K43: Civilization as a Thermodynamic System– Connecting Energy and Economics: Implications for What's Possible

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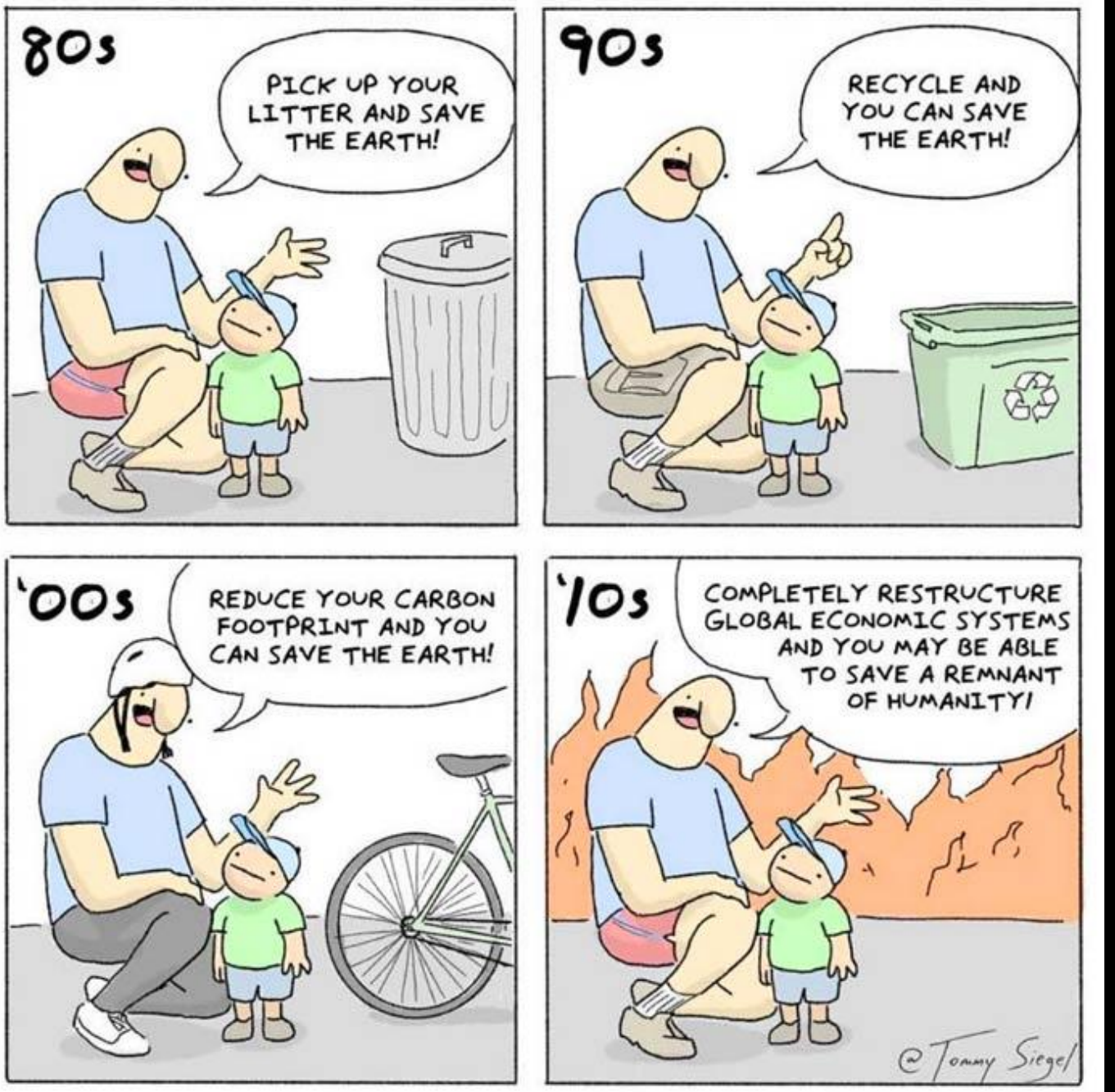
- How drastic must policy actions be?
- Is our goal to merely slow the descent into chaos, or is it rather to truly halt climate change?
- What is physically possible?
- Enter – the insights of cloud physicist Tim Garrett

IT'S THAT EASY!



“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

Civilization as a Thermodynamic System

- Cloud physicist Tim Garrett (**2012) (**and references therein) has developed a model of the relation between the global economy, primary energy consumption, and carbon emissions. The underlying approach has **wide applications across dynamical systems.**
- He applies thermodynamic thinking to the ordered system which is Civilization, and sees a simple relation which has held true in real-world data.
- If it remains true, this simple global relation between energy consumption rates and the accumulated inflation-adjusted Gross World Product (global GDP summed over all time) and its theoretical link to thermodynamics, is an insightful new synthesis and has **sobering implications**.

Garrett developed a quantitative climate physics/economic model (CThERM), identifying its key variables - which differ from those of traditional economic and IPCC modelling.

- He then shows such traditional models are missing key connections which impose important constraints on our possible climate actions.
- **Let's explore these discoveries…**

Here's my own framing of the logic of Civilization as a Thermodynamic System, which differs from Garrett's but arrives at a similar place…

- Garrett prefers thinking in terms of energy gradients, but I'm convinced that connecting to Civilization and better understanding among non-physicists, framing in terms of Entropy is superior.
- In the physical thermodynamics of a **closed system**, the incremental change in energy d**E**, (which includes internal energy, external energy being added, and including the Gibbs energy **dW** of useful energy or "work" **W** which can be extracted from the system by the production of entropy **S** ["disorder"] at constant temperature **T,** is related to entropy by…
- d**E** = **T**d**S**
- **Taking the derivative with respect to time, we see that the rate of energy consumption is ~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 provided by 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 $\mathbf{S_c}$ in the civilization+environment system.
- Growth in civilization must correspond to a reduction in civilization's portion of $\mathbf{S_c}$ at the expense of greater $\mathbf{S_c}$ in the total environment system, powered by the expenditure of physical ENERGY.

Transforming Dis-Order towards Order takes ENERGY

- Any economic spending to reduce disorder $\mathbf{S_c}$ 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 we civilized people want them.
- 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.

Garrett's (and others) Key Observation

- **Conventional** economics divides Civilization's value into Capital ("things", and money) and Labor.
- But Garrett observes "capital" *per se* is static, dead, and valueless without energy to power its USE.
- Life is **Motion**. Stillness is death, and has no value. And motion must be powered by **energy**. Value in any human meaningful sense, must then be intimately linked to energy consumption **rates**.
- **Energy is LIFE. And yet it is given no role in the central conventional economic relationship attempting to link economic value with its causes – the Cobb-Douglas Equation**

Economist Steve Keen expresses this most colorfully

“Labor without energy, is a corpse. Capital without energy, is a statue”

Why Does Conventional Economics Ignore the Central Role of Energy?

- You'd have to ask an economic historian, but I'll venture a guess – perhaps because most of modern economics was developed in the Industrial Age, when energy was cheap, plentiful, non-controversial, and easy to take for granted as inexhaustible.
- It's certainly not because it's "substitutable"
- Nothing can substitute for Energy. **ENERGY is EVERYTHING.** (You may argue that we **can** substitute within energy, but it turns out we're instead just adding new energy options, which only help power additional utilization for the niches of some other energy options. We're not actually substituting, despite greenwash to the contrary).

In Civilization's Market Economy…

- …Spending in general, 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 $\mathbf{S_c}$ therefore incurs higher **cost**, and requires proportionally higher physical **ENERGY** consumption **rates** to power it.

And Since Value Creations Tend to be Additive Over Time

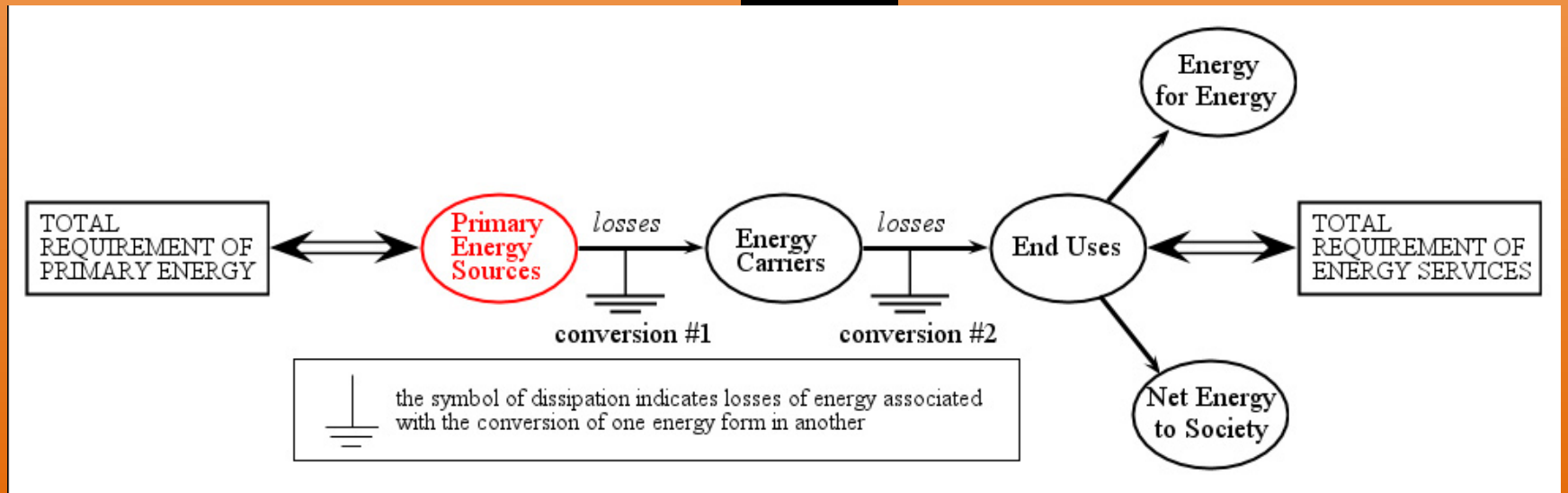
- …it would suggest that…
- Total inflation-adjusted past global spending might be proportional to the physical energy consumption rates needed in the present to sustain those creations and bring online new energy powering new creations.
- At least since the publishing of modern data (i.e. since 1970), this supposition turns out to be true

Garrett's Relation (which I'll refer to now as the **Power/Wealth Relation**):

The Current Rate of Primary Energy Consumption is Directly Proportional to The Global Sum Total of all Past Inflation-Adjusted Global Gross Domestic Product (GDP) (Garrett calls this sum "Wealth")

- This is raw primary energy from any source.
- Now, the CO2 production per unit energy consumed (the "carbonization" **c**) can, of course, change by human decision and efforts, so let this be a variable in the quantitative relationships.

The relevant energy in this relation is **PRIMARY Energy**. Energy in raw form provided by Nature. Why? Because civilization must process this into useable energy first, before it can be consumed, and this will incur energy losses. We must recognize the full costs of our energy to power Civilization. **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 potential of energy efficiency is largely ignored as the global primary energy system works "a little bit like a bathtub with a leak," Fischedick said.

"We put a lot of energy into the bathtub and at the end there are a lot of losses. We can use one third of the energy but two-thirds is lost," he added.

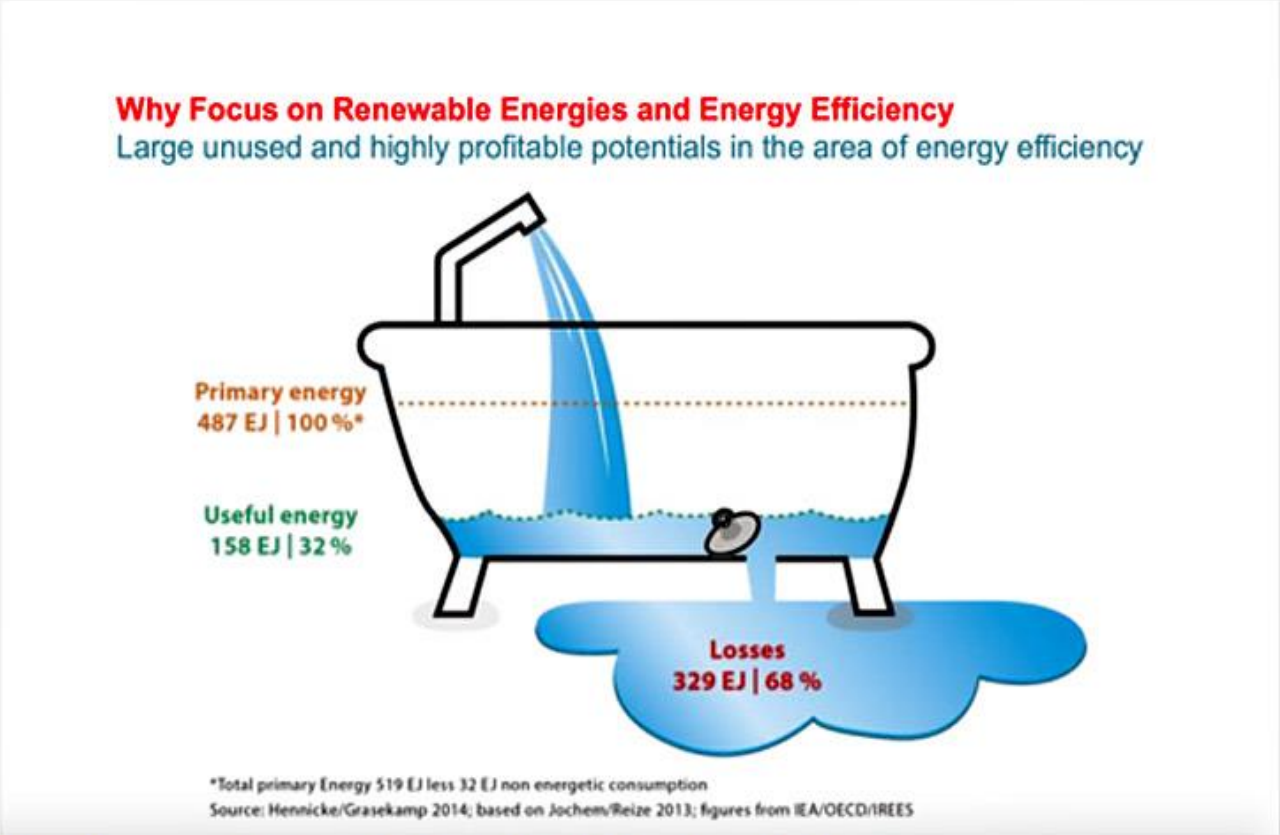


Photo courtesy of Manfred Fischedick

Nature only gives us PRIMARY energy. We must then invest money, effort **and additional energy** in converting it to <u>useful</u> energy. Graphs showing improving efficiency but don't calculate using PRIMARY energy are misleading. **Only about 1/3 of primary energy ends up as useful energy**

The Wealth/Power Relation Simplified: "Power Consumption Today is Proportional to Past Accumulated Wealth"

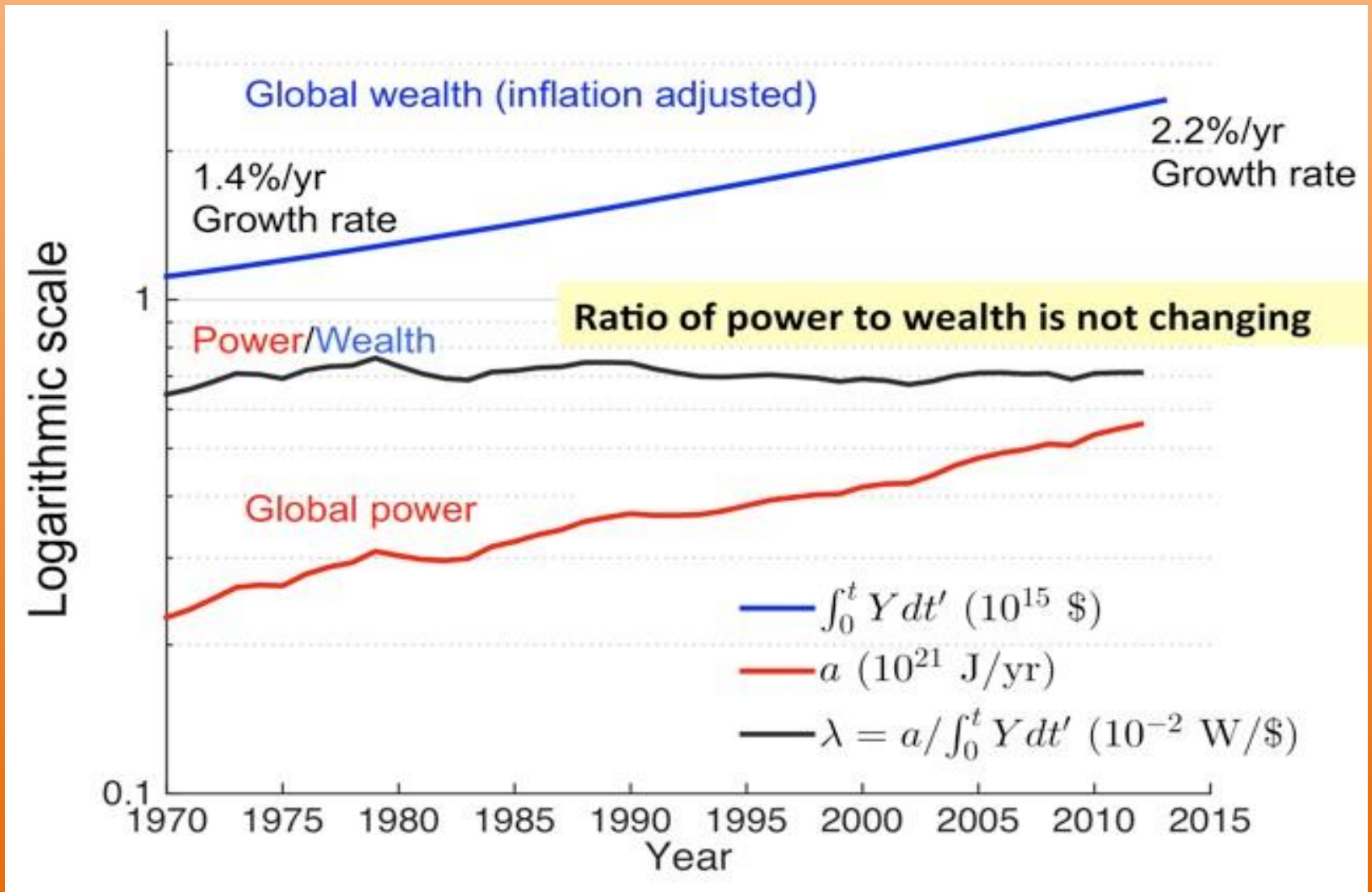
- *"The ratio of these two quantities remained essentially unchanged in each year between 1970 and today (2010), with a* ***standard deviation of just 3%*** *over a time period when wealth increased by 111% and global annual GDP increased by 238%"* (Garrett 2014).
- **Let's look in more detail why this might hold true…**

The theoretical basis for the equations follow from thermodynamics…

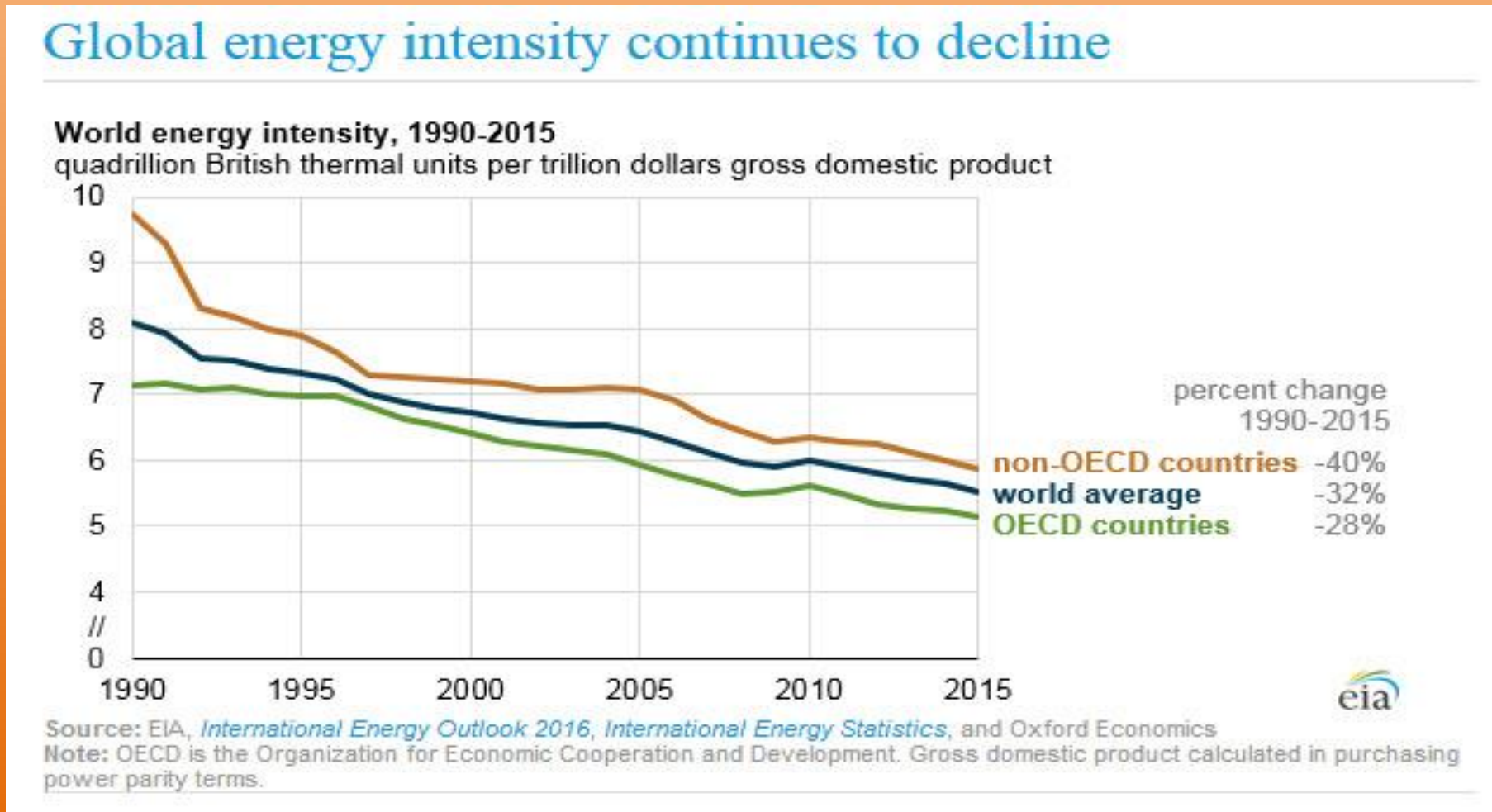
- **… the principles and equations governing the flow of heat, entropy, and energy, and their relation to generating useful work (see Garrett 2014)**
- Garrett's ***C****limate and* ***Th****ermodynamics* ***E****conomic* ***R****esponse* ***M****odel* (**CThERM**), a simple computational model which results from this, has been **successfully back-tested** against a history of past data, and shows high skill scores, significantly better than scores using extrapolations of trends.

- **This hypothesis is testable, and it succeeds…**

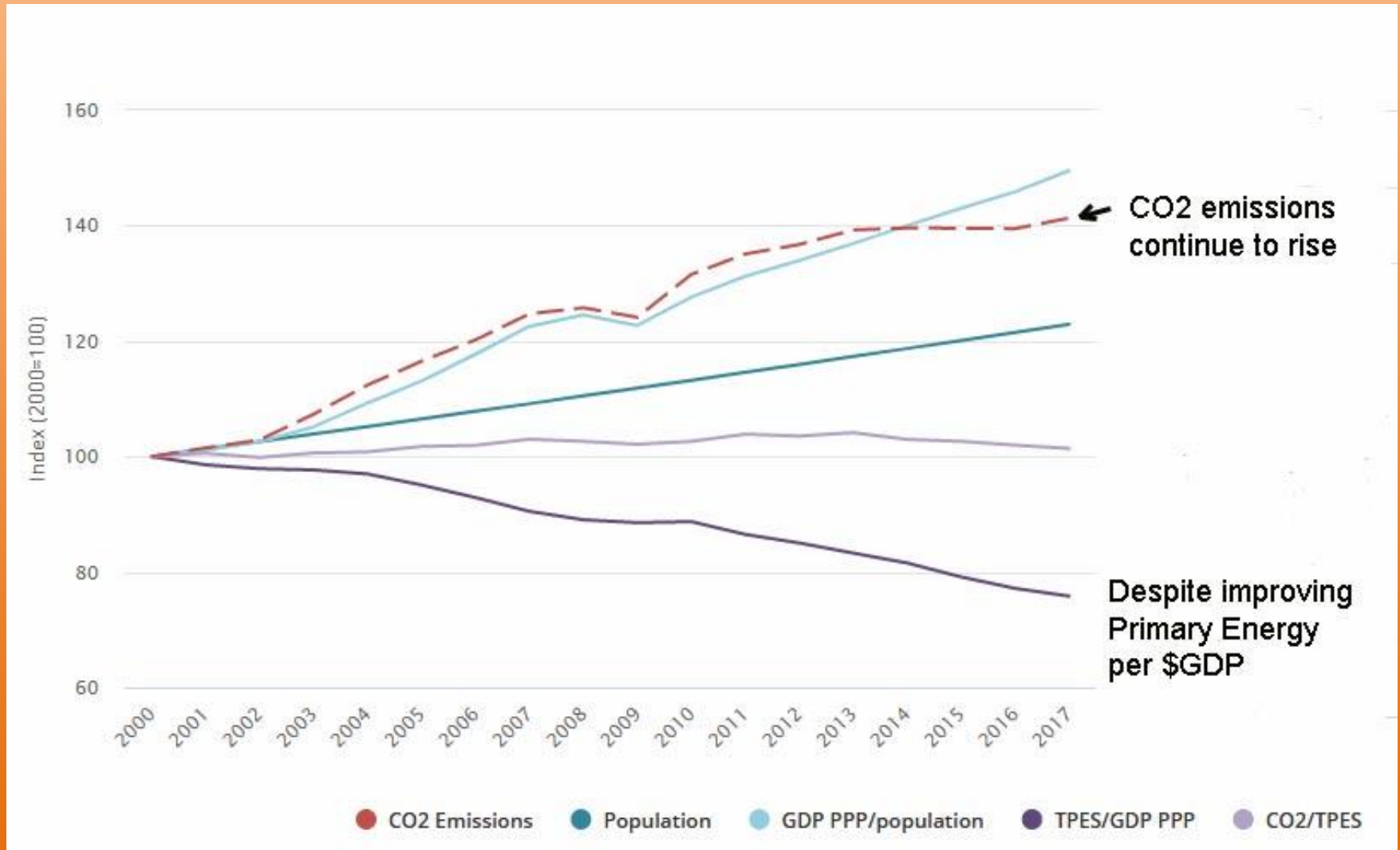
Historical energy consumption rate (power) and total accumulated Wealth, plotted on top of each other for clarity. Result? They're directly proportional; *i.e.* the ratio (black curve) is flat. λ=7.1 mW of new power is required to support every inflation-adjusted 2005 dollar of global GDP ever spent.



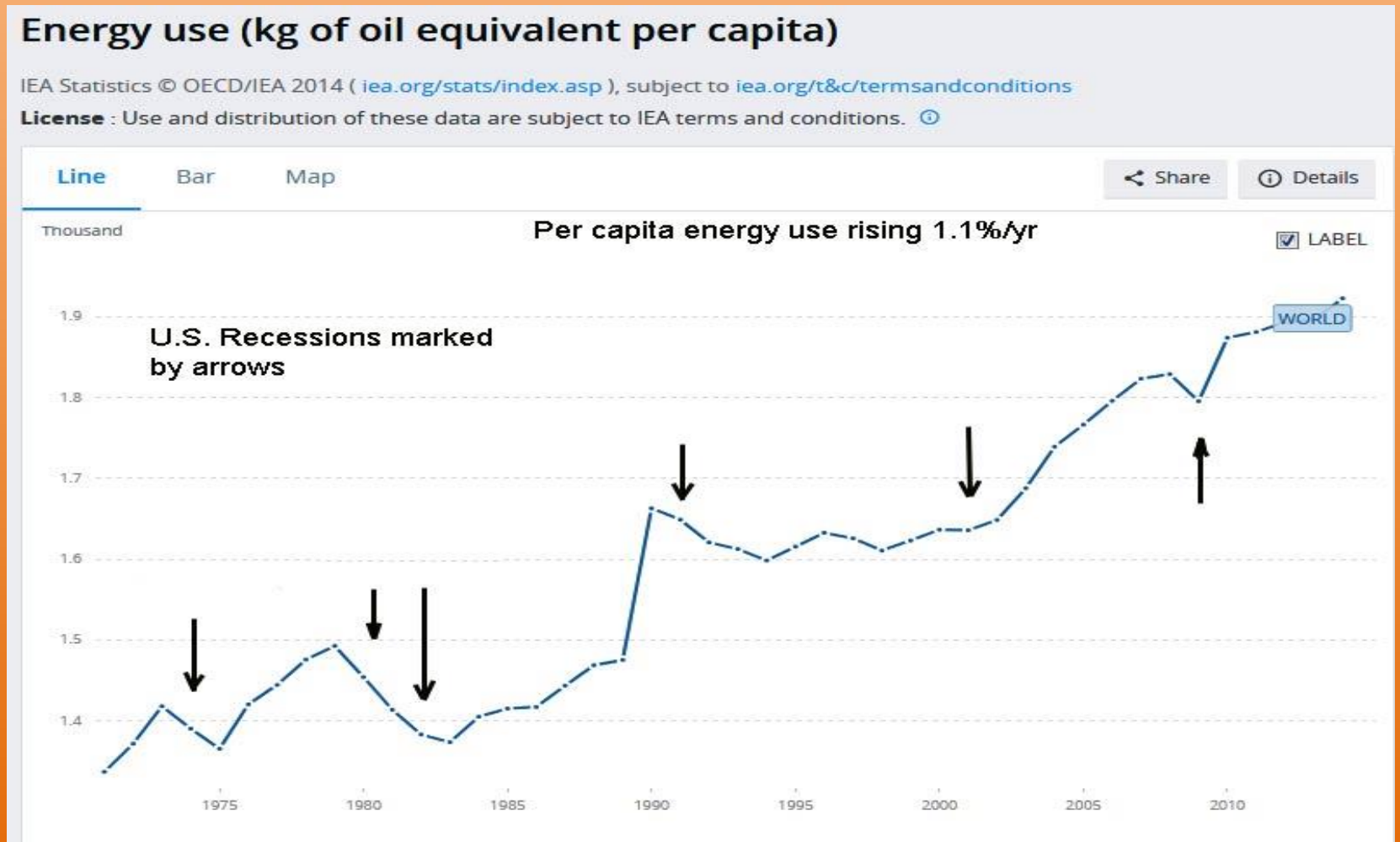
Let's compare to a very DIFFERENT ratio – the current primary energy consumed per unit of *CURRENT* GDP. Now, THAT ratio HAS been improving, decreasing fully 32% since 1990 (but using PPP accounting below, more on that later). Some economists accidentally or deliberately conflate these two ratios, then wrongly dismiss the Power/Wealth Relation.



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



Globally we continue to spend more and more energy per person. Then, convolved with rising population, energy efficiency gains are dwarfed by sheer energy needs



Why does the Power/Wealth Relation hold? First, the larger an economy, the more energy required merely to maintain its current state against natural decay

- Obvious, yes. But even the goods and services long gone in the distant past were essential in order to grow into what we are today.
- It's not in things themselves, but rather it is the active networks which are enhanced **between** things and people which constitute the "wealth".
- Enhanced active relationships are the **value** of that spending, and constitutes actual wealth. And it is along **networks** where frictional energy is consumed.
- Has this relation always held? I'm saving that for later.

Capital has value only when it is in USE…

- …In **motion**. In **action**. In **relationship**, to human beings and to other objects along networks of connection.
- And all **MOTION** requires **ENERGY CONSUMPTION** to maintain.
- Take away all **POWER**, and all **VALUE** disappears. Not just this year's, but all value ever created. All of civilization dies. Thus, the boundary condition of the Power/Wealth Relation, at least, makes perfect sense.
- 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 is needed to in order to grow that 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.**
- Even in the construction of information out of randomness, energy is dissipated.

Because these relationships are subtle and extend in countless directions not obvious at first, there is a quality of "emergence" to them…

- … which enhances their value beyond the most obvious initial consideration.
- Thus, the global rate of primary energy consumption might intuitively be expected to scale to the total inflation-adjusted ACCUMULATED spending of civilization over all time.
- There is a "ghost" remaining for every past dollar spent. That "ghost" exists today in having enabled current Civilization through compounded past efforts.

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 great discovery moments in physics have come from the realization and appreciation of elegant symmetries 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?

Open and Closed Systems

- A “closed system” is one which does not send relevant quantities across and outside its borders.
- The Earth is an open **thermodynamic** system (we receive and radiate energy to outer space),
- But it is a closed **economic** system (until the flying saucers arrive with their trading goods)

Climate too is global - recall that the global diffusion time for atmospheric GHG's is only a few weeks

- The atmosphere's greenhouse gases are "well mixed". This is fundamentally important. All countries' generated CO2 becomes all other countries' environmental CO2 very quickly.
- **Likewise, economies, too, are "well mixed" in the modern world** – the flow of wealth and material between countries is rapid in comparison to the evolution time scale of the global economic system as a whole.

Therefore, studying one country in isolation, and ignoring the flows of material, energy, and money across its borders can lead to dramatically wrong conclusions.

- In the same way, The **2nd Law of Thermodynamics** will **appear** violated if one only looks at that portion of the system of interest which is increasingly **ordered** and ignores the even larger amount of **disorder** imposed on the rest of the surrounding environment by the energy consumption, pollution, low grade waste heat required to create that complexity.

Jevons' Paradox

- **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.**
- 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 theory and fact.**

Those Who Deny The Reality of Jevons' Paradox

- …seem, in my experience, those with a vested interest in continued economic growth.
- Here's a good example from YouTube, **a talk by a spokesman for the corporation Hammer and Hand.** Listen, my students… and spot the logic flaws.
- How did you do? Let me help you…
- 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.

Headline Boosterism

- You've all seen the blurbs which show up on news sites about some new energy efficiency idea…
- ***"Mileage standards to increase to 45 mpg from current 25 mpg, saving a million tons of CO2 per year!"***
- ***"Wow! A million tons! Fantastic! We're on our Way!!***

Savings! We Love ‘em! But Note What is Being Ignored…

- You’re going to **spend** those savings to expand your life, and the Power/Wealth relation shows that encumbers an **increased rate of future energy consumption, including the carbon-based energy portion, to support the “civilizing” lower entropy (disorder) creations.**
- We maximize our profits. If you’re eco-spirited about buying a less-carbon-intensive car, you’re still almost certain to sell your old gas guzzler to someone else who can’t afford the more efficient cars, and so your old car will still be spewing CO2 till the end of its natural life.
- Actual carbon savings? Little, or none at all when you include the energy and entropy cost of creating the eco-car, and it doesn’t make such a happy story; so it’s ignored by the media.
- It’s depressing and undermines the gee-whiz salability of your splashy article, so editors and writers want to ignore these facts too; a fact I constantly have to fight in my educational efforts.

You MUST look several moves ahead to get the full picture. It's like a novice chess player, who, upon taking your rook with his pawn, gives a satisfied look of triumph, only to find 4 moves later that his king is trapped.

Appreciate George Soros' concept of **Reflexivity**.

The savings claim implicitly assumes that the "dollars" saved in efficiency are never spent. It assumes, essentially, that the wealth created by that savings, denominated by that money, is **destroyed.**

History shows quite the opposite

- **Instead, those new efficiency-created savings will be used to grow Civilization, both enabling and necessitating our accessing new energy sources.**
- And since there is 7.1 milliwatts of new ongoing power needed to support every (2005 inflation-adjusted) global GDP dollar ever spent on goods and services produced, then given our fossil fuel dominated global civilization, net CO2 savings do not happen, but in fact CO2 generation gets worse

This is a deeper 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 limited aspect of this phenomenon is commonly called **"Rebound"**
- **But "Rebound" misses the point that efficiency savings need not be spent on more of the same, they can be spent anywhere, and we spend everything we make, even borrowing against the savings within our fractional reserve financial system.**

The thermodynamic aspect of civilization says it does not matter *where* – <u>all</u> spending raises future energy consumption rates:

- **This is my formulation of what I call "Generalized Jevons' Paradox"**, to distinguish it from the more limited form that some economists like to use in order to dismiss the entire concept.
- **Energy efficiency? It just helps us to access yet more power to enable faster growth...**

“ALL” spending? But isn’t some spending better for climate?

- Couldn’t we spend on extra improvements to energy efficiency, for example?
- You could, but that would only generate yet more savings, spent mostly on consumption of something that gratifyingly “pays off”.
- 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 to take up the slack.

Those Who Dispute Generalized Jevons' Paradox, Look Closer…

- Narrowly interpreted ("rebound", *e.g.* coal steam engine to coal steam engine, say), yes, only partial rebound typically applies.
- It is **claimed**, for example, that "green taxes", do not display Jevons' Paradox,
- **But ALL economic activity requires energy.**
- **In my more frustrated moments, I refer to Generalized Jevons' Paradox as "Jevons' Revenge"**

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 2nd Law of Thermodynamics decay, 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.

We humans spend all we can afford, plus our children's inheritance

- We attempt to maximize profits – that's the "gift" of evolutionary biology to our emotional and chemical reward system drives.
- The observed historical relationship shows that **total accumulated GDP is proportional to current power consumption** – with no reference to WHAT you spend it on. Human nature has an optimization principle at work, allocating between spendings in different areas so as to optimize civilizing efforts, but thus maximizing future energy encumbered.
- Let's look more carefully at why this might be so…

These ideas may violently clash with your deeply held belief in efficiency as the savior of climate and civilization

- And yet – coming at this from a different direction but yielding the same implication, is the **"Maximum Power Principle"**, which some propose to elevate as the **4th law of Thermodynamics.**
- *"During self-organization, system designs (will) develop and prevail that maximize power intake, 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. **I'll reframe this principle slightly – the goal of why systems tend this way is so as to also maximize the rate of useful work done from that energy consumption.**
- **The value of improving energy efficiency is not in conflict with The Maximum Power Principle, because coupled with Jevons' Paradox, they lead to total energy consumption actually going UP, not down, with time.**

But Wait! You Say…

- “Money I save through efficiency might be spent in less energy-intensive ways. Maybe I’ll take the money saved and buy more vacation days, and on my vacation days I could go trail running or just reading.”
- First, if those dollars spent don’t build civilization and hence its energy needs, they provide a mis-match between global “wealth” and total money. This aspect is compensated, therefore, in the inflation correction.
- Remember the nature of Wealth: those dollars are still going towards enhancing your life, health, relationships, and therefore your ability to spend in the future. **They’re not quite the savings to Civilization’s ongoing power needs as you may think.**

Even those running shoes are helping you to become a better, healthier, happier, more expansive and longer-lived person and thereby increasing your future energy needs

- These considerations are already reflected in the historical data – the same data that confirms the **Power/Wealth Relation**.

Heck, for evidence, look at me at age 64, 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!

Even at zero growth - History shows that inflation-adjusted accumulated Wealth requires constant future energy be generated in order to maintain that Wealth against the forces of decay

- There is only one alternative – if wealth is actually destroyed or does not lead to further enhanced ability to exploit energy resources (*i.e.*, it was not productive wealth creation),
- In that case, it is a form of "inflation" in the **CThERM** quantitative model of Garrett.

Inflation

- If spending does NOT enhance civilization, that loss is reflected in the inflation term in the quantitative model describing these relationships.
- Inflation is a mis-match between growth rate of money, and the growth rate of the value it is meant to denominate. The “GDP deflator” dGDP is supposed to properly correct back to “real GDP”).
- Inflation, or “decay” in Garrett’s term is usually an involuntary drag, but note for future reference that it is at least possible for it to be a voluntary choice to invest in actions which do not grow civilization.
- More on the interesting and intricate considerations around inflation later in this Presentation…

Efficiency Gains Lead to MORE Total Energy Consumption, not LESS

- Why?
- Consider what humans actually DO with energy efficiency gains – we do not destroy those savings, we do not get happy with a static lifestyle that costs less. Instead, we plow those savings to grow further, creating new wealth linked with new networks and relationships along which energy dissipation must be countered with continued new consumption of energy at higher rates. Even converting our energy infrastructure “green” requires energy to make it happen.
- I’ve met many eco-friendlies who can’t seem to let in how profoundly this changes the numbers. Let’s try harder…

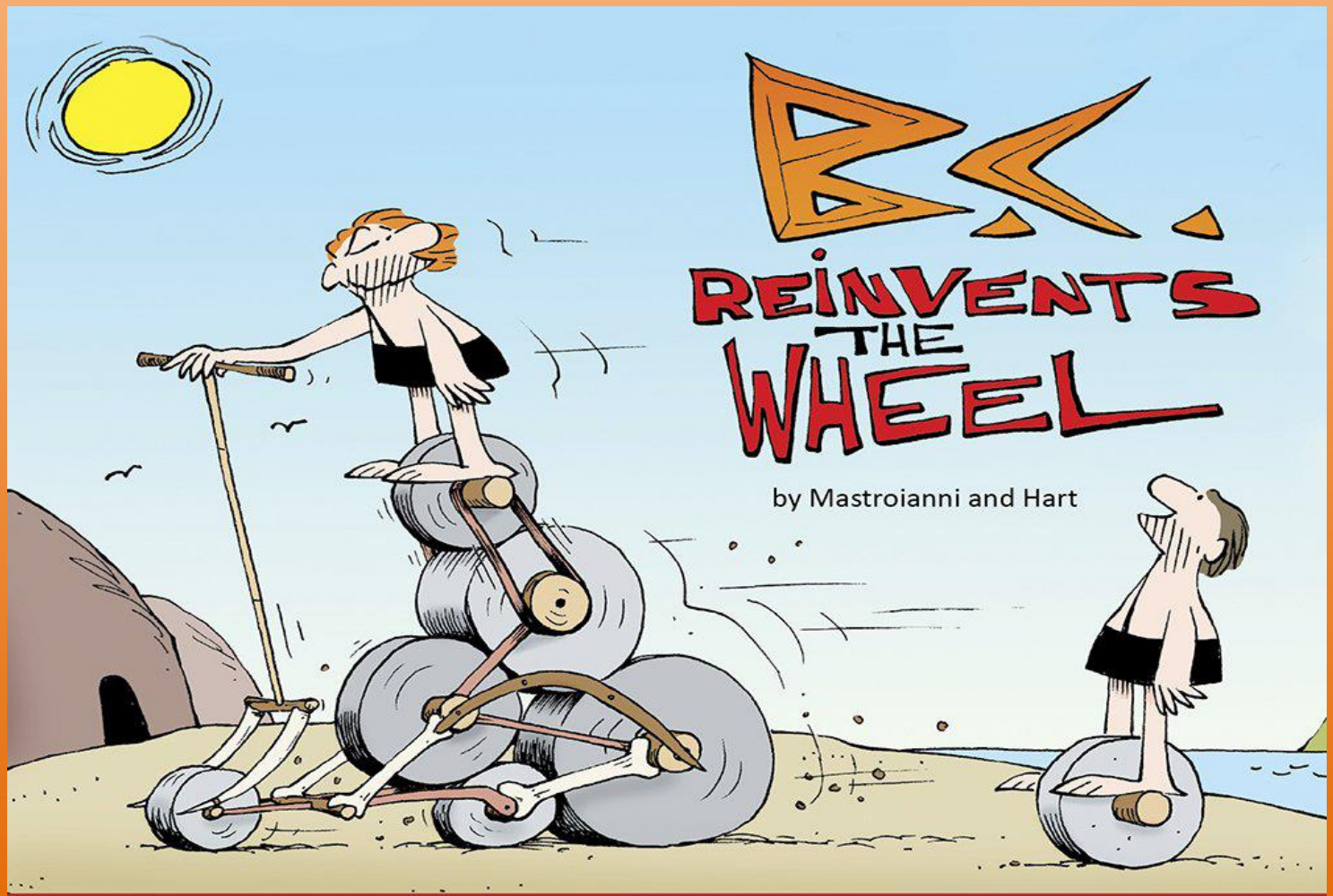
We've Dug a Very Deep Hole

- In the form of our 20 Terrawatts (trillion watts!) of continuous power needed to run today's civilization.
- And we need to dig the hole even deeper and faster to try to get out of it (solve climate by massive transformation).
- Reminds me of the Vietnam War media meme from journalist Peter Arnett - ***"We had to destroy the village in order to save it"***

We've All Heard the Urgings from the Eco-friendly Progressives…

- … if only we can mandate lighter vehicles instead of those heavy steel cars of old!
- … if only we would raise our mandated mileage standards for vehicles!
- … if only we can eliminate those darn "vampire power" losses in our appliances!
- … if only we would outlaw incandescent light bulbs and go to all compact fluorescent bulbs!
- ….if only we would outlaw those compact fluorescents and go to all LED lights!
- …if only we can eliminate cars and go to PRT (personal rapid transit) community vehicles!

And yet – We've been continually and dramatically 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.



The Reason that Improving Energy Efficiency is Not An Argument Against the Power/Wealth Relation today?

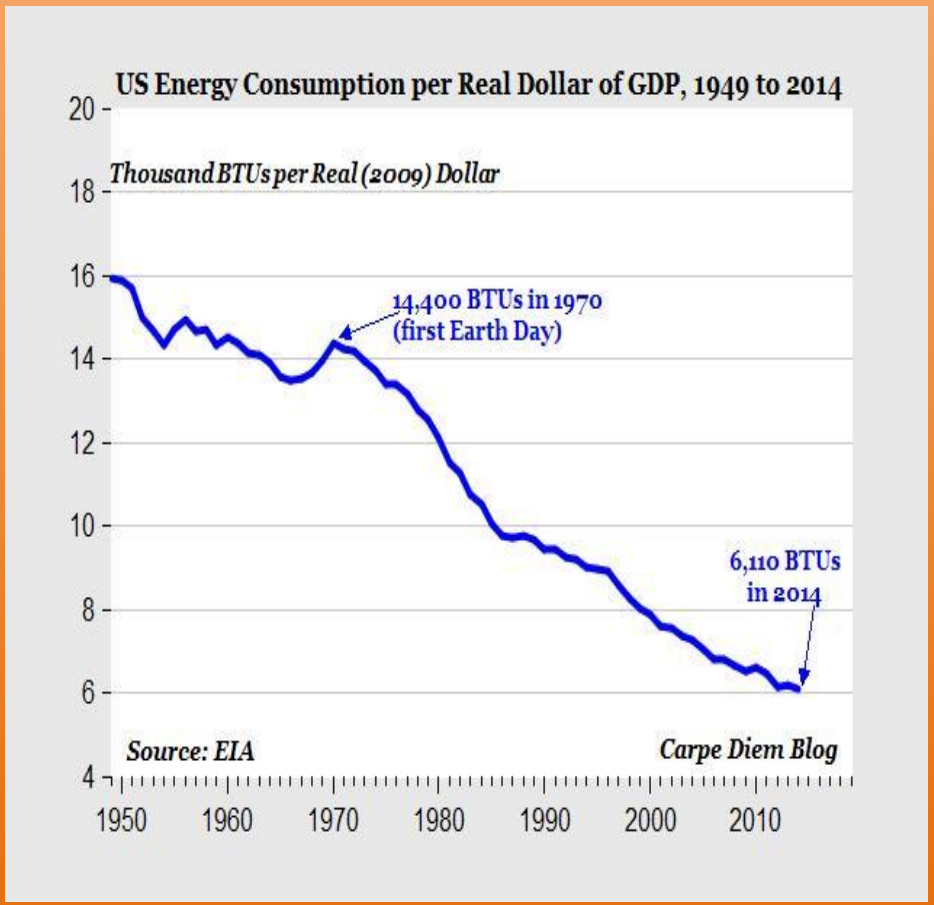
- Because improving efficiency has **always** been desirable for civilization growth; for climate activists and for Republicans too. For EVERYone.
- We've therefore **always** pursued it with our best efforts, but within the prime directive of maximizing profits. A later presentation will describe how this affects this relation in past data.
- Because it's always been such a win/win, I argue we can't (won't) do it any faster than the consistent post-1970 historical trend.

All biological systems follow scaling laws demonstrating optimization of energy efficiency towards a greater priority

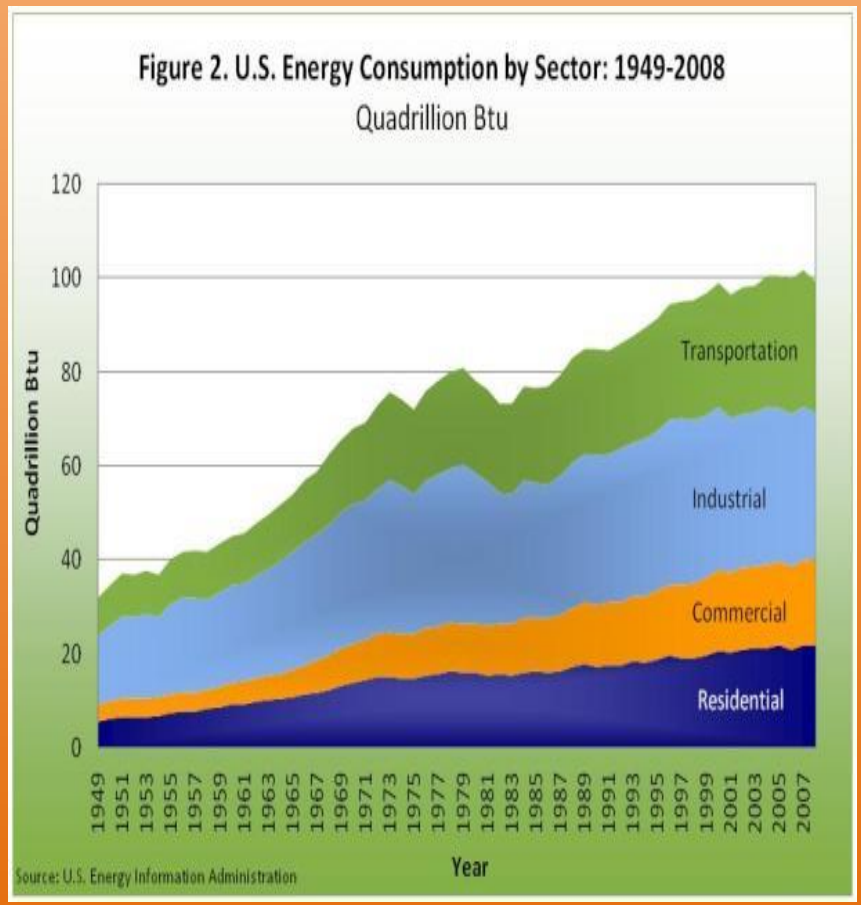
- The beautiful work of Geoffrey West (West and Brown and refs therein, 2005) and collaborators derives why there are impressive scaling laws obeyed by all aspects of biology, including civilization's networks, as a manifestation of our own biological system (West 2014), (West 2017)
- The energy requirements of biological systems are observed to scale as $(Mass)^{3/4}$. Why does this happen? "3" because of the 3 dimensions of space, and the 4=3+1 because of the 3 dimensions of space, plus 1. The "1" is due to the fractal nature of networks supporting biological and civilization systems, and the **optimization of energy efficiency** turns that fractal dimension of the networks to their **maximum theoretical value: 1, which means it is "space-filling". And 3+1=4.**

U.S. Energy Efficiency since 1950…

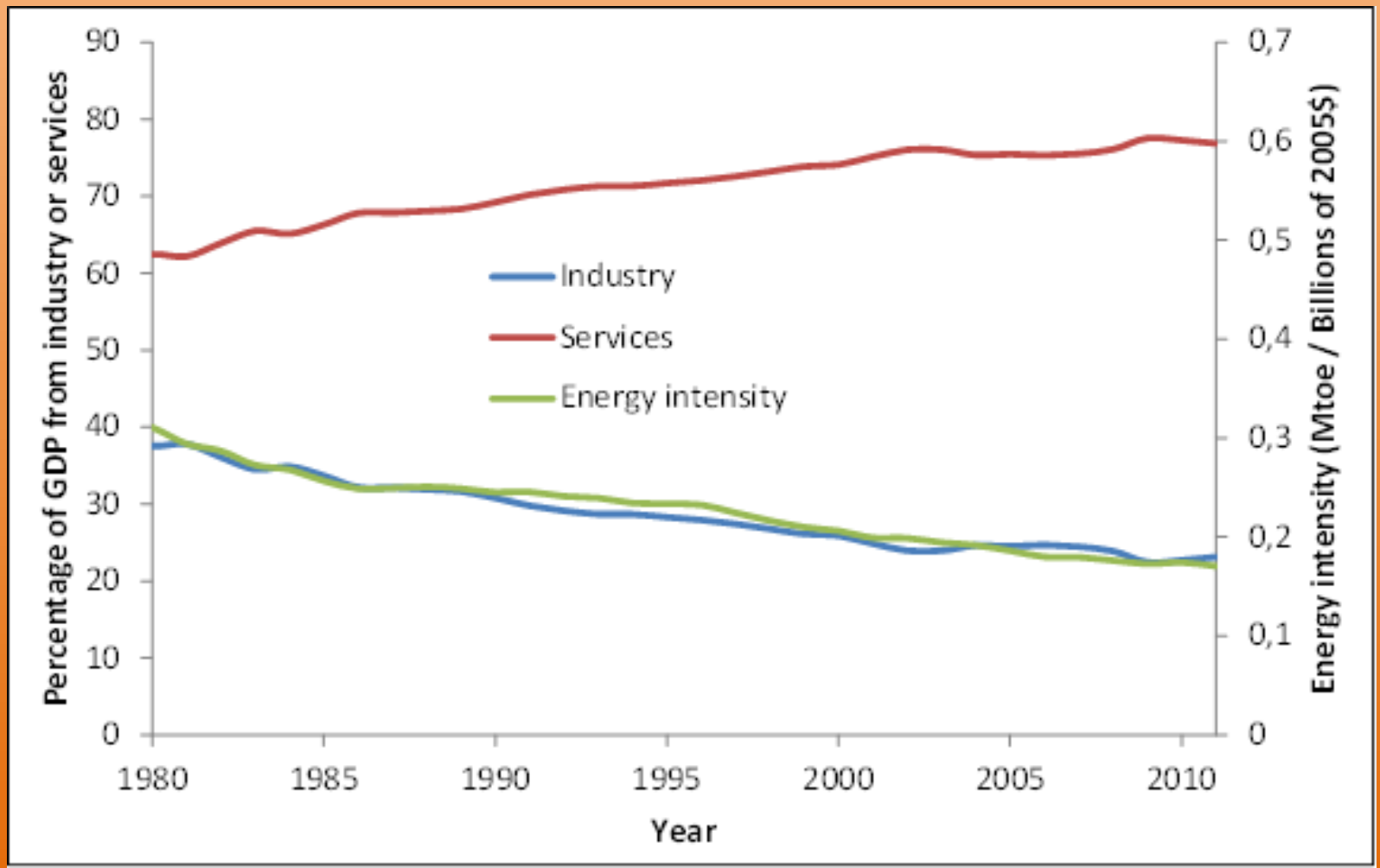
Spectacular 62% increase in energy efficiency. (except during oil-shock recessions of '70-'74). Has it lowered our consumption?...



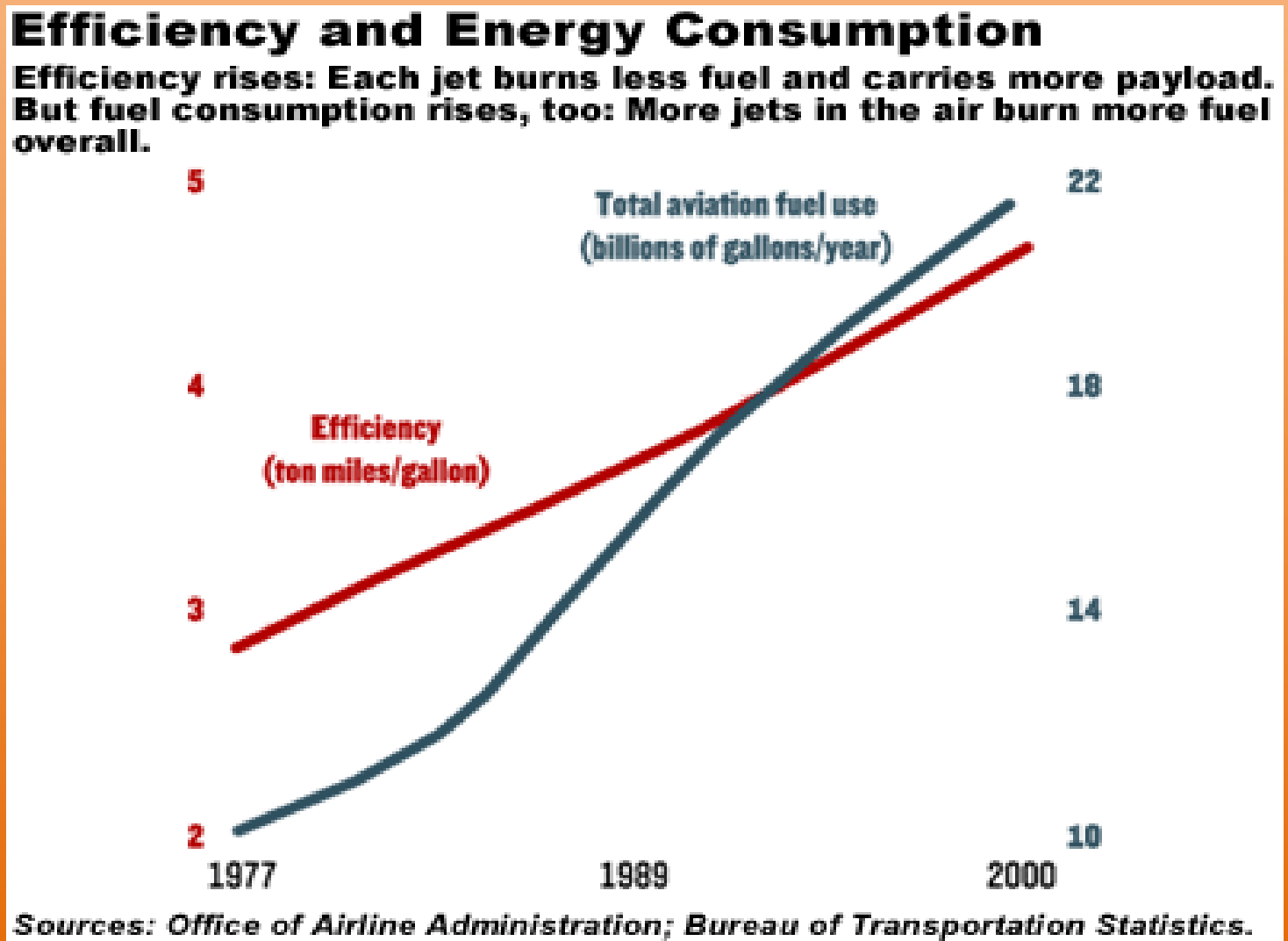
Not one bit! Energy consumption is up 300%, even given our off-shoring of much manufacturing



In fact, there is a perfect correlation over time between the off-shoring of U.S. industrial manufacturing (blue), and improving energy intensity of GDP (green curve).



Another: Miles/gallon for jet airplanes show striking improvements, enabling yet more, not less, jet fuel burned



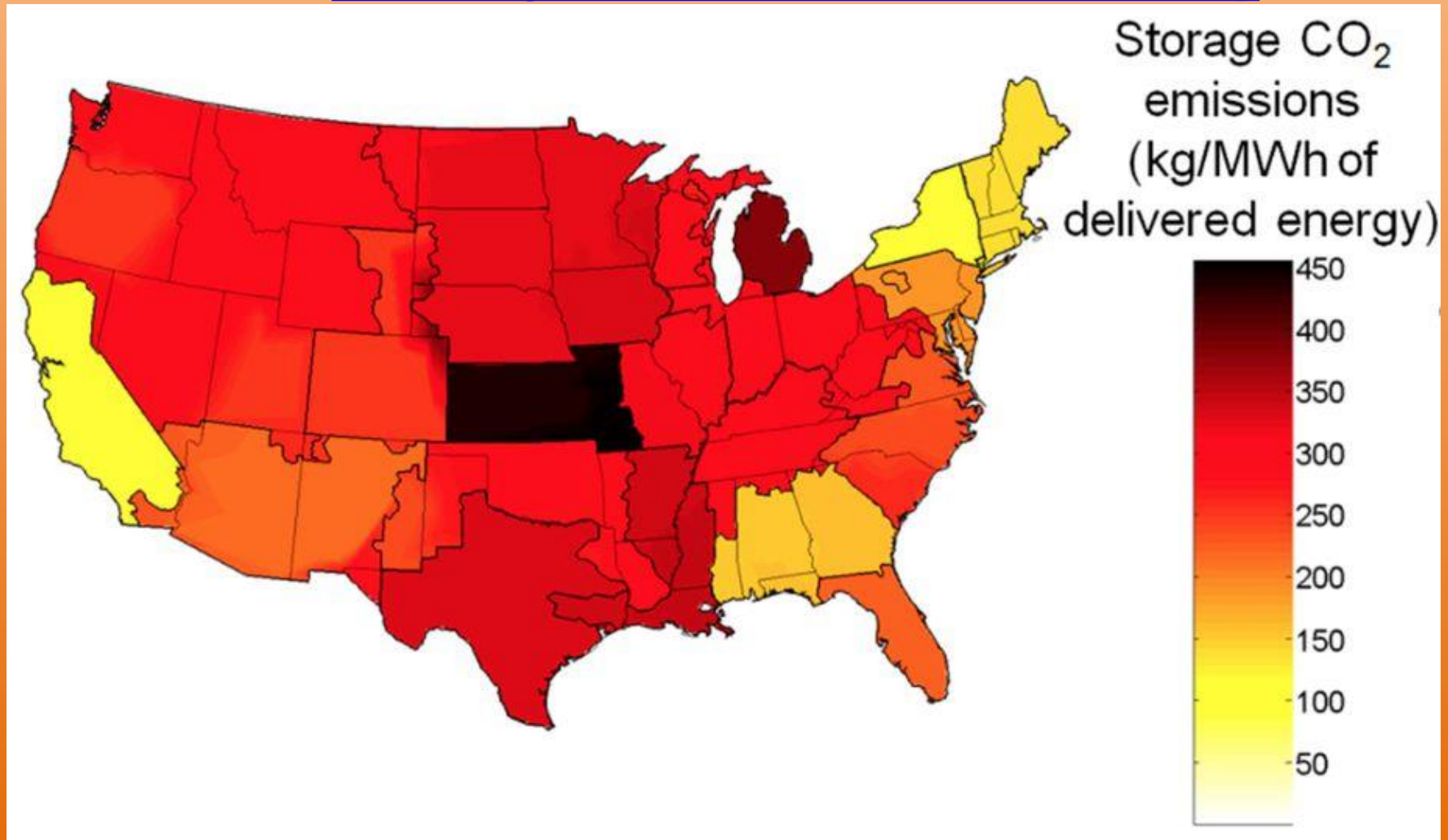
Then there's the Holy Grail of Energy: More Storage

- 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 *"It's difficult for storage to NOT increase emissions"* – **Vox Article – Dave Roberts 2018**

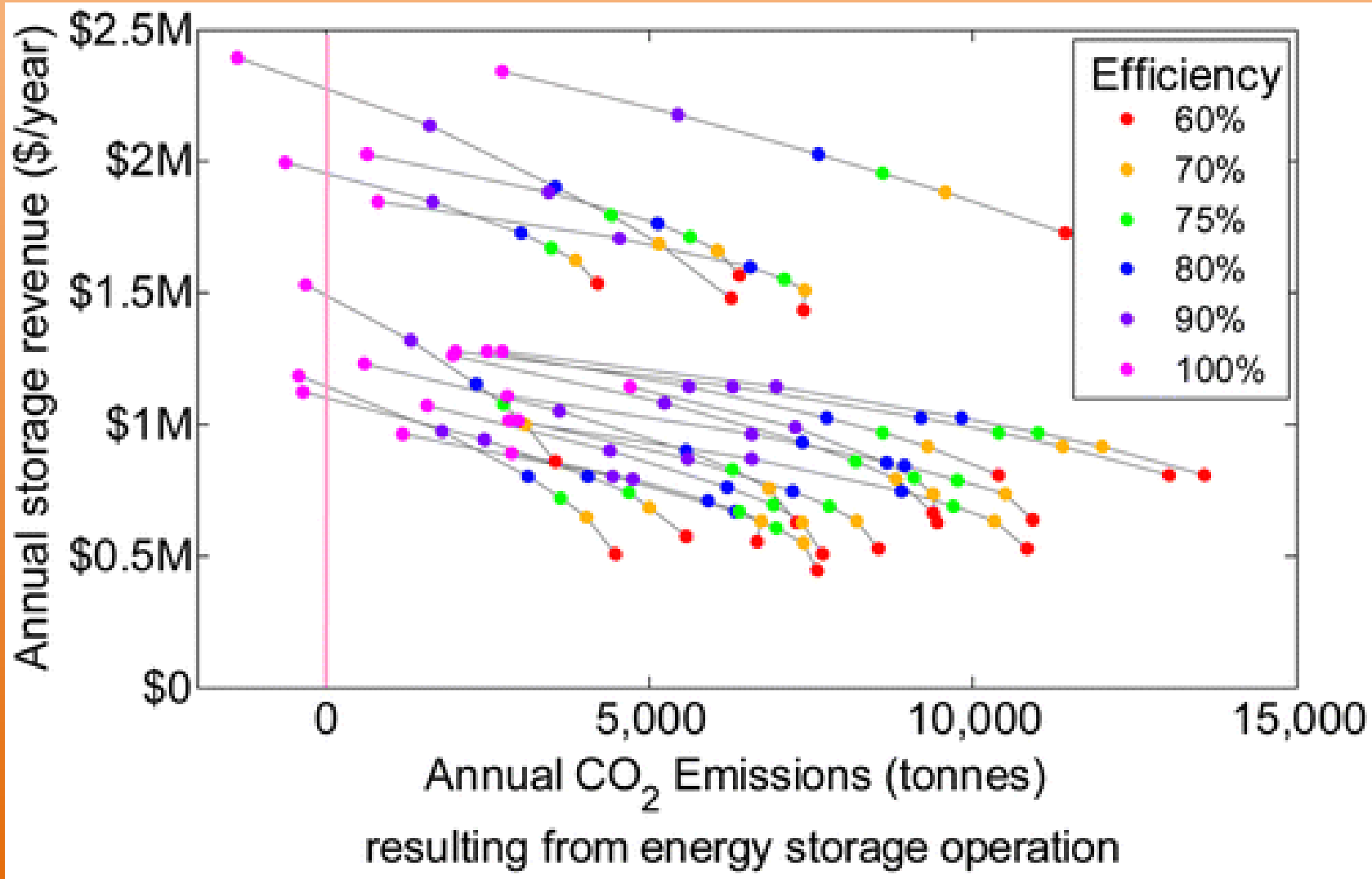
What?! How can that BE?

- **Energy Arbitrage** is the first reason: Storing energy when it is cheap and plentiful (coal power plants operating late at night, currently) and discharging it when it is more valuable (during the work day) encourages greater coal mining and 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).
- The **second reason** is the unavoidable energy losses during storage and discharge – losses which don't exist when consumption happens during always-on energy generation directly. The additional losses to/from storage must, by the **2nd Law of Thermodynamics**, consume new added energy.

Even paired with solar PV, storage today INCREASES CO2 emissions, when the full accounting is done (Fares and Webber 2017), and Hittinger and Azevedo 2017)



Energy Storage leads to higher CO2 emissions in all 20 U.S. grid regions, except under the assumption of perfect (unobtainable) lossless storage efficiency (Hittinger & Azevedo 2017) (left-most point)



Electric Vehicles charged on the 2013 grid average, produced WORSE net environmental damage than the gasoline cars they replaced – in this 2014 PNAS published study.

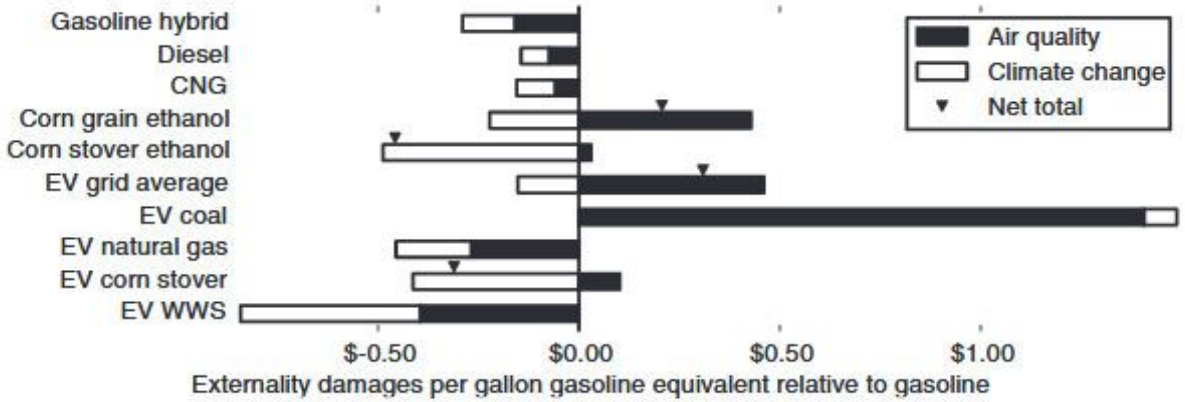


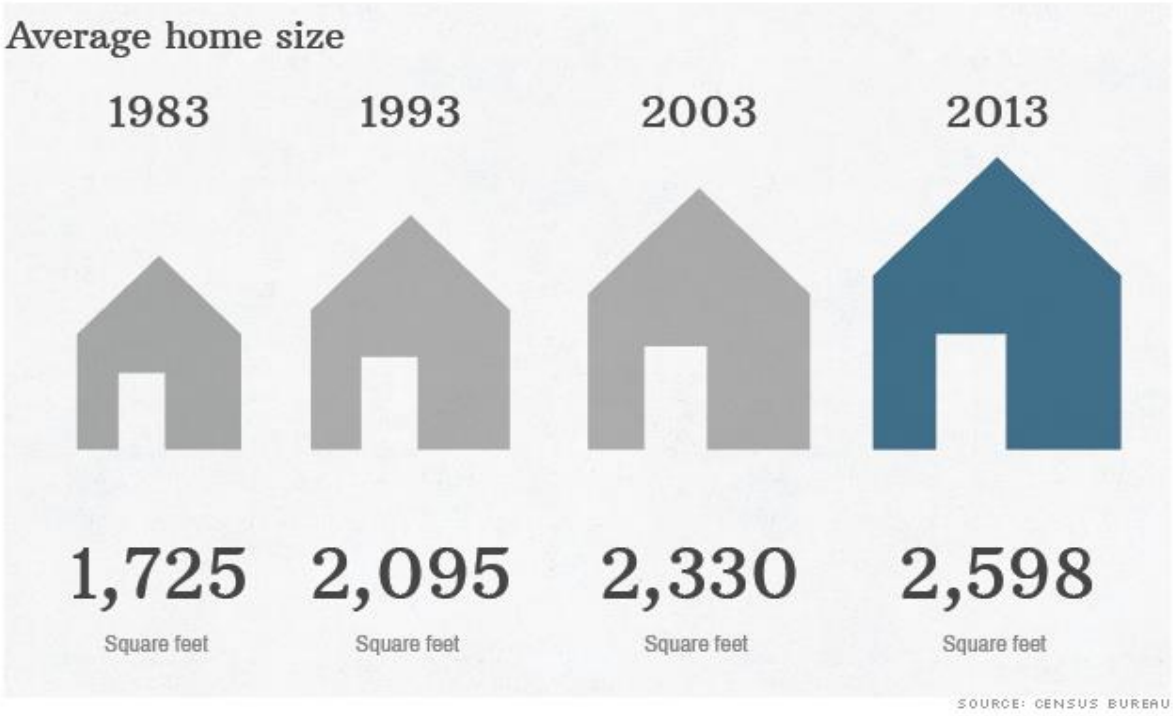
Fig. 3. Combined air quality plus climate change externalities attributable to each scenario, relative to the gasoline scenario. [The gasoline scenario impacts (air quality, $0.53/gallon; climate change, $0.46/gallon) would equal zero on this plot.] EV scenarios include battery production. Air quality impacts include $PM_{2.5}$ and O_3. For bars with both positive and negative values, the triangle above each bar shows the net total impact. GHG emissions from indirect land-use change are not included. See Fig. S4 for the impact of including indirect land-use change on net GHG emissions.

- **Tessum *et al.* 2014** show that when the full life-cycle costs in energy and pollution are assessed, the inefficiencies of converting "**EV Grid Average**" power into electricity, mean that charging your EV at home off the standard grid actually makes for dirtier pollution, and only a slight improvement in GHG emissions, *vs.* the gasoline car it replaces.
- However, in 2015 the Union of Concerned Scientists **did a study** comparing EV's to gasoline cars GHG life cycle emission and find EV's win in most parts of the U.S. at least. **Assumptions may have differed.**

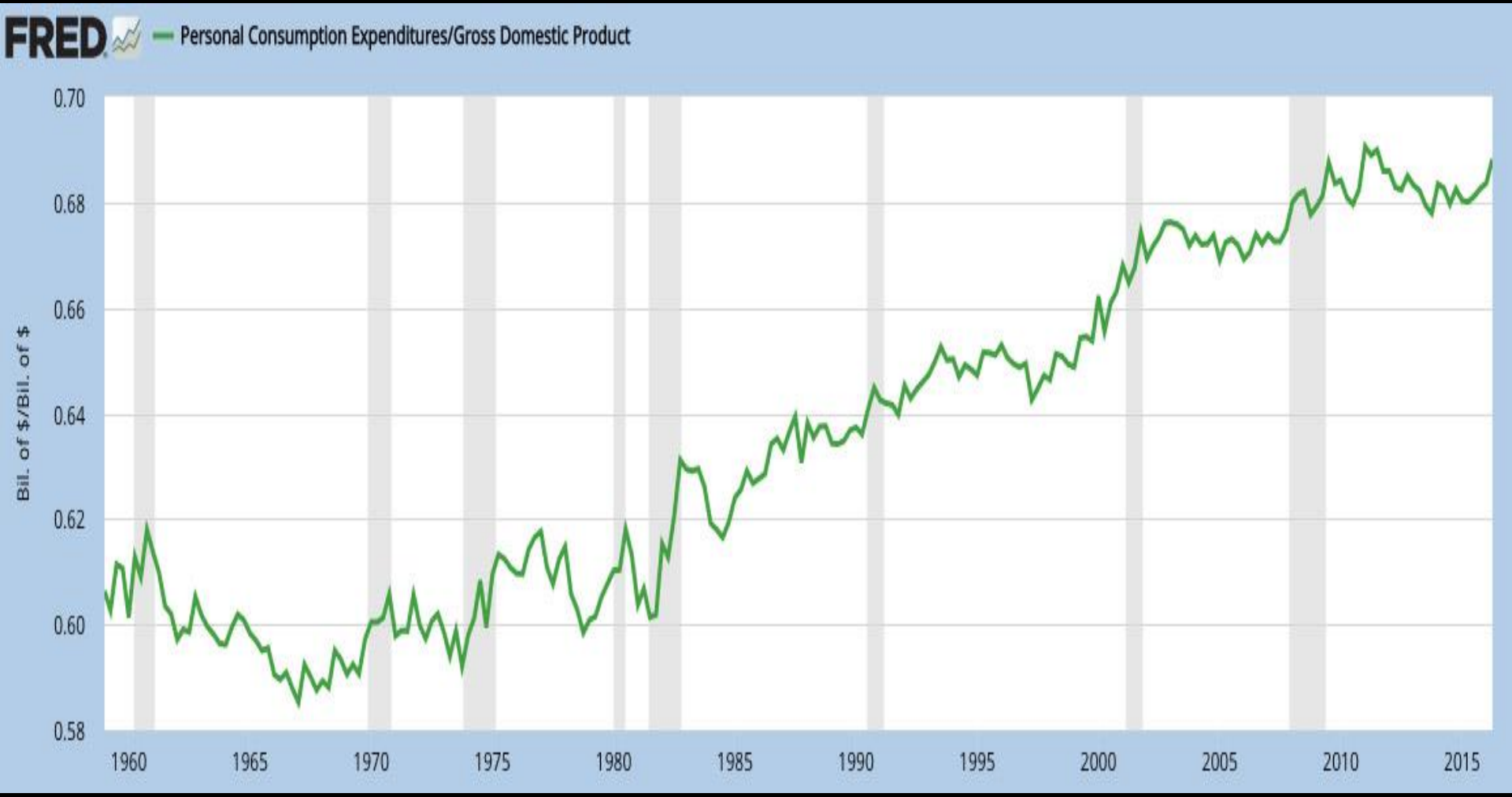
An Example of the Poor Grasp of "Jevons' Revenge" from the Otherwise Laudable National Resources Defense Council

- They failed to understand the basic Garrett Relation, attacking with the fact that current GDP does not scale with energy consumption. **True, and irrelevant!** The Garrett Relation is between total time-integrated global GDP, **not** current rise rate! This betrays a dismaying inattention to what one is reading, if not downright deliberate creation of a straw man to knock down in order to discredit what is, in fact, intriguing work.
- They then smear those who point out the existence of "rebound" as enemies of renewables (certainly not true), and then try to disprove rebound by cherry-picking individual countries such as Germany and the U.S., failing to recognize international trade and **off-shoring of CO2-generating manufacturing to Asia**

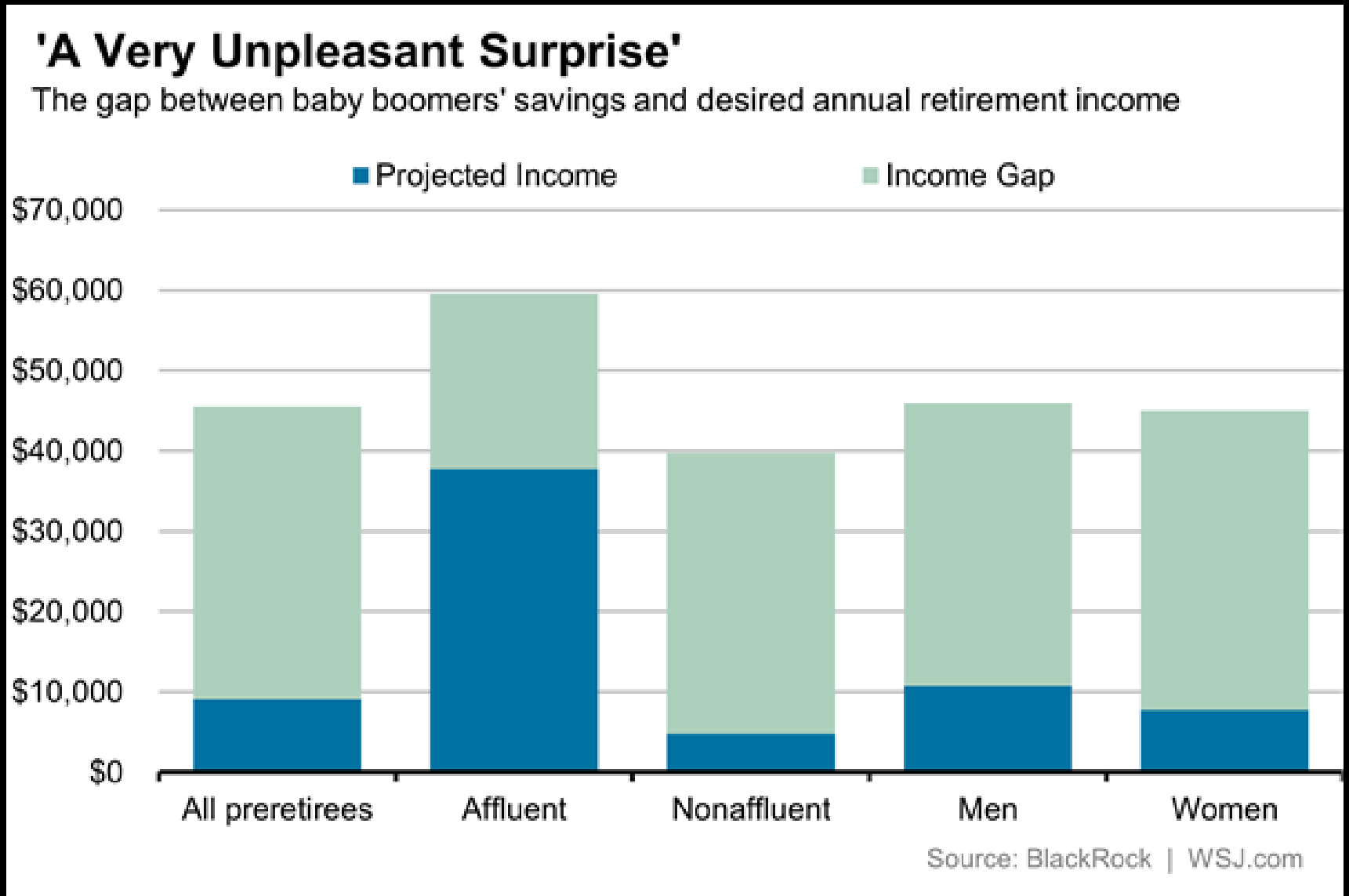
We Do NOT Save our Efficiency Savings, We SPEND them; on Bigger Homes…



…on more consumption spending per $ of GDP

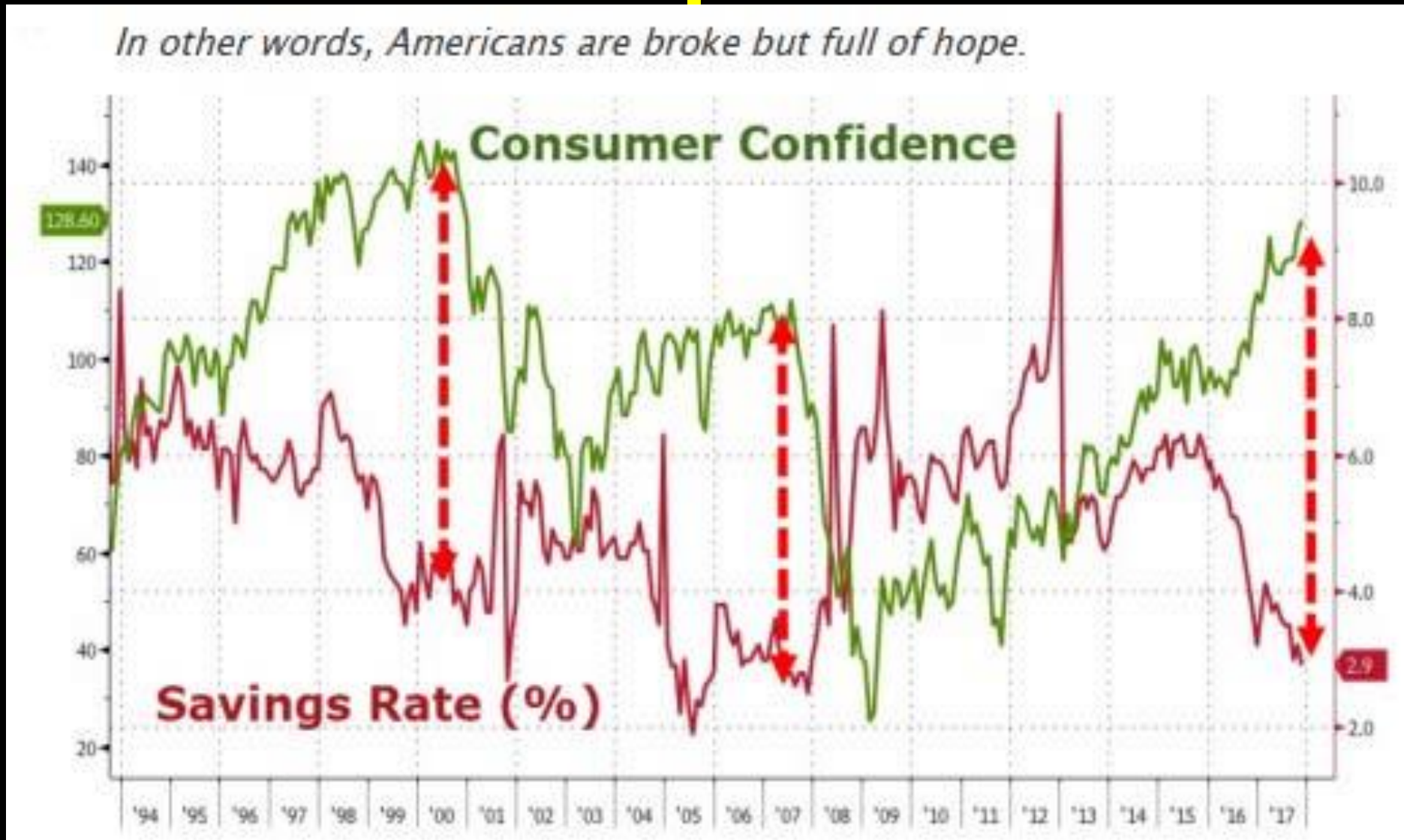


We're NOT net saving. Even for our own retirement

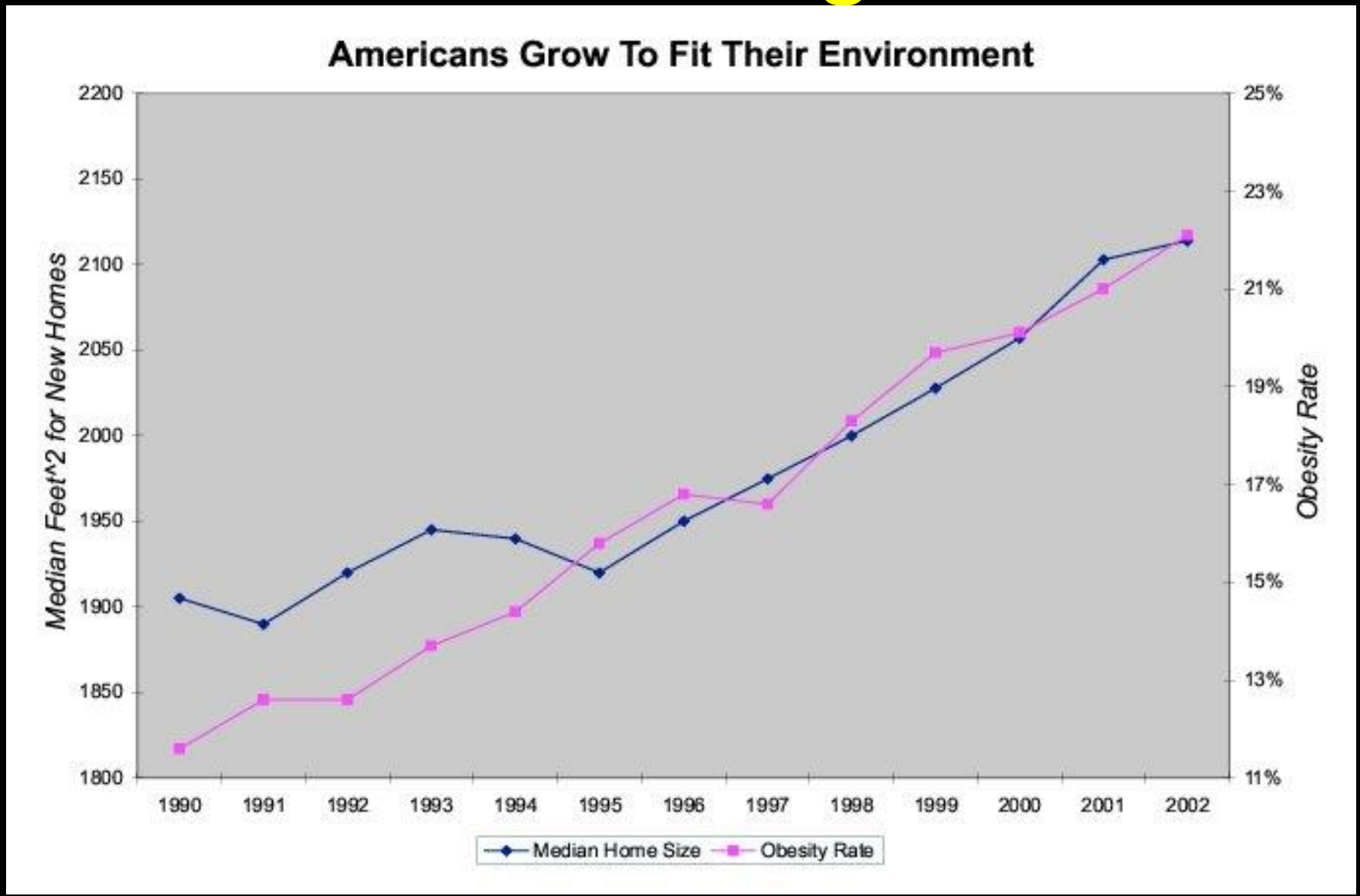


Millions of Americans are 1 missed paycheck away from financial disaster. 51% would need to dig into savings after just 1 missed paycheck, and can't afford a $400 emergency, and 22% would have to default on monthly bills

We're "Broke, but full of hope"



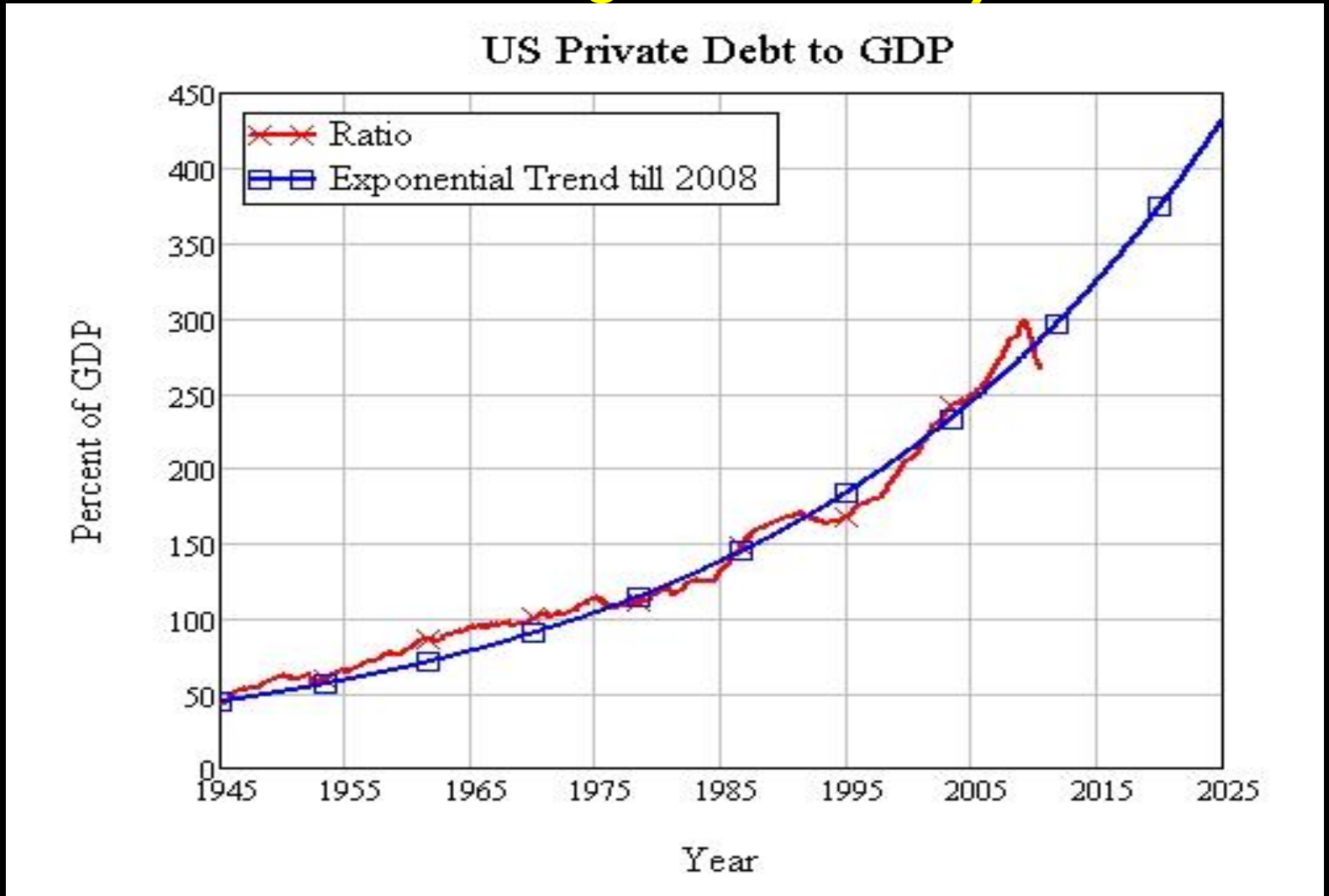
We're Increasingly Obese, and "Livin' Large"



In case you think education and new research has slowed this worsening obesity trend…

- ***No.*** It continues up through the present (**Hales *et al.* 2018**). Obesity rates among youth has gone up 10% in just the past decade, and even more – by 18% - among adults.
- People **know** eating carb-heavy junk food causes obesity, but they give in to their cravings anyway. **People do what they WANT,** helped by corporate advertising and their own brain's sugar-damaged leptin and dopamine receptors.
- Immediate gratification has EVERYTHING to do with the Thermodynamics of Civilization, Generalized Jevons' Paradox, and the failure of "impulse control" towards a healthy global future.
- People do just what they want. Almost as true for Progressives as it is for Conservatives, in my observation.

Even if we have to borrow from future generations, impoverishing them, to afford to do it. Private Debt is now 350% of GDP, exponentially Increasing. (Govt. debt rising even faster)



"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).

- 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**

Well, what if I just leave my energy efficiency savings in the bank?

- Even if you simply leave your savings in the bank, the bank uses those dollars as an asset base, enabling them to lend out a multiple of those dollars (newly minted money out of thin air) to others who will spend them. So that's also a no-win. (We all live, globally, within a fractional reserve banking system)
- Thus, if you're going to avoid expanding energy generation rates, you have to "destroy" the dollars saved through efficiency gains.
- But would even that be enough?...

So, we have to essentially BURN our piles of efficiency-gained cash??

I Wish it Were That Easy…

- The cash only denominates the Wealth, and if the wealth remains, the ability and reality it enables - that of further growth in energy consumption - remains.
- Burning the cash only makes for **“negative inflation”:** The remaining unburned dollars **gain** corresponding value by their increased scarcity.
- Negative inflation adds value to already existing savings, nullifying the effect of burning the new savings, so it doesn’t truly help in lowering our growth.

It doesn't solve our dilemma– how to LOWER Civilization's total energy consumption while still following our evolutionary biological drives

- We need to actually cripple civilization's ability to grow, or else voluntarily halt that growth by policy action or (impossibly hard) universal and continually generated biological energy-intensive human will-power **against** our desires.
- In a competitive world, this would seem *extremely* unlikely, and ultimately exhausting beyond the ability to continue.

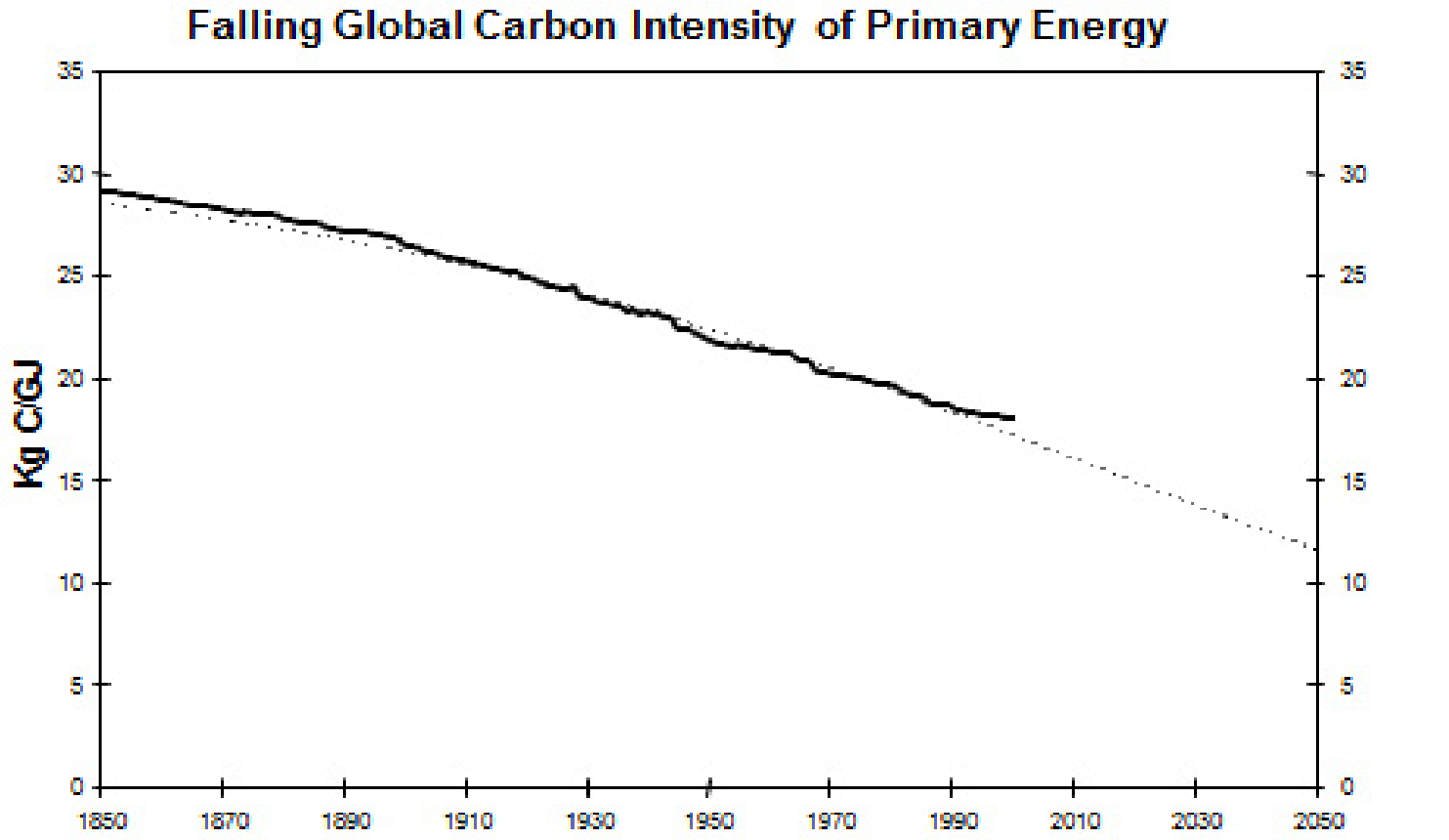
To avoid Generalized Jevons' Paradox, improved energy efficiencies cannot be spent elsewhere. Even spending them on de-carbonizing will require energy, and will raise CO2 emissions in the present (but better spent on decarbonizing than not).

- This last observation may help explain the history of our attempts to decarbonize energy, which many of you will find surprising…

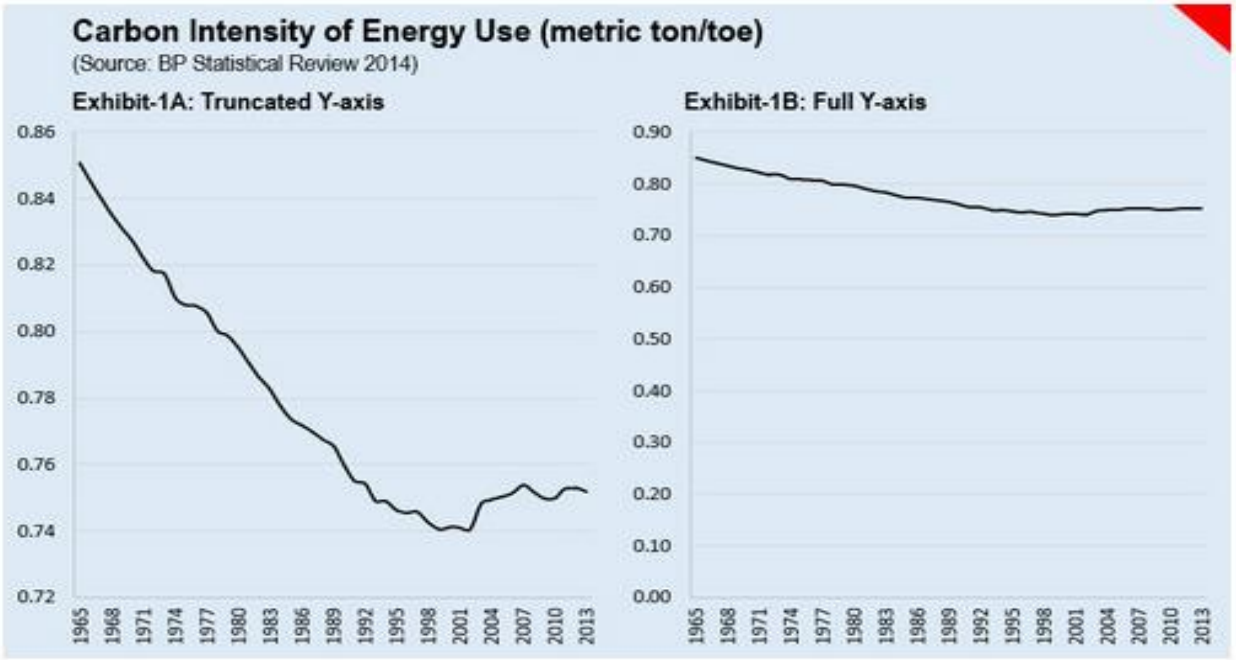
We've All Heard the Cheerleading: Solar and Wind Taking Over the World

- I'm guessing you expect the **c**arbon **i**ntensity of energy = **CI** (= CO_2 emission per joule of energy consumed) over time has been falling here in the 21st Century, after perhaps rising during the dirty, smog-choked industrial 20th Century.
- …You'd expect falling, as solar and wind take the place of coal and oil, after the Industrial Age ramped during the 20th Century and gives way to the **Clean Energy Century**…
- **Is that your guess? Let's look at the actual data…**

The 19th and 20th Centuries actually did show a steady fall in the carbonization of energy, as oil, hydro, and nuclear replaced dirtier coal. Right up to 2001. And after that…?

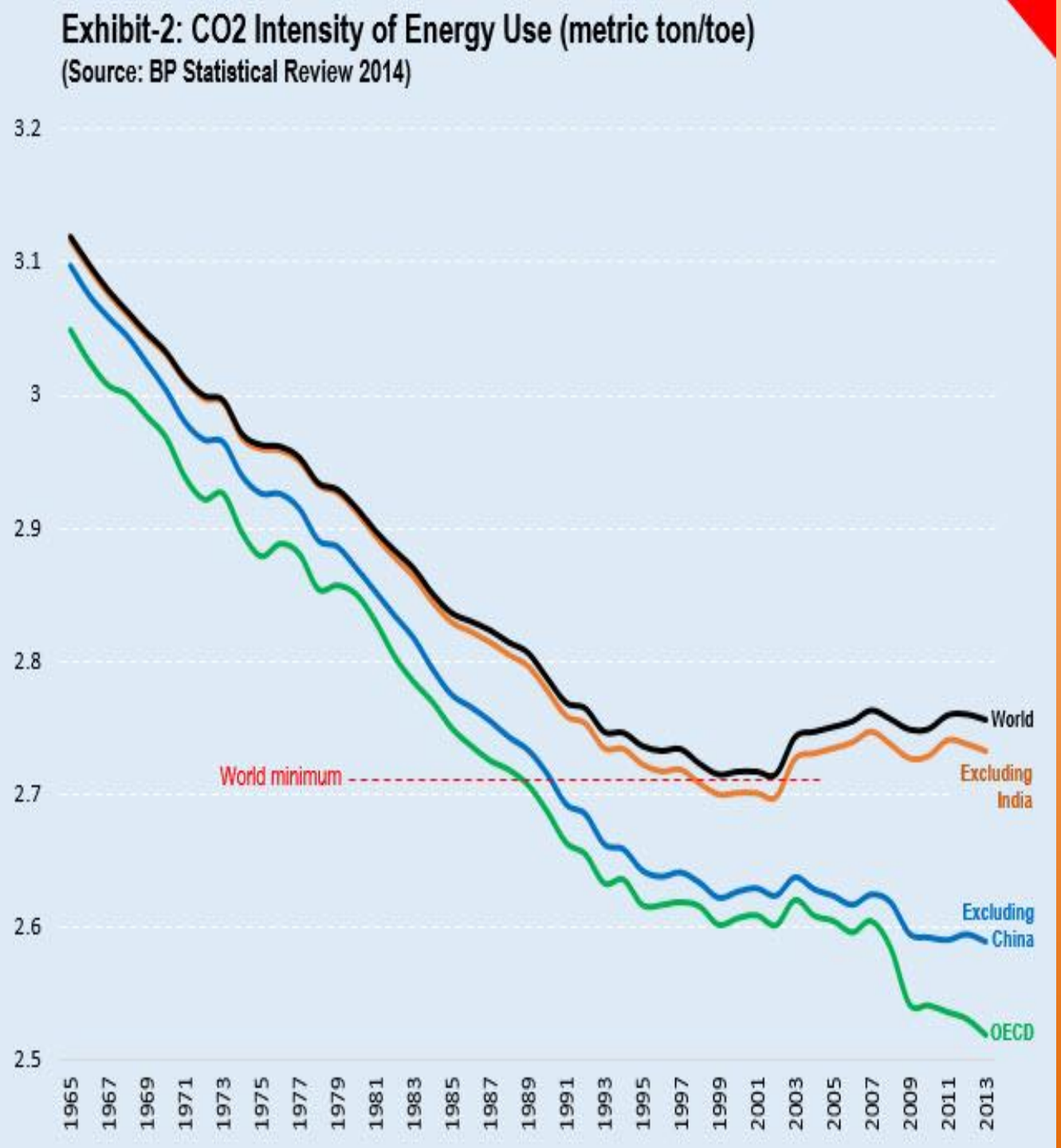


Global carbonization of energy dropped in the 20th century, yet rose in the 21st, then leveled, despite the rise of solar and wind power. Economic growth, now aided by China's entry to the WTO, has been faster than the strides made in renewables.



A Closer Look

From here on, the numbers will show CO2 intensity instead of carbon intensity, because the original data from BP and the EIA report CO2 emissions. To convert CO2 to units of carbon (C), simply divide by 3.667. Carbon intensity and CO2 intensity are used interchangeably in the text – both are ratios that depict emissions generated versus energy produced. In the relevant literature, CO2 intensity is also reported as a ratio of CO2 emissions to GDP--which includes the effects of prices. In this note however, CO2 intensity is measured in physical units--metric tons of CO2 per tonne of oil equivalent (toe). Also, 1965 is the first year for the data published by BP.



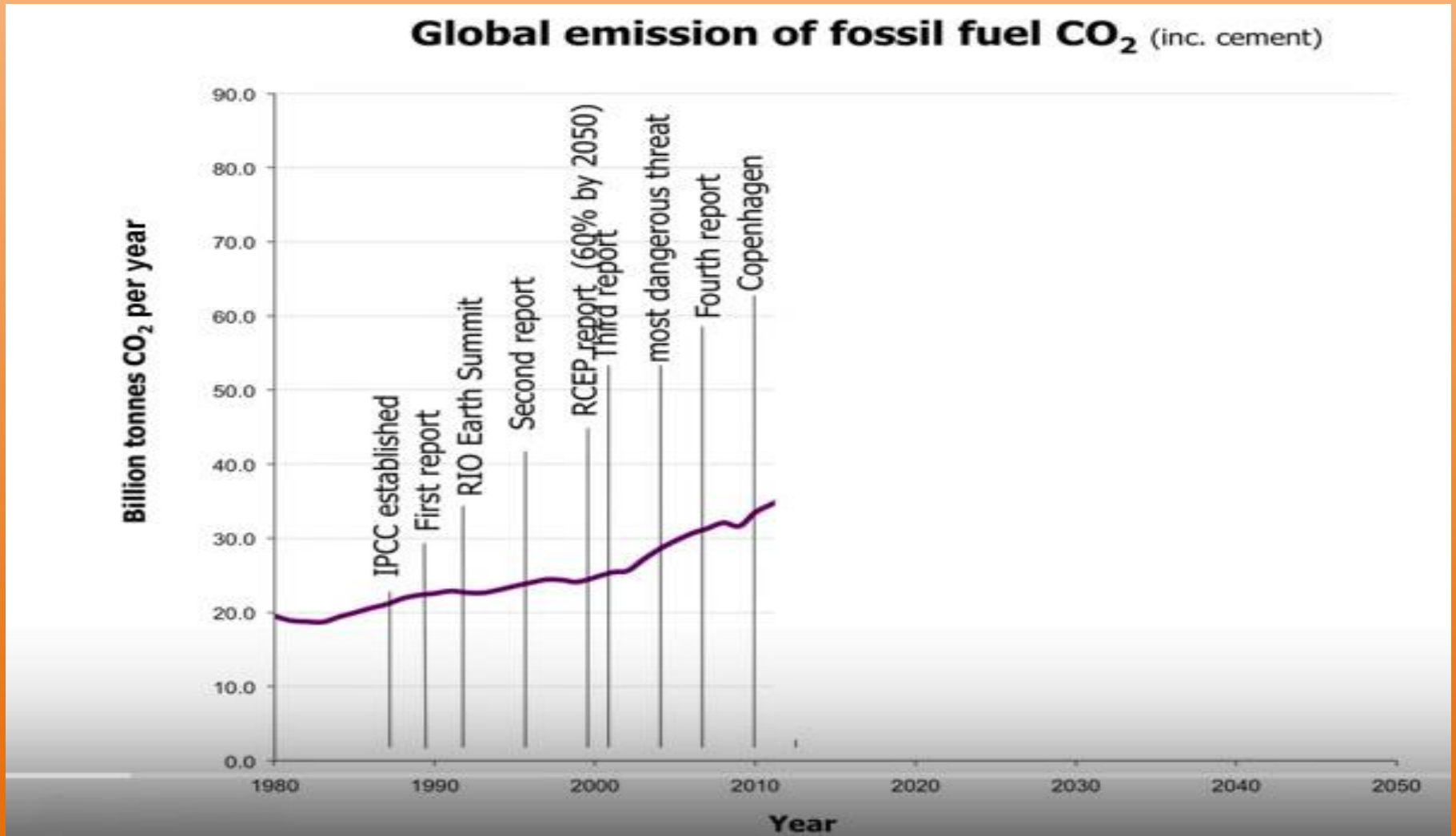
Plotted is CO2 intensity per unit of energy generated.
Strong growth from China (coal) halted decarbonization this century. Even the non-China world (blue) has slowed its de-carbonization, although it's still decarbonizing. The Developed world (OECD green) is doing better. But *Climate cares ONLY about the global data (world. In black)*

Note: The exponential halving time of carbonization (1965-2001) is **180 years**

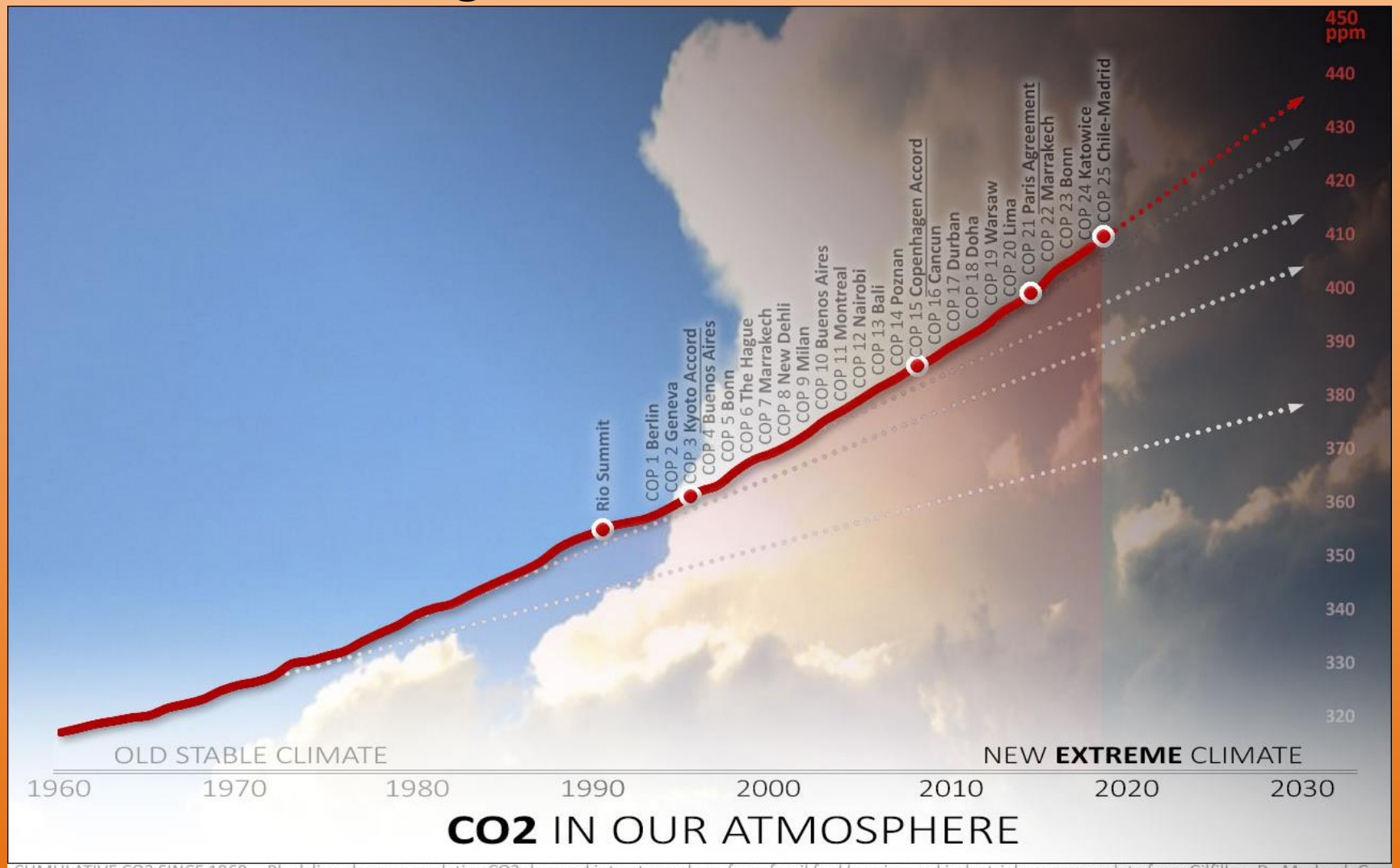
Well, OK. But we were decarbonizing for a while, Rick! We could do it again, no?

- We were indeed decarbonizing globally. Due to the world being economically dominated then by technologically advanced countries (U.S., Europe, Japan) and the adoption of nuclear power, hydro power.
- But for future reference, note that the smooth global carbonization curve from 1965 to its minimum in 2001, fit to a decaying exponential, produces a **halving of carbonization time scale of <u>180 years</u>. That's far too slow a time scale to save our future.**

Total Policy Failure: CO2 Annual Emission RATES Are Rising Relentlessly, despite IPCC Climate Summits. And it continues…

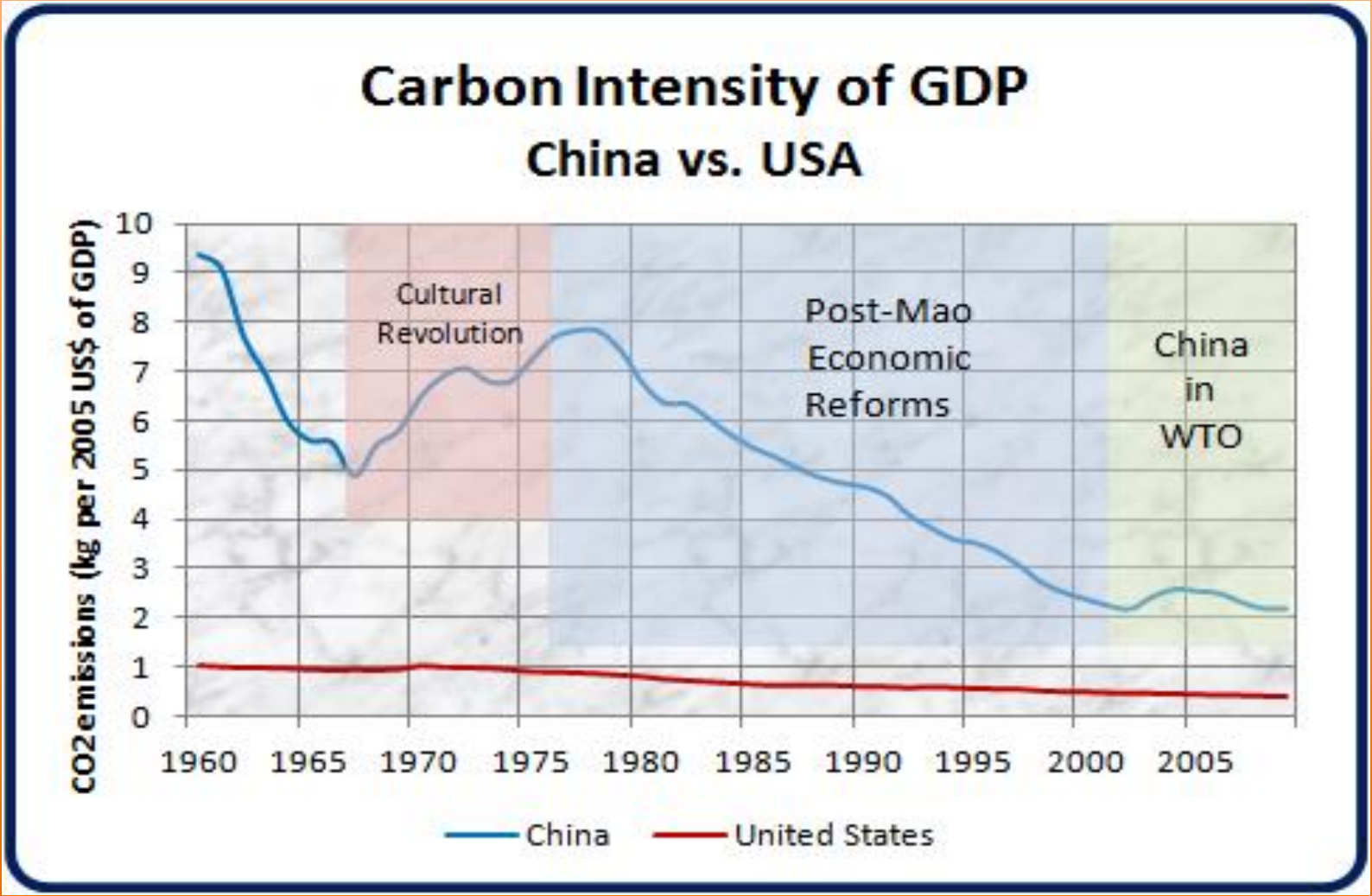


…there's a reason – You can't have an economy w/o CO2 emissions today, and we insist on economic growth as the Prime Directive

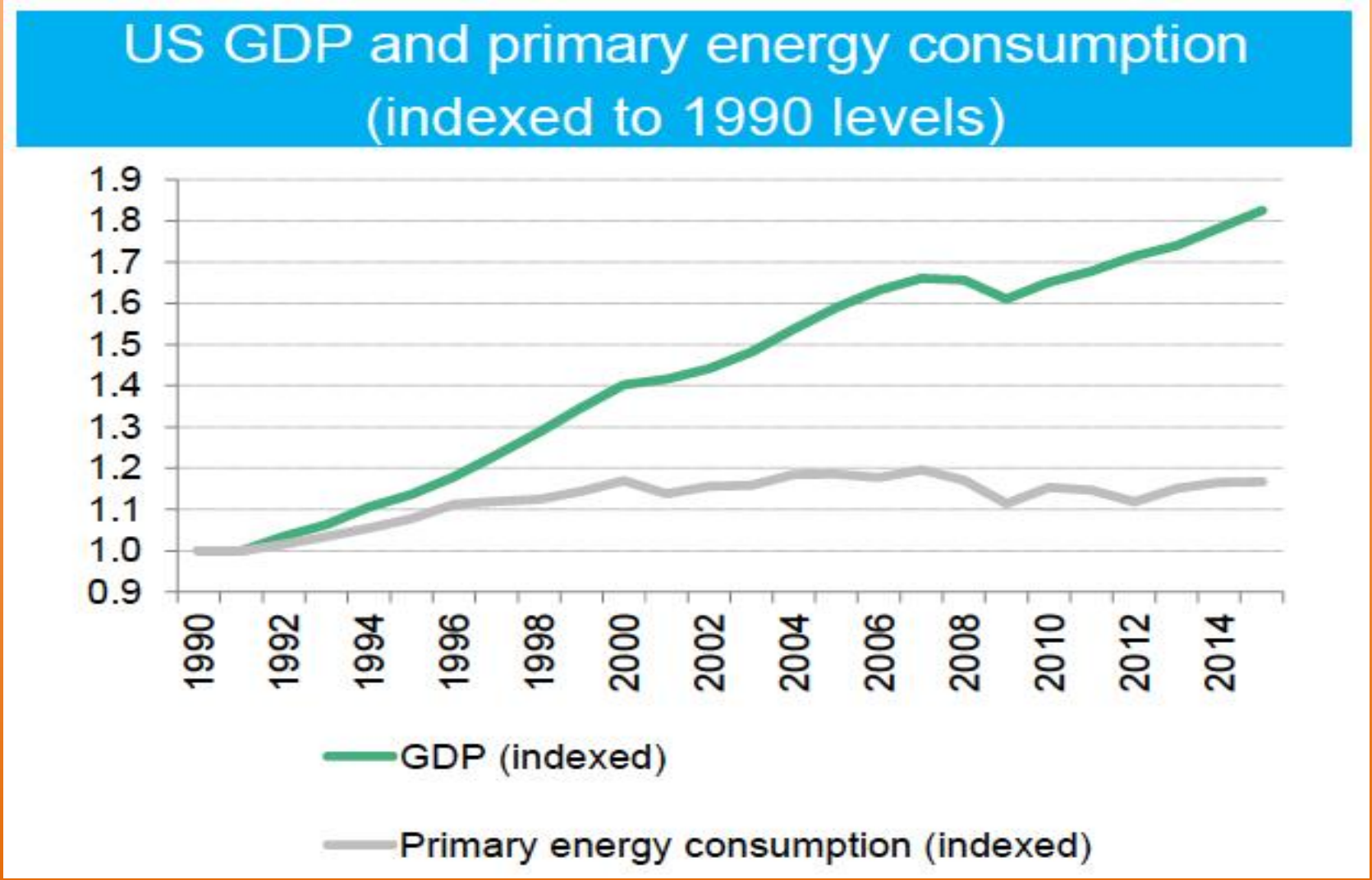


CUMULATIVE CO2 SINCE 1960 -- Black line shows cumulative CO2 dumped into atmosphere from fossil fuel burning and industrial processes: data from Gilfillan, D., Marland, G., Boden, T. and Andres, R.: Global, Regional, and National Fossil-Fuel CO2 Emissions, available at: https://energy.appstate.edu/CDIAC. Red line shows cumulative increase in CO2 in the atmosphere since 1960. Data from NOAA ESRL at www.esrl.noaa.gov/gmd/ccgg/trends/. Part-per-million (ppm) values converted via 7.81 GtCO2/ppm. Dotted lines show decade averages continued out to 2030. Chart by Barry Saxifrage at NationanalObserver.com and VisualCarbon.org. Dec 2019.

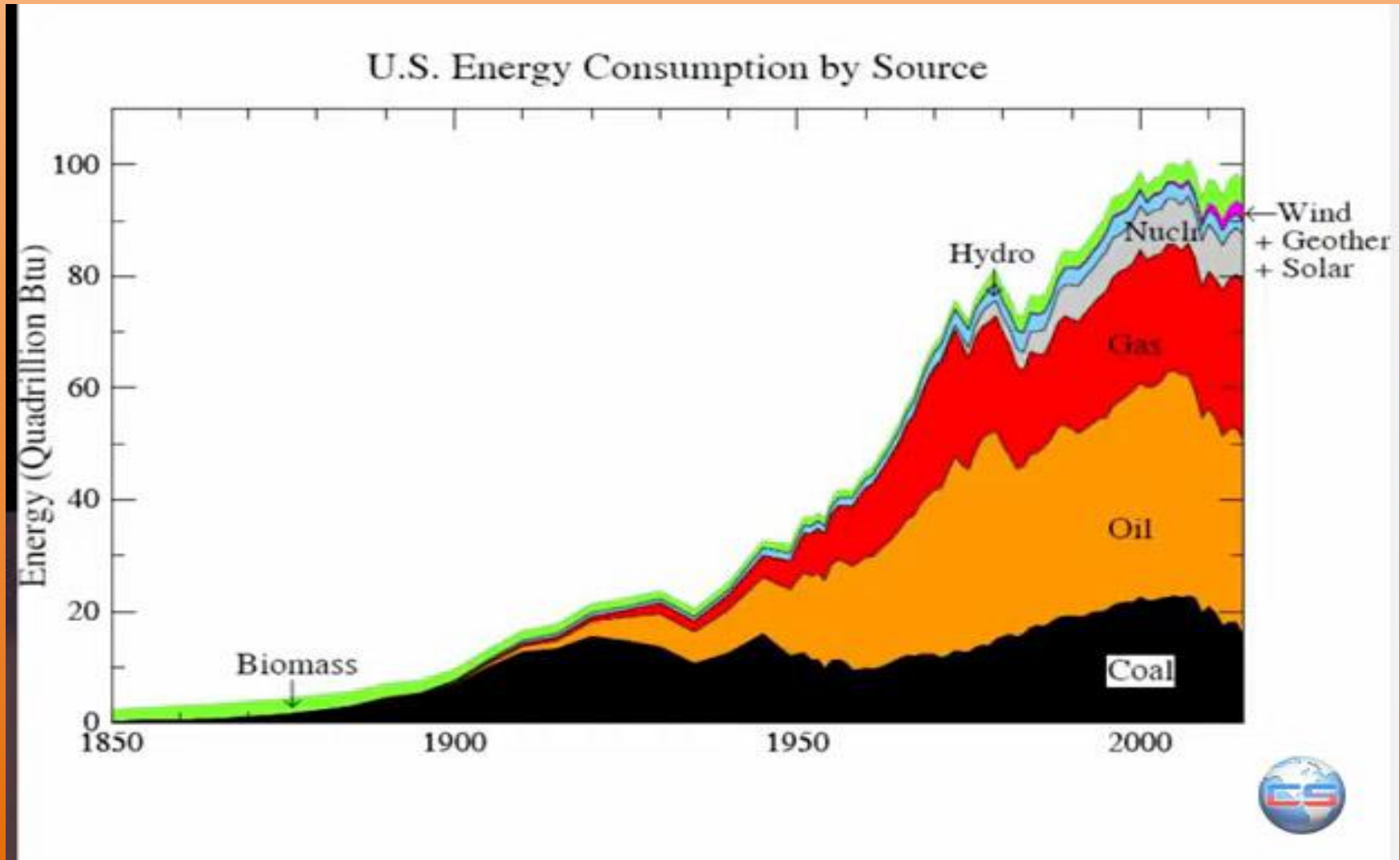
But Rick, look at how the carbon intensity of GDP has been cut in half during the past 70 years!



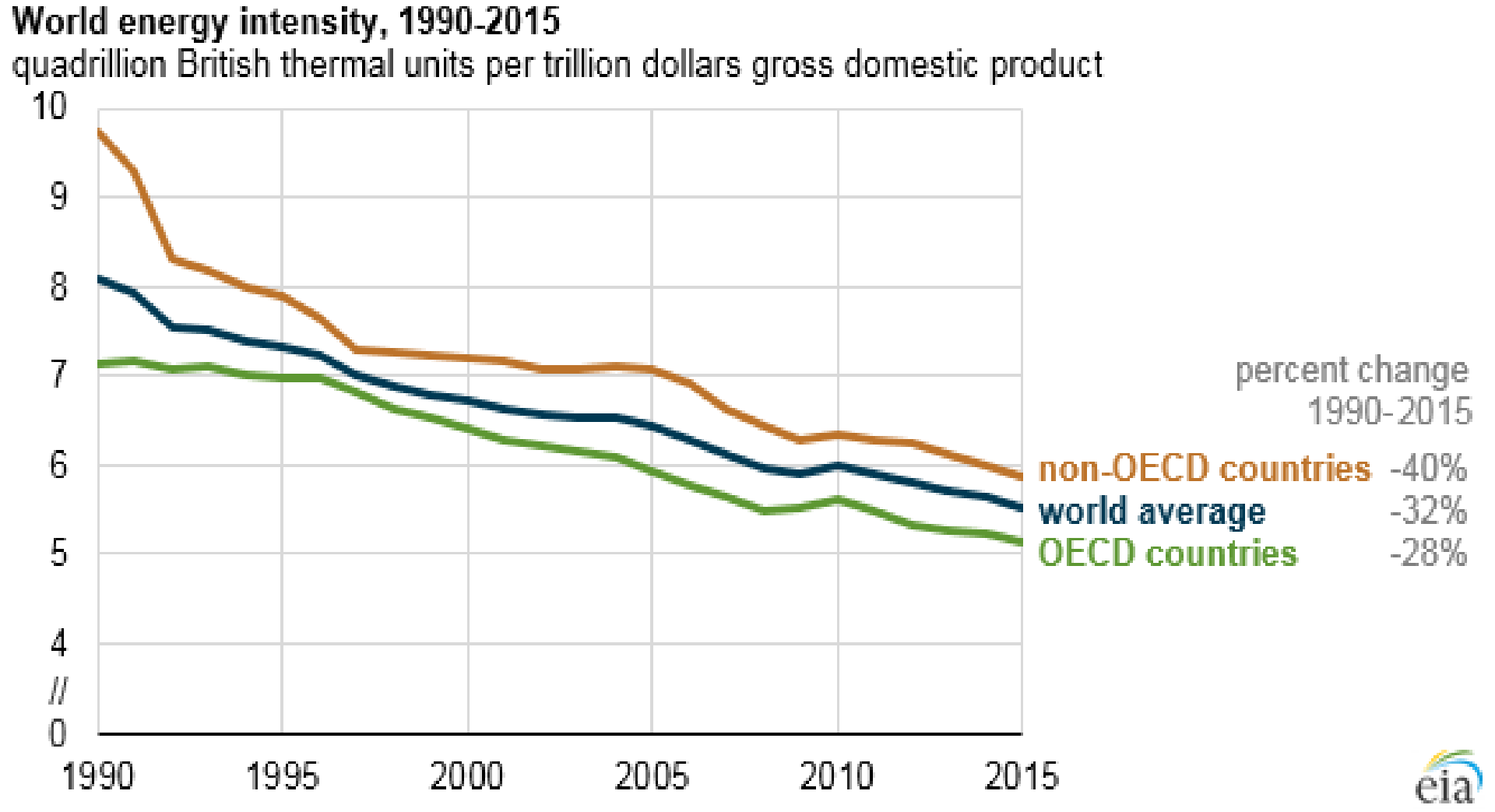
And Look at how U.S. GDP still rises while Primary Energy Consumption has Flattened! (gray)



And look at how the U.S. has flattened its total energy consumption this century (as of ‘15)



And look at how the global energy needed to generate a PPP dollar of GDP has dropped 32% from 1990->2015

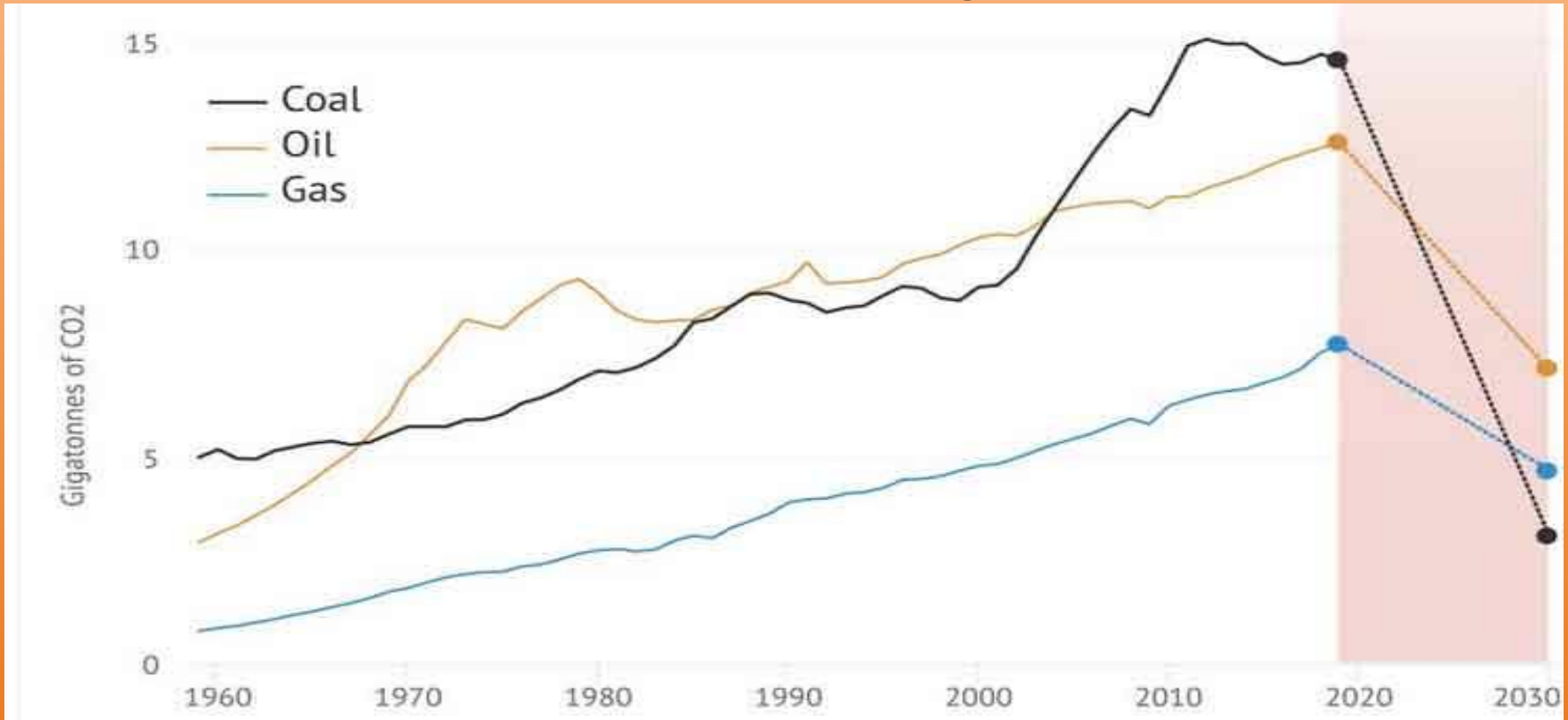


Yes. Impressive. But it's a case of classic mis-direction ("look here!" while the real action is over there). Here's 5 Reasons…

- **1.** These rich western countries have **outsourced their CO2 generating manufacturing to Asia**, whose CO2 emissions have been skyrocketing.
- **2.** The sources of such curves are often not careful about distinguishing **energy consumption** (*e.g.* kilowatt hrs on the meter) from **PRIMARY energy supply used**, which is what must first be processed to get useable energy. By not doing so, they neglect major energy costs in the early stages of energy processing, as we saw.

- **3.** The first curve shows the carbon intensity of GDP, **not of energy itself**, and it is the carbon intensity of ENERGY which is the climate-relevant quantity to consider, and since…
- **4.** It's not current GDP, but the sum total of ALL past global GDP that is the relevant denominator in the Power/Wealth ratio.
- Remember, we need to not only generate new GDP, but **support all past GDP** by our current energy consumption – and the past cannot be changed.
- **5.** Global economic growth in GDP is far **faster** than CO2/$GDP improvements, so **carbon emissions continue to grow**. Indeed, that growth is HELPED by these CO2/$GDP improvements. Climate doesn't care about your falling carbon intensity.

Look past all the Renewables victory dances among the promoter$, to the stark truth. Renewables are going up, yes – but ENERGY is EVERYTHING; we will use ALL we can lay hands on



carbonbrief.org

Analysis: Why coal use must plummet this decade to keep global warming below 1.5C | Carbon Brief

Are You Still Bothered with the Nagging Thought…

"But wait a minute! How can power consumption stubbornly remain proportional to sum total global GDP over all time, and yet we are continually getting more and more GDP for each unit of energy consumed?

It just doesn't seem RIGHT"

We Have Indeed Been Lowering the Amount of Energy Needed to Generate a Dollar of Global GDP

- And that is 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 a rate of **1.155%** per year. But real global GDP (MER accounting) has been rising faster; over **2%** per year.
- Look at the trend in global energy efficiency (next slide) and notice that the downtrend, while smooth, is not perfectly smooth, and notice when the kinks happen…

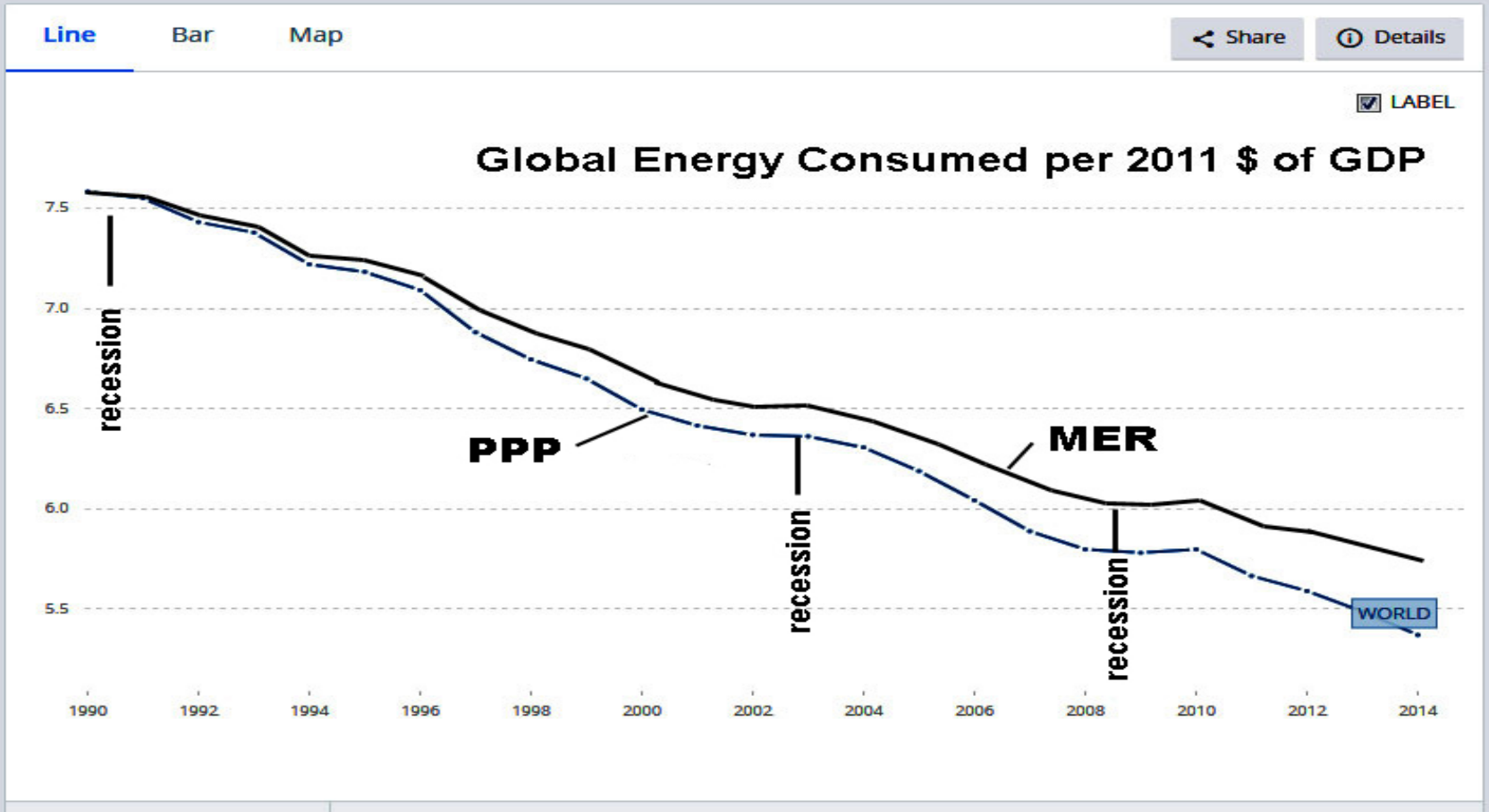
_f(t) == P(t)/G(t):_ Primary Energy Consumption Rate (_P_) per unit of global GDP (=_G_) is an approximately linearly dropping function. But note that during recessions (1990, 2001 and 2008/2009) _f(t)_ went flat, so that the slope went to zero.

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

Line Bar Map Share Details



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 a few years ago.

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

Differentiating with respect to time **t** gives…

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

Now, the Garrett Relation is…

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

Differentiating with respect to time **t** gives…

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

and substituting this into (2) then gives

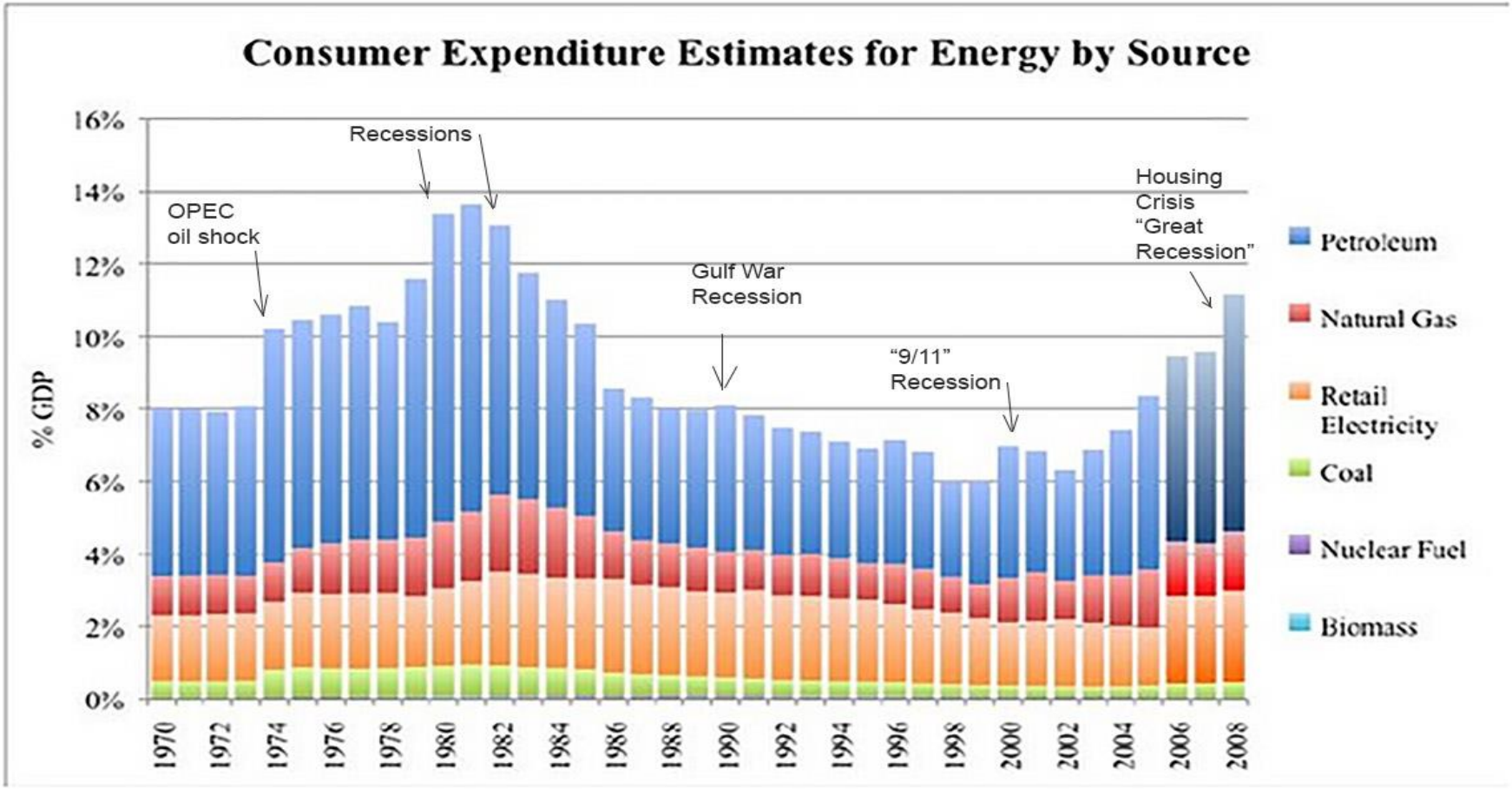
(5) $$\frac{1}{\lambda} = \frac{\partial f}{\partial t} + \frac{f}{G}\frac{\partial G}{\partial t}$$

And So…

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

- The left side is a constant, positive. But on the right side, the first term is (usually) negative and approximately constant (~linear down-sloping f; It's the slope of the curve 2 slides ago).
- The 2nd term **is** usually positive, over-ruling the first term as it must. However it is negative during economic recessions, when $\partial G/\partial t$ is negative. But that f graph showed indeed recessions are also when official $\partial f/\partial t$ rises to zero or even positive.
- Averaged over the noisy (and unreported error limits of the economists' data) boom and bust economic periods, the equation indeed holds...

The U.S. is often touted as a better example of energy efficiency and GDP. But note that every recession carries not only a worsening of GDP, but an increasing energy per $GDP, just as the Power/Wealth Relation requires globally (Hall & Balough 2009). Energy efficiency worsens during recessions.



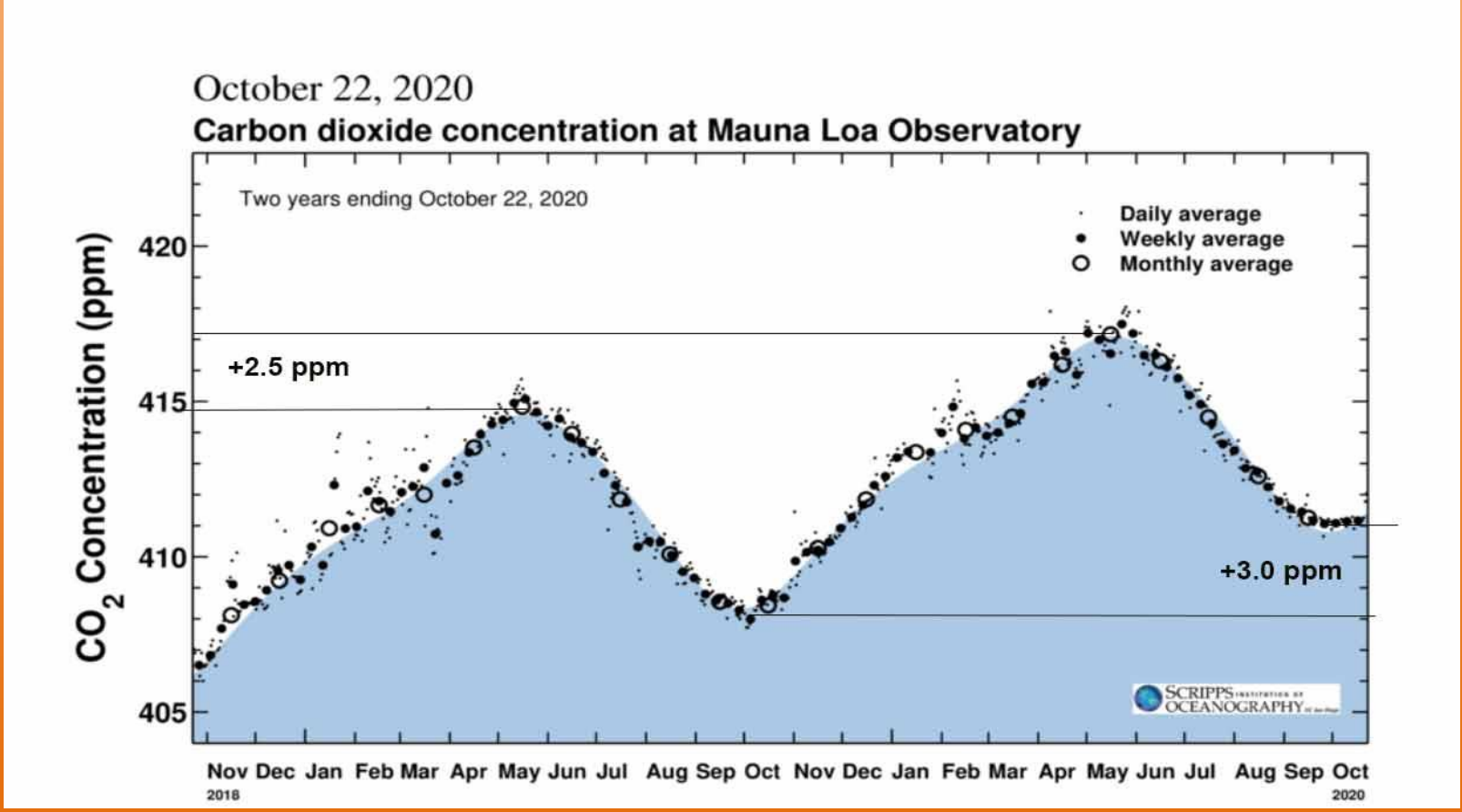
But Here is the Alarming Conclusion…

- If the relation continues to hold true, and we were to enter a prolonged recession, it suggests 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.
- **Energy Consumption then Grows FASTER than GDP.**
- The logic - as I see it – is this: We'd be struggling with, and prioritizing, merely maintaining past growth's Wealth against decay, so that current energy consumption would be growing FASTER than GDP.
- Limited Federal Reserve studies are consistent with this (see later).
- **This is a double-bind we'll come back to later as we consider the implications of the Power/Wealth Relation to our future.**

But Surely A Major Depression Would Lower CO2 Emissions, Right?

- We've just had one – the CoVid19 pandemic induced the 2020 Depression.
- Did it lower our emissions?
- The U.S. suffered a 34% drop in GDP in the 2nd quarter of 2020 (annualized). **34%!**
- China had their lockdown earlier, in the first quarter and 2nd quarter of 2020.
- **Did we see a significant drop in CO2 emissions? NO.**

The Keeling Curve Oct 2018 - Oct 2020. The peak-to-peak dropped a bit, from +3.0 ppm per year to +2.5 ppm per year. But 6 months later, trough to trough it shows NO reduction – still rising at 3.0 ppm per year



China, other Autocratic Countries: Over-Reporting GDP, Hence Over-Rosy Energy Efficiency Figures

- A review paper from the **St. Luis Federal Reserve** cites numerous studies indicating China's reported GDP growth is often as high as 1.65x to 2x overstated; for multiple reasons.
- Power consumption, on the other hand, is easier to measure even in China: Night luminosity by satellites is one proxy, and, after calibration, indicates a strong over-reporting by China officials of their GDP. (**Owyang and Shell 2017 – St. Louis Fed**). And **more recently**.
- If GDP is over-reported, it means China's energy efficiency improvements are also overstated. Globally as well, perhaps, since China is the world's second largest economy.

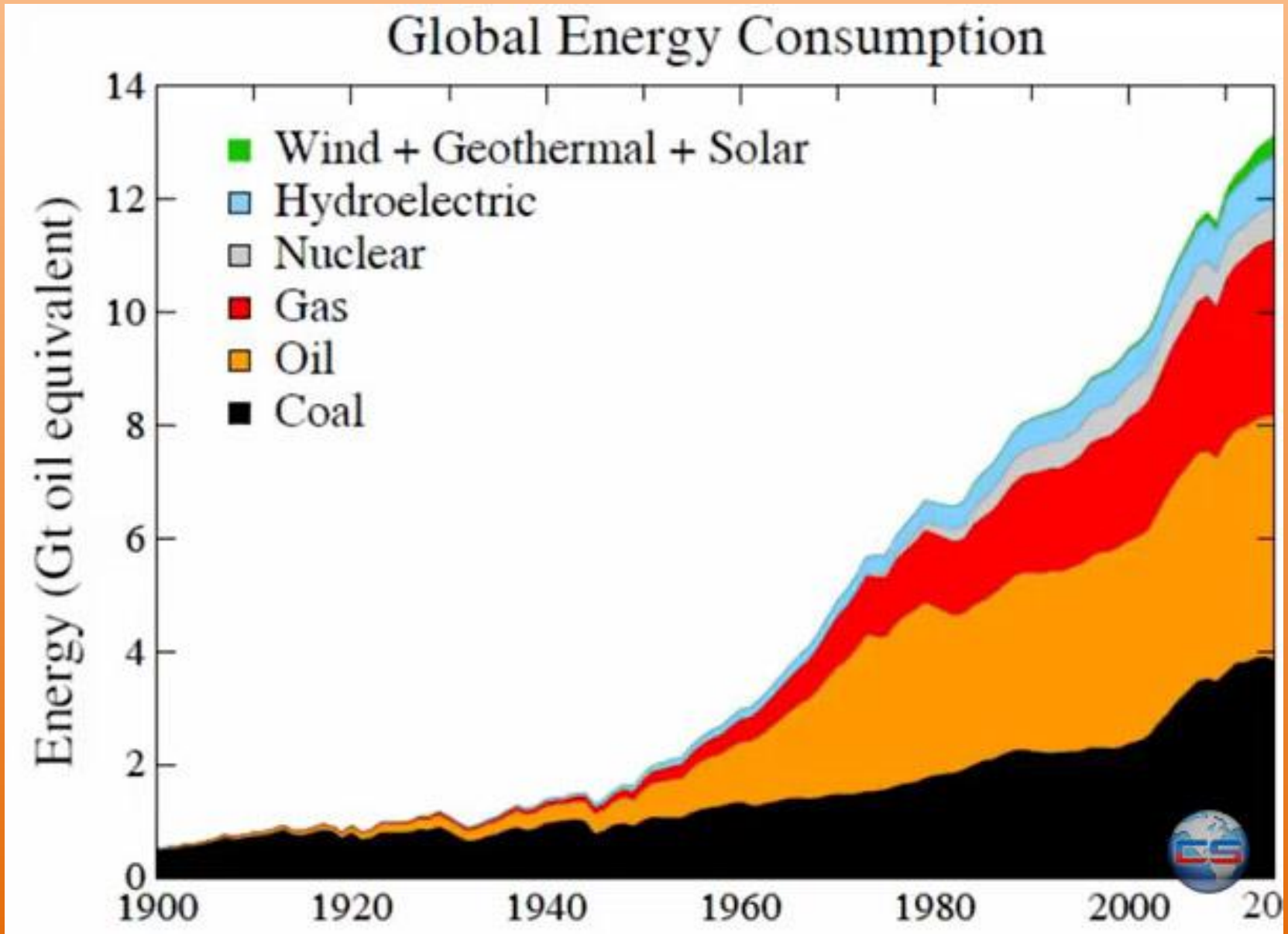
Worse, China and Globally too, UNDER-reporting GHG emissions

- Meaning, under-reporting energy consumption! Other countries as well. (**Mooney *et al.* *November* 2021**)
- This new study shows that emissions reporting, which folds into so many figures you'll see, are strongly biased to the rosy side.
- Global emissions are ~27% UNDER-reported. That's a staggering amount, as the shady accounting and gaffs in what's allowed, are fully taken advantage of by the policy people and economists they employ.

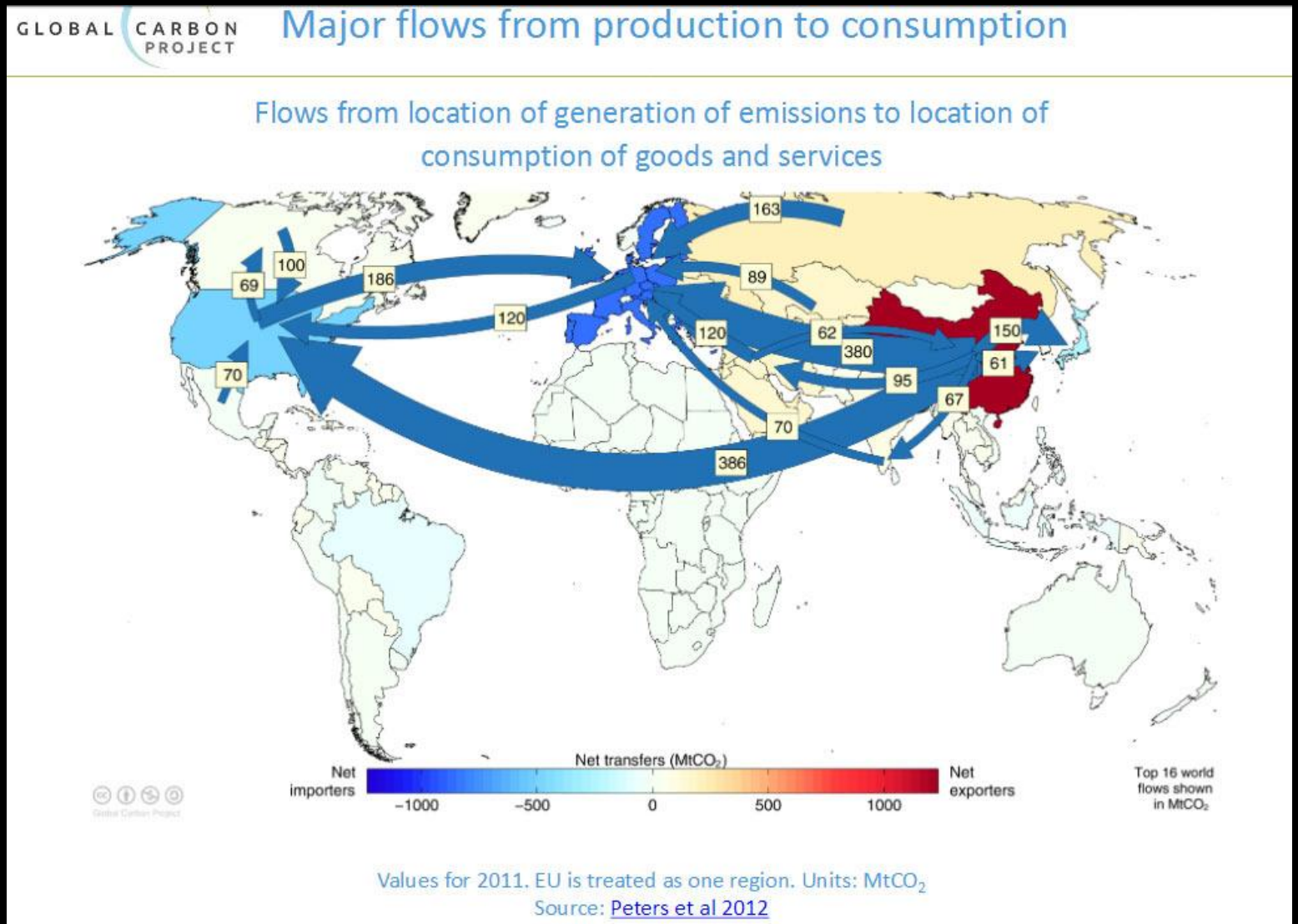
So In Fact, A Closer Look at the Validity of the Official GDP Data from China Supports the Power/Wealth Relation's Implications Here

- Energy efficiency data indeed indicates reversal during economic recessions… more on this later.
- I'll call this…
- **"The Recession - GDP Bias"**

Global energy consumption, including fossil fuels, continue to skyrocket (2017 data)



Strong CO2 Emissions in Asia generated by manufacturing goods flowing to the U.S. and Europe. We get the goods, they get the carbon guilt. An inconvenient fact not highlighted by policy people. U.S. trade deficit, mostly with China, set a new record $50 billion as I write this in early '18



For decades, China's Central Planning has put them through Cycles of Overbuilding (think "Ghost Cities"), followed by a fallow year or two. Excited declarations of "Peak Emissions" are premature. It's just cycles. There is no question China is determined to grow much larger, requiring more energy, still mostly provided by coal and other fossil carbon for now. GDP growth reported 7% in 2017

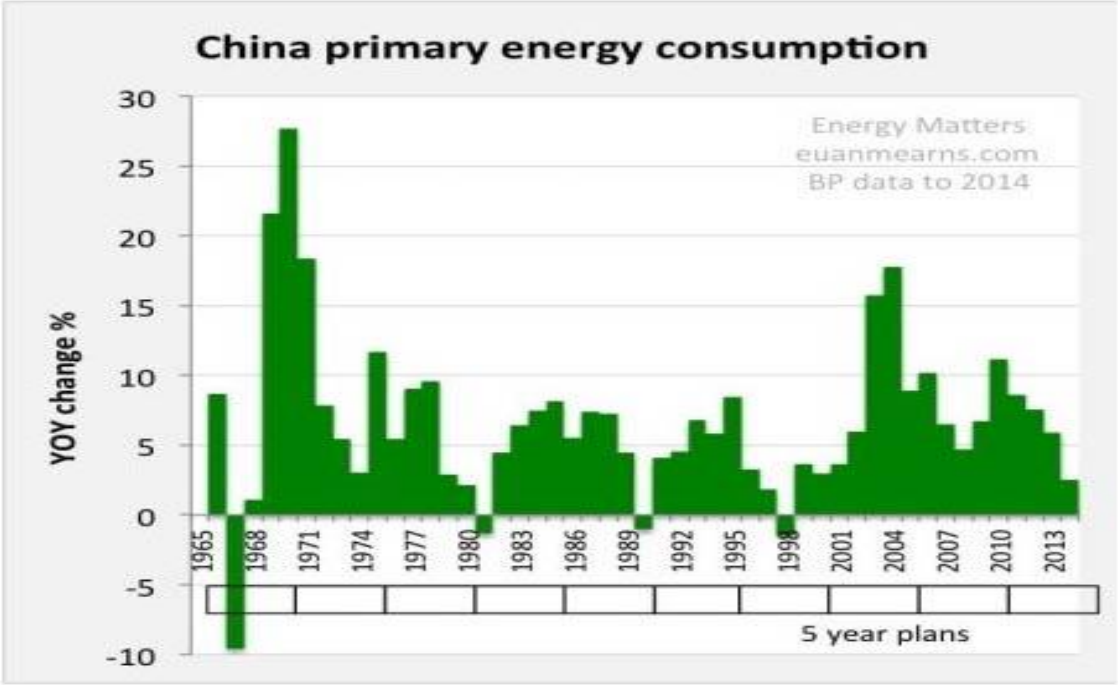
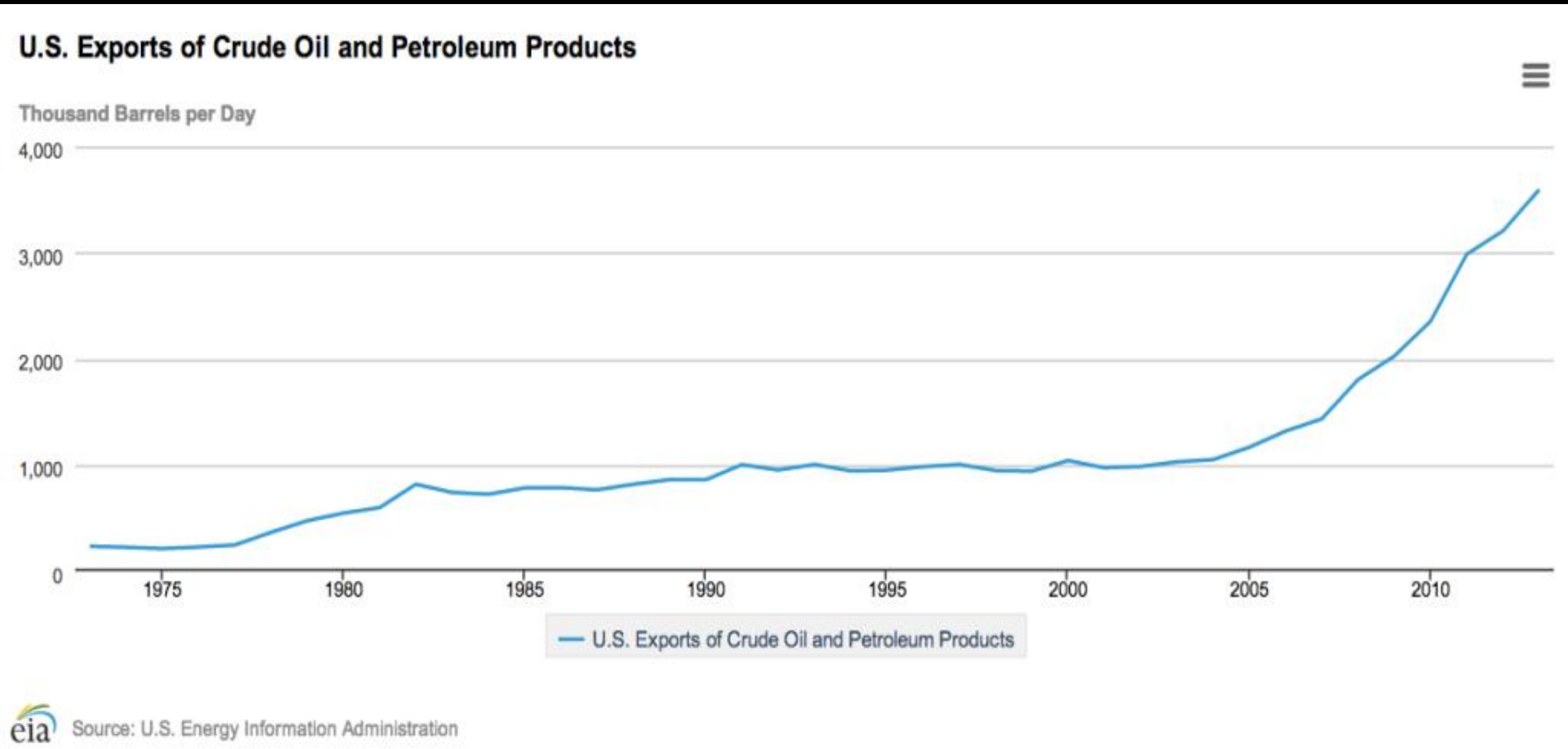
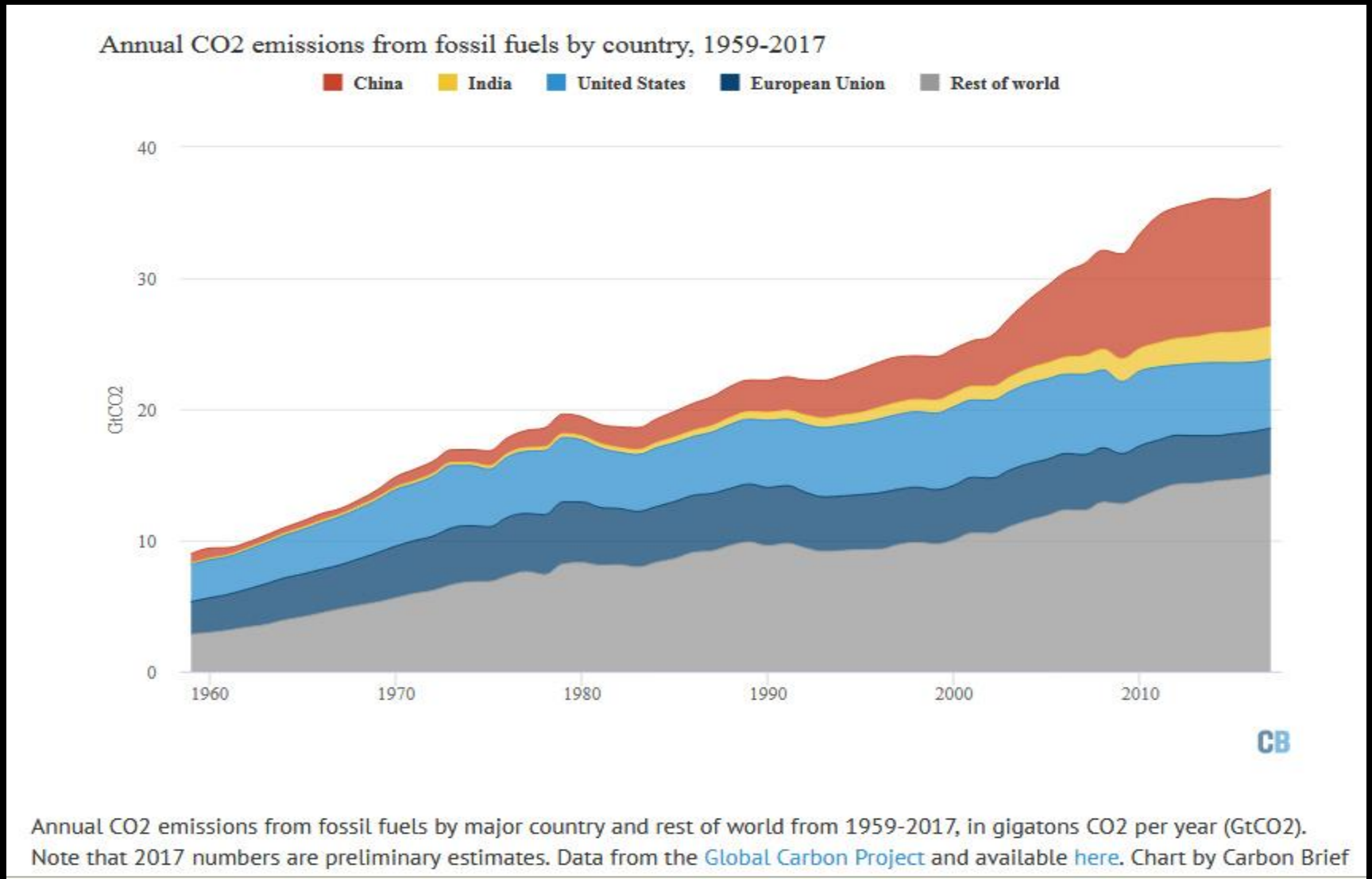


Figure 6 This chart plots the year on year (YOY) changes in China's energy consumption (Figure 2) and reveals this somewhat surprising and interesting pattern. There appears to be a quasi 9 year cycle with growth lows in 1967, 74, 81, 90, 98 and 2008. The recent slowdown in energy growth since 2010 is clear to see. It is tempting to speculate that this pattern is linked to the 5 year central planning cycle although it is not obviously so. If this pattern means anything, and it may not, then it may be 2017 before China's energy consumption accelerates again.

So, while we in the U.S. may not be burning quite as much… instead we're rapidly accelerating the exporting of our fossil fuels to other countries, especially Asia, and THEY burn it. Burned is burned - climate doesn't care WHO burned it



“Peak Emissions” Celebration? Put Away the Party Hats - 2017 CO2 Emissions Rise +2%, Led by China’s +3.5%. And continuing…



Annual CO2 emissions from fossil fuels by major country and rest of world from 1959-2017, in gigatons CO2 per year (GtCO2). Note that 2017 numbers are preliminary estimates. Data from the Global Carbon Project and available here. Chart by Carbon Brief

As of late 2018, the predictions are for steeply rising oil production going forward (source)

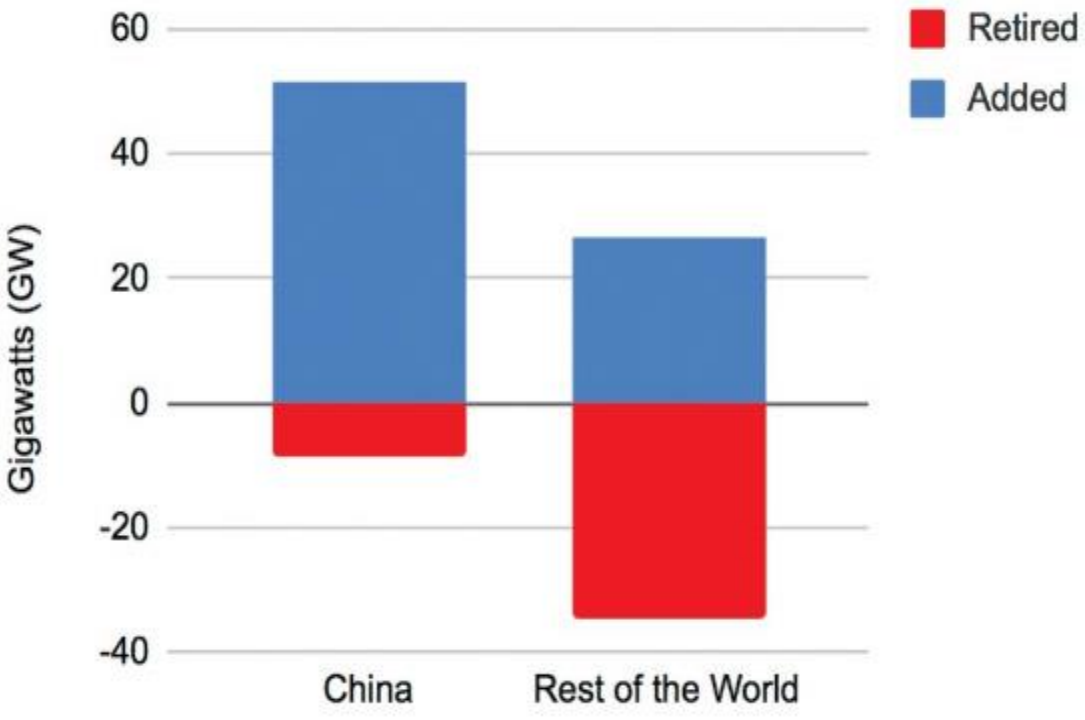
- Dramatic rise in air travel as wealth rises in developing countries, is an important contributor).
- By 2040 expected 2.4 billion global vehicles, more than double today's 1.1 billion.
- Renewables also expected to rise rapidly, accounting for 20% of global power demand by 2040, but fail to prevent oil demand from also rising, 13% by 2040.

China is lauded as leading in Renewable Energy Development, but the real story isn't as heart-warming…

- As of 2018, 259 GW worth of **new coal-fired power plants** are in the China pipeline, about the same as the **entire current coal-fired power of the U.S.**

New in 2019, The China Coal Story Gets Significantly Worse

Figure 1: From January 2018 to June 2019, countries outside of China decreased their total coal power capacity by 8.1 GW, while China increased its coal fleet by 42.9 GW.

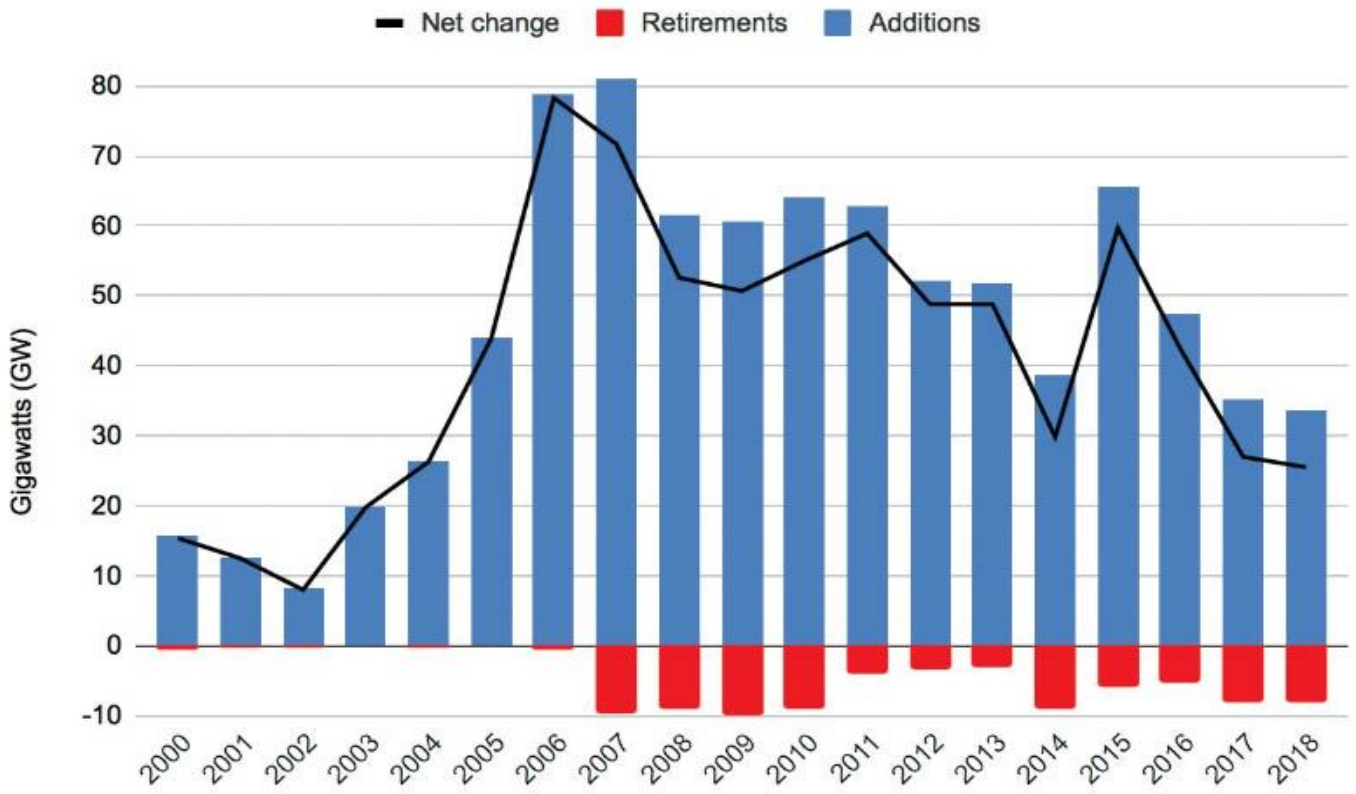


Source: GEM, Global Coal Plant Tracker, July 2019.

Shearer *et al.* 2019 show that China has added a remarkable 42 GW of new coal-power capacity – 2x more than the entire rest of the world. And **121 GW of new coal power construction is under way.**

Growth is China's Prime Directive: Growth is Economic, Political, and Global Power, and Power is Coal. Renewables Growing too, but only as a small add to the Power Portfolio

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

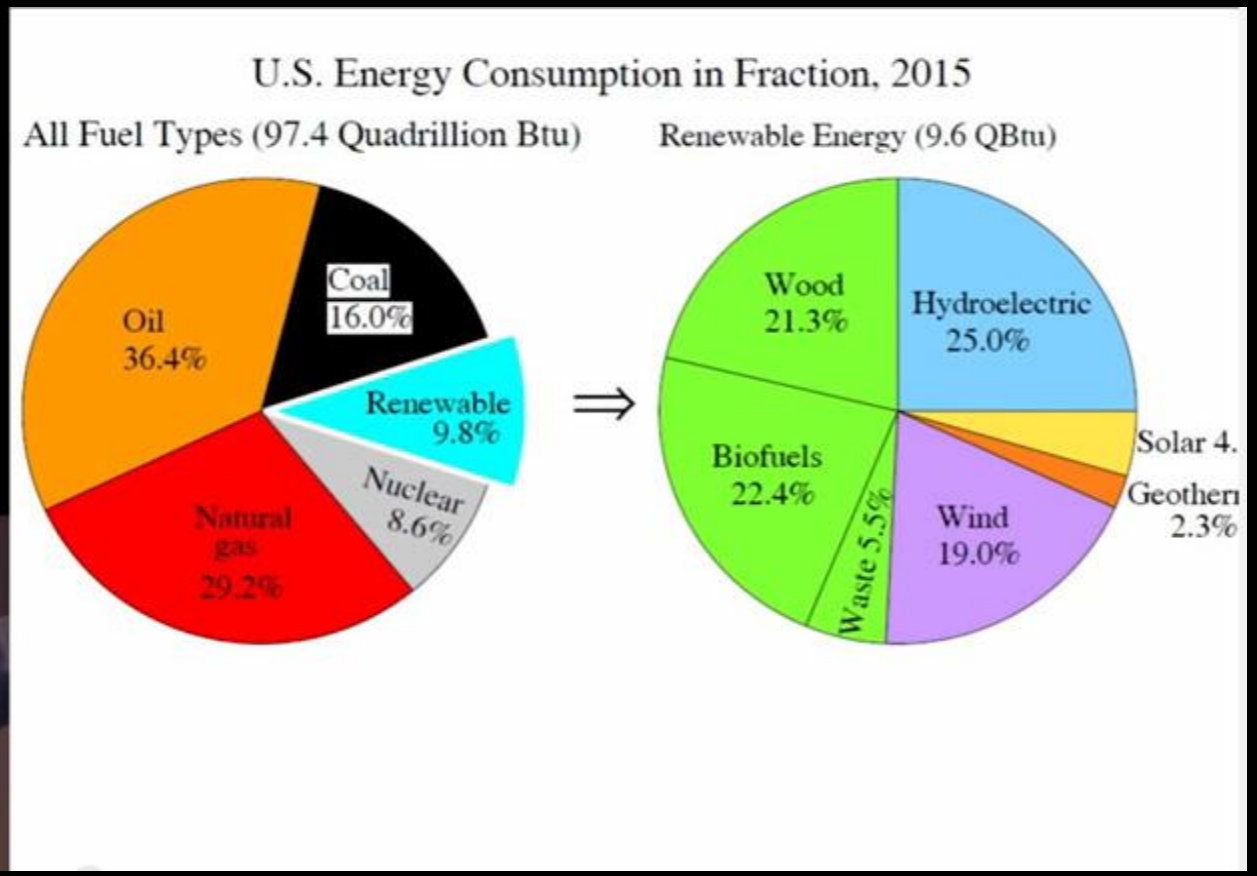


Source: GEM, Global Coal Plant Tracker, July 2019.

Totally Incompatible with their Paris Agreement Promises

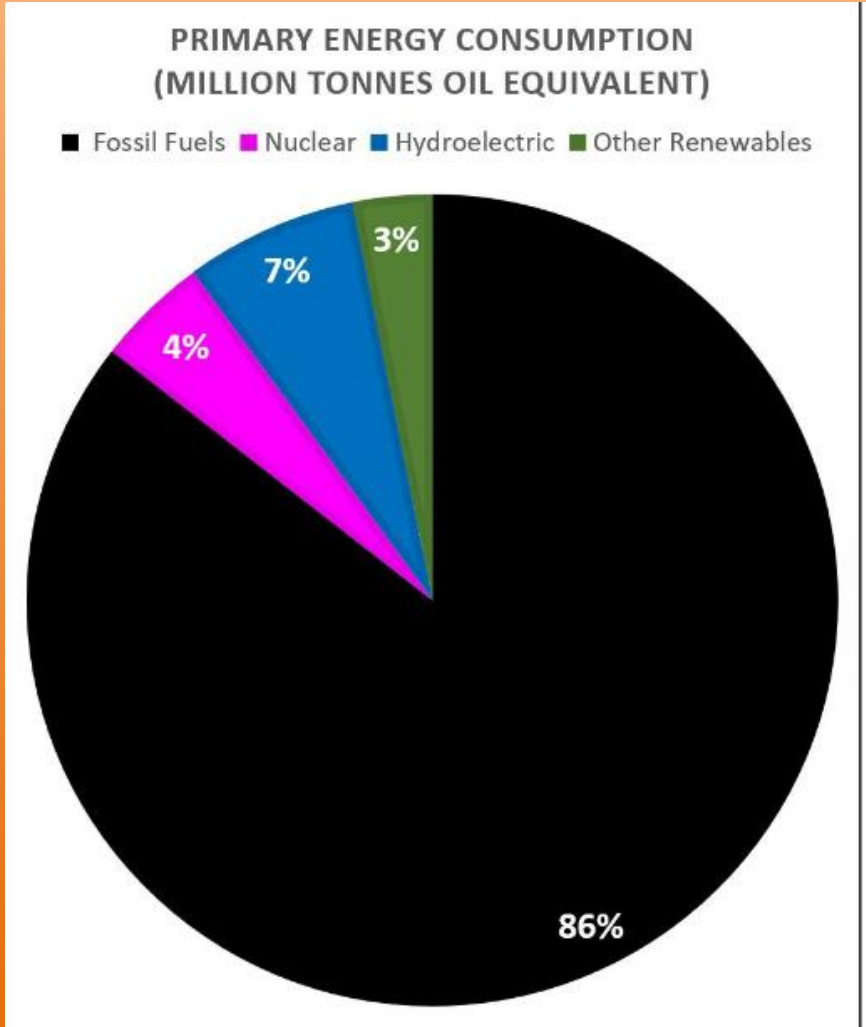
- *"China's proposed coal expansion is so far out of alignment with the Paris Agreement that it would put the necessary reductions in coal power out of reach,* ***even if every other country were to completely eliminate its coal fleet,*****"** said co-author Christine Shearer of the *Global Energy Monitor*. (**source**).
- Disregard the eco-promo promises. In 2020, the post-CoVid growth is **fueled by coal,** with associated scandal.

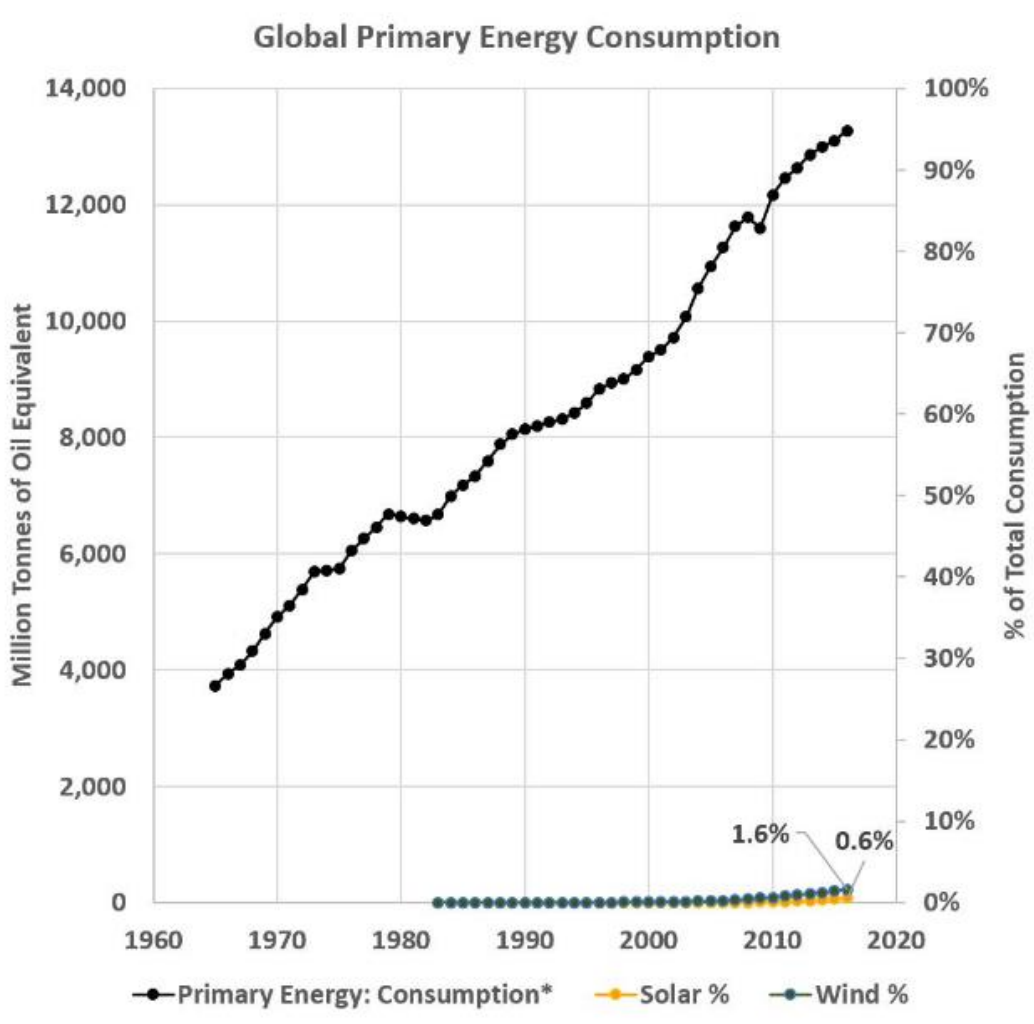
And then there's this spin on "Renewables" – You'll read that 10% of the U.S. Energy Mix is "Renewables" – Hurray!



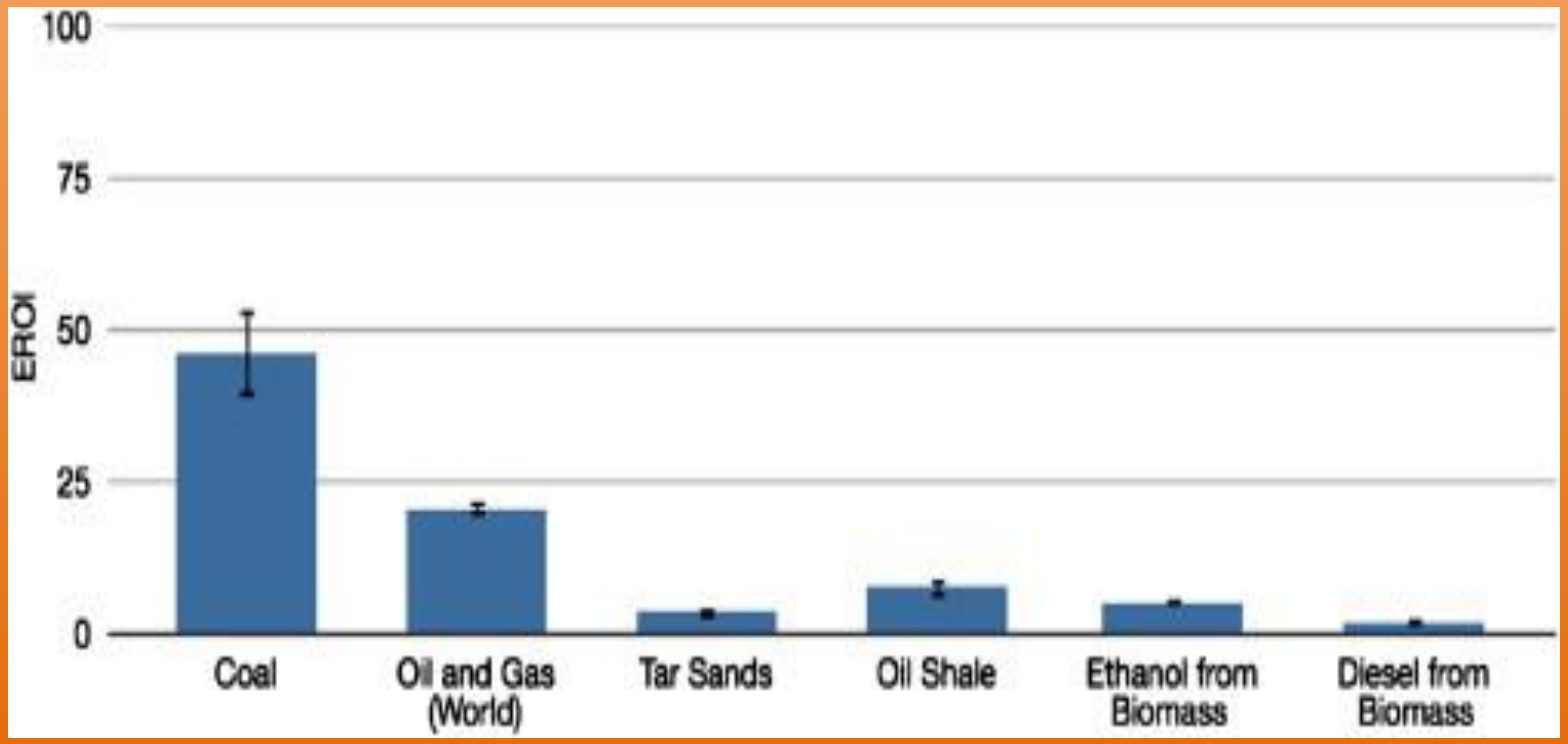
- But in fact, half of the "renewables" are actually the burning of wood, biofuels, and waste… none of which are, properly, even carbon neutral – once you account for inefficiencies, transportation, etc… and the energy needed in infrastructure to harvest and process these, so in fact the **real** number is more like 5%. That's James Hansen at lower left.

Even clearer – Global primary energy consumption is rising at a faster rate than Solar and Wind as of 2016





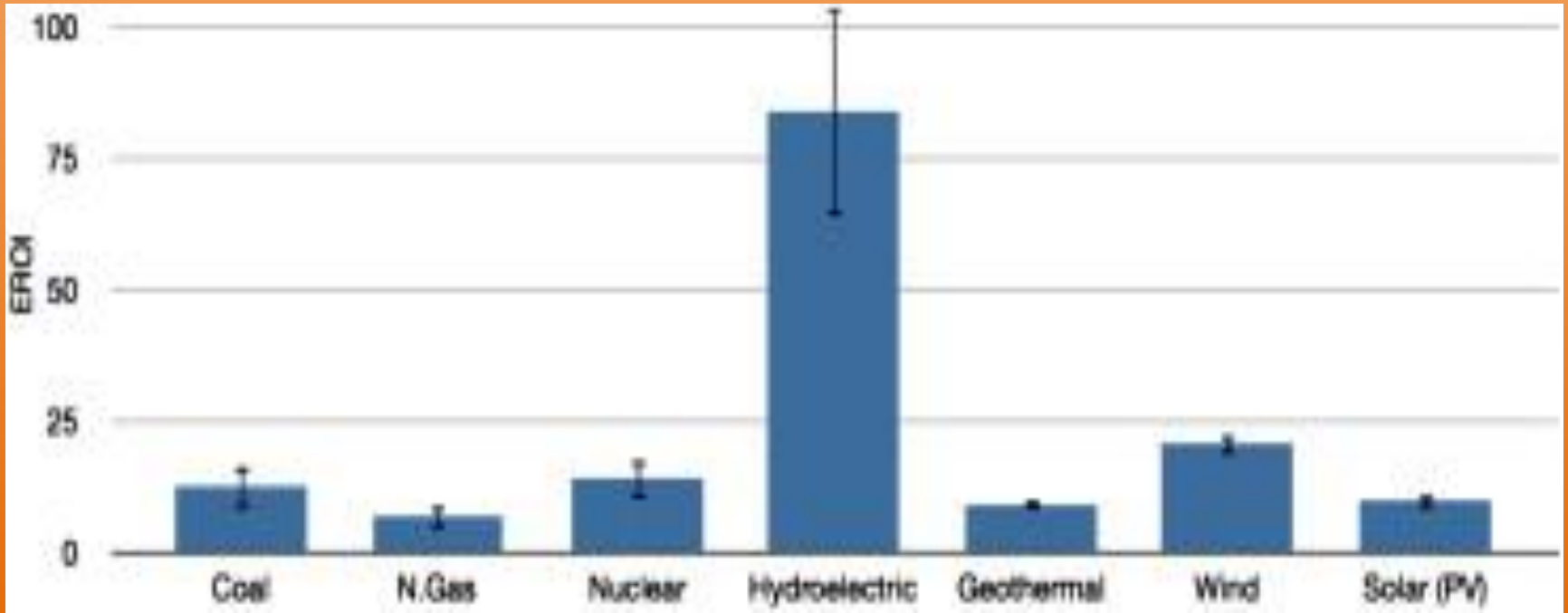
Why such heavy reliance on coal? Coal's Energy Return on Energy Invested (EROI) is far better than other sources (Hall *et al.* 2014)



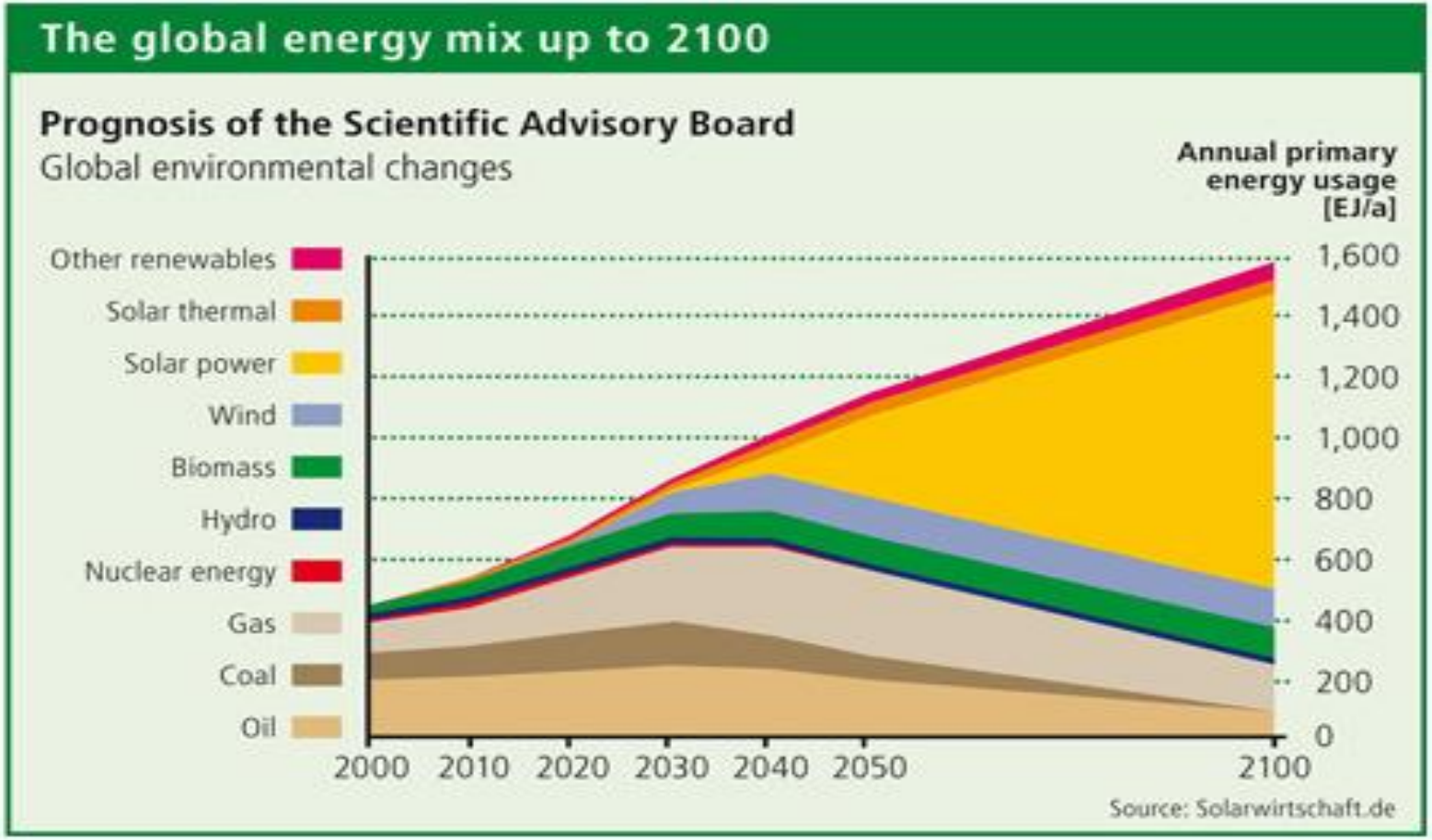
EROI for Renewables is Much Poorer.

- While solar PV panel costs are going down quickly, EROI is not dropping nearly as fast, and ultimately it is EROI which determines a civilization's fate.
- Be wary of EROI values published by renewables promoters. They are heavily influenced by assumptions. Example, **Hall et al.** point out their average for solar PV over a wide range of studies (next slide) don't include energy costs for backup and storage due to intermittancy.
- **This is what irks me about the promo pieces – they force educators like me to disentangle the truth from the froth, then endure the "party pooper" wrath of the eco-friendlies, while wasting my time. Time that could have been saved by simple intellectual honesty from the start.**
- Prieto and Hall find that…

While these need updating, note EROI for Solar PV, averaged over 79 different publications, from Hall *et al.* 2014 is ~10:1, but a more careful analysis gives only ~2.5:1 (Prieto and Hall 2012, Weissbach *et al.* 2013, Palmer 2013). Hydro does not include more recent studies showing alarming methane emissions from resulting drowned vegetation. Nuclear here is old style conventional, which wastes 99% of the available nuclear energy. Thorium molten salt breeder reactors have much higher promise.

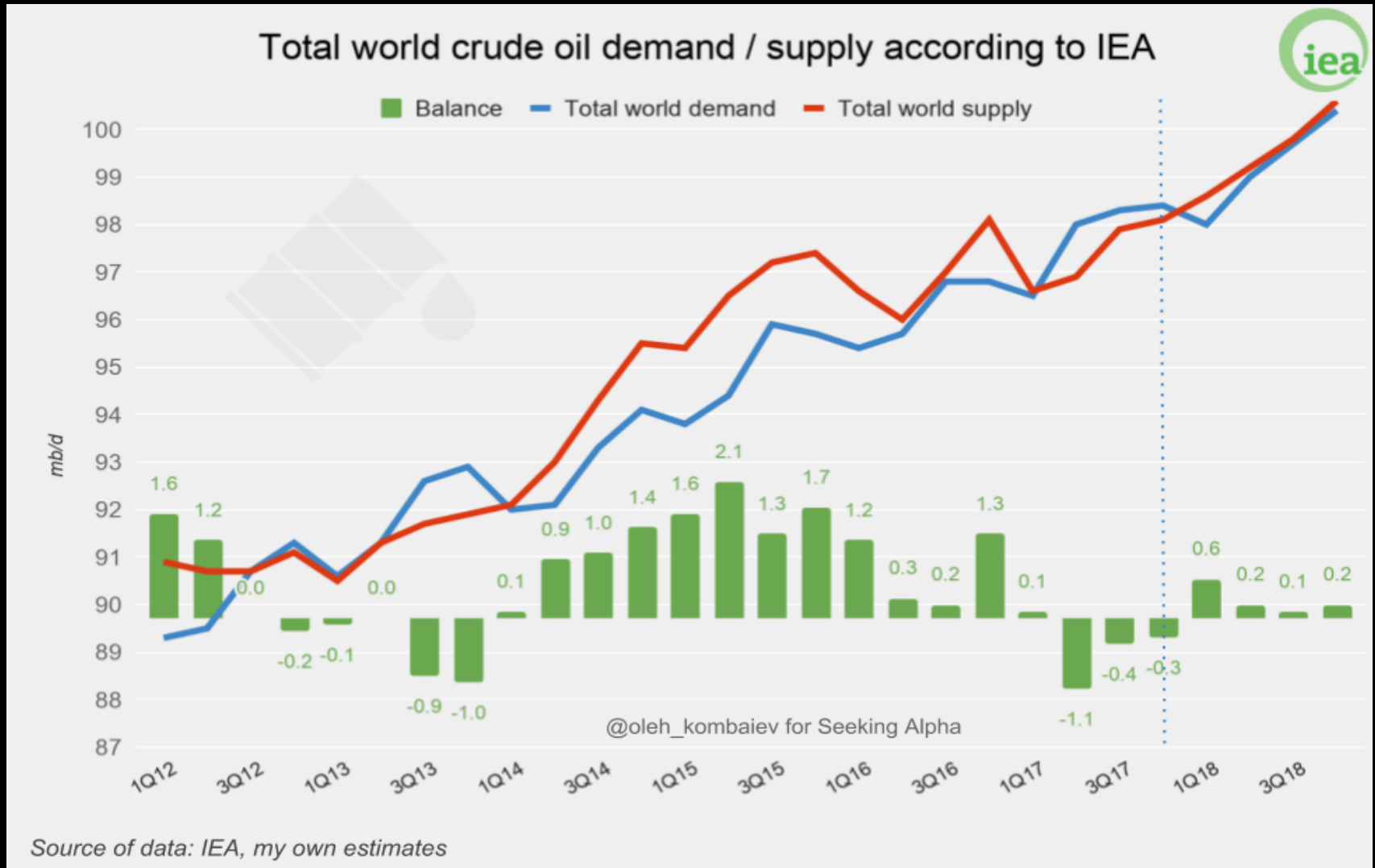


This analysis finds that global fossil fuel energy will continue to rise until peaking by 2040, and even staying higher than today right up till 2060; and this is from a solar energy organization's scientific advisory board, whom you'd guess would err on the side of solar optimism. Well-built fossil fuel power plants don't get decommissioned just to save the planet, not if they produce growth-inducing energy.



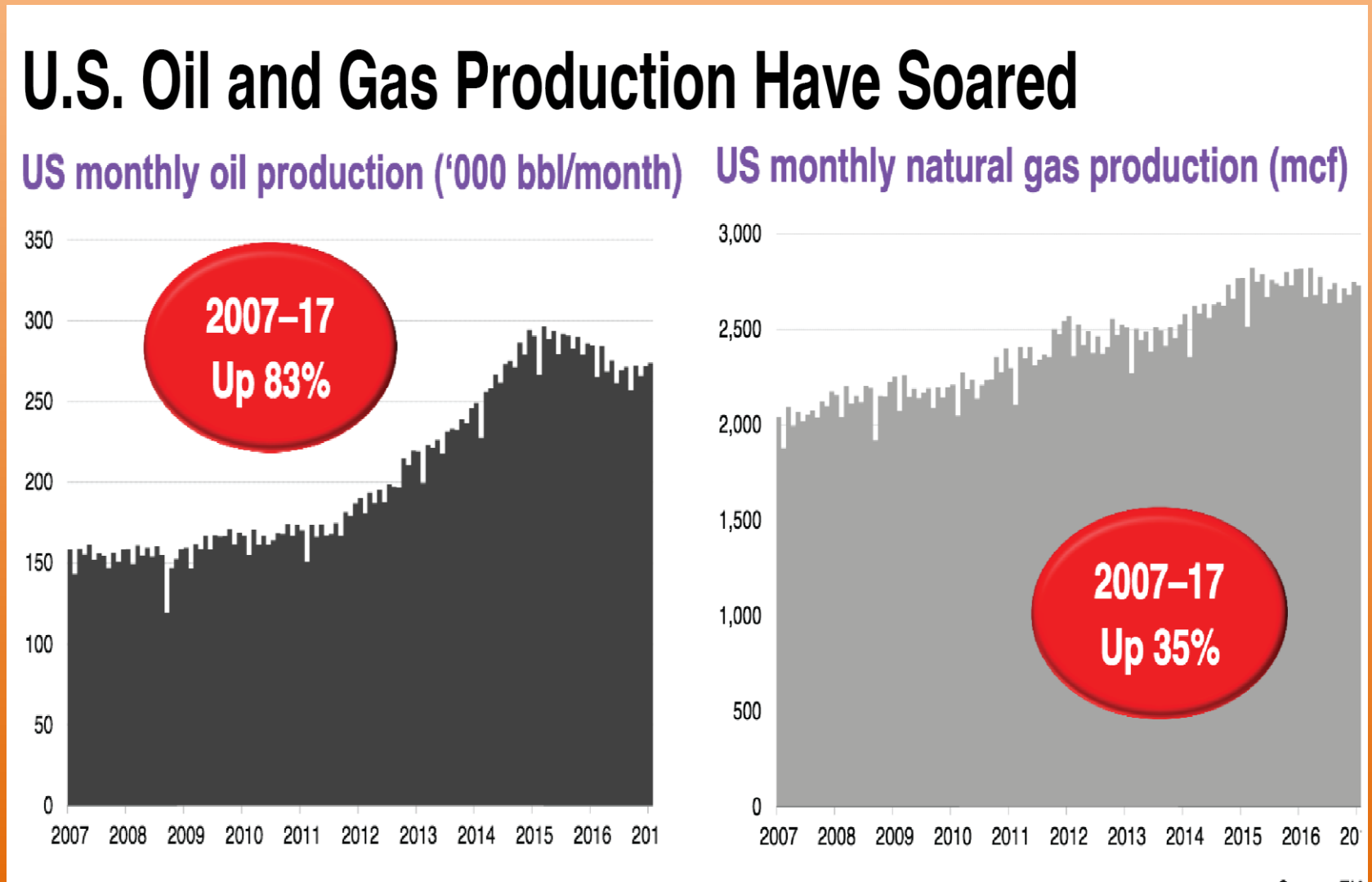
Source: http://www.solarwirtschaft.de

2012-18: Demand and supply continues to rise even during the global economic slowdown of '15/'16. Millions of barrels per day. Global oil demand growth rate 2013 to 2017 is 1.9% per year

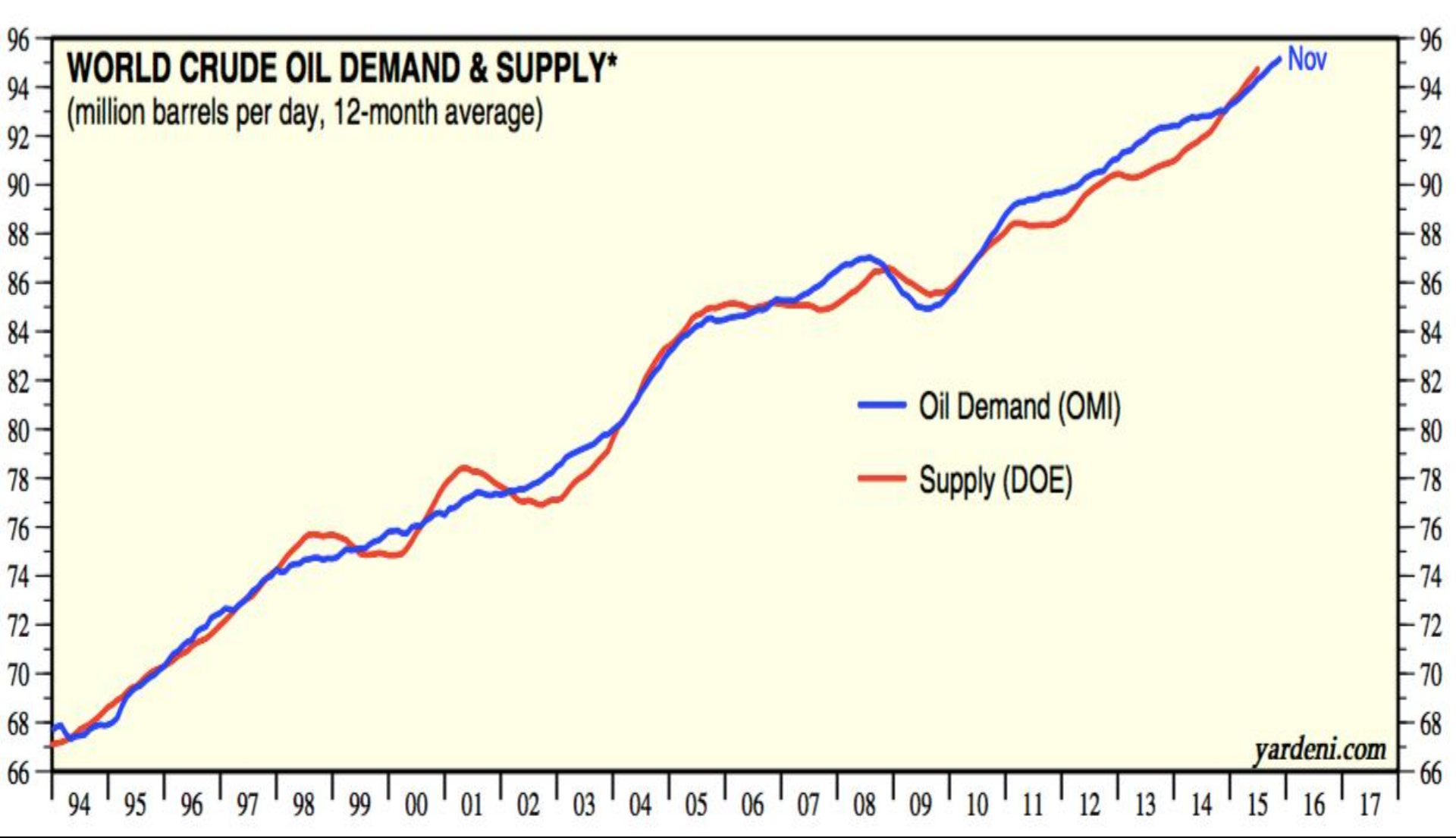


Source of data: IEA, my own estimates

If it's there to be drilled, we drill it - and sell it to other countries for THEM to burn. Why? We won't accept the loss of "stranded assets". U.S. Drilling rig count rose a strong 38% in 2017 alone.

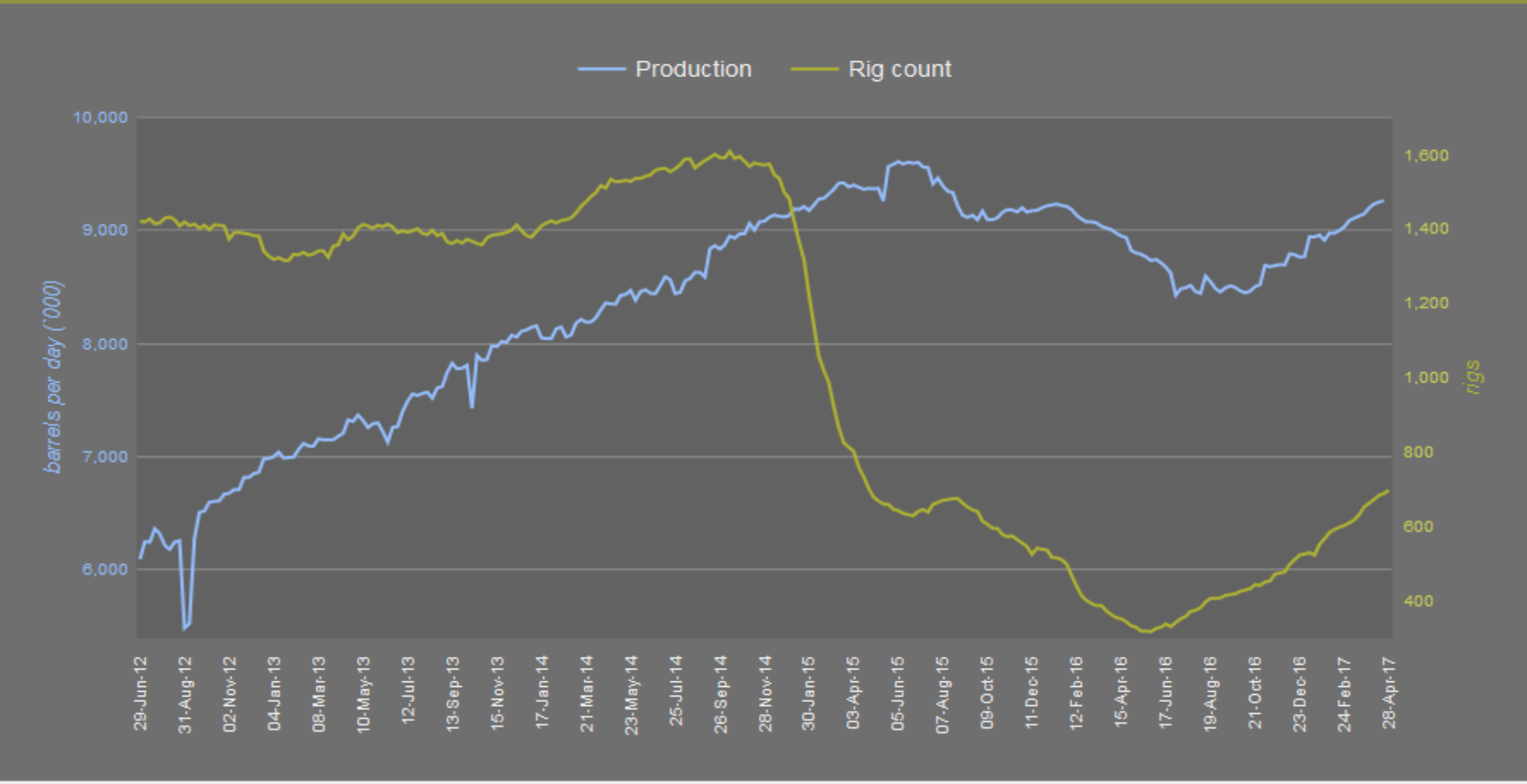


Past 25 Years, oil supply and demand rising 1.52%/year on average, with just small dips during the '01 and '08 "Great Recession". This is a rising RATE of demand curve, meaning CO2 emissions will be exponential, as indeed we saw



…Discouraging. But surely at least the U.S. is reducing its oil production, right? No. Oil production rose 50% in the 3 years up till summer '15, dipped, and then hit a new record in Dec '17, with rig counts rising once again

United States Oil Production and Rigs

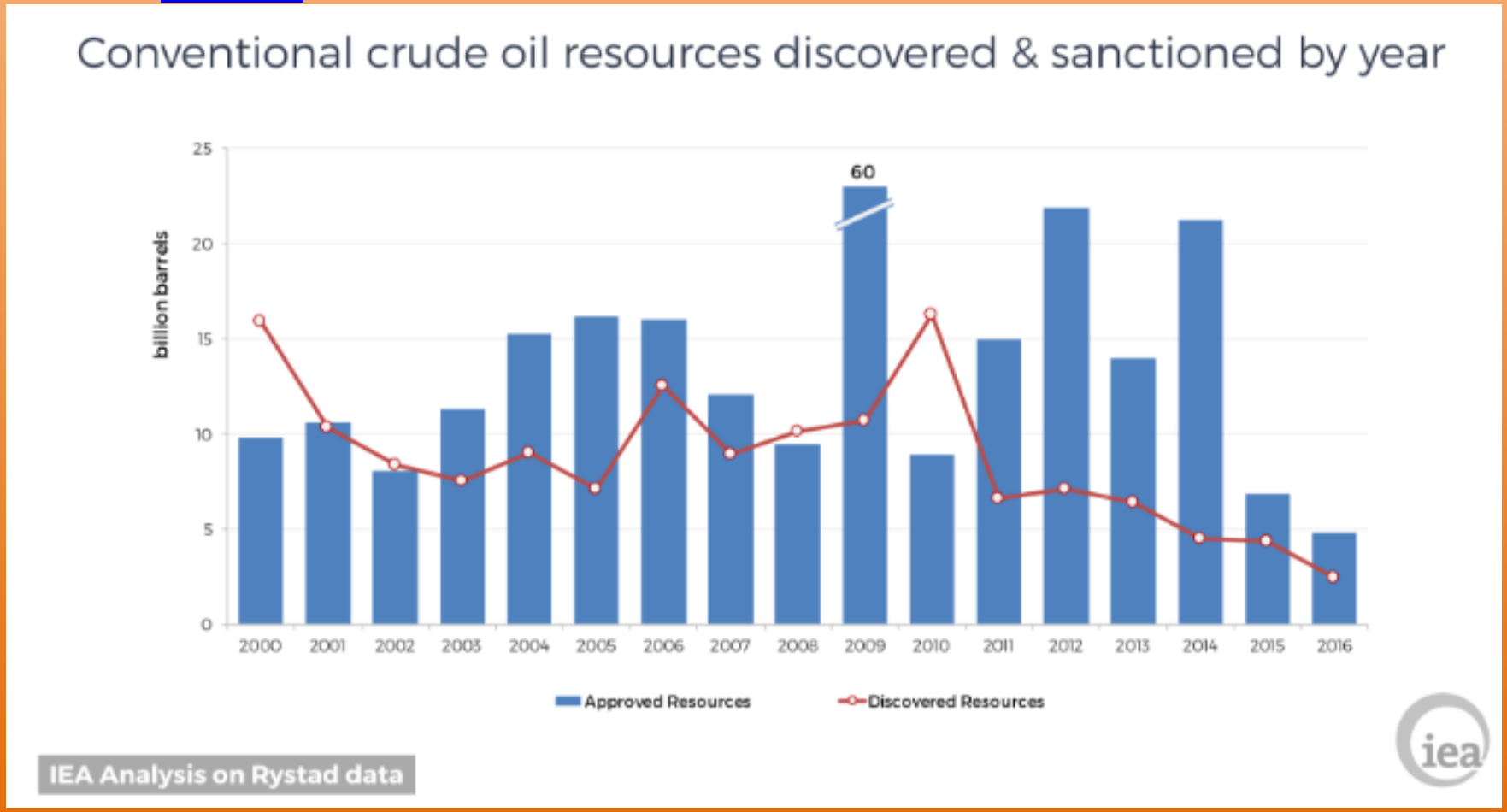


Source: U.S. Energy Information Administration, Baker Hughes

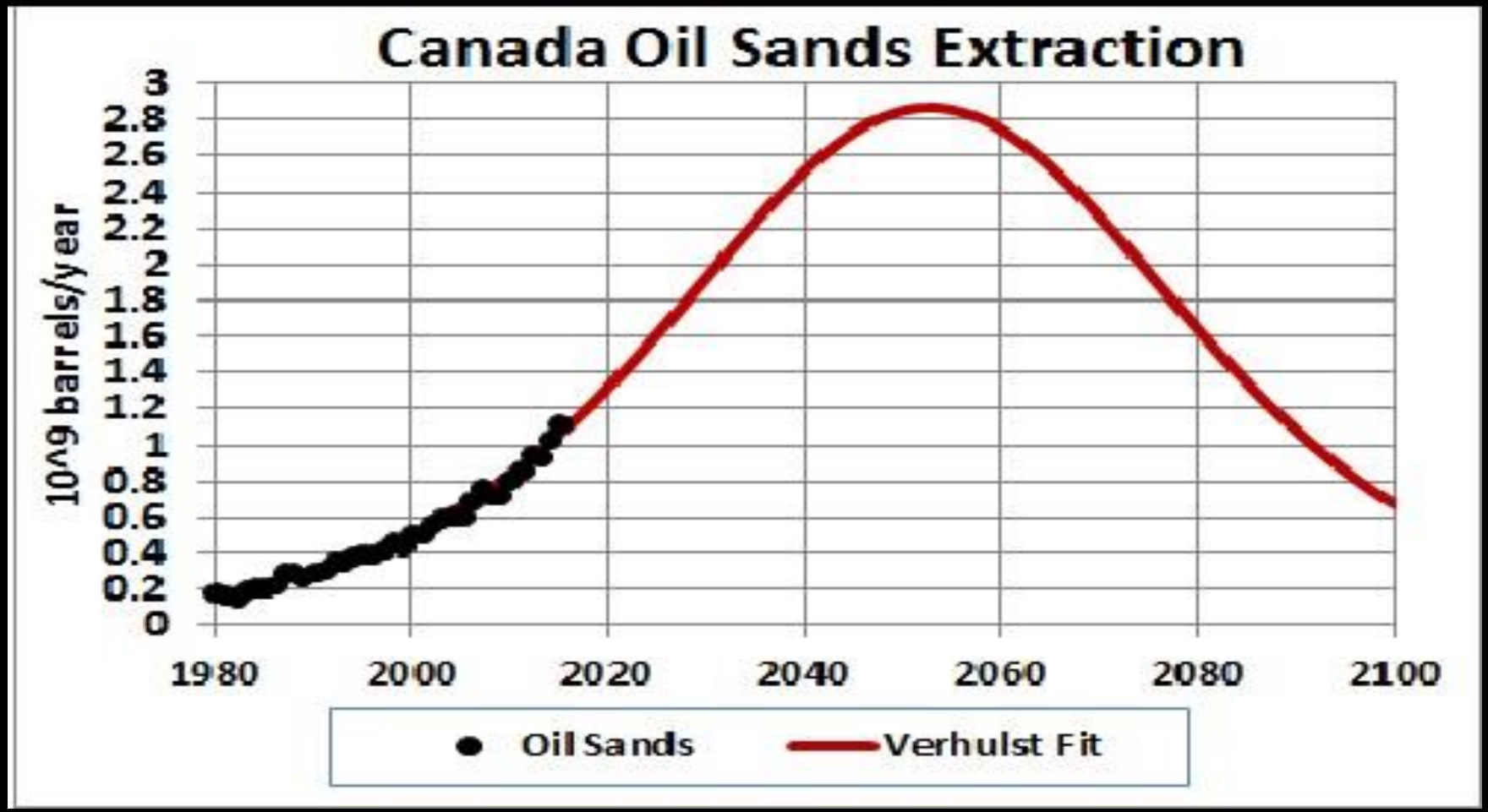
Last update: April 28, 2017, 13:20

These rises in oil use are happening despite the fact that conventional oil field discoveries were lately in decline. So is "Peak Oil" finally here?

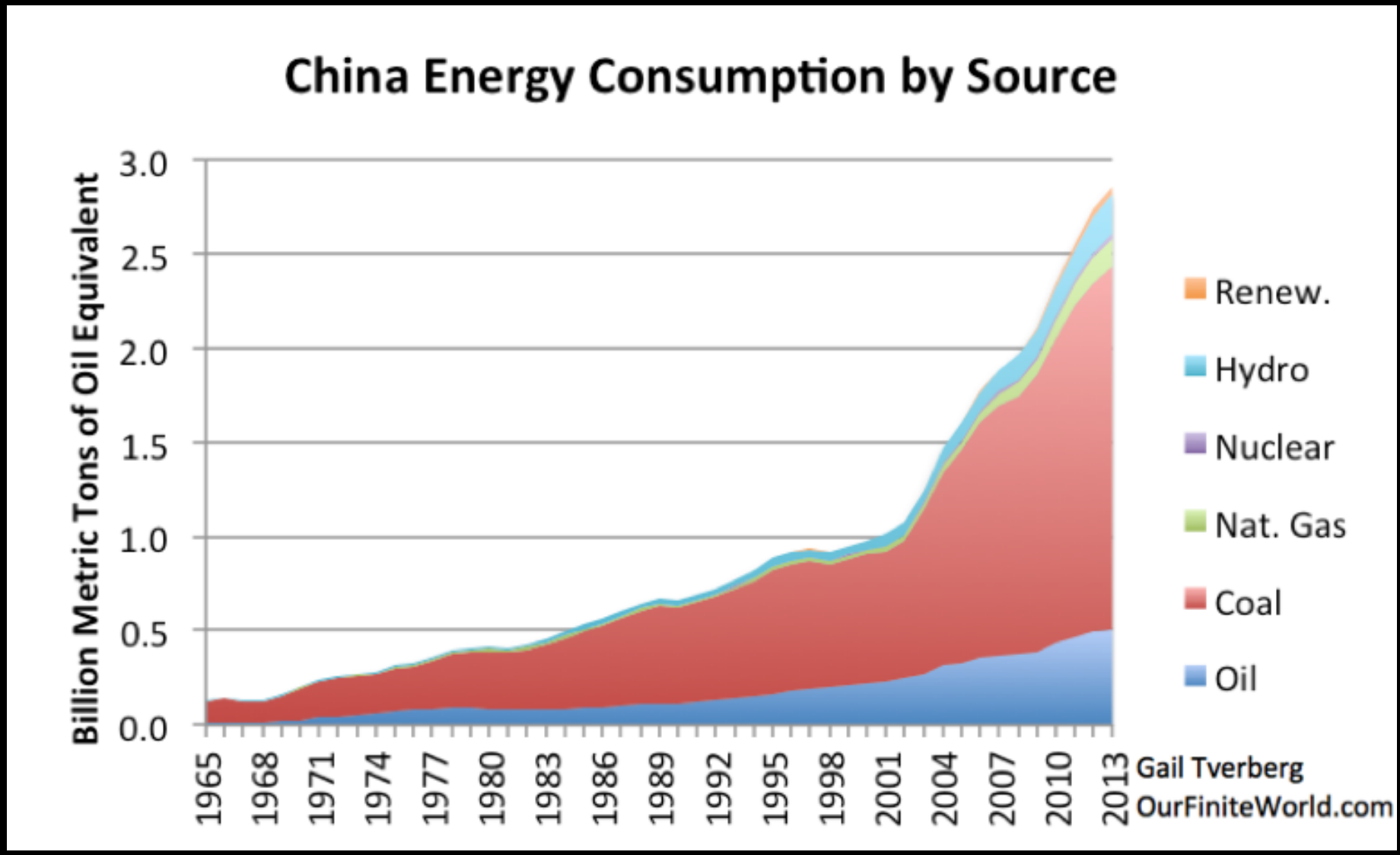
No. New global oil / gas projects rising 400% in 2019, and still unable to meet demand.



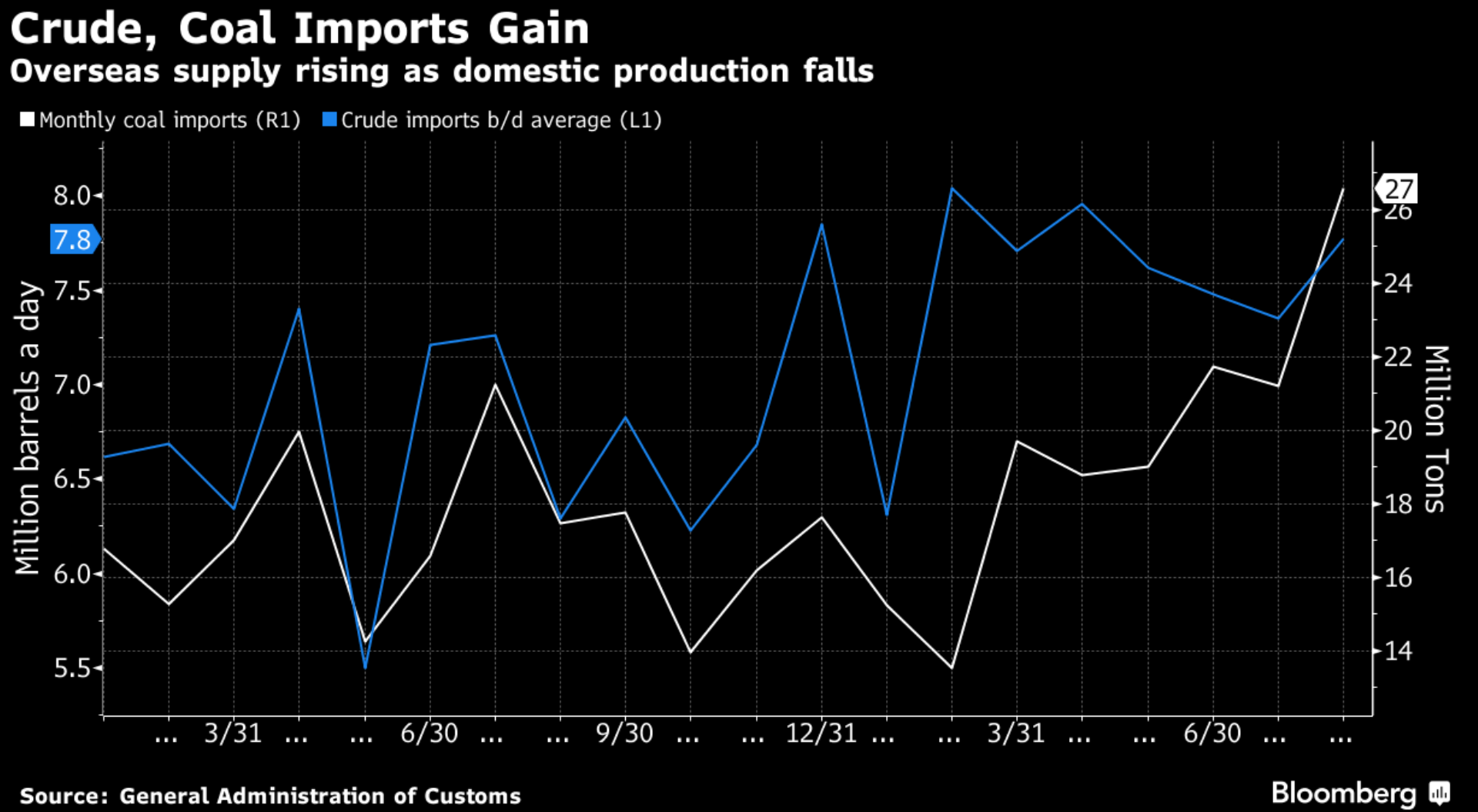
We continue to accelerate production rates every year for even the dirtiest of fossil fuels: Oil Sands. The red curve production rate fit is, of course, uncertain and depends on a speculative policy future. But the carbon is there to be exploited.



China – Energy consumption per year rising rapidly through 2013. Nearly all is carbon energy. But what about since 2013…?



Even in the near-recession year of 2015 and early 2016, China Imports of Coal and Crude Oil were Rising



Yes, China's Deploying More Renewables…

- They are growing their fraction of **new** power generation that is solar/wind. They deployed 34 GW of new solar in 2016, and expected in the 2016-2020 period to keep that pace, thus adding **110 GW of new solar**. That's admirable renewables growth.
- They've also *promised*, in 2017, to eliminate the production of new gas / diesel cars by the 2030-2040 time frame, as have many other countries (**source**). (But transportation is only 29% of energy consumption in the U.S., and only 25% globally - EIA figures)
- And the cost of (subsidized) solar is down to roughly that of (subsidized) natural gas, and solar is growing rapidly in the U.S. as well.
- **But that's progress in the service of economic growth, and therefore is making our ultimate dilemma of impacting Earth worse…**

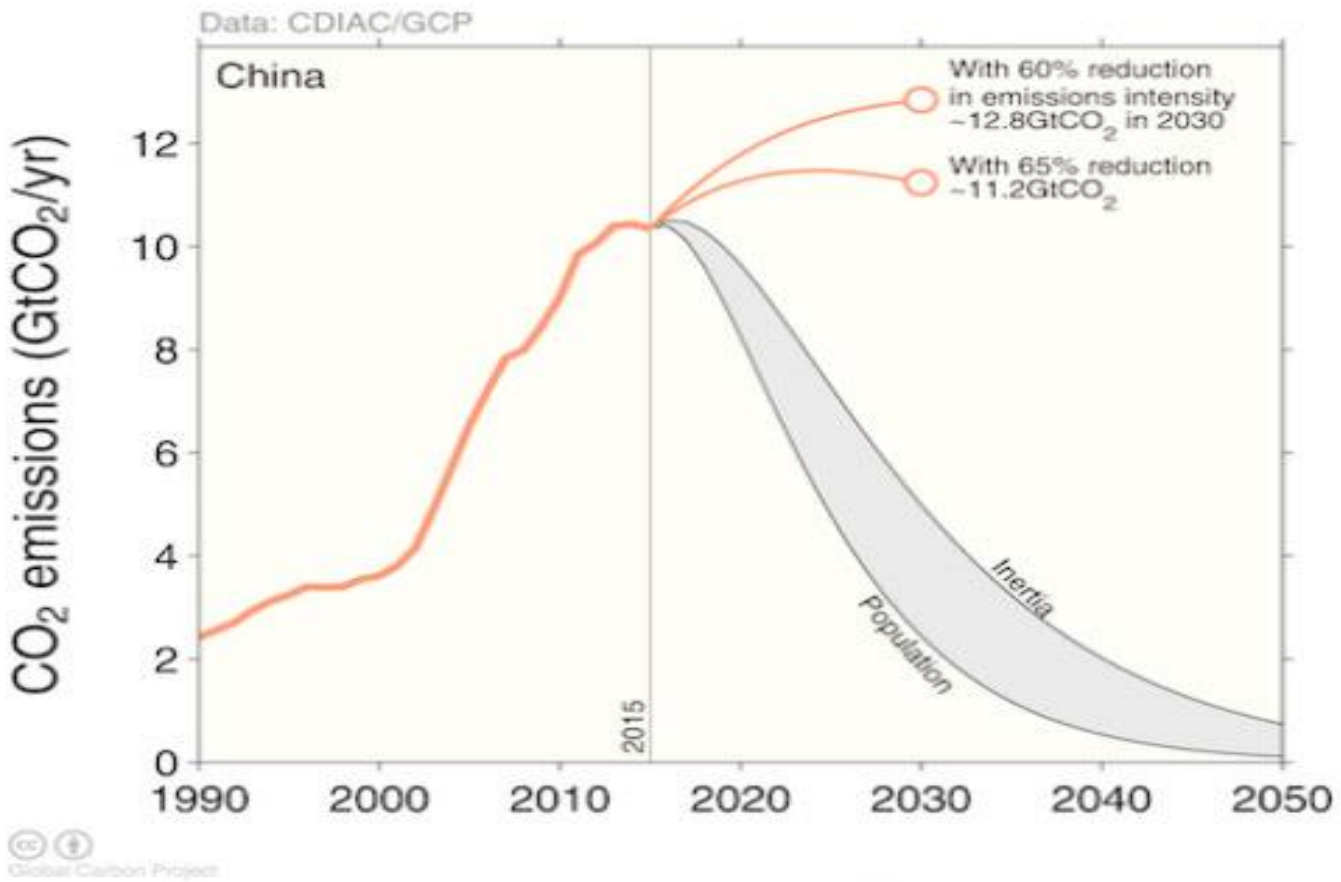
And now China too is outsourcing its CO2 intensive manufacturing…

- They have a growing middle class and rising wages and are themselves under increasing financial pressure to outsource CO2-intensive manufacturing to yet cheaper-wage countries. First to **Vietnam**, Thailand and Cambodia and now to more primitive countries in **Africa**, with higher carbon intensities.
- Expect to continue to chase the carbon pollution sources down the developing countries list until there are no more lower-wage countries with standards of living to bring up to Western standards… which will be devastatingly too late to save climate. It's highly unlikely the planet can afford that level of global energy consumption.
- **These decisions are clearly dictated by pursuit of economic wealth in the "now", not concern for the future Earth and future generations.**

Much Press has been made of China's Recent Promises to Lower CO2 Emissions

- But Glen Peters in **ClimateChangeNews (2017**) looks deeper and **advises strong skepticism,** based on under-reporting, boom/bust construction, and the unique way the numbers are reported.
- *"A recent **study** estimated that a **decline in construction activity explained about three-quarters of the decline in coal use**. This is since construction requires energy-intensive inputs of products such as cement and steel.*
- *"Economic woes are behind the recent slowdown in Chinese coal consumption and emissions, but growth in renewables and concerns about air pollution contributed."* Contributed…. Some.
- **So - Economic decline, not environmental concern and increasing energy efficiency, accounted for most of the decline in coal use. Consider…**

China's pledge of 60-65% reduction in CO2 emissions intensity by 2030 sounds *Planet-Savingly Dramatic*… until you convolve with their growth. Do the math and see what it means: CO2 Annual Emission Rates Keep Rising (circles)



The Chinese emission pledge (orange lines after 2015) is inconsistent with the recent slowdown in emissions growth (orange lines before 2015). The grey band shows where Chinese emissions need to go to remain consistent with a 2°C temperature limit. (Source: Cicero)

Let's Make Sure You Understand That Last Slide

- A promised 60% reduction in carbon intensity of energy (*i.e.* per unit of economic activity) by 2030 corresponds to an exponential halving time $\mathbf{t_{1/2}}$ of only **14 years!** Very Impressive – (perhaps impossibly so).
- We'll see how strikingly rapid that is, and certainly impossible without decommissioning perfectly working fossil fuel fired power plants; so be skeptical of the promise. **But even if true…. China's total annual emissions rates KEEP RISING at pace. (a good example of greenwash)**

In the REAL World – The climate forcing due to our GHG's is not only rising, the growth rate of rising is itself rising this century (from Hansen *et al.* 2017). Climate forcing rise rate by GHG's has risen an astounding 50% in just 13 years, and accelerating. This is dramatic exponential growth.

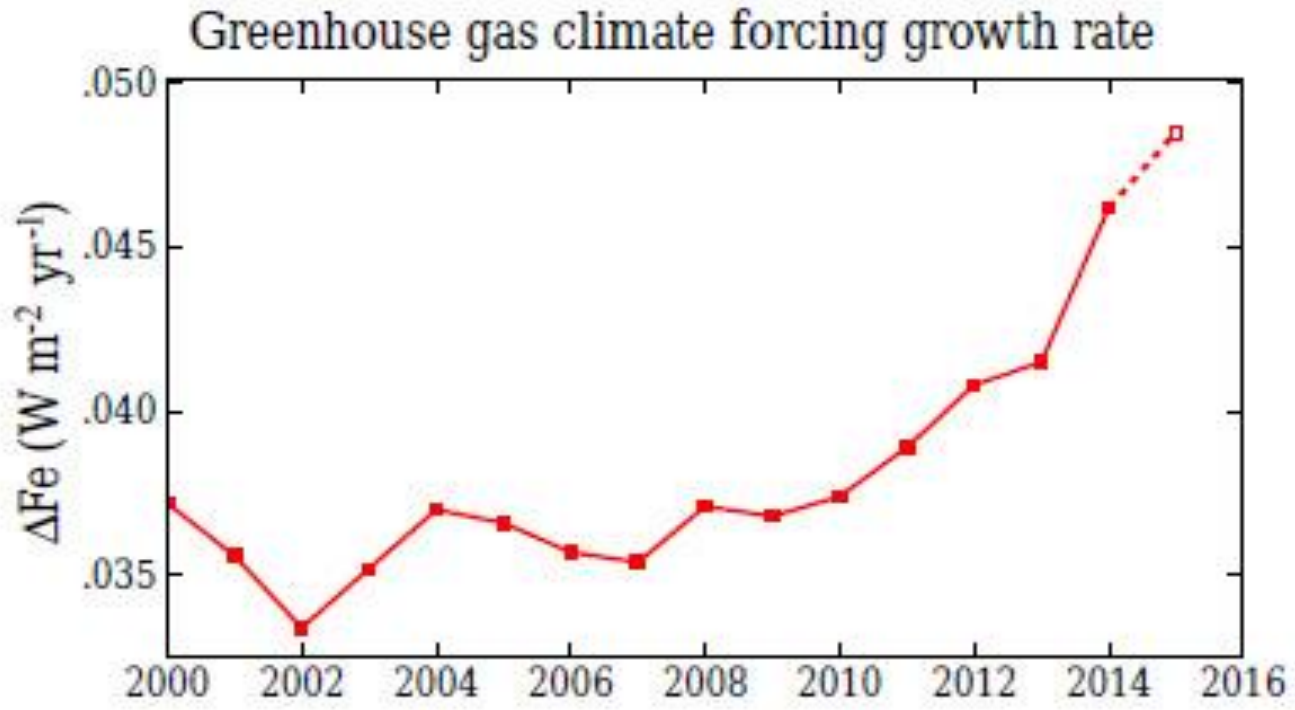
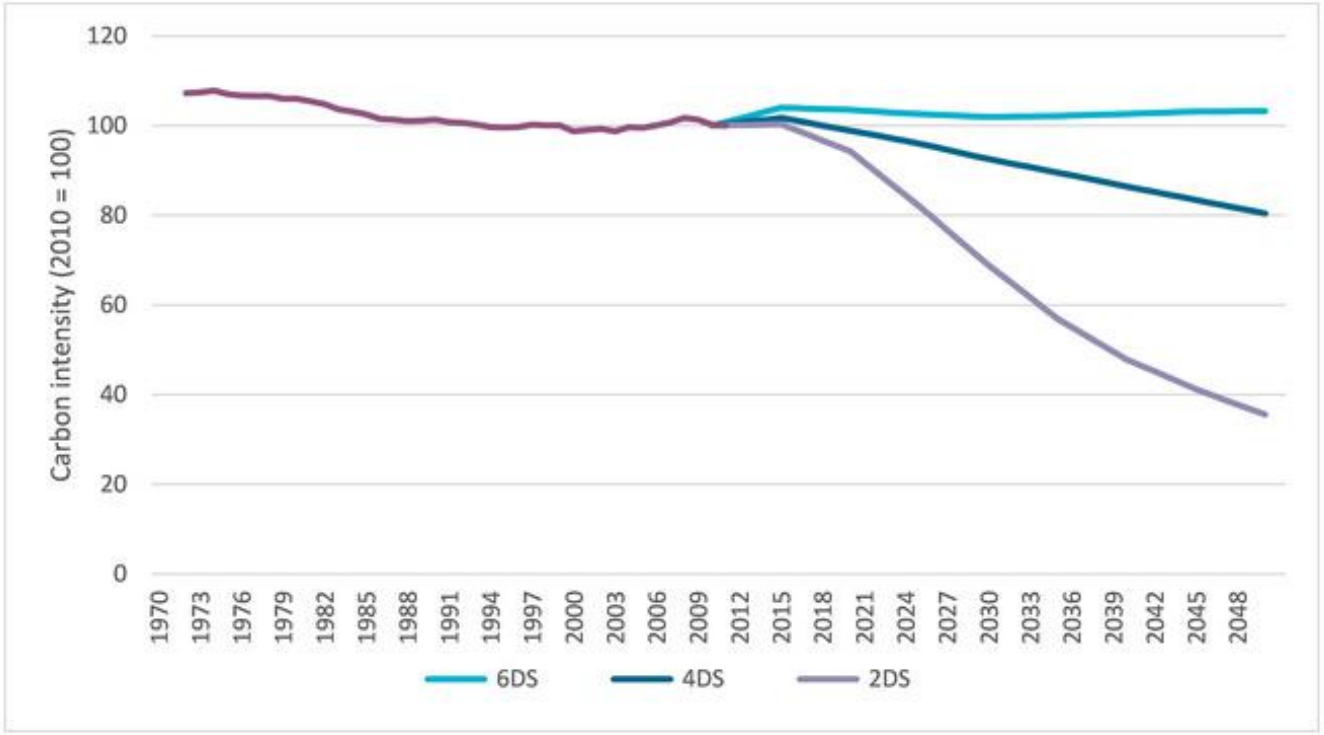


Figure 14. Recent growth rate of total GHG effective climate forcing; points are 5-year running means, except for 2015, which is a 3-year mean. See Fig. 8 for individual gases.

What if the flat trend in the Carbon Intensity of Global Energy in the 21st Century remains true? This study (blue) shows it results in a +6C hotter world by 2100. Can this happen? – Such extreme heat would very likely lead to the breakdown of Civilization, collapsing energy use before 2100

Fig. 2. Global carbon intensity, 1990-2010

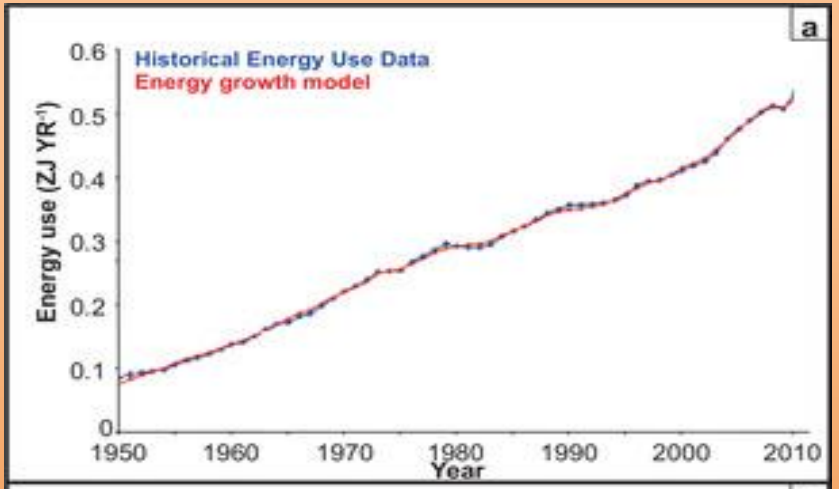


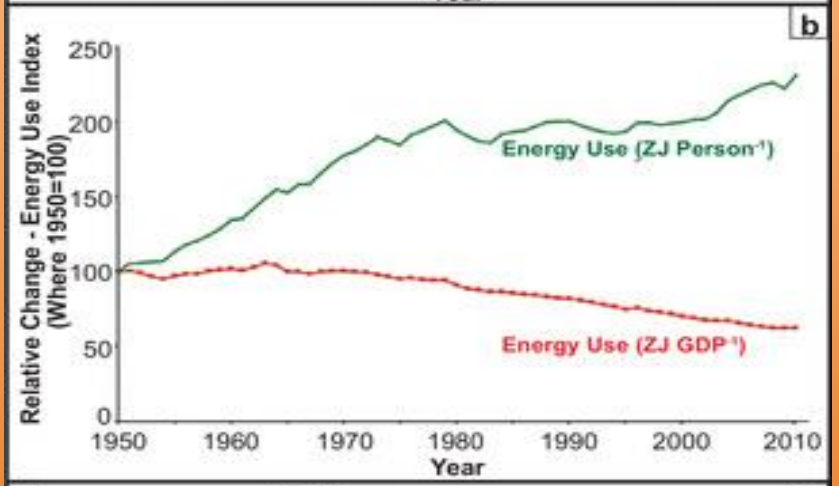
Source: International Energy Agency (2013), Tracking Clean Energy Progress 2013, OECD/IEA, Paris. 6DS: a trajectory assumed to result in temperature increase of 6 degrees C; 4DS a trajectory corresponding to 4 degrees C; and 2 DS corresponding to 2 degrees C.

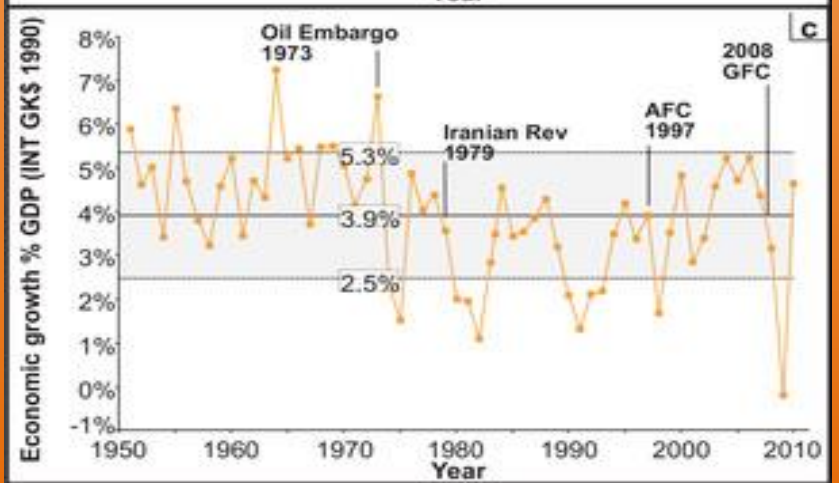
It's far faster than any historical decarbonization rates, and yet – at China's growth rate it still results in annual CO2 emission rates rising in 2030 by a further ~22% above today's. Look closer at the graph; there is no change in the upward slope of their annual emission rates this century

The conclusion is inescapable: Human compulsion for economic growth is the enemy of climate.

Within that paradigm, we cannot transition to renewables fast enough to avoid devastating climate change







We have been continually improving energy efficiency per dollar of GDP (red curve, middle plot). But the energy use per person has continued to rise as more Developing World people aspire to wealth (green curve), and compound that with rising population, and you see the total energy consumption rate continues to rise in an accelerating way (top curve) (Wagner *et al.* 2016).

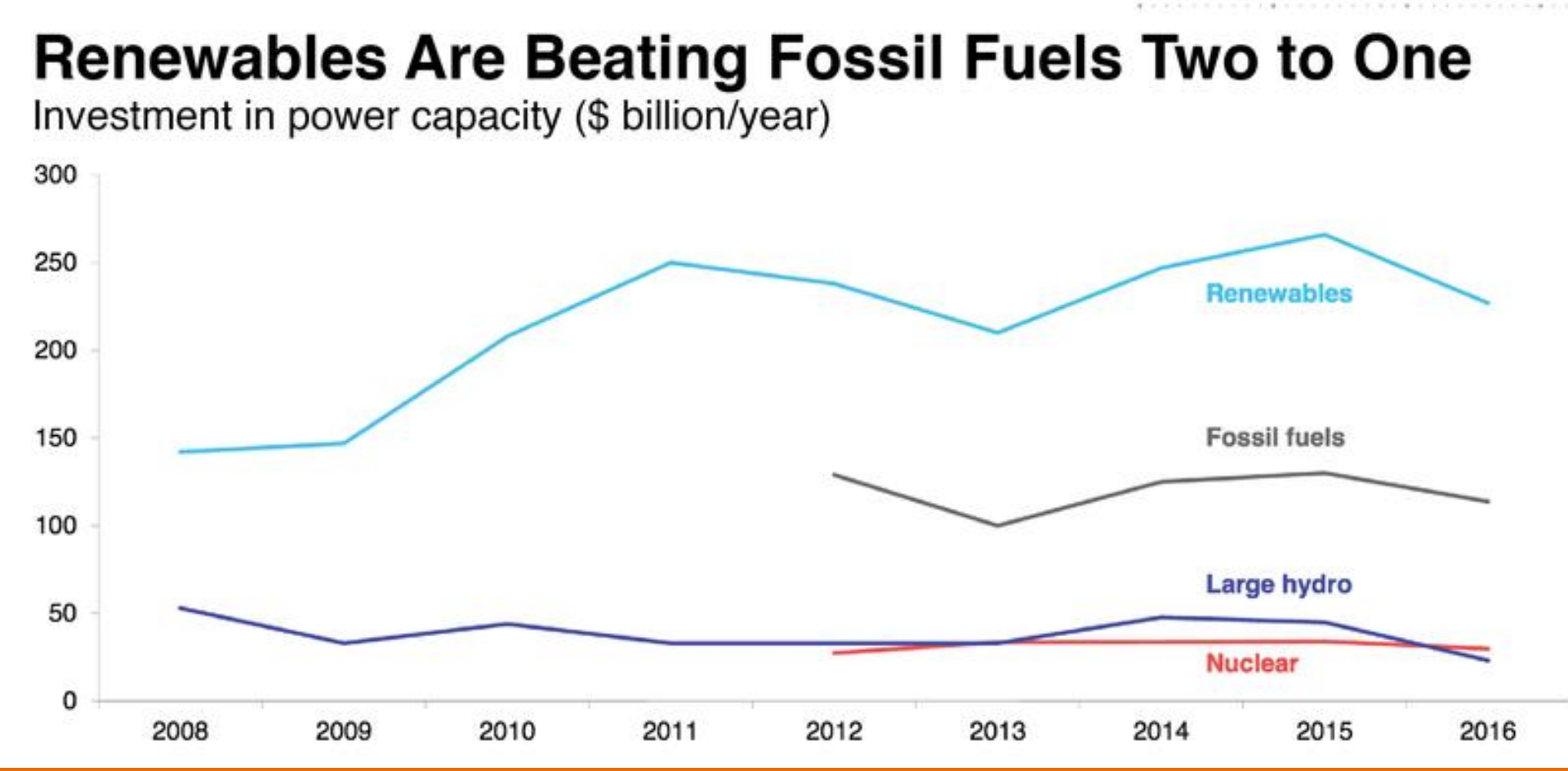
Like these confused shoppers on a viral YouTube video…

It's as if we're walking 5 mph down the stairs

…of a CO_2 escalator running upwards 10 mph

It is the very accomplishment of an improvement of energy efficiency which pushes the carrot of Energy Sufficiency further forwards, and always out of reach. Unacknowledged, and so we keep running harder to catch up to the carrot.

For all the renewables hoopla, the rate of U.S. investment in renewables during the last 6 years of the Obama Administration was flat; changing the same as our investment in fossil fuels. (Yet look at the spun-up title here)



Economists May Complain…

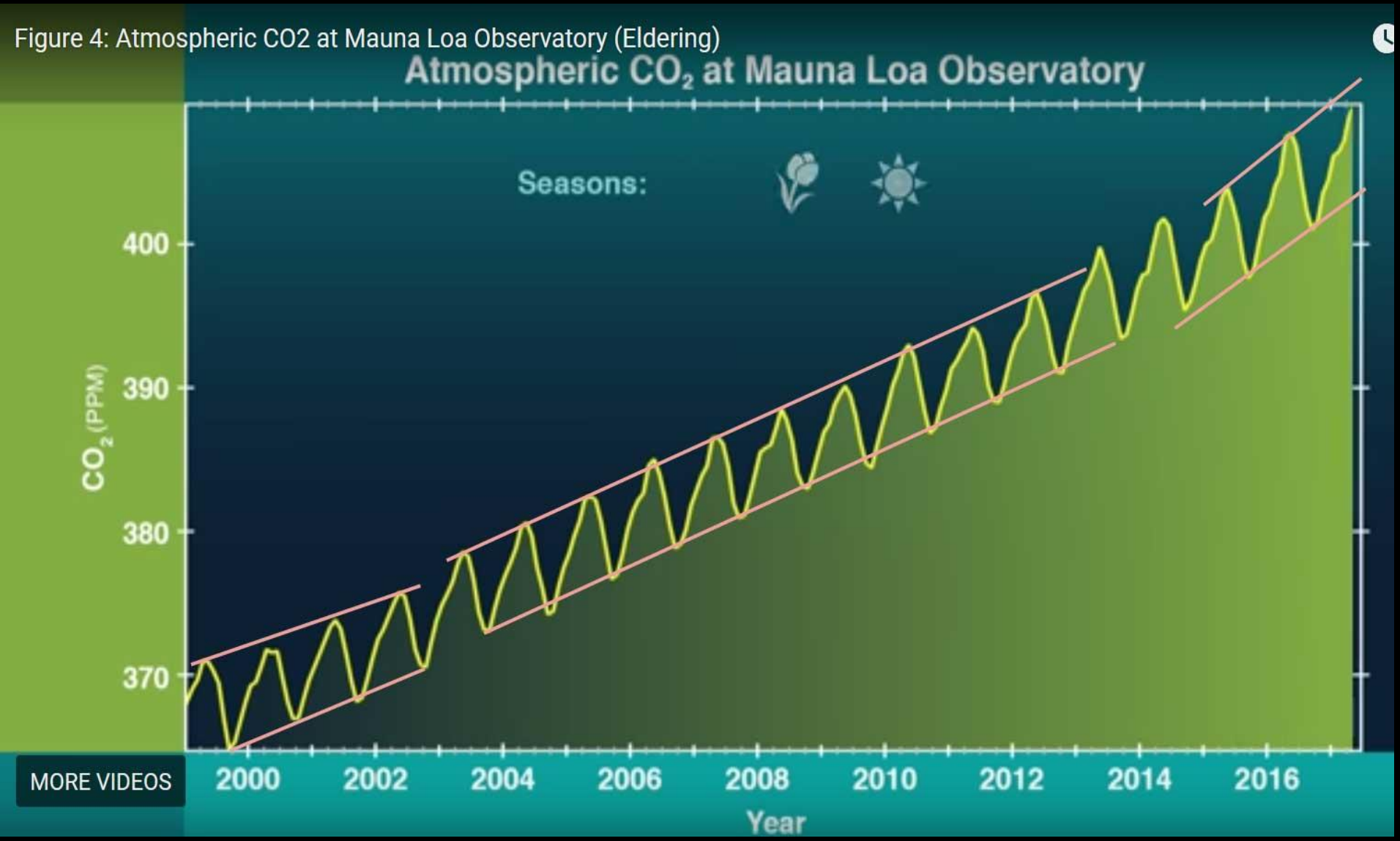
- ***But Rick - you can't argue that improving economic growth and energy efficiency IMPROVES our Standard of Living!***
- For many individuals in the short term? – yes. But Climate **DOES NOT CARE** about *per capita* enrichment, She cares ONLY about the global planetary TOTAL of GHG's. THAT's what determines climate, not declining CO2 per dollar of GDP, nor *per capita*.
- And Nature will compel **all** individuals to care about stark physics reality if they read the news.

For Climate, there is only ONE Curve that Matters

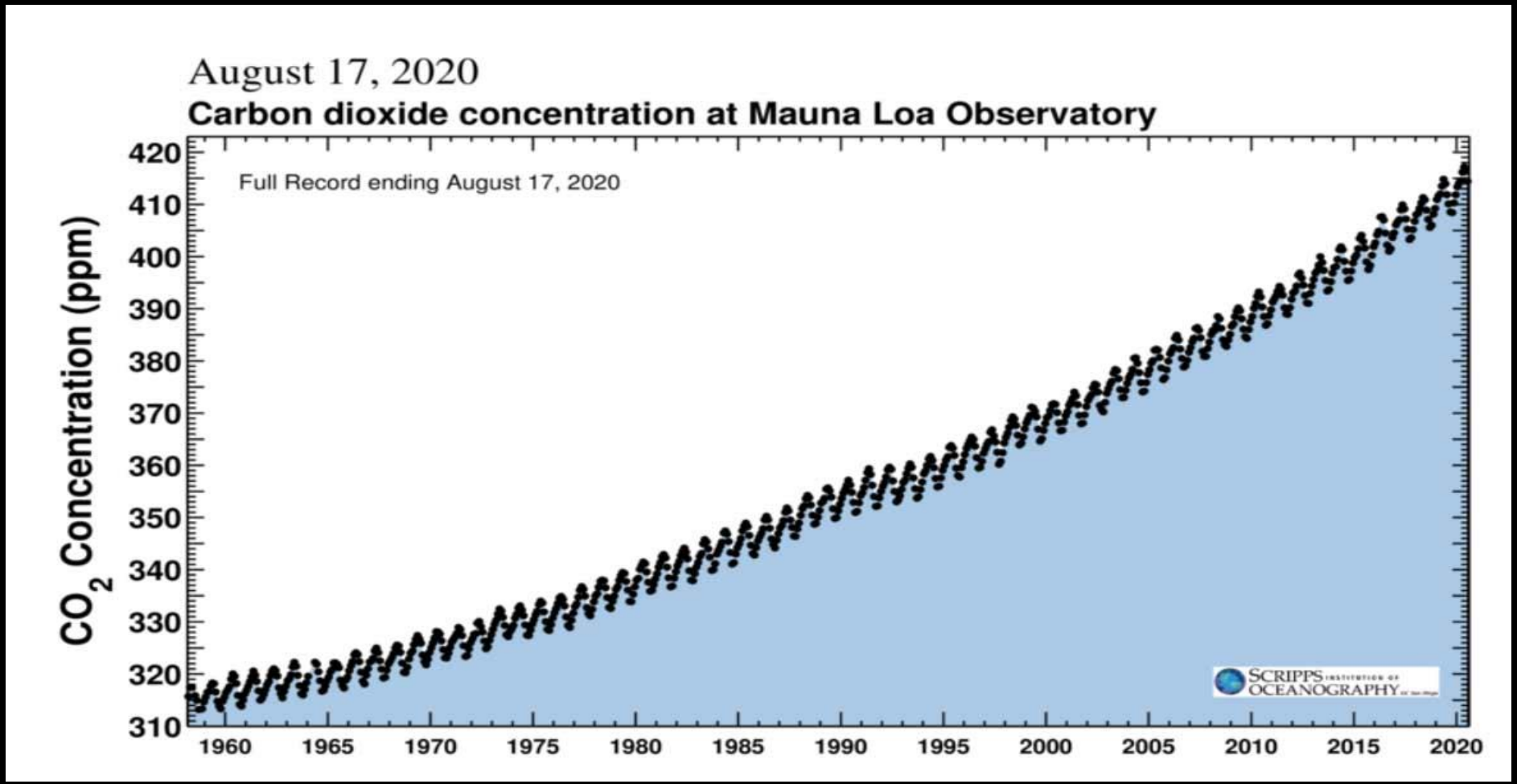
- …and that is the **Keeling Curve**: the concentration of atmospheric CO2. THAT (and other GHG's) are the curves that primarily determines global climate.
- From those rosy Western nations energy curves, and the warm glow from listening to biased policy cheerleaders, you probably expect to see at least a slight easing in the accelerating rate of our atmospheric CO2 rise, given that China and the U.S. emit most of the world's CO2, right?
- **But, no. (next slide)**
- It might also be relevant that China has been caught significantly under-reporting their CO2 emissions (**source**).

- **Nature, however, does not lie. She does not under-report. And her report is contained in the Keeling Curve**

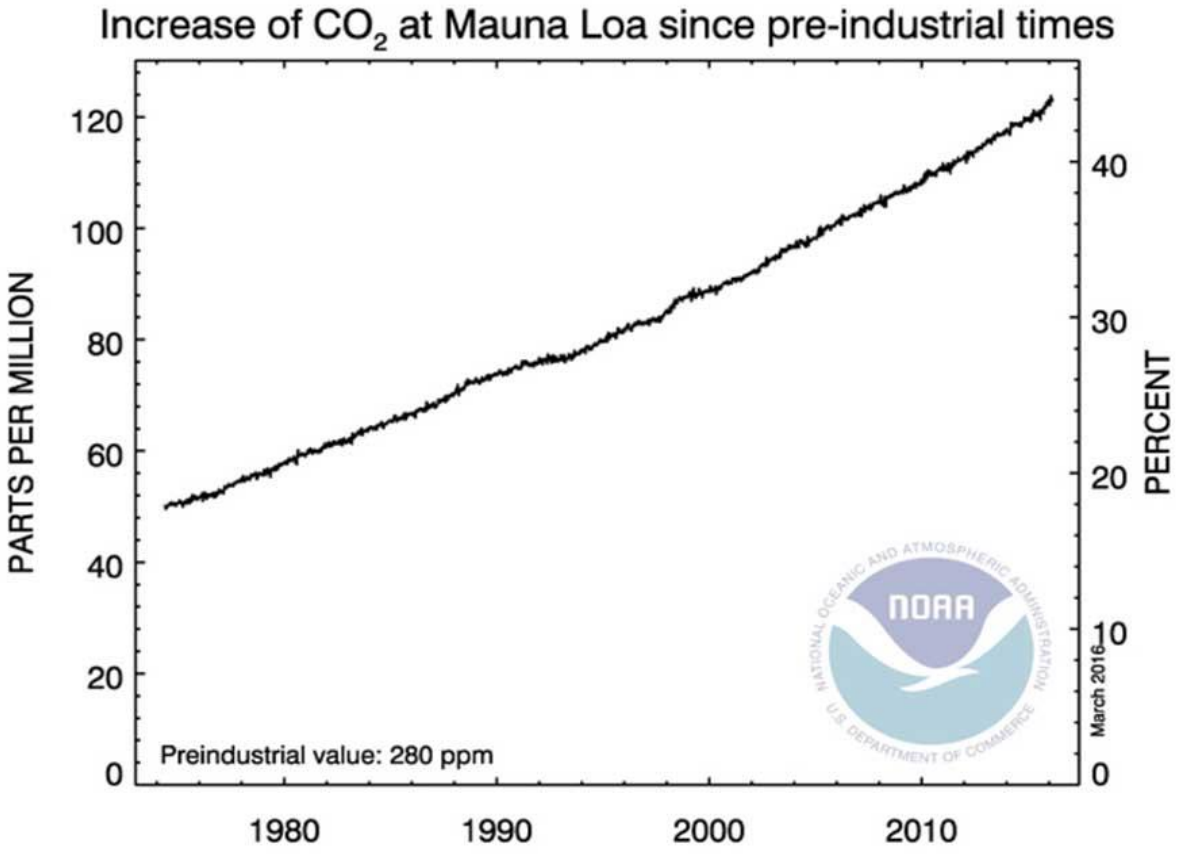
Accelerating Atmospheric CO2 Concentrations



CO_2 remains on an exponential rising curve. Now 422 parts per million (ppm) (May '22). Not just CO_2 levels, but the acceleration rate of atmospheric CO_2 sets new records each of the past few years. Partly due to the '15 El Nino, but only in part (~20%). Governments can lie, but Mother Nature does not. We've been increasing energy efficiency for millennia, so please - Let's STOP being delusional about what increasing energy efficiency GETS US. It results in HIGHER ENERGY CONSUMPTION RATES, not LOWER.

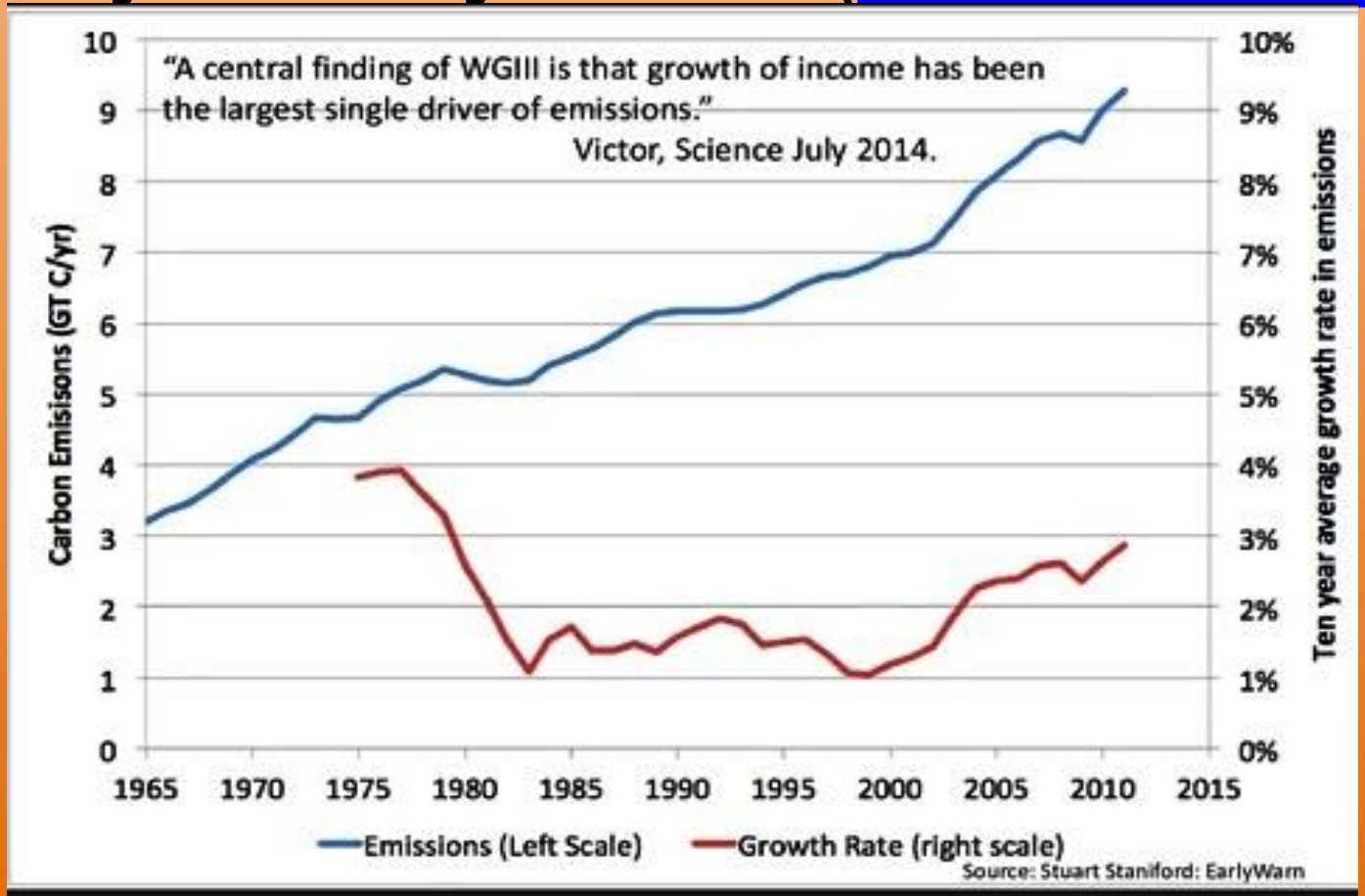


Atmospheric CO2, now seasonally adjusted, as of February 2016, set a new record in its ACCELERATION rate (New Scientist 2016), despite claims (vain hopes) of China beginning an era of declining CO2 emissions…except they've been caught under-reporting, and in 2016 were pausing after their "ghost cities" overbuilding. Indeed, China CO2 emissions growth increased again in 2017 by 3.5%, and again in '18.



Atmospheric increase of CO_2 over 280 ppm in weekly averages of CO_2 observed at Mauna Loa.

The IPCC Working Group III (on the science) found that the single biggest determiner of the growth in GHG emissions – is income growth. Not surprisingly, the UN policy people who must sign off on what's published, deleted this from the IPCC "Summary for Policy Makers" (ScienceDaily 2014)



Again: Current Power Consumption is Proportional to Global Real GDP Integrated Over All History

- The rest are details of who off-shores what aspect of energy consumption for whose increasing wealth.
- ***Climate is global, and so is Civilization's networks***.
- **You're not getting the true picture of our challenge if you limit your focus to a single cherry-picked country's GDP rate and CO2 emissions. Civilization dynamics do not allow simply assuming that one country's example can be copied by all others. Networks don't work that way.**
- CO2 emissions can only be reduced in a meaningful way by elimination of GLOBAL economic growth (but then, how to finance the massive transformation of the world's energy infrastructure?)
- **This is… The Great Catch 22**

Now let's look at the future implications, given the Power/Wealth Relation

- Garrett has run forward in time the global atmospheric CO2 concentration given the **Power/Wealth Relation**, and two sets of assumptions;
- **Assumption Set #1:** Assuming the 21st century growth rate of Global Wealth and global carbonization both continue to remain constant. Wealth growth at 2.2%/year, and also that decarbonization rate=0 (*i.e.* consistent with 21st century observations up to ~2014)
- This could be called the "Business as Usual" scenario…
- **I need to add – Garrett's curves include NO added CO2 from the indirect human-emissions sources – such as rising methane from tropical sources (a 44:1 temperature-dependent effect), and the Permafrost Carbon Feedback which we are now triggering (see more here). Therefore, the reality will very likely be significantly worse than his red curves here…**

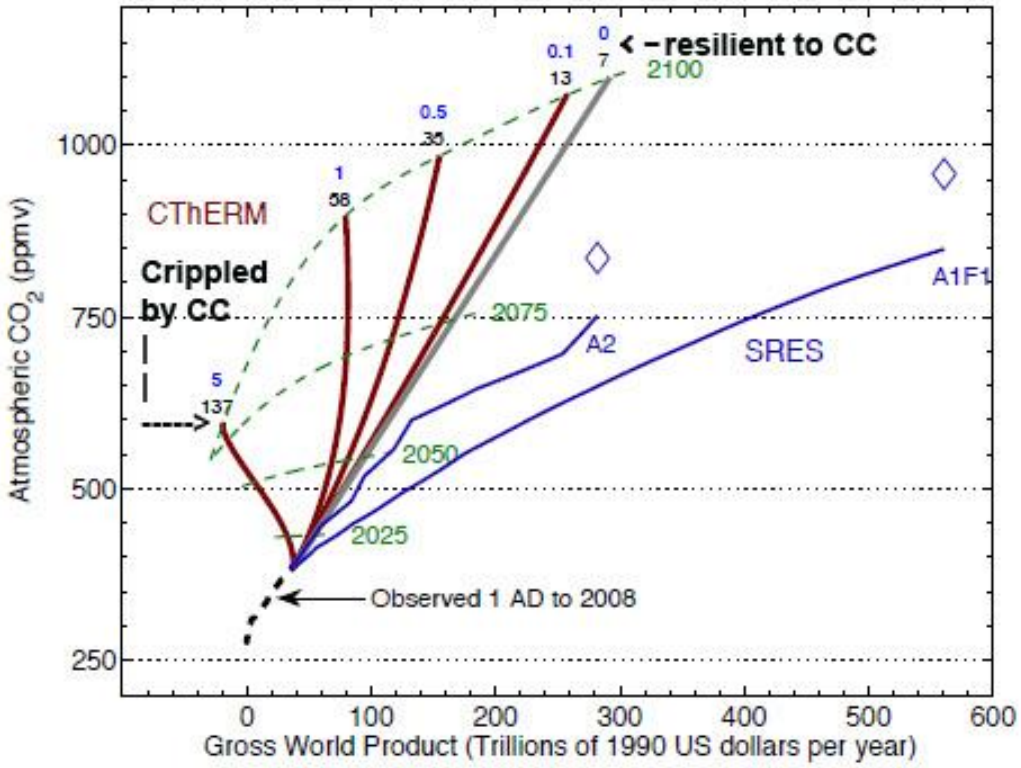


Fig. 6. As for Fig. 5, except for CThERM trajectories calculated out to 2100, with the model initialized with conditions in 2008 and assuming that $d\beta/dt = 0$ and $dc/dt = 0$ for a range of values of inverse resilience $1/\rho$ (blue numbers expressed in % yr^{-1} change in the decay coefficient γ per CO_2 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 CO_2. CO_2 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).

Garrett's CThERM model runs *vs*. range of assumed resilience of civilization to Climate Change: On this graph, de-carbonization continues its 21st century historical trend – *i.e.* no decarbonizing.

Even when civilization is assumed most crippled by climate change (CC curve), with strong decay corresponding (with his assumptions) to 137%/yr inflationary pressure, with GDP growth falling below zero (civilization in decline), still atmospheric CO2 rises 50% above current levels by 2100 and still rising. You prefer high resilience? Means more growth, CO2.

New research by Motesharrei *et al.* 2016 adds insight

- In the summary linked above is this quote from the paper: ***"…all societal collapses over the past 5,000 years have involved both 'the stretching of resources due to the strain placed on the ecological carrying capacity' and 'the economic stratification of society into Elites [rich] and Masses (or 'Commoners') [poor].' This 'Elite' population restricts the flow of resources accessible to the 'masses', accumulating a surplus for themselves that is high enough to strain natural resources. Eventually this situation will inevitably result in the destruction of society."***
- ***"Elite power, the report suggests, will buffer 'detrimental effects of the environmental collapse until much later than for the Commoners,' allowing the privileged to 'continue business as usual despite the impending catastrophe.'*** (it is disconcerting to read this, given Gilens and Page 2014)
- ***"'Science will surely save us', the nay-sayers may yell. But technology, argues Motesharrei, has only damned us further…"*** (by way of Generalized Jevon's Paradox, I will add)

From Garrett 2012

- ***"(if the Power/Wealth relation remains true) There are no plausible, thermodynamically supported solutions that avoid inflation rates less than 100% per year, and lead to stabilized atmospheric CO2 concentrations within this century"*** **(assuming decarbonization rates of ~0 in the 21st century, as has so far been the case, albeit not likely to continue this grim, we hope)**
- **100%+ per year – In other words, decay, not growth. (Garrett's 2012 paper considers "decay" as identical with, and cause of, inflation. This I disagree with.)**
- In other words: without decarbonization, civilization must contract (something it has never done), **rapidly, just to slow the further rate of increase of atmospheric CO2**

My Distinction to Add: The "Decay" Term Should be Kept Distinct from Nominal "Inflation"

- I contend it would be more reliable to express these curves in terms of "decay" alone, whereby spending is diverted to repair the crippling effects of climate change rather than civilization growth.
- Why? Because inflation is strongly affected by the politically influenced actions of Central Banks – and so should properly be kept separate.
- To put it simply, inflationary pressure can be answered by the Fed, at their discretion. (I made this point to Tim Garrett, and he agrees nominal inflation in the future is subject to this wild card and so yes – perhaps best to re-frame strictly in terms of civilization decay, which is indeed already a separate term in the CThERM Model. As of '20, he'd agreed his inflation framing might need changing, but decay is still central to his inflation thinking.

Collapse!? But can't we just Decarbonize our Power Sources Instead?

- Decarbonization is a two-edged sword. Higher CO2 levels mean a more climate-crippled civilization, which is, perversely, **good** in that it lowers civilization's growth rate and hence CO2 emissions growth rate
- Alleviating this crippling by steady decarbonizing enables faster civilization growth rates and hence MORE CO2 emissions from the power sources not yet decarbonized.
- **What is needed in order to stabilize, let alone reduce, atmospheric CO2 concentrations is a combination of BOTH Civilization negative growth and extremely steep rates of decarbonization.**
- This point is appreciated by climatologist Prof. Kevin Anderson as well, which we will see later in this course.

Decarbonization: Now Let's Examine Assumption Set #2: The CO2 concentration trends on the next slide assume we replace carbon energy with non-carbon energy at a rate such that the CO2 emission rate per unit of power drops exponentially with a rapid halving time of only $t_{1/2}$=50 years)

- Recall late 20th century decarbonization showed an exponential $t_{1/2}$ much slower: 180 years
- With **$t_{1/2}$=50 years**, let's follow the trajectory of CO2 in our atmosphere *vs.* growth in total wealth in the next slide's graph.
- It might be a bit confusing to look at, because time is not one of the axes. Instead, time ticks are the green dotted lines, generally upward along each of the curves.

First: The meaning of the “Resilience” of civilization to climate change…

- …the curves that have the strongest resilience, therefore the BEST economic growth, and the LOWEST inflation (decay), are precisely the scenarios that have the **WORST atmospheric CO2 red curves**.
- In other words - If we hope for lower and slower CO2 rise, we need to hope civilization is CRIPPLED by climate change so that it is FORCED **against its will** to grow more slowly or, better still for CO2, to enter long term de-growth.

Same resilience curves as earlier slide, now including steep de-carbonization with halving time $t_{1/2}$ = 50 years. All are significantly worse (red) than the IPCC eco-friendly scenarios (blue). CO2 levels never drop for CThERM scenarios except the most crippled and not till year 2100. Economic growth is far less, and CO2 far worse, than the simple IPCC scenarios. (IPCC SRES scenario assumptions will be examined in later slides here)

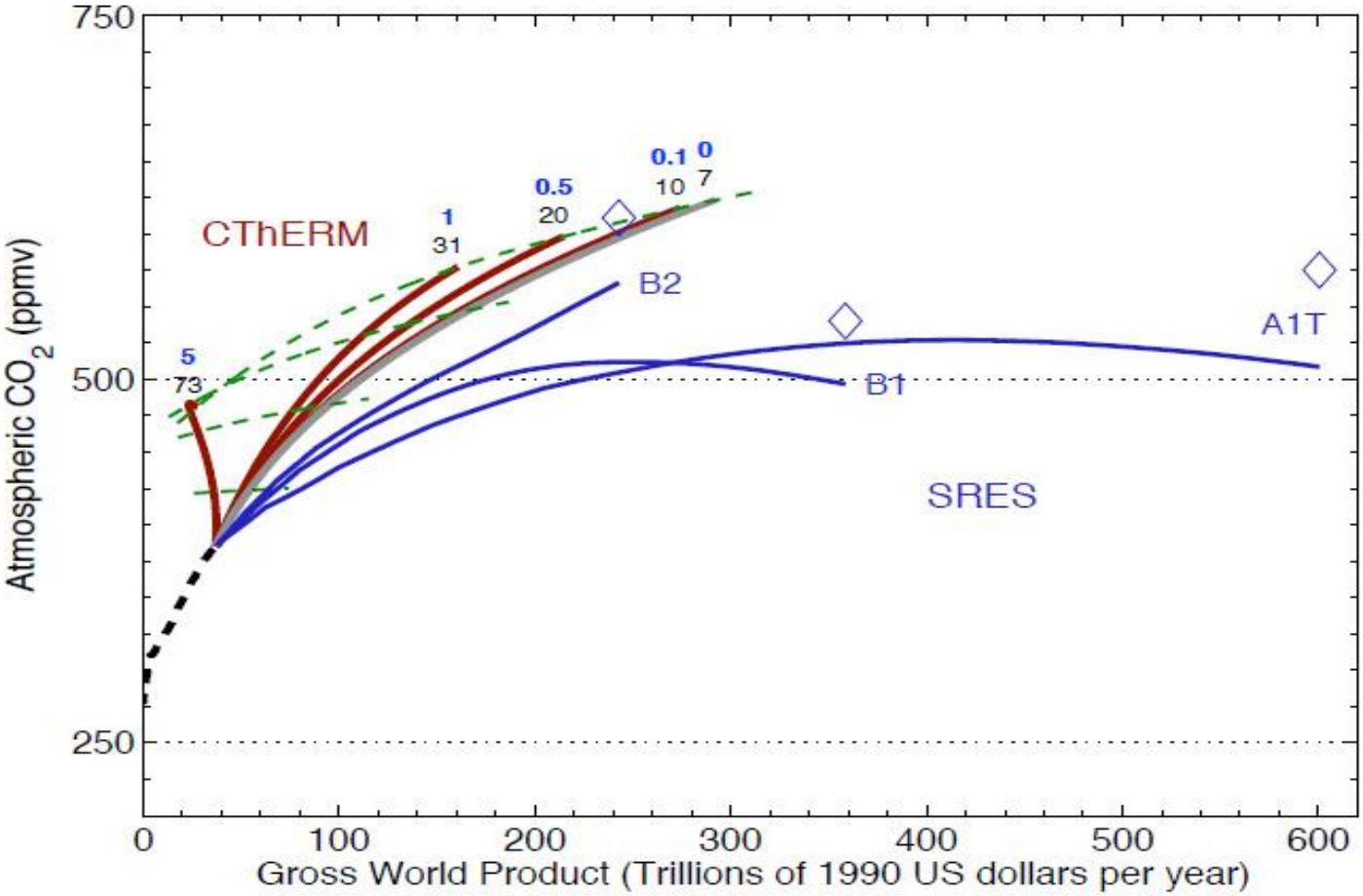
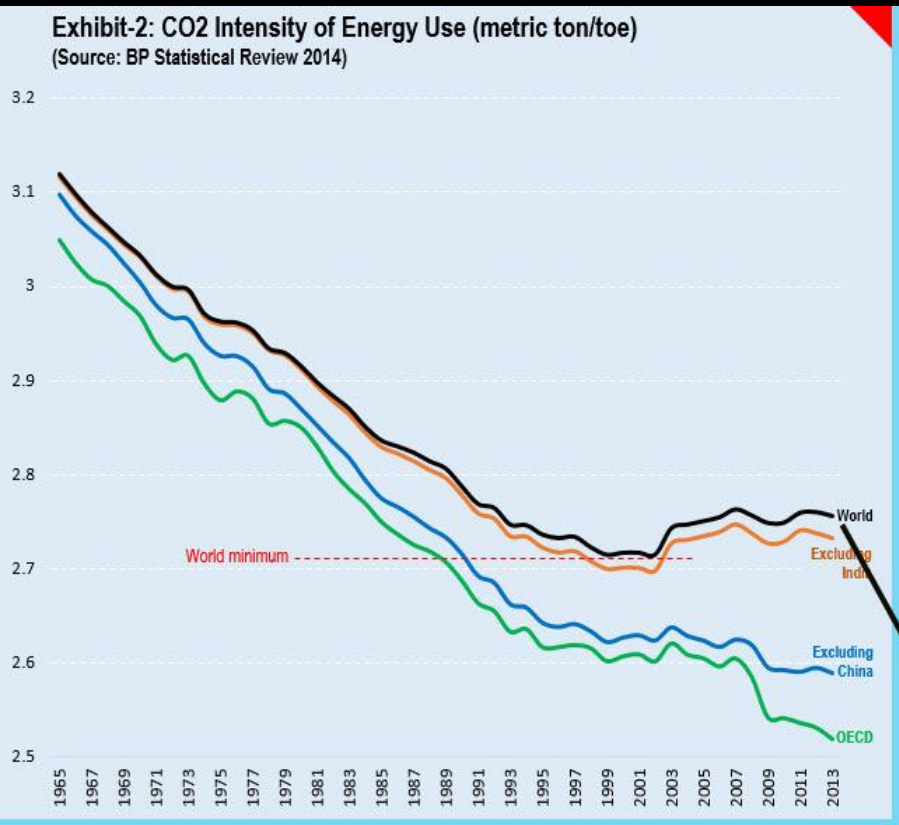


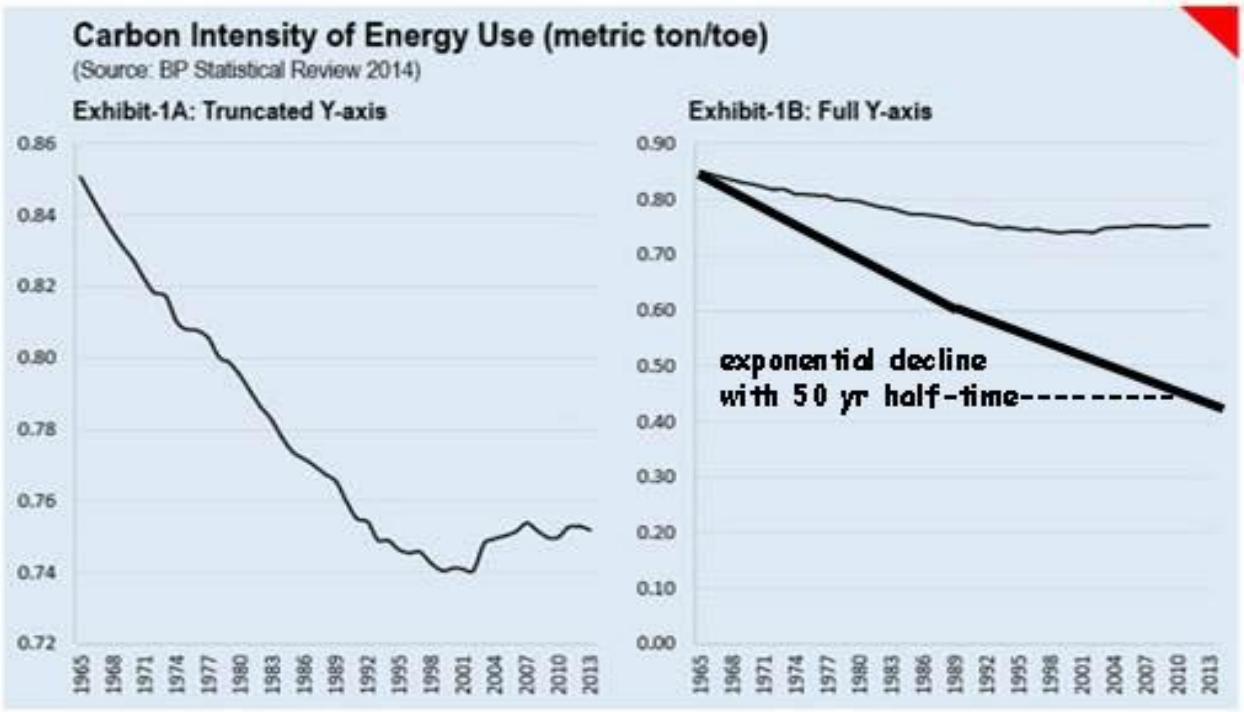
Fig. 7. As for Fig. 6 except that it is assumed that the value of carbonization c has an assumed halving time of 50 years. For comparison, the IPCC SRES trajectories that are considered are the A1T, B1 and B2 scenarios.



trend of linear approximation to exponential halving time of 50 years

Garrett's experimental scenario - assuming global future CO2 emission per unit of primary energy consumption drops with an exponential halving time of 50 years - is quite steep by historical standards

If we'd committed to steep $t_{1/2}$= 50 yrs decarbonization back in 1965 (right side, heavy line), *vs.* what our human nature-determined growth paradigm has actually done (thin line)



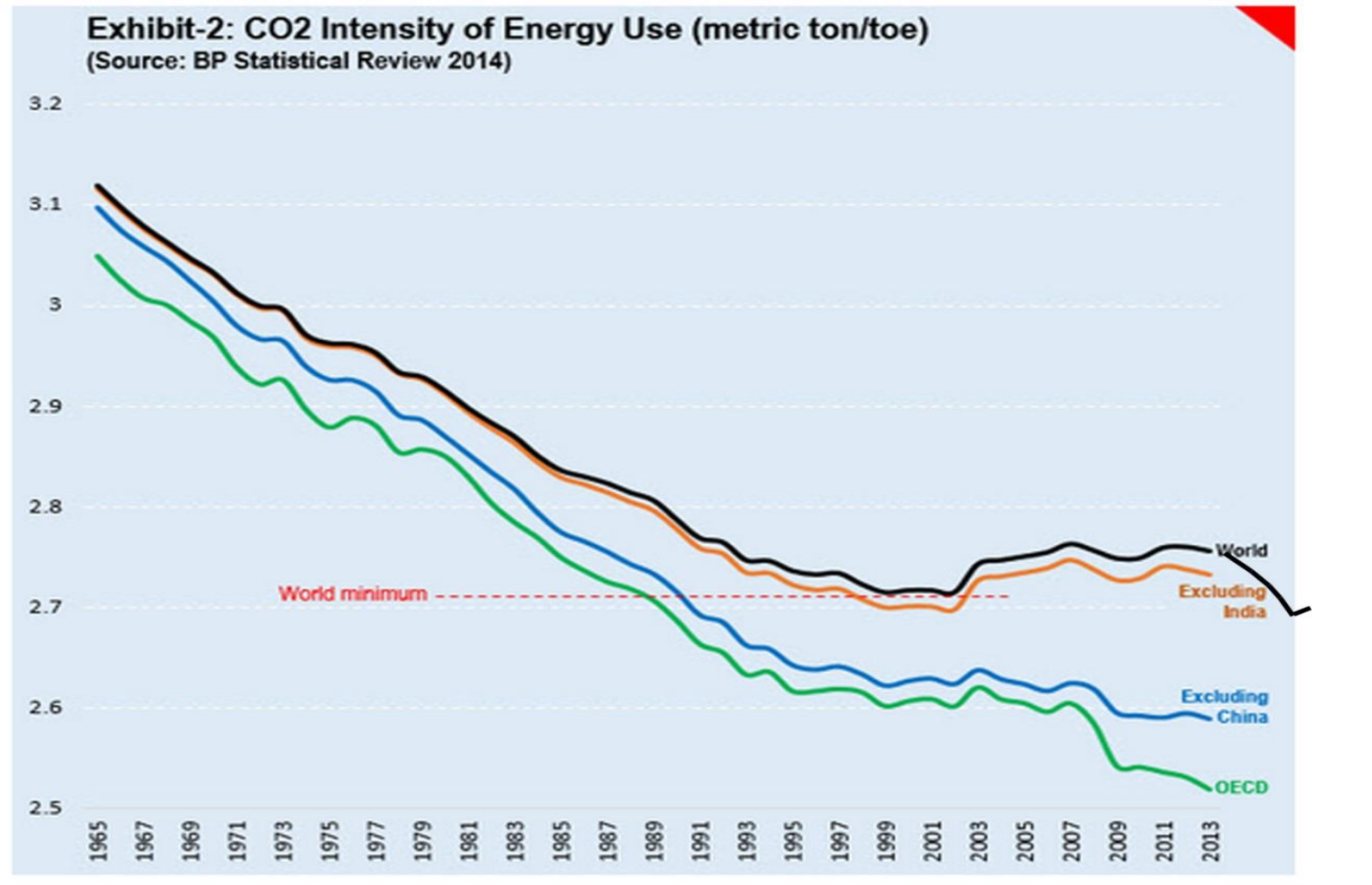
A Closer Look

From here on, the numbers will show CO2 intensity instead of carbon intensity, because the original data from BP and the EIA report CO2 emissions. To convert CO2 to units of carbon (C), simply divide by 3.667. Carbon intensity and CO2 intensity are used interchangeably in the text – both are ratios that depict emissions generated versus energy produced. In the relevant literature, CO2 intensity is also reported as a ratio of CO2 emissions to GDP--which includes the effects of prices. In this note however, CO2 intensity is measured in physical units--metric tons of CO2 per tonne of oil equivalent (toe). Also, 1965 is the first year for the data published by BP.

Let's Emphasize the Conclusion of that Atmospheric CO2 Slide…

- Even if we globally decarbonize at a historically unprecedented rate, such that the carbon intensity of energy drops in half every 50 years, even if climate change cripples civilization such that the growth rate in Global Wealth is cut in ~half by 2100, with (Garrett defined) inflation rates reaching 73% per year by 2100… (today's is about 3%).
- **…STILL, atmospheric CO2 levels climb, and are as high as 485 ppm by year 2100.** 485 ppm is high enough to trigger the tipping points for complete thaw of all permafrost, and likely **Hansen's (2016) grim scenarios**, if they haven't already. This would add substantial **indirect** human-caused carbon emissions to these graphs.
- Also, enhanced decarbonization will require (like everything) enhanced energy consumption and hence CO2 emissions, to accomplish. This is not coupled directly in the Garrett curves.

BP Statistical Review data through 2016, together with an estimate for 2017, suggests we are resuming decarbonization. This was expected and hopefully will continue. However, the recent drop shown is likely too steep, due to official GDP bias from China (as we'll see later).



Now Let's Pause and Consider the Global Wealth Rise Rate in the Most Crippled Case

- You might be thinking "*well OK, global wealth rising at only half its current rate... Doesn't really sound SO bad*…"
- But the global wealth rise rate since the Industrial Revolution has never declined. The rate of rise of Global wealth has itself ALWAYS risen, and at worst, it has plateaued for a time (as it has in the mid 2010's, at 2.2%/yr, and look at the tantrum that was causing on Wall St.), before new energy resources were discovered and growth rates could rise once again.
- **Our 2.2%/year real rate of return (on civilization Wealth and on energy invested) is higher than it has ever been.**
- **With new energy resources like solar and wind … will we instead respond with even higher energy consumption growth rates into the future, as we have in the past?**

If, on the other hand…

- …we somehow (impossibly?) transform **human nature** and reverse our growth…
- We're going to have to prepare for a very different world.
- Experiencing growth rates significantly less, or a long term global depression (a more likely scenario as climate change ramps up).

But What of all the Talk About IPCC Carbon Budgets and That we Still Have Decade(s)…

- …before we've used up that budget for keeping us below +2C temperatures?
- Alas, scientists **acknowledge** the IPCC AR5 and earlier **CMIP5 models** were missing many key climate dynamics and feedbacks, as well as the alarmingly steep rise in global temperatures since 2013's IPCC AR5 release.
- And also admit the arm-twisting that came from the political rep's, to relax the carbon budget

Listen to the tone and the evasive response here to the direct question on missing feedbacks and how carbon budgets should be changed

- Indeed, at very best, we're expected to use up the carbon budget for **+1.5C by 2020, and for +2C by 2032.** (and even that, makes wrong assumptions of pre-industrial baseline temperatures). The physics inertia of our massive civilization means that these temperatures, in fact, are unavoidable. Since these links were written, global surface temperatures have dramatically risen, ending 17 years of slower growth (see **K38a** for why).
- See my 2017 **talk "The New Post-IPCC Climate Science: A Darker Frame for our Options" for new physics making our plight significantly worse even than the above.**

Worse still, there are at least two more reasons why Garrett's atmospheric CO2 curves are likely too optimistic

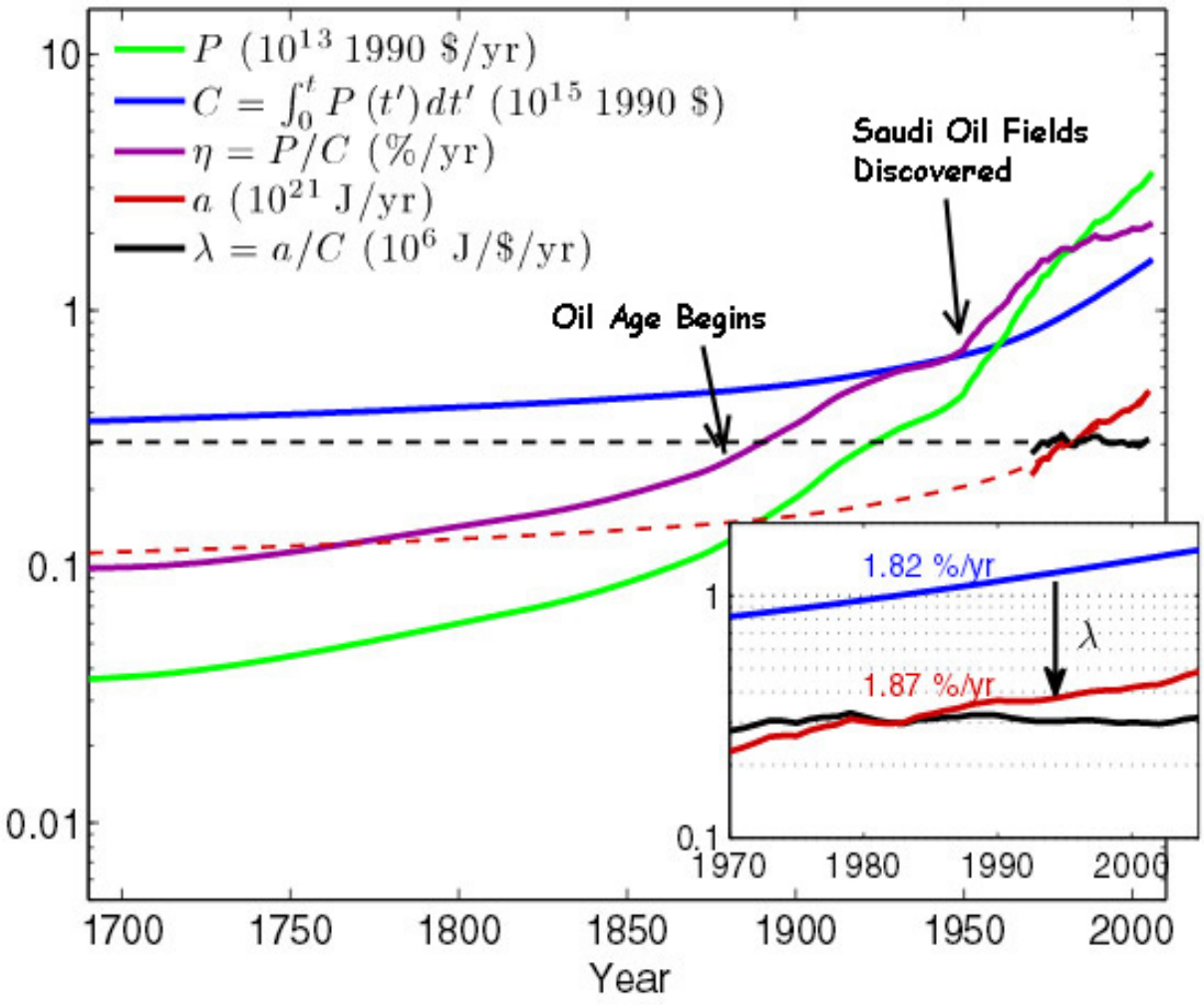
- **1.** They don't include explicitly the energy cost of transforming our energy systems from high EROI energy-dense fossil fuels, to dilute and low EROI renewables – and it would require complex and uncertain assumptions to even try to include this in his explicitly global model.
- **2.** His atmospheric CO2 model, for computational efficiency, is a simple parameterized source+sink model which, while it works well in hindcasts up till now, it neglects the effect of the inevitable higher temperatures to come on crippling of the ability of plants, oceans, and soil to uptake CO2 in non-linear ways, and the now-triggering **Permafrost Carbon Feedback** which adds significant non-human carbon to the atmosphere, and also neglects the likelihood of new higher climate state-dependent **ECS** measurements (see **here**) cascading these warming effects further.

While Increasing the Construction of Renewable Power Sources Will be Expensive at First…

- Their ongoing upkeep will likely be smaller than that for conventional power.
- If this results in increasing energy efficiency, and with the large amount of solar energy falling on the planet, it may be that we will see another surge in the **Global Return on Wealth (for a while)**, a surge such as we saw in the late 19th century from the discovery of oil, and again in the 1950's with the discovery of the vast and easily drilled oil fields of Saudi Arabia and the Middle East (next slide)
- If so, this will require an increase in consumption rates of all energy, including the remaining carbon energy. (**Jevons' Revenge**).
- In this case, Garrett's simulations may underestimate atmosphere CO2 levels yet again – since they conservatively assumed **Global Return on Wealth** will no longer rise but instead stay constant at 2.2%/year from here on.

The Purple Curve Shows the Rate of Growth of Global Wealth = the "feedback efficiency" of Wealth's ability to grow more Wealth. Note it has never declined, and is now at 2.2%/year. Inset box shows the Garrett Relation (black curve flat)

Fig. 3 Estimates of gross world product P in market exchange rate, 1990 US dollars and economic value C, defined by $P = dC/dt$. Also shown are recent global primary energy consumption a, the ratio $\lambda = a/C$, and the feedback efficiency $\eta = P/C$. *Dashed lines* correspond to extrapolations based on assuming $\lambda = 9.7$ mW per 1990 US dollar



How Were the IPCC SRES Emission Scenarios Arrived at?

- Conversations with IPCC scientists, relayed to me by energy expert Dr. Nate Hagens, report that what was done was to simply assume a set of global temperature growth numbers for year 2100, and a rather *ad hoc* guesstimate of a mix of energy sources evolving from present to 2100, and then CO2 from CO2 emitting energy sources summed to give the required assumed temperature rise, and not including all the missing climate physics discussed **here**.
- There was no appreciation in these forecasts of the actual couplings between civilization parameters as shown by Garrett's work.

It was Pro-Growth Non-science Policy People Who Drove the Framework

- High profile climate scientist Dr. Gerald Meehl **explains the sausage-making the scientists dealt with** from the policy people for CMIP6.
- The scientists were constrained by the UN IPCC policy people - ***"You (scientists) cannot be policy prescriptive!" (18 minutes into the talk)***. They were instead to assume astounding new science and engineering can somehow make the Policy people's desires valid.

How are the IPCC SRES and CThERM Models Different?

- The IPCC's SRES models split off the evolution of **population**, global average **standard of living**, and **energy efficiency** (*i.e.* energy expenditure's useful return to civilization) as separate drivers which they can set independently of each other (see IPCC **sec. 5 here**).
- But as Garrett points out, the actual behavior of our past shows that population and standard of living growth rates are only constrained by our access to energy and our ability to raise energy efficiency and so are actually dependent variables, not independent variables which can be arbitrarily set.
- If they are to be set to what is desired, it will have to be by strongly enforced, even repressively enforced, policy action, not by merely hoping that people will somehow magically be different.

Knowing Only The Amount of Accessible Energy and the Efficiency of that Energy in Growing Wealth…

- …Garrett shows historical population and standards of living growth can both be predicted knowing only the energy reserves and efficiency of energy consumption, given human nature…
- The **CThERM** model reproduces observed economic (available) growth rates accurate to 0.1% over the 1990-2014 period. The IPCC's SRES model only reproduces this with a particular "worst case" carbon scenario (**Raupach *et al.* 2007**).

Indeed - Stevenson and Pielke (2015)…

- … show that the **IPCC** scenarios implicitly include much rosier assumptions of "spontaneous decarbonization" and growth than any historical analysis can support
- "Spontaneous" – meaning, occurring without any impetus from policy changes

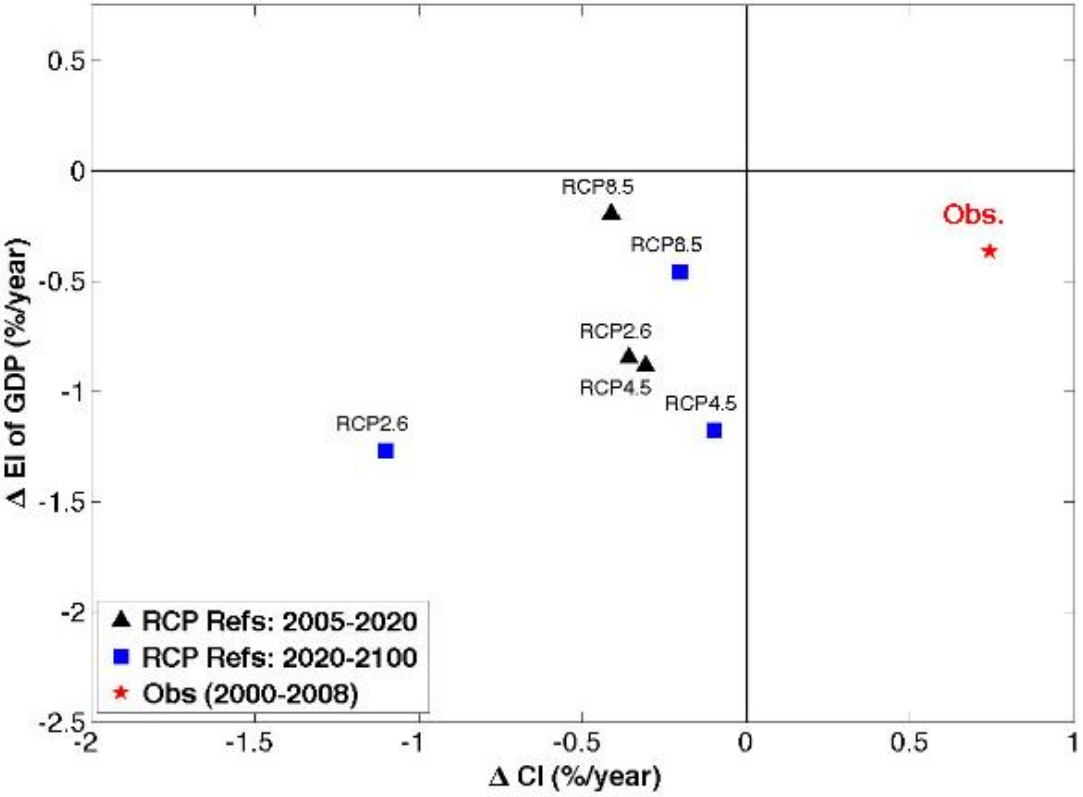


Figure 1: Rates of decarbonization in three of the RCP baseline scenarios for which data is available as compared with the observed rate. This figure is modeled after Figure 2 from [1].

From [Stevenson & Pielke (2015)]

All RCP scenarios, even the most dire RCP 8.5, assume declining carbon energy intensity (CI) over time. Observations (red) show in fact carbonization had been rising (as of 2008), not falling. More recent data suggests that may have reversed. These scenarios are the implicit baseline assumptions, without government enforced policy to motivate further improvements.

The point is, IPCC RCP scenarios so far have been unrealistic

- Garrett's presumed 50 yr halving time for CI (carbon intensity of energy) corresponds on this x-axis to -1.39%/yr; stronger even than any IPCC eco-friendly scenario.
- This is not to say it's unachievable. I think technologically it's achievable. But the political will has been lacking.

As the Kaya Identity Frames it…

CO_2 Emission Rate = P x S x E x C

- **P** = global population
- **E** = units of energy required per capital unit created (inverse of energy efficiency)
- **S** = Energy use per person (“standard of living”)
- **C** = Carbonization of our energy, *i.e*. how much CO_2 is emitted per unit of energy generated

CO_2 Emissions Rate = P x S x E x C

- **Reduce P? Very unlikely we'll reduce population voluntarily (although falling fertility rates may force that)**.
- Even at optimum wealth and education, with no undesired pregnancies, families still average 2 children (**Bradshaw and Brook 2014**). Important as population limits are, people WANT to have children (nothing psycho-pathological about that).
- And are correct that their ~2 children are **not** going to be **the** kids that tip the planet into chaos, but yet will provide them with enhanced **personal** happiness.

Reduce Standards of Living?!

- **Reduce S?** Even the Progressive Eco-Friendlies maintain that global economic equity is top priority, meaning efforts will continue to raise **standards of living = S**
- **Reduce E? Energy per unit GDP** has gone down, but as we showed, it has ALWAYS gone down, likely to continue unless civilization breaks down, but since it's always been a win/win, we're very unlikely to improve on the slope… yet CO2 emissions continue to rise.

That means that C=carbonization must take up the entire burden

- …the burden of overcoming the rise in P and S and then some beyond.
- **Yet, so far this century, C has not gone down at all.** It has declined slightly in the advanced countries, but is rising in 3rd World countries as they begin to afford fossil fuel powered modern life, as we saw.

We Want Wealth Stories…

…Not Spartan Stories…

- Dr. Dennis Meadows points out that what gets the attention is trying to increase energy efficiency (the E term), and trying to lower the carbonization by going to renewables (the C term)
- And **we don't want to think about** the first two terms
- But we haven't, and can't, make real progress on CO2 emissions without addressing growth *per se*; in population and in global economies. **And Garrett has shown why.**
- **New work (Manoli *et al.* 2016) finds that the diffusion rate of green technology must spread through Civilization fully 10x faster than any technology – even beloved technologies - ever in the past, to meet stated temperature goals. And this does not consider the indirect carbon emissions we're now triggering in the permafrost, nor worsening ECS dependence on climate state, etc.**

The Evolution of the Denial of "Limits to Growth" (From D. Meadows talk)

Evolution of the Criticisms

1970s: There are no effective limits.

1980s: There are limits, but they are far away.

1990s: The limits are near, but technology and markets can evade them easily.

2000s: Technology and markets do not always evade the limits, but the best policy is still to pursue GNP growth, so we will have more resources to solve problems.

2010s: If we had been able to sustain economic growth, we would not have had trouble with the limits.

What is the <u>Fundamental</u> Driver?

- Here are my thoughts, not necessarily Garrett's.
- During the long span human genetic history until now, it was an advantage to evolve a biological drive to fight for our place in a vast wilderness of dangers and competitors for our needed resources – ***<u>Grow, or Die.</u>***
- When we became more efficient, we became better at carving away that wilderness. This is reflected in the **CThERM** model, implicitly

Now in the 21st Century…

- …unconquered Nature is mostly gone, and
- We've taken 90% of all arable land for our own use, stripped the oceans, commandeered ~37% of the entire primary productivity of the planet to ourselves.
- **Sanity requires that growth must end, even reverse**.

Yet….We still have the same genetic inheritance

- …the felt impulse to grow, to expand, to exploit new energy and new resources, to be competitive even with each other - for “choice mating opportunities” (see Nate Hagens’ talks and **K40b**).
- Those who most loudly voice this unquestioned mindset are those with the brains (studies showed) least-practiced for error-checking and for dealing with complexity (the Conservatives) - see **K40b** for the studies confirming this.

But Wait, Isn't there a Point Where Even Energy Gluttons are Satiated?

- **The "larger" your life, the larger your energy needs, it's a thermodynamic law.**
- But is there a point where you're close to satiated? Studies show happiness improvements level off, but does the wealth lust? No. However, the wealth does increasingly go into asset price inflation rather than direct consumption. But even then…
- …most of the world is anything but "satiated", living on wages of $3.50/day or less. They are adamantly determined to spend whatever energy they can lay hands on in order to increase their wealth to at least the level of those Americans.
- So if there is such a prosperity point, it would appear to be too high to help with our emergency now.

Our Forebrain. Cause for Hope?

- The only bit of hope I see, is that as part of our evolutionary survival mechanisms, Nature also evolved in us a forebrain – capable of reason, of identifying principles, of applying them, and forecasting the future to enable better planning.
- Unlike molecules which collectively obey thermodynamic principles despite chaotic individual actions, people can learn from each other, if they wish, and do coherent, and unlikely things… at least, one can hope…

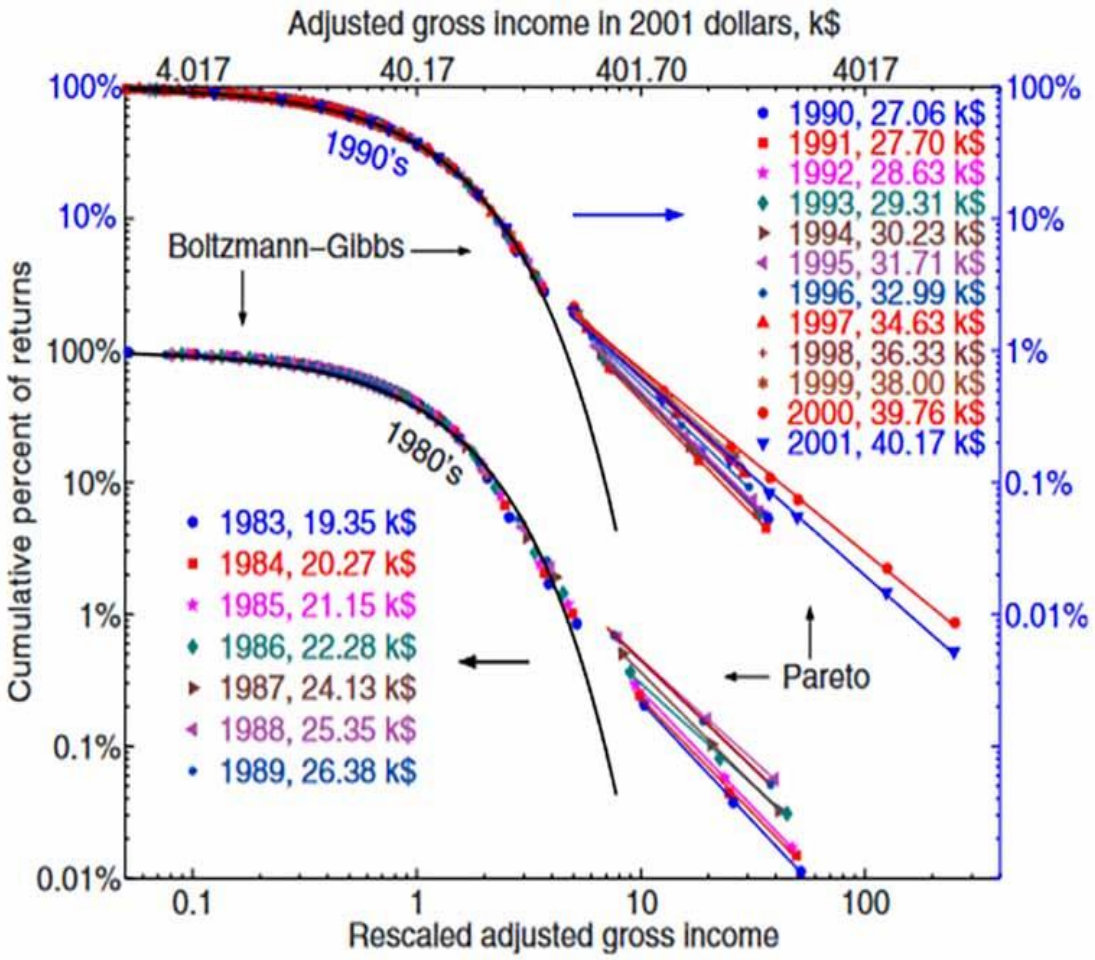


FIG. 7. (Color online) Cumulative probability distribution of tax returns plotted on log-log scale versus r/T_r (the annual income r normalized by the average income T_r in the exponential part of the distribution). The IRS data points are for 1983–2001, and the columns of numbers give the values of T_r for the corresponding years. From Silva and Yakovenko, 2005).

On the other hand, incomes have been shown to follow exactly a Boltzmann-Gibbs distribution; the thermodynamic energy distribution of molecules at a given temperature (**Yakovenko *et al.* 2009**). Physical thermodynamics and civilization thermodynamics have a close parallel, it seems, with “income” and “energy” having more than just a metaphorical relationship.

Do humans have Agency, or are we mere "meat machines" and slaves of thermodynamics?

- For most of our history, our forebrain and "reptilian brain" both aimed for the same goals – **Domination and gene propagation.**
- Now… they are in conflict, and our survival and well-being requires that our forebrain assume agency.
- Will we, can we, use our forebrain to do so, in time?
- **Scientists do, but they are ignored, suppressed, and even threatened if their work conflicts with the ruling paradigm of eternal economic growth.**

Natural Selection's imprint on our genetic nature is to impel us to grow, in competition with other species…

- As long as your species hasn't yet succeeded, the game can go on. The global tragedy is not when you lose - The world will go on without you just fine. But for *Homo Sapiens*…
- **The <u>real</u> tragedy happens…<u>WHEN YOU WIN.</u>**
- Because then, for a species as powerful as Humans, our final domination means the end of vast numbers of **other** species (and then us?), and a crippling change to the future of Earth.
- **For *Homo Sapiens*, we are at that point now. Today.**
- With "victory" in sight, it then requires a deep and fundamental transformation in our motivational biological genetic programming, else we crash the planet and ourselves, just as cancer kills its host. Can that transformation happen? How?

Can Human Nature Change?

- Can such deep fundamental change in human behavior globally happen?
- It must be achieved by the large majority of global population in order to change climate, such that we would voluntarily inflict on ourselves a substantial negative growth of civilization, affecting the decay/inflation term in CThERM and while still decarbonizing and allowing atmospheric CO2 to not rise beyond ~500 ppm?
- Garrett is quite skeptical and so am I, although I still hope that education may make some difference**.**
- **My maddening frustration, is in discovering how stubbornly resistant people are to this evidence.**

Inanimate Systems Have No Choice but to Obey the Laws of Thermodynamics PERFECTLY

- But humans have free will (…we hope. There's considerable question among researchers).
- We can voluntarily create legal enforced barriers to acting on our impulses and desires for immediate gratification, for the sake of a better future. We hope.
- It's going "uphill" in a thermodynamic system sense, against the grain, doing the hard thing… but it's perhaps not physically impossible.

It Requires Voluntary “Decay”

- In the **CThERM** model, what that would mean is voluntarily inducing civilization “decay” in the form of hard work which did NOT lead to expanding civilization.
- Decay that arose not by the involuntary crippling of society by the ravages of climate change and low resiliency, but was chosen voluntarily as a path (see my **K44-Policy** Presentation), hopefully more gracefully than Nature will choose **for** us, if we choose not.

Genetic Inheritance is Destiny?

- Remember from **Chapter 0** – our brain is only ~2% of our body mass, but uses 20% of our energy (which must come from food grown by our agricultural industry)
- If you've ever tried to over-rule your biological desires (going on a diet, say), you know how hard it is. It demands additional constant **energy consumption**.
- **Will power, requires the constant input of biological ENERGY.**
- Will-power will go only so far, because it takes real ongoing biological energy to fight against desires.
- Like holding up an Olympic barbell - no matter how strong you are, eventually that barbell is coming down

If instead, somehow, we could personally evolve…

- …to ENJOY a new “less is more” way of being, perhaps this consideration would not hold quite as much sway.
- But experience says that this will take such intensive individual human psychological maturing on a massively global scale, and so quickly, that it would seem impossibly unrealistic.

People CAN change, but for the vast majority, only after their dysfunctional habitual way of life forces them to “hit bottom”

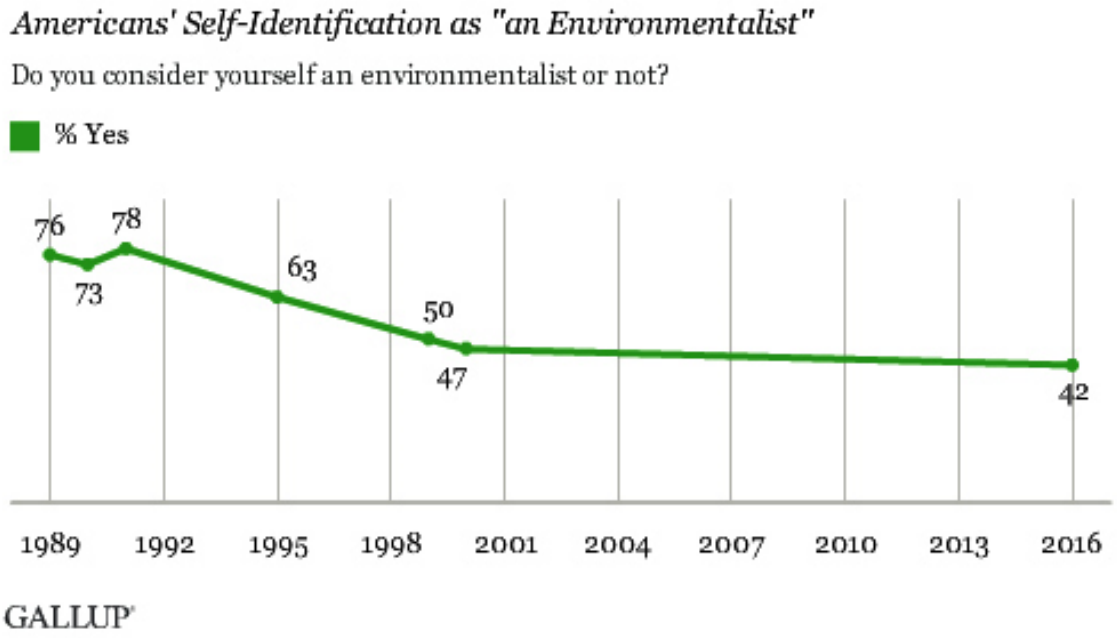
- Only truly deep **pain** felt by each of us individually might induce such a commitment for such deep personal growth, and even then, only if the person “hitting bottom” becomes aware of a better way.
- By the time climate chaos delivers us there, physics says it’ll be far too late to halt dire permanent climate change. Such is the inertia physics of large systems.
- Rather than rise to the massive organizational and technological challenges required, we’ll likely be struggling with bare survival as societal complexity breaks down into simplicity (**Strumsky, Lobo, and Tainter, 2010**).

Nolthenius' First Law: *"People Learn the Hard Way"*

- Psychologists have found it usually takes long-standing pain to motivate a person to change.
- And even then, it takes real work, real commitment, to overcome ingrained patterns of thought and achieve emotional maturity.
- How can we expect this of the entire global population?

Perhaps you're thinking that the growing degradation of the Environment is causing a global increase in Environmentalism? We'd expect Environmentalism to be strongest in the rich U.S. where we can afford such feelings. Is it? No.

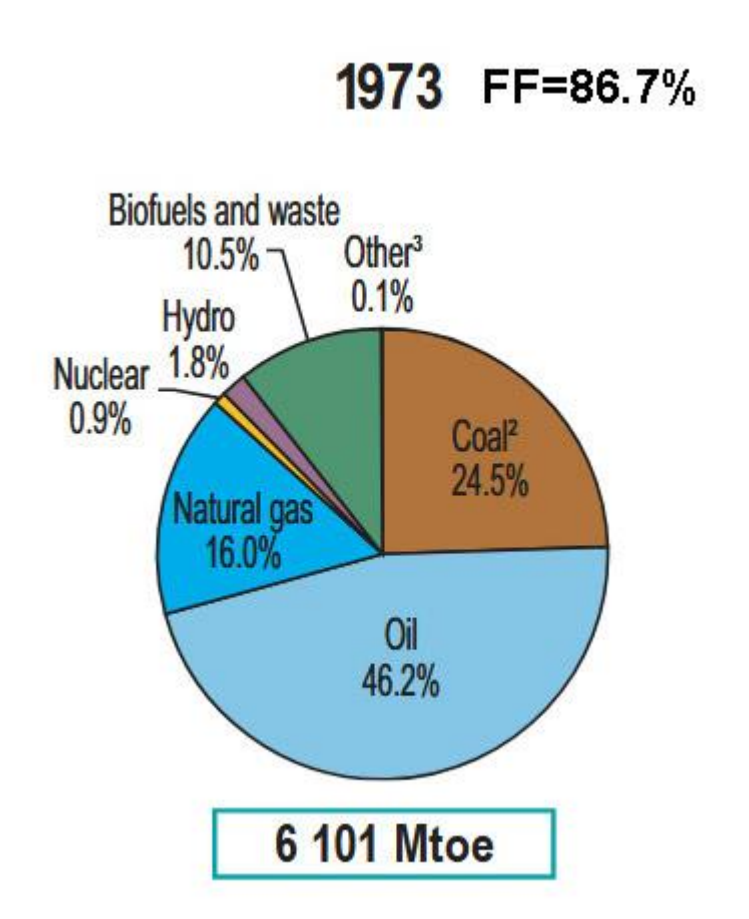
PRINCETON, N.J. -- As Americans observe Earth Day, Gallup finds 42% of Americans identifying themselves as environmentalists, down from an average of 76% in the late 1980s and early 1990s.

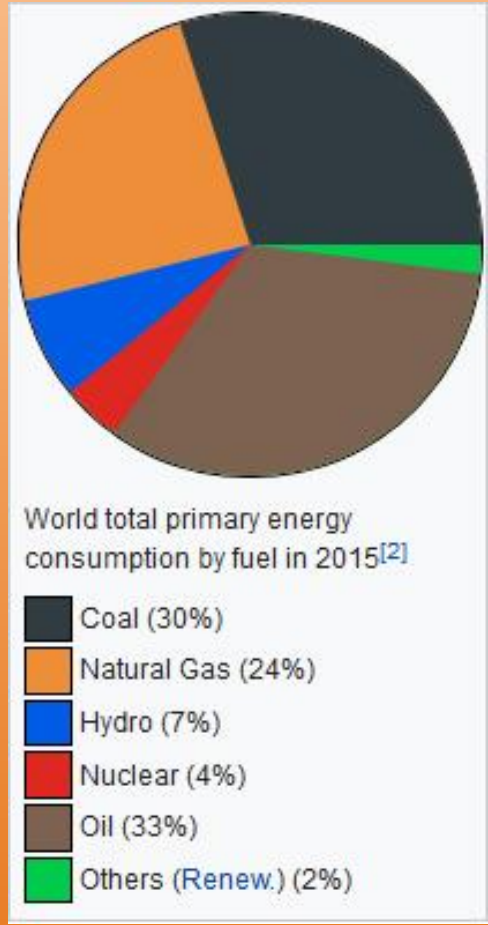


A few do learn…

- We hear their voices from the science community, and at least some from the Green community. But they are a tiny minority – the far tail of the distribution of people.
- Despite what economic growth is doing to this planet, most of the Earth is peopled by those desperate for MORE, not LESS. And not a single leader will dare talk of limiting population, or reversing growth in wealth, for fear of losing power.
- And worse, our global political/economic power systems are designed to reward short-term greed, not nurture long term planetary health (review **K44 – Policy** and especially the importance of **Gilens and Page 2014**).
- This attitude is incredibly pervasive both in and out of politics, as science writer **George Monbiot observes**.

To Show How Hard it Has Been To Change…





From 1973 to 2015: 42 years, fossil fuels (coal, oil, natural gas) as a % of total energy, has not dropped at all; remaining at 87% of (Total Primary Energy), while total consumption of all energy has more than doubled (BP Statistical review)

Merely Halting the Further Rise of CO2 Emission RATES is a Very Difficult Task

- In 2016, the global primary energy consumption rate was 17 trillion watts (TW), growing at about 1.5% per year (down from 2% for most of the 21st Century).
- That's 255 GW of additional power needed per year, or 700 MW of additional power generation installation per day.
- To keep CO2 emission rates constant, this additional 700 MW per day must be carbon-free power…

Considering Solar Photovoltaics as the Carbon-Free Power Source…

- …700 MW per day is equivalent to 3.5 gigawatts of "boiler plate" rating capacity per day (given the standard 20% capacity factor between peak output and actual average continuous output). Multiply by 365 days per year to get…
- **= 1,277 GW (rated) additional solar PV power to deploy every year**
- **= 4,100 square miles of solar PV active panel area, every year. Or, 11.23 square miles of solar panel area every day.**
- **That's equivalent to a square, 64 miles on a side, of solid PV panel, every year. Realize that is what's required not to reduce CO2 emissions, that's just to keep the annual human CO2 emissions rate merely constant, and not rising further.**

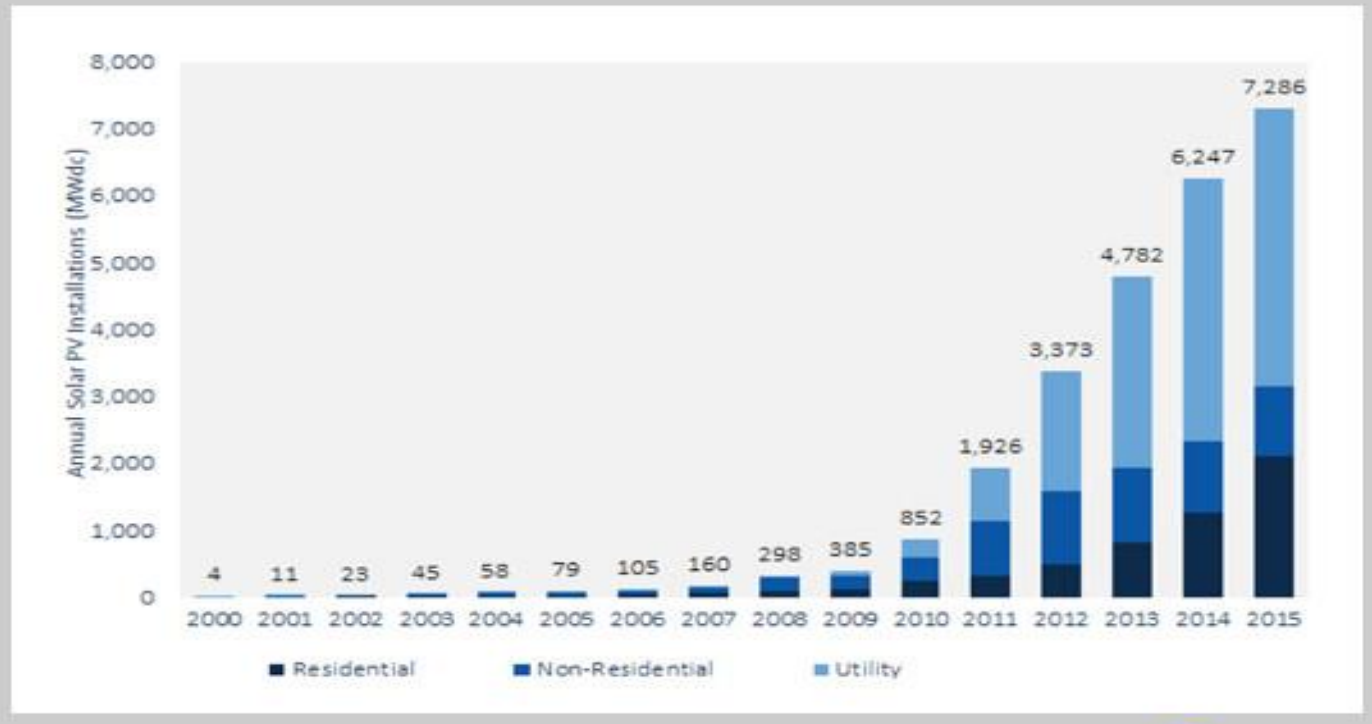
That's 11.23 square miles of PV panels or about 20 square miles including supporting infrastructure and land… taken away from other species and other human uses… every single day. Below is Carrizo Plain National Monument, CA. It is now the site of the $2.5 billion 10 mi^2 550 MW Topaz Solar Farm (world's 4^{th} largest currently)

To put 700 Megawatts/Day of carbon-free power into a Nuclear Power Plant Context

- The **Diablo Canyon Nuclear Power Plant** - the entire generating facility takes up only 12 acres - produces 2,055 MW of continuous power averaged over the year.
- Diablo Canyon is the equivalent of **33 square miles of modern solar PV panel area** (or very roughly 50 square miles of utility-scale solar power plant facility area, by today's standards).
- **Are you beginning to see the challenge of trying to transition from exploiting the concentrated ACCUMULATED energy of 50 million years of banked solar energy in the form of energy-dense fossil hydro-carbons, and instead running the same existing Civilization only on the dilute currently arriving solar energy?**

Let's assume a 30% capacity factor for the mix of solar (20%), and wind (~40%), which dominates renewables. New renewable power capacity was 161 GW in 2016. (but includes substantial biofuels which are not even carbon neutral). Still, be charitable and use 161 GW. That's 161x0.3 = 48 GW actual power output. **This is only 20% of the needed 255 GW needed to keep CO2 emission rates constant**

That's based on 1.5% global Wealth growth rates and therefore global energy consumption growth rates. Note that for the last 5 years plotted, solar deployment in the U.S. has risen only linearly, not exponentially. Most of the gain is in eco-damaging utility-scale projects). Trend continues through 2018



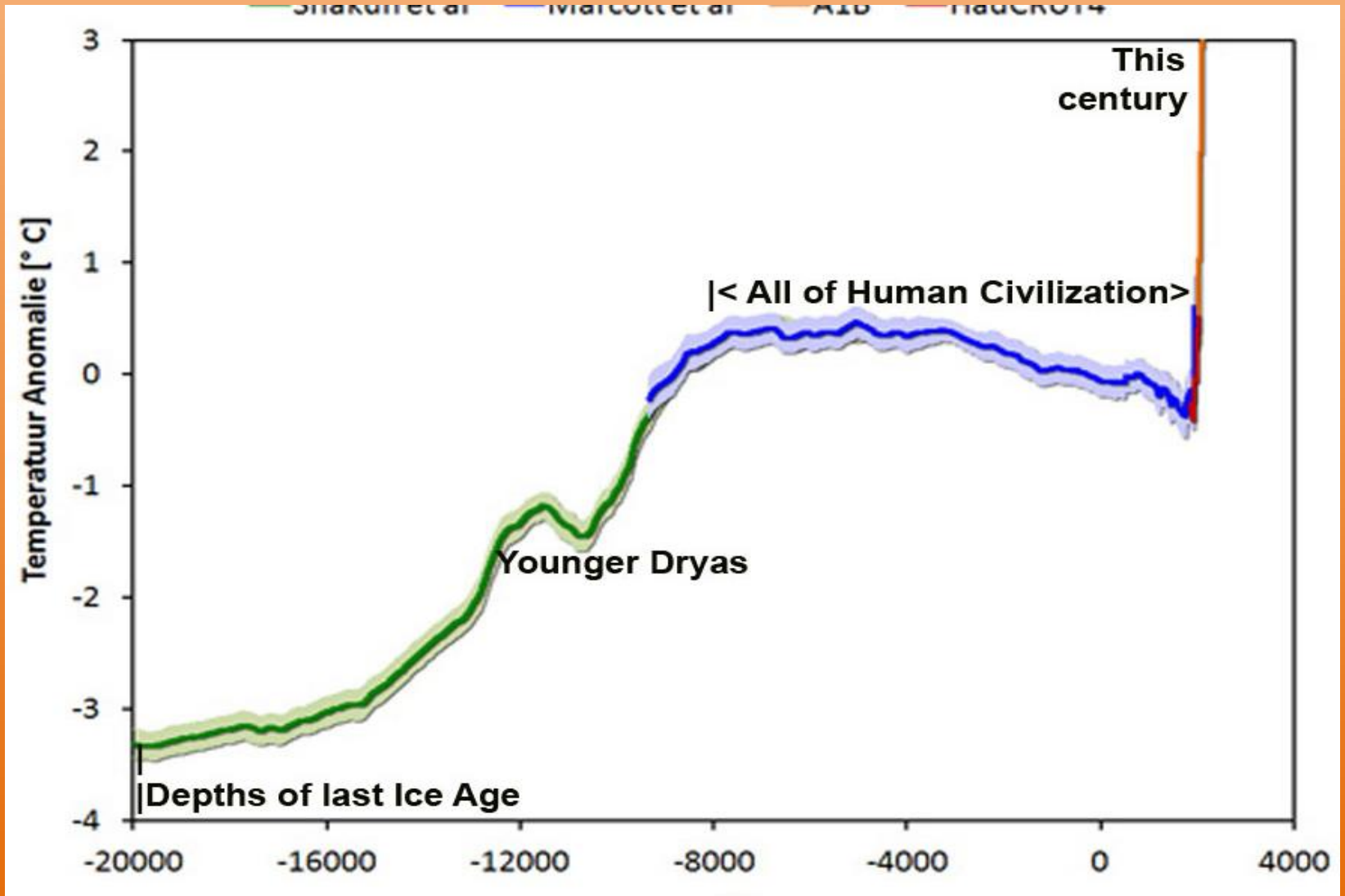
Suppose we DO deploy another 11 square miles of solar PV panels equivalent every single day… Would constant CO2 emission rates mean constant atmospheric CO2 levels?

- **No. This is a common misunderstanding by the lay public.**
- Instead it would mean that atmospheric CO2 would continue to rise, but now **linearly** (as an upward sloping **line** of the same rapid slope as we're currently seeing), rather than exponentially (an upwardly **accelerating curve**).
- Except, even that's very likely too optimistic, since at today's rising temperatures, we can't halt growing methane emissions and carbon release from the permafrost melt, so it is highly likely the CO2 rise rate would **still** be exponential (albeit with less acceleration than at present).

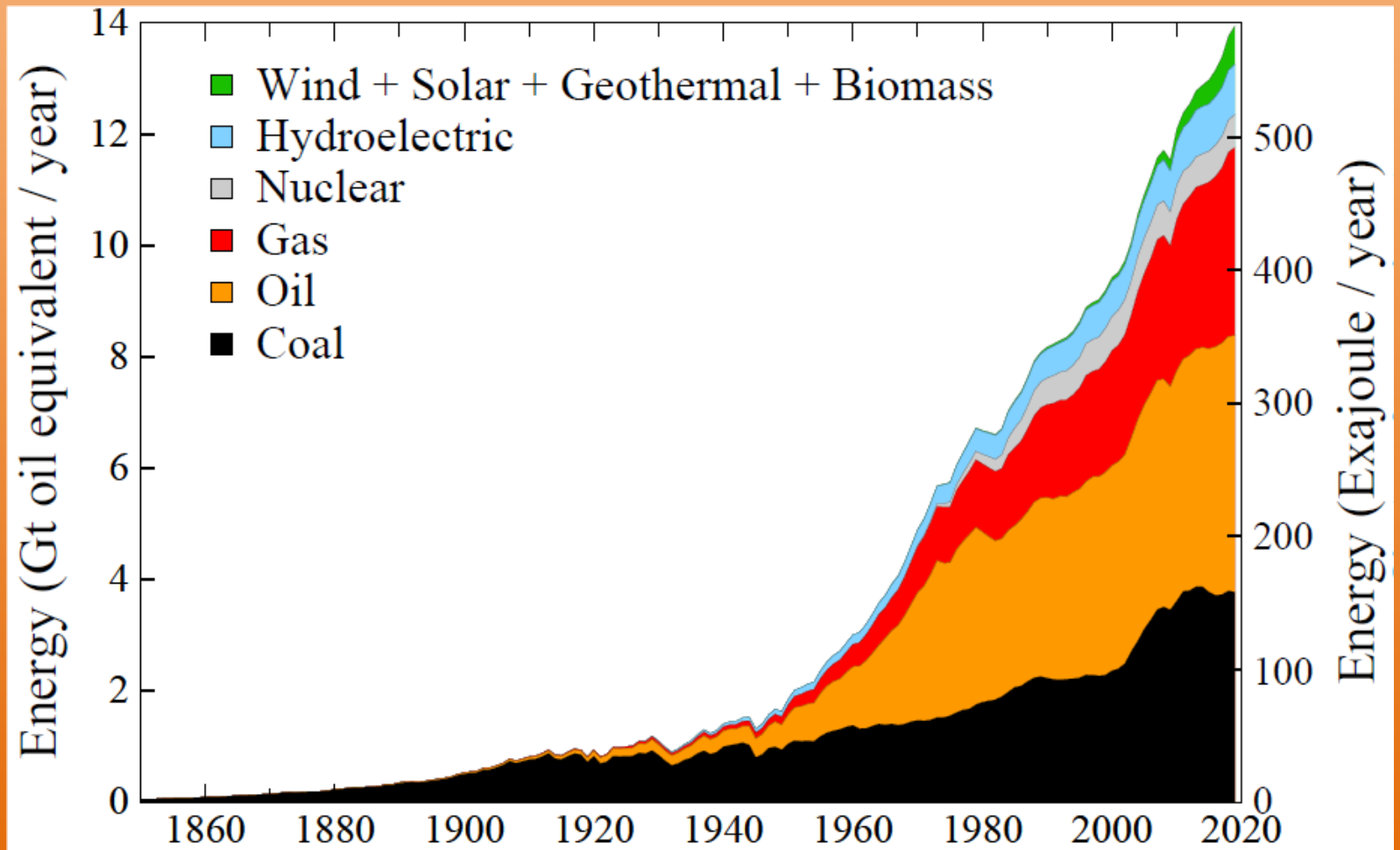
Prof. Kevin Anderson Points Out

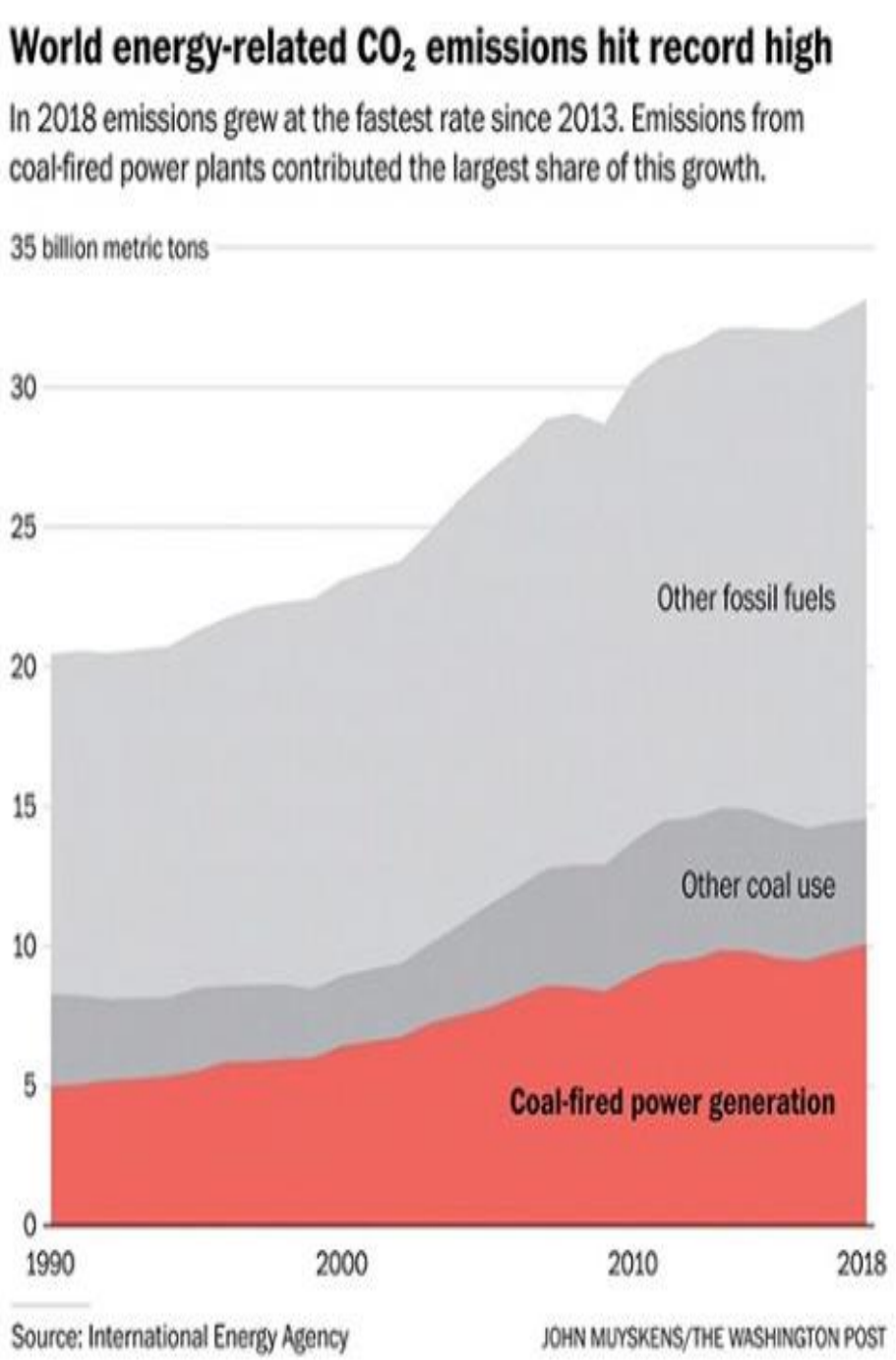
- Total global energy consumption in 2015 was 105,000,000 Gigawatt-hrs; Nuclear power provides 2.5% of that.
- Merely to get nuclear to provide ¼ of our power means we need to build 4,000 new nuclear power plants in the next 30 years. Instead, we have scheduled 70 (and dropping).
- His bottom line is, whether it's wind, solar, CCS, or whatever the new technology trumpeted **– *"you cannot build them fast enough*** *to prevent us from blowing through our carbon budget"* designed to hold temperature rise to ~+3C
- Anderson's **lecture presentation** reinforces the conclusions of Garrett, and highlights the unreality within so many policy reports delivered to climate policy negotiators.
- And Anderson's conclusions are without the additional constraints from the Garrett Relation, nor the new science on permafrost melt and rising ECS.

This temperature trend is both frightening, and much harder to turn around than you've been led to believe



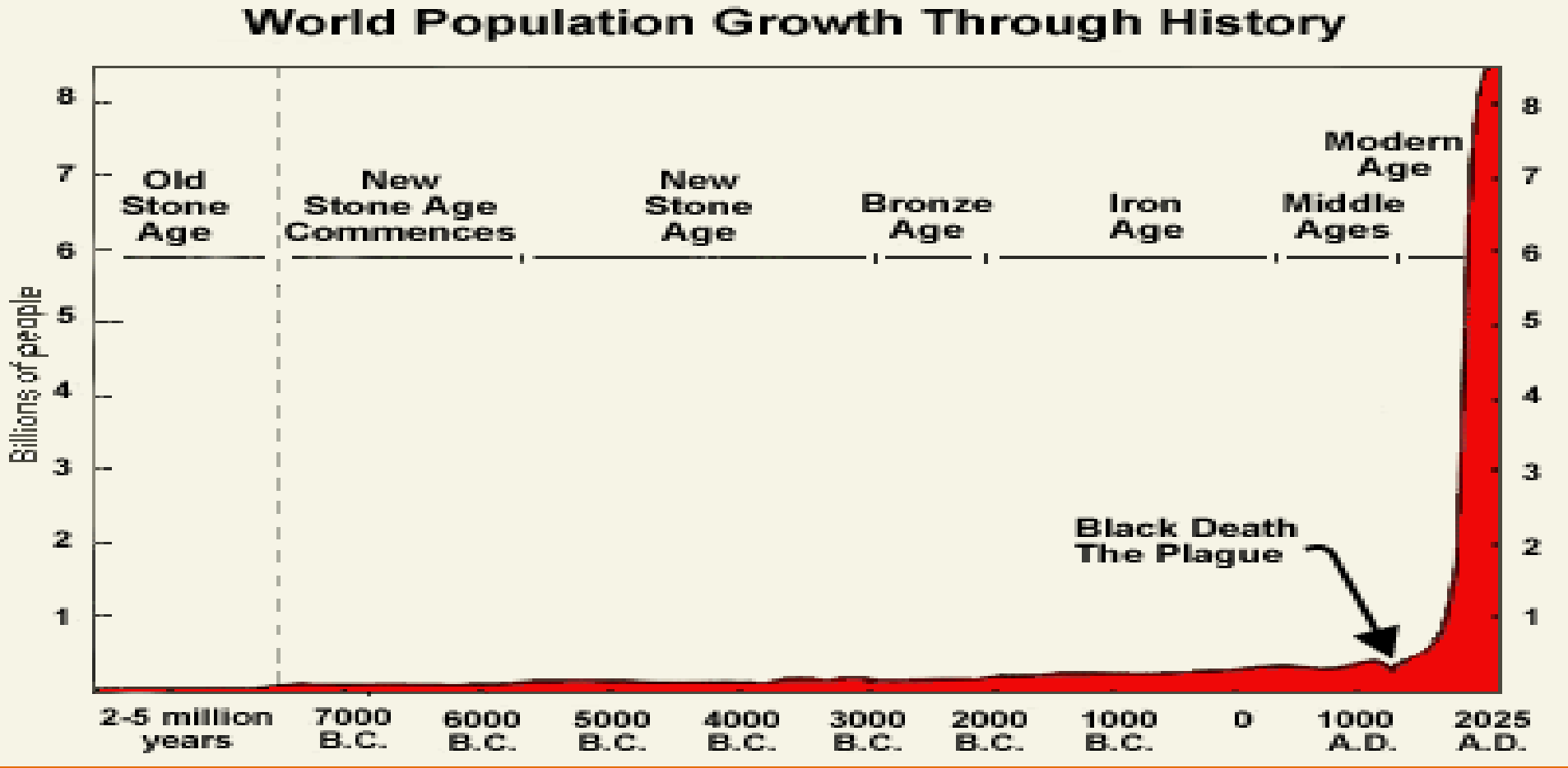
Global Energy per YEAR – Dominated by the discovery and burning of ~50 Million years of accumulated concentrated solar energy (fossil carbon) … The tiny blip of green is non-hydro renewables, on top of steeply rising fossil fuels. Hydro and Nuclear (gray) have not grown for decades.





Fossil Fuel Burning Continues to Set New Records. Energy is Everything. We will use ALL Energy We Can Lay Hands On.

Energy discovery allowed us to multiply ourselves, our Civilization. Now; we're stuck with supporting that bloated Civilization. That population is IN PLACE. That Wealth is IN PLACE. That infrastructure is IN PLACE, all needing constant feeding of more energy just to maintain it. Short of apocalypse, that is a FACT of our LIVES. We've dug a very deep hole: our power needs. That manna from heaven – fossil carbon – is killing our planet. It is IN PLACE as our energy source supporting the massive Civilization that it created, and we can't get off of it fast enough to avoid the planetary disaster it is creating. (1min History of Population)



Prof. Joseph Tainter, on Parallels with the Fall of the Roman Empire: Plundering ACCUMULATED Wealth *vs.* ONGOING GENERATED Wealth

- 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 neighbors it conquered.
- 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 so it collapsed.
- (especially **33 min into this talk**).

We are in the same situation

- We have multiplied our civilization by orders of magnitude by accessing millions of years worth of **accumulated** fossilized solar energy.
- We are faced with having grown vastly by using an energy source which in fact is a poison to our future, and face the necessity of having to shift support of our current vast civilization to only the **currently arriving (neglecting nuclear)**, not **accumulated**, solar energy.

How Robust is the Power/Wealth Relation?

- Even though oil prices have gone through huge spikes; in the ‘70’s Arab Oil Embargo, again during the Gulf War, and just before the “Great Recession” of ’09, with large drops in oil prices in between – still the constancy of (time-integrated inflation-adjusted GWP)/(Current energy consumption rate) - **the Relation - continues to hold.**
- Even though the rate of growth on global growth rates have slowed markedly in the past 20 of the 50 year dataset – still, **the Relation continues to hold.**

Oil Prices have bounced wildly over the past 50 years, but the P/W Relation remains constant

Even with the most populous nation on Earth – China – enforcing 35 years of 1-child-per-family, still the P/W Relation has held

- **Even though the efficiency with which energy can generate a dollar of global GDP has more than doubled since 1970, still the P/W Relation has held.**
- These are impressive confirmations. Yet we can ponder…
- **…What kind of shock would it take for this relation to be broken?**

Would a Giant Asteroid Impact do the Job?

- In that case, global wealth would be cut to a small fraction of today all at once, and so would our energy consumption rate.
- Yet, time-integrated global GDP would not change immediately since it includes all past GDP as well – and the past cannot be changed
- There would have to be quite a few years before that integral dropped low enough to again match lower energy consumption rates. **So does this reveal a flaw in the model?**

No. The CThERM model includes a key term – inflation.

- Remember that the **Power/Wealth Relation** applies only for inflation-adjusted wealth. A massive destruction of wealth would leave the existing nominal dollars of integrated GDP paired with far less actual wealth to denominate– *i.e.* the monetary number assigned to each unit of remaining wealth not destroyed by the asteroid would be far higher: **Inflation.**

Let's Clarify the Notion of Inflation

- There are two ways inflation can manifest. Inflation is the mismatch between the rate of change of money, and the rate of change of civilization wealth. One can see rising inflation either because there is **more money** in circulation OR because there is **less wealth** out there for the existing amount of money. Or a combination of both.
- Printing press money not justified by an increase in Wealth, is one form of inflation and it gets a lot of attention, nefarious though it is.
- But destruction of Wealth, if money supply remains constant, is another form of inflation.

Said Another Way…

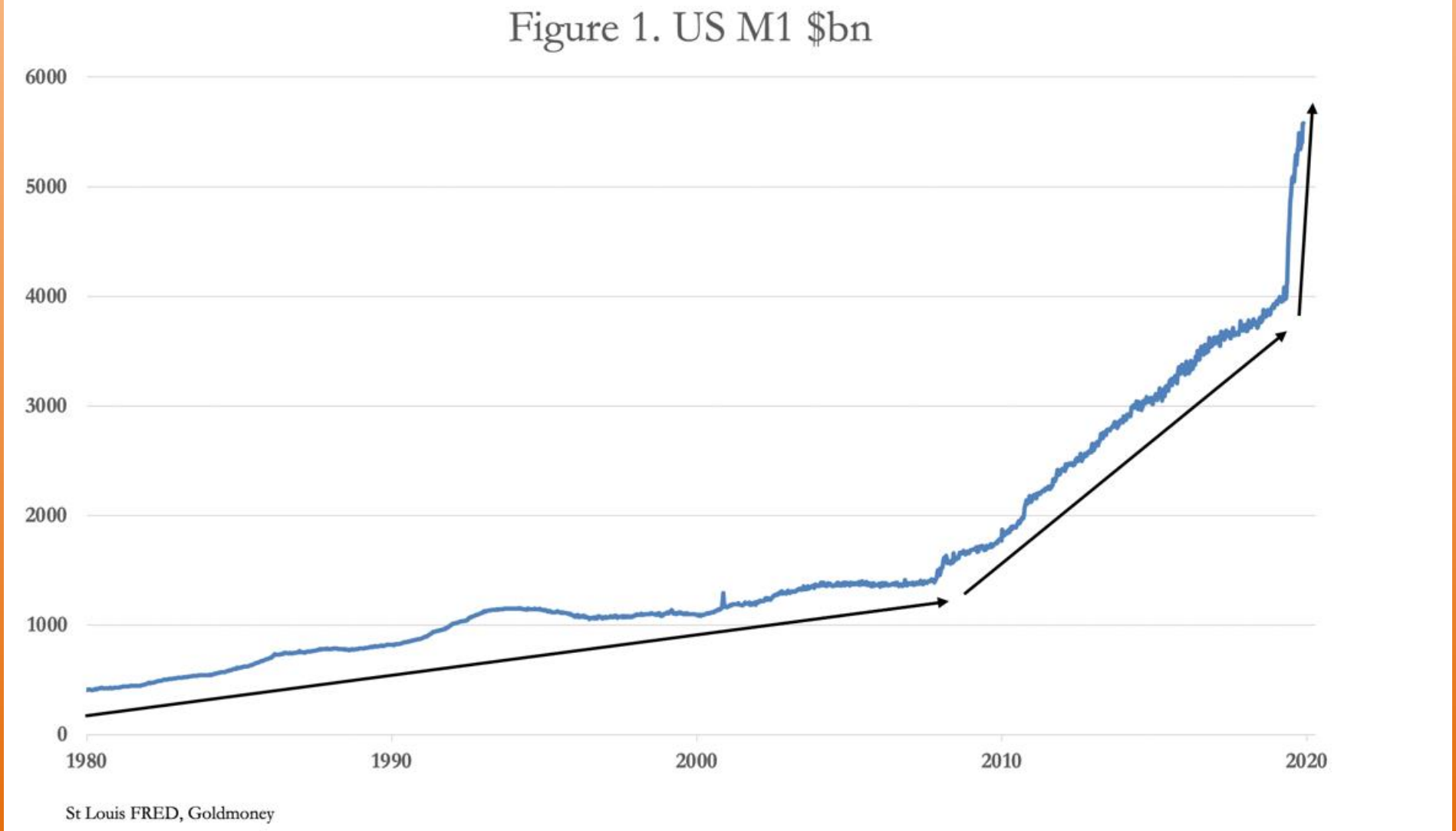
- The **CThERM** model includes inflation, and in cataclysms we see that governments and central banks in the past have tried to force savings to be invested for growth by penalizing savings via massive monetary inflation.
- Examples: Germany post WWI, Argentina in the 1970's, some African social/political cataclysms… but a notable exception being after the start of the U.S. Great Depression, when the Fed tightened credit in 1931, '33, and '37, exacerbating the Depression.
- A decision the current **Federal Reserve has vowed to never repeat**

Currency Wars to Out-Inflate your Competitor Countries

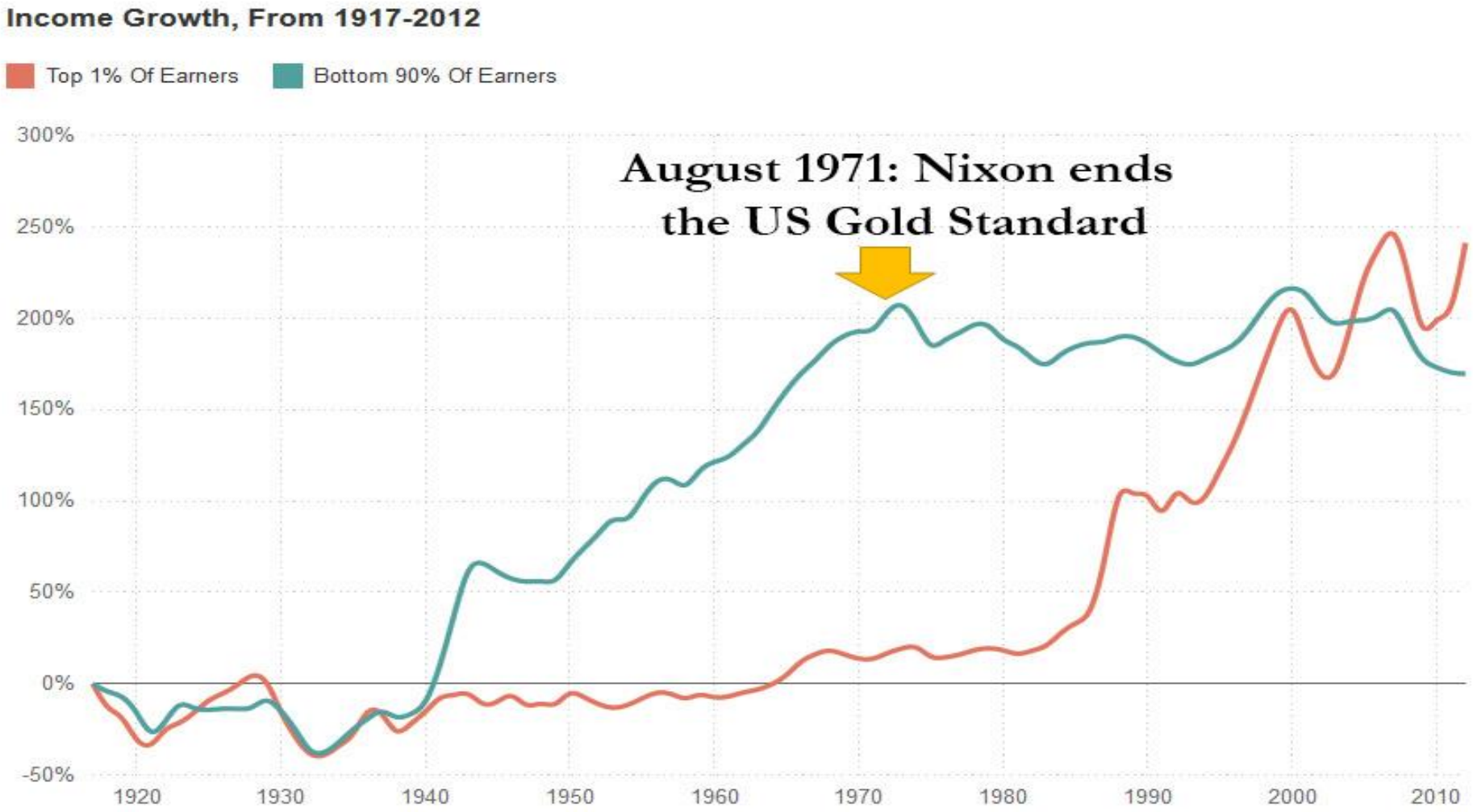
- The fact that economic growth rates of “only” 2%/year are not accelerating upward as Wall Street demands, are motivating central banks to fire up all-out currency wars in Japan, the U.S., Europe, Russia, China… to **devalue their currency** through massive creation of money, and
- “Nuclear Option” talk of negative interest rates as the ultimate weapon to pry-bar savings out of people’s pockets and into Wall Street risk assets markets, where the Economic Elites’ computer algorithms of ever increasing complexity are ready to further extract the wealth of the citizen owners.
- In Dec ‘17, an **ominous move** on the Federal Reserve from President Trump in this direction, appointing a Fed governor who wants to abolish cash, making it much easier to control your money, forcing it into risk assets through manipulated interest rates perhaps.

Monetary inflation leads to price inflation. So far in this post - "Great Recession" world, mostly confined to asset price inflation: houses, stocks…, since the average consumer is tapped out and can't afford higher prices.

M1 U.S. Money Supply. Going hyperbolic, as the Feb applies paddles to the chest to artificially stimulate an economy dying of debt-clogged arteries

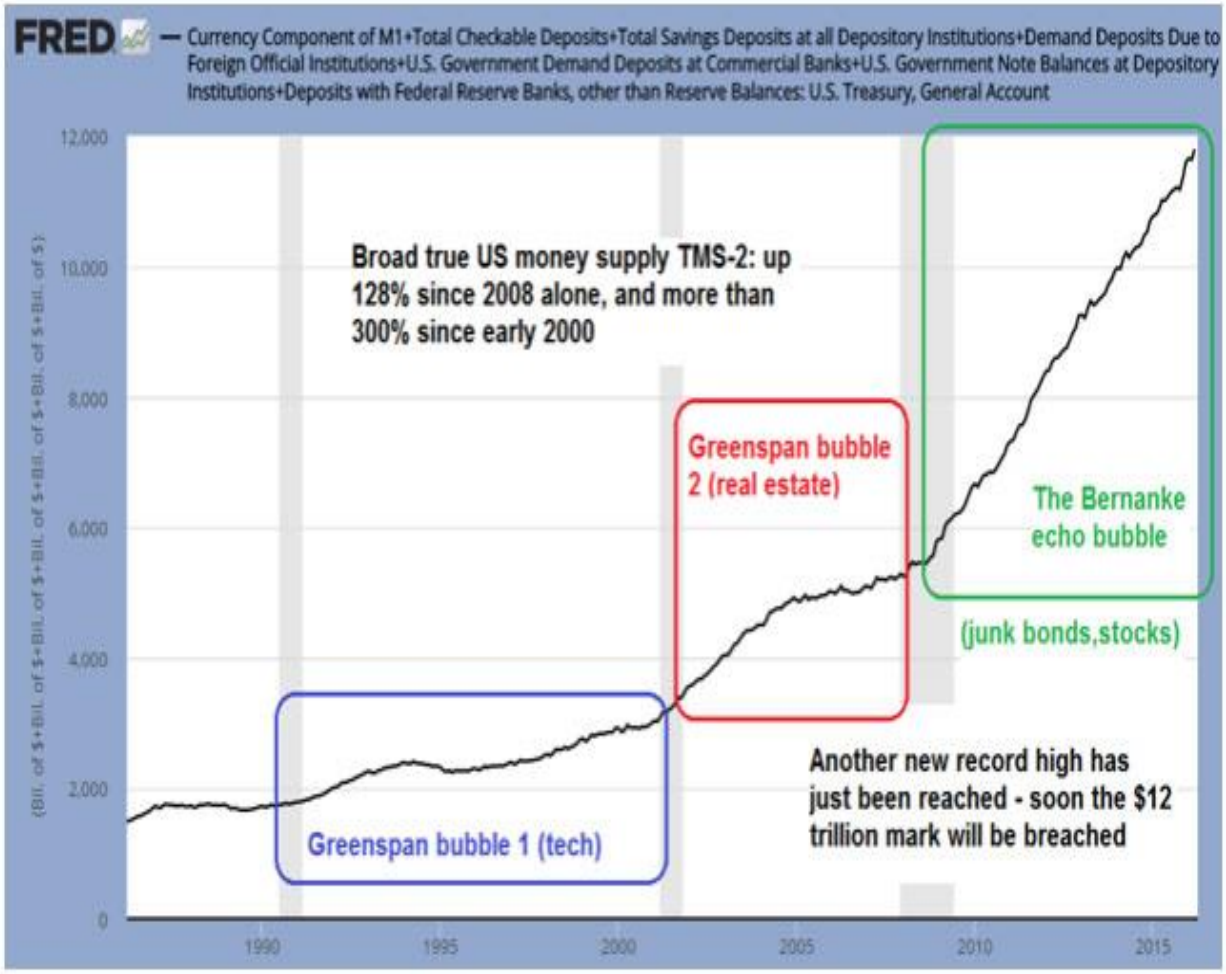


Monetary inflation worldwide was unleashed when governments ceased backing their currencies with gold (which cannot be inflated) so that dollars could be manufactured at will. This forces depreciating money into risk assets – equities - which are the first repository of new money, and which are primarily owned by the most wealthy



Economic growth is ~2% per year, but money supply inflation is 5-8% in the U.S this decade (as of 2016), 13% in the Eurozone, and even higher in Asia.

- Generalized inflation has the effect of lowering the efficiency (albeit raising the velocity of money) of the economy and thus lowering the rate of return on energy investment. It is impressive that the world has yet been able to maintain a 2.2% return on energy investment, despite this drag (yet does pure asset price inflation count the same as CPI inflation?).
- Global Central Banks are openly desperate to cause monetary inflation. The reason is that rising prices will spur consumers to buy now rather than save their increasingly devalued dollars for the future, and a higher velocity of money spurs GDP, making the economy numerically look good.
- It speaks to our unshakable addiction to at least the illusion of growth …
- Now - During the single year prior to Aug ‘20, US M2 money supply rose an astounding **24%** due to Fed actions during the CoVid pandemic.

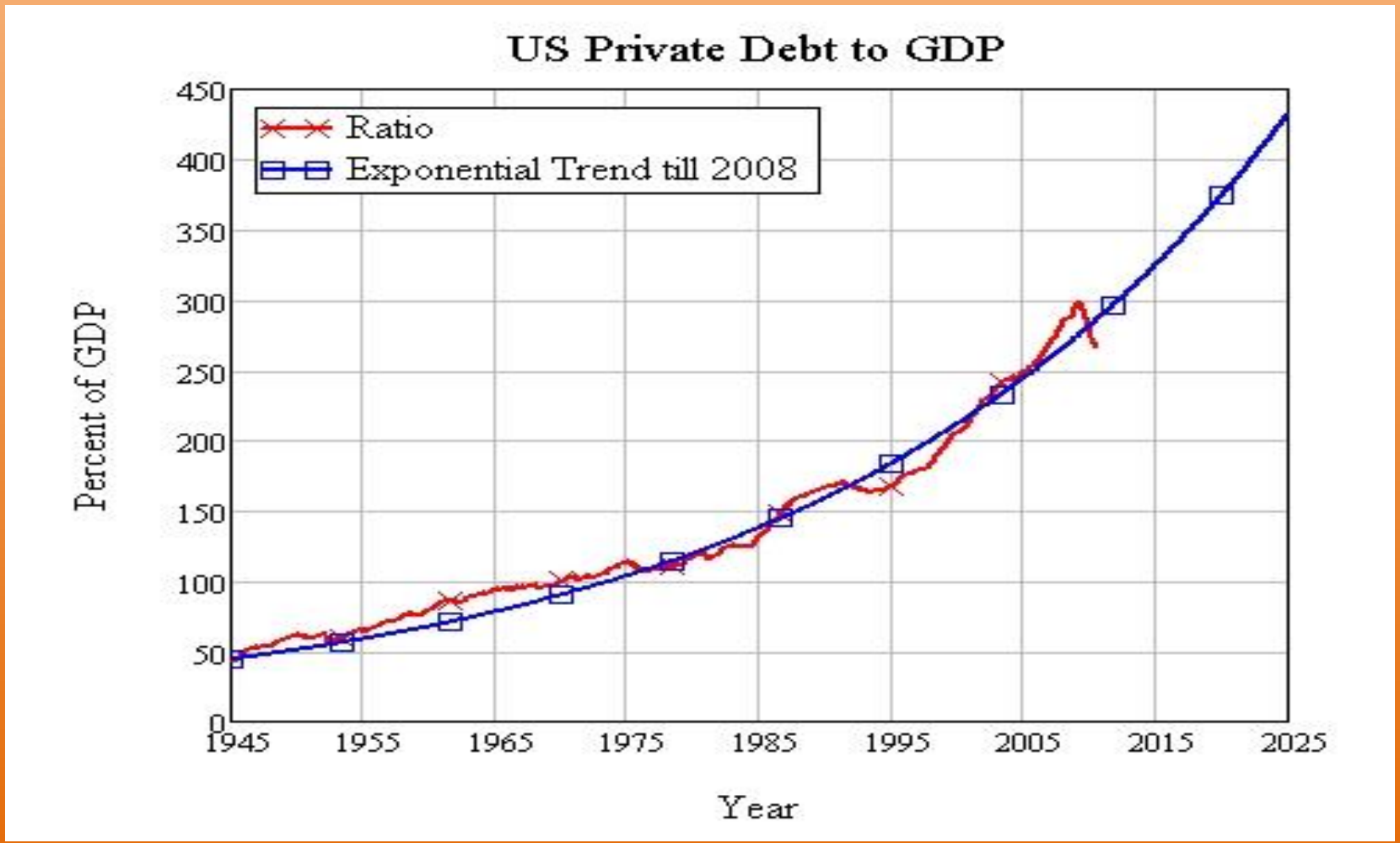


US money supply TMS-2 and the associated asset price booms since the late 1980s.

Currently, the true money supply is growing at 8% y/y in the US and 13.3% y/y in the eurozone. This remains historically a very high level, even though US money supply growth is well down from its 2009 and 2011 peaks:

U.S. Money Supply through 2016. The U.S. Federal Reserve is absolutely determined to raise economic growth rates, even if it requires massive money creation and enforced low interest rates, (even negative rates, in a number of countries). They are penalizing saving, and FORCING us to take money out of savings accounts and put them into risky "growth" assets. "Growth", even artificially induced, requires energy consumption

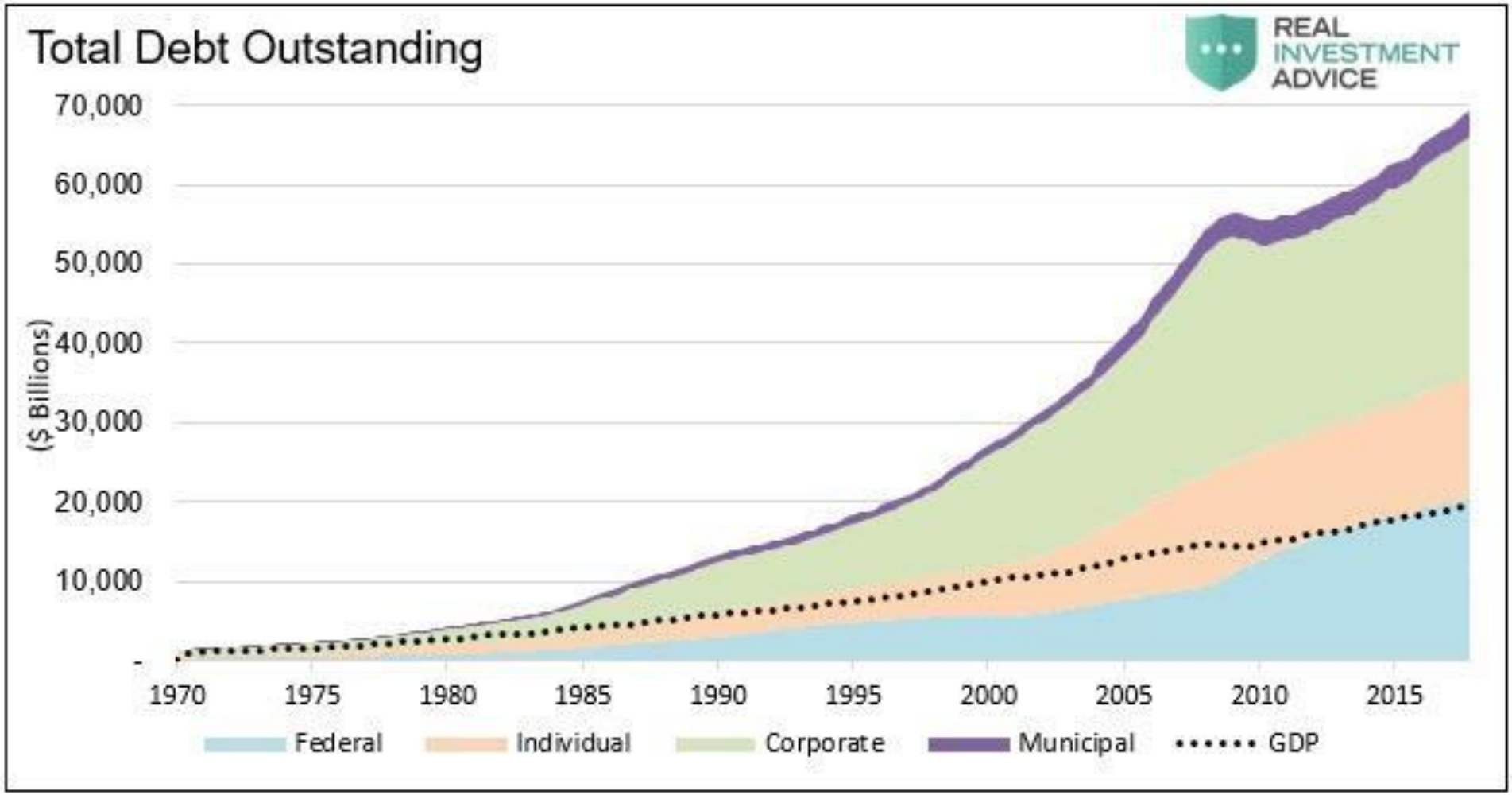
So we go even deeper into debt, which is borrowing from future generations (who aren't here to protest). In the U.S., Private Debt is exponentially crossing 370% of GDP in 2017, and 69% of families have less than $1,000 in savings (source)



In Pondering the Role of Debt in the P/W Relation's Accounting…

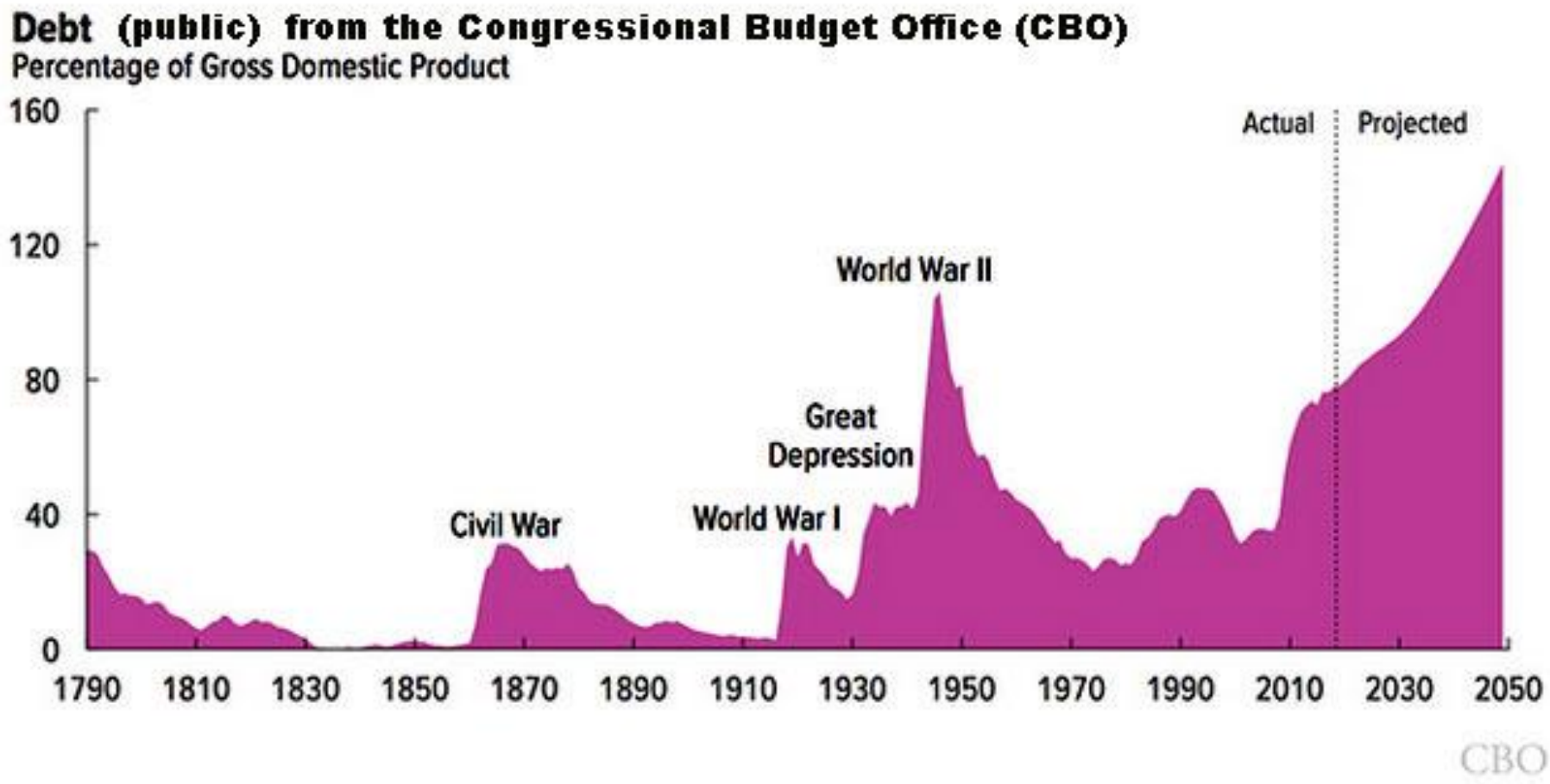
- Garrett points out that since the value of the spending is happening **today**, and the spending too is happening now and not the future, that in fact, the relation is valid as is.
- I agree. And I've come to realize the effect of debt instead will be in harming future growth as bond holders must be paid regularly and on time, and in the inflation term as it affects now. Again, the P/W Relation remains as is.

<u>Total</u> (public and private) U.S. debt is rising much faster than GDP, and now over 400% of GDP. ALL of our "growth" (and then some) is being created by borrowing from future generations. (Global is similar)



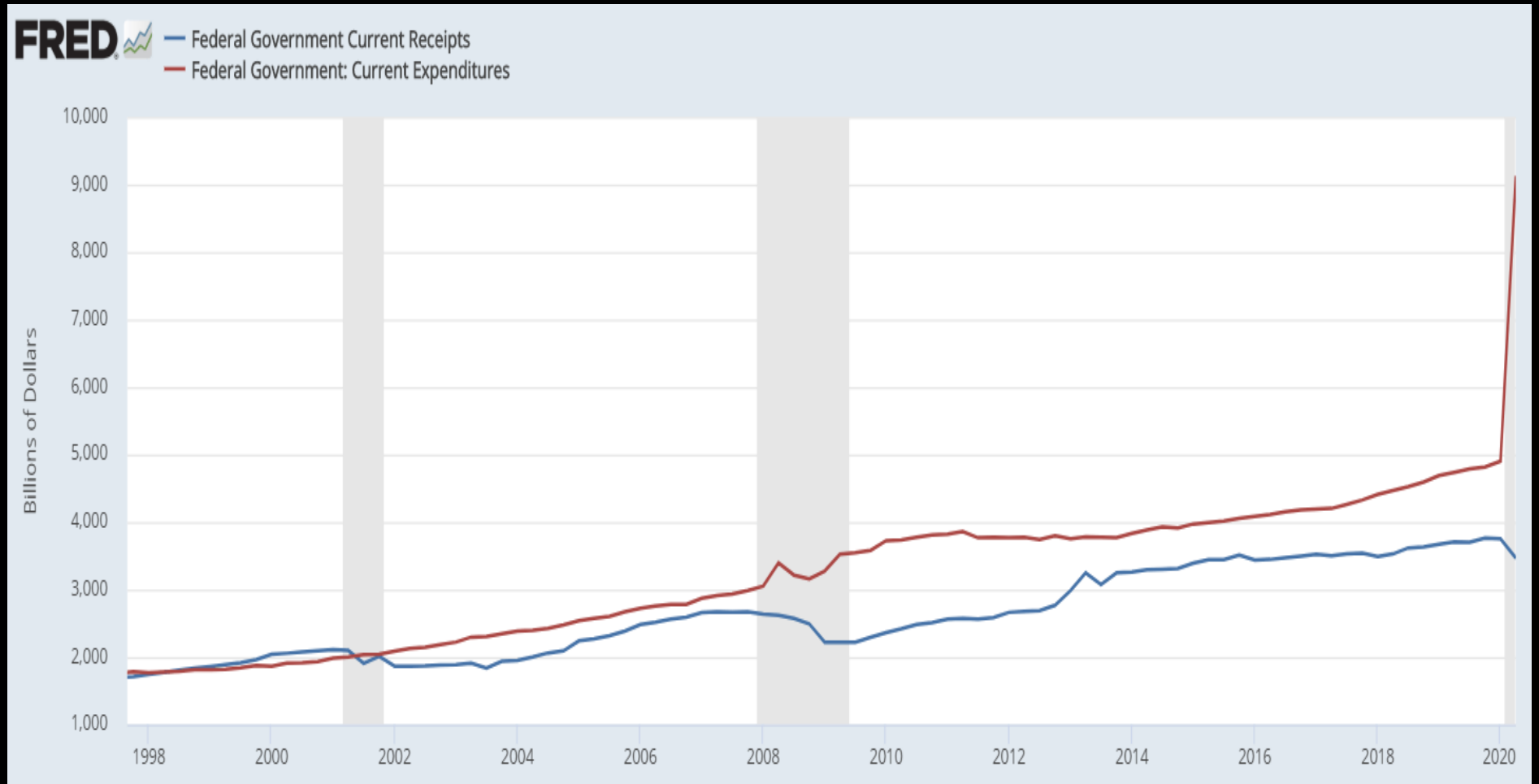
Data Courtesy St. Louis Federal Reserve and Bloomberg

And Projected to Get Much Worse: Federal Debt (Congressional Budget Office Study 2019)

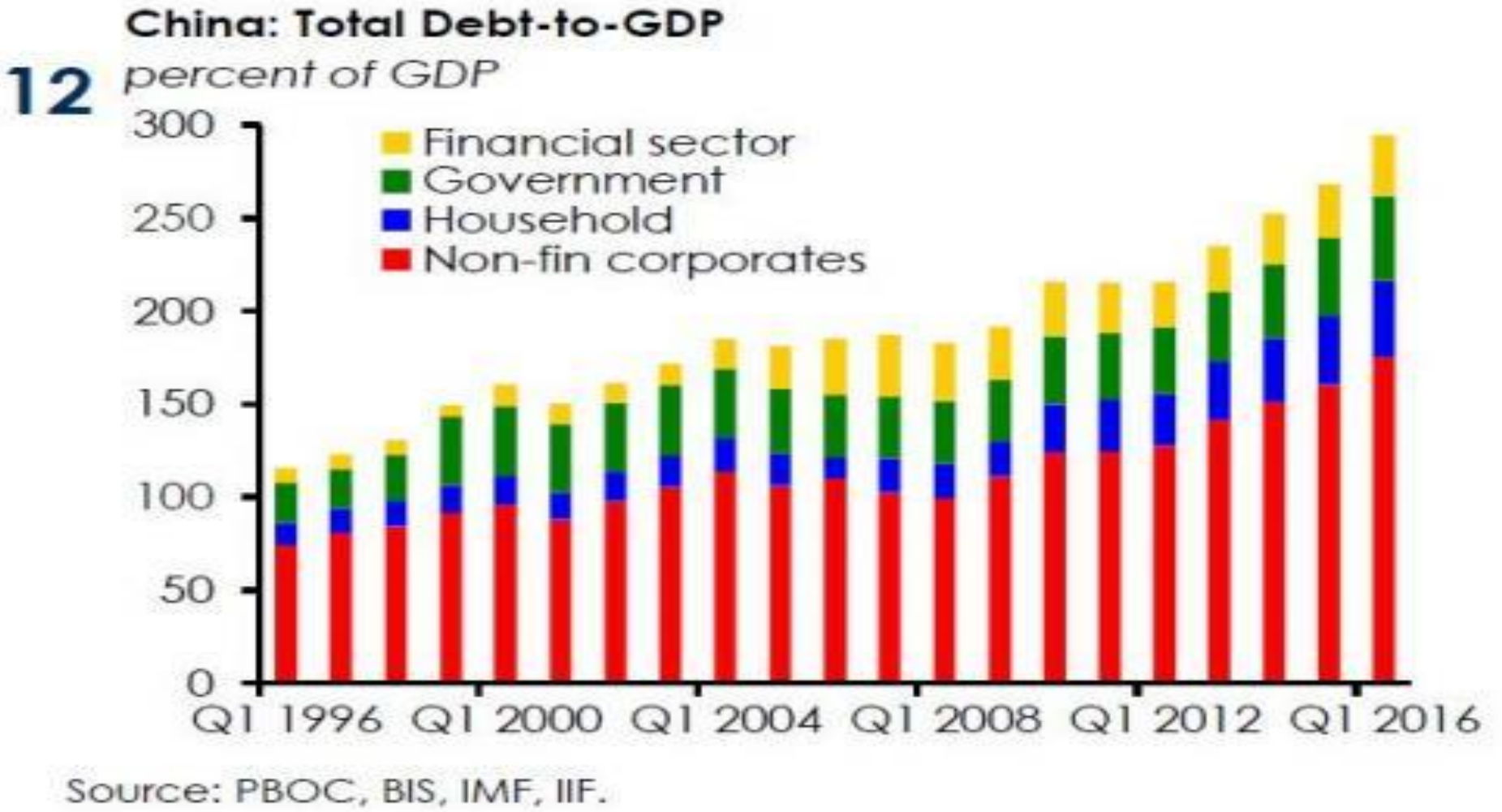


By 2049, U.S. debt will reach 149% of GDP, the CBO projects.

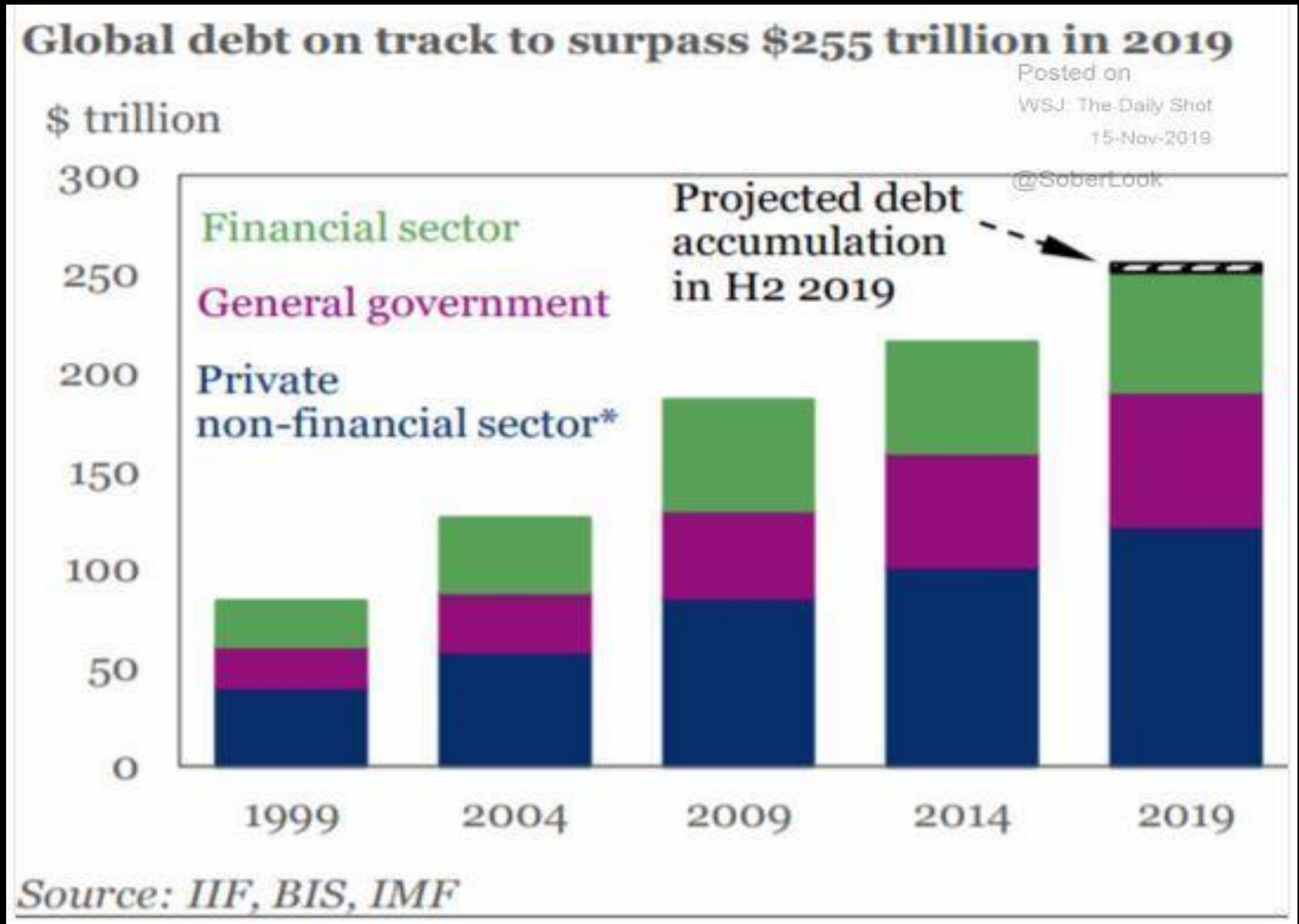
Federal Debt has already skyrocketed far past these projections only 1 year later - in the 2020 CoVid Pandemic Economic Recession, dwarfing the enormous debt from the “Great Recession” of ‘08



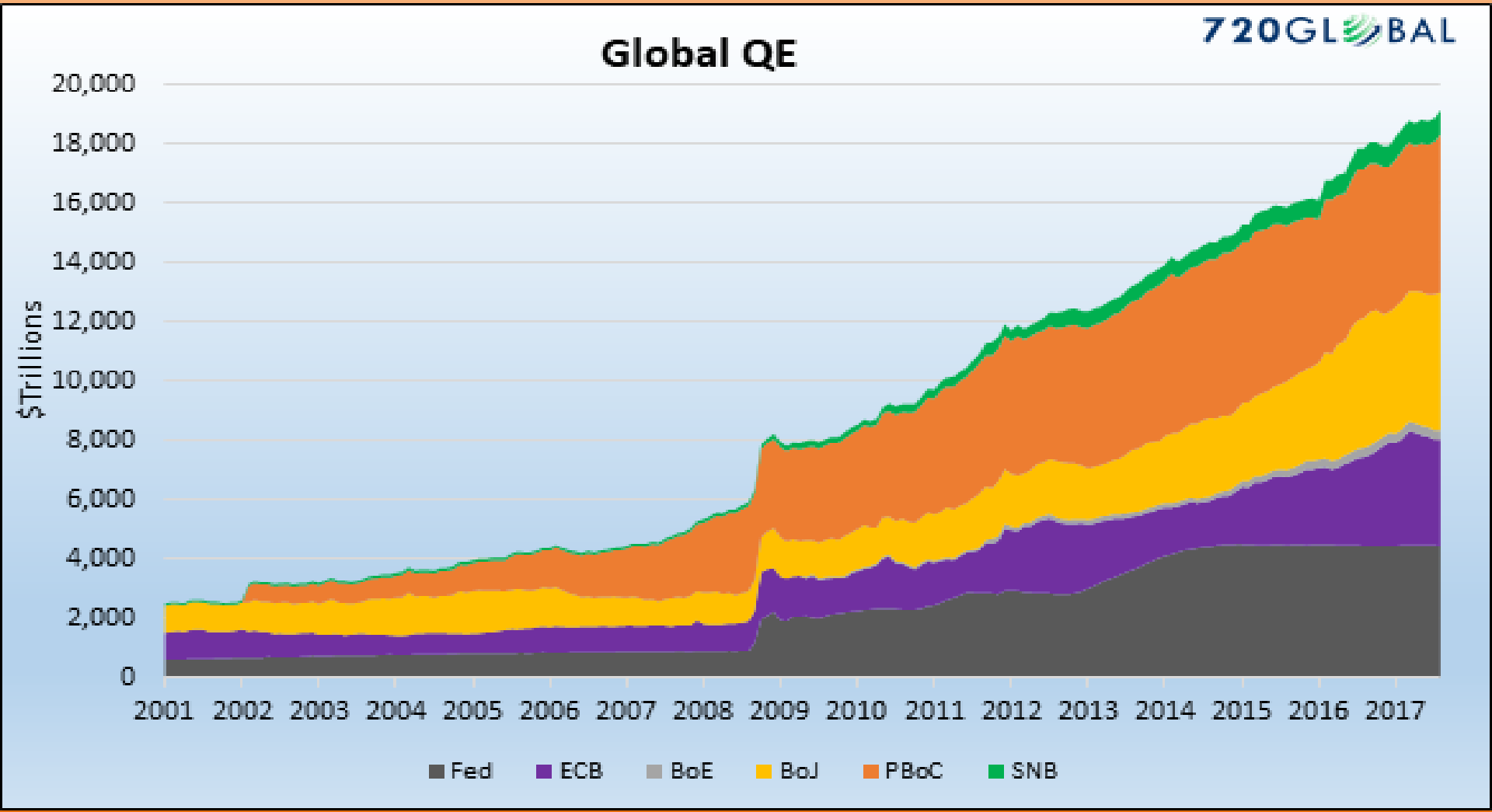
Same is true in China. Debt rocketing even faster than their GDP. In 20 years their total public+private debt has gone up 3x faster than GDP, and is now 3x higher than their GDP. Similarly – GLOBAL DEBT is rising 3x faster than global GDP. This trend will end badly.



…And Global Debt as well



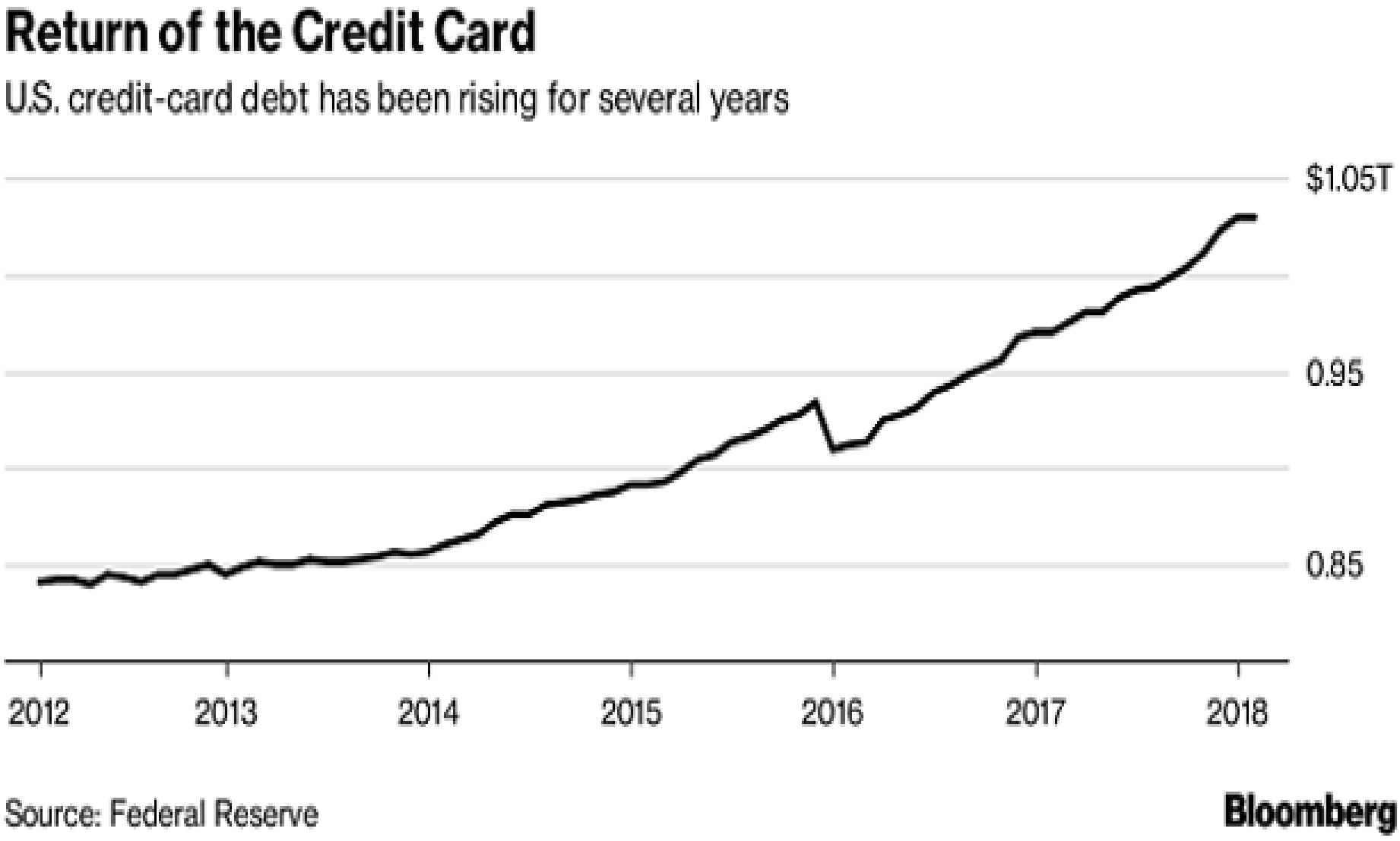
"QE": A euphemism for central banks issuing bond debt, and then buying it up themselves, to raise demand. Gone up by 900% in just 16 years. Graph below is for the 6 biggest global Central Banks: U.S., Europe, England, Japan, China…



But Rick - We LOVE QE! (Quantitative Easing). It's Boosted our Stock Markets!

- Sure, just like a new credit card to a shop-a-holic "solves" their financial problems... or so it appears to the short-sighted.
- Imagine McDonald's sending out employees to their stores to buy up most of their Big Mac's (because too many customers instead begin eating healthy, elsewhere?), so they can report to Wall Street some great sales figures on their next **quarterly Earnings Report**, and watch investors respond by bidding up their stock price.
- That's what the Fed has done. <u>THAT's what we've come to, in this crazy world.</u>

In fact, our private credit card debt is accelerating; up 21% in just 4 years



When the annual payments to the rapidly rising number of bond holders of that debt comprises too big a fraction of income…

- That's when the hope for continued growth ends, and a major re-pricing of assets happens.
- History suggests (recession-GDP bias) this moment will also end any desire to make the painful investments in transforming the energy structure for long term good of Earth
- Until then, investors are looking at each other and **FOMO**'ing each other into bidding up asset prices contributing to the illusion of growing real wealth.

The CThERM Model's Key Parameters

- Future projections require assuming …
- **1.** How fast can we decarbonize our energy?
- **2.** How fast can we create energy consumption efficiencies?
- Decarbonization is explicitly included by a free parameter; the decarbonization rate **c**
- Garrett parameterizes it as a simple exponential decline. Other assumptions are possible.

Removing CO2 from Carbon Burning is Costly in both $ and Energy

- The cost and energy input is comparable or greater than the energy gotten from the fossil fuels themselves by 40-60%, (making the whole enterprise pointless http://sciencepolicy.colorado.edu/admin/publication_files/2015.32.pdf whether natural gas or coal (Samuela Bassi, energy analyst).
- Professor Vaclav Smil calculates that even to capture and store just 20% of today's CO2 emissions *"would need a capacity 70 percent larger than the petroleum flow handled by the global crude oil industry"* (**source**). In other words, massive energy investment is required for this new infrastructure, producing more CO2 along the way.

Well, that's discouragingly expensive in CO2 emissions. But can't we just Do It anyway, and still have a better future?

- Better than not doing it – yes. But CO2 is a tough molecule. It doesn't go away. As Anderson emphasizes, studies show that ultimate equilibrium temperature depends only on the cumulative CO2 emissions. You can't fix later what you emit today unless you pull CO2 back out artificially.
- If CO2 is emitted, it raises global temperatures. **Permanently.** (absent atmospheric CO2 scrubbers at ~$300-600/ton CO2)
- Doesn't matter if it's emitted today, or in 20 years. You can't get away with emitting it now and then waiting for the ocean to absorb it later. Hysteresis in climate ruins that hope.
- Recall that temperatures rise until carbon emissions cease, and then remain constant thereafter, for thousands of years.
- **For climate, you can't afford to emit it in the first place.**

Suppose somehow, impossibly, we rapidly transform to a ~Zero Carbon global energy system…

- In such a new world, we have a landscape covered with solar PV panels and giant wind turbines, enough even to perhaps power atmospheric CO2 capture devices and induce lowering global temperatures.
- But if the ruling urges are still “Growth”, we must consume ever larger amounts of raw materials as well. Critical “Rare Earth” elements are already **almost impossible to find in mine-able ore quality** – yet mining rates must grow 12x by 2050 to meet projected demand. The only mines are in China, and in short supply there as well.
- …to perhaps only end up in a **“Blade Runner”** future

"Blade Runner" World: I don't find this inspiring

From the opening scenes of “Blade Runner 2045” – desert ecosystems eliminated, packed solid with solar thermal power plants. Not inspiring to anyone who loves Nature

Am I a genetic freak in feeling that Growth *Uber Alles* does not inspire?

- I hope not. The Earth is finite. We'll have to deal with it.
- Garrett observes that complex dynamical systems, including species, have a natural arc; of growth, peak, and decay.
- But for our civilization, how does decay just happen to be about to start **today? Scientists have learned to be skeptical of arguments that seem to require "fine tuning" of the time or parameters to work. But not so, here…**
- It's actually not surprising we find ourselves at this point, since a good fraction of the people who ever lived are alive today, thanks to exponential population growth enabled by the discovery of fossil fuels. The odds of "random you" being born in this particular era is not that low.
- You needn't feel massively unlucky, or that the "fine tuning" argument invalidates that today is **indeed the 11th hour**

Today's constant 'mere' 2% GDP growth, as Wall Street constantly bemoans, is still exponential growth

- It leads to a doubling of civilization - the consumption rate of energy, food and raw materials - every 36 years.
- Even if you pave the rest of the Earth with solar panels. **Earth is finite. Growth will end.**
- Our only choice is this: Do we learn that lesson BEFORE we trash and doom the last square mile of unspoiled Earth, or AFTER?
- If after, what end will **WE** meet?

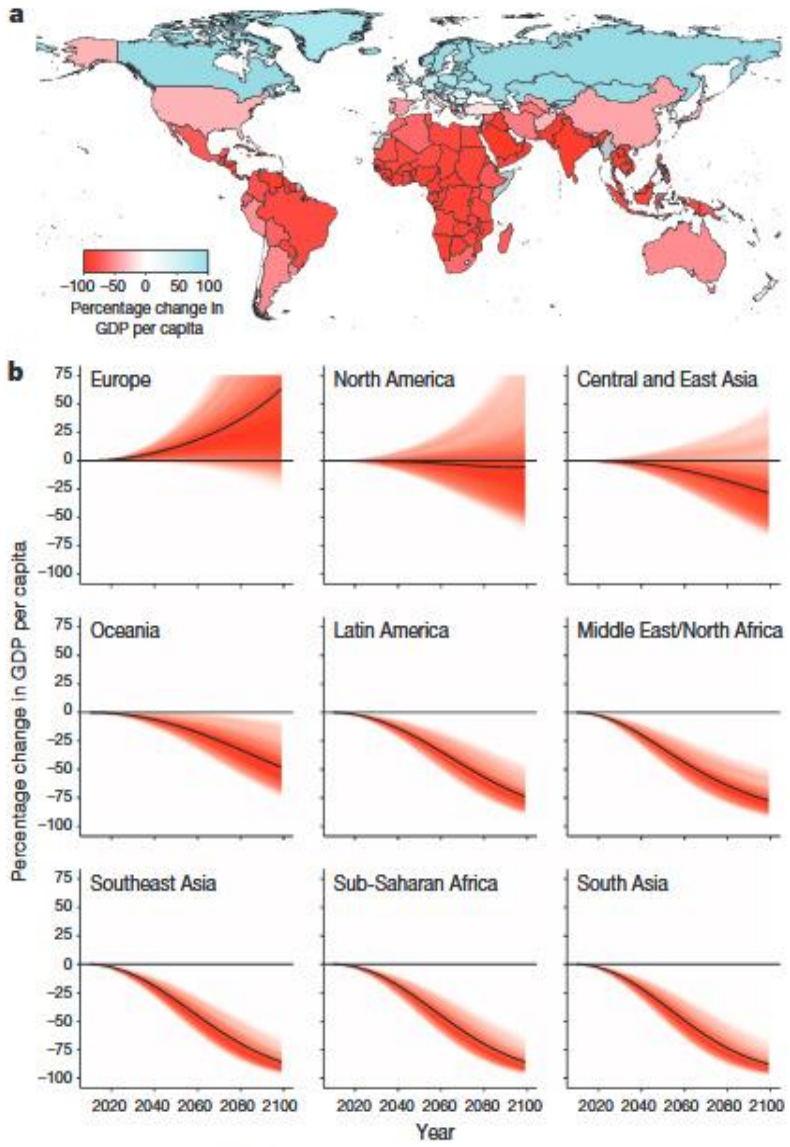


Figure 4 | Projected effect of temperature changes on regional economies. **a**, **b**, Change in GDP per capita (RCP8.5, SSP5) relative to projection using constant 1980–2010 average temperatures. **a**, Country-level estimates in 2100. **b**, Effects over time for nine regions. Black lines are projections using point estimates. Red shaded area is 95% confidence interval, colour saturation indicates estimated likelihood an income trajectory passes through a value[27]. Base maps by ESRI.

<u>GDP in Hot House Earth</u>: We saw that +4.5C temperatures by 2100 were likely even with concerted climate efforts. Stanford studies (Burke *et al.* 2015) improved on earlier work by accounting for the non-linear relations in temperature's effect on GDP, but not including the amplifying effects of societal fraying, sea level rise, storms, flooding. Yet still, Africa, Latin America, Southern Asia – most of Earth's population - suffer huge economic losses under "business as usual" IPCC projected temperatures rising to +4.5C by 2100. (far worse: see Kypke *et al.* 2022).

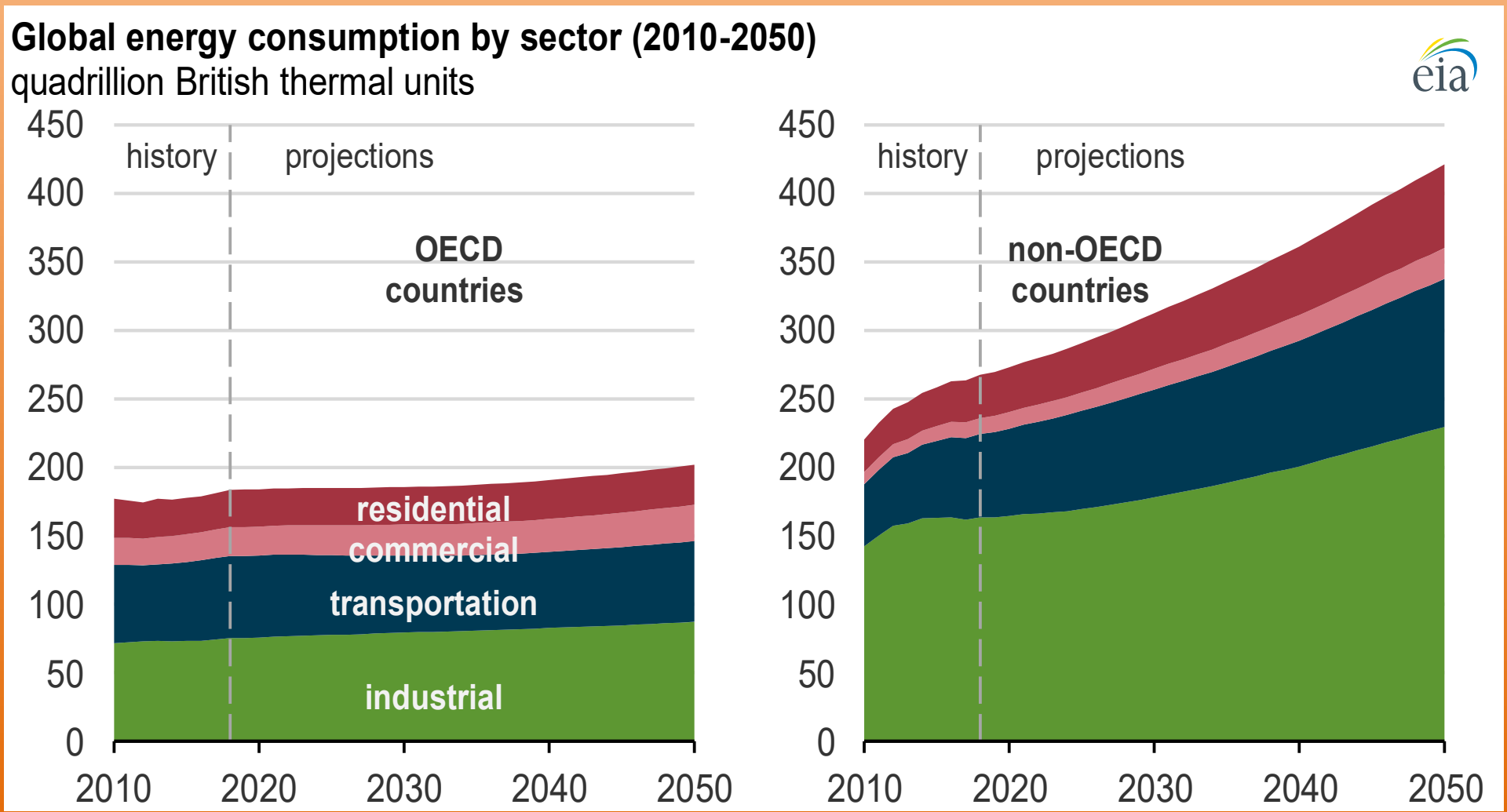
Massive Expense = Massive Energy Consumption Rates = Massive CO2 Emissions

- To transform the World's energy system is an expensive (and therefore power consumptive) enterprise
- It's not good enough to just draw some french curves through a past trend, ignore the ramifications, and then say *"Voil'a! Our Pathway to a Renewable Future!"*
- To **save** CO2 from entering the atmosphere tomorrow we have to engage massive CO2-**emitting** energy today in the manufacture and deployment of new low-carbon technology, above/beyond the energy needed to produce the bling and gadgets we crave, and support all past civilizing of this planet.
- And, new grid systems, new transmission lines, and new industries to service this new infrastructure. DAC carbon capture estimated to use ¼ of all global power by 2100 (**Realmonte *et al.* 2019**)

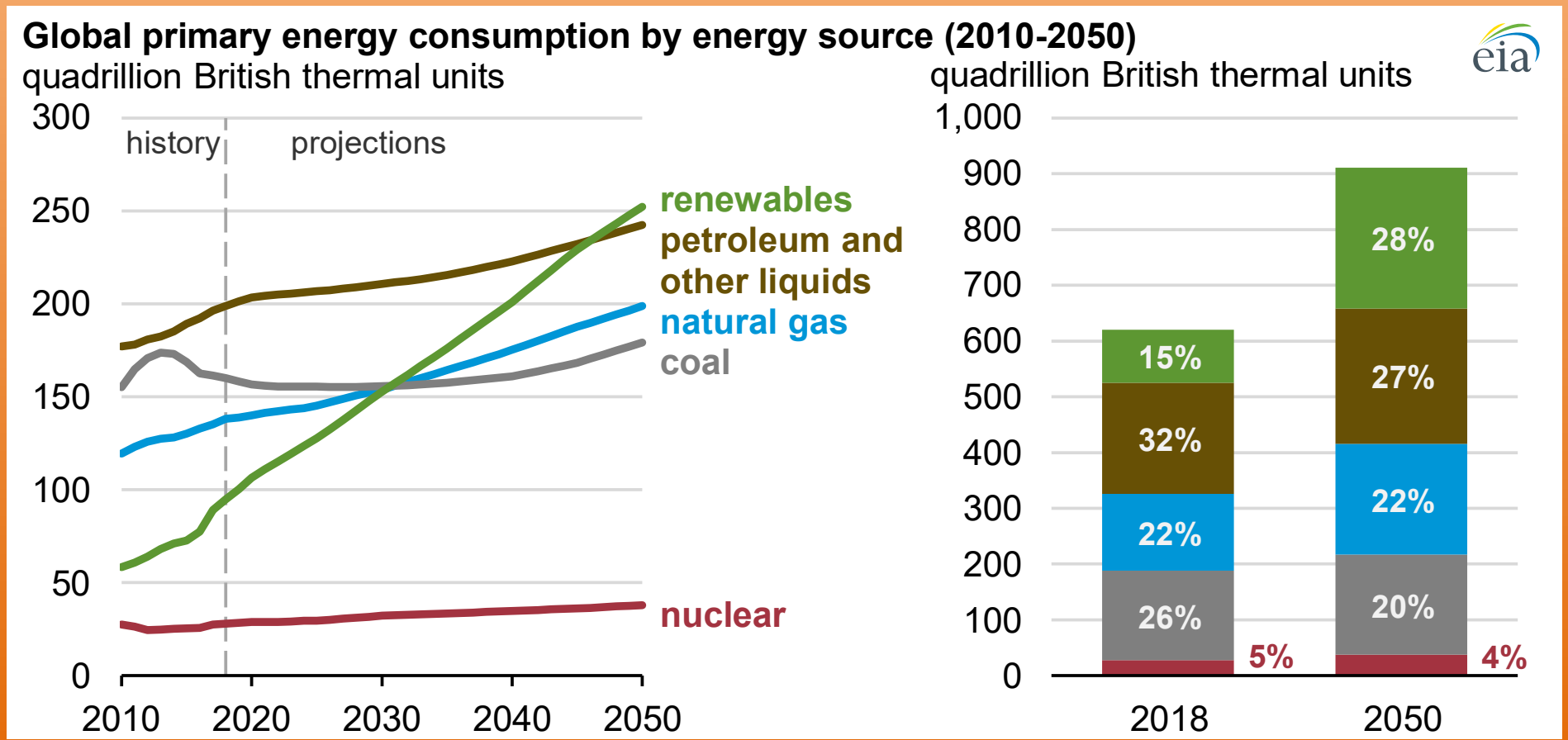
From Dr. Vaclav Smil…. …*”Turning around the world’s fossil fuel based energy system is a truly gargantuan task” (source)*

- *“That system now has an annual throughput of more than 7 billion metric tons of hard coal and lignite, about 4 billion metric tons of crude oil, and more than 3 trillion cubic meters of natural gas. This adds up to **14** trillion watts of power,” (*RN: **19** TW in 2020, rising on avg 2% per year this century*) “and its infrastructure—coal mines, oil and gas fields, refineries, pipelines, trains, trucks, tankers, filling stations, power plants, transformers, transmission and distribution lines, and hundreds of millions of gasoline, kerosene, diesel, and fuel oil engines—constitutes the costliest and most extensive set of installations, networks, and machines that the world has ever built, one that has taken generations and tens of trillions of dollars to put in place.”*

Total Global Energy Consumption rates Predicted to rise 50% from 2018 to 2050…



That's <u>including</u> an expectation that renewables will become the single biggest source of energy by 2050!



Dr. Smil Continues…

- ***"It is impossible to displace this super-system in a decade or two—or five, for that matter. Replacing it with an equally extensive and reliable alternative based on renewable energy flows is a task that will require decades of expensive commitment. It is the work of generations of engineers."***

- **Manoli *et al.* (2016)** find the "diffusion time" for green carbon-free tech must be no more than **6 years**, *vs*. the 60 years that is the typical historical diffusion time for industrialization technology. This, to succeed holding to +2C global temperature rise by 2100 – and this, again, uses the obsolete IPCC carbon budget, does not consider indirect human-caused carbon emissions from the permafrost thaw, nor higher ECS with hotter climate states, etc.
- I very much want to believe that human ingenuity and commitment may allow at least a little more optimism than this. In 5 decades, ~all current fossil fuel power plants will be too old and need replacement even if they are still economical. I suspect we'll do a little better than Smil's quote, but perhaps not by much.

Even Some Scientists Are Part of this Problem

- Tyndall Climate Centre director Prof. Kevin Anderson points out that too many scientists have no appreciation of engineering and how hard and how long it will take to transform the world to technological solutions.
- As much as I admire the science of high profile climatologist Michael Mann, I reluctantly may have to put him into this category, based on listening to a recent **interview of Mann here**, and contrast that with climatologist former engineer and Kevin Anderson **here**..

From my own past, as a Thermodynamics Engineer in the space program, I applaud Anderson for noting this critical scientist *vs.* engineer point

- It should temper your enthusiasm for certain promotions.
- I've also found that the most fervent promoters and unwavering devotees of the ***"scientists/engineers will save us"*** mantra are non-scientists/non-engineers. They have trouble distinguishing between solid work, and narrow-thinking promotional$ or out-right hype.

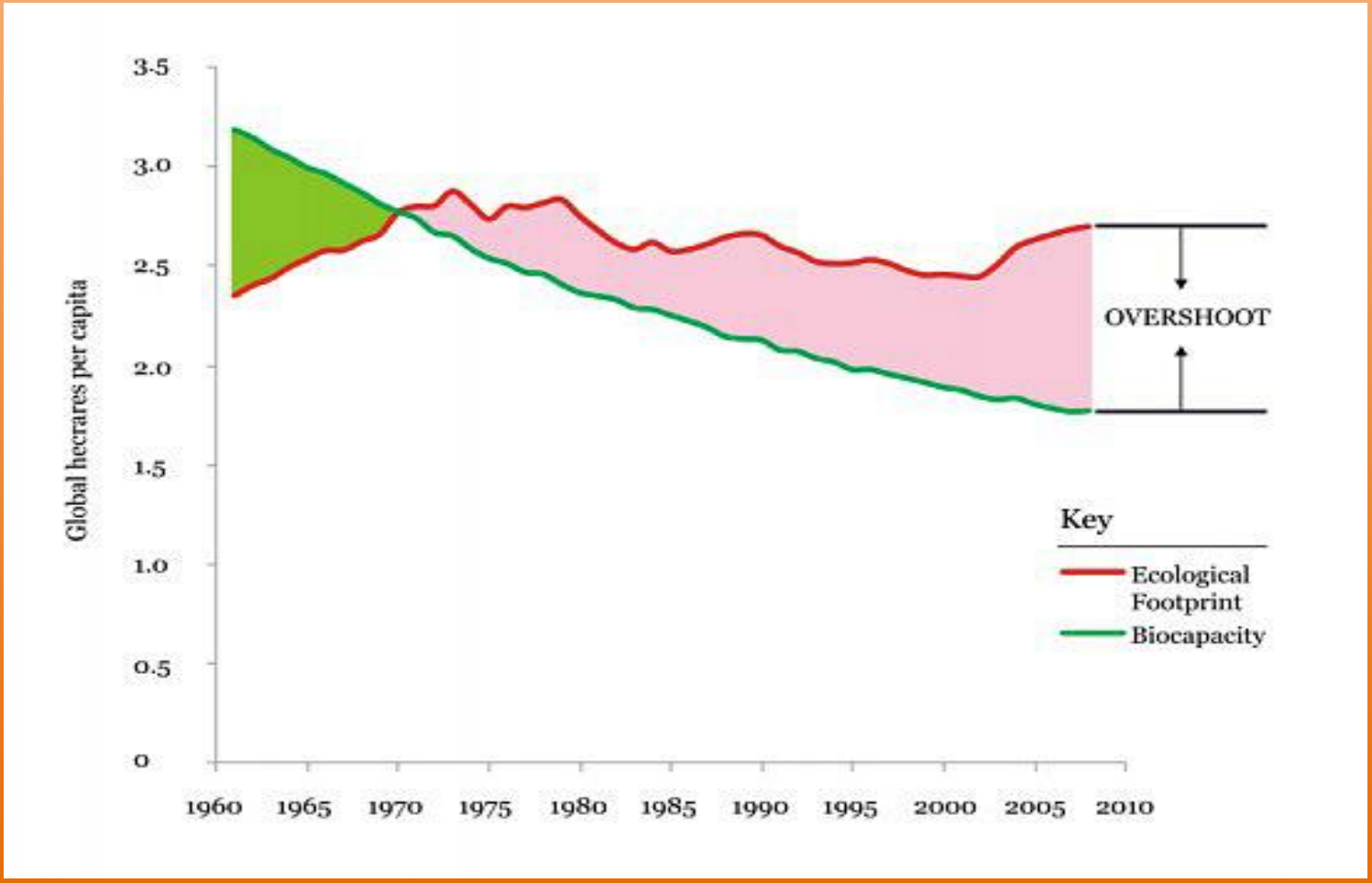
Dr. Kevin Anderson in an interview following the Paris COP21 Conference (boldface mine**)**

- *"In true Orwellian style, the political and economic dogma that has come to pervade all facets of society must not be questioned. For many years, green-growth oratory has quashed any voice with the audacity to suggest that the carbon budgets associated with 2 °C cannot be reconciled with the mantra of economic growth."*
- *"I was in Paris, and there was* ***a real sense of unease among many scientists present. The almost euphoric atmosphere that accompanied the circulation of the various drafts could not be squared with their content.*** *Desperate to maintain order, a club of senior figures and influential handlers briefed against those who dared to say so—just look at some of the Twitter discussions!"*
- *"It is pantomime season and the world has just gambled its future on the appearance in a puff of smoke of a carbon-sucking fairy godmother.* ***The Paris agreement is a road map to a better future? Oh no it's not."***

Consider the Blatant Manipulation of GHG data by the Officials of Governments Around the World

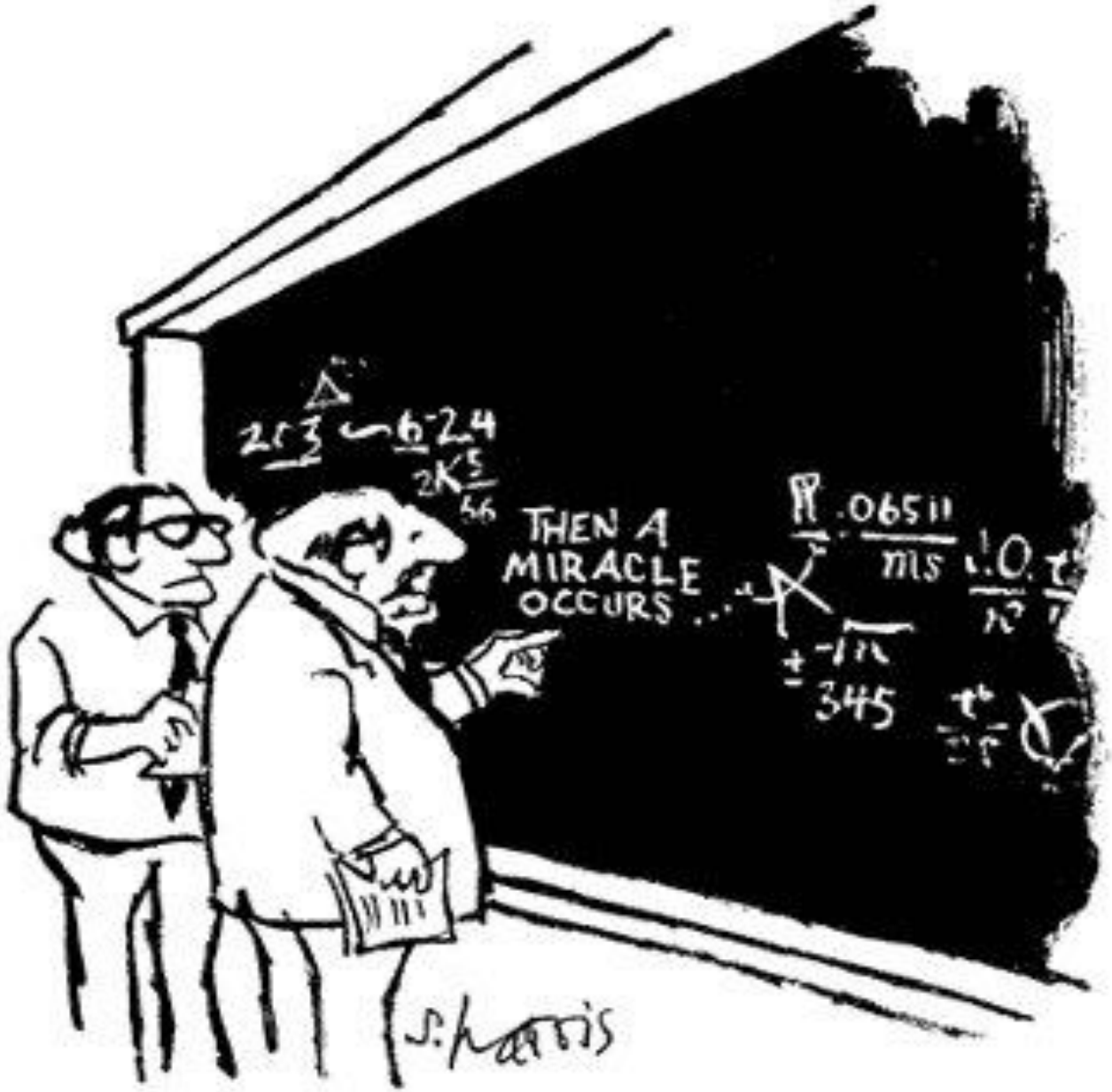
- *"'In the air, we see methane going up. The warming impact from that methane is enough to derail Paris.'*
- *The rules covering how countries report their emissions are currently being negotiated.*
- *But Prof Glen Peters, from the Centre for International Climate Research, in Oslo, said: 'The core part of Paris [is] the global stock-takes which are going to happen every five years, and after the stock-takes countries are meant to raise their ambition, but if you can't track progress sufficiently, which is the whole point of these stock-takes, you basically can't do anything. So, without good data as a basis, Paris essentially collapses. It just becomes a talkfest without much progress.'"* (source BBC news' Matt McGrath 2018)

By using consumption statistics for each country, and ecology studies on regeneration rates, the Global Footprint Network has kept track of Civilization's "Ecological Footprint". Here in 2017, we're using up Earth's resources at 1.70x the rate of Earth's regeneration capacity (*vs* 1.57x below in 2008), and this number is going up 2% per year (source)



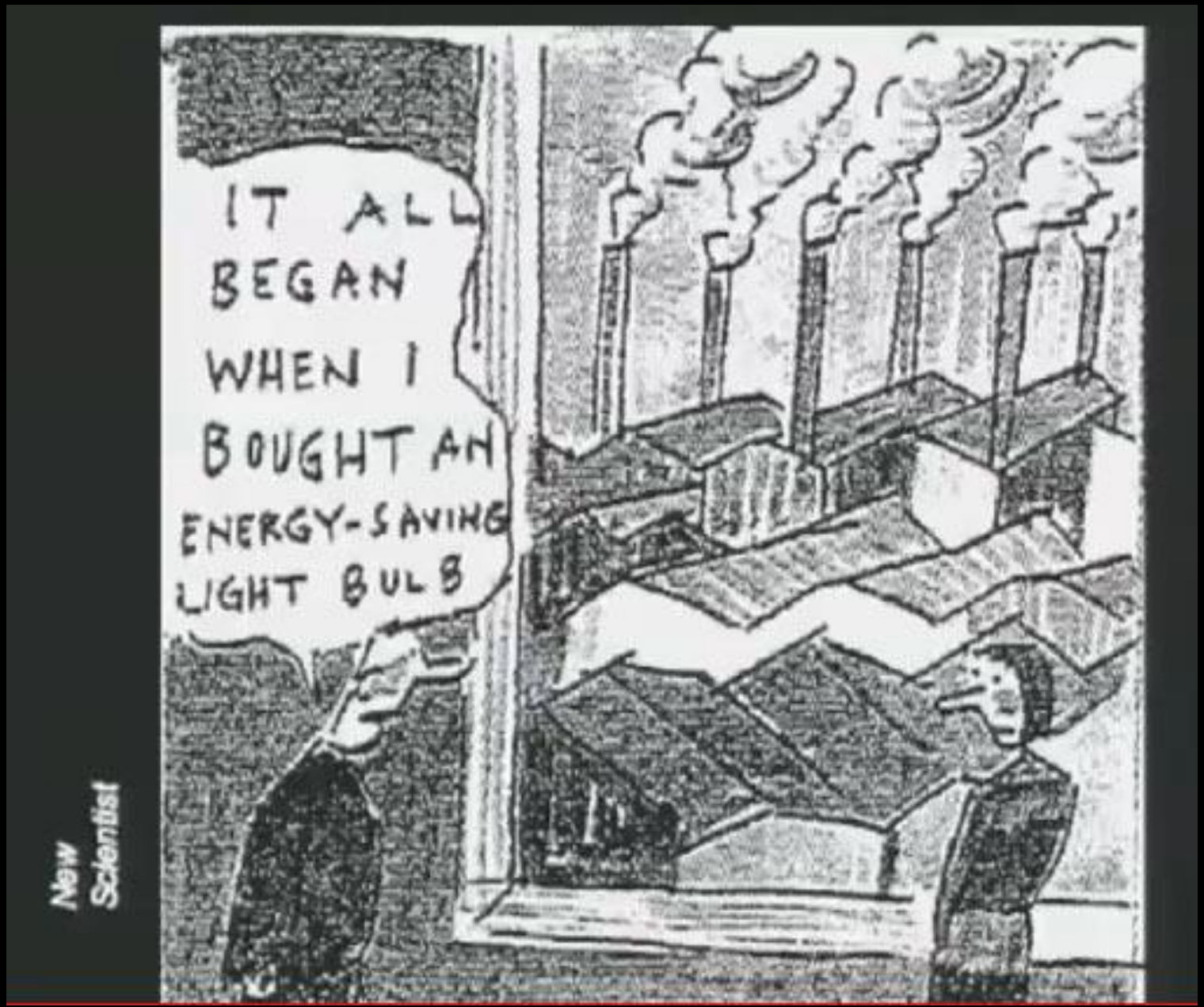
Another Interview in Paris, with Stanford's Mark Jacobson and Tyndall Climate's Kevin Anderson together

- Delucchi and Jacobson's policy publication showing how the world's different countries could split up renewable technologies between catagories in pursuit of 100% renewable, was a big hit among the negotiators, and eco-friendlies generally. Jacobson summarizes in this **Youtube interview**, with Anderson part of the interview as well.
- **A telling moment:** Notice Anderson pointing out that rising renewables need to REPLACE, not be an ADDITION to, carbon energy sources, and that in fact renewables now are simply globally being used on top of fossil fuels (*i.e.* the unstoppable prime directive continues - to engage any and all energy sources)…. **Jacobson's response was: silence**.
- Since Jacobson is now adored by the policy people, this was a very **important opportunity to reinforce this truth pointed out by Kevin Anderson, and he did not take it**.
- **Silence**, is how the World is reacting to these disturbing physics: the physics of the material world, and of human civilization.



"I think you should be more explicit here in step two."

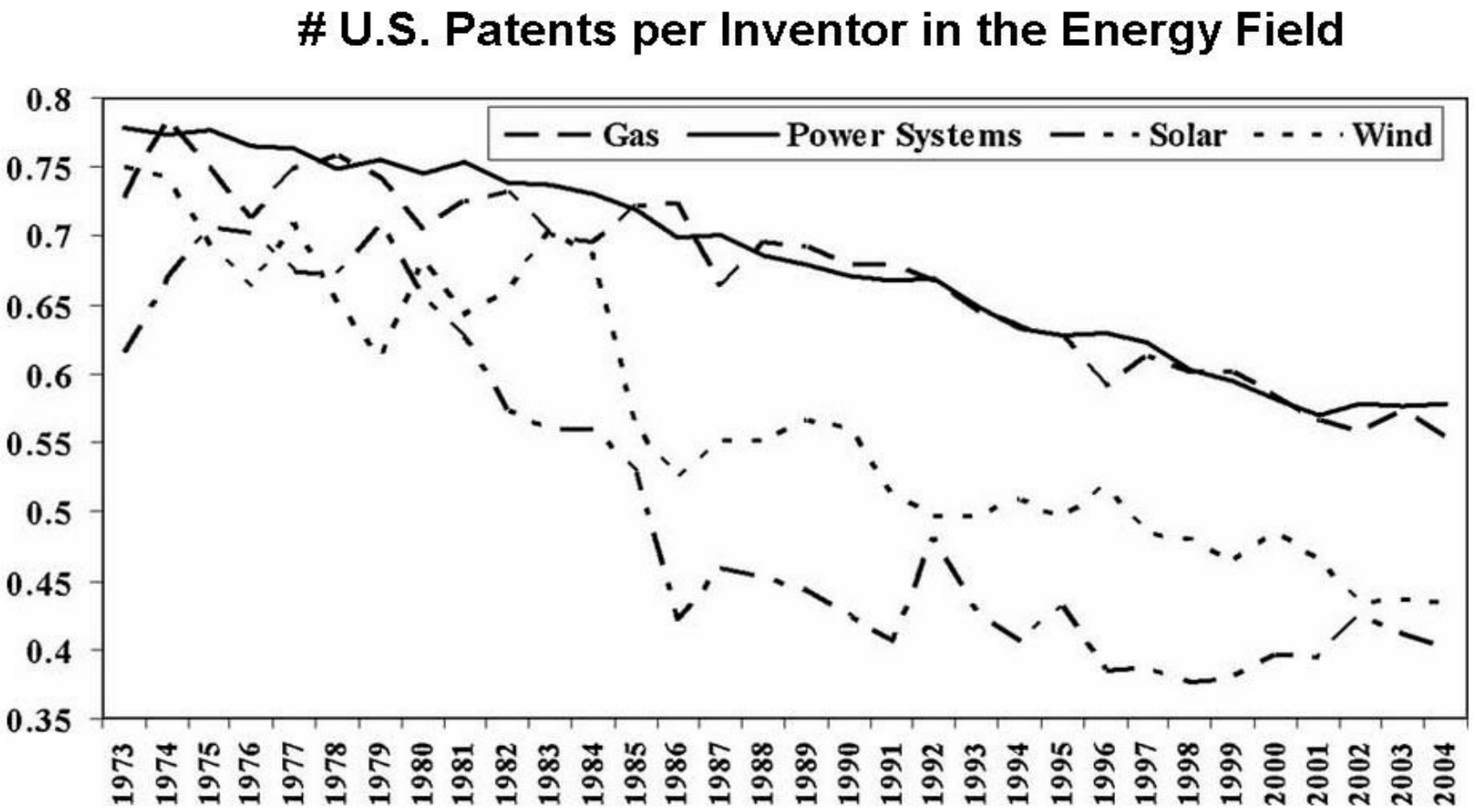
Jevons' Revenge: Prepare to pay the FULL costs when you embark on a global transformation



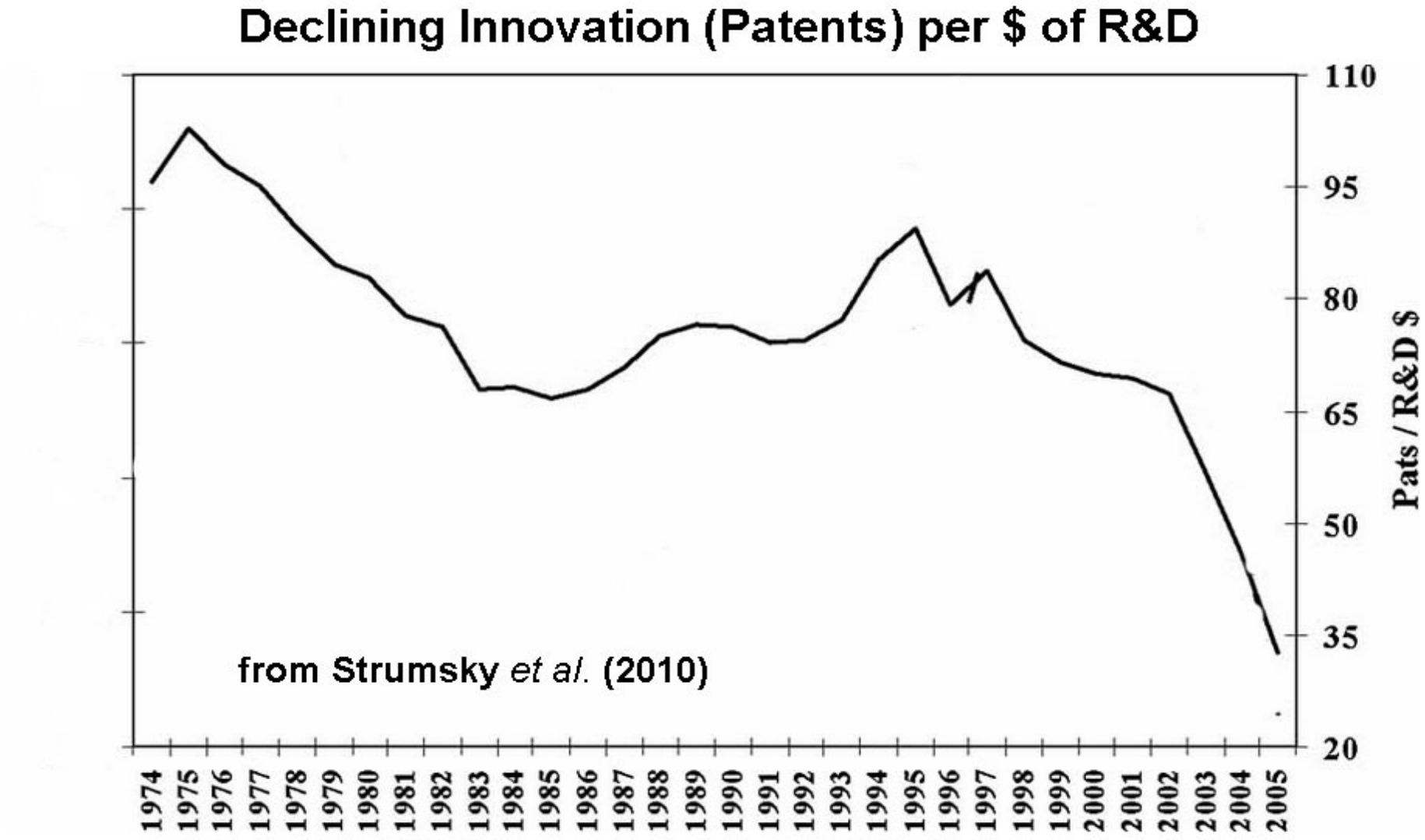
Closely Related: Increasing Complexity in Civilization leads to Diminishing Returns on Energy Invested

- This is the **work** of Prof. Joseph Tainter and colleagues.
- Link shows how the productivity of innovation is declining in all scientific and engineering fields they studied, over the past 50 years

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…



In every field, there are fewer and fewer patentable innovations per inflation-adjusted dollar of R&D, as the complexity of Civilization increases



Prof. Joseph Tainter: The Collapse of Sustainability

- Human beings only have a finite ability to master the knowledge accumulated from the (constantly growing) past, master the technology needed for today, and then make even more complex inventions for the future.
- A century ago, finishing High School got you a good job, having learned a high fraction of human knowledge at the frontiers. Now, it's 4 years of college, and then typically 6 years for a PhD, and then one or more post-doctoral apprentice positions (2 yrs each) before you're truly an expert in your sub-field.

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…"*
- Yet the rate of improvement of our human ability to digest information advances only at a genetic generational time scale (glacially slow by comparison).

Past civilizations have been forced to either massively simplify, or collapse

- …when they reach this point of diminishing returns on complexity.
- This work of Joseph Tainter and colleagues supports the conclusion that we are reaching that point now.
- Not good, when we have such challenges in front of us.
- In a wider sense, complexity often tends towards catastrophic collapse even in non-living systems (Gardner and Ashby 1970)

This is Very Depressing. So Let's Try Harder to Knock Down the Power/Wealth Relation - Can We Find Weaknesses in the Derivation and Data Confirmation?

Lines of Attack

- In the spirit of healthy skepticism, I can think of 5 general lines of attack to use in dissecting the validity of the **Power/Wealth Relation.**
- **#1.** Measuring the Inflation correction
- **#2.** GDP as a measure of thermodynamic spending
- **#3.** Calibration methods of GDP measures between nations to assemble a global measure
- **#4.** Bias in official GDP figures from Emerging Countries
- **#5.** Inflation *vs.* Decay in Civilization's Evolution

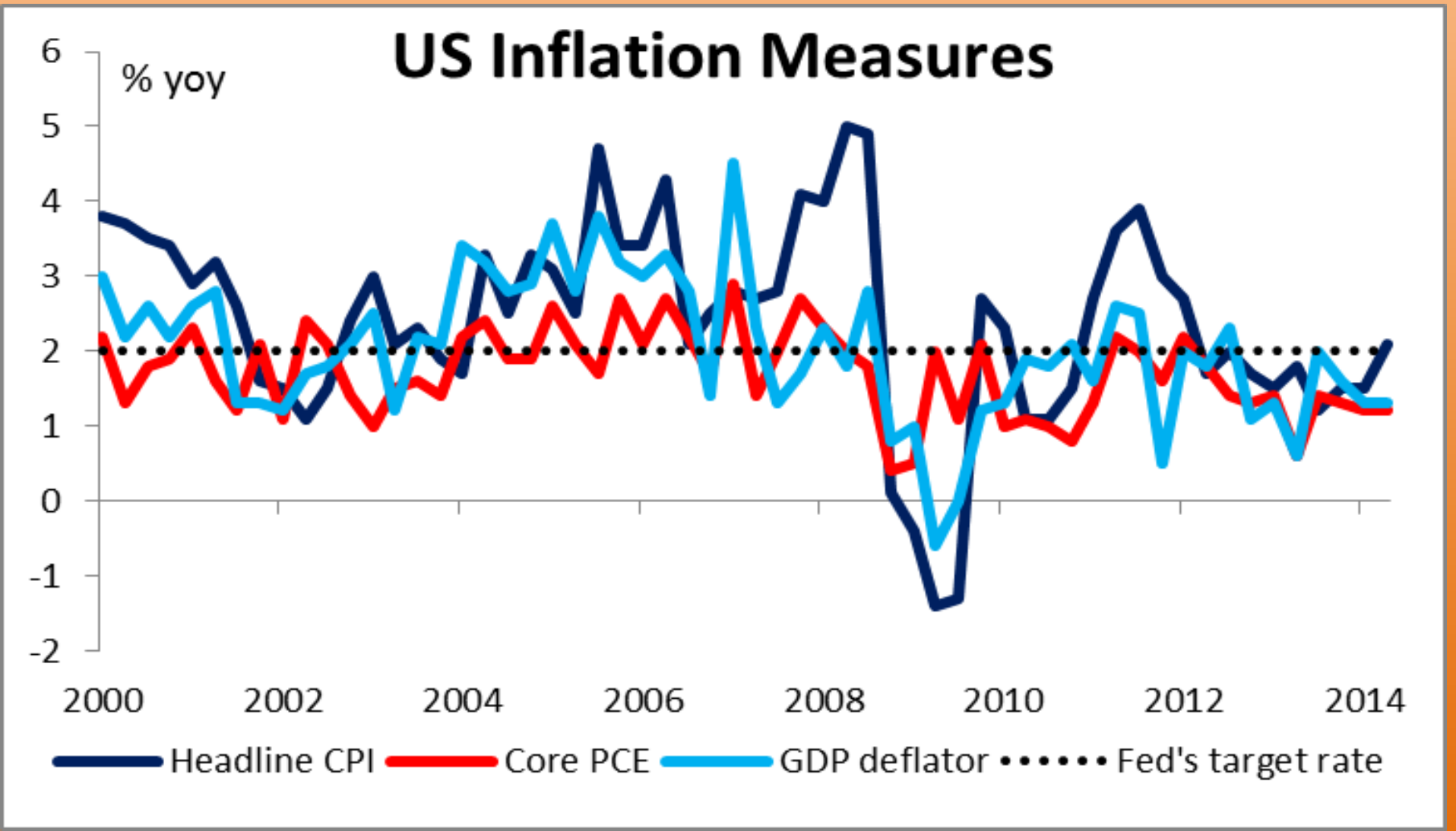
#1. The Treatment of Inflation

- The constancy of the P/W Relation requires past GDP figures to be inflation-adjusted. GDP figures are corrected for inflation by the **GDP Deflator (dGDP)**, which is calculated by governments from the prices of a basket of goods and services which varies year by year.
- **On the one hand, Garrett made post-dictions ("hind-casts") using the CThERM model and got results which matched observations quite well, strongly suggesting that up till now, the official GDP deflator measure captures the large majority of Garrett's deeper meaning of inflation.**
- **But on the other hand…**

Is the GDP Deflator really an accurate and unbiased measure of generalized inflation?

- First – some explanation: The **Consumer Price Index** (**CPI**) is a measure of the prices paid by consumers.
- The GDP Deflator (**dGDP**) is a wider measure of inflation which includes non-consumer items, meant to be more representative of the total economy.
- **U.S. CPI** has tended to be ~1% per year higher than the GDP Deflator lately, which seems reasonable as a reflection of adding in the increasing prices paid by the producers of goods and services and their rising profit margins (Sorry… Wall St. insists!)

The U.S. GDP Deflator follows the Consumer Price Index (CPI), with perhaps only a slight trend low of less than 1% year-on-year relative to “headline CPI” and shows no trend over time this century



Yet There is a Financial Motivation for Governments to Underestimate Official Inflation Figures

- …Because ~70 trillion dollars of U.S. government liabilities (*e.g.* social security, medicare… - that's $200,000 **per person!**) are indexed to CPI-derived inflation.
- By underestimating CPI inflation, this makes a significant improvement on the government's balance sheet, keeps international bond rating agencies from de-rating U.S. debt, and generally keeps the Debt Supercycle game going a while longer.
- And Europe and many other countries have followed the lead of the U.S. in doing similar accounting**.**
- **These are the richest countries on Earth, so this will have a significant effect on inflation corrections to Gross World Product**.

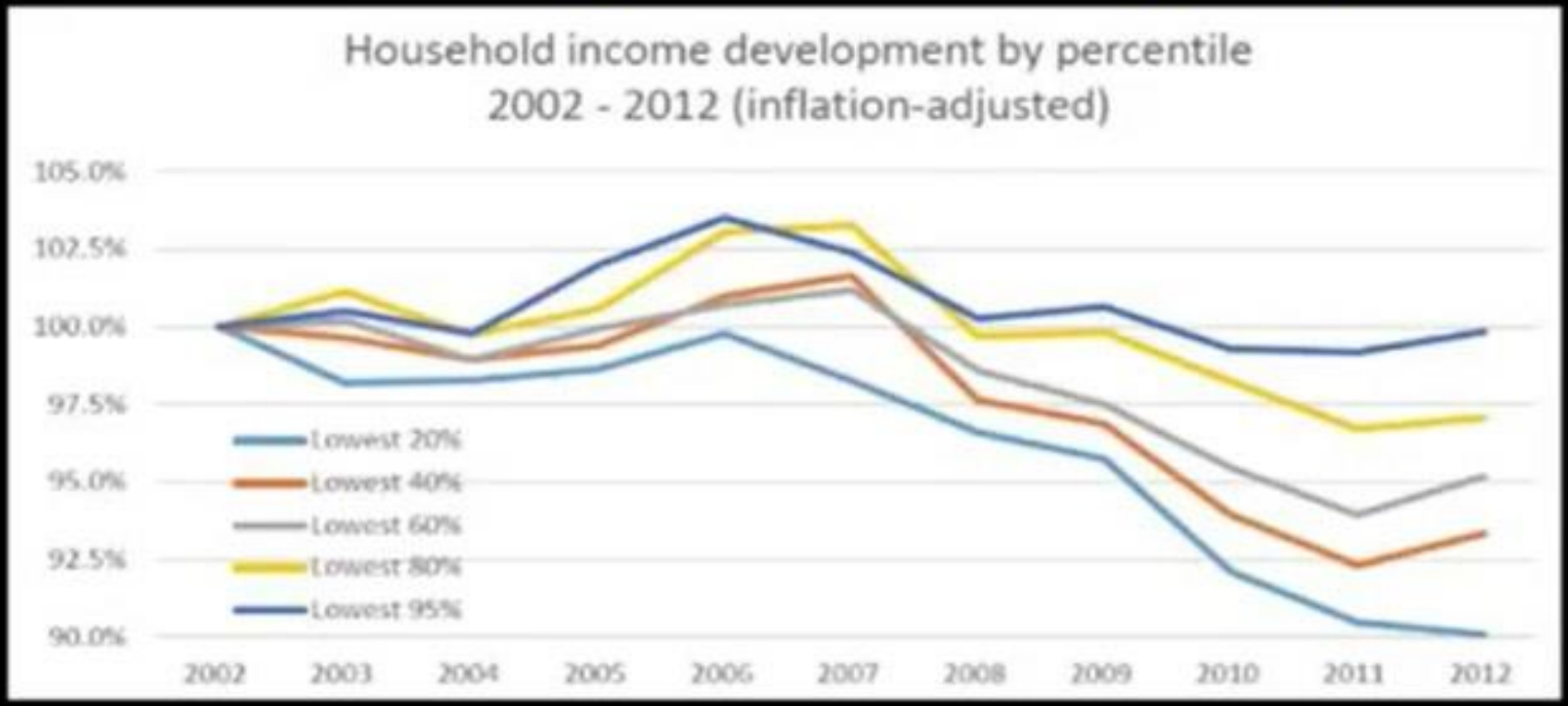
So…Is the CPI Biased Low?

- Consider: if prices rise faster than incomes for the vast majority of people (as has happened for decades; next 2 slides), then consumers are forced to continually migrate down scale in their purchases. A "changing basket" will therefore underestimate CPI.
- …down, from filet mignon, to T-bone steak, to chuck steak, and then to ground round, then to chicken, and then canned chicken, and finally to beans. **See the next 3 slides…**
- Other flaws: Healthcare is 18% of the U.S. Economy but only 8% of the CPI. Health insurance increases are not included at all. Rent-equivalent housing cost estimate low-balls actual mortgages and rents paid. Education costs rising faster than assumed. Plenty of other such examples.
- Hence, the official CPI is expected to be consistently beneath the true inflation rate. A bit less so for the GDP deflator, perhaps, but the consumer is ~70% of the U.S. economy, and a majority globally as well.

And yes – this is a significant effect. Income Growth never came back after the '01 Recession. In fact, since 1973…

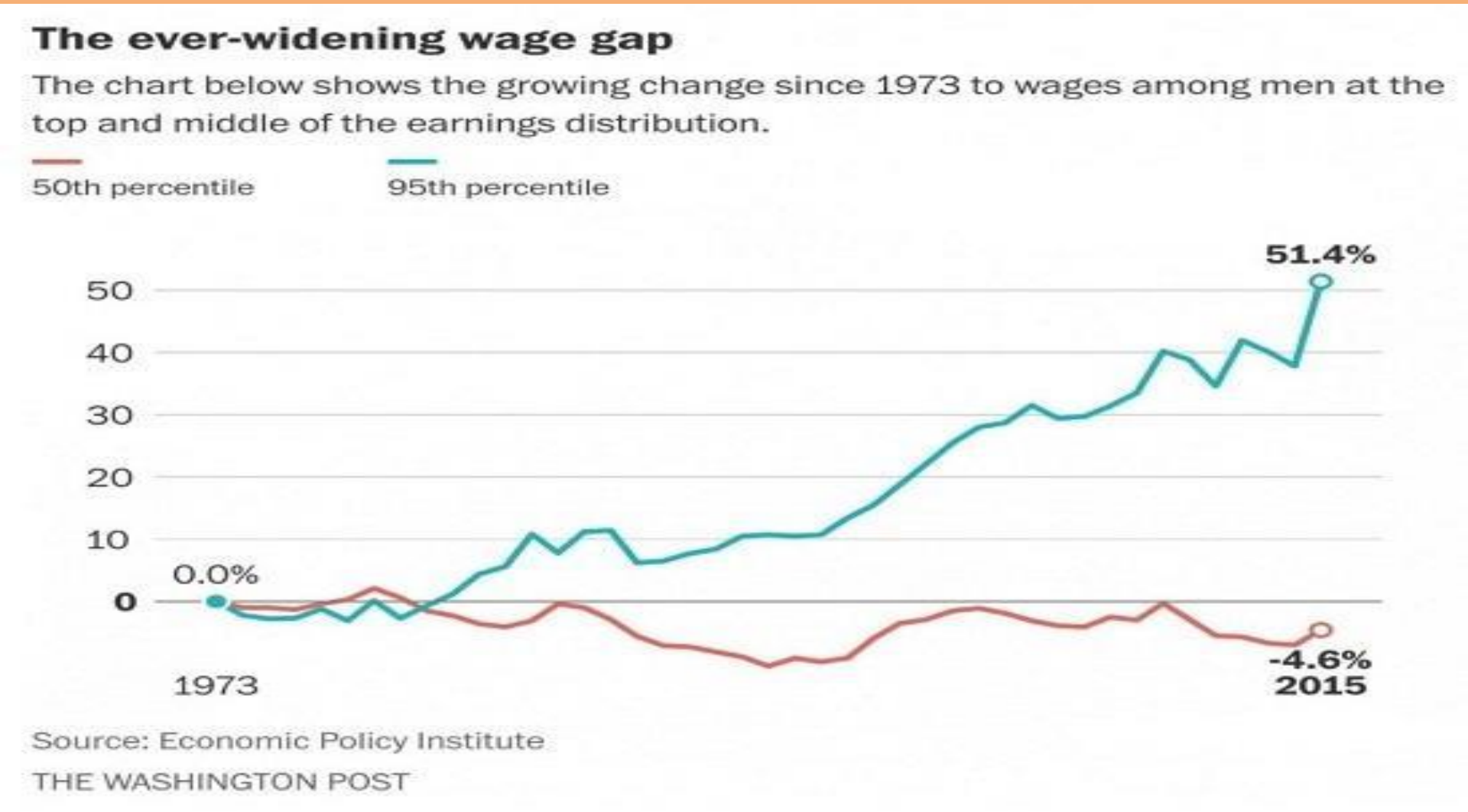
For most people growth is already over…

"lowest 95%" means top 5% of income earners (top curve)

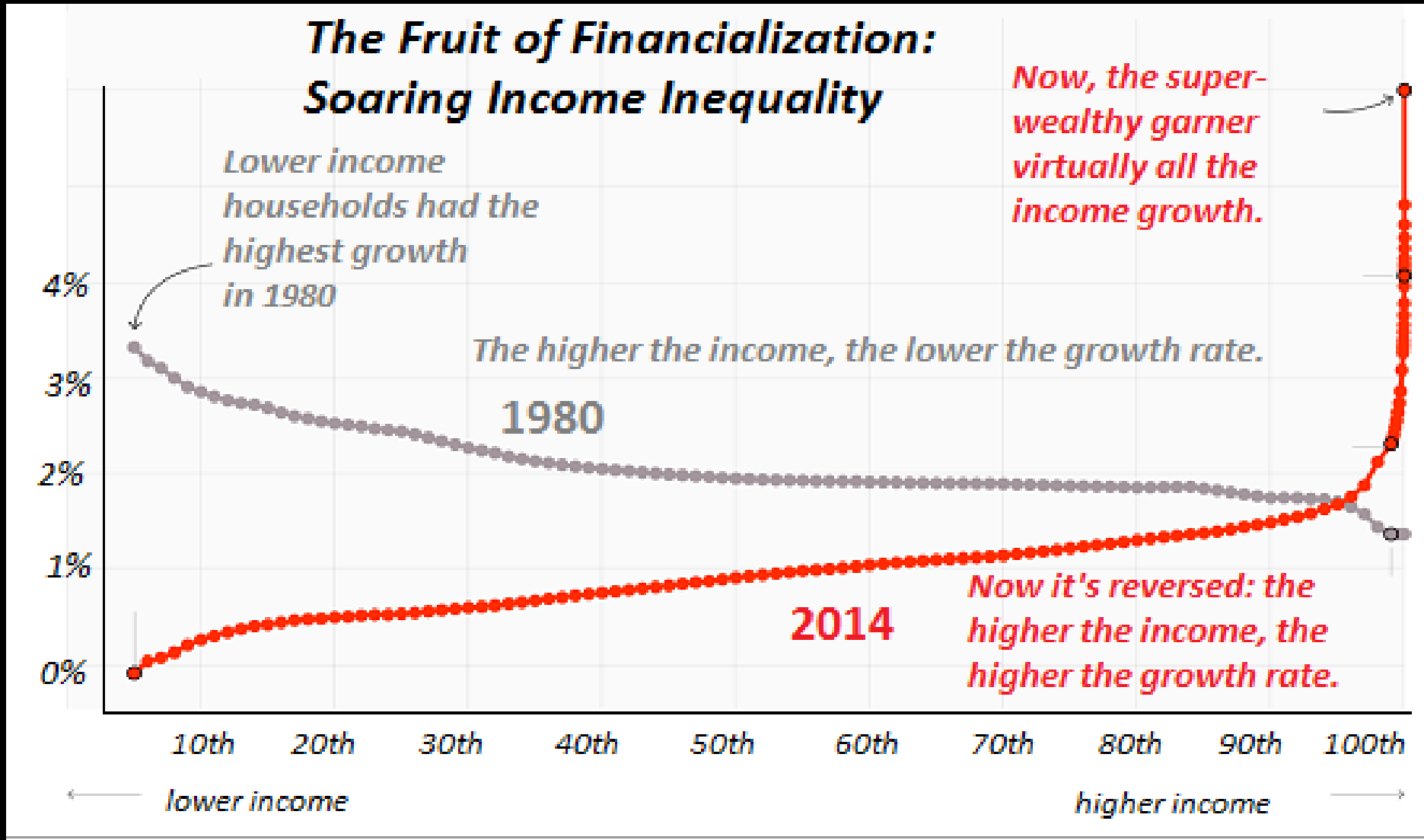


Income development 2002-2012, U.S. census data (www.census.gov), graphic IIER

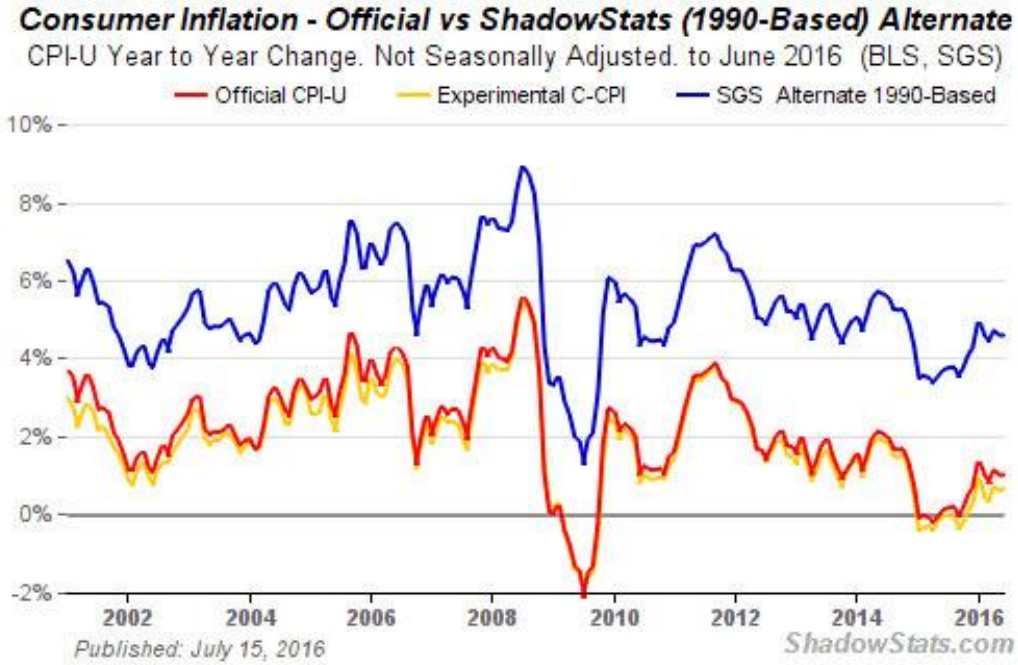
The top 5% (blue) have taken a dramatically larger share of all earnings, at the expense of the average wage earner (red), whose inflation-adjusted wages have actually dropped over the past 42 years. Globally, the top 1% now own fully half of the entire wealth of the World (as of Nov 2017)

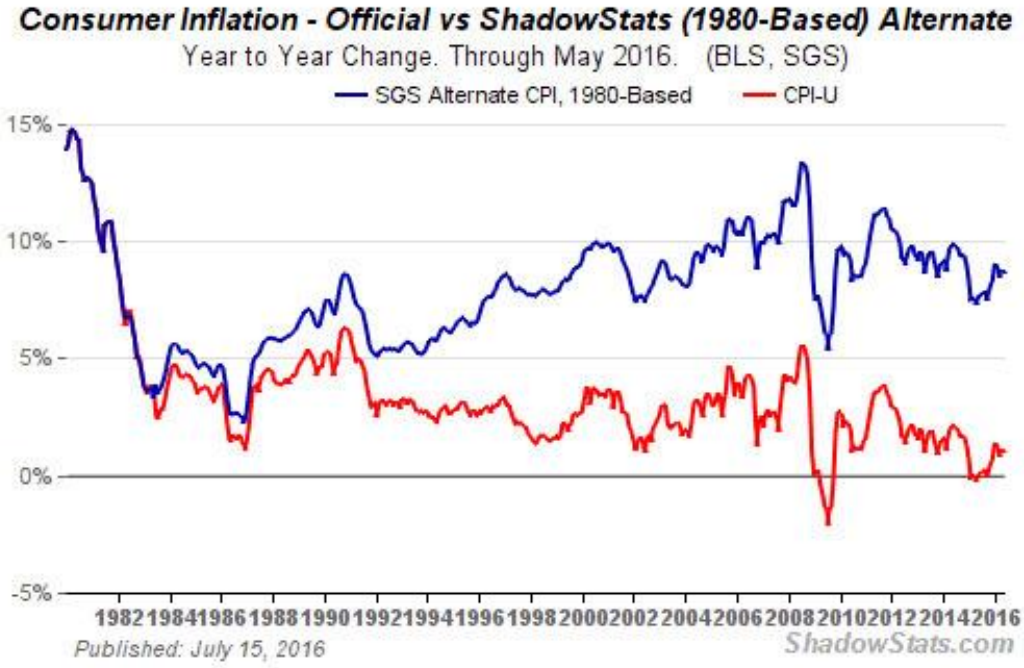


Conservatives claim "trickle down" economics enriches all, whereby $help given to corporations trickles down to the average workers. The truth is somewhat different...



source: New York Times 8/7/17





Therefore: CPI is Biased low:

ShadowStats uses the classic CPI method, before tampered with in the ’90’s) attempting to remove the bias, finding the actual U.S. CPI rate is consistently as much as 3.5-4% per year above headline CPI. As a ratio of percents, that’s roughly 2x higher than the stated CPI.

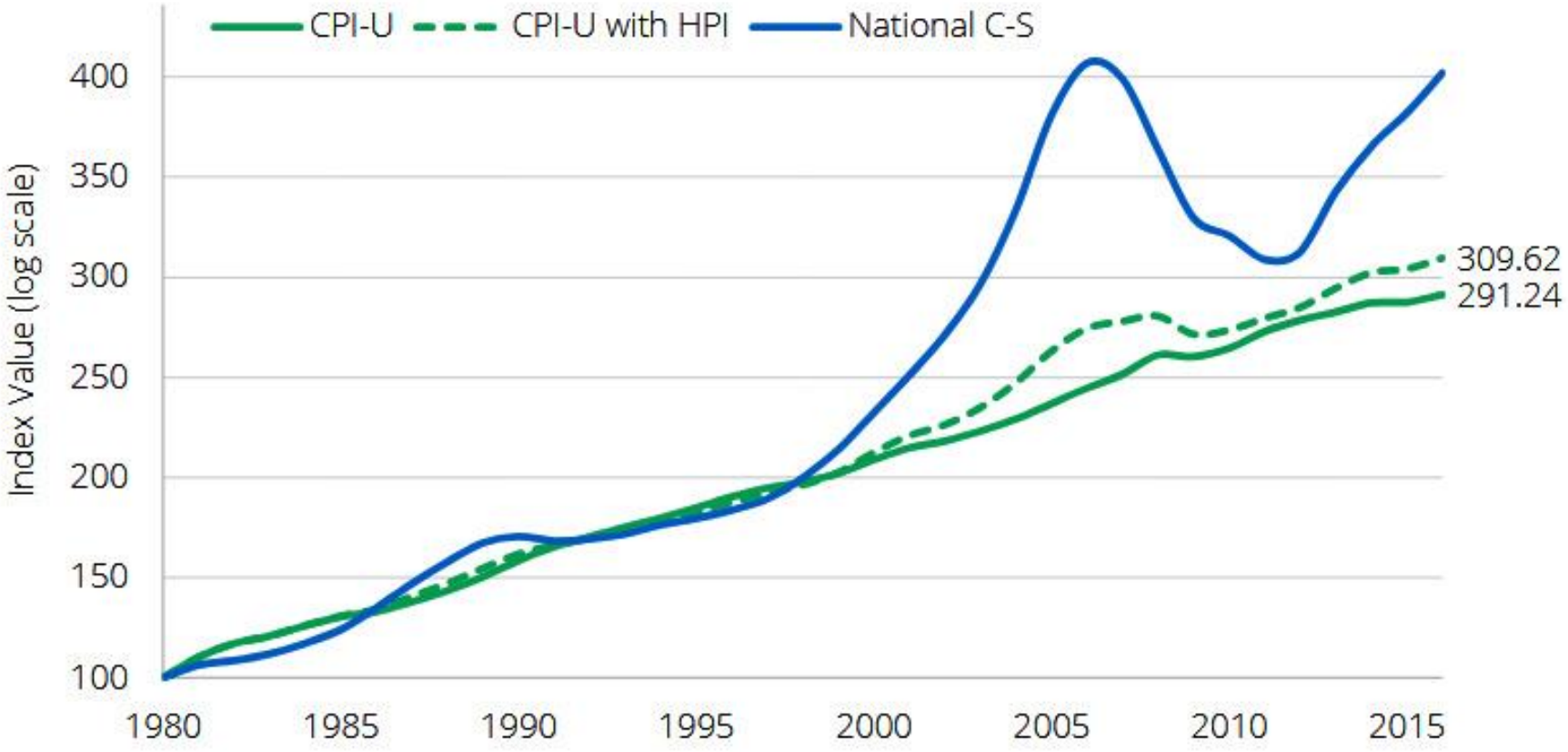
While **criticized** as “absurdly” high, the real issue is a difference in the nature of inflation.

ShadowStats' Contentions Have a Big Grain of Truth

- The Packwood/Moynihan assembled **Boskin Commission** in 1994, it's now widely accepted, was politically motivated to lower CPI-indexed liabilities to senior citizens and found that to make Social Security solvent, it needed to lower CPI by 1.1%.
- It accomplished this by reverse-engineering, largely using a suitable changing basket of goods and services (see **p. 301** in **"The Physics of Wall Street")**. Another widely criticized (*e.g*. **here**) bias-low, is using "owner-equivalent rent" instead of actual home prices (begun in 1983) – this is a large **(40%)** fraction of CPI, and CPIP is the dominant component of the GDP deflator (dGDP).
- Listen also (**Weinstein 2016, 9 min in**). While some of the Boskin Commission recommendations were rejected 5 yrs later, the key procedures, including an economist-selected changing basket of goods/services, remains.

Just one of the CPI changes; using rent *vs.* home prices, leads to a cumulative 20% low-biased CPI since 1997-2016; about ½% average per year (Lookabaugh *et al.* 2018)

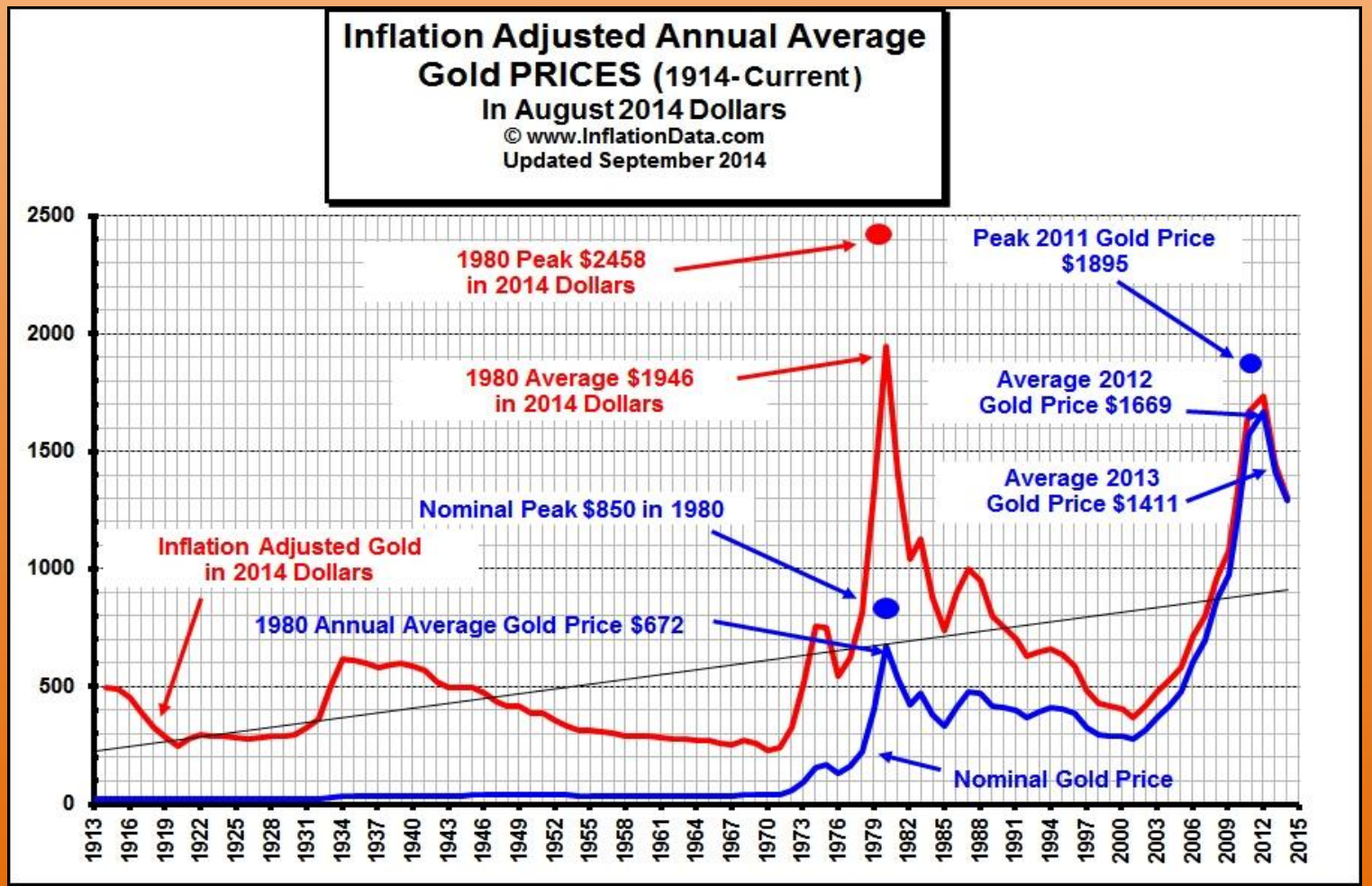
Figure 13. Projected CPIs—the official measure (CPI-U) and a hypothetical index that substitutes OER with HPI (CPI-U with HPI)—from 1983 to 2016. The difference accounts for a 50bp per year reduction in measured inflation (almost 20% over the 30-year period).



What SHOULD Inflation Measure?

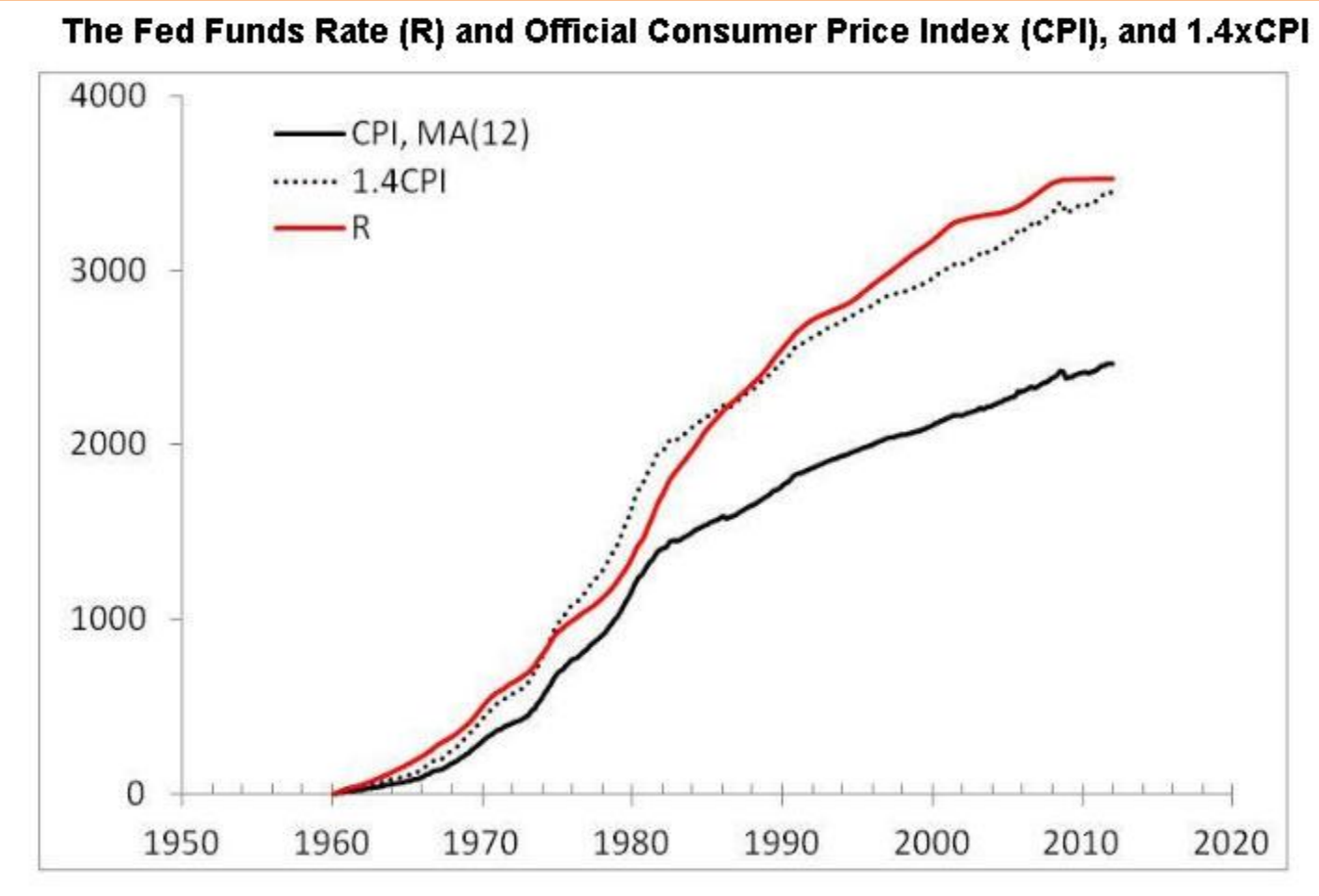
- Inflation relevant in the P/W Relation should measure the mismatch between global wealth, and global money supply. If money supply is growing faster than is global wealth, we have positive inflation.
- This is closer to the measure that ShadowStats is trying to measure.
- Consumer economic activity is most of the total spending in ~all global economies, so how CPI is measured is most important.
- But the BLS (Bureau of Labor Statistics) and some economists would prefer to consider CPI inflation as a measure of change in price of what consumers buy, redefined each year and therefore not fully accounting for substitution-induced missing inflation. There are nuances and other differences which combine to lower official reported inflation away from true inflation, as described **here**.

Alternative: The price of gold as dGDP? Turns out to be far too noisy and uncorrelated with official dGDP to be useful over this short period of 1994 to 2015.



Another Estimate: Kitov (2012) argues that developed countries in general, under-estimate the GDP Deflator.

- Kitov uses trend analysis to determine that the GDP Deflator for 14 industrialized countries needs to be multiplied by 1.37. This is milder than ShadowStats claimed 2x bias.
- What's intriguing is that this factor is the same as that by which the **Fed Funds Rate (R) (Federal Reserve interbank lending rate)** exceeds the nominal CPI, the inference being that, averaged over time, the Fed Funds Rate **R** is an accurate measure of true CPI inflation.
- The logic: If inflation is the mismatch between the growth in money supply and the true growth of the economy, and **if** the goal of the Federal Reserve (**if**!) is to aim for a neutral monetary policy, then **this is a credible argument that the Fed Funds Rate R is indeed a *de facto* better measure of CPI inflation**.



Kitov (2012) **Figure 5**, showing U.S. official CPI from the Bureau of Economic Analysis (black, scaling of y axis not explained), and when multiplied by the 1.4x factor determined independently from trend analysis going back to 1870 (dotted), remarkably gives the Fed Funds Interest Rate **R**.

Kitov Concludes…

- *"In the long run, the scaled **CPI** and **R** evolve along the same trend and intersect every fifteen to twenty years. One might assume that the main intention of the FRB (Federal Reserve Board) is to keep **R** above the rate of consumer price inflation, and the higher funds rate should suppress price inflation due to the effect of expensive money. In reality the FRB has been retaining the interest rate at the long term level of price inflation in order to create neutral conditions for money supply."*

- This has some logic to it. However CPI is only one component of dGDP, so the effect on dGDP may be slightly different than the 1.37x factor.
- Kitov dismisses the slope change of official GWP in ~1950 as bad analysis, without elaboration. But in fact there's a very good reason for the slope change, and much improved GDP vs. inflation then, as we'll see…

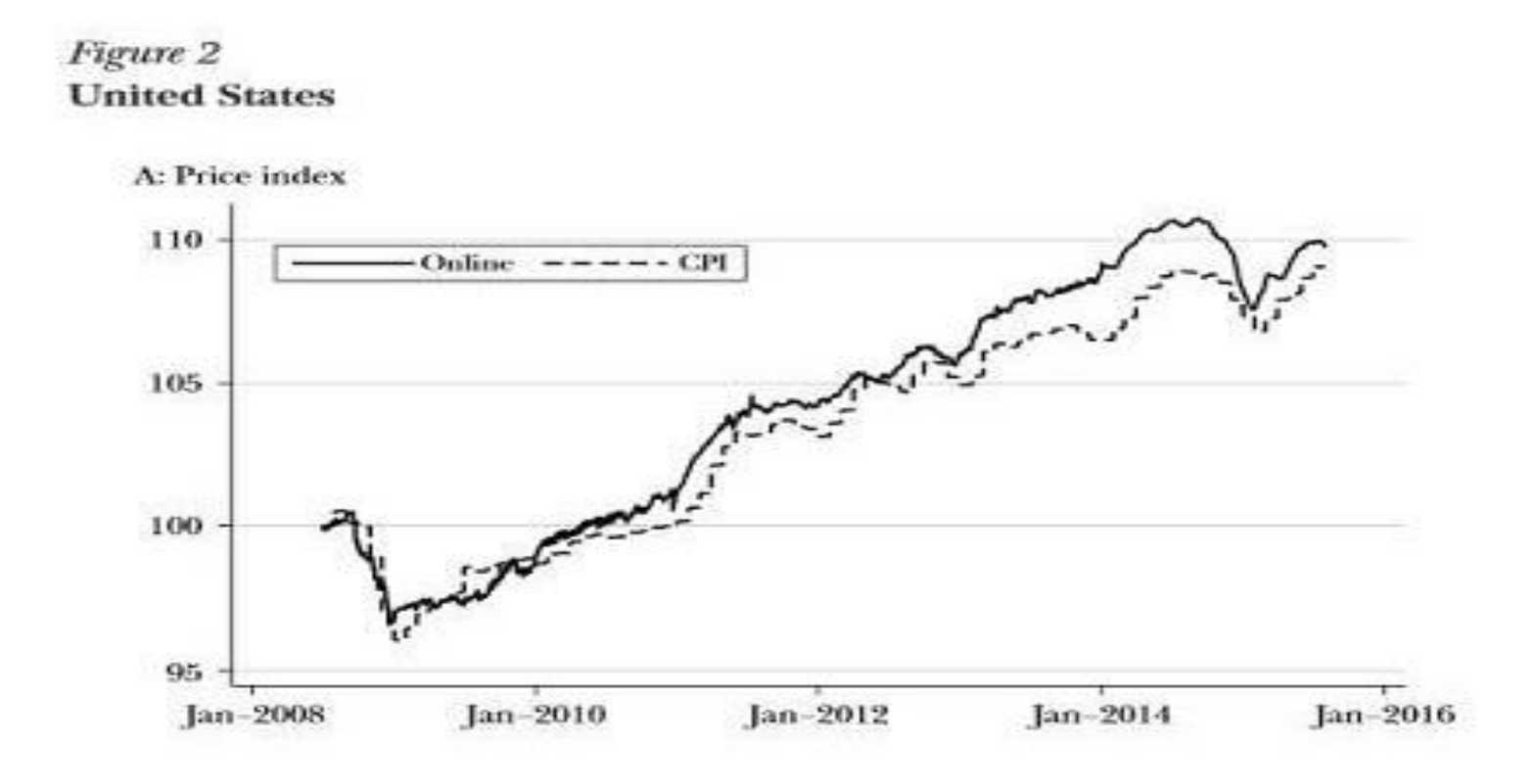
I Have 2 Arguments Against Kitov's Thesis…

- Kitov's analysis begins by assuming a constant GDP/capita rate must hold over time, and for more than a century. He doesn't justify why this should be true, although it does seem to hold in the Maddison (2004) approximate data.
- **That leaves it open to my major argument…**
- **…It completely ignores a very good reason why GDP per capita should indeed have taken a large jump upwards after 1950: The discovery and exploitation of vast cheap energy in the form of the shallow and easily-drilled Saudi oil fields, which continue to pump today.**

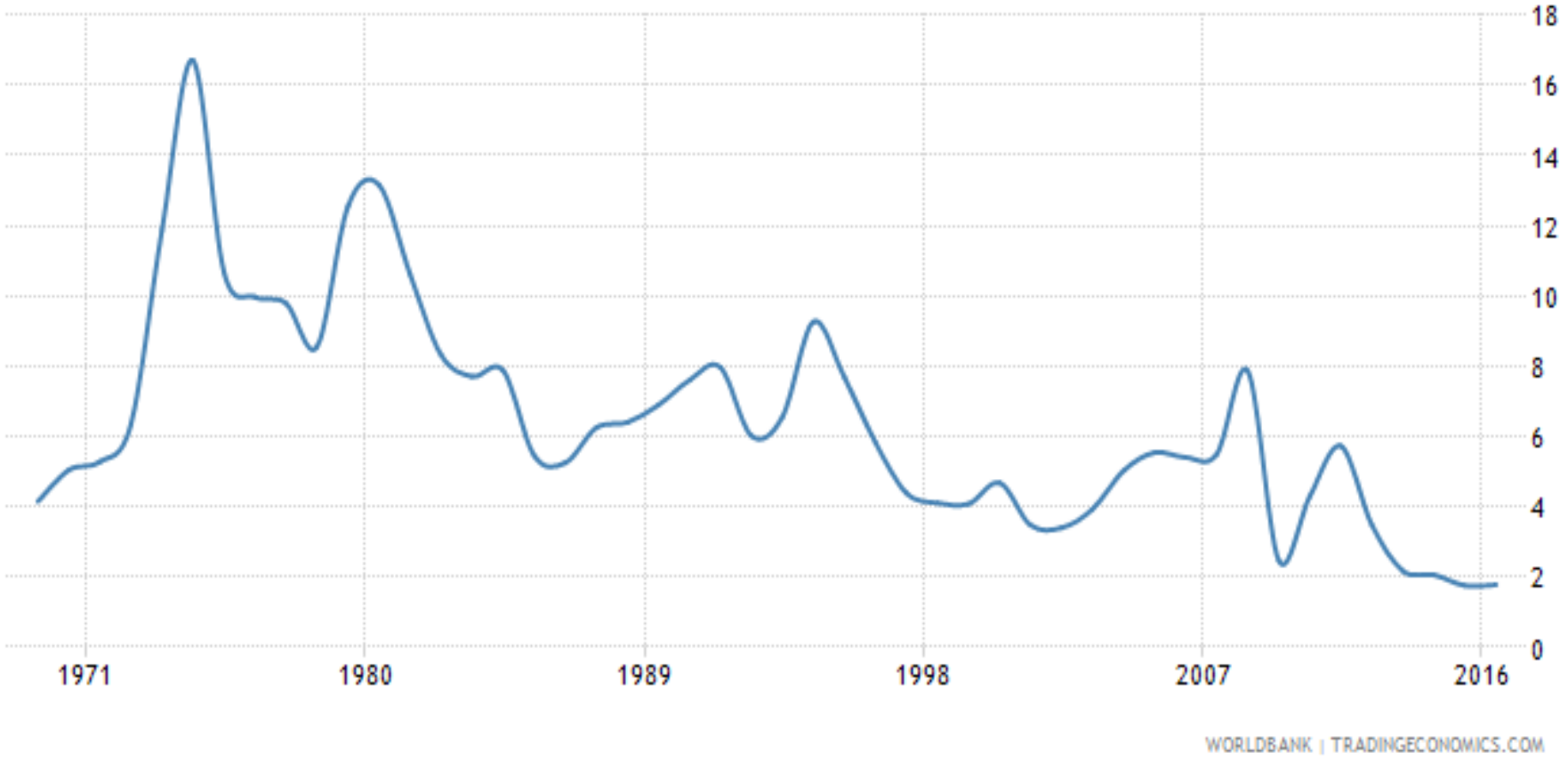
- **Energy is EVERYTHING**

- **Next, here's my final entry for an argument modifying the official global GDP deflator…**

MIT's BillionPrices Project uses a much wider range of global online prices to compile a more complete CPI. They too find official annual CPI (CPI_o) is understated, but by a much smaller amount: Official U.S. CPI since 2009 has averaged 1.567%, and BillionPrices CPI has averaged 1.826% per year). 17% higher. However, their methodology doesn't fix the inherent bias of a changing basket of goods, and so is likely still an under-estimate of global CPI



The World Bank Data for the Global GDP Deflator (The GDP deflator for the U.S. is generally lower). The 1994-2015 global dGDP is equivalent to a constant 4.49% annual rate



Let's Do a Quick Reasonable-ness Check

- Inflation is negative when genuine productivity outstrips money supply growth, positive if the reverse.
- **U.S. Labor Productivity** averaged **1.9%/yr** since 1990, (only 1% post-recession), about the same as since 1970.
- **M3 Money Supply**, the most comprehensive measure, has, according to ShadowStats, averaged **4.6%/yr** since 2003
- An additional and valid correction in inflation (**i**) figures is the adjustment for changing quality of the "same" goods - this is not identical to LABOR productivity, which has to do with manufacturing efficiency gains. Increasing quality counts as a negative inflation.
- So, taking the true GDP deflator in the U.S. as **d(M3-Productivity)/dt** gives **i=2.7%** this century, then minus an (unknown) correction for product quality improvements. Products HAVE improved, so the resulting dGDP is likely smaller than the ShadowStats 5%/yr .
- **Since 2003, the official U.S. dGDP has been ~1.95%/yr, likely too low**

Alternative Inflation Measures *vs.* Official CPI (CPI_o) and GDP Deflator (dGDP)

- ShadowStats claims true CPI is **~2.0x** CPI_o
- Kitov (2012) finds CPI is **1.37x** higher than CPI_o, and dGDP perhaps a little less than 1.37x higher, but misses the importance of Saudi oil fields in reducing inflation post-1950 and so likely should be ignored.
- The Billion Prices Project (BPP), using a much larger sample than official CPI, finds true CPI = **1.17x** higher than CPI_o for the U.S.
- Doing an admittedly over-simplified order-of-magnitude check by subtracting labor productivity from the rate of money supply growth gives a dGDP of **1.38xCPI_o** but this misses the product quality correction and so needs to be lower than 1.38. **The point is – <u>this makes a tentative case that ShadowStats' CPI is too high.</u>**

- **<u>Using the 17% overestimate from MIT's BillionPrices Project is likely too low, but will at least illustrate the point to be made on the inflation bias effect on the Power/Wealth Relation.</u>**

How would the BillionPrices adjustment affect the Garrett Relation's ratio?

- **Official global dGDP** as been 4.49% annualized since 1994. Let's assume the 1.17x increase found by the BPP applies globally as well.; multiplying by 1.17 gives 5.25% per year or 0.76% additional to official dGDP. It raises the Garrett Ratio (see slide 17) at the end point from **7.1 to 7.34, well within the narrow scatter band of the ratio** (On slide 17, the Garrett Ratio bounced between 6.8 and 7.6 during the entire period).
- For comparison, using ShadowStats would take the 7.1 to 7.7 and even this keeps the GR arguably constant, even flat since 1994,
- Garrett himself makes the pithy comment that, unlike scientists, economists don't put error bars on their numbers), this might be the best we can do for inflation for now.
- **Hence: The P/W Relation's constancy remains supported (even improved) by the existing inflation data at this time, within the uncertainties.**

#2. GDP as the Spending Measure in the Context of the Garrett Relation?

- Garrett has used tabulated global GDP as the widest measure of spending that is carefully compiled and available. But I contend that the thermodynamic framing argues that **all** spending, not just GDP spending, should be included.
- This is not fatal to the **P/W Relation** as long as true total spending shows a constant proportionality to official global GDP figures that Garrett used, over time.
- **Does it? Let's see**…

What IS GDP Composed of?

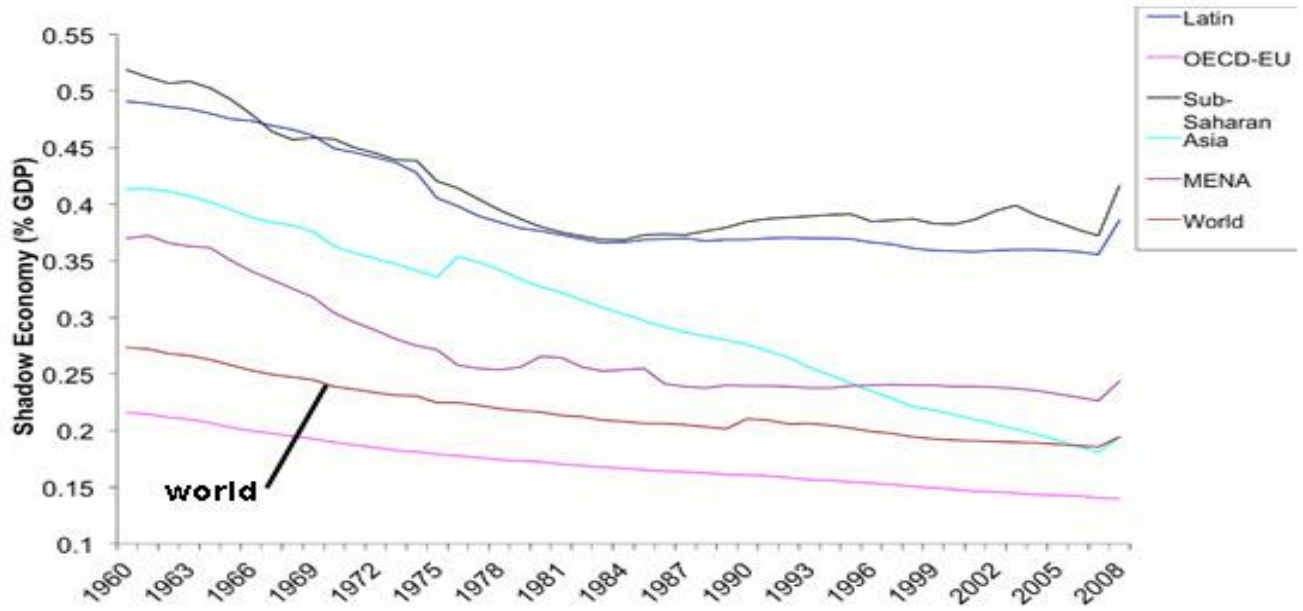
- GDP = private consumption + gross investment + government investment + government spending + (exports – imports).

GDP does not include barter, nor most black market activity… the "Shadow Economy"

- Many studies have attempted to quantify the "shadow economy" as a fraction of GDP, but have been marred by heterogeneous data and analysis techniques.
- **Elgin and Oztunali (2012)** developed an improved analysis method to produce the largest uniform dataset available in this historical time frame.
- They find the "Shadow Economy", as of 2010 was 22% of global GDP, down from 26% in 1950 (**Elgin and Oztunali 2012**), and they calculate it for each year. What does it show?

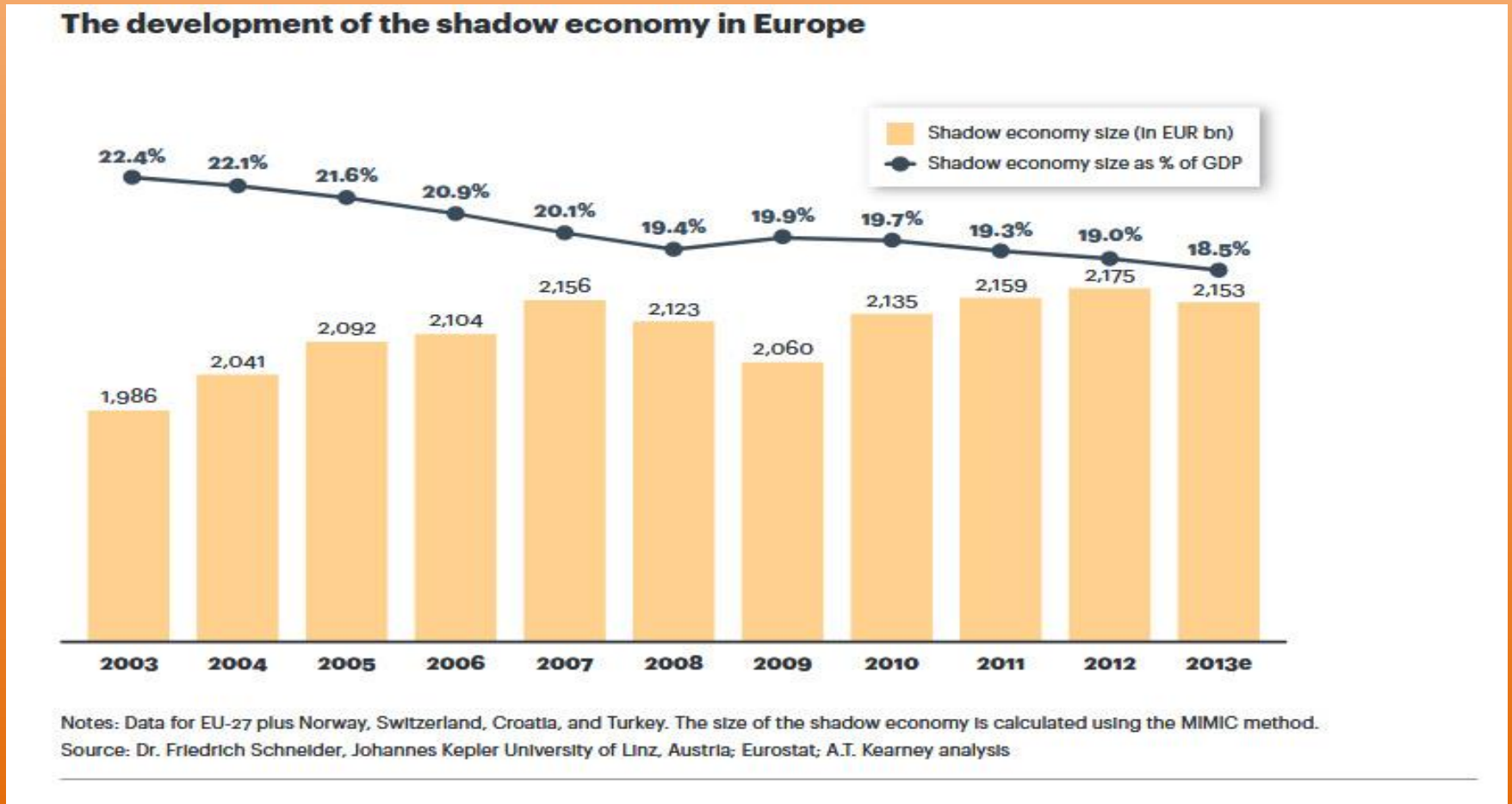
The Shadow Economy as % of global GDP dropped more steeply from 1960 to ~1975, shallowing afterwards (Elgin and Oztunali 2012). The "World" curve is falling gently with some bumps, while the OECD minus EU countries (bottom curve) fall gently but consistently. And for EU countries…?

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.

The "Shadow Economy" has also been a consistently declining fraction of GDP in the EU (Europe) (Schneider 2013), black curve below. Therefore the entire OECD world has shown a gently declining fraction for the "shadow economy". What does this imply for their (the 35 OECD countries) total spending *vs.* energy consumption?



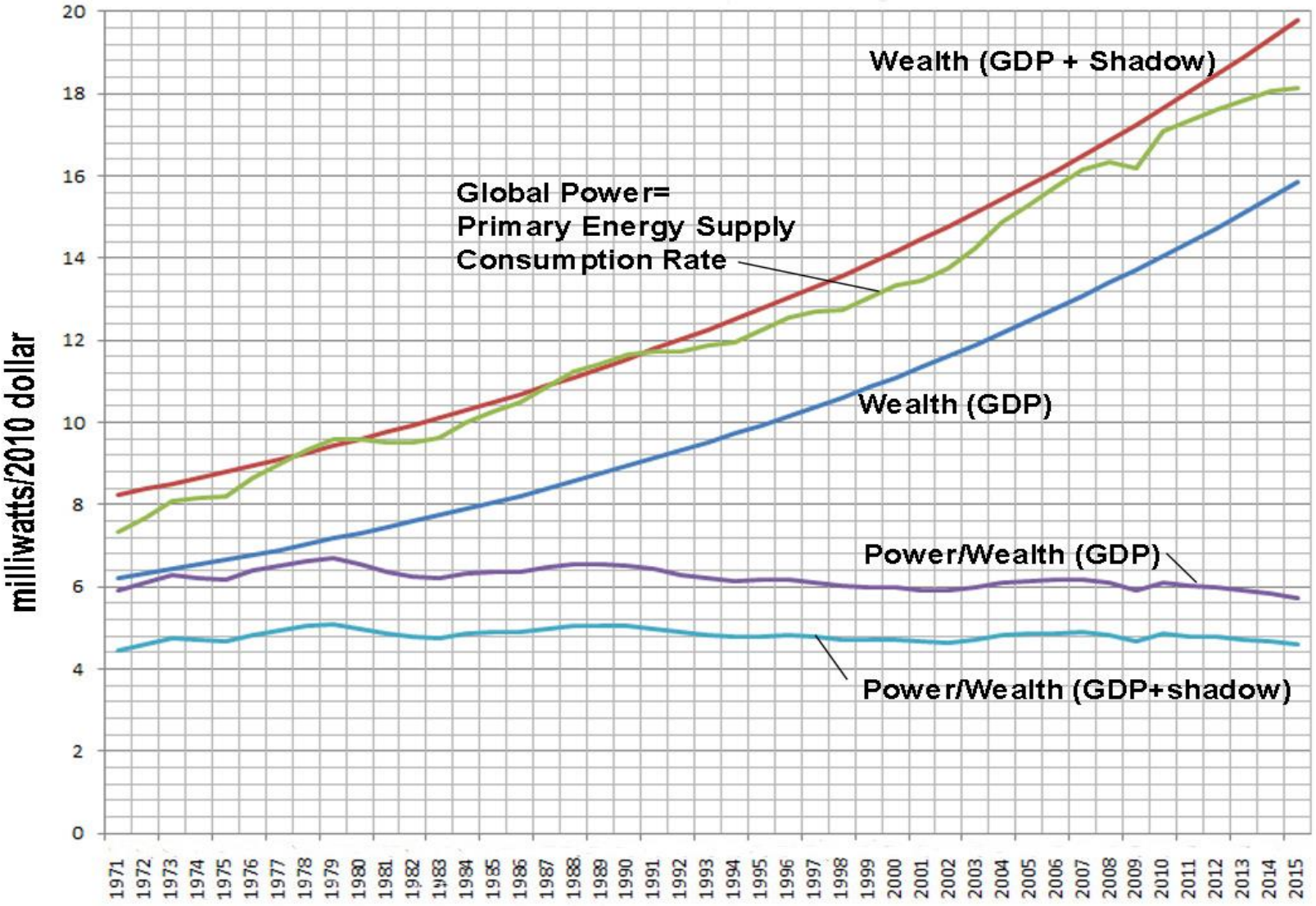
This means Total Spending in OECD Countries is Not Rising As Fast As Official GDP Figures

- If official GDP's are, as we now see, including a rising % of the total economy, then **total** economic spending isn't rising as fast as official GDP figures.
- This, in turn, says that energy efficiency ($ of GDP per joule of energy consumed) isn't rising as fast as official figures either.
- **Figures showing improving energy efficiency in the industrialized countries need to be lowered.**
- **But for the more important question here, on the implications for the P/W Relation…**

The global size of the shadow economy as a fraction of official GDP is also declining slowly. How does this affect the P/W Relation?

- Correcting GDP by including the Shadow Economy reduces the year-to-year scatter in the **P/W Relation** (=Current Power/Total Wealth = constant)
- It actually makes the **P/W Relation** trend flatter with less deviation from constancy; 16% wide band goes to less than 14%, and less still if we additionally correct for inflation bias assuming the **BillionPrices Project at M.I.T.**

The Power/Wealth Relation is Flatter Using Total Spending (light blue) *vs.* GDP Alone (purple). Both curves include dGDP correction from MIT's Billion Prices Project (my work).



#3. Converting Individual National GDP Data to a Single Global GDP: The Currency Calibration Choice

- One can convert between currencies using either of two different generally accepted methods: Basics **explained here.** The methods are:
- **PPP** = "**P**urchase **P**rice **P**arity". This attempts to look at consumer goods which are "identical" (near as can be judged) and measure how their prices differ between countries. It converts currencies so that a weighted average of a basket of such consumer prices is the same across countries. Poorly defined, difficult to calculate.
- **MER** = "**M**arket **E**xchange **R**ates". Currencies are traded freely on the world markets in large volume, and provide an instantaneously determined way of translating one currency to another. Real differences should be quickly arbitraged away by profit seekers expecting market inefficiencies will be temporary.

An Argument Against MER for Global GDP Growth Measurement?

- **Some countries artificially peg their exchange rate to major currencies**; mainly the Euro or Dollar. If their currency would otherwise rise in value, it would hurt their export industries, which likely motivates the peg.
- However, these pegs are periodically changed, which argues that they are merely coarser (in time) determinations of fair calibration value, lessening this argument. But PPP determinations are usually even more sparse in time, and so this whole argument carries little weight.

36 countries peg their exchange rates to other currencies, mainly the Euro, but the Dollar comes in second

- If their country's economy is growing faster than the pegged country, the effect is a faster rise in global GDP using PPP, and the opposite if they are growing slower.
- The list is dominated by small African countries with negligible GDP, but also included is Hong Kong, and Mideast oil countries Bahrain, Saudi Arabia, Qatar, and the UAE.

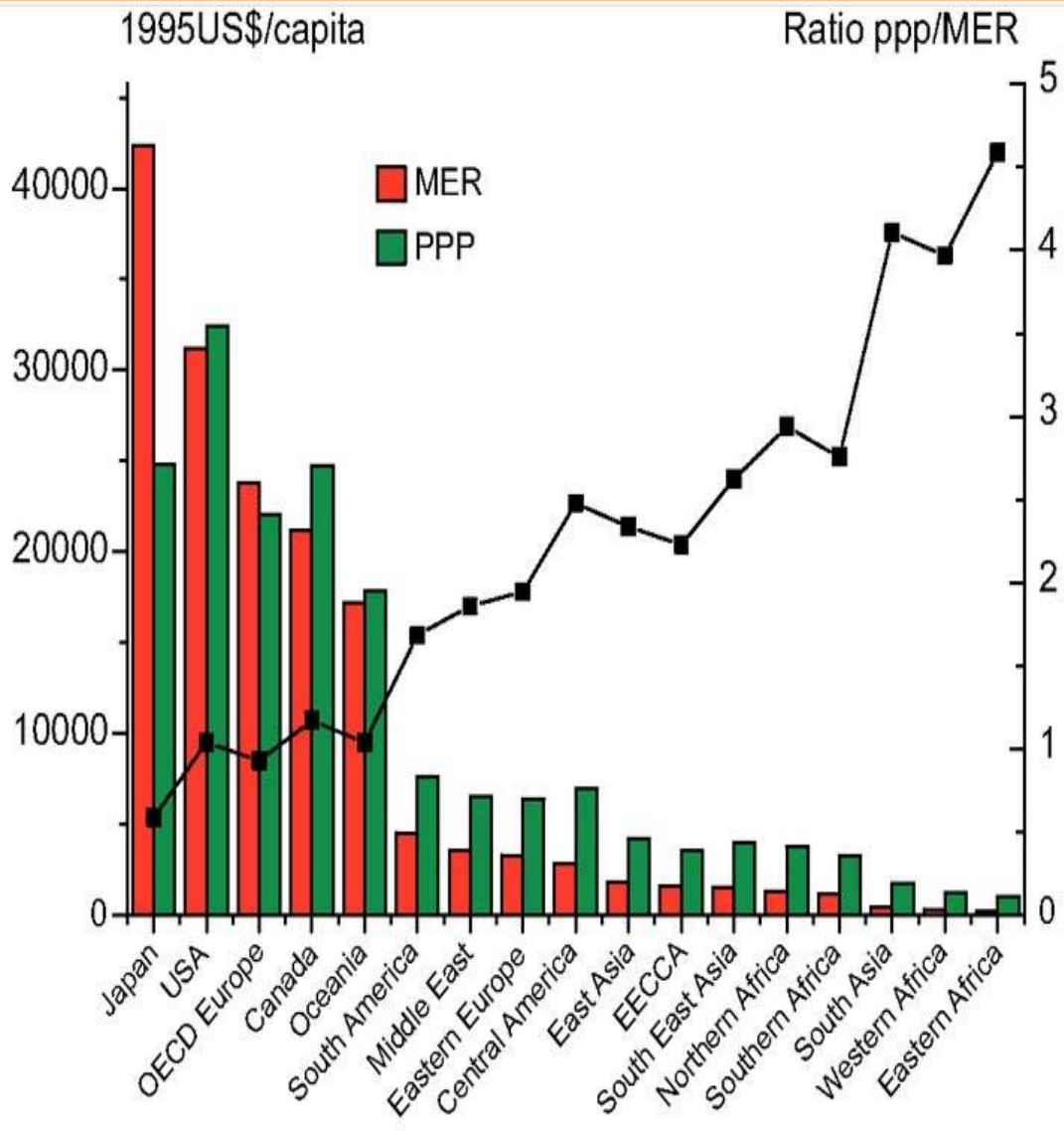


Figure 3.4: Regional GDP per person, expressed in MER and PPP on the basis of World Bank data aggregated to 17 global regions.

Note: The left y-axis and columns compare absolute data, while the right y-axis and line graph compare the ratio between PPP and MER data. EECCA = countries of Eastern Europe, the Caucasus and Central Asia.

Source: Van Vuuren and Alfsen, 2006.

From the IPCC AR4.

GDP_{PPP} is actually slightly **lower** than GDP_{MER} for the rich countries that dominate global GDP. Small developing countries are the opposite. Net global GDP growth rate is a bit higher using PPP. **But…**

Arguments Against PPP for Measuring Global GDP Growth

- PPP only measures consumer price levels, not the total economy. It's perhaps a better measure for standard of living, but not necessarily **economic activity** – which is what the **P/W Relation** is about.
- PPP is difficult and poorly determined. Less than 200 countries have any PPP calibrations determined.
- PPP has many subjective elements, particularly in trying to judge equivalencies in products. A loaf of bread in Yemen is a different thing than in Paris.
- PPP determinations open to influence by political motivations, as foreign aid to faster growing poor countries from rich countries can be influenced by perceived standards of living rise rates. Higher rise rates help politically justify the aid given.

Arguments in favor of MER over PPP Accounting

- Well-determined by large currency trading markets.
- Measures much wider segments of the economy than consumer prices.
- Available for longer time series.
- Economists agree it's the better measure when international trade is a strong component of what is desired to be measured. Certainly true in the context of evaluating the explicitly global **Power/Wealth Relation**.
- PPP is only measured every few years, and not for all countries. It might or might not measure standard of living better than MER, but … **We care instead about the energy consumption encumbered by the future from today's spending to enhance Civilization.**

This Brings Us to the Most Powerful Argument Against PPP Accounting for Our Purposes…

- The core of the P/W Relation is that the accumulated spending in building civilization's networks encumbers **future** energy consumption to support the growth enabled by that spending.
- And, given the exact same spending on a given good or service, civilization's network growth will be enhanced more strongly in a rich country than in a poor country, because the enhanced networks facilitating this growth are already in place in the richer country.

Economists Have Been Debating Why PPP Accounting Gives a Larger Global GDP Growth Rate Over Time than does MER Accounting

- A popular, if over-simplistic, measure of PPP accounting is the **"Big Mac" index** kept by ***"The Economist"*** publication.
- Garrett (private conversation) makes the point of the greater value to civilization growth (and hence to future energy consumption rates) supplied by a McDonald's "Big Mac" eaten in a rich country *vs.* in a poor country, and I agree. Let's look at the logic…

What's relevant is not Standard of Living, instead it is the future ENERGY encumbrance enabled and required by GDP spending.

- Justifications for PPP as a proper measure for "standard of living" argue that goods and services that are cheaper in **real** currency terms in a poorer country should reflect 1-to-1 with their measure of GDP. But in fact, there is an additional reduction in **value** that is not reflected in that accounting, because of the poorer growth-enabling networks in the poorer country.
- A "Big Mac" consumed in New York City by a high powered CEO will enable more Civilization network building and therefore require higher future power generation to support it, than will the exact same Big Mac consumed in a poor country, beyond the mere price conversion by PPP accounting.

PPP accounting narrowly assumes equal goods provide equal value

- Putting this together, I will offer that this may indeed be why we should **<u>expect</u>** PPP accounting to consistently over-estimate GDP growth in poor countries **in our energy-relevant context** - because this accounting inaccurately assumes equal value-to-civilization for equal goods and services across rich and poor countries, now and in the near forseeable future.
- Further I'll suggest that **market exchange rates** determined by currency traders recognize this. There's no one with more interest in doing his due diligence homework properly than someone with investment money at stake in a currency trade**: I'll argue the traders (who determine MER) get it right, on average**. It is crowd-sourced intelligence.

Even if all the arguments in favor of MER accounting were incorrect…

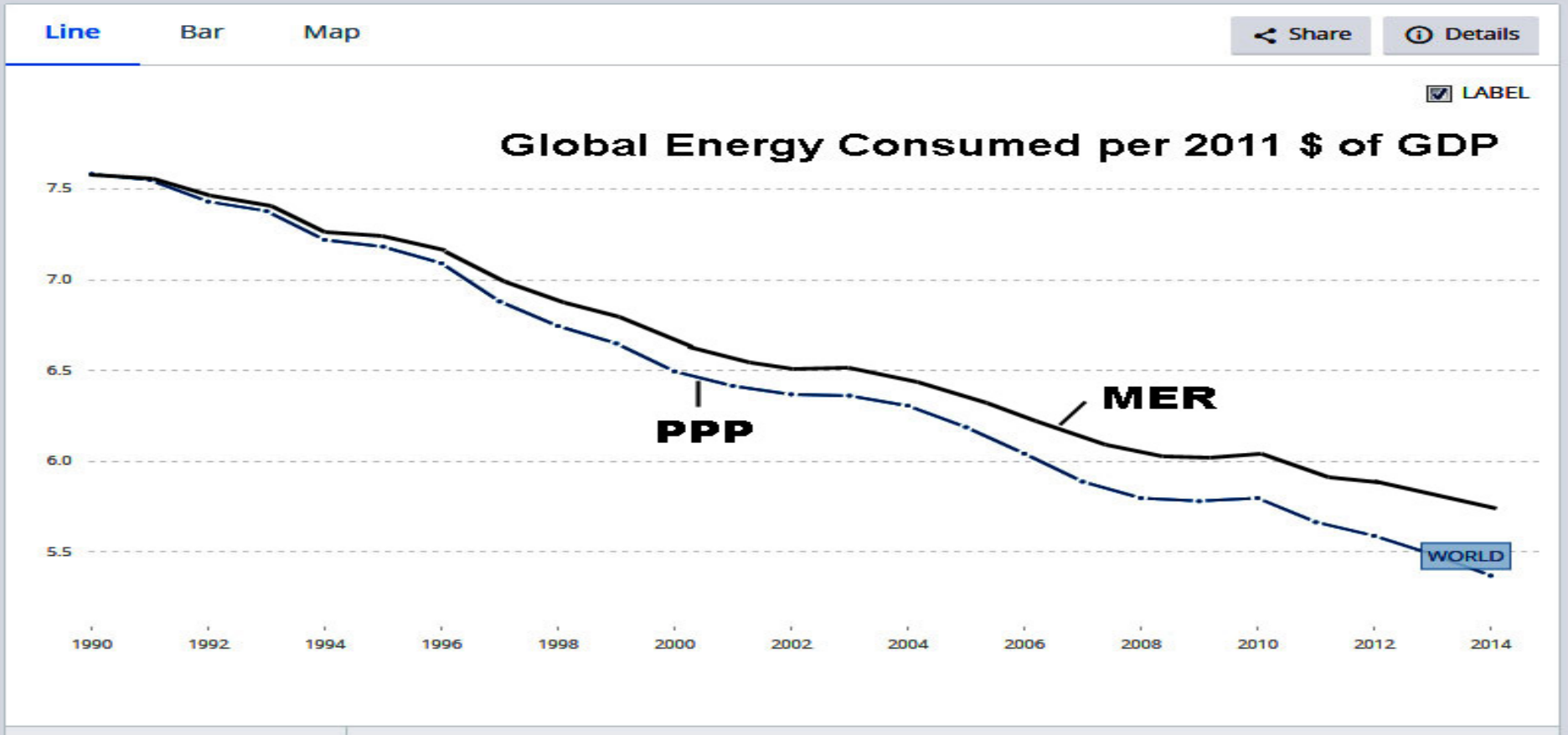
- It makes no difference to the pragmatic value sought in the **Power/Wealth Relation.**
- Wow. Really? Why?
- All it says, is that in doing future projections of global energy consumption vs GDP, that one be careful to use MER accounting and not PPP accounting. It is not actually important which philosophically is “better”.
- What’s more - MER accounting will always be available as data, and can be less easily manipulated than PPP for agenda-purposes.

Improvements in Energy Intensity per $GDP are not as strong using MER compared to PPP accounting, because of the bias just discussed – global GDP is not rising as fast as PPP accounting gives. The MER curve was normalized to the 1990 value, to better show the slope change. Note the Energy Intensity of GDP still continues to improve, and this does not contradict the Garrett Relation. Both curves woud be shallower still if the "shadow economy" were included.

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



In any case, would using PPP instead of MER accounting Make Any Difference in Validating the Garrett Relation?

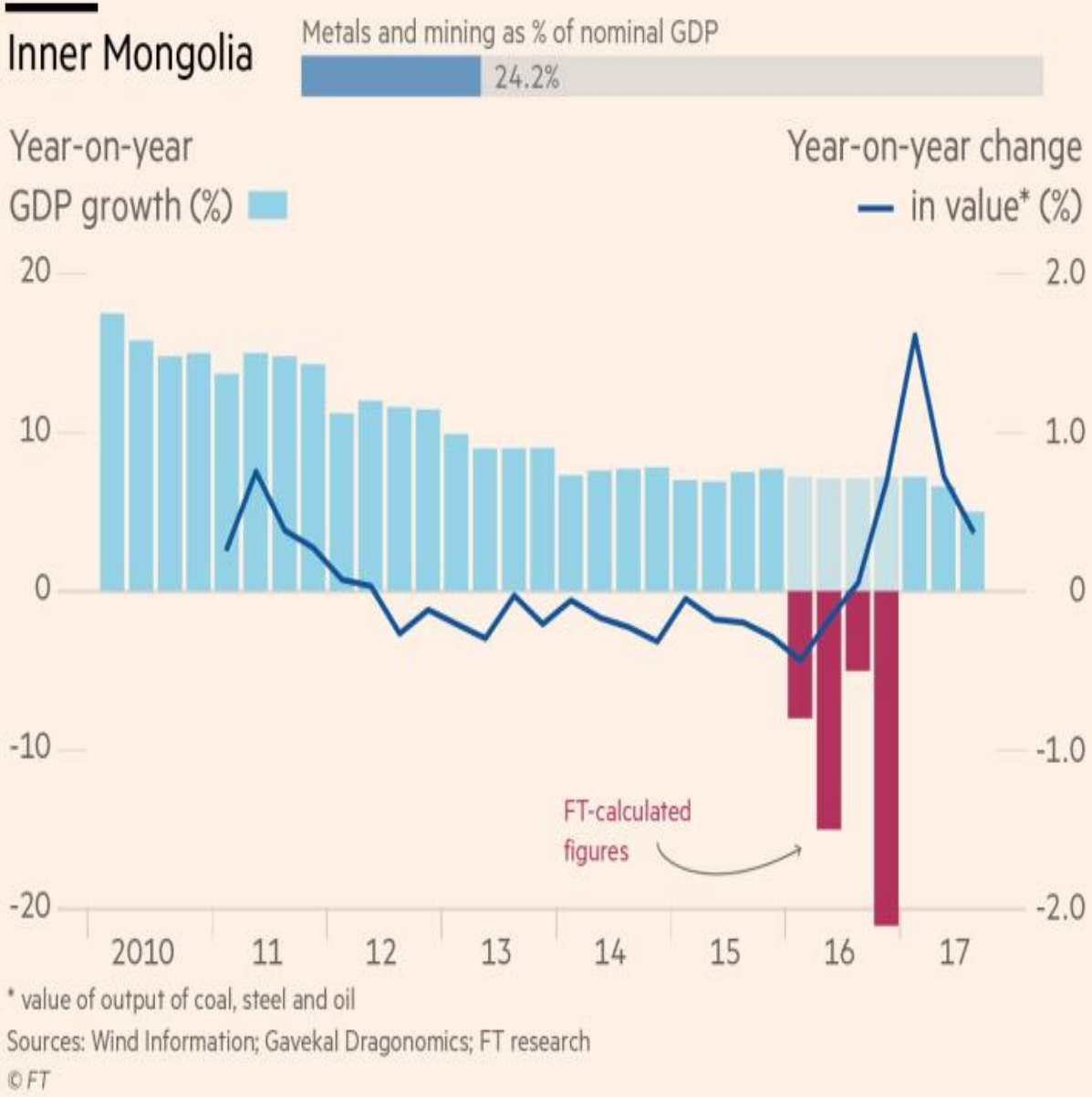
- Not as much as you might think. There are PPP determinations for many countries and from these, a fit between MER and PPP global GDP measures can be made
- To convert global MER GDP measures to PPP, multiply by…
- **1 + 0.258 exp((YR-1998)/73)** (**Garrett 2014**)
- It would skew the slope of the Garrett Ratio by only -3% from 1990 to 2014, the last of our data points. The final data point would be at 4.4, exactly the same as the 1971 start of the data series. (see Garrett Relation graph ~14 slides earlier)
- Even if we just split the difference, this gives a 1.5% drop for the final point in the P/W Ratio, from 4.7 to 4.6 mW/$.
- **Constancy remains fairly well supported, even if the less appropriate PPP accounting were used**

#4 Bias in Reported GDP Figures from Emerging Countries

- There are political and financial market motivations for government officials to overstate their GDP figures - Wall St. sets prices for equities on the basis of their earning GROWTH RATE, closely connected to GDP.
- Given the historical level of integrity of those involved in such areas, it's not surprising that figures are exaggerated (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.)

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 boom times, 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.



An even more dramatic example is Inner Mongolia. Official GDP was 7% but the *Financial Times* calculations show it was more like -10%, during the 2016 contraction.

Additional article

New Evidence for the Recession of 2020

- Global deployment plants for solar, wind, renewables **are being slashed**.
- **Priorities change when hard times come**. Artificial stimulus in the U.S. could have helped a bit (**but wasn't there**), but the real problem is cost and demand.
- **Goldman Sachs predicts** U.S. 2020 Q2 residential solar deployment to collapse 48% from one year earlier, and Q3 by 28%, and Q4 by 17%.
- China has been cutting back its solar plans as well, as we saw on an earlier slide.

The Recession - GDP Bias: Implications for Policy

- We saw that only declining global economic growth, ultimately to zero, leads to stabilized atmospheric CO2, even with unprecedented aggressive decarbonization of our energy consumption.
- But if the **Power/Wealth Relation** remains true during recessions, it also says that energy efficiency reverses to become increasing energy ***in***efficiency during recessions, as we prioritize supporting the civilization already created and hunker down, cutting investment in improving efficiencies.
- This implies a “no win” situation, given the human system. What’s needed is both radically improving energy efficiency AND an end to economic growth, and this requires a different human animal than is consistent with all historical data, and even with the psycho-biology of the human/civilization system (**Lustig 2018**).

Further: Optimal Foraging by the Human Animal as Reflected in the Garrett Relation

- It's remarkable; the Garrett Relation shows the value of **distant** past inflation-adjusted spending is equally as valuable as **recent and current** spending, in contributing to the total value of current civilization.
- This suggests to me that humans, on average, are highly evolved at optimal use of their talents and energies towards the **Prime Directive: Growth.** There is little waste in our decision-making.
- Our distant past spending contributed to its optimal potential in growing civilization as efficiently as possible to arrive at today.
- It shows how very far we are from a no-growth paradigm for a survivable future.

But Rick – People are not "Perfect Gas" Molecules!

- Yes, they are not perfect independent actors. They exhibit "emergent behavior", and this is reflected in learning, in legal constrictions shared by all within national borders, and economic legal system choices.
- These are seen to affect economic growth, energy efficiency achievement, and the ability to access new energy reserves in a coordinated way.
- And all systems are subject to the laws of thermodynamics.
- What we **don't** see, is the achievement of higher efficiencies and greater savings, and then just destroying those savings so they can't affect growth.
- Garrett does not see free will human agency as part of the picture. I suspect that will turn out to be mistaken (more later). But even if mistaken, it's not demonstrated that civilization can choose to avoid obeying the thermodynamic essence of the **Power/Wealth Relation.**

Theoretical Beauty *vs.* Real World Mayhem

- I confess to having two very different emotional reactions to pondering the work of Garrett.
- My astrophysicist side finds the theoretical results elegantly simple. And so I completely understand Garrett's reaction to the discovery of this principle - my physicist side roots for the Garrett Relation to be true, much like when I worked in Dark Matter research in the 1990's, finding **SUSY** a deep symmetry so beautifully tempting to believe it must be obeyed by Mother Nature, and providing Dark Matter candidate sub-atomic particles as a practical benefit to boot (alas, still elusively unconfirmed).

But my humanist side finds the P/W Relation frightening

- Our predicament is then much harder to escape from than if we could just “efficiency” our way to a happy ending, as so many policy people fervently and stubbornly hope. And that side of me hopes there is yet a fatal flaw somewhere, for the sake of my grand nieces and nephews, and all children worldwide.
- But… my efforts have only more strongly supported the validity of the **P/W Relation** in the best post 1970 real-world data.

#5. I Do Have One Bone to Pick with Garrett's CThERM Mathematical Model

- He makes an equation between inflation and "Decay".
- Recall "Decay" in the GR is the inevitable energy spent not on expanding civilization but instead on repairing climate-induced crippling of civilization's networks. Mathematically in CThERM, it is a subtraction from the civilization growth rate.

Both concepts are essential, but real-world inflation needed to correct nominal GDP is tied to easily manipulated money supply…

- …and a perfectly efficient set of global Central Banks with a proper (I believe) goal of zero inflation could simply alter the rules of the bank-produced money supply to insure zero inflation no matter how crippled we become.
- That would be relatively easy, compared to the large energy and effort of wealth creation/destruction on the other side of the equations.

The arbitrary, by-the-pen actions of Central Banks in setting reserve requirements…

- …for lending banks and QE actions affecting T-bond sales are not separately explicit in Garrett's equations linking the GDP deflator, inflation, with decay.
- Said another way, Garrett's term "inflation" while still faithfully linking real and nominal GDP, assumes central bank actions will not be related to the increasing decay caused by climate change. A better separation between decay and inflation is called for, I contend.
- **For now, the atmospheric CO2 curves in Garrett's future scenarios, I believe, should be exclusively denoted with the assumed decay term, and not with inflation – a word loaded with "freight".**

Global Central Bank Assets have risen an astounding 11.4% **per year** this century

- … while dGDP hovers around 2-3%, and supposed real GDP growth in the 2% area. 2+2.5=4.5, not 11.4, so the inflation has not gone into the old-fashioned items we measure it with. **It's into asset prices, primarily.**
- I've not found any carefully constructed rebuttal to the Garrett Relation, but neither do I see widespread acceptance. It remains an unappreciated piece of important work. I expect that increasing shenanigans involving official inflation measures may only make this appreciation harder to come by.

A Caution for the Future of the Garrett Relation

- Correcting for inflation is crucial to evaluate the continuing validity of the relation.
- Yet the political forces, and human tendency to want the rosy picture, both will conspire in increasing ways (I expect) to cloud the true measure of inflation necessary for an honest appraisal of the relation.
- I have another criticism: Garrett claims that it is a reversal in energy efficiency which causes recessions, but in fact recessions can come from a variety of causes. Instead, I would argue that it is the recessions which instead cause reversals in energy efficiency, as we struggle to merely maintain what we have rather than invest in new efficiencies.
- **Cause/effect runs opposite to Garrett's claim, I contend.**

The Quantitative Proof the Power/Wealth Relation Must ALWAYS be True

- Is elusive…
- And likely it is **not strictly** true (save for a future presentation).
- But for the post-1970 world and beyond, I believe it is true and reliable.
- **I've shown two quantitative verifications:**

1. Boundary condition: End all current power, everything dies, and all past Wealth(time integrated global GDP) disappears.
2. **The Recession – GDP bias** I've identified in the data, shows on short time scales the P/W Relation is also correct in its predictions.

We Appear Stuck with the P/W Relation's Sobering Implications for now. And yet...?

- Garrett's shown that energy exploitation has only been limited by opportunity, not human will power.
- I strongly expect this will stay true as long as we have billions of people living well below the standard of living of Western Europe and the U.S. and even more so, given the drive for relative status-seeking by the human animal.
- But what if, at a certain high standard of living – say that reached by a well-to-do state like California – increasing Wealth led to less energy-intensive leisure time and growth stopped? There are only so many hours in a day and so many days in a life.

Can the world make it to such a place before it is terminally crippled?

- The evidence suggests not - the Western lifestyle is enjoyed by only 20% or less of World population.
- There are too many poor but hard-working people seeking to RAISE their energy consumption. For quite some time, that will be carbon-releasing energy consumption.

Cryptocurrencies: A New Entry in the Complexity / Energy Conundrum

- The cyber-war to protect financial transactions against fraud and cyber-theft (and prying government tax eyes) has created BitCoin, which the world is now in love with, along with a growing list of alternate cyber-currencies.
- But the process of creating block-chains is **deliberately** extremely energy intensive for computers to accomplish. The numbers are staggering. As of mid November 2017…
- **…it costs 273,000 kilowatt-hours of energy to enable one BitCoin transaction (source). This is enough to power a typical American house for over 9 days! (sorry – that was Nov '17 figures)**
- **(now it is 12.2 days of power for that house, just 2 months later in mid Jan '18**
- **Sorry, now 34 days as of late May '18)**

BitCoin *vs.* Credit Cards

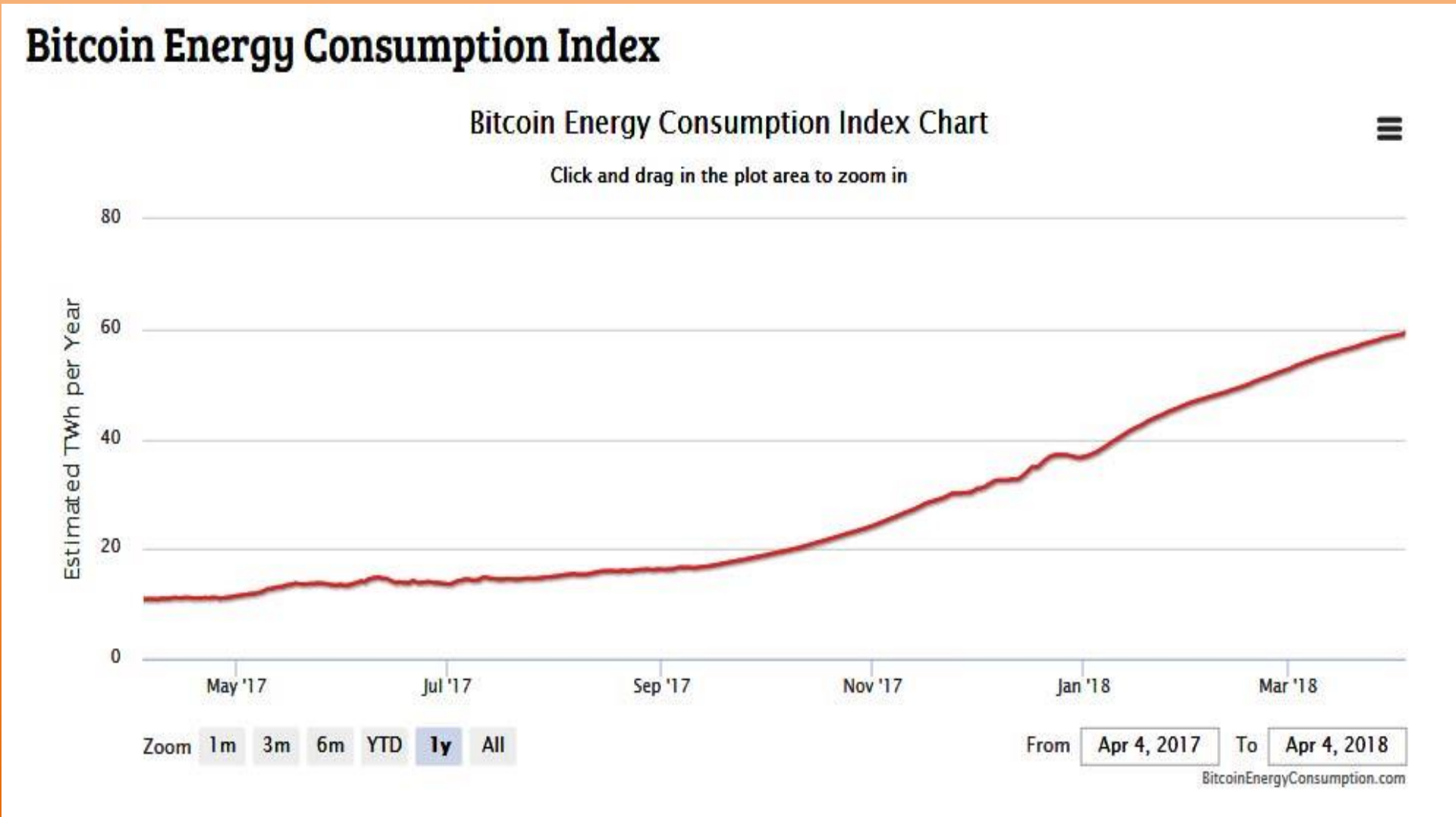
- Each BitCoin transaction consumes **5,000 times as much energy as a Visa credit card transaction**, as of January 2017, and rising.
- The computational difficulty of creating a new entry in the block chain is continually raised to compensate for higher processing power, in order to keep security high. While alternative algorithms and block creation ideas exist, they are not favored by those desiring hack-proof security, so that *"the power-sucking BitCoin leech will remain ravenous for the forseeable future"* (*source*).
- Globally, **BitCoin currently consumes electric energy at a rate that is equal to the entire country of Chile (Bitcoin Energy Index)**

Even doing math with no obvious PHYSICALLY MOVING things going on – consumes energy

- **Landauer's Principle:** Every bit flip (*i.e.* 0 to 1) requires a bare minimum of **kT ln(2)** joules of energy at perfect efficiency.
- *"Any logically irreversible manipulation of information, such as the erasure of a bit or the merging of two computation paths, must be accompanied by a corresponding entropy increase in non-information-bearing degrees of freedom of the information-processing apparatus or its environment".*[1]
- *Another way of phrasing Landauer's principle is that* ***if an observer loses information about a physical system, the observer loses the ability to extract work from that system.***
- ***We're nowhere near that limit right now – computers use 3 orders of magnitude more energy per bit flip than this. But at current rates of increasing efficiency, we'll reach this limit about the year 2050."***

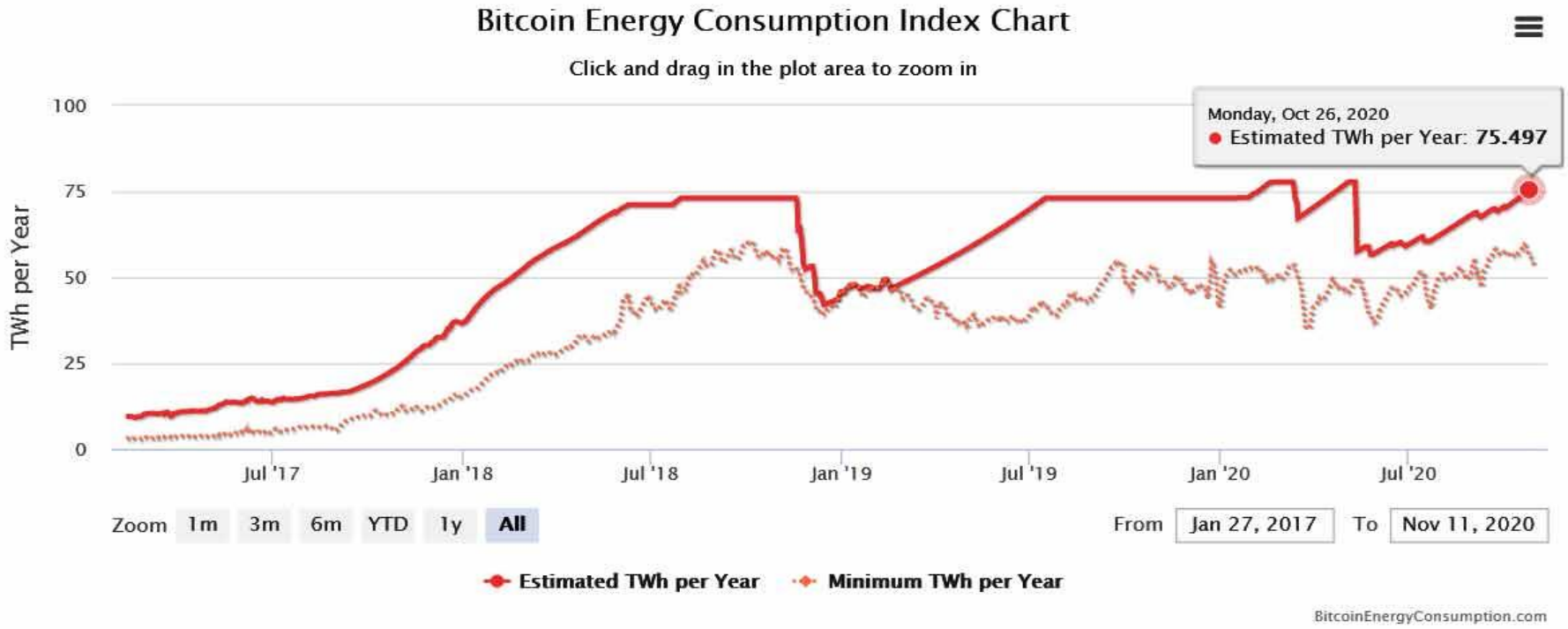
Apr ‘18 – Crypto-currencies had been tumbling in value… BitCoin down 60% in ‘18 (and that’s a logarithmic scale)

Has that dampened bitcoin mining? And has the push towards finding cheaper mining energy sources dampened BitCoin mining's energy consumption trend? No; UP 50% in just the first 4 months of 2018. Is it just a fad by small-scale back-room miners? No. In late July '18 IBM launched a major collaboration in new blockchain operations.



Bitcoin Energy Index Trend (Nov 2020) - is now at record levels. Does not include the proliferating other cryptocurrencies. And De Vries (2020) shows inefficiencies in miners adds at least another 20% on top of the top curve

NEW: Study reveals Bitcoin's electricity consumption is underestimated and finds the network "represents close to half of the current global data centre electricity use" (August 2020).



“Magical” Transformation Needed?

- Striving solely for energy efficiency is NOT the answer (I completely agree with Garrett on this part).
- Left with human nature as is, it will **hurt**, not help our future.
- **Increasing energy efficiency, with unreconstructed human nature, is a dangerous combination** as history shows it leads to even stronger growth in a world already far past sustainability.
- This is not to advocate against increasing energy efficiency – it is to advocate **for** transforming human nature.

What is first required is a deep transformation of the global psyche

- …a radical, pervasive personal growth which is strong enough to overcome the envy of others' riches, of material wealth as the measure of virtue, and instead embracing the value of unspoiled Nature, and seeing other species as fellow travelers on this planet and not just fodder for our advantage.
- The possibility of such a transformation of humanity before **Nolthenius' First Law** takes full effect, appears remote as I write this. Resistance to learning strong.

Nate Hagens argues such human transformation is not possible – we are slaves to our inherited hormonally driven compulsion for relative status, and for out-competing the neighbors

- And yet, I don't feel such overwhelming compulsions, and I know of others (well, a few) who also (largely) don't.
- Are we genetic freaks? Or is the power to mature in this way still within us all?
- I highly recommend spending an hour to listen to this insightful and excellent **2016 talk by Hagens on our predicament** **and his later talks.**

I'd argue transformation needs to include policy-enforced reduction in population growth

- It is tightly correlated with energy consumption.
- Up till now, population growth has been limited only by our ability to exploit energy resources and improve energy efficiency in expanding Civilization.
- Unwanted pregnancies in much of the world have high infant mortality if energy (=wealth) cannot sustain them, so if increasing wealth includes reduced infant mortality, then evidence indicates that greater education and access to birth control **globally** will change adult population growth only in a relatively minor way. (**Bradshaw and Brooks 2014**)
- Children are a joy; if we can **personally** afford them (never mind the Planet), we have them, on average; it's how Nature designed us).

To ReFrame the Bottom Line:

- **Increasing energy efficiency only accelerates our energy use and environmental degradation, until we have transformed our very human nature first (…if that's possible; I believe Garrett considers it ~impossible.)**
- Unlike the thermodynamics of inanimate systems, human systems have choice (although many scientists argue the very existence of free will), even if against-the-grain hard.
- This is not to say the CThERM mathematical model is wrong. In fact, the voluntary choice to throttle back from growth would enter the CThERM model through the inflation and decay terms – engaging in energy consumptive activities which do NOT expand civilization (*e.g.* dismantling rather than constructing, having FEWER children than you can afford or desire…).

It is physically possible to live simply and frugally, and even happily

- Social pressure to conform to the **"Rat Race"** only keeps us from appreciating where true happiness really comes from.
- Those wedded to high-energy life-styles can subtly or not-so-subtly exert social pressure on those living simply and frugally.

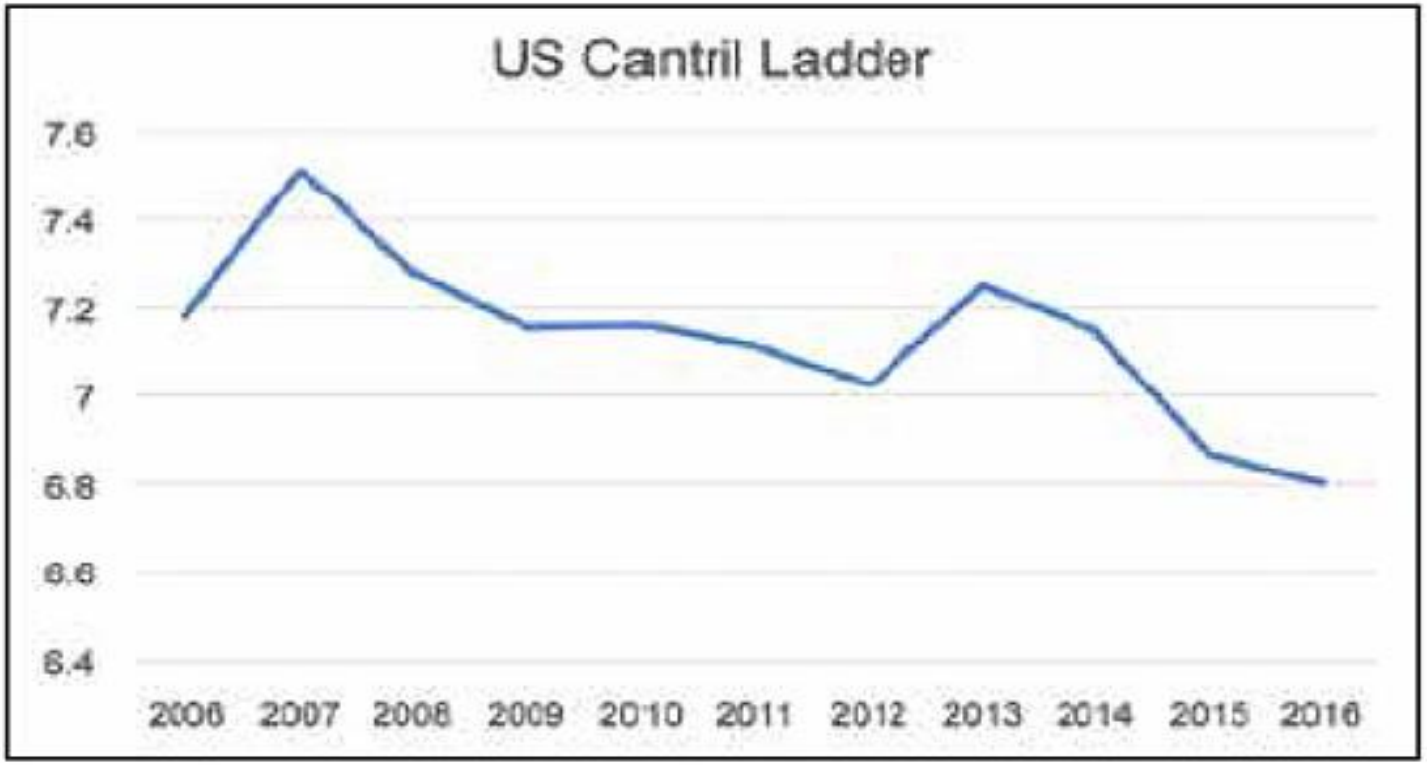
Get your dopamine fix from engaging Nature, not the treadmill of relative status-seeking. Try it. You'll Like it!

But remember: if you save your earnings, investing or putting them in the bank…

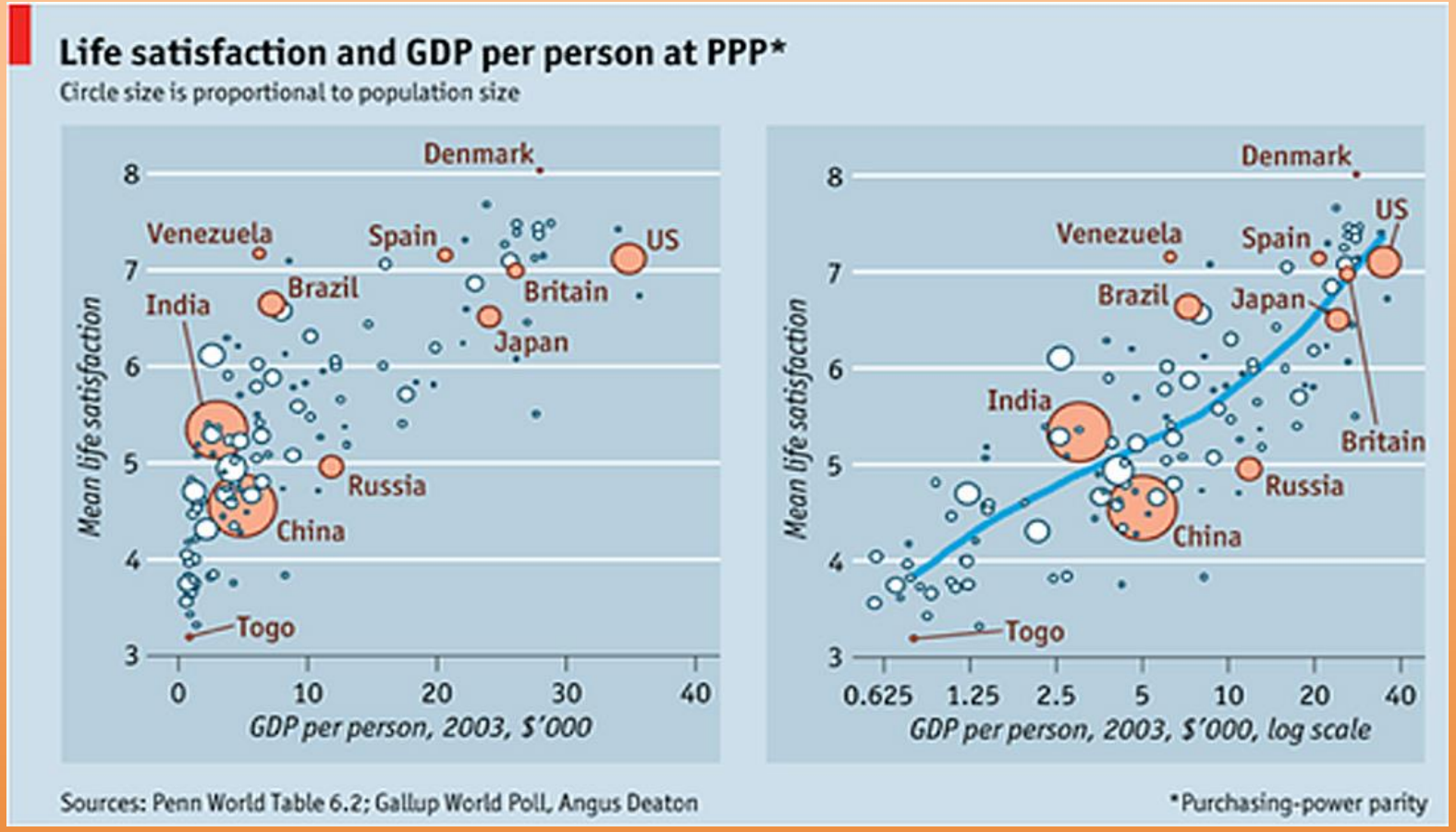
- …they are STILL going to be borrowed by others to do the energy-intensive things you swore off of.
- I run and bike everywhere I can, but don't torch my savings (alas, I "donate" some - investing in renewable energy companies - to the voracious Wall Street 'bots and algo's, run by guys who DO spend it!)
- I don't run and bike to make a big show of my carbon footprint. I do it for my sanity, trying to generate moments of primal happiness in this insane culture.

Alas, most people are ruled by relative status, and income inequality is making Americans more and more unhappy, despite rising per capita income. Historically, growing income inequality can end in societal collapse (Motesharrei *et al.* 2014)

Figure 7.1. US Happiness Score, 2006-2016



Source: Gallup International Cantril ladder



The biggest and fastest rising carbon polluters are firmly engaged in the "rat race". India and China (and all other countries) are struggling to climb up the rising portion of the **Life Satisfaction *vs.* per capita GDP** curve. **The log scale at right shows that <u>for life satisfaction to increase merely linearly, income must grow exponentially</u>.** This is fatal to climate. The "fuel" of desire impels us to rising power consumption.

Put Another Way. It's a Conflict in Human Inclinations: <u>With</u> *vs.* <u>Against</u>

- <u>The "solutions" one hears in the media are **easy** because we love them:</u>
- **1.** Increasing energy efficiency? We LOVE doing this! It's an intriguing engineering challenge and gets us more wealth
- **2.** Recycling, biking instead of driving, etc? Most LOVE doing this! – we feel empowered, healthier and indeed are healthier.
- **3.** Creating techno-fixes like better-adapted crops and conserving or re-cycling? We LOVE doing this! It's an invigorating scientific challenge, and gets us more nutrition and more wealth and the game goes a little longer.
- **4.** Creating transformed cities that draw people into them? Studies find that cities judged to be the most successful, are those that show not just exponential growth, but exponential **of** exponential growth. That means more energy .

But these all INCREASE energy's efficiency in ENHANCING Civilization growth…

- …at a rate that more than compensates for the efficiency (proven in the data by the Power/Wealth Relation), and hence…
- **They raise energy consumption rates**
- This is Generalized Jevons' Paradox, as we saw.

Instead, the real solutions include actions AGAINST human desire, so very few want to talk about them…

A. Involuntary strong population control, globally.
B. Putting civilization's growth sanely and gracefully (if that is possible) into reverse
C. Ending carbon emissions even before we can fully replace with renewables, and thereby requiring unprecedented belt-tightening
D. Changing how political leaders are empowered, so such policies have some hope of being enacted, **against** our individual desires, but **for** our civilization's long term health


GROWTH
1886-2007

The Actions which Reverse Growth are HARD, precisely because we HATE to do them

- These run AGAINST the innate programming of humans. I see stiff resistance to even admitting the possibility of truth to these, so myopically are people focused on the local and the short-term, and which ignore global and longer term reality.
- That includes many if not most, who are politically “Green”.

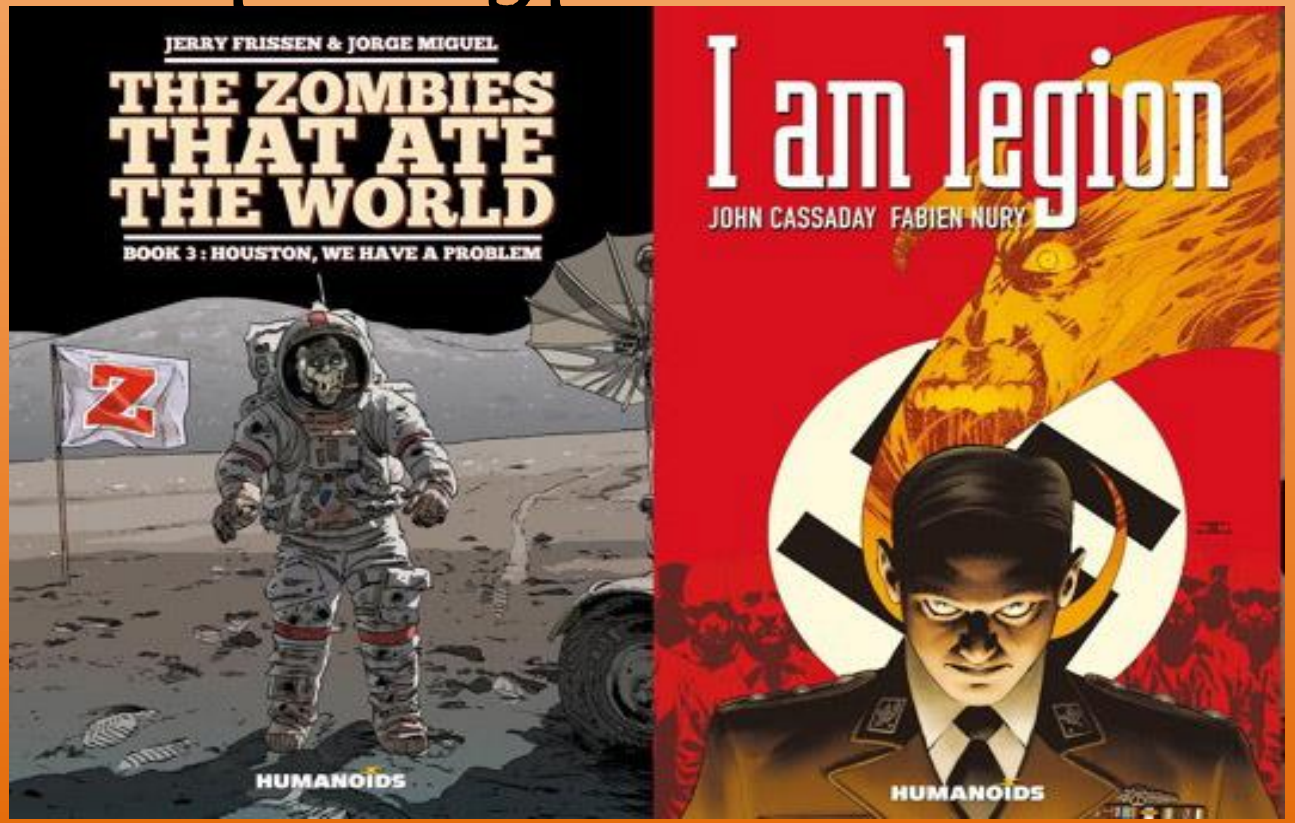
Are we genetically programmed for the Rat Race?

- If so, only crippling confrontation with resulting pain might make the average person reconsider it all – Nolthenius' First Law: "People Learn the Hard Way" – a principle I've taught my students for 34 years
- So far I see no evidence of any such transformation in human nature, even among too many Greens (except perhaps in small pockets of people who are already rich enough to afford such personal evolution. The low-hanging fruit, the far tail of the curve for human transformation). The evolution of the rest may be very hard and slow.
- Speculating now into the wild blue yonder (with a bit of black humor?)… what about CRISPr technology, applied to human nature genetic alterations, on an advanced, industrial scale (I suggested this to Nate Hagens a few years back)?

…Churning out millions of genetically re-programmed replacement humans without our flawed urges?

Or would that turn out badly, on an

Apocalyptic scale?



Is the Free Will to Change our Fate an Illusion?

- Some research suggests this (**Morris review 2009**, **Bear 2016**). Garrett is of the opinion that human civilization is a deterministic system and our freedom to change is much less (*i.e.* ~zero) than we imagine.
- I am not convinced. While impulse and snap judgments certainly exist, and we can indeed falsely re-write our experience to feel it was our free choice to do what was, in fact, a snap judgment actually decided unconsciously… yet in my experience it is possible to pause and reflect consciously, and then decide differently (see next slide).
- I have more to say on human **Free Will** later in this Presentation. For now, just some contrary evidence against the notion that **Free Will** is an illusion…

Garrett Believes Civilization is Firmly Deterministic, and Human Agency is Illusory

- However, I have a refutation of the claim that **free will** is an illusion: We, like all animals, are optimal foragers – Nature evolves our bodies over generations, and evolves our minds to be as energy-efficient as possible. We don't waste energy or material matter where there is no pay-off.
- See this **entertaining explanation from Derek Muller** of some basics of the operation of the brain in this regard, and its "discomfort".

Why, then, would Nature evolve what we call “consciousness”?

- Of what value is spending the energy and constructing the structural biological material and power funding needs to create self-awareness, and creating the ability and interest in forming percepts into concepts, into principles, and into understandings from that self-awareness? Clearly, it is to inform our **choices** if we so choose to exert that mental energy (which we may not choose to do, of course).
- But the point is, Nature would not invest in us the energy-intensive machinery for self-awareness as part of our brain’s capabilities if choice were, *de facto*, an illusion. That machinery would be superfluous in the prime evolutionary motive to leave more fit offspring, instead we’d be mere “meat machines”, stimulus/response organisms reacting blindly to our environment.
- Energy parsimony also explains why most of us don’t focus when needed, unless by act of will

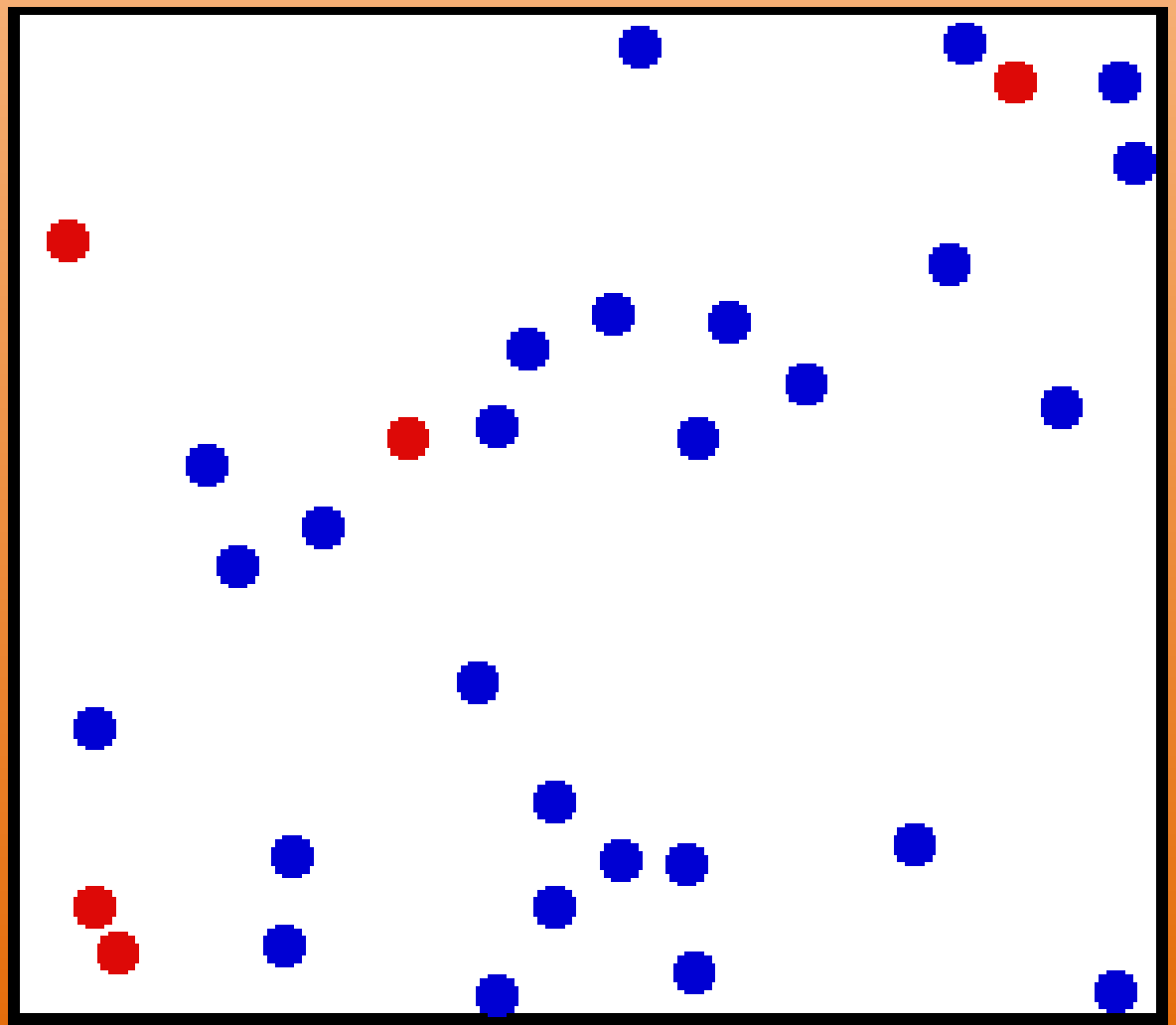
Yet, for those doggedly attached to the power of individual action…

- Consider: It is impossible even in principle to determine the path of individual molecules in a gas, no matter how much computer power one has.
- It is fundamentally indeterminate.
- Molecules have ultimate “free will” of a kind!
- **But yet…**

Yet the Laws of Thermodynamics for that same gas dictate that pressure, temperature, heat capacitance, entropy… are all well described with precision

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

Only the system as a WHOLE has predictable behavior. Given the Laws of Human Nature, unrestrained by repressive governments, civilization as a WHOLE follows similarly.



Let me hammer in again, the still unappreciated link between our climate future and human nature

- Recently I had a long lunch with a dedicated climate activist which convinced me that the point I’m about to make may not be as obvious to all, alas, as I once thought. So I try again:

EVERY instance of improved efficiency enables expanded growth. <u>They are reciprocal cause and effect</u>. Thus, true sustainability lies continually out of reach.

Yet I see in the eyes of the climate activists I know, that they just don't get it, even fight "getting it"

- **They cling fiercely to the notion that energy efficiency is the path to climate salvation. But it's *checkers* thinking, not *chess* thinking!**
- Improved energy efficiency, with an un-reconstructed Human Nature, is instead the path to more rapid growth, more rapid exploitaton of the environment, more rapid population growth, speeding the descent into **tipping point disasters** ultimately reversing civilization growth.

Nobel Prize Winning Psychologist Daniel Kahneman, on People and Climate Change:

"No amount of psychological awareness will overcome people's reluctance to lower their standard of living. So that's my bottom line. There's not much hope. I'm thoroughly pessimistic. I'm sorry." (*source*)

My Agenda is NOT "We're Doomed! - Accept your Demise"

- The message to those involved in trying to save future climate, is not to give up, but to **UP the ANTE.**
- The task is FAR beyond the cheerleading I hear even from the climate activists who are the good guys in this tragic drama. **They fail to appreciate the numbers!** They hear a happy techno-news lure for investor $ and fail to appreciate it's downstream effects, and just how far down the black hole we already are, and the forces that have taken us there, by our own hand.

Their meme is -*"You can HAVE your growth and a wonderful future too!"*

- Realize the concerted interests of the well-capitalized stake-holders and those they control, to have you believing we're already on our way, so just be patient and smile and don't panic…
- …and, above all, **don't agitate for any radical political/economic changes to the *status quo*.**
- Neoclassical economists – who have become the politically dominant paradigm - are employed by these people and are firmly aligned with this mindset

Too many HappyTalkers come from a salesmanship place that believes, like Colonel Jessup in "*A Few Good Men*"…

"You Want the *Truth*"?!!

And yet… If that's truly the way it is, then we indeed ARE doomed.

- Notice the fatal either-or assumption at the heart of this attitude…
- If climate activists believe the only choices that people are willing to make is…
- **EITHER:** *"OK, I'll make some small changes, and even those, only if they promise stronger personal economic growth <u>for me</u>".*
- **OR**: *"I'll stay in denial"*, thus onward with the ***Business as Usual*** trajectory
- **THEN** Indeed, we're doomed. Because neither saves our future.

According to Tyndall Climate Centre's Kevin Anderson…

- Policy intermediaries – acting between the scientists and the politicians – are judged to be "successful" when they paint happy pictures for the politicians who ultimately employ them, so the politicians (meaning, the corporations who bought/installed them) can quote them in their speeches advocating for **Economic GROWTH**.

As always in our sad world – "Follow the Money". Or better – Follow the Reward System

- Scientists, on the other hand, joined their field to satisfy curiosity. They love to figure out the true nature of things. They also, of course, like prestige and to be well-paid… BUT, the key is that the scientific culture and career system rewards them with such tangibles ONLY when they show they are good at **actually** figuring things out, and communicating with solid logic and evidence. The "coin of the realm" is **actual evidential truth!**

Clipped from a recent talk by James Hansen…

Eisenhower, scientists, and Sputnik

By John S. Rigdon, Physics Today, June 2007

Eisenhower, in conversation with James Killian, shortly before Eisenhower's death:

"You know, Jim, this bunch of scientists was one of the few groups that I encountered in Washington who seemed to be there to help the country and not to help themselves."

After realizing all this…

- … I am no longer scratching my head over Professor Kevin Anderson's conversations with, and **depressing accounts** of, policy people's avoidance of the facts on the key considerations outlined here.
- The incentive systems motivate too many policy professionals' refusal to confront and communicate clearly these facts.
- See **"Post-IPCC Climate Science"** for more on this, and **K40b: "The Psychopathologies of Climate Denial"**.

Strong evidence shows that politely asking our "Parents" in Washington DC for better policy has gone - and will continue to go - <u>nowhere</u>

- This, despite the spin and continuously ballyhoo'd "encouraging signs" which seduce one to believe that *"we're turning the corner".*
- The corner we're turning, is towards a dire future, which physics insures, if we cannot shake ourselves out of our very nature, it seems.
- This is the subject of the next Presentation: **K44 - "Strategies: Policy"**

From my experiences with people…

- I fear that we will not learn, until far too late. The sharpest and most accomplished thinkers in this area that I've found, agree.
- Governments are installed by the economically powerful. We're even flag-wavingly proud of the fact that anyone who can fog a mirror and is born in the U.S. can be voted into national office by the most uninformed, selfish, racist, small-minded people among us. Their vote counts the same as the wisest, most benevolent, and the most far-thinking. And the **non-living corporations' desires count most of all**. I see no hint that this will change,
- **I see no backbone for the necessary level of confrontation with government-as-it-is, to transform it to government-as-it-needs-to-be, to achieve a climate livable future by going against the grain of our flawed human nature**.

So How Do I See the Future Unfolding?

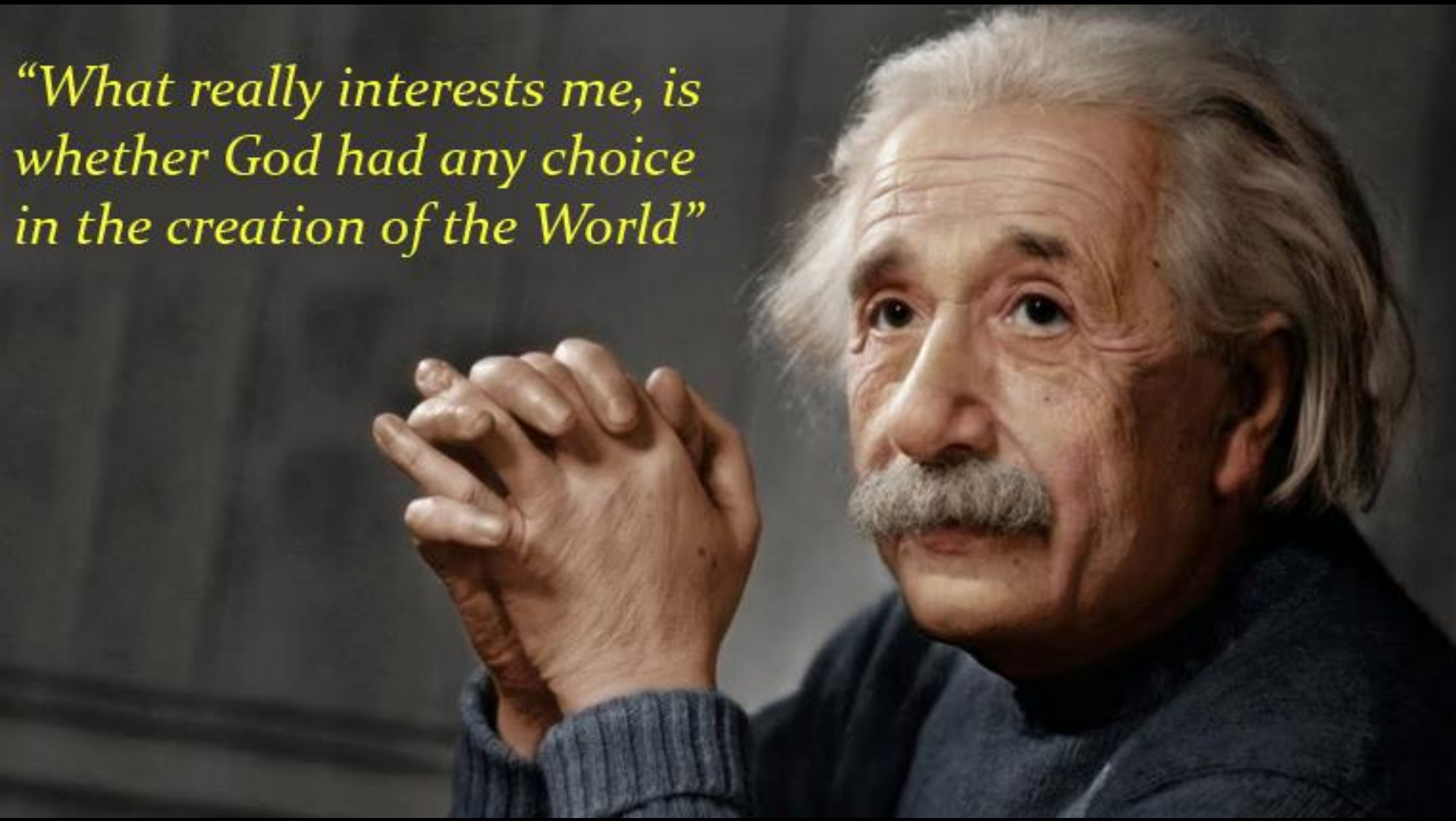
- I see continued and reasonably successful efforts in improving energy efficiency, which will expand civilization and hence by necessity, energy consumption rates. This has been the history of civilization and it will continue for a while.
- I see continued rising standards of living in the 3rd World, and hence energy consumption rates, …until climate chaos really sets in, triggered likely first in the tropics, sending waves of desperate immigrants north.
- I see a resumption in global decarbonization, perhaps even to the rate of 50% reduction per 50 years, as Garrett thinks is extremely optimistic. I don't agree. My impression is that it's do-able, and even perhaps likely, at least for a while, **if we somehow avoid societal collapse. But – it's not enough.**

We will only do what is economical, what is cheaper, what is the short term <u>comfortable</u> thing to do, mostly for ourselves personally

We will not make, individually and voluntarily, the hard sacrifices GLOBALLY that the **climate physics** show are necessary to save the future and to respect other species.

That’s our history - Human beings make their decisions “on the margin”.

Civilization and Human Agency



Many bright thinkers will claim humans have no Free Will and that our civilization system is completely deterministic

- It's seductive: it relieves one of the moral outrage against what we have done; against the continued irrationality of our responses to the climate problem.
- But my tentative conclusion from seeing the vast differences in how people respond to challenges, is that determinism may not strictly apply here.
- My experiences suggest that Free Will, of a sort, does exist but only in one narrow choice…

To Focus, or Not to Focus – That is the Question

- Looking inward, and in educating thousands of students over the years – I believe our power of choice still exists in this Shakespearean choice.
- I accept as true the **fMRI studies** showing that decisions are reached subconsciously and **then** rise to consciousness and we re-write the chronology in order to feel more in-control, fooling ourselves we have free will. But that doesn't change my conclusion.

My Contention: Your free will comes in only at the very start: To Focus, or not to Focus.

- **After** that fundamental decision, Free Will then takes a back seat to the mechanisms of our brain's decision tree and the connecting links from your programming of your unconscious, to the conscious mind.
- Philosopher **Sam Harris has given many talks** over the years on claiming we have no Free Will, but with sparse argument and evidence. I offer my hypothesis as a rebuttal consistent both with the research facts he states, and also with the existence of a limited but vital place for "Free Will" of a kind.

Once We Choose to Exert That Effort – to Focus, and Stoke the Desire for Clarity…

- We then experience the sway of what will guide that focus.
- One can mentally step to one side and observe the process internally...
- Will I choose to follow my pre-existing leanings?
- Or may I instead choose to **raise** my effort level, my biological mental energy, with the guideline to actually seek the “light bulb” experience that goes with non-contradictory integration of the logical or illogical connections with the new information in front of me?

We can re-phrase this fundamental choice this way…

- To be CONSCIOUS? Or, to let the tendency towards mental passivity have its sway, and remain partially or completely UNCONSCIOUS in dealing with the decision placed before me.
- I agree with thinkers like Sam Harris when he contends that we don't have the free will to change what comes **up** into consciousness. What he calls the "Libertarian notion of Free Will". I agree the Libertarian notion is false.
- But what we do, perhaps, have power over, is the will to consciously make that fundamental first decision: **Shall I remain conscious? Or not?**

Yes, you don't direct the answers from your brain. But I believe you do direct the questions you put to it

- **…and you have control over the care in which you provide it data, and goals. Through choosing to be CONSCIOUS, not UNCONSCIOUS. But yes, the programming then arrives at the answers and you don't have Free Will over those answers. They come as they will.**
- Once I've engaged consciousness and the desire for genuine clarity of understanding, it is the unconscious which will do the work and arrive at an outcome and present it back to consciousness.
- Because this **final step** is from the unconscious, I believe that has fooled many into thinking that we have no aspect of Free Will whatsoever. I believe that's false. Our free will is restricted, but not zero.

The New Science of Neuroplasticity Argues…

- That once we raise our mental focus and achieve the light bulb experience of new integrations of new knowledge, we change our brain's wiring.
- And then our reactions change, our decisions change. Our emotions change. **We** change.
- But it will not come from an attitude of passivity and unconfidence. It can only come from a **will** to summon your internal **energy, and effort,** and focus consciously.
- That, I believe, is where Free Will happens, and perhaps it is the only place that Free Will happens. In that moment when you decide…
- **To focus your awareness, or sink to passivity.**

Nature gives us that choice, because it has survival value – the energy consequences are large

- **Your brain uses calories at a 10x higher rate, per pound, than the rest of you…** Calories (in the old days) hard won by having to chase down wild animals and cook them, or climb dangerous trees for the high hanging fruit.
- We're parsimonious creations, like all Life. So we won't burn those calories without a good reason. Nature gave us the choice to be conscious, so we could be optimally aware of new information, and the higher energy cost of that FOCUS was judged by Natural Selection to be worth it.
- Wisdom, Free Will, take energy. Without free will, what would have been the point of Nature embarking on that energy cost? It only makes sense, if being truly conscious **matters**.

I Argue it is THE Fundamental Choice, and Exercise, of our Agency.

- Once that choice is made – **to focus** – THEN the full array of other knowledge you've gained enters the awareness and the process of arriving at a decision, then brought from unconscious work into consciousness.
- This last step will indeed feel "deterministic", "unwilled", or whatever wordings you prefer for the description of the outcomes seen in fMRI studies and your personal experience.

That's my contribution to hopeful essay'ing on Free Will in human affairs…

- …that's my tentative conclusion. Crucial Free Will of a limited kind does exist. I may be wrong. I'll stay open-minded on further thought.
- I'll now speculate on how the future may unfold…

The “Resiliency” term in the CThERM model will, I suspect, turn out to be fairly high

Human ingenuity will find a way to further wrestle resources out of an increasingly crippled planet and march the **Growth of Civilization** forward to a surprisingly large extent... for a while.

And therefore, atmospheric CO2 will pass 500 ppm, we will pass the tipping points dooming our coastal cities, dooming permafrost carbon, dooming the livability of the tropics, quite possibly dooming us to an era of super-storms and mass extinctions as Greenland’s melt accelerates, and the AMOC shuts down.

Indeed, we may have already passed them, thanks to the lies from Big Oil and their shills in education, in media, and in Government, aided by our willing complicity in wanting the short-term easy path.

Standard business practice is to apply a discount rate to the value of the future of ~3% per year

- That says we value the world of year 2100 only 8% as much to us as we value Today. It's absurd.
- And the stark choice we've been given: **Us** and our present comforts *vs*. **all future generations** – with rare exceptions we choose our own short term comforts. My apology if it doesn't apply to you personally - it is only the global sum that counts for climate, where it is certainly true.
- This was at first a shocking, even traumatic surprise to me, as there's plenty of evidence of people's love for their own children, and children in general. But not, it seems, for their children's world, which can only be safe-guarded by intelligent and benevolent governments, which we refuse to install.
- **This logic disconnect is amazing to behold.**

In Large - People Do What they Want to Do… Unless Compelled Otherwise

- From my 10 years in climate science, I observe this to be as true among Liberals as among Conservatives (discussed in **K40b**).
- It is, alas, too rare for people to assess new evidence, identify their faulty positions, change their tribal alliances, their world view, and follow the actions their goals now rationally require.
- People do what they WANT, and this follows perfectly with **Generalized Jevons' Paradox**, and with the **Garrett Relation**, and why I remain pessimistic we will solve climate.

It's a very tough Human Nature reversal that is needed.

The key and fundamental fatal flaw in the political/economic system that runs Civilization, is this…

- Doing **personal** activities that benefit ourselves and our family in significant and material ways are, of course, the humane thing to do. We are genetically designed to experience powerful human motivation to do these things. It's not a psychopathology.
- If our **personal** activities hurt climate and our future, they do so in such an infinitesimal and completely negligible amount, that it provides no rational brake on doing those activities. And yet its only our **personal** actions that we have the significant power to control.
- Marginal Economics' horrific consequences.

For Climate – which is GLOBAL, ONLY Government action can change this…

- ***Homo Economicus*** = Modern *Homo Sapien*, makes his economic decisions **"on the margin"**, where climate is not affected, and **therefore we will continue to destroy our future by each of us individually doing our tiny part.**
- ONLY government action enforced can change this…
- (As a former Libertarian, I still find it wry to hear myself say this. Yes – government is corrupt, insensitive, staffed by un-brilliant people. But the solution isn't to destroy it, it's to make it better.). Unlikely, but its our only hope.

POGO HAS IT RIGHT

The Power/Wealth Relation *vs.* Conventional Eco-Solutions Thinking

- The inner core of why we remain on the path of self destruction and the destruction of Nature, is not getting through to people
- I meet people every day, who remain obsessed with what I'm coming to call **"Techno-Porn"** – hyped seemingly eco-friendly (sometimes even genuinely eco-friendly) changes which make us more efficient in our use of materials and energy and promoted as SOLUTIONS.
- I don't see people getting this. They may politely listen to my talks, but in the end, I get my mailbox filled yet again with more **techno-fix ads** from many of them.

I recently watched DiCaprio's "The 11th Hour"

- …made in 2007, and with all the hope given to techno-solutions, and essentially nothing about solving the incompatible **nature** of the human animal with true sustainability at zero growth.
- Would the makers of the film be surprised that see some of the world's biggest countries are, in 2020, now anti-environmental fascist wanna-be dictatorships, including ours?
- …and that global fossil fuels emissions continue to grow every year with no hint of a turn?

Even if a few of these tech ideas do seem promising (amid more that are just dangerous greenwash for sleepy investors)…

- …I find myself unexcited, unimpressed.
- And, disheartened that the real issue simply does not want to be faced, by either Progressives, or certainly by Conservatives.
- **WE**, our very **nature**, are the problem.
- The single-minded search for ever more efficient means to continue our growth – only keeps us on a path to Nature's demise. And then, to a major extent, the demise of human self-respect as we look at what we have done.

Other Explorations by Physicists into Economic Theory and Practice

- The field of **Econo-physics**, dating back to the 1990's with hints earlier, is primarily concerned with the rules governing equity pricing 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 starts with similar premises as Garrett.

Chap K43: Key Points – Civilization as a Thermodynamic System

- **The P/W Relation:** Civilization's energy consumption rate is directly proportional to the total inflation-adjusted global Gross Domestic Product (**GDP**) accumulated over all time. Civilization requires energy consumption even at zero growth rate, to support past growth.
- Civilization has always and continually increased the energy efficiency per $ of **GDP** produced. This, and its win/win nature argue we cannot steepen that improvement rate.
- **Generalized Jevon's Paradox:** Increasing energy efficiency leads to INCREASED global energy usage, not decreased, since it improves civilization's ability to expand, necessitating exploitation of new energy.
- Our global growth rate, holding CO2 emission rates constant requires the equivalent of a new 1.5 GW (rated capacity) solar PV power plant per day.
- Solar/wind deployment not keeping up with FF's. Merely added to our portfolio of energy sources. Energy is EVERYTHING. We exploit all we can.
- Power/Wealth Relation is even stronger after closer look at inflation, at total *vs.* reported **GDP** spending, and at PPP *vs*. MER accounting
- No future thermodynamically consistent scenario leads to lower atmospheric CO2 on any time scale short of a century+, except for a de-growth of civilization plus extremely rapid decarbonization and Geo-Engineering.