

4 Energy economics



Fission is in Fashion

Value of energy to civilization

Thermodynamics and economy

Systems, entropy, exergy

Energy return on investment

$GDP = f \{ \text{capital, labor, energy} \}$

GDP, energy, happiness

Cheap energy: the only answer

Energy Realism

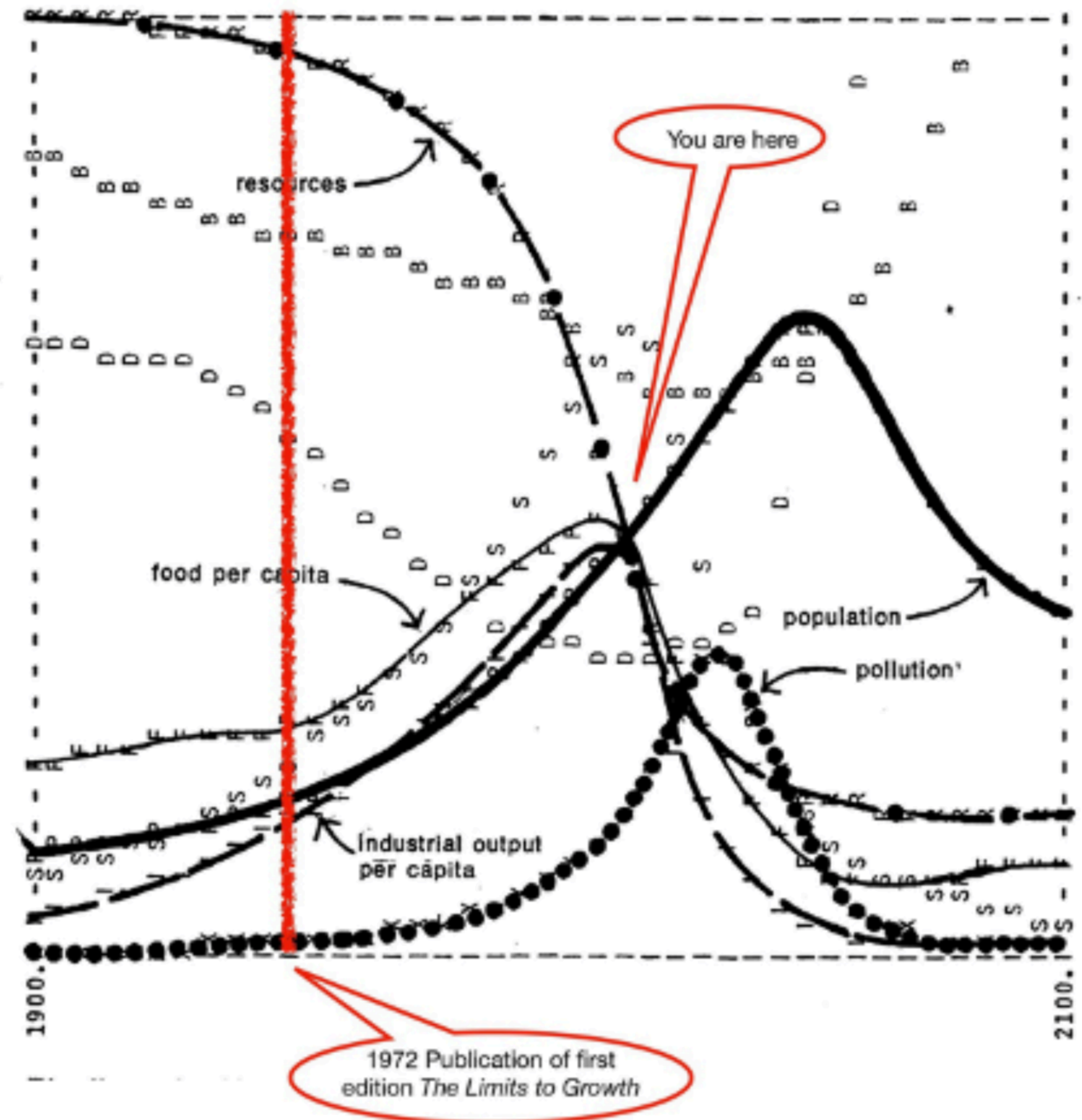
1. Energy **IS** the economy. \$1 GDP demands ~1.5 kWh heat, ~0.2 kWh electricity.
2. Earth's carbon battery supplies the energy that enabled our civilization.
3. Harvesting fossil fuels is becoming more energy intensive, so more economic productivity (GDP) is being diverted to obtaining the needed energy.
4. The energy return on invested energy (EROI) from wind, solar, and storage is too low to sustain our civilization.
5. Burning fossil fuels releases CO₂ that exacerbates global warming.
6. Fission-sourced energy can power the world for centuries.

March 2022

50th anniversary of Club of Rome

Limits to Growth

Dennis Meadows of MIT and Dartmouth used system dynamics to model the earth's resources, industry, food, population, etc

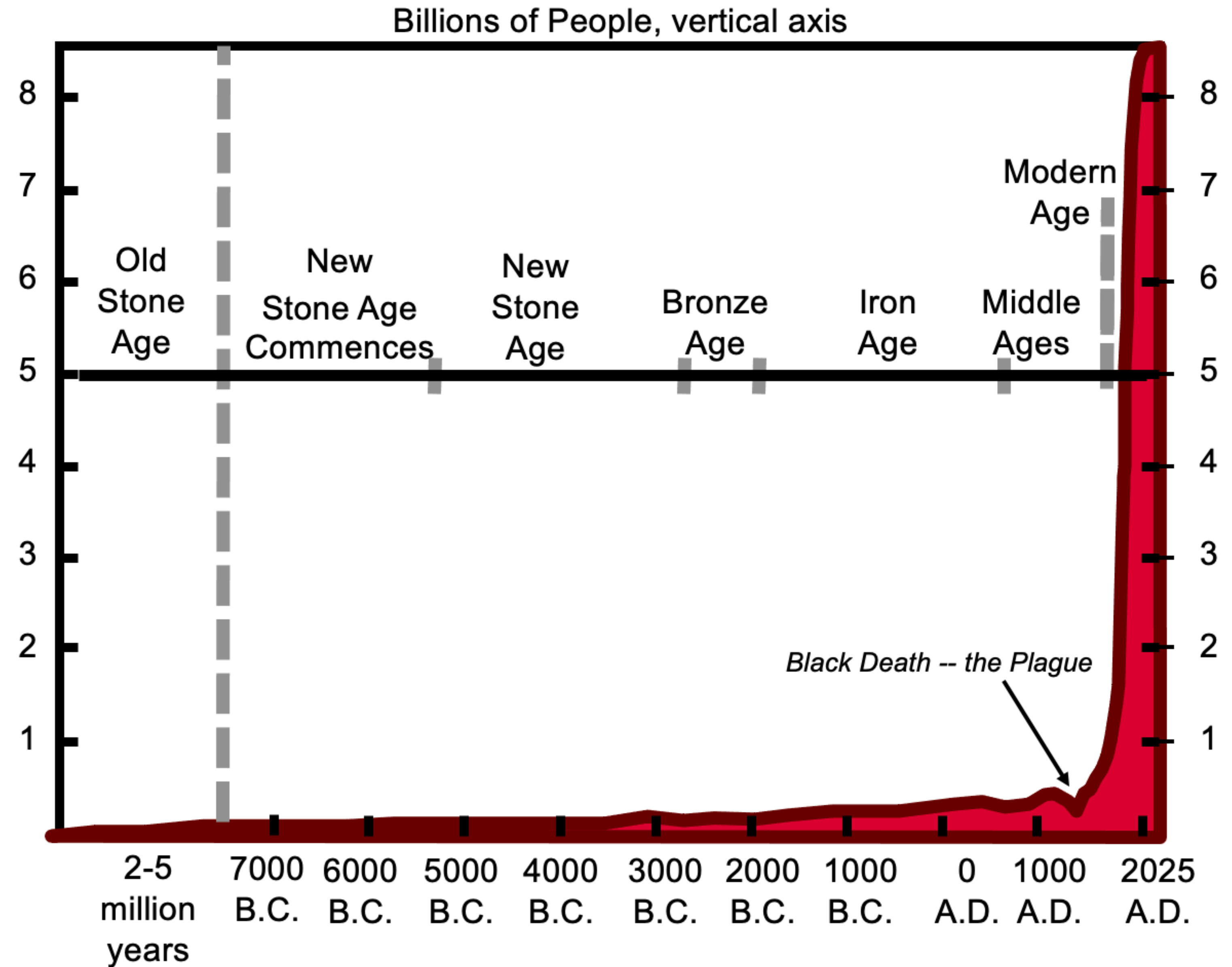


Real income is dropping for 96.5% of US earners. Why?

- Change in U.S. mean real total money earnings, by educational group, 2000 through 2016.

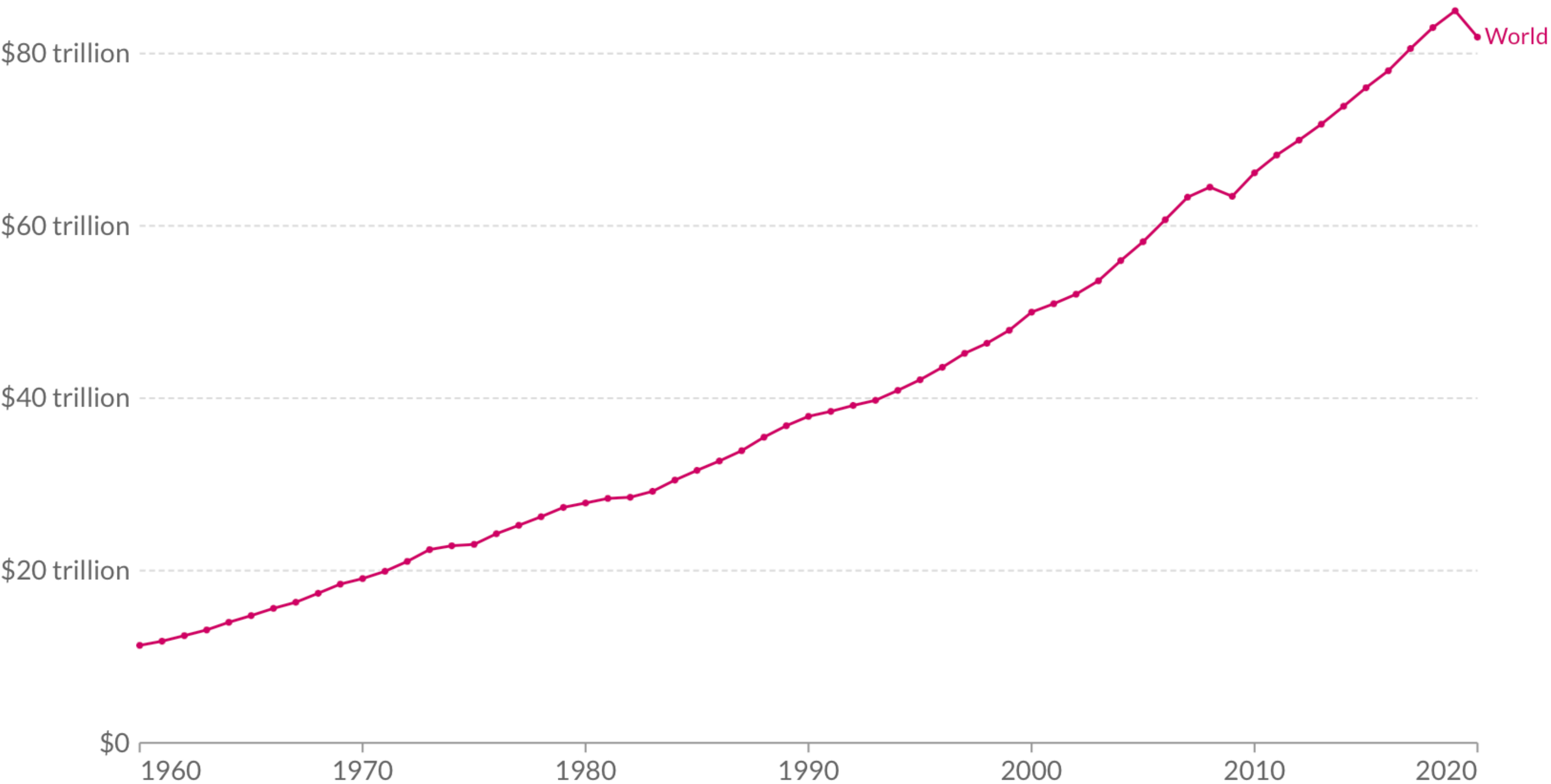
<u>Group</u>	<u>Employment Share</u>	<u>Earnings Change</u>
HS or Less	37.6%	-0.7%
Some College	27.0%	-7.2%
College Grad.	22.0%	-4.3%
Masters	9.9%	-5.5%
MD,JD,MBA	1.5%	+2.9%
PhD	2.0%	+4.3%

What's the value of energy to civilization?

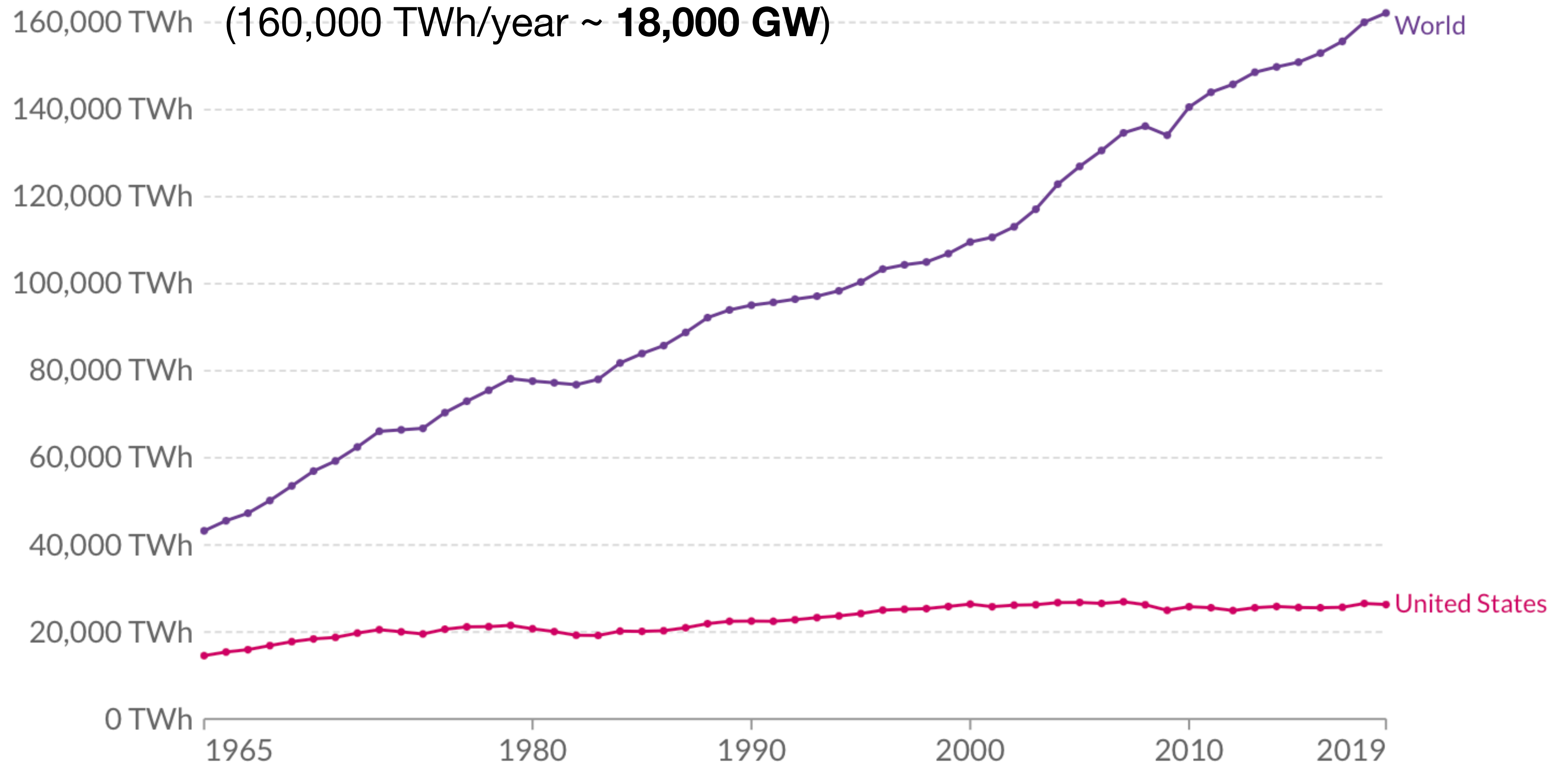


Gross world product (World GDP)

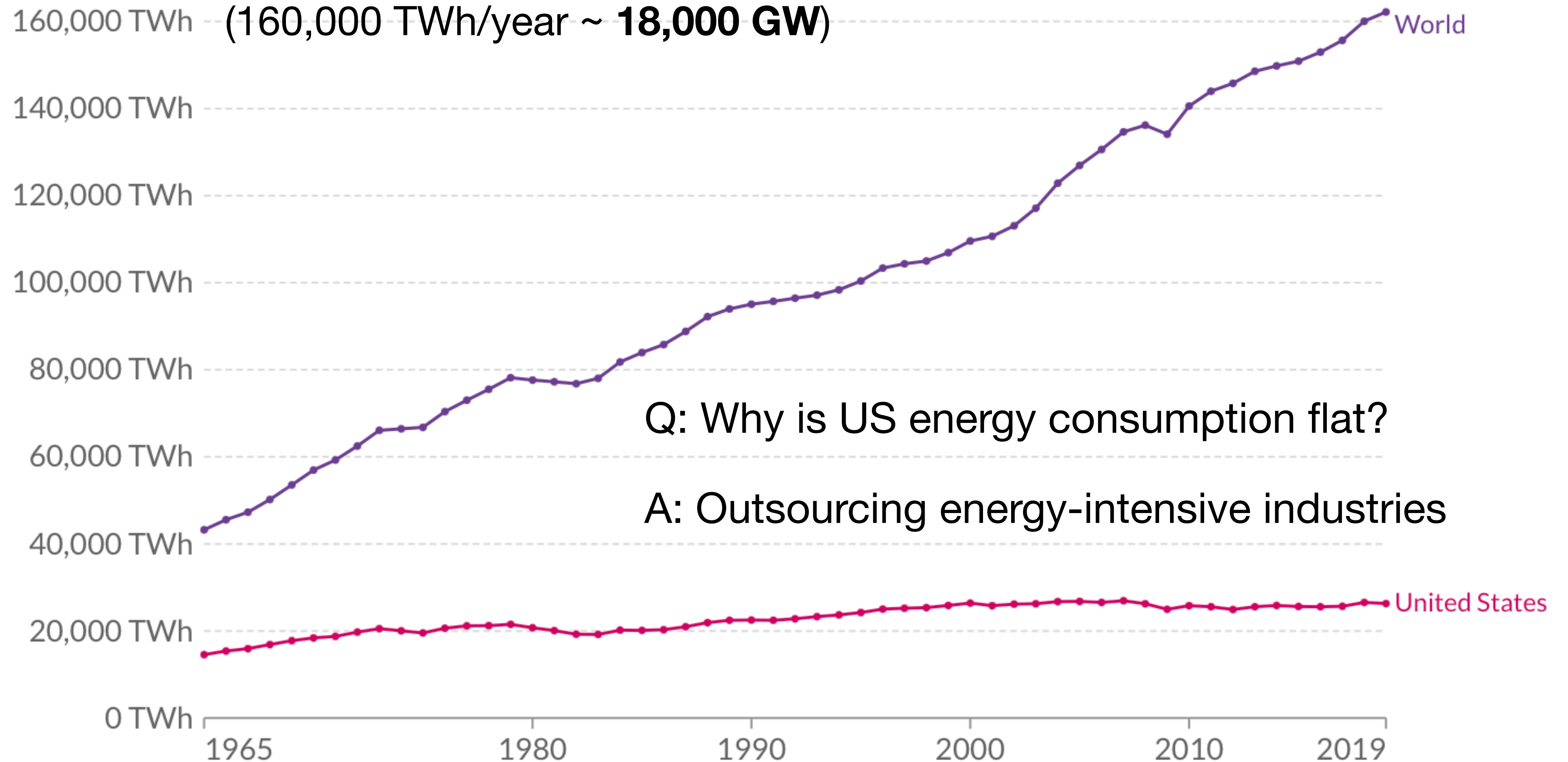
(US dollars)



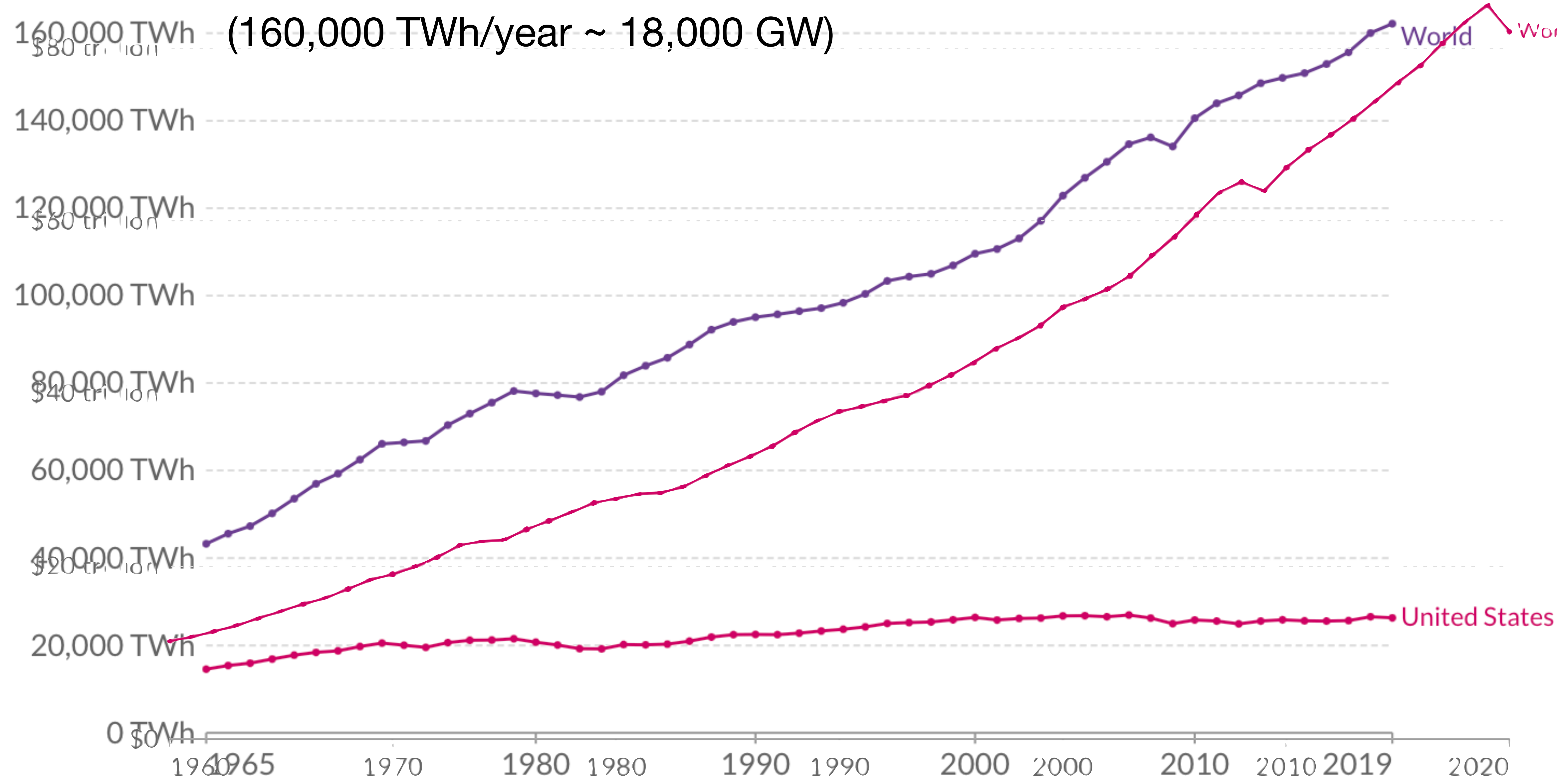
World energy consumption, per year (thermal, primary, heat energy)



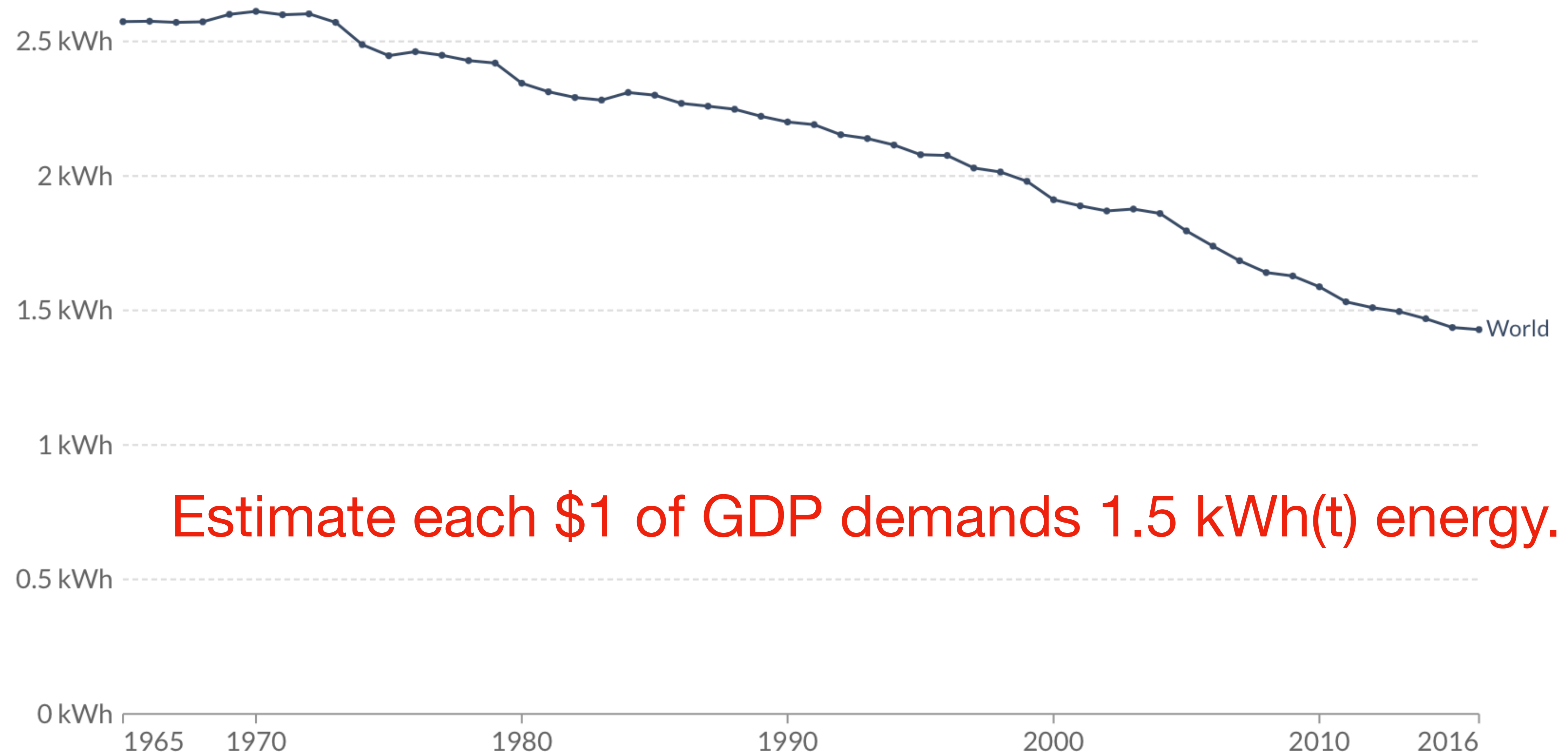
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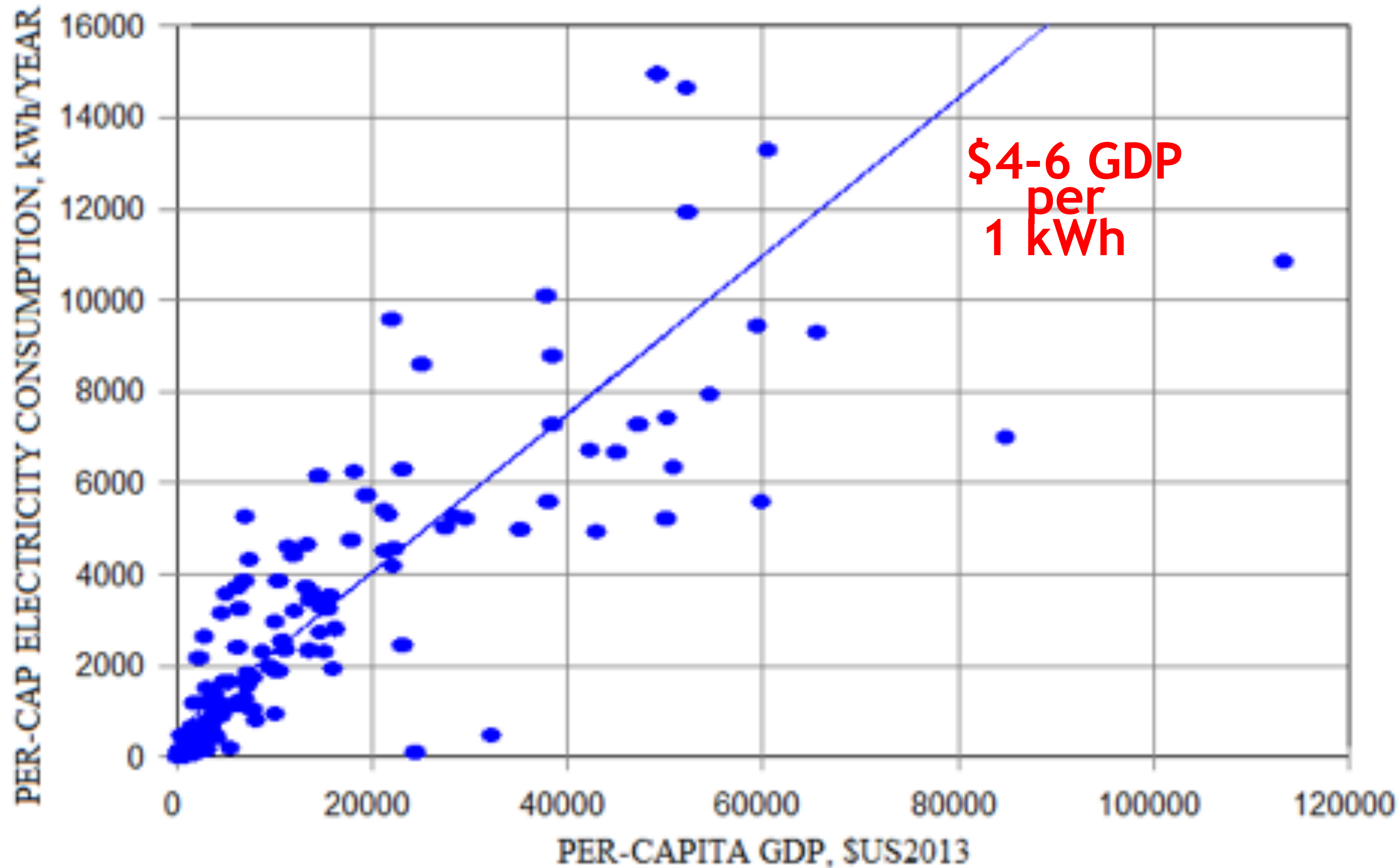
Overlay world GDP on world energy...



World energy intensity, kWh/\$ (\$-2011, PPP)



Each \$1 of GDP demands ~ 0.2 kWh electric energy.



\$GDP vs kWh/yr

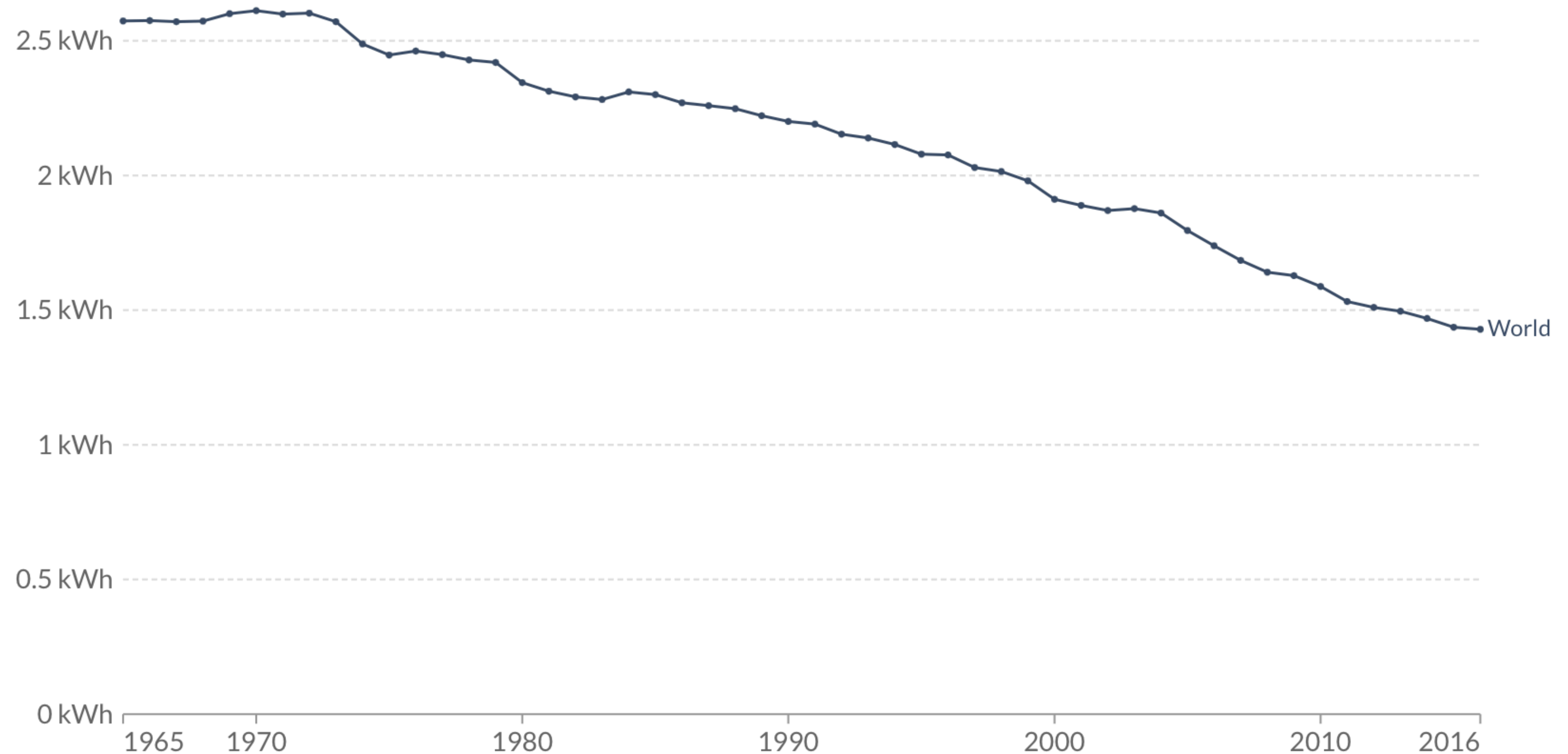
per capita
each dot a nation

Sources

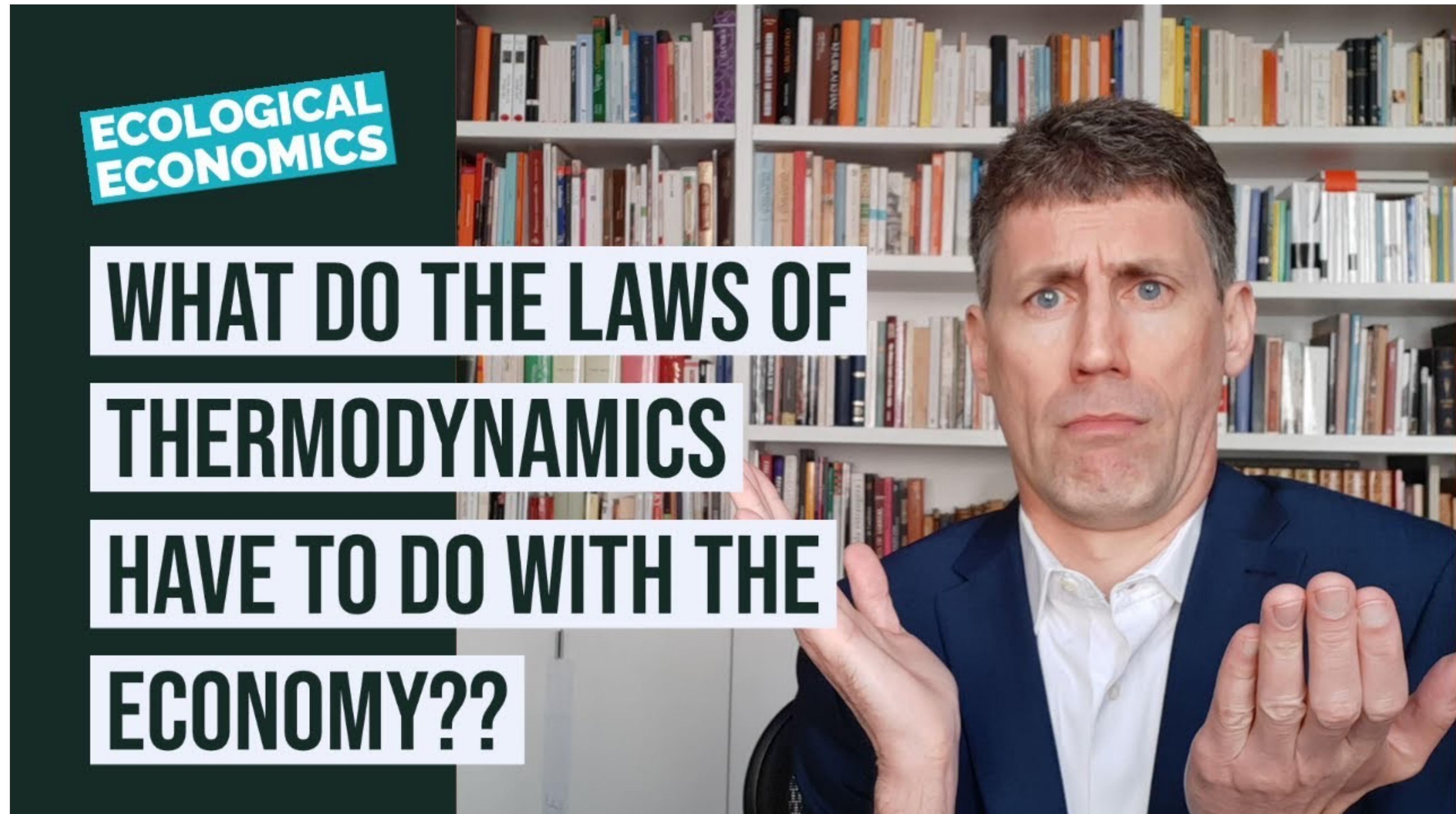
<http://euanmearns.com/electricity-and-the-wealth-of-nations/>

Robert Ayres and Benjamin Warr, The Economic Growth Engine: How Energy and Work Drive Material Prosperity (The International Institute for Applied Systems Analysis)

Summary: Each \$1 of GDP demands ~1.5 kWh(t) heat energy, and ~0.2 kWh(e) electric energy.

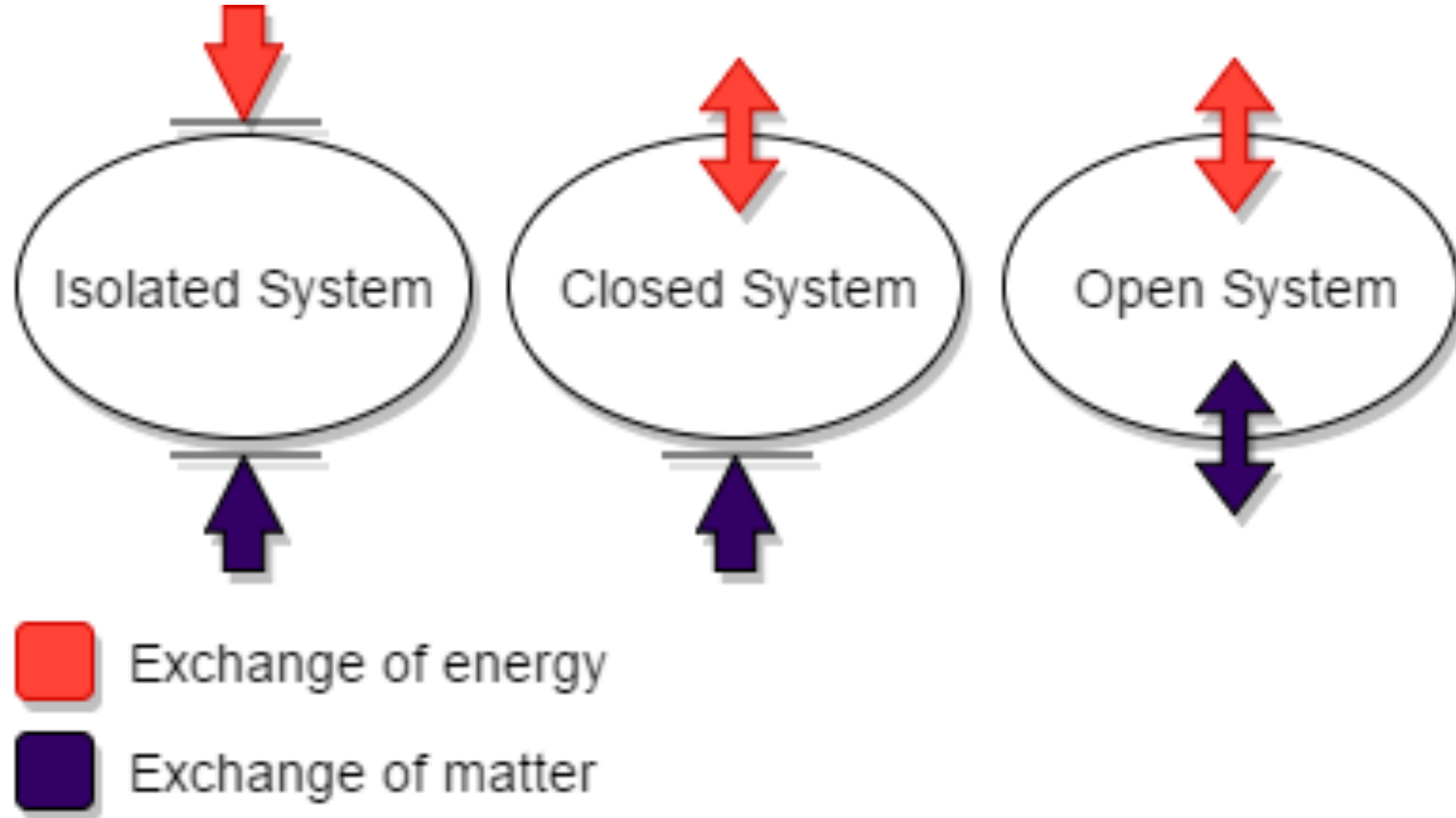


Laws of Thermodynamics and the Economy Dan O'Neill



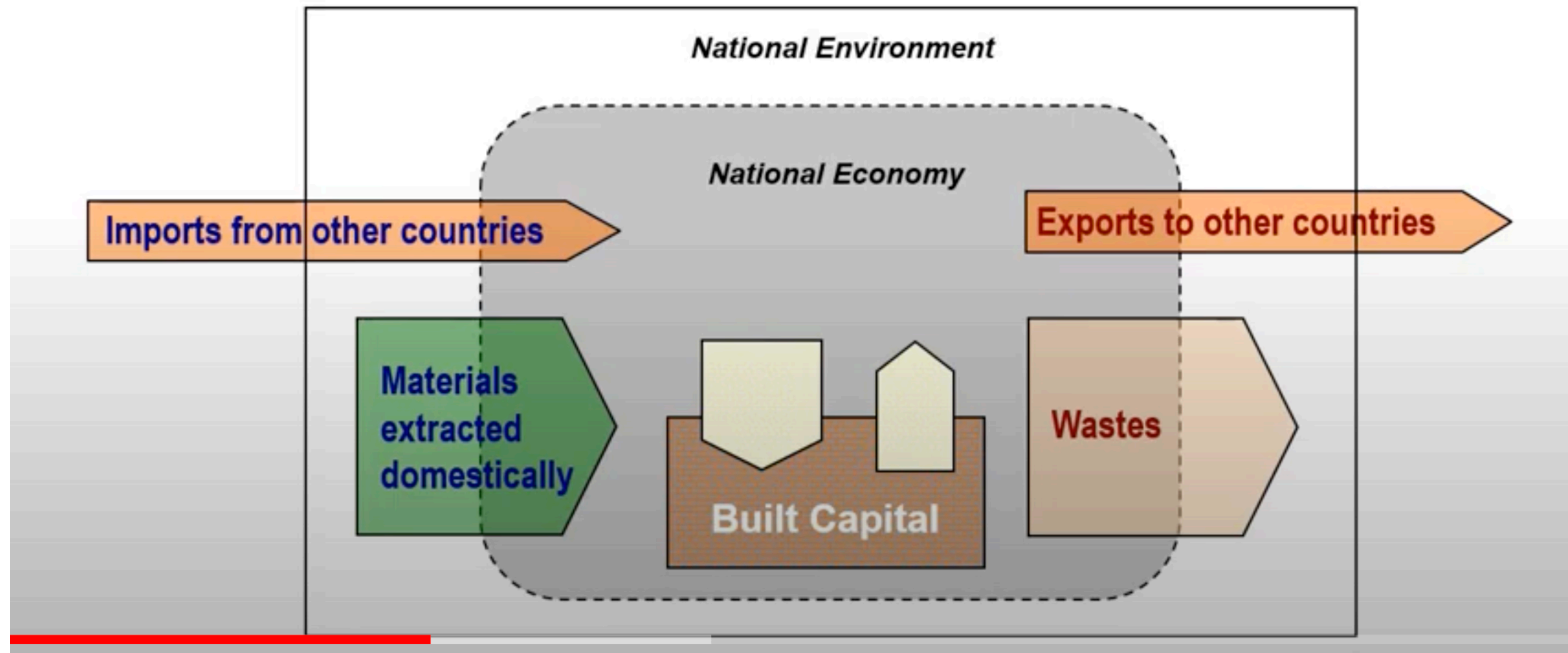
Laws of Thermodynamics and the Economy

Dan O'Neill



1st law of thermodynamics: conservation of energy

- *Energy is always conserved; it cannot be created or destroyed*
- The same applies to matter (due to the Law of Conservation of Mass)



2nd Law of Thermodynamics

- ▣ *In any isolated system, **entropy** will inevitably increase over time*
- ▣ What is entropy?
 - A measure of the amount of energy that is unavailable to do work
 - A measure of disorder or randomness

Implications of 2nd Law of Thermodynamics

- Materials can be recycled, but not 100%
- Energy cannot be recycled at all
- All physical processes convert **low-entropy** energy and materials into **high-entropy** wastes
- The structure of any physical good degrades over time, and energy inputs are needed to counteract this
- A decrease in entropy in one place, means a larger increase somewhere else

Natural systems

1. **Isolated**, physical systems drive to the lowest **equilibrium** energy state.
Example: rock falling, hot and cold water mixing.
2. **Natural** systems are in **disequilibrium**. Matter and energy may flow in and out. Example: organism.
3. Natural systems may be in **steady state disequilibrium**.
4. Natural systems are sustained by **external energy** sources.

Thermodynamic of the economic system

- The economy is a system that transforms **low-entropy raw materials** into **high-entropy wastes**, in order to satisfy human needs and wants
- The order in the economic system can only be maintained by a steady stream of low-entropy materials and energy
- All economic production is based on the resources provided by nature
- Whatever we produce must eventually decay, fall apart, or dissipate, returning as waste to nature

Energy and Economic Growth (starring Exergy and EROI)

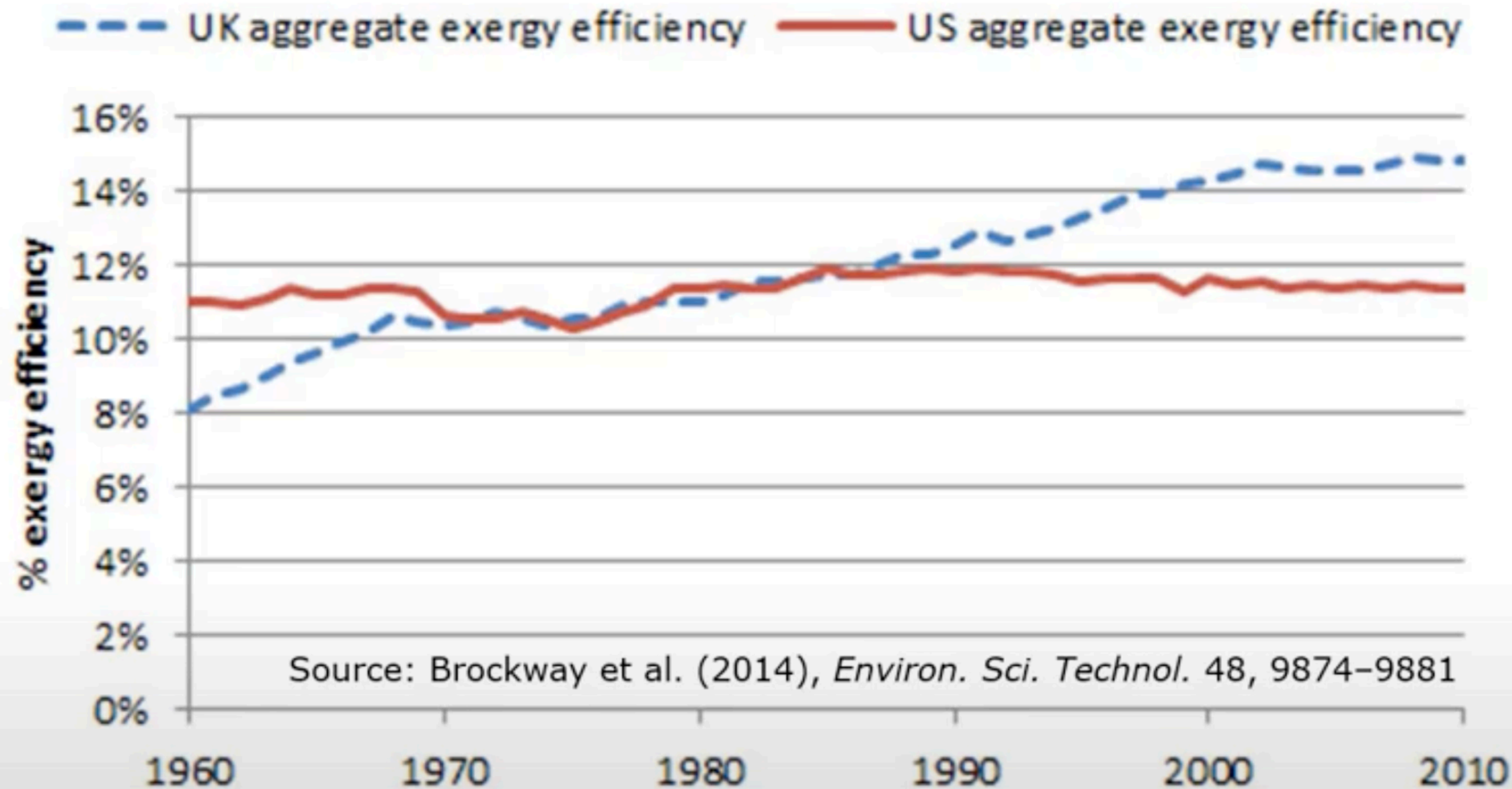


The exergy growth cycle may be weakening.

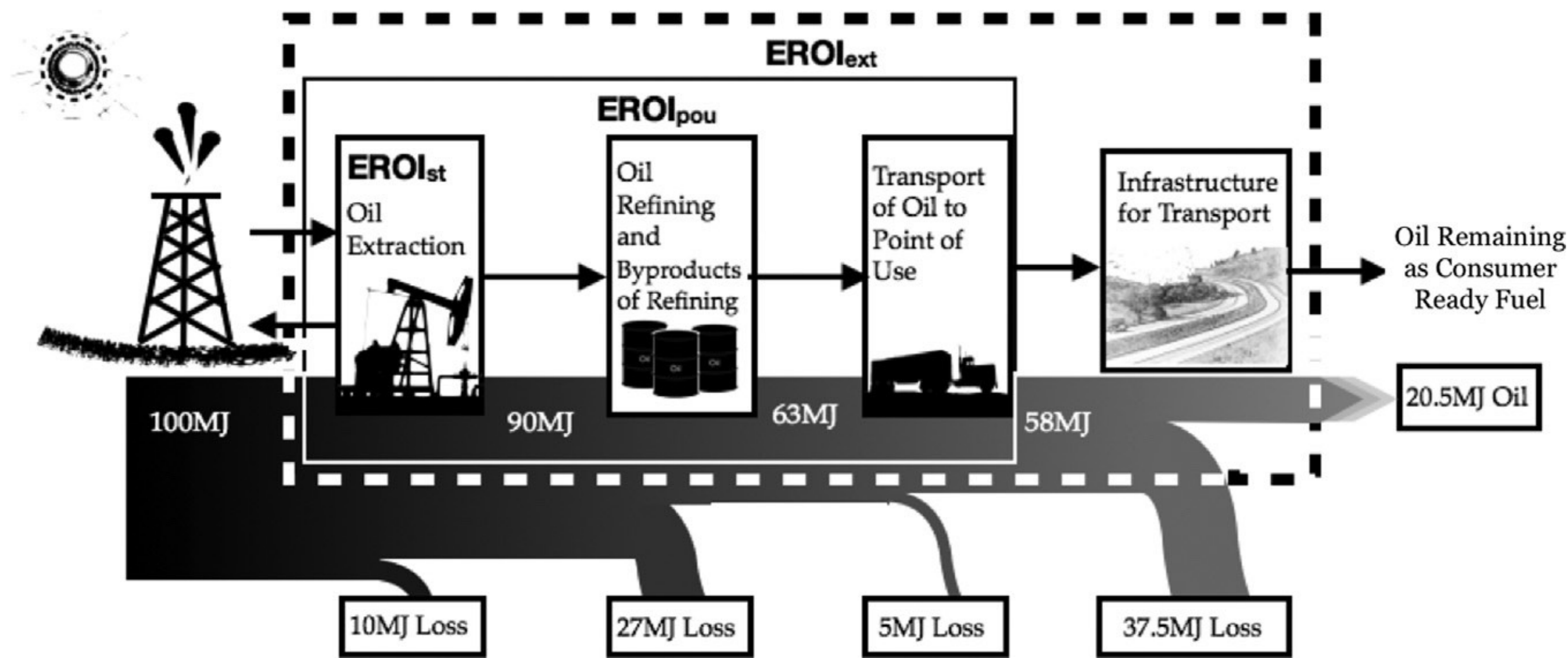
eg: CC gas turbine 62% efficiency approaches Carnot's limit.



Paul Brockway

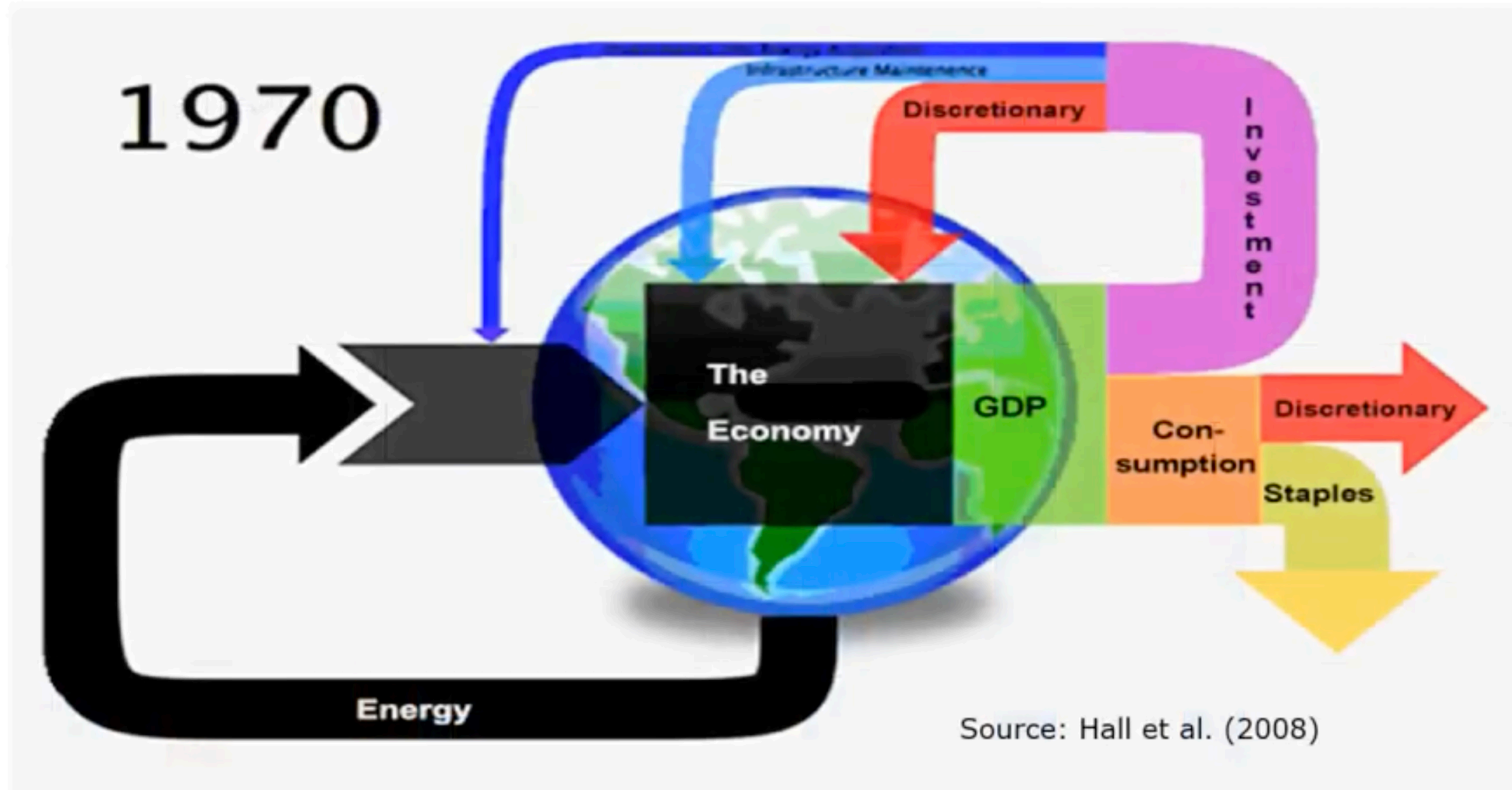


EROI example: Invest 79.5 MJ to get 20.5 MJ to consumer use.



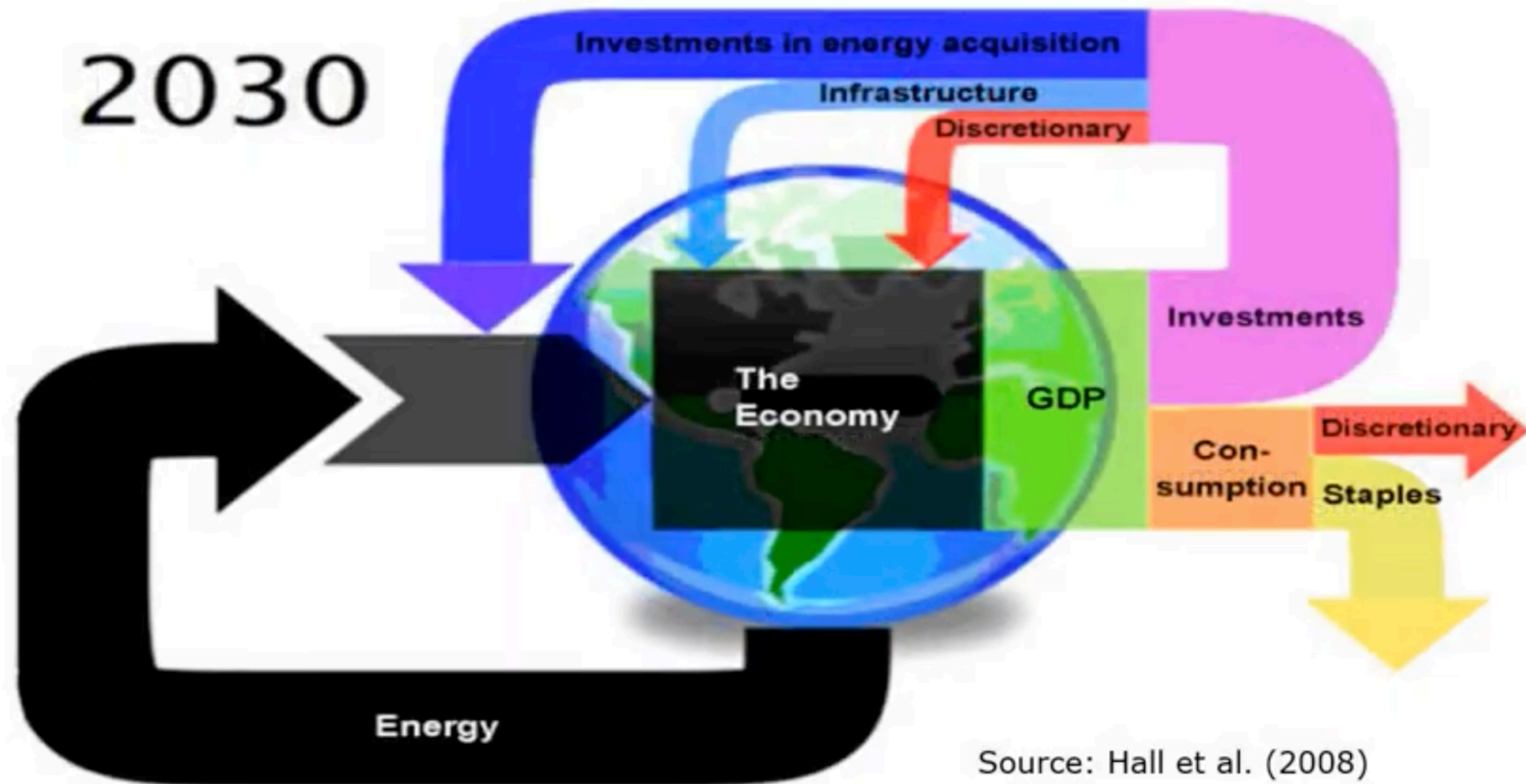
Oil’s 100 MJ is “free”, created from sunlight 100 million years ago.

Society's discretionary investment and consumption high. High EROI

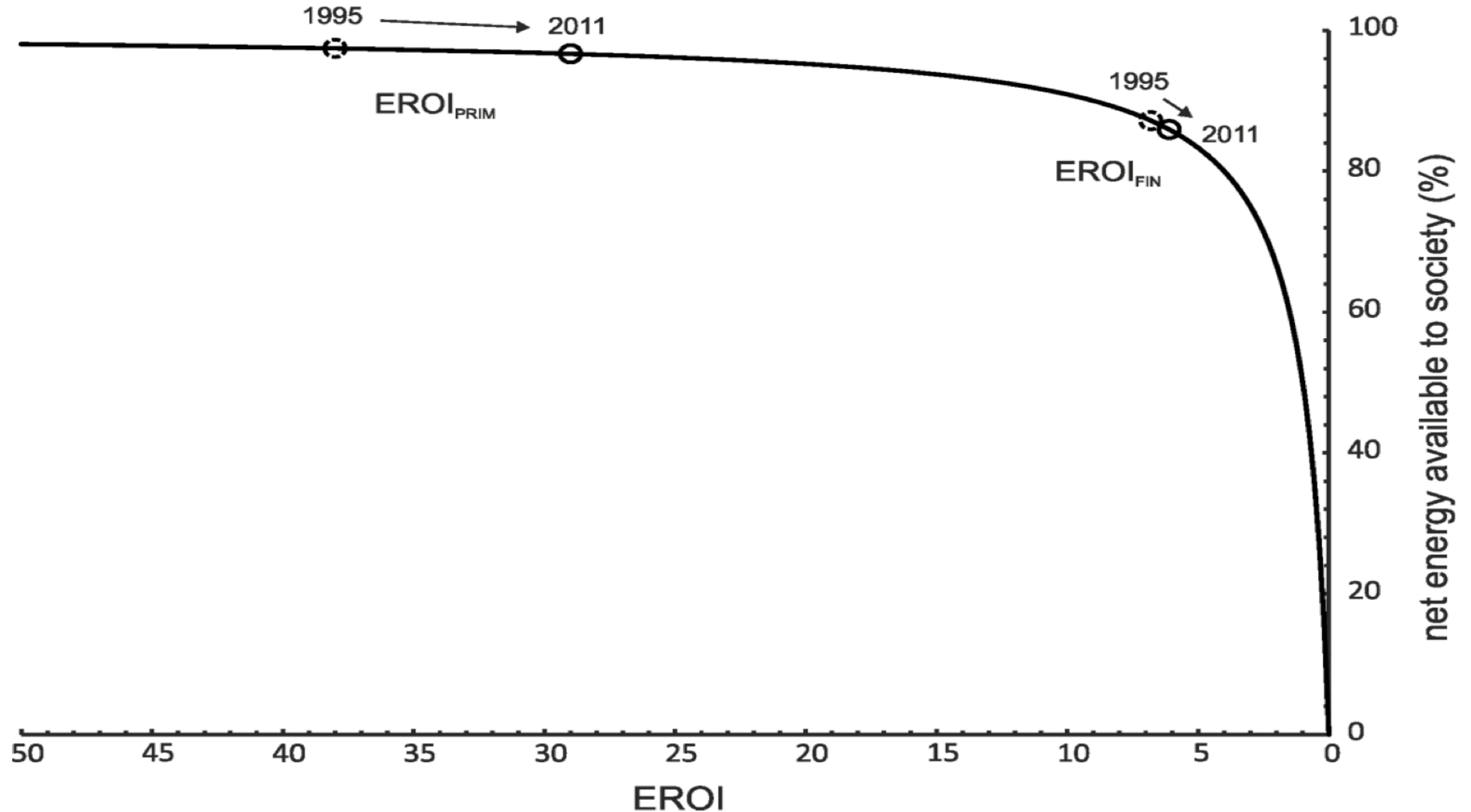


Society's discretionary investment and consumption low.

Low EROI



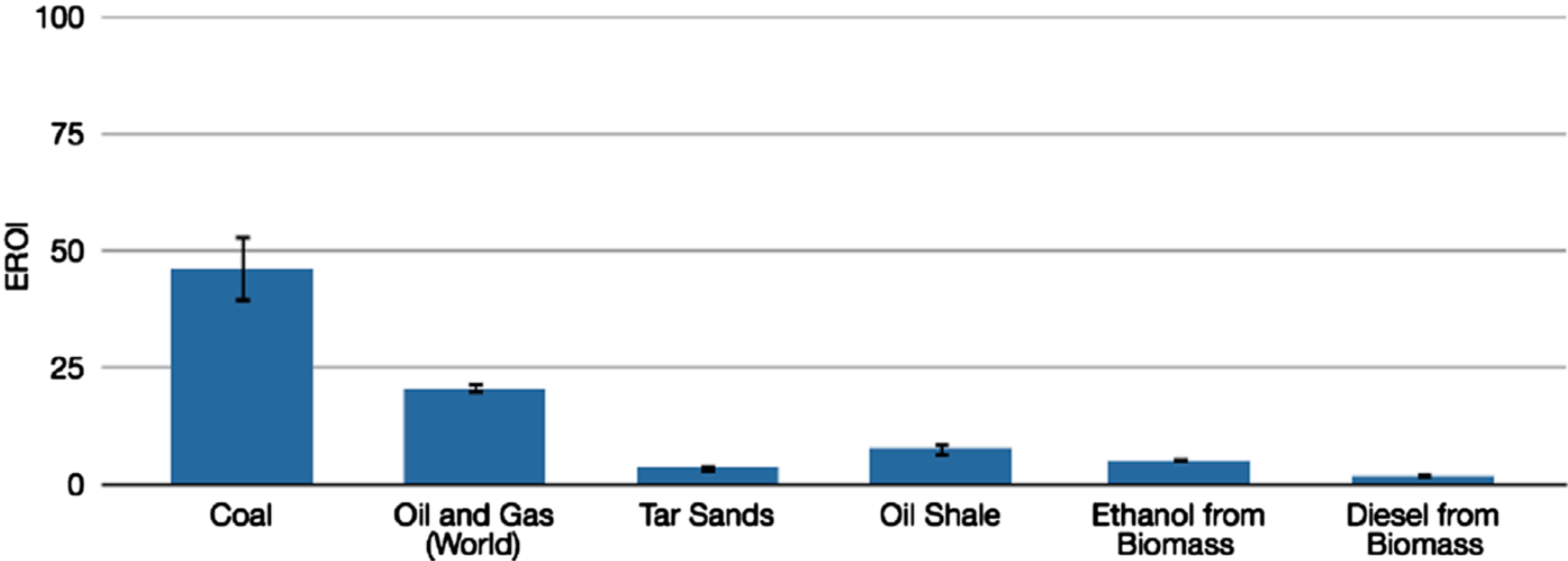
As EROI declines, less useful energy is available to society.



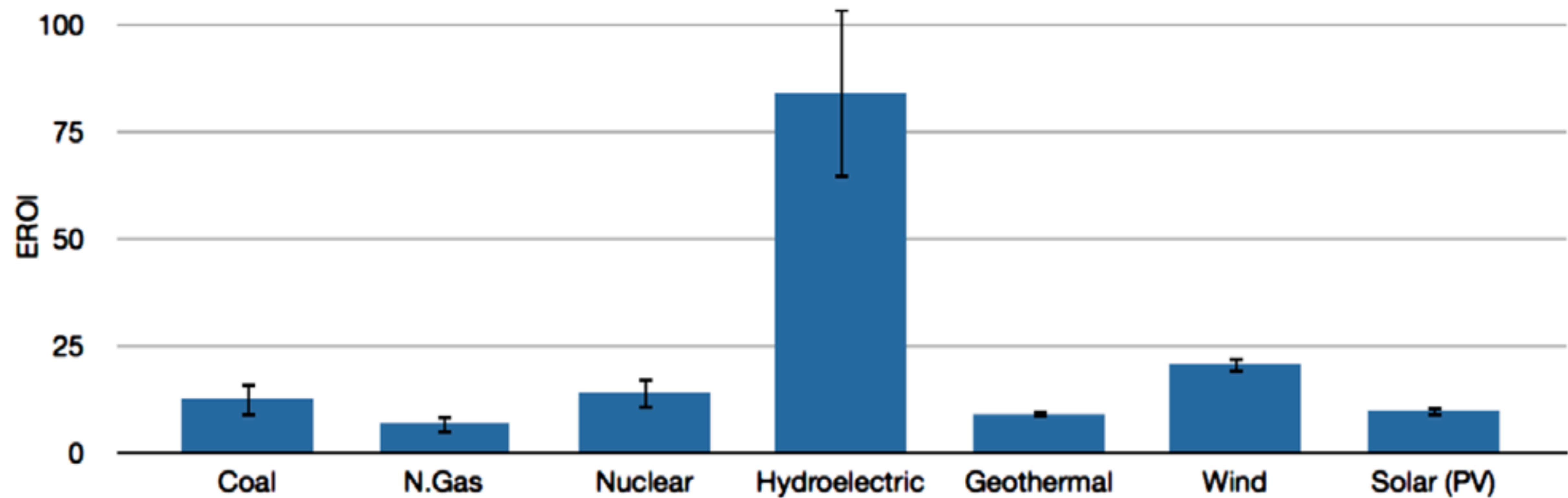
Hall: EROI from oil sources is declining.

Discovering oil	1000:1 1919	5:1 2010
Producing oil	25:1 1970s	10:1 2007
Shale oil		7:1 2012
Tar sands		4:1 2012

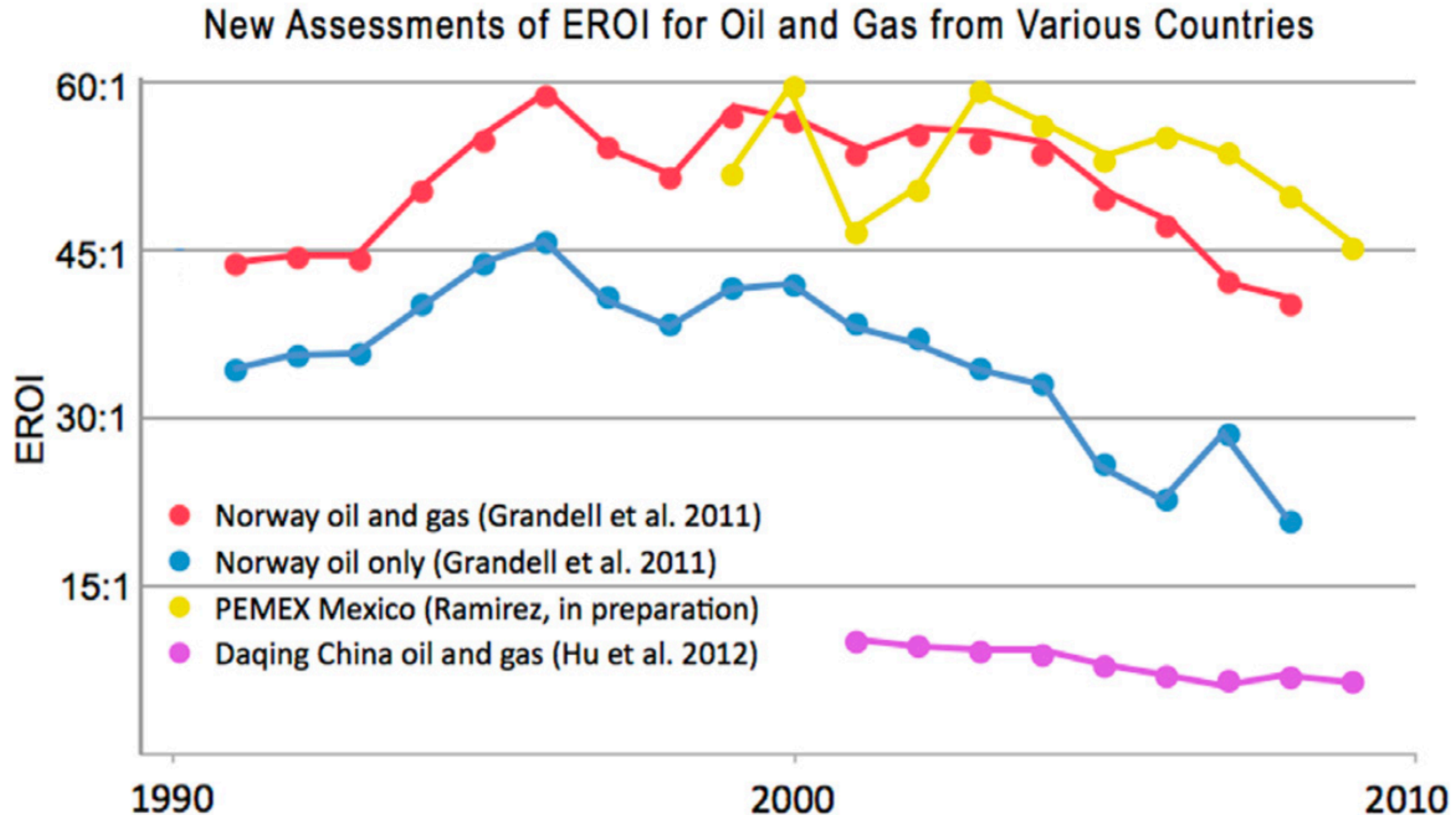
Hall: (Thermal) Energy Return on Invested Energy



Hall: Electrical Energy Return on Invested Energy



EROI declines in Norway, Mexico, and China



Goehring & Rozenchwajg: EROI explains world prosperity.

				Energy uses			
Year	Energy sources	GJ/yr/capita	EROI	Energy	Food	Shelter, work	Surplus
ancient	Food, feed, wood	5	5:1				
1	Food, feed, wood	17	5:1	3	4	10	<< 1
1650	No forest wood Coal discovery	20	10:1	2	4	10	4

5 GJ/yr = ~160 watts

Goehring & Rozencwajg: EROI explains world prosperity.

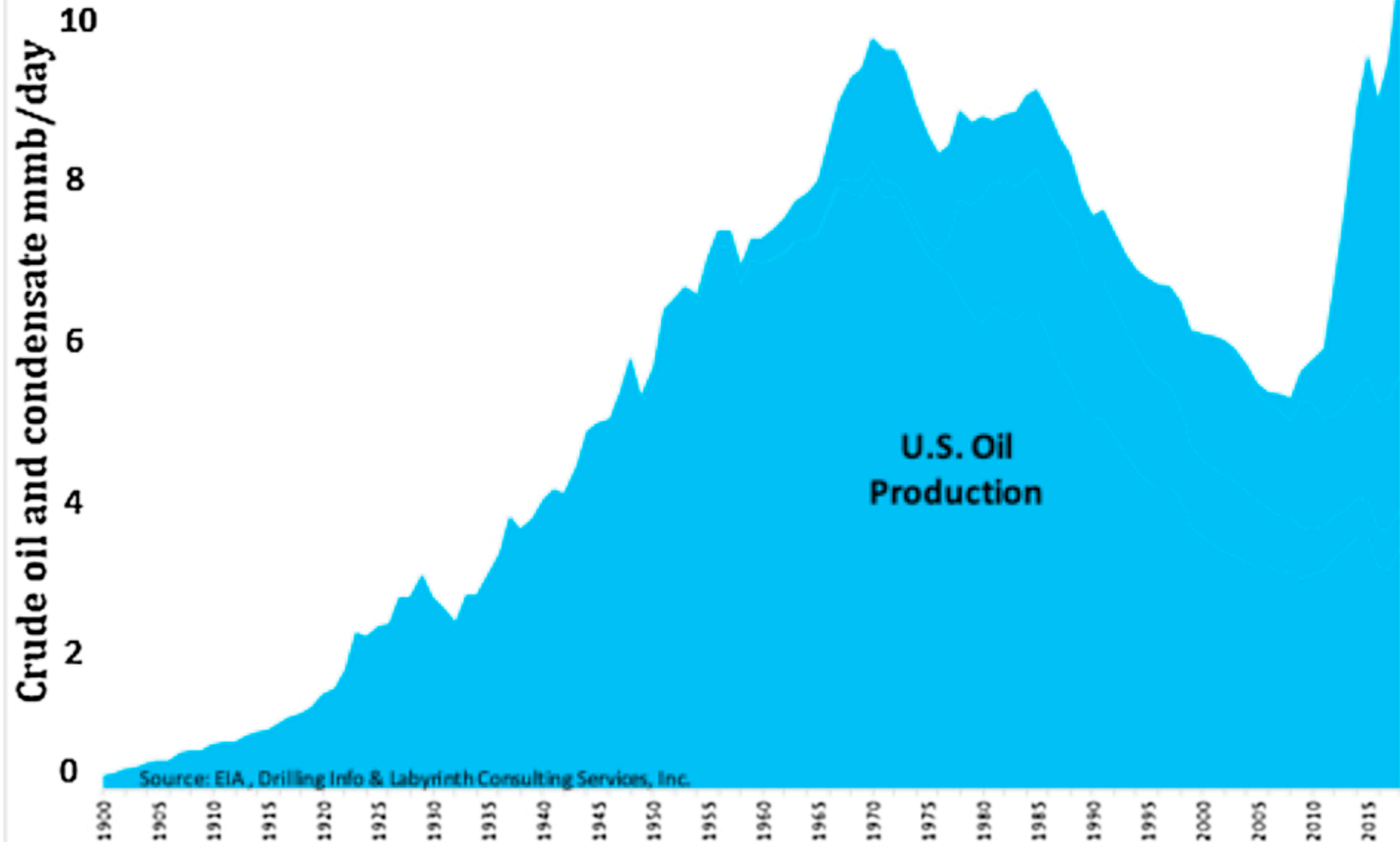
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1900	Oil, gas, coal	25	30:1	1	4	10	10
2019	Oil, gas, coal	75	30:1	1	4	10	56

Goehring & Rozenchwajg: EROI explains world prosperity.

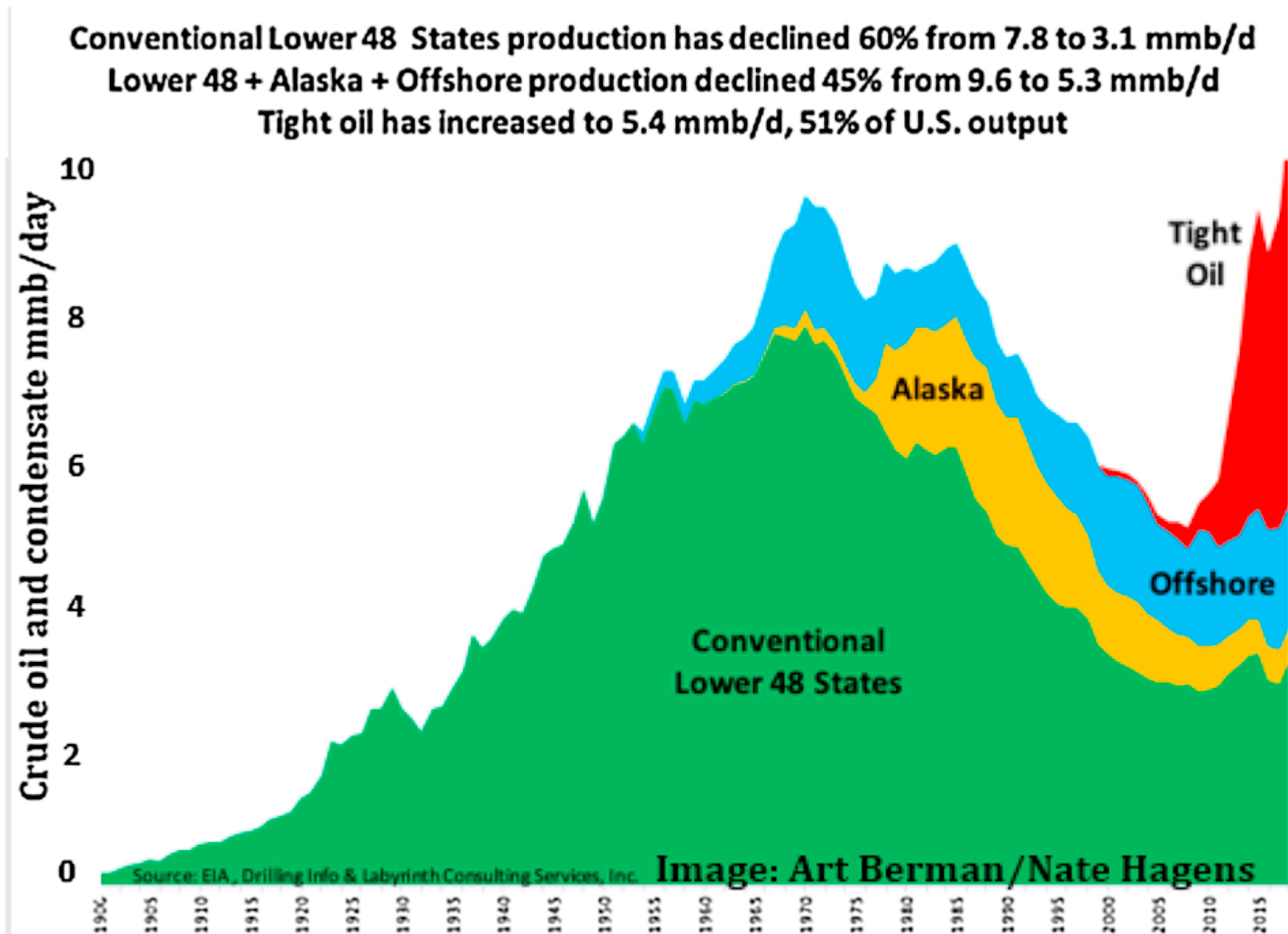
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2030 ?	Wind, solar	75?	3.5:1	25?	4	10	-39?

Misleading view: new technology made US #1 oil producer.

Using better technology, USA exceeds 1970 peak,
surpasses Saudi Arabia and Russia as worlds #1 producer



Realism: fracking technology increased drilling costs 350%.



Minimum EROI useful to society: ~ 3:1

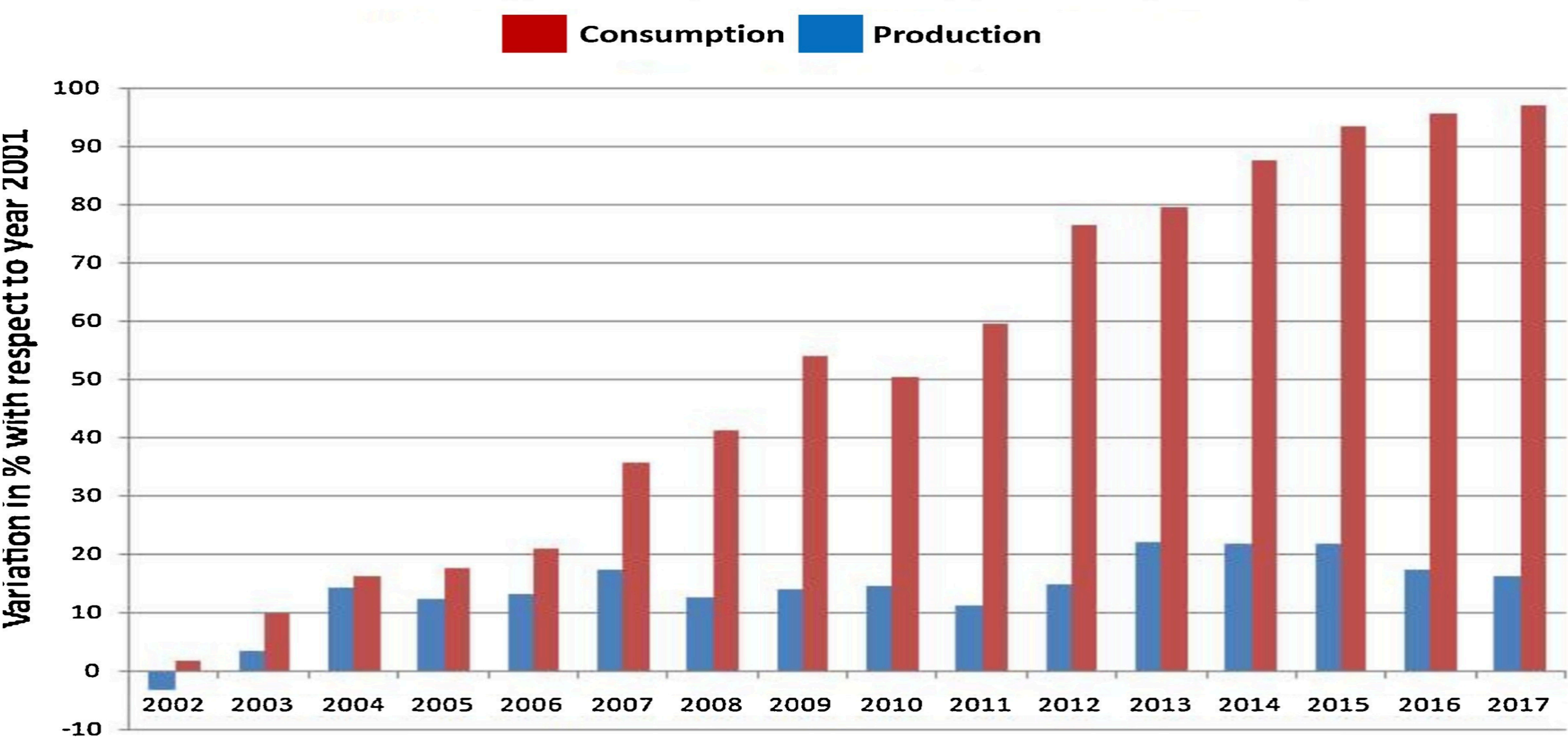
Ethanol from cellulose from wood. **0.64:1**

Diesel from biomass: **2:1**

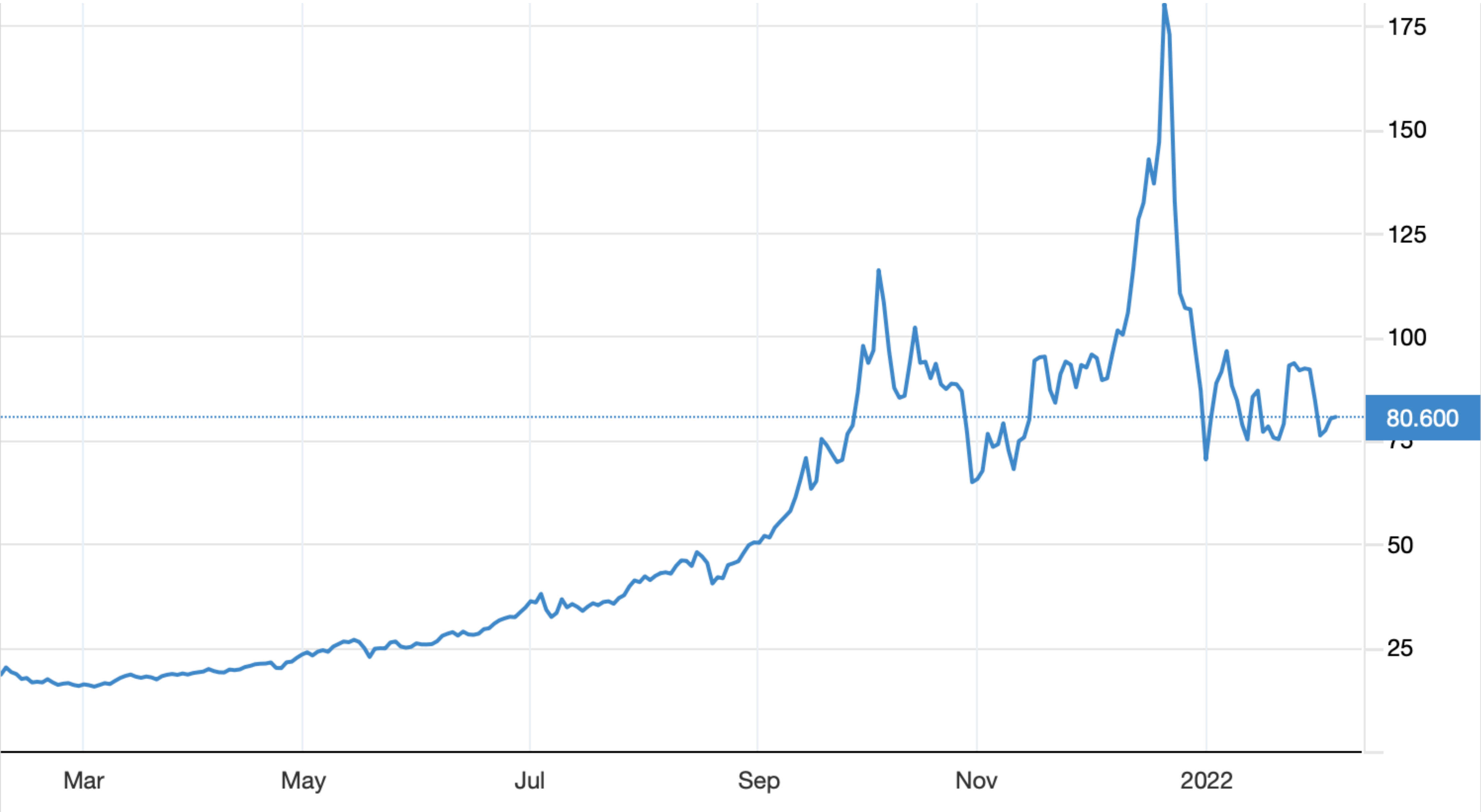
Diesel from coal: < 1:1 Reason= ?

Energy to mine copper increases as best ores are depleted.

Production and energy consumption of the copper mining industry in Chile



EU natural gas costs rose from 20 to 80 € per MWh(t).



**Aluminum Prices Can't Keep Up With Energy Costs,
Driving Wave of Closures. WSJ 2/3/22**

Soaring Energy Prices Fuel Mayhem For The Metals Industry

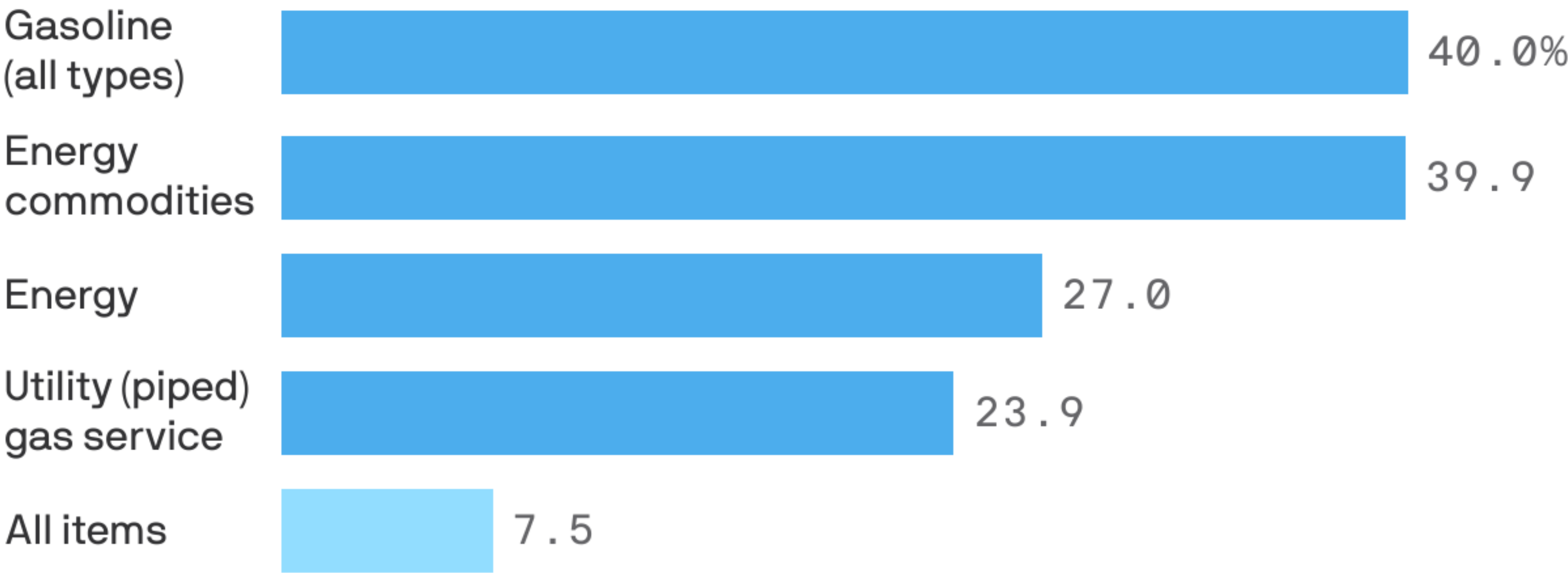
By Alex Kimani - Jan 31, 2022, 5:00 PM CST

- ▶ Rising energy prices fuel mayhem in the industrial metals sector.
- ▶ Aluminium smelters have curtailed production as a result of quickly rising energy costs.
- ▶ And traders now fear that the wave of closures will not only continue driving aluminum prices up but also make it increasingly difficult to secure supply in the market.

US energy prices rose in 2021.

Percentage increase in energy prices

Seasonally unadjusted; January 2021 to January 2022

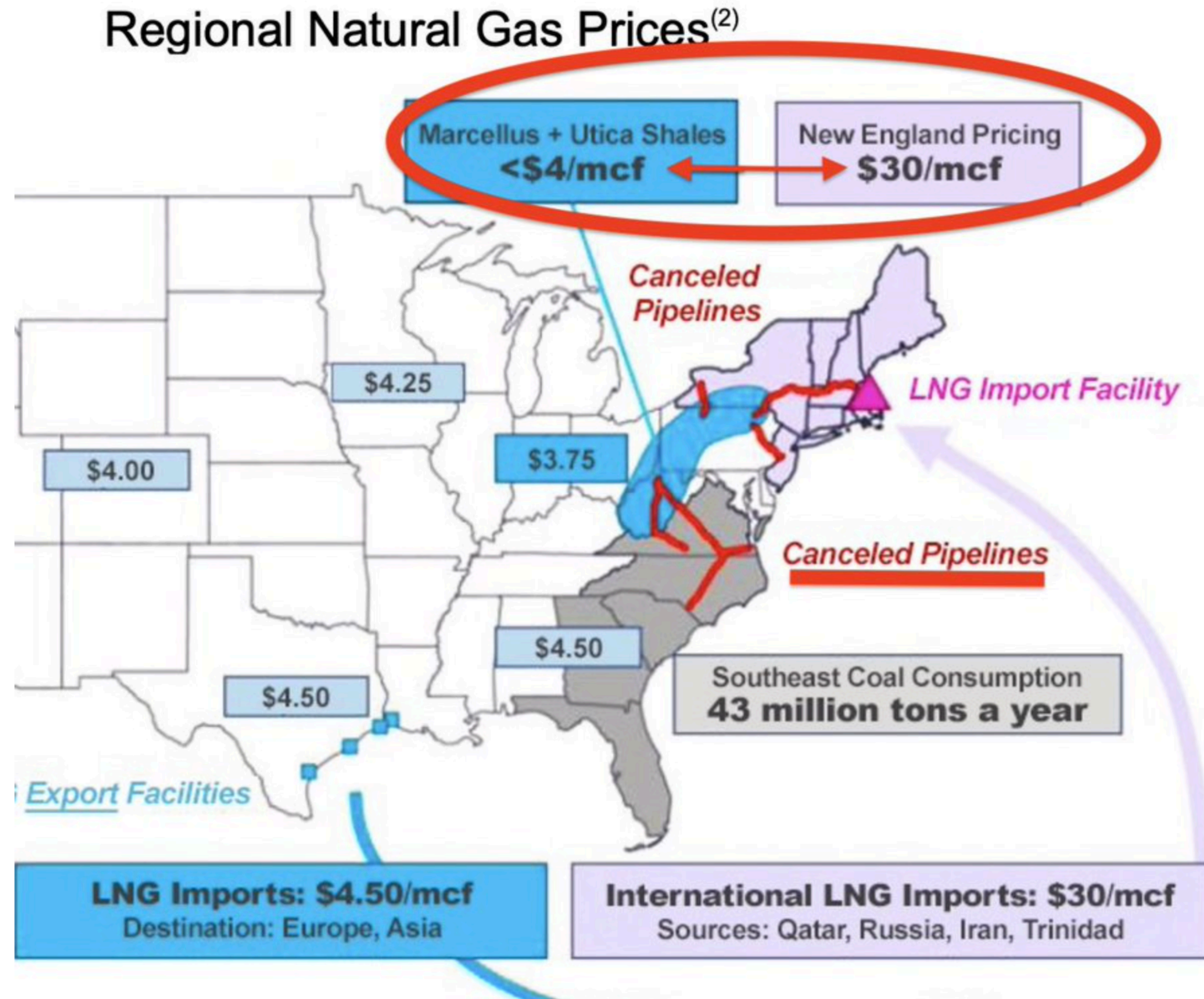


Limited pipeline gas boosted by expensive LNG imports.

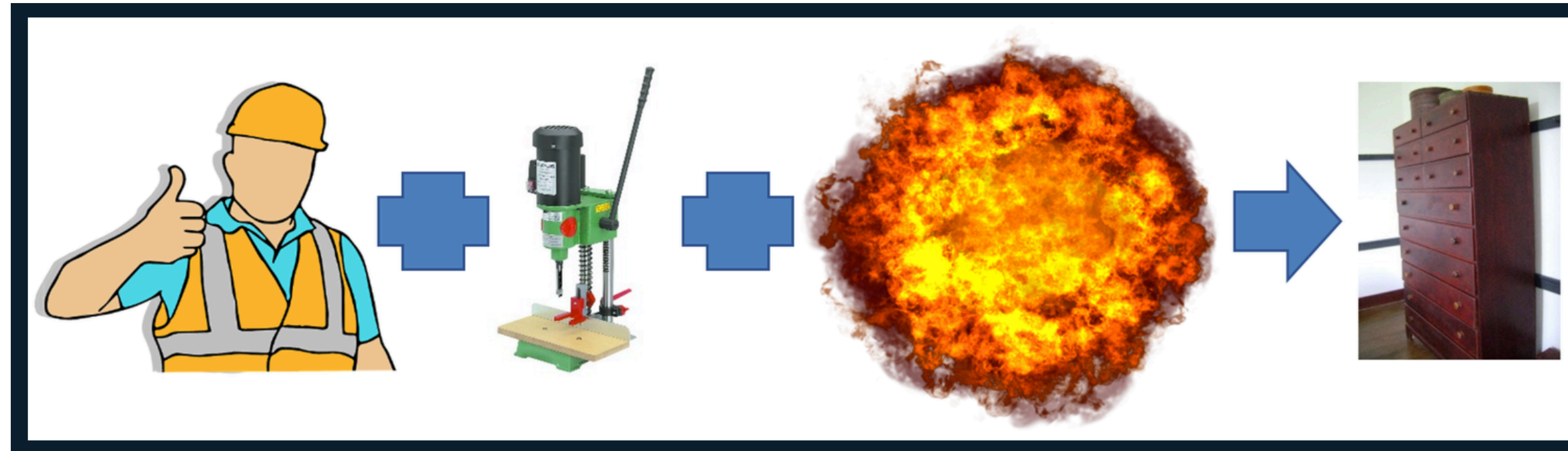
January, 2022	Natural Gas (\$/million Btu)		Electricity (\$/MWh)	
	Price	Percent Change*	Price	Percent Change*
New England	30.50	+29.8	208.24	+16.7
New York City	20.05	+139.3	216.64	+29.5
Mid-Atlantic	7.04	+20.5	96.03	+40.5
Midwest	5.12	+15.4	49.40	-11.2
Louisiana	5.69	+28.4	69.75	+74.4
Houston	5.28	+26.3	43.50	+6.7
Southwest	5.02	+9.1	44.75	-0.6
Southern CA	5.34	+7.0	54.35	+15.0
Northern CA	5.39	+9.3	54.98	+10.7
Northwest	5.06	+10.1	36.50	-4.4

Special interest groups stop major infrastructure projects.

- pipeline
- transmission lines
- Jones Act



How does GDP depend on energy? Steve Keen



Classical economics



Modern economics

GDP depends on capital and labor, which depend on energy.

Feudal times:	GDP = function { land }
Classical economics:	GDP = function { capital, labor }
Three factor fix:	GDP = function { capital, labor, energy }
Modern economics:	GDP = function { capital(energy), labor(energy) }

Tim Garrett:

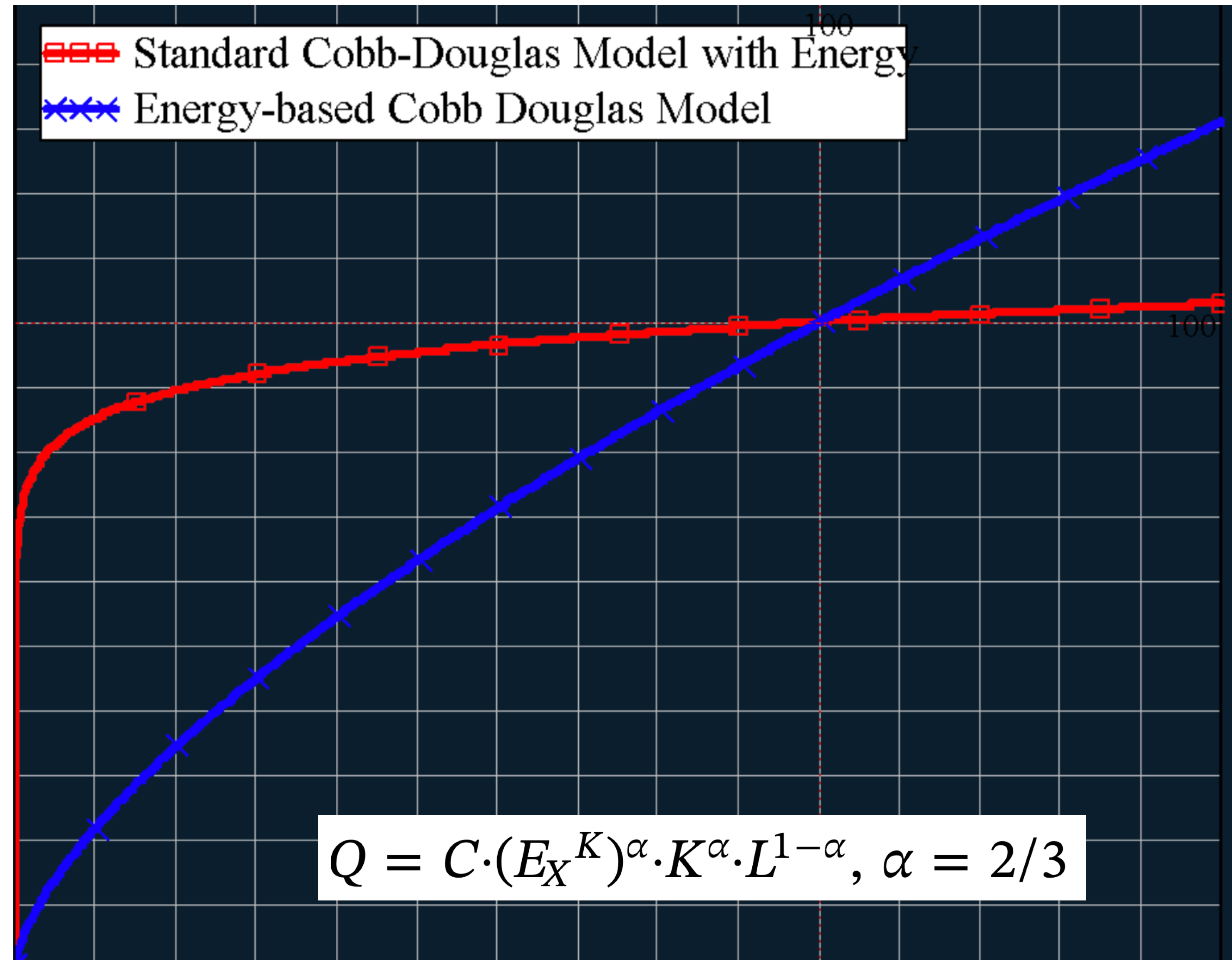
$$Q = C \cdot (E_X^K)^\alpha \cdot K^\alpha \cdot L^{1-\alpha}, \alpha = 2/3$$

Steve Keen:

$$Y = \Lambda \times (E_K \times e_K \times K)^\alpha \times L^{1-\alpha} \quad \text{alpha} = 0.8$$

Energy's contribution to production is much higher than its share of GDP.

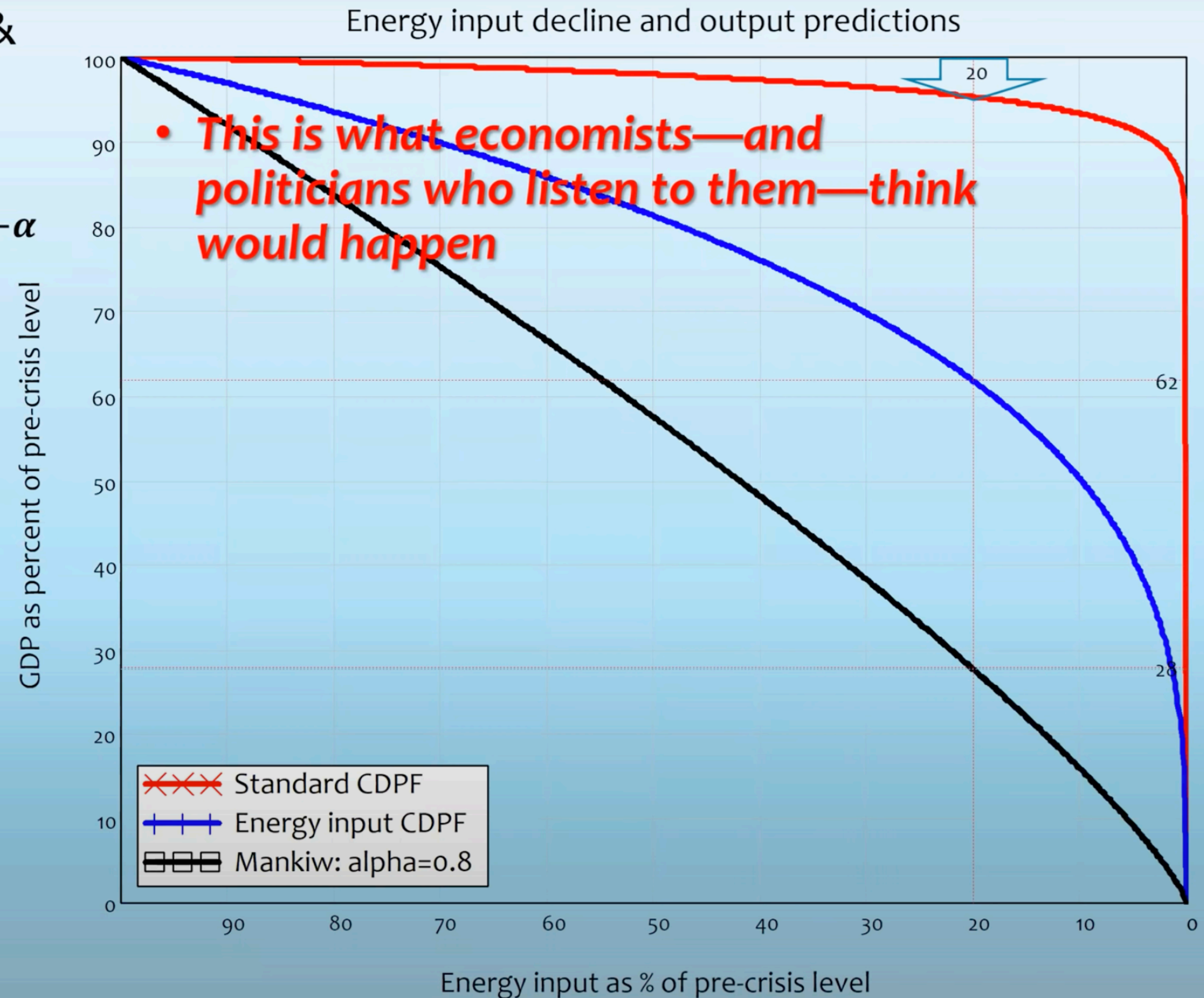
Looks nearly linear!



Energy's value to GDP is much more than its cost share.

Integrating economics, energy, and ecology

- My solution: standard model (& Mankiw's stats) omit energy
- Include it **with** $\alpha = 0.8$ in
- $Y = A \times (E_K \times e_K \times K)^\alpha \times L^{1-\alpha}$
- **80%** fall in energy
- **72%** fall in GDP
- This is why Larry was right that “when there wasn't any electricity there wasn't really going to be much economy”



Steve Keen

- Concept of labour and capital without energy is absurd
 - ***Labour without energy is a corpse***
 - ***Capital without energy is a sculpture***
- Think of them instead as means to harness “free” energy
- And think of GDP as “useful work”. Then we start with

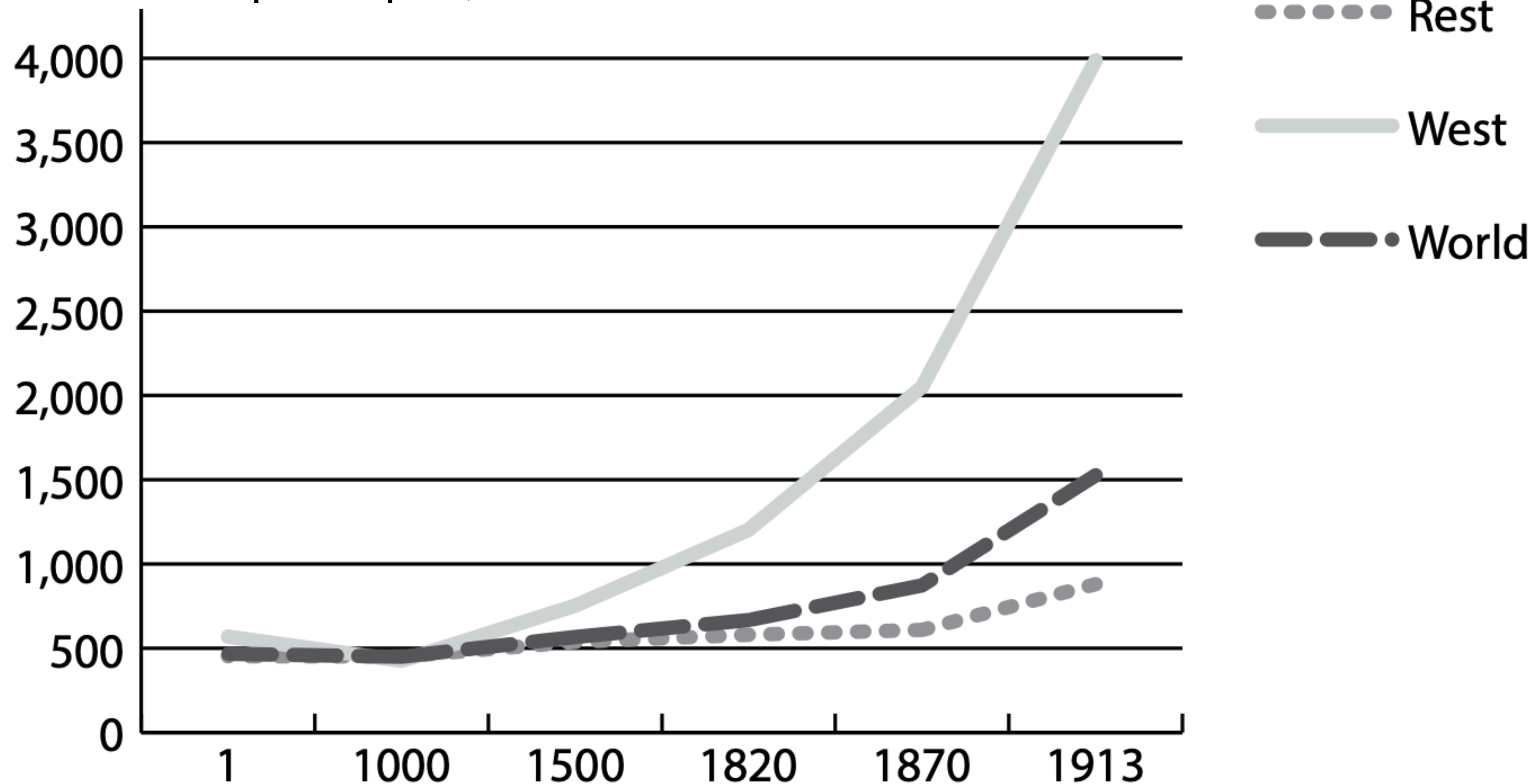
$$Y(E) = f(K(E), L(E))$$

$$Y = \Lambda \times (E_K \times e_K \times K)^\alpha \times L^{1-\alpha} \quad \alpha = 2/3$$

John Constable: Energy, Entropy and the Theory of Wealth

Why were we poor for so long?

4,500 GDP per capita, 1990\$



Nature of energy

Sun sourced, sparce

Variable, seasonally, yearly

UK coal near surface

Steam also enhanced old
technolgies, wood, ships.

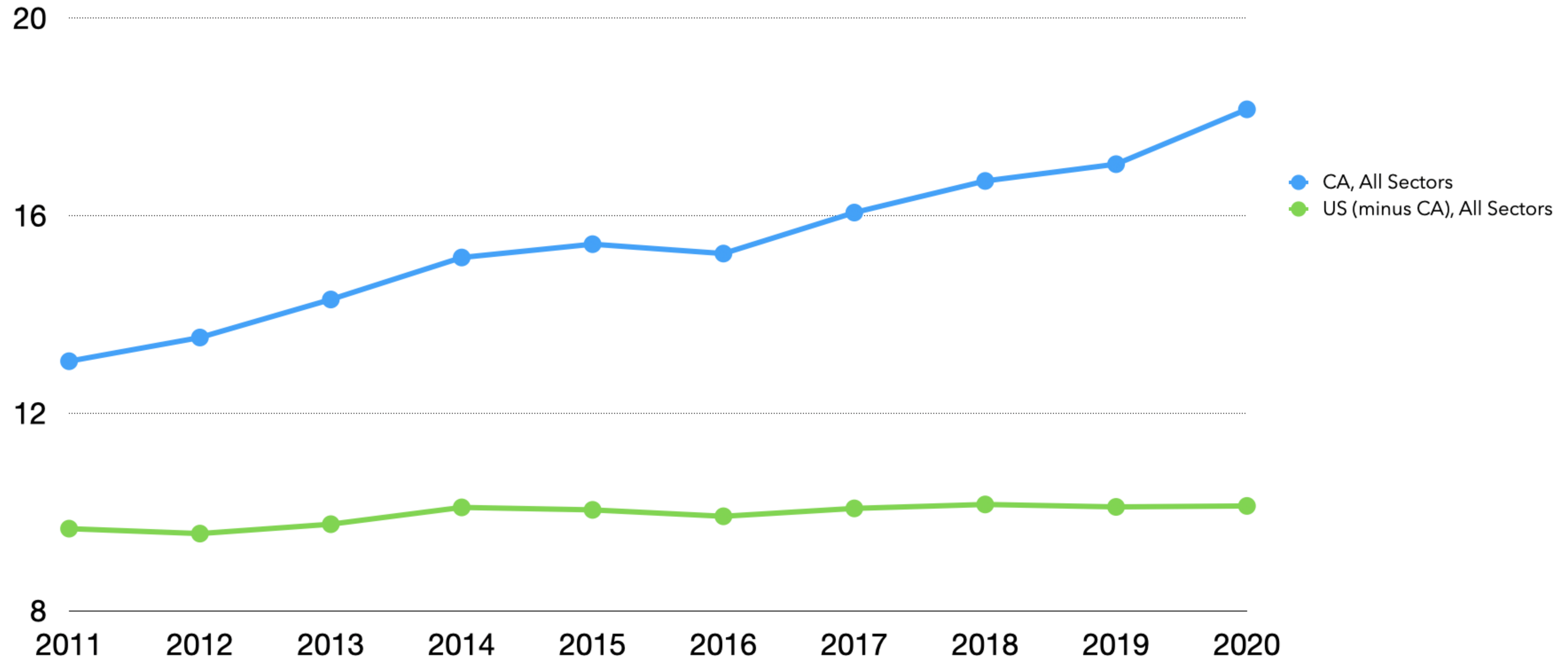
Decouple economy from energy?

“The suggestion that we can stay rich without consuming resources, particularly energy, is incompatible with what we know thermodynamically about the world.”

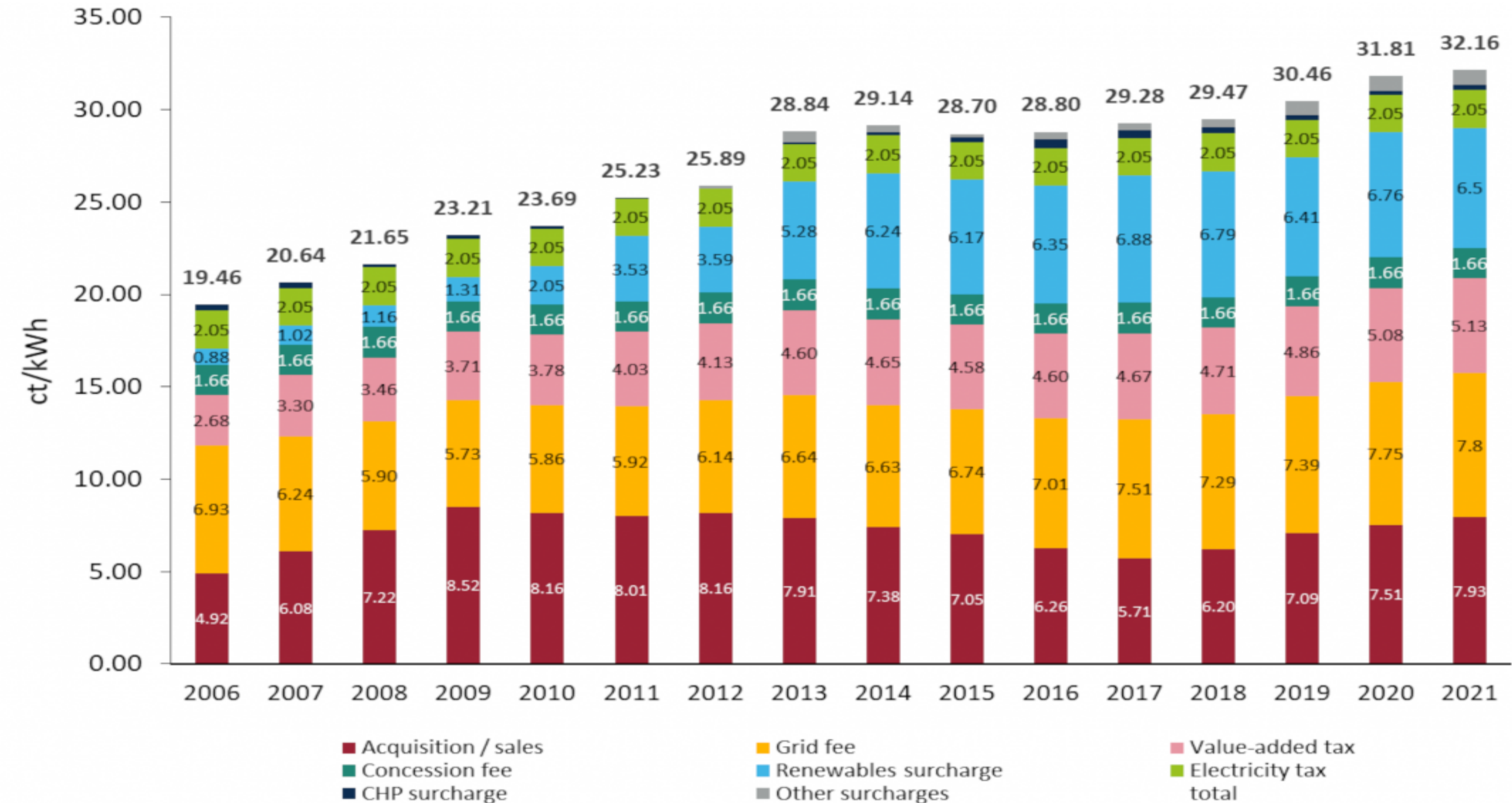
Constable: cheap energy is the only answer

- The current energy and climate policies are extremely unstable
 - Only low cost emissions reductions have any political future
 - Invention and innovation policies required
- Taxes on energy should be avoided
- OECD economies are all to some degree poisoned with high cost capital stocks resulting from decades of taxation and levies
 - Flushing with cheap energy is the only answer

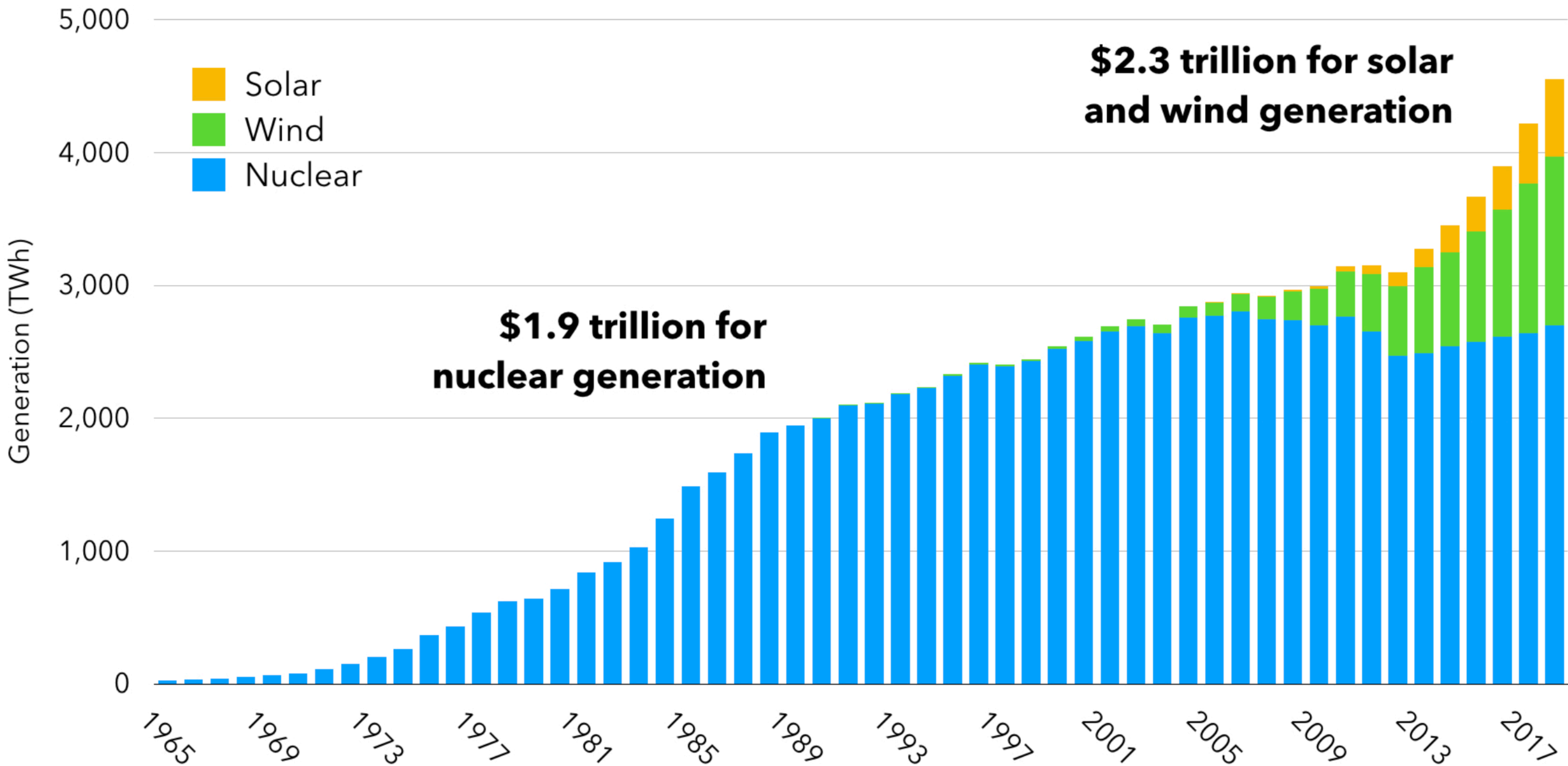
Electricity Prices in California rose 8x more than in rest of the U.S.



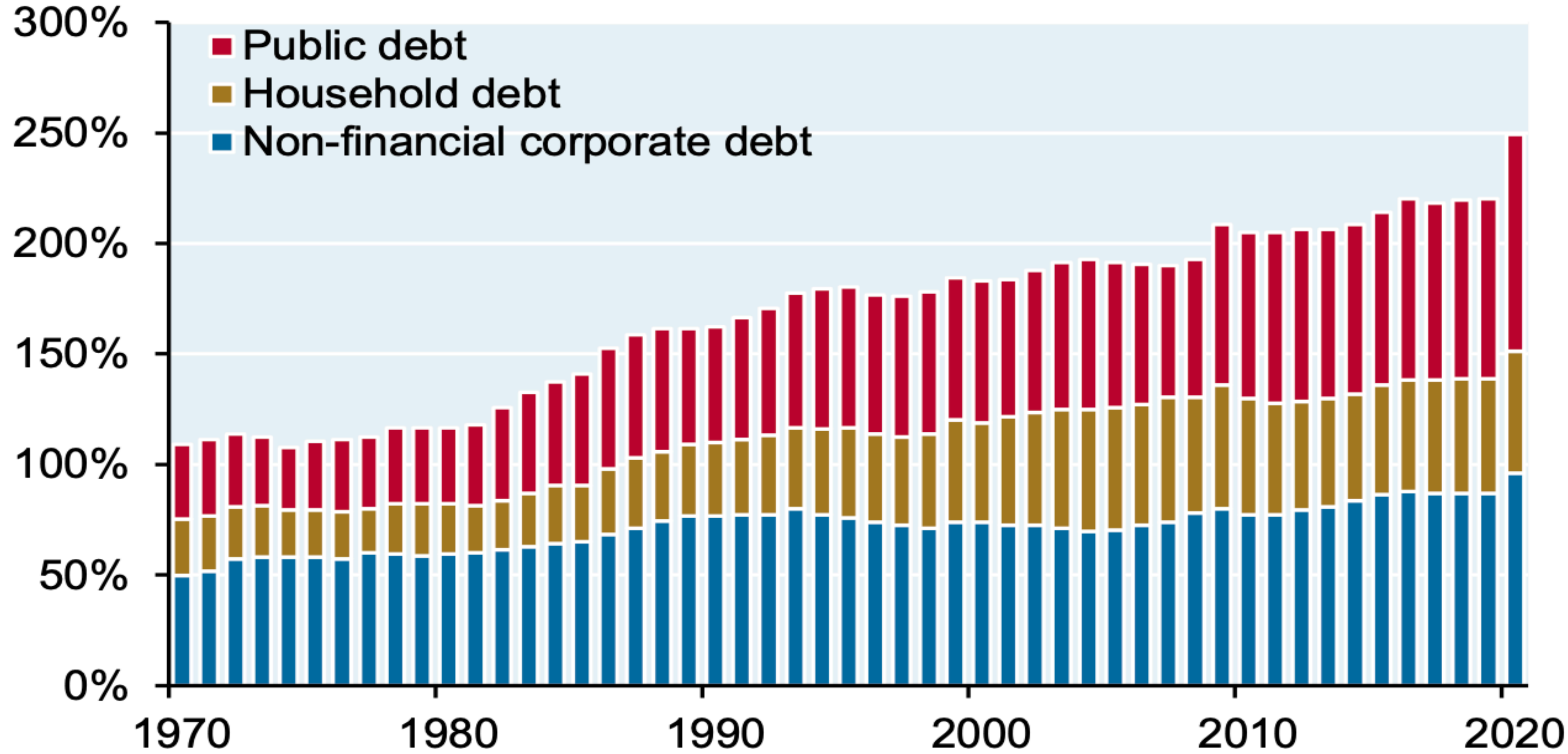
German renewables surcharges increase electricity costs.



Fission power 10X more cost-effective than wind and solar.

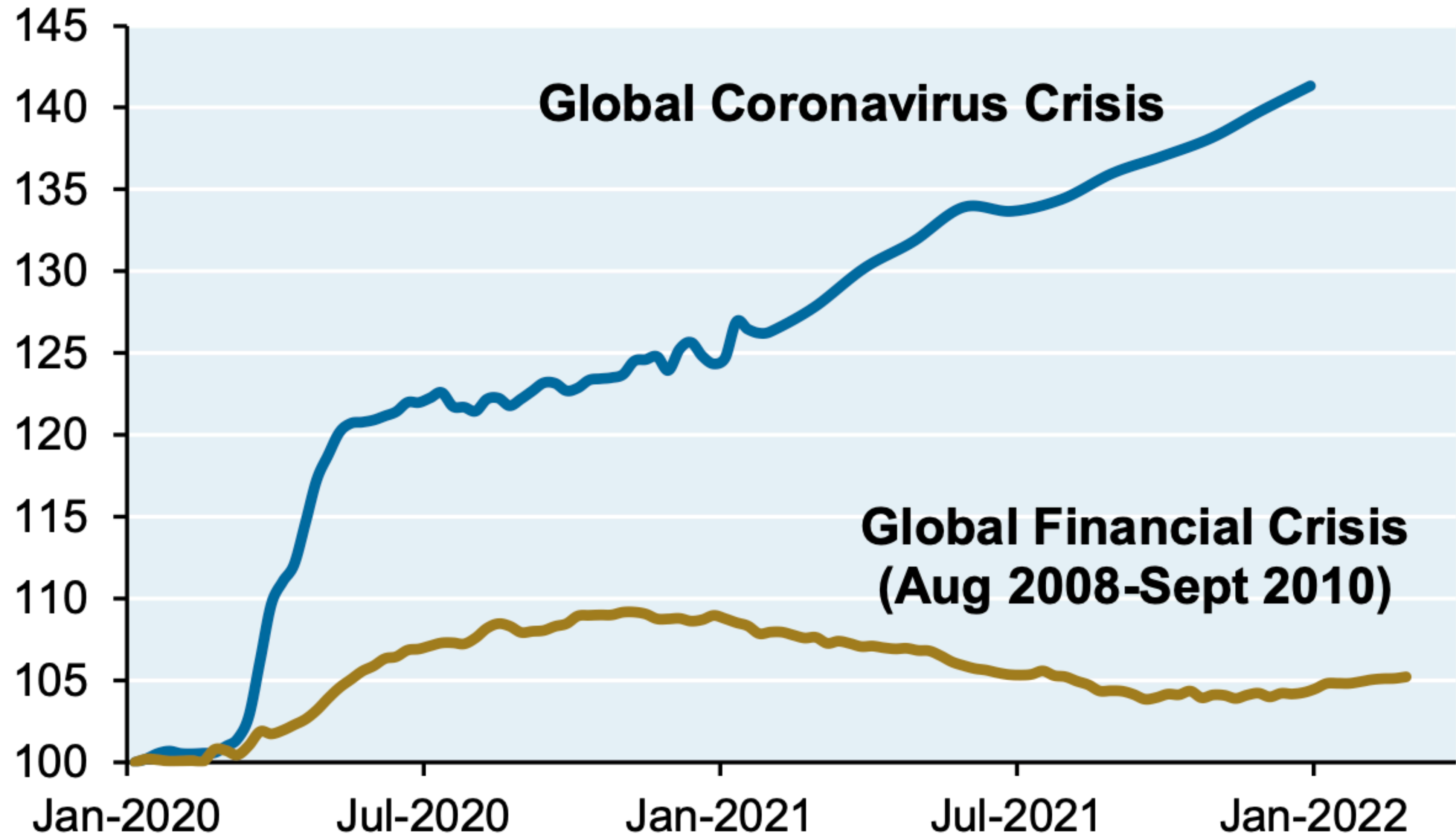


Global debt, as %GDP



Source: IMF. 2020.

M2 money supply + institutional money market fund balances, index



Source: St Louis Fed, ICI, J.P. Morgan Asset Management. Dec 2021.

Some argue against excessive fiat money supply.

Money basis: gold? fiat? US\$? petroleum? uranium? joule?



- Energy IS the economy. Each \$1 GDP demands ~1.5 kWh heat, ~ 0.2 kWh electricity.
- Ford, Edison proposed energy dollar.

(1 MJ = 0.28 kWh)

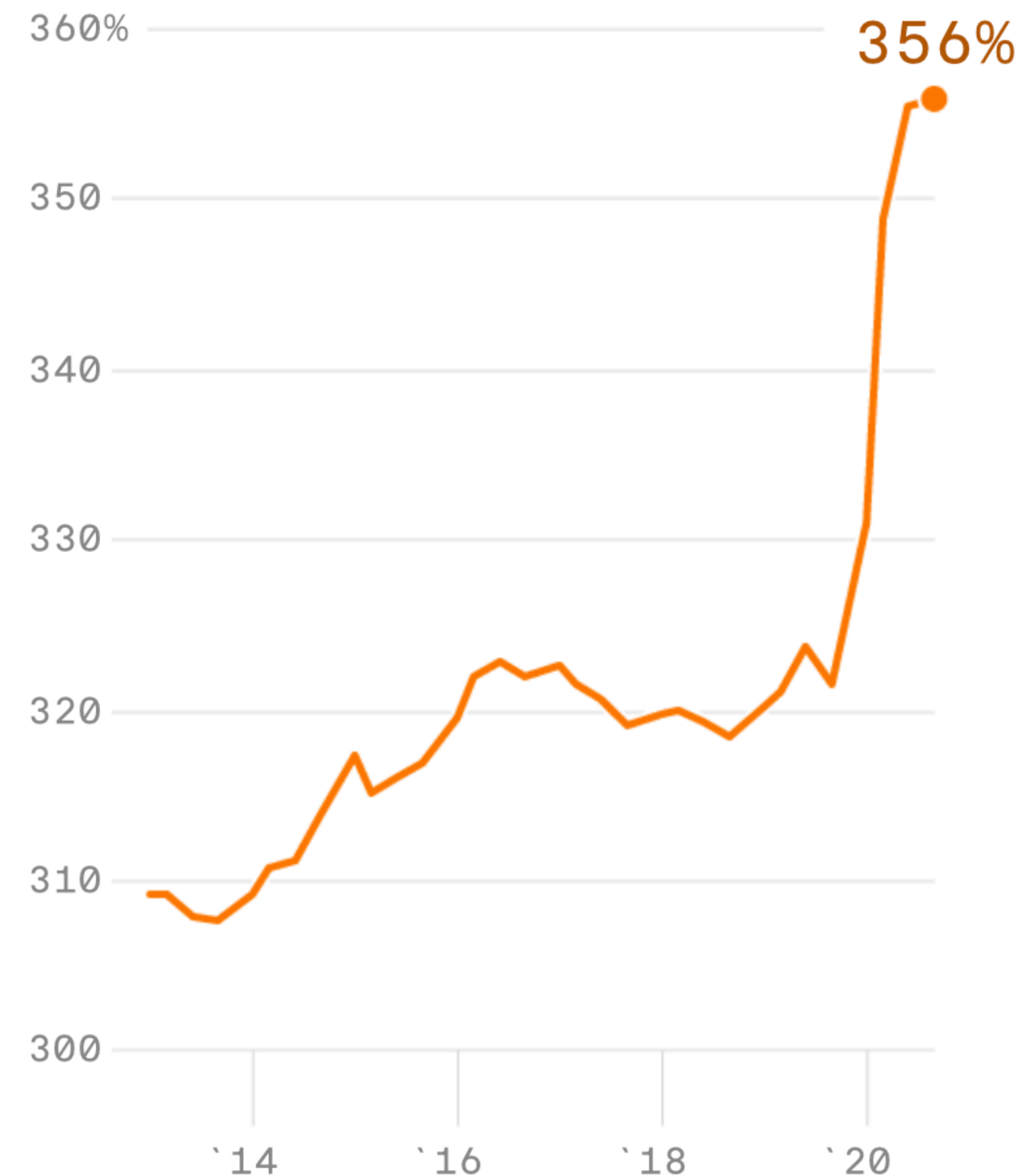
Fission-sourced energy of uranium and thorium can power the world for centuries.

Debt is a call on future earnings.

Total global debt Q1 2013 to Q4 2020



As share of GDP



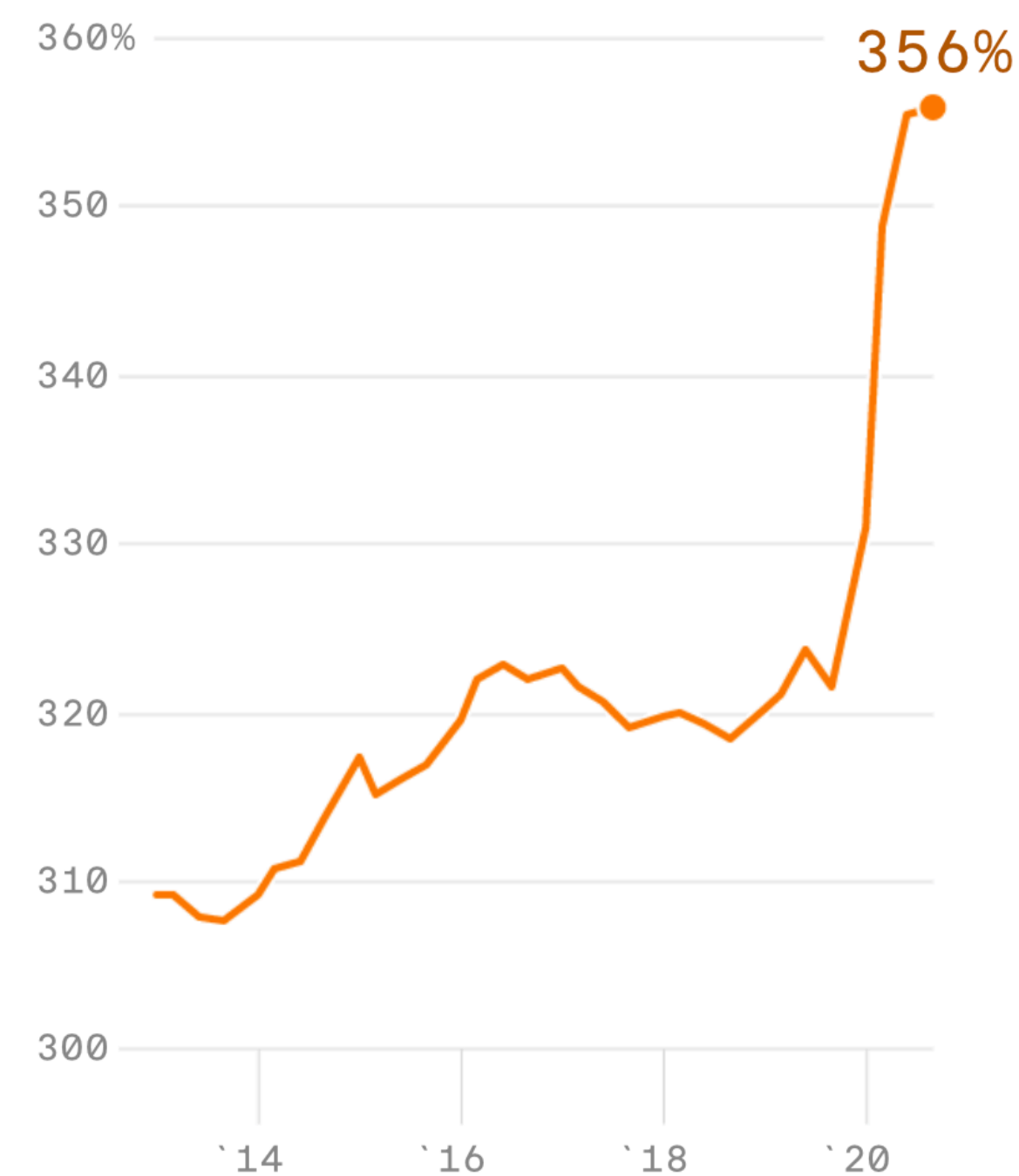
Debt is a lien on future energy!

**1.5 kWh/\$ x \$281 trillion = 48,000 GW-years
= 2.6 years of world energy production!
But EROI is going down.**

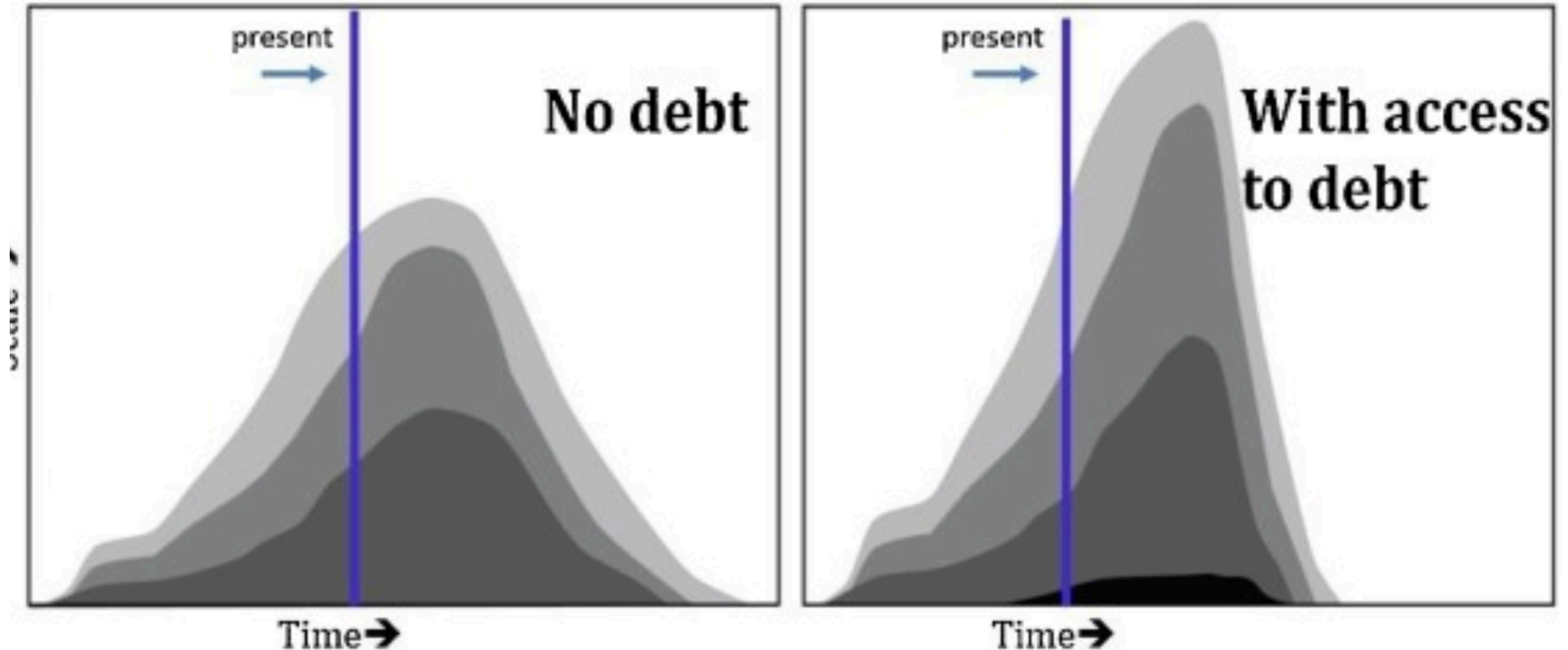
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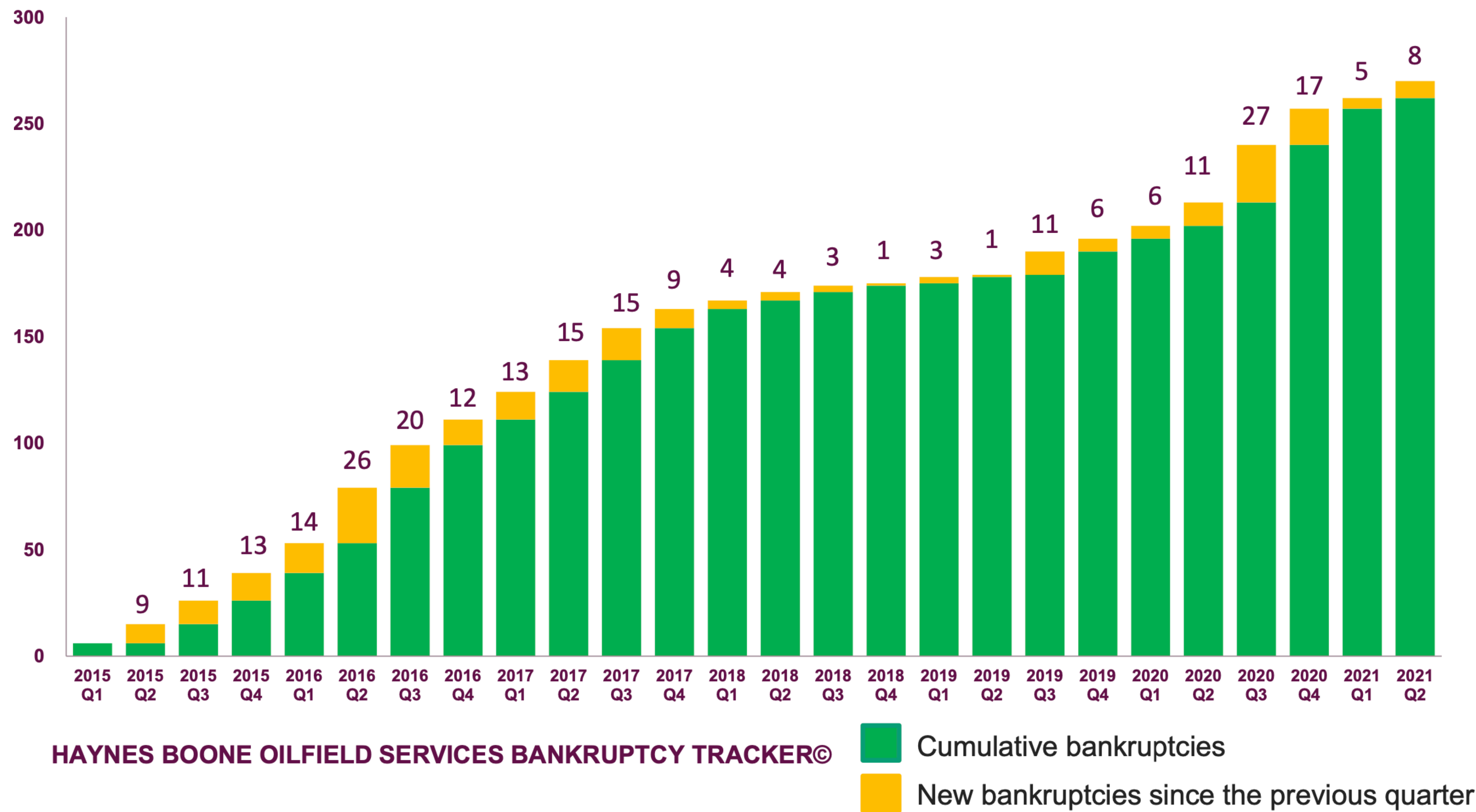
As share of GDP



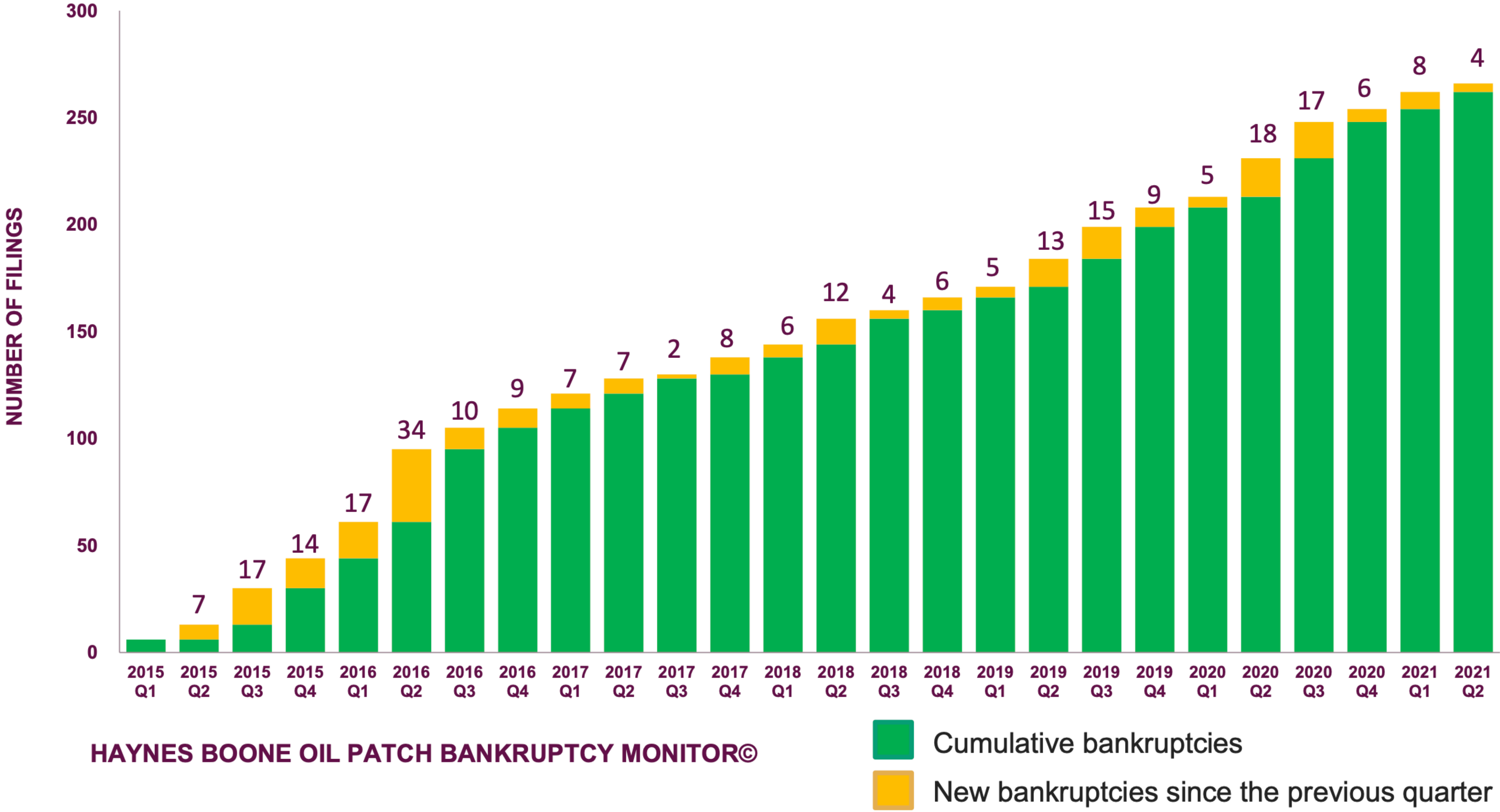
Hagens' concept: cheap debt funding allowed oil companies to extract new higher-cost oil (dark black on right panel)



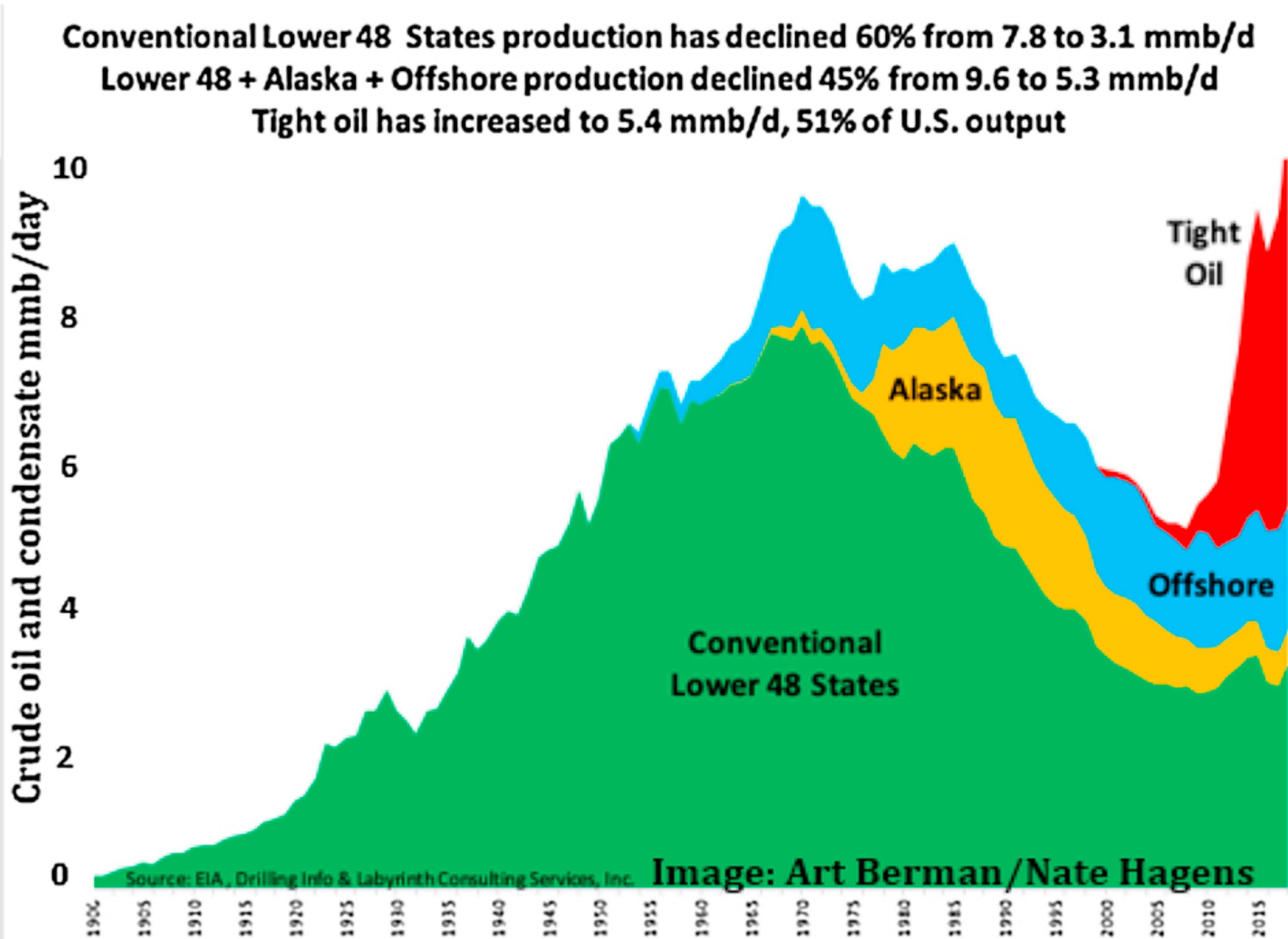
Oilfield services bankruptcies: \$117 billion, 2015-2021



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



Realism: fracking technology increased drilling costs 350%.

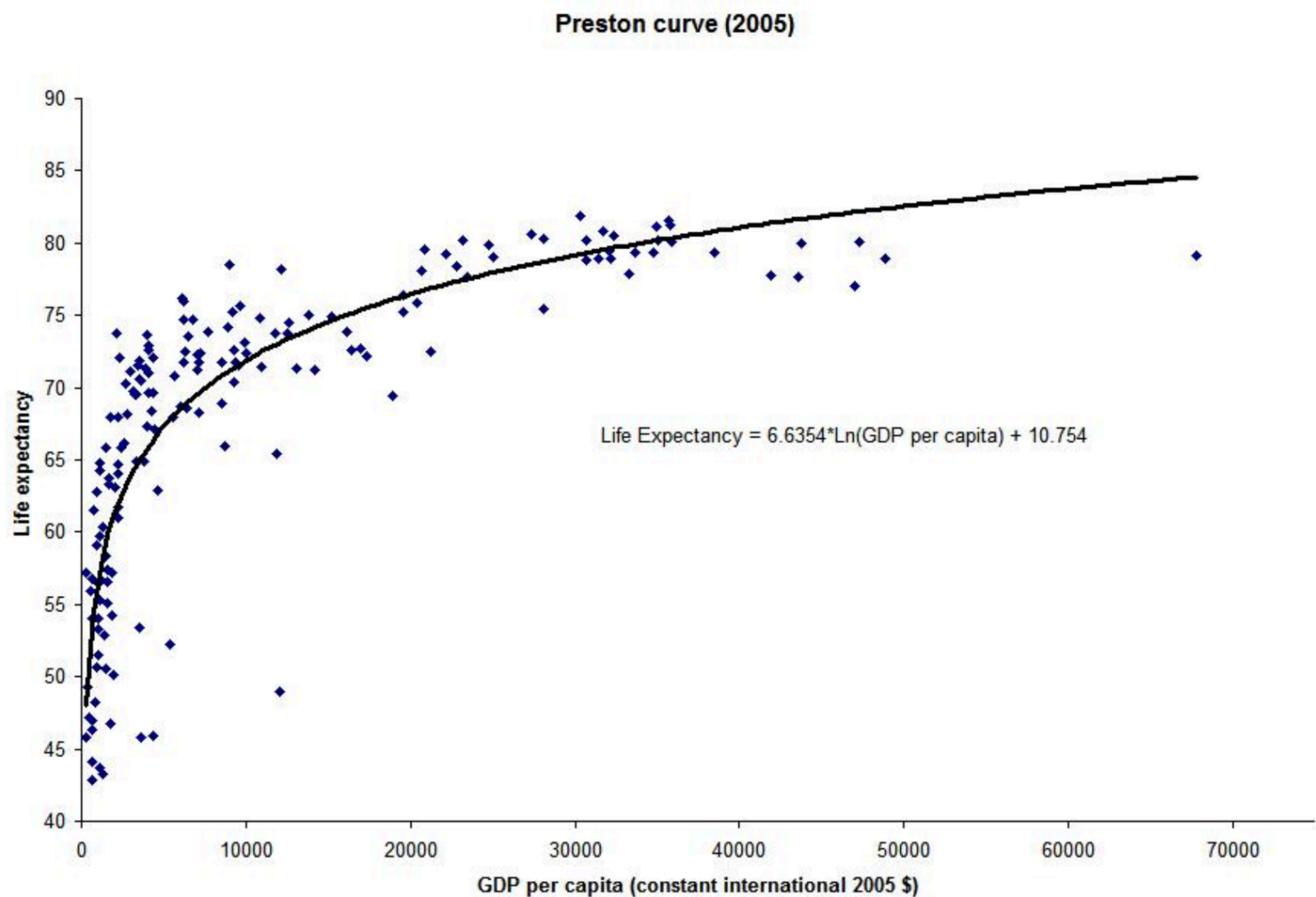


Real income is dropping for 96.5% of US earners.

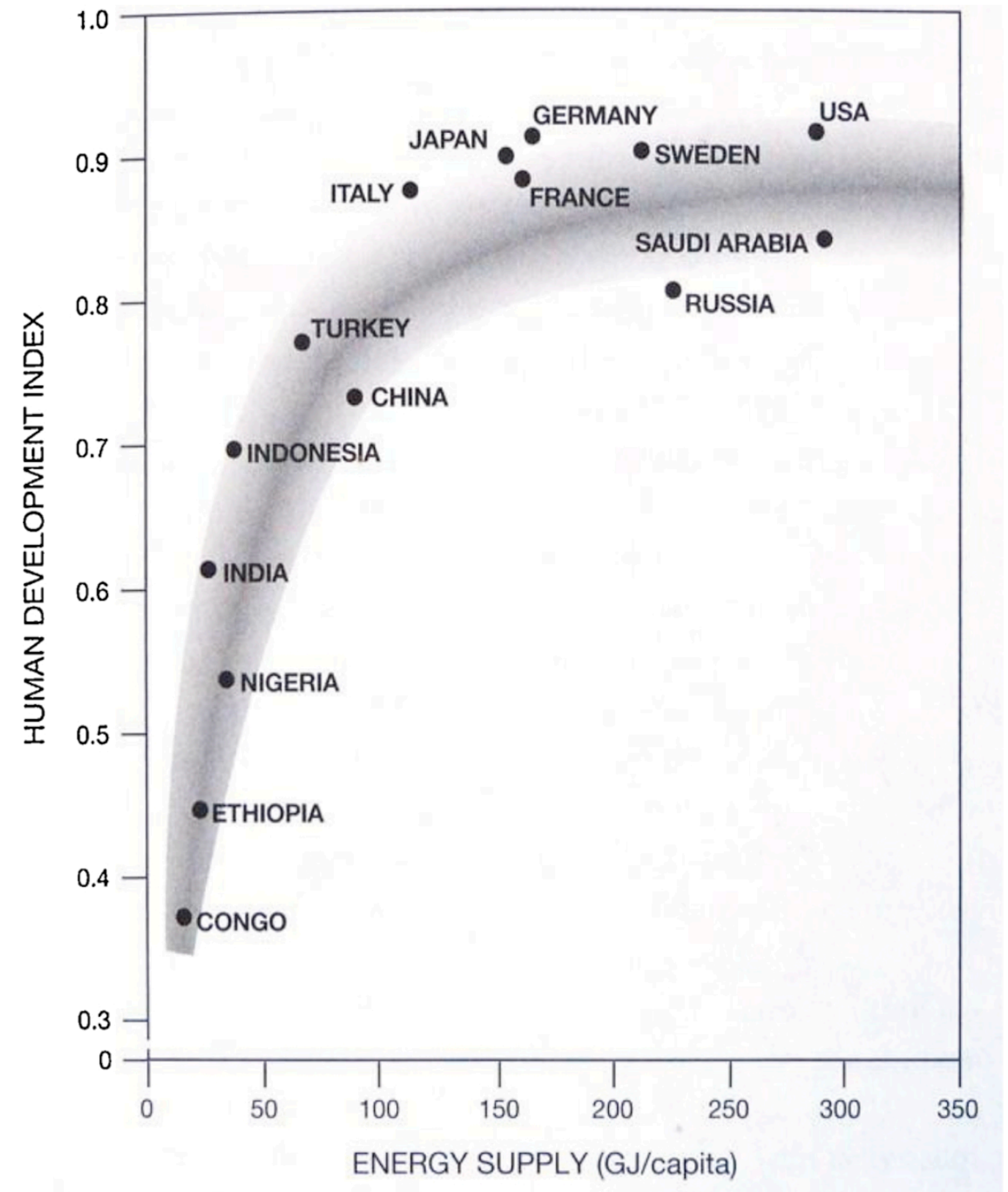
- Change in U.S. mean real total money earnings, by educational group, 2000 through 2016.

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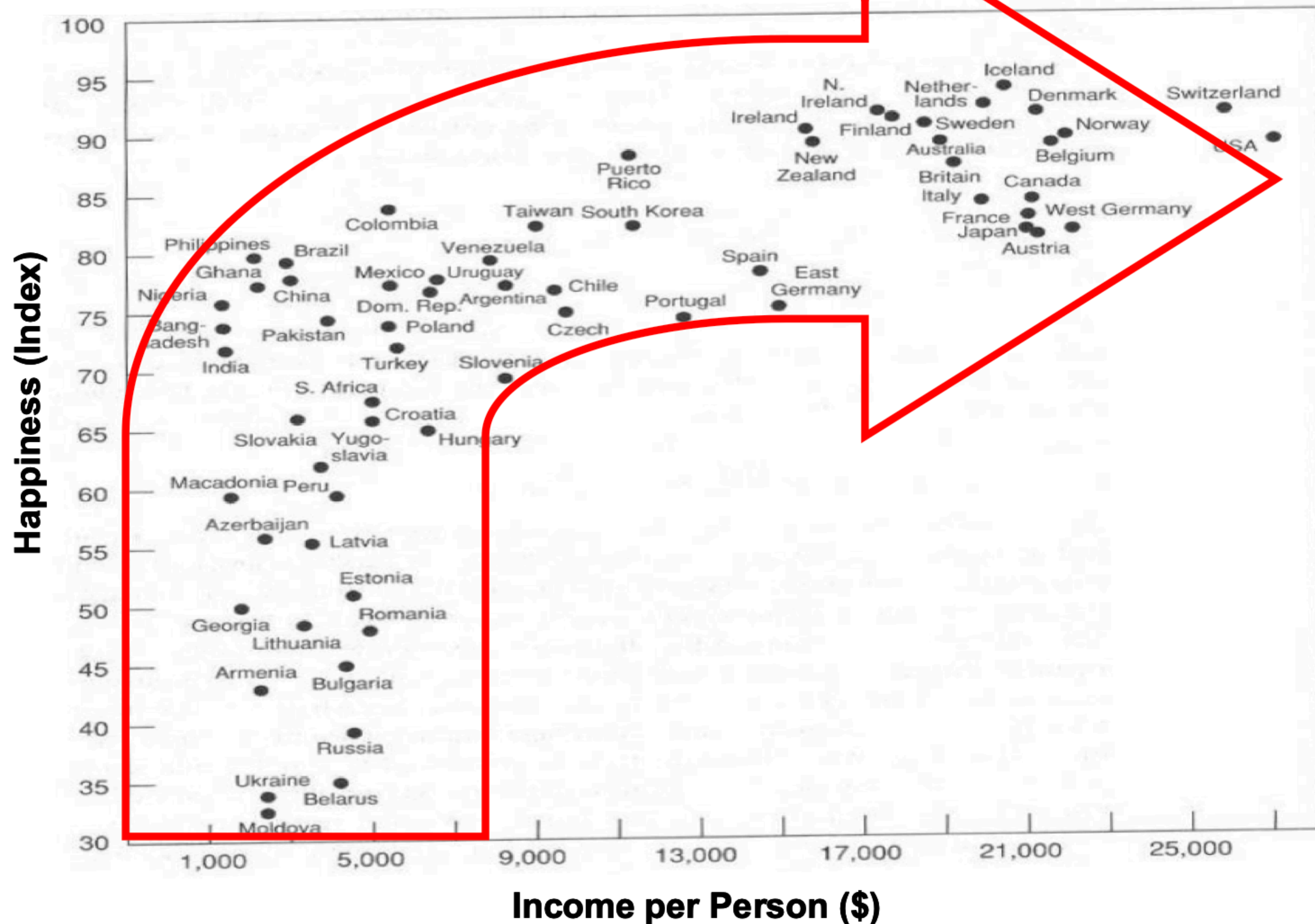
Life expectancy as function of GDP/capita



Human development index vs global energy supply



Income and happiness by country



What's the value of energy to happiness?



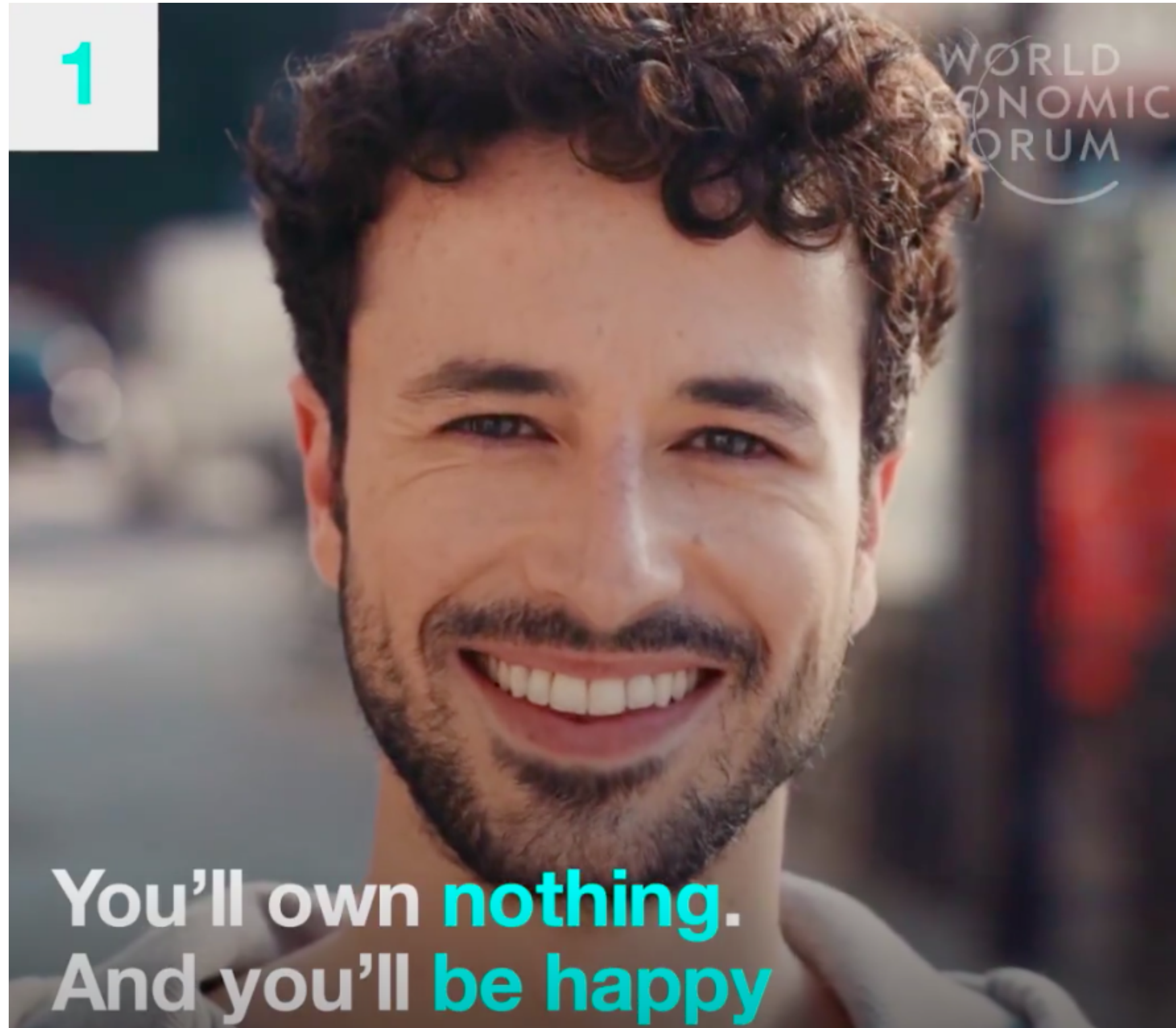
Davos

World Economic Forum

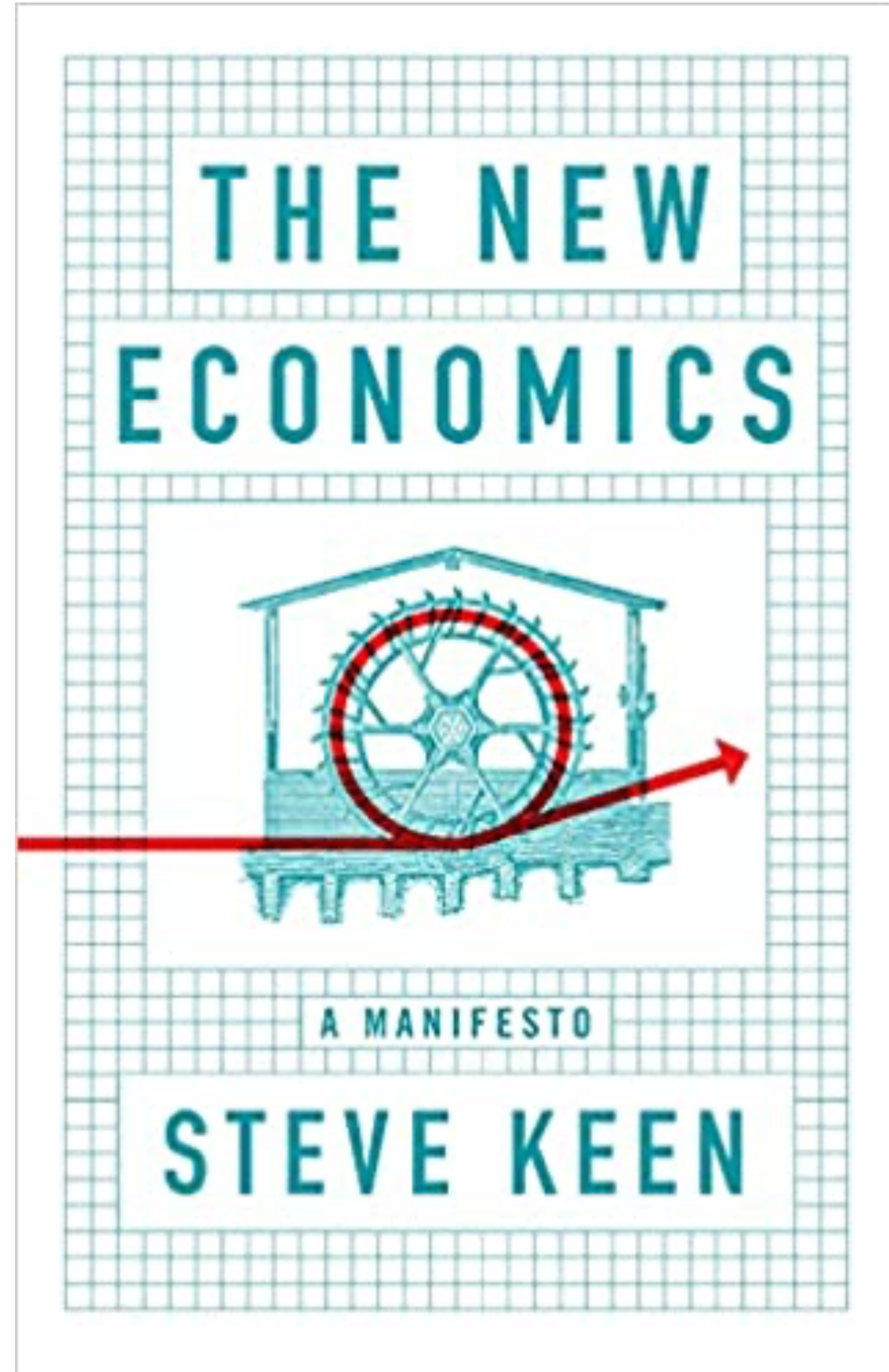
Jan 2021

The Great Reset

50th annual meeting of
the World Economic
Forum



**Some economists argue
against excessive fiat money
supply.**



Some argue against excessive fiat money supply.

Tim Garrett



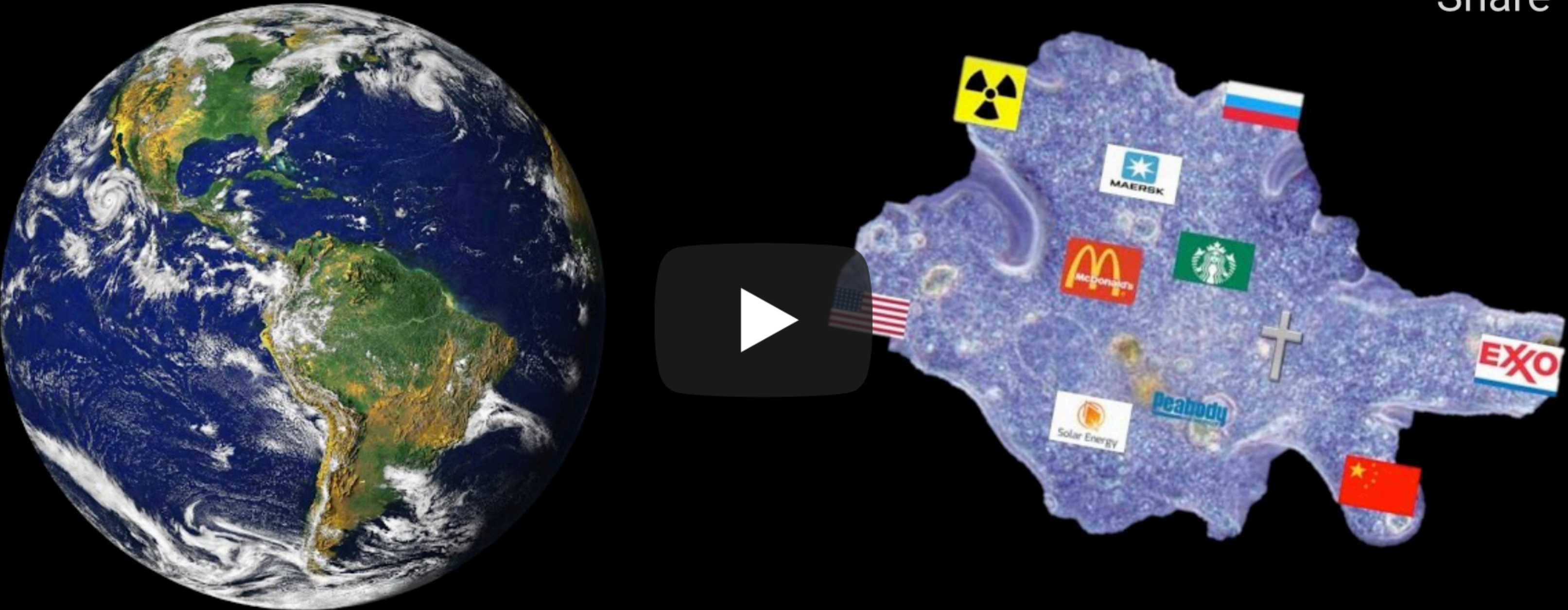
<http://nephologue.blogspot.com>


Some argue against excessive fiat money supply.

Nate Hagens: The Great Simplification

Earth vs. The Amoeba

Share



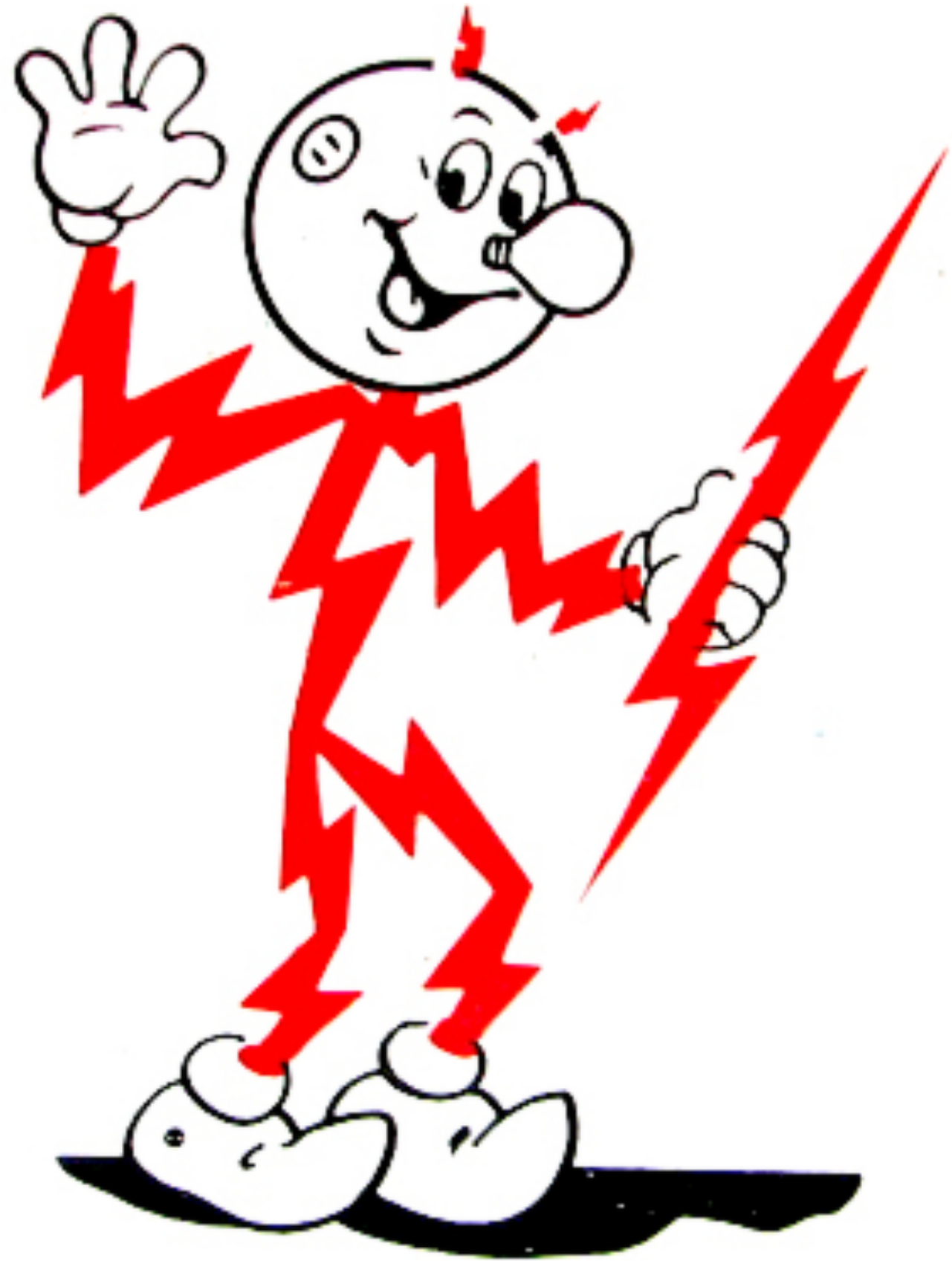
Watch on  YouTube

Nathan John Hagens
www.energyandourfuture.org
Stockholm, WI
Earth Day 2019

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Systems, entropy, exergy

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