The background features a dark blue gradient with a starry space pattern. Overlaid on this are several technical diagrams, including circular gauges with numerical scales (e.g., 40, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, 260) and various circular arrows indicating clockwise and counter-clockwise directions.

CIVILIZATION AS A THERMODYNAMIC SYSTEM: IMPLICATIONS FOR ACHIEVING SUSTAINABILITY

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WARNING: COMPLETE SENTENCES AHEAD!

- My presentations are the text material for my Climate Science course, so I tend to give complete sentences.
- I realize that's not standard PowerPoint protocol.

PART 1: FREE WILL – AND HOW DOES IT RELATE TO CIVILIZATION THERMODYNAMICS?

- Are we a deterministic system? ...Just “Meat machines” helplessly following internal orders at each moment, like any collection of molecules, or do we have at least some form of human agency?
- The evidence says we’re a large helping of the former, but many, including me, still (tentatively) believe we have at least a crucial bit of the latter: agency, “free will” if you like.

WHY INCLUDE “FREE WILL” IN THIS DISCUSSION?

- Physical thermodynamics laws operate precisely and without choice by its components. The quantitative relationships ARE obeyed.
- Civilization thermodynamics has an added wild card – are the humans who make up its “molecules” operating strictly on orders which they cannot change? Or is there some aspect of human agency?
- Without agency, is there any point to the efforts we seek to encourage??
- Many politically conservative economists would argue that since humans have ultimate Free Will, that we are not subject to thermodynamic laws narrowing our behavior, so this entire presentation is moot.



**My dear Rick, you
over estimate the
power of the Gestapo
Here in Casablanca
I am Master of my
Fate, Captain of...**

THE ECONOMIC NOTION OF “FREE WILL” ...

WE RISK HUBRIS WHEN
WE NEGLECT THE
THERMODYNAMIC
LIMITS TO WHAT IS
POSSIBLE

**Colonel Strasser
is here, Sir!**

...you were saying...?



PHILOSOPHER SAM HARRIS ARGUES THAT FREE WILL IS ENTIRELY AN ILLUSION, AND DEBUNKS WHAT HE CALLS THE “LIBERTARIAN NOTION OF FREE WILL”

- Likewise, cloud physicist Tim Garrett, advocate of the Power/Wealth relation (see later here), is firmly in the Determinist camp, as is biologist Anthony Cashmore, neuroendocrinologist Robert Sapolsky. And, many others have debated this, mostly coming to the no-free-will side.
- Psychological Comfort: As many psychologists observe, we would rather feel just about ANYTHING except “out of control”.
- Yet in fact, luck and chance have far more to do with great fortune than most like to admit (Derek Mueller’s “Veritasium” 2022 and 2020)

ENERGY PARSIMONY AND “FREE WILL”

- Pound for pound, our brains consume energy at a rate fully 10x higher than the rest of our bodies.
- Thinking: It requires energy and effort, and...
- We are bred by eons of scarcity to be parsimonious. We “think” to the level Nature decides the payoff is worth the energy investment.
- I would expect that Natural Selection led us, then, towards only a rather limited, but still vital, place for energy consumptive “Free Will”.

SLOWING DOWN MY OWN THOUGHT PROCESS AND OBSERVING INWARD...

- ...I see what is popularly described as “conscious thought”, is actually of content not subject to my will, instead it rises up from the unconscious to present itself into awareness.
- This content is controlled by a life-long dendritic sequence of life decisions guiding the laying down and reinforcing of our neural pathways.
- But there is one moment in this process where I believe we may retain agency and choice. It’s that moment of stillness after thoughts arise, when it feels to me that we can choose...
- ...To FOCUS, or to DEFLECT - the content arriving into our awareness, and thereby let our brains’ natural function of integration and error-checking go to work on it.

ENERGY PARSIMONY: WOULD THIS SEEM TO RELEGATE LIBERTARIAN NOTIONS OF “FREE WILL” TO INSTEAD BE AUTOMATED RETRIEVALS FROM THE UNCONSCIOUS

- However, some decisions can be so life-altering that evolutionary biology may have over-ruled energy parsimony and engaged within us a final choice: To Focus, or Not To Focus .
- Why? For example, to process immediate new information not yet integrated into our neuronal habit-formed pathways.
- **I would also argue that if, instead, we were purely “meat machines”, then of what fitness value is consciousness? While admittedly a vague and often mis-used word, consciousness is nevertheless, energy intensive. If willful choice is not valuable for species success, it would likely not have evolved.**

DOES “FREE WILL” REQUIRE SPOOKY DISEMBODIED SPIRITS?

- Does “Free Will” require a belief in some form of ghostly non-physics? Disembodied conscious spirits as the agents?
- Stanford neuroendocrinologist Robert Sapolsky has said he believes “yes”.
- If true, I would agree with Sapolsky that Free Will makes no sense. But is it so? This is a more subtle and complex question than anyone has successfully tackled so far as I can tell. I do not see the logical necessity that this be so. Eric Weinstein has framed it, that we have “As if” Free Will.
- “Laplace’s Demon” has been rendered impotent by the realization of the quantum nature of Reality.
- The older Copenhagen School of quantum mechanics hypothesizes that quantum wave functions collapse into certainty under witness by consciousness. Many scientists think this has given undeserved primacy to spooky spiritualism. But how “conscious” does the observer need to be? A human? What about a frog? A bacteria? One quickly sees *reductio ad absurdum* from this interpretation. Nevertheless, it powered a whole raft of New Age books in the late 20th century, and the sentiment remains among some adherents.
- The “Many Worlds” interpretation of Quantum Mechanics neatly avoids this pitfall.

THE UPSHOT OF “FREE WILL” AND CIVILIZATION THERMODYNAMICS

- “Free will” is limited, and the bulk decision-making of civilization has a strong component of inevitability bred by Natural Selection.
- This has strong thermodynamic aspects which deserve attention they are not getting from the conventional Economics establishment.
- But an “As if” human agency does, most people experience, exist, and attention to effort and focus would seem possible to change decision making, at least on an individual basis.

PART 2: A BRIEF LOOK AT INSIGHTS ON
ECONOMICS AS PHYSICS; SOME FROM ME,
MOST FROM VIKTOR YAKOVENKO AND
COLLEAGUES

***“Learning about thermodynamics
is a critical part of being an
informed decision-maker in a
Democracy, in dealing with our
energy problems”***

-Dr. Thomas Homer-Dixon

[1:10:40 into this lecture](#)

RELATING THERMODYNAMIC / STATISTICAL PHYSICS TO LARGE SCALE ECONOMIC QUANTITIES...

- **Kinetic energy** is the ability of a particle to kinetically affect its physical environment.
- In physics: Temperature = the average kinetic energy per particle.
- In economics: If “Temperature” is defined as the average **income per capita**, then remarkable thermodynamic laws are seen to carry over into the economic realm.
- In parallel, such a defined “temperature” is the average ability of a member of an economy to affect their larger economic environment.

NEWLY CREATED MONEY FLOWING INTO A PRE-EXISTING PRICE STRUCTURE WILL HAVE A HIGHER POTENTIAL “ENERGY” (BUYING POWER) WHEN IT IS FIRST SPENT, BEFORE ITS DIFFUSION INTO THE ECONOMY RAISES GENERAL PRICES, AND THUS DEGRADES THIS POTENTIAL ENERGY GRADIENT

- Money follows this common pathway: First it enters the most liquid vehicles – assets (stocks, bonds, real estate, commodities, currency trading...) while it awaits optimal value-added spending later.
- As money diffuses out of financial assets into the real economy the potential energy gradient degrades. New money diffusion into the general economy will cause prices to rise: Inflation results, if that money doesn't create equivalent value.

THINK OF WATER FLOWING FROM A HIGHER LEVEL INTO A RATHER FLEXIBLE BATHTUB

- The volume of the bathtub is then the real value of the civilization, and the general price level is the water mark on the bathtub
- The water, is money pouring in. Some will create real VALUE.
- If the real value created increases, the bathtub will increase in volume. If the increased value is equivalent to the new money input, then the price level will remain constant as it is offset by a larger bathtub.
- If no real value is created, then the water level would rise, and be considered “Inflation”.

REMARKABLY, THE DIFFUSION OF MONEY THROUGH THE ECONOMY IS WELL DESCRIBED BY THE FOKKER-PLANCK EQUATION FROM STATISTICAL PARTICLE PHYSICS

- If the velocity of money through an economy is rapid compared to the rate at which new money is injected into the economy (as it is), the distribution of incomes is seen to be well fit by the Boltzmann-Gibbs distribution, which was originally derived to describe the distribution of energies in an equilibrium gas of molecules.
- Importantly, the validity of the Boltzmann-Gibbs equation for physical particles carries with it the realization of the maximization of entropy (maximum number of statistical states associated with bulk quantities).

MAXIMUM ENTROPY – IN THE ECONOMIC SETTING

- The tendency towards maximization of entropy means maximization of the number of different ways economic participants can re-arrange themselves and their actions and still be associated with a given macroscopic state: **GDP, average income, inequality (Gini coefficient)**, and other quantities.
- This suggests that individual actions which entail reciprocal actions from others, may make ~no difference to the large scale numerical civilization states relevant for climate and global sustainability. **We thus follow paths which are determined by thermodynamic relations.**
- Example: less spent on X means more \$ available to buy Y, and supply/demand curve positions shift to insure perceived optimal spending. Doesn't matter the names of the actors, only the actions.

UNDER CONSERVATION OF MONEY (LIKE ENERGY, ON SHORT TIME SCALES), DIFFUSION OF MONEY LEADS INCOME DISTRIBUTIONS TO FOLLOW SIMPLE THERMODYNAMIC PHYSICS (YAKOVENKO *et al.* 2004)

Diffusion model for income kinetics

Suppose income changes by small amounts Δr over time Δt . Then $P(r,t)$ satisfies the Fokker-Planck equation for $0 < r < \infty$:

$$\frac{\partial P}{\partial t} = \frac{\partial}{\partial r} \left(AP + \frac{\partial}{\partial r} (BP) \right), \quad A = - \left\langle \frac{\Delta r}{\Delta t} \right\rangle, \quad B = \left\langle \frac{(\Delta r)^2}{2\Delta t} \right\rangle.$$

For a stationary distribution, $\partial_t P = 0$ and $\frac{\partial}{\partial r} (BP) = -AP$.

For the **lower class**, Δr are independent of r – **additive diffusion**, so A and B are constants. Then, $P(r) \propto \exp(-r/T)$, where $T = B/A$, – an **exponential distribution**.

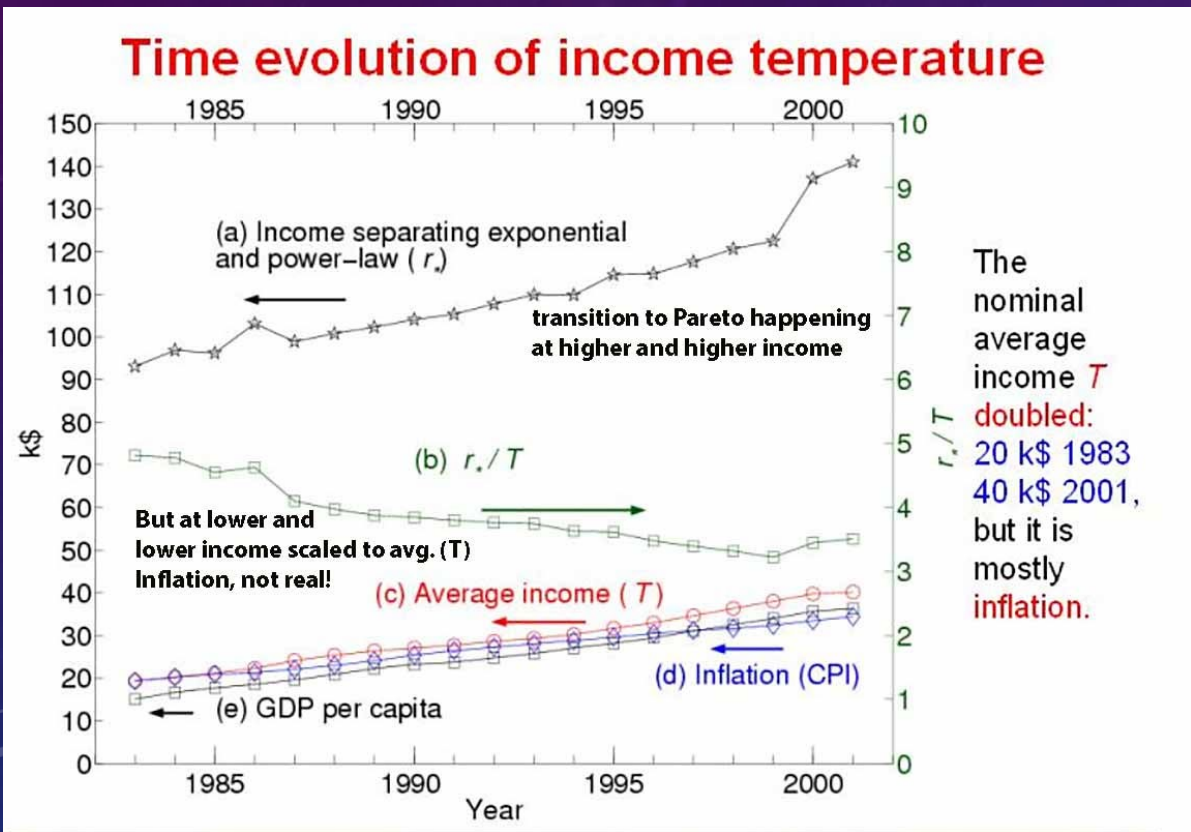
For the **upper class**, $\Delta r \propto r$ – **multiplicative diffusion**, so $A = ar$ and $B = br^2$. Then, $P(r) \propto 1/r^{\alpha+1}$, where $\alpha = 1+ab$, – a **power-law distribution**.

For the **upper class**, income does change in **percentages**, as shown by Fujiwara, Souma, Aoyama, Kaizoji, and Aoki (2003) for the tax data in Japan. For the **lower class**, the data is not known yet.

- Note that the energy intensive / carbon-intensive portion of our economy is the money spent by the “lower class”, nearly all of which is consumption.
- Here, the diffusion coefficient (A) of money is \sim independent of income. And if the “drift” coefficient is designated (B), then the effective “temperature” of the economy is simply $T=B/A$

- $T = B/A$

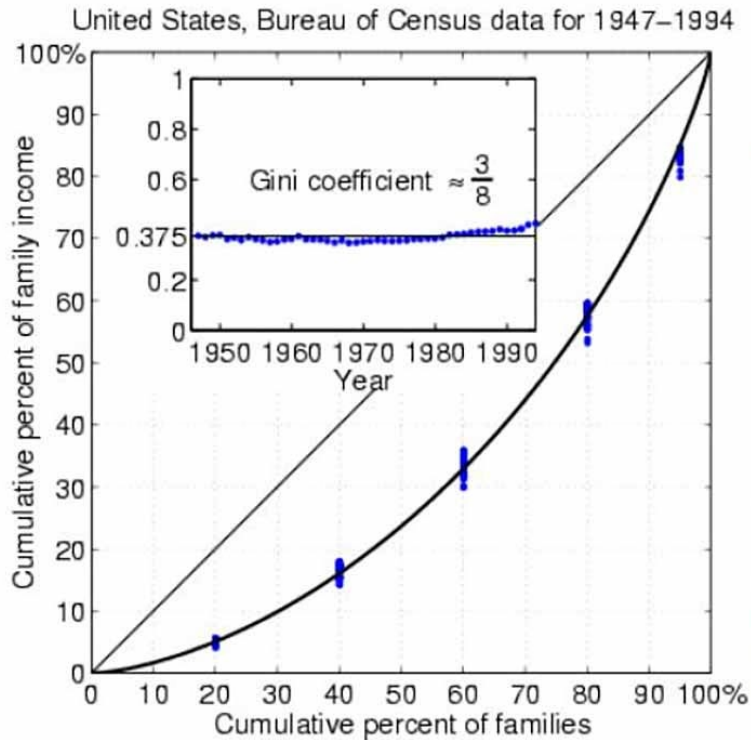
THE “TEMPERATURE” T EVOLVES OVER TIME, AS NEW MONEY IS INJECTED (UNDER FEDERAL RESERVE CONSTRAINTS). BUT AS ENERGY GETS MORE EXPENSIVE, ONLY A DECLINING FRACTION BECOMES REAL GROWTH. THE REST OF THE NOMINAL T INCREASE IS INFLATION.



- And over time, more and more of income is in the Pareto power law, which results from asset price inflation and financial market traders.
- This Pareto fraction declines during asset bubble collapses (2001/02, 2008/09, 2022 examples).
- It's easier to take money from others (e.g. algorithmic trading) than to generate new wealth from value-added production, in such times.

MAXIMUM ENTROPY LEADS TO THE INEQUALITY OF INCOMES REACHING AN EQUILIBRIUM LEVEL. GINI COEFF = 1/2 FOR INDIVIDUALS

Lorenz curve and Gini coefficient for families



Lorenz curve is calculated for families $P_2(r) \propto r \exp(-r/T)$. The calculated Gini coefficient for families is $G=3/8=37.5\%$

No significant changes in Gini and Lorenz for the last 50 years. The exponential (“thermal”) Boltzmann-Gibbs distribution is very stable, since it maximizes entropy.

Maximum entropy (the 2nd law of thermodynamics) \Rightarrow **equilibrium inequality:** $G=1/2$ for individuals, $G=3/8$ for families.

- During the 50 year period of this Yakovenko *et al.* study (1947-94), the Gini coefficients (quantifying the income inequality in the economy), has been ~unchanged although there’s been a detectable rise away from max entropy value during the post-’70 Neoclassical dominance era.

THE DISTRIBUTION OF INCOMES FOLLOWS A NATURAL THERMODYNAMIC DISTRIBUTION FOR THE LARGE MAJORITY.

- ...A “natural distribution” (Yakovenko), which follows the Boltzmann-Gibbs function (~95% of the wealth)...
- ...And a power-law (Pareto) distribution describing the artificial wealth of asset price inflation, from the top few percent of the total “particles” (income earners), and rises and falls as financial trading market value rises and falls. ([Yakovenko](#)).
- The area under these curves (next slide) will rise as new money infuses.

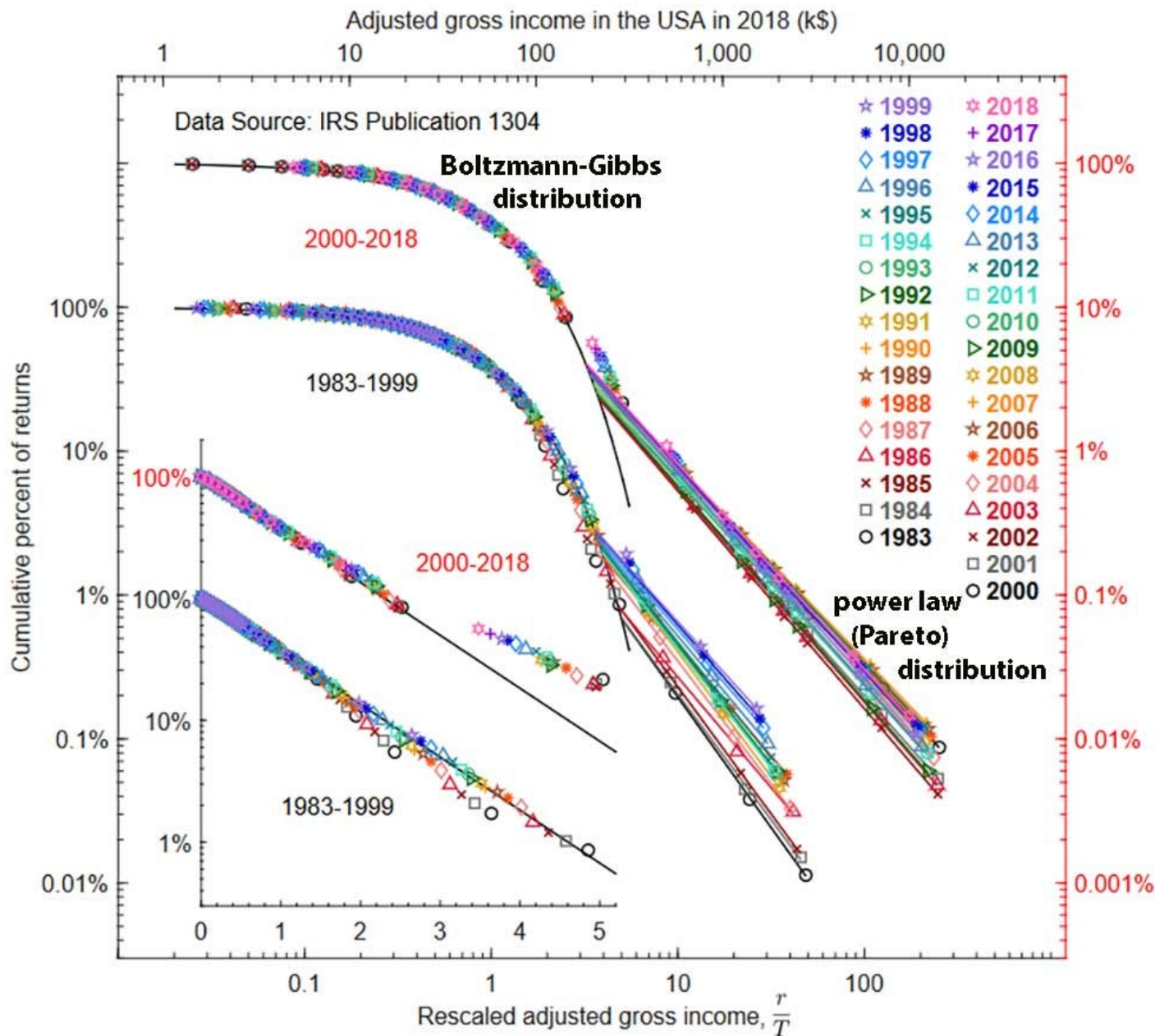


Figure 1. The cumulative distribution function $C(r)$ versus the rescaled income r/T in the USA for 1983–2018. The main panel is in log-log scale, whereas the inset is in log-linear scale.

GRAPHICALLY: THE INCOME DISTRIBUTION FOR THE BOTTOM ~95% FOLLOWS A PERFECT BOLTZMANN-GIBBS FUNCTION, JUST AS DOES THE ENERGY OF MOLECULES. THE TOP ~5% FIT A POWER LAW DUE TO NON-ECONOMIC WEALTH FROM ASSET PRICE INFLATION.

THE HEAT ENGINE OF THE GLOBAL ECONOMY

- Money will flow from **rich** (high Temperature) economies to **poorer** (low Temperature) economies who ship back manufactured goods at lower prices. This thermal gradient is most efficient if it is steep.
- Globalization, given wealth disparity, adds to the power of the economic thermal engine, by this flow.
- De-globalization - as is happening today and perhaps the future due to wars and climate damage and scarcity-induced anti-immigration policies – would thus appear to progressively slow the engine.
- The dream of many Progressives is perfect equality among all countries... But then the thermal gradient goes to zero – “heat death”?
(No doubt an oversimplification, however, as trade, even on a micro-level, is still economically valuable.)

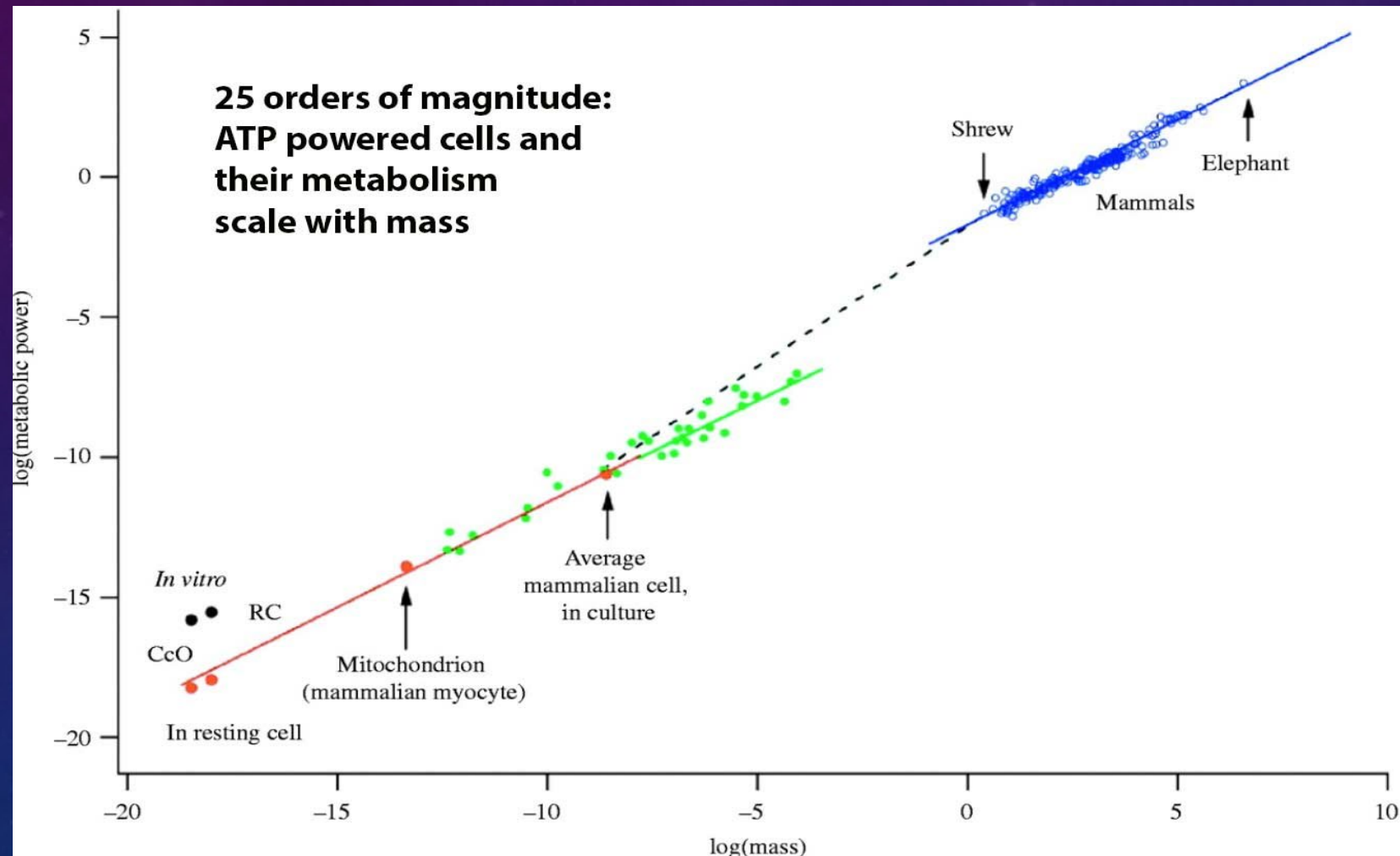
THE POINT? HUMANS AS ATOMS ARE INTERACTING AGENTS, WITH RECIPROCAL INFLUENCES AND EMERGENT CONSERVATION LAWS

- Whether we retain some “free will” agency or not, we are constrained by our Nature to follow the Laws of Thermodynamics. We’ll show this more explicitly later here.
- I would contend that modellers of the future should incorporate the insights of thermodynamic framing into their projections. As a civilization... *“we are not free to violate the laws of thermodynamics”* – Tim Garrett.
- And it is only as a global civilization that climate and sustainability matter for the long term future.

OTHER EXPLORATIONS BY PHYSICISTS INTO ECONOMIC THEORY AND PRACTICE (AT YOUR LEISURE...)

- The field of Econo-physics, dating back to the 1990's with hints earlier, is primarily concerned with the rules governing equity pricing and trading and its relation to statistical mechanics; not so relevant here.
- More closely related here, is studies loosely grouped under the term ThermoEconomics aka “**Biophysical Economics**”, which sees economics in thermodynamic terms.
- And see the new exploration of the Power/Wealth relation with more explicit economic ties (Garrett, Grasselli and Keen 2020)

PART 3: ENERGY EFFICIENCY, THE MAXIMUM POWER PRINCIPLE, AND THE SCALING LAWS OF BIOLOGICAL AND CIVILIZATION SYSTEMS – THE WORK OF GEOFFREY WEST *et al.*



LINKING THERMODYNAMICS AND DARWINIAN EVOLUTION – THE MAXIMUM POWER PRINCIPLE - THE 4TH LAW OF THERMODYNAMICS?

It has been pointed out by Boltzmann that the fundamental object of contention in the life-struggle, in the evolution of the organic world, is available energy. In accord with this observation is the principle that, in the struggle for existence, the advantage must go to those organisms whose energy-capturing devices are most efficient in directing available energy into channels favorable to the preservation of the species.

— A.J. Lotka 1922a, p. 147

...it seems to this author appropriate to unite the biological and physical traditions by giving the Darwinian principle of natural selection the citation as the *fourth law of thermodynamics*, since it is the controlling principle in rate of heat generation and efficiency settings in irreversible biological processes.

— H.T. Odum 1963, p. 437

...it may be time to recognize the maximum power principle as the fourth thermodynamic law as suggested by Lotka.

— H.T. Odum 1994

“DURING SELF-ORGANIZATION, SYSTEM DESIGNS (WILL) DEVELOP AND PREVAIL THAT MAXIMIZE POWER INTAKE,...” (AND USEFUL OUTPUT!)

- *“... energy transformation, and those uses that reinforce production and efficiency.” (H.T. Odum 1995, p. 311)*
- Systems gain an advantage over competing systems if they can maximize their rate of energy consumption.
- **The goal is to maximize the rate of useful work done from that energy consumption. The Useful Work portion generally goes up when Total energy consumption goes up.**



ENERGY EFFICIENCY IS
NICE TOO.... BUT
MAXIMUM USEFUL
POWER IS THE REAL
COMPETITIVE PAYOFF

THE LITTLE YELLOW GAS-SAVER
HERE IS BEING SCHOOLED ON THIS
POINT.

IN ECOLOGICAL SYSTEMS, FRAMED THERMODYNAMICALLY...

- First note that a living system is **out** of equilibrium almost by definition. To be in thermodynamic equilibrium with your environment, is to be dead. Now, consider this framing below by Sven Jorgensen *et al.* ([source](#))
- *“If a system receives an input of exergy, then it will utilize this exergy to perform work.*
- *“The work performed is first applied to **maintain** the system (far) away from thermodynamic equilibrium whereby exergy is lost by transformation into heat at the temperature of the environment. If more exergy is available, then the system is moved further away from thermodynamic equilibrium, reflected in growth of gradients.”*

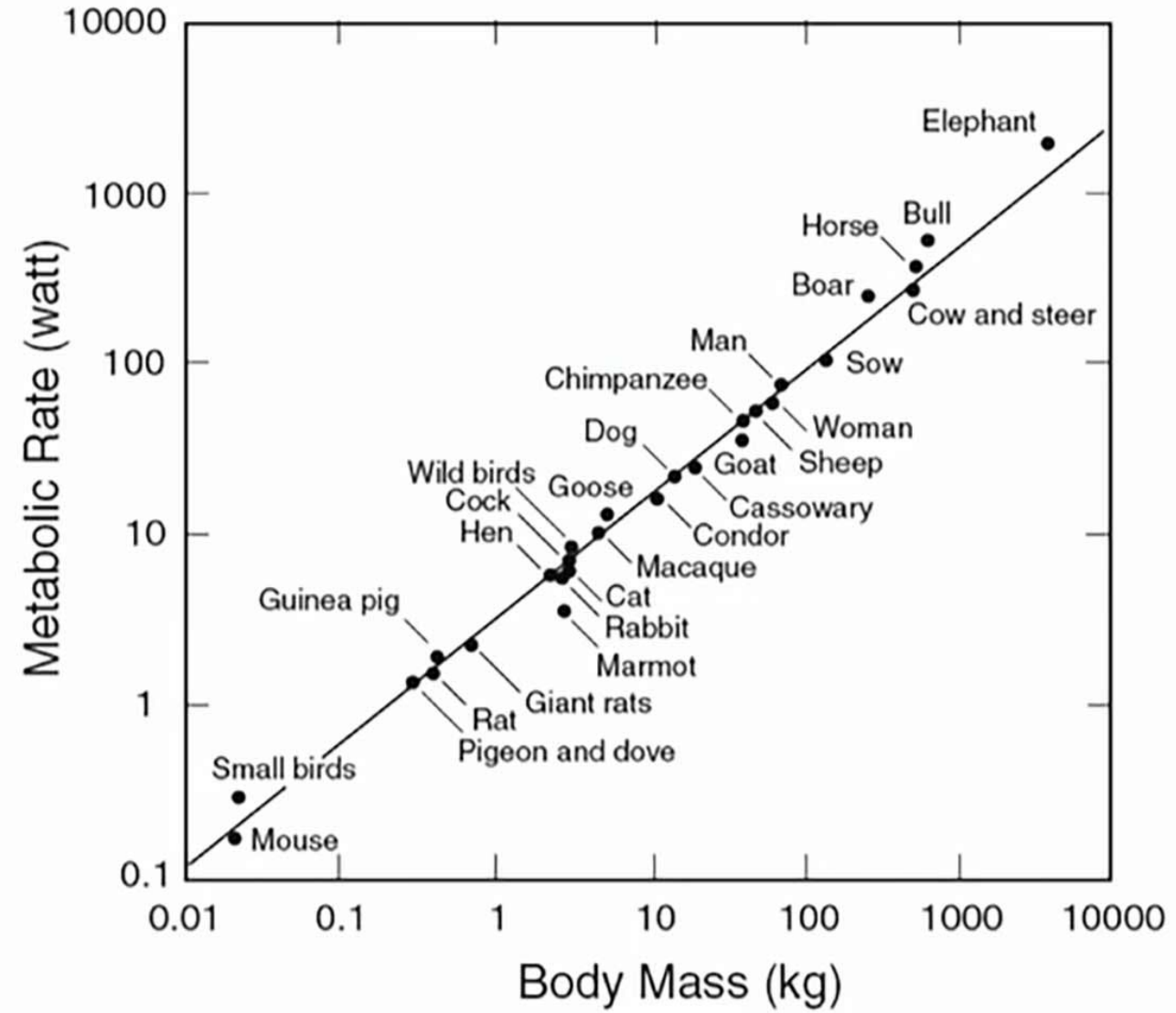
“IF THERE IS OFFERED MORE THAN ONE PATHWAY TO DEPART FROM EQUILIBRIUM, THEN THE ONE YIELDING THE HIGHEST ECO-EXERGY STORAGE (DENOTED X) WILL TEND TO BE SELECTED.”

- “Or expressed differently: Among the many ways for ecosystems to move away from thermodynamic equilibrium, the one maximizing dX/dt (power) under the prevailing conditions will have a propensity to be selected.”*

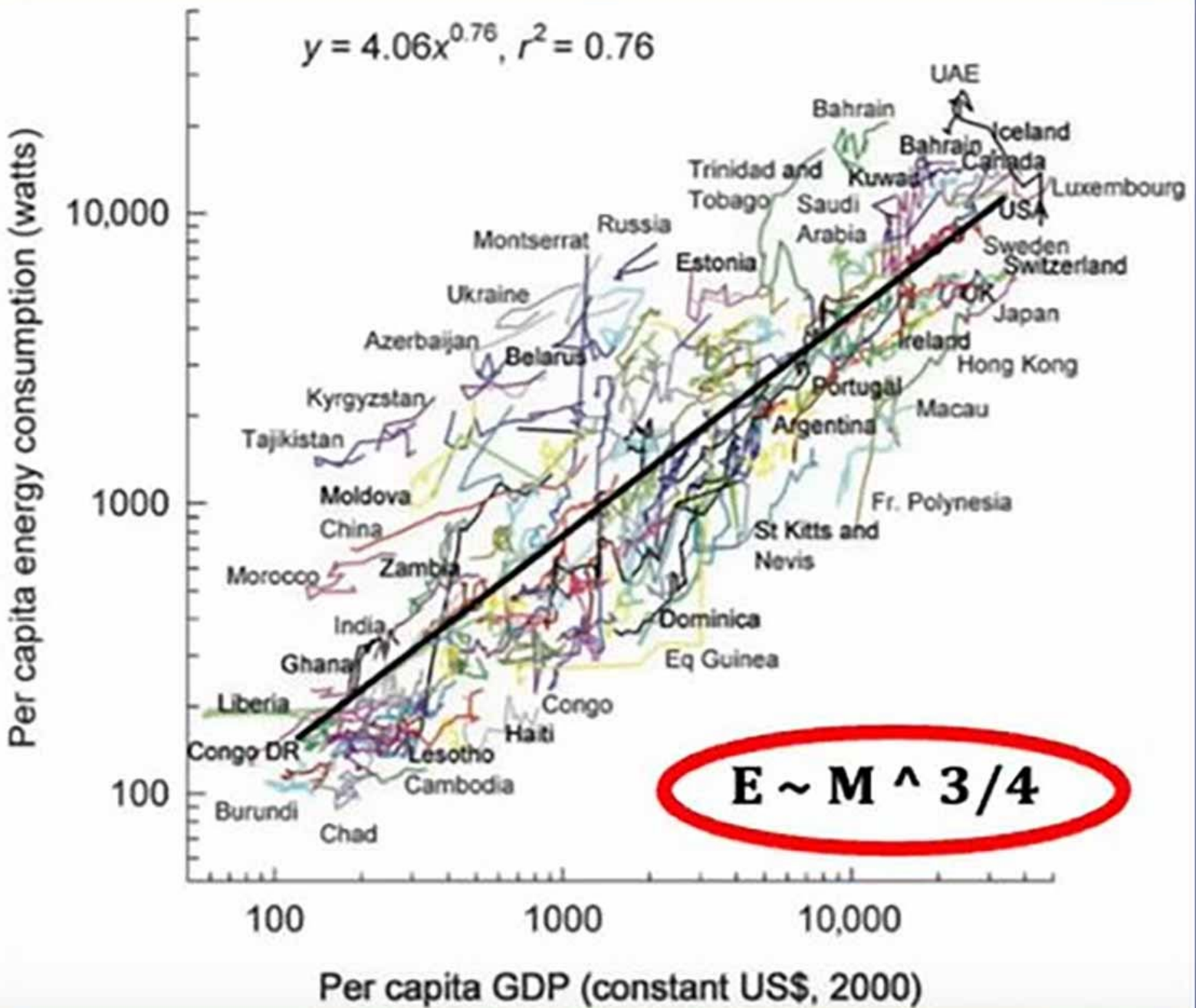
KLEIBER'S LAW AND METABOLIC EFFICIENCY

- Kleiber's Law: For oxidative metabolic animals (who use ATP for cell energy generation) –metabolism scales with mass to the $\frac{3}{4}$ power.

Oxidative Metabolic Animals Energy Consumption Rate Scales as $(\text{Mass})^{0.75}$



SLOPE = $\frac{3}{4} < 1$ SUB-LINEAR



THIS SAME $\frac{3}{4}$ POWER LAW APPLIES TO ENERGY EFFICIENCY vs. THE SIZE OF NATIONAL ECONOMIES, ALBEIT WITHIN A WIDE BAND. (FIGURE FROM NATE HAGENS (2023) TALK "THE MORDOR ECONOMY"). RICHER COUNTRIES ARE MORE URBANIZED, WHERE ENERGY EFFICIENCY IS HIGHER, BUT ALSO TOTAL PER CAPITA ENERGY IS HIGHER.

KLEIBER'S LAW: A CONSEQUENCE OF ENERGY OPTIMIZATION

- The sublinear $\frac{3}{4}$ power says there are economies of scale at work. But what determines that particular scaling?
- [West et al. 1997](#) find they can derive this $\frac{3}{4}$ power law by assuming evolutionary biology optimizes on the efficiency of the energy that goes *towards basic metabolism*, averaged over its life.
- This then maximizes the remaining energy available for growth, and successful competition for choice mating opportunities and gene propagation.

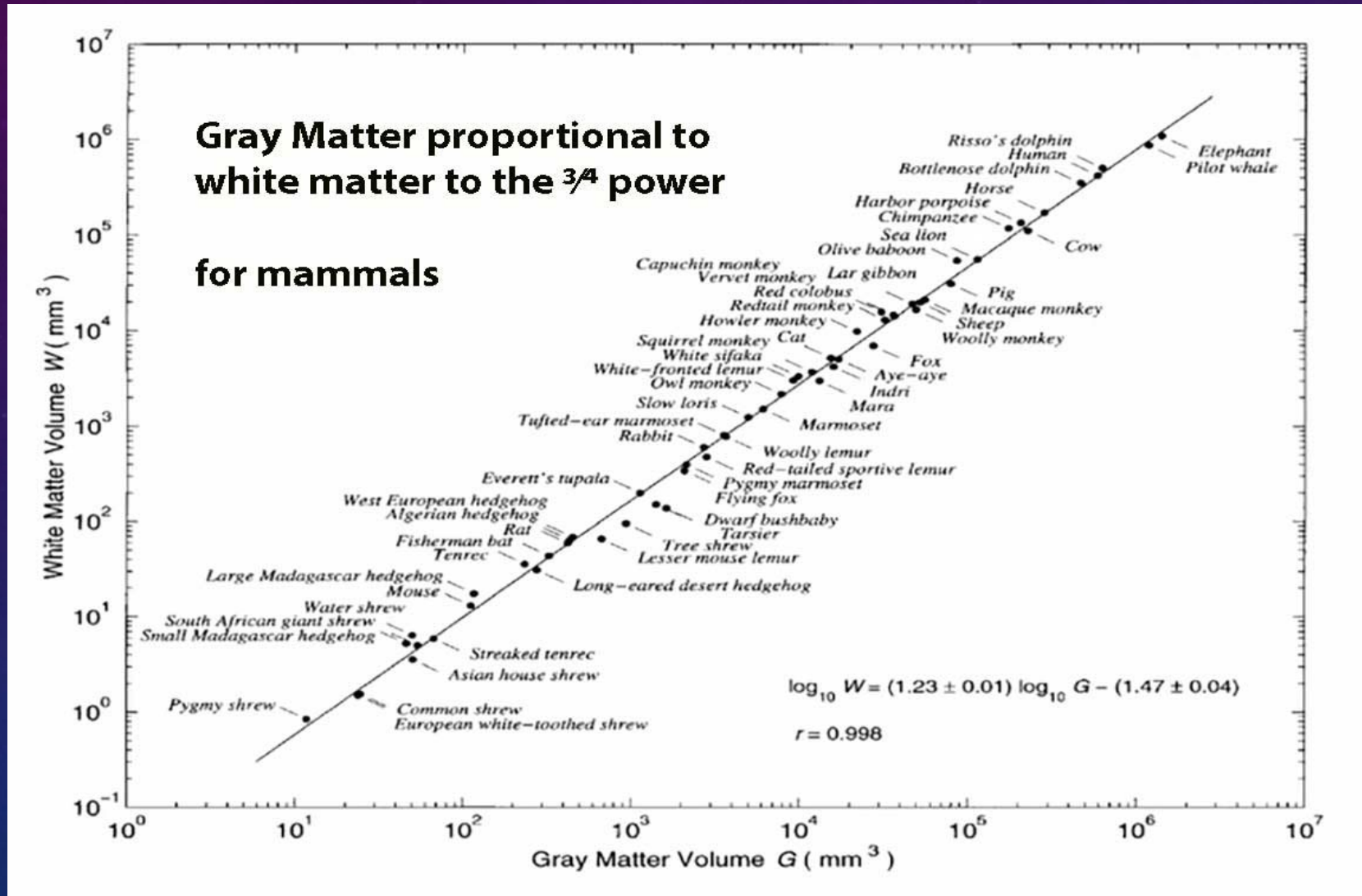
BUT WHY $\frac{3}{4}$?...

- *“These designs are based on three simple principles (Brown, West and Enquist 2005)... :*
- *(1) A space-filling network that branches hierarchically to supply all parts of the three-dimensional body;*
- *(2) Body-size-invariant terminal units, such as capillaries or leaf petioles; and*
- *(3) Minimization of the energy and time required to distribute resources.”*

NETWORKS ARE THE KEY MEANS OF SUPPORT AND MAINTENANCE IN DYNAMICAL SYSTEMS (INCLUDING LIVING SYSTEMS AND CIVILIZATION), OBEYING THE THERMODYNAMICS OF FRICTIONAL TRANSPORT OF NUTRIENTS AND WASTE

- Branching networks in our 3 dimensional world, to be optimal, will approach a fractal dimensionality.
- The maximum **increase** in fractal dimensionality for optimal efficiency is **+1**
- $3+1 = 4$
- 3 dimensions of space, one additional dimension from optimal fractality of networks, hence...
- **$\frac{3}{4}$!**
- For more details, see [Brown, West *et al.*'s](#) elegant refutation of early criticisms of the original [1997 West *et al.*](#) paper

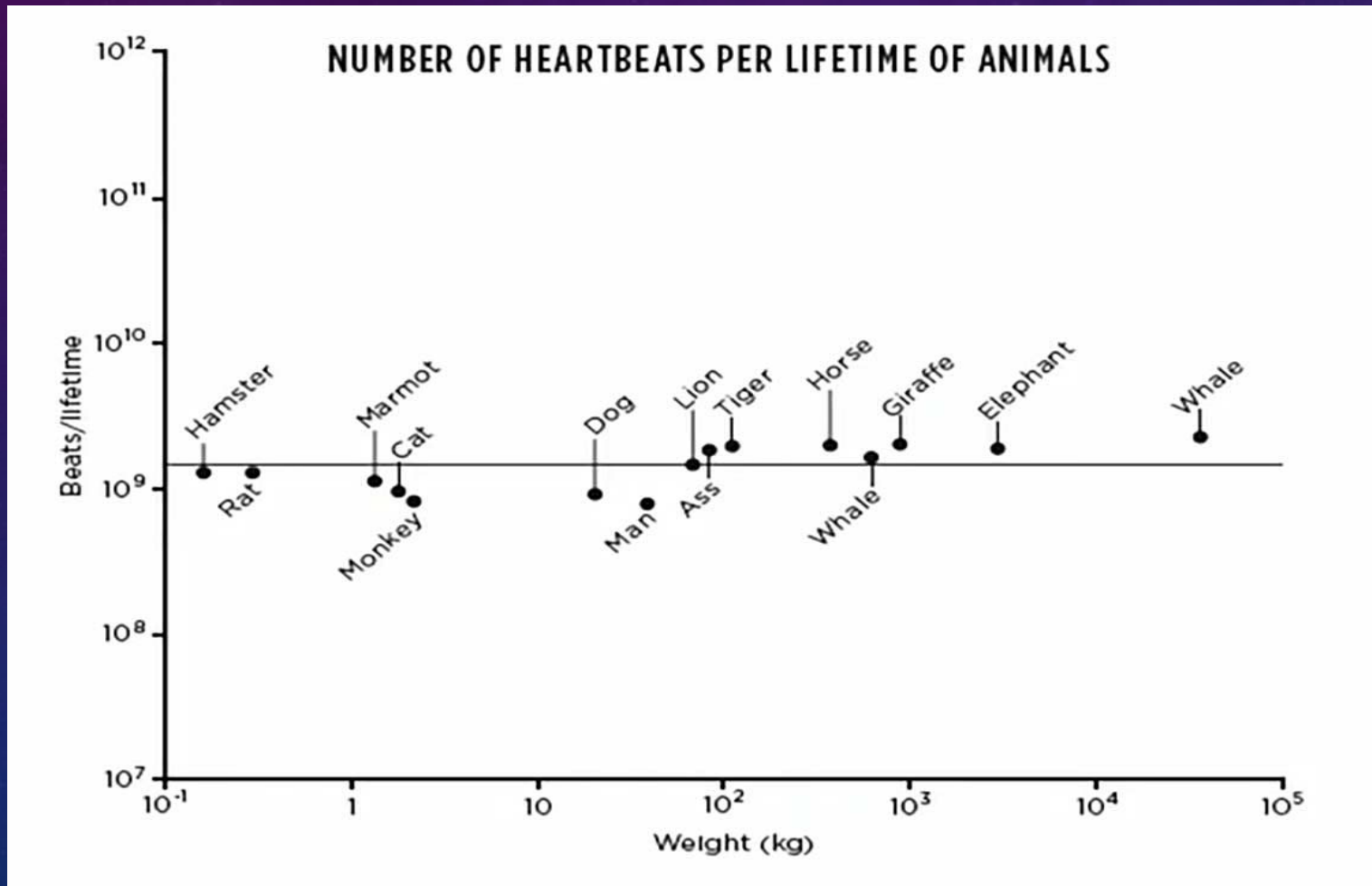
MAMMAL BRAINS TOO - GRAY MATTER VOLUME/WHITE MATTER VOLUME SCALES TO THE $\frac{3}{4}$ POWER. GRAY MATTER POWER REQUIREMENTS ARE $\sim 4X$ HIGHER THAN THOSE OF WHITE MATTER.



THIS SUB-LINEAR SCALING MEANS THAT ORGANISM GROWTH SLOWS WITH TIME. ADD IN FRICTION AND DISSIPATION (THE 2ND LAW OF THERMODYNAMICS), AND WEST FINDS THIS LEADS TO FINITE LIFETIMES, AND BOUNDED GROWTH

- This bounded growth applies only to **INDIVIDUAL** organisms.
- It is due to the fundamental biology of sublinear metabolic scaling ([p. 31 Geoffrey West “Scale”](#)).

SUB-LINEAR METABOLIC SCALING, ATP ENERGY (COMMON TO ALL MAMMALIAN CELLS) PRODUCTION EFFICIENCY, AND RISING 2ND LAW COSTS WITH TIME, LEADS TO FINITE LIFETIMES AND AN INTERESTING CONSTANCY IN THE TOTAL HEARTBEATS (THE METABOLIC PRIME MOVER) FOR ALL OXYGEN-POWERED SPECIES. ABOUT 2 BILLION HEARTBEATS PER NORMAL LIFETIME.



BUT IF, UNDER THE EVOLUTIONARY BIOLOGY-INDUCED COMPETITION FOR SCARCE RESOURCES, THOSE ECONOMIES OF SCALE ACTING INSIDE INDIVIDUALS ARE COMPLETELY EMPLOYED TOWARDS NEW OPPORTUNITIES FOR FASTER GROUP (CIVILIZATION) GROWTH...

- ...then there is the realization of its inverse: of super-linear scaling of growth.
- **On a finite planet, unchecked, this leads to ultimate tragedy.**

CITIES AS CIVILIZATION'S MOST EFFICIENT SYSTEMS...

- Plumbing, roads, electrical lines, sewer lines... are all **branching networks** servicing civilization maintenance, and must reach every inhabited place.
- Very much like blood and lymph networks in animals, which must reach every cell.
- By minimizing maintenance energy, they maximize available energy for social interaction and growth through learning from others.

Assume a spherical cow of uniform density



BUT CITIES ARE NOT NEARLY AS SPACE-FILLINGLY ~SPHERICAL AS MAMMALS ARE, SO WE MIGHT EXPECT LOWER ECONOMIES OF SCALE TO EMERGE...

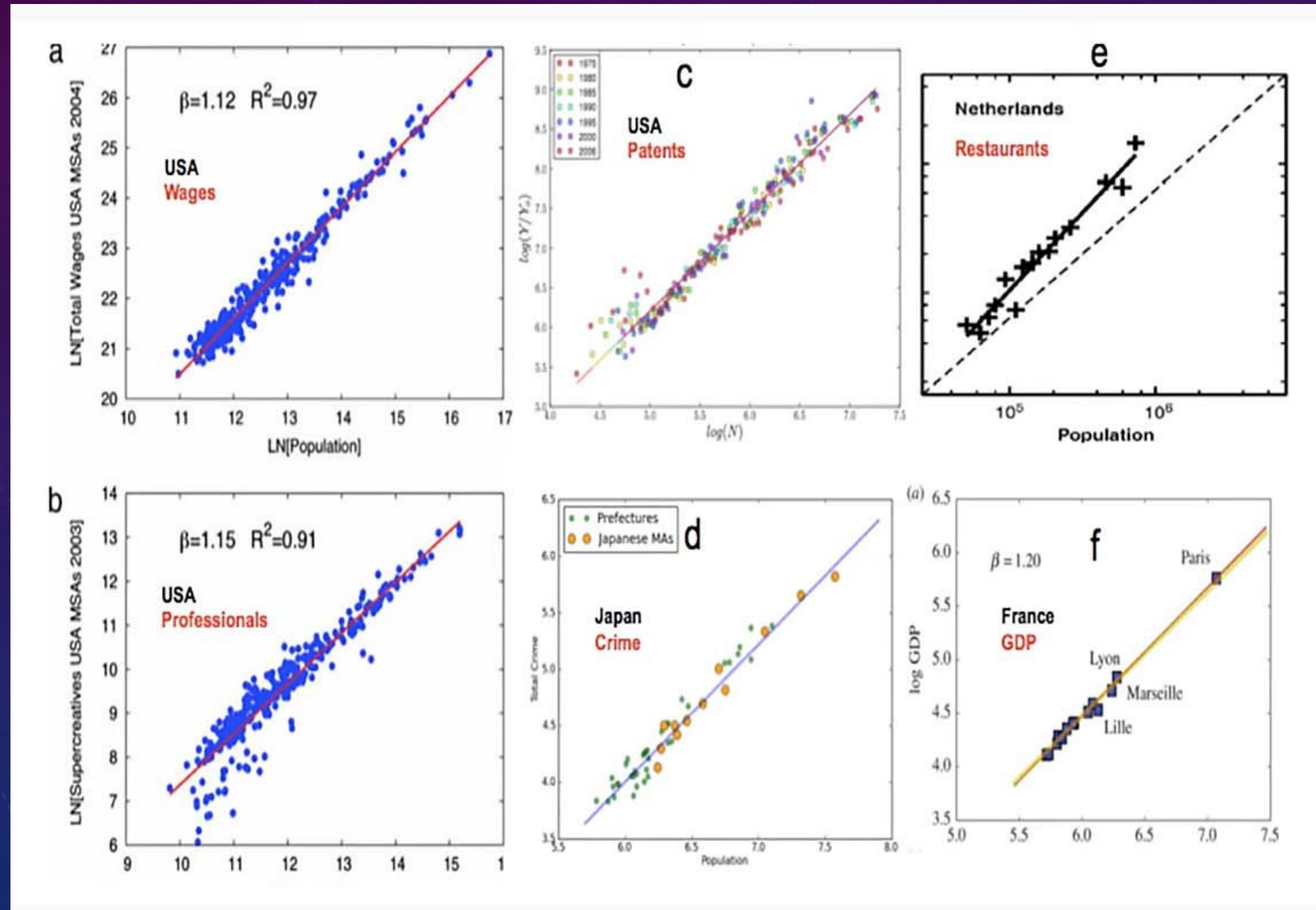
SMALLER CITIES TEND TO BE RATHER 2-DIMENSIONAL,
BIGGER CITIES ARE A BIT MORE VERTICAL, ESPECIALLY
DOWNTOWNS AND MAJOR CITIES, YET STILL MUCH MORE
FLAT THAN MOST ANIMALS

- One result is that city's infrastructure scaling power law exponent isn't as favorable as $\frac{3}{4} = 0.75$.
- Data shows infrastructure mass scales with population as a power law of exponent 0.85

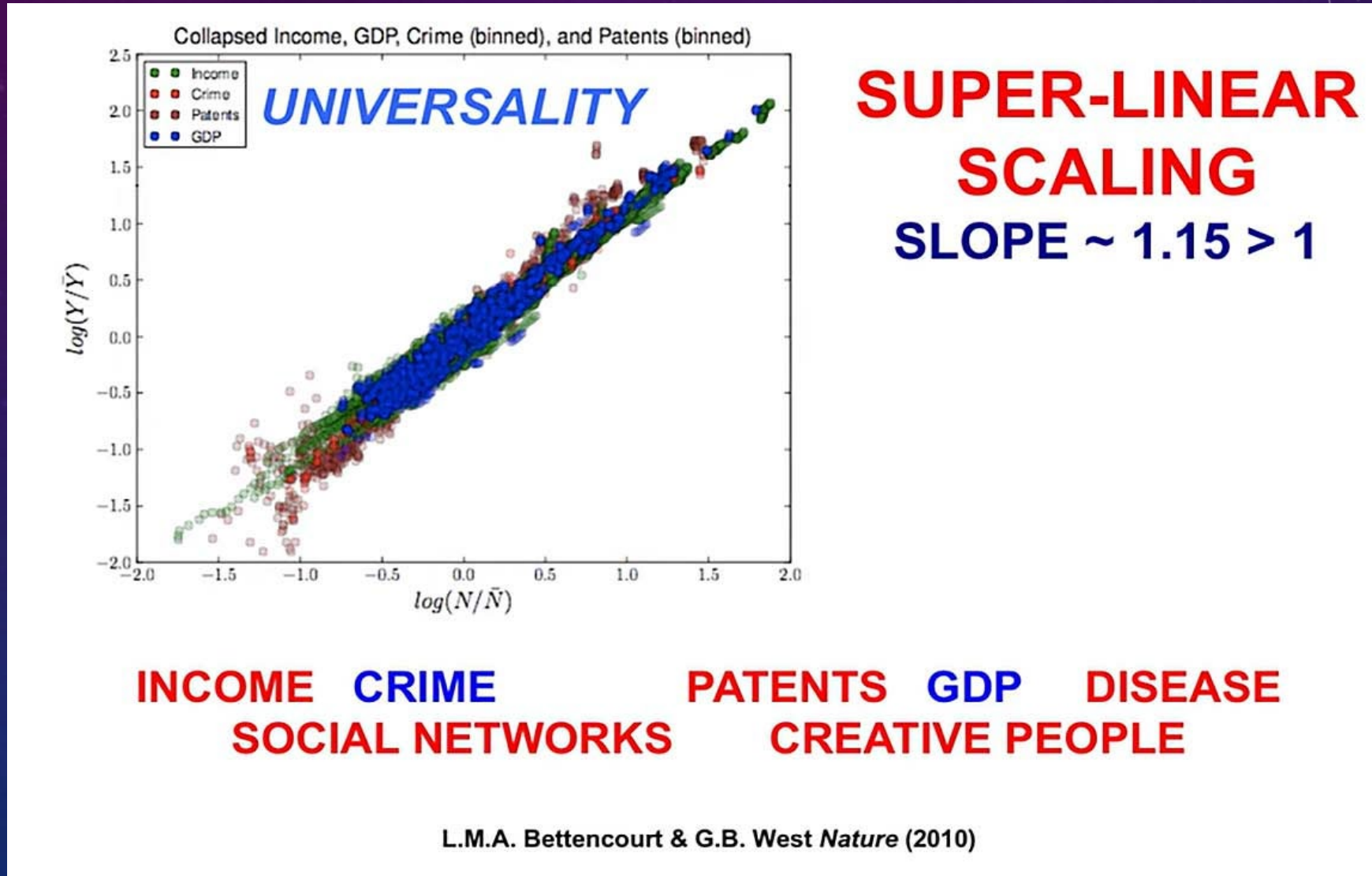
STILL, $0.85 < 1$, SO AN ECONOMY OF SCALE IS STILL OPERATING, WHICH IS REFLECTED IN CIVILIZATION'S GROWTH

- The savings in infrastructure permit more efficient growth via proximity for the people living IN the cities, by almost all measures studied.
- Patents, income, life pace, personal growth measures... and many more, all scale SUPER-linearly with about the same power law...
- This leads to: Socioeconomic activity in cities scaling super-linearly; observed as a power law of population with exponent=1.15

A COLLECTION OF VARIED SOCIOECONOMIC QUANTITIES – BOTH GOOD AND BAD – ALL SCALE AS (POPULATION)^{1.15}



PACE AND PRODUCTIVITY OF CITY LIFE SCALES SUPER-LINEARLY, AS A POWER LAW OF EXPONENT ~ 1.15



HOW INTERESTING: NOTE THAT $1/.85 \sim 1.15$.
COINCIDENCE?

I do not see coincidence

A man with a shaved head and sunglasses is sitting in a red, tufted leather chair. He is wearing a dark, patterned shirt and has his hands clasped in his lap. The background is dark and out of focus. The text "I do not see coincidence" is overlaid in white on the image.

“WHAT IF I TOLD YOU....”

- ...that Natural Selection drives us to take all of that 15% efficiency gain and use it to grow civilization proportionally faster, inverting the Kleiber-like power law.
- All urban socio-economic quantities studied grow at this particular exponential rate (West), indicating maximum utilization of infrastructure economies of scale.

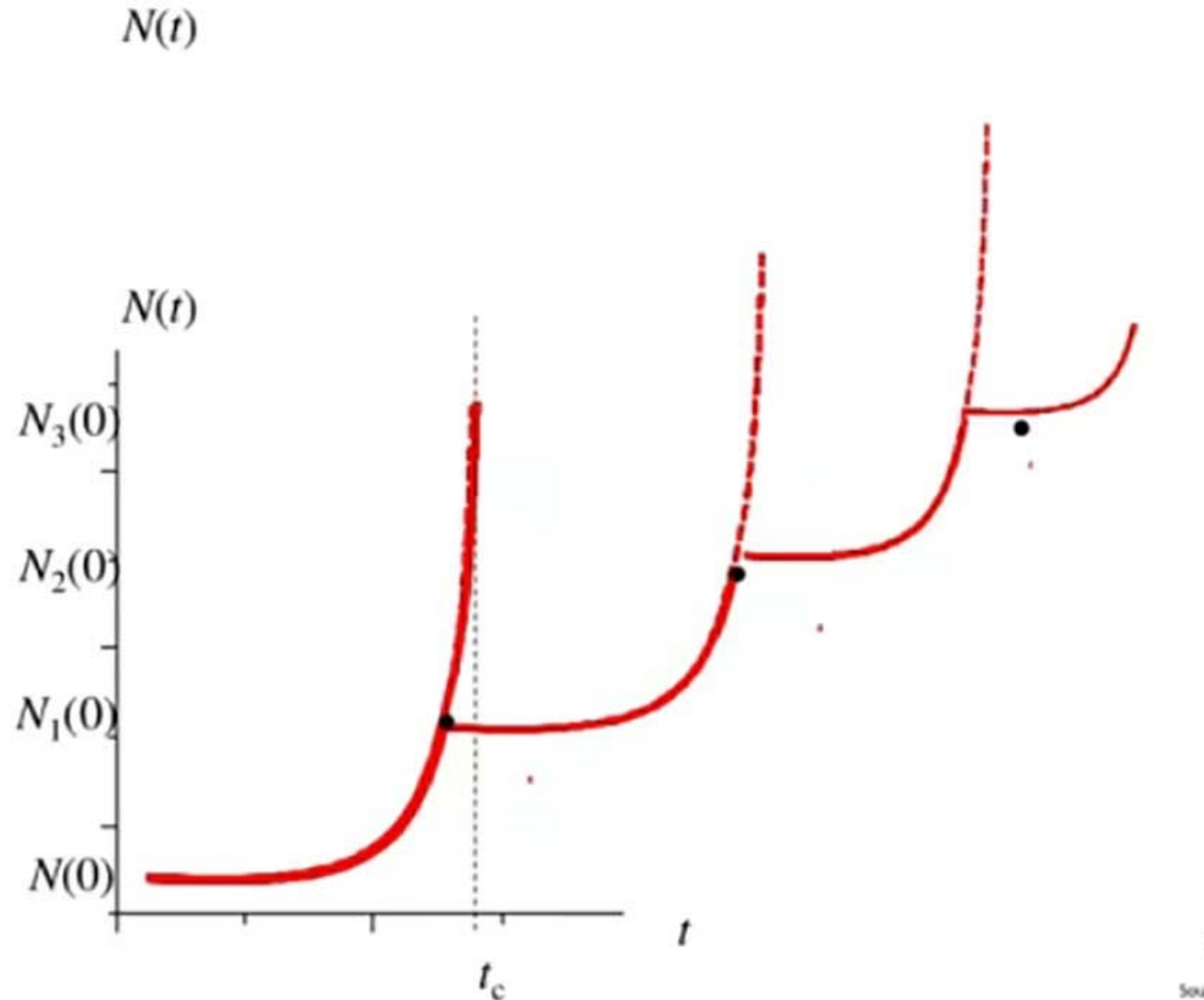
EXPONENTIAL GROWTH LED MALTHUS AND LATER, PAUL EHRLICH, TO EXTRAPOLATE A DATE FOR CIVILIZATION'S DOOM. THOSE PREDICTIONS FAILED...

- ...as conventional economists are endlessly fond of pointing out: they failed to account for the power of innovation (and for Malthus, for the discovery of fossil fuels).
- Clearly a more detailed look is called for.
- So consider...

INNOVATION: SHORT-TERM SAVIOR; AND LONG-TERM ULTIMATE CURSE?

- On a finite world, exponential growth leads to a “finite time singularity” (Geoff West). Innovation can temporarily solve this and reset the declining marginal returns.
- **But as a true INNOVATION, a true advance, a true improvement at the moment of introduction, in keeping with the ever-advancing compulsion to grow, each new innovation will have a shorter time to its own singularity.**
- Each innovation will progress through faster and faster periods to their own obsolescence and ever faster approach to a singularity in declining returns.
- **This time-shortening progression of innovations, trying to avoid their own singularity, will therefore reach a singularity of singularities.**

Unbounded Growth Requires Accelerating Cycles of Innovation to Avoid Collapse



A CONCEPTUAL DIAGRAM OF RISING ENERGY COSTS PER \$GDP, WHICH ARE RE-SET BY NEW INNOVATIONS.

YES, WE TEMPORARILY AVOID COLLAPSE. BUT THE INNOVATION PROGRESSION ITSELF HAS A FINITE TIME SINGULARITY.

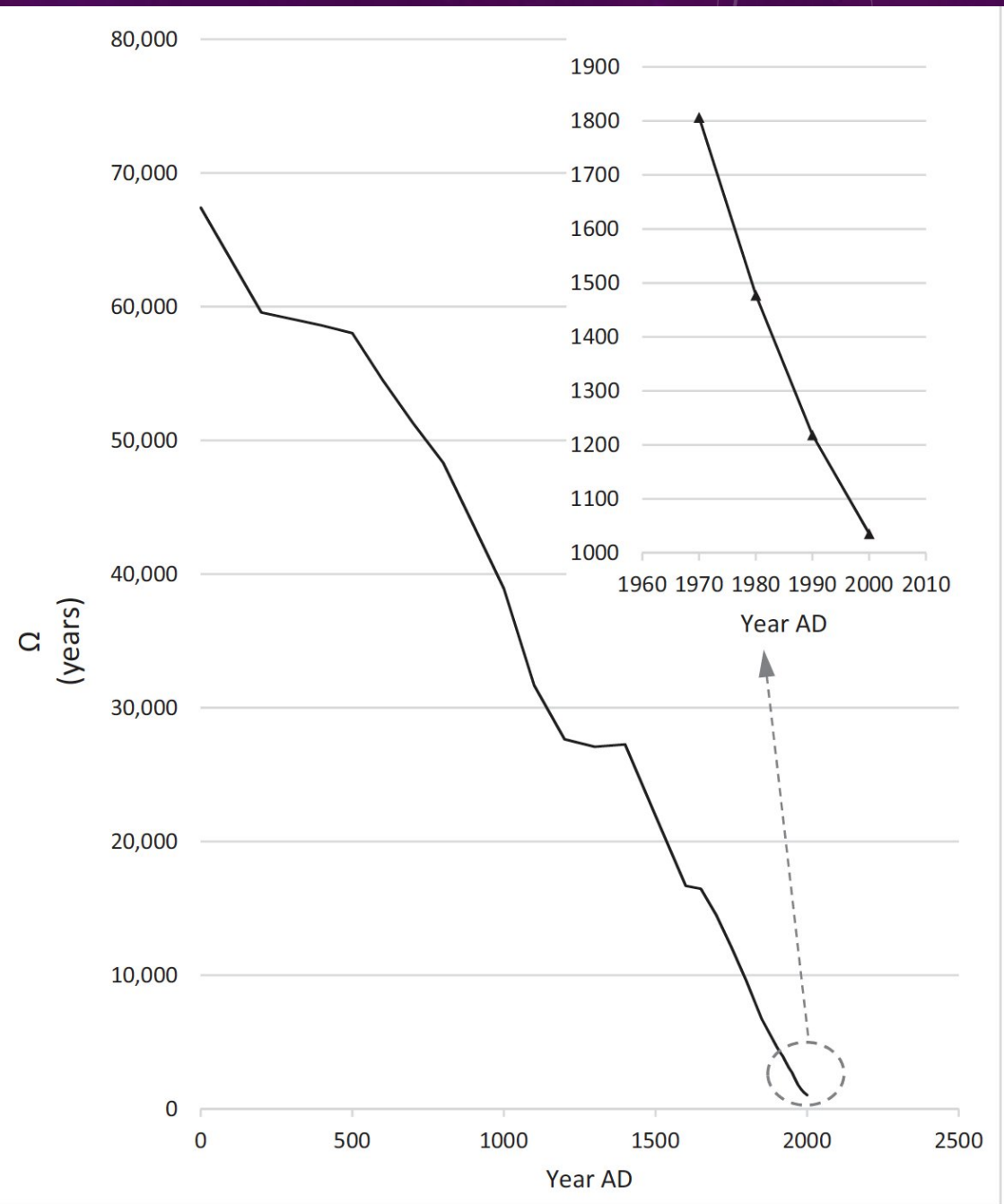


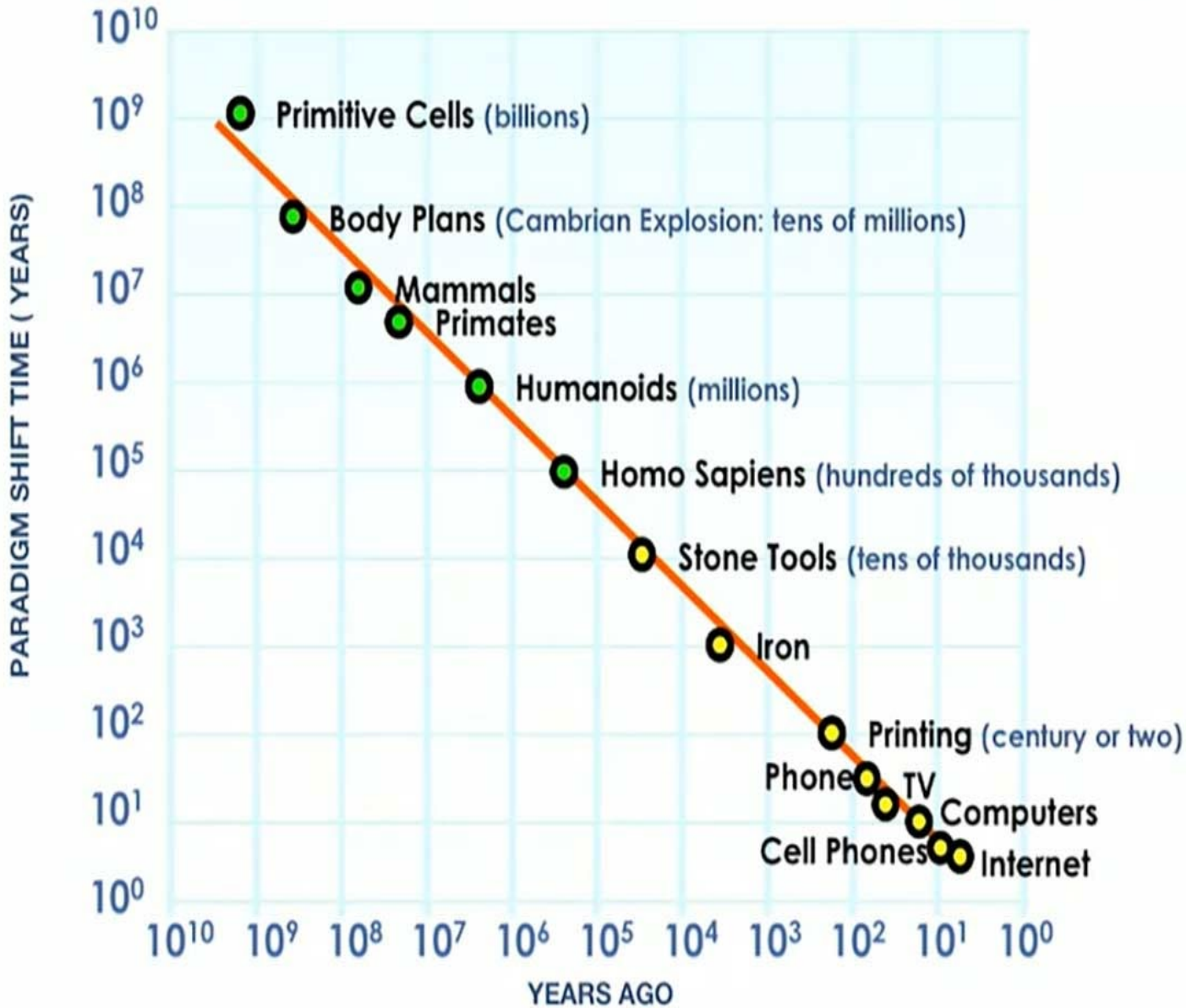
Fig. 5. Number of years of phytomass food potentially available to feed the global human population. Calculated from the total stored phytomass energy of the planet divided by the metabolic energy needs to feed the global population for 1 y

EXAMPLE: THE NUMBER OF YEARS OF PHYTO MASS POTENTIALLY AVAILABLE TO FEED THE GLOBAL POPULATION.

CALCULATED FROM GLOBAL BIOMASS AND POPULATION, DIVIDED BY METABOLIC ENERGY NEED PER CAPITA.

I FIND THE LINEARIZED TREND SINCE 1960 REACHES ZERO IN THE YEAR 2037.

THE "GREEN REVOLUTION" INDEED DELAYED STARVATION. PER ACRE WE INCREASED YIELDS BY 4X SINCE 1900, BUT AT THE COST OF 100X HIGHER ENERGY PER YIELD.



NUMBERS BELOW FROM FUTURIST RAY KURZWEIL'S "THE SINGULARITY IS NEAR". THE RED LINE IS THE PREDICTION SLOPE FROM GEOFFREY WEST'S THEORY. AN EXCELLENT FIT, BUT THESE TWO AUTHORS HAVE RADICALLY DIFFERENT REACTIONS TO THESE DATA...

I SAY: IF YOU WANT TO KNOW WHAT ARRIVING AT A SINGULARITY WILL ACTUALLY BE LIKE, ASK AN ASTRONOMER: (THINK - BLACK HOLES, AND “DON’T CROSS THE BEAMS!”)

- West sees the likelihood of civilization collapse unless a radically different global paradigm is rapidly instituted.
- Kurzweil is a well-paid speaker for corporations to give his very upbeat talks about the power of innovation and the coming Singularity, when everything will be ~free. West openly thinks Kurzweil’s ideas are “looney” ... I agree.
- From Kurzweil’s “The Singularity is Near” *“We will have the requisite hardware to emulate human intelligence with supercomputers by the end of this decade.”* (said in 2005. Yet here in 2022 it’s still far, far away).
- I suppose “Life will be beautiful all the time” (1960’s popular song by Napoleon XIV)

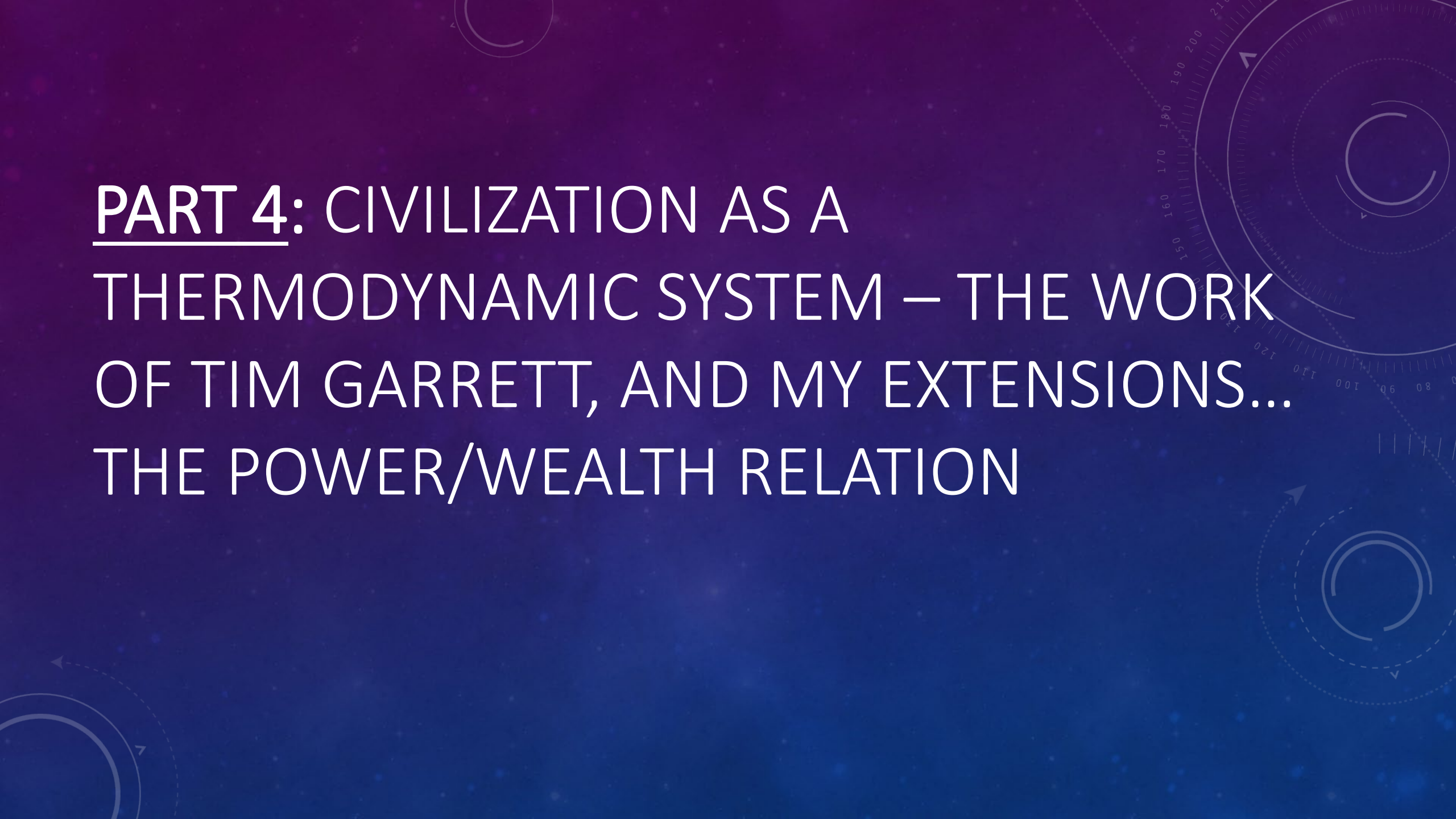
WEST PONDERES THAT THESE RAPIDLY CONVERGING CYCLES OF INNOVATION SPEED THE PACE OF LIFE TO THE POINT THAT WE MAY EXPERIENCE A CIVILIZATION “HEART ATTACK”

- Consider *Homo Sapiens*' innate ability to cope. Our mental, psychological, and energy mechanisms evolve only over multi-generational Natural Selection time scales, and the rising strain now obvious around the world suggests our human ability to cope might be approaching its limits.
- Joseph Tainter's work argues that when we reach diminishing marginal returns on successive innovations, then collapse comes soon ([Strumsky, Lobo and Tainter 2010](#), and recently taken further by [Bonaiuti 2018](#)).
- **The Power/Wealth Relation would appear to imply the same – see our next section: Part 4.**

IN 2010, ERIC SCHMIDT, THEN THE CEO OF GOOGLE,
SHARED A CONCERN WITH THE WORLD...

- ...***“Every two days, we create as much information as we did from the dawn of civilization until 2003.*”**
- *I spend most of my time assuming the world is not ready for the technology revolution...”*

PART 4: CIVILIZATION AS A
THERMODYNAMIC SYSTEM – THE WORK
OF TIM GARRETT, AND MY EXTENSIONS...
THE POWER/WEALTH RELATION

The background features a blue gradient with several faint, semi-transparent circular gauges and arrows. One gauge in the upper right has numerical markings from 80 to 210. Another gauge in the lower right has markings from 0 to 120. The overall aesthetic is technical and scientific.

“If your theory is found to be against the Second Law of Thermodynamics, there is nothing for it but to collapse in deepest humiliation”

– *Sir Arthur Eddington*

HERE'S MY OWN FRAMING OF THE LOGIC OF CIVILIZATION AS A THERMODYNAMIC SYSTEM, WHICH DIFFERS FROM TIM GARRETT'S BUT ARRIVES AT A SIMILAR PLACE...

- Garrett prefers describing in terms of energy gradients, and does so with great insight ([Garrett 2014](#), [Garrett et al. 2020](#)).
- However, I'm convinced that connecting energy consumption with the process of civilization is more transparent when framed and spoken in terms of entropy and its connection with energy. This frame, I believe, may especially aid better understanding among economists and other non-physicists.
- The two approaches are complimentary.

ENTROPY, ENERGY CHANGE, AND TEMPERATURE

- In the physical thermodynamics of a **closed system**, the incremental change in energy of the system dE (= change in internal energy dU plus the useful work dW (“Gibbs free energy”) extracted from the system by the production of incremental entropy dS [“disorder”] at constant temperature T , obeys...
- $dE = TdS$ and $dE = dU + dW$
- Taking the derivative with respect to time, we see that the rate of energy consumption is \sim proportional to the rate of entropy change.

NOW FOR CIVILIZATION...

- The analog of “total energy” is called “**Primary Energy Supply**” in the databases: this is the raw energy direct from Nature.
- Useful work accomplishes innate human values – powering the networks of our relationships to each other and to material things, and the enhancement and growth of civilization.

THE ANALOG FOR PHYSICAL ENTROPY S , IS THE
AMOUNT OF DISORDER S_c IN THE
CIVILIZATION+ENVIRONMENT SYSTEM

- From the 2nd Law: Growth in civilization must correspond to a reduction in civilization's portion of specific S_c together with an even greater rise in S_c in the total environment system.
- This is powered by the expenditure of physical ENERGY.

dE CAN BE USEFULLY SPLIT CONCEPTUALLY INTO SEVERAL COMPONENTS, IN THE CONTEXT OF CIVILIZATION...

- 1. The Gibbs Free Energy (*i.e.* useful work which can be done; dW).
- 2. Inefficiency ultimately into waste heat (degraded energy, now in the form of microscopic randomness).

But the Gibbs Free Energy itself can be further segregated into 4 categories, in order of civilization's priority they are...

- 1. The energy used to tap new energy sources. TOP PRIORITY.
- 2. The energy used to repair/maintain existing civilization against the 2nd Law's decay
- 3. The energy used to power new growth in Civilization
- 4. The energy employed to improve the energy efficiency per \$GDP

ANY ECONOMIC SPENDING TO REDUCE DISORDER S_c IS TAKING THINGS FROM THE WAY THAT THEY WOULD HAVE BEEN IN THE NATURAL TENDENCY TOWARDS DECAY AND DISORDER (2ND LAW OF THERMODYNAMICS), TOWARDS THE WAY CIVILIZED PEOPLE WANT THEM TO BE.

- This means, from relative **dis-order**, towards increased “civilizing” **order**:
- **Order** – in the form of new and stronger networks linking people, energy, systems, and materials.
- **Order** – in the form of enhanced relationships, flows of materials, information, and energy in supporting enhanced growth and hence larger energy consumption rates.
- And all new ordering must further be maintained by an ongoing new expenditure of energy, countering the 2nd Law.

NOW, IN CIVILIZATION'S MARKET ECONOMY...

- ...Pricing, Spending, has a close relationship to Cost, given competition and hence typically thin profit margins.
- We infer, then, that cost is proportional to the amount of change needing to be effected upon our physical and mental states to achieve our civilized “ordering” goals.
- Laborious, time-consuming effort to make a high reduction in Civilization's entropy S_c therefore incurs higher **cost**, and requires proportionally higher physical **ENERGY** consumption rates to power it.

THE DESIRED LOWER ENTROPY OF OUR CIVILIZATION MUST BE CONSTANTLY MAINTAINED AGAINST THE 2ND LAW'S DECAY RATE

- By pondering how snowflakes grow through the operation of gradients, Garrett speculated on how potential energy gradients would also control Civilization economically, possibly in a simple mathematical way.
- He knew that annual GDP would not be proportional to current power consumption, because one of the enterprises we engage in is to try to improve energy efficiency in producing GDP.
- But “Production”, (real GDP) will add over time, and compound into new production, as well as provide the means for discovering and expanding new energy sources.
- This suggested that a different relation might prove true... and indeed it appears to be so:

I'LL REFER TO GARRETT'S RELATION NOW AS THE
POWER/WEALTH RELATION:

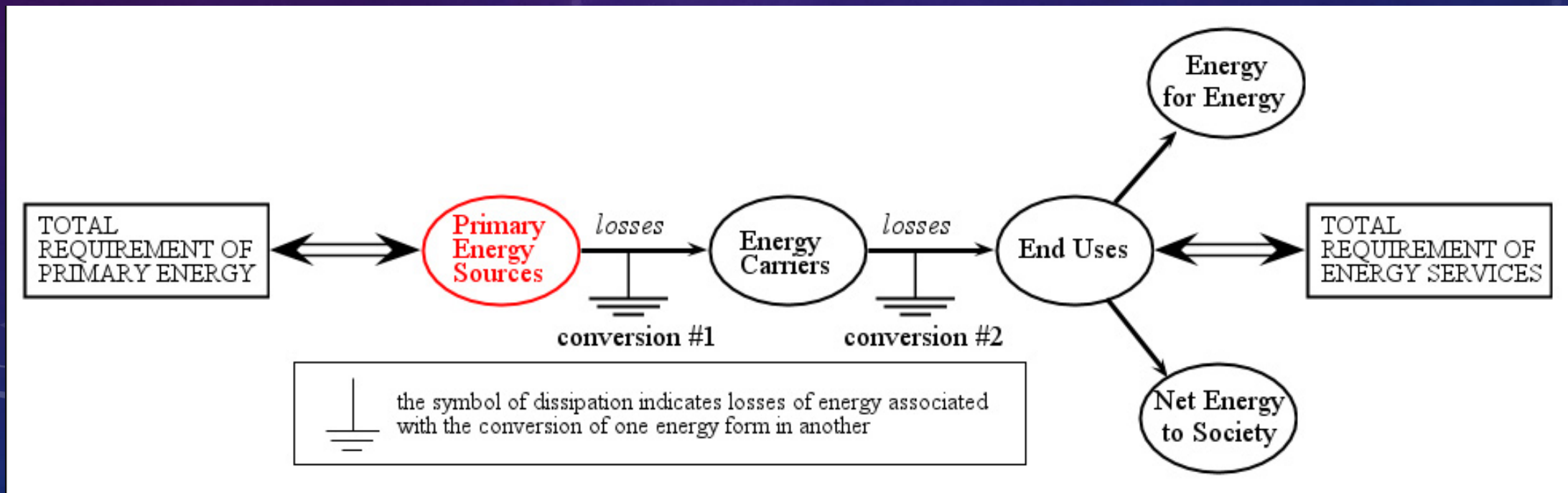
*The Current Global Rate of Primary Energy
Consumption is Directly Proportional to The Sum Total
of All Past Inflation-Adjusted Global Gross Domestic
Product (GDP)*

Garrett calls this sum "Wealth".

*(it's just a short-hand term he chose, don't over-interpret a personal
political/philosophical meaning!)*

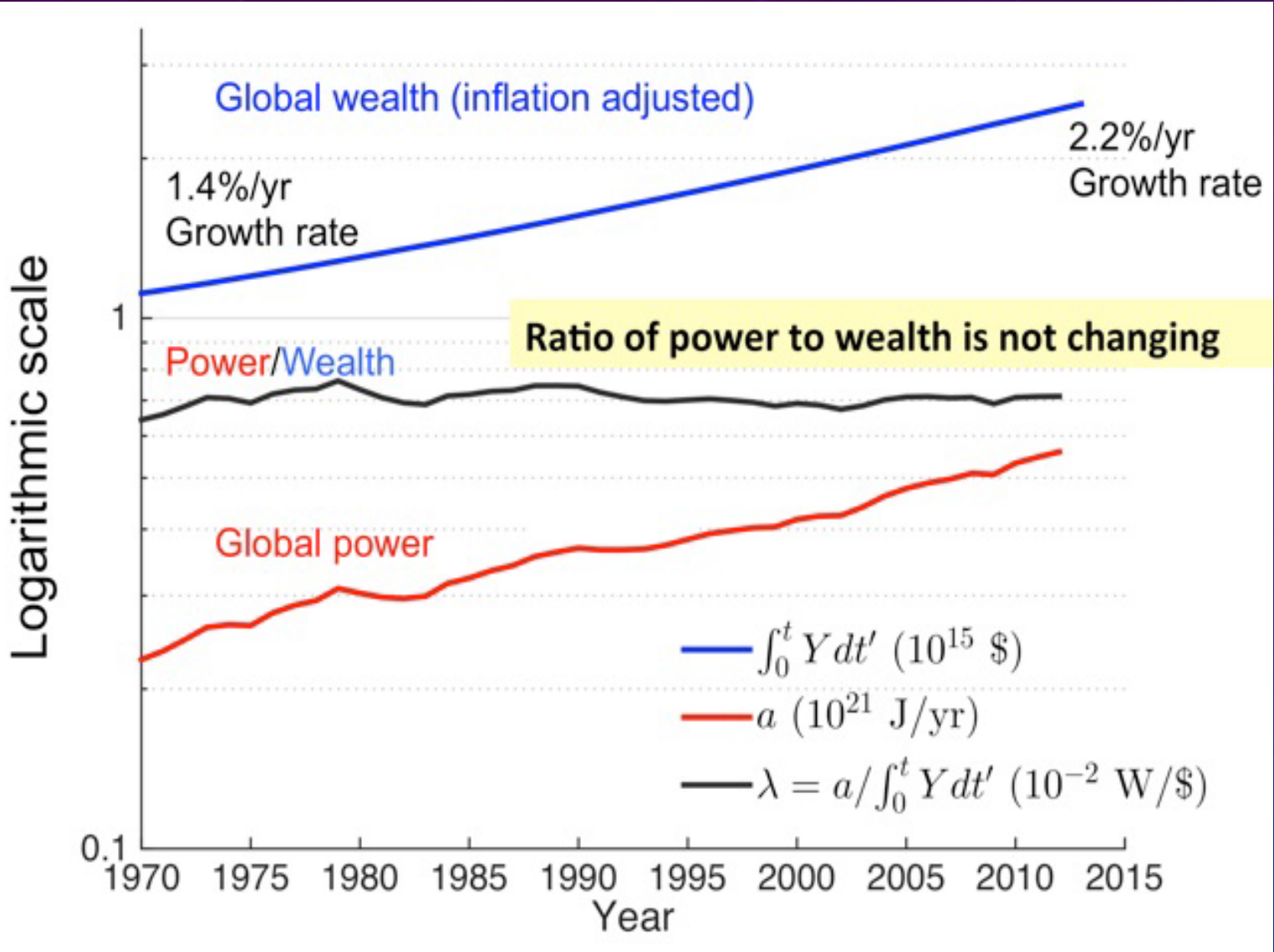
THE RELEVANT ENERGY IN THIS RELATION IS PRIMARY ENERGY.
ENERGY IN RAW FORM PROVIDED BY NATURE

LOOKING AT PROMOTIONAL GRAPHS WHICH ONLY PRESENT OUR PROGRESS IN TERMS OF PROCESSED ENERGY (*e.g.* ELECTRICITY) WILL BE CHEERY, BUT UNREALISTIC IN TRUE COST.



THE POWER/WEALTH RELATION SIMPLIFIED: *“THE GLOBAL POWER CONSUMPTION RATE TODAY IS PROPORTIONAL TO THE SUM OF ALL PAST REAL SPENDING”*

- *“The ratio of these two quantities remained essentially unchanged in each year between 1970 and today (2010), with a **standard deviation of just 3%** over a time period when wealth increased by 111% and global annual GDP increased by 238%” ([Garrett 2014](#)).*
- I’ve subjected this relation to additional refinements and testing since Garrett’s papers were published. It still holds up. Let’s examine...



CURRENT ENERGY CONSUMPTION RATE (POWER) AND TOTAL PAST ACCUMULATED WEALTH ARE SEEN DIRECTLY PROPORTIONAL; *i.e.* THE RATIO (BLACK CURVE) IS FLAT (GARRETT 2010)

WE ADD $\lambda=7.1$ MW OF NEW CONTINUOUS POWER CONSUMPTION FOR EVERY INFLATION-ADJUSTED 2005 DOLLAR OF GLOBAL GDP EVER SPENT.

VALUE IS MANIFEST ONLY WHEN CAPITAL IS IN USE...

- ...In **motion**. In **action**. In **relationship** to human beings, and along networks of connection.
- *“Labor without energy is a corpse. Capital without energy is a statue” – Economist Steve Keen*
- And all **MOTION** requires **ENERGY CONSUMPTION** to maintain it.
- All **MOTION**, whether resulting in useful work or not, will entail frictional losses, and so a continuous supply of **new energy** is required to maintain constant value. And additional energy beyond that is needed in order to grow that value, and to find the new energy to power its value.
- ...electrons through wires, fluid through pipes, blood through arteries, people in cars, trains and ships. **Only in the dissipation of that energy is value made manifest.**

IMPORTANT BOUNDARY CONDITION: END ALL POWER CONSUMPTION - AND ALL VALUE AND ALL WEALTH DISAPPEARS.

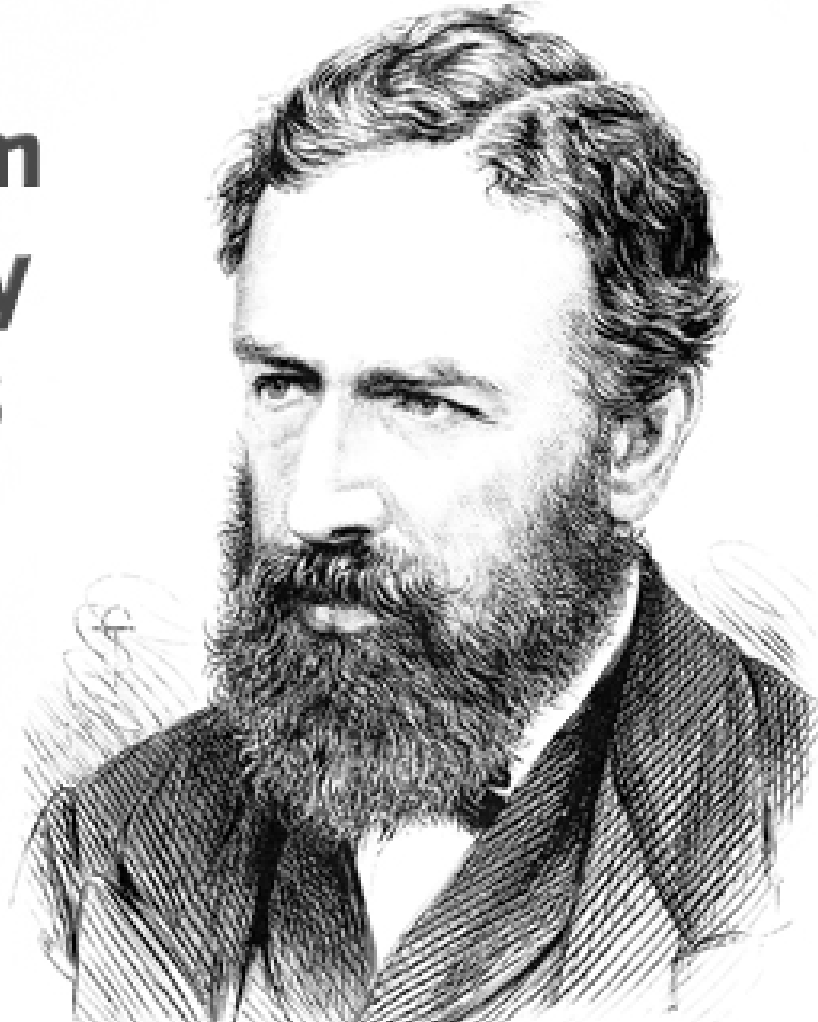
- Not just this year's GDP, but all value ever created.
- All of civilization crumbles and disappears, and so do the people. Inflation applied to all that exists, goes infinite when value goes to zero by turning to dust. Total inflation-adjusted past global GDP now is zero. It's decayed and dead. See later here for a fuller explanation of this.
- So on the large scale...
- A vital boundary condition of the power/wealth relation is thus seen satisfied. I'll show later that on the small time scale, a different boundary condition is also apparently satisfied.

THERMODYNAMIC LAWS ARE SIMPLEST IN A CLOSED SYSTEM. IT SEEMS ENERGY CONSUMPTION AND ECONOMIC GROWTH MIGHT BE ELEGANTLY SIMPLE AS WELL, BUT ONLY WHEN SEEN IN A GLOBAL (HENCE CLOSED) ECONOMIC SYSTEM

- The Power/Wealth relation is not obeyed inside individual countries or regions since they are not CLOSED ECONOMIC SYSTEMS. Cross border movements of money and goods is rapid compared to the system characteristic time scale. **The Power/Wealth relation is only obeyed globally.**
- Many of the great discovery moments in physics have come from the realization of elegant symmetries and optimizations obeyed in Nature.
- Should we be surprised that one product of Nature – humans and human enterprise – might also obey elegant simplicities when the artificial borders important to most employed economists are removed?
- Likewise, well-mixed GHG's cross borders quickly, to anticipate the link to climate.

JEVONS' PARADOX

**William
Stanley
Jevons**



IMPLICIT IN THE OBSERVED POWER/WEALTH RELATION IS THE OBSERVATIONAL CONFIRMATION OF WHAT I HAVE COME TO CALL “GENERALIZED JEVONS’ PARADOX”.

- This is distinct from the older, original formulation by William Stanley Jevons – 19th century British energy economist.
- Garrett has referred to my formulation as a “*more explicitly thermodynamic expression*”
- Most eco-friendly advocates and policy cheerleaders who compose “white papers” and speeches will claim that if we just increase energy efficiency, we’ll make big strides in cutting CO2 emissions.
- **That’s false, both in historical fact, and proper theory.**

GENERALIZED JEVONS' PARADOX

Any increase in energy efficiency will lead to savings. Those savings will not be destroyed but rather they will be spent, and ALL spending requires the ongoing consumption of new energy to support the resulting “civilizing” against decay from the 2nd Law of Thermodynamics, while also expanding our ability to discover and exploit new energy at a faster rate. These combined effects more than offset the efficiency-gained reductions in power. Future global power consumption goes up, not down.

THIS IS A WIDER FORMULATION OF THE ORIGINAL “JEVONS’ PARADOX”

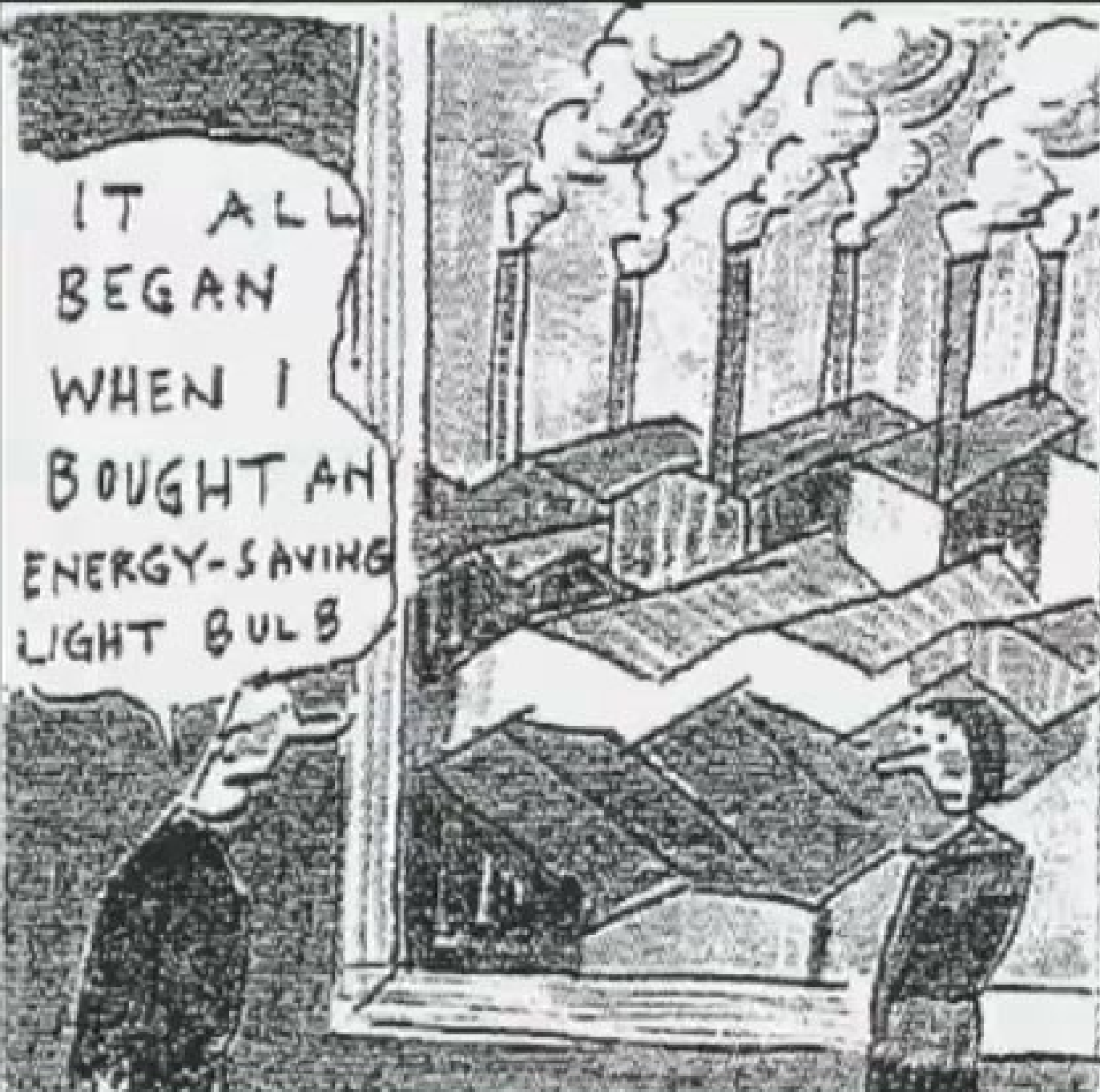
- William Stanley Jevons in 1865 observed that increasing the efficiency of steam engines’ burning of coal should, and did, make for a significant INCREASE, not decrease, in coal consumption.
- A more restricted and limited aspect of this phenomenon is commonly called “Rebound”
- But “Rebound” ignores that efficiency savings need not be spent on more of the same. Savings can be spent anywhere, and we spend everything we make, even borrowing from the future (debt) as a percentage of savings, within our fractional reserve financial system.
- Global sustainability and climate change care only about the *total* spending, not about narrow like-for-like spending.

CONVENTIONAL ECONOMISTS LIKE TO POINT OUT THE EXAMPLE OF IMPROVED GASOLINE EFFICIENCY IN CARS AS DISPROVING JEVONS' PARADOX. BUT THIS FAILS TO UNDERSTAND THE ISSUE.

- True: if we double the miles-per-gallon efficiency of our car, we are highly unlikely to then double our driving miles just because we can now afford to. Yes. But irrelevant and a completely misleading use by economists.
- That efficiency leads to savings. And all savings are spent.
- The Power/Wealth relation expresses that current energy consumption rates are proportional to the sum total of all past real spending. Whether on driving more miles, or anything else.
- Improving efficiency is associated with HIGHER energy consumption rates.

THE THERMODYNAMIC ASPECT OF CIVILIZATION SAYS – ALL SPENDING RAISES FUTURE ENERGY CONSUMPTION RATES, WHETHER JUDGED “GREEN” SPENDING OR NOT

- Energy efficiency - It just helps us to access yet more power to enable yet faster growth.
- Which is exactly why we spend the effort and seed money to engage in improved energy efficiencies.
- That’s what history shows...



New
Scientist

JEVONS' REVENGE:
PREPARE TO PAY THE
FULL COSTS WHEN
YOU EMBARK ON A
GLOBAL
TRANSFORMATION

“ALL” SPENDING? BUT ISN’T SOME SPENDING BETTER FOR CLIMATE?

- Couldn’t we spend on extra improvements to energy efficiency, for example?
- We could, but that would only generate yet more savings and more “civilizing”, needing yet more ongoing 2nd Law maintenance.
- Consumption is 70% of U.S. spending and similar elsewhere.
- More generally, we act as a large system of actors and lowering demand for what you might think are more climate-damaging spending only alters the supply / demand price curve so as to increase motivation by others less climate-concerned consumers to take up the slack.
- And just as important; increasing energy efficiency is the lowest of our priorities. Why? Energy efficiency only pays off in the discounted future.

BUT MORE TO THE POINT – WE INVEST IN ENERGY EFFICIENCY ONLY TO THE EXTENT THE COST WILL BE MORE THAN COMPENSATED BY EVEN STRONGER GDP GROWTH

- Example: We're globally willing to pay for ~1.1%/year energy efficiency gain ONLY if it will generate an additional ~2.1%/year GDP gain.
- Profits as the Prime Directive: guarantees that energy efficiency improvement rates will *never* catch up to the rates of GDP rise,
- ...and that means that we cannot solve our fundamental energy problem by merely pursuing additional efficiency.
- If it doesn't pay, it doesn't get done; under the command of our conventional "Growth Uber Alles" economics paradigm.

THE POWER/WEALTH RELATION IS A CONVOLUTION OF PHYSICS THERMODYNAMIC LAWS, AND “HUMAN THERMODYNAMIC” LAWS.

- We spend on energy efficiency to the extent we get a pay-back in that higher standard of living (higher spending ability) that we long for. Not otherwise.
- We apportion our energy consumption between the physical categories (slide 61) according to what is most profitable. First, we insure we maintain what civilizing we already have in place (2nd law spending). Second in line, is finding new energy for growth.
- Only with leftovers do we spend on investing in improving energy efficiencies. It is a lower priority, since it's for a discounted future.

I'LL TAKE A RISK AND QUOTE MYSELF HERE...

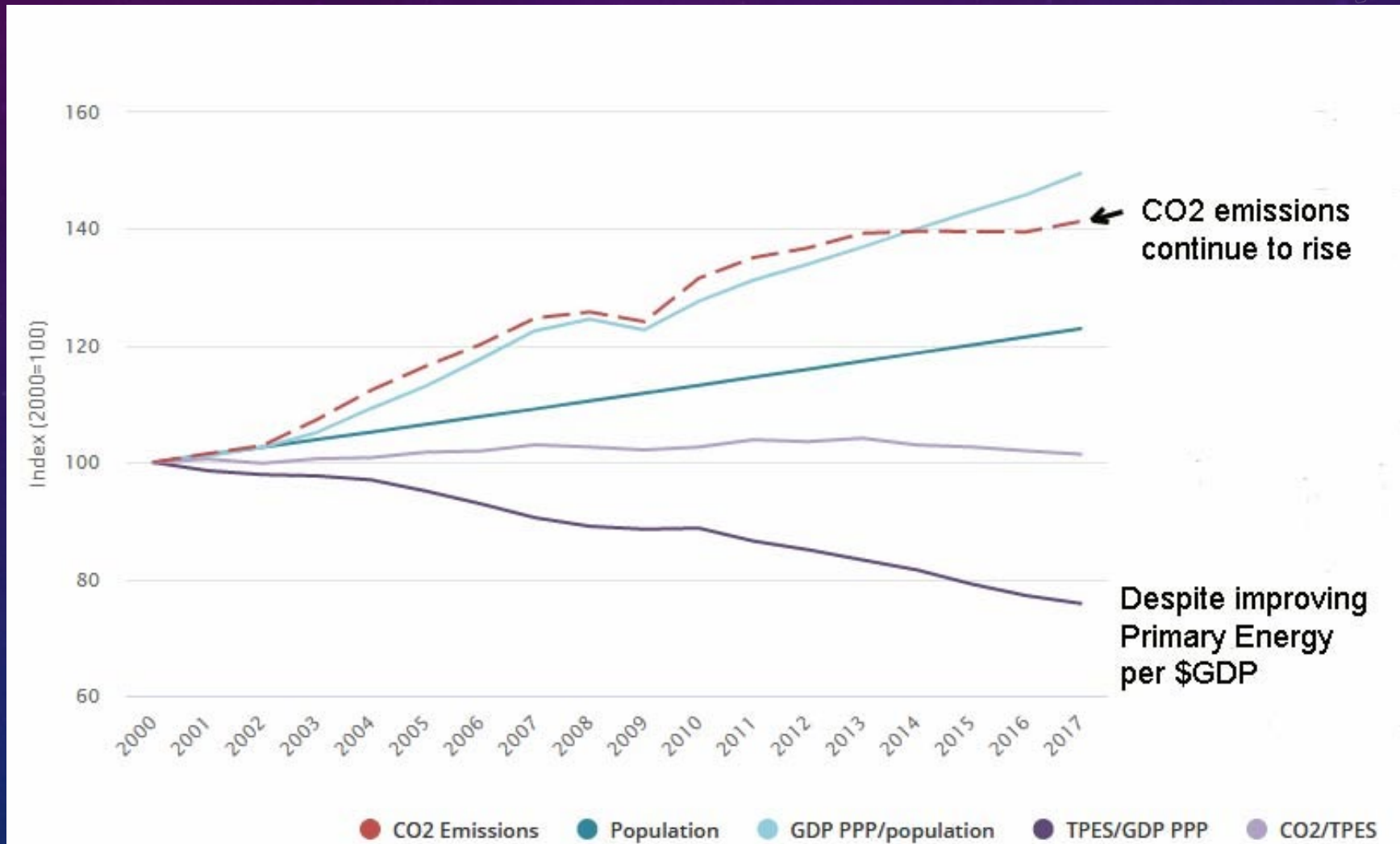
*“Rates of energy efficiency improvement will
~always, year by year, be smaller than the
rates of real GDP gain”*

*“And if annual GDP gains end up being
negative, energy efficiency gains will be even
more negative. It's what short-term profitable
decision-making requires”*

THOSE WHO WRONGLY MIS-CAST AND DISMISS THE REALITY OF JEVONS' PARADOX...

- ...seem, in my experience, those with a vested interest in promoting continued economic growth, biasing their objectivity.
- Here's a good example on YouTube; [a talk by a spokesman for the corporation Hammer and Hand](#). Listen, and spot the logic flaws.
- He explicitly ignores international trade, and limits his examples to the old like-for-like limited interpretation of Jevons' Paradox – which is irrelevant for our global economic and climate systems.

ANNUAL CO2 EMISSION RATES CONTINUE TO RISE, DESPITE STEADY STEEP IMPROVEMENTS IN PRIMARY ENERGY EXPENDED PER \$GDP EARNED. THIS TELLS US THERE'S MORE TO THE STORY THAN THE ROSY EFFICIENCY NUMBERS



WHAT IF I'M ECO-FRIENDLY, AND JUST SPEND MY SAVINGS ON TRAIL RUNNING SHOES?

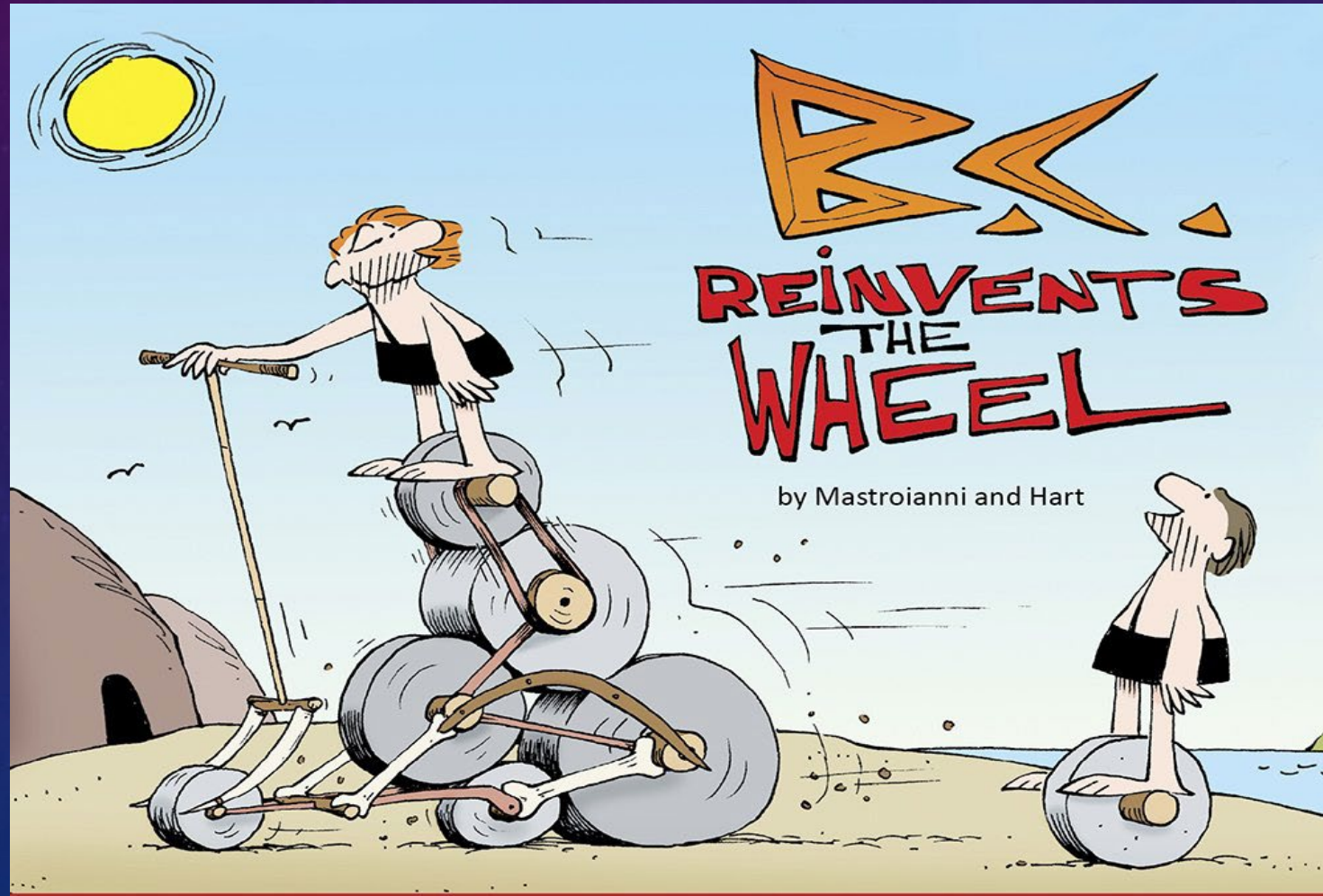
- Even those running shoes are helping me to become a better, healthier, happier, more productive and longer-lived person and thereby increasing my future energy needs.
- These considerations are already reflected in the historical data – the same data that confirms the **Power/Wealth Relation.**



ME, AGE=64 IN THE PHOTO, SOLO-RUNNING A 17 MILE WILDERNESS TRAIL IN THOSE RUNNING SHOES.

I COULD LIVE TO BE 100 AT THIS RATE, AND AT 17 TONS OF CO₂/YR FOR THE AVERAGE AMERICAN, I'LL OUT-CO₂-IMPACT MY SHORTER-LIVED COMPATRIOTS BY MANY TONS, WHILE THEY ARE CHEETOH'ING AND BEER-GUZZLING THEIR WAY TO A CO₂-CONSERVING EARLY GRAVE.

RE-DOUBLE OUR EFFORTS AT ENERGY EFFICIENCY, AS ECONOMIST/POLICY PEOPLE CLAIM IS THE SOLUTION? BUT WE'VE BEEN CONTINUALLY INCREASING ENERGY EFFICIENCY EVER SINCE THE INVENTION OF THE WHEEL. WE'RE "OPTIMAL FORAGERS", AS ARE ALL OTHER ANIMALS, SEEKING TO LOWER OUR ENERGY SPENT PER UNIT OF ECONOMIC UTILITY GAINED IF PROFITABLE.



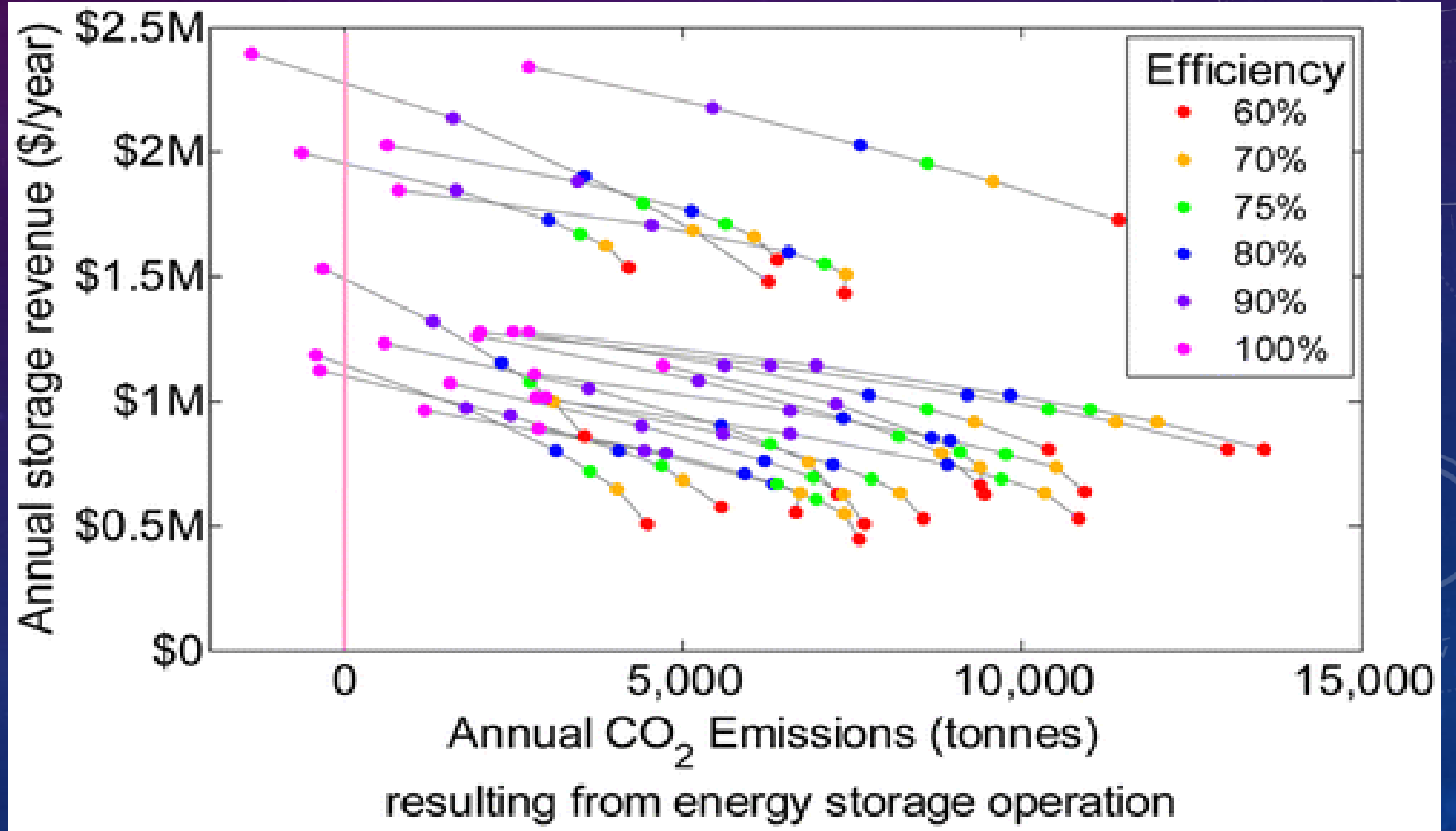
WHAT ABOUT THE HOLY GRAIL OF ENERGY: MORE ENERGY STORAGE ENABLING MORE RENEWABLES

- Surely, energy storage is showing the way to lower CO2 emissions – right?
- No. It's showing the way to HIGHER energy consumption and HIGHER CO2 emissions, in today's economics.
- *"It's difficult for storage to NOT increase emissions"* – Vox
Article – Dave Roberts 2018

PROFIT-GOAL'D ECONOMICS IS AGAIN THE VILLAIN, AT THE HANDS OF THERMODYNAMICS

- **First reason: Energy Arbitrage**: Storing energy when it is cheap and plentiful (coal power plants operating late at night, currently) and releasing the energy it when it is more valuable (during the work day) encourages greater coal mining and coal utilization.
- So energy storage increases the value of the source it draws from (coal), and decreases the value of what it competes against (in this case, solar).
- **Second reason: The 2nd Law** - The additional frictional losses going to, and then sitting in, and then additionally from, storage; will consume an additional % of the primary energy.

ENERGY STORAGE LEADS TO HIGHER CO₂ EMISSIONS (X-AXIS) IN ALL 20 U.S. GRID REGIONS, AND ONLY UNDER THE ASSUMPTION OF PERFECT (UNOBTAINABLE) LOSSLESS STORAGE EFFICIENCY DOES IT LOWER EMISSIONS, AND EVEN THEN, ONLY IN 5 REGIONS (HITTINGER & AZEVEDO 2017) (PURPLE POINTS, LEFT OF 0)



“BEING ABLE TO FALSIFY A RESULT LIES AT THE CORE OF THE SCIENTIFIC METHOD. IT MUST BE POSSIBLE TO SET UP A TEST THAT COULD LEAD TO A MODEL BEING DISCARDED.” – [TIM GARRETT](#)

- The above is from Garrett’s article with the provocative title [“Is Macroeconomics a Science?”](#)
- Integrating physics (thermodynamics) with civilization’s economic aspects, on the other hand, is science (*i.e.* it makes testable quantitative predictions)...
- *“Current global rates of energy consumption growth and global GDP growth [can be accurately predicted](#) based on conditions observed in the 1950’s, knowing only the key thermodynamic civilization relations and without appealing to any observations in the interim, with skill scores >90%.”* (Garrett - from same article).
- **I’ve tested and extended the Power/Wealth Relation in additional ways – see later in this talk...**
- For a more detailed study of Garrett’s work, see key papers linked [near the top of this page](#) of mine. The most mathematically detailed paper is [Garrett 2014](#). **Clearest links to economics is in [Garrett et al. 2020](#)**).

WELL... THEN, WHAT SHOULD WE DO WITH OUR EFFICIENCY-GAINED SAVINGS?

- Just leave the savings in the bank? No – in our fractional reserve banking system, a multiple of it will just be lent out to others who WILL spend it.
- In fact, in any free market, lowering demand by an *e.g.* eco-friendly group will only, to first order, move the price of the relevant goods along the supply/demand price curve to better enable its purchase by others.

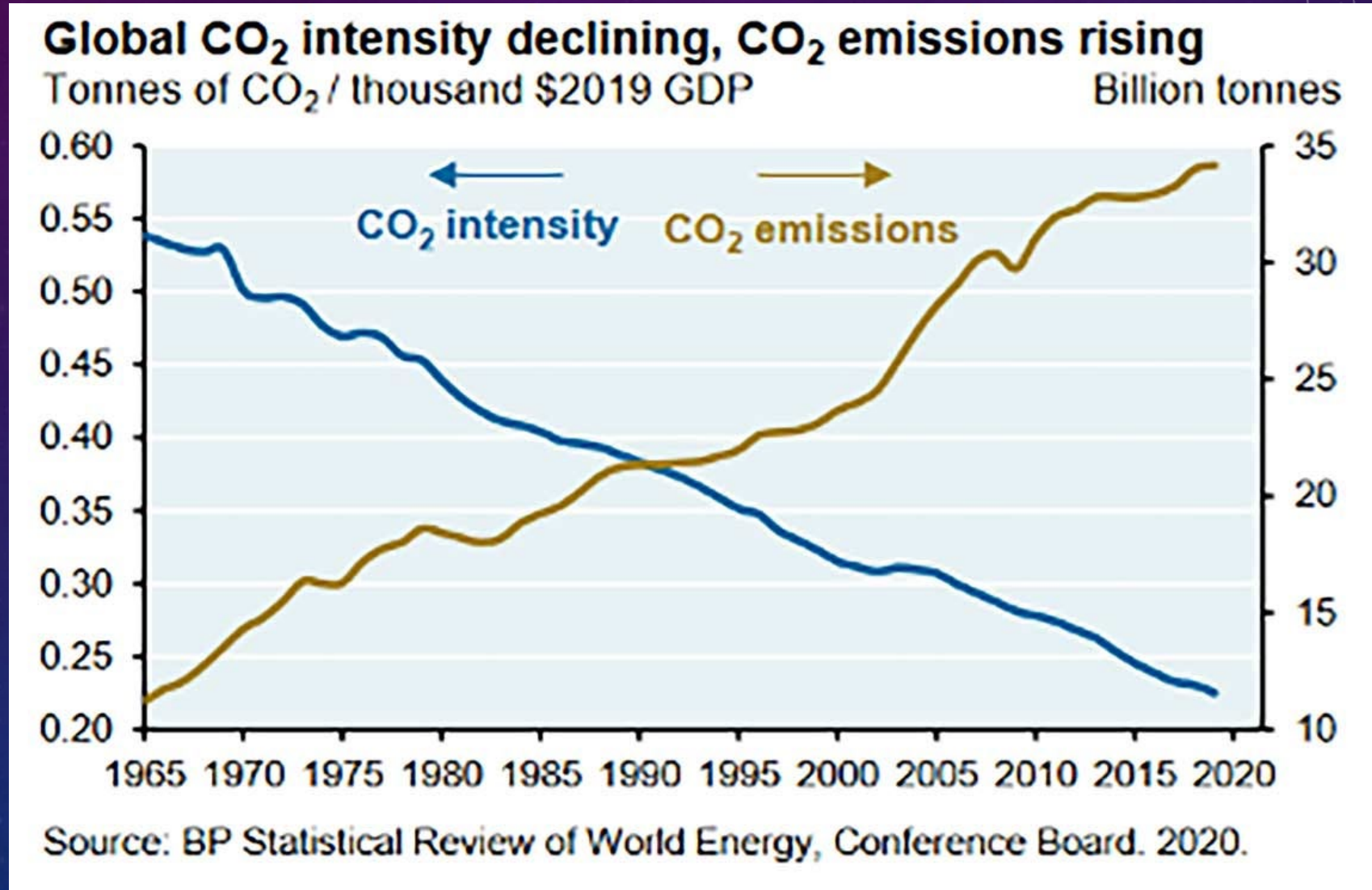


THEN DO WE *BURN* THE
CASH?? – THAT WON'T
WORK EITHER.
LOWERING THE MONEY
SUPPLY BUT LEAVING
OUR WEALTH-
PRODUCING CAPACITY
UNCHANGED ONLY
MAKES THE REMAINING
MONEY SUPPLY MORE
VALUABLE. THAT'S
NEGATIVE INFLATION.

IT DOESN'T SOLVE OUR DILEMMA— HOW TO LOWER CIVILIZATION'S TOTAL ENERGY CONSUMPTION WHILE STILL BEING CONTROLLED BY OUR EVOLUTIONARY BIOLOGICAL DRIVES

- We need to actually cripple civilization's ability to grow, or voluntarily halt that growth by enforced policy action created by (impossibly hard) universal and continually generated biological energy-intensive human will-power **against** our inbred compulsions (assuming we even have “free will”, that is).
- In a competitive world, this would seem extremely unlikely, and ultimately exhausting.

THE CO₂ INTENSITY OF GLOBAL GDP SINCE 1965 - FALLING IMPRESSIVELY SINCE 1920 (BLUE). “GENERALIZED JEVONS’ PARADOX” CORRECTLY PREDICTS RISING CO₂ EMISSIONS WILL BE THE RESULT (BROWN).



WE HAVE INDEED BEEN STEADILY LOWERING THE AMOUNT OF ENERGY NEEDED TO GENERATE A DOLLAR OF GLOBAL GDP

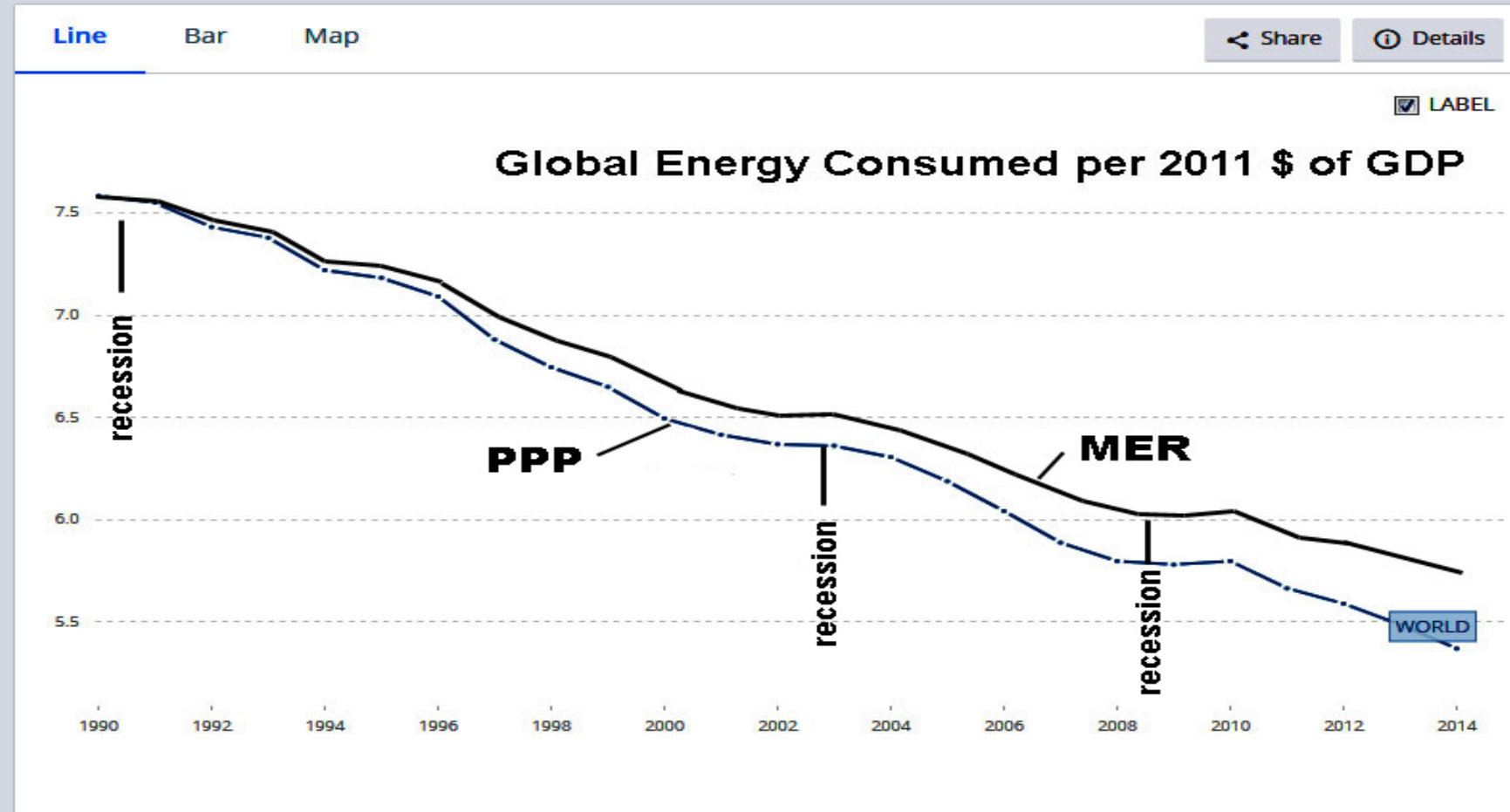
- Perfectly consistent with the Power/Wealth Relation... as long as GDP is rising at a faster rate than is energy efficiency.
- Since 1990, global primary energy efficiency has been improving at an average rate of **1.155%** per year. But real global GDP (proper “market exchange rate” (MER) accounting) has been rising faster; over **2%** per year (faster still if using “purchasing power parity” (PPP) accounting).
- Now look at the trend in global energy efficiency (next slide) and notice that the downtrend, while impressively linearly improving, is not perfectly smooth, and notice when the kinks happen...

$F(T) == P(T)/G(T)$: PRIMARY ENERGY CONSUMPTION RATE (P) PER UNIT OF GLOBAL GDP ($=G$) IS AN APPROXIMATELY LINEARLY DROPPING FUNCTION. BUT NOTE THAT DURING RECESSIONS (1990, 2001 AND 2008/2009) $F(T)$ WENT FLAT, SO THAT THE SLOPE WENT TO ZERO.

Energy intensity level of primary energy (MJ/\$2011 PPP GDP)

World Bank, Sustainable Energy for All (SE4ALL) database from the SE4ALL Global Tracking Framework led jointly by the World Bank, International Energy Agency, and the Energy Sector Management Assistance Program.

License: [Open](#)



The World Bank data on the previous slide shows the global primary energy consumption rate (power P) per unit of officially reported inflation-adjusted global GDP G). Call that changing ratio f . f is a declining function. I presented this in a Wikipedia article I wrote a few years ago.

$$(1) \quad f(t) \equiv P(t)/G(t)$$

Differentiating with respect to time t gives...

$$(2) \quad \frac{\partial P}{\partial t} = G \frac{\partial f}{\partial t} + f \frac{\partial G}{\partial t}$$

Now, the Power/Wealth Relation is...

$$(3) \quad W(t) = \int_0^t G(t') dt' = \lambda P(t)$$

Differentiating with respect to time t gives...

$$(4) \quad \frac{\partial P}{\partial t} = \frac{G}{\lambda}$$

and substituting this into (2) then gives

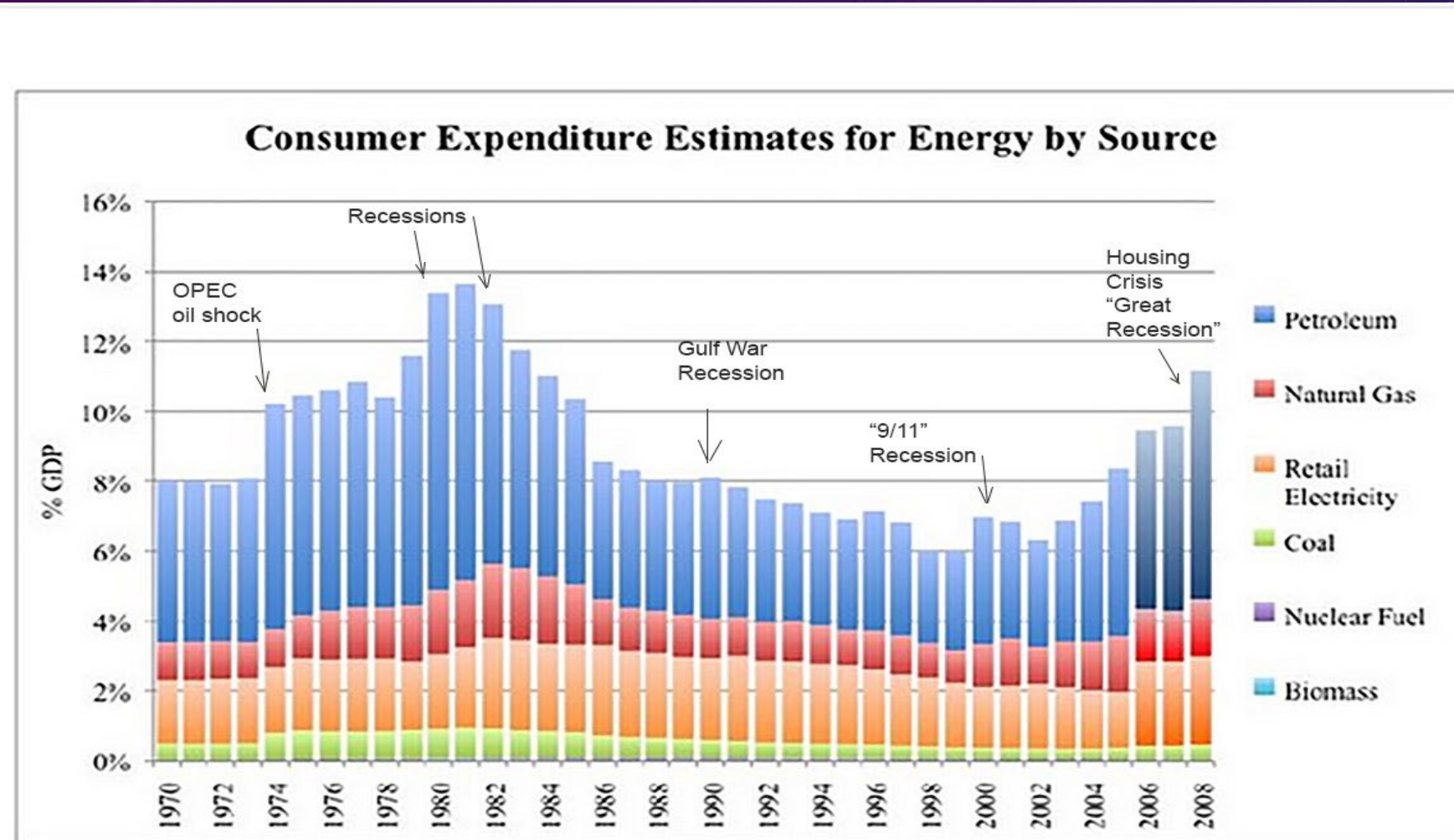
$$(5) \quad \frac{1}{\lambda} = \frac{\partial f}{\partial t} + \frac{f}{G} \frac{\partial G}{\partial t}$$

AND SO...

$$\frac{1}{\lambda} = \frac{\partial f}{\partial t} + \frac{f}{G} \frac{\partial G}{\partial t}$$

- The left side is a positive constant. But on the right side, the first term is (usually) negative and approximately constant (~linear down-sloping f ; It's the slope of the efficiency curve on last slide).
- In the 2nd term, f is always positive, and G is positive (unless we've utterly collapsed), over-ruling the first term as it must. However the second term is negative during economic recessions, when $\partial G / \partial t$ is negative. So does this invalidate the Power/Wealth relation? No. The Recession-GDP bias says not. See later.
- Now note on the previous graph that recessions are also when official $\partial f / \partial t$ rises to zero slope (and even positive - see later).

THE U.S. IS OFTEN TOUTED AS A GREAT EXAMPLE OF ENERGY EFFICIENCY AND GDP. BUT NOTE (HALL & BALOUGH 2009) THAT EVERY U.S. RECESSION CARRIES NOT ONLY A WORSENING OF GDP, BUT AN INCREASING ENERGY CONSUMPTION PER \$GDP, JUST AS THE POWER/WEALTH RELATION REQUIRES. GLOBALLY, ENERGY EFFICIENCY WORSENS DURING RECESSIONS.



SO HERE IS THE ALARMING CONCLUSION... (PERHAPS THE MOST CRUCIAL POINT IN THIS TALK)

- If the Power/Wealth Relation continues to hold true, and if we enter a long-term recession to pull within planetary boundaries, it says that we could not (or would not) continue to improve the energy efficiency of global GDP, so that $\partial f / \partial t$ would have to turn positive, meaning...
- Energy Consumption rates then Grow FASTER than GDP.
- Limited Federal Reserve studies are consistent with this (see later).
- **This is a double-bind we'll come back to as we consider the implications of the Power/Wealth Relation to our future.**

DURING RECESSIONS, THE HUMAN ECONOMIC LOGIC IS THIS...

- Top priority is to preserve present production ability against the 2nd Law, preservation of capital is #1 goal.
- This includes finding continual new energy to power the present.
- By contrast, funding improving energy efficiency is an investment towards future profits, therefore of lower priority, since economists discount the future.

NOTE THIS INTERPRETATION DIFFERS FROM GARRETT'S, WHO BELIEVES IT IS IMPROVING ENERGY EFFICIENCY WHICH IS THE CAUSE OF FASTER GROWTH, AND WORSENING ENERGY EFFICIENCY WHICH CAUSES REVERSALS OF ECONOMIC GROWTH.

- While growth and efficiency are clearly correlated, it makes more economic sense to see cause-and-effect in the opposite direction.
- Recessions can have a variety of causes unrelated to energy efficiency: mal-investment in speculative assets, virus pandemics, restrictive Fed policy, oil wars...
- Declining GDP will set priority so that first, we hang on to what we already have created, and de-prioritize trying to improve energy efficiency which only helps the (devalued by economists) future.

MORE CONFIRMATION: CHINA, (AND OTHER AUTOCRATIC COUNTRIES?): OVER-REPORTING GDP, HENCE OVER-ROSY ENERGY EFFICIENCY FIGURES

- **St. Luis Federal Reserve** cites numerous studies (below) indicating China's reported GDP growth is often 1.65x to 2x overstated; for multiple reasons.
- Power consumption - easier to measure even in China: Calibrated satellite night luminosity is just one proxy indicating a strong over-reporting by China officials of their GDP. (Owyang and Shell 2017 – St. Louis Fed). And more recently.
- GDP over-reported, means energy efficiency improvements are also overstated.
- I have not found corresponding global studies . But since China is the world's second largest economy, and the U.S. is also widely suspected of having similar biased estimates, it strongly suggests that this trend is global.

ANOTHER NEW STUDY: CHINA, AND OTHER COUNTRIES, UNDER-REPORTING GHG EMISSIONS

- Meaning, under-reporting energy consumption.
- Global emissions are ~27% UNDER-reported. . (Mooney et al. November 2021). That's a staggering amount.
- Corrupt accounting and errors in what's allowed, are fully taken advantage of by the policy people and the economists they employ.

BIAS IN REPORTED GDP FIGURES FROM EMERGING COUNTRIES

- There are political and financial market motivations for government officials to overstate their GDP figures – Why? Wall St. sets prices for equities on the basis of their earnings growth rate, closely connected to GDP growth.
- Integrity is questionable ([Clark et al. 2017 from the New York Federal Reserve Bank](#)), albeit by a difficult to quantify amount. The [Li Keqiang Index](#) is considered the most reliable proxy for true GDP in China.
- Different proxies give different results, but overstatement of GDP is widespread.
- It is important to notice that GDP growth is most overstated during recessions ([Mayger 2018](#), but also see [Owyang and Shell 2017](#), [Heubl 2018](#).)

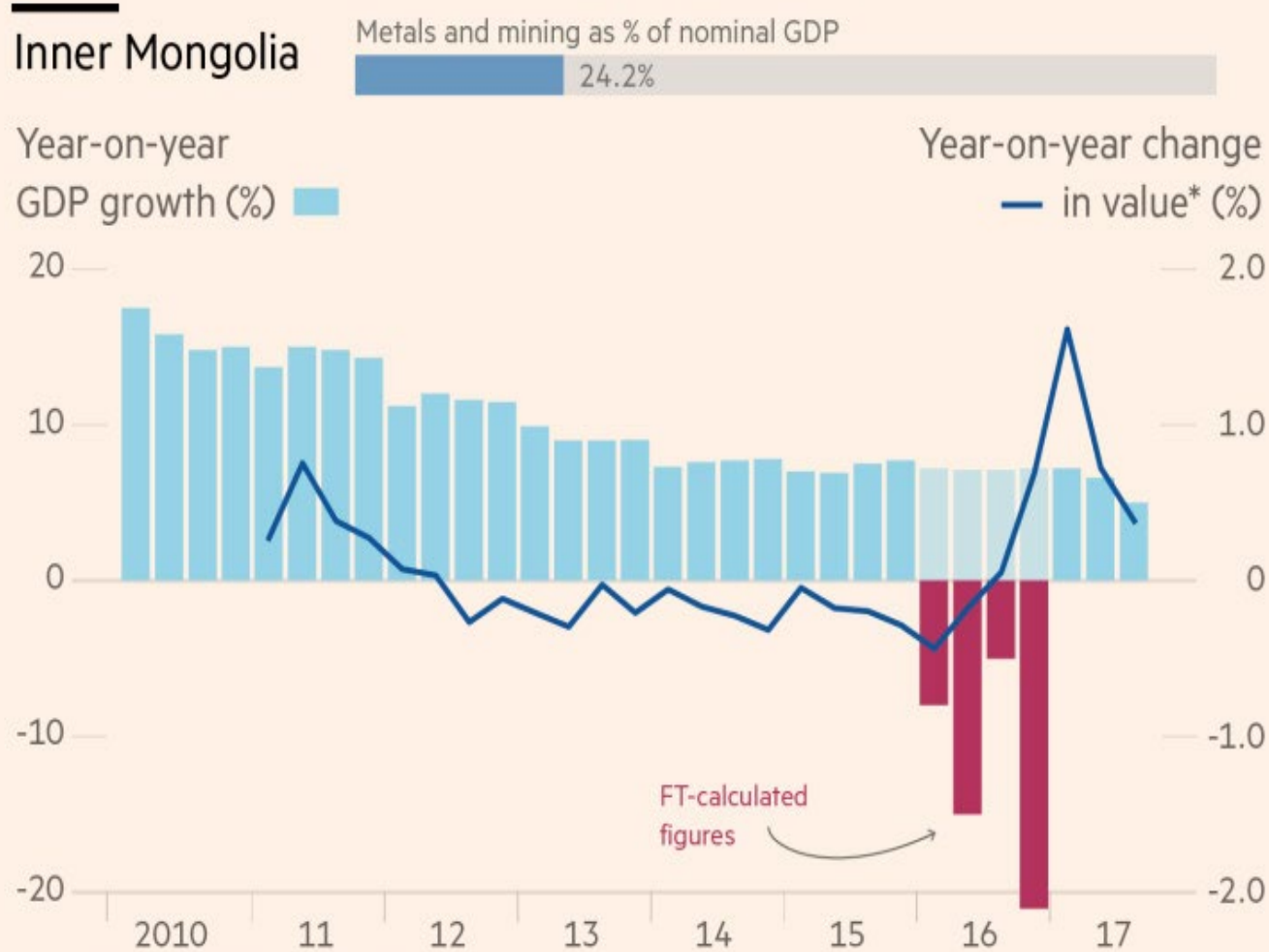
I CALL THIS - *“THE RECESSION - GDP BIAS”*

- Implication: Energy efficiency improvements don't just flatten, they indeed reverse during economic recessions, in agreement with the Power/Wealth Relation

THE RECESSION – GDP BIAS. IN CHINA'S COMMAND ECONOMY, LOCAL PARTY OFFICIALS TEND TO REPORT THE PRODUCTION NUMBERS THEY WERE MANDATED BY BEIJING TO MAKE, NOT THE REALITY (BEST APPROXIMATED BY THE LI KEQIANG INDEX, SAY ECONOMISTS). SO IN RECESSIONS, GDP IS OVER-REPORTED, BUT THEN TO COMPENSATE, DURING THE RECOVERY BOOM TIMES (LIKE 2016-7) THEY TEND TO UNDER-REPORT.



Below is a chart showing the declared GDP growth of Inner Mongolia since 2011, and the contraction of 2016, assuming no other revisions.



Sources: Wind Information; Gavekal Dragonomics; FT research

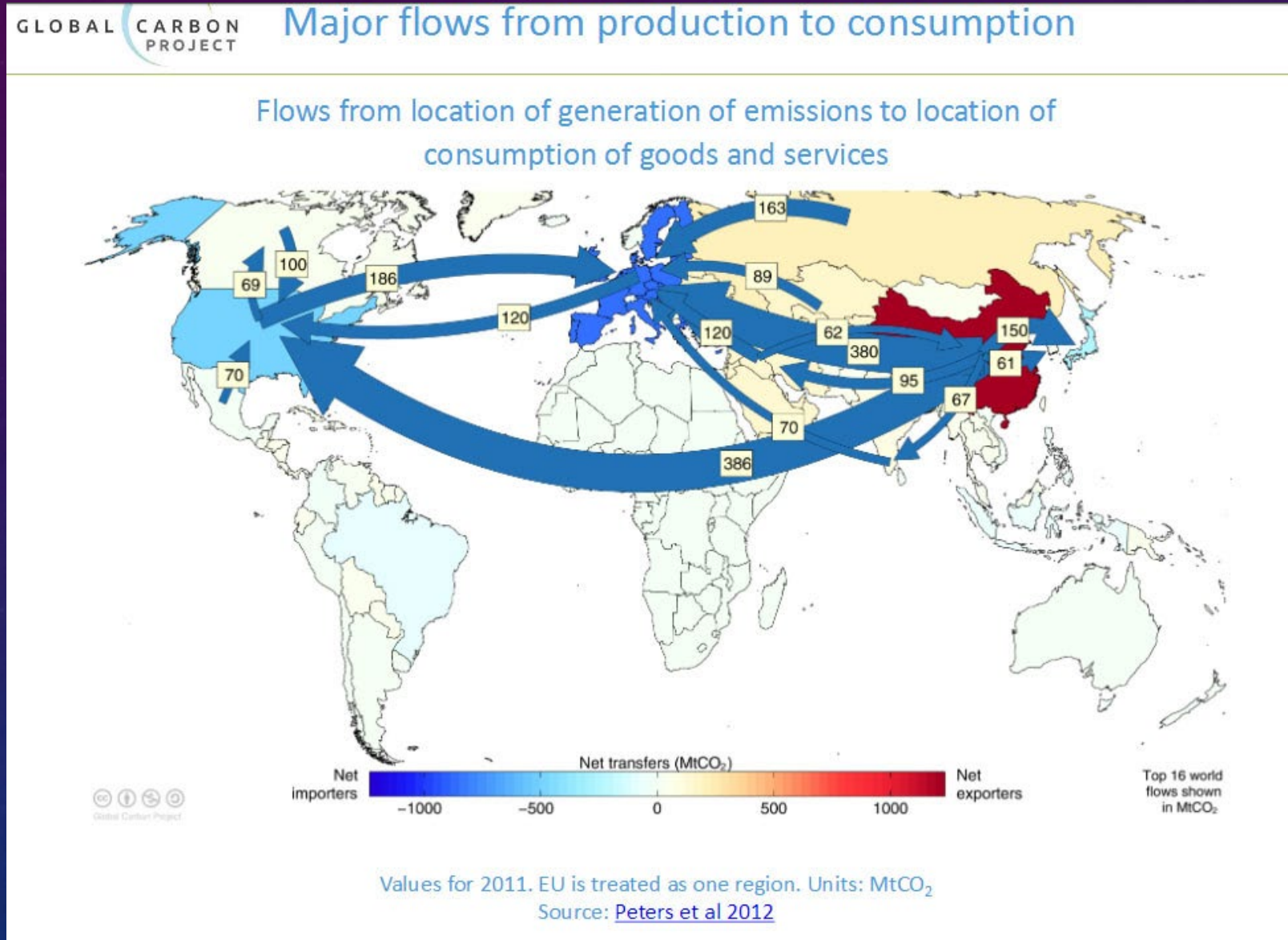
© FT

AN EVEN MORE DRAMATIC EXAMPLE IS INNER MONGOLIA.

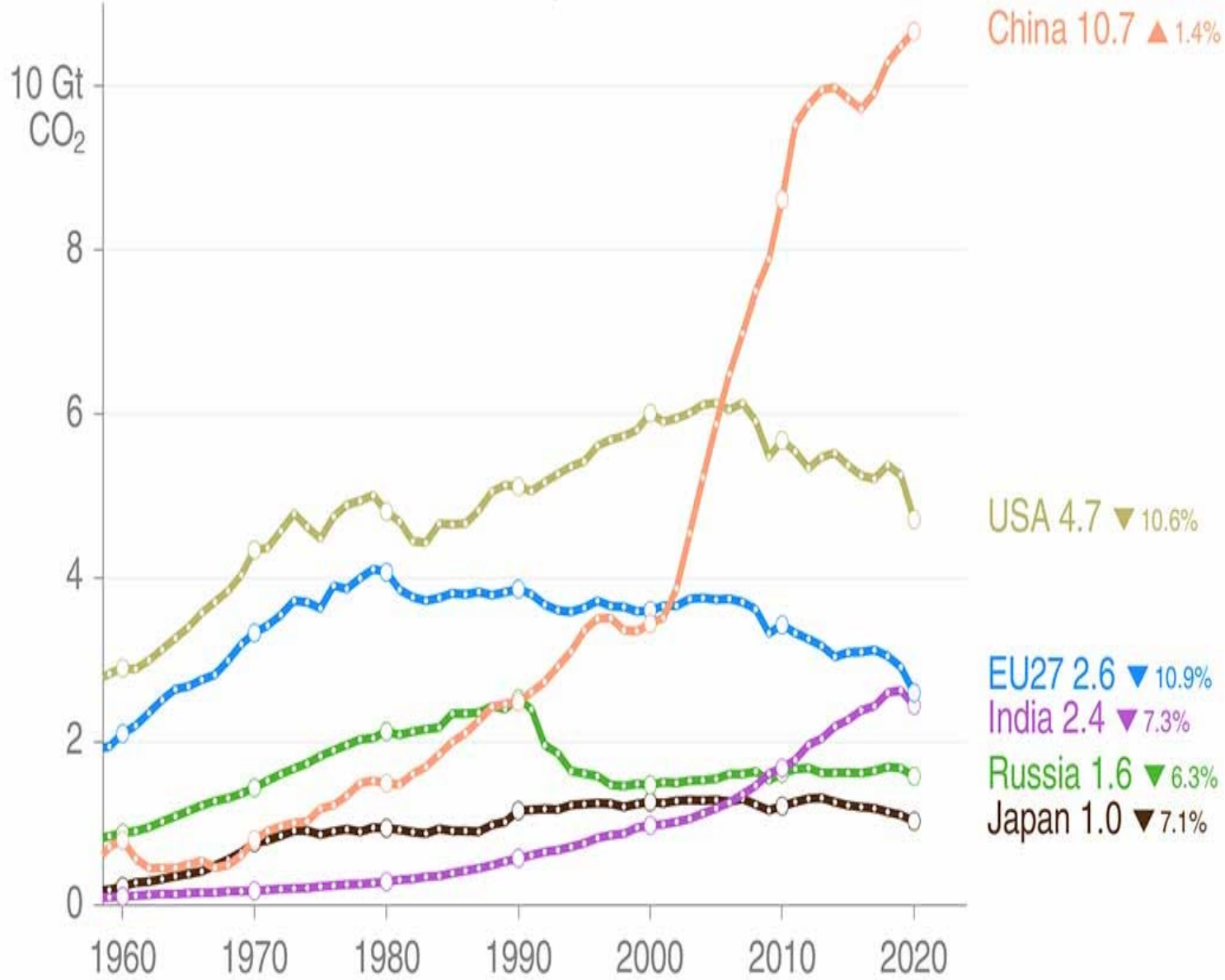
OFFICIAL GDP (BLUE) WAS +7% BUT THE *FINANCIAL TIMES* CALCULATIONS SHOW IT WAS MORE LIKE -10% (RED), DURING THE 2016 CONTRACTION.

[ADDITIONAL ARTICLE](#)

BY INCLUDING THE CARBON EMISSIONS FROM OFF-SHORED MANUFACTURED GOODS IMPORTED TO THE U.S. ... (NEXT SLIDE)



Annual Fossil CO₂ Emissions: Top Six Emitters

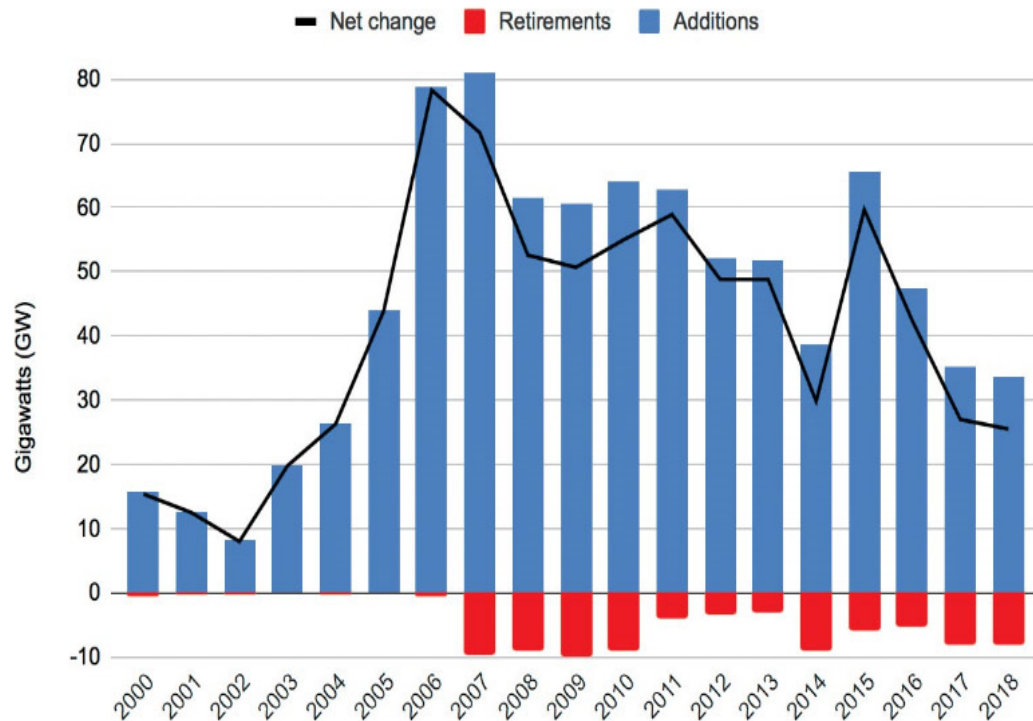


...IT RAISES U.S. ACTUAL CO₂ EMISSIONS BY 30% ABOVE THIS GRAPH'S ROSY TREND.

(QUOTED BY NATE HAGENS 2022)

ECONOMIC GROWTH = POLITICAL POWER. THAT MEANS CALORIC POWER: COAL. NEW GLOBAL RECORD IN COAL-POWERED ENERGY IN 2021 (IEA 2021)

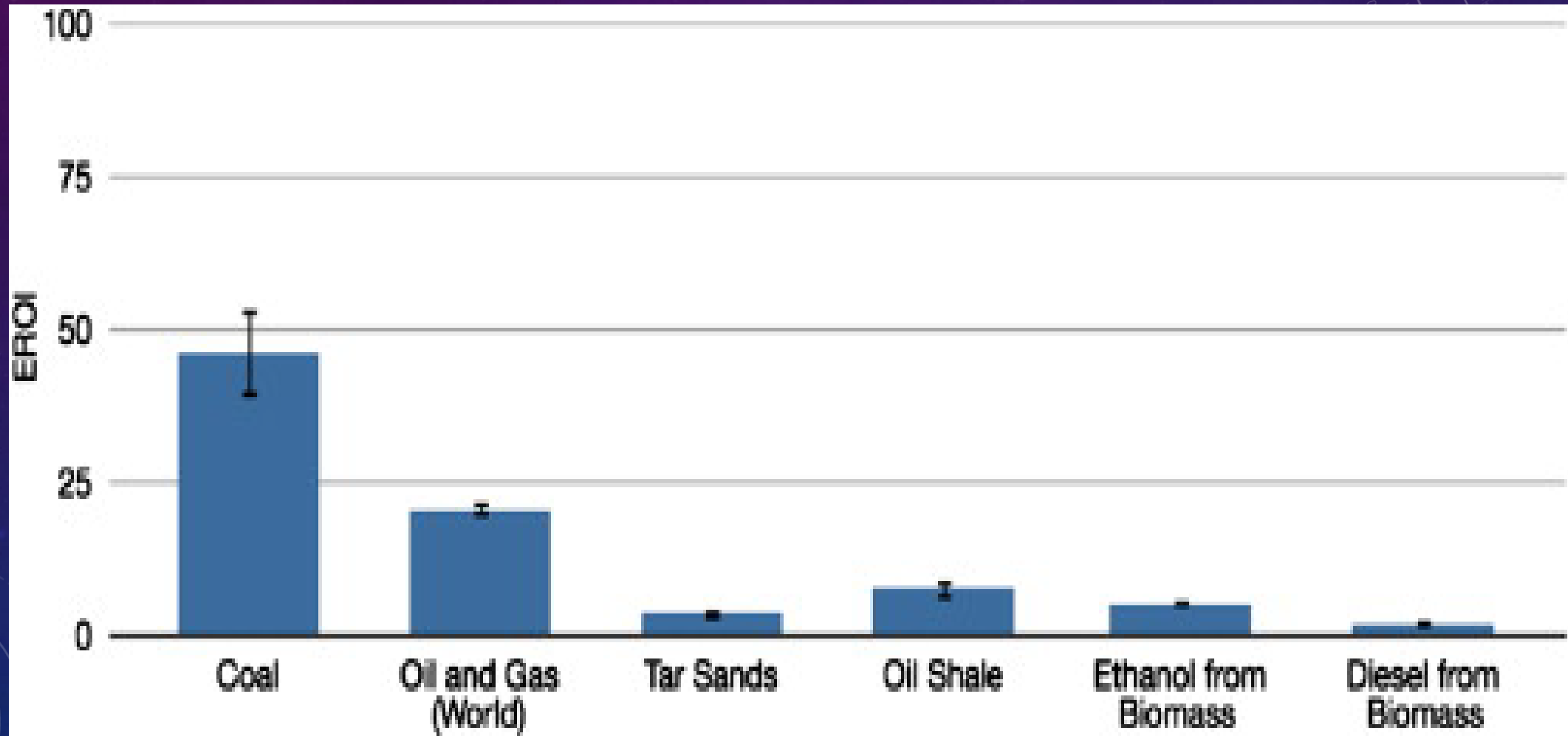
Figure 4: Added (blue) and retired (red) coal-fired power capacity in China by year, and the net change (black line).



Source: GEM, Global Coal Plant Tracker, July 2019.

- Renewables growing too, but only as a small add-on to the Power Portfolio.
- So, be cautious accepting the spin on China as the renewables revolutionary leader. They too are allied with “Growth Uber Alles” as I showed in my economics talks.

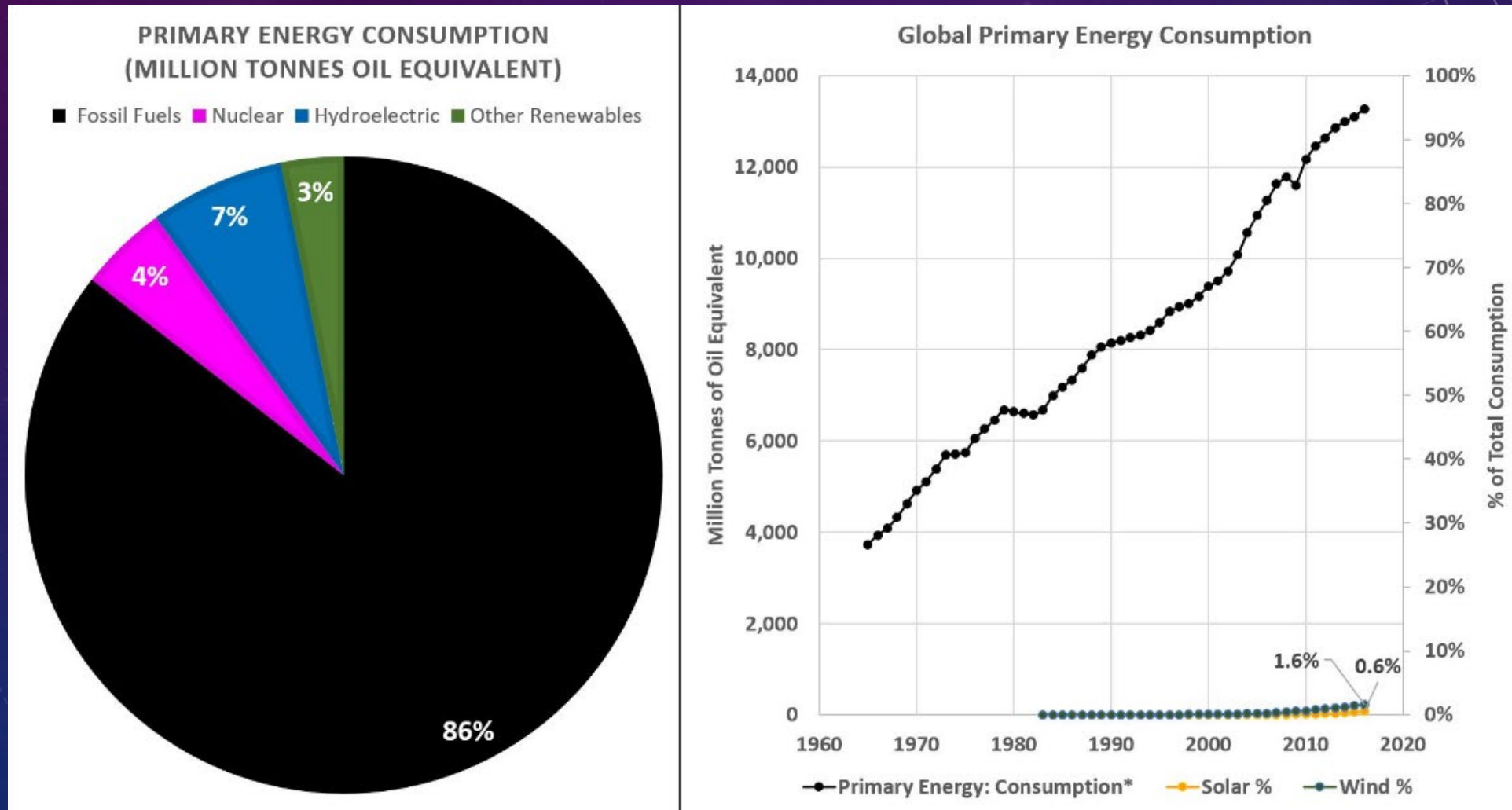
WHY SUCH RELIANCE ON COAL? COAL'S ENERGY RETURN ON ENERGY INVESTED (EROI) IS FAR BETTER THAN OTHER SOURCES ([HALL *et al.* 2014](#)). FOR COMPARISON, SOLAR PV HAS AN EROI OF ONLY ~2.5 ([HALL 2016](#)), WHEN CALCULATED FAIRLY AND SELF-CONSISTENTLY.



THE EROI OF ENERGY SOURCES IS RELATED TO THE GLOBAL INFLATION RATE, CITES GARRETT

- The success of the Power/Wealth Relation carries with it the implication that the global inflation rate is intimately associated with the “decay rate”, with inflation seen as the manifestation of this decay rate ([Garrett 2012](#)).
- The EROI of the collective global energy mix, is just the inverse of the global inflation rate, concludes Garrett ([Appendix A of Garrett 2012](#)).
- If this is true, the switch to the much lower EROI of incoming solar and wind (vs. millions of years of accumulated concentrated solar energy (fossil fuels)) will have profound and unfortunate implications for civilization.

THE EVOLUTIONARY BIOLOGY IMPERATIVE IS GROWTH: GLOBAL PRIMARY ENERGY CONSUMPTION IS RISING AT A FASTER RATE THAN SOLAR AND WIND AS OF 2016



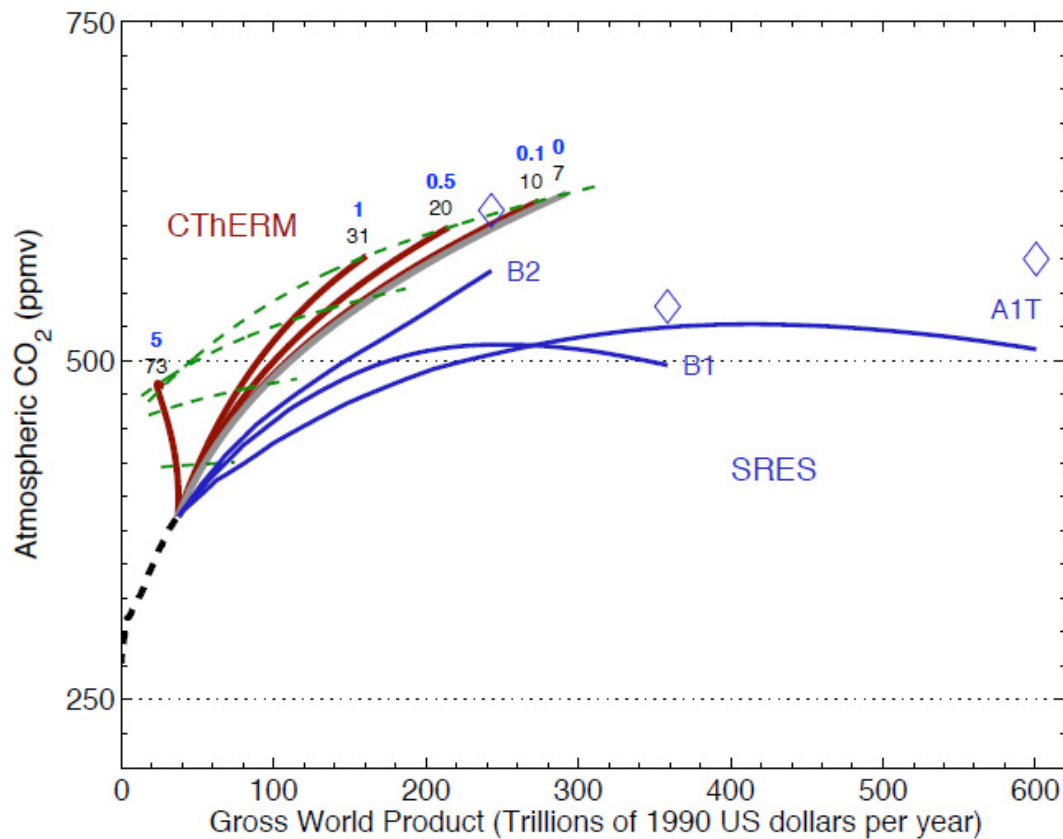


Fig. 7. As for Fig. 6 except that it is assumed that the value of carbonization c has an assumed halving time of 50 years. For comparison, the IPCC SRES trajectories that are considered are the A1T, B1 and B2 scenarios.

Model initialized with conditions in 2008 and assuming a range of values of inverse resilience $1/\rho$ (blue numbers expressed in % yr⁻¹ change in the decay coefficient γ per CO₂ doubling). Small numbers in black correspond to the calculated inflationary pressure $i = \gamma/\beta$ (Eq. 25) in year 2100. Green dashed lines represent the modeled year. Shown for comparison are the IPCC SRES A1F1 and A2 scenarios based on the CThERM linear sink model for CO₂. CO₂ concentrations for these scenarios using the Bern carbon cycle model are shown by blue diamonds. Historical data from 1 AD to 2008 is added for reference (see Appendix C in Garrett 2012).

FROM GARRETT 2012. RESILIENCE (Eq. 26) CURVES INCLUDING STEEP DE-CARBONIZATION WITH HALVING TIME $T_{1/2} = 50$ YEARS. ALL ARE SIGNIFICANTLY WORSE (RED) THAN THE POLICY-INFLUENCED IPCC ECO-FRIENDLY SCENARIOS (BLUE).

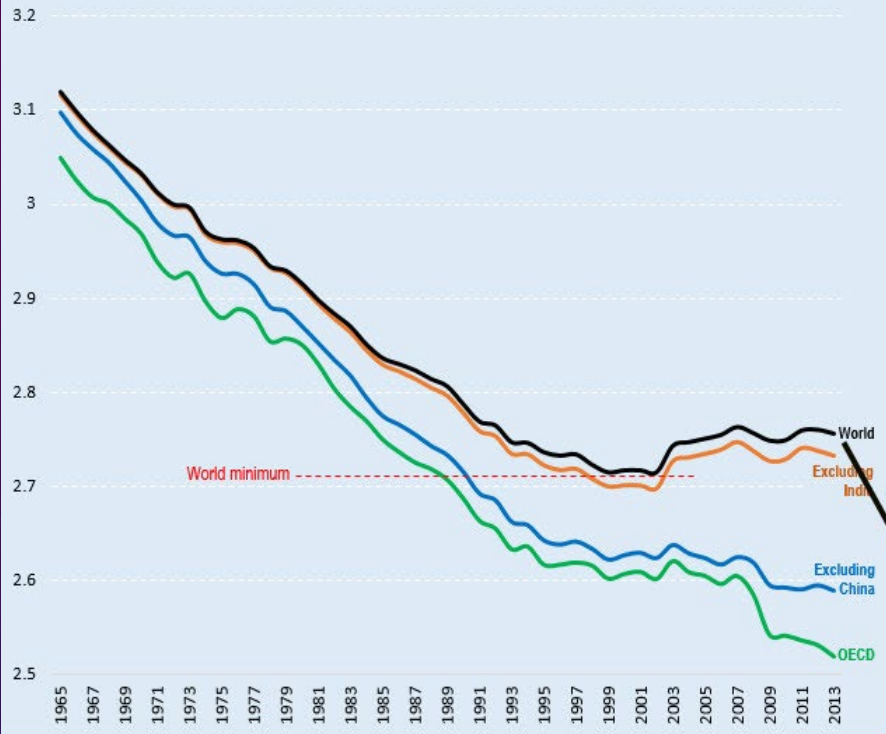
BE CAREFUL WHAT YOU WISH FOR: STRONGER CIVILIZATION RESILIENCE TO CO₂ DAMAGE MEANS FASTER GROWTH OF CO₂ EMISSIONS. ONLY FOR THE DECAY RATE REACHING 73% THAT OF PRODUCTION (LEFT RED CURVE) DOES CO₂ TOP OUT, IN 2100. HOWEVER, THIS STUDY IS OVER 10 YEARS OLD, AND SO THE BRANCHING STARTING POINT OF THESE CURVES NEEDS TO BE SIGNIFICANTLY SHIFTED HIGHER; WE'VE DONE NOTHING BUT STAY ON "BUSINESS AS USUAL" IN THOSE 10+ YEARS.

ECONOMIC GROWTH IS LESS, AND CO₂ FAR WORSE, THAN THE SIMPLE IPCC SCENARIOS (BLUE) WHICH UNCOUPLE KEY VARIABLES AND ARBITRARILY IMPOSE POLICY-DESIRED TRENDS, IGNORING THERMODYNAMIC COUPLINGS.

IS GARRETT TOO OPTIMISTIC? ONLY DIRECT HUMAN EMISSIONS CONSIDERED, NOT THE INDIRECT EMISSIONS FROM CLIMATE FEEDBACKS, AND NO COST AND ENERGY ALLOWANCE FOR CONVERTING TO LOW EROI RENEWABLES FROM CHEAP, EROI-DENSE FOSSIL FUELS AS DECARBONIZATION PROCEEDS.

Exhibit-2: CO2 Intensity of Energy Use (metric ton/toe)

(Source: BP Statistical Review 2014)

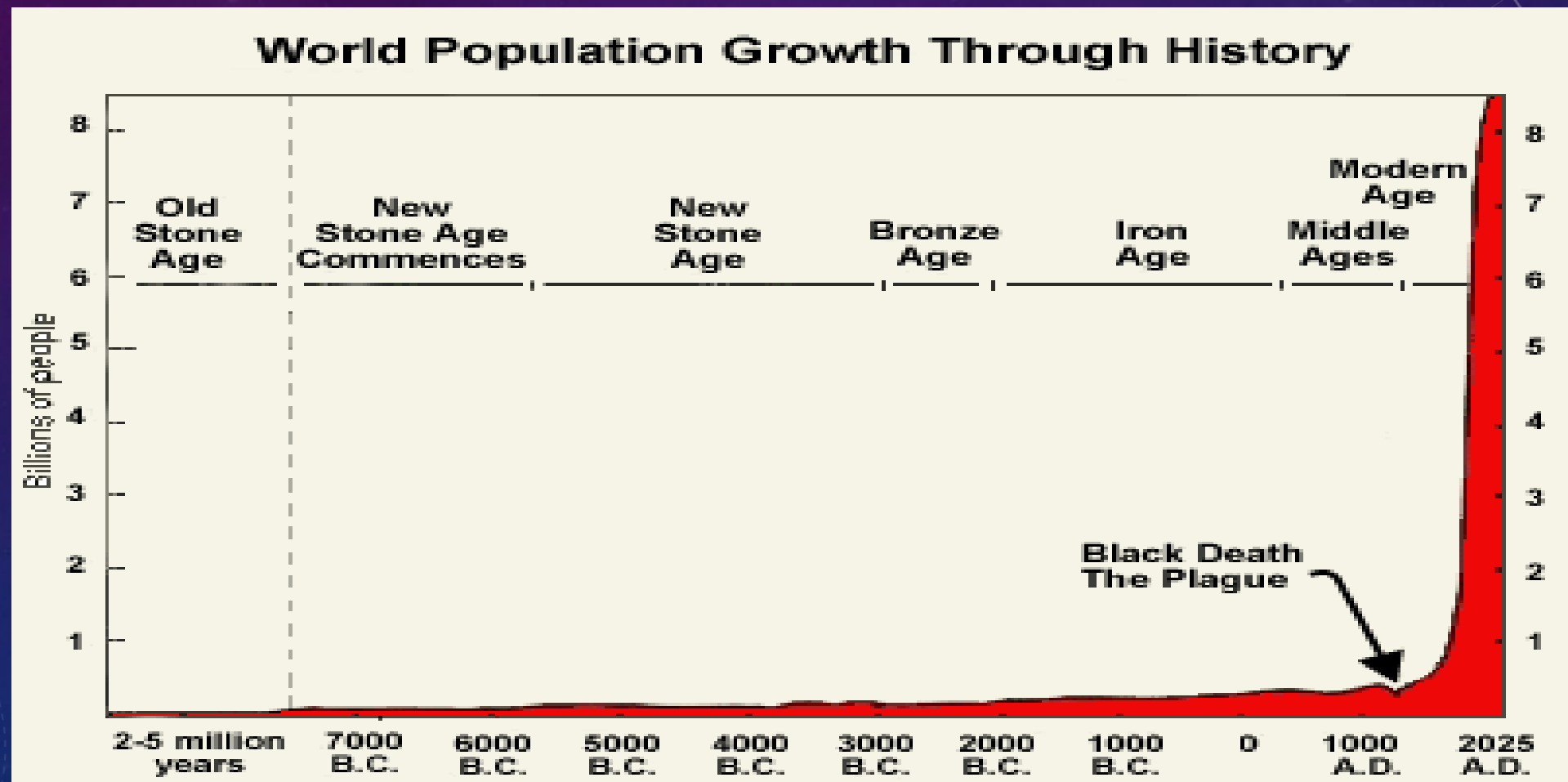


trend of linear approximation to exponential halving time of 50 years

GARRETT'S EXPERIMENTAL SCENARIO SHOWN ON PREVIOUS SLIDE ASSUMES THE CO2-INTENSITY OF ENERGY STRONGLY DROPS WITH A HALF-LIFE OF ONLY 50 YEARS.

THAT IS QUITE OPTIMISTIC BY HISTORICAL STANDARDS

ENERGY DISCOVERY ALLOWED US TO MULTIPLY OURSELVES, OUR CIVILIZATION. NOW; WE'RE STUCK WITH SUPPORTING THAT BLOATED CIVILIZATION. THE PAST CANNOT BE CHANGED, AND THE 2ND LAW OF THERMODYNAMICS CANNOT BE REPEALED.



UTAH STATE UNIVERSITY'S JOSEPH TAINTER, ON PARALLELS WITH THE FALL OF THE ROMAN EMPIRE

- Rome grew by conquering neighbors and then plundering the accumulated wealth of those neighbors.
- Rome could keep growing because its larger needs could be met by absorbing not merely the on-going generated wealth of conquered neighbors, but rather the much larger accumulated wealth of those conquered neighbors.
- When Rome ran out of rich neighbors to exploit, it could not sustain itself with merely the currently generated new wealth of its existing slaves and the sun (*via* agriculture)... and it collapsed (33 min into this talk).

OUR ENERGY, STUBBORNLY ACCOUNTING FOR 85% OF GLOBAL PRIMARY ENERGY SINCE THE 1970'S, IS FOSSIL CARBON – THAT'S ~100 MILLION YEARS OF DENSE, ACCUMULATED SOLAR ENERGY

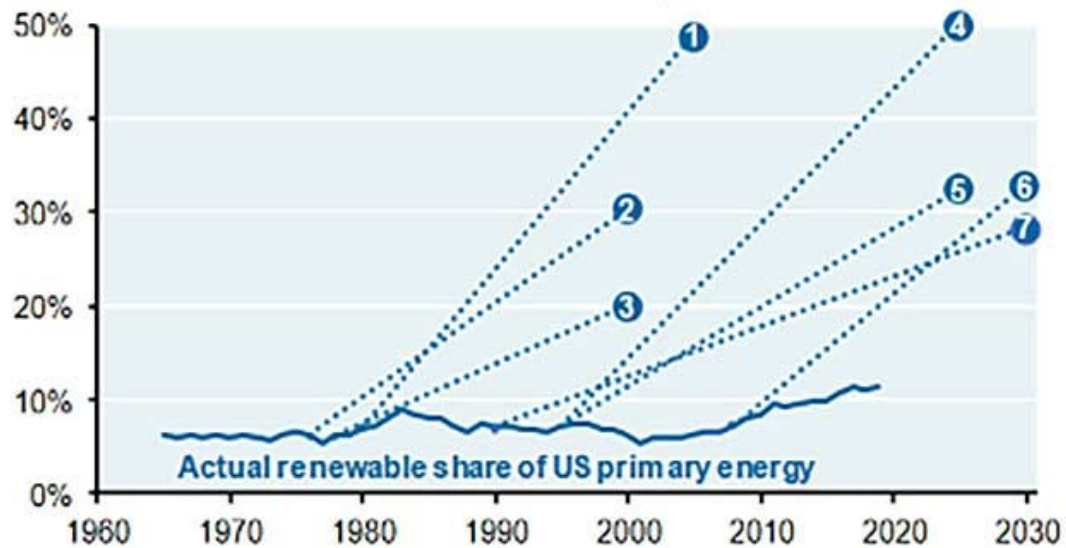
- Now we're being urged to convert to only currently-arriving solar energy in a very dilute, irregularly arriving form.
- This was Rome's plight, and their hubris was being unwilling to re-consider their "*Growth Uber Alles*" mindset.
- That decision ended badly for them.
- What about the environmental damage of going all-in with solar/wind? Controversial, and beyond the scope here.

FROM THE ANNUAL J.P. MORGAN ASSESSMENT OF OUR GLOBAL ENERGY SITUATION. THE CHALLENGE OF THE 4TH GREAT ENERGY TRANSITION IS CONTINUALLY UNDER-APPRECIATED BY THE PRO-GROWTH PROPONENTS (AT RIGHT). EXAMPLE: [AMORY LOVINS](#)

As always, I would like to acknowledge the insights and oversight provided by our technical advisor **Vaclav Smil**, who has patiently guided my energy journey since this paper's inception 11 years ago. This effort has been one of the most rewarding experiences in my 34 years at JP Morgan.

Overly ambitious forecasts of the 4th great energy transition

Renewable share of US primary energy consumption
Lines start when forecasts were made and end in year of forecast



- ① Physicist Bent Sorensen
- ② Amory Lovins, Rocky Mountain Institute
- ③ Carter Administration (solar only)
- ④ Clinton Presidential Advisory Panel
- ⑤ Intergovernmental Panel on Climate Change
- ⑥ Google 2030 Clean Energy Plan
- ⑦ National Renewable Energy Laboratory

In 2020, Mark Jacobson (Stanford) forecast 80% by 2030

Source: EIA, listed authors, Vaclav Smil, JPMAM. 2019. Renewables include wind, solar, hydropower, geothermal, biomass, wood and waste.

ANOTHER EXAMPLE: 2017 - THE FIRST COMMERCIAL AIR CAPTURE CO2 INSTALLATION



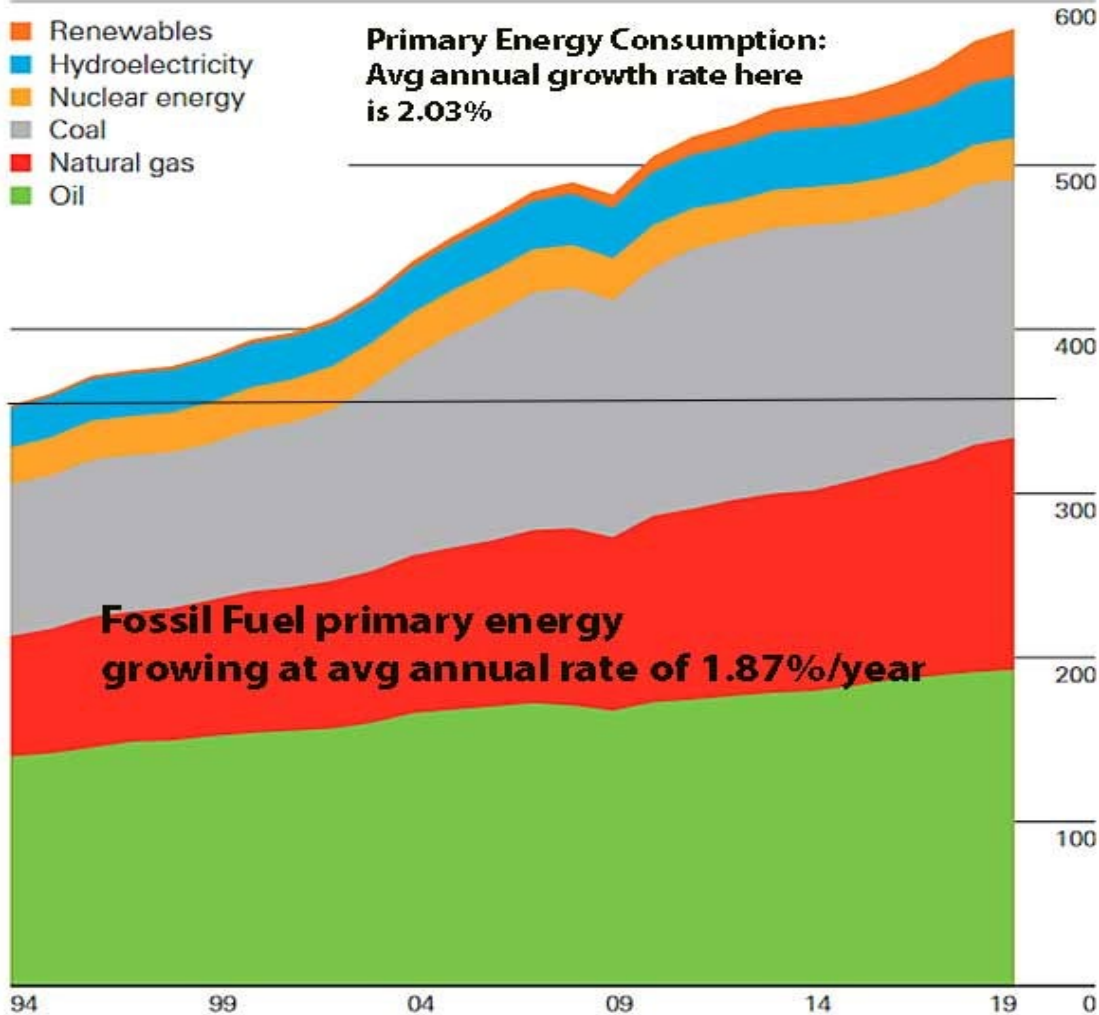
...By Climeworks, Inc. in Switzerland. (The CO2 is sold for fertilizer, not sequestered). Estimated \$400/ton CO2 to capture and \$20 to sequester, except feasibility of climate-scale sequestration is highly speculative at present.

Their stated plan is to build 250,000 of these air capture plants by the mid 2020's. If they succeed, that would capture 1% of our current emissions.

It is now only 2 months from year 2023... and they've, in fact, built not 250,000. They've built 18.

World consumption

Exajoules



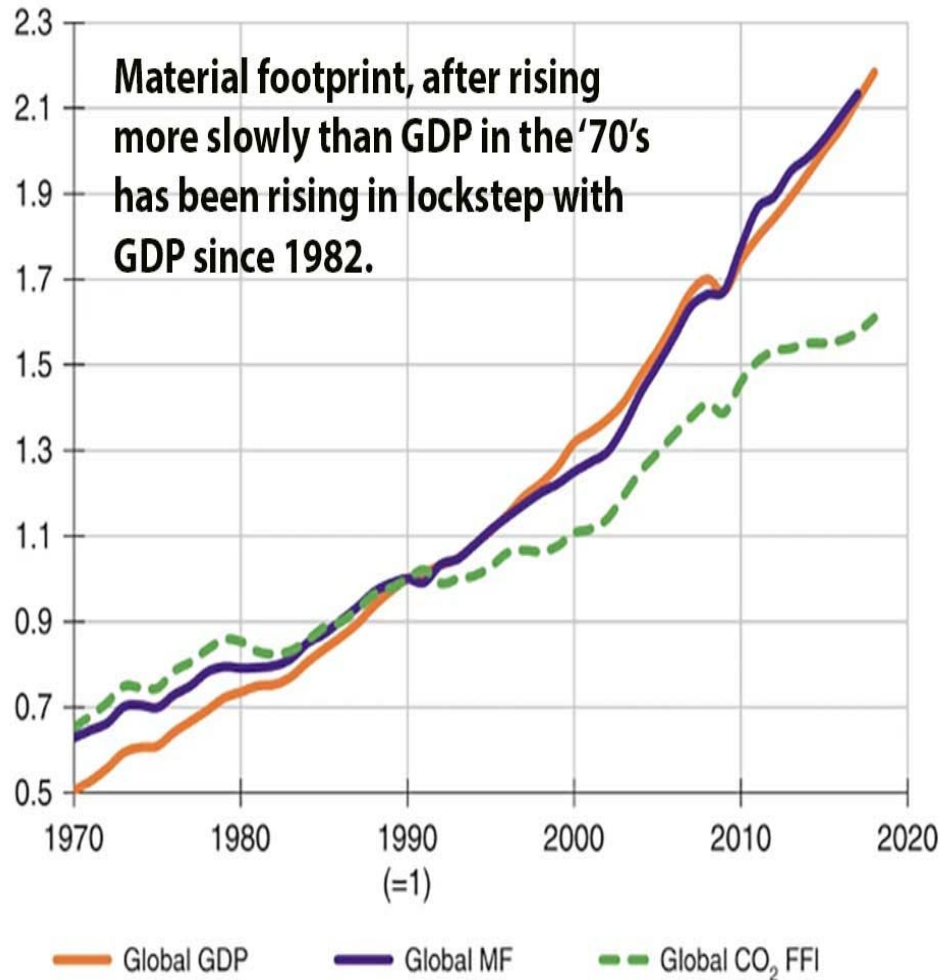
Primary energy consumption rose by 1.3% last year, less than half its rate in 2018 (2.8%). Growth was driven by renewables (3.2 EJ) and natural gas (2.8 EJ), which together contributed three quarters of the increase. All fuels grew at a slower rate than their 10-year averages, apart from nuclear, with coal consumption falling for the fourth time in six years (-0.9 EJ). By region, consumption fell in North America, Europe and CIS and growth was below average in South & Central America. In the other regions, growth was roughly in line with historical averages. China was the biggest individual driver of primary energy growth, accounting for more than three quarters of net global growth.

Renewables are not replacing fossil fuels.

They're only growing on top of a fossil fuel growth rate which is almost as high as total primary energy consumption growth, as of 2019. And after the 2020 CoVid pandemic arrived, FF's are rising even faster. Coal use at a new record in 2021, and another new record in 2022.

Fig. 1: Relative change in main global economic and environmental indicators from 1970 to 2017.

From: [Scientists' warning on affluence](#)



Shown is how the global material footprint (MF, equal to global raw material extraction) and global CO₂ emissions from fossil-fuel combustion and industrial processes (CO₂ FFI) changed compared with global GDP (constant 2010 USD). Indexed to 1 in 1990. Data sources:

<https://www.resourcepanel.org/global-material-flows-database>, <http://www.globalcarbonatlas.org> and <https://data.worldbank.org>.

MATERIALS? GLOBAL MATERIAL FOOTPRINT SINCE 1982

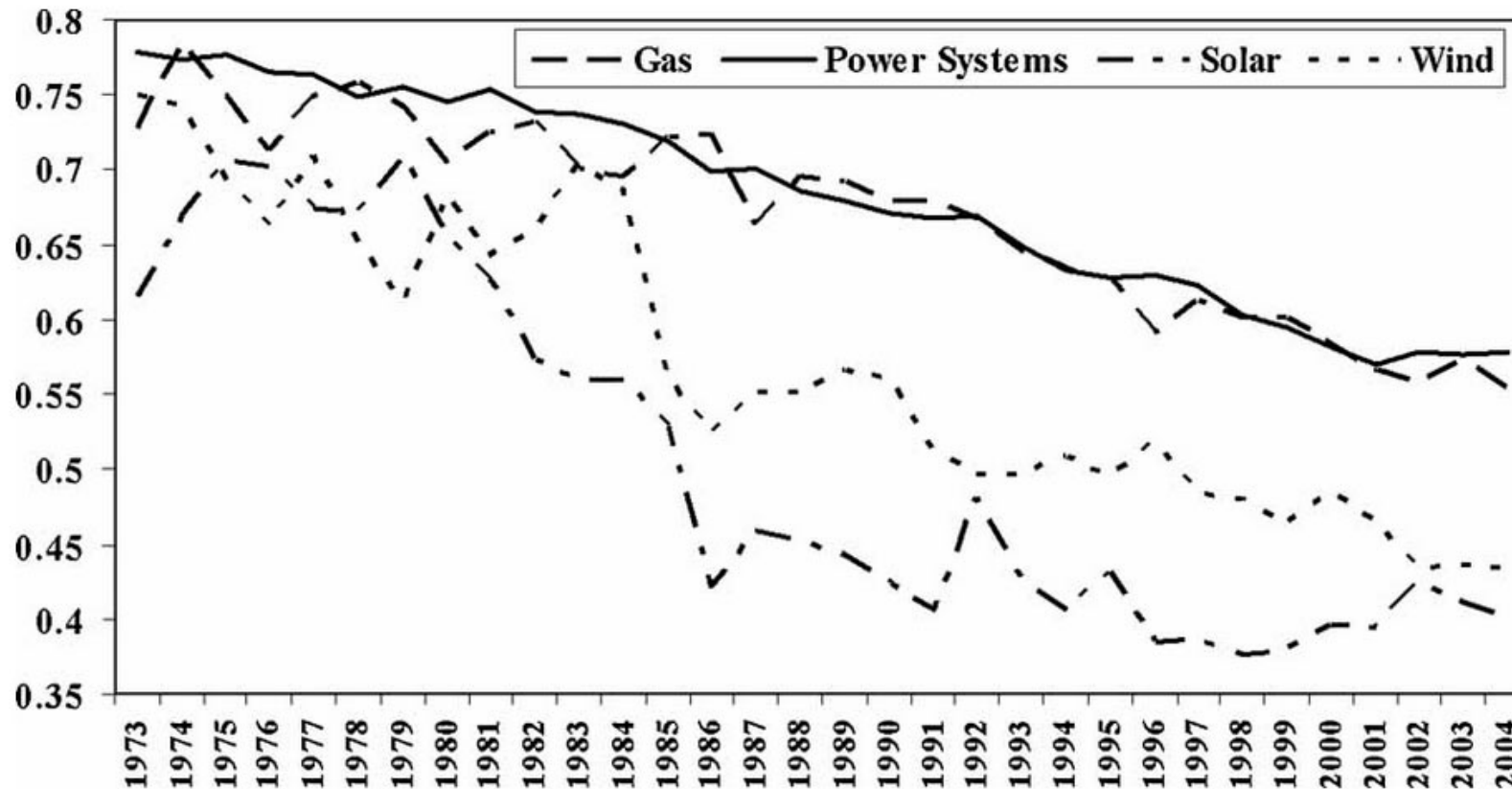
...IS IN PERFECT PROPORTION TO GLOBAL GDP.

IF SOLAR/WIND WILL BE OUR ENERGY SOURCES, EXPECT THIS TREND TO WORSEN AS ENERGY STORAGE'S MATERIALS ADD IN.

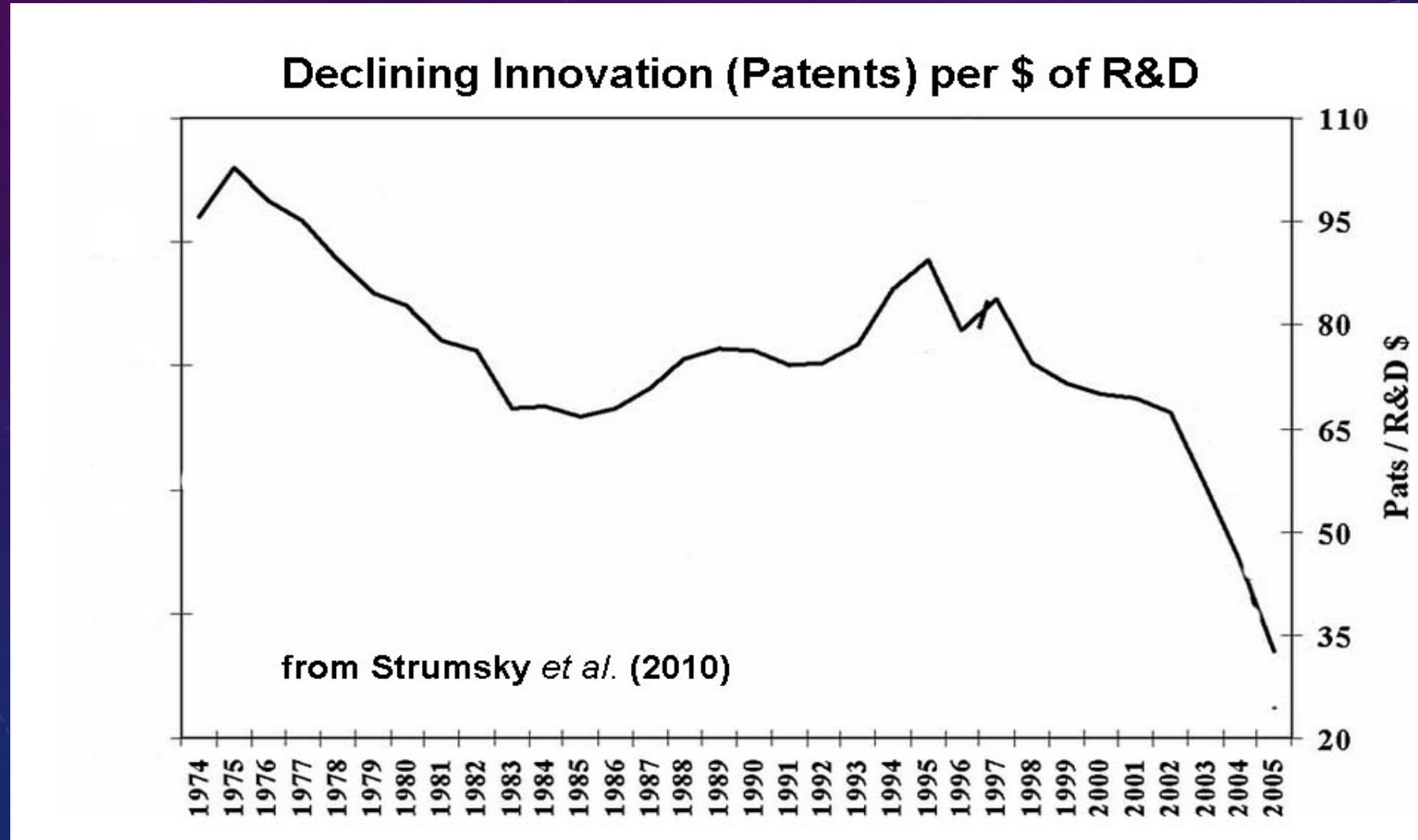
THE "DE-MATERIALIZATION OF THE ECONOMY" IS A CONVENIENT, BUT COMPLACENCY-INDUCING, MYTH

HIGHER COMPLEXITY AND WORSENING ENERGY RETURN ON ENERGY INVESTED (EROI) SLOWS INNOVATION IN ALL FIELDS, INCLUDING IN ENERGY (STRUMSKY, LOBO AND TAINTER [2010](#)). A STEADY 30 YEAR DECLINE TO 2004... (I THINK AN UPDATE WOULD BE HIGHLY INTERESTING).

U.S. Patents per Inventor in the Energy Field



IN EVERY FIELD, THERE ARE FEWER AND FEWER PATENTABLE INNOVATIONS PER INFLATION-ADJUSTED DOLLAR OF R&D, AS THE COMPLEXITY OF CIVILIZATION INCREASES; DESPITE PATENT LAW CHANGES THAT ENCOURAGE SMALLER INCREMENTAL IMPROVEMENTS AS PATENTABLE ([STRUMSKY, LOBO, TANTER '10](#))



CLARIFYING INFLATION AND DEPRECIATION IN THE POWER/WEALTH RELATION

- The Power/Wealth relation applies to real GDP, and that is converted from nominal GDP by the [GDP Deflator](#) (dGDP). Depreciation on individual creations does not enter explicitly, despite what one's intuition might assume.
- For the U.S., each year, dGDP is calculated by the Bureau of Economic Analysis. Real global GDP since 1970 is tabulated by the World Bank, and other databases.
- The inflation correction is chained year by year, to convert past year's GDPs to a chosen common reference year.
- Thus, civilization's distant past creations carry a much higher today \$value than original, when denominated in year=2005 dollars. However, civilization was also much smaller. Most of the total integrated past global inflation-adjusted GDP has been created since 1960. Distant past real GDP data was taken from [the Maddison Project](#). See Garrett (2014 and references therein) for more details, and [Bolt and van Zanden \(2020\)](#) for recent changes and estimates of error bars on PPP GDP's.

BOUNDARY CONDITIONS, AND INFLATION IN THE CASE OF CIVILIZATION DECAY

- Let's emphasize the two key boundary conditions that the Power/Wealth relation satisfies:
- First – the short-time scale condition. Energy efficiency rates of improvement go negative during recessions.
- The official figures from the World Bank shown earlier do not include the well-documented (by the Federal Reserve of the United States) over-reporting of GDP by the Chinese, nor the under-reporting of CPI inflation by the Bureau of Labor Statistics (see the work of MIT Business School's "Billion Prices Project" and more detail [here](#)). When these are included, the trend of energy efficiency goes negative during recessions, as required by the Power/Wealth Relation.

SECOND: LARGE SCALE CONDITION - END ALL CURRENT POWER CONSUMPTION, THEN ALL INTEGRATED INFLATION-ADJUSTED WEALTH DISAPPEARS, AS DO ALL PEOPLE.

- This deserves more explanation...
- We live (so far) in a world in which inflation levels are low, so nominal GDP gains are reduced only by small amount to yield real GDP gains.
- We are accustomed to recessions only causing a temporary lowering of absolute real GDP gains.
- We have not yet been in a world where total time-integrated Wealth is actually in decline.

IF RESOURCE WARS AND DESPERATION BY DYING TROPICAL COUNTRIES PROCEEDS BADLY, THEN ACCORDING TO THE POWER/WEALTH RELATION, GDP DEFLATOR $dGDP$ VALUES MUST BE ASSOCIATED WITH CIVILIZATION DECAY

- Without showing why in the real world this is true, Garrett (2010) indeed makes this assumption.
- This is in disagreement with economists' notion of inflation.
- It may well be that only in the limiting case of low inflation might this decay term Garrett associates with "inflation", agree with the tabulated values of global $dGDP$.
- Why?...

EVEN WERE CONVENTIONAL $dGDP$ TO GO TO INFINITY GLOBALLY, IT ONLY MAKES REAL CURRENT ANNUAL GDP GO, AT WORST, TO ZERO. THUS, THE SUM TOTAL OF ALL PAST REAL GDP COULD NEVER DECLINE, AT WORST STAYING CONSTANT AFTER COLLAPSE.

- But in order for the Power/Wealth Relation to be true in the event of collapse of Wealth, then the inflationary adjustment would have to subtract the wealth already created during past times.
- Garrett's expression which he calls "inflation" is in fact (as he states) "decay", and decay can exceed production and subtract from sum total production. My contention is that this should not carry the term "inflation". Inflation behaves mathematically rather differently. It's not impossible, though, that at low levels of global inflation, that $dGDP$ approximates what he calls "decay". This area has bothered me for several years and clearly requires more clarity. For one...
- **Is it possible to verify that $dGDP$ should in fact be theoretically and observationally associated with net decay, or at least make a logical plausible case that it is so at low $dGDP$ values?**

CONSIDER THE LIMITING CASE OF AN IDEAL ZERO-GROWTH WORLD

- In this case, Spending still happens, but that spending only keeps the world at a total Wealth that is unchanging.
- The spending in this case, only offsets the 2nd Law decay.
- Annual real GDP must, in Garrett's parlance, be zero, and the total time-integrated Wealth of civilization remains constant.
- dGDP then completely offsets nominal GDP gain. This is what the Power / Wealth Relation implies, if it is to remain true in this zero-growth world.
- In Garrett's parlance, inflation is now 100%. "Inflation" of 100% complexly offsets nominal production, giving zero net total gain. But this isn't economists' notion of inflation; certainly not at these high values.
- For an economist, 100% annual inflation means that nominal prices double each year on products of the same unchanged value; *i.e.* their price should stay constant.

MONEY SUPPLY AND INFLATION AND DECAY

- Money supply can increase or decrease by the whims of the Central Banks, regardless of actual real production. But this money supply will get reflected in tabulated official inflation values.
- Real production can go up or down in a way unconnected with money supply. Or such is certainly possible, depending on the politics of the Central Banks and their abilities.
- This is the problem with trying to validate the Power / Wealth relation using real world values of dGDP and “inflation”.

A PHILOSOPHICAL POINT: SCIENCE *vs.* NEOCLASSICAL ECONOMICS...

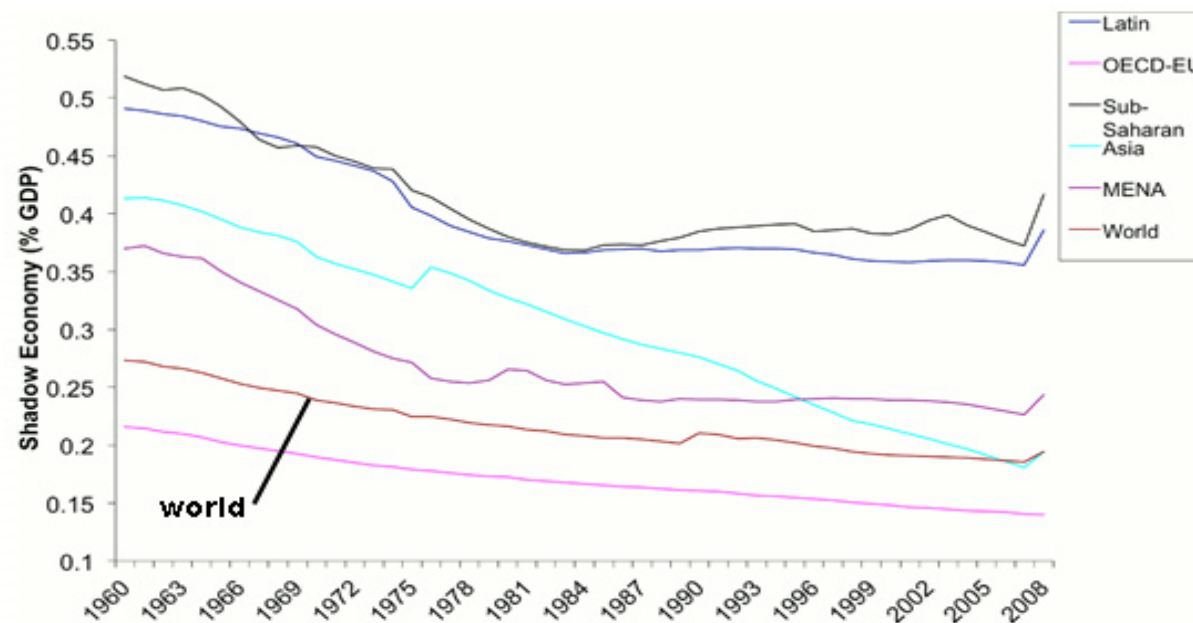
- Science has been spectacularly successful in understanding Reality.
- In science, we observe Reality as carefully and objectively as we have the means to do. We search for patterns. When we find them, we search for logical reasons for the patterns.
- If we find none, we may dismiss the pattern as chance if Bayesian statistics so indicates.
- But if we find that a compelling logical case grows for the reality of the persistence of this pattern, we take it seriously and seek deeper understanding from a wider interdisciplinary view, and we test for further confirmations, and we seek clarity on the implications for the future.
- In the Neoclassical economics paradigm, by contrast, has shown a strong tendency to start from a questionable ideological stance, and then invent and twist the ideologically driven formulae to try and make them fit data. Or even distort the data entirely. These four EFI talks on the economics of climate damage and the thermodynamics of civilization, I hope have made this clear.

ANY WEAK POINTS IN GARRETT'S FORMULATION OF THE POWER/WEALTH RELATION?

- 1. PPP vs MER accounting to convert all currencies to dollars? Garrett was correct: use MER: My reasoning: It includes near future valuations (properly) by currency traders, more comprehensive data, reliable quality, and unbiased by econo/political tinkering for ulterior motives (No time to say more, here).
- 2. Pre-1970 data? Too much remains to be said here, but no clear P/W conflict. Most of total accumulated global Wealth was created after 1970.
- 3. Inflation correction? Published dGDP is (politically) biased low, most especially after early 1990's. I use MIT Business School's "Billion Prices Project" data as a better adjustment.
- 4. The thermodynamic argument for the P/W relation says to me we should be including not just published dollar-ized GDP as Garrett did, but include the "shadow economy" as well. Best work here is [Elgin & Oztunali 2012... Fig 2.](#)

THE “SHADOW ECONOMY” AS % OF GLOBAL GDP DROPPED FROM 27% IN 1960 TO 23% IN 1975, SHALLOWER DOWNTREND AFTERWARDS ([ELGIN AND OZTUNALI 2012](#)).

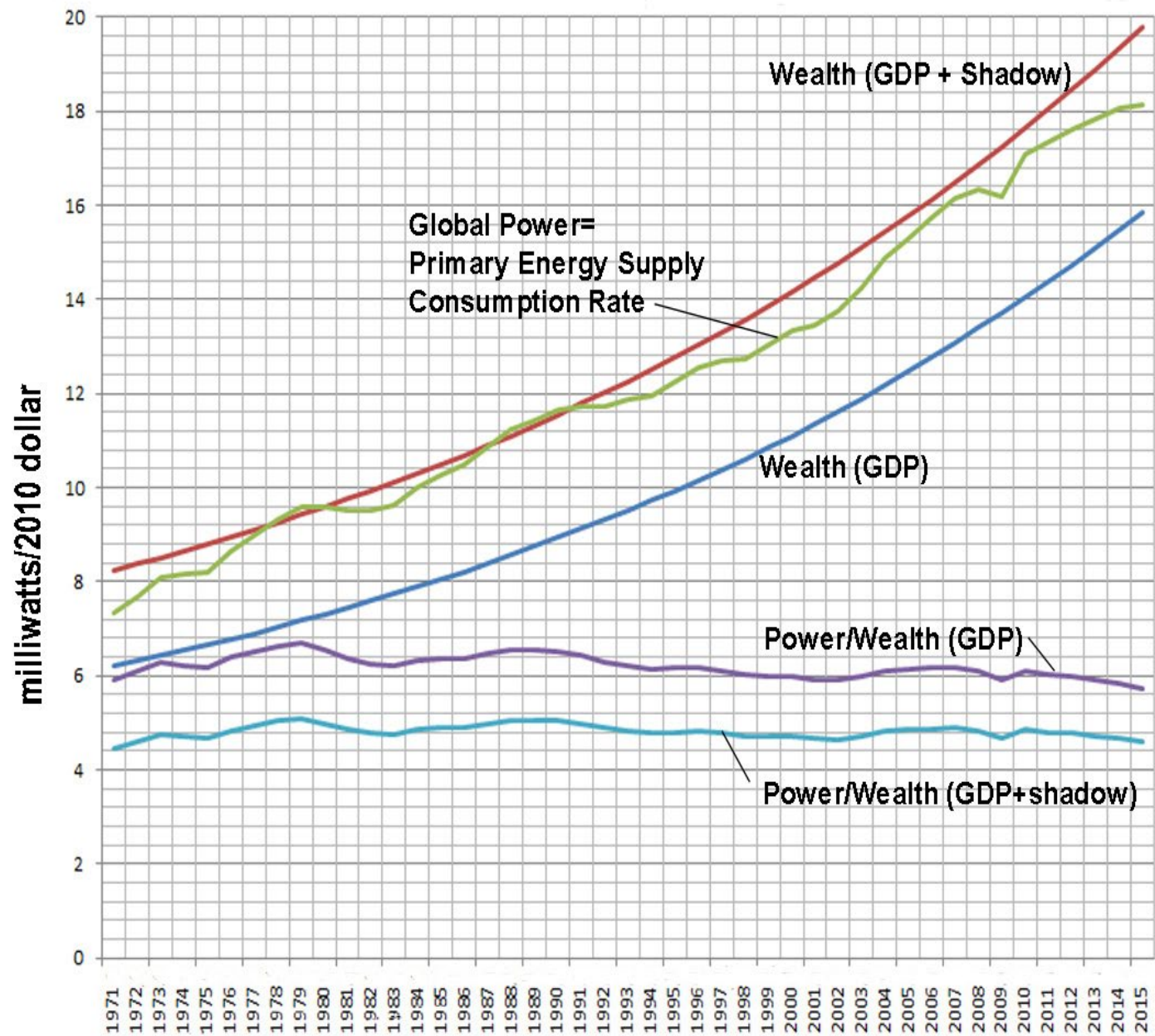
Figure 1. GDP-weighted shadow economy size (as % of GDP) over time



In Figure 2, we group countries with respect to GDP per-capita and then report the average GDP-weighted shadow economy size in each group. Here, we divide the countries into five categories – poorest, second, third, fourth and the richest 20%. Not surprisingly, richer countries tend to have a smaller shadow economy; however, Figure 2 shows that this relationship is not exactly linear, especially in a cross-country sense. Even though further research is required, this might be considered as a support for informality dimension of the Kuznets Curve hypothesis.

INFLATION: WHICH DATA AND INTERPRETATION IS APPROPRIATE?

- Garrett interprets “inflation” as inverse to “decay”. While there’s insight and a big grain of truth here, the problem is that for the Power/Wealth Relation was justified from economists’ data on inflation, not Garrett’s equivalence with “decay”. And that’s the trouble.
- Inflation formally is a mismatch between the growth of the money supply vs. real wealth.
- This formal inflation is not necessarily the same as decay. The Federal Reserve and money-center banks control the money supply, with political motives other than accounting for decay.
- Worse, CPI is widely realized to be understated for political / government solvency purposes. The govt is on the hook for unfunded liabilities (Medicare, Soc Security...) which are legally scaled to CPI, so there’s a conflict of interest at the Federal level. Lots of literature to support the underestimated CPI and hence dGDP. See “[ShadowStats](#)”, MIT’s “[Billion Prices Project](#)”, and my deeper discussion [here](#).
- **Bottom line**. Inflation remains a thorny issue. Garrett may be able to frame dGDP as “decay” only in the limiting case of small decay. It’s more complicated. Needs more study.



MY MODIFICATION OF THE POWER/WEALTH RELATION USING TOTAL SPENDING (LIGHT BLUE) IS ACTUALLY EVEN FLATTER THAN GARRETT'S WHICH USES ONLY PUBLISHED REAL GDP ALONE (PURPLE).

BOTH RED AND LIGHT BLUE CURVES INCLUDE GDP DEFLATOR (dGDP) CORRECTED USING MIT'S BILLION PRICES PROJECT.

BOTTOM LINE: THE POWER/WEALTH RELATION REMAINS WELL SUPPORTED

THE THEORETICAL IRON-CLAD “PROOF” THAT THE POWER/WEALTH RELATION MUST ALWAYS BE TRUE, ON INTO THE FUTURE...?

- ...is elusive. Nate Hagens suspects it will deviate at some point (I’ve no details on this opinion).
- **Beyond the quantitative verifications, and Garret’s “hindcast” validations (Garrett 2012), I will say this:** I believe dGDP determined P/W will remain true as long as the post-1971 economic paradigm remains. The key features of post-1971 which control this, I believe, are...
 1. The dollar decoupled from gold. Central Banks can (via the money-center banks) create money which will enter a price-system which is out of thermodynamic equilibrium with respect to the new money created, and a potential “energy” (\$) flow stimulating energy consumption is created.
 2. A stronger motivation to include improving energy efficiency in our economic decision-making after the OPEC Oil Embargo of the early 70’s, but (as always) constrained ultimately by the profit potential of paying for that improvement.

If instead we were to be more cavalier, buoyed with the euphoria of incredibly cheap and powerful fossil fuel energy (like early/mid 20th century), our plight would have been worse.

THE KEY CONCLUSIONS OF THE POWER/WEALTH RELATION PUT US IN A SOBERING DILEMMA...

- In order to reduce our energy consumption rate, we must reduce total global Wealth (time-integrated real GDP).
- But to reverse Wealth itself, is to send civilization into secular decline.
- **And yet energy efficiency gain per \$realGDP goes negative in a recession.**
- Actual declining Wealth, then, simultaneously reduces our ability to service civilization against the 2nd Law, while amplifying our energy needs merely to stand still against the 2nd Law.
- Therefore, if the Power/Wealth Relation is an unalterable true expression of physical and human thermodynamics, declining Wealth induces an amplifying feedback of decay and collapse.
- Indeed, collapse is the fate of most non-linear dynamical systems at some point.

THE PRACTICAL VALUE OF THE POWER/WEALTH RELATION...

- ...is to enable streamlined energy inclusion into *e.g.* **Integrated Assessment Models (IAM's)** favored by economists in their highly questionable climate damage assessments.
- It is vastly too hard to try to separately estimate all the myriad components of civilization with their widely differing rates of physical depreciation, their connections to all other aspects of civilization, and positive and negative feedbacks therein. Yet in complexity lies simplicity; much like the microscopic chaos of a macroscopic gas, its macro thermodynamic properties obey simple relations obeying intuitive logic.
- Yet the P/W Relation, if it remains true, says that to reduce energy consumption and pull within Earth sustainable limits, civilization must contract. Yet that very contraction will be more rapid than will be the energy consumption rate needed during the transition, thus inducing a negative feedback towards collapse.
- As long as we do only what is short-term most profitable, following our historical behavior, we appear doomed to civilization collapse. **“Market-friendly” is not friendly.**

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WE DON'T WANT COLLAPSE...

- ...But each of us, pursuing our marginal utility gains, and recognizing that our resulting individual marginal induced costs to Earth's sustainability is infinitesimally small, will in fact bring about that collapse just the same.
- Human Will power? Our evolutionary biology is embedded in the Power/Wealth relation. And "Will Power" summoned against this biology will itself take continual biological energy, ultimately exhausting.
- Human Wisdom? We've constructed an economic / political system which selects against leaders with moral wisdom, in favor of short term profits scalped from whomever is most vulnerable. The wisest are those who are *least* in control of political policy power. This has been true since the dawn of civilization. Far sighted wisdom is displayed by only a few among us; they are marginalized, and outside the circles of power. I don't see how this can change without a wholesale revolution, which may be quite ugly.

WE NEED A MUCH DEEPER TRANSFORMATION OF HUMANITY AND THE ECONOMIC SYSTEM IT CURRENTLY INSISTS UPON, IN ORDER THAT HOPE FOR THE FUTURE IS TO BE REALISTIC

- Growth must, and will, end, on this finite planet.
- To do so, gracefully, will take a radically different level of maturity and far-sighted wisdom than the global leadership we have empowered and/or tolerated, throughout history. Timid Progressives so far have not led me to be optimistic this will change.

IT'S THAT EASY!



SORRY.... EVEN THE LAST PANEL HERE MAY NOT BE DRASTIC ENOUGH: DO WE HAVE THE AGENCY? CAN WE CHANGE OUR VERY NATURE TO ENABLE THAT RE-STRUCTURE? IT'S NOT THAT EASY



The Matrix has you

For the SYSTEM (hence climate and sustainability) as a whole it may well be that ***The Power/Wealth Relation Has You***