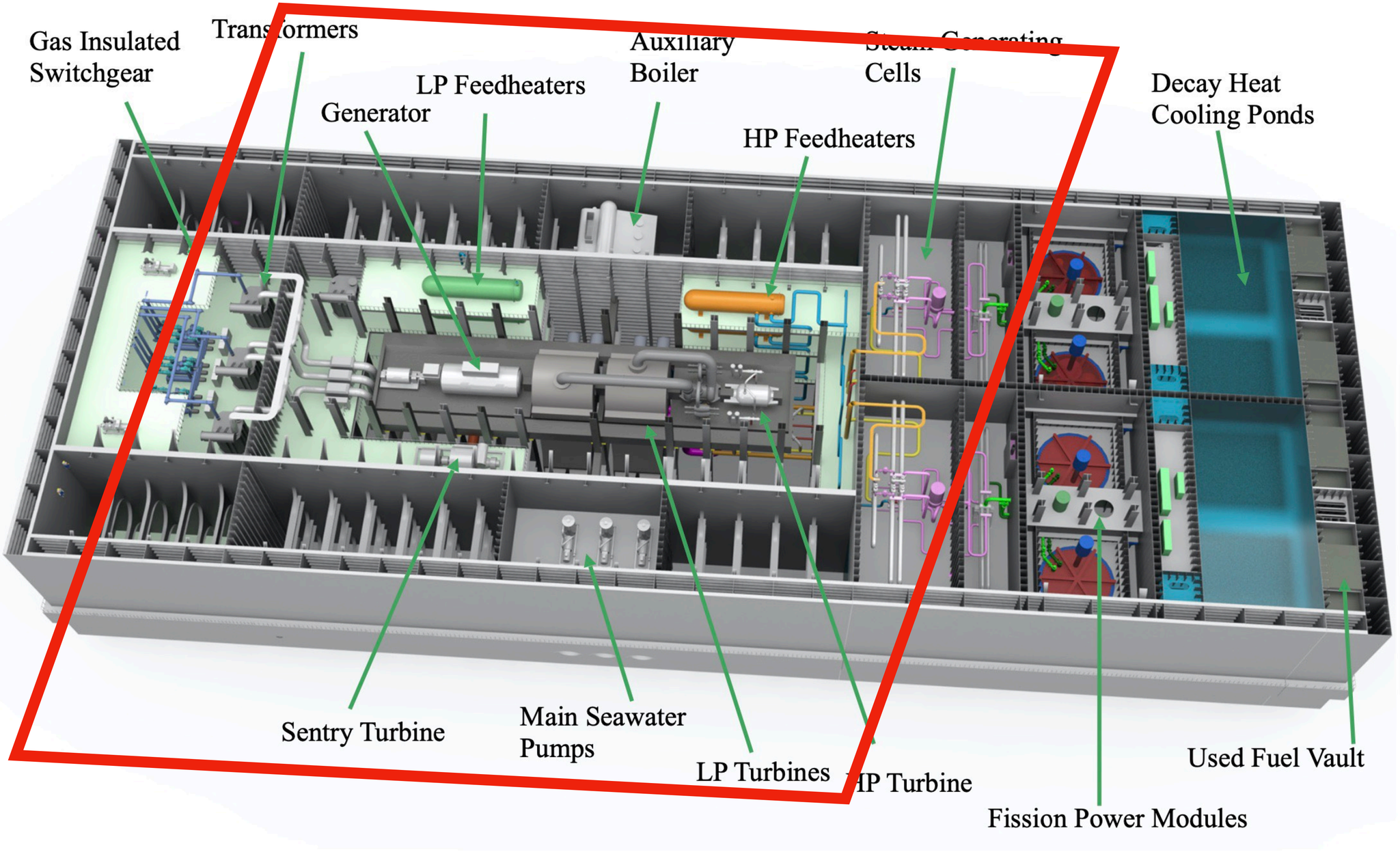


Efficiency = W / Q_H

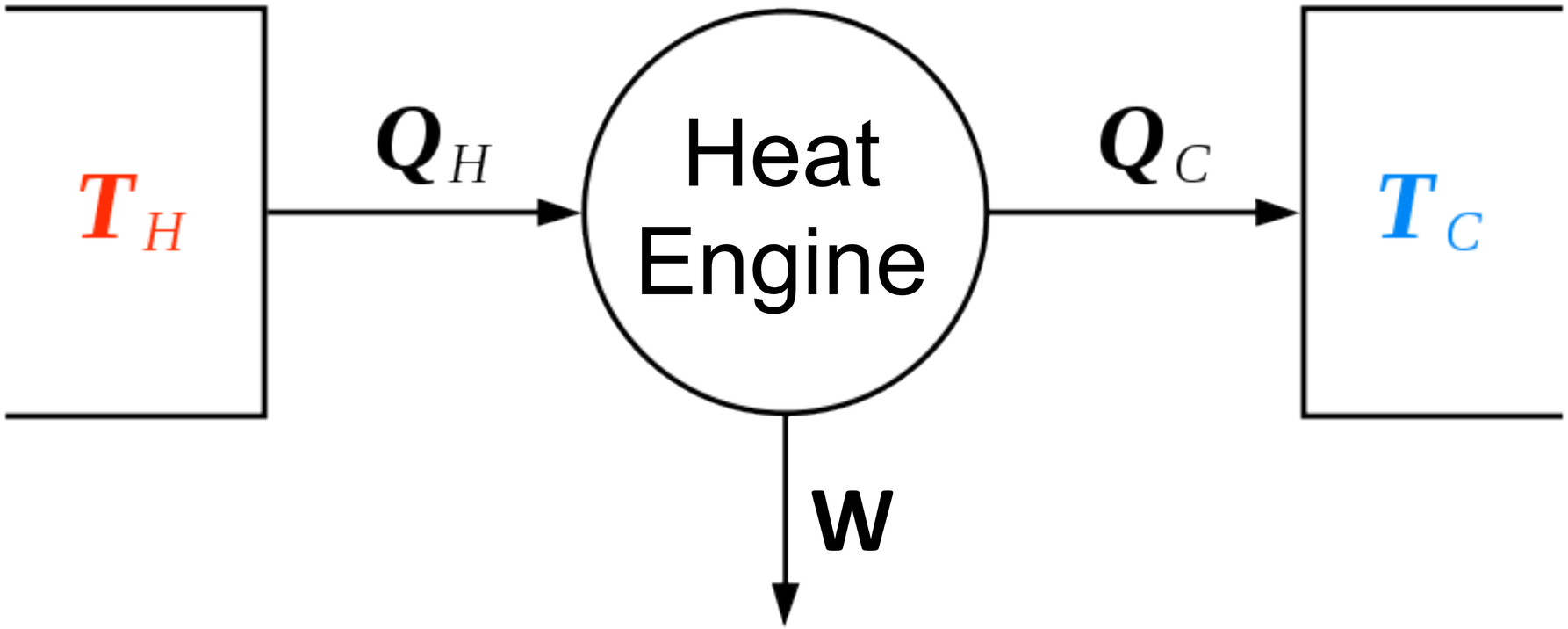
Efficiency **max** = (T_H - T_C) / T_H
(Carnot theorem)

eg: 100°C to 0°C
(373K - 273K) / 373K
= 100/373 = 27%

The *heat engine* is the biggest part of a power plant.



In a power plant, Qc is termed rejected heat, denigrated as waste heat.



Cogeneration
Rejected heat can be transferred in hot water to heat buildings.

ENERGY notation: heat kWh(t) useful kWh(e)

"thermal" "electric"

Heat and useful energy both measured in joules (J) (watt-seconds) so we distinguish them as:

1 **kWh(t)** = kilowatt-hour thermal = (3600 x 1000 J)

1 **kWh(e)** = kilowatt-hour electric = (3600 x 1000 J)

[I rarely see J(t) clearly distinguished from J(e)]

POWER notation: heat kW(t) useful kW(e)

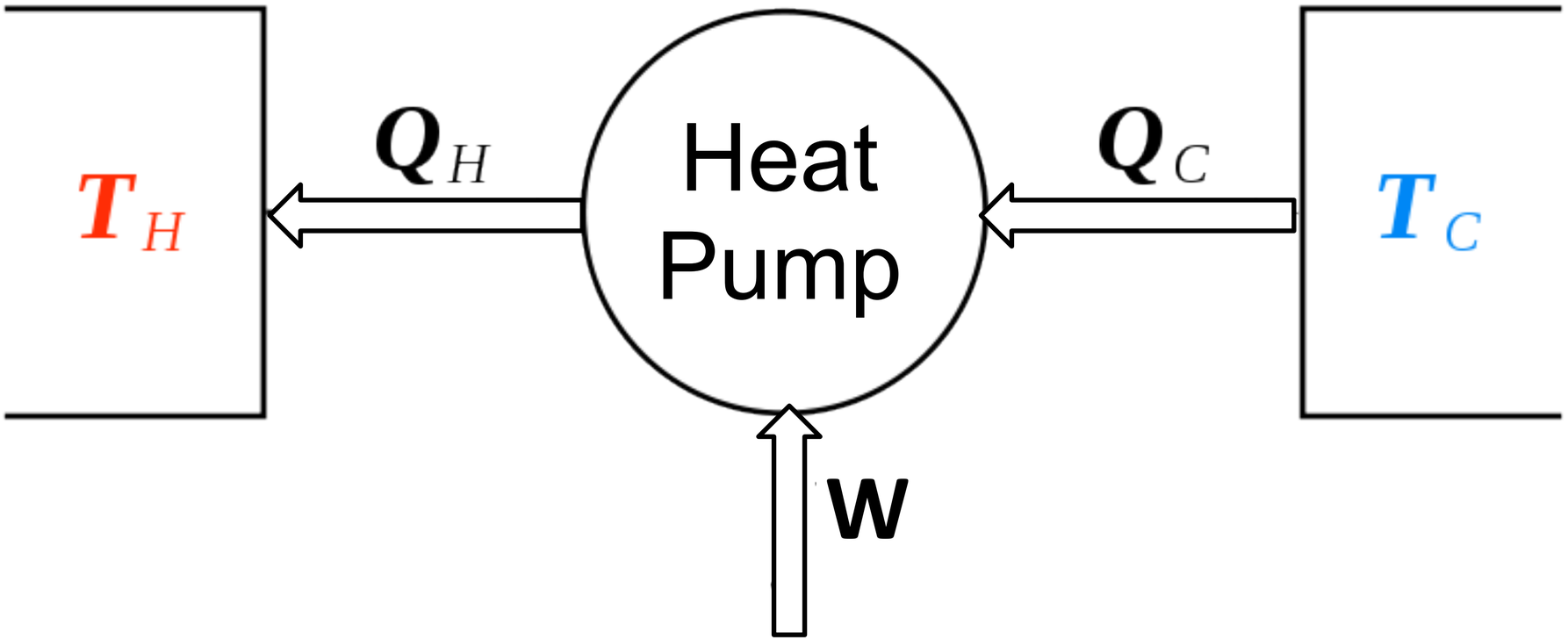
"thermal" "electric"

Heat flow and electric power both measured in watt units (joules/sec), so distinguish them as:

1 **kW(t)** = kilowatt thermal = (3600 x 1000 J/sec)

1 **kW(e)** = kilowatt electrical = (3600 x 1000 J/sec)

Using *work* energy, *heat* can flow in reverse from cold to *hot*.

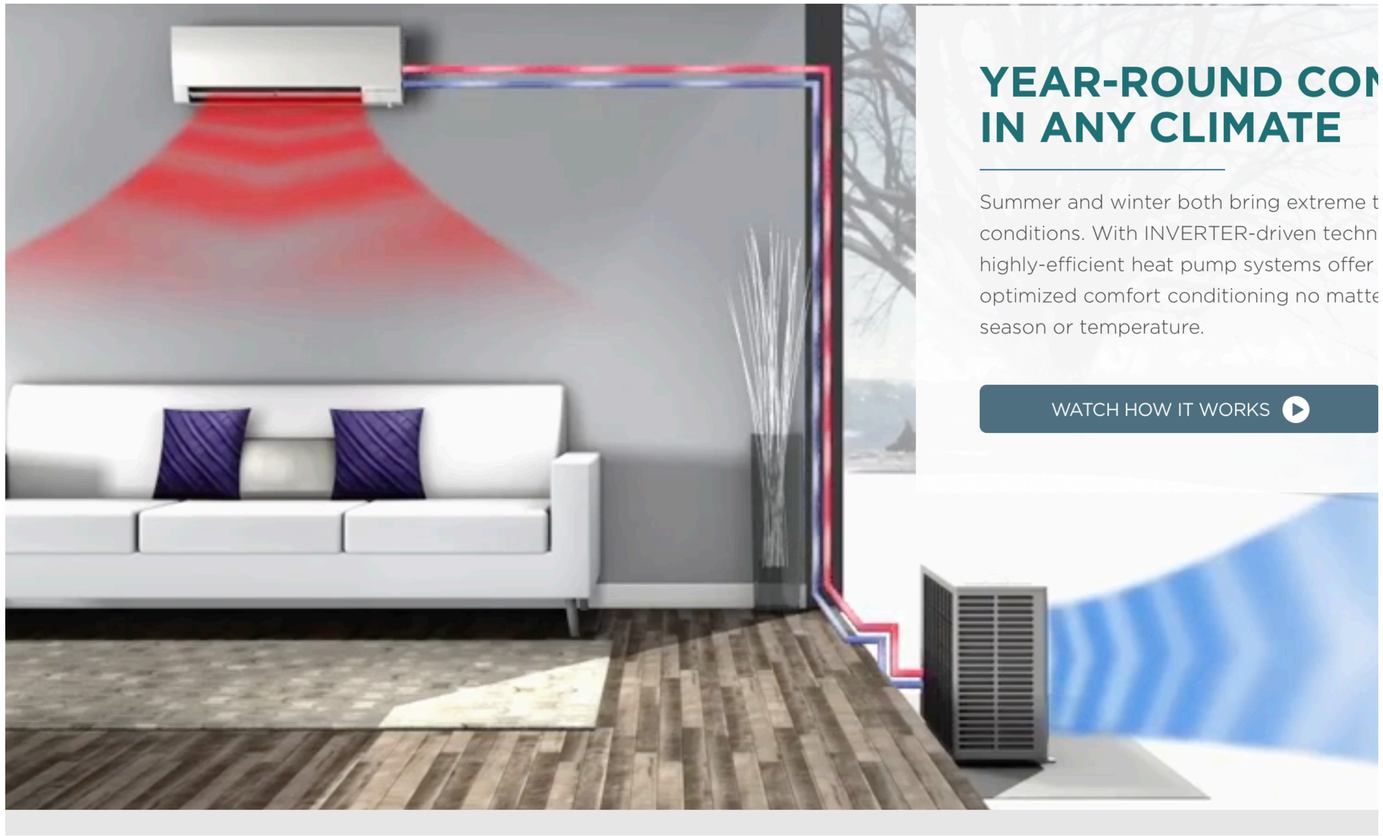


Heat pump examples:

LG air conditioner

For cooling

Mitsubishi air source heat pump



For heating and cooling

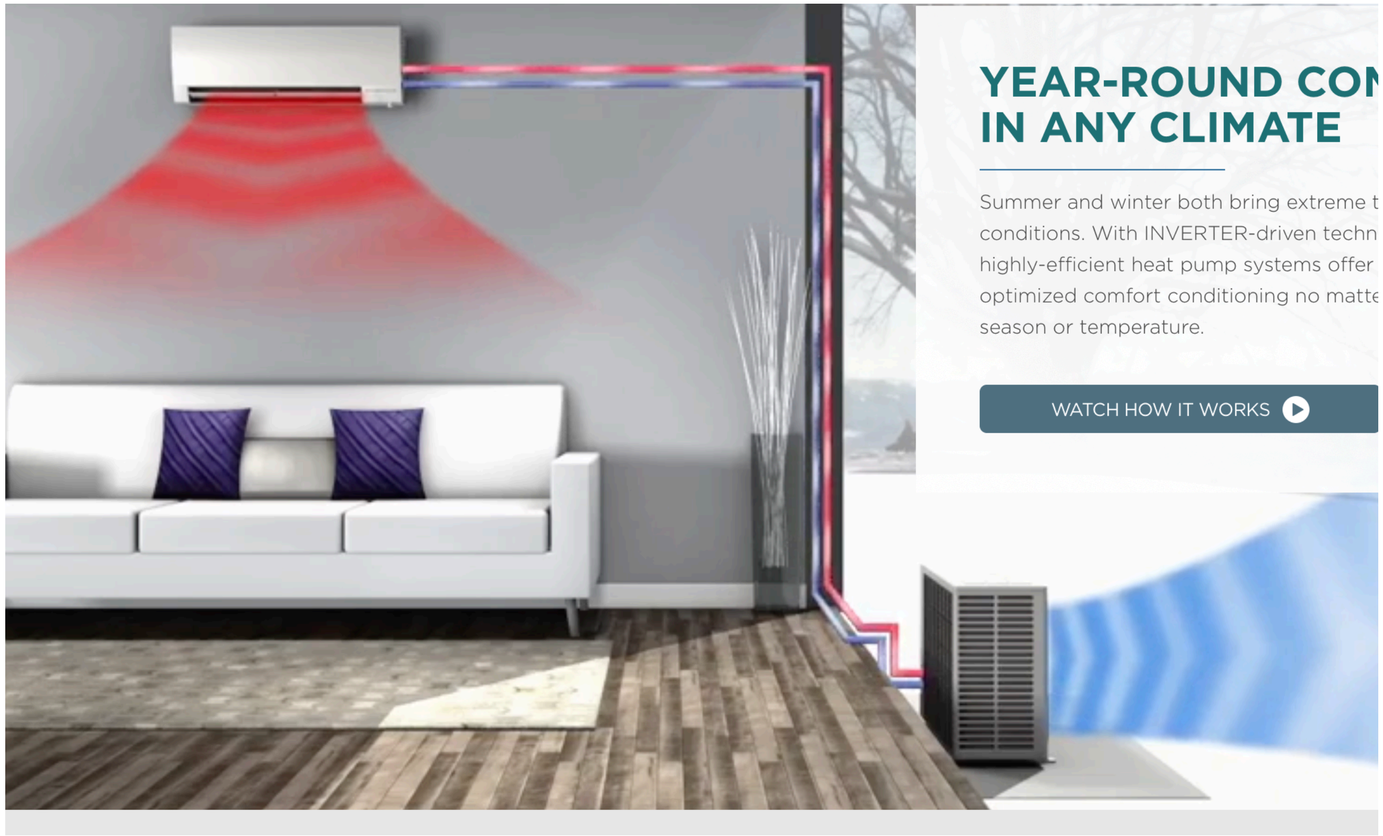
Heat pump

Coefficient of Performance
= kW(t) / kW(e)
= heat output / electicity input

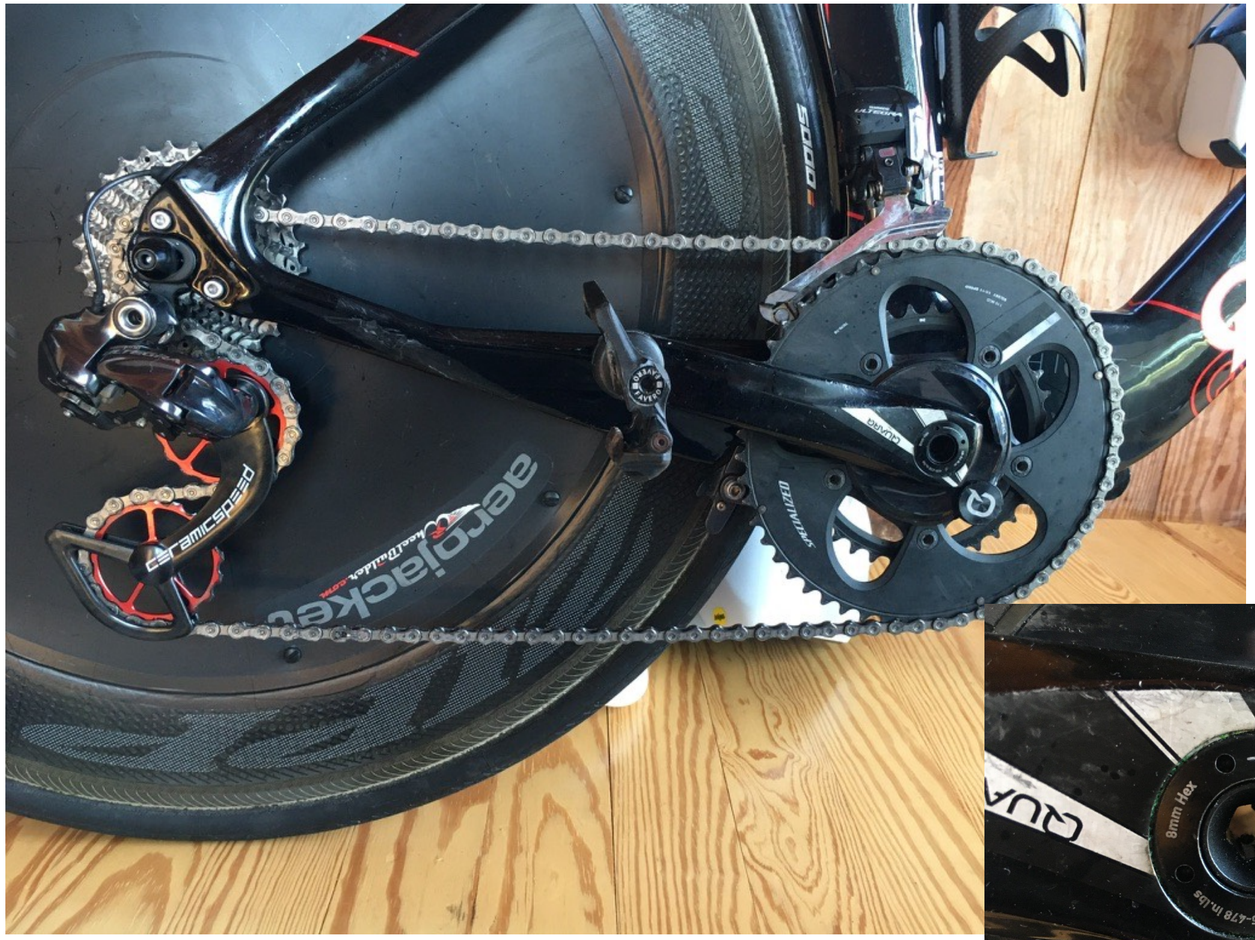
COP
~ 3.8 to 2.9

As air temperature drops
from 55°F to 5°F
heat output may drop
from 7 kW(t) to 3 kW(t).

Mitsubishi air source heat pump



Power = energy ***flow,***
measured in joules/sec = watts



NH Electric Coop buys/sells *energy* @ 6.6 cents/kWh.
It provided me *power* service up to 96 kilowatts.

Account Number	Cycle	Service Locatio
0303139512	1	4 STONE WAY

Meter Information — CANAAN

Rate	Meter #	Reading Dates Prev	Reading Dates Pres	Meter Re Prev
B	824271	07/01/2020	08/03/2020	4871

NHEC ELECTRIC CHARGES			AMOUNT
MEMBER SERVICE CHARGE			29.32
DELIVERY CHARGE	632 kWh x	0.040310	25.48
SYSTEM BENEFIT CHARGE	632 kWh x	0.006780	4.29
REGIONAL ACCESS CHARGE	632 kWh x	0.027060	17.10
CO-OP POWER	632 kWh x	0.066150	41.81
CURRENT NHEC ELECTRIC CHARGES			118.00

incl Power service -->
Transmission -->
Grant programs-->
Transmission -->
Energy -->

Oops, 2022 price jumped from 6.6 to 17.0 cents/kWh.

NHEC ELECTRIC CHARGES			
MEMBER SERVICE CHARGE			
DELIVERY CHARGE	79 kWh	x	0.040310
SYSTEM BENEFIT CHARGE	79 kWh	x	0.006780
REGIONAL ACCESS CHARGE	79 kWh	x	0.028470
CO-OP POWER	79 kWh	x	0.169830

Power = energy *flow,* measured in watts

Dumb answers to real questions:

Q: How far away is Burlington? distance
A: 65 miles per hour distance/time

Q: How much energy is stored in world batteries?
A: 180 megawatts energy/time

Next: California's grid operator and its largest newspaper print similar nonsense.

California ISO

Renewables Grid Initiative

"As of September 2019, global tracked energy storage totalled nearly 188 GW"

https://www.caiso.com/Documents/EnergyStorage-PerspectivesFromCalifornia-Europe.pdf

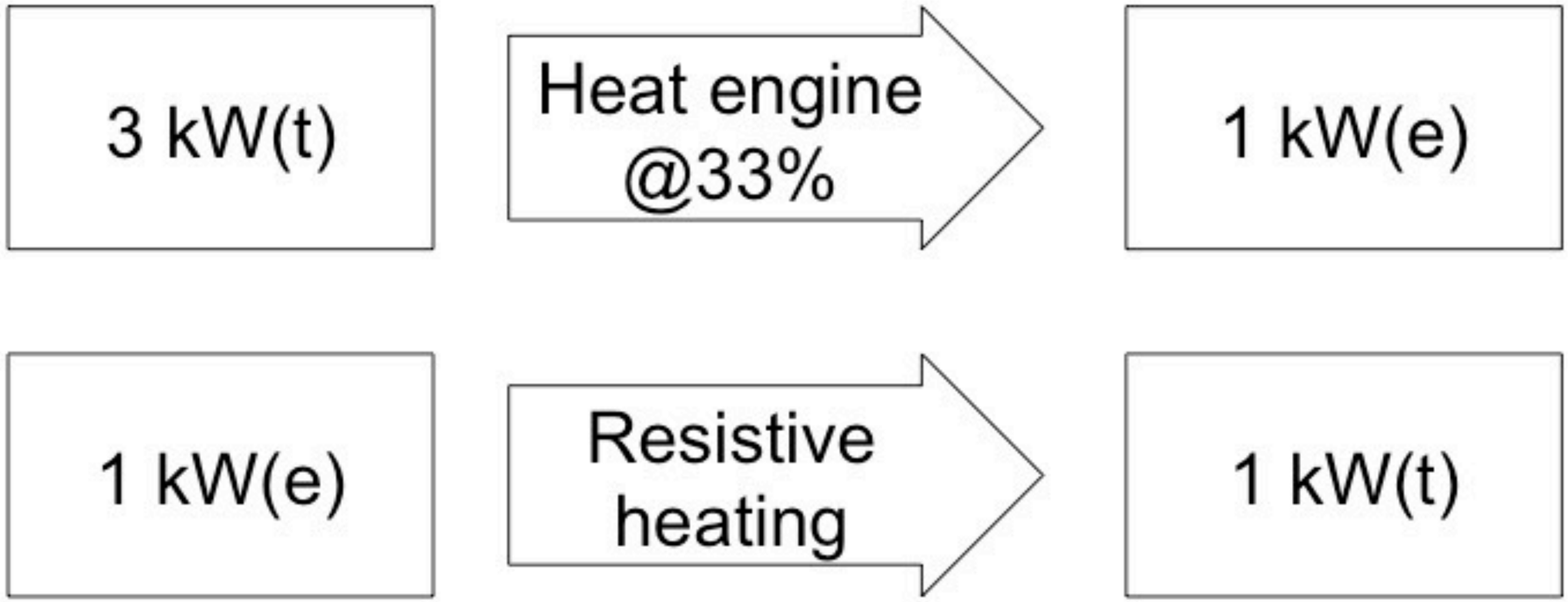
BUSINESS

Giant batteries, key to solar and wind power plans, start to get bank backing

"The U.S. has about 1,400 megawatts of battery storage — equivalent to the output of two natural-gas-fired power plants"

https://www.latimes.com/business/story/2020-03-04/solar-batteries-banks

Typical efficiency.



Useful energy decays to heat. [2nd Law]

kWh(e)

kWh(t) heat

Never add Wh(t) and Wh(e) and call it "total energy".

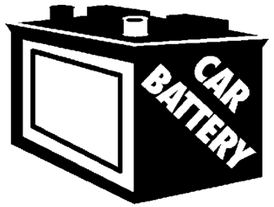
kWh(e)

kWh(t) heat

It’s like adding Miles + Kilometers, and calling it Distance!

Examples: energy, flowing (power), to energy

Lithium ion battery



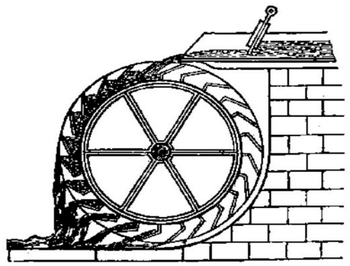
Chemical potential energy

200 kW
electric power

Electric car

Kinetic energy

Hydro power plant



Gravitational potential energy

1000 W
electric power

Toaster

Thermal energy

You now know more about energy and power than policy makers, politicians and reporters. You can

Distinguish **heat energy** from **useful energy.**

Distinguish **power** from **energy.**

Useful energy includes electricity, kinetic energy, gravitational potential energy, to do **work** (force x distance)

Power is energy **flow** (energy per unit time)

Distinguish **heat** power from **useful** power.

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.

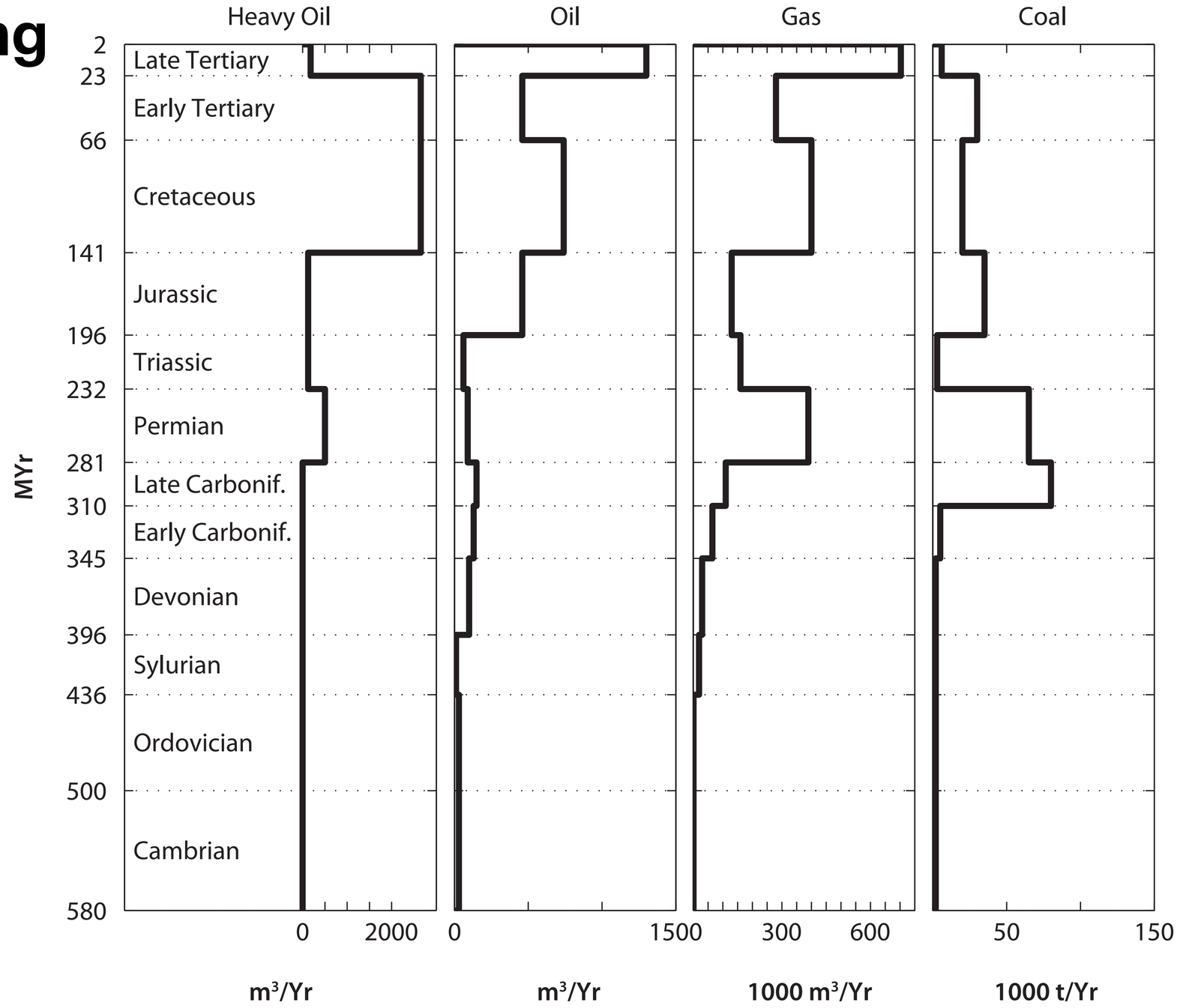
How the World Really Works by Vaclav Smil — what powers our economies

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



https://12dadd6d-9c4d-e9cc-5e32-ec7b4524c1a4.filesusr.com/ugd/eca6d5_75b738f056fb44a5ae1f2b7ead8f8fcb.ppt?dn=SPU-14%20Glacial%20Cycles%202016.ppt

Annual discharge of world carbon battery

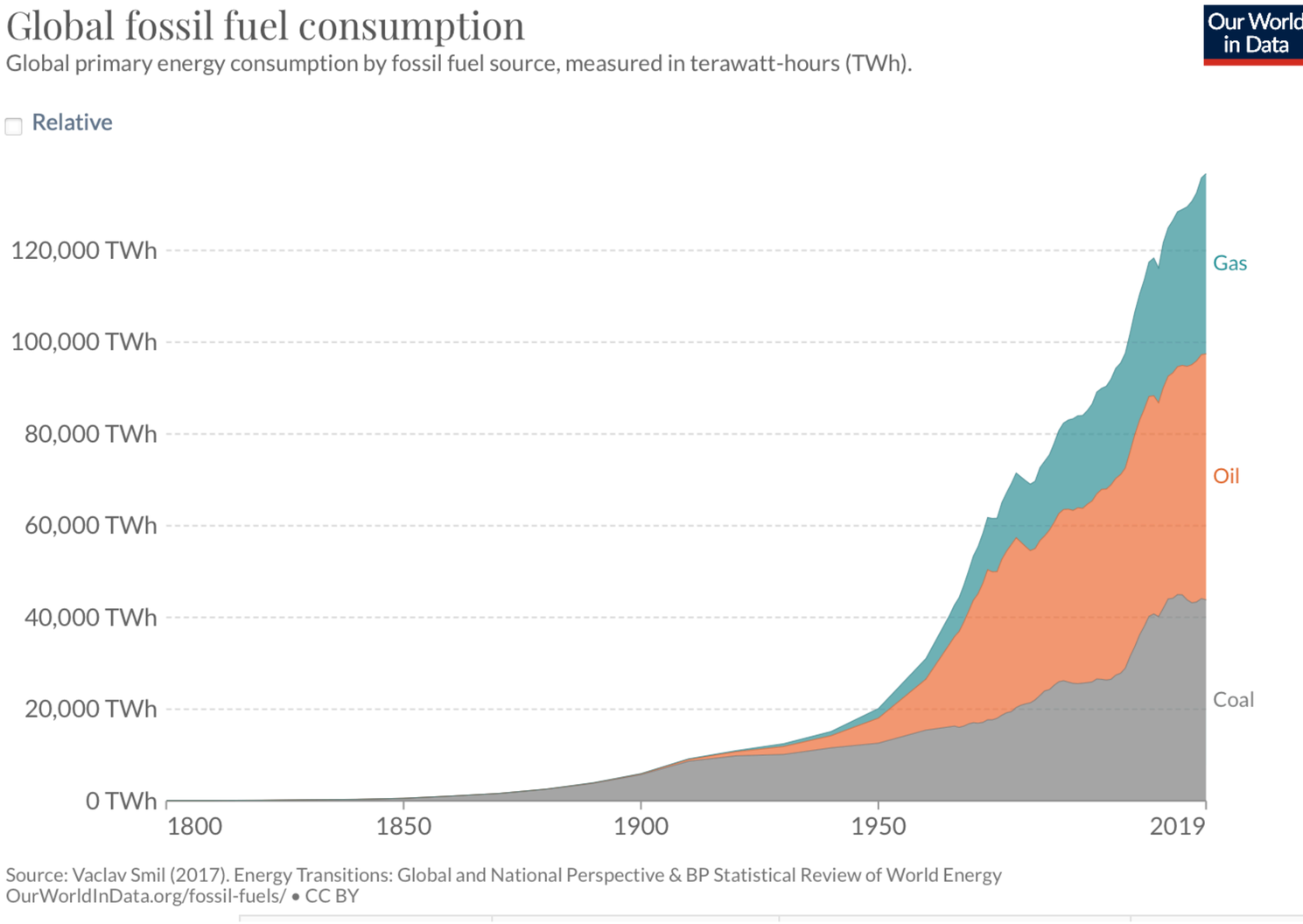
130,000 TWh (heat)

~ 468 EJ

~ 40 billion tons of oil or coal

~ 4 cubic miles of oil

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



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

https://ourworldindata.org/explorers/energy?tab=chart&facet=none&country=USA~GBR~CHN~OWID_WRL~IND~BRA~ZAF&Total+or+Breakdown=Total&Energy+or+Electricity=Primary+energy&Metric=Annual+consumption

King Hubbert, for Shell, 1956

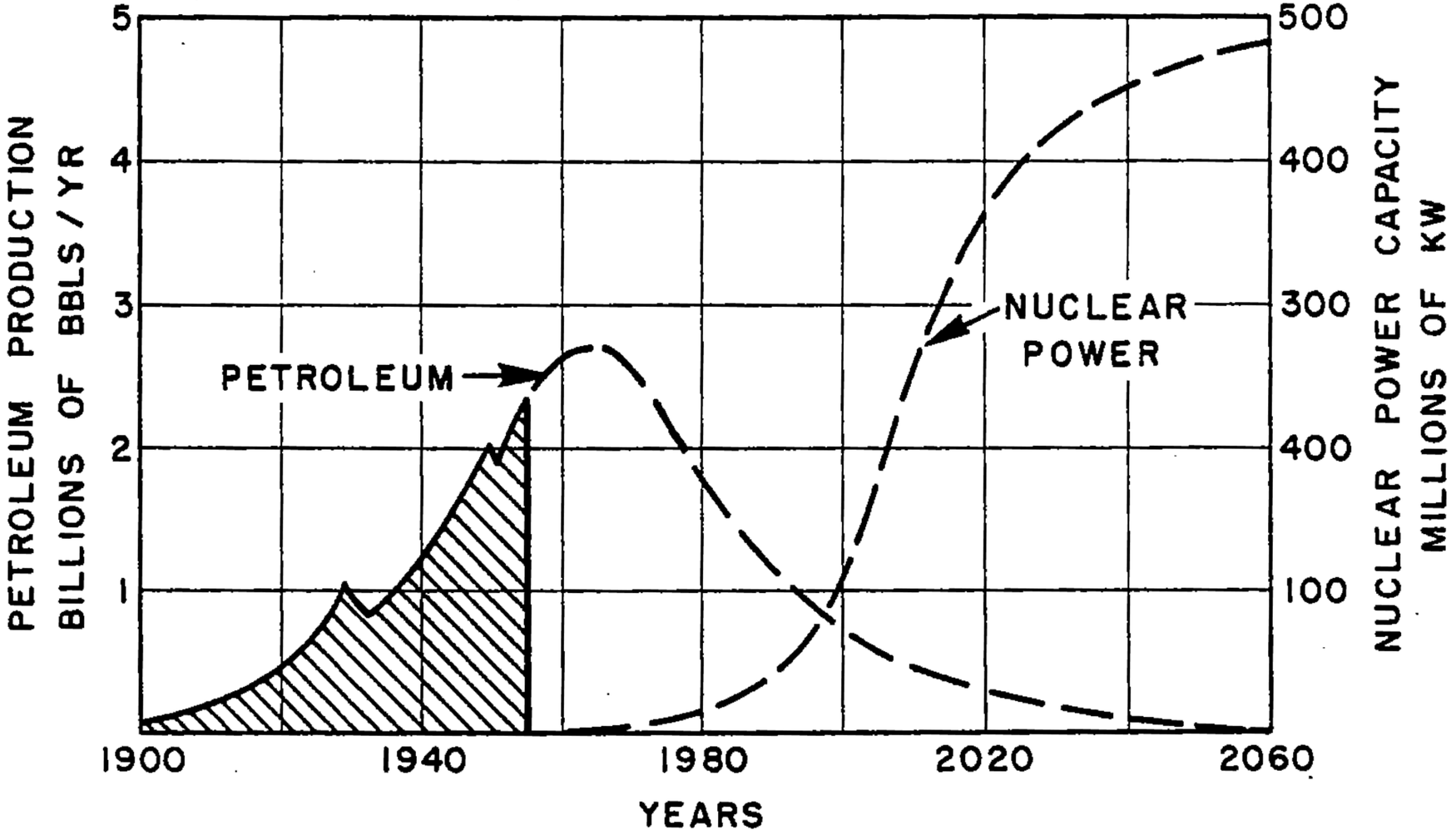
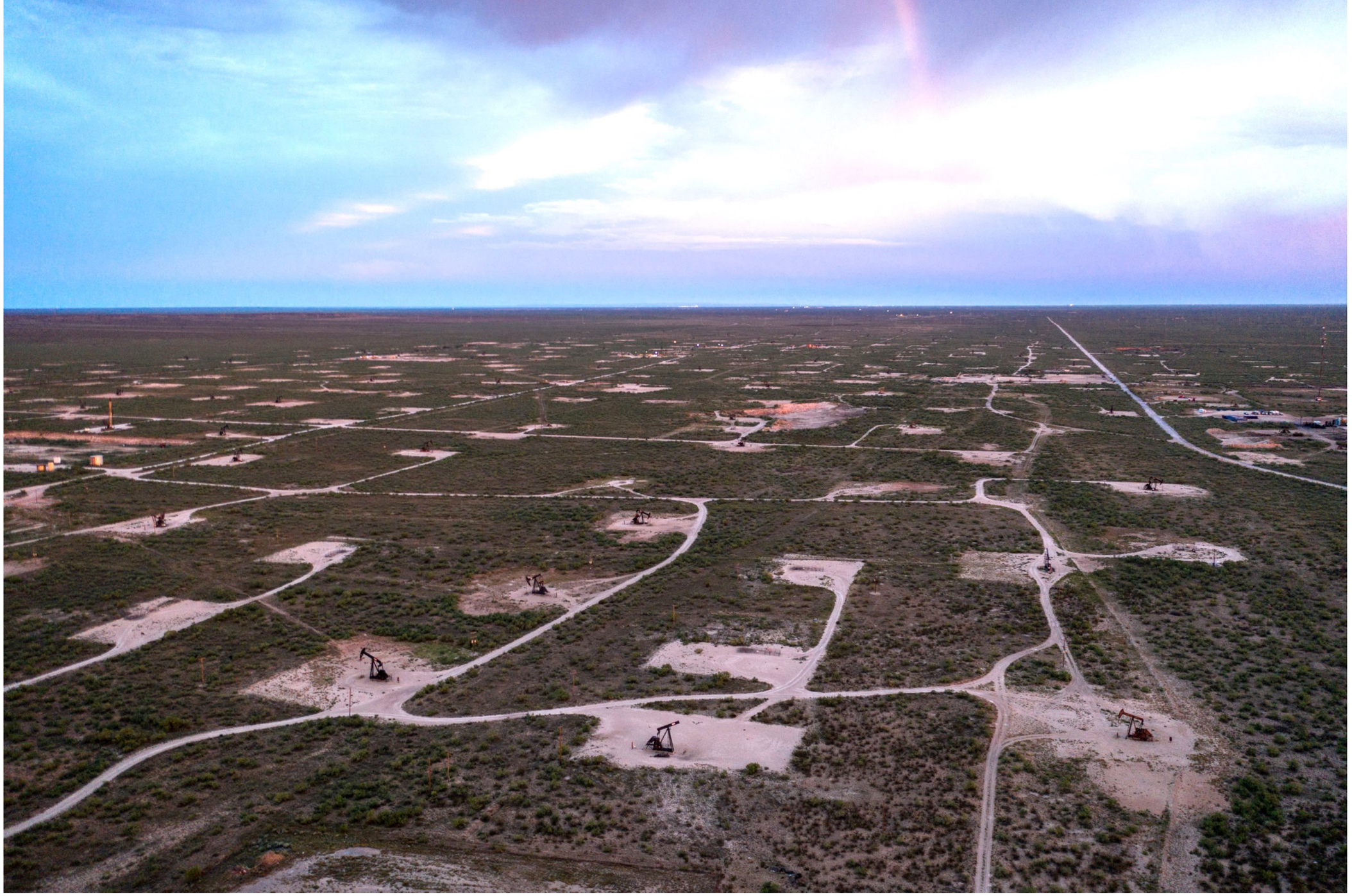


Figure 29 - Concurrent decline of petroleum production and rise of production of nuclear power in the United States. Growth rate of 10 percent per year for nuclear power is assumed; actual rate may be twice this amount.

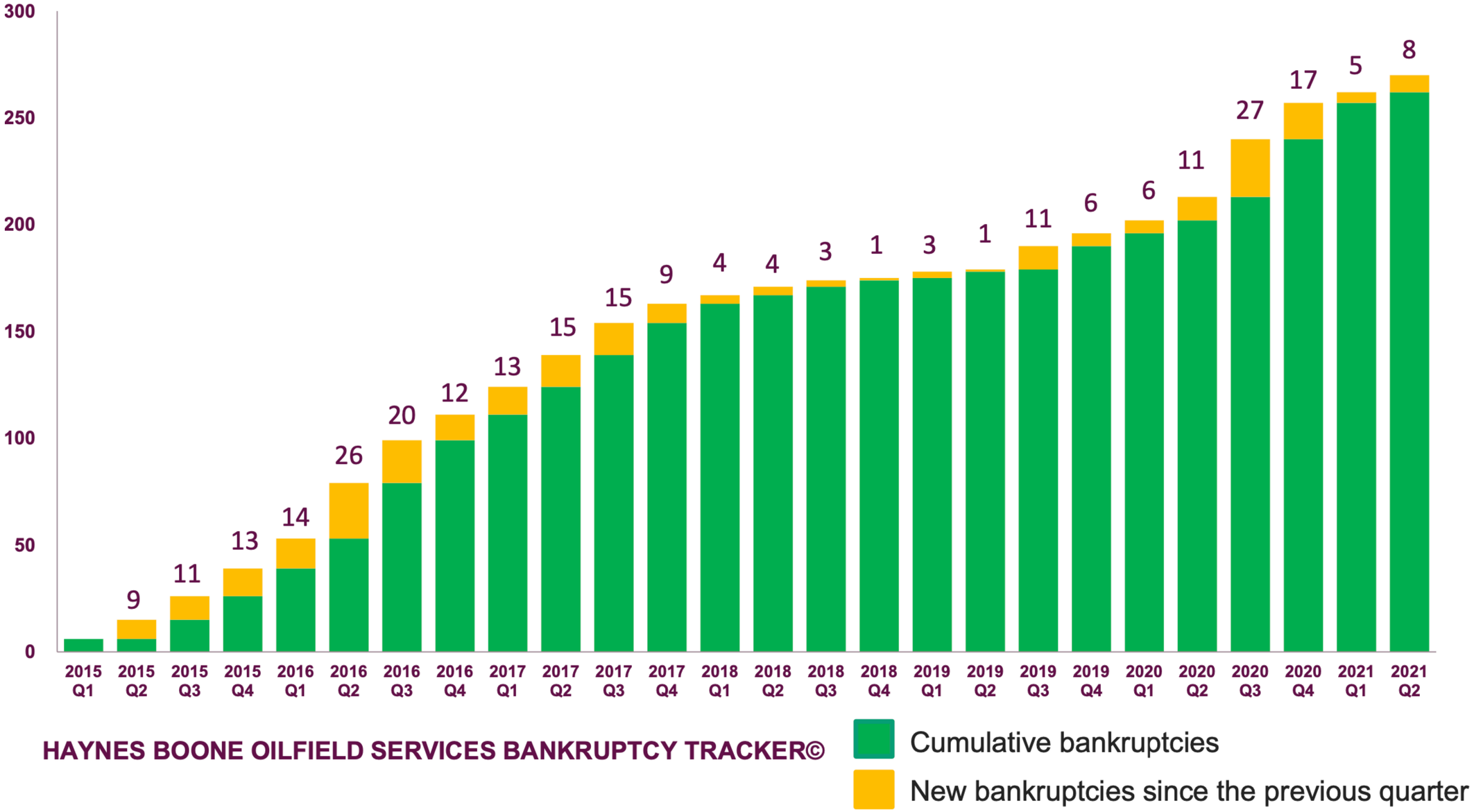
http://www.energycrisis.com/Hubbert/1956/1956.pdf

Penwell, TX, 2020



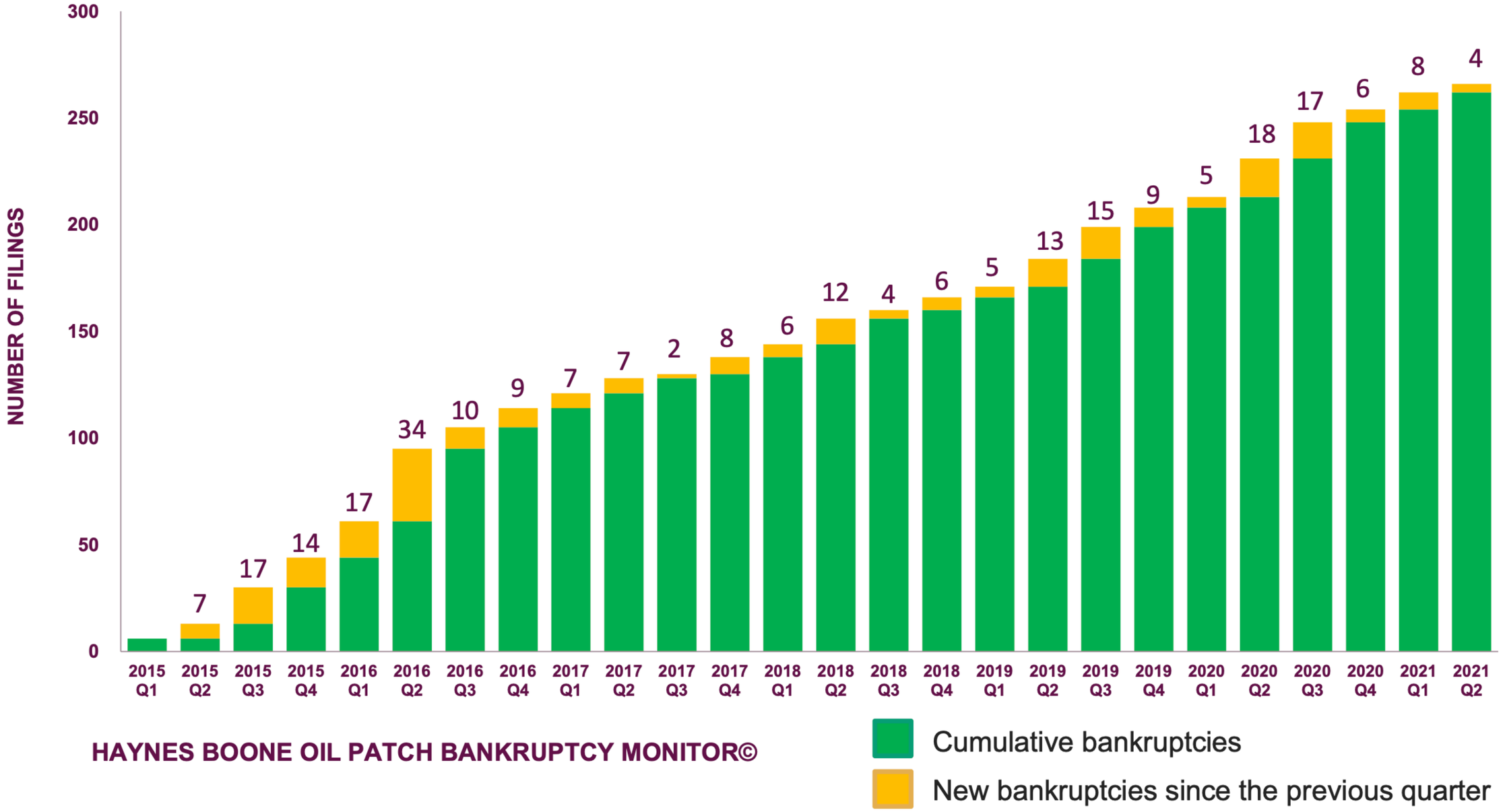
https://www.wsj.com/articles/fracking-oil-prices-shale-boom-11643824329?mod=hp_lead_pos4

Oilfield services bankruptcies: $117 billion, 2015-2021



https://www.haynesboone.com/-/media/project/haynesboone/haynesboone/pdfs/energy_bankruptcy_reports/oilfield_services_bankruptcy_tracker.pdf?rev=9854fe54a05f4611ad63dda65c2a1f26&hash=52EF867504D7FA8EC9F4CF9F1453090D

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



https://www.haynesboone.com/-/media/project/haynesboone/haynesboone/pdfs/energy_bankruptcy_reports/oil_patch_bankruptcy_monitor.pdf?rev=61c2606a5be547598c8d716d1a795c39&hash=97ECA4B149560404B19497FA37CB2B50

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

WSJ
Feb 3, 2020

“despite the highest oil prices in years”

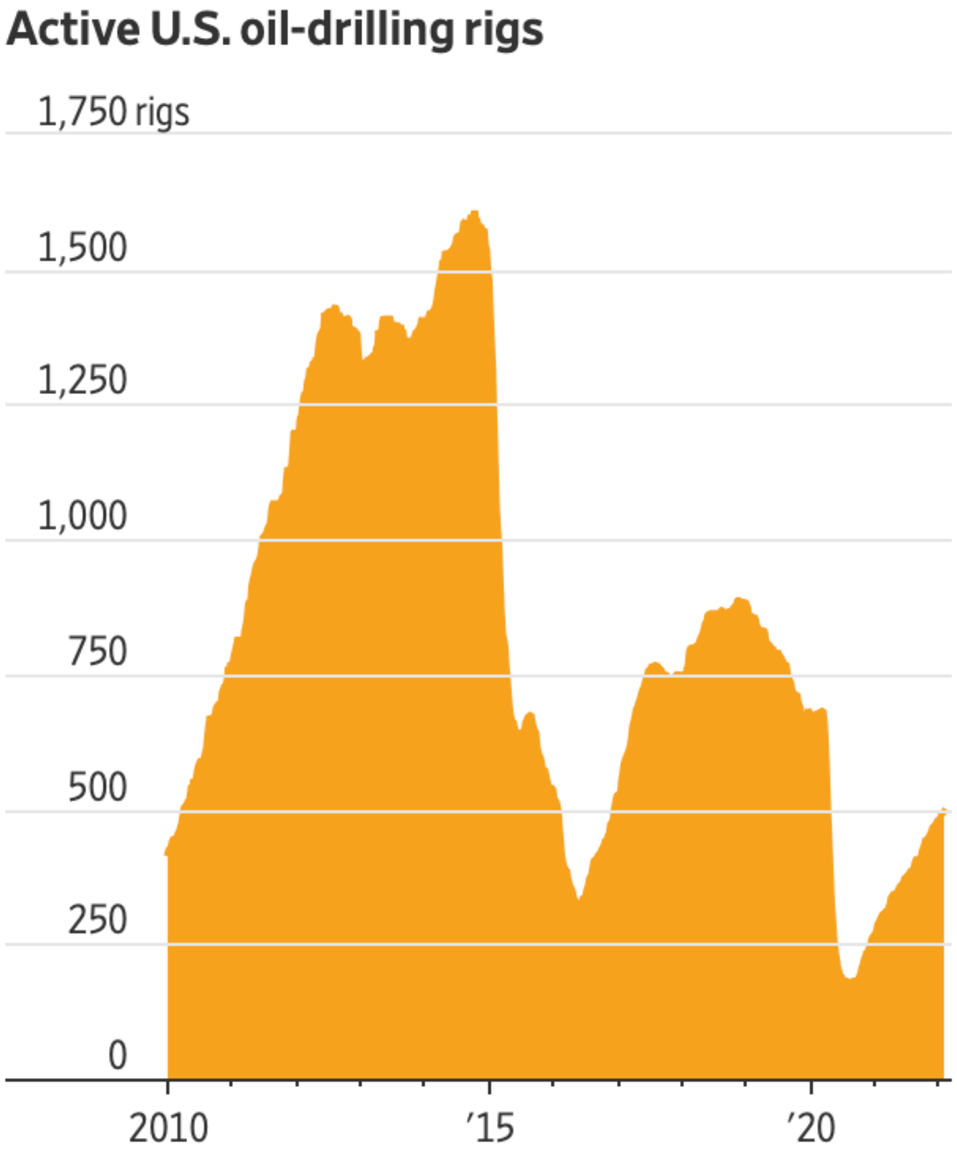
“pressured companies to slow production growth and return cash to shareholders rather than pump it back into drilling”

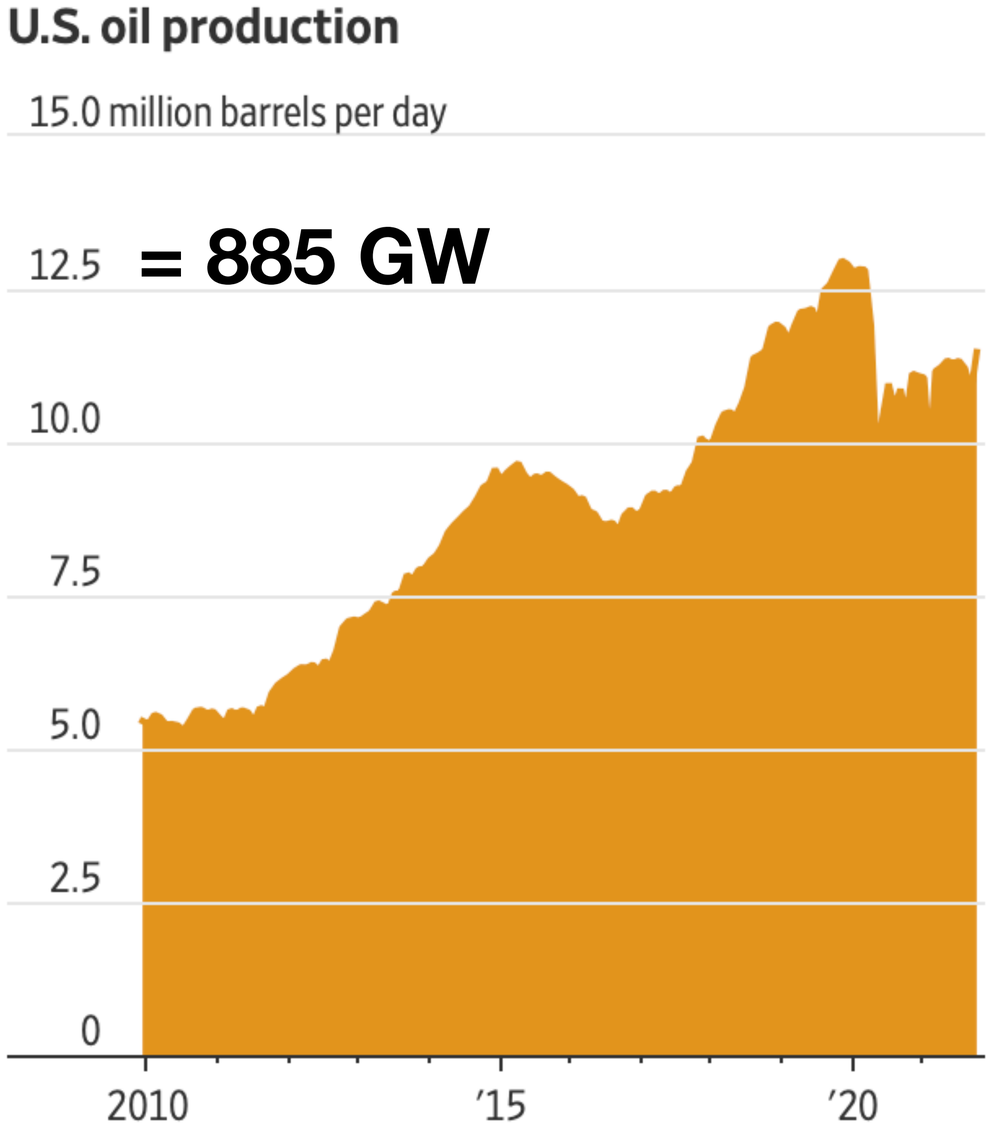
https://www.wsj.com/articles/fracking-oil-prices-shale-boom-11643824329?mod=hp_lead_pos4

US drilled but uncompleted oil wells

https://doomberg.substack.com/p/shooting-oil-in-a-barrel

Pump, baby, pump.

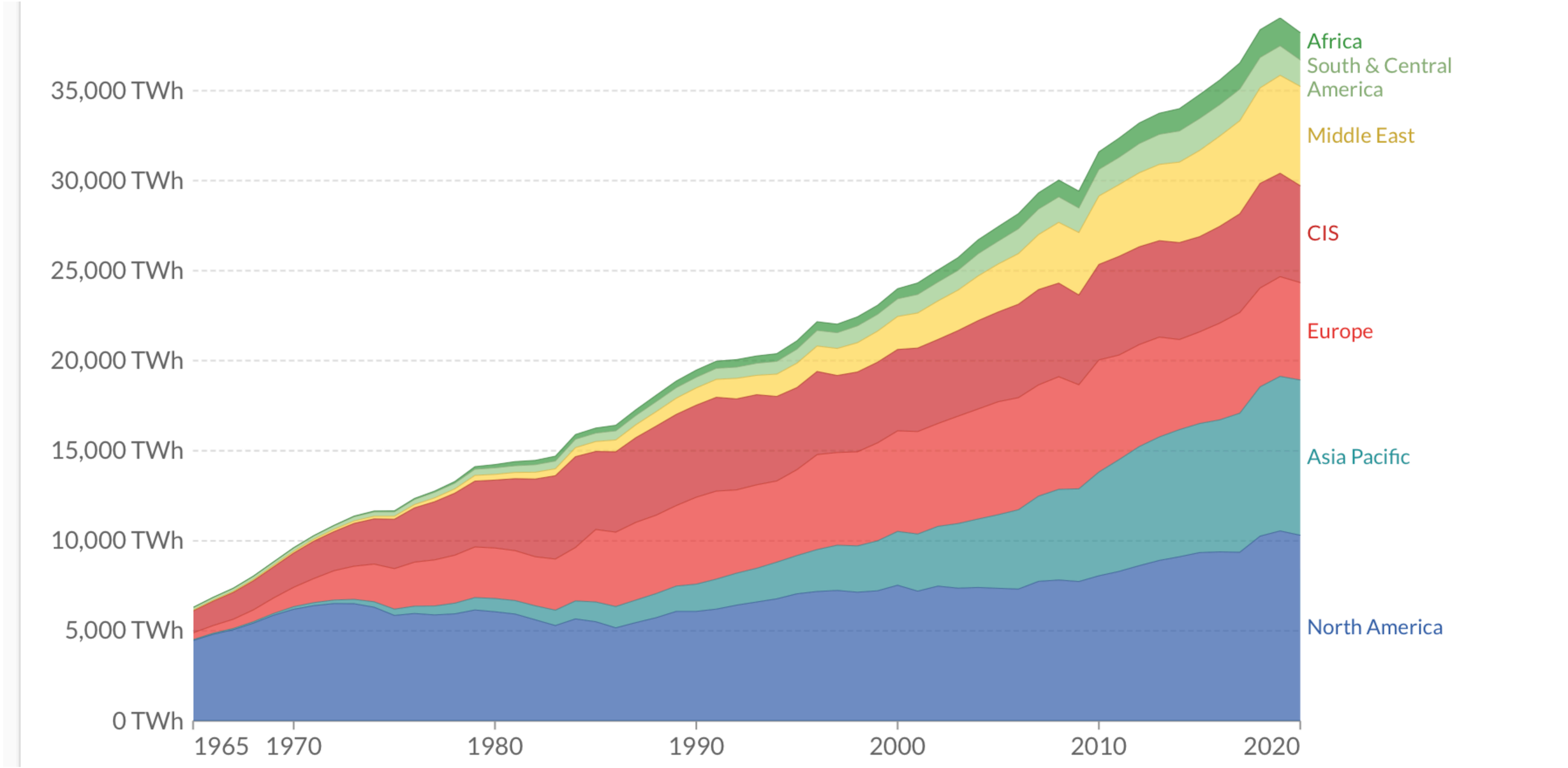




https://www.wsj.com/articles/fracking-oil-prices-shale-boom-11643824329?mod=hp_lead_pos4

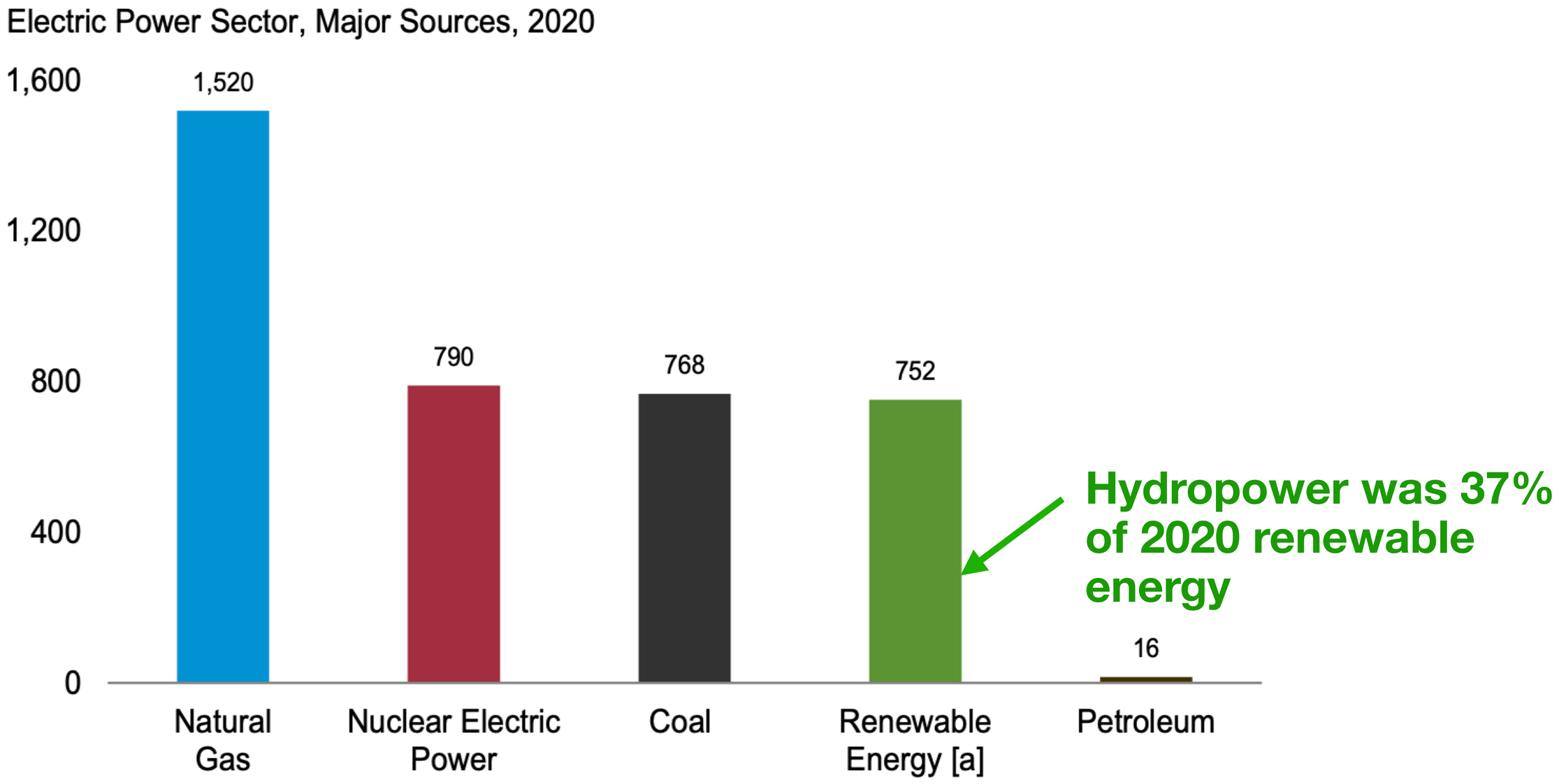
Gas consumption by region (2020)

4,400 GW total



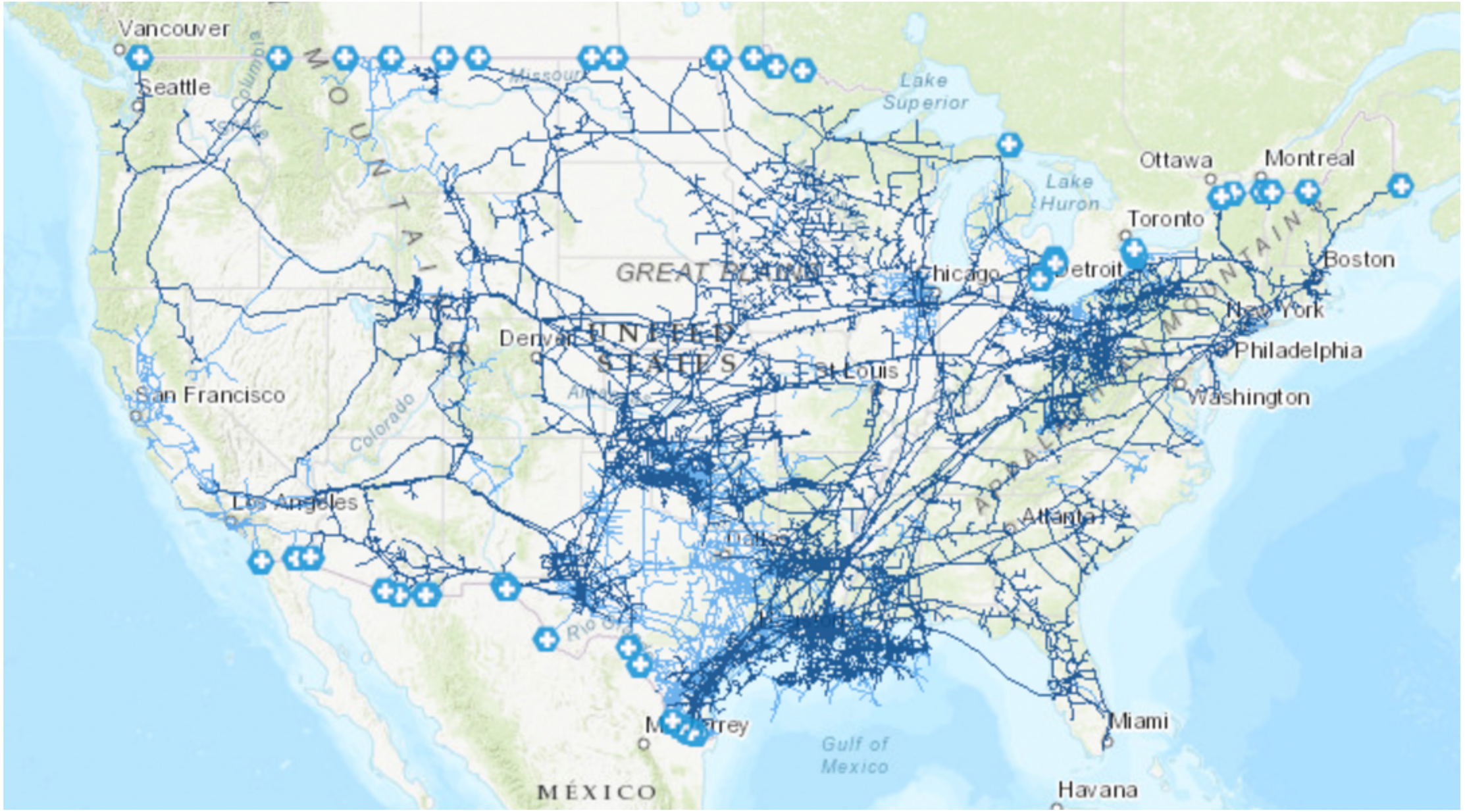
https://ourworldindata.org/grapher/natural-gas-consumption-by-region

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



https://www.eia.gov/totalenergy/data/monthly/pdf/sec7.pdf https://www.eia.gov/energyexplained/hydropower/

US pipelines supply natural gas for electricity and heating.



https://doomberg.substack.com/p/have-fun-staying-cold?s=w

Liquified Natural Gas liquefaction and transport

Sabine Pass, liquefaction train #4

$2 to 4 billion each

https://pgjonline.com/news/2017/10/sabine-pass-train-4-placed-in-service

Typical $200 million LNG tankship

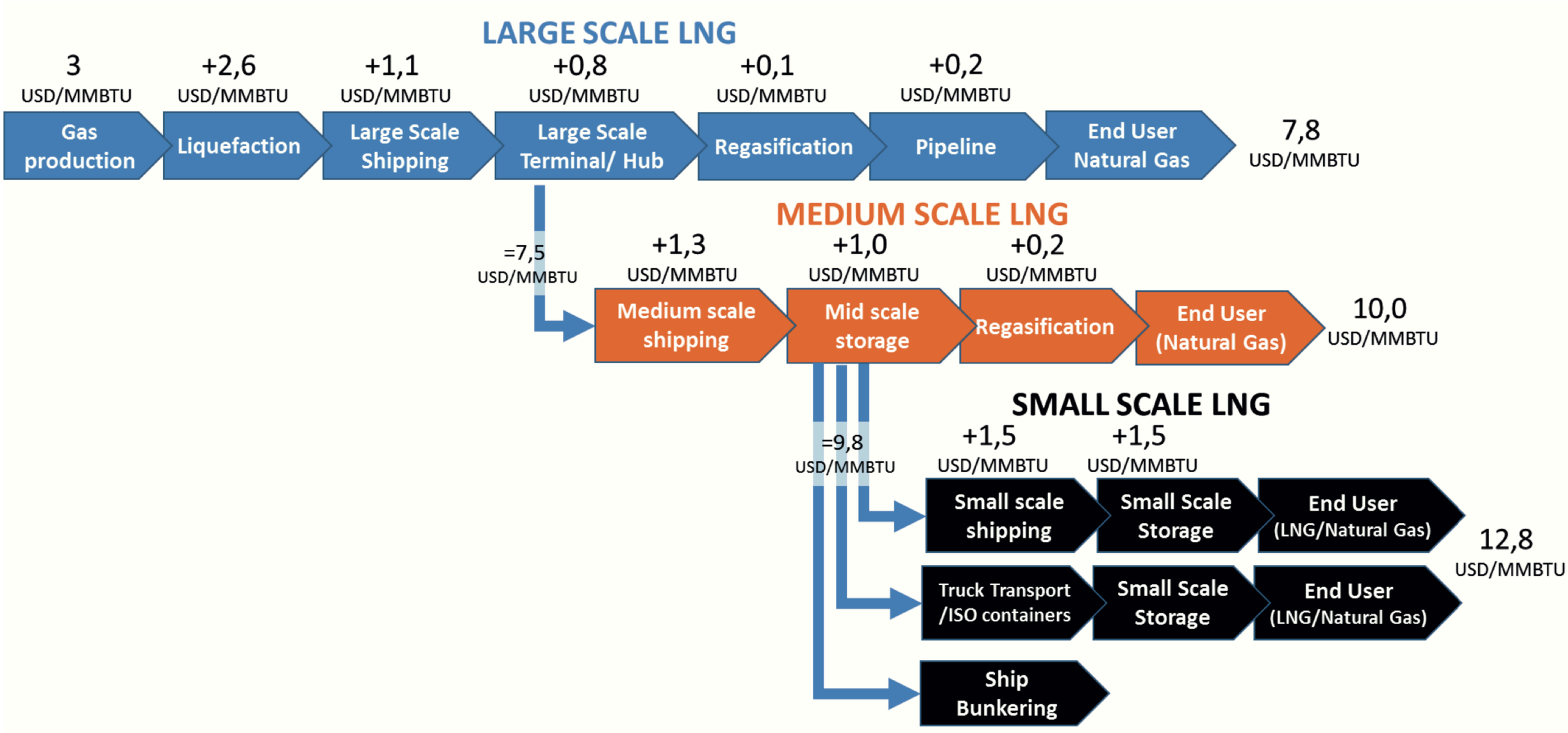
LNG liquid at -160°C

https://pgjonline.com/news/2017/10/sabine-pass-train-4-placed-in-service

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

https://www.econnectenergy.com/articles/how-does-regasification-of-lng-work

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



https://cdn.wartsila.com/docs/default-source/oil-gas-documents/white-paper-o-lng-logistics-chain.pdf?sfvrsn=4

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

LNG Flows in December 2021

in million tons of LNG

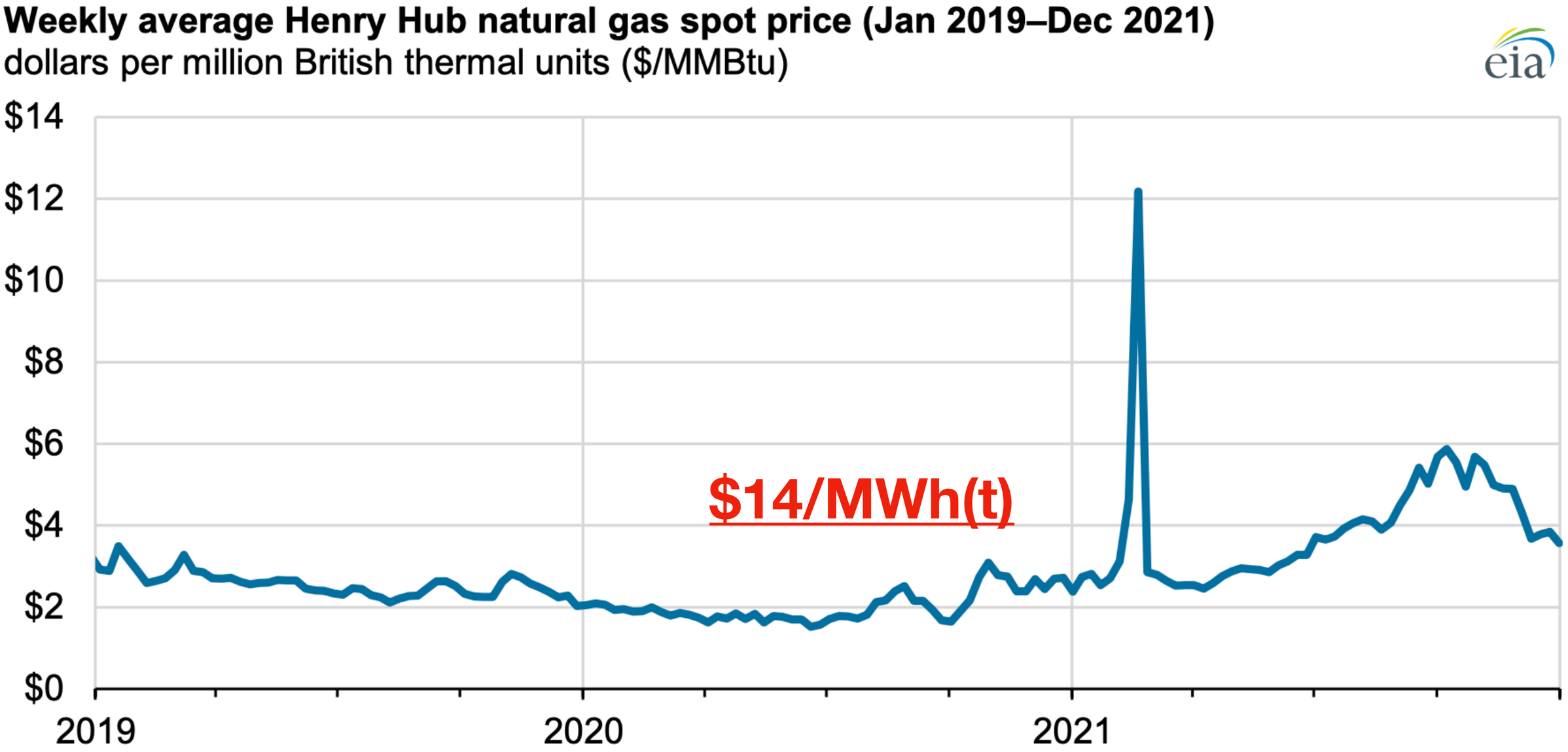
From / To	Asia	Europe	Americas	Total
Qatar	5.67	1.05	0.09	**6.80**
United States	1.91	4.17	0.73	**6.80**
Africa	1.14	2.73	0.14	**4.01**
Russia (West)	0.37	1.44	0.00	**1.81**
Australia	7.14	0.00	0.00	**7.14**
Rest of Asia	5.90	0.03	0.07	**5.97**
Russia (East)	1.03	0.00	0.00	**1.03**
Rest of World	1.14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

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

Europe total natural gas 488 GW;135 GW from LNG

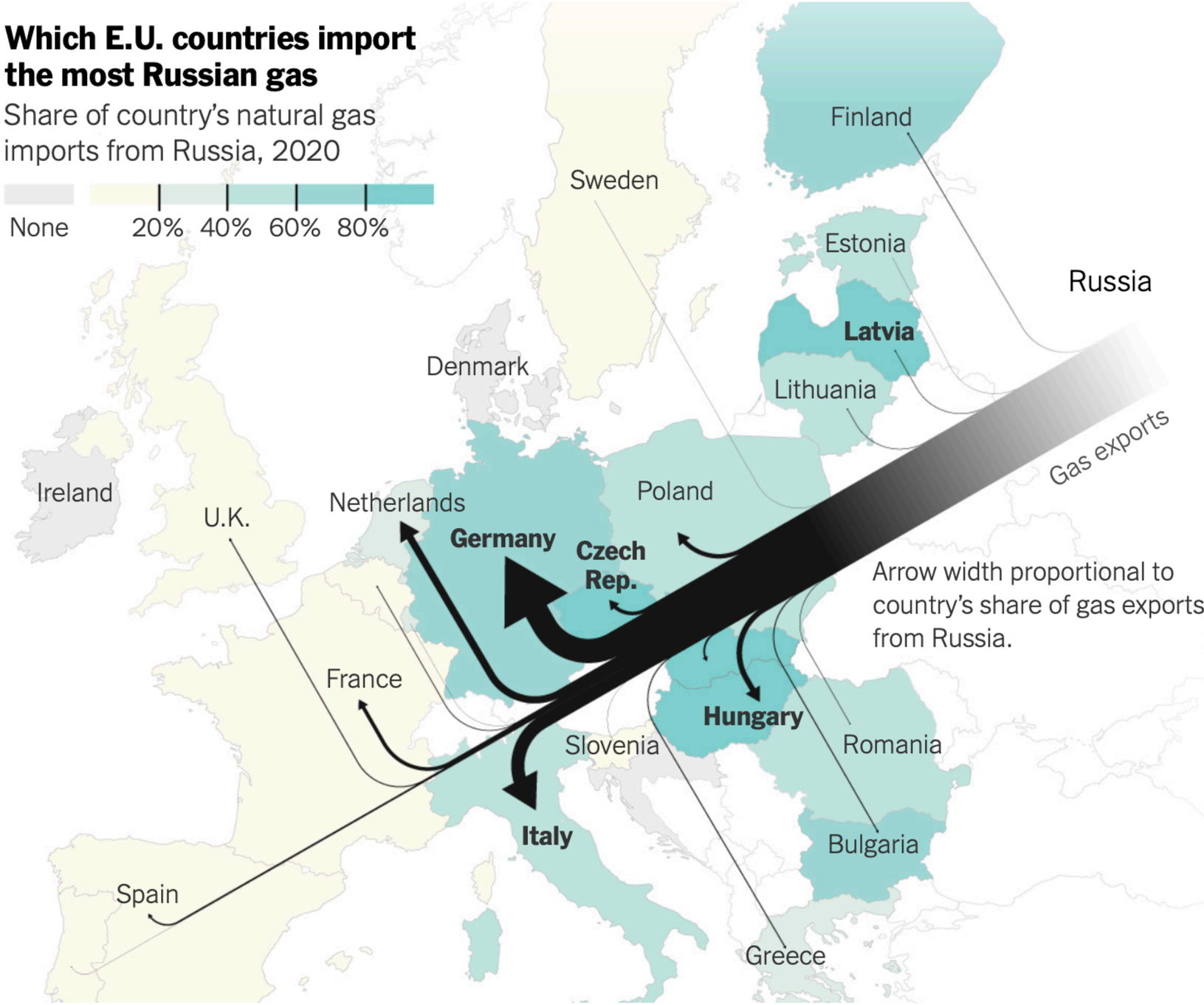
1 million tons of LNG ~ 1.17 tons oil equivalent

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



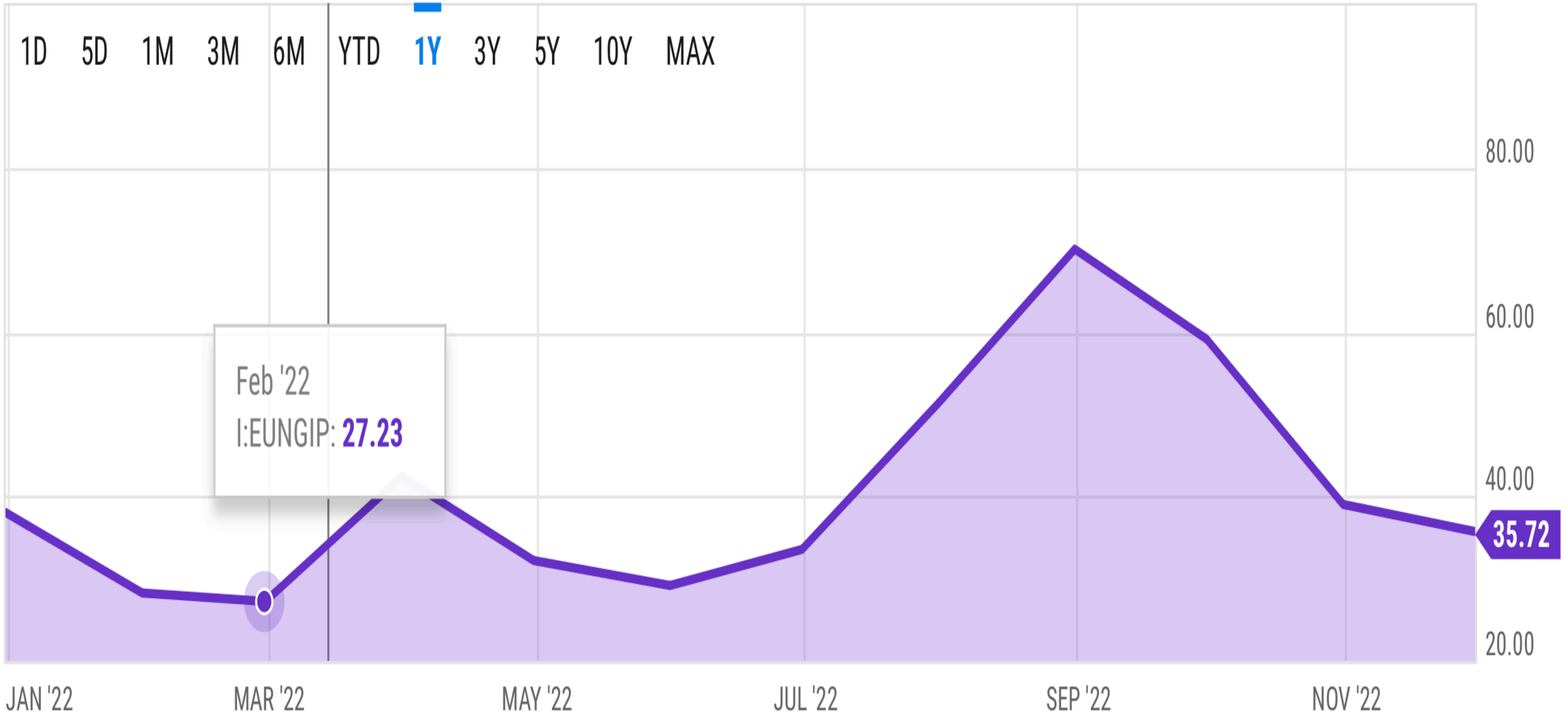
https://www.eia.gov/todayinenergy/detail.php?id=50778

Russia dominates natural gas supplies to Europe.



https://www.nytimes.com/interactive/2022/02/15/business/energy-environment/russia-gas-europe-ukraine.html https://www.eia.gov/energyexplained/hydropower/

European Union Natural Gas Import Price $35.72/MMBtu



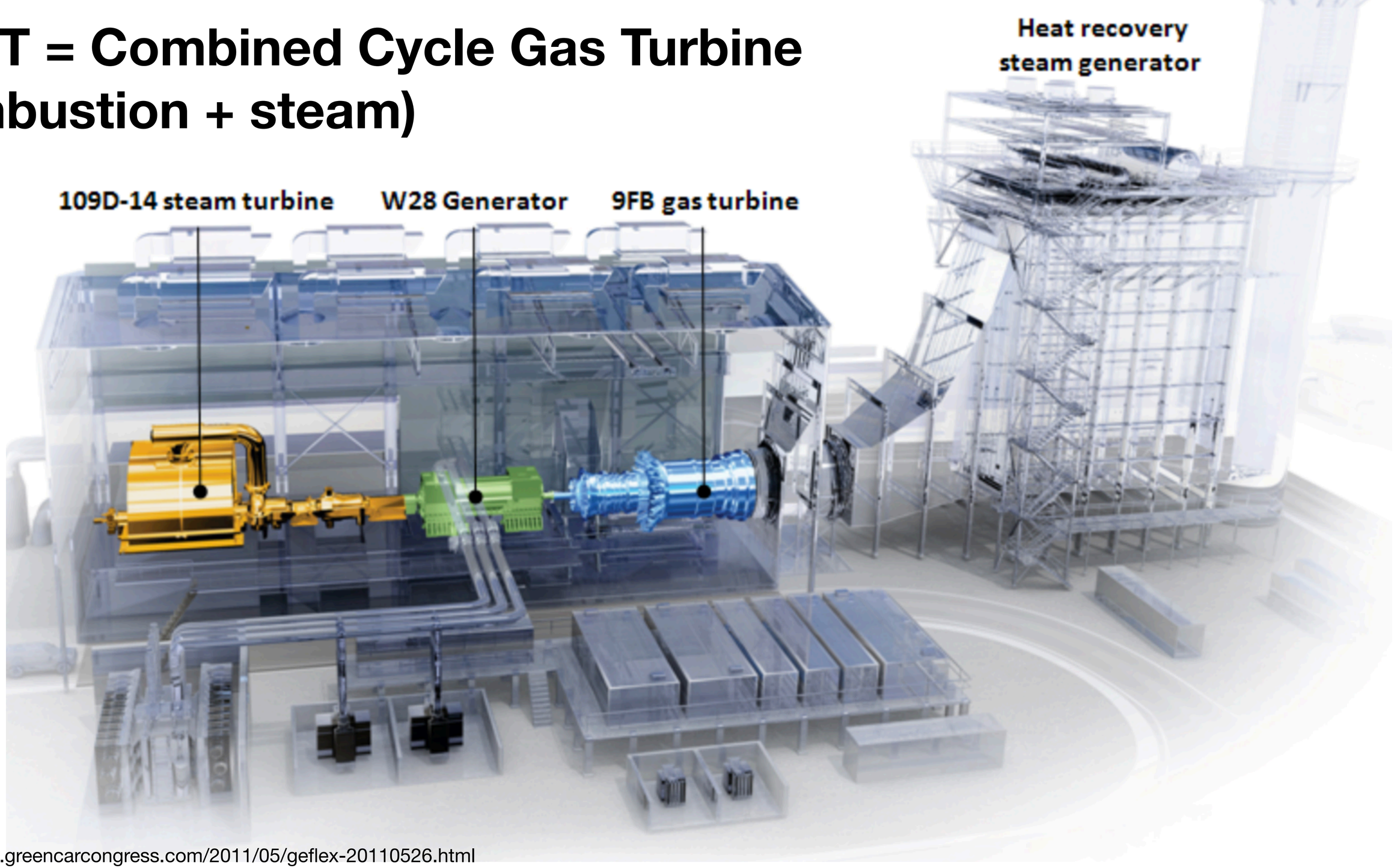
https://ycharts.com/indicators/europe_natural_gas_price

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

photo https://www.ge.com/news/reports/ges-new-repair-tech-center-in-singapore-helps-asia-flip-the-switch-to-gas-power

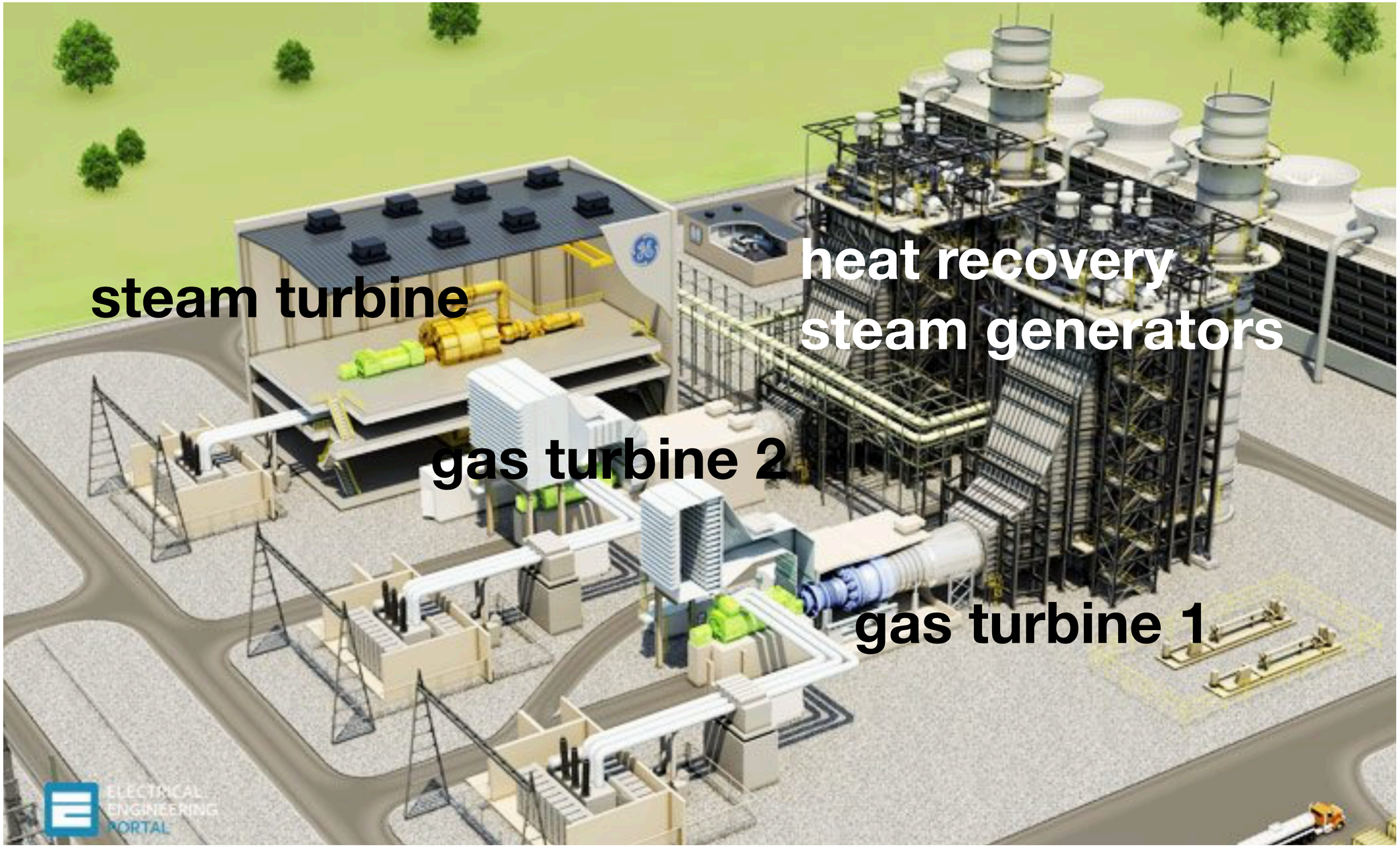
US DOE EIA data

CCGT = Combined Cycle Gas Turbine (combustion + steam)



https://www.greencarcongress.com/2011/05/geflex-20110526.html

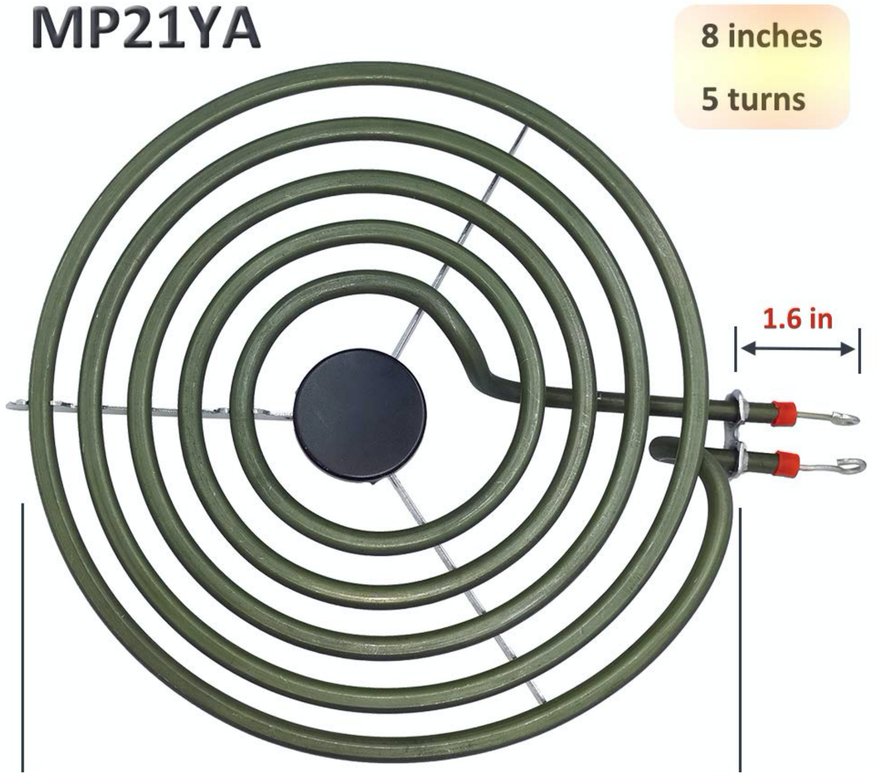
CCGT plant, 53% efficiency: $1100/kW



https://electrical-engineering-portal.com/an-overview-of-combined-cycle-power-plant

Banning home gas stoves burns more gas.

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



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.

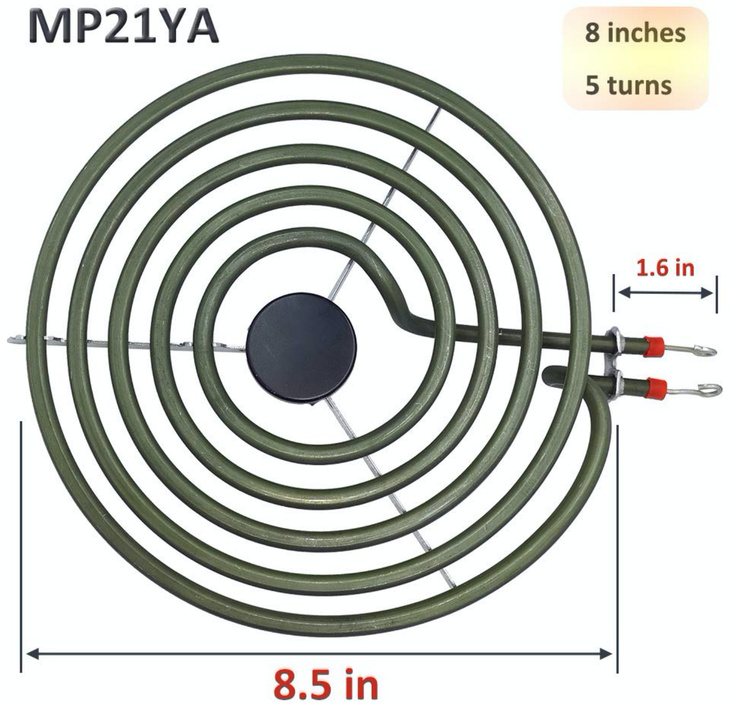
BUT, fission, wind, or solar power would cause no CO2 emissions.

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

Solar power not available for evening meal cooking.

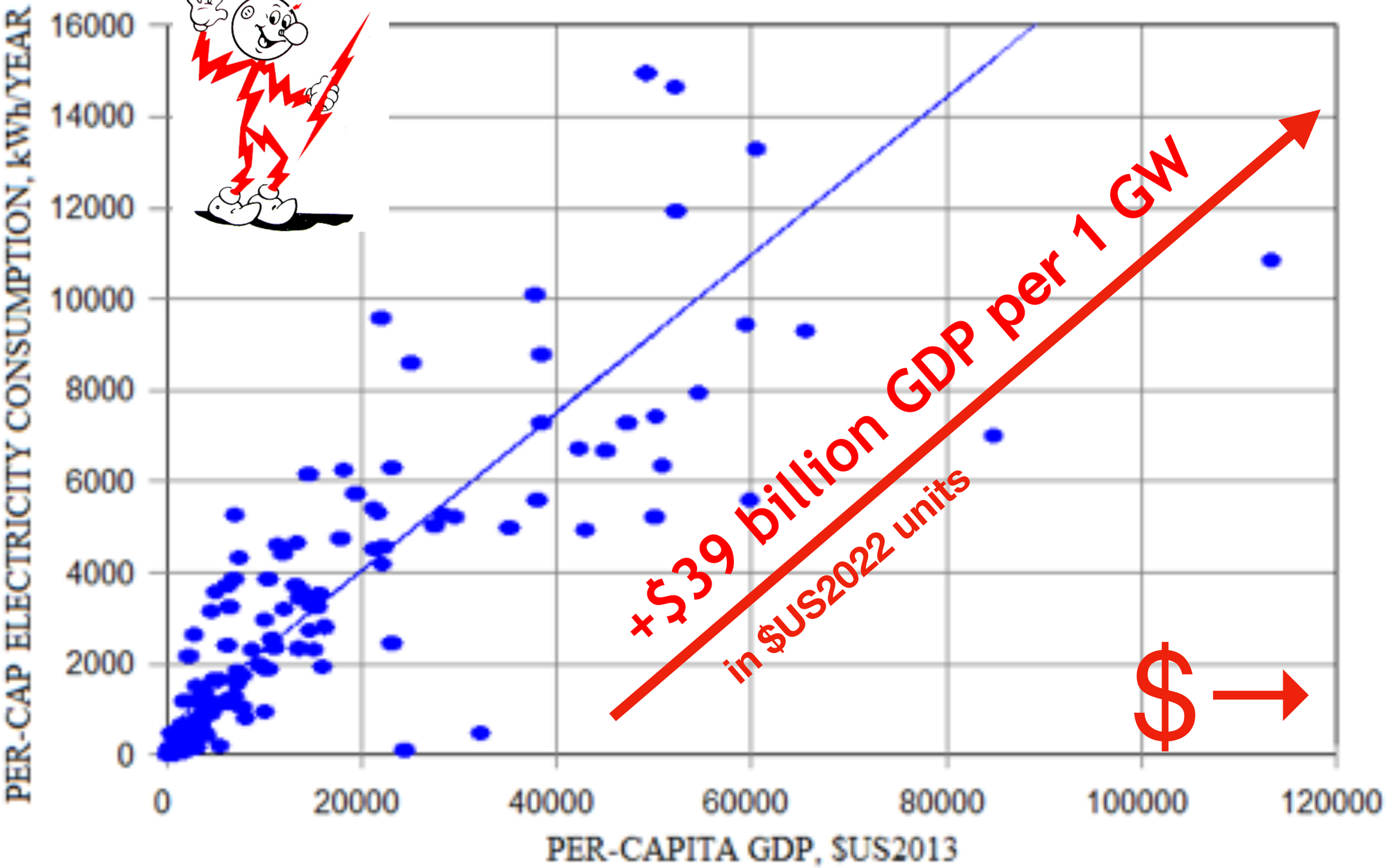
Wind does not speed up when you turn the stove on.

Dispatchable power on demand is needed.

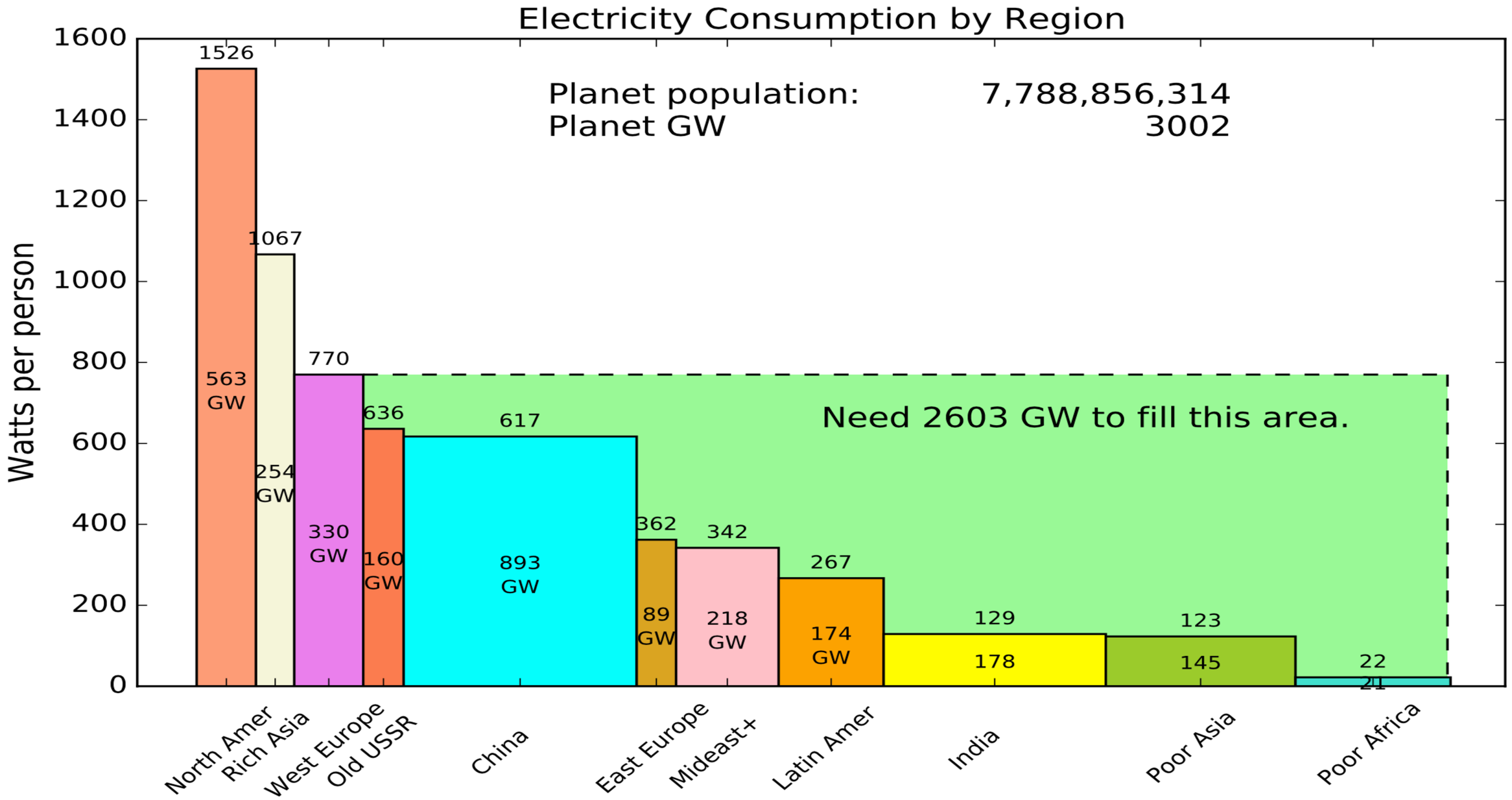


Power company burns
~ 4.5 kW(t) natural gas
to generate 2 kW(e) of electricity
to make 2 kW(t) of heat

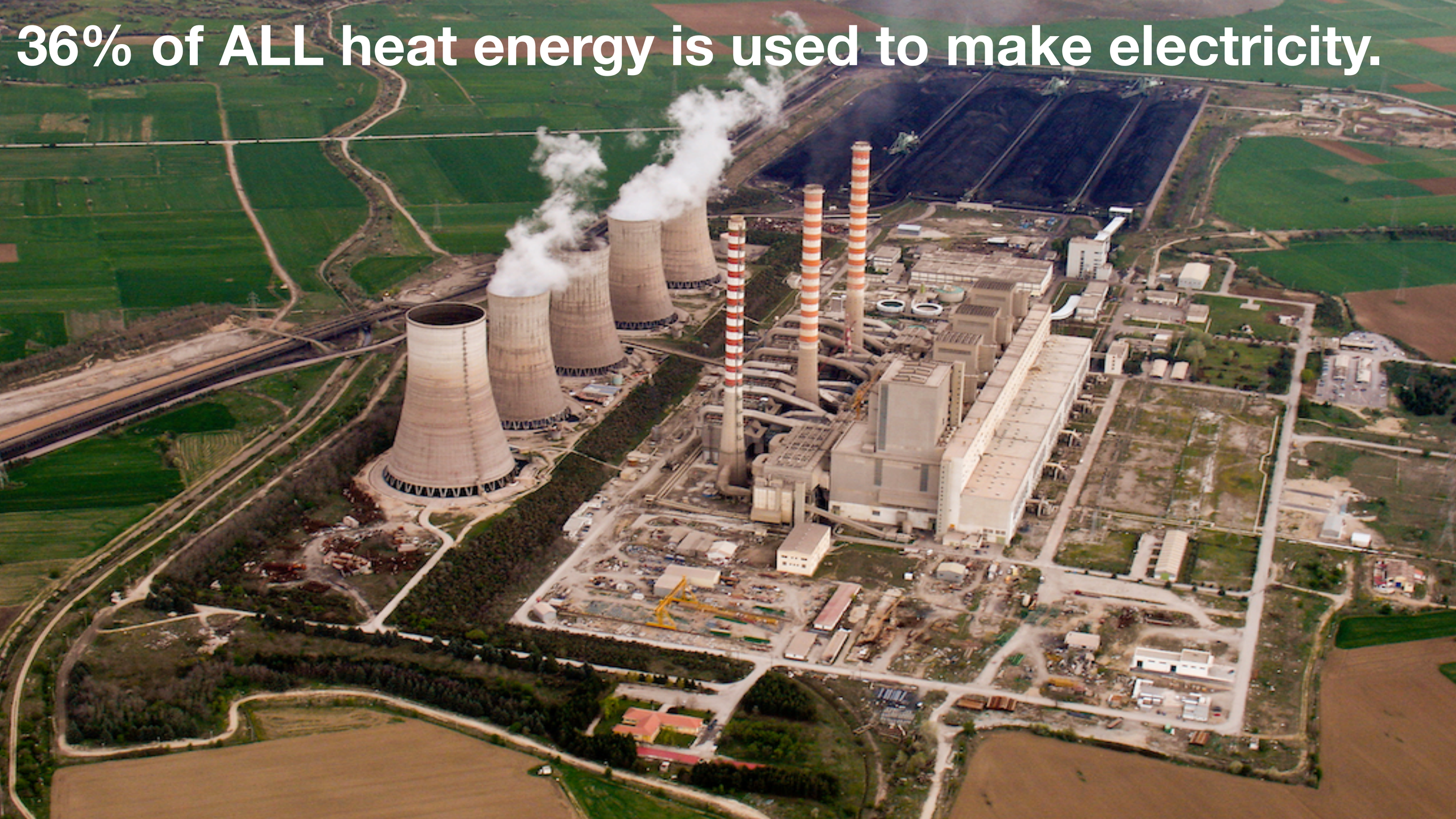
Nations' GDPs are proportionate to electric power.



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



36% of ALL heat energy is used to make electricity.



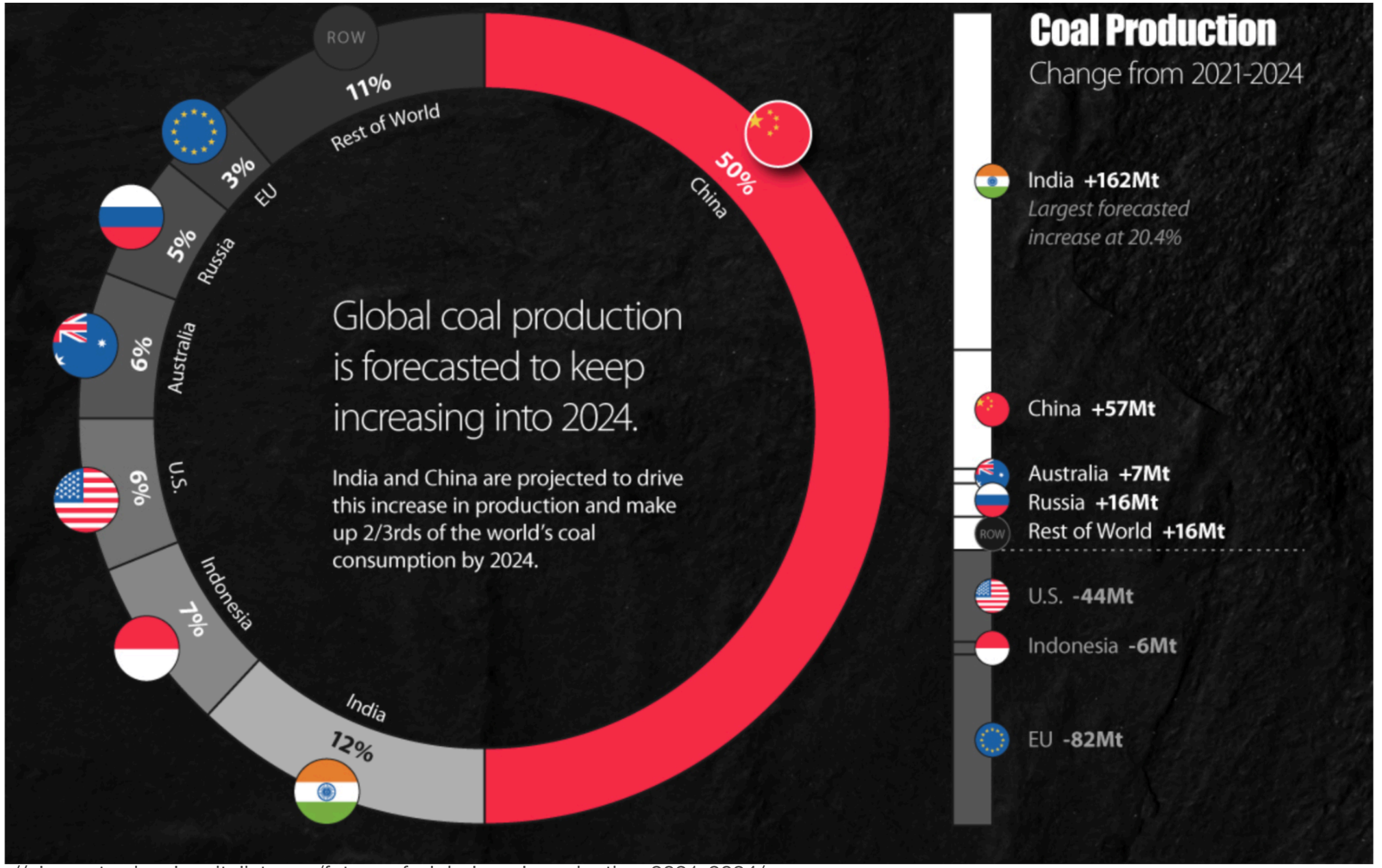
574 GW of ***new*** power plants will be coal fired, the economic choice of developing nations.

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
Sudan	0	0	0	0	0
Jordan	0	0	0	30	0
Total	**338,571**	**235,633**	**574,204**	**483,160**	**2,015,280**

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

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



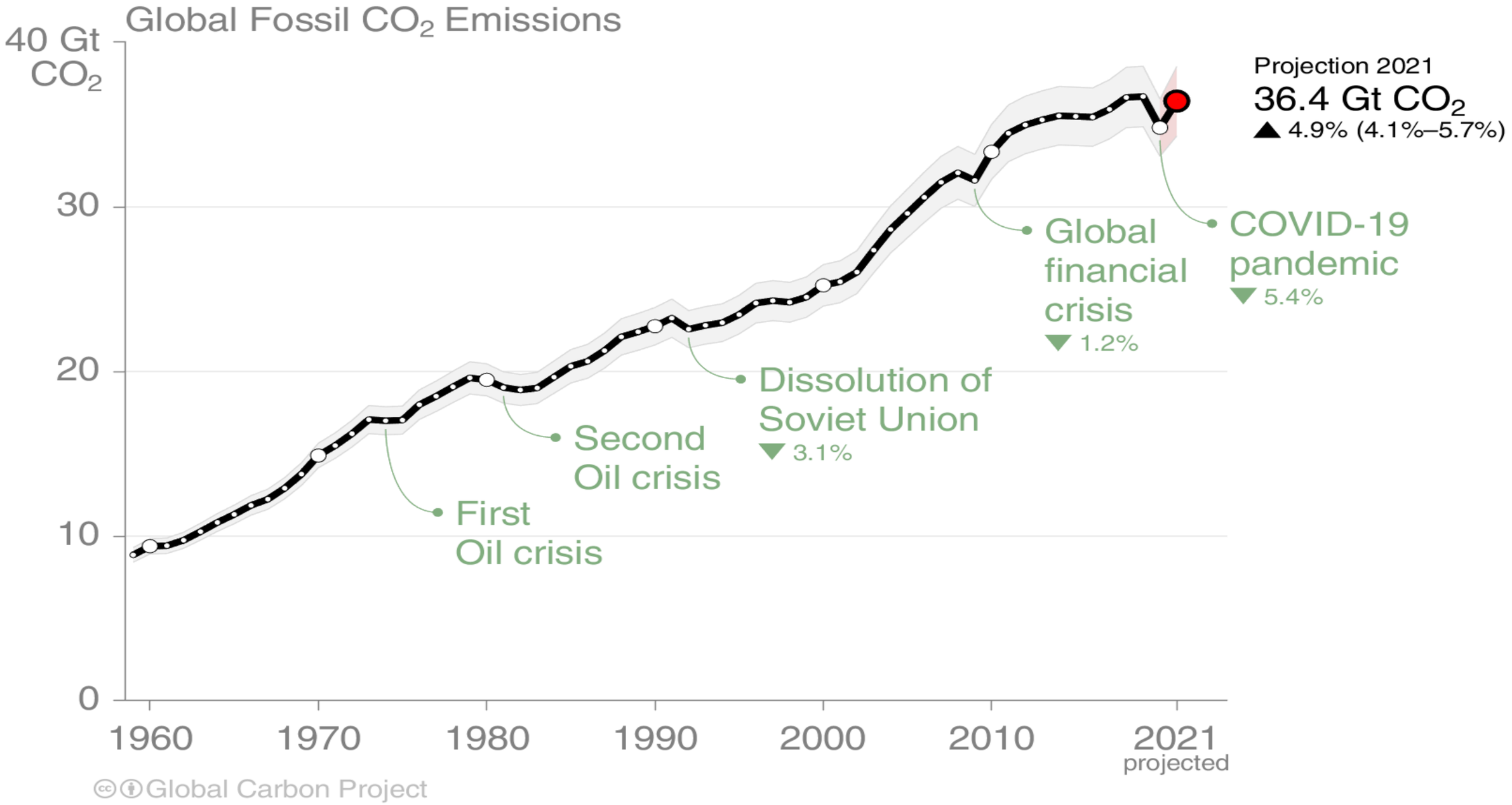
China
U.S.
India
Russia
Australia

did not join the COP26 pledge to reduce coal production.

Why?

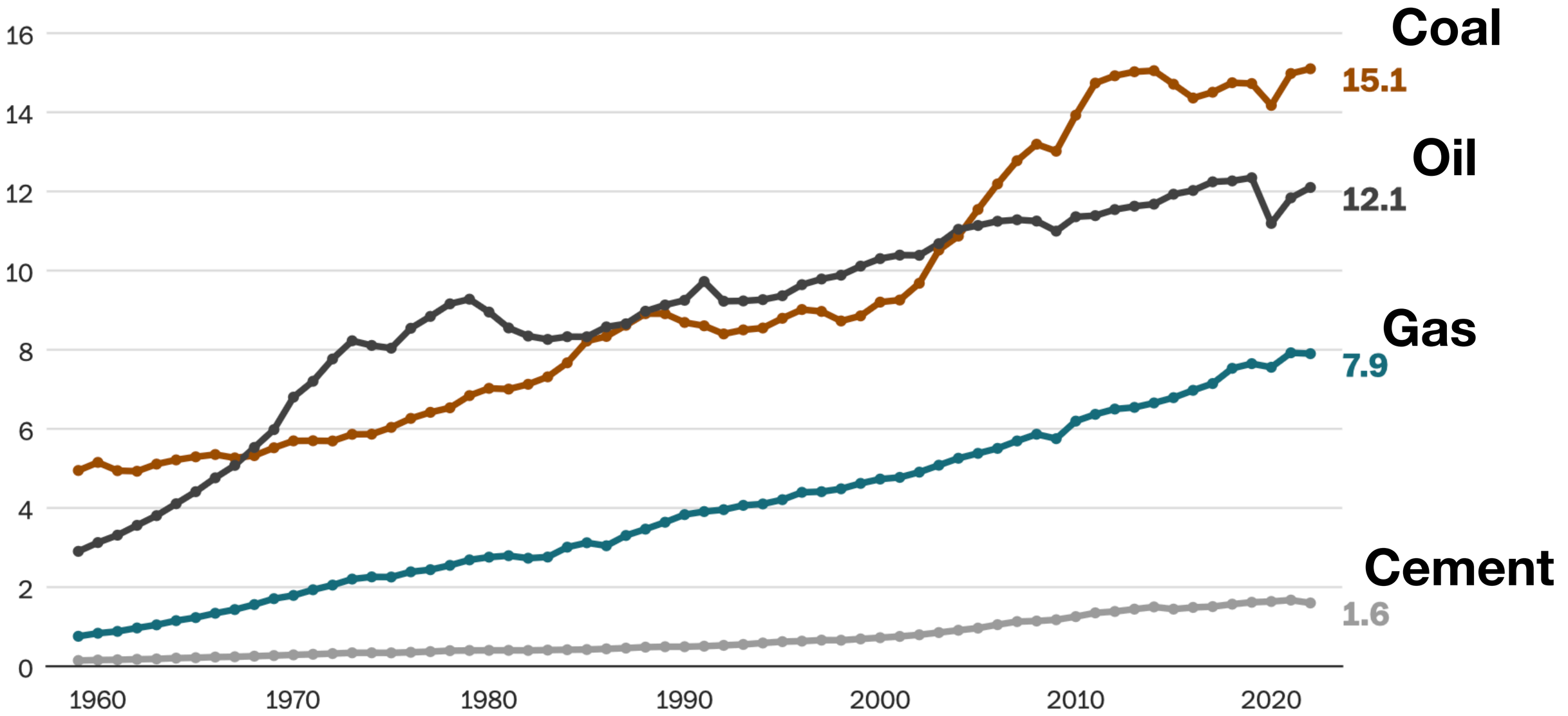
https://elements.visualcapitalist.com/future-of-global-coal-production-2021-2024/

Annual additions to atmospheric CO2 continue to increase.



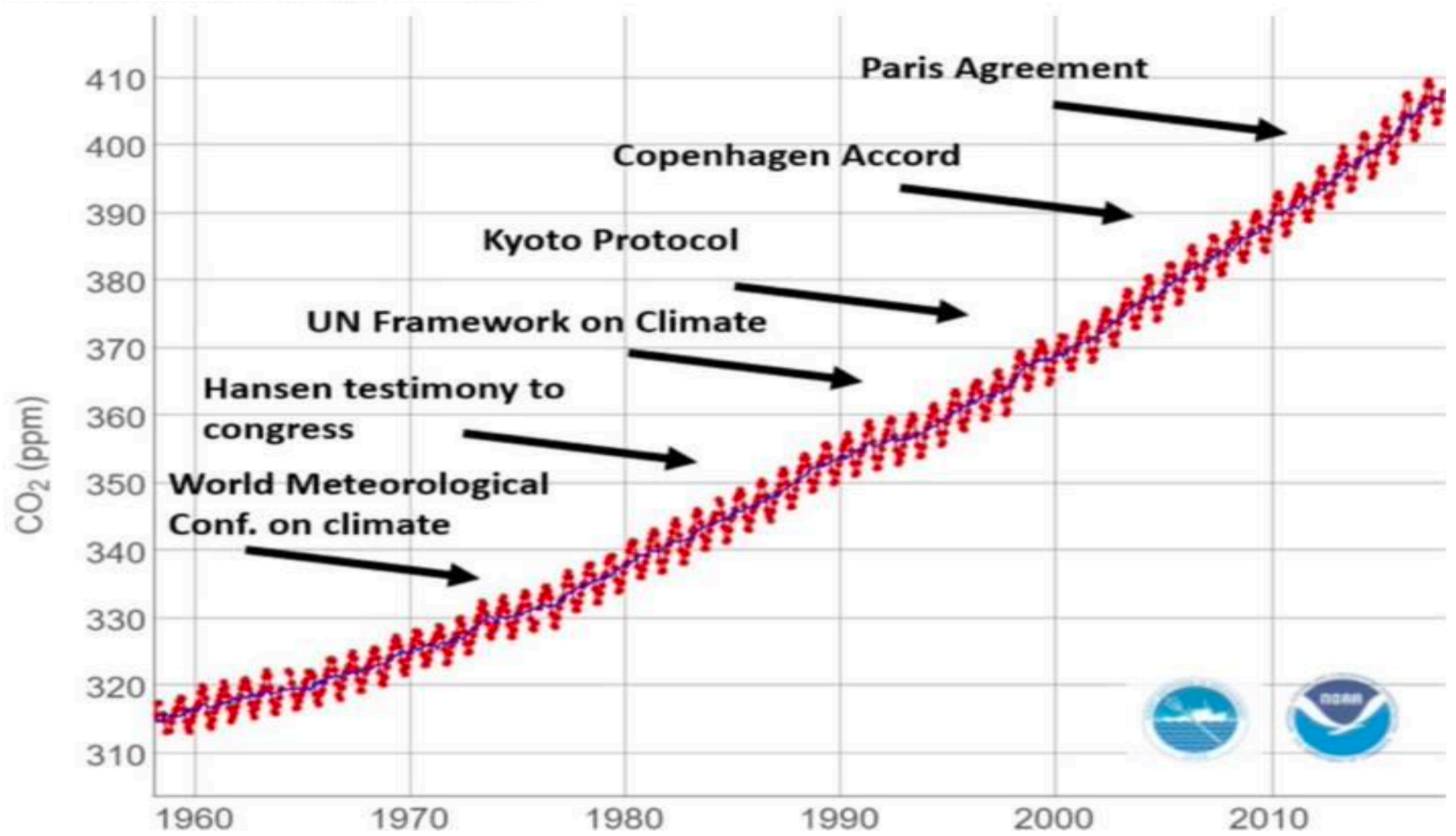
https://robbieandrew.github.io/GCB2021/

Global CO2 emissions by source, in gigatons CO2 per year



https://www.washingtonpost.com/climate-environment/2022/12/05/carbon-emissions-peak-record-2022/?mc_cid=31685cb856&mc_eid=0c0eac7096

Politicians have zero effect on CO2, as measured.



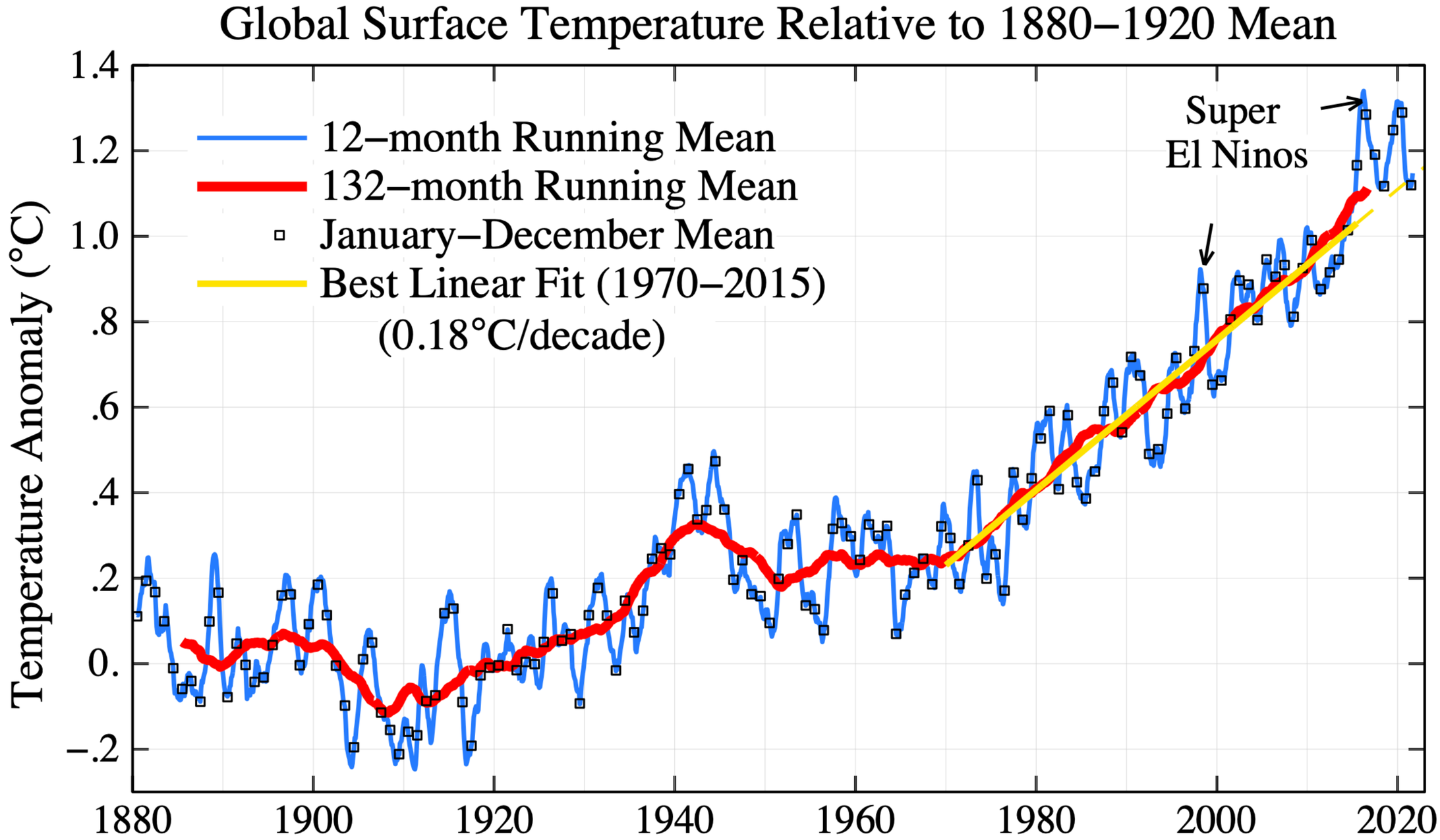
https://www.esrl.noaa.gov/gmd/ccgg/trends/

Politicians move goalposts.

Ripu Malhotra's Brief History of Earth Summits and COPs

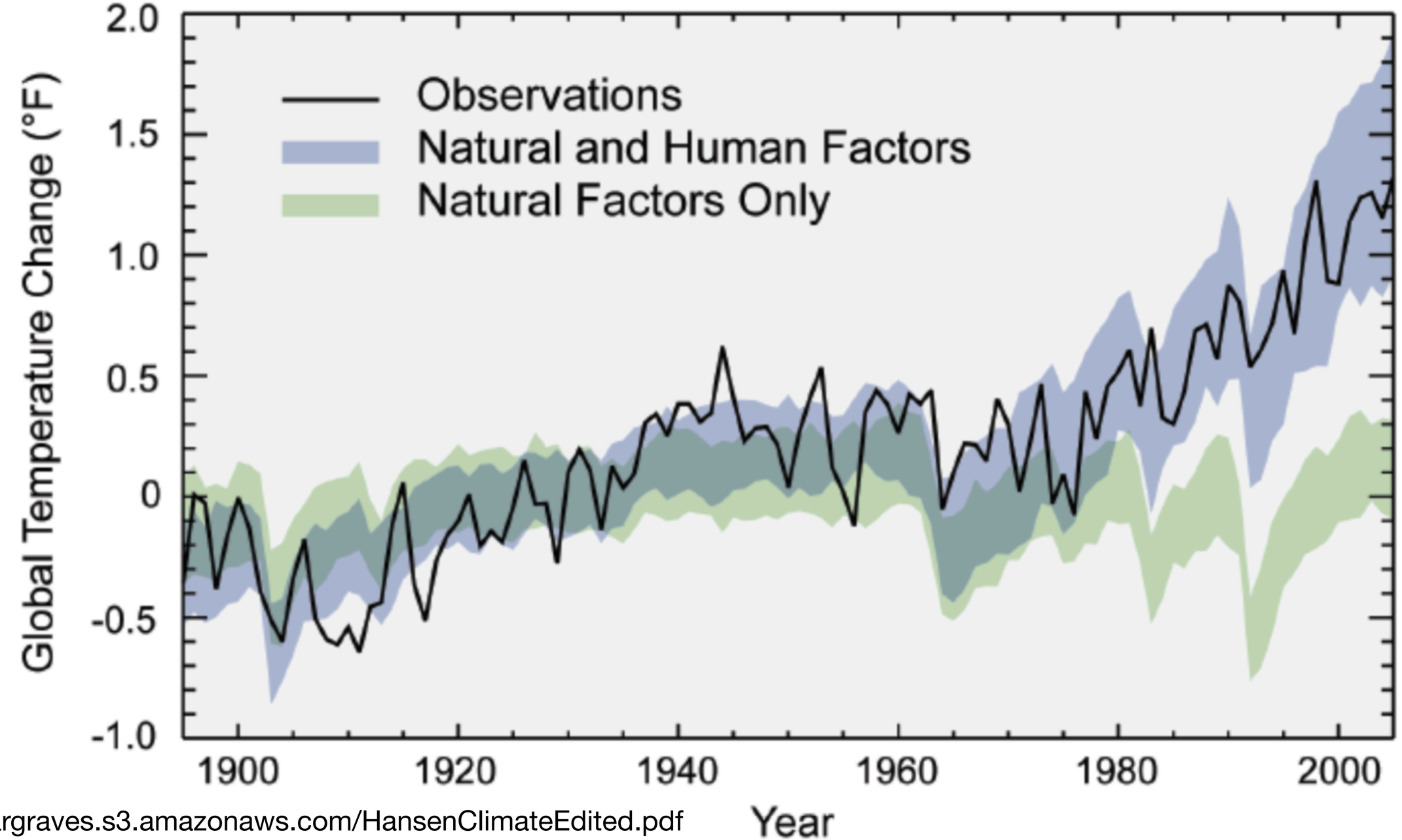
Year/City	Emissions (GT/yr)	Stated Goal	Atmos. CO_2 (ppm)
1992/Rio	22	Reduce emissions	360
2000/Kyoto	24	Achieve 350 ppm by 2022	372
2015/Paris	35	Net-zero by 2050	400
2022/Sharm el-Sheikh	35	Reparations fund	416

Climate is changing, rapidly.



www.columbia.edu/~mhs119/Temperature/

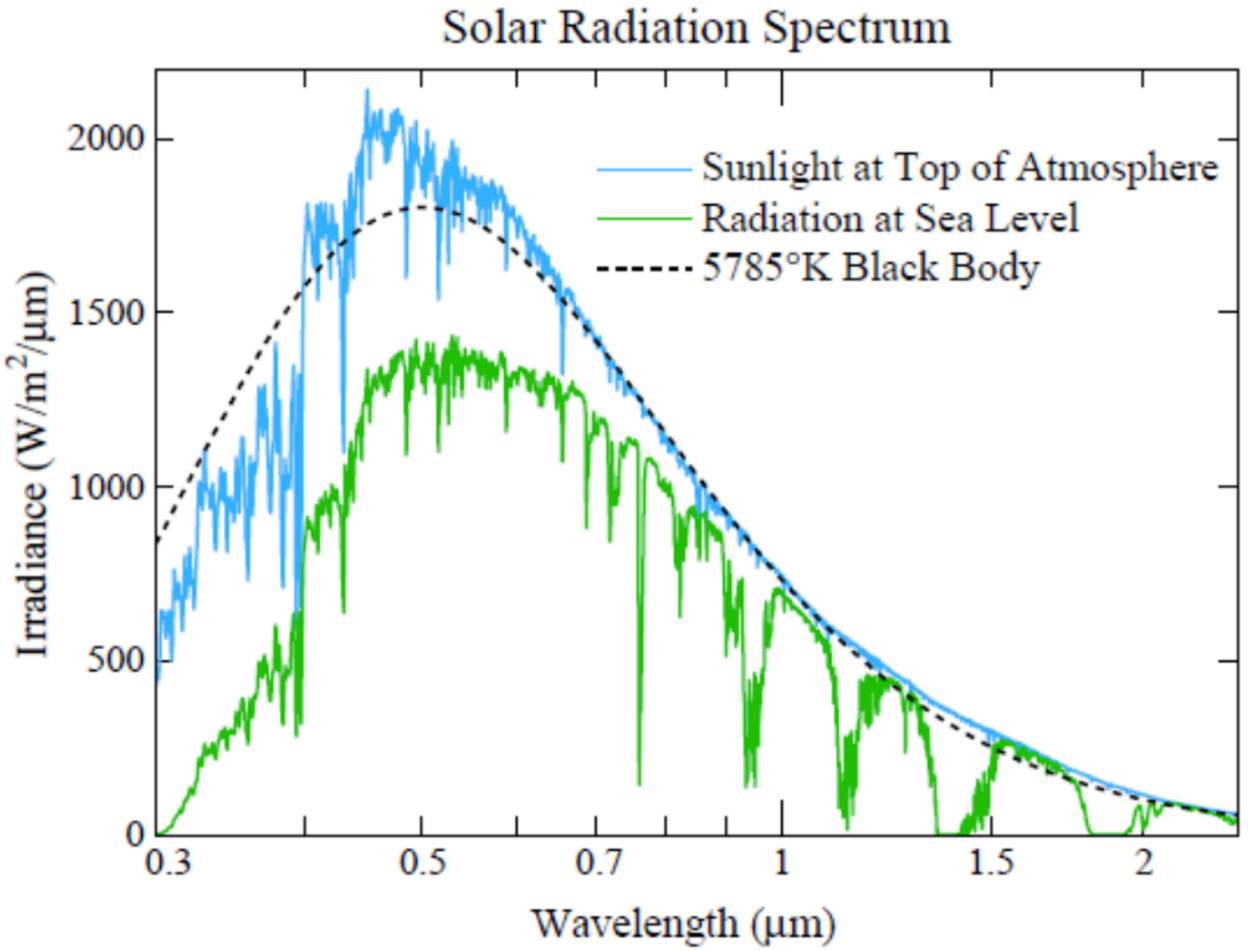
Warming has risen out of the range of natural variability.



https://hargraves.s3.amazonaws.com/HansenClimateEdited.pdf

Incoming visible radiation

Outgoing infrared radiation



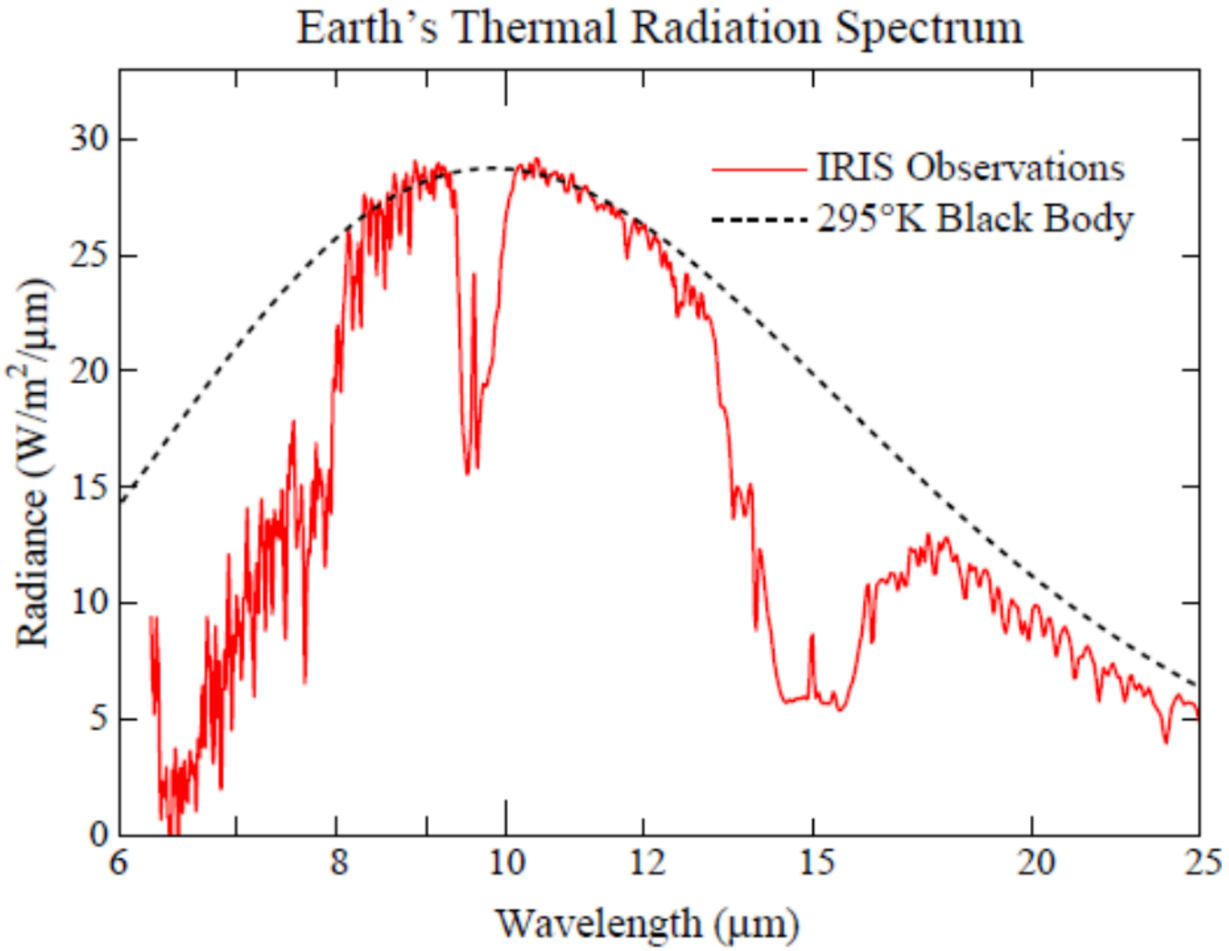
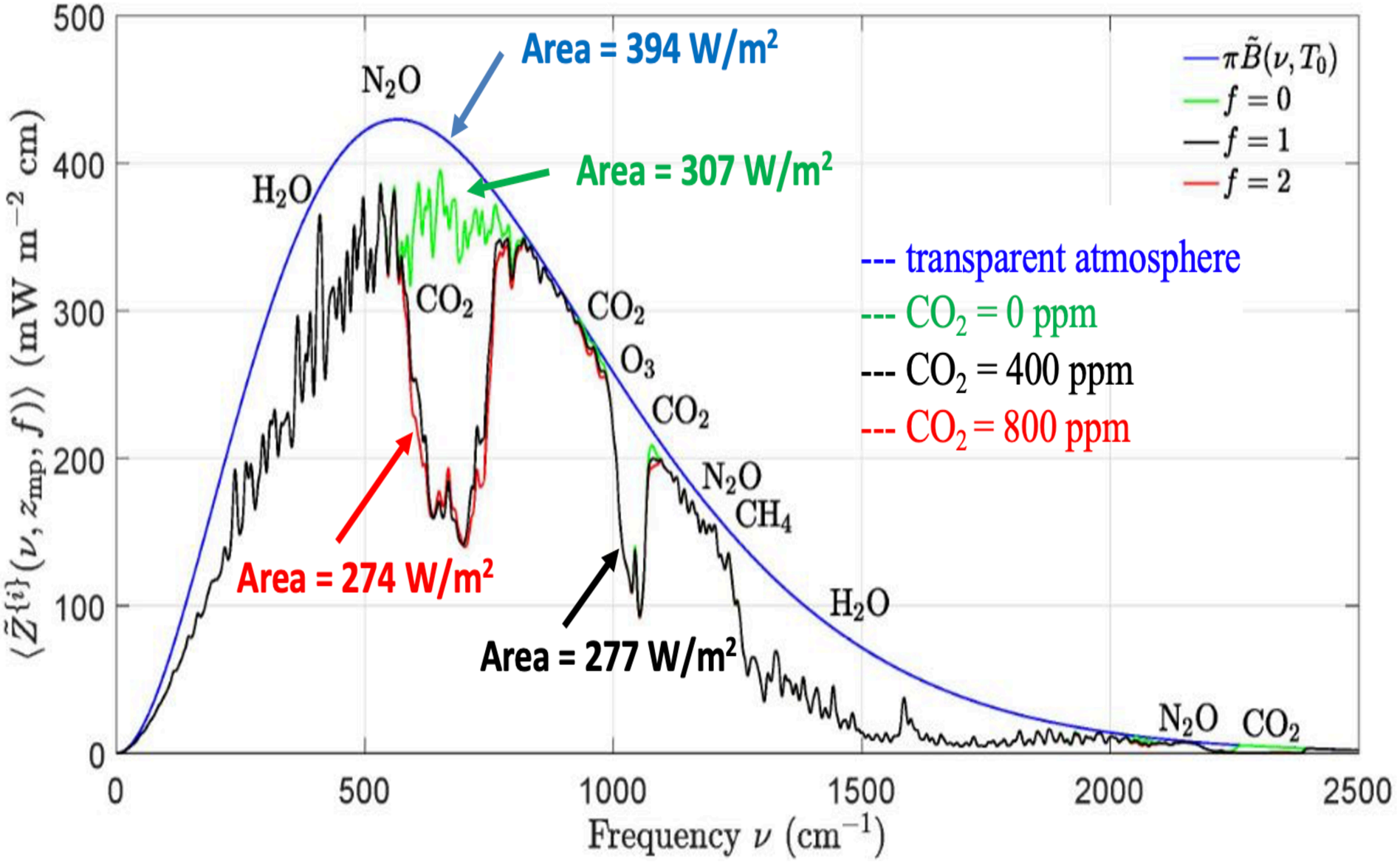


Fig. 31.1. Sunlight reaching Earth and reaching the ground for clear sky conditions (left). Thermal (heat) radiation to space measured from a satellite over the Sahara desert (right).

Source: Jim Hansen book draft http://www.columbia.edu/~jeh1/SophiePlanet/Planet.Chapter31.pdf

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

https://arxiv.org/abs/2006.03098

Happer and Lindzen 2022 Congressional testimony shows IPCC reports are political consensus, not science.

IPCC SPM Rule No.1: All Summaries for Policymakers (SPMs) Are Approved Line by Line by Member Governments

"IPCC Fact Sheet: How does the IPCC approve reports? 'Approval' is the process used for **IPCC Summaries for Policymakers (SPMs). Approval signifies that the material has been subject to detailed, line-by-line discussion, leading to agreement among the participating IPCC member countries**, in consultation with the scientists responsible for drafting the report."[9]

IPCC Reports Rule No. 2: Government SPMs Override Any Inconsistent Conclusions Scientists Write for IPCC Reports

Jim Hansen:
It's a shame that the UN created the IPCC to obfuscate climate science.

https://www.sec.gov/comments/s7-10-22/s71022-20132171-302668.pdf

CCS, carbon capture and storage, is not feasible.

Petra Nova CO2 capture at NRG coal plant, Texas, killed in 2020. DOE, $195M grantor, still optimistic.

$1 billion total

Goal: 33% capture from 240 MW boiler

81 mile pipeline to oil field to sell CO2 for injection to push up more oil

Uses 45 MW natural gas power, halving CO2 savings

https://www.reuters.com/article/us-usa-energy-carbon-capture-idUSKCN2523K8

Lake Nyos CO_2 suffocated 1,746 people overnight.

Its deep waters became a high-pressure CO_2 storage unit. It overturned, releasing hundreds of thousands of tons of CO_2, suffocating people.

Offsets? Planting trees can't absorb enough CO2.

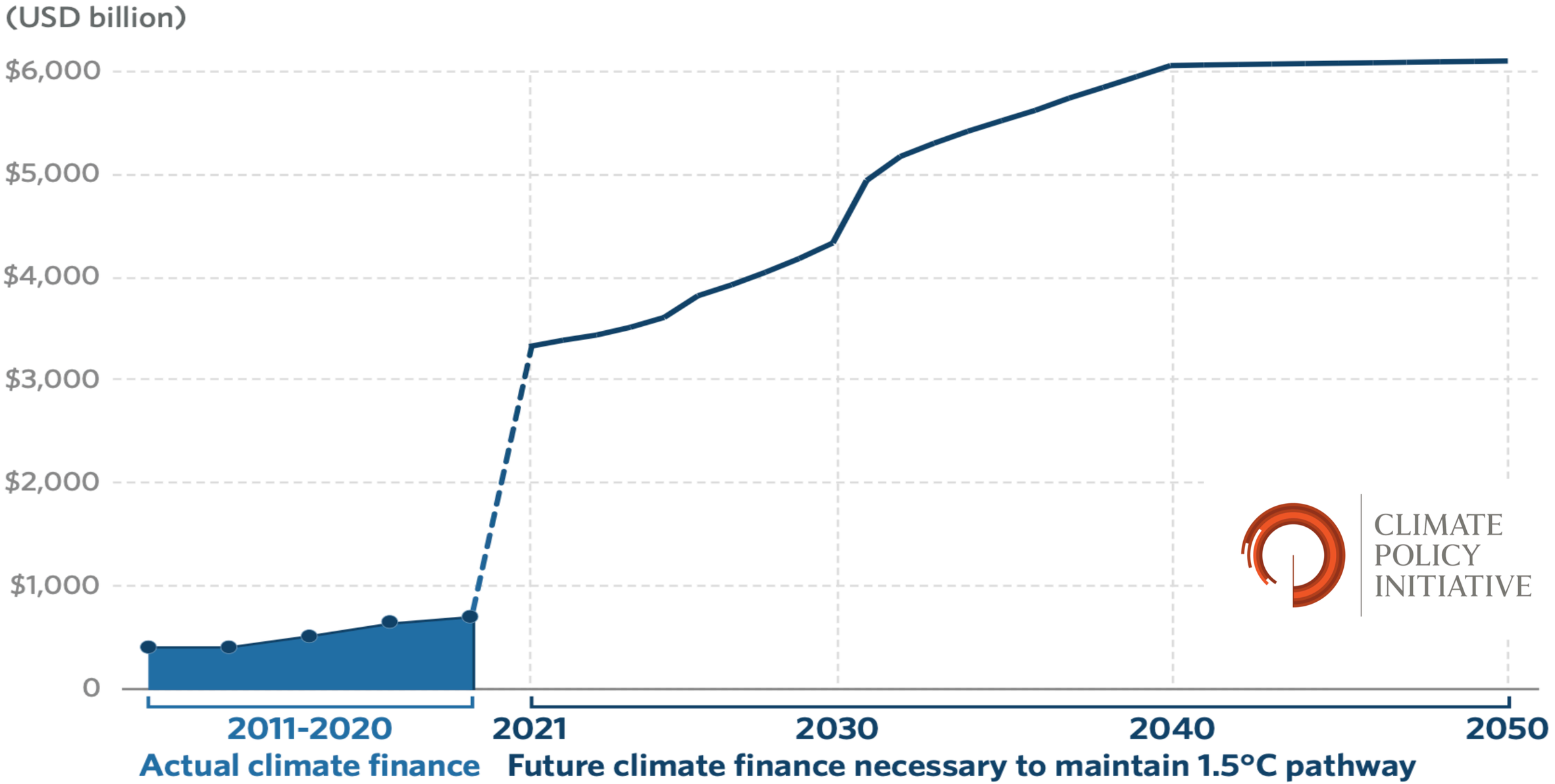
Global forests cover
4 billion hectares.

Add a billion ha more?

- **Mature** forests emit as much CO2 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 CO2 emissions are ~ 50 Gt per year.

https://www.1t.org Davos World Economic Forum

$6 trillion per year on “climate finance”?



https://www.climatepolicyinitiative.org/wp-content/uploads/2021/10/Full-report-Global-Landscape-of-Climate-Finance-2021.pdf

Economic suicide?

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

Vaclav Smil:

Energy from burning carbon is the basis of civilization.

https://www.wyodaily.com/photos/big/11242/12