Climate Solutions: A Critical Assessment

Richard Nolthenius, PhD

Cabrillo College

Nov 29, 2018

My Background

- Chair of the Astronomy Department at Cabrillo College for 32 years
- Lecturer and visiting researcher in astronomy at **UC Santa Cruz**
- Masters Degree in Aerospace (U. Az) Thesis: computer code design for thermodynamics of fluid systems.
- 2 years in private industry as Thermodynamics Engineer at General Dynamics – Convair Space Division, designing and analyzing thermal systems and performance for spacecraft and space payloads
- Lead thermal designer on General Dynamic's entry for the first round of what became the ISS (International Space Station)
- Doctoral work at Stanford University in Applied Physics, finishing PhD in Astronomy and Astrophysics at UCLA
- Post doctoral fellowship at Steward Observatory, University of Arizona.
- Part of the Dark Matter team at UCSC led by Joel Primack, computer modelling of the evolution of Dark Matter cosmological simulation galaxies and comparison with real world galaxies.
- Co-investigator with Sandra Faber team on characterizing the Fundamental Plane of dissipative stellar systems
- Began Climate work in 2009, shifted focus from Astronomy to Climate in 2010

Climate Solutions… to Accomplish What?

- As long as one continues to think that the problem is just too much CO2 and GHG’s in our atmosphere, we’re not going to solve the real problem.
- Seeing Civilization as a Thermodynamic System integrated with physics is essential to properly assess techno-fixes and policy ideas.
- **<u>Any techno fixes that ignore the human drives and physics inherent in the nature of the human / civilization system at root, are doomed to fail. We’ll return to this…</u>**

Outline for Tonight

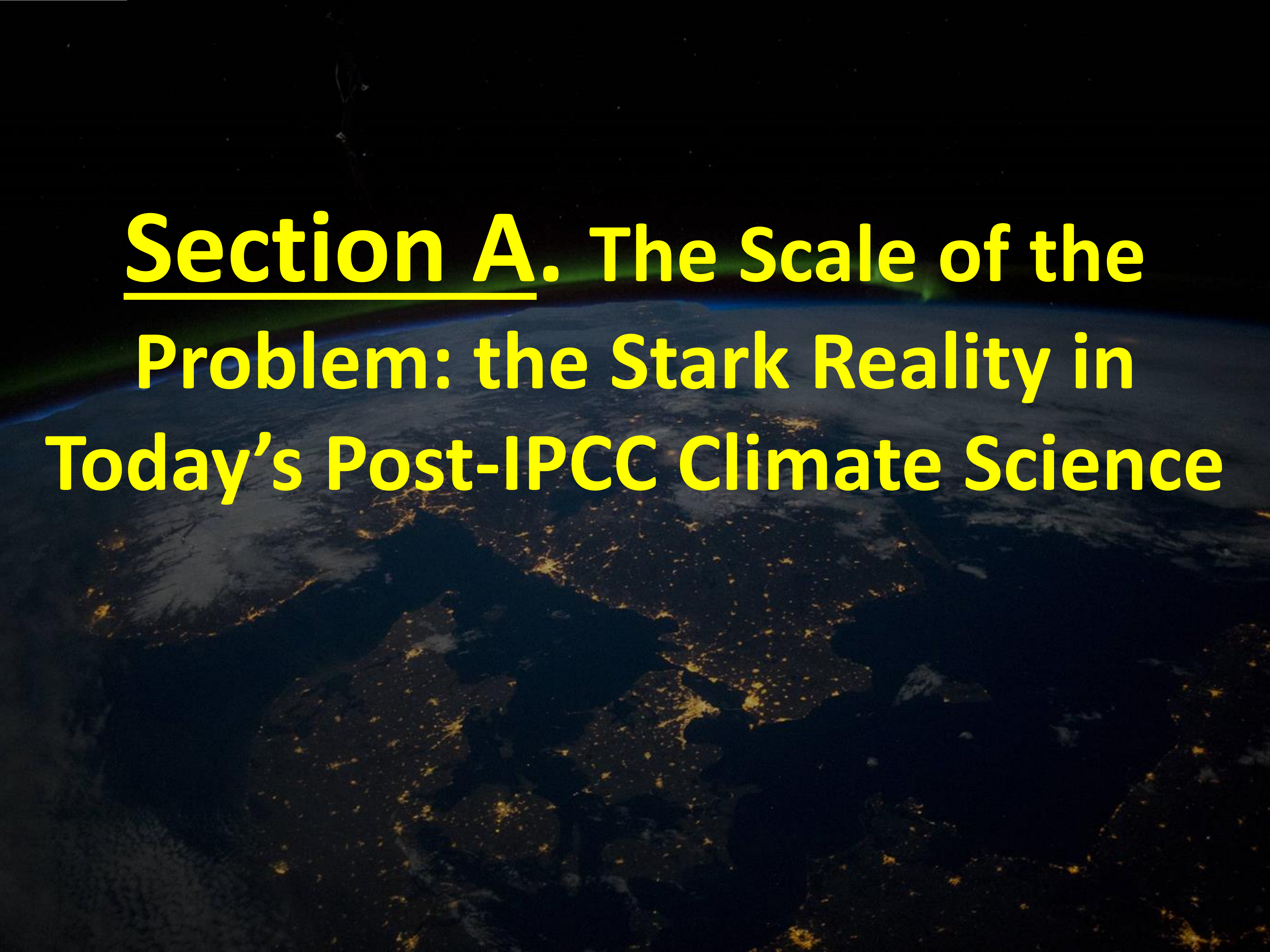
- A. Scale of the problem: future projections, ECS, the Permafrost Carbon Feedback
- B. A New Framework: Efficacy and Safety
- C. Energy Alternatives: solar, wind, geothermal, wave, debunking biofuels…
- D. Energy Storage for renewables
- E. Carbon Capture and Sequestration
- F. The Garrett Relation and Civilization
- G. GeoEngineering
- H. Policy
- Summary of our plight

"We got here according to the laws of physics and we are subject to those laws and must live within them. We can't be guilty of magical thinking in predicting our future."

- UCSC Astronomer and member of the National Academy of Sciences – Prof. Sandra Faber

"What I seek to accomplish is to serve, with my feeble capacity, truth and justice at the risk of pleasing no one"

- Albert Einstein



Section A. The Scale of the Problem: the Stark Reality in Today’s Post-IPCC Climate Science

Are the UN Intergovernmental Panel on Climate Change (IPCC) Assessment Reports the Gold Standard of Climate Science? Unfortunately, No.

- *Dr. Peter Wadhams: "The Summary for Policymakers is a document of appeasement, not fit for purpose. In reality, if my calculations are correct, we not only don't have much of a carbon budget left, we have already overshot that budget – we're in overdraft."*
- *And indeed – he's right.*
- *How did this happen?*

The IPCC Assessment Reports: Require 100% Consensus before Publication

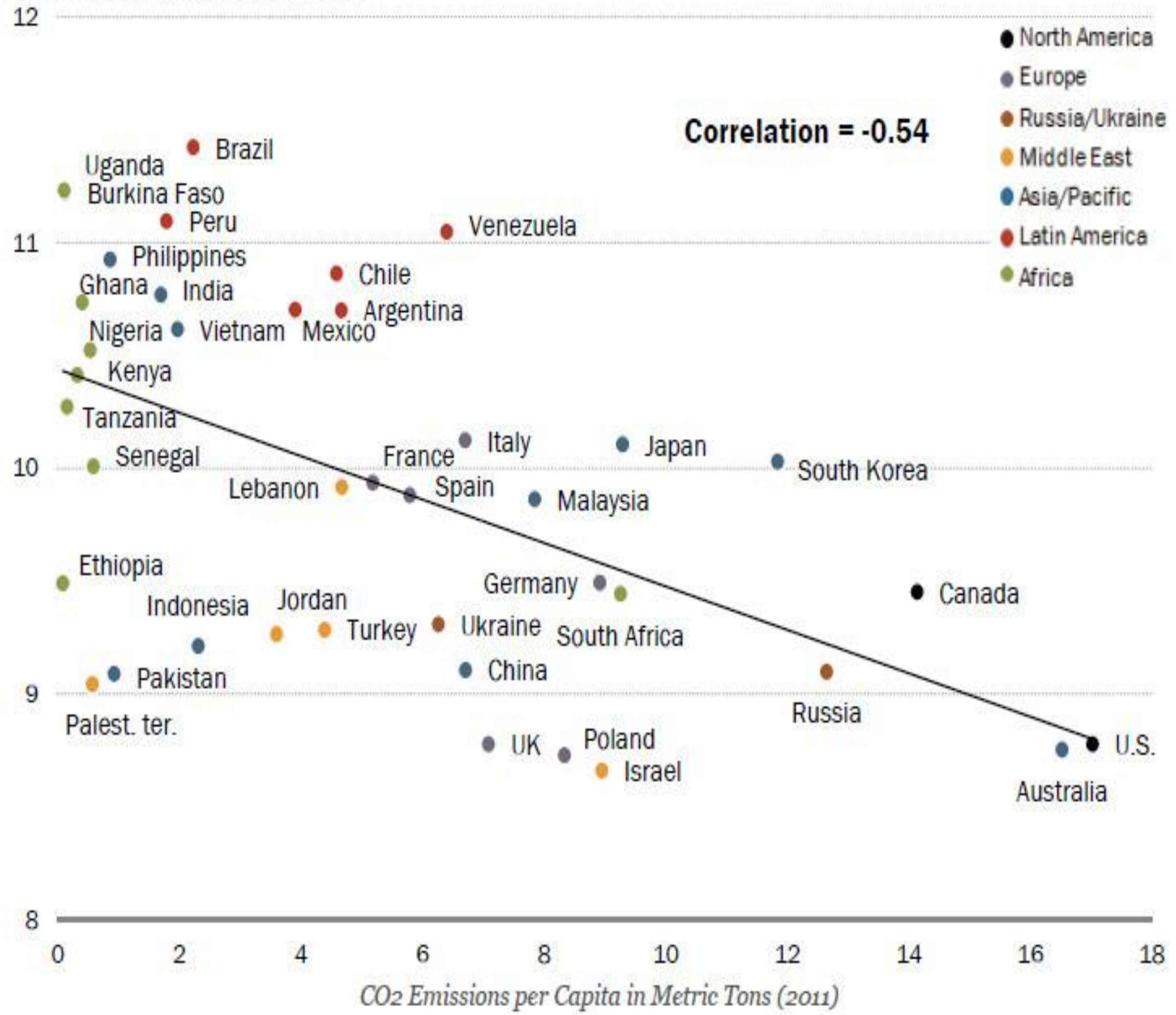
- Hundreds of scientists contribute. In their Purpose Statement…
- *"Authors for the IPCC reports are chosen from a list of researchers **prepared by governments** and **participating organizations (RN: like industry)**, and by the Working Group/Task Force Bureau, as well as other experts known through their published work. The choice of authors aims for a **range of views**, **expertise** and geographical representation, ensuring representation of experts from developing and developed countries and countries with economies in transition." (**source**)*

“Range of views”, “Consensus”…. Sounds seductively Progressive and Inclusive.

- But in practice, it puts veto power in the hands of the political representatives and fossil fuel industry representatives.
- They are agenda-driven, not truth-driven
- Most have no interest in learning from the scientists – and they play HARD BALL

High CO_2 Emitters Are Less Intensely Concerned about Climate Change

*Global climate change concern scale**



* Concern about global climate change is measured using a three-item index ranging from 3-12, with 12 representing the most concerned about climate change. Respondents were coded as 4 if they believe climate change is a very serious problem; if they think climate change is harming people now; and if they say they are very concerned that climate change will harm them personally at some point in their lifetime. The mean score for each country is used in this analysis. (See Appendix for more details.)

Source: Spring 2015 Global Attitudes survey. Q32, Q41 & Q42. Data for CO_2 emissions per capita from World Bank Data Bank, accessed August 5, 2015.

PEW RESEARCH CENTER

The highest CO2 emitting countries are the most politically motivated to minimize the perception of climate danger. The U.S. (even in pre-Trump 2015), is the worst

It Makes One Wonder…

- The Scientists' Seduction: *"Beautiful! The UN's IPCC will be our mechanism to inform policy makers that lead to Real World change!"*
- But was it instead a brilliant and nefarious mechanism to neuter and muffle the science, by insisting on political and industry veto power?
- Scientists' training: ill-equipped in this political arena.
- **In the end, the scientists were the ones who blinked.**

UK Climatologist Dr. Peter Cox, Commenting on the Paris COP21 and IPCC Scenarios…

- IPCC statement: *"Global Surface Temperature Change for the end of the 21st Century is likely to exceed +1.5C for all scenarios"*
- **Cox:** *"…but this is the understatement of the century!... and scientists are not allowed in the negotiations (at least not scientists like me, who might say something)…and I went there thinking 'we've got to TELL them; 1.5?? we're nowhere near +2, we're nearer +3C!'. And we all got side-tracked, as they put this shiney thing up (waving a key fob) '1.5 is over here, don't look at the 3, don't look at the 2'. There was an optimistic BUBBLE. But it needs to become…REAL."*

"A Document of Appeasement" – IPCC's Prof. David Wasdell (source)

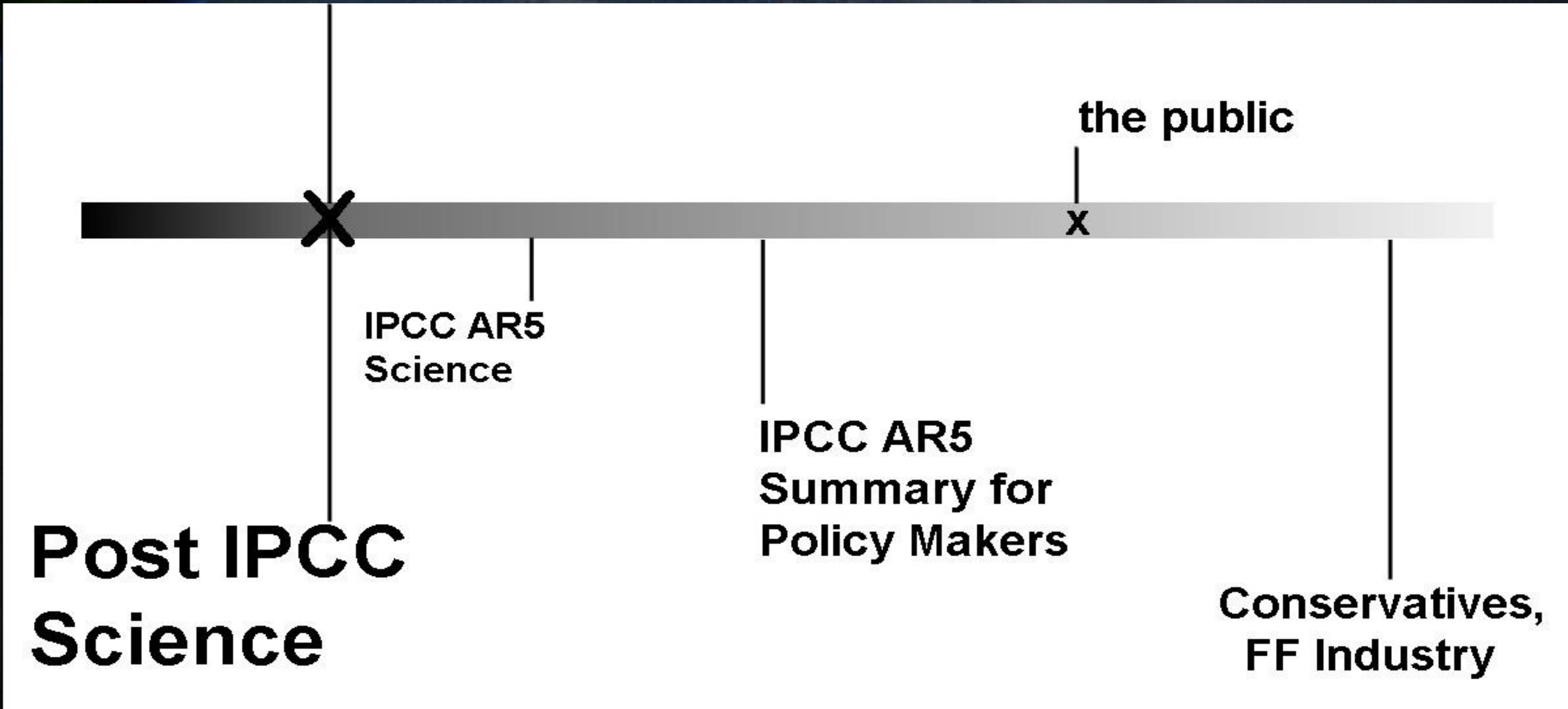
- *"Wasdell said that the draft submitted by scientists contained a metric projecting cumulative total anthropogenic carbon dioxide emissions, on the basis of which a 'carbon budget' was estimated – the quantity of carbon that could be safely emitted without breaking the 2 degrees Celsius limit to avoid dangerous global warming. He said that* ***the final version approved by governments significantly amended the original metric to increase the amount of carbon that could still be emitted. (and this is the version Policy people use)"***

The political manipulation of the science in the IPCC's summary report corroborated by other IPCC scientists

In a letter addressed to senior IPCC chairs dated 17th April, Prof Robert Stavins - a lead author for the ***IPCC's Working Group 3*** *focusing on climate mitigation - complained of his "frustration" that*

The government approval process "built political credibility by sacrificing scientific integrity."

The political forces at work to muzzle the communication of the dire nature of the actual science, have been extremely effective. "*The report further notes that although 'a fast emergency-scale transition to a post-fossil fuel world is absolutely necessary to address climate change…. yet this is excluded from consideration by policymakers because it is considered to be too disruptive.' And so the paper claims 'we have a policy failure of epic proportions.'" (source).* ***How Bright is our Future?***



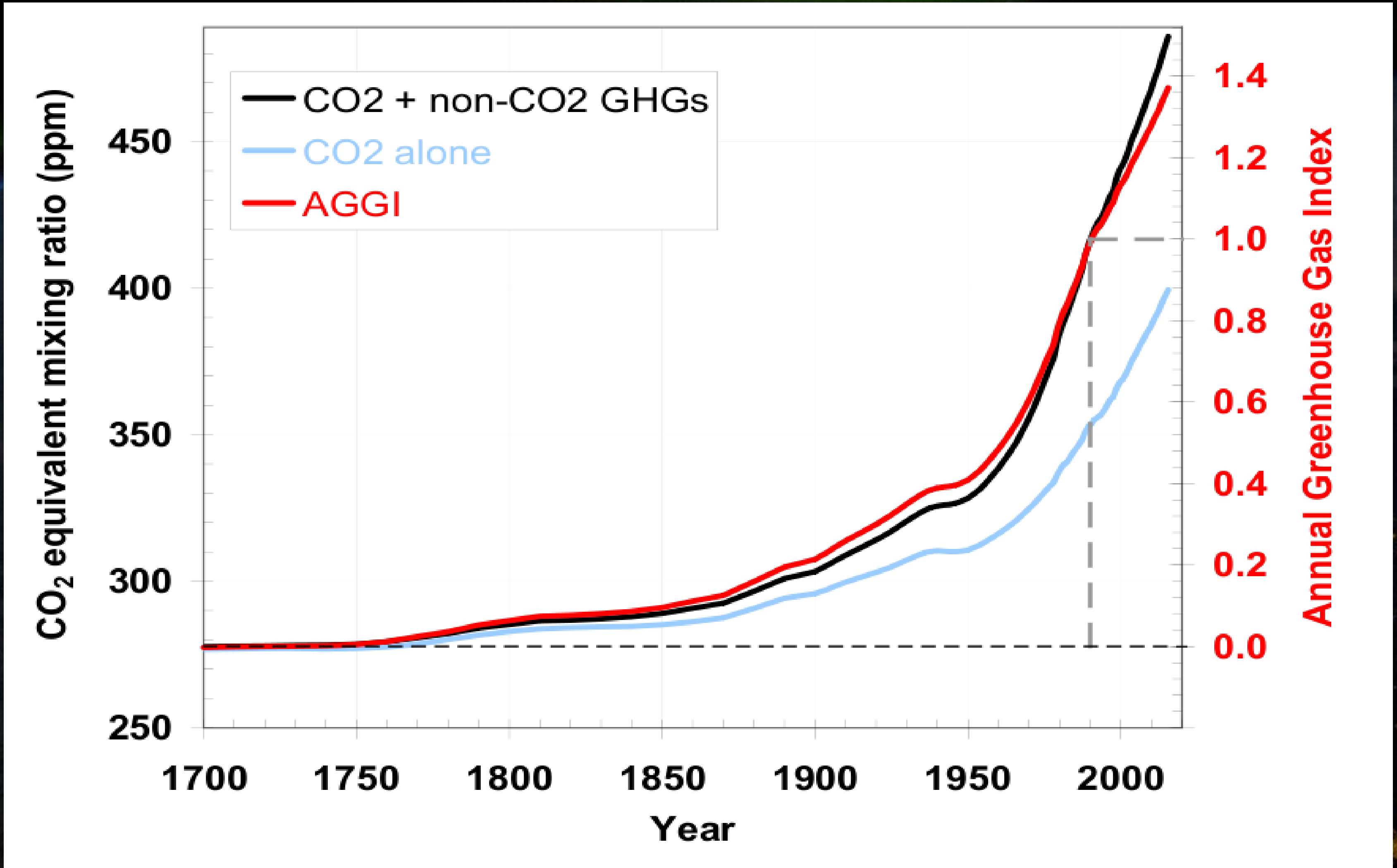
<u>SO, MY FIRST RECOMMENDATION</u>:

- The IPCC Scientists should DIVORCE themselves from the UN.
- Publish their assembled digestion of the science since the last Assessment Report, and a **Summary for Policymakers**, as is current practice.
- But written and worded ONLY by the scientists, and insist on <u>only 90-95% </u>consensus agreement to reach publication: do not let the few industry-installed "scientists" have veto power

The IPCC Carbon Budgets used so widely in the "white papers" and promotionals for techno-fixes – are just wrong.

- Not just political meddling - the climate models are missing too many key climate drivers and amplifying feedbacks, as IPCC scientists readily acknowledge.
- While largely innocent in cause (lack of full understanding of these processes and the expense/inability of running high resolution climate models with them), it is nevertheless unfortunate that this missing physics wasn't highlighted better, or simple (CPU cheap) reasonable guess formulae included to estimate resulting effects.

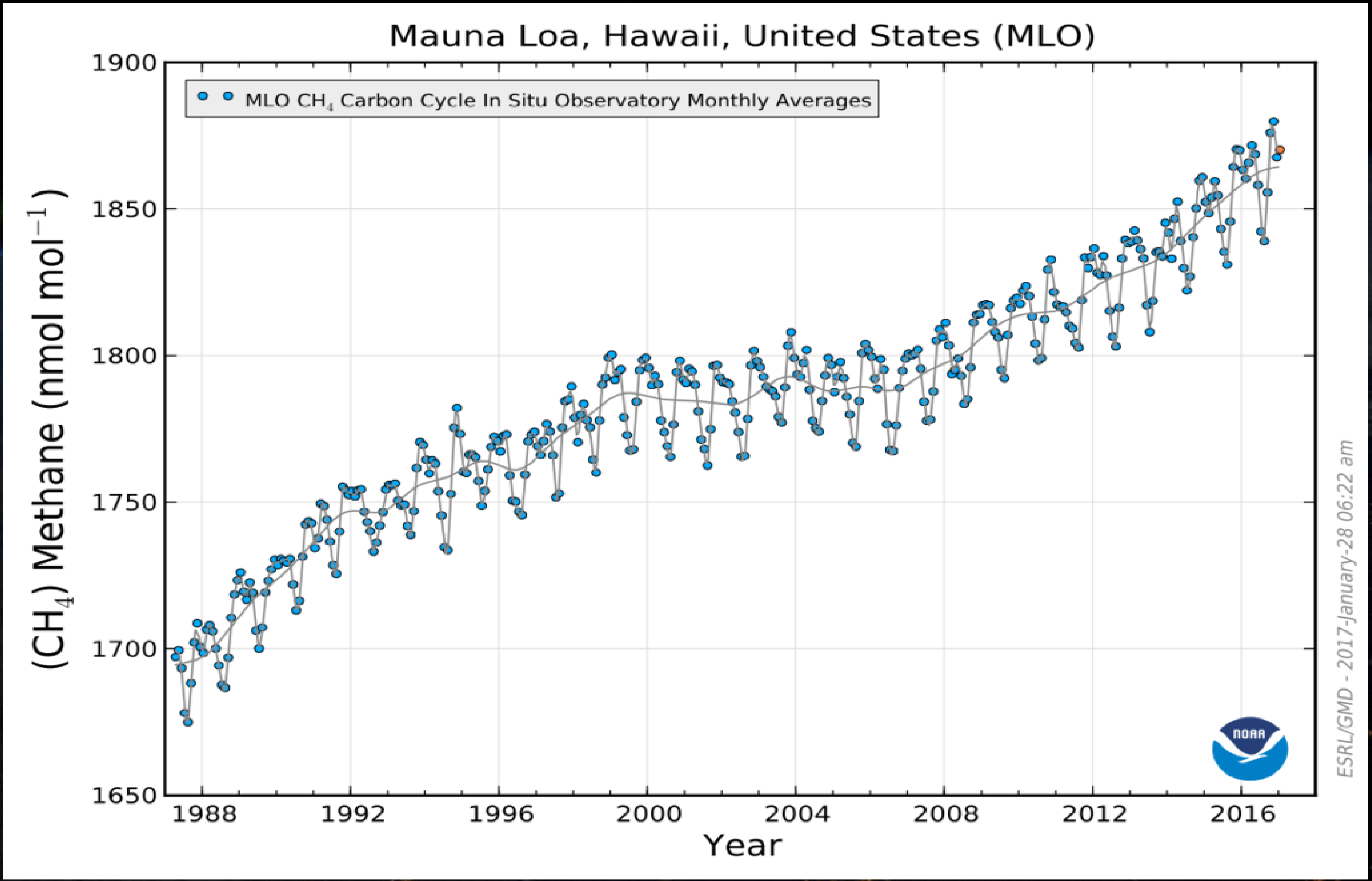
IPCC Models assumed quick elimination of: methane, ozone, CFC's, HFC's, N_x0 from agriculture, and others. So, only CO2 included. Yet The total CO2 equivalent: CO2e = 500 ppm, <u>not</u> CO2's 410 ppm



The Argument was that These Short-Lived GHG's would be Banned and Decay Away within Decades

- But will they?
- Methane: Will increase from permafrost thaw, and wetlands rise with 44:1 temperature amplifier. Methane emissions will not stop.
- Banning cattle? Politically impossible.
- HFC's (hydro-fluorocarbons)? - these replaced CFC's (chloro-fluorocarbons) as refrigerants after the ozone hole discovery and the Montreal Accords of 1989 banning CFC's...

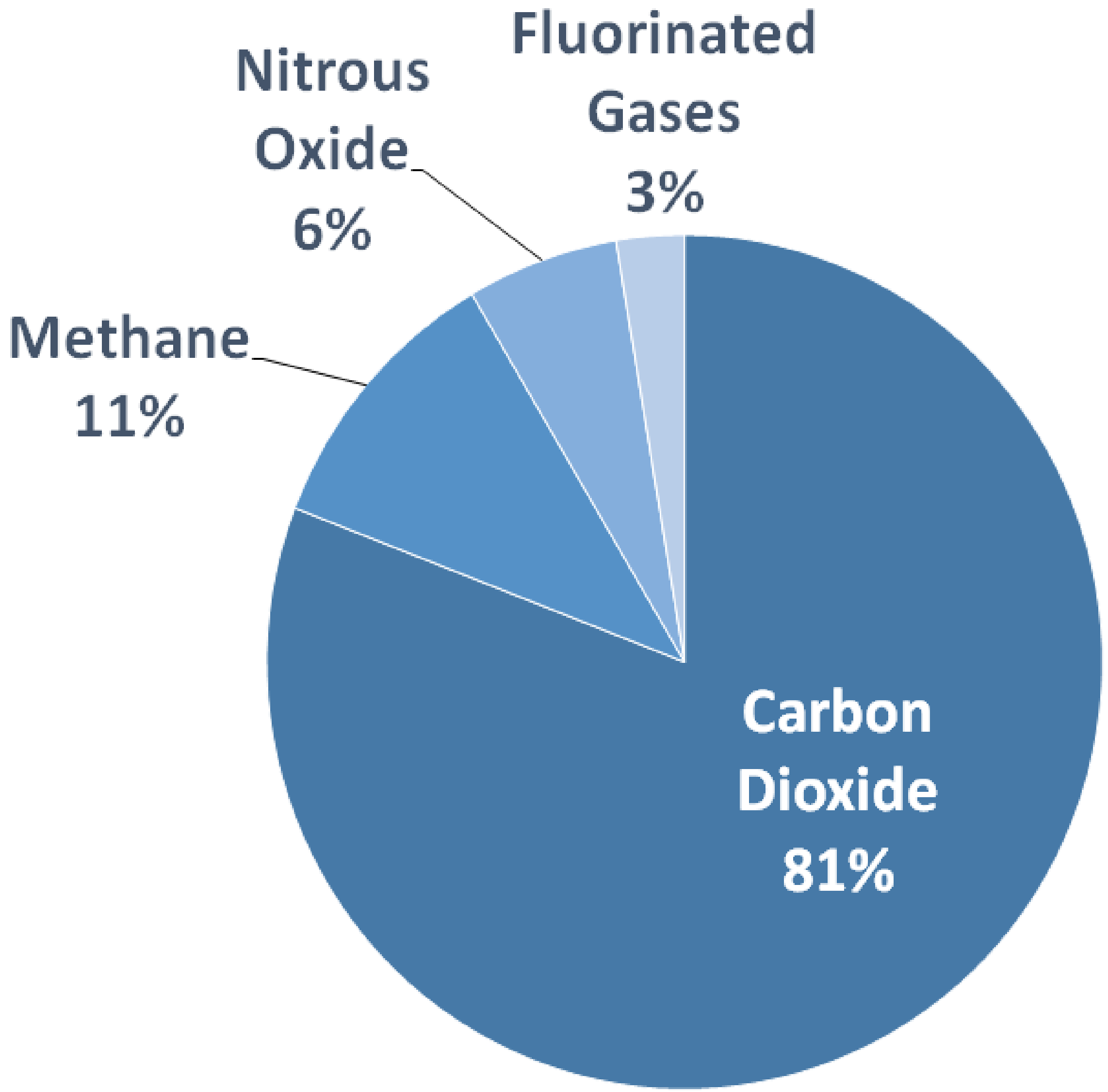
Emissions are Overwhelming Natural Oxidation; Methane Levels are Accelerating



As Just One Example – Agreement to Eliminate most HydroFluoroCarbon Refrigerants (HFC’s)

- Here’s some of policy people’s hype: ***“the single most important step that the world can take to limit global warming.”****,* and **from Sec of State John Kerry - *a “monumental step forward”***
- **Is it?** Consider: *“Between 2020 and 2050, 80 billion tons of CO2 equivalent, comparable to the emissions of nearly 500 million cars, will be prevented from entering the atmosphere thanks to a progressive reduction of HFCs.”* (from ClimateHome)
- Hype or hope?

U.S. Greenhouse Gas Emissions in 2014



Yet - HFC's "flourinated gases") are only ~3% of U.S. GHG emissions (in CO2 equivalent measures

So, Is this Agreement Significant? Not Really

- Even assuming we halt global growth in CO2 emissions, so for these next 30 years 2020 - 2050 it remains at 38 billion tons of CO2/year, and accepting for the moment the 70 billion ton CO2e value on the prior slide…
- Then, if there is no cheating (a problem for HFC and CFC's) **…The agreement (80 billion tons) amounts to less than 6% reduction of CO2 equivalent emissions**, and doesn't affect emissions from the other non-CO2 GHG's like N_2O and methane, and human-triggered natural GHG's from the melting permafrost and tropical wetlands.
- But wait: <u>we're certainly **not** going to end refrigeration</u> from Civilization, so what will replace these HFC's?

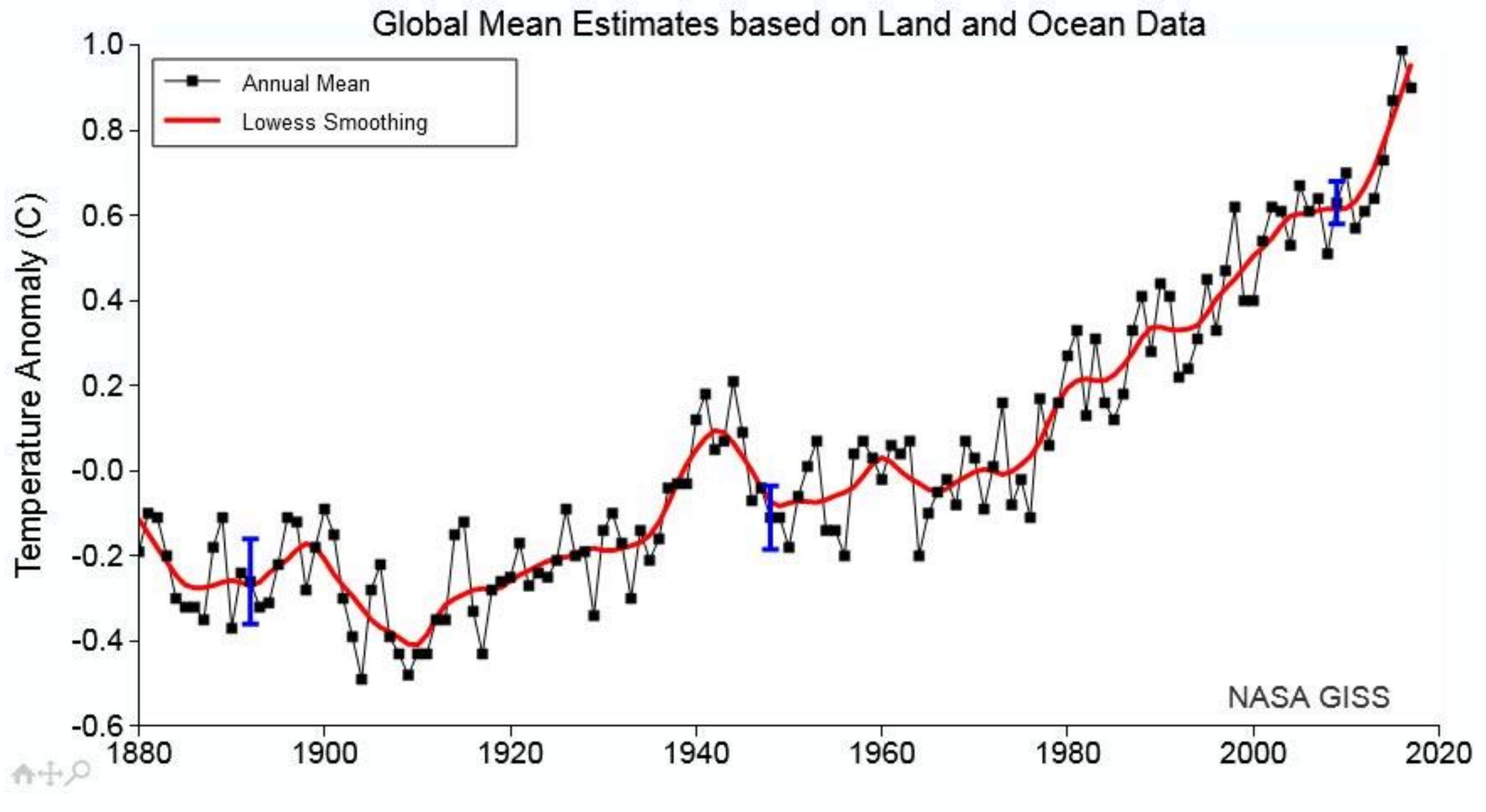
There is No Mention of the Required <u>Rise</u> in Alternative Refrigerants

- Remember that <u>**ALL molecules except symmetric diatomic molecules (mainly N_2, O_2) are greenhouse gases**</u>. Even simple ones like the older refrigerant ammonia.
- Replacing current HFC refrigerants with the optimum lower GWP (global warming potential) alternatives, results in a reduction in net CO2 equivalent emissions by refrigerants of only about 1/3 (<u>**Beshr *et al.* May 2017**</u>). Said another way, **that wedge which is HFC's will still be 2/3 as large as it is now, once they are all replaced by their best-judged equivalent safer refrigerants.**
- <u>**And therefore, the REAL savings in total CO2e from the HFC ban agreement is not 6%, but less than 2%. And that assumes no cheating (which CFC's still suffer from, despite the 1989 Montreal Accords)**</u>

If We Reduce or Even Eliminate our GHG Emissions, Will that Solve the Climate Problem?

NO

<u>No</u>?? But, Look, Rick! We're Only at +1C. And +2C is the Safe Limit… Right? So We have Time! …Right?



Land-ocean temperature index, 1880 to present, with base period 1951-1980. The solid black line is the global annual mean and the solid red line is the five-year lowess smooth. The blue uncertainty bars (95% confidence limit) account only for incomplete spatial sampling. [This is an update of Fig. 9a in Hansen et al. (2010).]

No. Wrong on Several Counts…

First, notice the chosen zero point baseline year for this NASA/GISS data (which <u>is</u> good data): the <u>1951-1980</u> Average. That's NOT "Pre-Industrial". 1880-1910 avg has been conventional "Pre-Industrial" for many years.

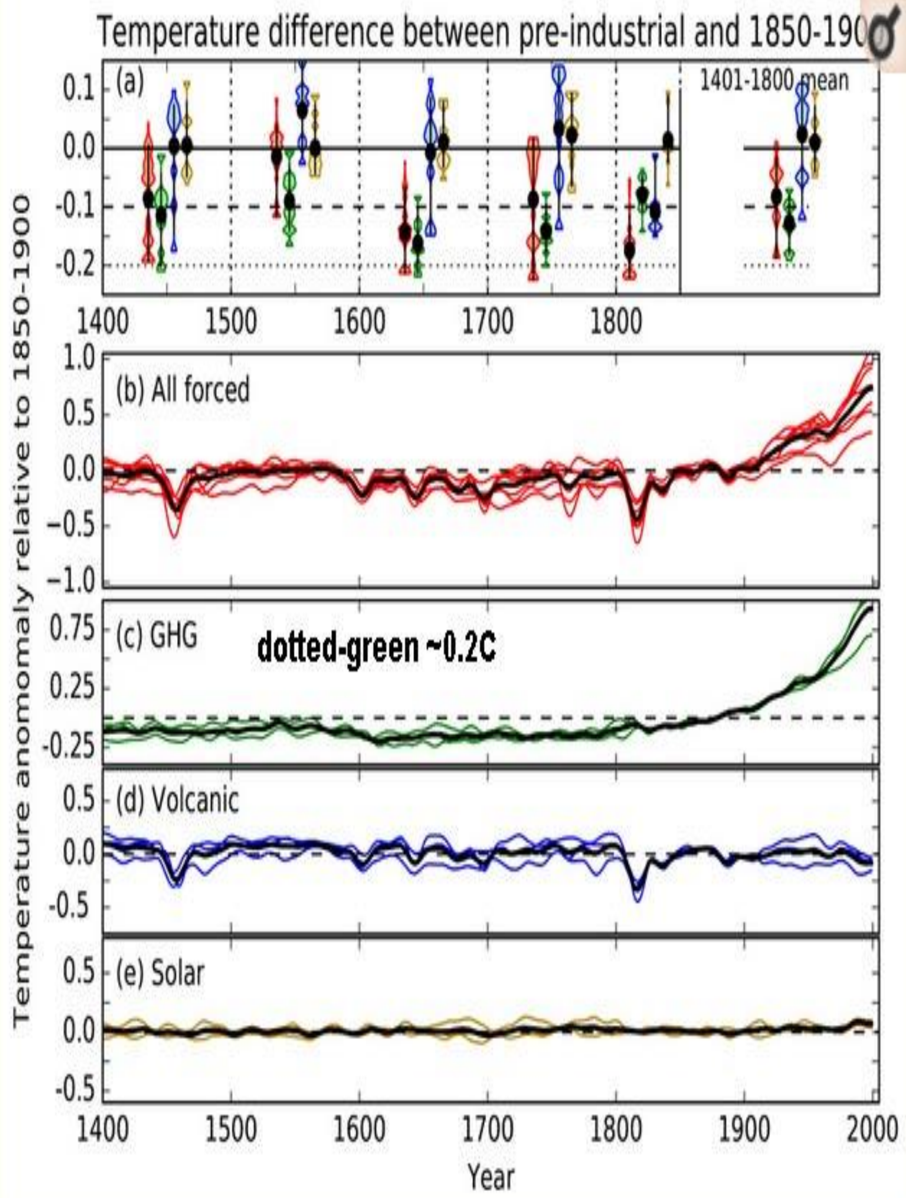
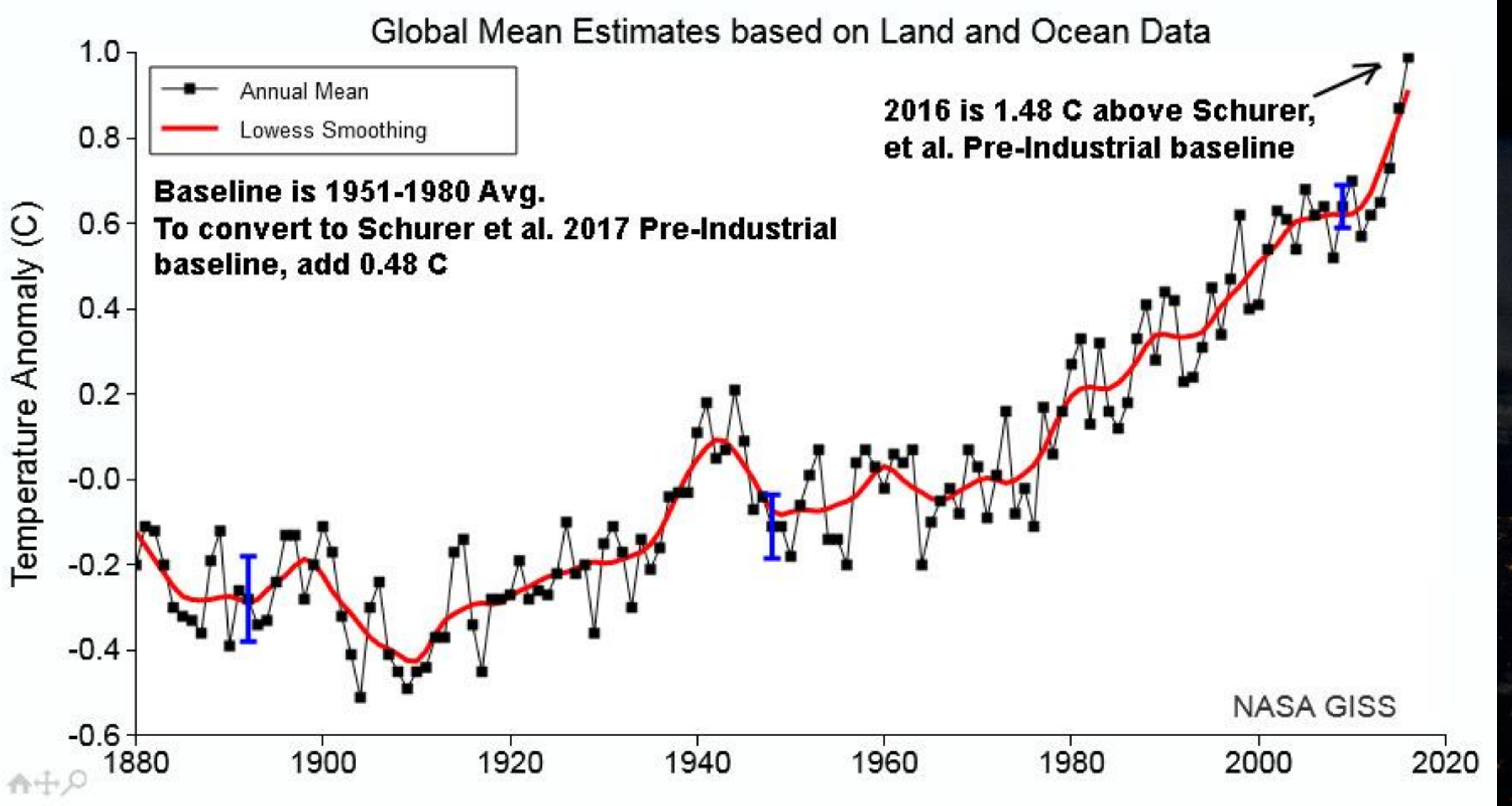


Fig 2

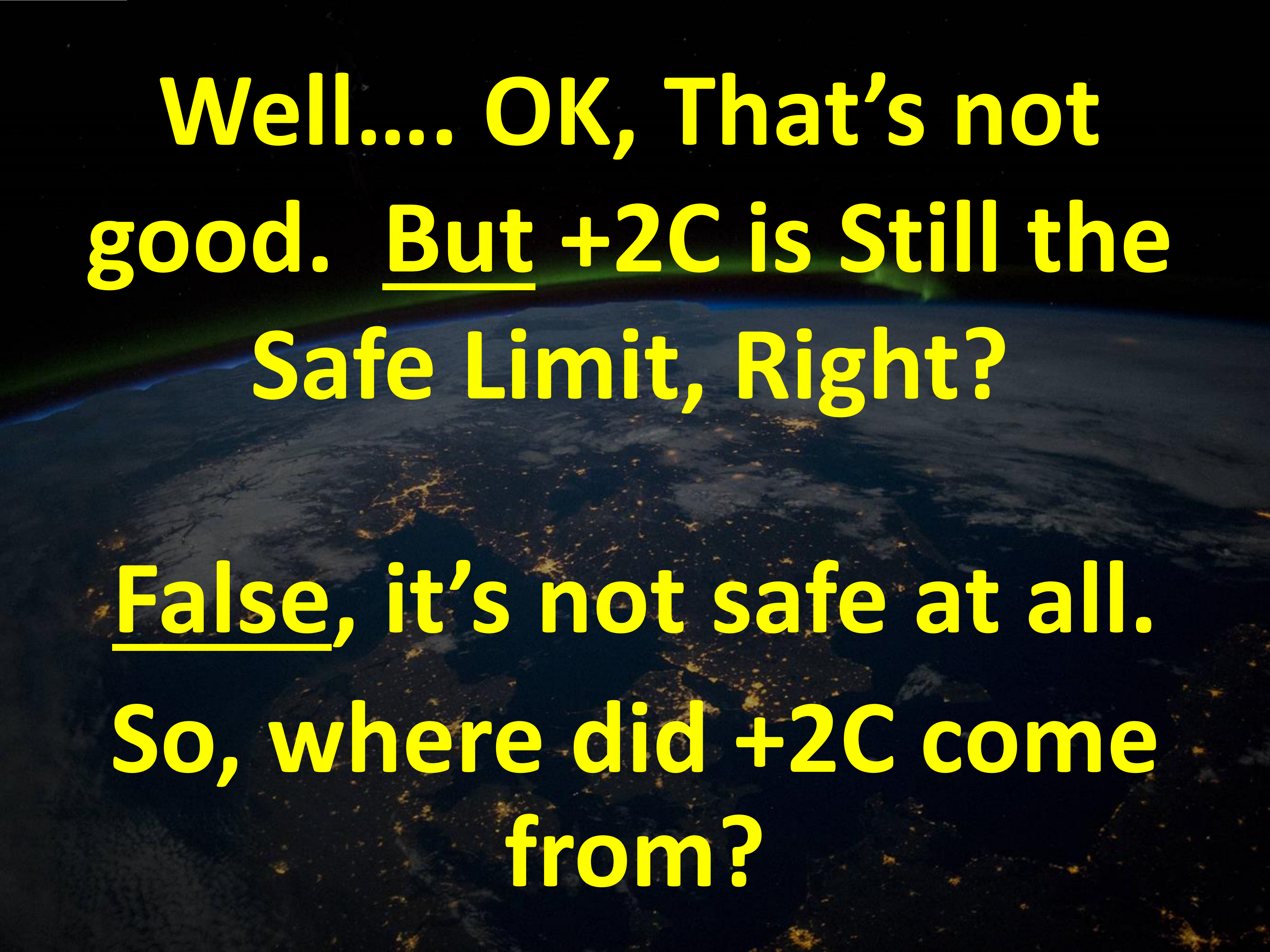
Model simulated difference in global mean temperature between different pre-industrial periods and 1850-1900.

But **even that baseline's too high: Left -** The last 600 years of climate forcing. GHG baseline (green) is **another 0.20C** below the 1880-1910 (dashed line) conventional "Pre-Industrial" baseline, (**Schurer, Mann *et al.* 2017**), **and therefore:**

Our ACTUAL temperature in 2016 = +1.48C. At close of 2017, +1.40C using Red Smoothed Curve… This makes a mockery of the COP21 Paris climate promises



Land-ocean temperature index, 1880 to present, with base period 1951-1980. The solid black line is the global annual mean and the solid red line is the five-year lowess smooth. The blue uncertainty bars (95% confidence limit) account only for incomplete spatial sampling. [This is an update of Fig. 9a in Hansen et al. (2010).]

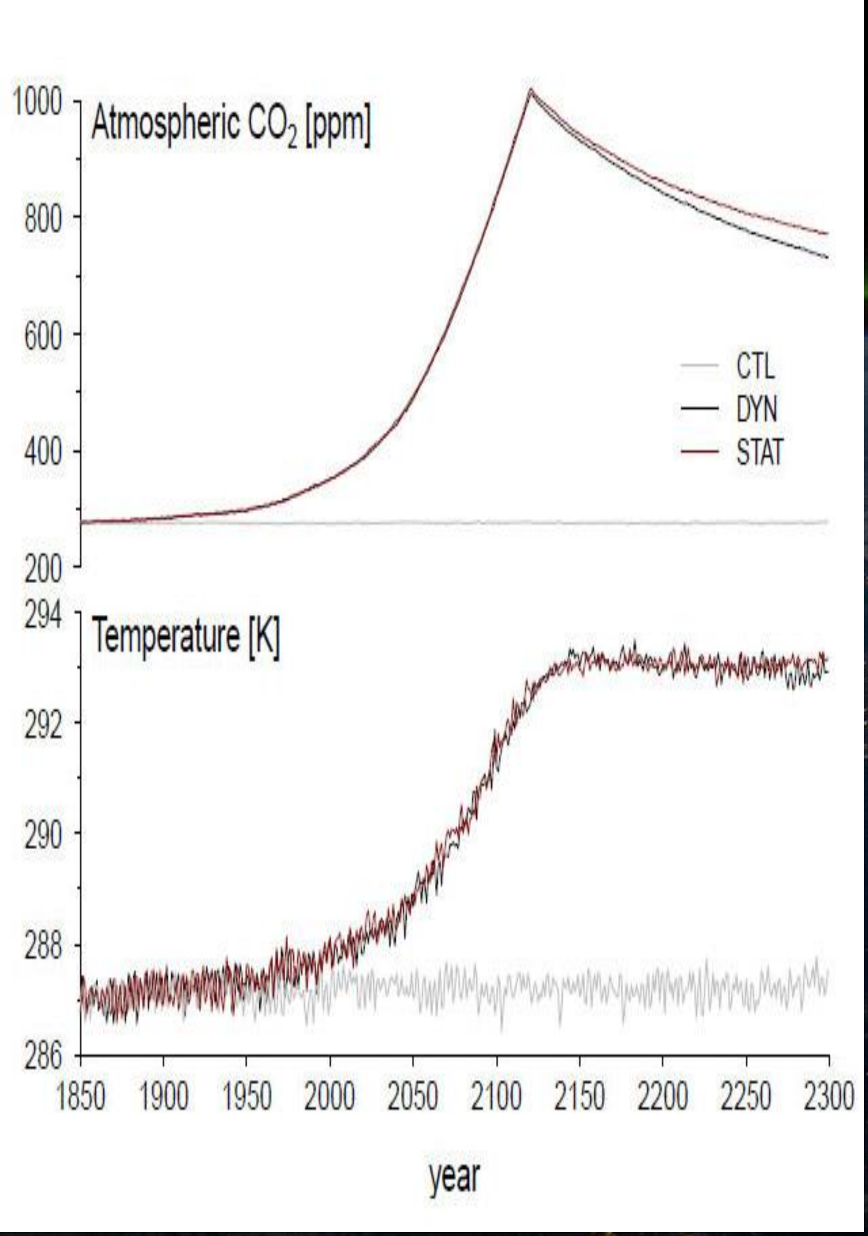

Well…. OK, That's not good. But +2C is Still the Safe Limit, Right?
False, it's not safe at all.
So, where did +2C come from?

An Economist’s Decision

- *“In his 1975 paper **Can We Control Carbon Dioxide?**, William Nordhaus ‘thinks out loud’ as to what a reasonable limit on CO2 might be. He believed it would be reasonable to keep climatic variations within the ‘normal range of climatic variation’. He also asserted that science alone cannot set a limit; importantly, it must account for both society’s values and available technologies. He concluded that a reasonable upper limit would be the temperature increase one would observe from a doubling of preindustrial CO2 levels, which he believed equated to a temperature increase of about 2C.” (**source**)*
- **Yes. A deeply flawed 43 year old paper… By pro-growth economist!**
- **Dr. James Hansen has shown that (his words) “+2C is a Prescription for Disaster”. Worse, as we’ll see later, a doubling of CO2 will yield a temperature more like +4.5C or higher:**

But Still, Rick – If we simply STOP hurting the Earth, the Earth will heal, won't it?

- **NO.**
- **This is a Key Fact that most of the Public fail to appreciate (media never mentions)**
  - If we STOP emitting ALL GHG's, even stop the **indirect** GHG's we're now triggering, therefore doing better even than a totally renewable-powered world, even then **Temperatures will still NOT go back down.**
- **~EVER.**



Not Even in the The Older, Happier Models (Solomon *et al.* 2009 , Mathews and Weaver 2010, etc.), with NO Indirect anthropogenic GHG's

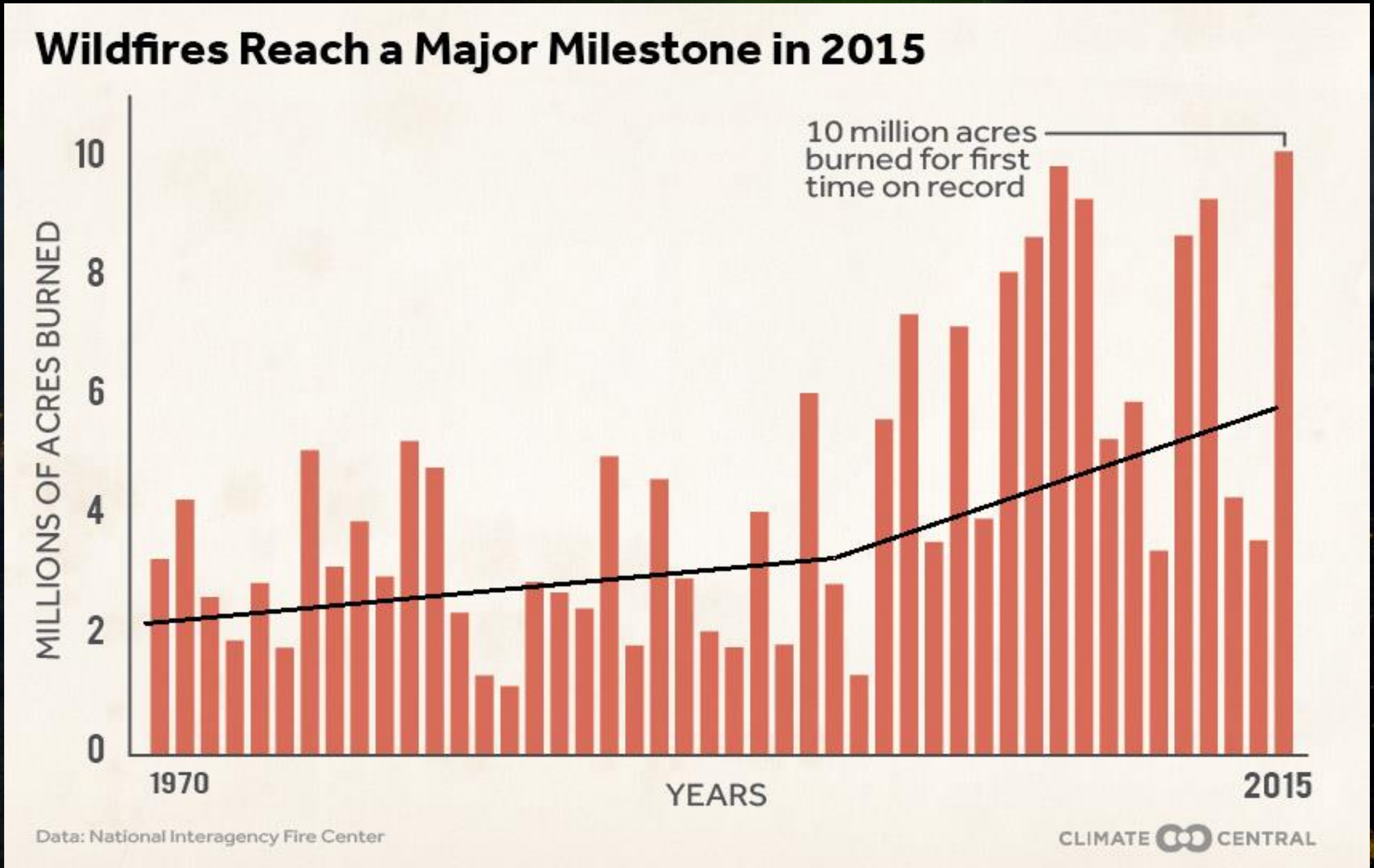
Still, ending ALL direct anthro-GHG's only succeeds in keeping temperature constant, not declining.
Why? 0.58W/m^2 radiative imbalance, and the ocean (with 700x thermal capacitance and 93% of our GHG-induced heat) gives heat right back to the cooling atmosphere.

Beyond Temperature Baseline Shennanigans…

More Serious, is the Missing Physics from the IPCC Modelling…

The Lastest IPCC AR5 Report was in 2013. Note the Dates on The Research to Come…

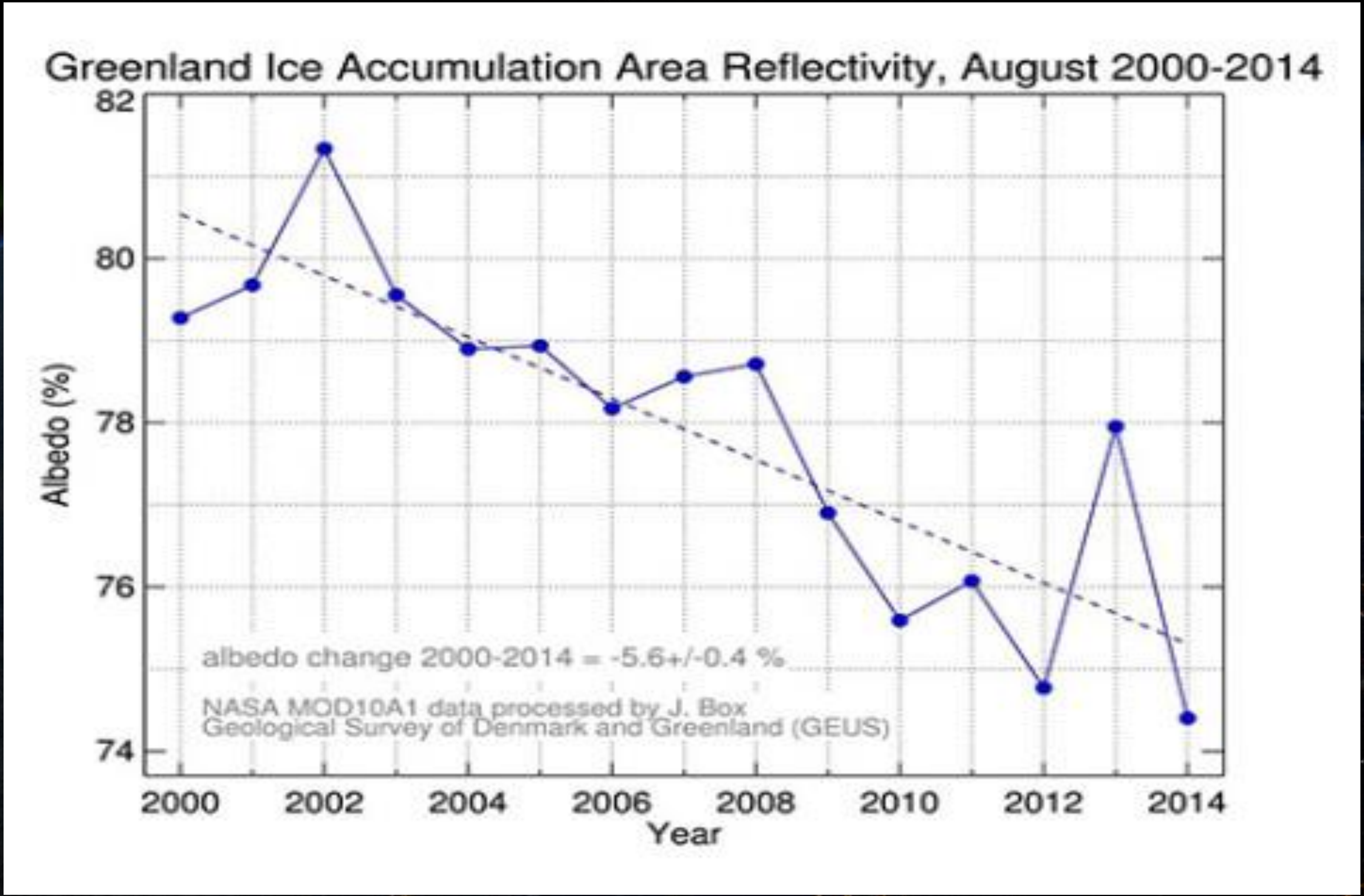
<u>IPCC Models Do Not Include</u>: Increasing wildfires and their smoke (80+% are human-caused: <u>Balch *et al.* 2016</u>)



IPCC Models Do Not Include: Ice surface meltwater generates algae and other microbe colonies which further darken the ice, absorbing more sunlight

Yes, that's Summer Greenland Ice.

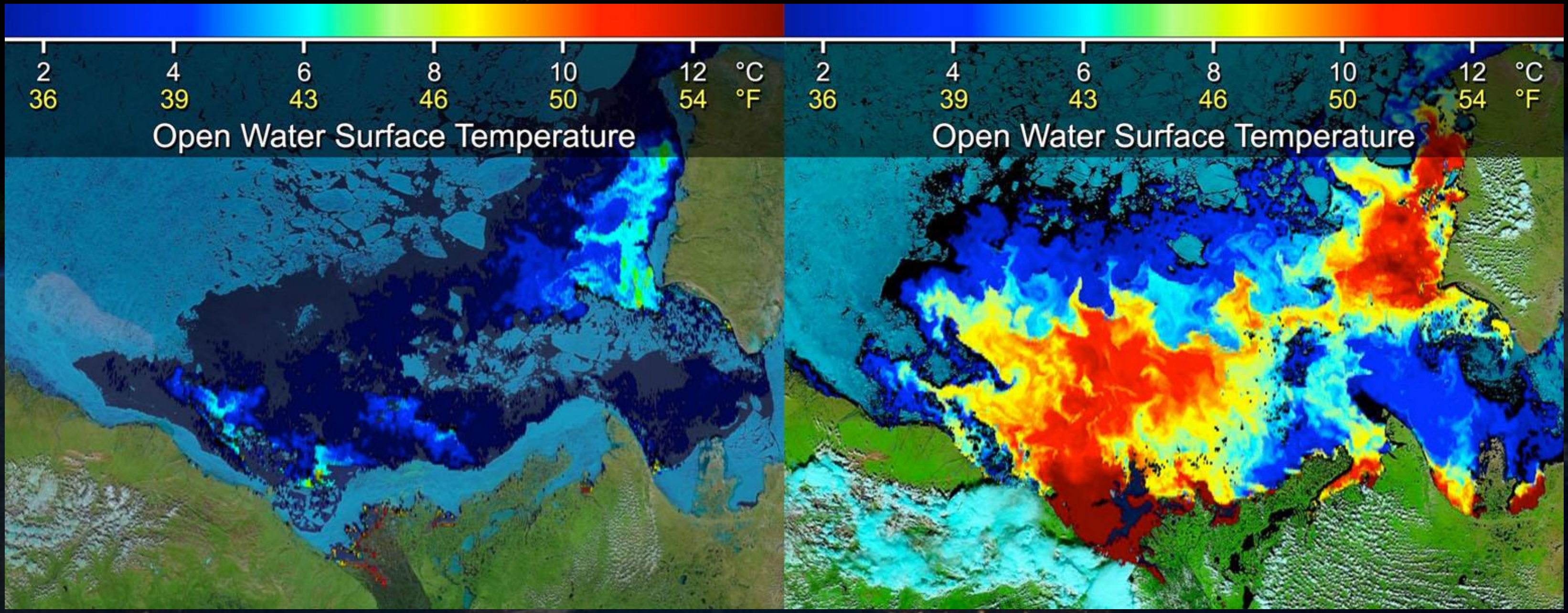
<u>And So: IPCC Models Don't Include</u> Summer Albedo (reflectivity) dropping in Greenland



<u>IPCC Models Do Not Include</u>:

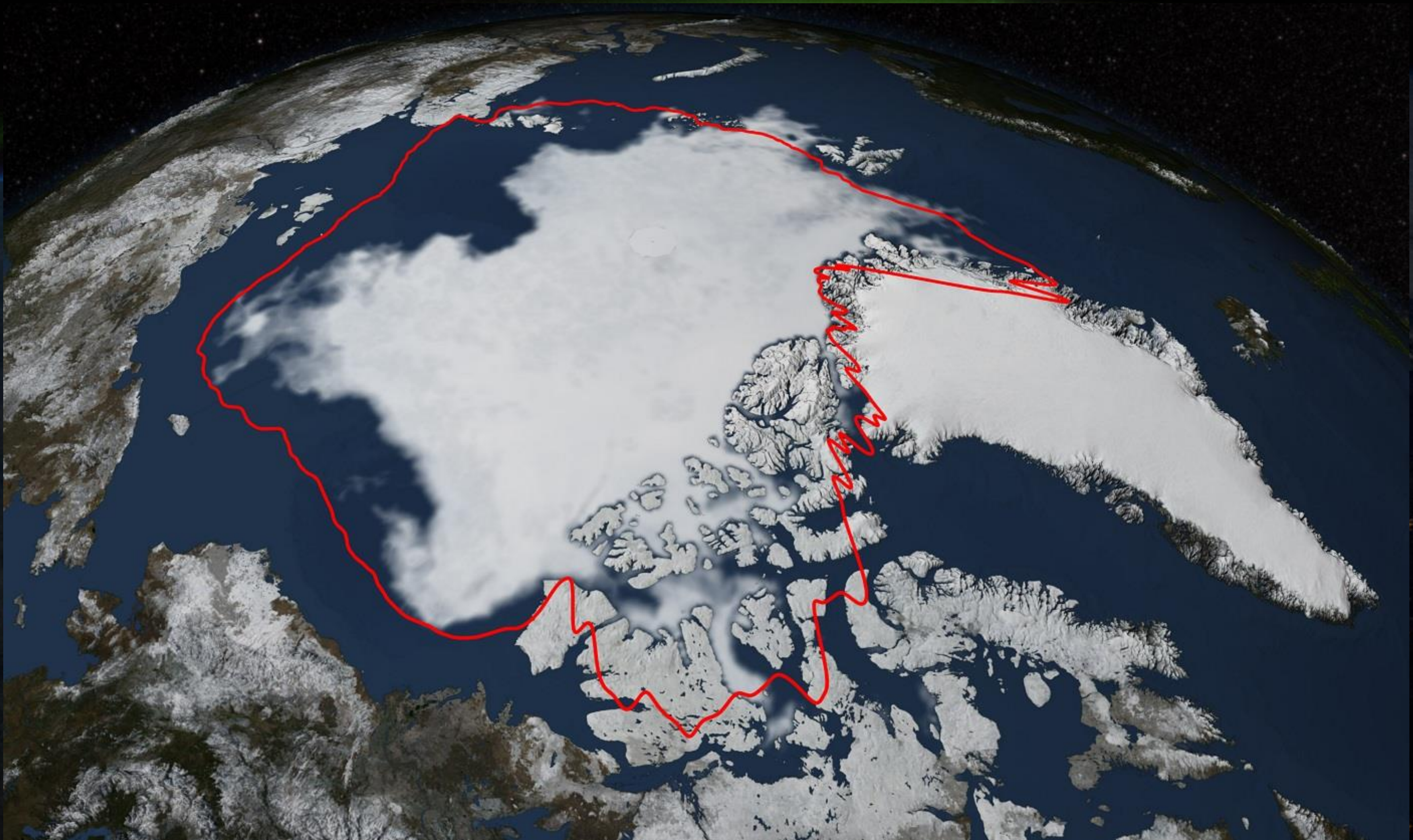
Surface melt on Greenland generating rivers of water causing <u>hydro-fracturing</u>, driving heavier water through lighter ice, generating moulins – taking water miles deep, softening the base of the ice sheet accelerating glacier

IPCC Models do not include: The large heat influx from warm river water into the Arctic Ocean (Ngheim *et al.* 2014, described here

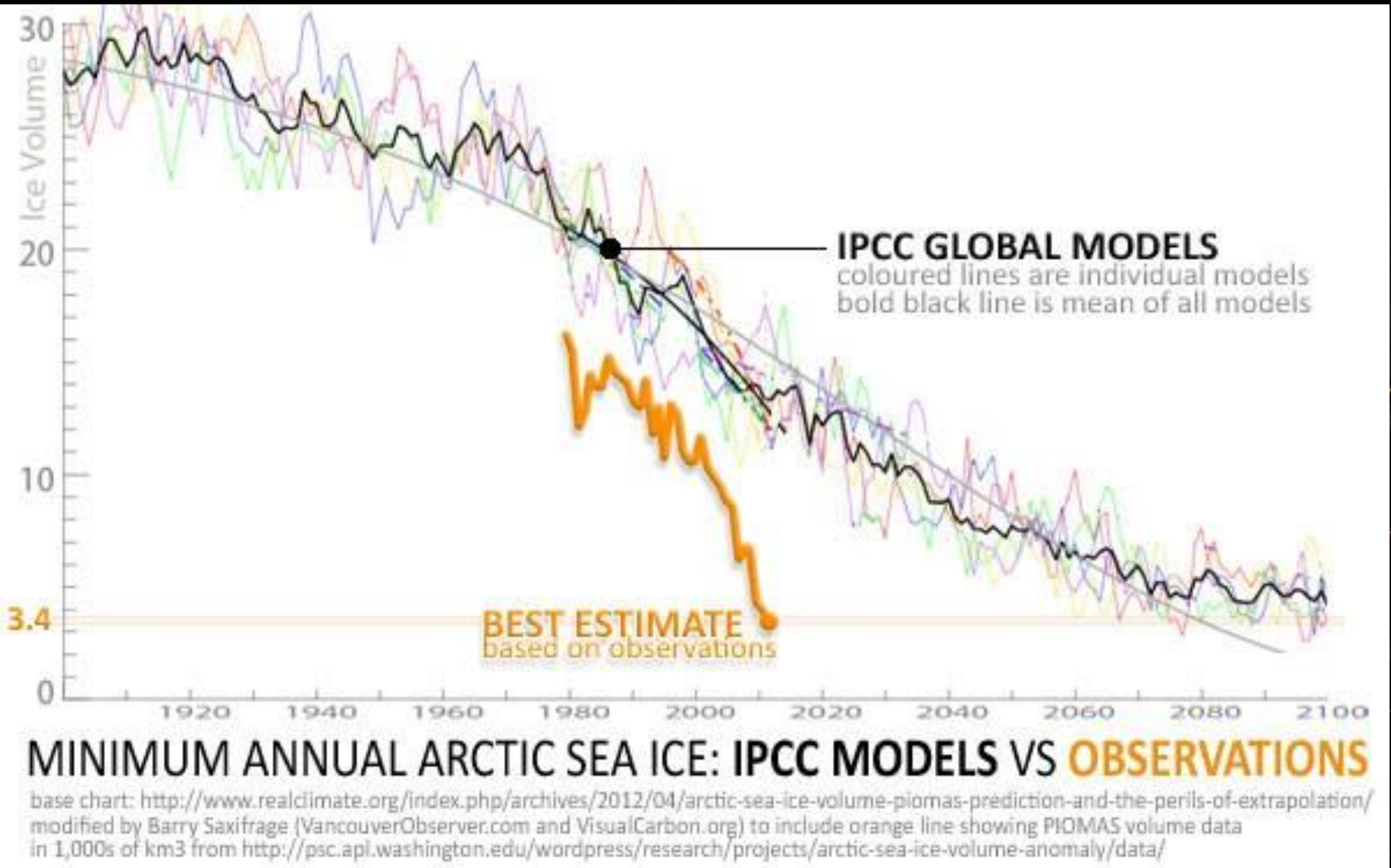


The Arctic Ocean, with warm water (reds and yellows) from the MacKenzie River in Canada Scientists saw an increase of 11.7 degrees Fahrenheit **(+6.5 degrees Celsius)** in the surface temperature of the open water, which enhanced sea ice melt.

IPCC Models Do Not Include: Non-linear breakup of thinning Arctic sea ice, driven by wind and waves as more open water wind fetch appears, and subsequent iceberg drift south past Greenland.

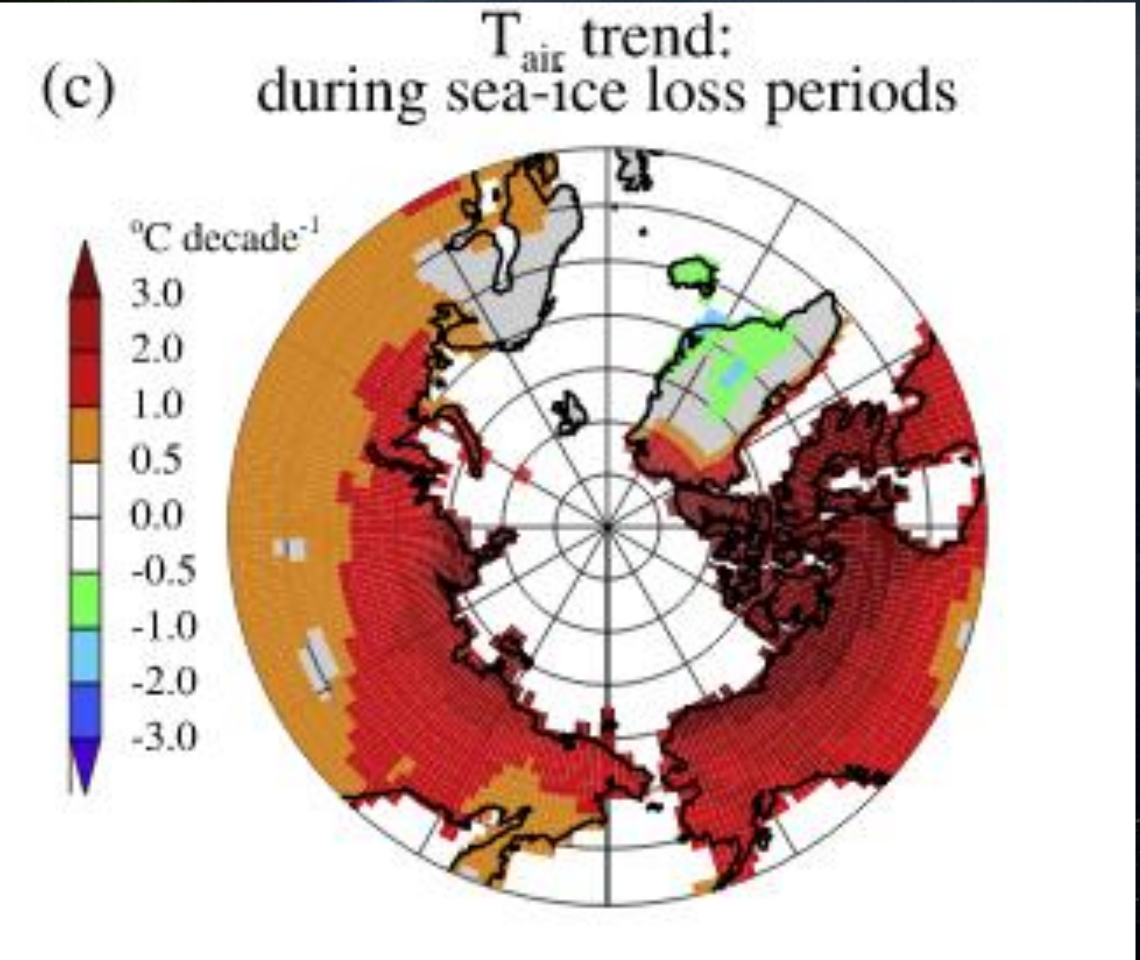


ALL of these contribute to the dramatic under-estimation of sea ice loss. Implications? …



<u>This Loss of the Arctic Ocean's Ice</u> …sends a pulse of heat 1500 km south of the Arctic shorelines (<u>Lawrence *et al.* 2008</u>), <u>across the Permafrost</u>.

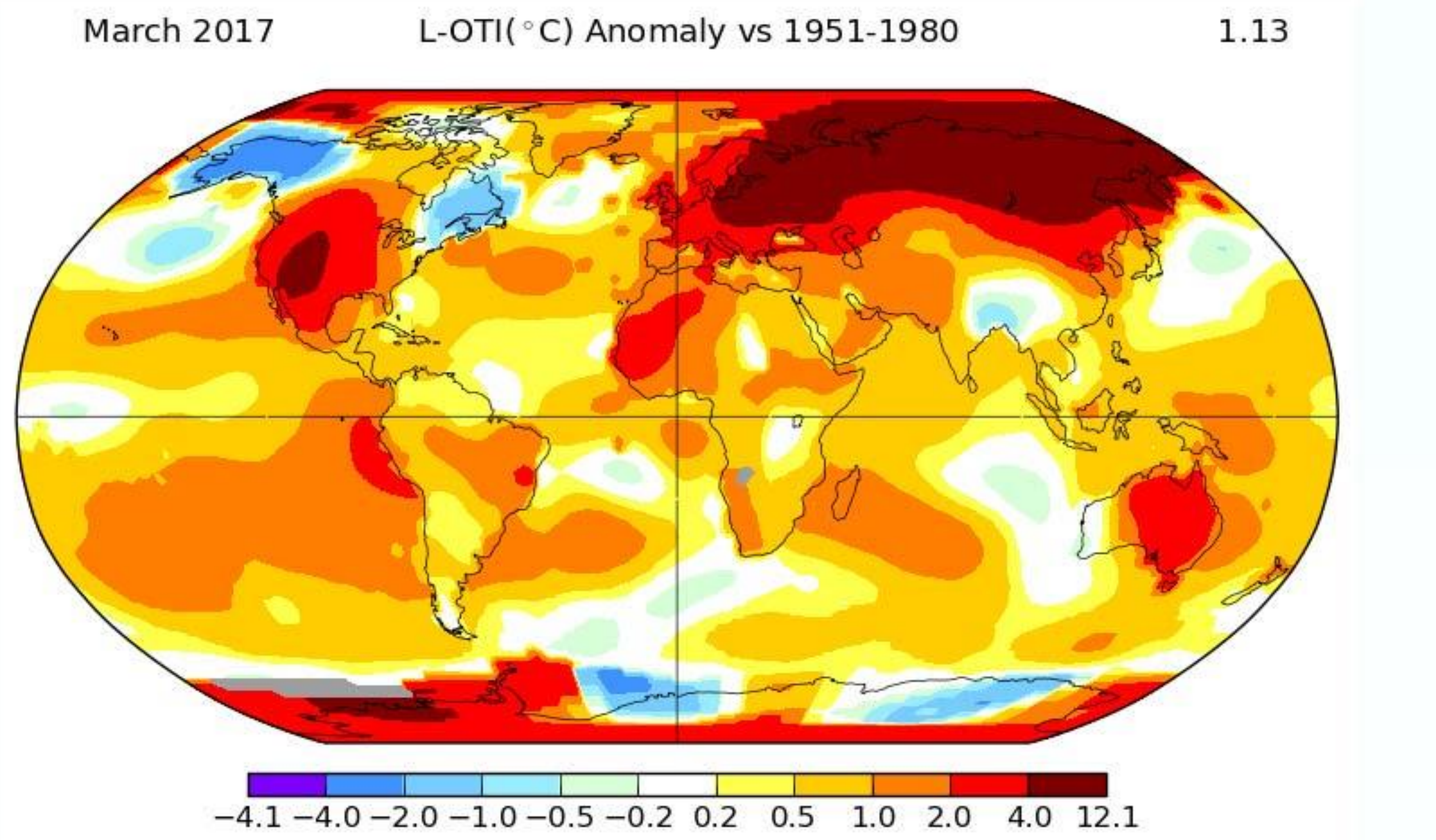
Below: temperature trend map. Hot in Siberia, but even hotter in North America. So if Siberia melts, North America will as well, and likely sooner



Vaks *et al.* 2013, showed from Paleo data that the tipping point for the melt of ~all Siberian permafrost (and therefore all global permafrost), occurs at +1.5C above pre-industrial temperatures

- From the paper's conclusion section: *"Warming of ~1.5°C (i.e., as in MIS-11) causes a substantial thaw of continuous permafrost as far north as 60°N…(near the Arctic coastline) Such warming …can potentially lead to* ***substantial release of carbon trapped in the permafrost into the atmosphere****."* (see **interview on YouTube**)

<u>So How Close Are We to +1.5C...?</u> As we just saw – we're at +1.4C, with another ~0.4C "committed, in the pipeline" and inevitable, regardless of how impossibly drastic you imagine our response might be, due to physics inertia.

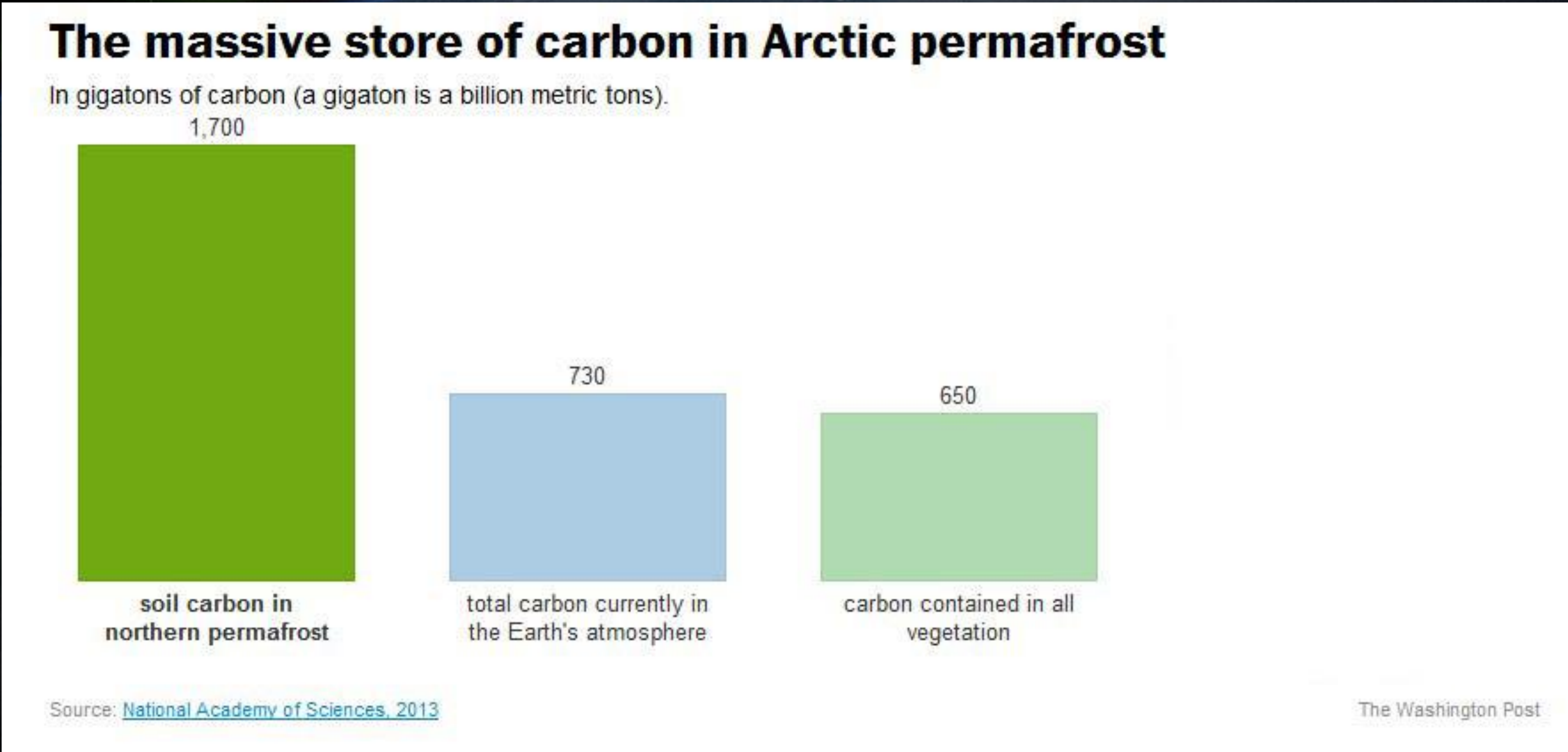


Indeed, the Permafrost is Now Melting

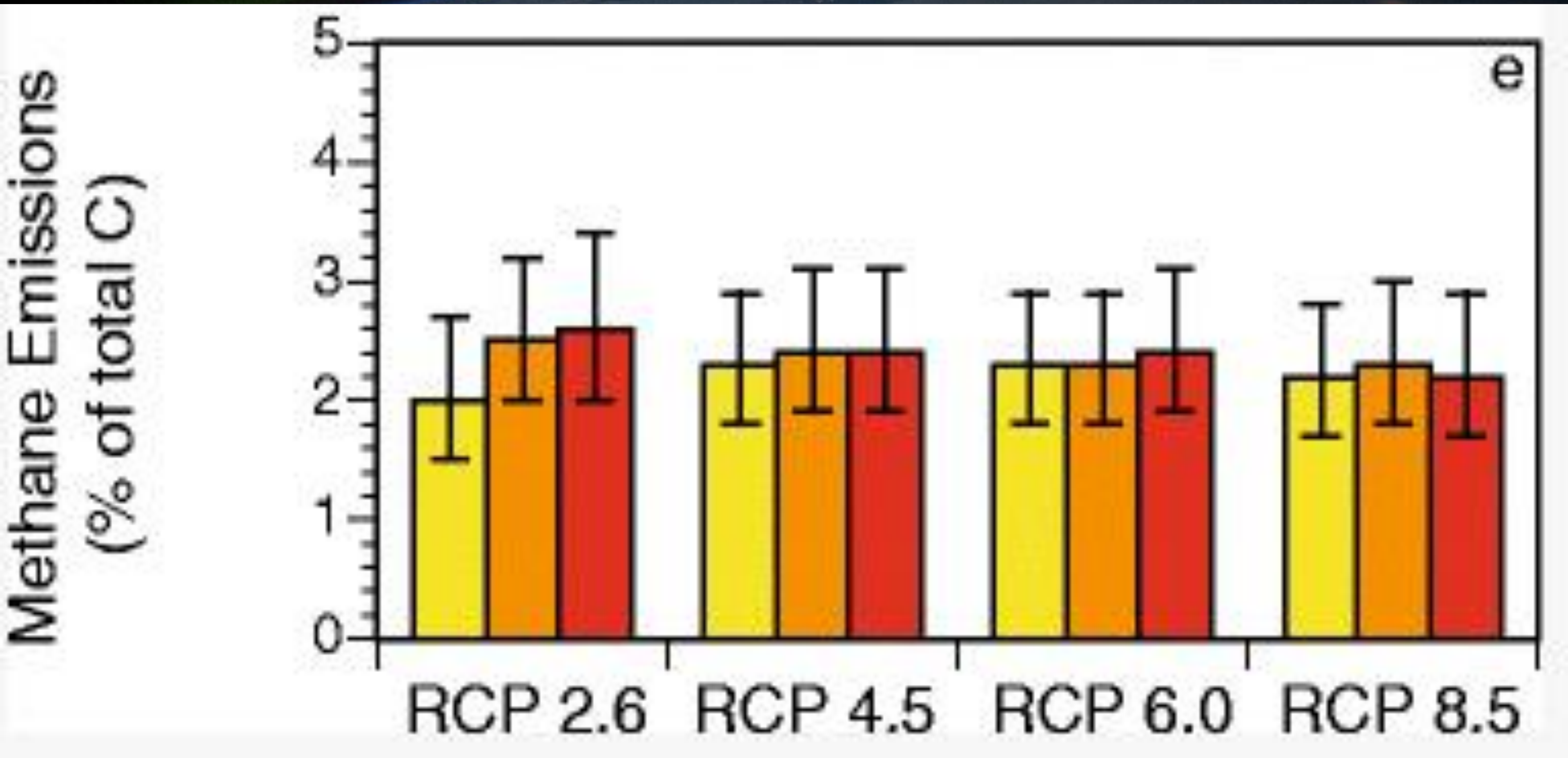
Is the Carbon Release in Thawing Permafrost Incorporated into the IPCC Assessment Reports and Projections?

- **No.**
- *"The concept is actually relatively new,"* says Dr. **Kevin Schaefer** of the **National Snow and Ice Data Center** at the University of Colorado in Boulder. *"It was first proposed in 2005. And the first estimates came out in 2011. Indeed, the problem is so new that it has not yet made its way into major climate projections",* Schaefer says.
- **It is not in even the latest IPCC AR5 report projections, with the rosy carbon budgets**

Could this be significant? Yes! There's more carbon in the permafrost than in the entire atmosphere plus all of Earth's vegetation… combined



Consensus from permafrost experts: 2.3% of emerging carbon will be in the form of methane (Schuur *et al.* 2013, review paper) - regardless of human emission scenario. (bar colors are for years 2040, 2100, 2300). That will DOUBLE the Greenhouse Forcing of the remaining 97.7% as CO2



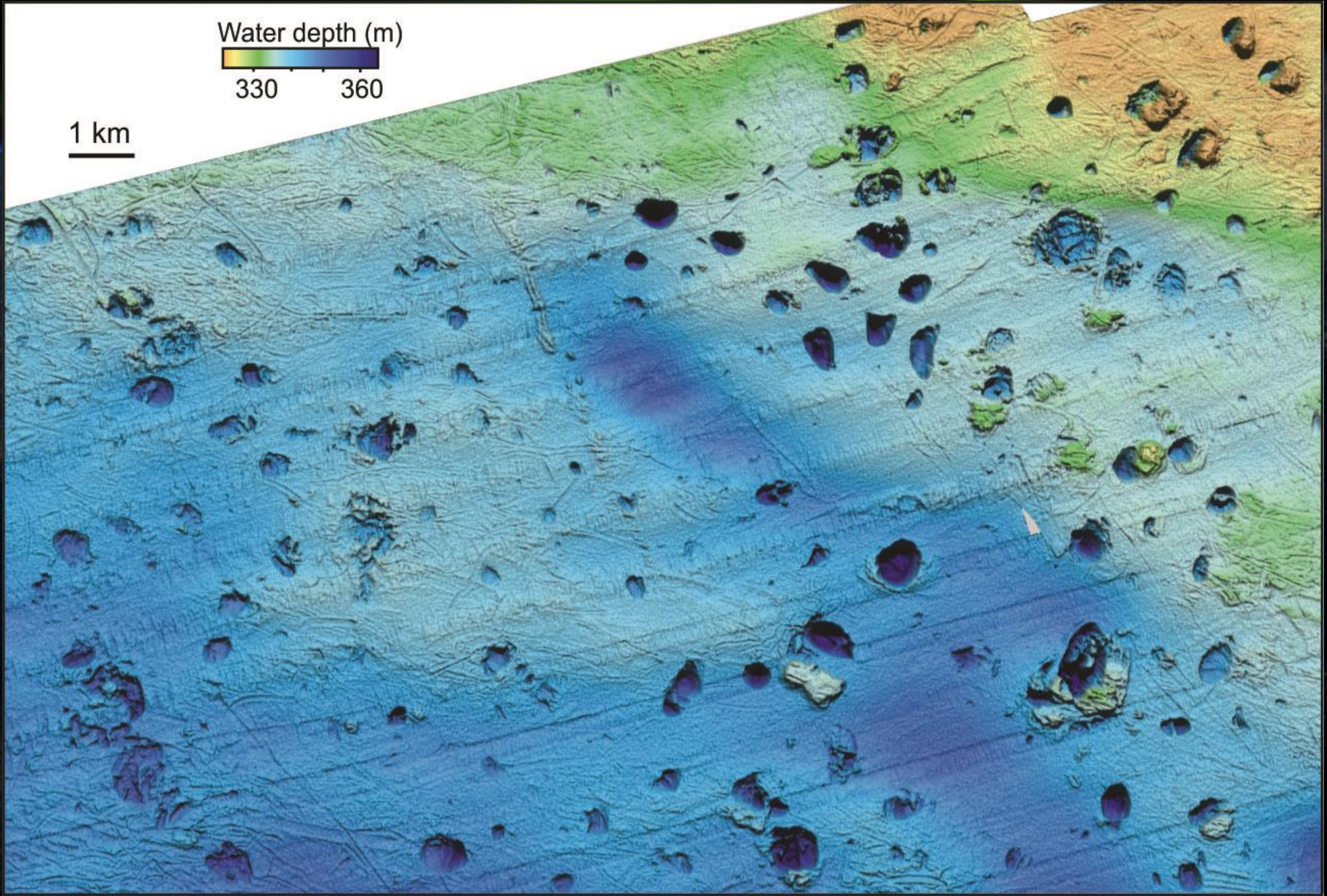
<u>IPCC Models Do Not Include:</u> Pingos melting and filling with deep methane, then exploding and leaving large craters. While it would take many many thousands of such craters to be a significant force in global climate…

… more are being discovered all the time

New in 2017, scientists are discovering…

- …Over **7,000 new domes filled with methane** *(link above)*, in the Yamal and Gydan Peninsulas of Siberia alone

Methane Hydrate Explosion Craters up to 1 km across. Hundreds, off Svaalbard. Age=12,000 yrs. Could similar happen soon in West Antarctica and Greenland as overlying ice melts?



Methane Hydrate Instability?

- These "clathrates" require pressures found only at ~350m depth and deeper, beyond the depth of the Arctic Ocean depth in most places.
- And conduction to that depth in sediments is extremely slow…
- Therefore, danger of catastrophic release is thought now to be small. Slow and rising methane release is likely, however.

The IPCC Models Also Assumed the Sensitivity of Climate to CO2…

- …defined as **ECS "Equilibrium Climate Sensitivity",** was a constant +3C of global temperature rise per CO2 doubling in the atmosphere.
- In an idealized world driven only by CO2 and linearly coupled GHG's (*e.g.* water vapor), that's not a bad number.
- And averaged over both glacial and interglacial periods, it's also not a bad estimate.
- **But it's not the real world of today, and the future, with CO2 far above all past interglacial warm periods, and new feedbacks kicking in with strong forcing**.

~All Post-IPCC studies find HIGHER ECS in HOTTER climate states (within each color dot set, there is upward slope). This is NOT in the IPCC projections. (from review paper: von der Heydt *et al.* 2016). Arguably the best study is the most recent…. (next slide)

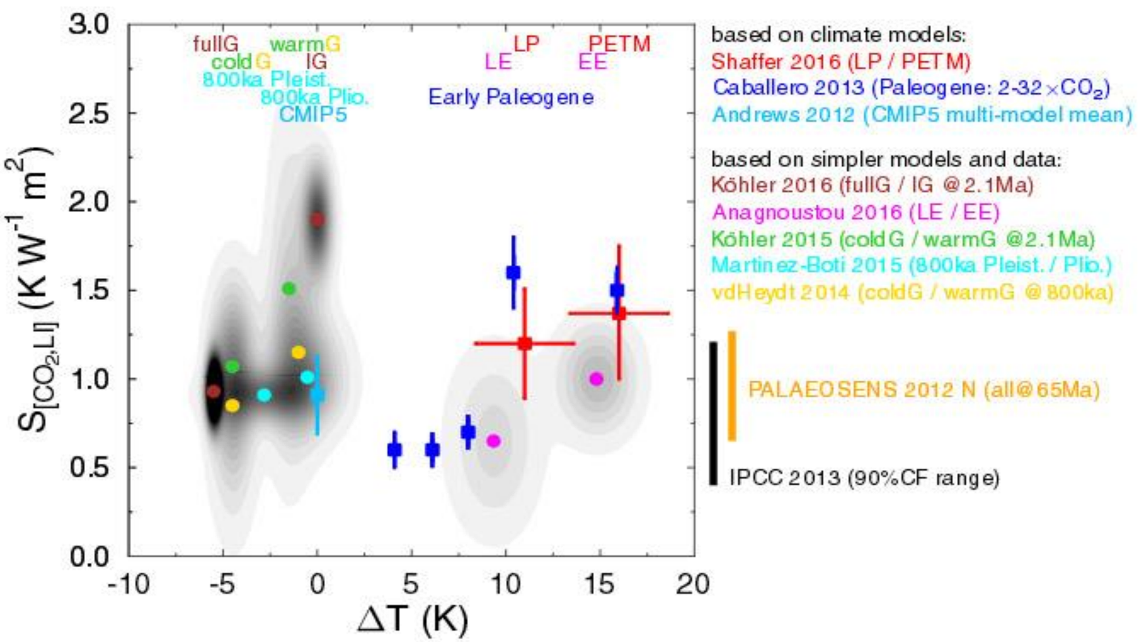
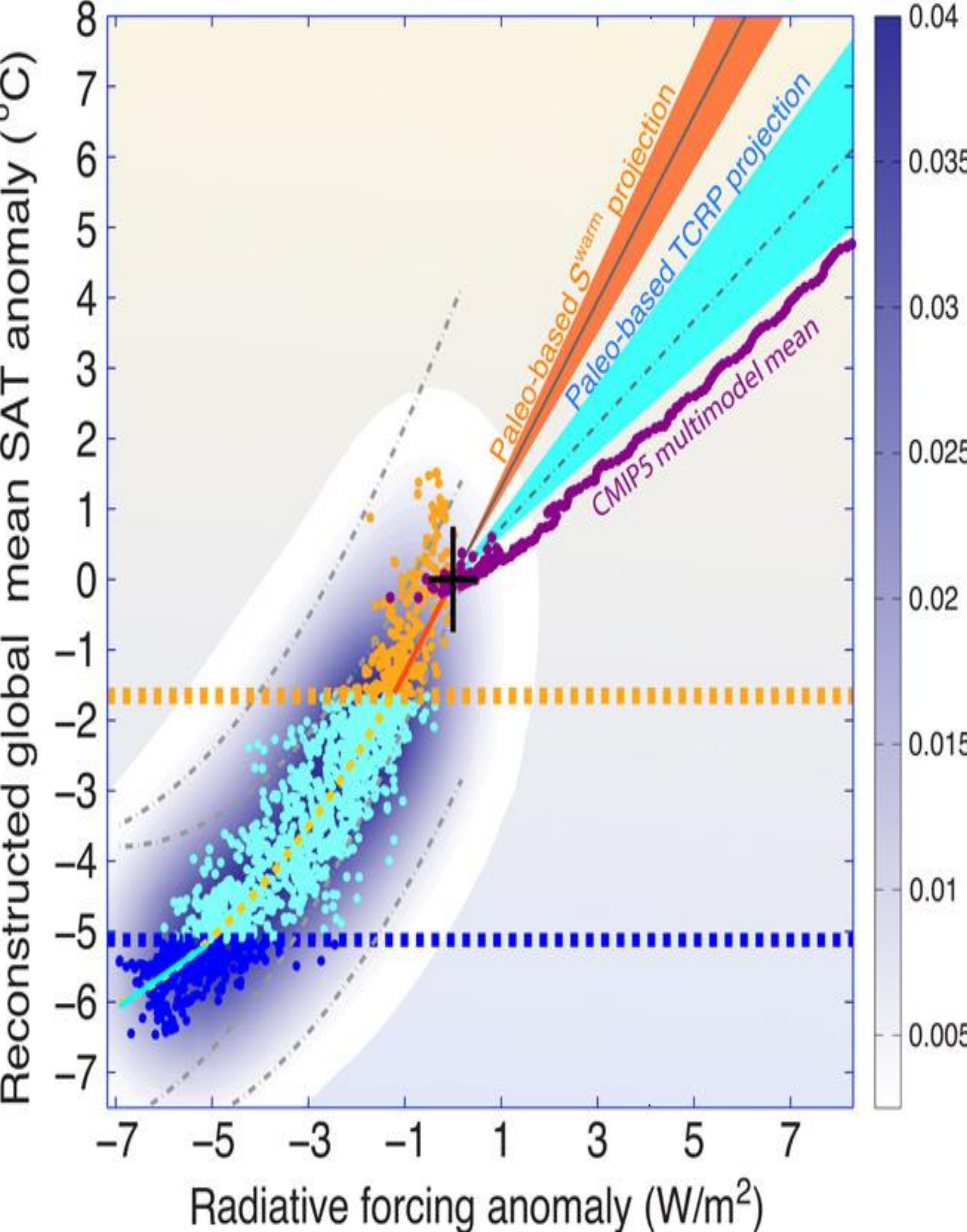


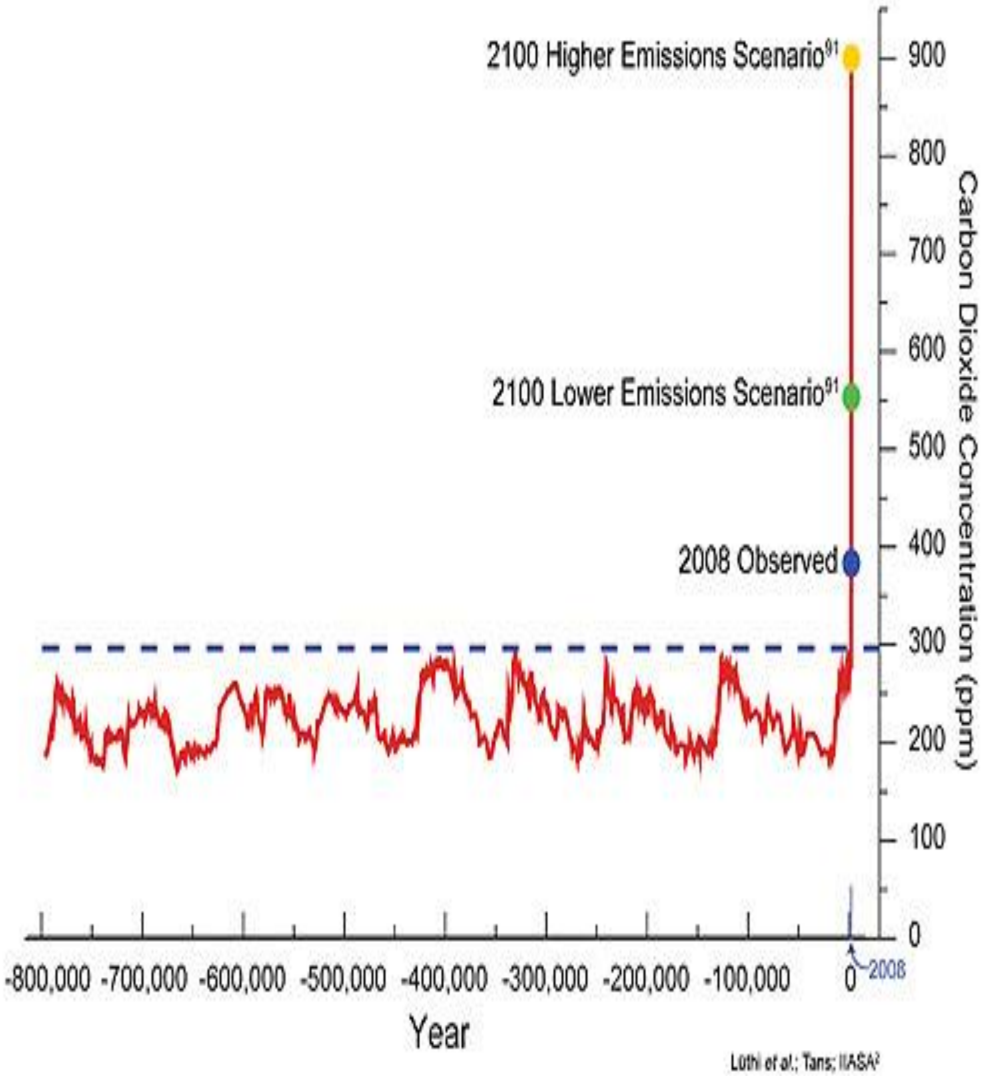
Fig. 1 Published paleo-based values of $S_{[CO_2,LI]}$ (specific equilibrium climate sensitivity parameter caused by CO_2 radiative forcing and corrected by variations in land-ice (LI) feedbacks) indicating its state dependence. Only studies published after the PALAEOSENS review paper [21] are considered. For comparison, the state-independent values from PALAEOSENS, and from the IPCC report [3], and the CMIP5 multi-model mean for present day [41] are also shown. All values of $S_{[CO_2,LI]}$ were given as mean (*or most likely*) $\pm 1\sigma$, apart from IPCC, which is the 90 % confidence (CF) range. Climate background states are given by ΔT from pre-industrial and are marked as estimated ranges (or $\pm 2\sigma$). In [42], further corrections for other slow feedbacks have been calculated, which has been ignored here, leading to different values of ΔT than published. To increase the clarity of the figure, the data-based results are visualised by *colour-coded circles* (mean values), while their uncertainties are combined in a cumulative probability density distribution (*grey shading*) assuming normal distributed values. Results based on climate models are shown by *colour-coded squares* (mean) including their uncertainties (*bars*). *G* glacial, *IG* interglacial, *LE* late Eocene, *EE* early Eocene, *LP* pre-PETM/late Paleocene, *PETM* Paleocene-Eocene thermal maximum. Reference numbers of the given citations: IPCC 2013 [3], PALAEOSENS 2012 [21], Andrews 2012 [41], Caballero 2013 [43] vdHeydt 2014 [20], Martinez-Boti 2015 [44] Köhler 2015 [32], Anagnoustou 2016 [42], Köhler 2016 [45], and Shaffer 2016 [46]



Friedrich *et al.* (2016) find strong upward curvature in climate forcing *vs*. global temperature; says **higher ECS applies during warm Interglacials**

Their (orange) fit finds ECS=4.88C for the interglacial warm periods (and 3.2C avg over warm+cold times

Michael Mann finds this study *"sound and the conclusions quite defensible"*. We should take it seriously…

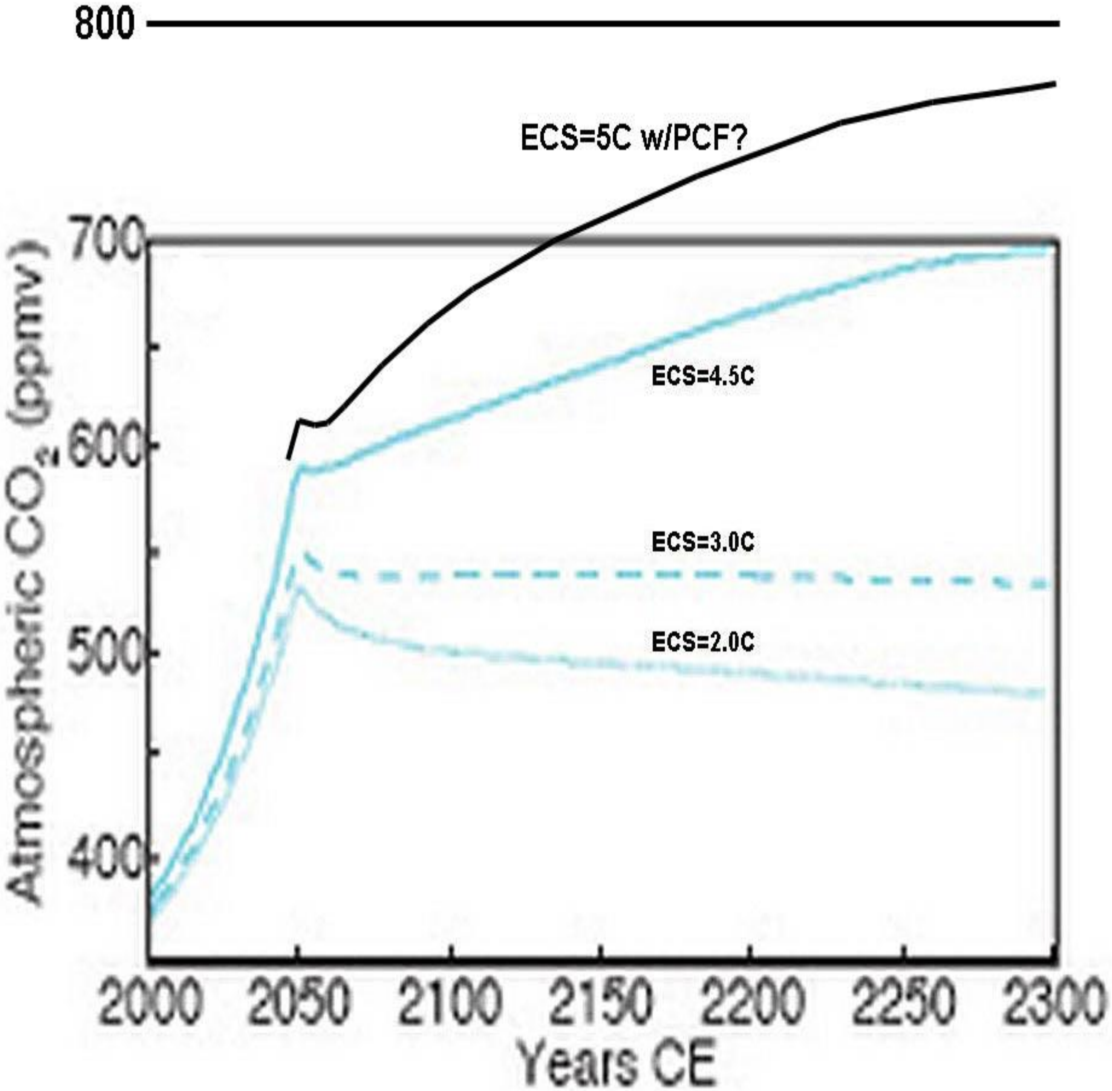


Analysis of air bubbles trapped in an Antarctic ice core extending back 800,000 years documents the Earth's changing carbon dioxide concentration. Over this long period, natural factors have caused the atmospheric carbon dioxide concentration to vary within a range of about 170 to 300 parts per million (ppm). Temperature-related data make clear that these variations have played a central role in determining the global climate. As a result of human activities, the present carbon dioxide concentration of about 385 ppm is about 30 percent above its highest level over at least the last 800,000 years. In the absence of strong control measures, emissions projected for this century would result in the carbon dioxide concentration increasing to a level that is roughly 2 to 3 times the highest level occurring over the glacial-interglacial era that spans the last 800,000 or more years.

Alas, We don't LIVE in an average Interglacial Warm Period. So ECS may well end up being even higher

Now Combine this Higher Climate Sensitivity with the Permafrost Thaw Results

- I'm going to show curves of future atmospheric CO2 from the work of MacDougall *et al.'s* 2012 , but corrected for two effects:
- (1) Schadel *et al.* 2014 finds the depth of the active layer (the annual freeze/thaw layer near the surface) is 40% smaller than MacDougall *et al. 2013* assumed. (2)
- But MacDougall *et al's* climate model includes no methane, so methane must be put in by hand from the Schuur *et al.* work quoted earlier…



Shutdown in 2050

Assume "Business as Usual" emissions, then 100% shutdown of all direct human GHG's in just 22 years. Then for ECS=5C permafrost melt drives atmospheric CO2e to 770 ppm by 2300. This corresponds to a global ECS-induced temperature rise of ~6.9C. <u>This would be manifestly incompatible with the existence of an "organized society" ("ungovernable" in James Hansen's measured tone)</u>

How Does Economic Civilization Do in a +4C (being optimistic) World in Year 2100?

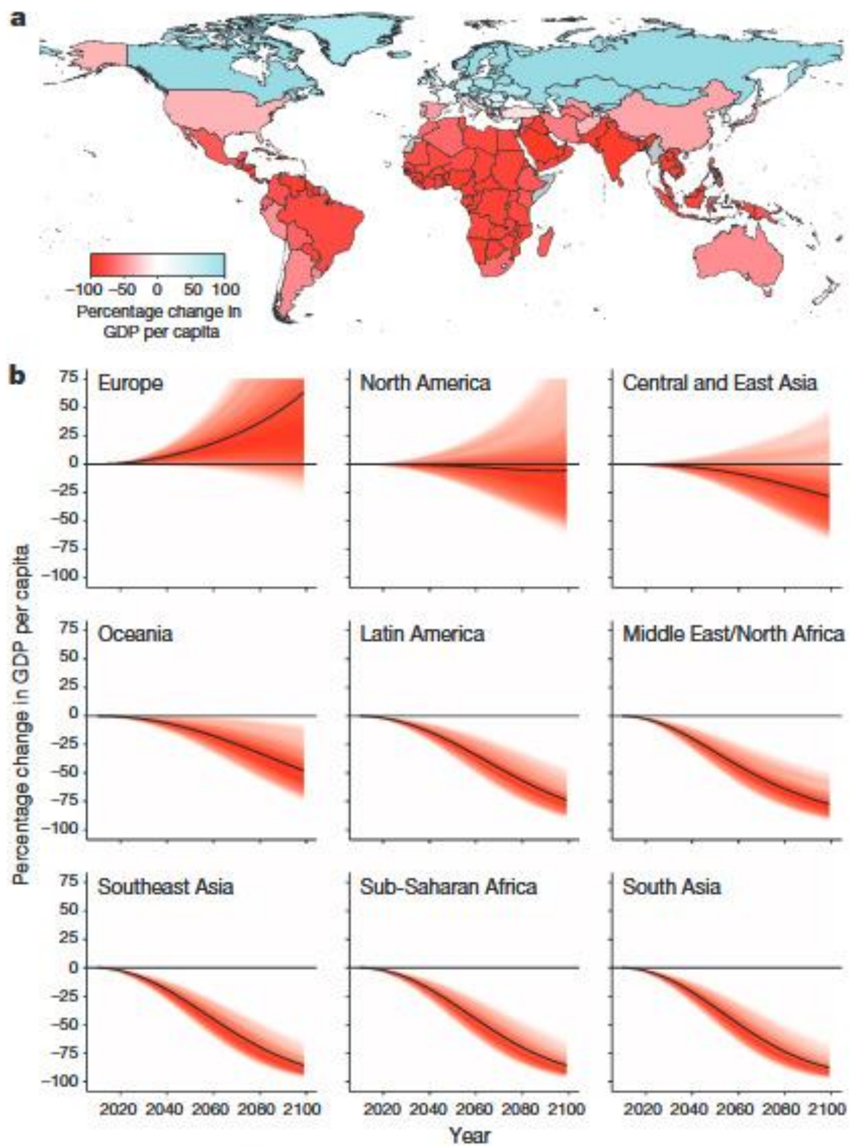


Figure 4 | Projected effect of temperature changes on regional economies. **a, b,** Change in GDP per capita (RCP8.5, SSP5) relative to projection using constant 1980–2010 average temperatures. **a,** Country-level estimates in 2100. **b,** Effects over time for nine regions. Black lines are projections 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.

This Stanford study (**Burke *et al.* 2015**) used historical data and temperature projections from the **IPCC** to find that **GDP collapses by ~70-80+% (and still falling) by 2100** for essentially the entire Tropics: Africa, the Middle East, Southern Asia, South America, Central America. However, this does not consider the non-linear interdependence of global trade, nor the unprecedented global conflicts resulting from such a collapse, so this is very likely too optimistic.

Russia is the biggest "winner", likely to affect their choices in participating in, or even allowing other nations to engage in, measures to halt climate change.

Realize temperature rise never stops, only slows. There is no "equilibrium", since longer term climate feedbacks then take over and ~DOUBLE the temperature change from short term ECS alone (Hansen *et al*). Does that mean +13C?? This would kill nearly all species on Earth: A Truly Apocalyptic World

So, If We're Serious About Preserving the Stable Climate and Sea Levels Human Civilization Evolved in for 10,000 yrs…

- *…"It's not enough to pull the excess that's in the atmosphere at that time — we'd also have to pull out what went into the oceans," he said.* ***"If we want to undo this, we would have to artificially pull out*** ***<u>all</u>*** ***of the cumulative emissions since preindustrial times."*** *– <u>**Dr. Pieter Tans**</u> at NOAA's Greenhouse Gas Reference Network (<u>**source**</u>)*

- ***350.org needs to be re-purposed and re-named as "280.org"***

To Summarize…

- We need to do more than “reduce emissions”
- …more than eliminate all fossil fuel burning
- … more than eliminate all other GHG emissions
- … more than additionally halt all indirect (permafrost, wetlands, soil degradation, forests dying…) emissions
- … we need to UNDO all that we’ve done to the Planet. Remove the CO2 we dissolved into the ocean, and let the heat we put there radiate back to space.
- And do it quickly… Only this, will stabilize climate long term.

The Task is Beyond Enormous.

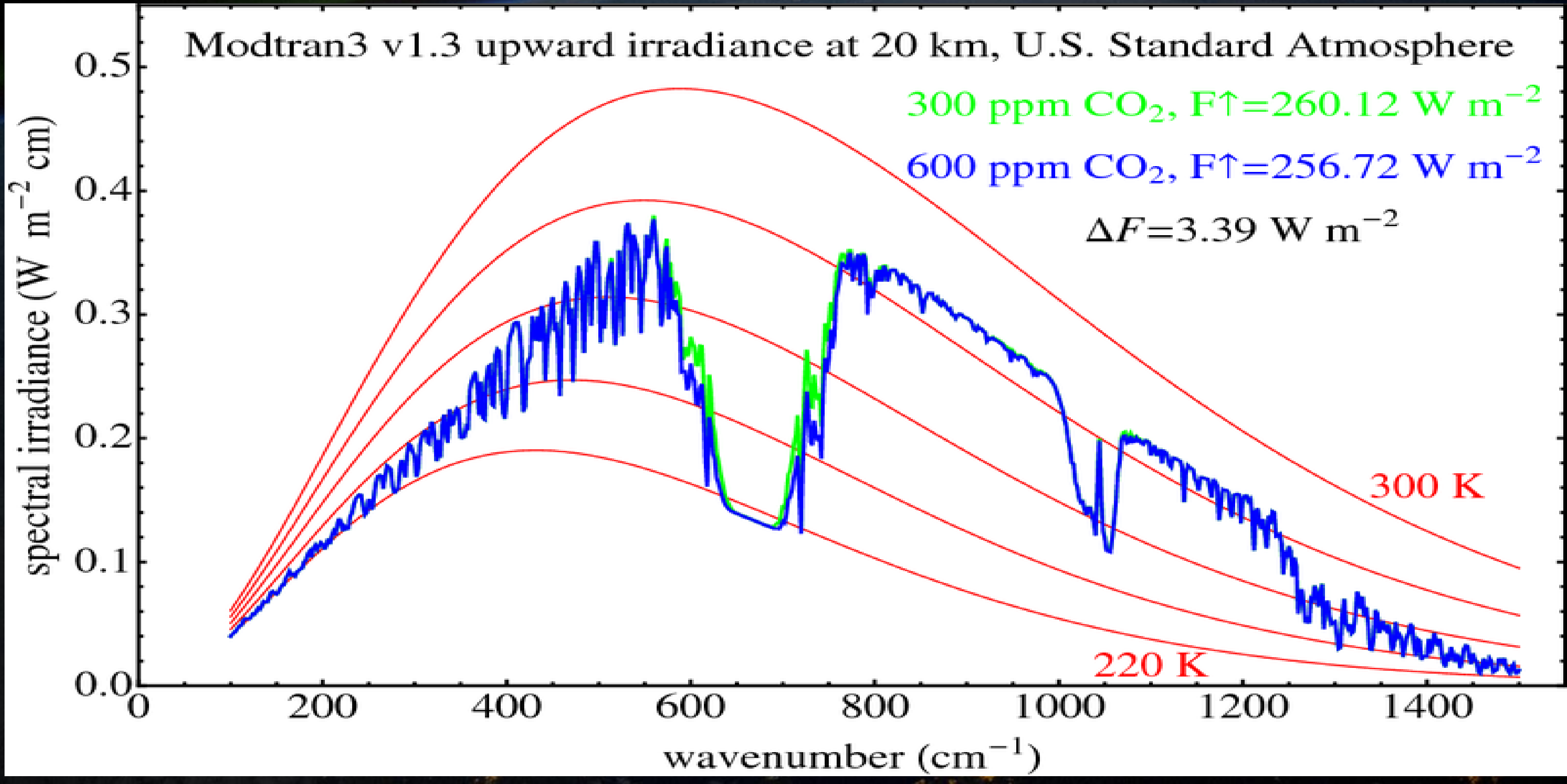
- Imagine the entire Fossil Fuel mining industry, halted, and then operating in reverse, pumping liquified CO2 back INTO the ground, at tonnage ~3x higher than we're mining it OUT now, since we're also now burying precious oxygen from our atmosphere in the burning process (CO2 weighs over 3x as much as CH2).
- As Cambridge University climate engineering expert Hugh Hunt observes… "We don't do ANYTHING today at that scale" (the necessary scale for climate rehabilitation).

<u>Section B</u>. A Framework for Judging <u>Efficacy</u> and <u>Safety</u> of Climate Strategies

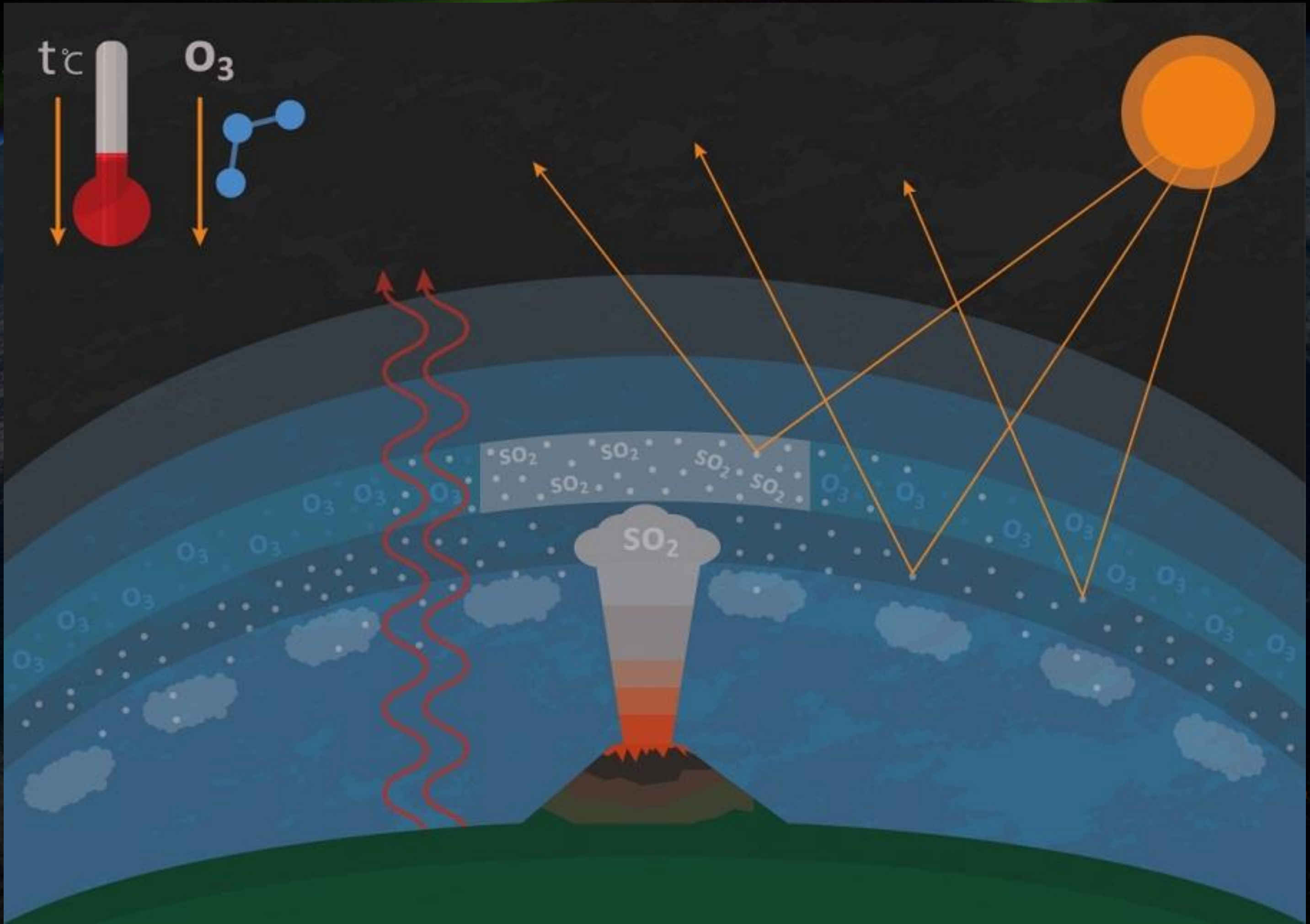
The Core Physics Problem: A Growing Thermal Imbalance

- Incoming sunlight: <u>Constant</u>
- Varies by only 0.1% peak-to-trough during the 11 year solar cycle. Detectable, but dwarfed by the forcing we're producing
- And it's oscillating, not trending

But growing GHG's forbid the Earth from heating up enough to radiate all that solar energy back to space. Therefore…



All Effective Strategies Fall Into Just Two Categories



A. Reduce the influx of solar radiation reaching the ground and troposphere

- Also called the "SunShade" or "SRM" category (SRM=Solar Radiation Management)
- Ideas include: Enhancing low clouds, stratospheric sulfate aerosols, sunlight reflectors in space, lots of white paint, raising the albedo of darker areas of Earth's surface… all fall into this category; they're saved for the **Geo-Engineering** section

B. <u>Raise</u> the Ability of Earth to Re-radiate its Heat to Outer Space

- The only solutions I know of that are in this category center on lowering atmospheric greenhouse gases.
- These relate to energy consumption, energy efficiency, renewables, and carbon sequestration… a big subject.

Heat MUST End Up in Outer Space. There Are No Other Options

There is nowhere else to dump our excess heat.

* It's HOTTER beneath Earth's crust, so that won't work

* The ocean? Will convect back to the surface its already absorbed heat, if you attempt to cool the atmosphere above it. You can't use the ocean as a heat dump.

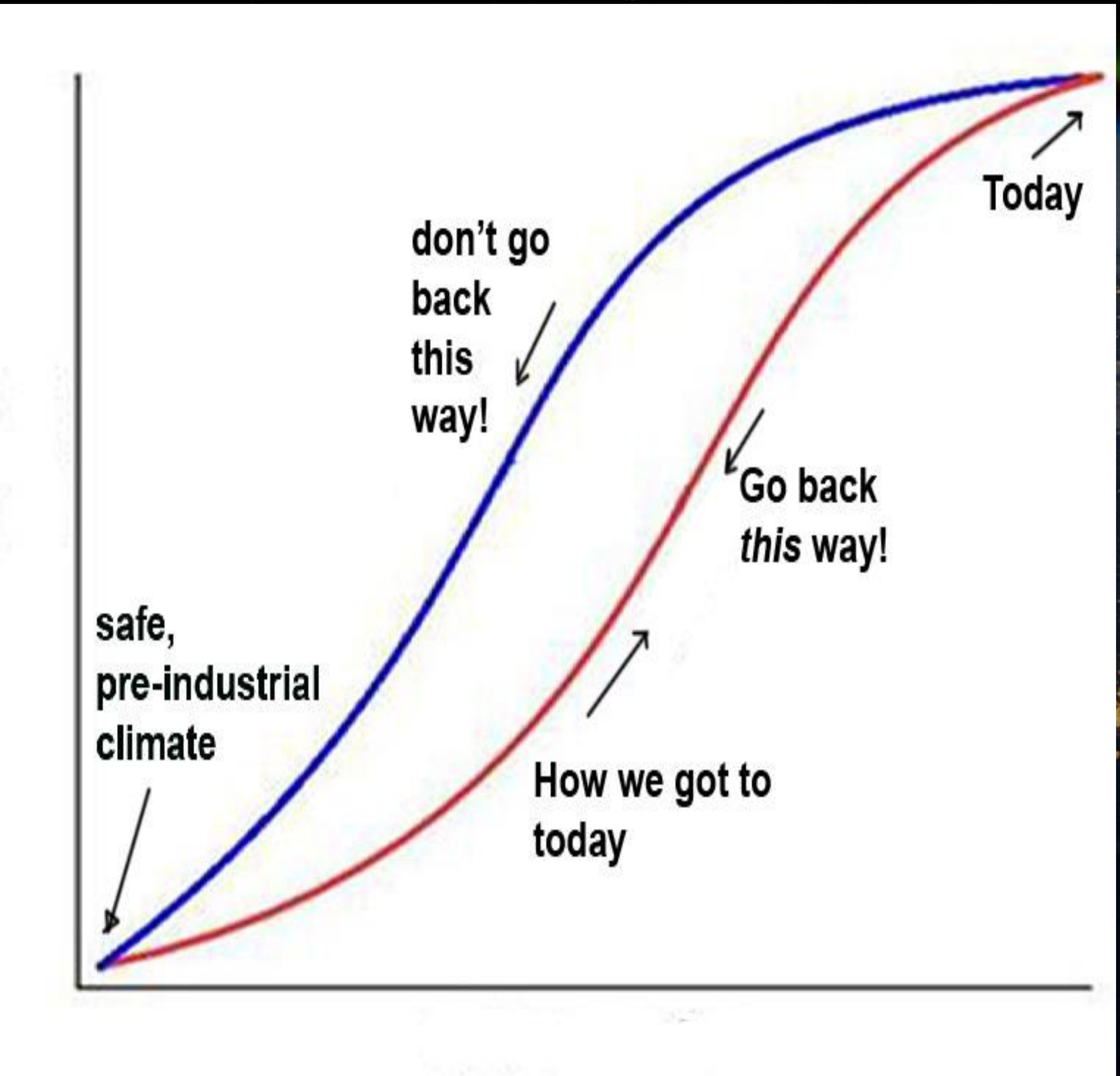
We Can't Just Sweep Our Excess Heat Under the Rug.

- It re-emerges later, making things even WORSE than doing nothing.
- Such "Loan Shark" Ideas <u>End Badly,</u> as we'll see.

Climate Proposals: SAFETY

- The “Efficacy” thoughts we just looked at are nothing new. Well known and acknowledged from the beginning.
- But the SAFETY criteria to follow I’ve yet to see even mentioned, let alone discussed. Why? Because the media is instead clogged with <u>**profit-seeking promoters**</u>, and **their** criteria is COST and POLITICS

Safety Criterion #1: Minimal Hysteresis in Returning to ~Pre-Industrial Climate.



- **Meaning: they will NOT** produce changes to the Earth System in ways significantly different than any we have seen on our path to today. **Safe climate = what all species have already adaptively evolved to.**

When you discover you're in a mine field – you carefully retrace your steps. You don't run in new directions! We don't understand ecology to anywhere near the level necessary. Don't be seduced by Profit-seekers going for *"Fast, Cheap, and Out of Control"*

Safety Criterion #2: Minimal Alteration to Earth's SURFACE

- **We share this planet with a million other species, and nearly all live ~on the surface.**
- Leave the surface in the natural state that species evolved to be in harmony with.
- Again, we don't understand the ecology of our million species anywhere near well enough to know what will happen with massive unnatural alterations.
- Beware of profit-hunters whose narrow focus is altering the surface to benefit their pockets, to the detriment of a long term stable climate

Some Abbreviations:

- **EC#1** = Efficacy category #1; reflects sunlight back to space
- **EC#2** = Efficacy category #2; enhances Earth re-radiation of heat back to space
- **SC#1** = Safety category #1; retraces Earth system approximately back the way we got here
- **SC#2** = Leaves Earth surface approximately unchanged or rehabs back towards natural state.

Costs *vs.* Quality of Our Future

- ***"We can't know what to do, until we know what we aspire to"*** – Prof. Nate Hagens, energy expert

I Believe That in Our Most Sacred Moments, We Aspire…

- …to a **natural** world. With respect to all of the millions of other species we share it with, in the stable climate that we have all evolved in for 10,000 years.
- My focus will be on how strategies measure up to this, and confrontation with the innate human drives which took us, instead, to here.
- **As for costs - we should aspire to the best, not the cheapest. We clean up our mess and stop complaining about the cost.**

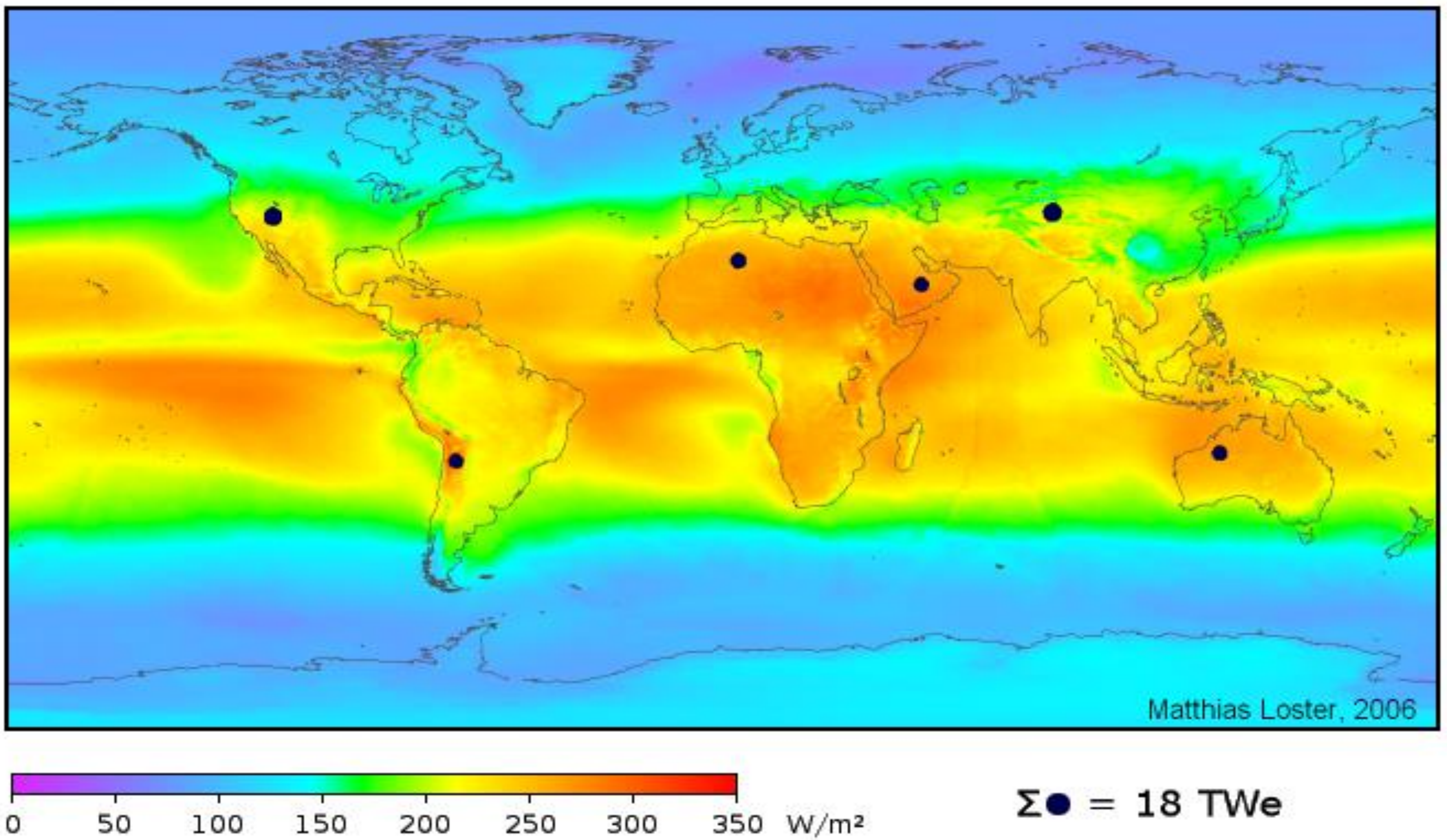
Section C:
Low Carbon Energy

- Low-Carbon Energy satisfies **Efficacy Category #2**, as long as it REPLACES carbon-producing energy (that’s a BIG “IF” as we’ll see later).
- Some **Low Carbon Energy** ideas also satisfy both safety criteria.
- Let’s look at ideas…

Best!: Solar PhotoVoltaics on Structures

- Turns sunlight directly into DC electricity, a high potential energy source of power.
- Satisfies EC#2 and both SC#1 and SC#2
- First let’s tell the good news side…

Solar PV Accessible Power Potential, Including Cloud Cover. Sum of black dot areas = total global power needs



Rooftop PV: Offset utility bills, sell excess. Great!

Solar PV on Multi-Family Roofs

Solar PV on Parking Lots: Residential or Commercial, it's all good

Solar PV on Manufacturing Buildings

Solar PV on canals even; power, and reduce evaporation losses too

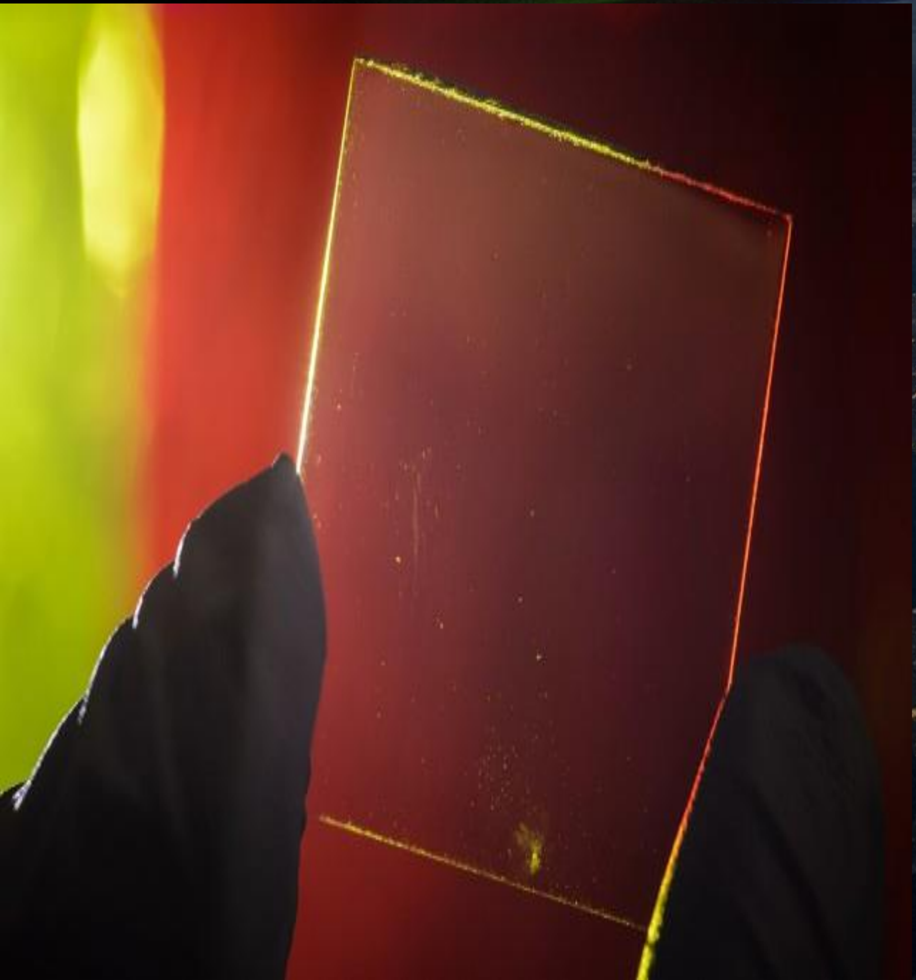
Solar Roadways and Bikeways?

…Probably A Bad Investment

- Panels will always be dirty, scratched
- Mostly poor angle to the sun, amplifies reflective losses by Snell's Law
- Low efficiency
- Very expensive: $1,200 per square meter. 50 yr payback time
- $0.86/ Kwh *vs* $0.19 for offshore wind, *vs* $0.05 for conventional electricity
- And this is for a lightly-stressed bikelanes, not the much more demanding Solar Roadways (which are also far too expensive $65T ($160,000 for every man, woman, child in the U.S.), and not tough enough)

Solar PV Windows. Extremely low efficiency and high cost. *"Miles away from commercially viable"*

Solar PV on transparent glass?
<u>Surprising, but true!</u>



- Organic salts convert UV and IR to IR luminescence, collected at the edge.
- Still in development.
- Costs: <u>don't ask</u>!

But The Low-Hanging Fruit's Been Picked

- And for Solar PV to take over the world, there's problems...

Potential Rooftop PV? In the U.S., less than half of what's needed (Gagnon *et al.* 2016)

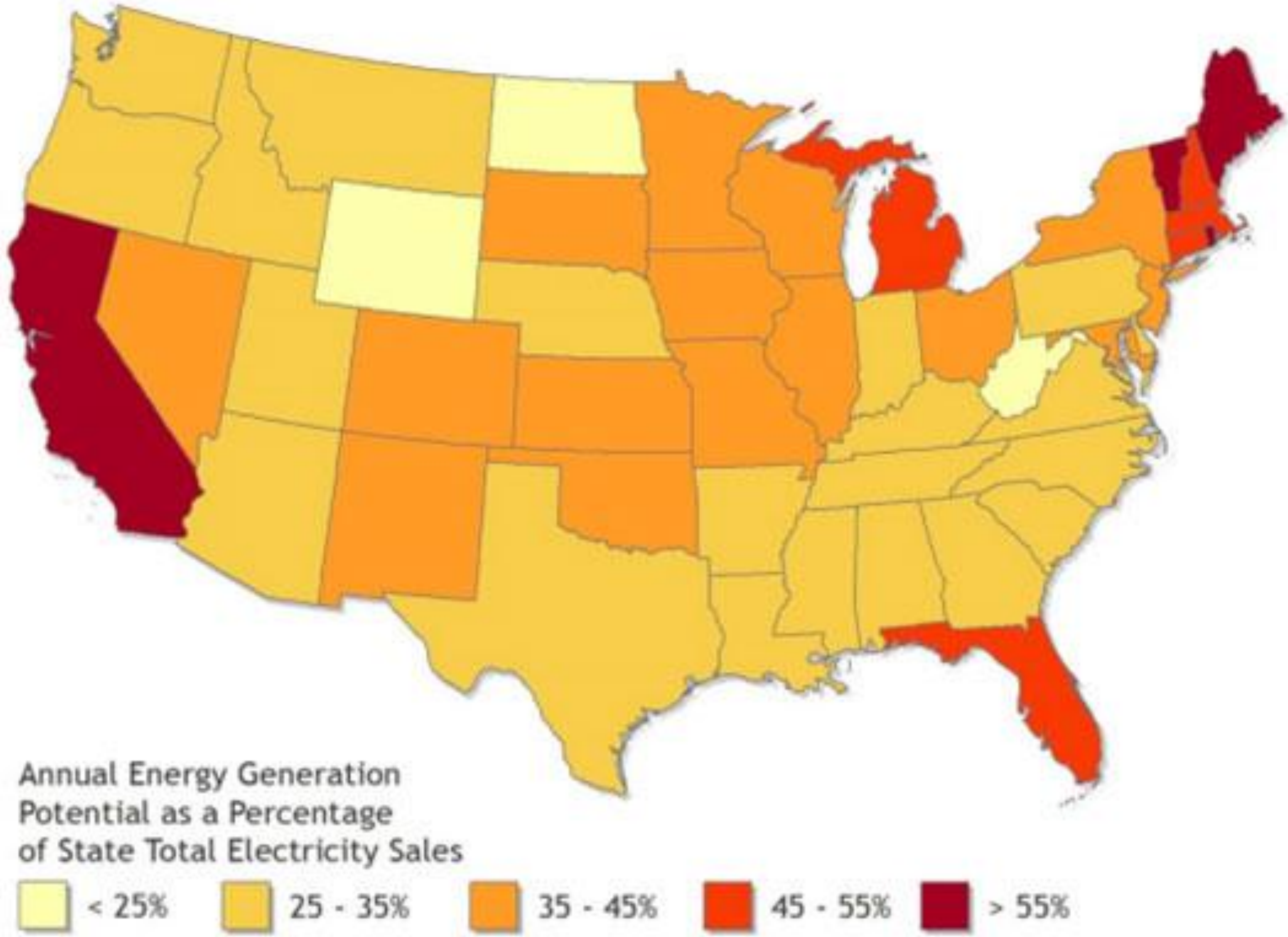


Figure ES-2. Potential rooftop PV annual generation from all buildings as a percentage of each state's total electricity sales in 2013

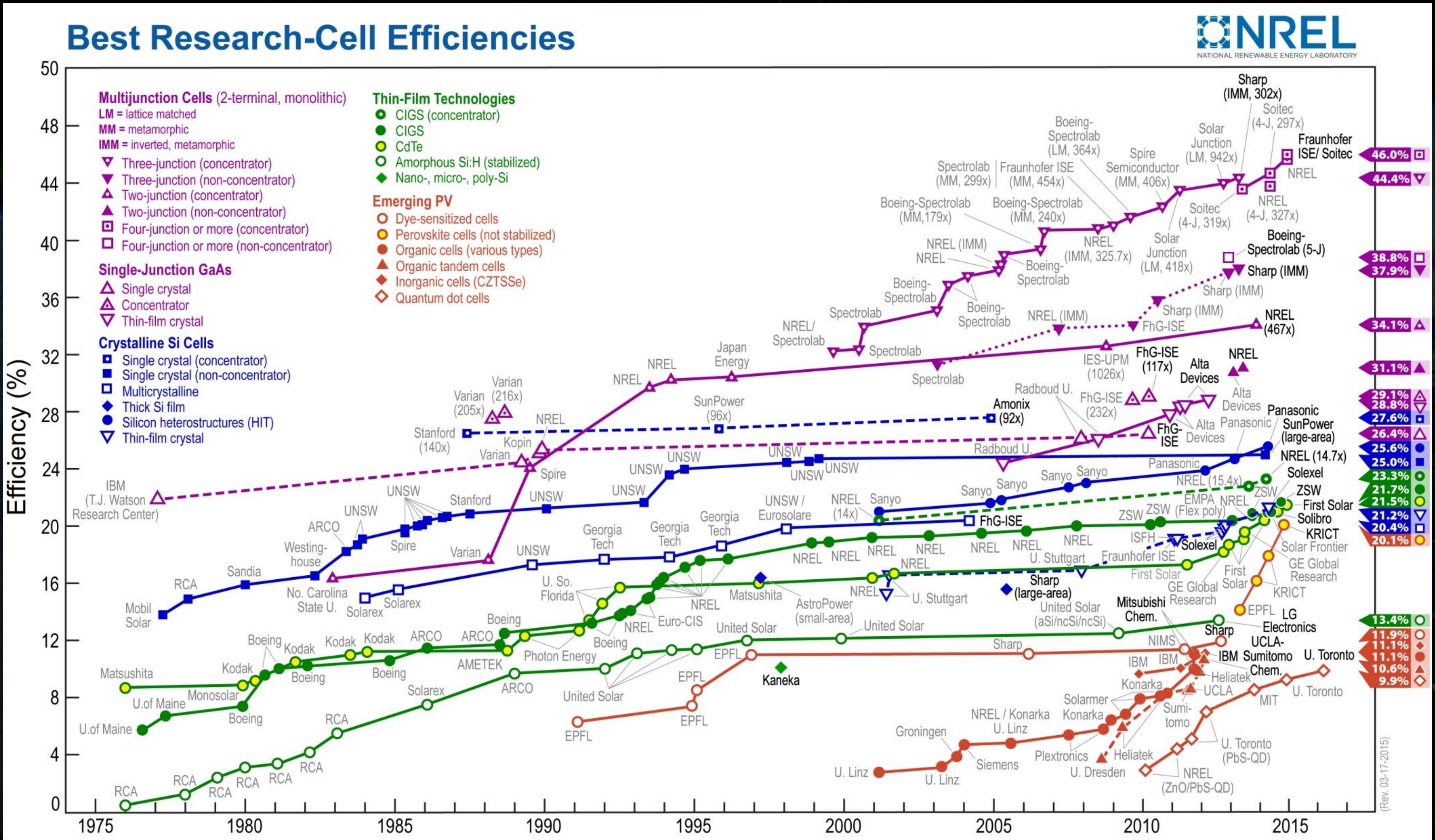
Rooftop Solar Can't Do it All

- In the US, if every building had rooftop solar, it might supply up to 39% of our 2013 electricity. Gagnon *et al.* 2016 (but too rosy? in a "white paper" from the National Renewable Energy Lab). Sunny CA better: ~400% of CA power (*Nature: Climate Change*, and discussed here)
- However, even uber-optimist Mark Jacobson sees rooftop solar only giving 7% of US power by 2050, and that is with "enormous, heroic assumptions about social and political change" (source quote)

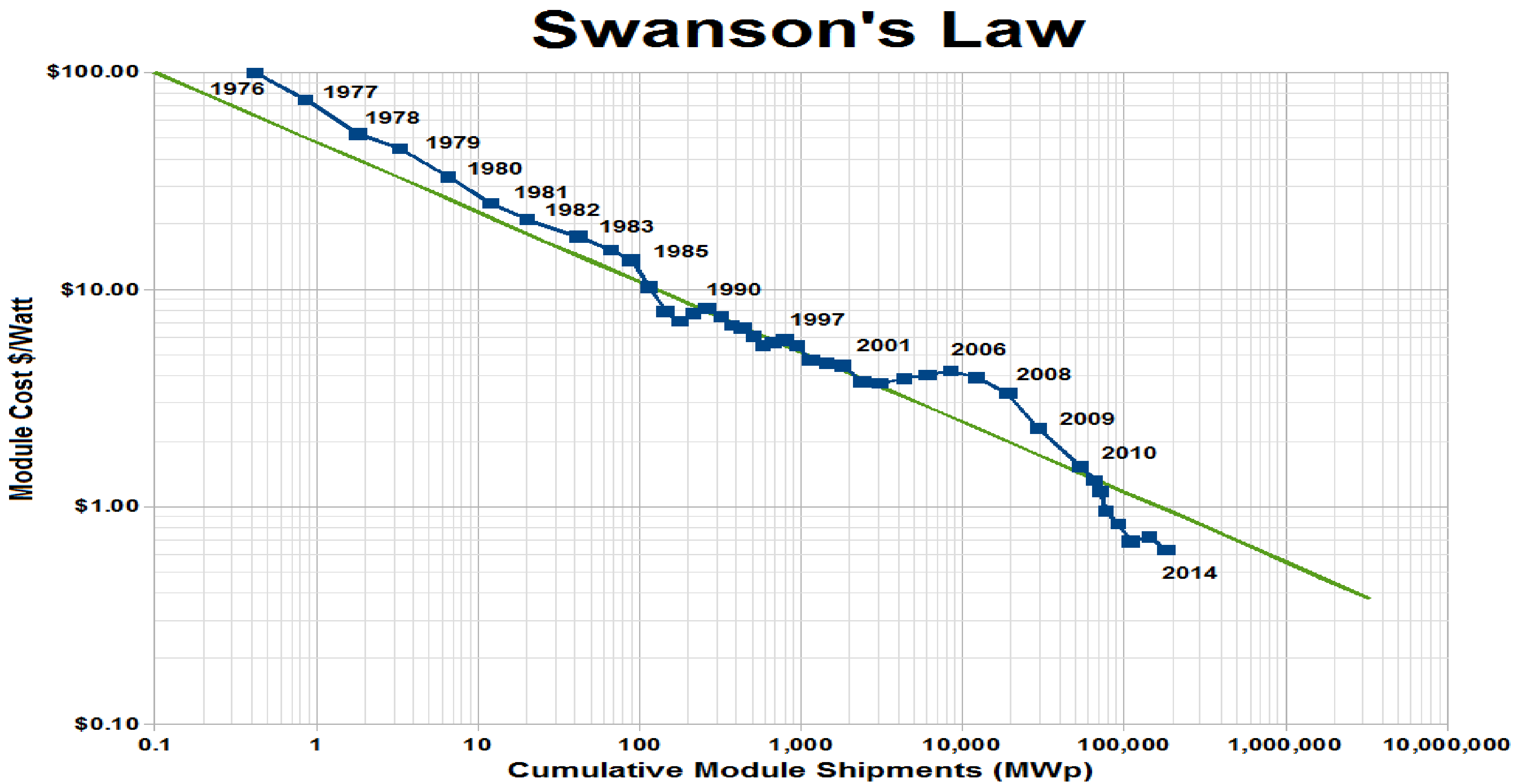
More important for cost…

- Solar cell efficiency are mostly already accomplished, as are the gains due to economies of manufacturing scale.
- Solar is already a significant industry, with scaling cost reductions mostly accomplished, especially by the Chinese. Solar costs will not follow a steep "Moore's Law" like semiconductor chips.
- Gains will now be slower
- BEWARE of promoters who simply extrapolate past curves into the future, ignoring the true, evolving source of future costs (next slides)

Theoretical Thermodynamic Max Efficiency for single junction cells is 33%. For a theoretical (impossible) infinite stack, 69%. Multi-junction cells max 46%, but these are 100x higher cost per power delivered.



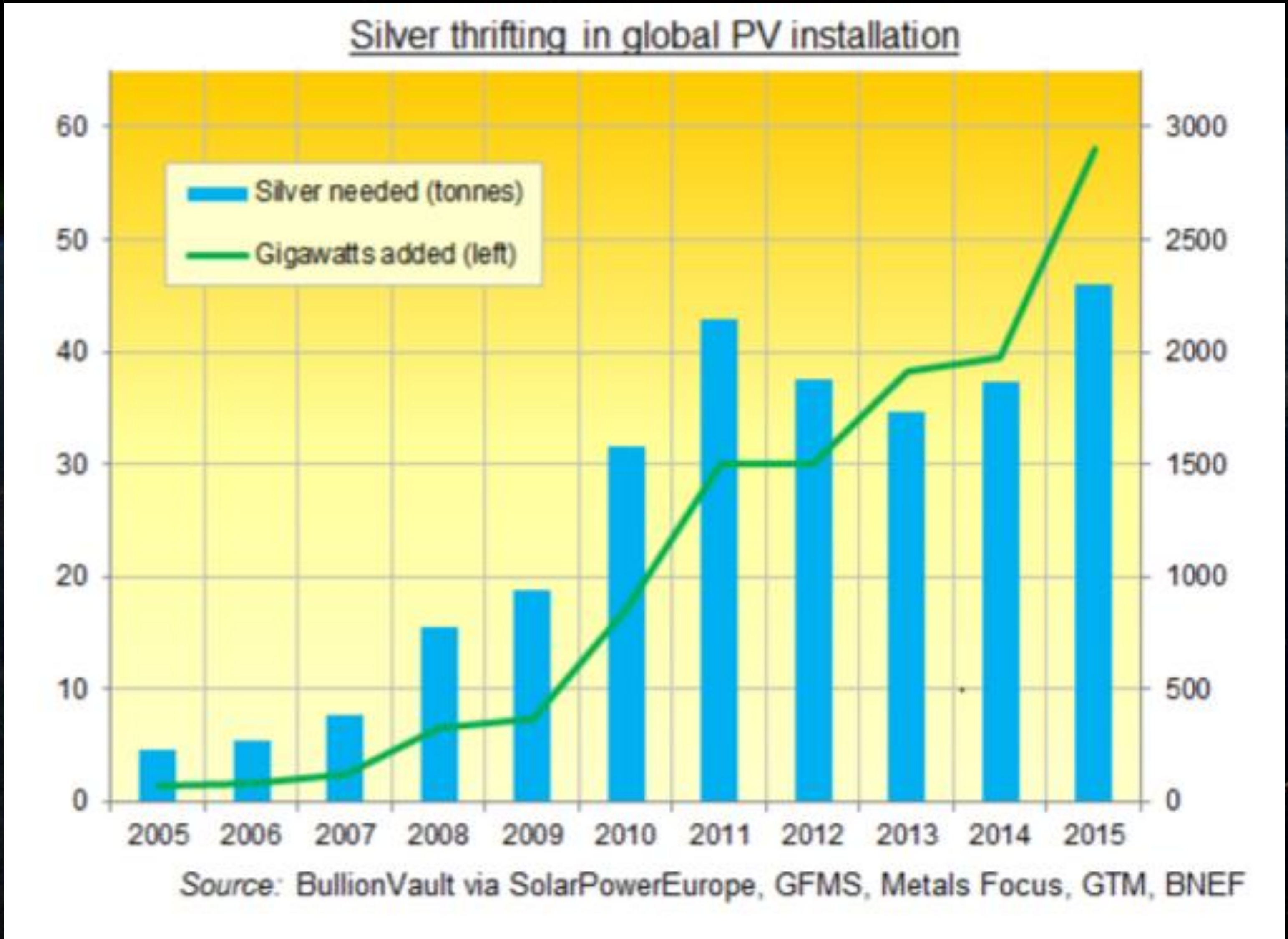
Note past decade's deviation from Swanson's Power Law, It's been steepening: falling module costs are not leading to increased shipments at same rate as earlier, as more of the costs are not in the modules, but other costs which are not falling so much; structure, installation, labor…



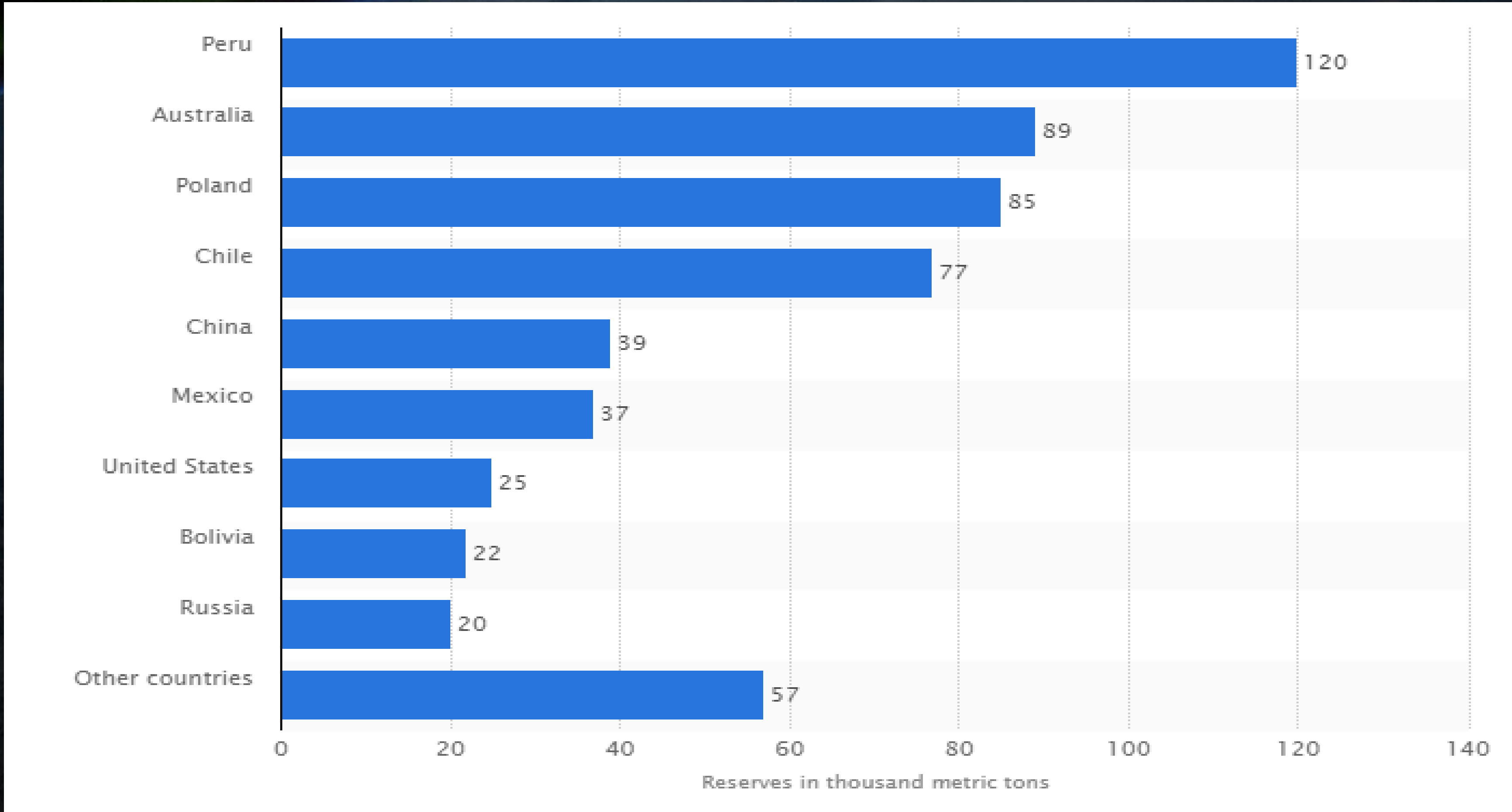
There's Potentially Another Problem: <u>Available Silver</u>

- Current solar panels (1.8 m^2) require 20g of silver.
- That's 11.1 <u>tons</u> of silver for 1 square km of solar PV panels.
- **In order to power the world with current solar PV panels, it would take 5.62 million <u>tons</u> of silver.**
- **Even assuming silver per GW of power will drop to only ¼ of today's), that's still 1.4 million tons of silver.**
- Today's panels already use far less than they did 10 years ago, motivated by high silver cost. So this hypothetical drop may not be easy – it's been an issue for years and the easy solutions are already done

While silver needed per unit of power is falling at 5%/yr, the total silver required keeps rising, as solar deployment continues



The problem is, what's required is <u>more than twice the estimated silver reserves on Earth</u>. While above-ground stores (*e.g.* old coins) can be put to use here, only at astronomically escalating higher prices and on only a small fraction of it.

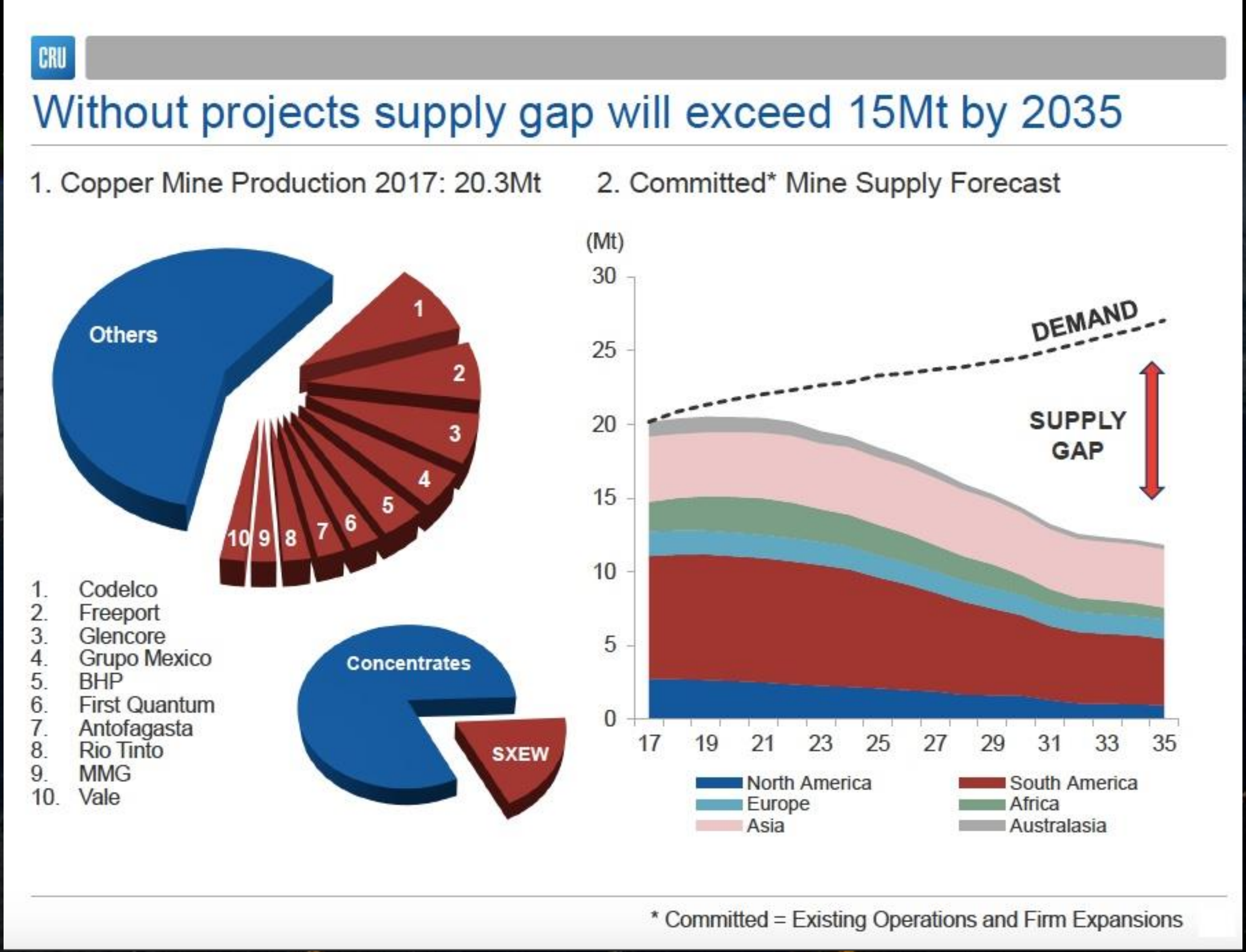


- <u>**Solar panels lose efficiency**</u> at a rate of 0.2% to 1% per year, requiring ongoing new silver even at zero global solar power growth (even with recycling).
- Other industrial processes require silver, which would then not be available for solar panels.
- Merely adding to energy needs at standard global 2% growth rates would consume almost double the current rate of silver mining today, yet this is <u>after</u> consuming the more than double all known reserves to reach solar PV powering the world.
- I've seen a lot of pro-solar rosy projections and promotions… but this issue never seems to be highlighted, hardly ever even mentioned.

Can’t we just replace silver with aluminum or copper for solar PV panels?

- Some makers are, but copper prices are rising too.
- And, silver has the highest reflectivity and the highest conductivity of any available metal.
- Resulting lower efficiency means more solar panels to do the same job, accelerating the amount of required silver which is still used.
- And, copper now tipping into long term supply/demand crunch…

Copper – demand/supply will tip over by 2020, according to new estimates, spiking prices. Existing mine production will fall to barely over 50% of today, by 2034. All the while, China and Asia expect to be skyrocketing their demand.



This issue was just one contributor … Solar panel prices stopped falling and indeed <u>rose significantly</u> in the U.S. in 2017. Module costs rose 23%

2.5 U.S. Polysilicon, Wafer, Cell and Module Prices, Q4 2016-Q4 2017

	Q4 2016	Q1 2017	Q2 2017	Q3 2017	Q4 2017
Polysilicon ($/kg)	$14.98	$16.93	$14.39	$16.69	$18.03
Wafer ($/W)	$0.15	$0.15	$0.14	$0.15	$0.15
Cell ($/W)	$0.21	$0.21	$0.21	$0.23	$0.22
Module ($/W)	$0.39	$0.38	$0.40	$0.45	$0.48

Source: GTM Research

The remaining solar PV costs…

- … are in labor and materials, electronic components like inverters, and other segments which have already matured and are not plummeting in cost as fast.
- For the panels alone, residential solar PV panels are about $1.00/watt, from a 2018 google search. But the total installed cost is about $4/ watt, or 4 times higher
- These facts argue that the large drops in solar costs have already occurred, and future declines will be more incremental

Utility Scale Solar PV on virgin land: cheaper than residential scale, so that's the attraction. Sorry, other species! Your lives don't matter.

Combining Utility Solar + Wind. Better Land Use

- plants, mirrors between rows also look helpful

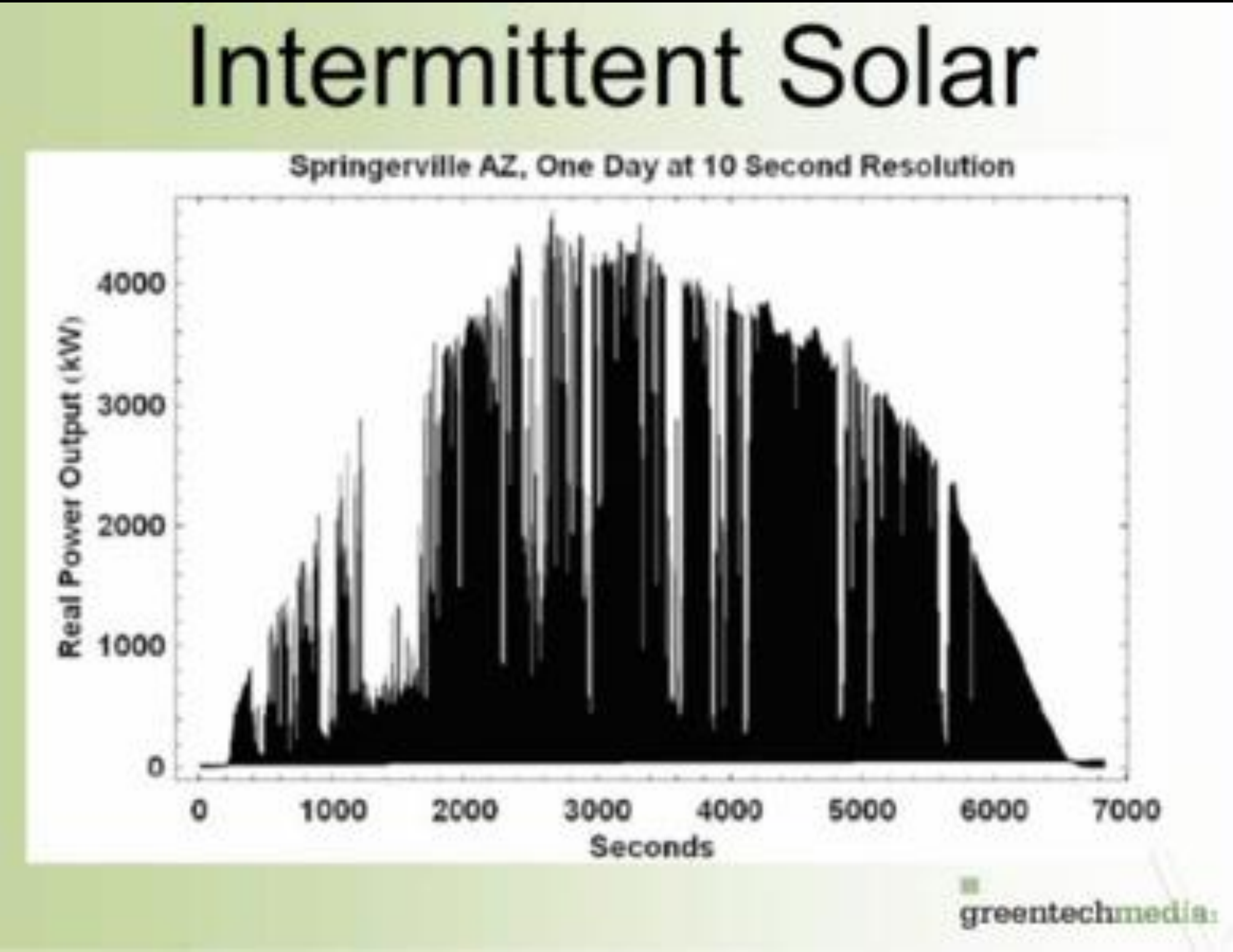
Solar Manufacture: Carbon Cost

- 2008 study found 280 kwh input energy is needed to produce 1 square meter of solar panel
- Some more recent advertising claims are of 1.4 years to pay back carbon footprint.
- ~2.5 years payback is more the average seen in 2015 literature.
- **~25 year life of a panel (?) so solar PV is about 1/10th the carbon intensity of fossil fuel energy**
- 280 kwh/m^2 means about 2.2×10^{14} kwh needed to make enough solar panels to power the world

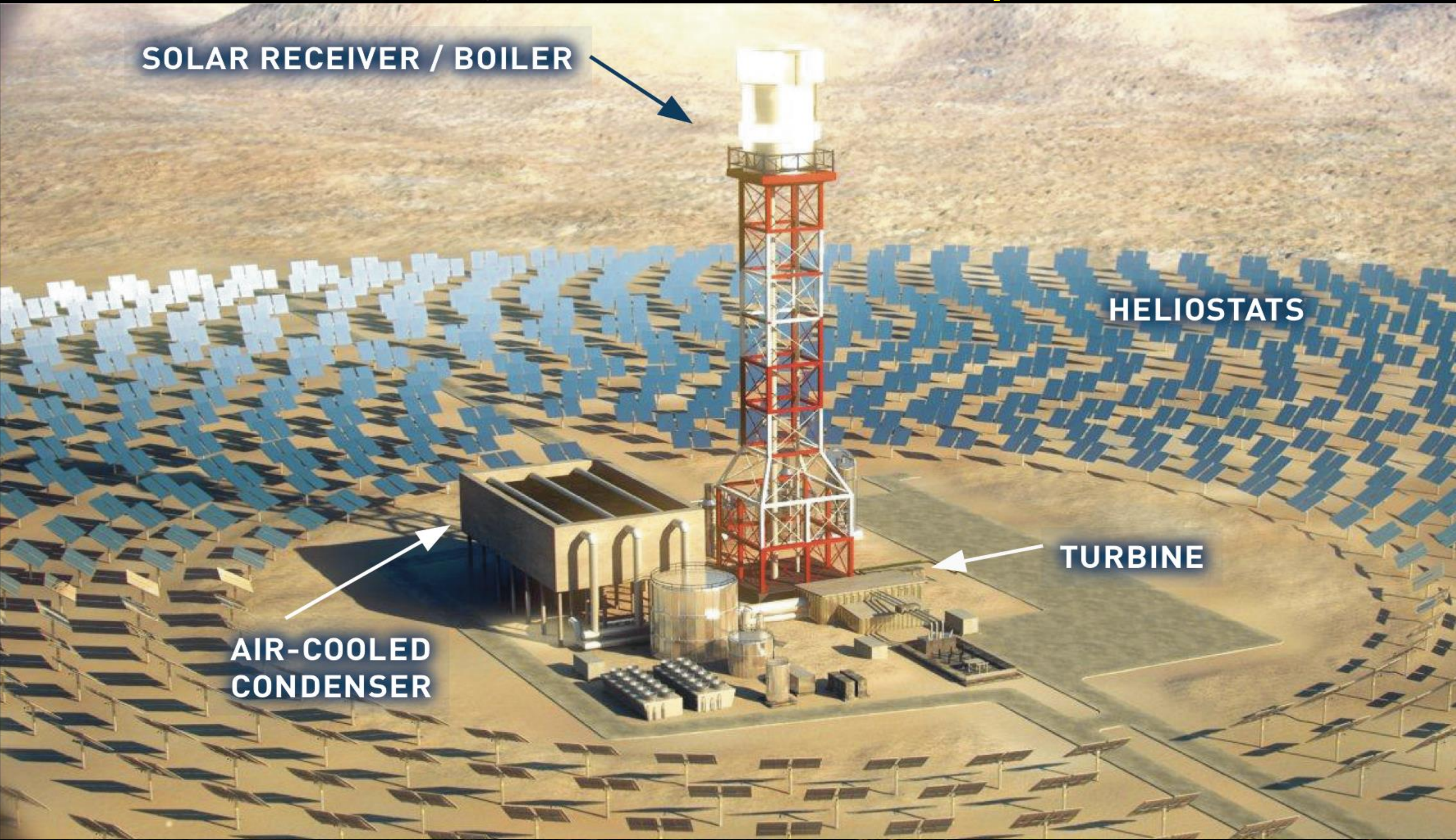
1 Kwh of Energy, generated by a mix of fossil fuels, generates about 1 kg = 2.2 lb of CO2

- So that's 2.2 x 2.2 x 10^{14} lb of CO2 to make enough solar panels to power the Earth
- That's 2.4 x 10^{11} tons of CO2
- That's 240 gigatons of CO2 , or about **7 years of total current global emissions of CO2 from all sources, to make enough solar panels to power the world.**
- But likely an underestimate – must first build the infrastructure to make all those factories before powering them. And the supporting industry (inverters, etc) and the power to run them as well.
- That's a lot, but not a deal-killer.

Solar PV (and Wind) Needs Good Storage to Become More Widely Used

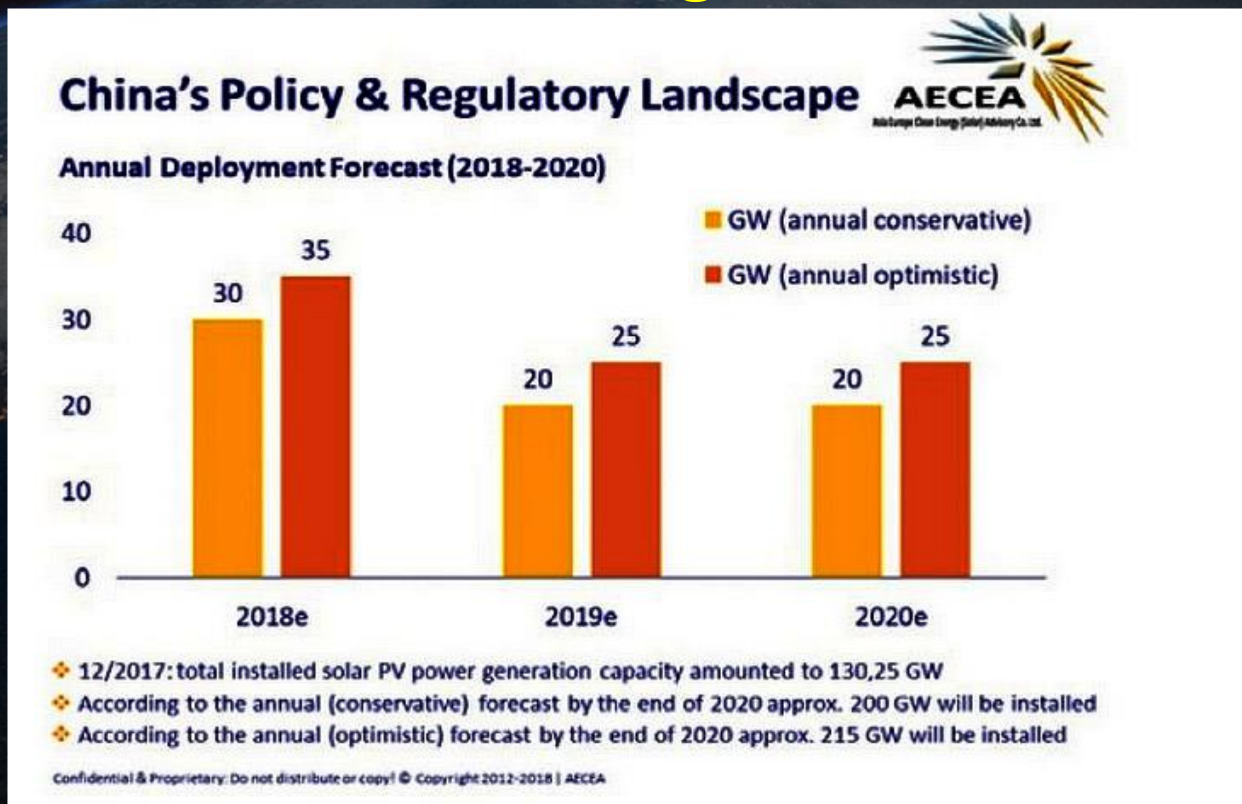


Solar Thermal boils water for a turbine, from reflected concentrated sunlight, and can generate power much of the night. High land/power ratio, unfortunately. But if you don't care about desert, it's no more expensive than PV



2018, China strongly cutting support for Solar PV: Demand can't justify supply

- China deployment of solar PV expected to be 30% lower in 2019 and again in 2020



AECEA noted that total cumulative deployments could reach between 200GW to 215GW, targeting only annual deployments in a range
20GW to 25GW over the next two years. Image: AECEA

Revenge of the Duck!

- Variable and semi-unpredictable output from solar and wind translate into high costs once they make up more than 20% of power generation in today's grid.
- The low-hanging fruit of initial deployment of solar and wind… that fruit's been pretty much picked, especially for solar-friendly places like California and southern Europe

The Duck Curve – Power Demand *vs.* Supply *vs.* Hour of the Day.

Cost inefficiency rises with increasing adoption of solar and wind.

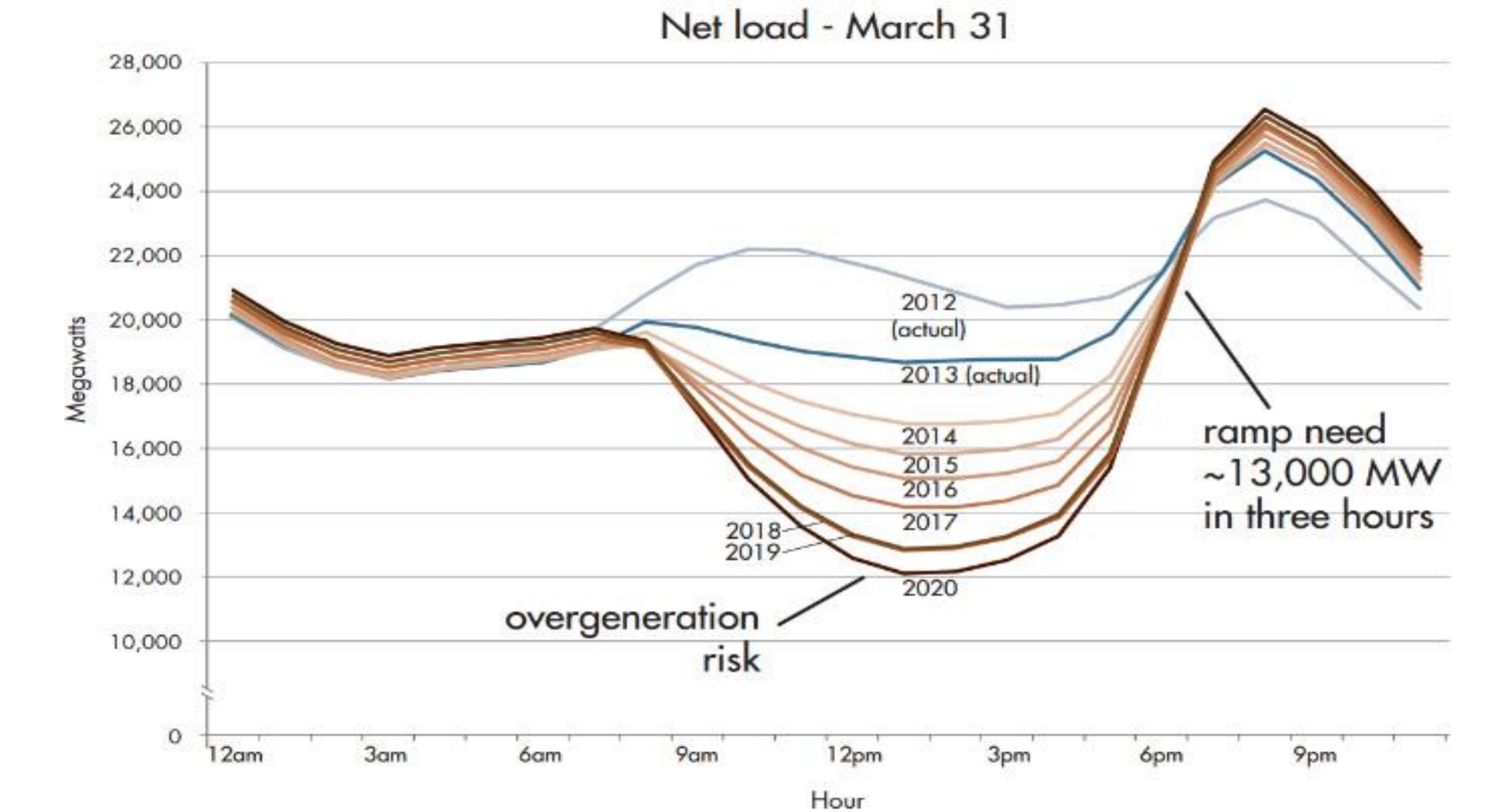


Figure 1. The CAISO duck chart

Source: CAISO 2013

Even starting from zero solar/wind, still – adding 11% solar plus 11% wind capacity (equally), to total system capacity yields only a 9% reduction in base capacity needed, even in this typical optimistic example from sunny California

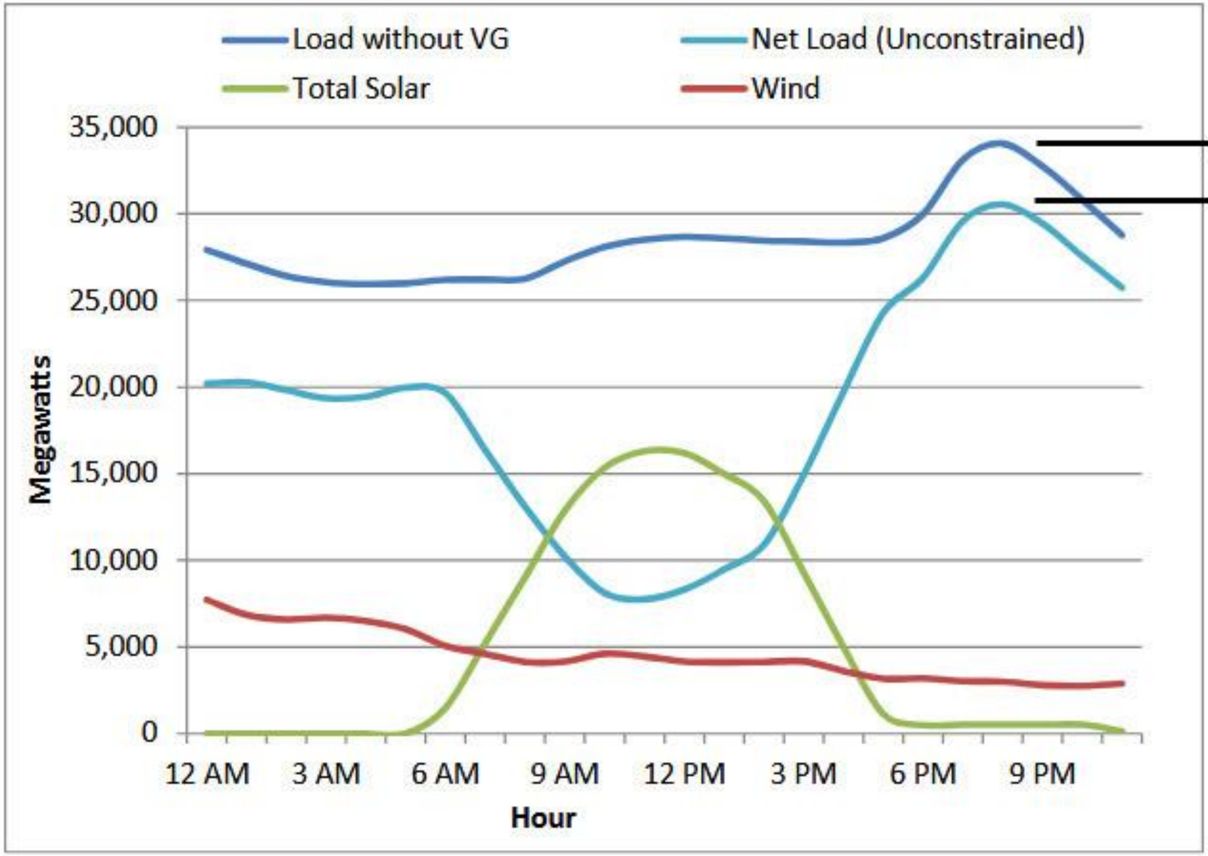


Figure 7. Load, solar, and wind profiles for California on March 29 in a scenario with 11% annual wind and 11% annual solar assuming no curtailment

The more renewables (RPS) we add, the more of its power must be **wasted ("curtailed")** to avoid danger to the grid and its users, especially costly for the marginal (*i.e.* newly added) renewables being costed out (National Renewable Energy Labs 2016)

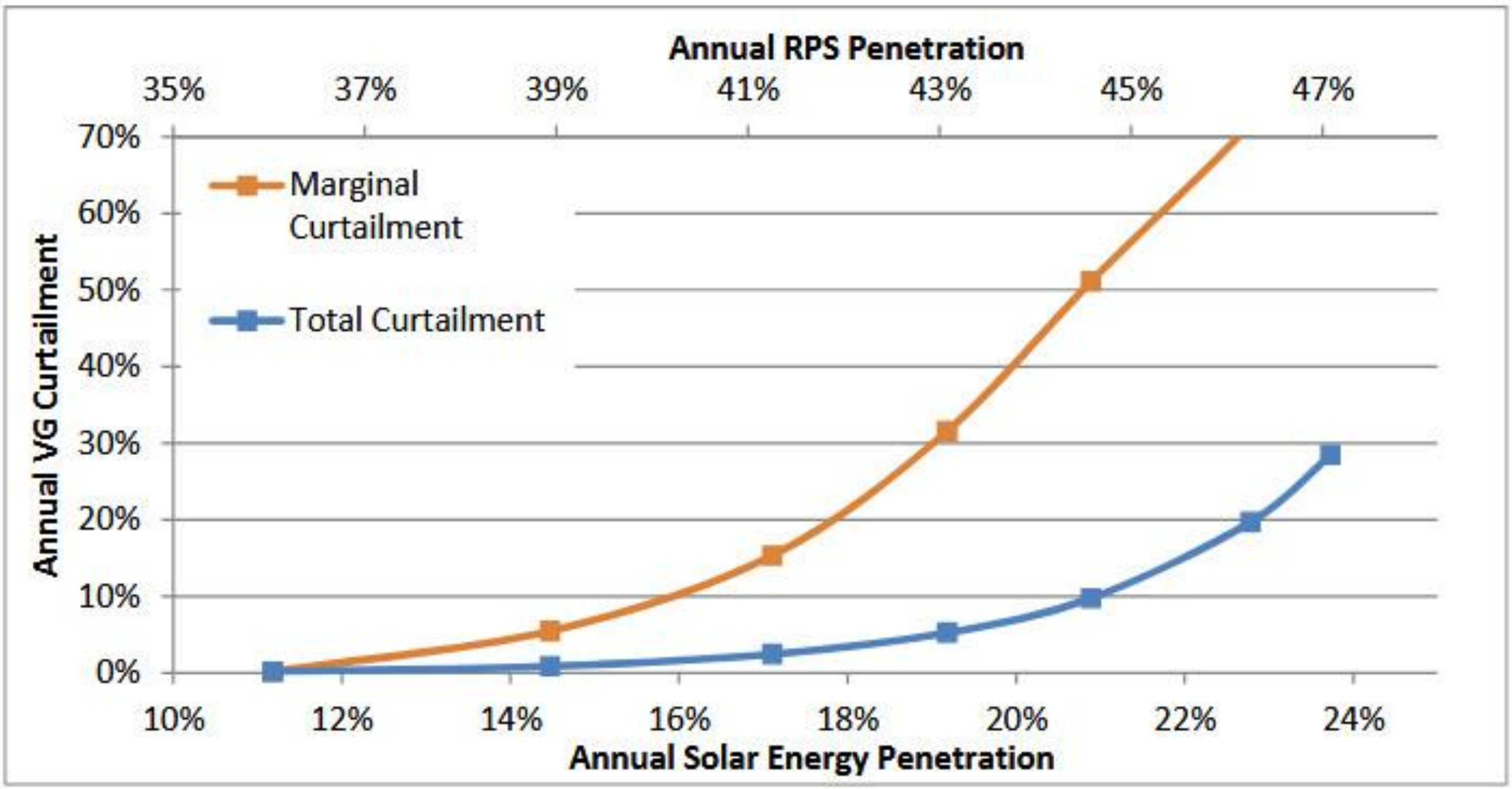


Figure 17. Marginal and average curtailment due to overgeneration under increasing penetration of PV in California with a 60% instantaneous penetration limit

Solar PV: Even with only ~20% penetration into today's grid, it's been economically uncompetitive to add more (orange), although this is improving with more storage and better load balancing from wind

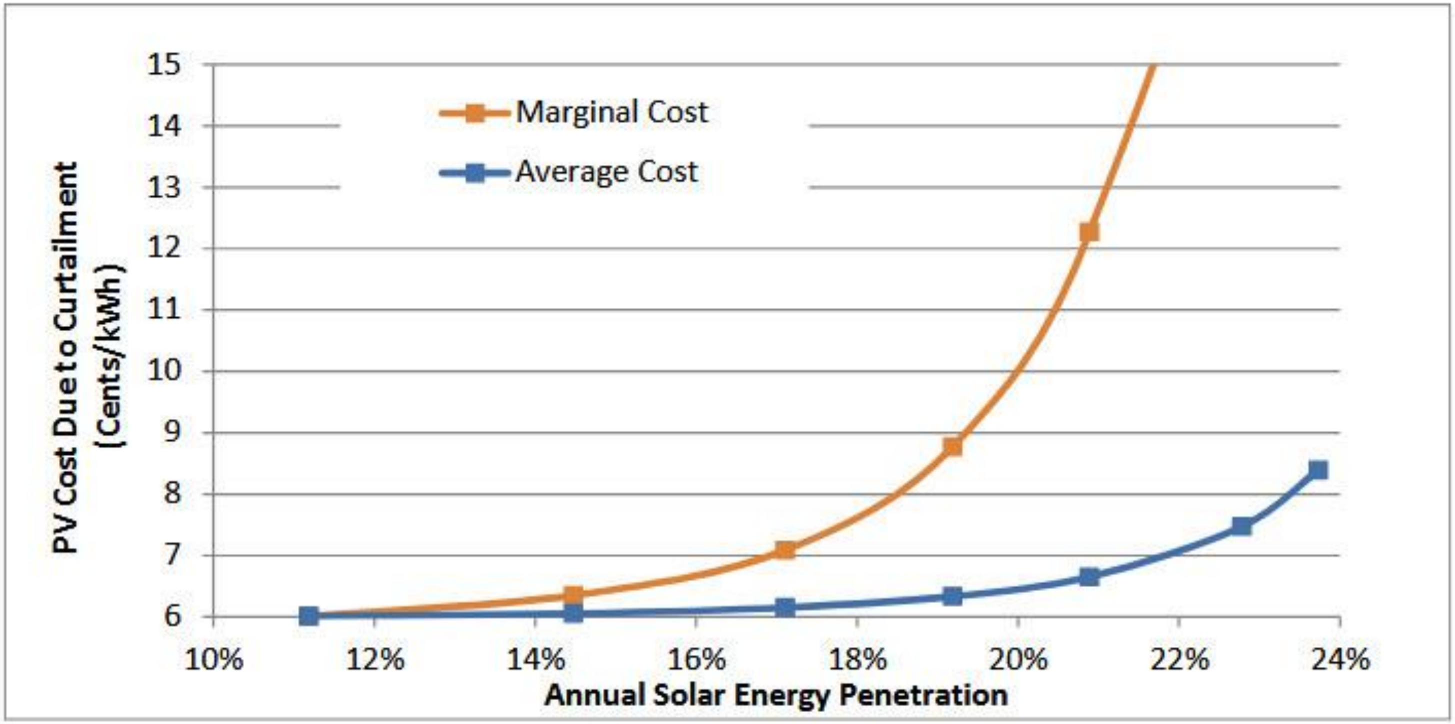
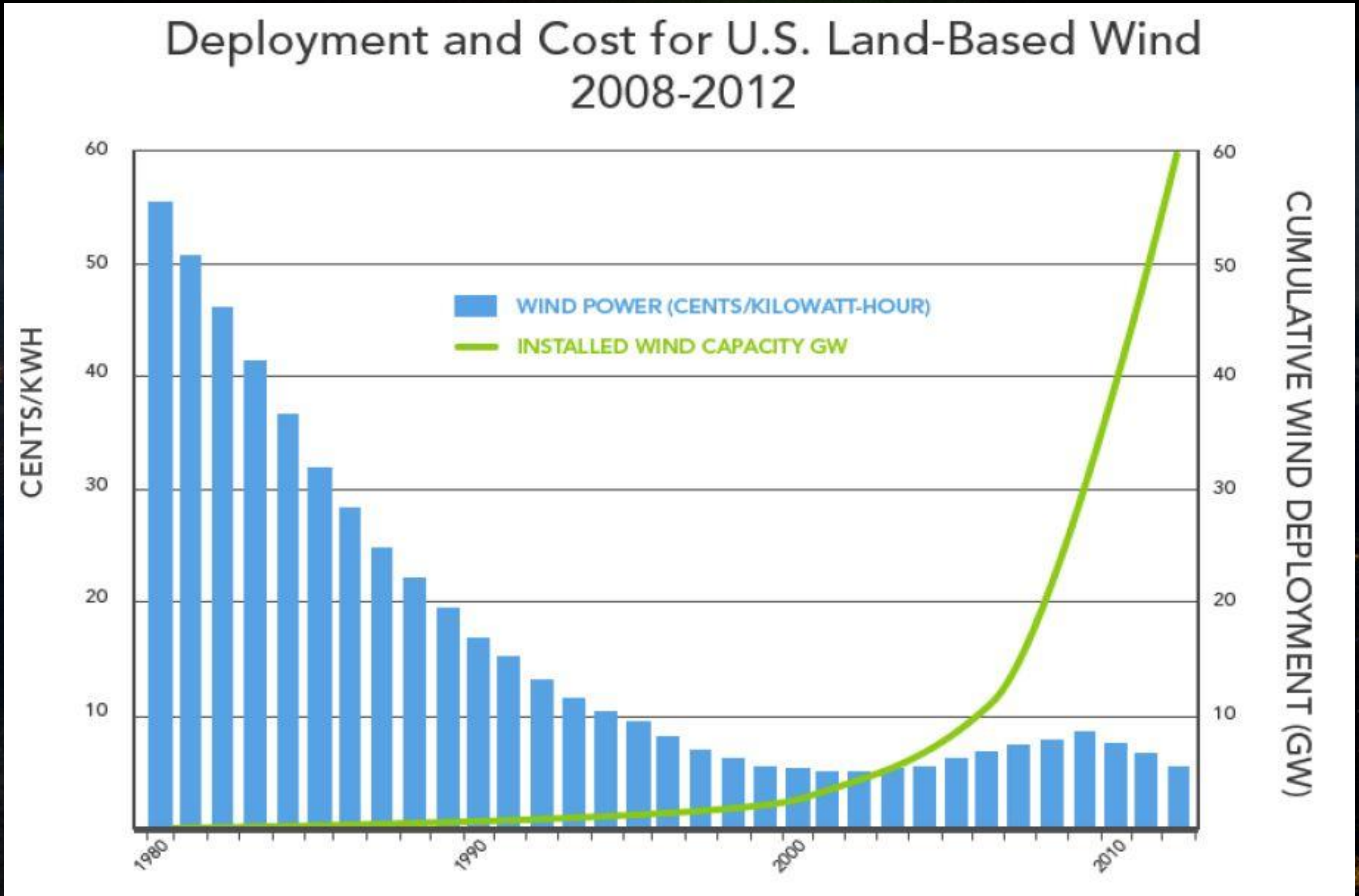


Figure 18. Marginal and average PV LCOE (based on SunShot goals) due to overgeneration under increasing penetration of PV in California with a 60% instantaneous penetration limit

Figure 18 shows the importance of examining marginal curtailment rates. While average rates can remain relatively low, marginal rates determine the cost and value of adding the next unit of solar to the grid. Actual investment decisions may be driven by these marginal values.

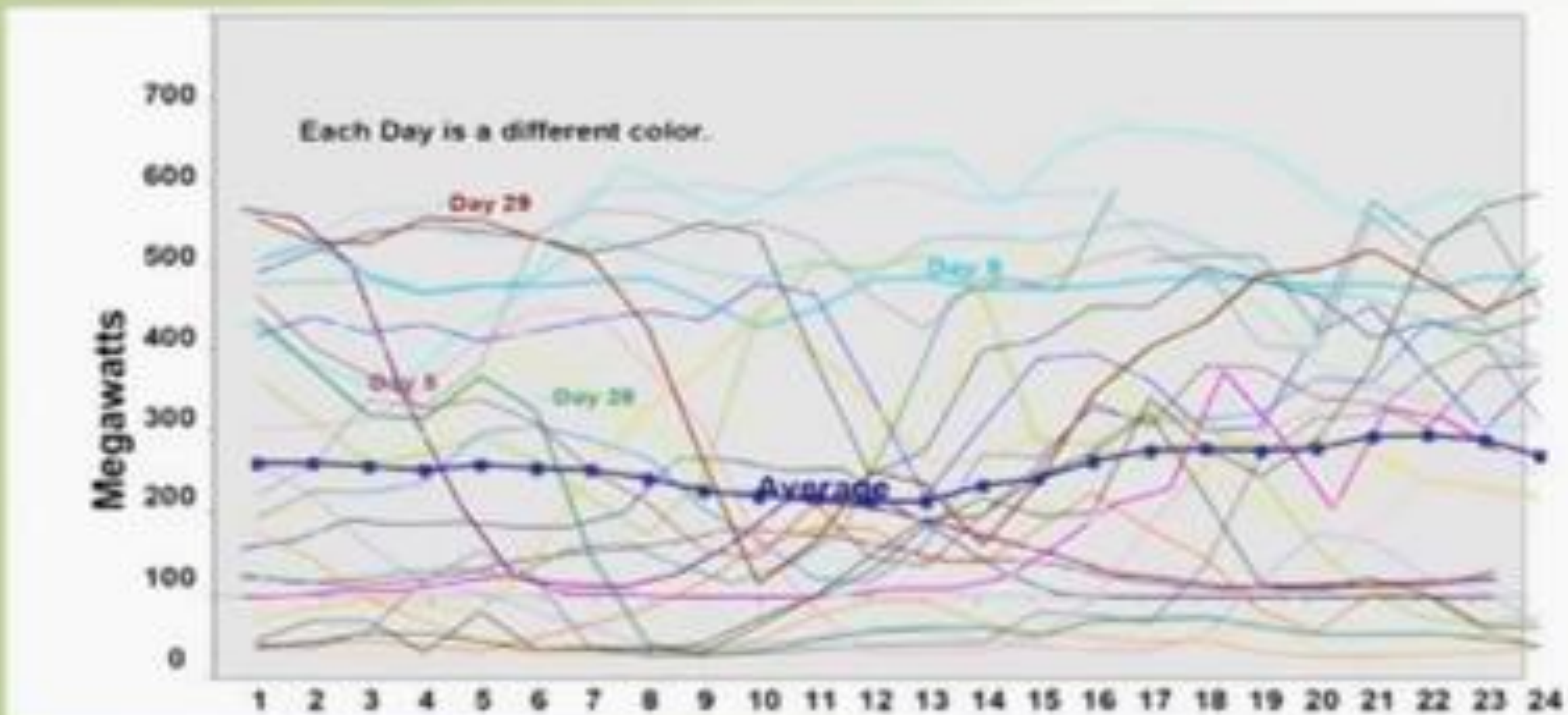
Wind: Often the Cheapest of Renewables, but…

The big technology and cost advances may be over. Cost improvements ~ceased 18 years ago. U.S. Deployment went from exponential to merely linear (green curve). The best, windiest, most concentrated sites built out first, of course



Wind Unpredictable. Tough on our current grid, which was built for predictability

Unpredictable Wind



greentechmedia

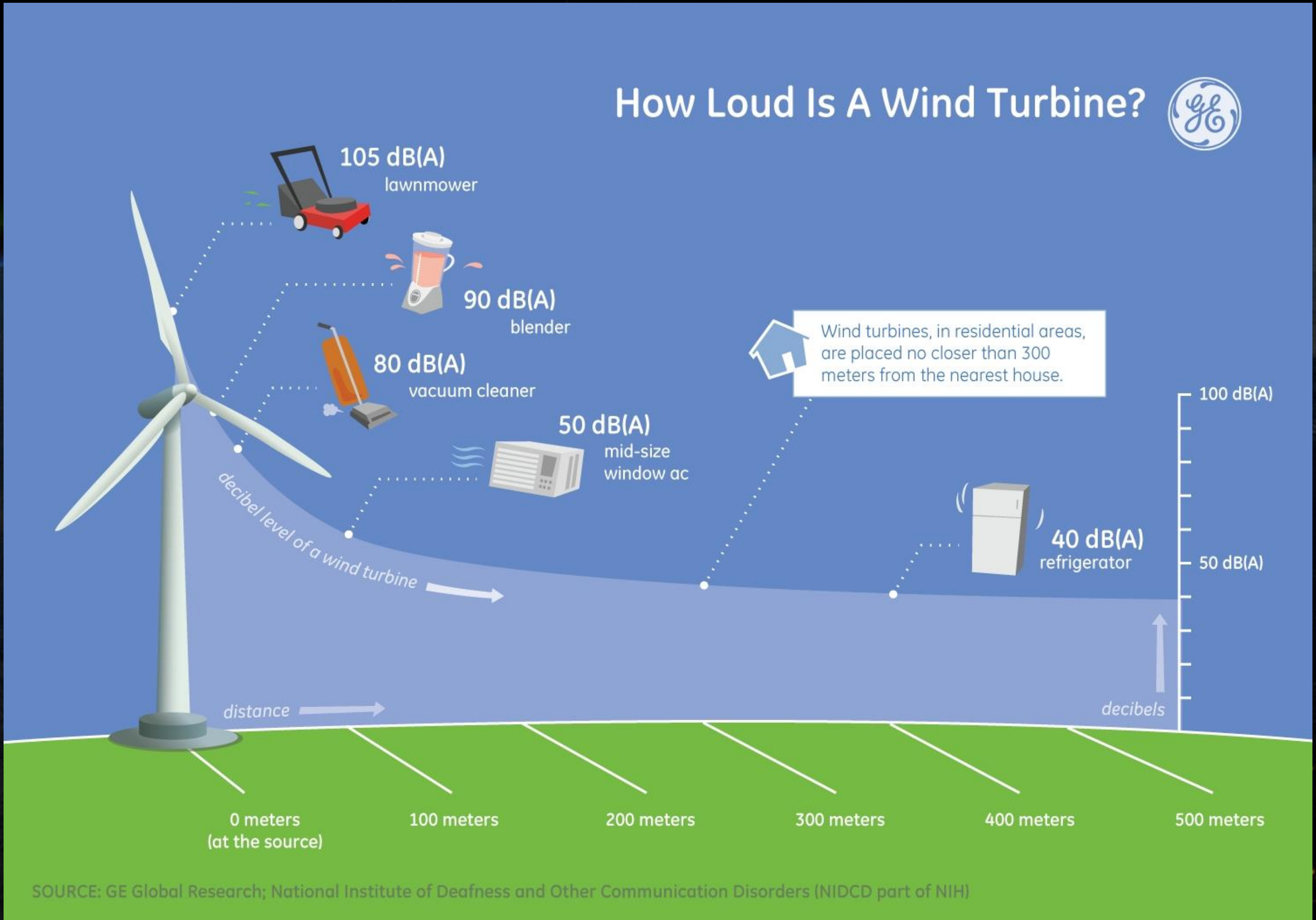
Wind: Downtime May Be Less of a Problem than Fossil Fuel Power Plants

- …says this white paper (not necessarily unbiased).
- Turbine maintenance is done individually, and power per turbine is much less than for a single large fossil fuel power plant, so maintenance less disruptive to power delivered.
- Also finds in Texas that wind variability will impose negligible additional cost for required additional capacity. Let's hope they're right!

But: Human Costs of Wind

- The New Generation of turbines are <u>much larger</u>, capturing higher wind speeds above the boundary layer
- But those living nearby: strobe and "whoosh" effects drives some people "crazy"

Even at ½ km: Loud as a Refrigerator 40dB(A) "Whoosh…Whoosh…"



And, Wind Turbines Cause a WARMING at Earth's Surface

- Say what? (Miller *et al.* 2018, discussed here)
- **Cooler denser surface air gets mixed with warmer air aloft.**
- A "massive deployment" of wind turbines could warm surface temperatures by +1C.

Still some bugs to work out: Fires 10x more than predicted

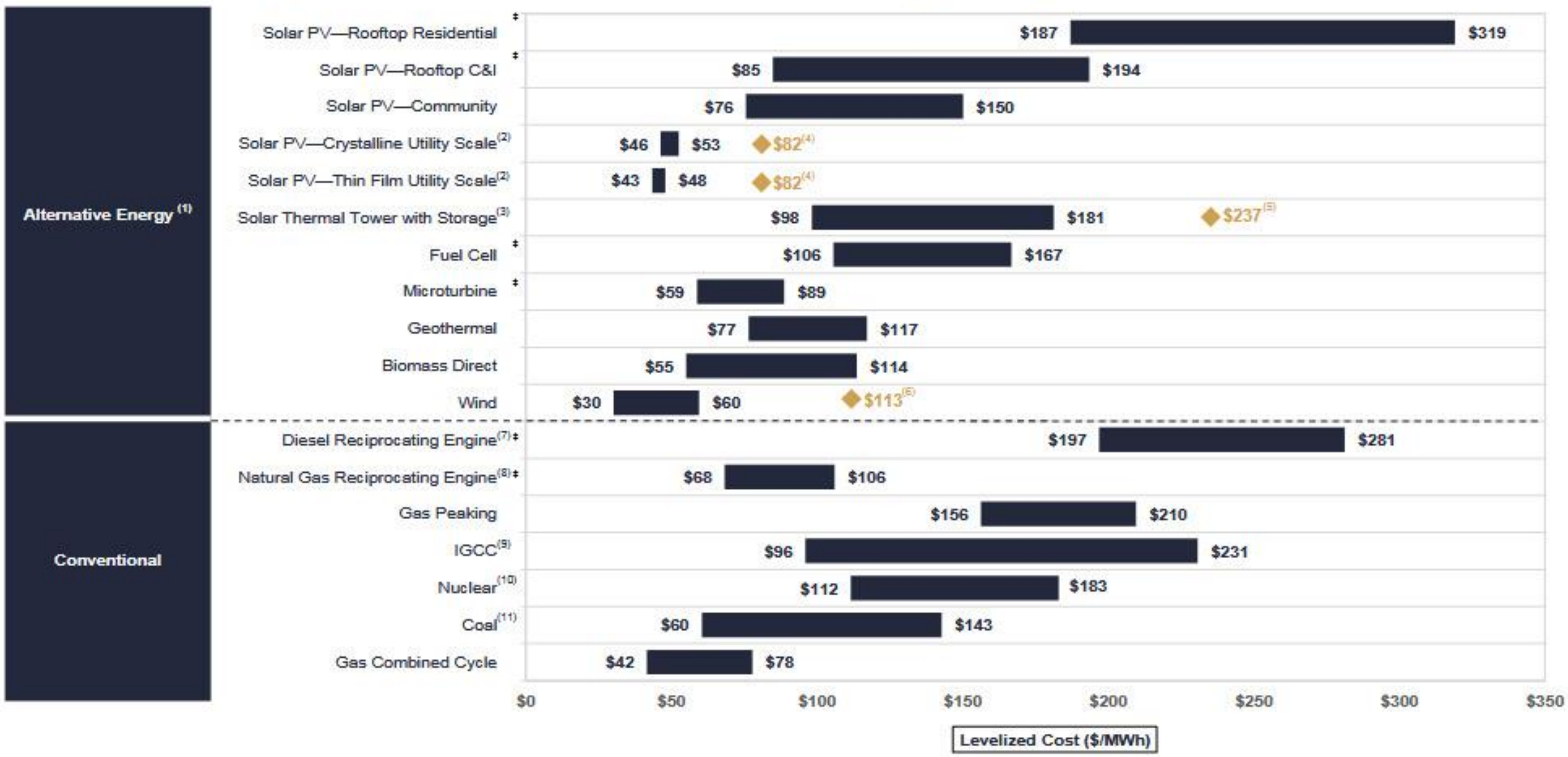
Offshore Wind: Better Use of Land, More Consistent Wind

- Should be confined to certain places with shallow water, no shipping.
- Servicing more expensive
- Isolating salt water from power lines?

Levelized Costs: Highly dependent on assumptions. At least, these below have consistent assumptions

Unsubsidized Levelized Cost of Energy Comparison

Certain Alternative Energy generation technologies are cost-competitive with conventional generation technologies under some scenarios; such observation does not take into account potential social and environmental externalities (e.g., social costs of distributed generation, environmental consequences of certain conventional generation technologies, etc.), reliability or intermittency-related considerations (e.g., transmission and back-up generation costs associated with certain Alternative Energy technologies)



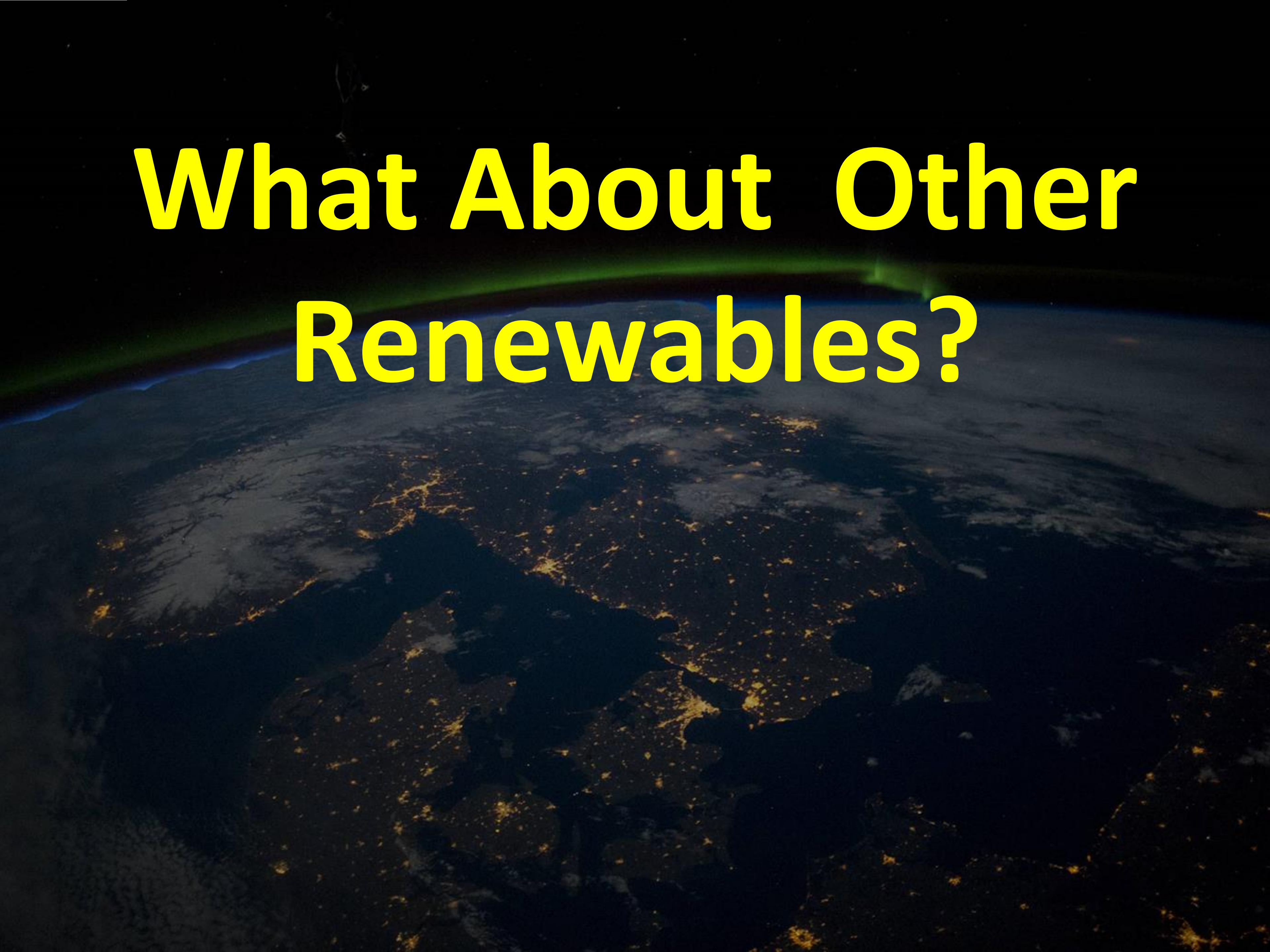
Source: *Lazard estimates.*

Note: Here and throughout this presentation, unless otherwise indicated, analysis assumes 60% debt at 8% interest rate and 40% equity at 12% cost for conventional and Alternative Energy generation technologies. Reflects global, illustrative costs of capital, which may be significantly higher than OECD country costs of capital. See "Unsubsidized Levelized Cost of Energy—Cost of Capital Comparison" page for additional details on cost of capital. Analysis does not reflect potential impact of recent draft rule to regulate carbon emissions under Section 111(d). See Appendix for fuel costs for each technology. See following page for footnotes.

‡ Denotes distributed generation technology.

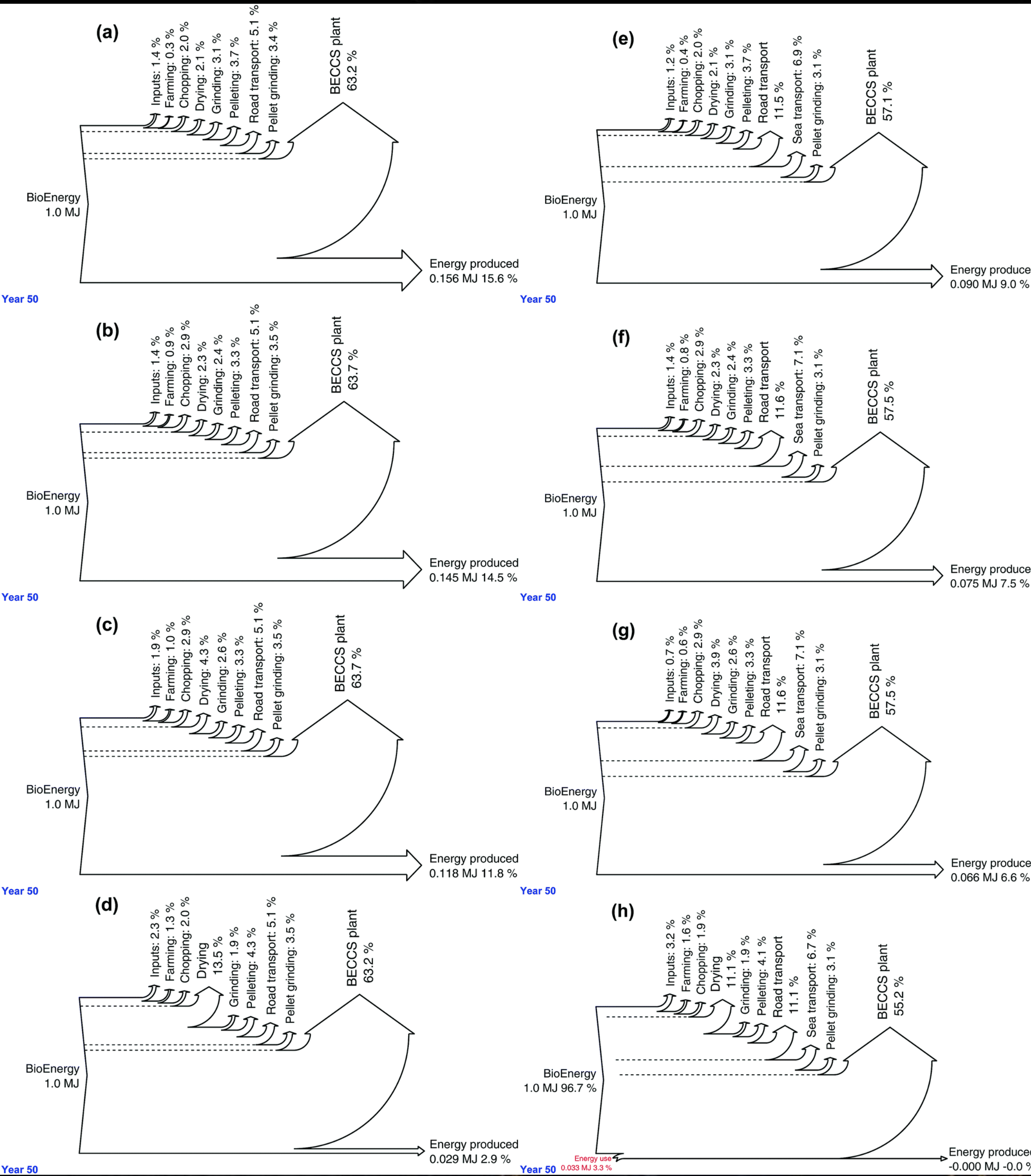
LAZARD

What About Other Renewables?

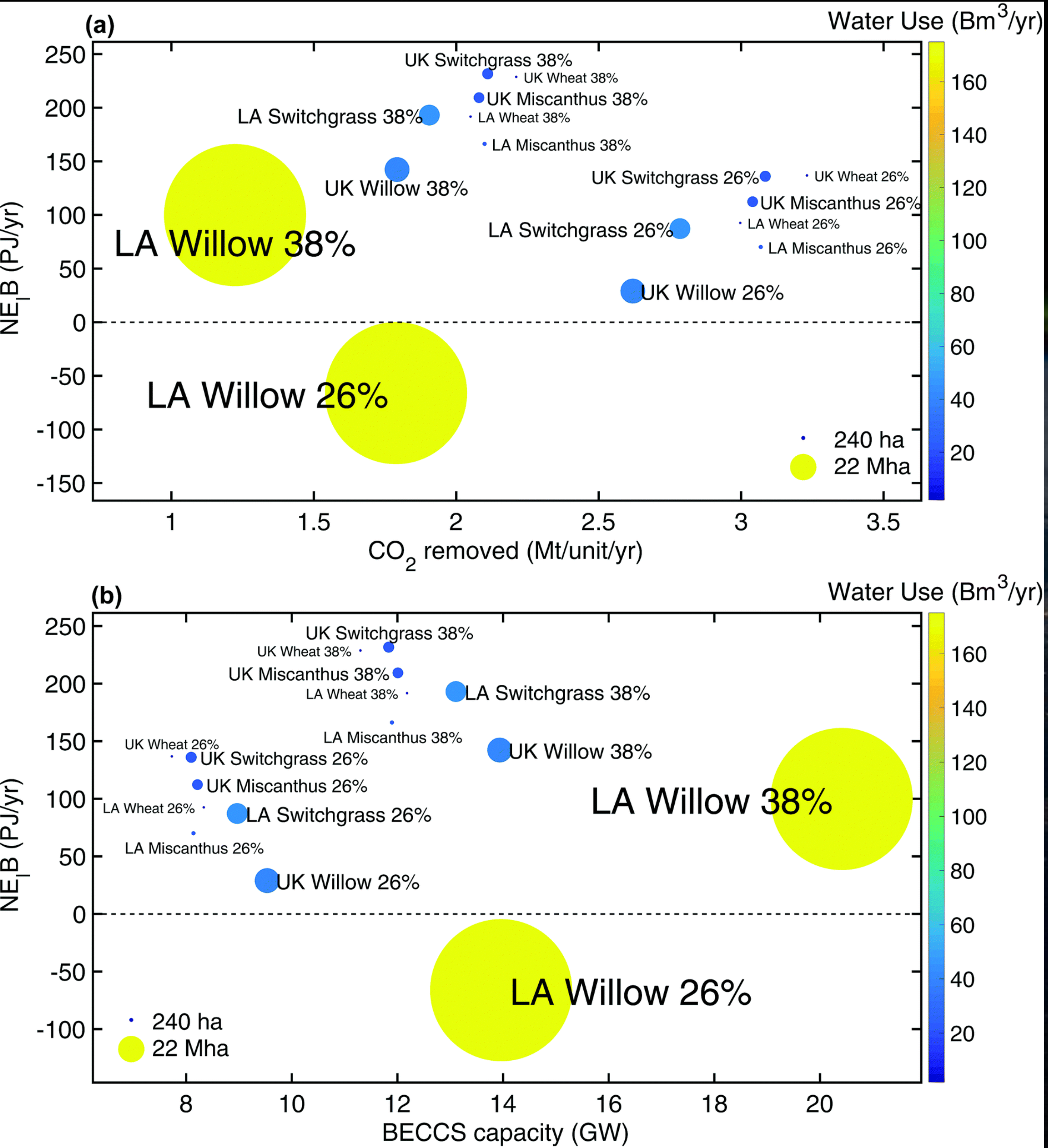


BECCS Looks Bad – May cost more energy to run it than it returns from the “bio energy”

- See (**Fajardy and MacDowell** 2018)
- Requires an area 4 times the size of India merely to grow the trees. CC is slow, requiring large land for throughput
- Was it political pressure that got this into the IPCC AR5??



Net Energy Produced? on Ragged Edge of Zero (bottom, flat arrow)



BECCS: 1,000 tons of fresh water to remove 1 ton of CO2, even for the most Optimistic Scenario

BECCS: Must Trade off Power Efficiency *vs.* CO2 Removal

- *"Increasing BECCS power generation efficiency would improve the system net energy balance, but would also result in a lower CO_2 removal per BECCS unit, hence requiring greater BECCS facility, as we have discussed previously,[40] and to a smaller extent, a higher amount of land and water required to meet a given carbon removal target."* (**Fajardy and MacDowell** 2018)

BECCS Damages Soil Health

- BECCS removes carbon, but also other nutrients and minerals from the soil, impoverishing it, accelerating erosion and desertification.
- Artificially fertilize denuded soil? Then what about the NOx greenhouse gases that result?
- Lost opportunity costs of the land?

BECCS Causes MORE, not LESS Environmental Damage

- *"We show that while large-scale BECCS is intended to lower the pressure on the PB's (**P**lanetary **B**oundaries) for climate change, it would most likely steer the Earth system **closer** to the PB for freshwater use and lead to further transgression of the PB's for land-system change, biosphere integrity and biogeochemical flows.*
- Source: The **Potsdam Institute for Climate Impact Research** (#1 rated climate research institute by U. Penn) (Heck *et al*. 2017)…
- *Clearly it fails all of our Framework efficacy, safety criteria*

Biofuels: Relentlessly Marketed, but Another Climate Non-Starter

BioFuels INCREASE CO2 Emissions, not reduce

- New study from the U. Michigan *"examined crop data to evaluate whether enough CO2 was absorbed on farmland to balance out the CO2 emitted when biofuels are burned. It turns out that once all the emissions associated with growing feedstock crops and manufacturing biofuel are factored in, biofuels actually increase CO2 emissions rather than reducing them."* (DeCicco *et al.* 2016)

But, it does provide big subsidies to farm states, to be highlighted during election campaigns.

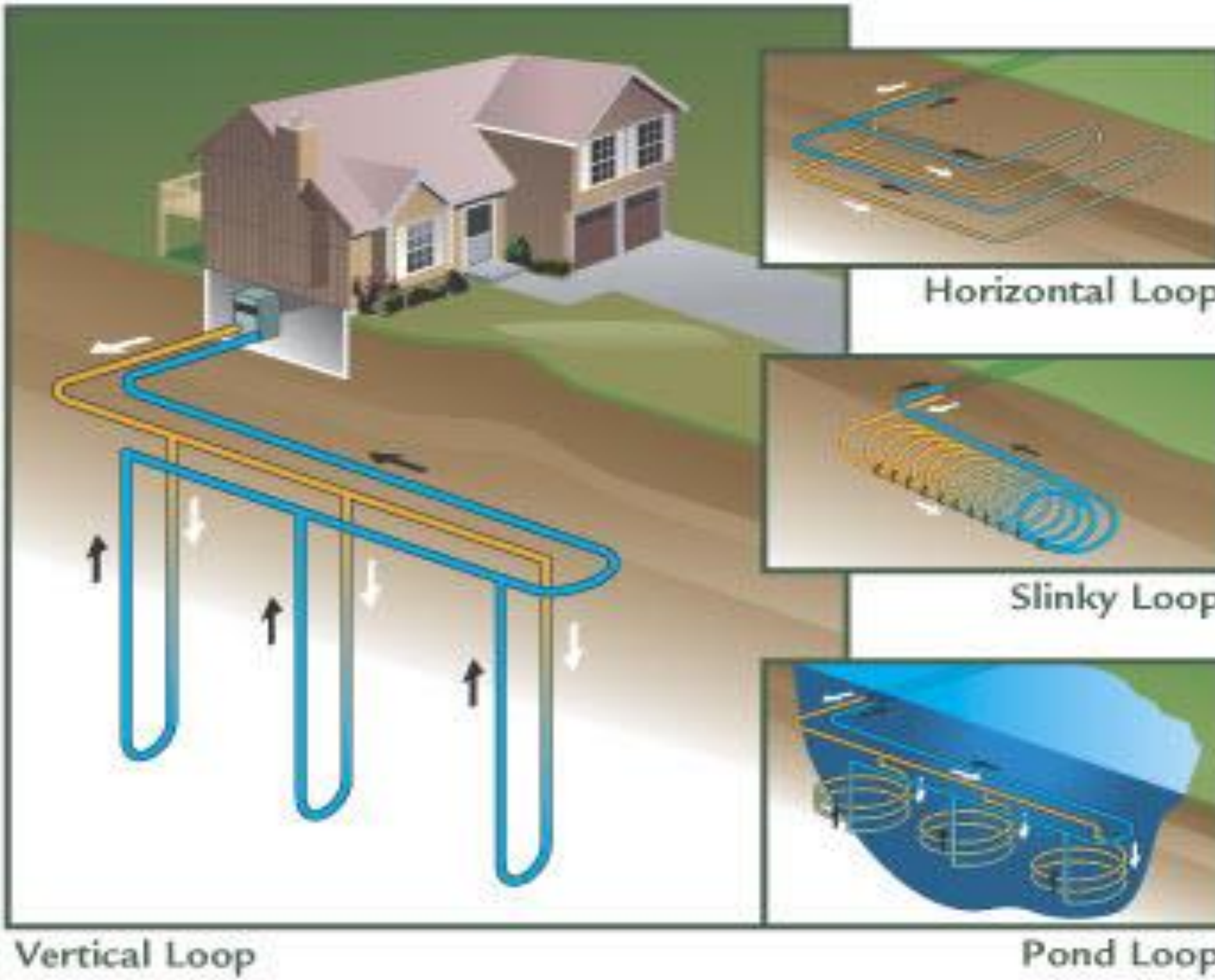
The plants grown for biofuels pull out only 37% of the atmospheric CO2 that is generated by burning the biofuel they produce!

- *"When it comes to the emissions that cause global warming, it turns out that biofuels are <u>worse</u> than gasoline," DeCicco said. "So the underpinnings of policies used to promote biofuels for reasons of climate have now been proven to be scientifically incorrect. (<u>source</u>)*

Geothermal Energy

- High grade geothermal (*i.e.* hot!) – can power electric generation but only in very rare places, like certain places in Iceland.
- Not enough to be climate-significant
- Not true for Low-grade geothermal; so can help heat/cool homes and should be used more widely.

Geothermal Energy for the Home



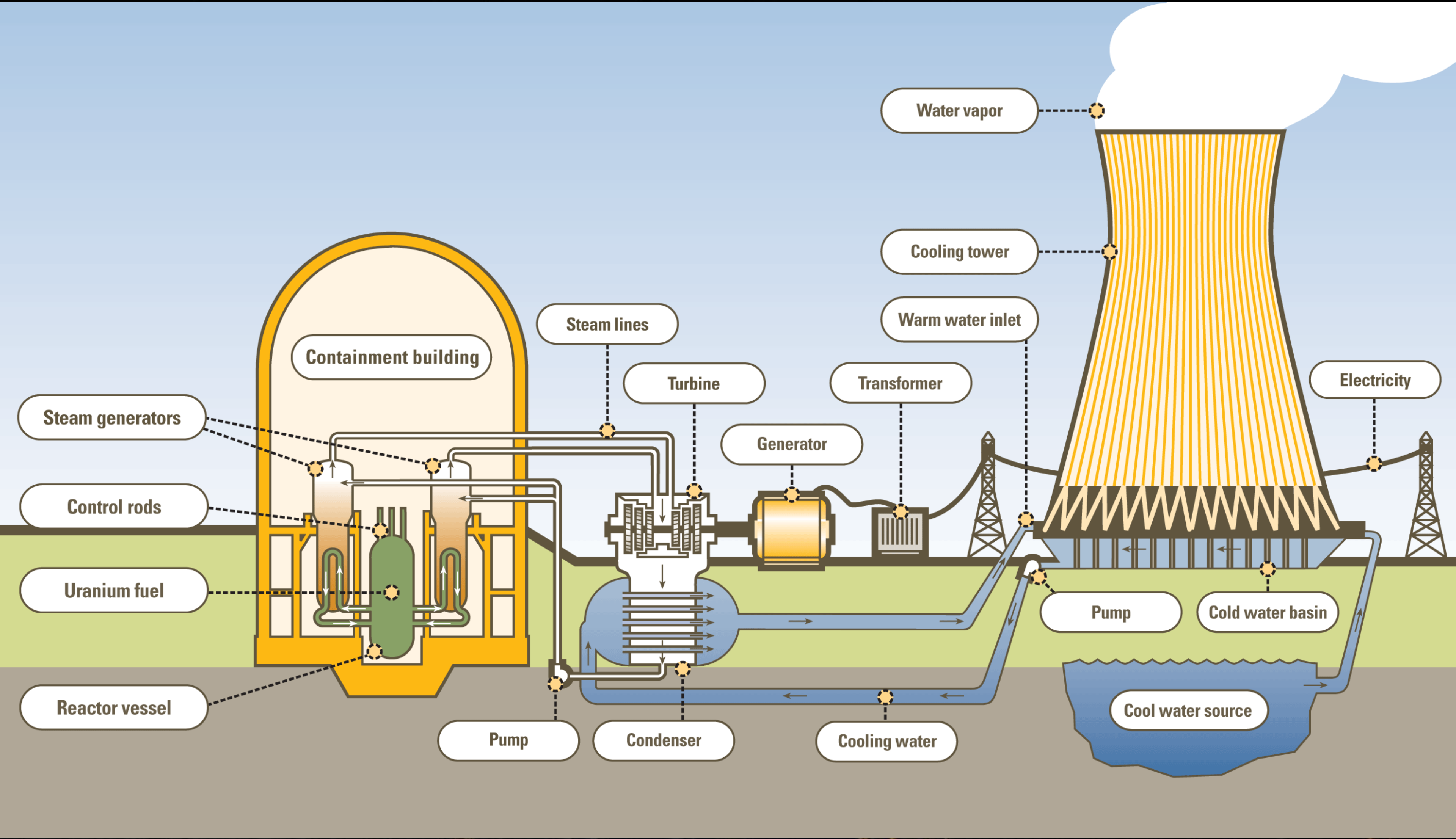
The Problem with low-grade Geo-Thermal is Cost

- It's up to $25,000 to put in place, for a single-family home sited on the ground. Govt credits can help.
- Typical payback time is roughly 10 yrs.
- Lifetime of the system is 15-25 yrs, so if you'll be living in the home for long enough, it can eventually pay off.
- However, it limits landscaping and other land-use options and that may lower home values, depending on buyers

Urbanization Doesn't Favor Geothermal

- With rising housing cost driving more high-rise and apartment dwellings, geothermal for multi-family will be much harder.
- Low-cost natural gas already has an in-place pipeline infrastructure and geo-thermal will likely only begin to win when fossil fuel alternatives get much more expensive.

Nuclear Power



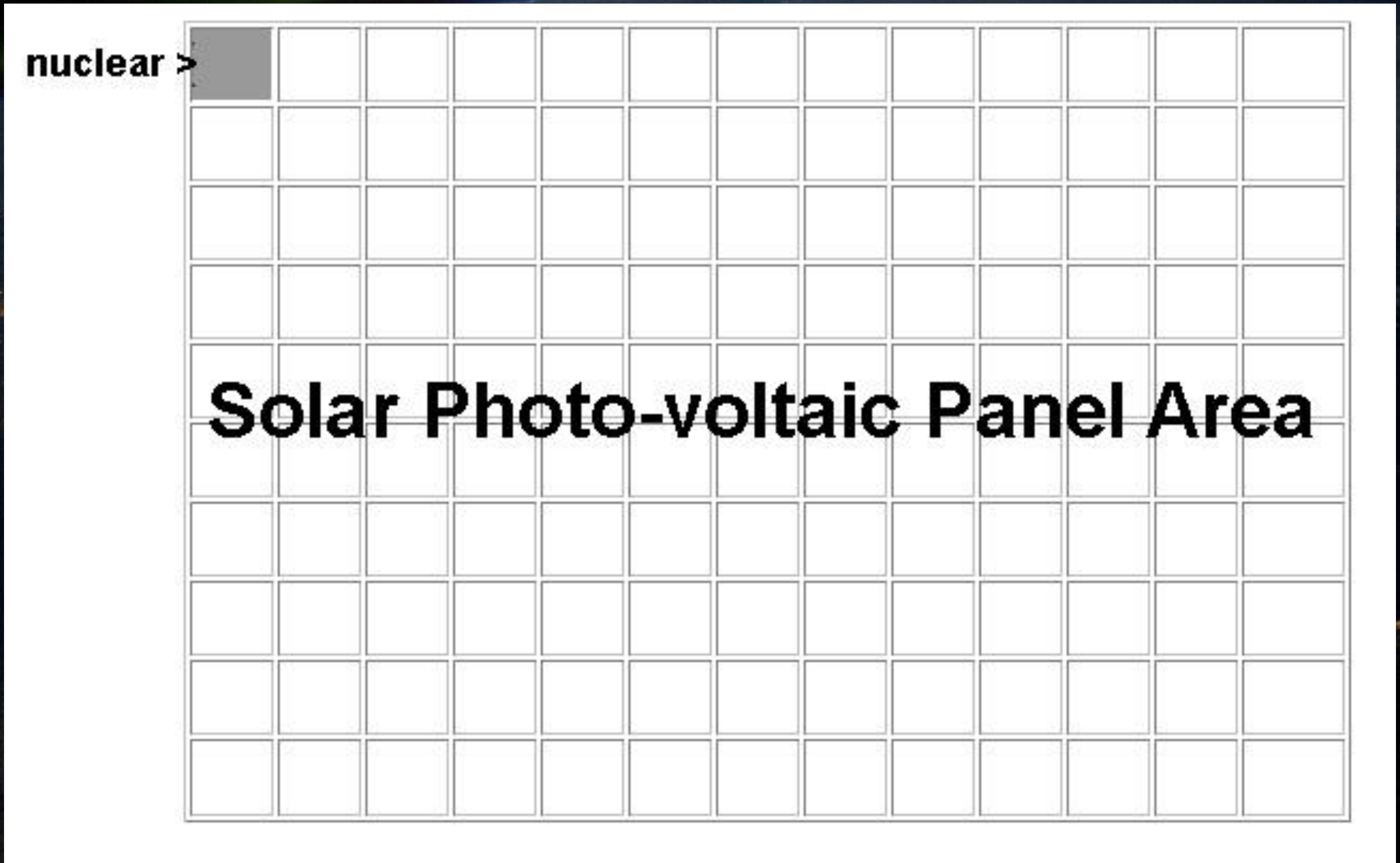
Nuclear – The Advantages over Solar/Wind

- "Always on" - minimal change to existing grid
- Can be sited almost anywhere; not wind or sunlight dependent.
- They take up VASTLY less land than equivalent solar and wind installations.
- Carbon footprint is very low, although on-going fueling and enrichment/security costs are significant *vs.* <u>no</u> fuel costs for solar, wind, geothermal, hydro

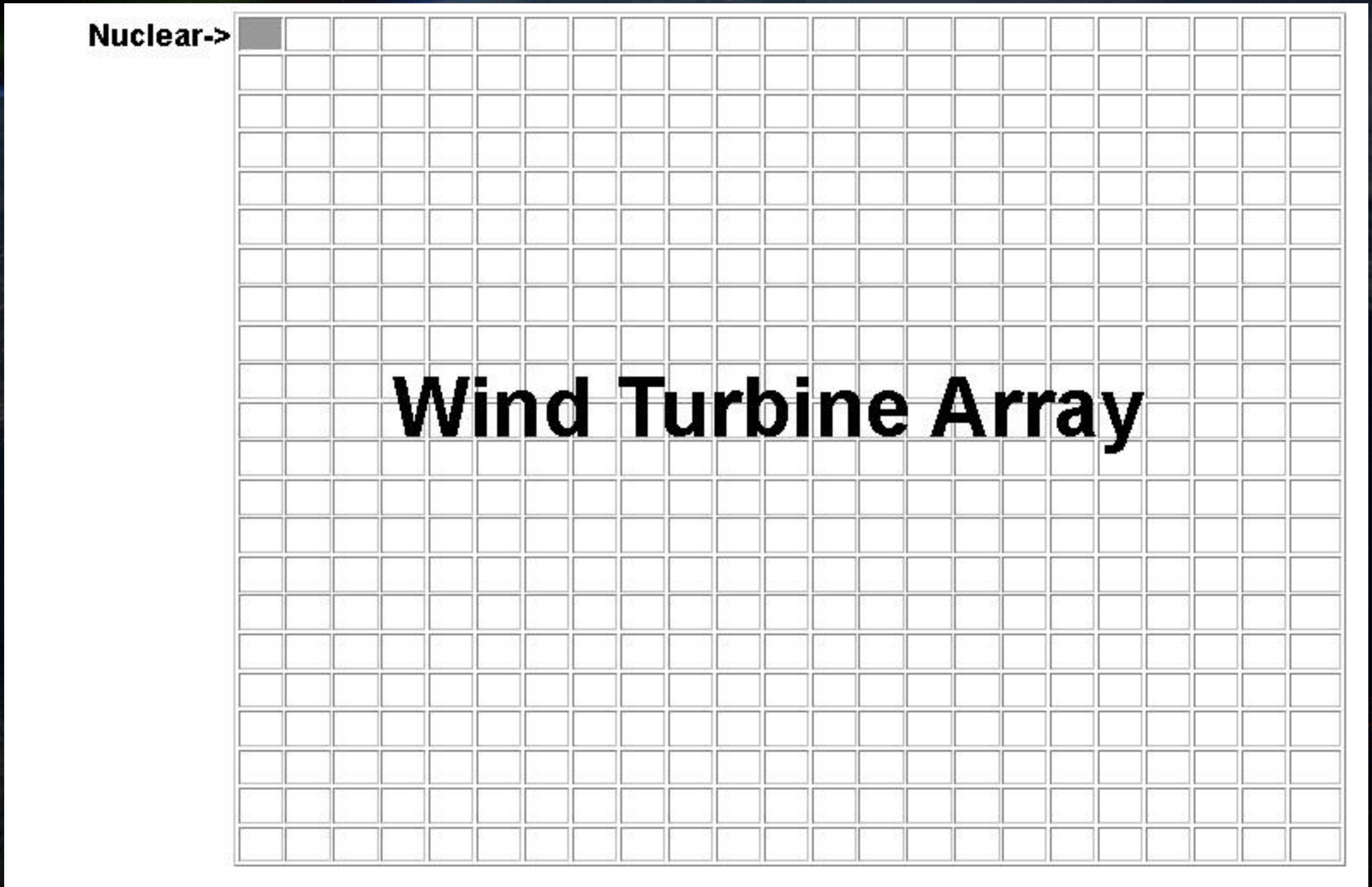
Eco-Efficient: Virtually All Species Need Sunlight. Only ONE Species (us) Can Use Thorium or Uranium

- 33 square miles of PV panels, and additional support area around them, would be needed to replace <u>one</u> 12-acre nuclear power plant (Diablo Canyon Nuclear Power Plant. Older design, even).
- That’s a lot of land to commandeer

Solar PV panel area is 125+ times larger than the land footprint for an equivalent nuclear power plant



Equivalent wind turbines is even worse: 500 times that for nuclear.
However, land underneath can be often be selectively used; *e.g.* agriculture, solar PV



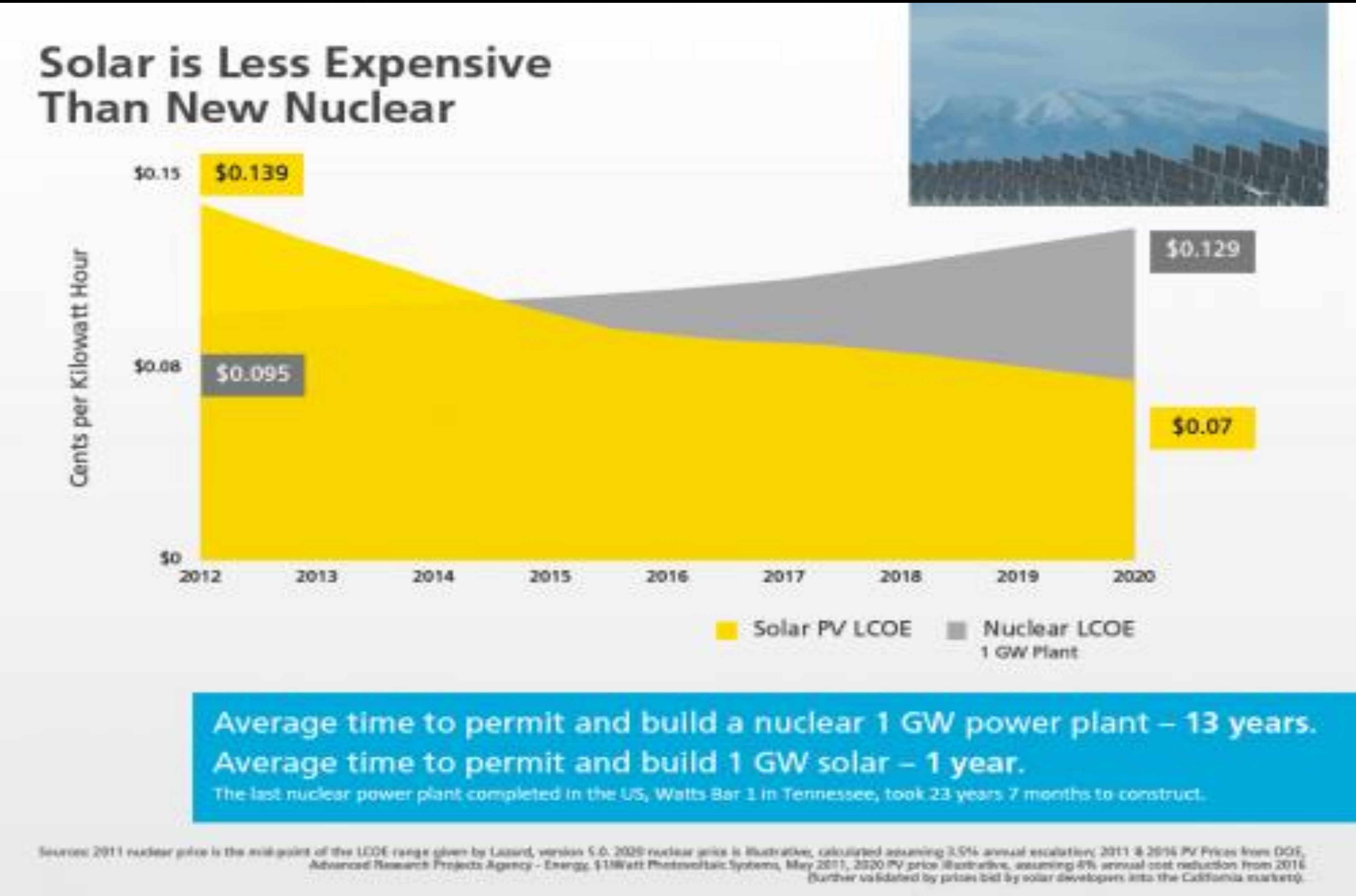
Nuclear – the Disadvantages *vs.* Solar/Wind

- Big and expensive. No car-sized "Mr. Fusion" is on anyone's horizon
- Safety - When they go wrong, they can go VERY wrong. Remember, bad engineers get jobs too.

Don’t worry about “The China Syndrome”, worry about the “Homer Simpson Syndrome”

- Nuclear Regulatory Commission employees caught surfing the web for porn while on the job (Washington Times article)
- Regulators sleeping with the industry people (literally) that they’re supposed to be regulating.

But – a Big Problem with Existing Nuclear Designs is Rapidly Escalating Cost:



And Doesn't Include Insurance. Uninsurable?

- Yes, says a German 2011 study (**here**) …
- …finds that insurance would cost at least as much as the electricity produced; $0.20/KwH at a bare minimum, on up to 15 times the price of the electricity produced ($3.40/KwH)
- Can newer, safer designs beat this? We hope! Too early to say.

But There's an Even Bigger Problem with Going Nuclear…

- We won't solve climate change unless we eliminate nearly all carbon emissions globally…
- The rapidly rising CO2 emissions are coming from the Developing World…
- **So…** here's the $64,000 question:

Will the U.S. and Europe Provide the Technology, Knowledge and Nuclear Materials…

- …to countries like Iran, Syria, Egypt, Yemen, Somalia, Libya, African dictatorships, etc, to help them transform their energy system to nuclear, as they envy American wealthly lifestyles and energy footprints?
- **Seems vastly unlikely**, especially in a world entering an era of climate chaos, desperation from “have not” countries, rising tribalism, and walls going up on national borders, and the very real possibility of societal breakdown this century.

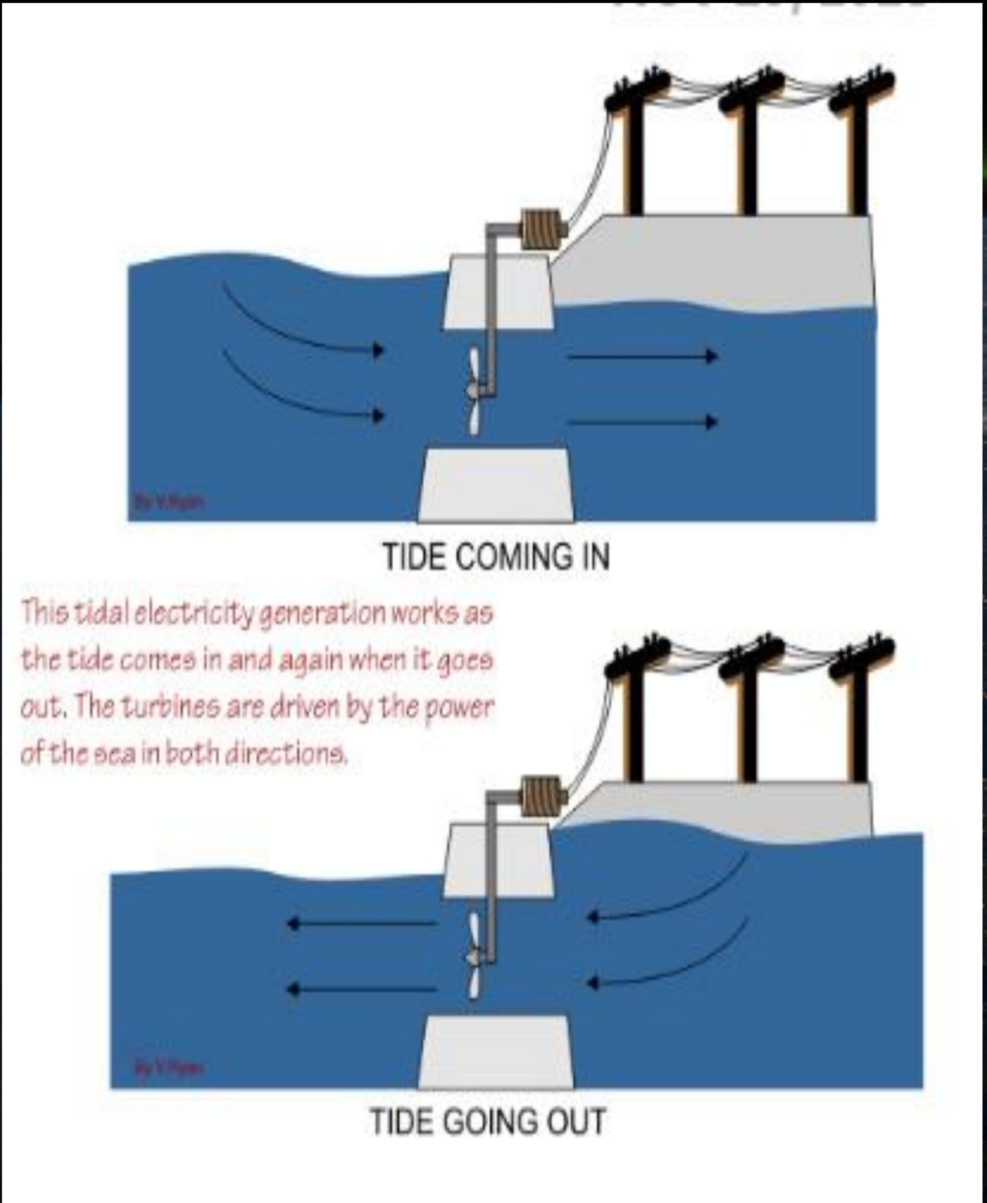
Nuclear Safety: Waste and Terrorism, and Breeder Solutions

- Conventional Uranium light water reactors extract only ~1% of the available nuclear energy.
- Thermal breeders like some Thorium designs use a much higher fraction, produce much less nuclear waste.
- Fast Breeders: can “burn” most of the nuclear waste we’re trying to figure out how to dispose of.
- Small remaining waste is radioactive for a couple of centuries, not millennia.

Molten Salt Thorium Reactors (MSRs)

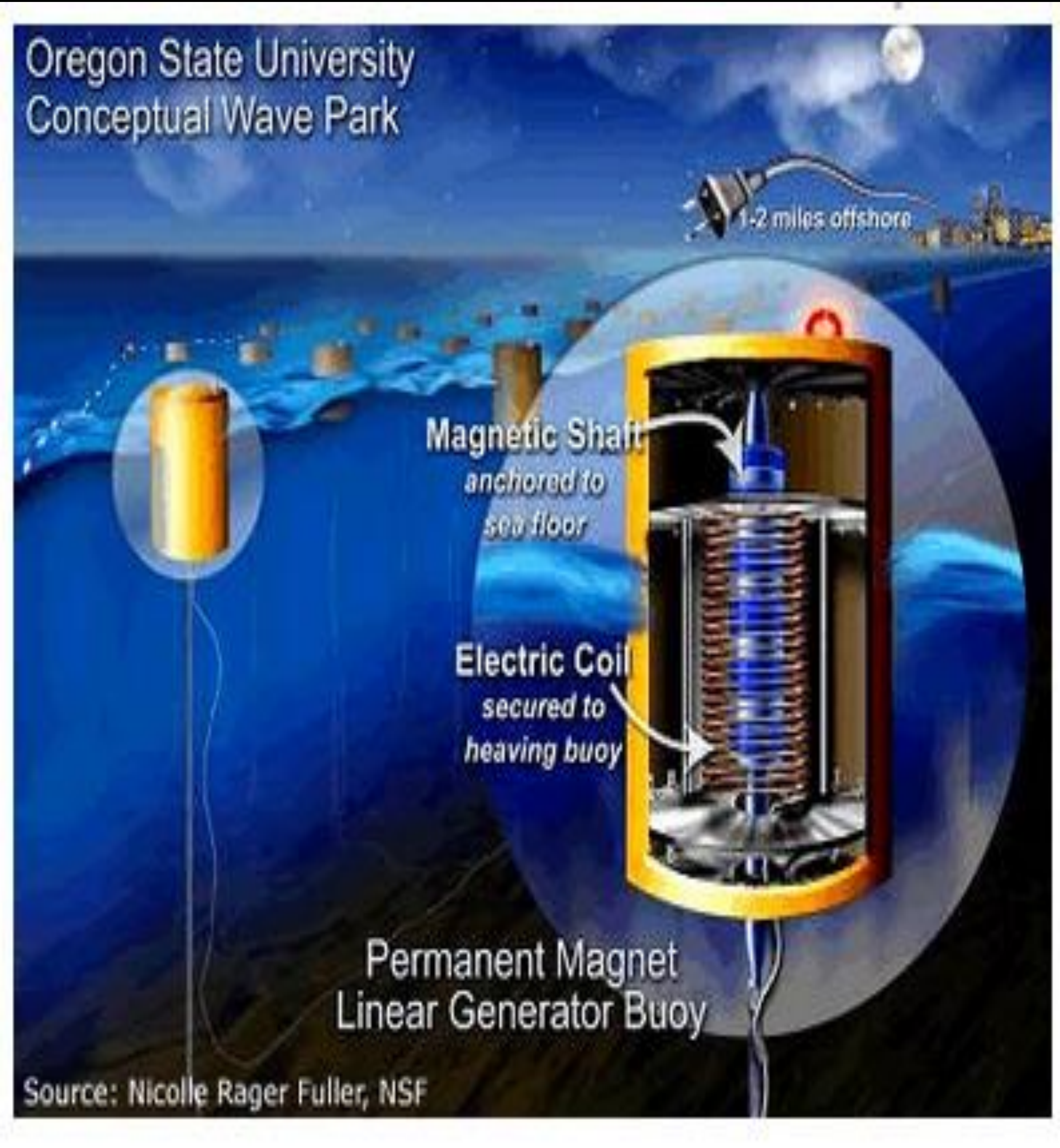
- …are getting a lot of interest. Liquid fuel allow designs making melt-down impossible
- Thorium, unlike Uranium, supplies will last for a thousand years
- Bomb-grade U-233 is in the thorium nuclear cycle. It's burned, still it must be safe-guarded.
- Radioactive waste. It's much less than conventional nuclear, but inventory tracking of these particular nuclear materials very difficult
- So MSR's are promising, but not perfect.

Tidal Energy



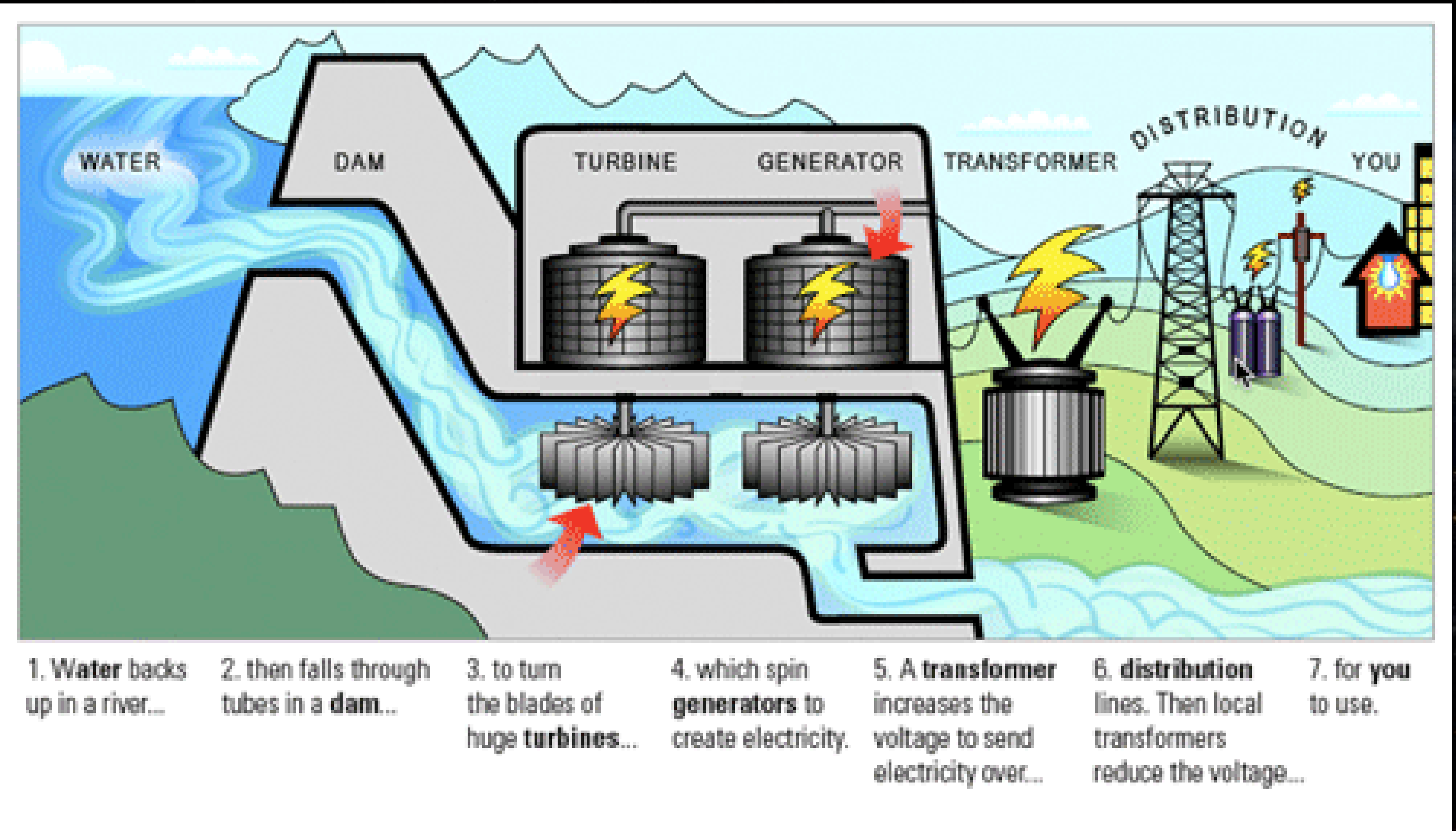
- Coastlines are the most precious, valuable lands and ecosystems we have
- Do we really want to build huge facilities to interfere with these?
- Built at narrows of large inlets, can concentrate power. Even so, the commercial SeaGen plant at such a location in Ireland, produces only 1/1,000th the power of a large conventional power plant.

Wave Energy



- Essentially a more intrusive and indirect way to tap wind energy, but needs to be in the coastal ocean ecosystem and corrosive salt water environment.
- Low power density.
- Shallow continental shelf is where most ocean eco-productivity is. Do we really <u>want</u> these things here?

Hydroelectric Power



Hydroelectric is very cost effective; high EROI (Energy Return on Energy Invested), BUT…

- …most of the usable sites are already dammed
- It's not scalable
- Costly to local ecologies,
- Expensive and scarring to remove dams once they silt up.
- Climate-caused drought will hurt mid-latitude river flows going forward.
- Power can be constant <u>on</u> (unlike wind, solar)…. (at least until reservoir runs dry, or silts up… then constant <u>off</u>!)

In 2013 hydroelectric accounted for fully **50%** of U.S. renewable energy

- …and 6.8% of electricity generation in the U.S.
- Globally, hydro supplies 16% of total electricity generation (not the same as total energy generation), but has displaced 60 million people.
- And has been expected (hoped?) to grow at about 3% per year for coming years, but in fact it has not been growing significantly for decades.

Hydroelectric Dams Often Produce More GHGs Than they Prevent!

- Decaying drowned vegetation produces methane. **Large reservoirs produce as much methane as the entire global Fossil Fuel industry…**

- *"In 2012 study, researchers in Singapore found that greenhouse gas emissions from hydropower reservoirs globally are likely greater than previously estimated, warning that "rapid hydropower development and increasing carbon emissions from hydroelectric reservoirs to the atmosphere should not be downplayed."*
- *Those researchers suggest all large reservoirs globally could emit up to 104 teragrams of methane annually. By comparison, NASA estimates that global methane emissions associated with burning fossil fuels totals between 80 and 120 teragrams annually." (source)*

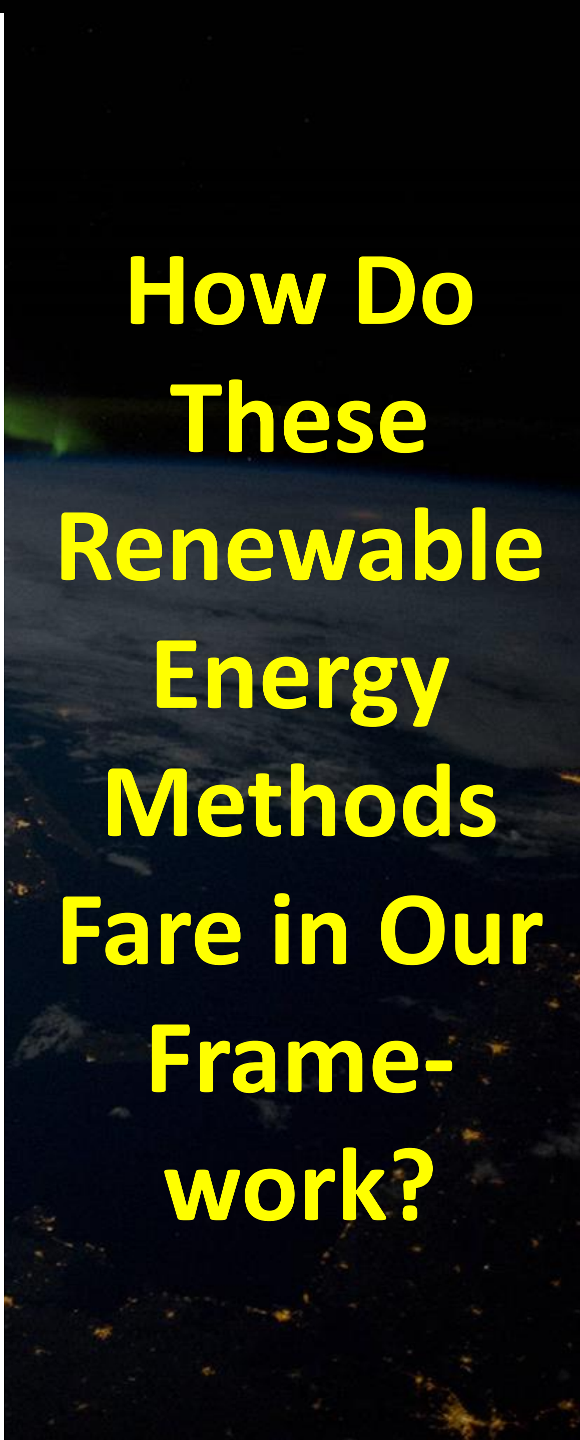
Dr. Joe Romm Writes…

- *"A 2011 study published in the science journal Science found that the ability of terrestrial ecosystems to act as carbon sinks, which contain greenhouse gases and keep them out of the atmosphere, could be up to 25% less than previously thought when the greenhouse gas release from reservoirs is taken into consideration."*

New Cement Technology; Sequestering CO2 While Making Stronger Concrete

- Traditional cement making heats limestone and releases CO2 to get the lime.
- The new tech mixes in CO2 grabbed from the atmosphere or fossil fuel plants while it's being made, sequestering it while it hardens, and also strengthening the resulting concrete.
- Estimated that if adopted worldwide, would reduce anthropogenic CO2 emissions by up to 5%.
- The added cost of the process is balanced by needing less cement because it is stronger. Still, adoption rates are low, so far; only 1.6% of cement-making plants in U.S. + Canada are using it.

How Do These Renewable Energy Methods Fare in Our Frame-work?



Renewable Energy Method	Reduce FF Use	Respect Earth Surface	Friendly to Existing Grid	Scalable to Climate Significant
Solar PV on Structures	Very Good	Very Good	Poor	yes
Utility Scale Solar PV	Very Good	Poor	Poor	yes
Solar Thermal	Very Good	Poor	Medium-good	OK - yes
Wind (on land)	Very Good	Fair to Poor	Medium	yes
Wind (off shore)	Very Good	Medium	Medium	Yes?
Geothermal (high grade)	Very Good	Good	Very Good	no
Geothermal (low grade)	Fair-Good	Good	Very Good	some
Nuclear (new designs)	Very Good	Excellent	Excellent	yes
Tidal and Wave	good	poor	Medium	Only at great ecological cost
Biofuels	No	No	N/A	poor
Hydroelectric	No	No	Yes	poor

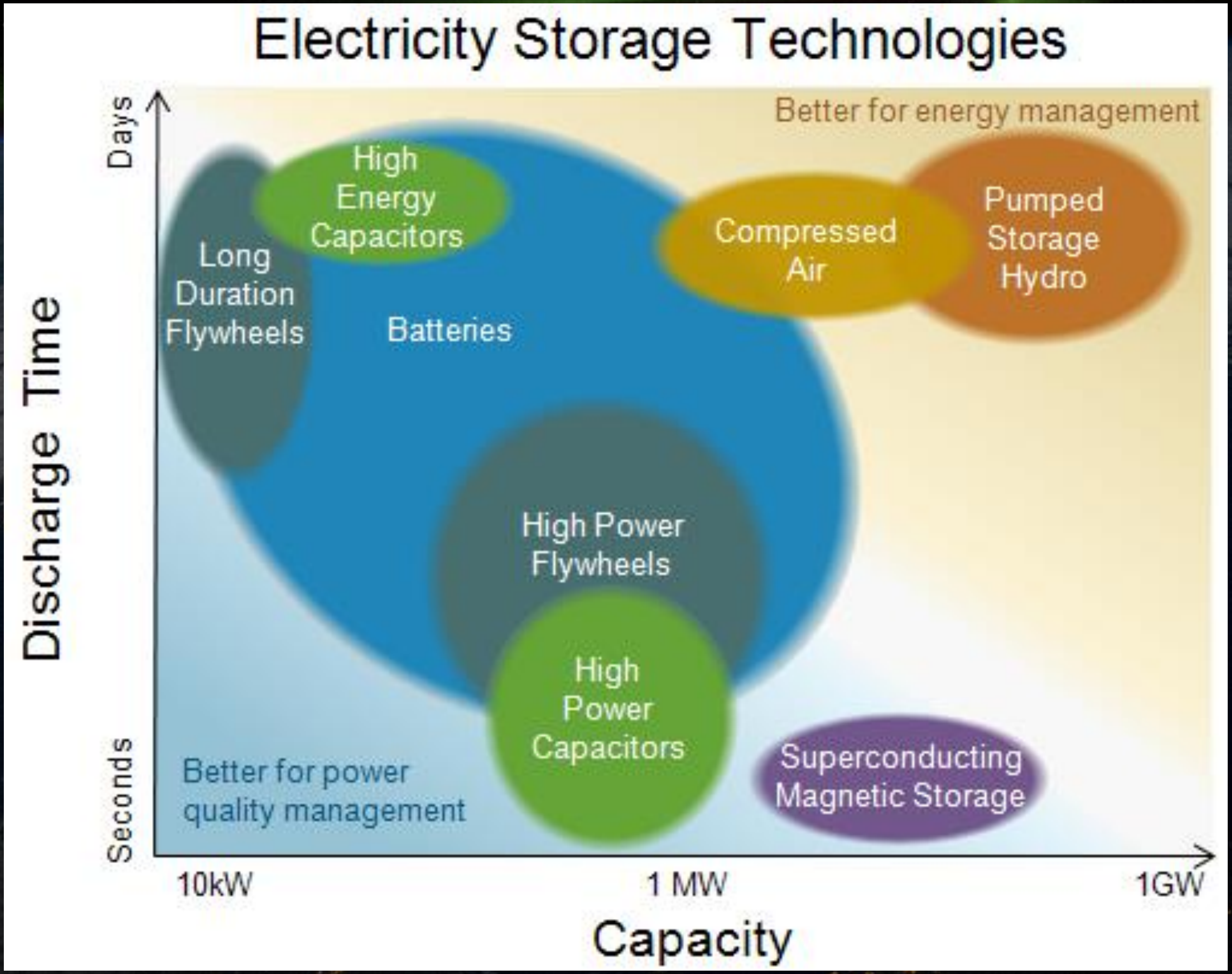
Summary on Renewable Energy

- **Solar PV on structures is a no-brainer win/win**
- Utility-scale solar PV/Thermal has been damaging to natural ecosystems, but still necessary.
- Wind; cheap, best combined with solar farms and Ag land to minimize footprints
- Residential geo-thermal expensive, but good use of thermal Earth inertia to save AC/heating
- New nuclear: safer, much less waste, but likely expensive and nuclear proliferation still problem. Uninsurable?
- Tidal, Wave, new hydroelectric all environmentally poor-to-fail

Section D. Energy Storage

Necessary if Solar and Wind is to make up a substantial fraction of our power

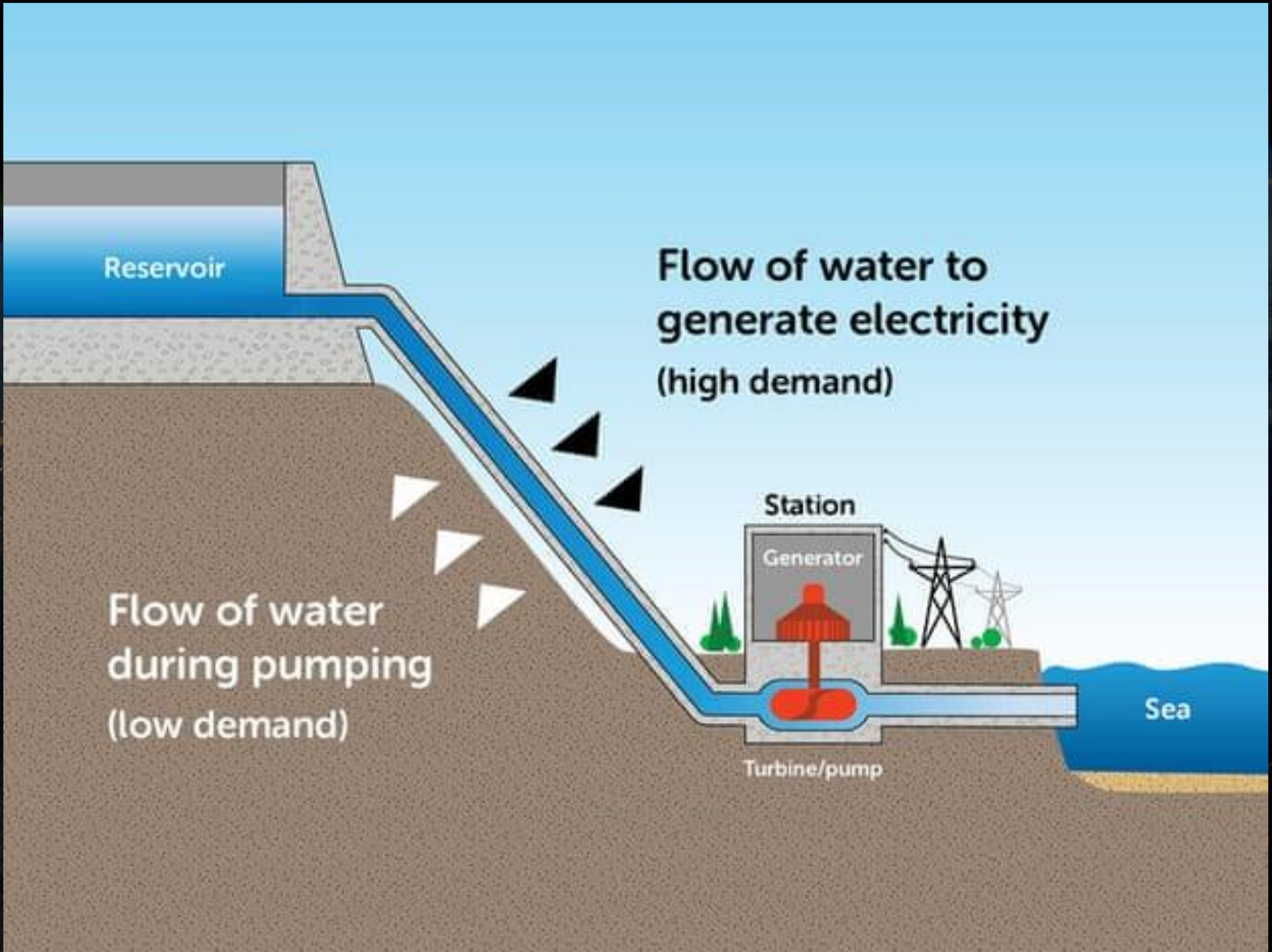
Ideal is High Capacity and High Recharge / Discharge Rate, Especially for Transportation. We're Not Quite There



Ultra Capacitors

- Simple: Two electric plates and an insulator between them, and store charge on one side
- Ultra-Capacitors charge and discharge very fast.
- Elon Musk was totally enamored with them in college, decades ago!
- So what happened?...
- Their charge leaks away too quickly. Like a bicycle tire with a pin prick leak. Maddening!
- Otherwise, they'd be great for EV's.

Pumped Hydro Storage: Systems Have Existed for Decades



Pros/Cons of Pumped Hydro

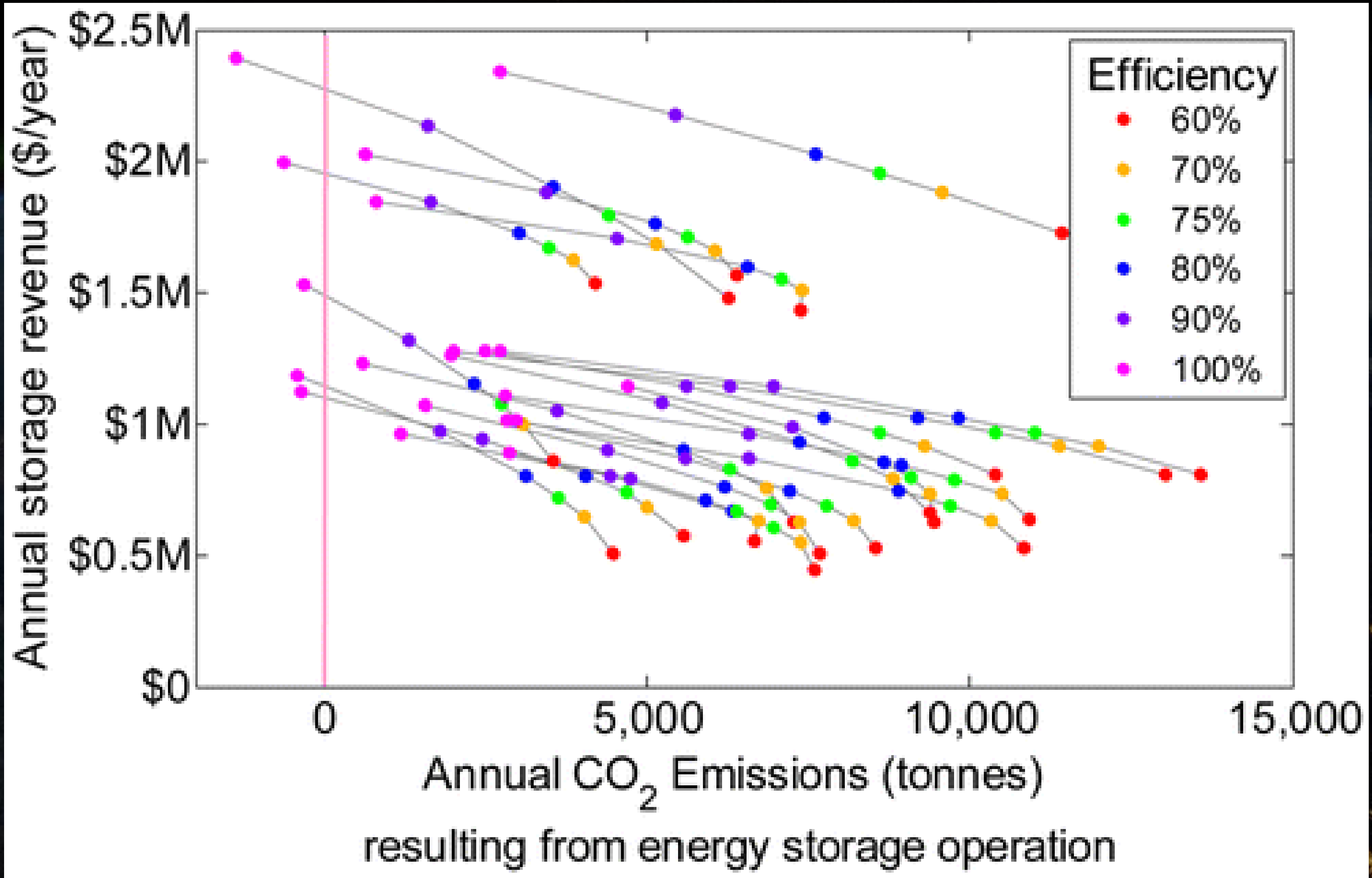
- Only select locations: Need water source, safe reservoir, significant elevation. Most suitable sites have already been used, (same for compressed air in geological formations).
- Water flow can't do fast adaptation to changing load.
- Cheapest form of storage, far cheaper than batteries. 99% of current utility energy storage is by pumped hydro!
- Energy stored w/o loss for unlimited time, unlike batteries or most other ideas

"Energy Cache": Gravity-based "ski lift" of Gravel Buckets. More Suitable Sites than Pumped Hydro. Still Need Topography

"Energy Vault" – Gravity System of Rising and Falling 30 Ton Bricks on Cranes. Don't Need Mountains. Quicker Adaptation to Load than Pumped Hydro, but Much More Expensive Per Energy Storage Unit

Li – Ion Battery Packs. Very Expensive. This Facility Provides only 300 MWh of Storage and 50MW of Power, sits on 4 acres. That’s only 5% of the output of a typical power plant on the same acreage

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



Yow! Why??

- Because they add to the economics of coal-fired power plants, which still produce most of our power.
- Coal power plants can generate energy when not needed, store it, release it during high-demand times when it can be priced higher.
- But the storage and release both involved energy losses, which must be made up by HIGHER coal power production.

Electric Vehicles plugged into our existing grid, produce WORSE net environmental damage than the gasoline cars they replace – *Proceedings of the National Academy of Sciences* paper in 2018

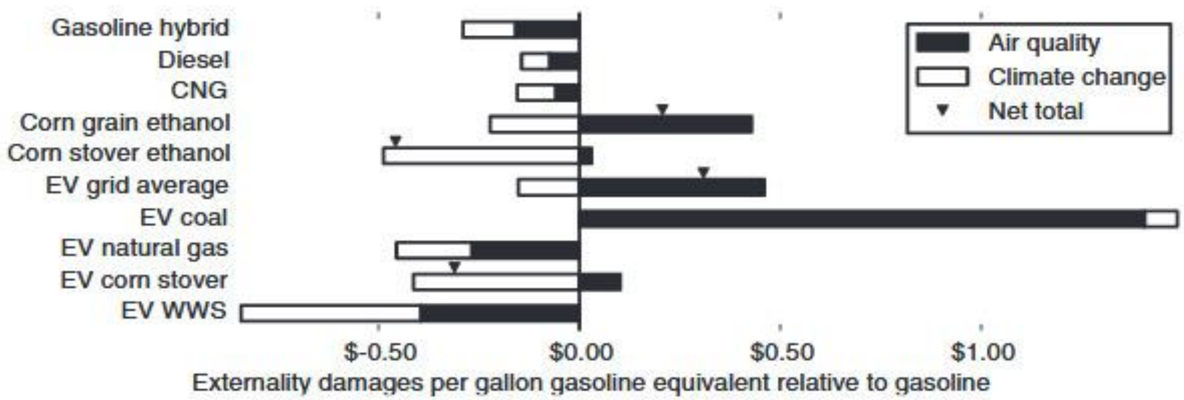


Fig. 3. Combined air quality plus climate change externalities attributable to each scenario, relative to the gasoline scenario. [The gasoline scenario impacts (air quality, $0.53/gallon; climate change, $0.46/gallon) would equal zero on this plot.] EV scenarios include battery production. Air quality 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.* 2018 show that when the true 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

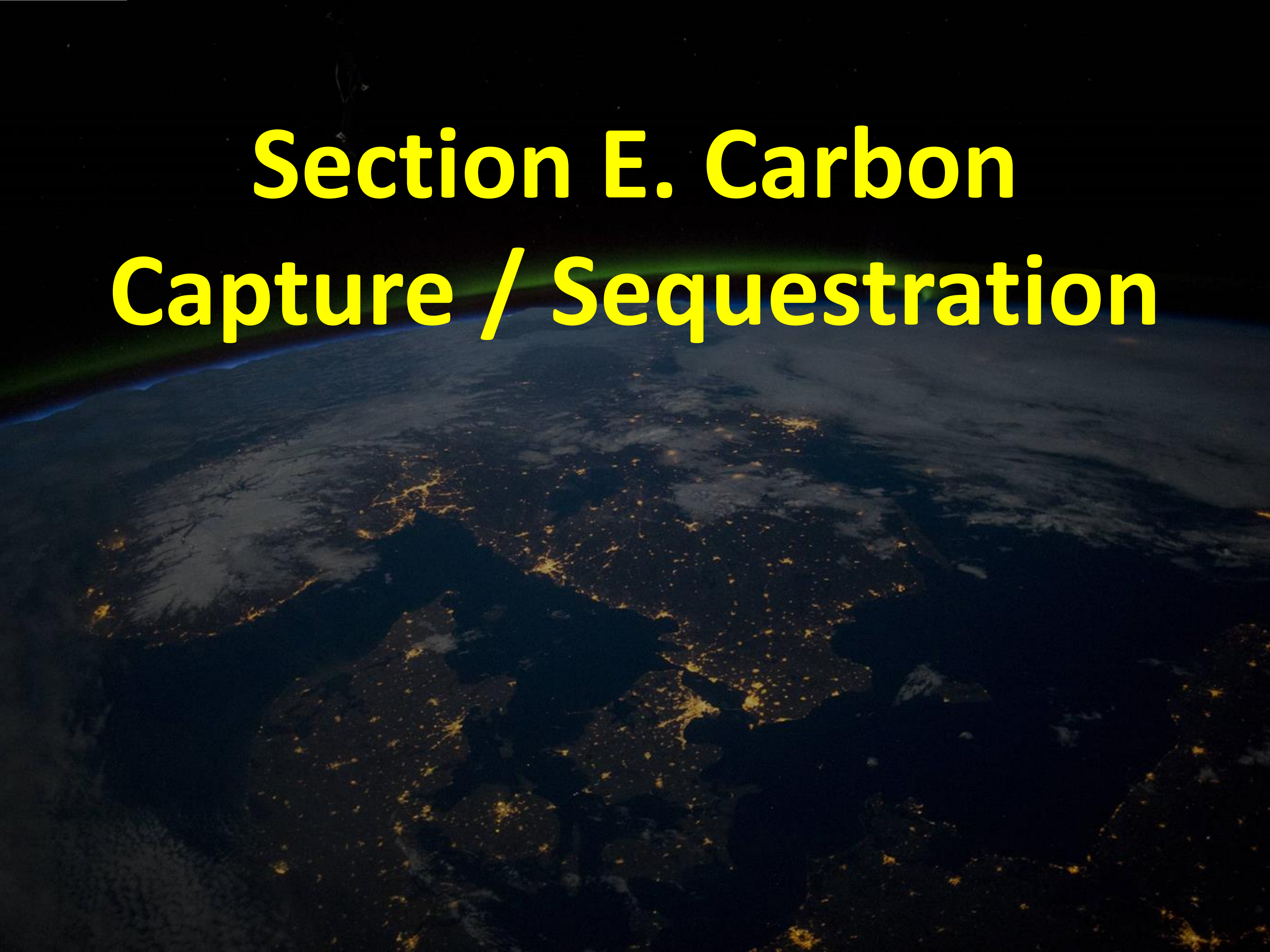
The Staggering Impact on Natural Resources for these High-Tech Solar/ Battery / Storage Needs

- Herrington *et al.* 2019 show that to meet… *"electric car targets for 2050, we would need to produce just under two times the current total annual world cobalt production, nearly the entire world production of neodymium, three quarters the world's lithium production and at least half of the world's copper production."*

While You Let That Sink In…

- …realize these vast resources are **not** what's required to satisfy GLOBAL electric car demand for zero emissions…
- No, that amount of mining, even if possible…
- **…is just to meet the electric car demand for zero emissions in the United Kingdom alone. ONE country, not the World.**
- **So, Is this even possible, we wonder?**

Section E. Carbon Capture / Sequestration



2018 Nature Conservancy Study: Max possible avoided CO2e =21% of U.S. emissions, and only with ~12x higher carbon market prices than present

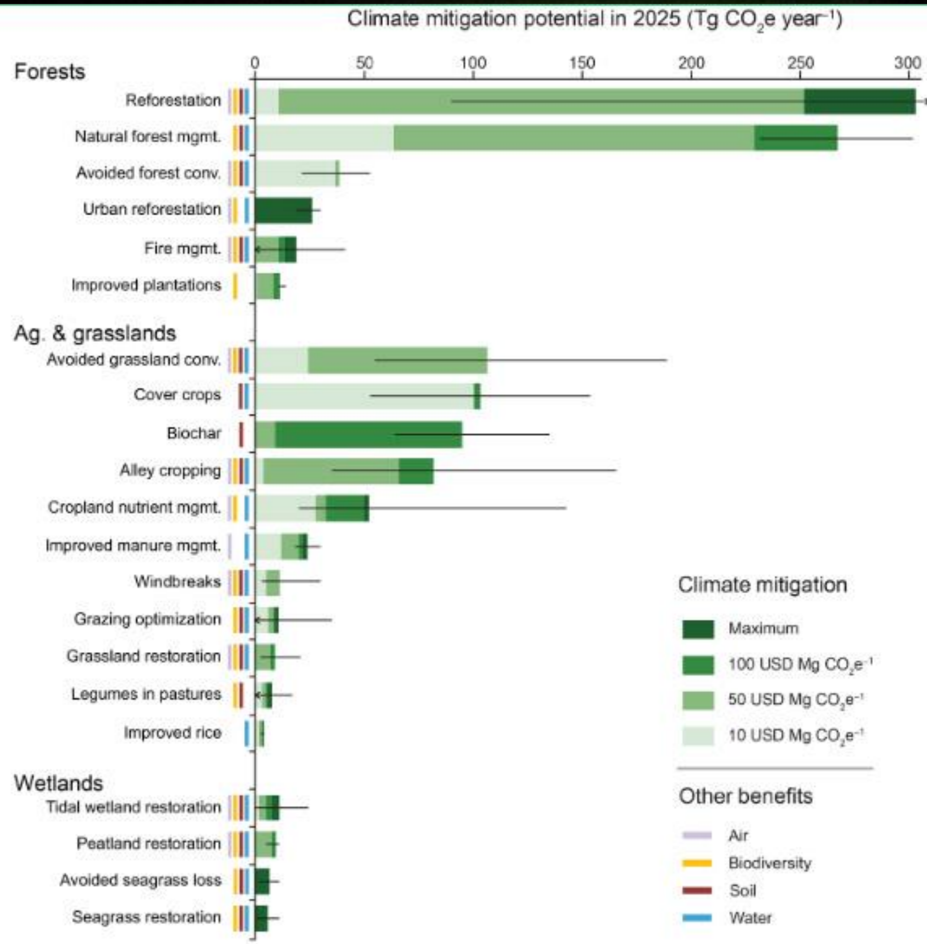


Fig. 1. Climate mitigation potential of 21 NCS in the United States. Black lines indicate the 95% CI or reported range (see table S1). Ecosystem service benefits linked with each NCS are indicated by colored bars for air (filtration), biodiversity (habitat protection or restoration), soil (enrichment), and water (filtration and flood control). See the Supplementary Materials for detailed findings and sources.

CCS has become CCUS

- **C**arbon **C**apture, **U**se, or **S**equestration (Hunton & Williams 2012), mainly goes to?... **enhanced oil recovery (!)**
- **It makes one tempted to CCUS out loud, long and harshly, about the decision-making we're doing!**

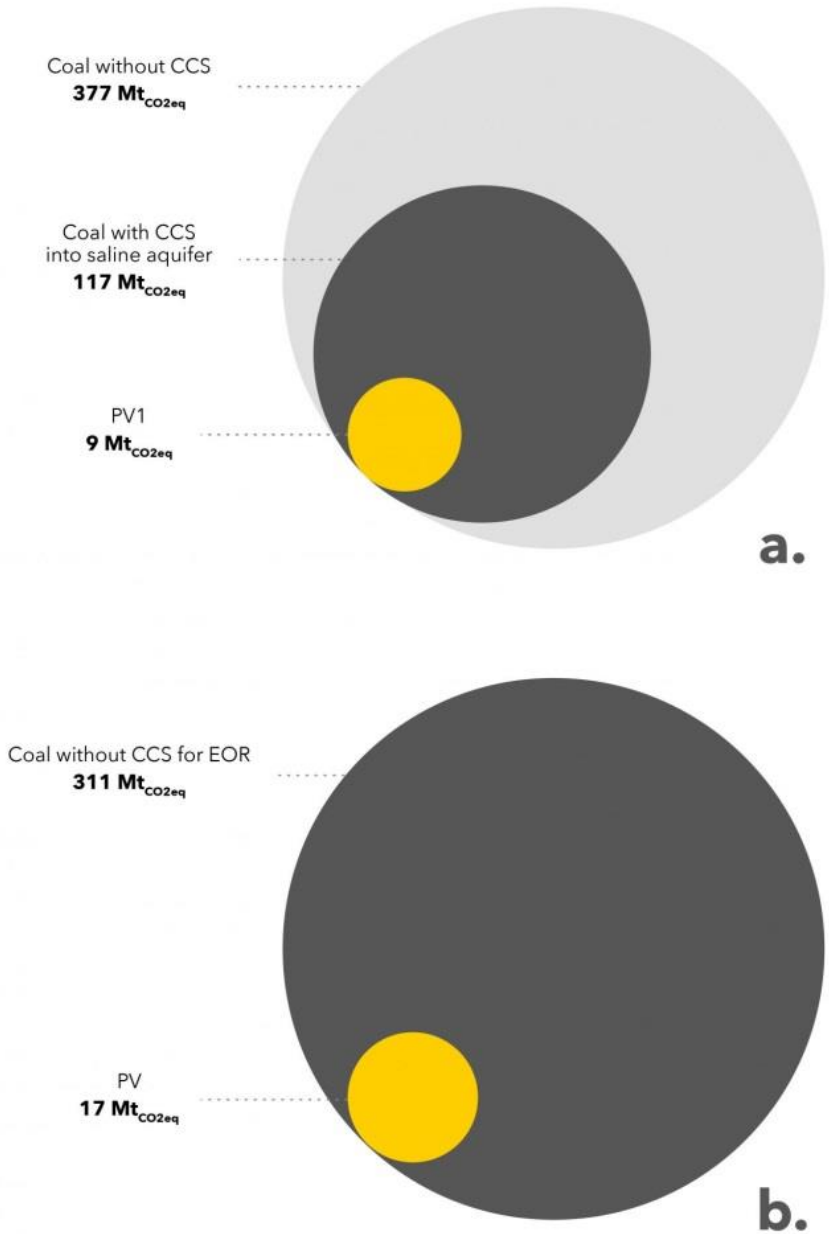
Fossil Fuel Advocates Say That Fossil Fuel Carbon Power Plant Capture and Storage (CCS) is the Answer. Is it?

- **No.**
- Here's the CEO of the largest private coal miner in the U.S. saying – "Clean Coal and CCS doesn't work"
- It's ridiculously too expensive compared to switching to renewables. Permanent sequestration sites not same as power plant sites, so extensive new pipeline grid would be needed to take CO2 to sequestration sites.

Disregard the ***Clean Coal Carolers***

Offsetting U.S. Coal Mining By Tree Planting? A Complete Non-Starter.

- *"A one-gigawatt coal-fired plant would require a new forest larger than the state of Maryland for all of its carbon to be neutralized without CCS.*
- *"Applying the best-case …by coal-fired power plants would mean using **62 percent of the nation's arable land… 89% of the land already forested" (!)***
- *In comparison, **solar cells require 13 times less land** to become carbon neutral and **five times less than the best-case coal scenario**." (AAAS 2018 digest) of Groesbeck & Pearce 2018*



For the same carbon offset power delivered; coal would need to cover 62% of the U.S. arable land area in new forest

To Power the Entire U.S. With Solar PV: Would require an area the size of Kentucky in solid PV panel'ing

Coal, Even with CCS, is Absurdly Non-Competitive in Climate

- With saline aquifer CS, coal still produces **13x** more GHG's than Solar PV *(Groesbeck & Pearce 2018)*
- With no CCS, it's **41x** more GHG's
- With coal CO2 capture -> enhanced oil recovery burned for electricity generation, it produces **18x** more GHG's than solar PV
- BUT…But as a short-term emergency measure while still on FF's, it's cheaper than **D**irect **A**ir **C**apture of CO2. Can we bolt-on CCS to existing plants? I don't see estimates of time frame for that *vs.* replace with renewables.

Organic Farming and Carbon Sequestration in Soil

- Good! We need to do this!
- But, how helpful to solve our emissions? Topsoil only absorbs till a climax community is established.
- Claims that organic farming can sequester enough carbon to halt CO2 rise (Rodale white paper) neglect this fact, from my reading.
- At strong variance with nearly all authoritative studies cited by the IPCC.

In a Hotter Climate -> Soil Gives Up More Carbon

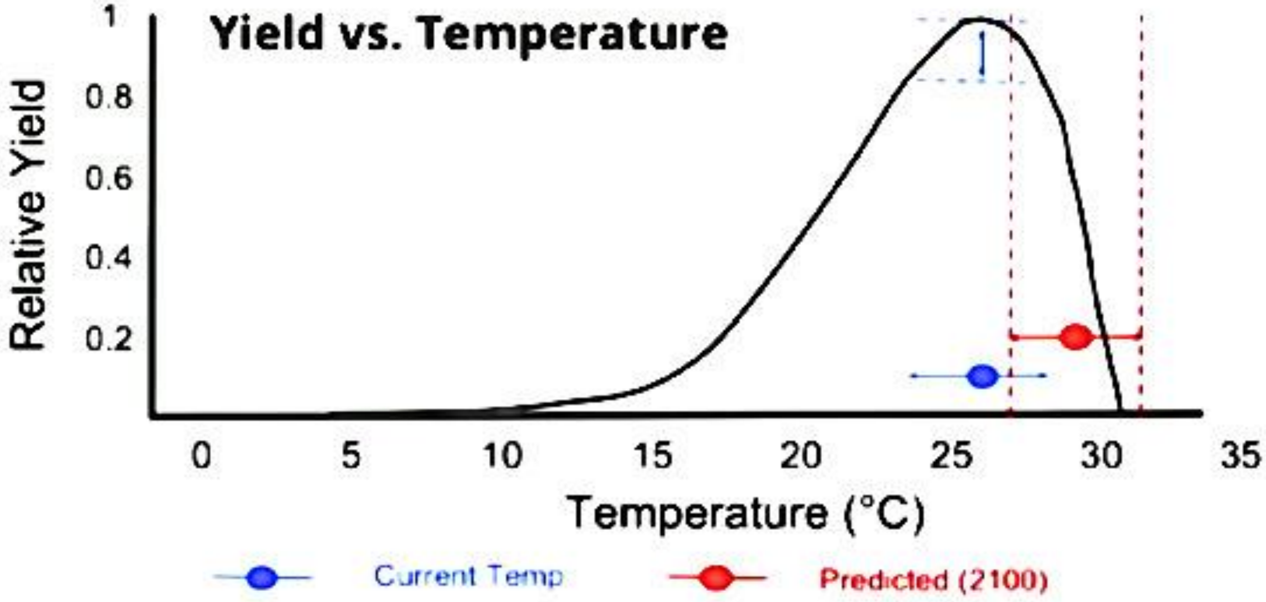
- Oxidation and microbe metabolism returns soil carbon to the atmosphere as CO_2, and…
- Cooler soil temperatures do the opposite (Post *et al.* 1982).
- Hence: Rich carbonaceous soils of the rain forests of the Pacific Northwest, and massive permafrost carbon, *vs.* the famously poor soils of the tropics.
- Therefore global warming will be taking carbon OUT of the soil INTO the atmosphere, independent of soil management.

We're seeing this, strongly, in the Amazon

- In just 10 years, the Amazon's carbon absorbing power has dropped 33% and,
- Since the 1990's the Amazon's carbon stores have declined a total of 30%.
- The Amazon has been responsible for fully ¼ of all land absorption of atmospheric CO2, so this is alarming.
- This calls into serious question the strategy of counting on soils to sequester MORE carbon: We first have to reverse the trend of soils giving UP more carbon to the atmosphere.

As temperatures rise, even mid-latitude crop yields (and also carbon sequestration in soil), plummet. One heat wave can completely kill vast areas, as climate warms this century

Higher Mean Temperature Increases Volatility in Mid-Latitude Yields



After Tewksbury et al 2008; see also: Urban et al. 2012, Climatic Change 112: 525-533

Potential Carbon Uptake with Best Ag Practices

- Good review (Stockmann *et al.* 2013) with comprehensive links on soil organic carbon (SOC) and soil carbon sequestration (SCS)
- Returning cropland to forest or pasture has the most potential for increasing SCS (Post and Kwon 2000) (but then, where to grow crops??)

IPCC: Global Ag Soil Potential: Only 5% of Annual GHG Emissions

- *The IPPC (Smith et al., 2007) AR4 digestion finds an annual sequestration potential of 1.4–2.9 Gt of CO_2-equivalents through global agricultural soils, where soils would reach C saturation after 50–100 years.* (sec. 5 of Stockmann *et al.* 2013)
- **Great. But this is only ~5% of annual global anthropogenic CO2 emission rates.**
- **Worse, see He *et al.* 2016 discussed later here, showing IPCC significantly overestimated soil carbon uptake**

Best Organic and "No Till" Soil Practices: Potential Soil Carbon Sequestration Rates are Small *vs.* Human Emissions

- Stockmann *et al.* 2013 sec. 5 continued…. (NT="no tillage of soil")
- *"In contrast, a recent publication by Chatterjee and Lal (2009) suggests a sequestration potential of agricultural soils of up to 6 Gt of CO_2-equivalents per year by 2030 (*=about 15% of human emissions*). In this regard, Table 7 summarizes potential rates of SOC sequestration by adoption of best management practices for principal biomes whereas Table 8 compiles actual measured rates of SOC sequestration.*
- *For instance, most meta-data analysis (Table 8) suggest that if NT farming is adopted, there is a slight overall increase in SOC in the surface soil compared to full-inversion-tillage (FIT) and that this increase improves with time (Angers and Eriksen-Hamel, 2008, Luo et al., 2010a and Virto et al., 2012). However, when considering the whole soil profile, there seems to be a limited effect of NT on SOC stocks (Luo et al., 2010a). Virto et al. (2012) found that some of the variability (up to 30%) in response to NT can be attributed to differences in yield and C inputs. As seen in Table 8 there are some case studies where NT does not increase SOC (e.g. Loke et al., 2012) or where NT results in SOC increase at very great depth (Boddey et al., 2010)."*

Why Such Wide Disparities?

- Soils which are very deep in some places and planted with certain grasses can sequester significantly more carbon, given water (note that global warming calls for increasing drought in mid-latitudes where such soils primarily exist), and stable climate.
- But beware of simple global land scale-ups
- Big claims come from US "white papers" working in very choice places like American Midwest and California's Central Valley.
- There may be other reasons. Complicated!
- I would trust peer-reviewed journal studies *vs.* conflict-of-interest profit-seekingindustry "white papers"

Bio-Char as Sequestration?

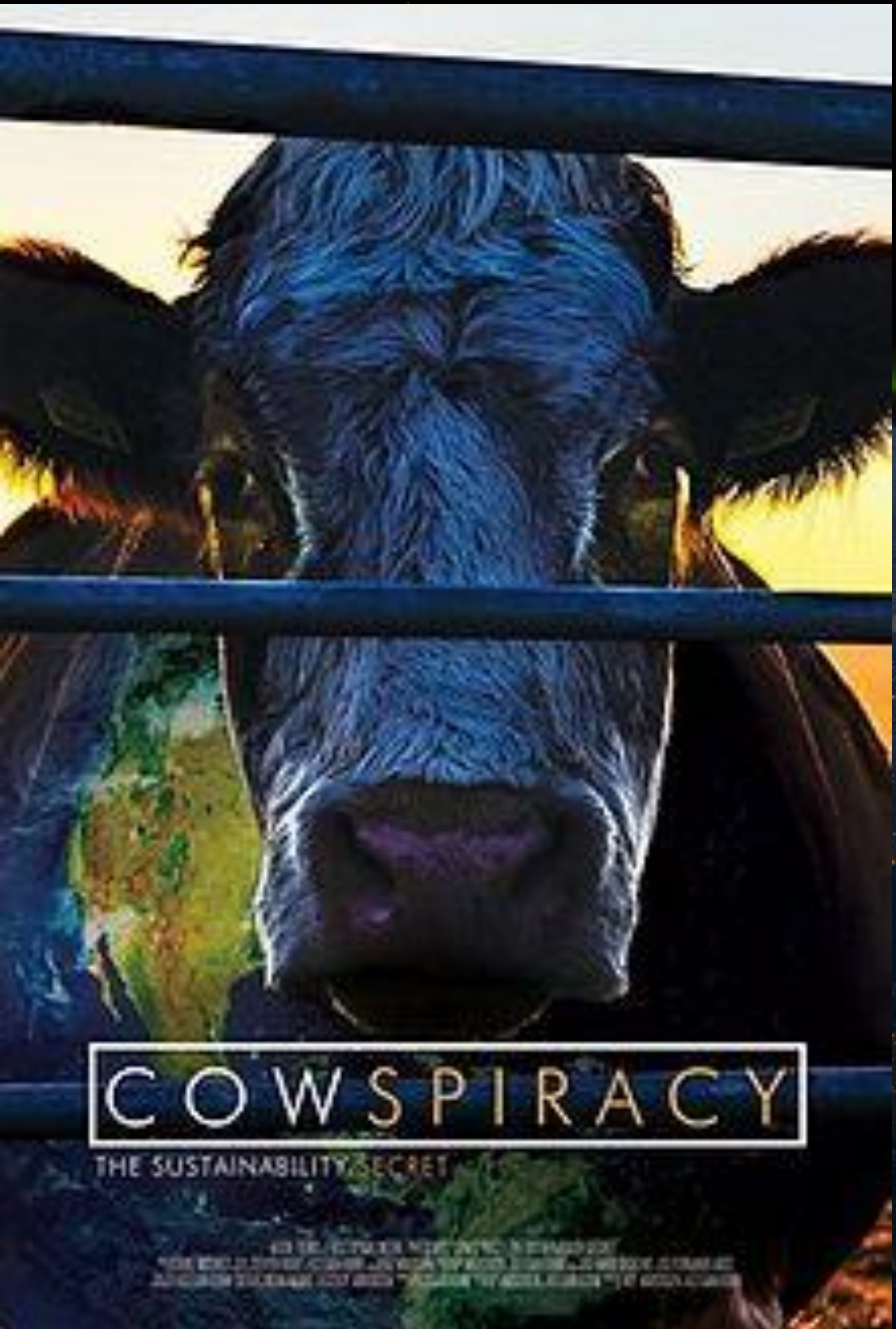
- Lenton & Vaughn 2009 : "In the most optimistic scenarios, air capture and storage by BECCS, combined with afforestation and bio-char production claimed to have the potential to remove 100 ppm of CO2 from the atmosphere…". (with **very** optimistic and questionable assumptions)
- BUT – the biochar must be very pure or it'll give back its carbon to the atmosphere in a century or two, or less. We don't yet have the technology to make such pure bio-char, at scale
- James Hansen and other scientists remain highly skeptical of the promotions at this time.

No-Till Helps Soil Carbon, but amount is likely small, and in dispute. And…

- We've put soils 'on steroids" **precisely because this is the most labor cost-effective way** to get crops out of the soil.
- **Selling price minus cost** means everything to a farmer. We see riots when basic staple crops rise in price even by just 20-30%, (*e.g*. "Arab Spring" revolutions)
- Worse, modern Ag practices are causing topsoil loss of ~1%/year, leading to estimates we have only ~60 years of farming left at current trends.

New, and Worse: Faulty Measuring Has Overestimated the Speed of Soil Carbon Uptake

- He *et al.* (2016 and discussed here) use radiocarbon dating of over 150 global soil 1m depth samples to measure the age of their carbon, to determine that Earth System Models relied on by the IPCC in their summaries **have overestimated the rate of carbon soil uptake by ~40%.**
- They conclude that *"it will take hundreds or even thousands of years for soils to soak up large amounts of the extra CO2 pumped into the atmosphere by human activity – far too long to be relied upon as a way to help the world avoid dangerous global warming this century."*
- …the prospect of adapting soils so they suck up more carbon is "unlikely", especially in the short-term, according to He.



Agenda-Oriented "Cowspiracy" Film has Bad Science, and has Sidetracked Some Eco-Friendlies away from the Real Culprit

Claims that 51% of greenhouse emissions come from animal agriculture.

- This is just bad-accounting-false. The claims come from 2 people in a non-peer-reviewed article.
- Turns out their big boost to CO2 accounting comes from counting the exhaled breath of the animals, and ignoring that plants also “breathe out” CO2, at night.
- Proper accounting: IPCC AR5 summary of peer-reviewed science finds the figure is about **18%.**

- **Animal Ag produces 18%, not 51% of GHG’s**

Bottom Line: Yes, ReHab Our Soils!

- Organic and no-till, enhance C, end soil-erosive practices, better rangeland *via* Alan Savory ideas, cover crops, etc…
- Expensive, but necessary.
- But don't expect a soil carbon capture miracle.
- We should be more worried about saving our soils from alarming erosion rates than using them to capture all the necessary carbon. Without farming, we're doomed.

DAC: Direct Air Capture of CO2

- We saw that merely ending emissions won’t save us.
- Temperatures will not drop unless we go beyond, and artificially cool Earth.
- We need to pull our mess back OUT of the Air and natural means are too slow and small, and are ruining ocean and land ecosystems right now.

As of 2014, Klaus Lackner's conception of an Air Capture Installation

2017: First Commercial Air Capture CO2 Installation

By Climeworks, Inc. in Switzerland. Very small scale.

CO_2 is sold for fertilizer, not sequestered

ClimeWorks Math

- Their 10 year ambitious goal - build 250,000 of these air capture plants.
- That would capture 1% of our current emissions. Estimate $400/ton CO2 to capture and $20 to sequester, <u>except feasibility of climate-scale sequestration is highly speculative at present</u>.
- **$420/ton means to drop atmosphere from 410 ppm to 350 ppm <u>costs $16,000 for every man, woman, child on Earth</u>**
- **But, what's Earth worth? $Infinity, right?**

Carbon Engineering, Inc. in 2018

- Claims their DAC of CO2 for **$94-232/ton CO2**, based on modelling and small pilot plant. (Keith *et al.* 2018)
- Cost savings is in using a lower pressure process, and siting only where renewable energy to power the process is plentiful, since "avoided emissions" from grid power is a large part of their math.
- **And selling CO2, for lower end of cost range, which is clearly not relevant at climate-significant scales**
- **Estimating Life Cycle costs for a full scale commercial plant were "beyond the scope" of this paper, however.**

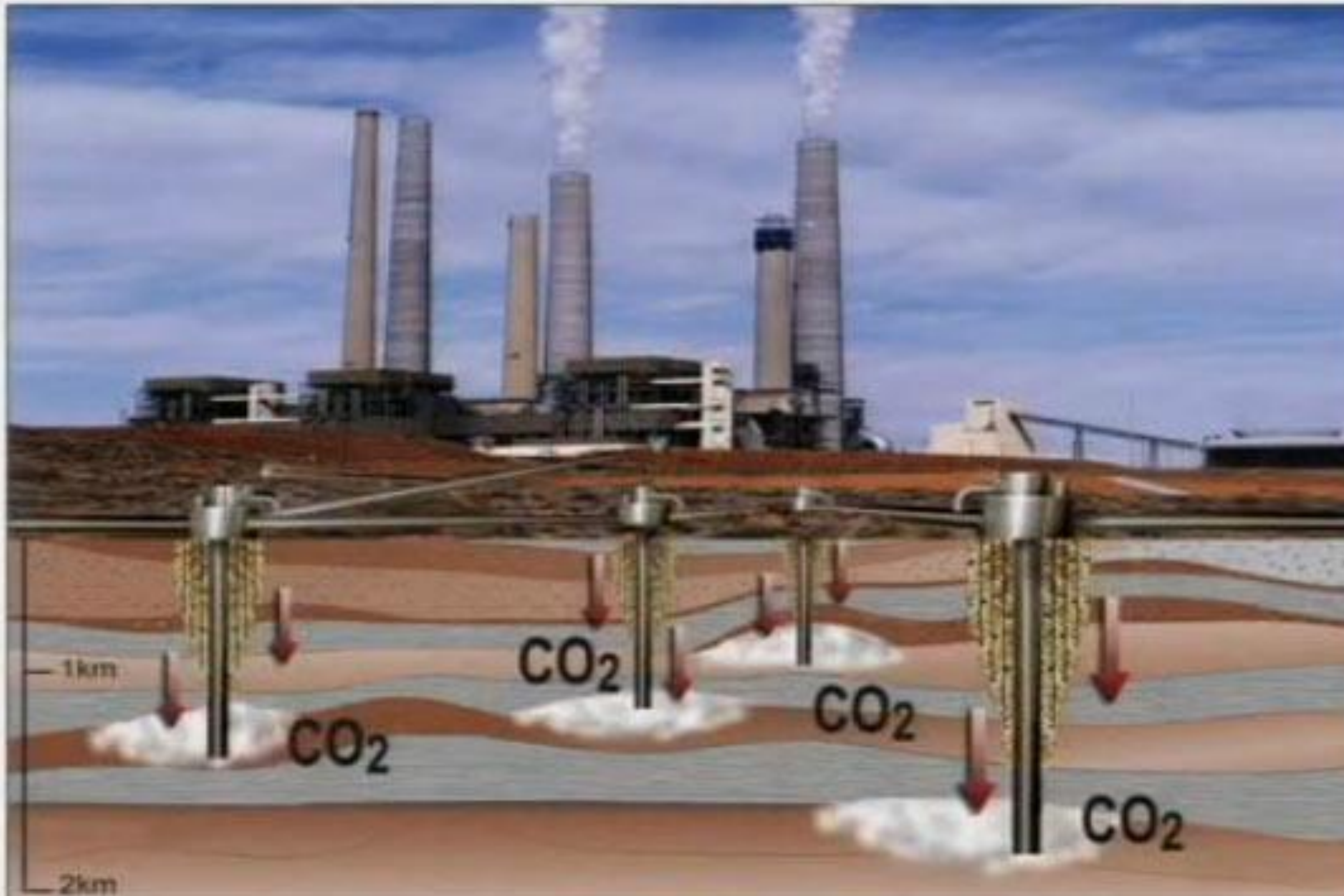
A More Realistic Figure When Considering Pulling Atmospheric CO2 …

- … would not use “avoided emissions”.
- If we’ve got a renewables grid and are seeking to pull CO2 down to close to pre-industrial levels, not selling the carbon as fuel, but permanent sequestration - the figure could be more like $400/ton
- This article points out both the hype and the hope in a realistic way

Where to Sequester Long Term?

- High pore-space sandstones capped by impervious clay layers. Even 1% leakage/yr is fatal to purpose.
- And, saline aquifer formations, common in the Gulf Coast area.
- Stanford's Sally Benson says there's more than enough good geology, but <u>spotty globally</u>.
- US West has lots. India has none. Russia good, China not as much.
- Costs vary <u>widely</u>. IPCC had up to $100/ton. Fossil fuel industry experts say much less: Power plant electricity 1.5 – 2x costlier with CCS. To save the planet? Let's not pinch pennies!

Carbon Dioxide Capture and Geologic Storage



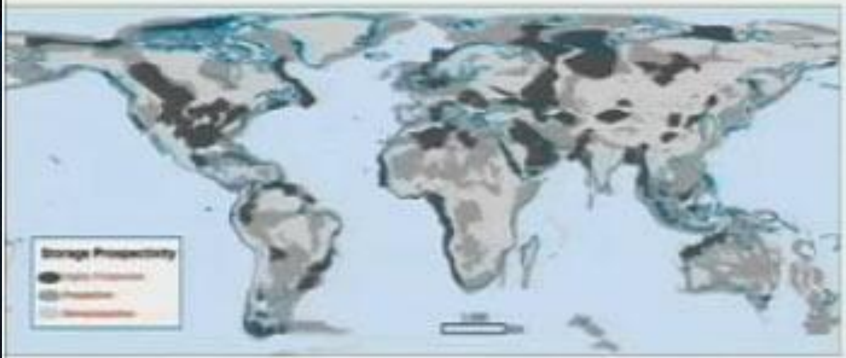
Capture → Compression → Pipeline Transport → Underground Injection

Dark Areas: Potentially Suitable Storage Formations

What Types of Rock Formations are Suitable for Geological Storage?

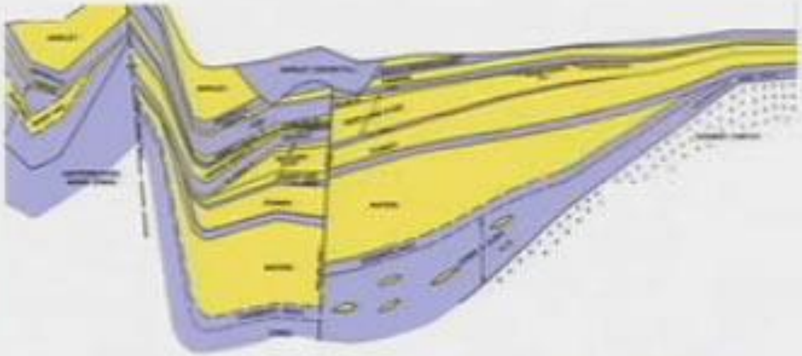
GCEP

Rocks in deep sedimentary basins are suitable for CO_2 storage.



Map showing world-wide sedimentary basins ranked according to prospectivity for storage

100 km

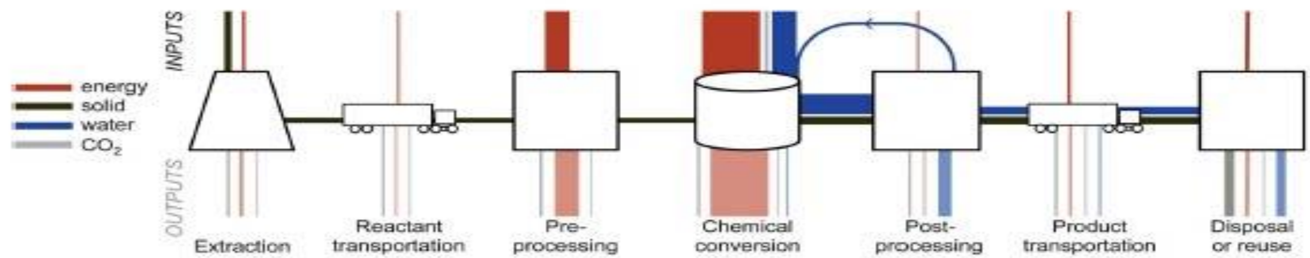


Northern California Sedimentary Basin

Example of a sedimentary basin with alternating layers of coarse and fine textured sedimentary rocks.

Mineral Carbonization for Sequestration: CO2 + Crushed Olivine: Similar to Nature's "Long Carbon Cycle"

- Cost: ~$1,000/ton if coal energy powered. Even more if renewable energy; Source. A non-starter.



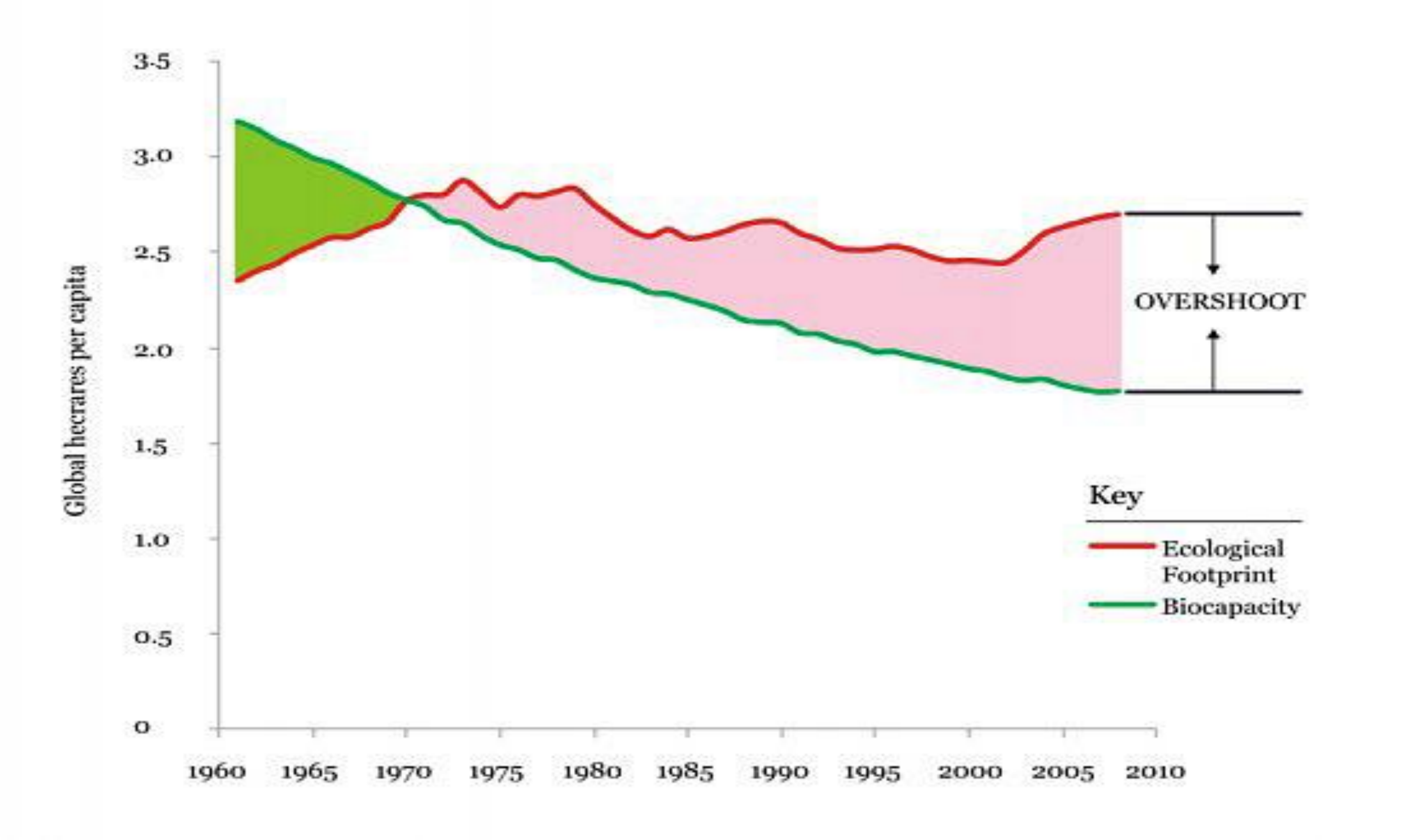
	Extraction	Reactant transportation	Pre-processing	Chemical conversion	Post-processing	Product transportation	Disposal or reuse
Inputs							
Energy (GJ)	188	52	846	3,185	8	150	223
Solid material (t)	1,944	1,924	1,866	1,848	2,819	2,791	2,707
Water (t)	0	0	0	6,659	7,317	2,791	2,707
Recycled water (t)	0	0	0	731	0	0	0
Carbon dioxide (t)	0	0	0	1,000	0	0	0
Outputs							
Solid material (t)	1,924	1,866	1,848	2,819	2,791	2,707	2,707
Water (t)	0	0	0	7,317	2,791	2,707	2,707
Water for recycle (t)	0	0	0	0	731	0	0
Waste material (t)	19	58	19	102	3,822	168	0
Waste energy (GJ)	188	52	846	3,185	8	150	223
CO_2 emissions (t)	11	3	62	166	1	10	13

FIGURE 3.1 Life-cycle process model schematic that shows all of the steps associated with mineral carbonation of 1,000 tCO_2 with mined and crushed olivine, which is a silicate mineral rich in Mg^{2+}. This schematic shows the number of components required for mineral carbonation, including mineral extraction, transportation, preprocessing (e.g., grinding), chemical conversion, postprocessing, product transport, and disposal. The thickness of lines is scaled to the energy and mass fluxes (inputs enter from the top, outputs leave through the bottom). This process does not include the separation of CO_2, and it is questionable whether atmospheric CO_2 is in great enough concentration to achieve adequate conversion. It is likely that the CO_2 would have to be concentrated to some extent to improve mineral carbonation conversion on timescales of interest. Taking into account the total energy (4.65 GJ/tCO_2) as shown for each step results in a cost of ~$1,000/$tCO_2$ provided coal is the electric energy source. SOURCE: Kirchofer et al., 2012.

Section F. The Garrett Relation and Jevons' Revenge

- Alas, I'm deeply skeptical we will solve climate by any of these ideas.
- We're genetically programmed for GROWTH, for ourselves, our family, our tribe, and our civilization.
- On a finite planet, this is fatal.

We're using 1.7 Earths Worth of Biocapacity. Stripping an area the size of England in rainforest every year, accelerating worse as ocean acidification, land degradation worsen, especially in Asia. We KNOW this, and do it anyway. Why?



We Make Our Decisions “On the Margin”

- The MARGINAL cost of my activities to climate **is ~zero**
- But to myself and the family I support: **benefit = large**
- It’s the “rationally irrational” thing to do
- People in the Santa Cruz Bubble with excess wealth and time, may suffer from “locality bias” and tribal bonds, and assume the global population is all like them. They’re not.

"We're making the transition towards an all-electric future. We can now leave fossil fuels in the ground and thwart climate breakdown…."

- *"… Or so you might imagine if you follow the technology news.*
- *So how come oil production, for the first time in history, is about to hit 100 million barrels per day? How come the oil industry expects demand to climb until the 2030s? How is it that in Germany, whose energy transition (Energiewende) was supposed to be a model for the world, protesters are being beaten up by police as they try to defend the 12,000-year-old Hambacher Forest from an opencast mine extracting lignite: the dirtiest form of coal? Why have investments in Canadian tar sands – the dirtiest source of oil – doubled in the past year?*

-George Monbiot

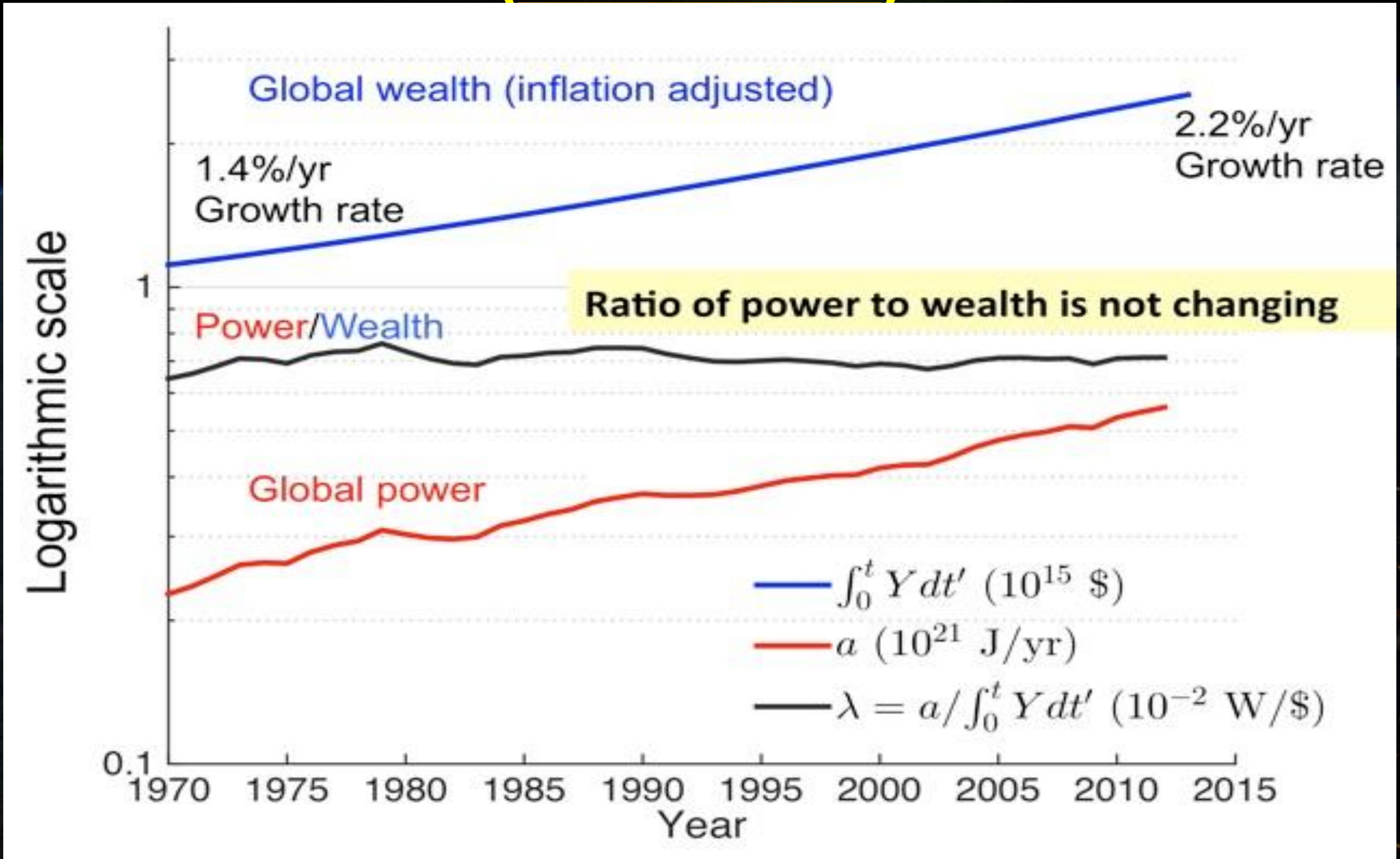
Yes, Why Indeed? Thermodynamic Principles Applied to Civilization Predict: The Garrett Relation…

The current rate of global civilization's primary energy consumption ("Power")…

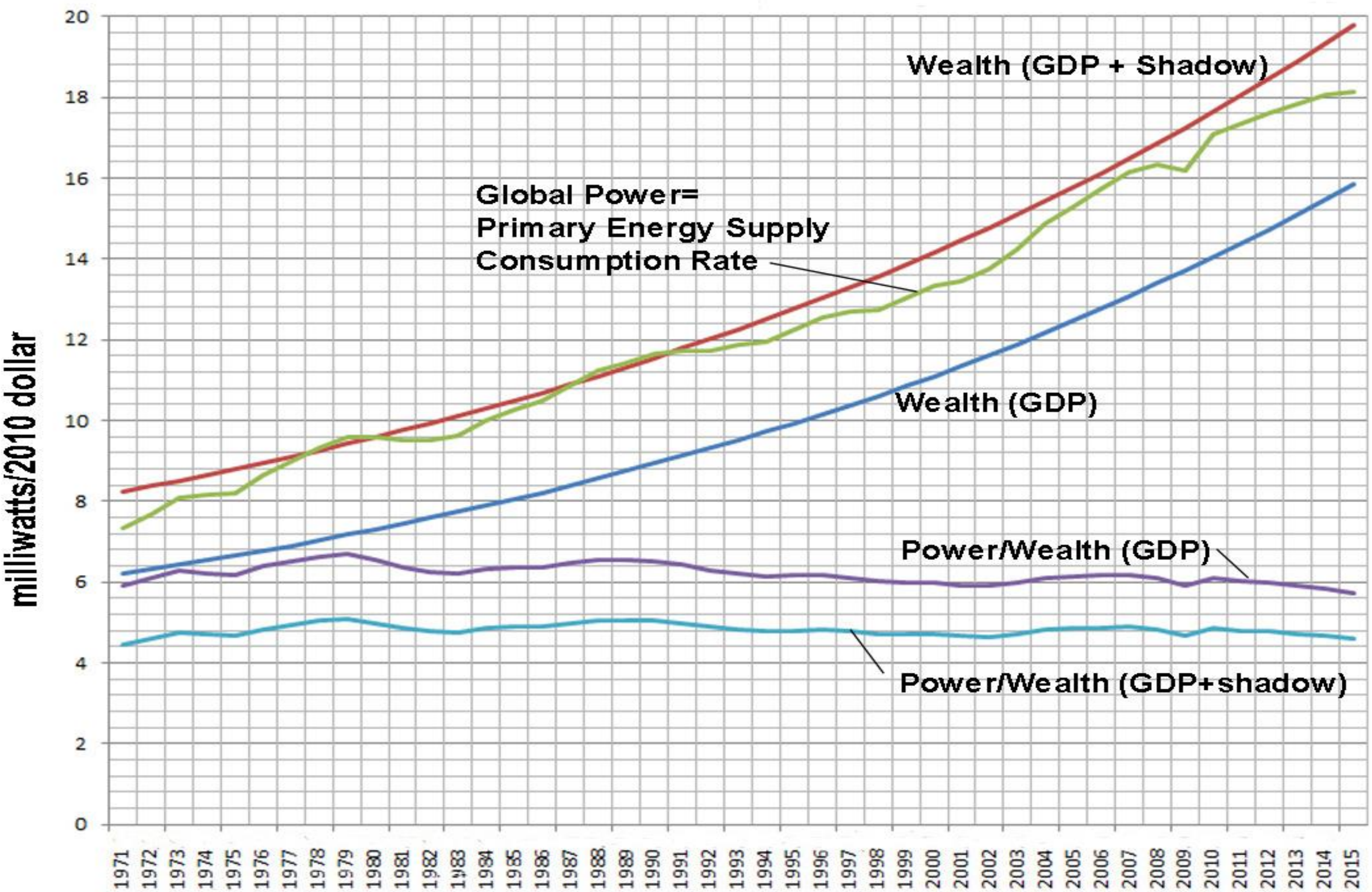
is directly proportional to

…The total integrated, inflation-adjusted Gross World Product summed over all countries and over all of time (="Wealth")

The Garrett Relation Confirmed: 7.1milliwatts of continous power needed to support every (inflation-adjusted to 2005) GWP dollar ever spent (Garrett 2012)



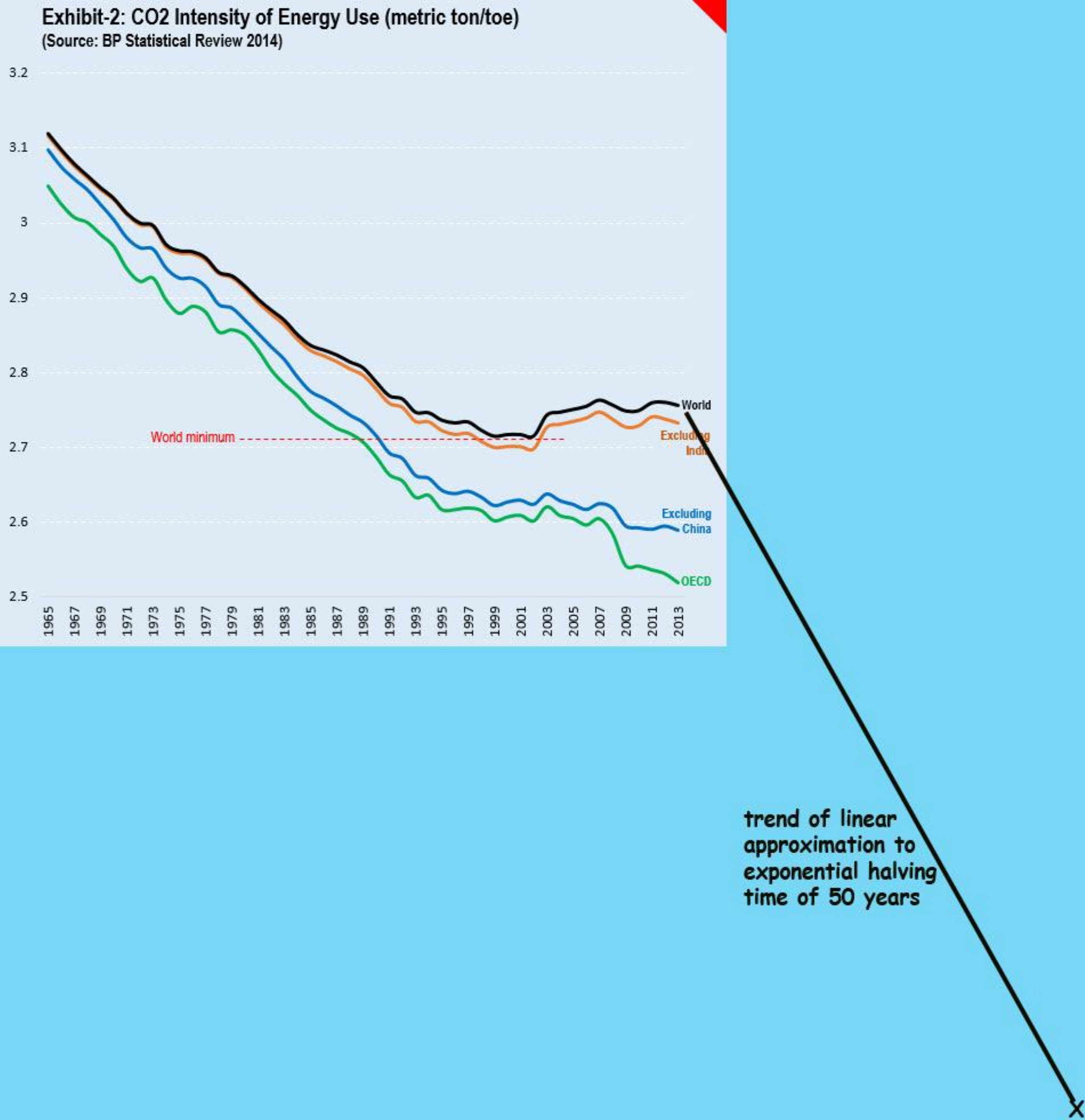
My Own Work: The Garrett Relation is Flatter Using Total Spending (light blue) *vs.* GDP Alone (purple). Both curves include GDP Deflator correction from MIT's "Billion Prices" Project. Using ShadowStats Inflation figures would remove any small post-1994 down trend



Grasp the Meaning…

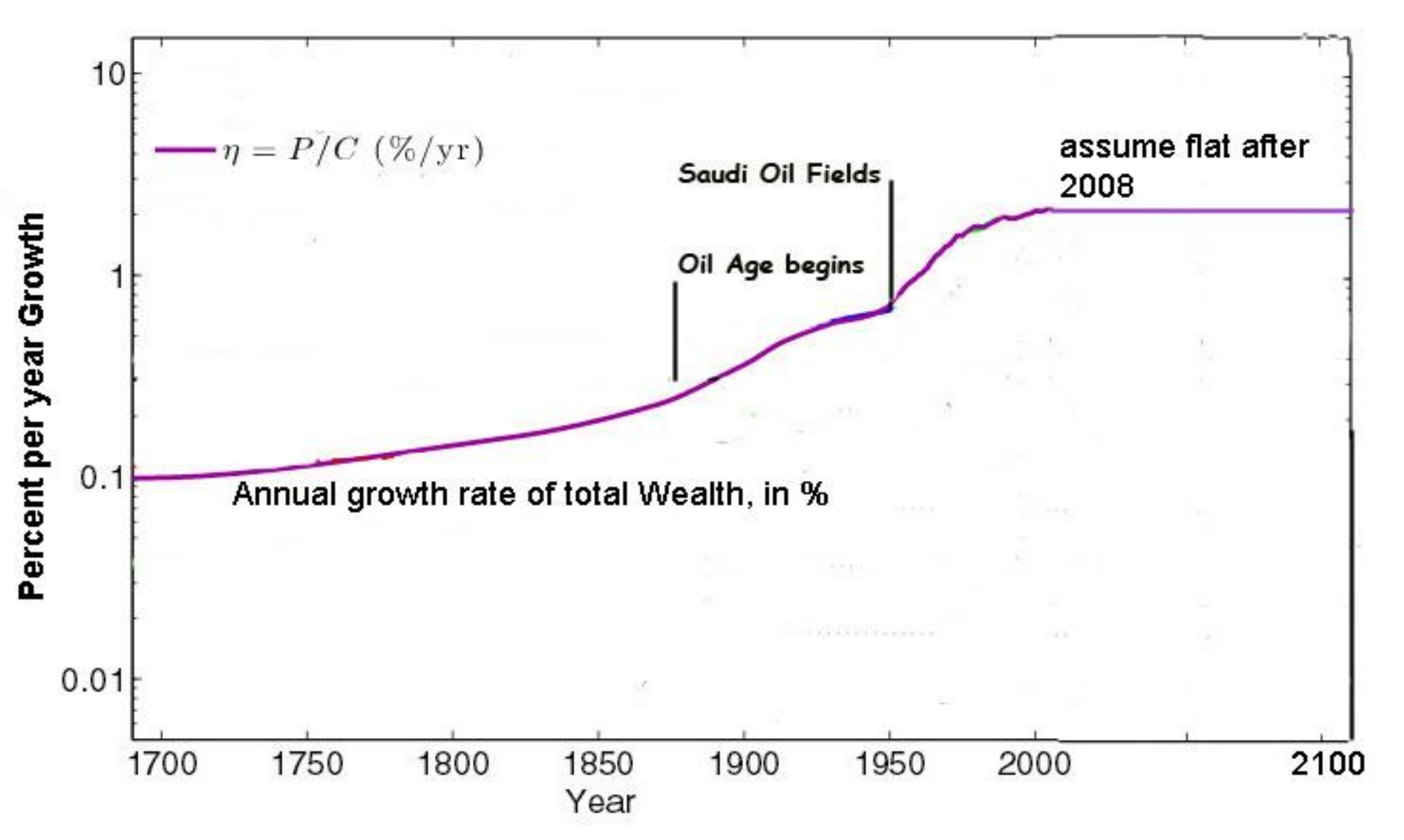
- Every dollar ever spent, was done to create products and networks of relationships to enhance civilization. Bringing order out of disorder. Fighting entropy. Flows of material and energy along these networks dissipate energy continually.
- Every action of the past is a stair step, carrying a ghost of itself into the future, embodied by the vast civilization we have today.
- ALL of it MUST be supported by continual energy consumption, by the 2nd Law of Thermodynamics. And the larger it is, the higher the rate of that consumption.
- It is thermodynamics applied to the ordered system we call HUMAN CIVILIZATION

What Does the Garrett Relation Imply, when we include it in Calculations of the Future of Atmospheric CO2 Concentrations?



Let's assume we now de-carbonize our energy sources at an exponential rate, with halving time of 50 yrs – very steep by historical standards…

Further Optimistically Assume: Growth Rate of "Wealth" (= sum total of all Civilization spending over all time), goes flat (not likely, given our new solar and wind power coming online)



Even these conservative assumptions lead to significantly more dire Atmospheric CO2 (Red Curves) when the Garrett Relation is included: Atmospheric CO2 Relentlessly Rises. And Higher Resiliency means faster economic growth and higher CO2 at year 2100. Only in the most crippled case, with growth in decline, does CO2 stabilize (and inflation reaches 73%/yr in 2100). IPCC eco-friendlier SRES scenarios (blue) were naively optimistic, not recognizing how civilization actually operates

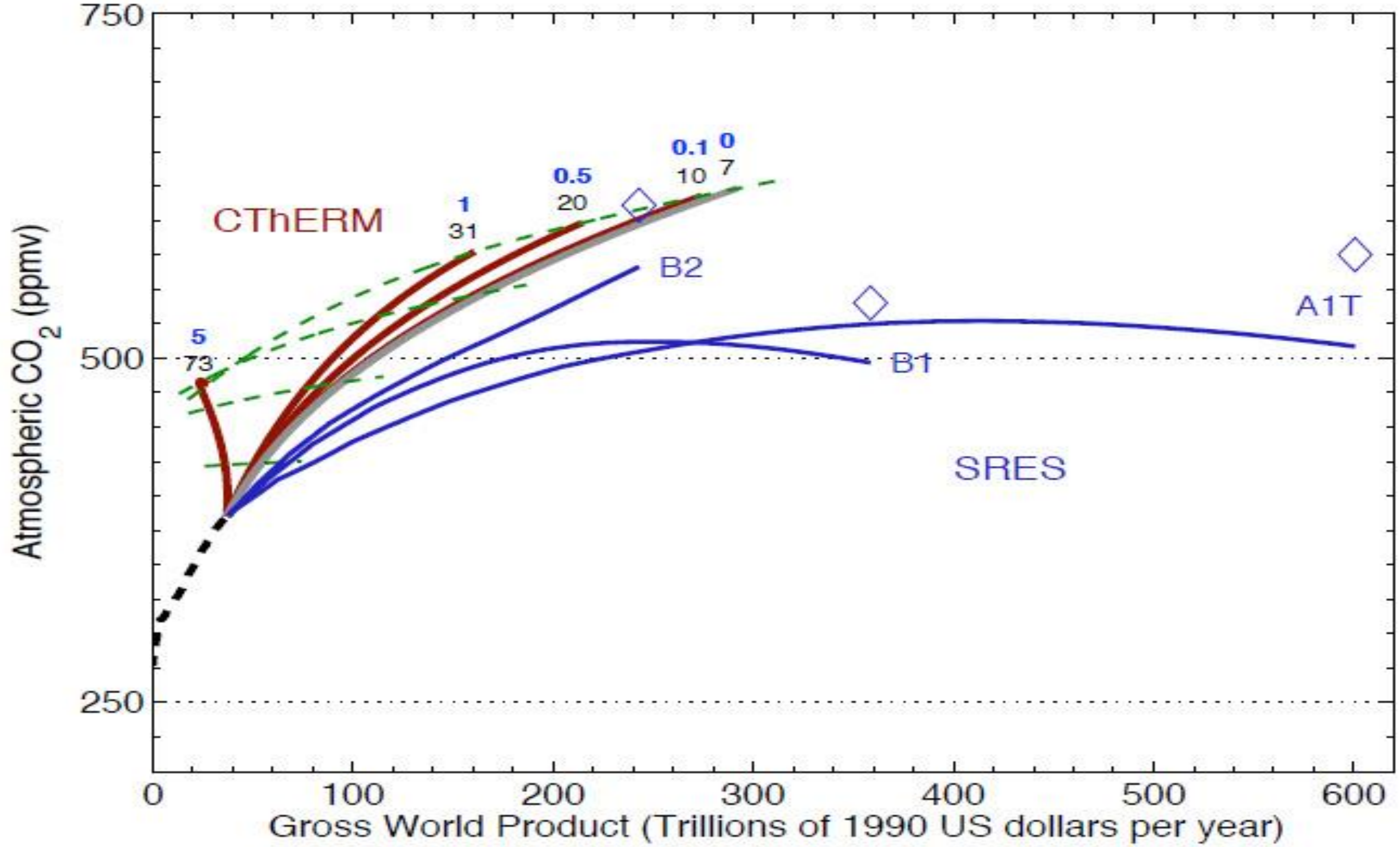


Fig. 7. As for Fig. 6 except that it is assumed that the value of carbonization c has an assumed halving time of 50 years. For comparison, the IPCC SRES trajectories that are considered are the A1T, B1 and B2 scenarios.

And Even Garrett's Curves Are Too Optimistic

They do not include indirect CO2 emissions from the post-IPCC science we outlined (permafrost, soil degradation, 44:1 amplification of methane from tropical wetlands, non-CO2 human GHG's, and other pathways for indirect human CO2 emissions…

Garrett's curves ONLY show CO2 from our direct energy-related economic emissions


Sorry!
The lifestyle you ordered is currently out of stock

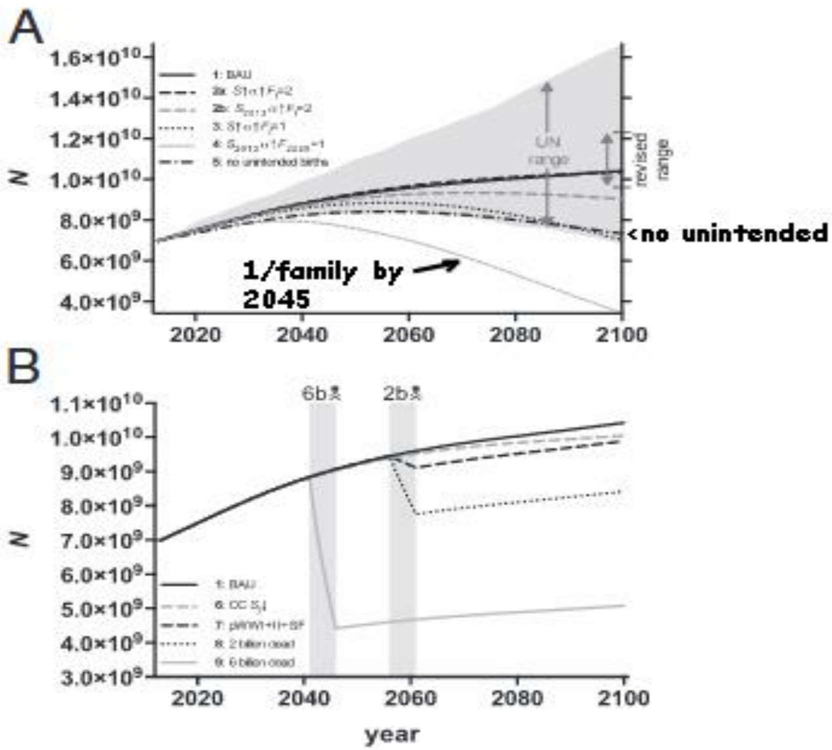


Fig. 1. Scenario-based projections of world population from 2013 to 2100. (*A*) Scenario 1: BAU population growth (constant 2013 age-specific vital rates); Scenario 2a: reducing mortality (*M*), increasing age at primiparity (α), declining fertility to two children per female ($F_t = 2$) by 2100; Scenario 2b: same as Scenario 2a, but without reduced mortality; Scenario 3: same as Scenario 2a, but $F_t = 1$; Scenario 4: same as Scenario 3, but without reduced mortality and $F_t = 1$ by 2045 and thereafter constant to 2100; Scenario 5: avoiding all unintended pregnancies resulting in annual births. High and low projections by the United Nations (12) are shown as a grayed area, and the revised range for 2100 (13) is also indicated. (*B*) Scenario 6: elevated childhood mortality (M_j) from climate change (CC); Scenario 7: mass mortality event over a 5-y period starting 2056, equal to the proportion of combined number of deaths from World War I, World War II, and Spanish flu scaled to the mid-21st century population; Scenario 8: 2 billion people killed because of a global pandemic or war spread over 5 y, starting midway (i.e., 2056) through the projection interval; Scenario 9: 6 billion people killed because of a global pandemic or war spread over 5 y and initiated one-third of the way through the projection interval (i.e., 2041). The mass mortality windows are indicated as gray bars.

Bradshaw and Brook (2014) show that even eliminating all unintended pregnancies worldwide, still - population continues to grow until mid-century. 1-child per family eventually gets us down to 4 billion by 2100, which will not be sustainable by then, considering degradation rates

“We’ll…” (you say), “We’ll just CHANGE! We’ll get more EFFICIENT with our energy consumption!”

Enter - **Jevons’ Revenge**

Generalized Jevons' Paradox

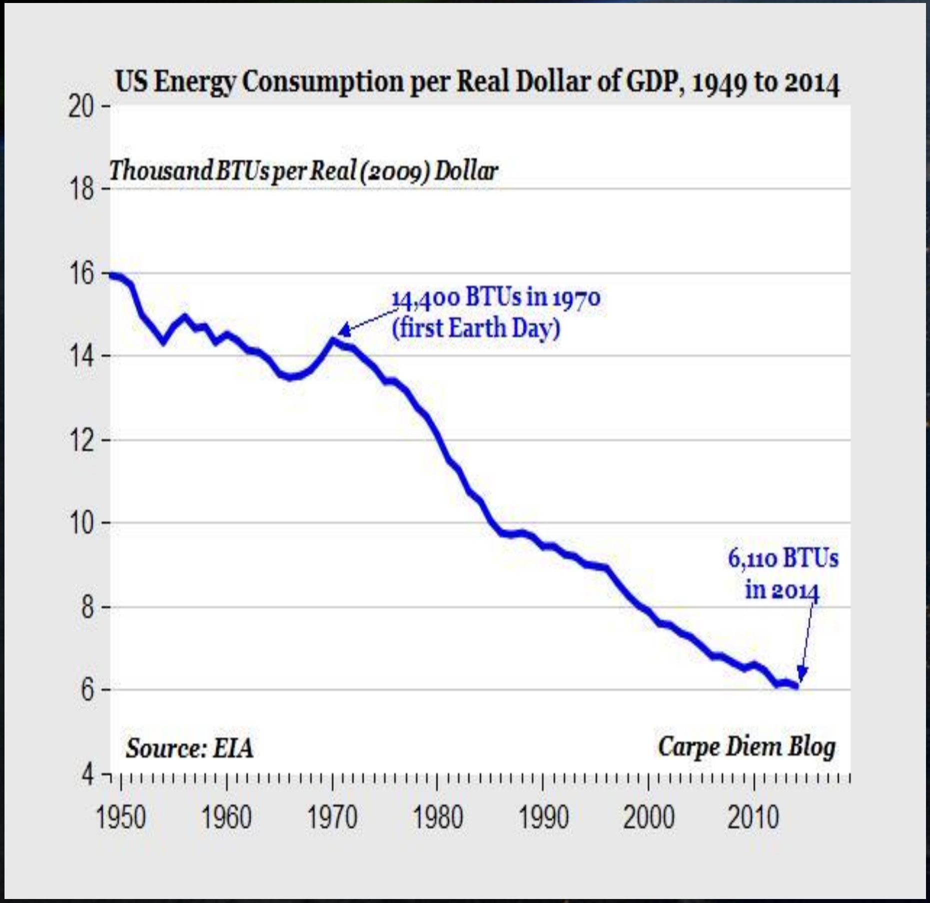
- Energy Efficiency gains produce savings
- Those savings can and will be spent.
- They can be spent **ANYwhere**, not just on what you made the savings with! Don't get fooled by the original "Jevons' Paradox" of 1865 and like-for-like spending.
- ALL spending encumbers new ongoing power to support what it accomplishes – the turning of a portion of the Global System **from less ordered to more ordered…** A reduction in Civilization ENTROPY, and the 2^{nd} Law of Thermodynamics requires new power to support against decay

Further….

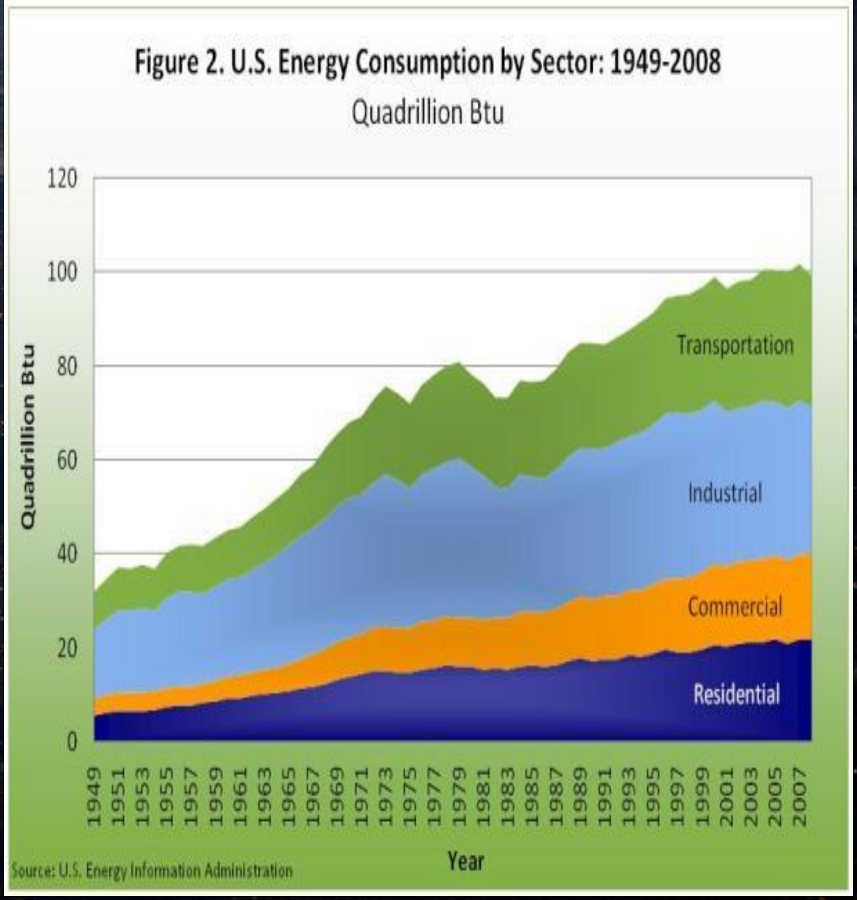
- A Larger Civilization has MORE ability to mine NEW energy, and that's exactly what it does.
- So total power consumption goes UP, not DOWN.
- Power per $GDP is NOT the same as TOTAL POWER, and climate cares only about TOTAL POWER; TOTAL CO2 generation.
- Civilization was a creation. First by ancient individual Man, then his Tribe, then his Village, eventually his Nation…. <u>All to facilitate GROWTH.</u> The BIOLOGICAL IMPERATIVE. Powered by the pleasure mechanisms of our brain, created by millions of years of Evolution.

Increase energy efficiency? – We've ALWAYS been raising energy efficiency!

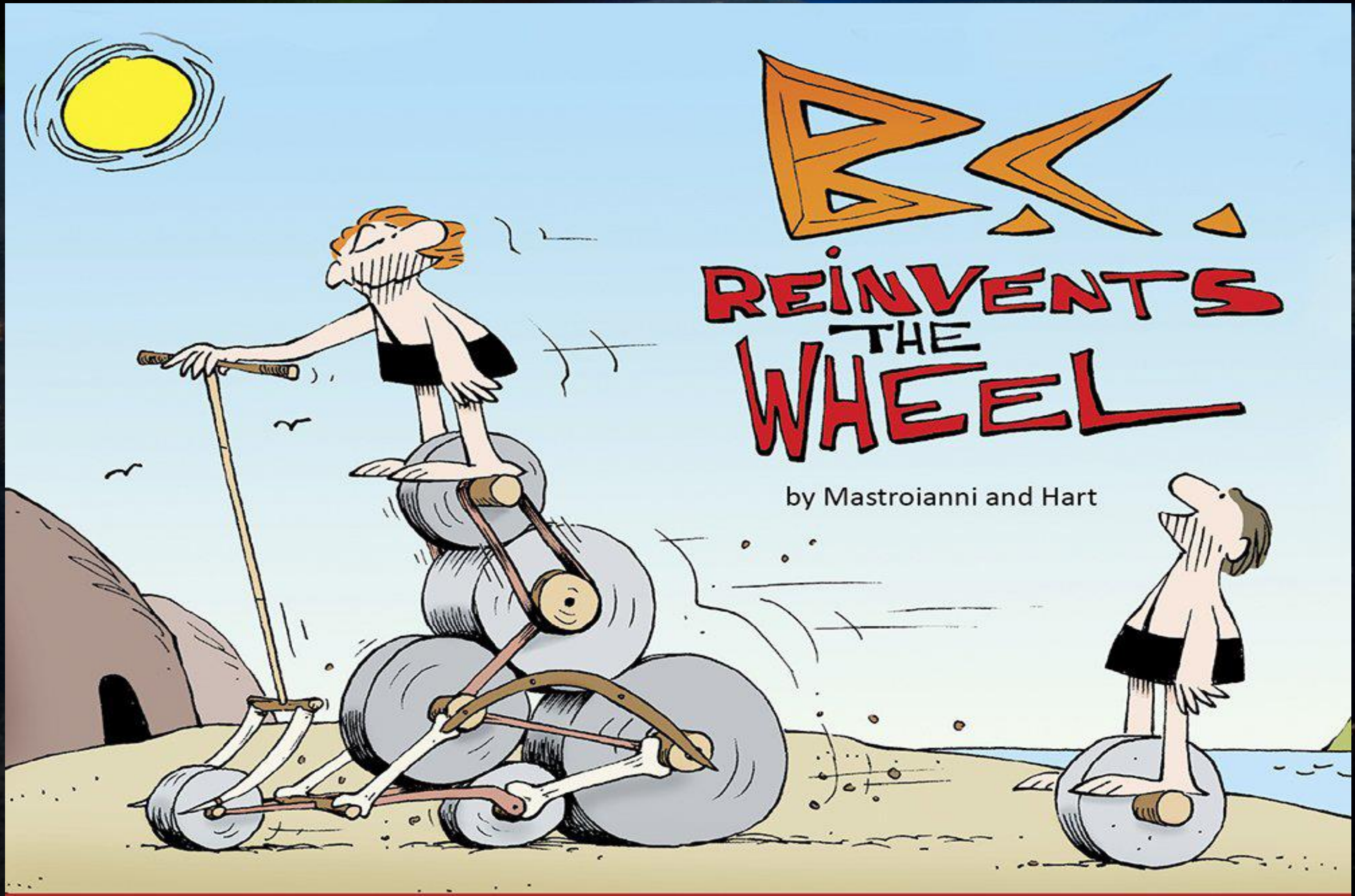
70 yrs of spectacular increases in U.S. Energy Efficiency! Has it lowered energy consumption?...



No! Energy consumption continues to rise, even given our off-shoring of much manufacturing to Asia



We've been 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. ALWAYS. ALREADY. And will continue to do so!



We’ve Been Improving Energy Efficiency as FAST as we CAN. And We’ve Been Doing it <u>Forever</u>. <u>Why?</u>

- Because it makes SAVINGS for us which allows us to spend more, on new stuff!

- We don’t have to cattle prod ourselves – we’re efficiency’ing as FAST AS WE CAN already. WE <u>ALWAYS</u> HAVE.
- No. Efficiency *per se* won’t save us.
- What we have to do, is STOP GROWING

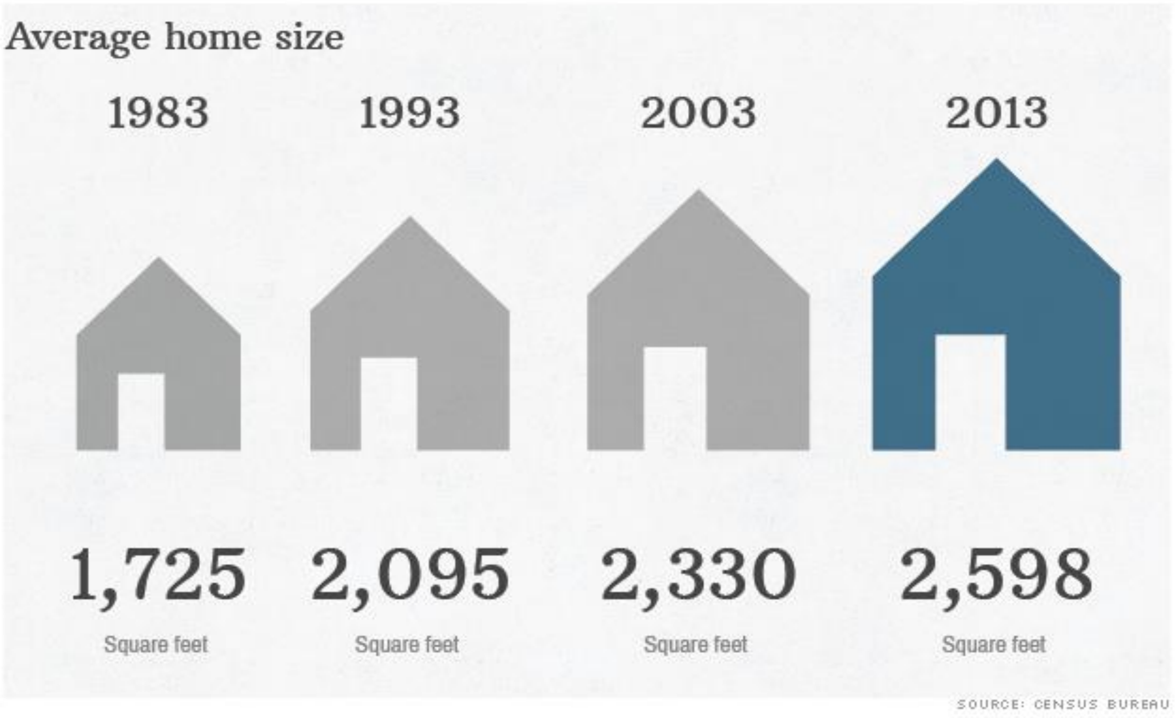
Like these confused shoppers on a viral YouTube video…
It’s as if we’re walking 5 mph down the stairs …of a CO_2 escalator running upwards 10 mph

It is the very accomplishment of an improvement of energy efficiency which expands civilization, pushing the goal of Energy Sufficiency further forwards, continually out of reach. We're Insatiable When It Comes to ENERGY. We ALWAYS want more.

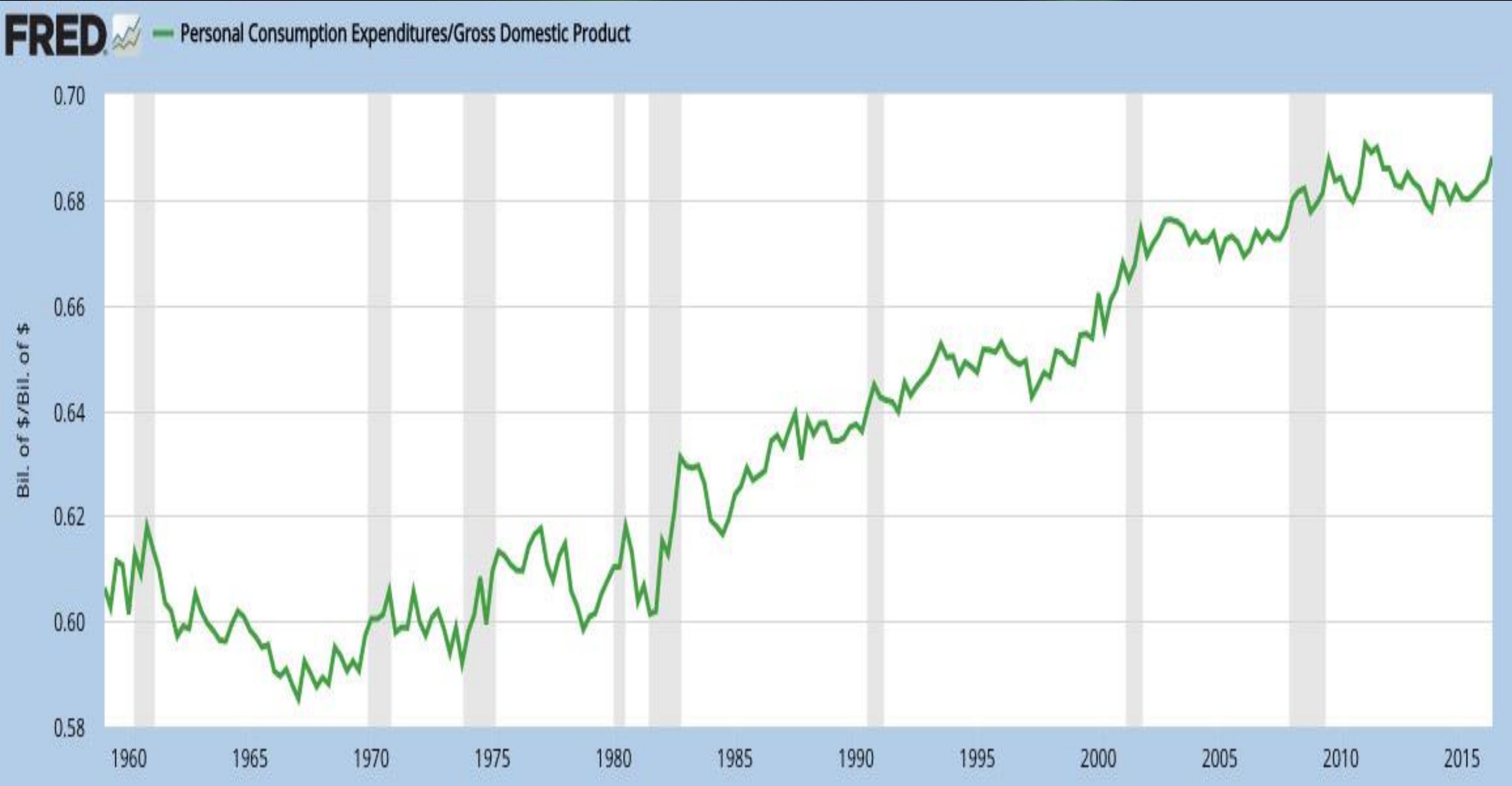
Implicit in the Garrett Relation…

- …is, in fact, this continual improvement in energy efficiency.
- If we had never attempted to improve energy efficiency, and only recently decided to do so, then we can expect there would indeed be a "kink" in the Power/Wealth trend over time. A kink we do not see. Why?
- Because such behavior would violate human nature. We **love** energy efficiency, and we ALWAYS have, and therefore we have ALWAYS been doing such improvements to the best of our ability, and therefore it is already part of the long term trend of Power/Wealth.
- It means that continual further improvement in energy efficiency is also contained in the future trajectory graph we looked at. We can't count on continual efforts at energy efficiency to save the situation because they're already "priced in".

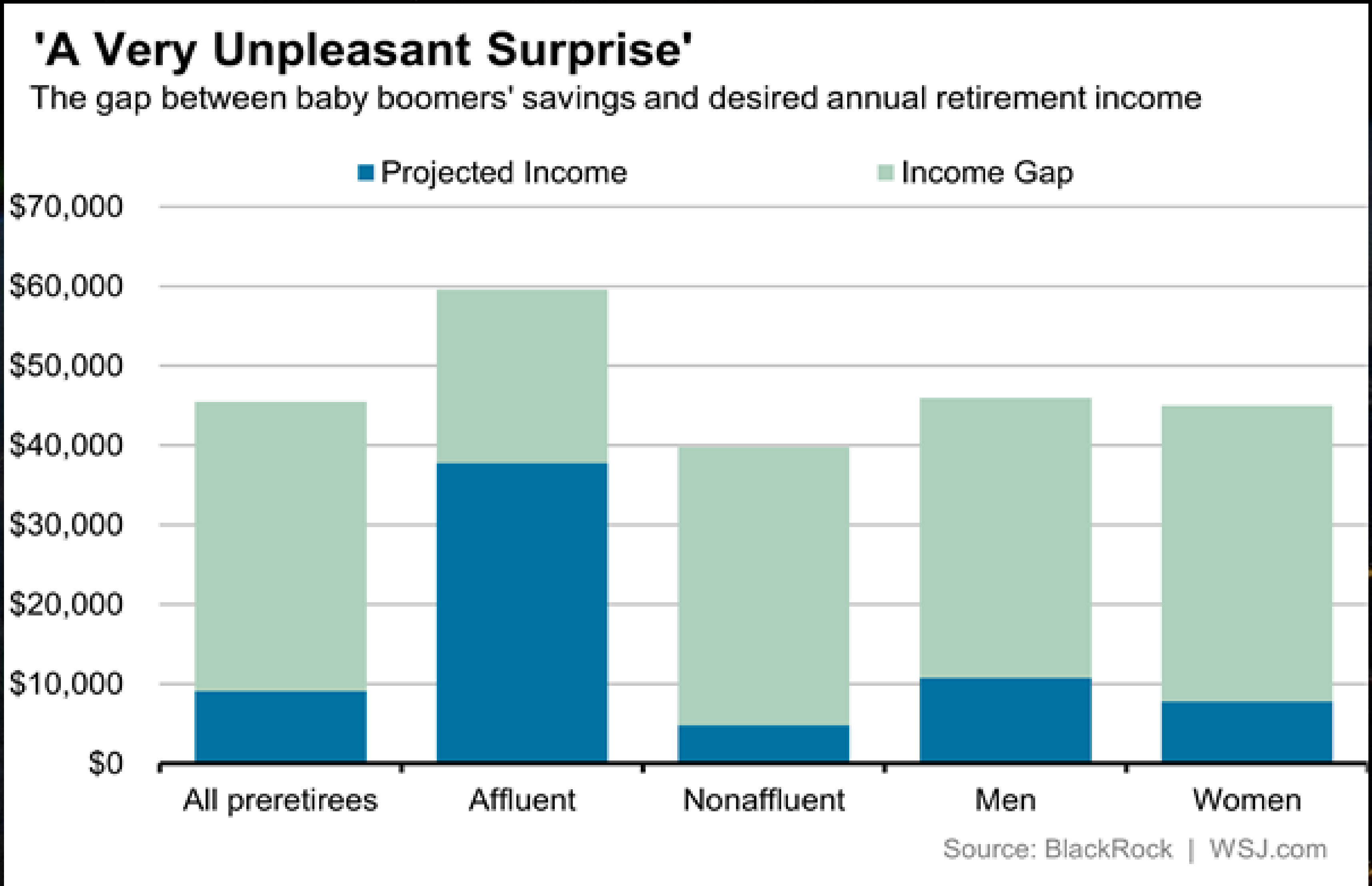
Even in the wealthy U.S. …We do NOT save our efficiency gains. We SPEND them; on Bigger Homes…



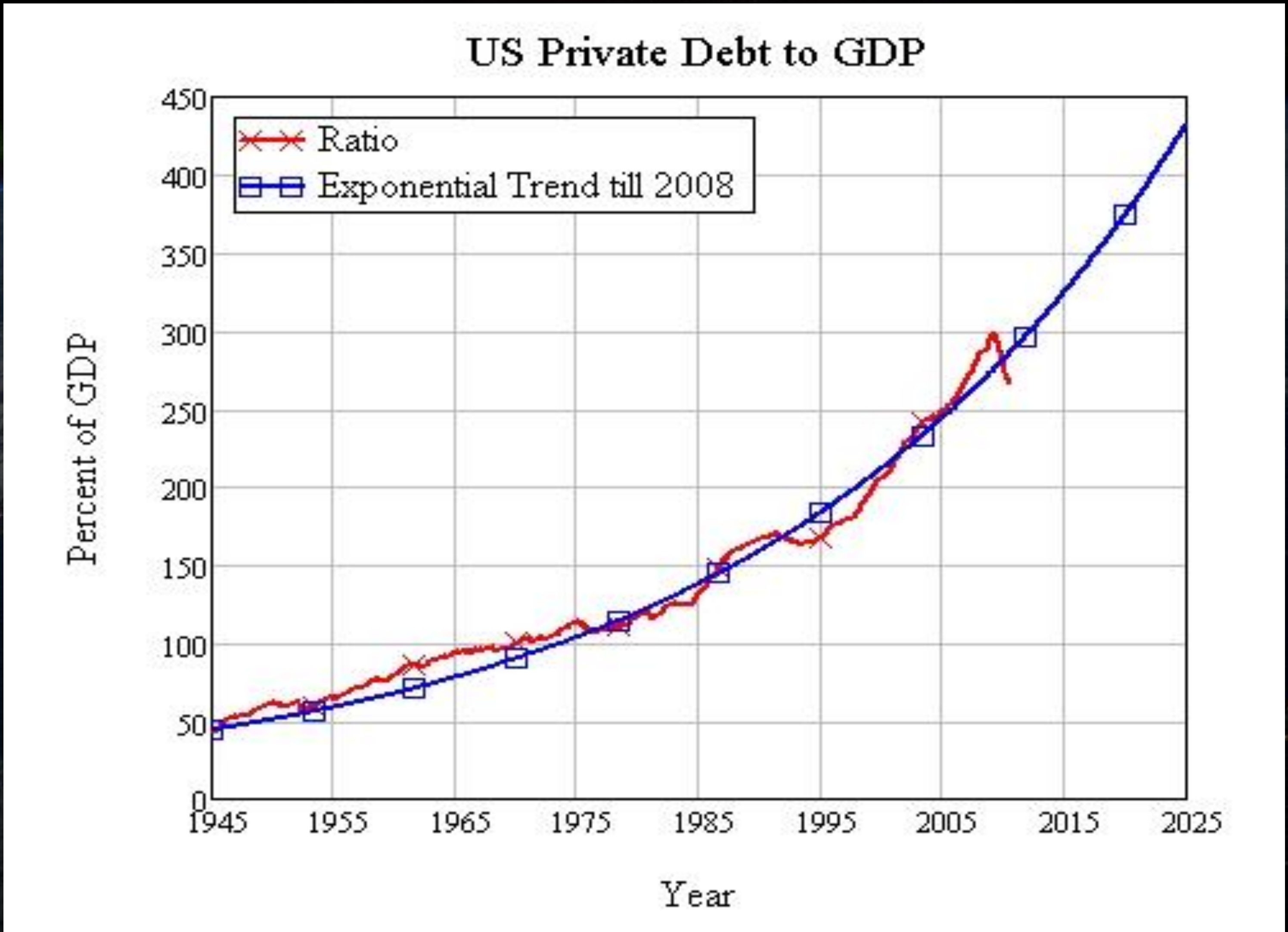
…on more consumption spending per $ of GDP



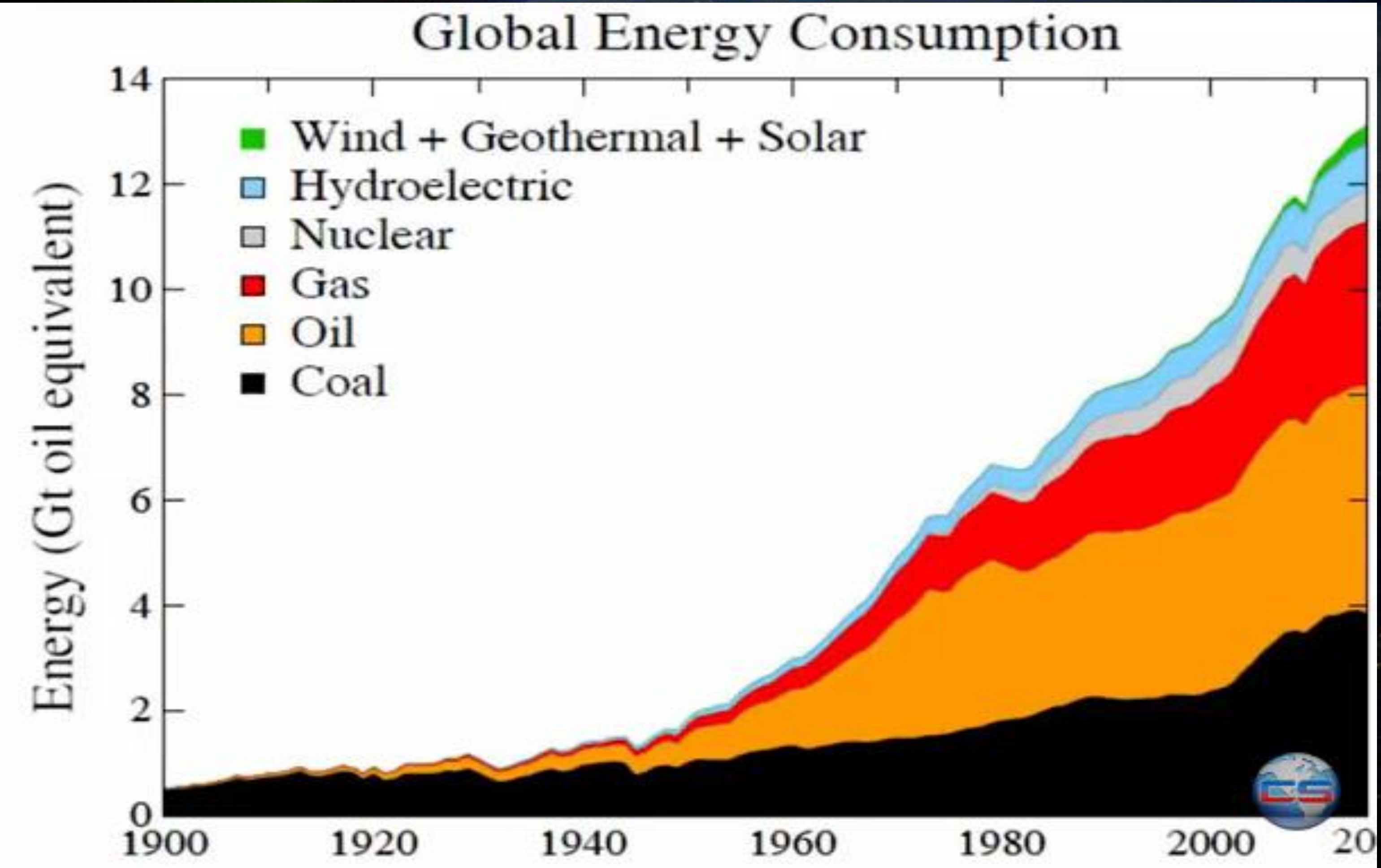
We're NOT Saving... Even for our own retirement



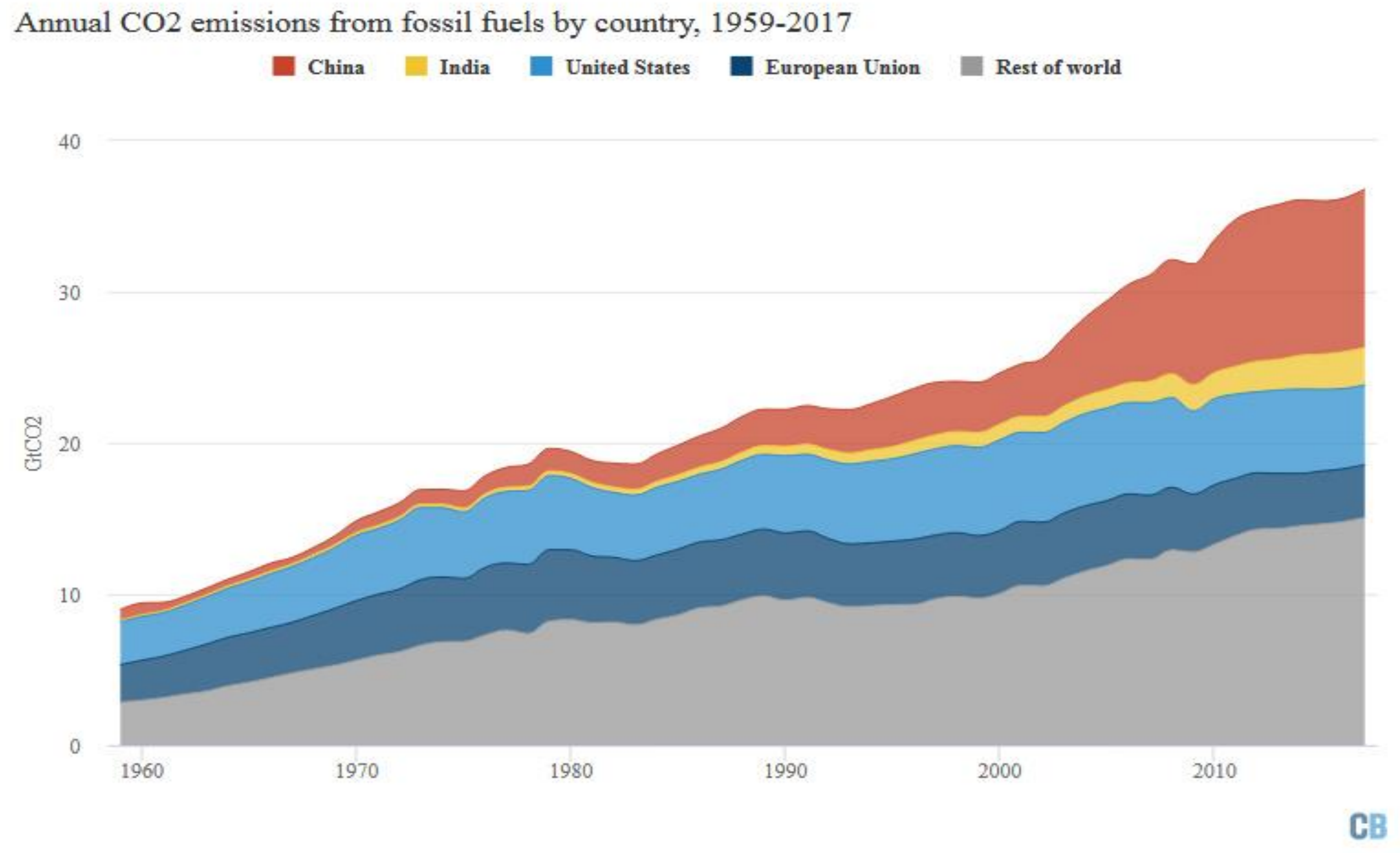
We SPEND. Not stopping with bankrupting ourselves, we go on to spend our children's and grandchildren's inheritance: Debt/GDP is exponentially increasing



Civilization will exploit ANY and ALL energy it can lay hands on. Yes, new power plants are increasingly solar and wind, <u>when cheaper</u>. But FF power will not be unplugged just to save the planet, they'll be unplugged only at the end of their natural lives… The tiny blip of green is non-hydro renewables, on top of rising fossil fuels underneath. Hydro and Nuclear have grown little for decades

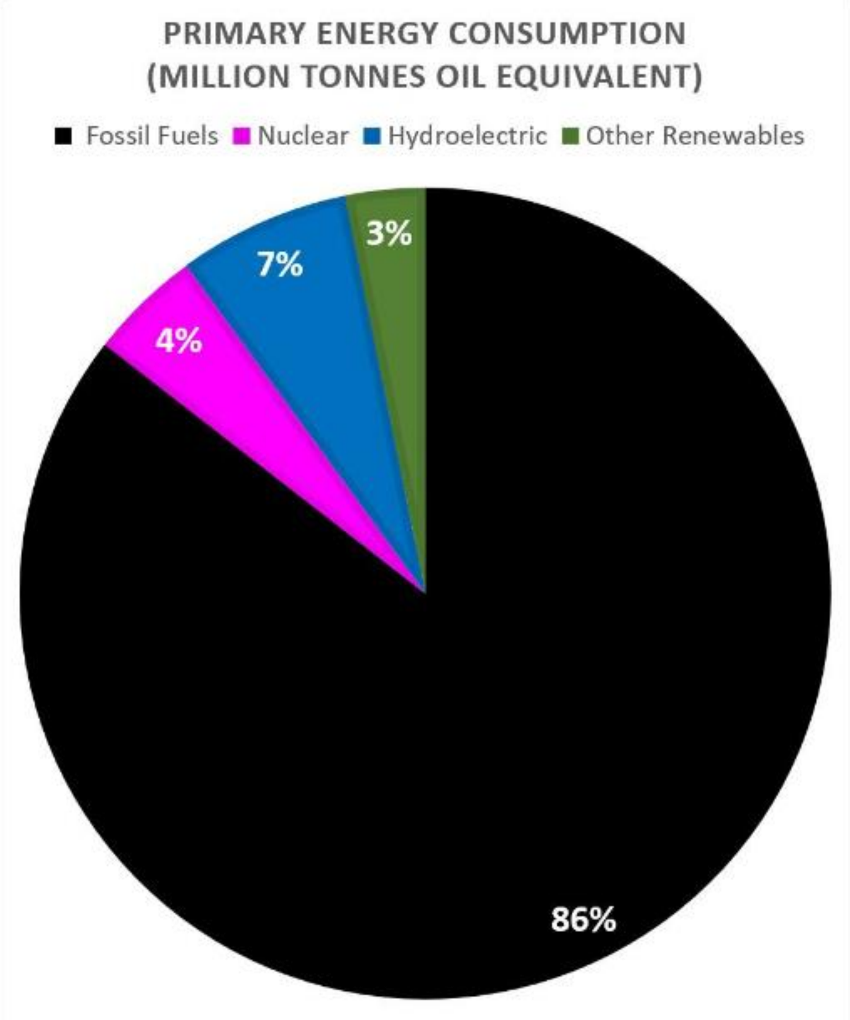


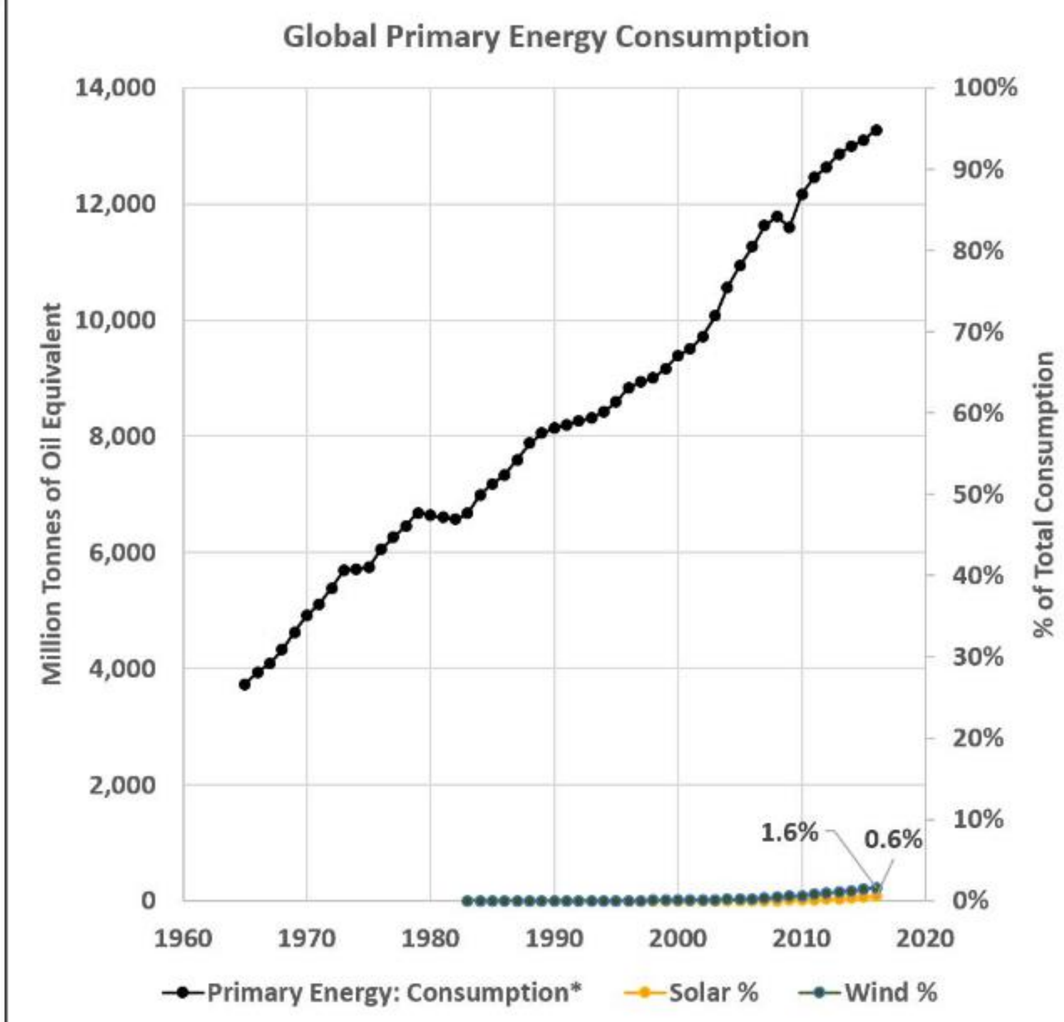
“Peak Emissions” Celebration? Put Away the Party Hats - 2017 CO2 Emissions Rise +2% over ‘16, Led by China’s +3.5%. 2018 rose yet again.



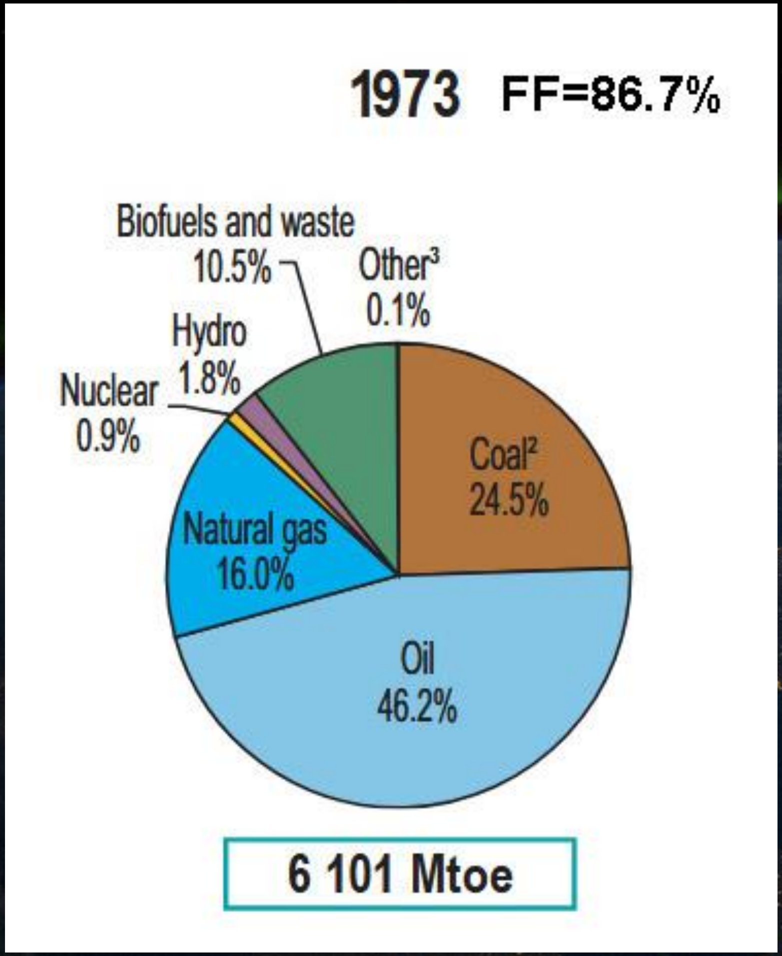
Annual CO2 emissions from fossil fuels by major country and rest of world from 1959-2017, in gigatons CO2 per year (GtCO2). Note that 2017 numbers are preliminary estimates. Data from the Global Carbon Project and available here. Chart by Carbon Brief

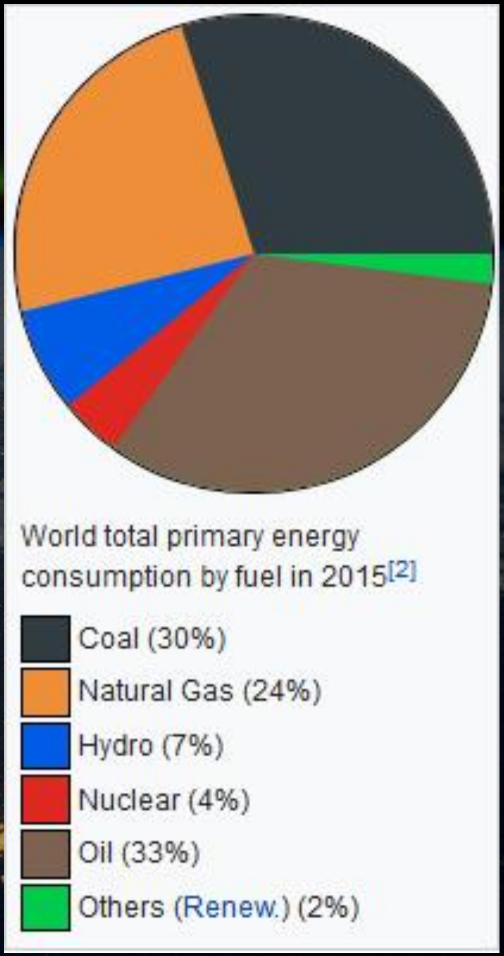
Rising total primary energy, mostly Fossil Fuels, is out-running Solar and Wind (2016).





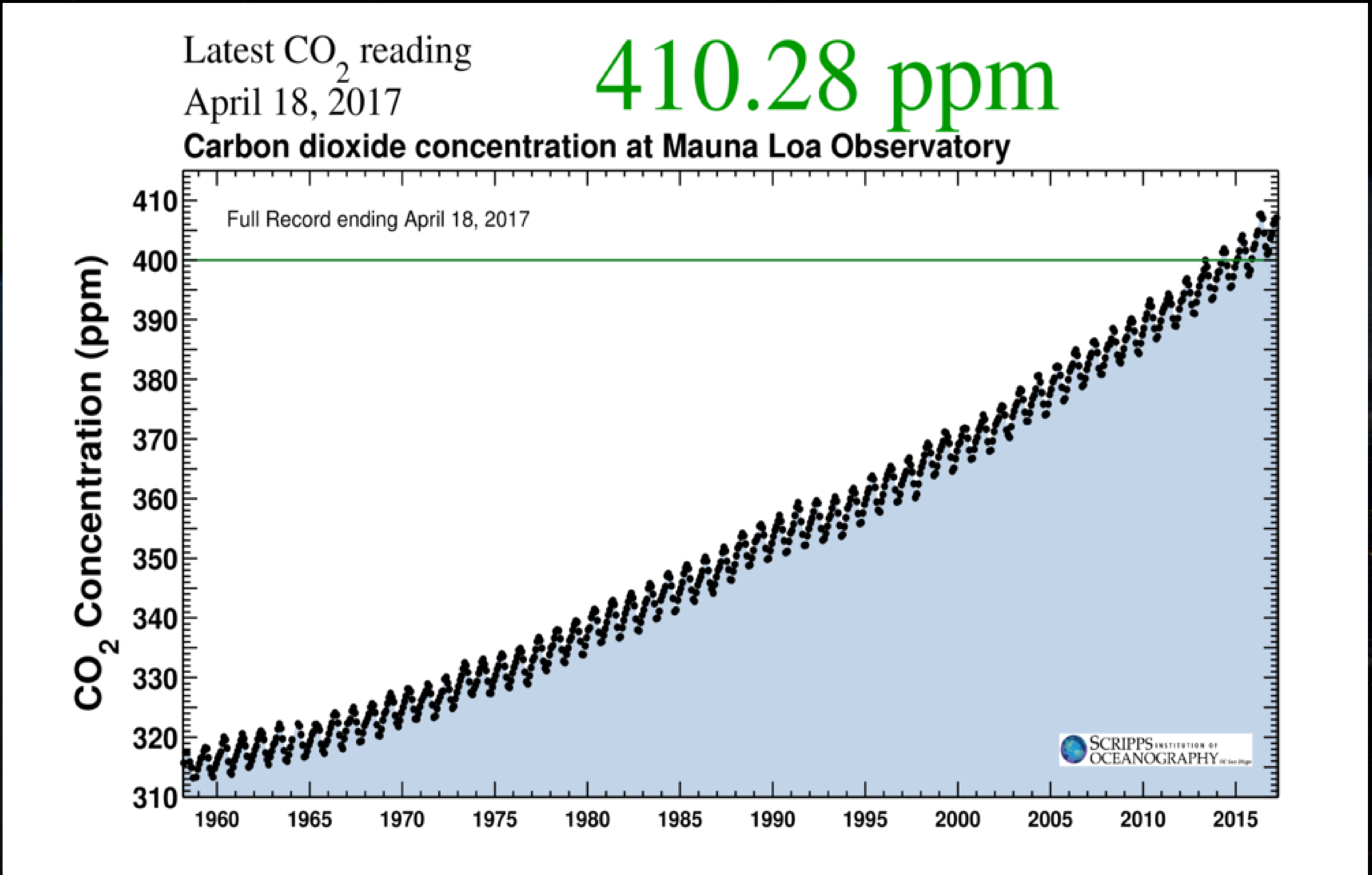
In 42 years, fossil fuels (coal, oil, natural gas) as a % of the total power has not dropped. At all.





…Remaining at 87% (of Total Primary Energy), while total consumption of all energy has more than doubled (BP Statistical review)

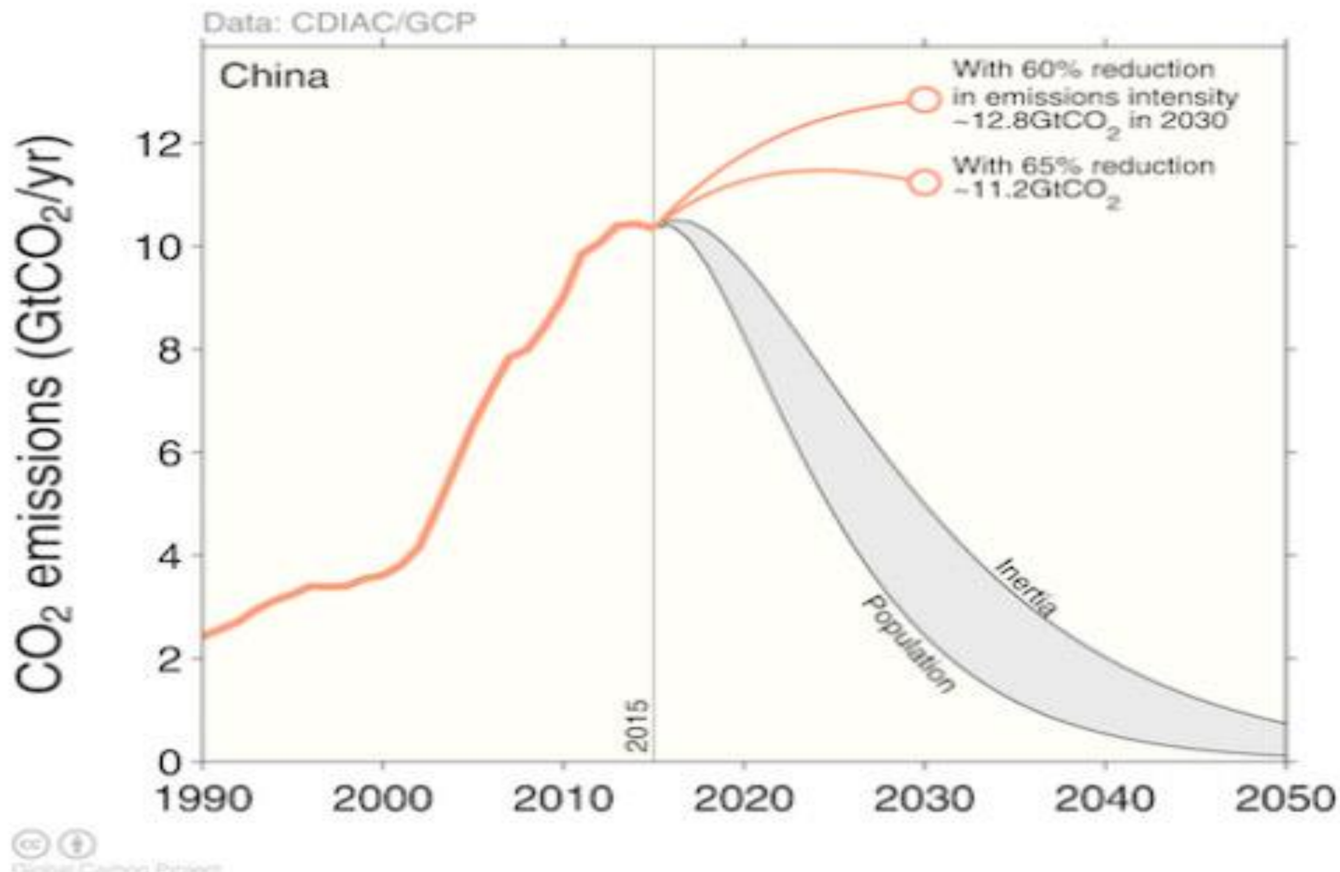
So - in the Real World: Atmospheric CO2 Continues to Accelerate, with No Break



China, far from eliminating coal power plants, is deploying more of them, not only in China, but in Africa, Serbia…

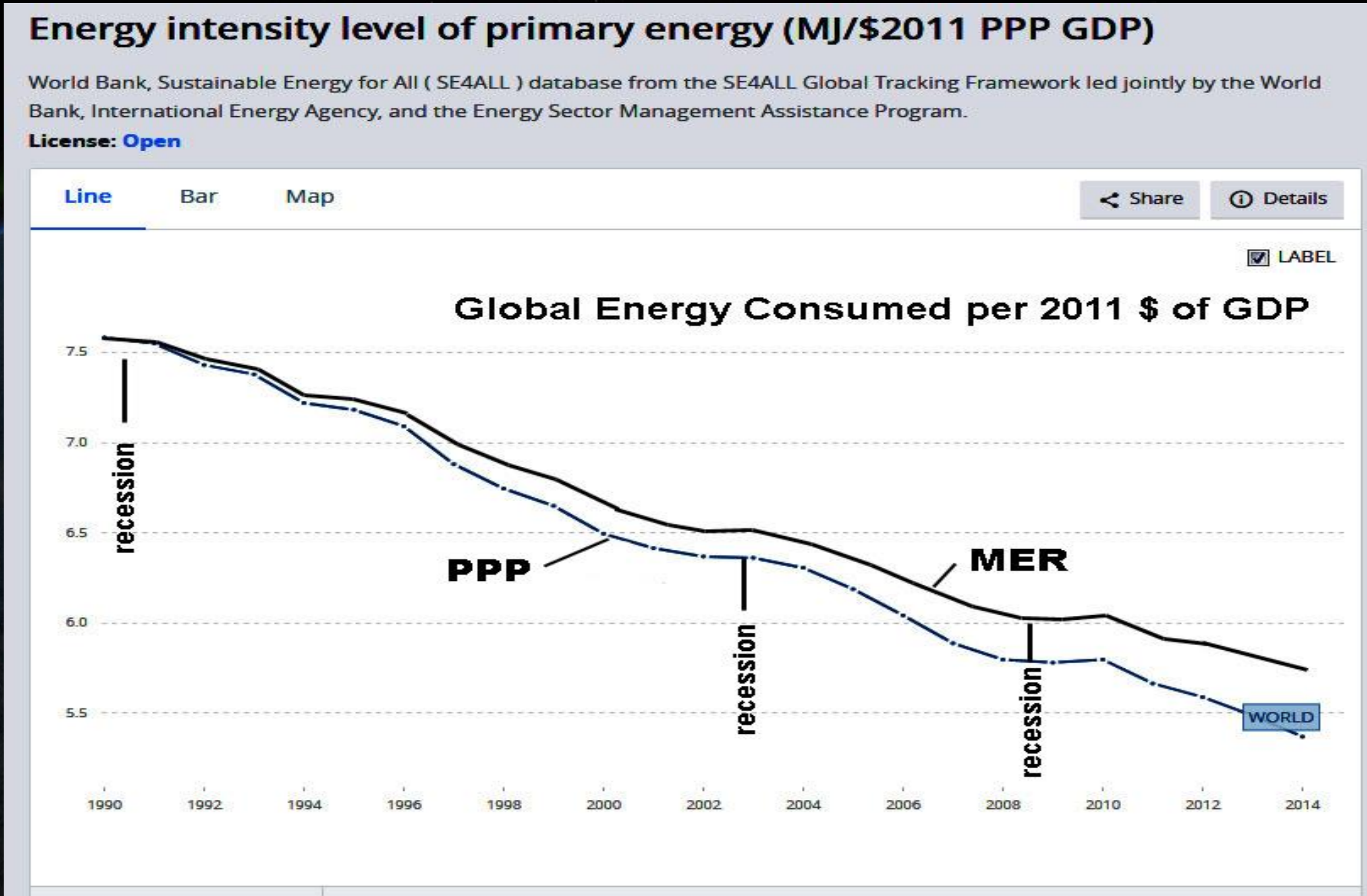
- *Pera Markovic, a lawyer with Cekor, an environmental group, is critical of the company's failure to limit pollution in the local area.*
- *But he concedes that Serbia is heavily dependent on coal for its power.*
- *For how long? "Decades," Mr. Markovic says.*
- *That's likely to be the same in many other countries too, whatever climate scientists say is needed.*

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)

f(t) == P(t)/G(t): **Primary Energy Consumption Rate (*P*) per unit of global GDP (*G*) is an approximately linearly dropping function. Energy Efficiency Improving! But note that during recessions (1990, 2001 and 2008/2009) the slope of f(t) went to zero. Perhaps even positive?**



The World Bank data on the previous slide shows the global energy consumption rate (power ***P***) per unit of officially reported global GDP ***G***. Call that changing ratio ***f***. It's usually a nicely declining function.

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

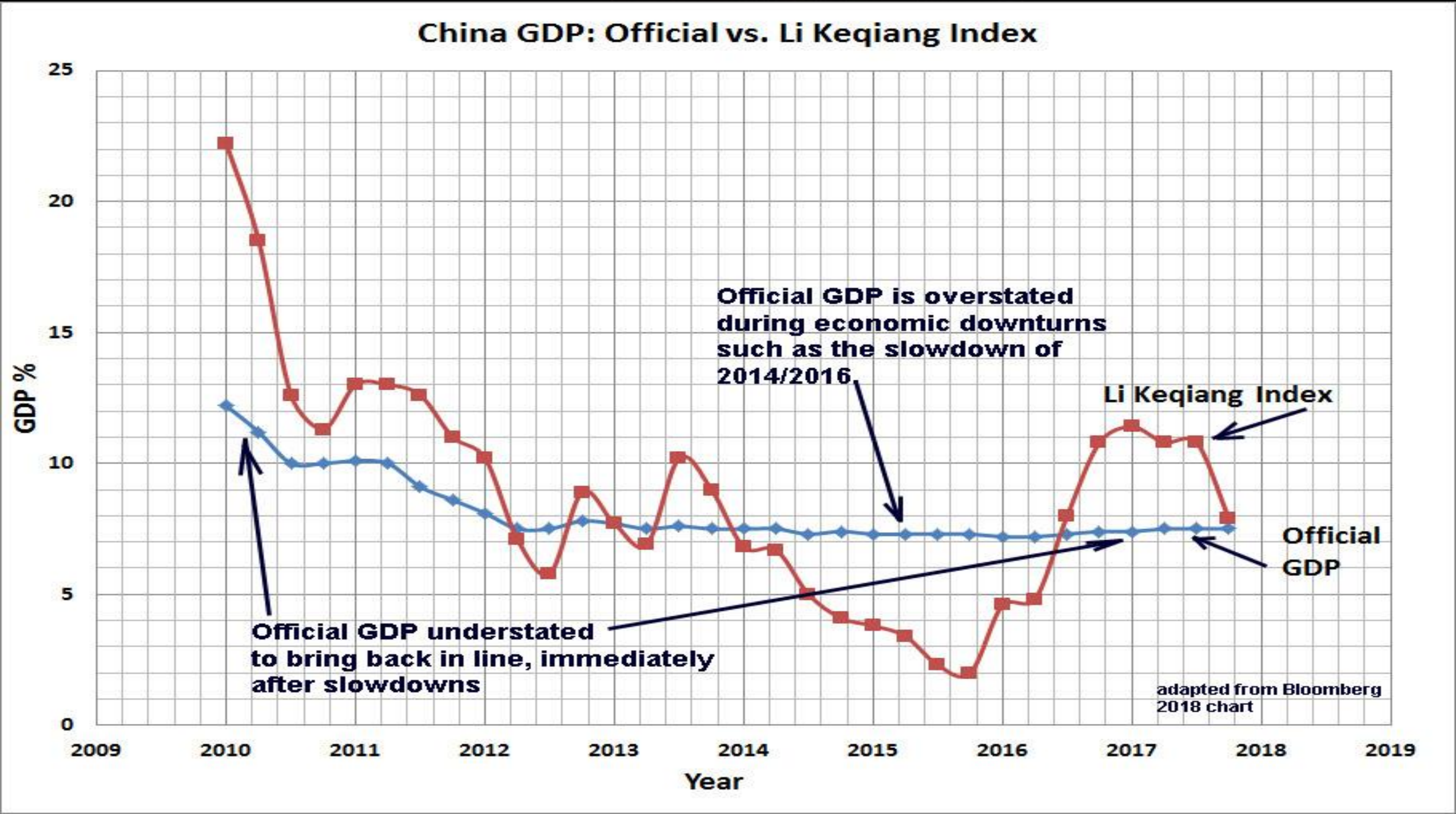
and substituting this into (2) then gives

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

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

- The left side is constant positive. On the right side, the first term is (historically, usually) negative and approximately constant (~linear downward sloping f. It's the slope of the curve on the last page). The 2nd term is usually positive. It is negative only during the economic recessions, when $\partial G/\partial t$ is negative. But that World Bank f curve showed this is also when official $\partial f/\partial t$ rises to zero or even positive.
- Averaged over the noisy (and unreported uncertainty limits of the economists' data) boom and bust economic periods, the equation holds true (Garrett 2010).
- **But note - If we were to enter a prolonged recession, it suggests that we could not simultaneously continue to improve the energy efficiency of global GDP, so that $\partial f/\partial t$ would have to turn positive. In other words - we'd be struggling with merely maintaining past growth's Wealth, so current energy consumption would be growing FASTER than GDP, as hinted in the last recession.**
- **So, DOES Energy Efficiency reverse during actual recessions? Data is incomplete, but for biggest CO2 emitter China: Yes…**

The Recession – GDP Bias. In China's command economy, local party officials tend to report the 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 worse than reported, but then to compensate, they under-report in boom times. Result? GDP Overstated during recessions: Energy Efficiency WORSE; $\partial f/\partial t > 0$.



You May Be Grumbling…

- …that my talks are “negative”, a “downer” and no one wants to hear that sort of thing. Right. So I’ve been told. Now, to continue…

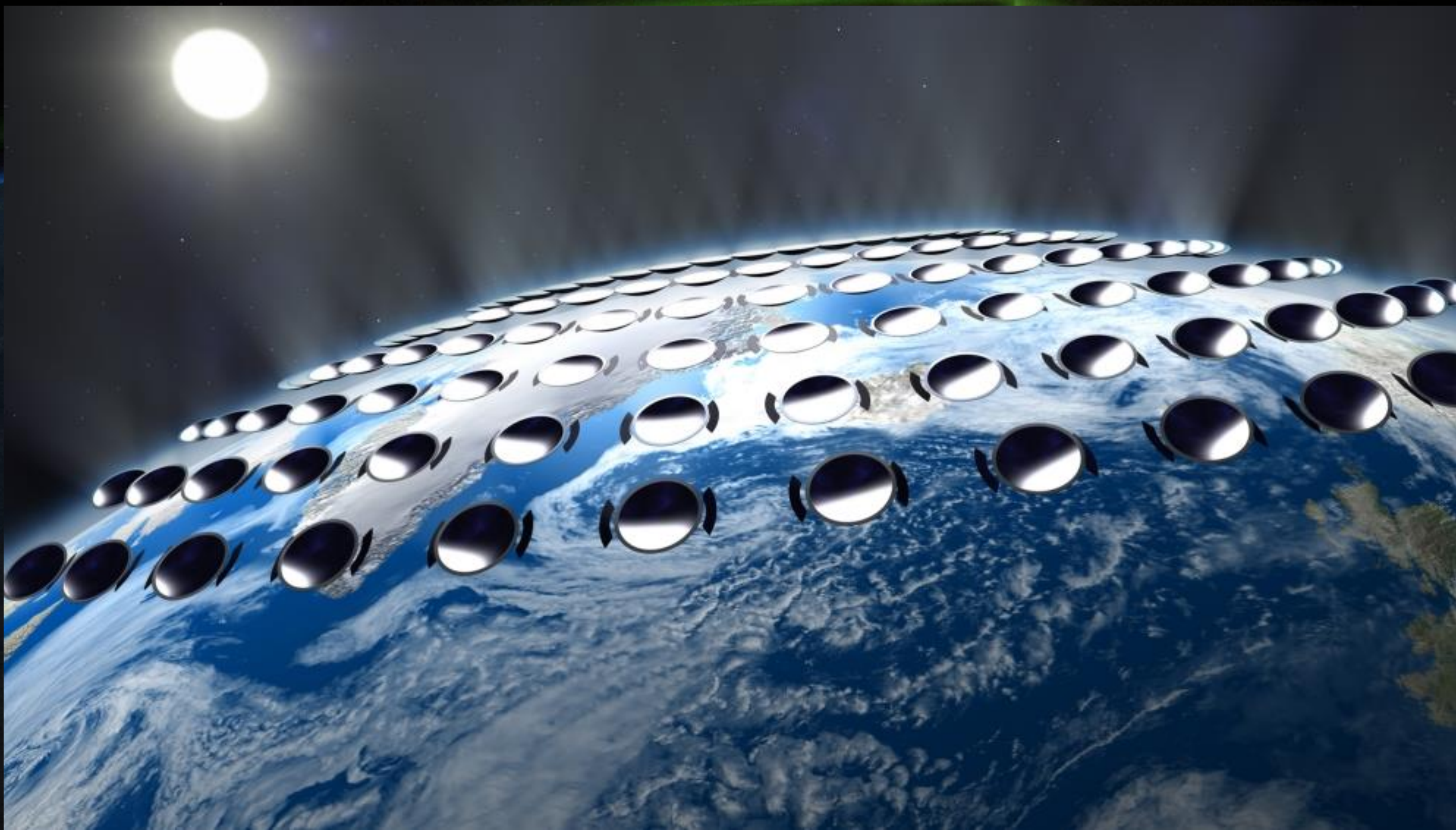
We Instead Want….

Nobel Laureate Psychologist Daniel Kahneman, on People and Climate Change

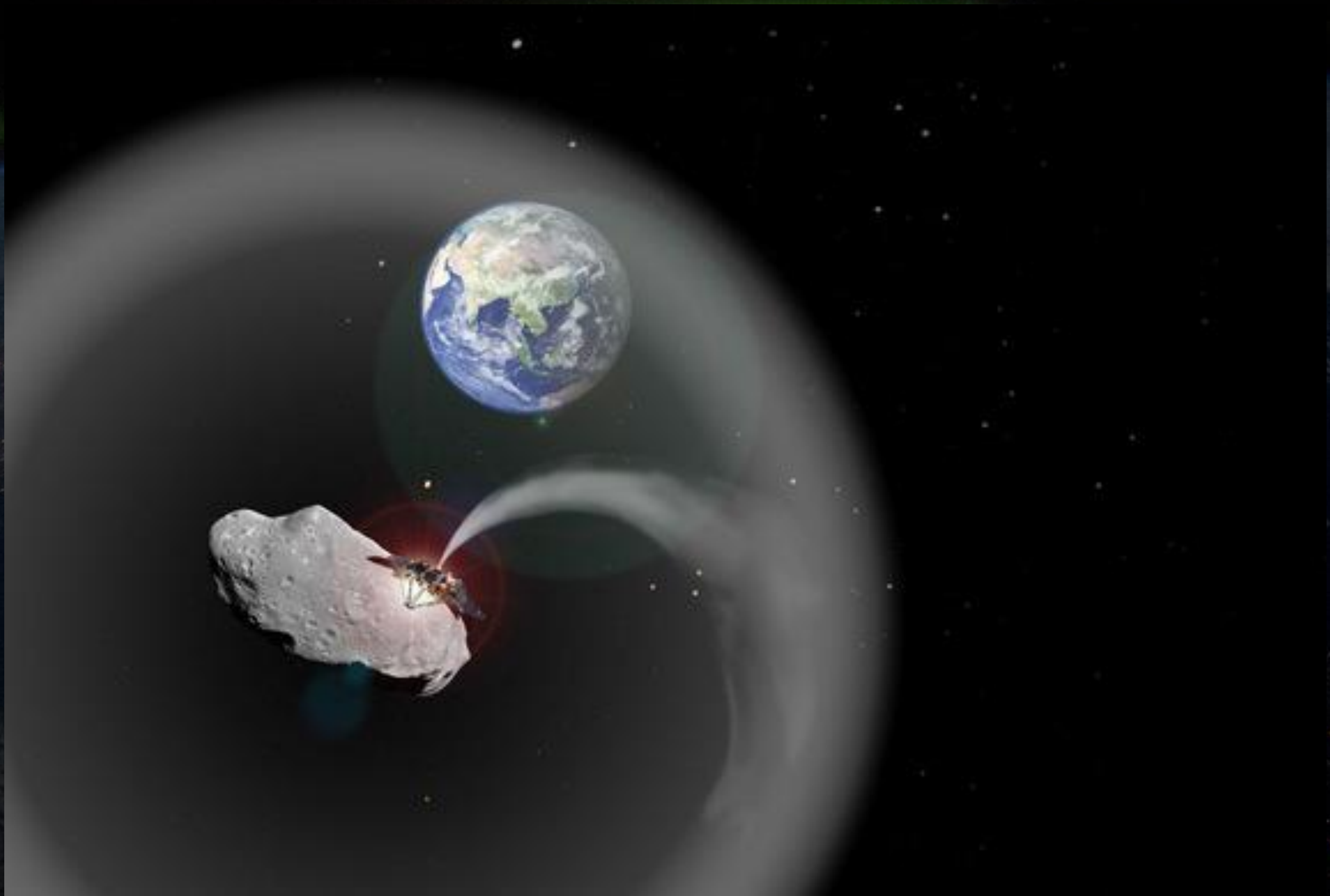
"No amount of psychological awareness will overcome people's reluctance to lower their standard of living. So that's my bottom line. There's not much hope. I'm thoroughly pessimistic. I'm sorry." (source)

- **If that failure of will power continues to rule our voting, then I agree with his thorough pessimism – there's no hope.**

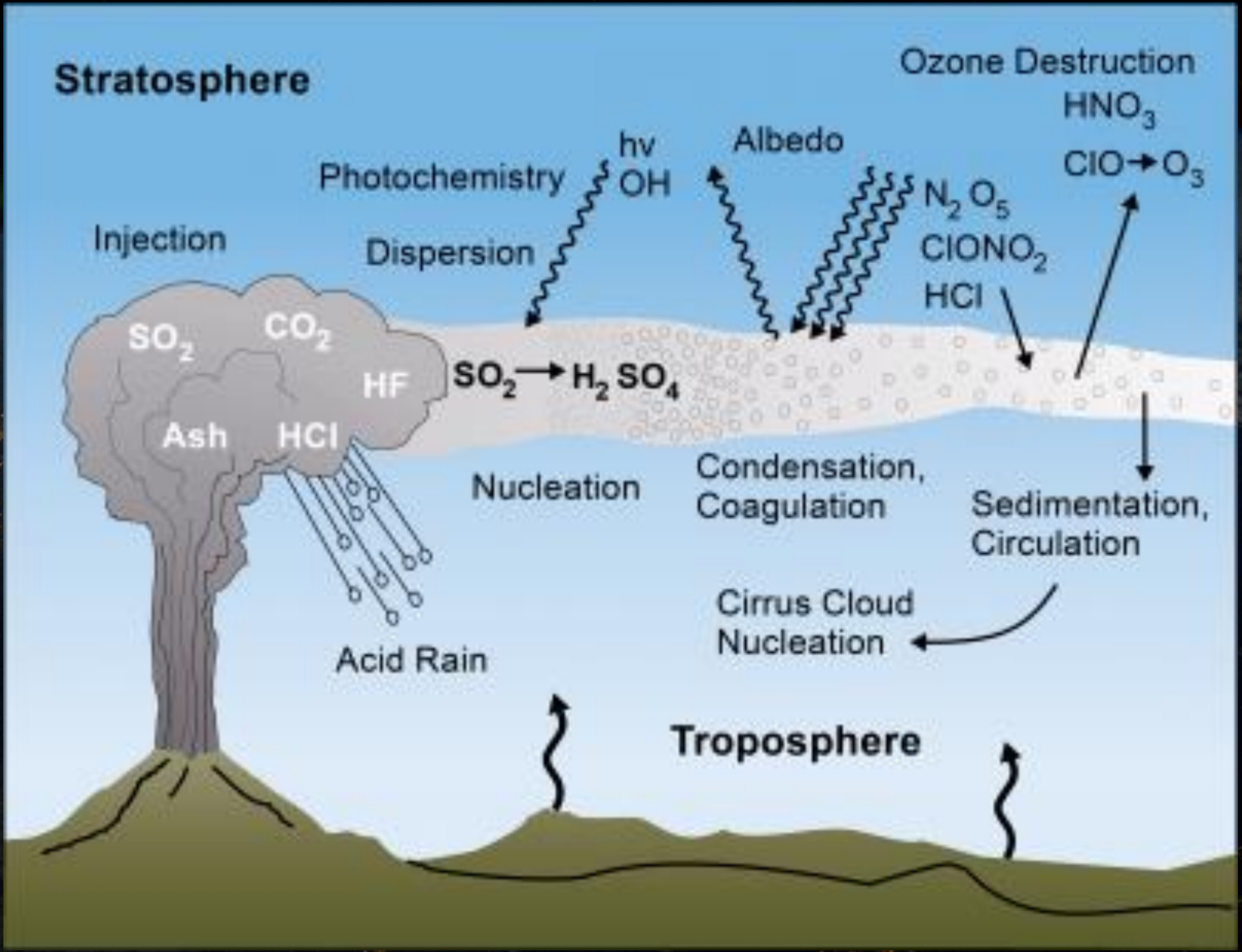
Section G. GeoEngineering



Move an asteroid to the L1 Lagrangian point between us and Sun, and sputter dust off of it to attenuate sunlight? But L1 is a gravitational “hill”, unstable. Lose positioning control gives 50/50 chance it’ll fall on top of us



Injecting Reflective Aerosols into the Stratosphere



More Climate-Warming High Clouds?

- The "aerosol indirect effect" (seeding clouds) would hopefully not apply. In fact, if the aerosols actually caused an excess formation of cirrus clouds at this altitude, this would WARM the Earth, not cool it.
- Currently, this altitude, fortunately, has almost no cloud nucleation aerosols. But that would appear to change with this strategy.
- However, ice nucleation is less sensitive to CCN's and the guess is that this will not be a serious problem

Other Points with Aerosol Injection

- ~2-yr lifetime for particles up there, so continuous injection necessary
- Atmospheric sulfates make sulfuric acid. Continuous acid rain on our surface waters. Significant? Maybe not.
- Cheap. That's what's got the profit-hunters attention
- Lowered Temperatures would help soils sequester more carbon, on the plus side

Ozone Loss: How Serious?

- Mt Pinatubo's eruption in 1991 caused losses of total column ozone of 6% (Schoeberl *et al.* 1993, Chandra 1993) for ~6 months.
- But we need continuous on-going injections. If these losses turn out not to be additive with the continuous aerosol injections, then ~6% decreases might not be unacceptable, given Robock's study of injections at the rate of ¼ of a Mt. Pinatubo per year.

More Issues

- Sulfate aerosols partially block Earth's outgoing radiative cooling, but their high reflectivity for incoming sunlight more than make up for this
- Astronomers would not be happy (but, they're not a significant voting block, so who cares?)
- Lowered incoming sunlight would reduce photosynthesis but aid soil organic carbon retension.
- **The moral hazard…. An excuse to foot-drag on actual and long term solutions.**
- **– ALL sun shade strategies at best only cool the planet. By themselves, they do nothing to help the problem of CO2-induced ocean acidification if we continue to burn carbon.**

"Barking Mad"?

- James Anderson says we need to do real-world experiments to find out.
- Geophysicist Raymond Pierre-Humbert judges the idea "barking mad".
- Award winning environmental film maker <u>David Suzuki calls the idea "insane"</u>
- Rutgers Professor Martin Bunzl argues that the worst problem with stratospheric aerosol SRM is that it <u>cannot be tested</u>. It can only be <u>fully</u> implemented and then wait long enough for the signal of its effects to rise above the weather statistical noise and find out if it was a good idea. Global weather patterns, crop growing areas WILL be changed, in poorly known ways.

CaCO3 or Salt Instead of Sulfates?

- So far only at the hypothesis stage, but Harvard's David Keith and colleagues are now exploring this.
- Using CaCO3 aerosol rather than sulfuric acid droplets should negate acid rain. But it's the droplet spherical geometry which is so sunlight reflective – the very thing you get with sulfates and water, but not CaCO3
- Ground salt instead? Energy source to pulverize to 0.5 micron optimal size? Rainwater would be saltier, but perhaps not significantly so.

SRM is Dangerous to Climate Patterns we have Evolved with

- Why so? I’ve not seen this explicitly explained, so I’m doing it here…
- SRM cools preferentially where sunlight falls – the Tropics, in daytime only
- But CO_2 inhibits <u>outgoing</u> radiation, which is from <u>everywhere on Earth day and night</u>.
- So the regional heat balances now shift.
- So rain patterns will shift too. How? Complicated, we’re not sure.

Climate Wars:

- Could well be a strong disruptor of the climate System that Life has adapted to for 10,000 yrs. Global civilization for thousands of years has been built and fine-tuned around precisely the rain patterns that have been stable during the history of civilization. There will be rain “winners” and rain “losers” among continents and countries.
- What will the losers do? Shoot down the aerosol-makers? Start wars? Do their own counter-attacks with even more poorly understood climate weapons?

Serious Political Problems with Climate Intervention Strategies, including Stratospheric Aerosols

- Any scheme could be used as a weapon to *e.g.* increase/decrease rain for one country at the expense of neighbors or political enemies.
- Russia has no evident interest in halting global warming. They benefit from thawing of the Arctic permafrost and easier access to massive underground natural gas reserves there, and in the off-shore Arctic oil reserves, and are definitely a relative winner as global warming harms the rest of the world more.
- Russian President Putin plans to take advantage of the melting of the Arctic (links here).
- Any unilateral attempt by the US and/or Europe to begin massive stratospheric aerosol injection to re-freeze the Arctic may well be regarded as an Act of War.

The CarbFix Project

- Forces CO2 dissolved in water into deep underground basalt formations, where in a matter of a few years it turns to carbonate rock. Basically, the silicon is replaced by carbon in silicate-rich basaltic rock
- Pilot project shows some success at very small and slow scales, in thermally favorable locations in Iceland.
- Idea is pumping liquid “carbonated” water and letting the porous surface of underground basaltic rock do the chemistry

Can CarbFix Work on a GeoEngineering Scale?

- On the plus side…
- The required basalt is common worldwide. The Pacific Northwest Columbia River formation might, very optimistically, hold 100 Gt of CO2, or ~3 years of current annual global CO2 emissions.
- Original paper (Matter *et al.* 2009) was a decade ago. The latest update (Matter *et al.* 2016) shows that if the water is pre-alkalized sufficiently (cost??), then mineralization of their small pilot project amounts still took fully 2 years to happen. Slow.

CarbFix – Minuses…

- Requires 25 tons of water for every 1 ton of CO2.
- Pilot project was tiny.
- And likely worse…

Contact Area in Basalt

- Simply looking at tonnage of basalt makes the implicit assumption that all of that basalt is contact-available to the alkalized water. But basalt isn't generally so porous that fossil ~millimeter size bubble pores connect with each other except a small fraction of the time
- Once the contact space in the pores is covered, further CO2 is isolated from the necessary rock chemistry. They don't discuss this. Especially worrisome on climate-relevant scales.
- Optimal contact requires **powdered basalt**, not rocks.

CarbFix – Minuses Continued…

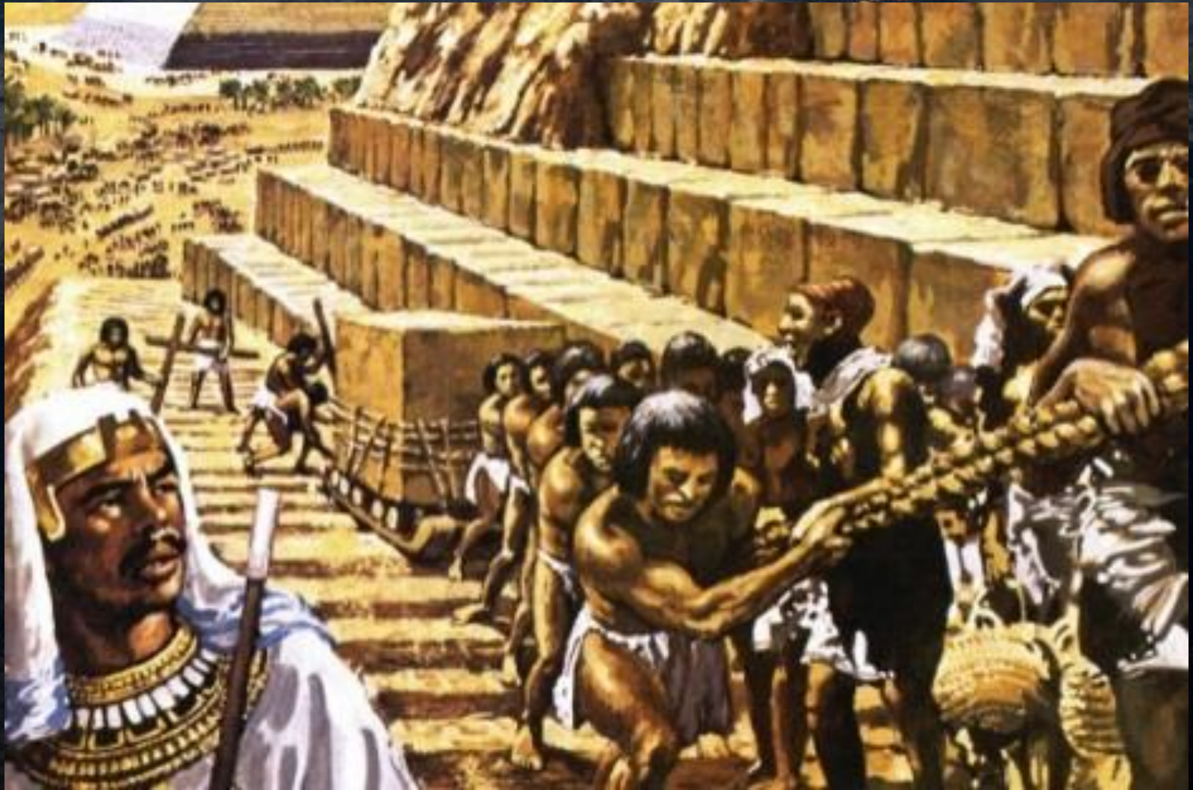
- Pumping expense in energy and dollars, to get high pressures necessary to force down ~1/2 km underground – if energy source is fossil fuel burning, how's the net sequestered?
- Toxic metals are mobilized in the process, go into ground water.
- Costs are conspicuously absent in update paper of 2016. Other flue gas CCS underground projects are well over $100/ton CO2. Would be much higher applied to the atmospheric CO2 which is 1000x more dilute
- Still, it is worth more study

Add CaCO3 to Upwelling Areas?

- …sequesters an additional 0.3 billion tons of CO_2 per year (less than 1% of what we add by fossil fuel burning).
- Would seem to be a pretty minimal effect, and Stanford’s geoEngineering specialist Prof. Ken Caldeira agrees.
- The ocean is home to vital and precious life. Don’t these ecosystems deserve stability?
- **Bottom line – doesn’t look promising**

Make $CaCO_3$ bricks out of captured CO_2? Need Mt Everest sized block to return to 280ppm. Very Energy intensive. A non-starter.

And yet… emotionally satisfying to ponder the Oil Corp CEO's who've lied to us for decades, toiling to make the "Great Carbonate Pyramids"



A.I.M. Arctic Ice Management: Re-Freeze Arctic Ocean with Wind-Powered Pumps

- Desch *et al.* (2017) calculate we could re-freeze the Arctic Ocean by using 100 million bouy-mounted wind-powered pumps to coat the cold surface of winter ice with sea water, freezing it.
- They include latent heat, ice conductivity, cloud cover, and past studies' empirical relations, to find that pumping 1.3 meters of additional sea water onto the surface of the ice would yield an extra 1m of ice per winter. This could prevent thaw next summer, making ice cap once again year-round

How Does A.I.M. Fit Our Safety and Efficacy Criteria?

- **It passes nicely!...**
- **SC #2:** Repair modification on crippled Arctic Ocean ice surface only.
- **SC #1:** A.I.M. retraces backwards the damage we have done in melting the Arctic Ocean ice cap, without apparent bad side-effects.
- **Fits EC #1:** A.I.M. reflects sunlight back out into space in the natural way it did for hundreds of thousands of years prior to the 21st century and human carbon emissions
- The main question is: Can the engineering feasibility be solved?

Need only 10 million pumps if limited to most favorable areas, but ultimate hope to expand to 100 million (entire Arctic Ocean) as Arctic re-freezes

- 10 yr implementation of 10 million pumps per year would require 7% of global steel production. That's only 2-3 years of the level of growth we already have.
- Deployment of 10 million pre-built pumps to Arctic in 1 year would require half of global shipping capacity, but 1 million per year spread over 10 years only requires use of less than existing idle shipping capacity

Direct Costs?

- High, but not astronomical, and not infeasible. They assume maintenance costs are less than manufacturing costs over life of pump
- $500 billion/yr for 10 yrs covers all Arctic Ocean
- This is only 0.64% of Global GDP, and far less than Big Oil's existing government subsidies
- It's about 40% more than the annual revenue of U.S. auto manufacturers
- It's also about what was spent on the Iraq war (whose main product was suffering).
- To cover 10% of Arctic would be 1/10 of above

A.I.M.: Environmental Costs?

- Manufacture raises global CO2 emission by only ~0.5%
- No atmospheric chemicals, no toxic fuels, doesn’t tamper with the global ocean thermocline, doesn’t enlist novel and dangerous changes to global ecosystems, nor tropospheric nor stratospheric chemistry. Some steel might sink, but that’s not toxic.
- Nice! This is the BEST of the techno GE ideas

Climate-Significant? Yes!

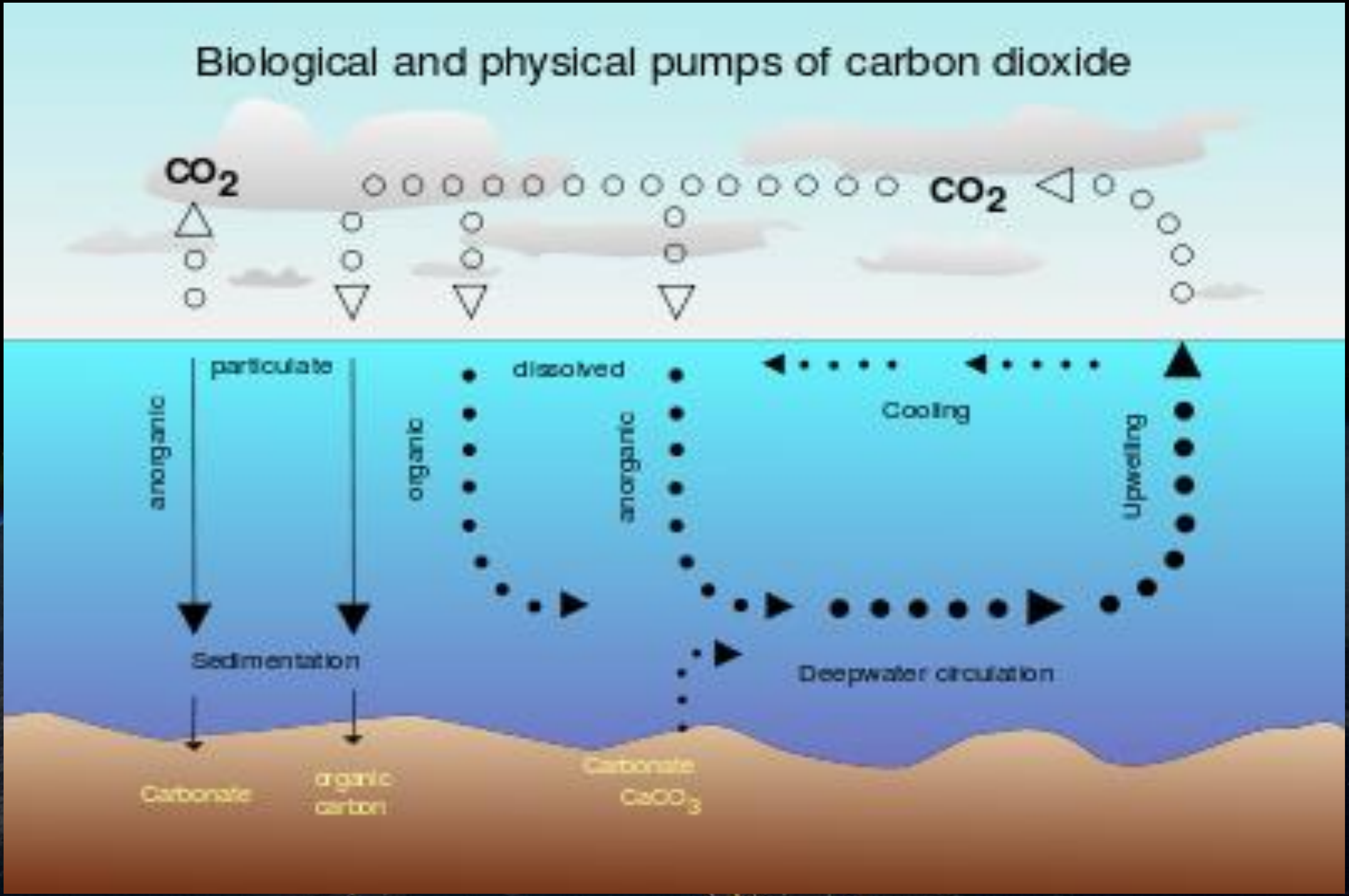
- De-icing of the Arctic Ocean has added fully 25% as much global heating as all CO2 changes we’ve seen (Pistone *et al.* (2014)

OIF: Seeding the Ocean with Iron to Stimulate Algae Absorption of CO2

- Originally suggested by John Gribbin in 1988. **O**cean **I**ron **F**ertilization: **OIF**
- Sprinkle iron in iron-poor (but not silica-poor) areas of ocean surface, as iron is critical for photosynthesis, stimulating algae blooms.
- Silica needed for diatoms, foram's and other calcium-carbonate building phytoplankton. Without the silica, iron won't help, studies show.
- OIF clearly fails safety criterion #2 by radically affecting global ecosystems in poorly understood ways. Mid oceans have NEVER been forced to be iron-rich: Our fore-fathers oceans won't be brought back with OIF.
- Early tests show such iron fertilization does stimulate algae blooms – but is that good?

Algae bloom off Argentina.

So, how does this idea work?



- Iron is (and always has been) critically low in many areas of the open ocean, limiting phytoplankton. Given iron fertilization so they can multiply, certain species make carbonate skeletons, which then sink when they die. Even most of this carbon gets recycled, but some sink deeper where much gets dissolved in colder waters.
- The dissolved CO2 in the deep is sequestered from the surface ocean for decades and optimistically to centuries (but then resurfaces, releasing to the atmosphere. Not good)
- A much smaller fraction sinks to the sediments and remains; a net sink of carbon, but very slow. Same thing happens naturally on geological time scales.

Iron Fertilization: How Effective? Not Much of a Dent in Our CO2 Emissions

- If the <u>entire </u>Southern Ocean's (the most promising region) nitrate and phosphate were combined with fertilized iron by plankton, it theoretically could absorb only 1.1 Gt of carbon and deposit to 100m depth, per year (<u>Buesseler and Boyd 2003</u>). Realize even that's an impossible theoretical maximum.
- <u>**Even so, this is only about 10% of the rate of what humans emit to the atmosphere**</u>. And doesn't consider the indirect human-caused CO2 from thawing permafrost, nor the other GHG's. Even this may be too optimistic, as we'll see…

How About Surface Iron Fertilization in the Tropical Ocean?

- Winckler *et al.* 2016 studied the correlation between iron concentrations in the tropical Pacific ocean and productivity over the past 500,000 years with sediment data and finds there is no correlation.
- *"Over the past half-million years, the equatorial Pacific Ocean has seen five spikes in the amount of iron-laden dust blown in from the continents. In theory, those bursts should have turbo-charged the growth of the ocean's carbon-capturing algae – algae need iron to grow – but a new study shows that the excess iron had little to no effect…At some points, as levels of iron-bearing dust increased, productivity actually decreased."* – from discussion at Columbia University
- This confirms an earlier study using paleo data from just the last glacial maximum.

Iron Fertilization: Ineffective in the Tropical Pacific, Despite Favorable Ocean Nutrient Profiles

- *“Neither natural variability of iron sources in the past nor purposeful addition of iron to equatorial Pacific surface water today, proposed as a mechanism for mitigating the anthropogenic increase in atmospheric CO_2 inventory, would have a significant impact,”* the authors concluded.

The CLAW Hypothesis – Good or Bad?

- It is hypothesized that since some phytoplankton produce dimethyl sulfide, that some of this could combine in the surface atmosphere to make sulfate aerosols, and, by the aerosol indirect effect, seed additional low clouds – a climate coolant by reflectivity.
- This is the CLAW Hypothesis (Charleson *et al.* 1987).
- But – even if the CLAW Hypothesis turns out correct here, tropospheric aerosols rain out quickly, so only long term continuous large-scale iron seeding would have this additional radiative effect. Also, putting such artificial clouds into the global climate system in highly regional ways could well alter circulations and rainfall patterns.

Summary of Review Paper on the 13 OIF Experiments in past 25 years (Yoon *et al.* 2016, p. 15)

*"To test the Martin Hypothesis, a total 13 artificial OIF experiments for scientific study were conducted in the HNLC (*high nutrient low chlorophyll*) Regions during the last 25 years The biogeochemical responses to OIF experiments were observed in the increases of primary production as a result of drawdowns of macro nutrients and DIC (*dissolved carbon*) . In most experiments, the dominant phytoplankton group tended to be shifted from small sized groups to large sized groups, resulting in a diatom dominated phytoplankton community .*

However, the effectiveness in export production enhancing ocean biological pump (**meaning: carbon sequestering to the deeper ocean*****) was not clearly confirmed by the OIF experiments except in one, EIFEX.***

Likewise the possible environmental side effects in response to iron addition, such as production of greenhouse gases, development of hypoxia/anoxia in water column, and toxic algal blooms were not fully evaluated due to inconsistent outcomes with large uncertainty depending on OIF experiment conditions and settings"

How Much Iron to Sequester How Much Carbon?

- Lab theory suggested 1 ton of iron would, with ideal chemistry, sequester 106,000 tons of carbon.
- But only **one** of the 13 OIF experiments found any real-world carbon was dropping even a couple hundred meters (but described as "sequestered to the deep ocean"), with a ratio only 2,600 to 1 (deBaar *et al.* 2008). Assuming that ratio would not drop further even when going to climate-significant scales (a big assumption, considering the other nutrients used up), that would mean 300,000 tons of powdered pure iron to sequester 1 gigaton of carbon, or 10% of human annual CO2 emissions.
- For how long could that go on, using up the other nutrients in the ocean in the process? Not clear.

Here is the IPCC (2013) AR5's Summary Table on Iron Fertilization as a Strategy

- **Iron Fertilization - More dangers than promise…**
- The OIF experiments done so far have not studied these issues, or done so inadequately. The recent experiments we looked at here show that adding iron in one area removes more nutrients which are then unavailable elsewhere as the ocean currents move.
- Large enhanced carbon in deep ocean will consume oxygen, expanded "dead zones", acidifying it as well.

Enhanced biological production and storage in ocean	Ocean iron fertilisation[k] Algae farming and burial[l] Blue carbon (mangrove, kelp farming)[m] Modifying ocean upwelling to bring nutrients from deep ocean to surface ocean[n]	Biological	Ocean	[k,n] Inorganic [l,m] Organic	[k]May lead to expanded regions with low oxygen concentration, increased N_2O production, deep ocean acidification and disruptions to marine ecosystems and regional carbon cycle [n]Disruptions to regional carbon cycle

Safety? At climate-significant levels, OIF is a massive change to the existing ecosystem, which does not have algae blooms in the open ocean. Fails our Safety Criterion.

- A 2010 study (Trick *et al.* 2010) of iron fertilization in an oceanic high-nitrate, low-chlorophyll environment (exactly the environment that is necessary for this strategy) found that fertilized *Pseudo-nitzschia* diatoms, which are generally nontoxic in the open ocean, began producing toxic levels of domoic acid.
- Even short-lived blooms containing such toxins could have *"detrimental effects"* (their delicate words) on marine food webs.
- Finally, **Sigman and Hain (2012)** in **Nature: Education (p. 12)** point out some fatal flaws in the entire OIF paradigm

Sigman and Hain (2012) explain why Iron fertilization is ineffective as a GeoEngineering strategy

- *"First, even if iron fertilization were to lead to complete consumption of nutrients, it takes too long for the deep waters to cycle through the polar ocean surface to substantially alter the currently rapid rise in atmospheric CO2 (Peng & Broecker 1991). Second, humans appear incapable of intentionally fertilizing a significant fraction of the Southern Ocean on a continuous basis; with only sporadic fertilization, a substantial portion of the additional CO2 sequestered in the deep ocean would upwell back to the surface to be released. Third, any modest increase in carbon storage that such fertilization does cause will come at the expense of lower oxygen concentrations in the ocean interior, one climate consequence of which may be enhanced release of the greenhouse gas nitrous oxide to the atmosphere (Jin & Gruber 2003)."*

The Jin and Gruber (2003) Paper is Quite Sobering on the Prospects of the Powerful GHG N_2O being Produced by Iron Fertilization

- In the tropical oceans *"by assessing the CO_2 and N_2O only over the areas fertilized, one will overestimate the climate radiative benefit by 500%. <u>Therefore, verifications of the benefits of ocean fertilization require essentially global-scale assessments</u>, which are very difficult to obtain given the small signals and the presence of natural variability"*
- Such facts won't stop the promoters though…

OIF: Conflict of Interests. Biases of $Promoters - Politics and Economics

- The existing laws involving carbon credits make OIF tempting for polluters. They can pollute the atmosphere with CO2 by then buying cheap carbon offsets in the form of funded OIF (Fuentes-George 2017), which may very well then severely damage the ocean ecosystems evolved in the pre-Industrial / pre-OIF epoch.
- **A Two-fer! Double the damage to the Earth System, for the same money.**

BEWARE the PROMOTIONALS!

- You'll certainly be told about increased fish yields in the one "successful" OIF experiment in the Pacific Northwest. And the money to be made there because of it (paid by the poor native cultures whose fisheries were destroyed by us already).
- You'll certainly catch the flavor that this is the miracle we've been hoping for, and the dangers unmentioned.
- One thing you won't hear, is that the salmon and other fish eagerly taken out of the sea will be eaten and so all that fish carbon from the phytoplankton doesn't get sequestered, instead entering the "fast carbon cycle" and re-entering the atmosphere.

Last:
The “Loan Shark” Category

OTEC Pipes to Cool Ocean Surface And Earth?

- **O**cean **T**hermal **E**nergy **C**onversion (OTEC) is an idea that has been around for a hundred years, and even put into practice in a few places for limited time, producing limited power.
- The idea is to tap the temperature difference between deep ocean (~40F) and tropical surface (~77F) to drive a heat engine to generate power
- Considered too costly for a widespread power source
- But what about OTEC as a way to power cold water upwelling to the surface, where it will absorb heat and thereby cool the atmosphere?

…Elephants deal with heat by sending warm blood to those big heat exchangers – ears! Surface heat is able to radiate away easily. CORE heat is buried and unable to leave. Yes, in all ways, a great strategy! <u>Keep this in mind in what follows…</u>

Pulling up cold water to the surface of the ocean will indeed cool climate – initially

- But you are now TRAPPING the absorbed heat by burying it under that cap. (sounds a bit like atmospheric GHG's, no?)
- Recall another basic fact, that it is the thermal inertia of the oceans (~700x that of the atmosphere) which prevents temperatures from dropping even if we halt all GHG emissions. The ocean is the Elephant, and the sea surface and atmosphere are the Ears.
- **Clearly - we need to HELP the oceans get rid of their excess heat, not make it harder**

So it should not be surprising that the long term effects of OTEC are very negative.

- Kwiatkowski, Ricke and Caldiera 2015 in Envir. Res. Lett. (hereafter KRC15) studied the effects on climate of blanketing the oceans with OTEC pipes (summaries are here and here)

KRC15's Methods:

- A high resolution fully-coupled climate model integrating ocean, land, air, cryosphere (land and sea ice), with cloud cover and bio/geo chemistry, and time-stepped 1200 years after thermocline altered as it would be by widespread use of OTEC pipes to 1 km depth, and left pumping throughout.
- Their standard case ran OTEC pipes at sufficient strength to reduce ocean surface temperatures by 7C. They also ran smaller vertical mixing strengths of 10% and 1% of standard. The 10% run reduced ocean surface temperatures by 3C which is closest to what was initially proposed by Alan Miller and his "Cool-it Earth" initiative for climate cooling.
- Each case assumed "business as usual" IPCC RCP8.5 human carbon emissions continuing (solid curves) and also a zero emissions control case in which "pre-industrial" atmospheric CO_2 was left alone (dotted curves in graphs that follow)

KRC15 Standard Case: The initial effect is to cool the surface, as warm surface water is displaced deeper by upwelling pipes (left). But ~50 years later (right), the re-emerging buried heat raises the temperature of the entire 1km depth of the pipes, raising sea surface temperatures even higher than if OTEC pipes were never installed. True whether with continuing human CO2 emissions (solid), or without (dashed)

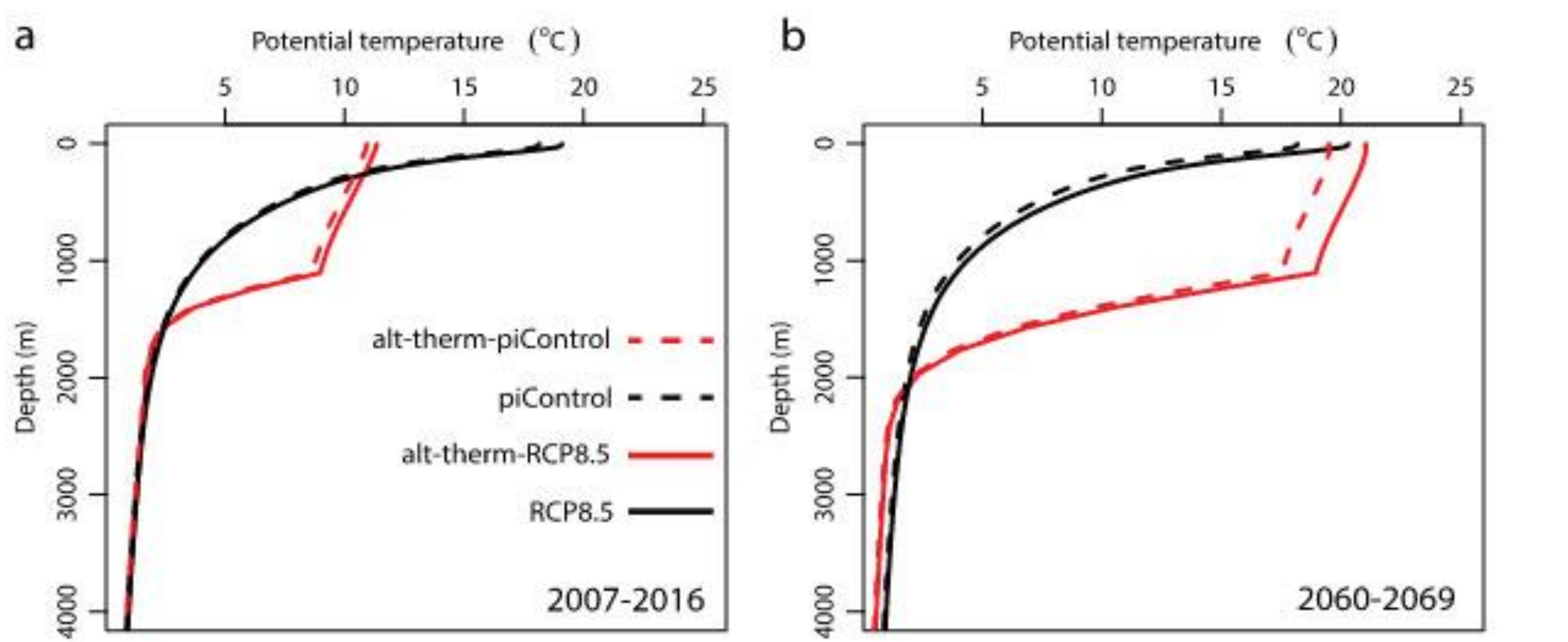


Figure 1. Thermocline impact. Mean (a) 2007–2016 and (b) 2060–2069 global potential temperature across the upper 4000 m of the water column.

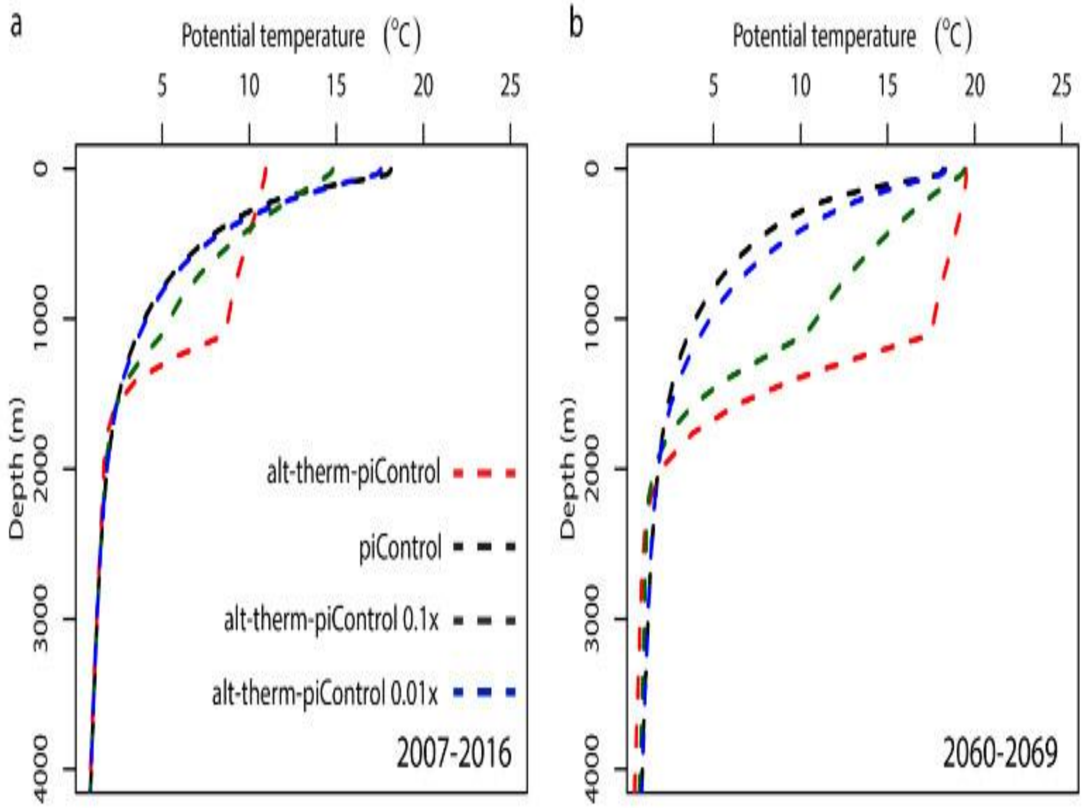


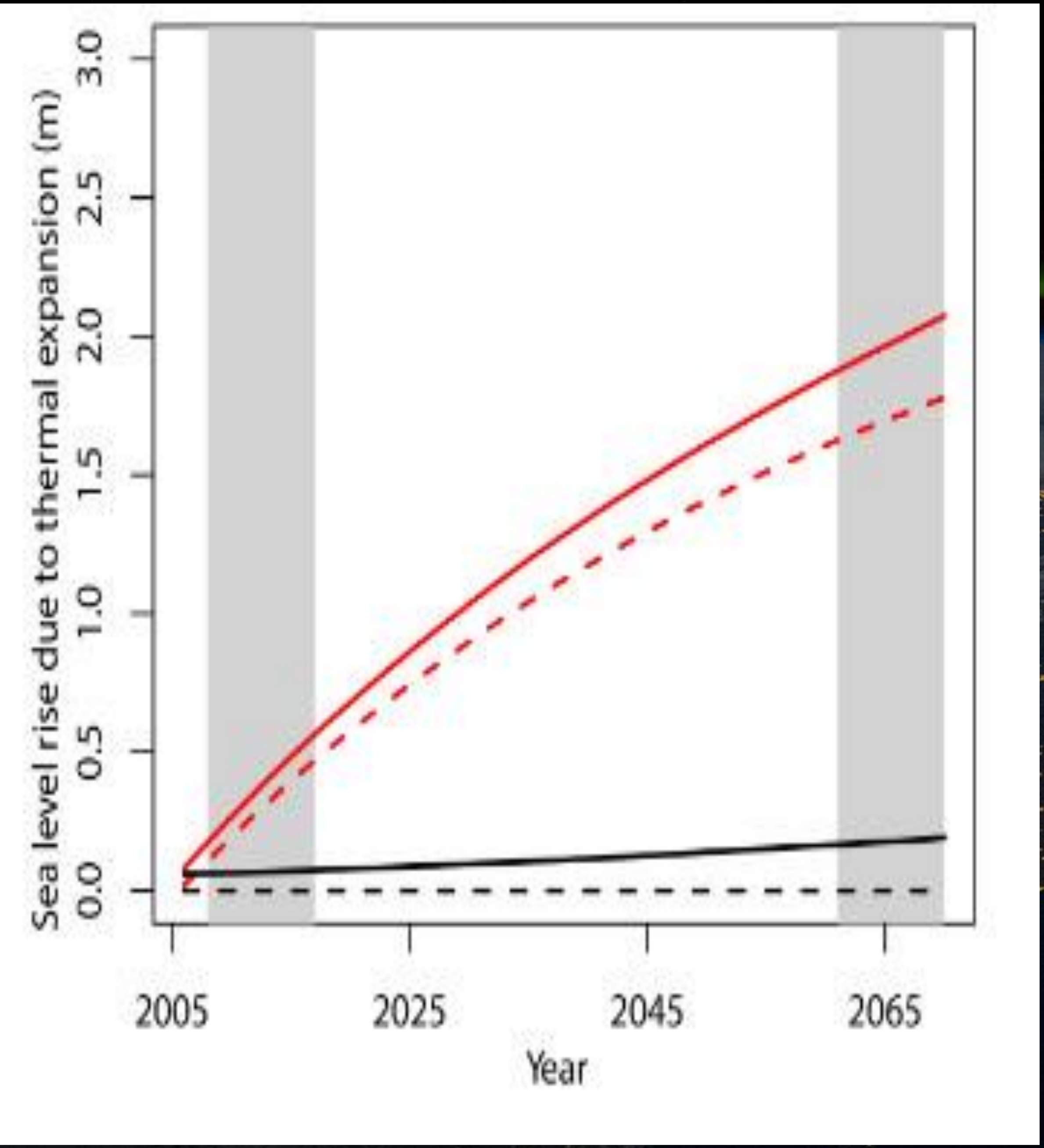
Figure S18. Thermocline sensitivity analysis. Mean a, 2007-2016 and b, 2060-2069 global potential temperature across the upper 4000m of the water column. The *piControl* simulation is shown in black and the standard thermocline disruption simulation in red. Enhanced vertical mixing simulations of 10% ($6cm^2s^{-1}$) and 1% ($0.6cm^2s^{-1}$) of the *alt-therm-piControl* simulation are shown in green and blue respectively.

This is true even in the much milder 10% (green) and 1% (blue) cases. All runs - 100%, 10% and 1% thermal mixing - show rising ocean temperatures right to the surface, as time goes on.

And again, all curves on this page assume NO HUMAN CO2 Emissions. Yet future temperatures STILL rise.

More bad effects: Reduction in climate-cooling low clouds…

- You’re differentially cooling the ocean more than the continents, leading to **massive change in air pressure-driven weather patterns.**
- For one, the cooling ocean leads to descending denser air over it (since the continents are not directly cooled and so are relatively warmer), reducing convection and marine cloud cover, so incoming sunlight sees dark absorptive ocean (albedo 4%) instead of reflective cloud tops (albedo ~83%) – raising Earth’s absorption of solar heat, worsening our problems.
-
- And additional crippling effects…



KRC15 Standard case: The trapped heat causes thermal expansion in the deeper ocean waters, raising sea levels. Solid curve: RCP8.5 human emissions continue. Dashed curve: CO2 at “pre-industrial” and no emissions - so sea level rise here is clearly due almost entirely to trapped existing heat.

That’s almost 2 meters of additional sea level rise by 2065!

Yet More Trouble: For the large majority of the Ocean - The more OTEC is deployed, the more atmospheric CO2 is Boosted

- Pumping deep cold water to the surface also brings with it the buried CO2 within that water.
- As that water continues to warm near the sunlit surface, it can hold less CO2 and so will de-gas that CO2 back into the atmosphere.
- The oceans become a CO2 source, rather than the sink that it is now. This is NOT GOOD.

Ancient CO_2 Re-animated?

- This outgased CO_2 is from the deep ocean; it’s CO_2 that had long ago been sequestered, not the recent CO_2 of what had been the undisturbed surface layers.
- So we may be taking CO_2 that had not been an immediate danger of outgasing, and driving it into the atmosphere. That net adds CO_2 to the atmosphere. There is some take-up of CO_2 by land soils (Oschlies *et al*. 2010) from reduced respiration during initial climate cooling… but only until global temperatures go back up.

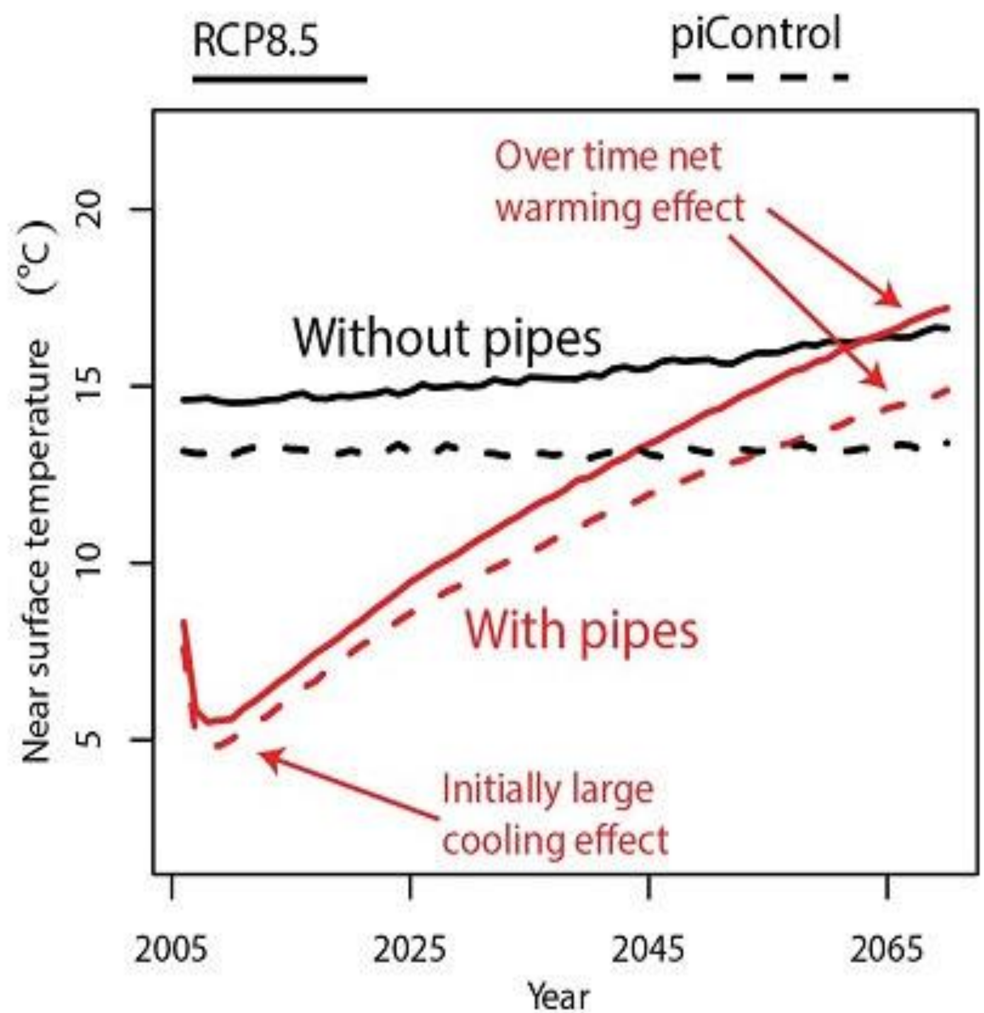
OTEC and Altered Phytoplankton Ecology

- These temperature changes would also significantly affect the phytoplankton ecology currently existing in these warmer mid-ocean surface waters in poorly known ways, as the ecological web is large and complex and with only bits and pieces so far studied. Initial claims that mid-ocean upwelling via pipes would capture CO2 via photosynthesis and then sequester it when it drops are guesses (or worse - see next slide).
- Would it merely get re-circulated? Pipe currents are very different than coastal upwelling. Upwelled nutrients, after all, are just the bodies of carbon-rich sea life that were already heading downward towards sequestration.
- ~1/2 of Earth’s oxygen is generated by ocean phytoplankton.

The promoters' claim that enhanced upwelling will stimulate phytoplankton to sequester more atmospheric carbon, is not supported

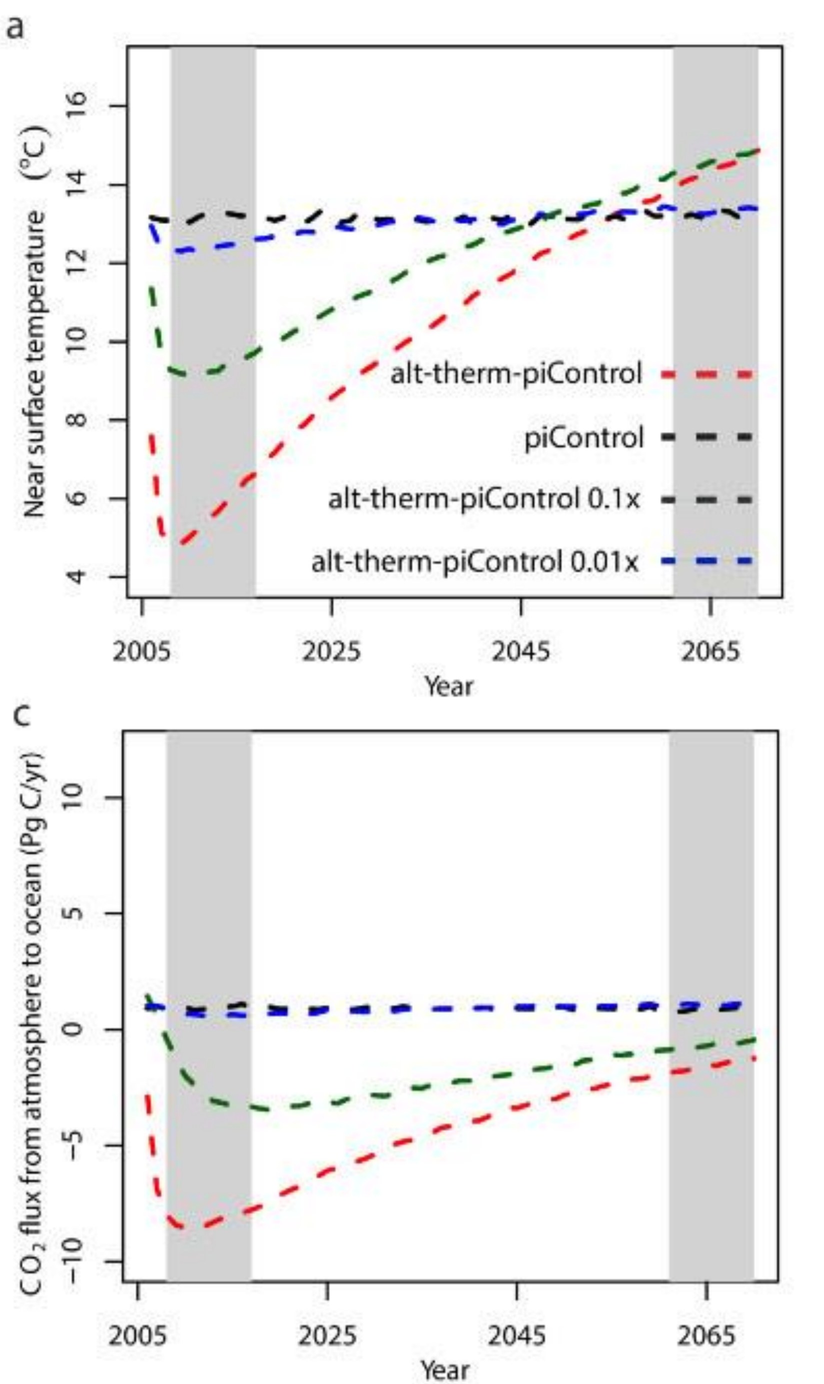
- From Sigman and Hain (2012) in **Nature: Education (p. 12)**…
- *"To address a common misconception, the capacity of ocean productivity to lower atmospheric CO2 is not typically made stronger by simply increasing ocean upwelling rates. Increased upwelling increases the nutrient supply for productivity, but also exposes to the atmosphere the CO2 previously sequestered by the soft tissue pump.* ***In the low latitude ocean, these effects roughly offset one another****. Productivity is highest in the polar regions (Figure 4), and yet the incompleteness of nutrient consumption in these regions causes them to release biologically sequestered CO2 back to the atmosphere (Figure 6). For a given concentration of the ocean's major nutrients, it is the completeness of nutrient consumption rather than the rate of organic matter export that matters for CO2 sequestration. This is true up to the time scale of 100 thousand years or more" .*
- **I'll add – and doing OTEC for power at high latitudes won't work since the ocean temperature gradient is too low. So - no power, and no added cooling either. A double negative.**

KRC15 Standard Case; Re-emerging buried heat added from below to current arriving insolation heat from above leads to global surface temperatures even HIGHER than if OTEC was never installed. Note in particular that most of the temperature rise is NOT due to continuing RCP8.5 emissions (solid) but rises even with NO CO2 emissions (dashed). Artificially buried heat is arriving back to the surface by bouyancy: Warm water rises! No surprise.



Caption: This figure shows the change in near surface temperatures over time with ocean pipes and without pipes. It is provided courtesy of Lester Kwiatkowski, Ken Caldeira, and Katharine Ricke.

(Top image credit: NOAA Climate Program Office, NABOS 2006 Expedition. Photographer: Mike Dunn, NC State Museum of Natural Sciences.)



Top: Even the much milder KRC15 10% and 1% OTEC cases, with no human CO2 emissions, show OTEC pipes' buried heat re-emerges (with a vengeance for 10% case) by mid-century, rising past the "no OTEC" temperatures.

Bottom: Indeed, except for the 1% case (blue), deep ocean CO2 outgases back into the atmosphere when OTEC pipes are turned on.

Piping cold water from beneath the thermocline to the surface on a climate-significant scale, looks to be a disaster for future climate and future Earth systems

- **<u>OTEC Pipes-for-Climate fails ALL of our essential efficacy and safety climate solution criteria:</u>**
- When cloud changes are included, it neither raises Earth albedo, nor aids Earth in radiating, and at climate-relevant scales, it makes profound changes to ocean thermal and convective normality, with large and damaging effects on not only climate, but ocean ecology, currents, atmospheric winds, rainfall patterns, ice melt at the poles… and likely more not yet realized.
- **Far worse, it ruins future climate with loan-shark levels of pay-back of the temporarily constipated heat**

The Claims…

- As of mid 2016, the promo claims half the world's power needs would be solved, by using OTEC power generation to make huge amounts of ammonia on **~70,000 floating factories hooked to OTEC pipes**, to be visited by tankers to carry the ammonia to land where it could be burned as fuel to power the world. An ammonia-powered world economy?
- The title of the promo is ***"We CAN hold Temperature to +2C, even +1.5C!"***, a claim at strong variance with simple thermodynamics, and detailed evidence both.

Ammonia as Our New Energy Source?

- The combustion of ammonia to nitrogen and water is exothermic:
- $4\ NH_3 + 3\ O_2 \rightarrow 2\ N_2 + 6\ H_2O\ (g)$ ($\Delta H°_r = −1267.20$ kJ/mol) The standard enthalpy change of combustion, $\Delta H°_c$, expressed per mole of ammonia and with condensation of the water formed, is −382.81 kJ/mol. Dinitrogen is the thermodynamic product of combustion: all nitrogen oxides are unstable with respect to N_2 and O_2, which is the principle behind the catalytic converter. Nitrogen oxides can be formed as kinetic products in the presence of appropriate catalysts, a reaction of great industrial importance in the production of nitric acid:
- $4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$, which in the presence of oxygen, such as would happen in air, leads to NO_2 by the reaction
- $2\ NO + O_2 \rightarrow 2\ NO_2$ (a powerful greenhouse gas)
- ***Also, the combustion of ammonia in air is very difficult in the absence of a catalyst (such as platinum gauze or warm chromium(III) oxide),*** because the temperature of the flame is usually lower than the ignition temperature of the ammonia–air mixture. The flammable range of ammonia in air is 16–25%.[22]

- So this would not appear to be an energetically or cost-favorable fuel (**platinum** catalysts, dangerous chromium?), although the greenhouse warming power of the combustion products would be less than from carbon-based fuels.
- Miller highly optimistically assumes that the cost curve for the pipes will follow the same as did solar PV panels. But tiny PV chips were vastly more favorable for dramatic technological advance and cost cuts.
- His 10 meter diameter OTEC pipes are lower-tech and more of the cost is in materials, labor, and structure, and not in technology. Such costs typically rise, not fall, with inflation).
- He estimates (mid ‘16) they’d cost $1.2B apiece
- **That’s $84 trillion for 70,000, which works out to $12,000 for every man, woman, and child on Earth.**

- Consider the dangers of these floating factories…

Toxicity of Ammonia

- It is not particularly dangerous to humans and other mammals, which have a biological mechanism – the urea mechanism - for removing ammonia from their systems.
- It IS highly dangerous, however for fish, amphibians, and other aquatic species…
- *"Ammonia even at dilute concentrations is <u>highly toxic to aquatic animals</u>, and for this reason it is <u>classified</u> as dangerous for the environment." (<u>wikipedia</u>)*

70,000 free-floating toxic ammonia factories on the far open ocean, beyond the continental shelf so they have access to ~1 km deep cold water. Is this a good idea in the coming era of Super Storms (Hansen *et al.* 2016)?

Oschlies *et al.* 2010 also studied artificial upwelling's effect on climate

- They use a very different climate model and assumptions.
- They employ pipes only where the ocean vertical profile suggests surface CO2 would not increase when OTEC is turned on. However, where these rare places are, are very different depending on data and model choice (their Fig 1)
- *Their UVic climate model includes **no cloud modelling**, and so the strong negative effects of a cooling ocean on low cloud formation found by the Stanford team are missed.*
- *Yet, the cooling-induced decrease in marine clouds was a major contributor to the later rising temperatures in the KRC15 models. If this physics is missing in the Oschlies studies, it calls their climate results into serious question.*

Even Very Limited OTEC Deployment Still Ultimately Causes Rising Ocean, Air Temps

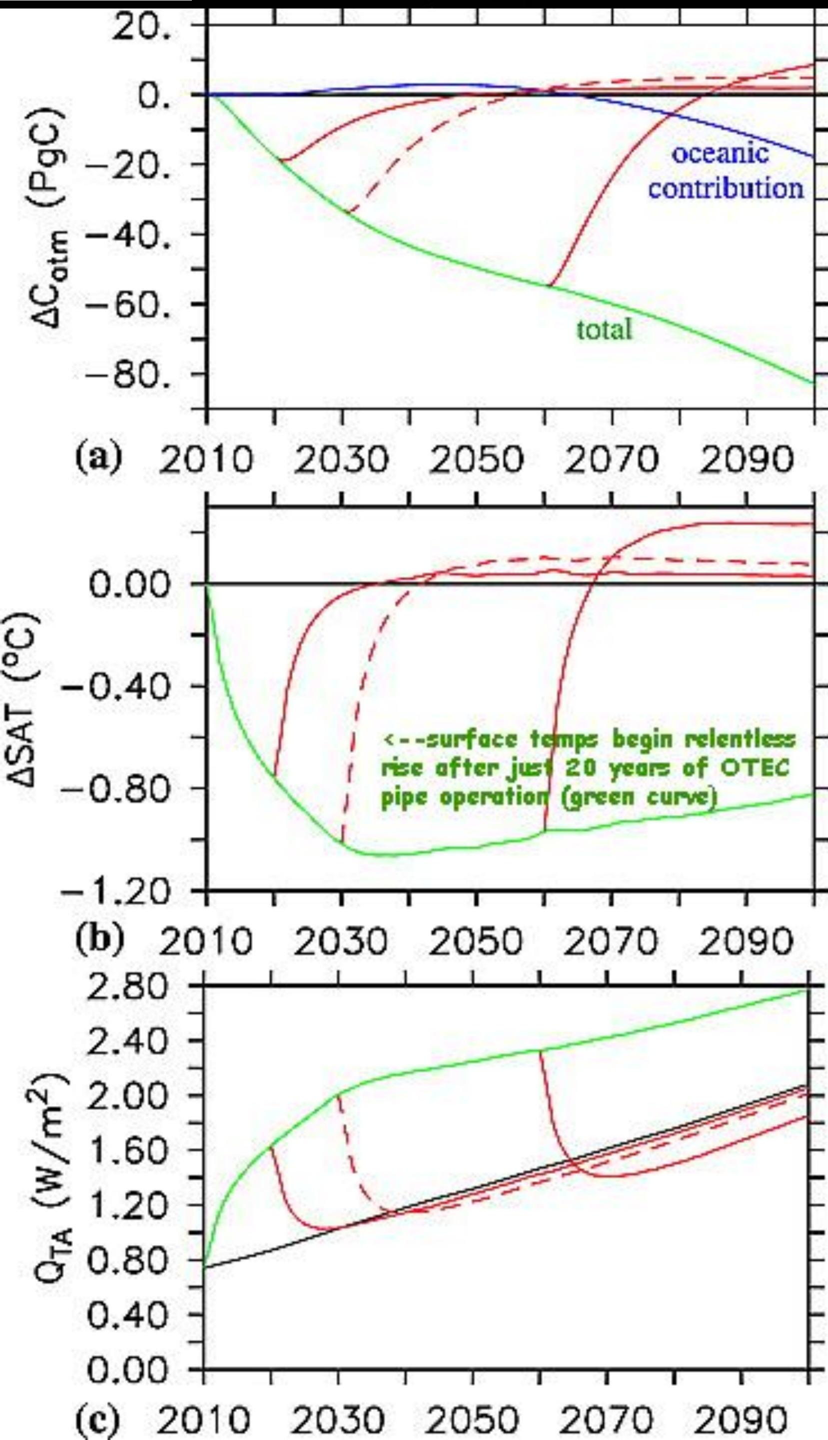
- Even the much smaller and more optimized OTEC deployment studied by (Oschlies *et al.* 2010) found that when the pipes are shut off, Earth warms to HOTTER than it would have been if no pipes had ever been deployed.
- Promoter Miller's quick, glib rebuttal (WiSE talk in Santa Cruz, Fall 2016) was – *"why ever turn them off"?*
- There could be many reasons - like unforeseen tragedy to eco-systems, to weather patterns, failure of the ammonia economy to take hold globally, or better, cheaper, less dangerous technology arriving, for powering civilization. Like solar and wind generating direct electricity and removing the inefficiencies of combustion altogether.

Worse – Even if the pipes are NEVER shut off…

- …the surface ocean begins consistent warming only ~20 years after deployment (next slide).
- Miller responded (private comm.) that this was because human CO2 emissions continue (in the Oschlies *et al.* 2010 study). **No.** The evidence says otherwise… note that in the KRC15 studies – in which there is NO human CO2 emissions – that even in the mildest 1% case and when there is NO ocean-vented CO2 release (in fact, oceans continue to absorb atmospheric CO2, as shown), **still surface temperatures rise after a brief initial drop.**

The Real Reason is basic thermodynamics – Conservation of Energy.

- **Buried heat does not simply vanish from existence. Heat in fluids ultimately must rise, overcoming worsened radiative imbalance:** Again note in the KRC15 studies that human CO2 emissions do not dominate the rising OTEC temperatures, as we highlighted.
- Oschlies *et al. 2010* did not run a control case with zero human CO2 emissions - a fatal flaw in Miller's claims - which would have made the cause of their own rising temperatures clearer.



From Oschlies *et al.* 2010

(a) Simulated sequestration of atmospheric CO_2 relative to the standard run without pipes. (b) Simulated surface air temperature difference of ocean pipe simulation relative to the standard run without pipes. (c) Simulated radiation balance at the top of the atmosphere. Green lines refer to the standard pipe experiment with pipes deployed wherever a reduction in surface pCO_2 can be expected, and with a maximum vertical pipe extension of 1000 m. Red lines show results from simulations with artificial upwelling stopped after 10, 20, and 50 years, respectively. The blue line in Figure 2a denotes carbon sequestration due to oceanic uptake, the black line in Figure 2b refers to the control experiment without pipes. All simulations assume A2 emissions continue. No control case of no-emissions was run.

(b) (RN: NOTE THAT GLOBAL TEMPERATURES (MIDDLE GRAPH IN GREEN CURVE) REVERSE AND BEGIN RISING AFTER ONLY 20 YEARS, AS TRAPPED HEAT BEGINS TO RE-EMERGE , AND THE LONGER THE PIPES ARE ON, THE GREATER THE OVERSHOOT IN EVENTUAL TEMPERATURES. THE TREND AND ENERGY CONSERVATION SAYS THAT EVEN WITH NO PIPE SHUTOFF, TEMPERATURES WILL EVENTUALLY GO HIGHER THAN IF NO PIPES HAD EVER HAPPENED, JUST AS KRC15 FOUND. For Oschlies et al, some of this is due to human emissions, but according to KRC15, most is trapped heat)

OTEC pipes continually displace warm surface water from where it CAN radiate to space, down to depths where it CANNOT

- Simple freshman physics (Conservation of Energy) says that heat WILL build up, and the longer you engage these pipes, the bigger the thermal disaster when that heat becomes too large to hold down any longer by pipe action, whether or not pipes are ultimately shut off.
- Remember, incoming heat from the sun is very constant, Think of this as ongoing **"Heat Constipation"**
- This is just not arguable; it's the "loan shark" (buried heat) coming for his payment, payment which balloons with interest and *"past due"* with each passing year.

Key Questions Remain Unanswered by Alan Miller - Promoter of this Idea

- Why seek venture capital money to launch such an ambitious expensive venture when the science is so clearly negative? Venture capital expects a **return on investment**, *i.e.* expects the wisdom of deployment is already settled in the affirmative. Indeed, Lockheed-Martin abandoned OTEC at the time the Stanford studies came out.
- This should raise skepticism and “red flag alerts” to anyone.
- Why not instead seek grant money for climate research to clarify the effects? Was any application made for NSF money for such studies?
- Or alternatively, was any attempt made to form a non-profit for donations for supporting your small group for further studies?

- Another questionable claim: OTEC-induced cooling would increase polar ice, setting off an albedo feedback that would continue to keep the Earth cool.
- But the KRC15 studies show otherwise. They find that despite the initial rise caused by cooling in the early years of OTEC deployment, sea ice steadily declines as the surface ocean then reverses and warms as buried heat re-emerges (next slide).
- Unlike the Ice Ages, which were initiated by astronomically induced lowered summer Arctic sunlight, OTEC will BURY existing heat. This must be very temporary, by conservation of energy. Missing cloud modelling contributes trouble here as well, as previously quoted research showed.

KRC15: Even for the strongest OTEC cooling case (100% of standard case, no human CO2 emissions), much stronger than Miller's proposal… the initial jump in sea ice (red dotted, left graph) begins decaying back down, and is even lower than initial by year 2070

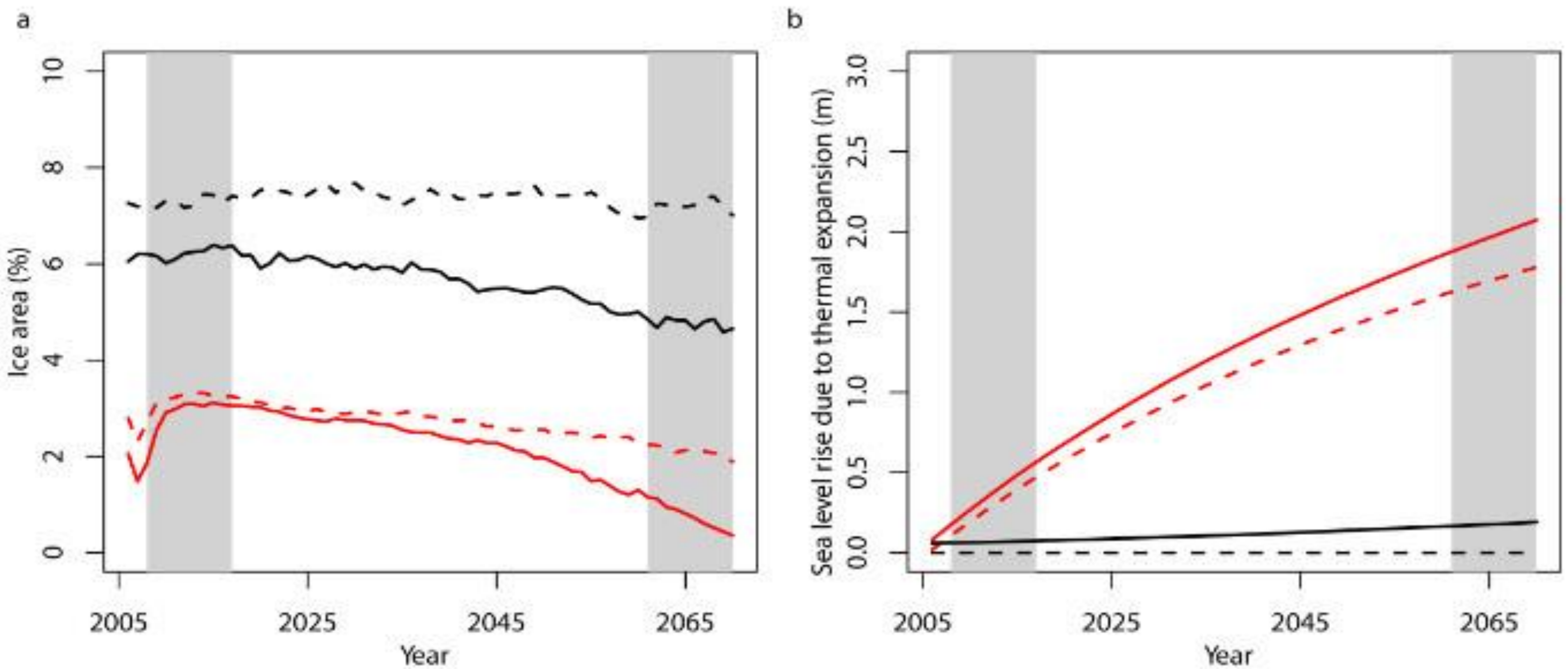
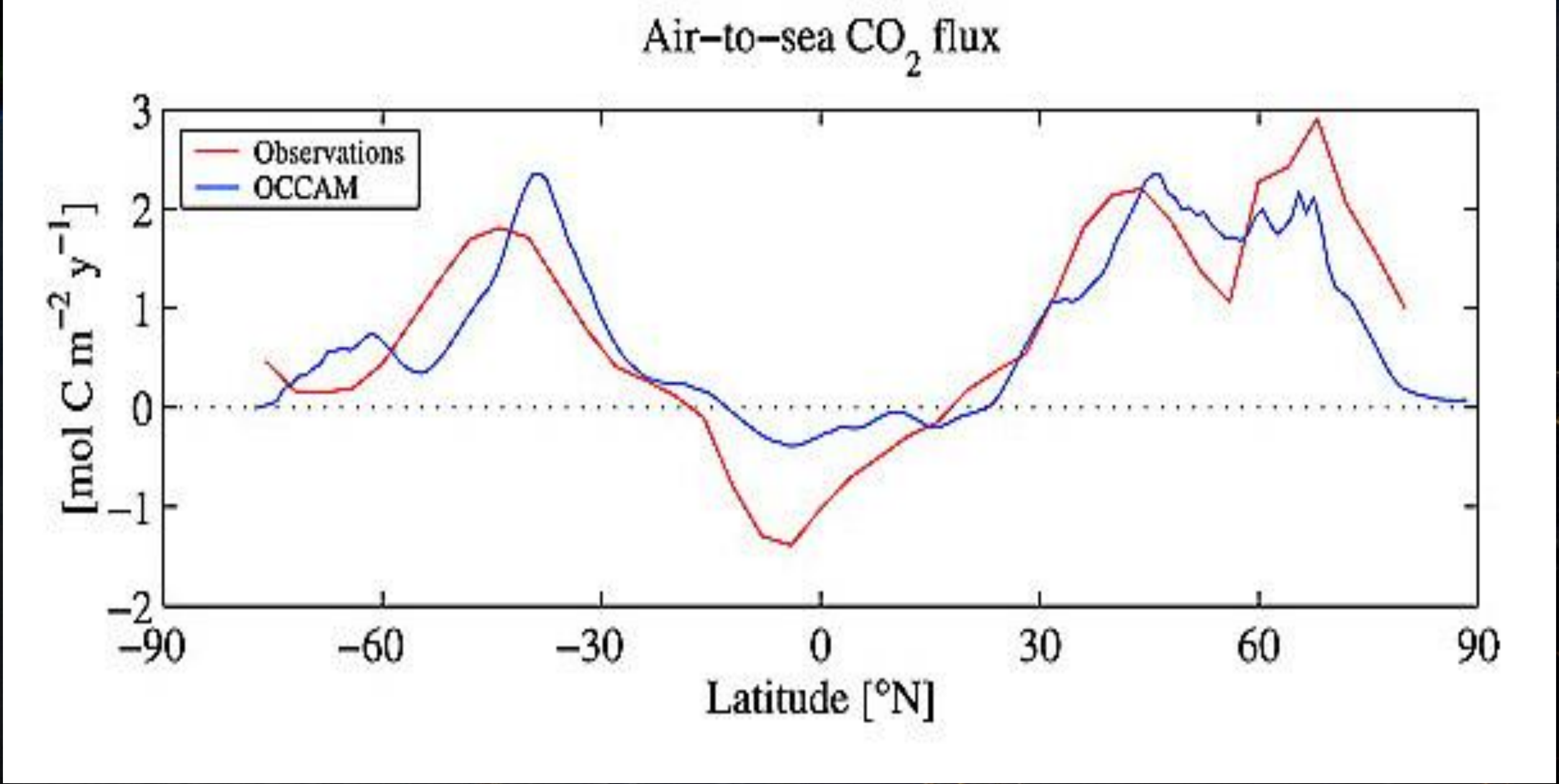


Figure S3. Mean global sea ice area (%) (a), and sea level rise (m) due to thermal expansion (b), for RCP8.5 (bold lines) and pre-industrial control (dashed lines) scenarios. *RCP8.5* and *piControl* simulations are shown in black and thermocline disruption simulations in red. Sea level rise due to thermal expansion is calculated based on (Kuhlbrodt and Gregory, 2012).

While the KRC15 Study May Not Fully Accurately Capture Polar Ice Behavior in a Smaller so more Realistic OTEC Scenario…

- … since their climate model did not include horizontal ocean transport around the pipes, it's also true that only in the tropics can OTEC have warm surface water and acceptable vertical temperature gradients, and horizontal transport of heat would then leave the high latitude oceans WARMER – highly antagonistic to the formation of surface ice to help albedo, as one study showed.
- It seems pretty difficult to contend that OTEC at climate–significant scales, would increase polar ice and improve albedo, when energy balance shows that either the buried heat would emerge at the poles, and/or it would emerge later in other places as well, and cause much worse heating in the longer term.

Observations and Theory (red, blue curves) both show that in the tropics, which is where OTEC pipes must be in order to temporarily cool the air and also to tap thermal gradients strong enough to power the pumps, are precisely where the rising colder water would outgas previously sequestered CO2, and thereby worsen our atmospheric CO2 problem. Below, Fig. 1 from Yool *et al.* 2009



- ***"I cannot envisage any scenario in which a large scale global implementation of ocean pipes would be advisable," lead author Kwiatkowski (of KRC15) said. "In fact, our study shows it could exacerbate long-term warming and is therefore highly inadvisable at global scales."***
- (Kwiatkowski video summary)

To Summarize: Techno-Fixes Will NOT Save Us. Not with Human Nature and Thermodynamics as We've Seen

- We Need Technology, but only wedded to a complete Re-Thinking of Our Relationship to Nature.
- Nature bred in us the compulsion, the desire, the lust for the brain chemicals that go for **competitive growth**. **"Grow or Die".**
- To out-compete for your place in the ecosystems.
- To beat back the wilderness and other species and take your place.
- To duel for choice mating opportunities!

You May Think the Tragedy is if <u>Your</u> Species Loses This Struggle

But no – the <u>Real</u> tragedy is when you WIN.

- If you lose, only <u>your</u> species perishes.
- But with the power humans have amassed and the ruthless efficiency of *Laissez Faire* market economics…
- **…When <u>HUMANS</u> <u>win</u> it is the entire planet which loses. And then, humans too.**
- **We are at that point now. <u>Today</u>. After 6,666 generations of Homo Sapiens. How will we transform our very impulses and political/economic Systems to avoid catastrophe? Will we? I see no evidence of this yet.**

Section H. Policy

"We have only two modes - complacency and panic."

— James R. Schlesinger, the first U.S. Dept. of Energy secretary, in 1977, on the country's approach to energy

I’ll add: **We’ve tried complacency. It has failed.**

In fact, Americans are more afraid of Clowns than Climate Change [2016 study]

What do we DO About This?

So What Do We Tell Our Students to Do?

- Encouraging voluntary individual conservation has psychic value, **but ~no climate value**. The entire U.S., in fact, is a minor contributor (today less than 14% annually) to additional CO2 now. Asia is #1.
- **Only GLOBAL actions can affect LOCAL climate** – unlike almost any other environmental problem.
- **Techno-fixes are essential, but Garrett's work shows it can't succeed in a civilization committed to growth.**
- **We need to create and enforce Global Governmental Policy. It is the Policy and Education Environment that needs our Efforts. Techno-fixes without that, are just another credit card to a shop-a-holic species, another kick-of-the-can down the road.**

Even if you Inspire 1 Billion People to Voluntarily Cut their Total Carbon Footprint by 50%

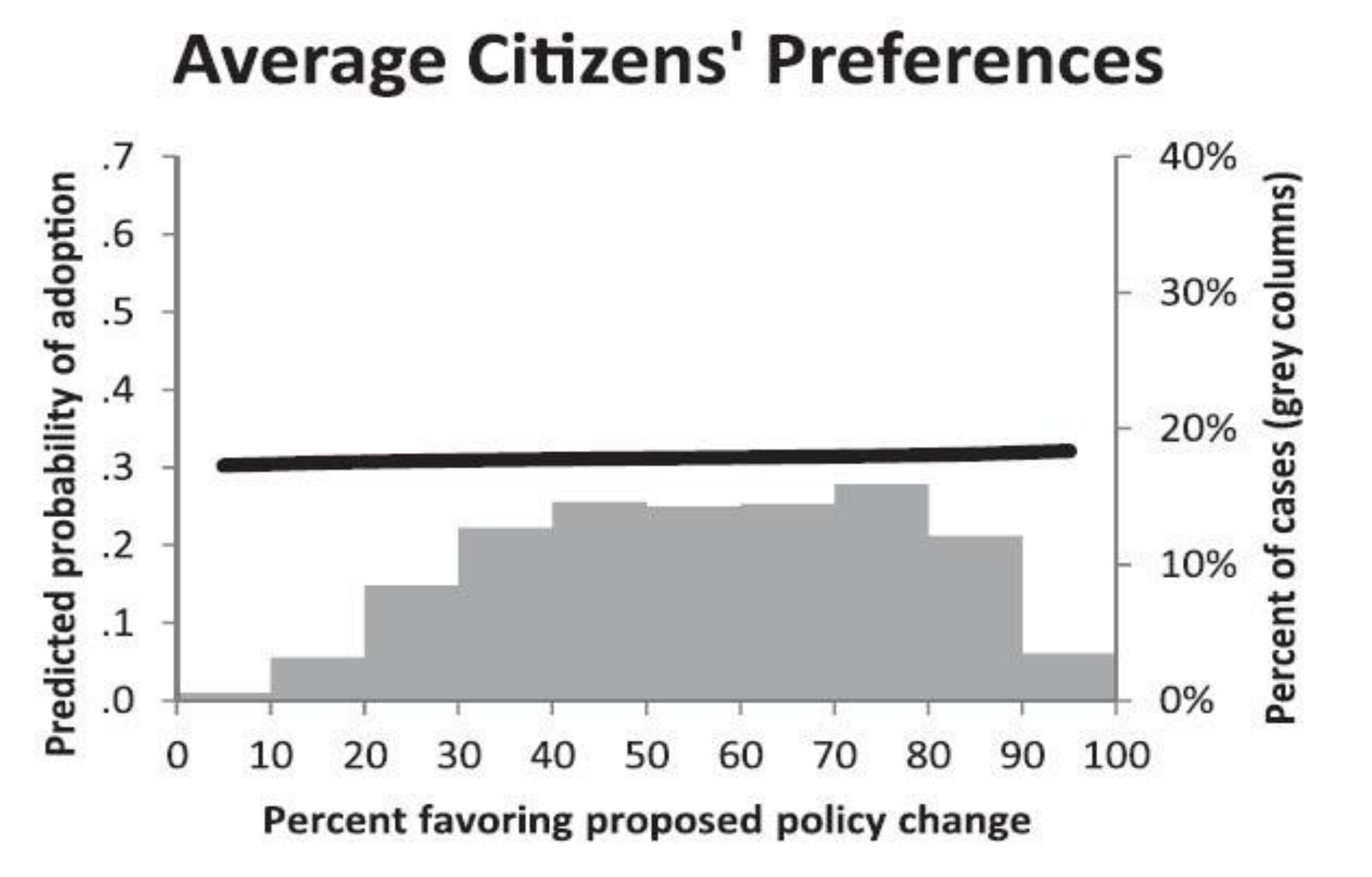
- You lower our CO2 emissions globally by only 13%, almost negligible compared to the problem we face
- Of course, your efforts WON'T inspire a billion people to voluntarily cut their footprint in half…
- **We're not a hive-mind Borg. Peer pressure has only a limited effect when confronted by the fact of real personal economic pain**

Global Government Enforced Policy is Essential to Compel The Sacrifices Needed”

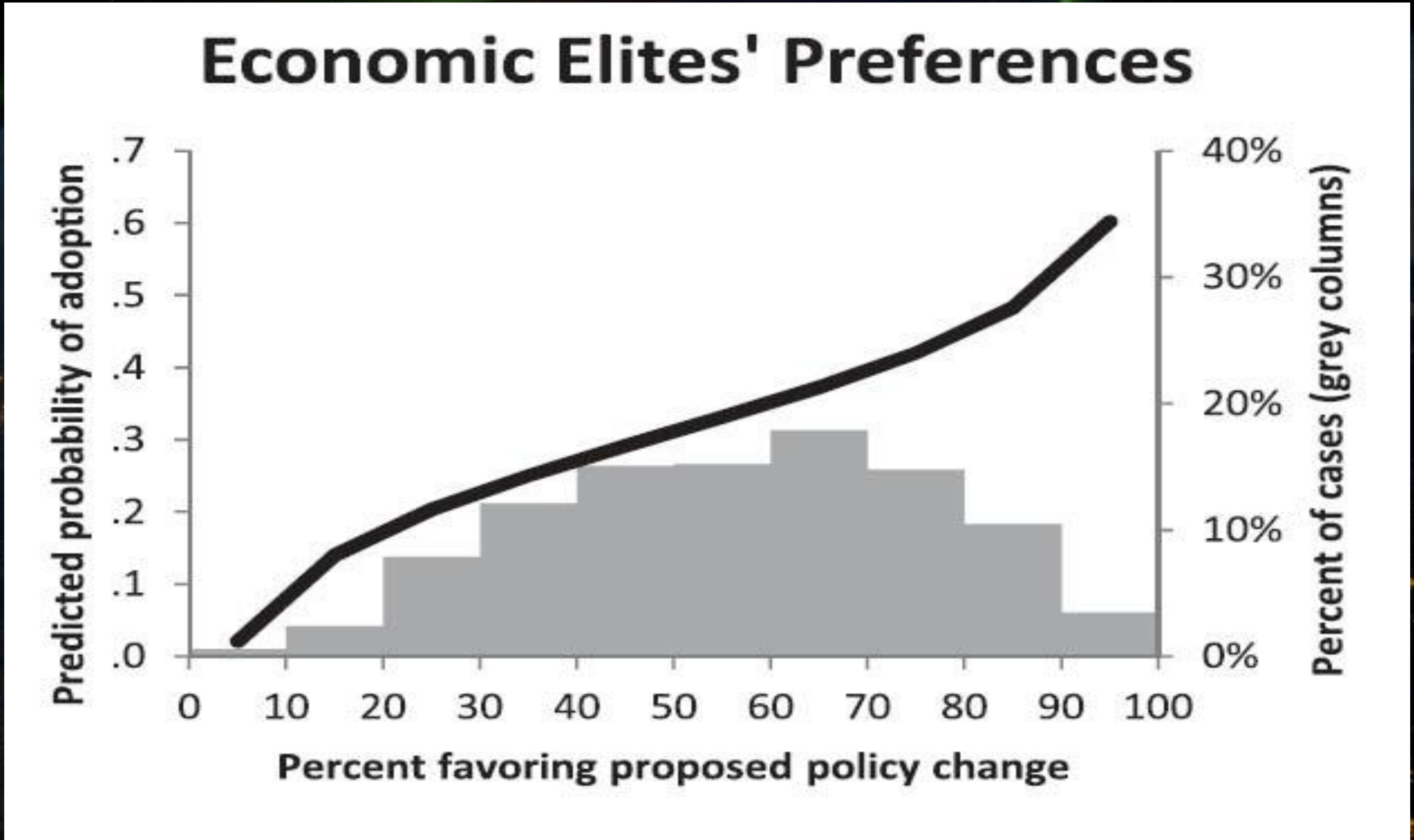
So shall we ask our congress to pass a stiff carbon tax?

History shows they just don’t care about the average voters’ desires

There is ZERO correlation (=flat) between what legislation is desired by average citizens, and what actually gets enacted (Princeton/Northwestern U research Gilens and Page 2014), when corrected to measure independent influence.



…but Near-Perfect correlation between what the Economic Elites want and what gets adopted. True over 20 years of both Republican and Democratic Governments. And a perfect batting average at killing legislation they hate (bottom left) This is a deep systemic dysfunction.



Yikes! Well… Can we <u>Trust</u> the Economic Elites? Alas, No…

- …fully **<u>21% of corporate CEO's fit the diagnosis as Psychopaths,</u> the same fraction as found in prisons.** (**<u>Brooks *et al.* 2016</u>**, published in ***The European Journal of Psychology***)

- **In the general population, using their criteria, the rate is only 1%, as they point out.**

Your Political Influence is ***<u>ZERO</u>***

<u>It is not noble to "HOPE" that banging your head against a brick wall will break the wall before it breaks your head… and your heart</u>

<u>"We Are What We Repeatedly Do" – Aristotle</u>

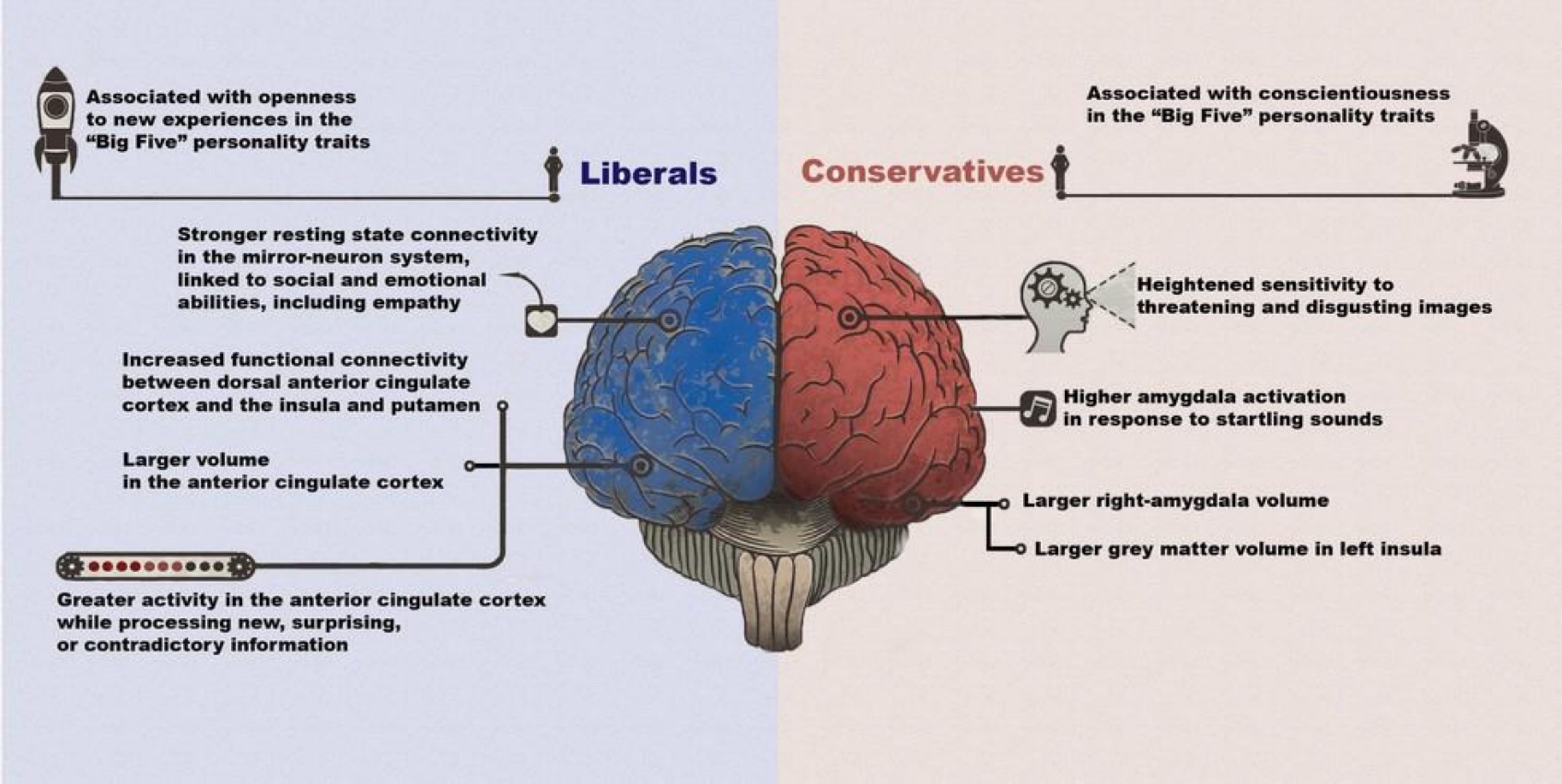
<u>What does that say about Washington DC's Integrity?</u>

<u>Congress</u> Makes the Laws that Control <u>Congress</u>

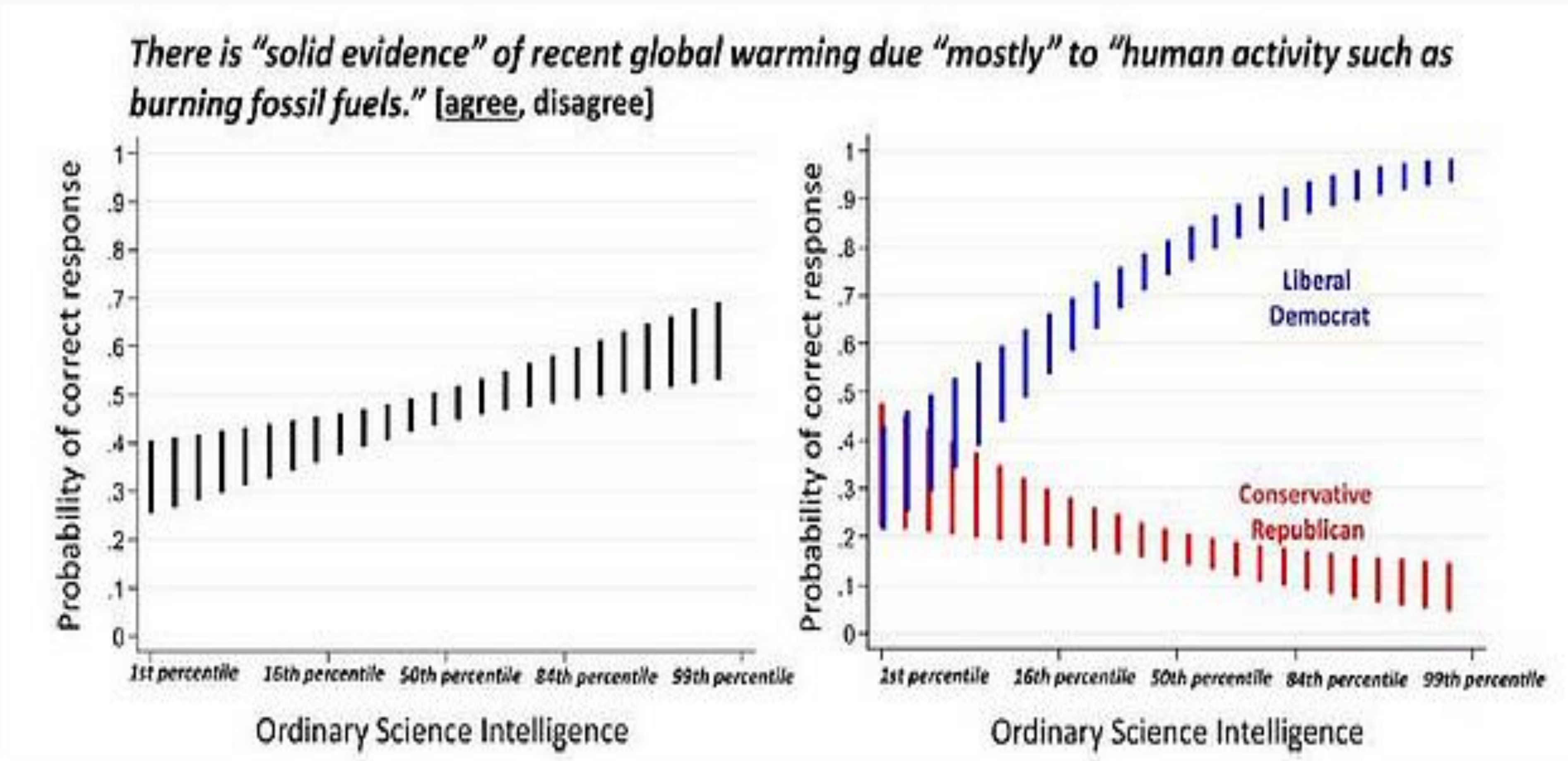
- Including laws for campaign financing, “dark pool” money sources, influence peddling, slap-on-wrist punishments, and everything else.
- So it’s a closed loop. An air-tight system which **has not** and **will not** change by politely asking “please?”.
- **It’s a closed System**.
- **THEY** are on the inside. **YOU** are on the outside.
- ***<u>Sorry!</u>***……… **<u>Deal with it!</u>**
- It’s really simple. If you find it hard to accept, perhaps study up on **<u>Stockholm Syndrome</u>**

On Political Action: I Sometimes I feel like Sarah Connor in *"Terminator 2";* in the nightmare scene at the playground, shouting to her younger naïve self *"Wake! Up!!"*

Conservatives Run Our Country… They Exhibit Psychopathologies, backed up by numerous brain studies



The more scientifically intelligent, then the more convinced Liberals are of human-caused global warming. But it is the opposite for Conservatives (Kahan *et al.* 2015 , discussed here). Trying to reason with Conservatives makes them LESS Rational. We must route AROUND them, not WITH them



- **Realize – the Gilens and Page 2014 Dataset is** …BEFORE The Trump era
- …BEFORE "**Citizen's United**" allowed dark money to flow where it increasingly flows – attacking climate scientists
- So have things gotten better?
- **No.**

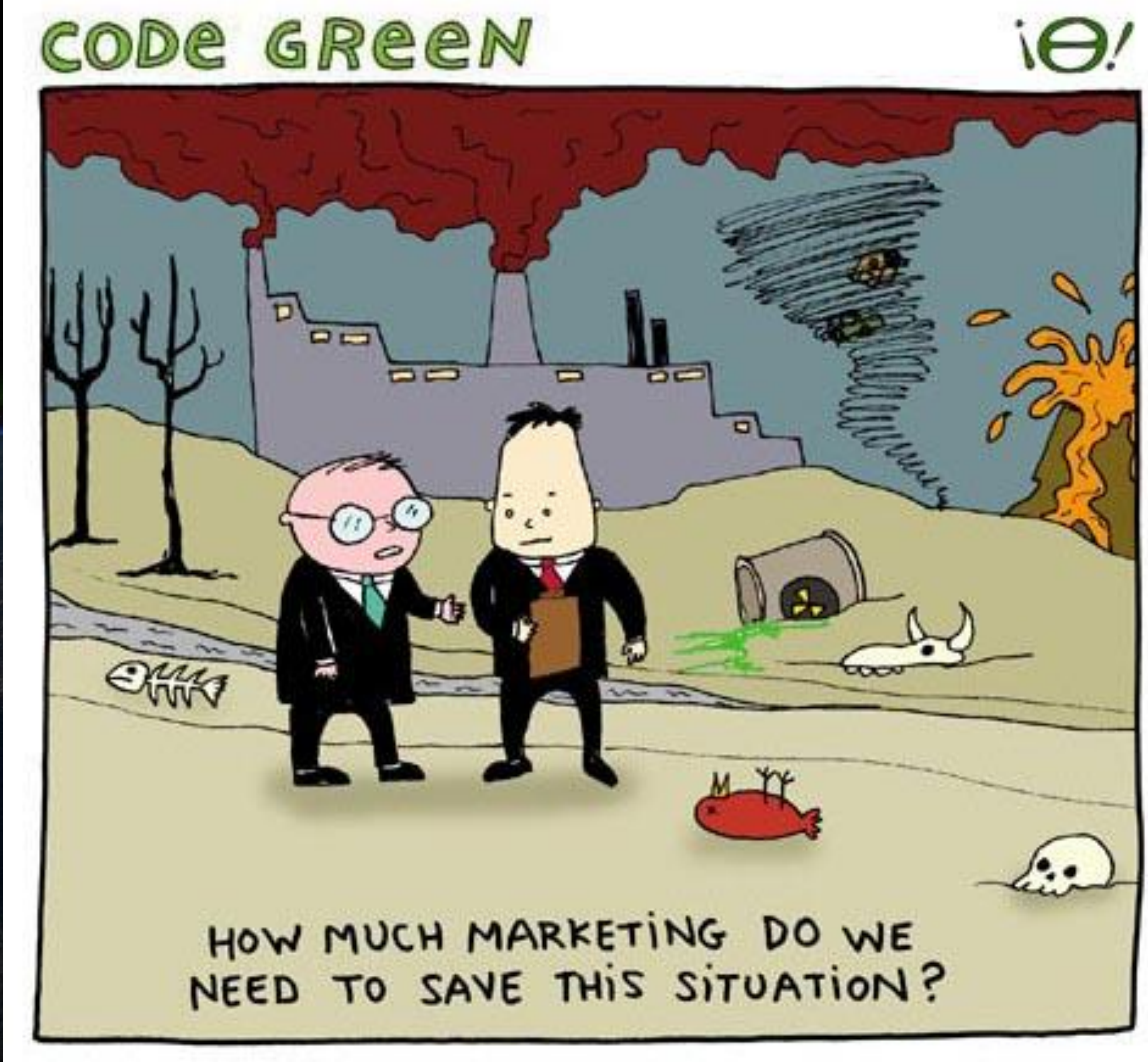
Can We Trust *Laissez Faire* Capitalism? My Best Analogy is…

"Listen, and Understand…"

- ***"…that Terminator is <u>out</u> there! It can't be bargained with! It can't be reasoned with! It doesn't feel pity! Or remorse! Or fear! And it absolutely WILL not STOP. <u>EVER</u>! Until you are <u>DEAD</u>!" (<u>video</u>)***

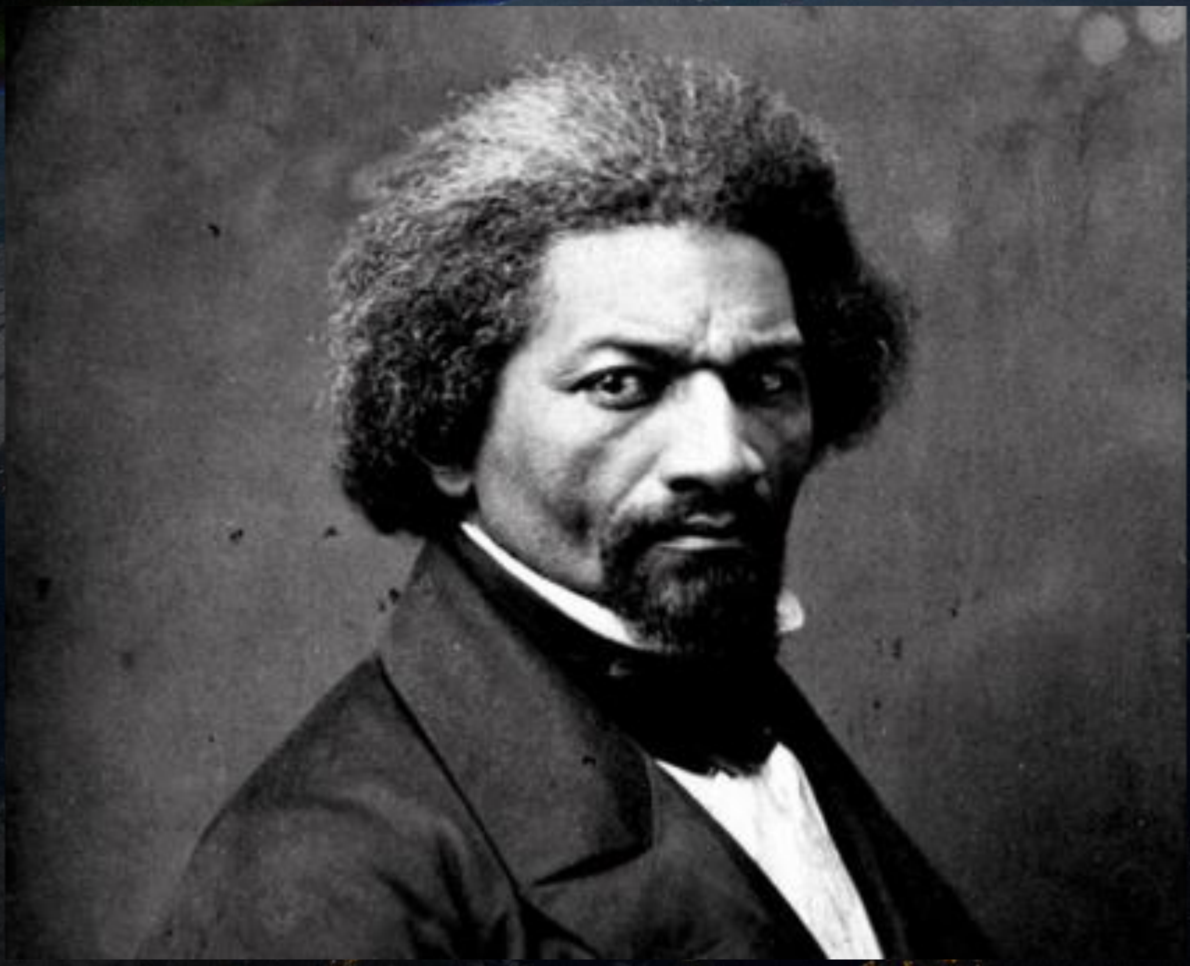
Capitalism is AMORAL

- Not IMMORAL, but AMORAL.
- Morality simply does not enter the equation, except indirectly in the form of laws with significant punishments, meant to interfere with the PRIME DIRECTIVE - which is…
- ***To accrue money to the major shareholders and the corporation***


CODE GREEN
HOW MUCH MARKETING DO WE NEED TO SAVE THIS SITUATION?

"Power yields nothing without demand. It never did, and it never will"

- Fredrick Douglass



I Offer This: OCCUPY Washington D.C.

- If climate activists, rather than celebrating inconsequential meetings with their congressman, instead got educated, using resources such as I and others have assembled, and then internet-canvassed the country to get just 100,000 to 1 million people who would commit to going to Washington D.C. for a different kind of demonstration…

- **With such images stirring public conscience, the power of media attention can be instantaneous. Witness the Standing Rock Nation standing up to Big Oil**
- **We either deal with climate change, or little else really matters**

OCCUPY DC’s Goal Would be…

- To nonviolently, peacefully exercise 1st Amendment Rights, but with determination, and by sheer numbers, prevent *“Business as Usual”* from continuing…
-
- **It would be to OCCUPY Washington DC, slowing its political “business as usual” to a halt, until congressional leadership publicly spoke to the assembled press and the People with a commitment to pass the legislative demands outlined earlier.**

You Should NEVER Corner a Dangerous Animal Without Giving it an "Out"

- 100,000 – 1 million is far too many to jail, or shoo away, as happened with the previous OCCUPY attempts.
- And our government <u>is</u> a dangerous animal
- The "out", is a set of legislative demands and a sincere promise to leave when demands are met.

Gentle-Folk have Said to Me…

- …this strategy is inviting government violence against the citizens.
- My response: Think about what you're saying… You're saying that our government is so corrupt, so willing to violate the Constitution, that they would kill hundreds or thousands of innocent citizens peacefully (unarmed!) expressing their 1st amendment rights, even though the universal reaction from the rest of the citizens would be horror, then anger, then utter rebellion, and a civil war ending in that government's own destruction. Is our government so stupid?
- **Do you instead advise cowering in fear forever?**
- The amazing thing, is, this has been said to me by the very same people who are writing letters to their Congressmen pleading for a climate-safe future.
- So which is it? Rational reasonable congress moved by your letters, or a Capitol filled with psychopaths willing to gun down their own climate concerned citizens? **You can't claim it's both ways.**

Even a Political Realist and Pessimist Such as I, Do NOT Predict Violence

- You don't have to be a 3D Chess player to see that government bloodshed against unarmed, peaceful citizens would spell the end of power for that government one or two moves ahead (we're not yet a tin-horn dictatorship, I believe).
- Even our current obtuse government would see this. An **"Occupy DC"** with such numbers would be an "all in" moment, and the People, I believe, would win.
- Now, what legislation does Climate require?...

Action #1. Tax-and-Dividend

- This idea was first proposed by former head of the Goddard Institute for Space Sciences, climatologist James Hansen. **And carried forward by CCL.** Linked here: Carbon Tax-and-Dividend
- **Tax** carbon wherever it enter our borders, whether at the well-head in mining and drilling locations, or at ports of entry by ships.
- And let's be honest - it's a TAX, for those who are taxed – the fossil fuel industry. It's not a "fee". They get nothing for having to pay it. It's a **tax** just as surely as any other tax, regardless of the fact that calling it a "fee" makes it more politically nice-sounding and sale-able.

Neither carbon taxes nor Cap-and-Trade have impeded carbon emissions.

- As written, they're merely a revenue generator for Big Oil, green-washed by our government.
- Dr. Aldyen Donnelly **shows why and how** in fact, she argues the government doesn't want them to work, as it limits their revenue.
- The parallel is cigarette taxes. The government doesn't want them to actually be so high as to inhibit cigarette smoking, since that limits their tax revenue.
- What **actually** lowered smoking rates was outright outlawing it in more and more contexts, at state and local levels. Donnelly argues this is the only successful path to carbon emissions reductions.

Why is Cap-And-Trade a Failure?

- Govt gives carbon allowances to the Big Carbon emitters (think "Economic Elites" a'la Gilens/Page 2014) which are far in excess of the max possible they could possibly use. So they sell the excess to other emitters, so THEY can emit, thus <u>maximizing</u> emissions, and generating free income and therefore business vitality to Big Oil. It's insane.
- Worse – if a company doesn't want to buy allowances, they can instead buy "carbon offsets" whose rules permit *e.g.* burning coal and emitting CO2 while offsetting by planting palm oil trees in the (deforested!) Amazon, or tossing some iron flakes on the open ocean.
- The British Columbia Carbon Tax, she shows, was actually a manifest failure which has been **Greenwashed** by neglecting the actual Great Recession it lived in.

Cap-and-Trade: A Dysfunctional Program

- 43 of the 44 cap-trade programs, pollution entitlements are far beyond what industry needs to continue “Business as Usual”. Those entitlements are given to the biggest emitters. They love it! Because…
- They can sell the remainder to smaller emitters who need them – enabling their emissions.
- The PR is that the reason for the over-allotment is so that “eminent domain” compensation could be avoided when CO2 emission caps begin to bite, years later… except they never do. Politicians at the command of Big Oil, always abandon at that point, and instead create new allowances each year, so surplus never gets worked off.

California: A Dysfunctional Example

- Carbon offsets – only allowed to be 4%
- As an emitter, you can buy either allowances, or offsets. They're equivalent, which de-values offsets to the level of the (over-inflated) carbon allowances, ~1/5 of true offset costs, so even though having PR value, carbon offsets are generally not done.
- Even when they are, the laws enable sketchy carbon removal schemes as valid "sequestration", such as sinking carbon beneath the ocean surface for just a few decades or even less, which is NOT true sequestration.
- Or planting palm oil trees in clear-cut rainforest, as "tree planting" (!)

Carbon Taxes: Who Pays, is Key

- Mandating less carbon per energy unit delivered, is essentially the same as a carbon tax at the wellhead/border. Violators pay a fine – essentially a tax. THIS is the way to go – force re-thinking of energy company investors.
- It is NOT the same as a gasoline tax or other familiar taxes that hit the end consumer. The middle class and rich don’t care about such taxes because they’re tiny compared to their income. The poor DO care. Carbon taxes as written, are very regressive, and don’t effectively limit carbon emissions. Thus, these are the form of carbon tax that are favored by Big Oil. Greenwashing, at the expense of the most vulnerable. Wake up, people! This game seems eternal.

Action #2. End Government Subsidies to Fossil Fuel Corporations

- Including externalized environmental costs, we subsidized fossil fuel corporations in the amount of $1,000,000,000,000 in 2012 alone (source).
- In 2014, the U.S. directly subsidized fossil fuel corporations by **$21 billion for exploration and production.**
- That's a fantastically profitable ROI (return-on-investment) of 1,200% on their $1.8 billion spent for lobbying. That's a FAR better ROI than re-making their business model to "Go Green".

Globally, Subsidies Estimated at a Staggering $4.9 Trillion in 2014

- These are subsidies in the form of direct cash, tax breaks, and breaks on external environmental costs
- Less than ¼ of this is due to current climate change and no accounting is made for the vastly higher environmental costs of coming climate change (summary of linked IMF report)
- This same report shows China has subsidized fossil fuels at the rate of $2,300 billion, and the U.S. at $700 billion.
- Global subsidies rise to $5,300 billion for 2015. (**New 2017 study** shows even more)
- **This is over 6% of Gross World Product; more than is spent globally on all healthcare**

Carbon Tax-and-Dividend Needs to be STEEP to have Any Climate Impact

BC's CFT experience NY Times article :

- *"Carbon emissions started rising again after the province froze the tax at 30 Canadian dollars in 2012. An advisory panel to the Ministry of the Environment recently laid out the problem: British Columbia is missing its goal of cutting greenhouse gas emissions by a third from 2007 to 2020. On its current path, the province will also miss its target of an 80 percent reduction by 2050.*

$700 Tax per Ton of CO2?

- *"Look at it this way. A study by Michael Greenstone and Thomas Covert of the University of Chicago and Professor Knittel concluded that* ***at current battery prices, for an electric vehicle to be cheaper to run than a gas-power car, oil would have to cost $350 a barrel.***
- ***Last year, it averaged $50. To make up the difference would require a carbon tax of $700 a ton of carbon dioxide."***
- This tax would BANKRUPT Big Oil, so of course they won't permit this.

Action #3: Severe trade sanctions against all countries who do not enact Tax/Div and end fossil fuel subsidies

- Most carbon emissions are not from the U.S., and the U.S. fraction is dropping every day. Passing these laws only for the U.S. will do little to slow CO2 emissions.
- It is essential that other countries are compelled to do the same, especially China.
- Unfortunately, China is transitioning from being the manufacturing exporter to the world, to catering to its growing middle class consumers at home, so this may be harder to accomplish by trade sanctions.
- Will it work? We can hope. Game theory suggests it's the best idea we have so far.

Action #4: More generally, devise an efficient mechanism to impose Tax/Dividend on <u>all</u> externalized costs, not just CO2

- As population grows, and as migration to cities grows even faster, one person's actions impact others in a way which is accelerating over time
- We have no mechanism for the imposed costs on others except for prohibitively expensive to launch class action law suits (thanks, lawyers, for benefitting yourselves first)
- We need a mechanism to tax the source and distribute the punitive and compensatory proceeds to those affected in a low-cost and efficient way. Micro-payments look too expensive to transact. Modified tax laws?
- As long as we can injure others by our choices and escape paying for it, we'll continue to do it.

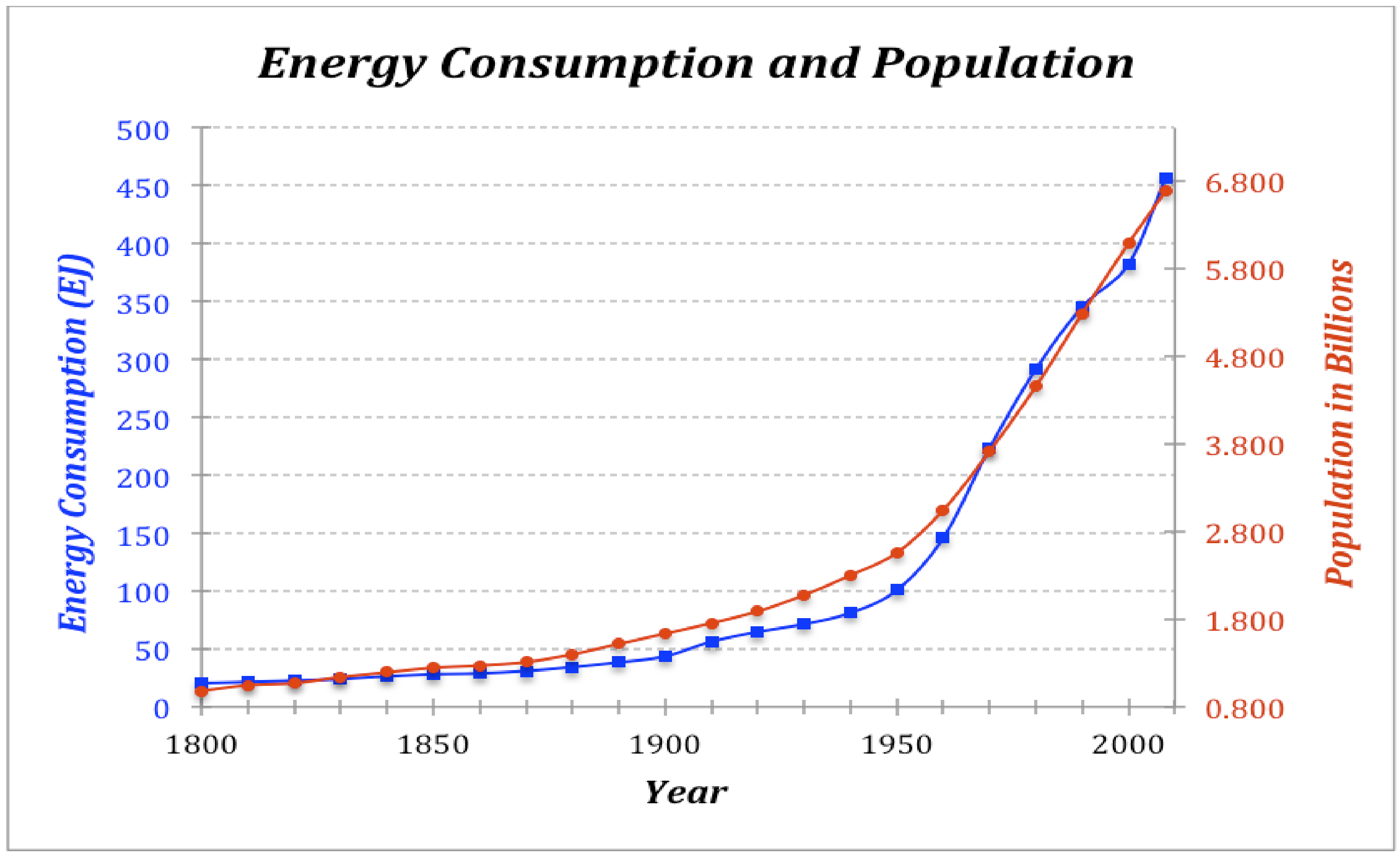
Action #5. Tax Consumption, Not Income

- An obvious truism is – if you want less of something, tax it. If you want more of something, tax it less.
- It is the pillage of the natural world's animals, forests, and landscape which is destroying our commons, and our future - and needs to be economically dis-incentivized.
- There is nothing inherently wrong with income *per se*, that it should be taxed. There IS something inherently damaging about consumption on a planet which is already using up its resources at a pace far beyond what can be replaced and healed by Nature. Climate is just one aspect of this.

Action #6. End the Child Tax Credit, and promote policies which economically discourage population growth

- Overpopulation is a key source (#1 in "Drawdown") of the vast environmental and climate problems we have created. Children are adorable, and parents usually find the psychic rewards of having children far outweigh the damage to the Earth that their OWN children will have (remember from Econ 101: "all economic decisions are made 'on the margin'" *i.e.* "my one kid won't destroy the Earth, after all")
- Very true. But such argument can be made individually by all ~billion families on Earth, and this economic reasoning "on the margin" can therefore only be blunted by policy <u>universally</u> enforced.
- It's another example of **The Tragedy of the Commons.** Think globally, not locally.

Energy consumption rate (exajoules per year) is growing faster than global population. Can CO2 be controlled without enforced global population policy? Extremely unlikely



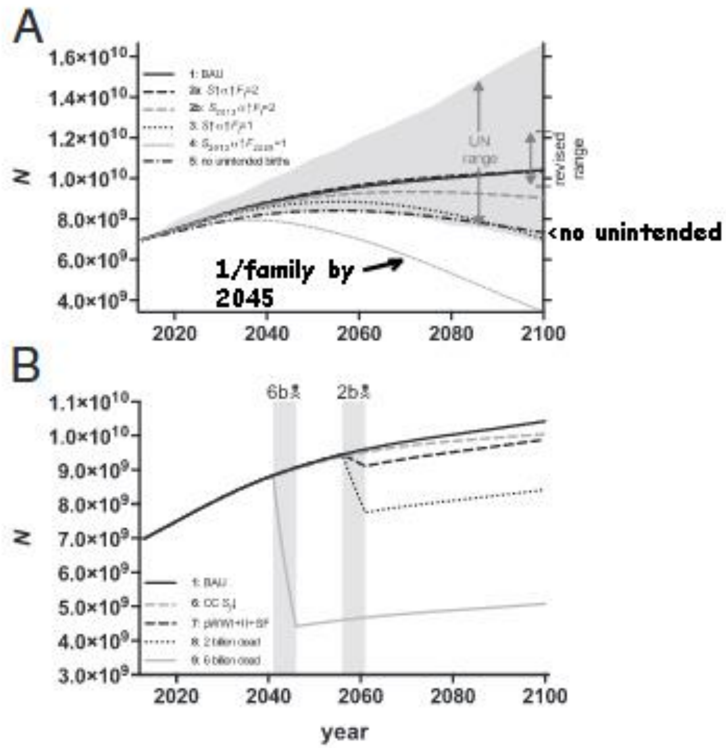


Fig. 1. Scenario-based projections of world population from 2013 to 2100. (*A*) Scenario 1: BAU population growth (constant 2013 age-specific vital rates); Scenario 2a: reducing mortality (*M*), increasing age at primiparity (α), declining fertility to two children per female ($F_t = 2$) by 2100; Scenario 2b: same as Scenario 2a, but without reduced mortality; Scenario 3: same as Scenario 2a, but $F_t = 1$; Scenario 4: same as Scenario 3, but without reduced mortality and $F_t = 1$ by 2045 and thereafter constant to 2100; Scenario 5: avoiding all unintended pregnancies resulting in annual births. High and low projections by the United Nations (12) are shown as a grayed area, and the revised range for 2100 (13) is also indicated. (*B*) Scenario 6: elevated childhood mortality (M_j) from climate change (CC); Scenario 7: mass mortality event over a 5-y period starting 2056, equal to the proportion of combined number of deaths from World War I, World War II, and Spanish flu scaled to the mid-21st century population; Scenario 8: 2 billion people killed because of a global pandemic or war spread over 5 y, starting midway (i.e., 2056) through the projection interval; Scenario 9: 6 billion people killed because of a global pandemic or war spread over 5 y and initiated one-third of the way through the projection interval (i.e., 2041). The mass mortality windows are indicated as gray bars.

If, globally, all women are educated and given birth control so that there are **no unintended births**, still population rises till mid century, and is still as high as today's 7.5 billion by century end. **This shows education isn't enough – we need legally mandated population control**

Only if **1-child per family** is universal by 2045 and no attempts are made to reduce infant mortality, does population fall - to about 4 billion by 2100. Even this is not fast enough to alleviate the over-stress we're imposing on the planet

Action #7. A 28th Amendment to the Constitution

- I propose a 28th Amendment to the Constitution…

- ***Congress shall permit no law denying the rights of present and future citizens to safe commons, including air, ground water, river water, natural forest, and ice caps. Congress shall permit no laws which interfere with the existence of a natural environment in harmony with the right to life and the pursuit of happiness by future as well as present citizens.***

Action #8: Change Global Central Banks' Policy Goal to NEGATIVE Inflation

- The U.S. Federal Reserve policy has a stated goal of +2% inflation per year, because that makes savings worth less and motivates you to cut savings and **spend** or invest it in *e.g.* the stock market
- But if economic growth is the enemy of climate, then let's reverse this and make savings MORE valuable as time goes on. Pull money FROM risk assets BACK to savings. Change fractional reserve rules to lower lending, not encourage it.
- Cut economic growth voluntarily rather than have it forced on us by overshoot-and-crash in resources, in climate change, in financial bubbles…

Rogue 1: NASA Scientists Join the Resistance. Perhaps You Should Too

Suing Governments for Gross Negligence

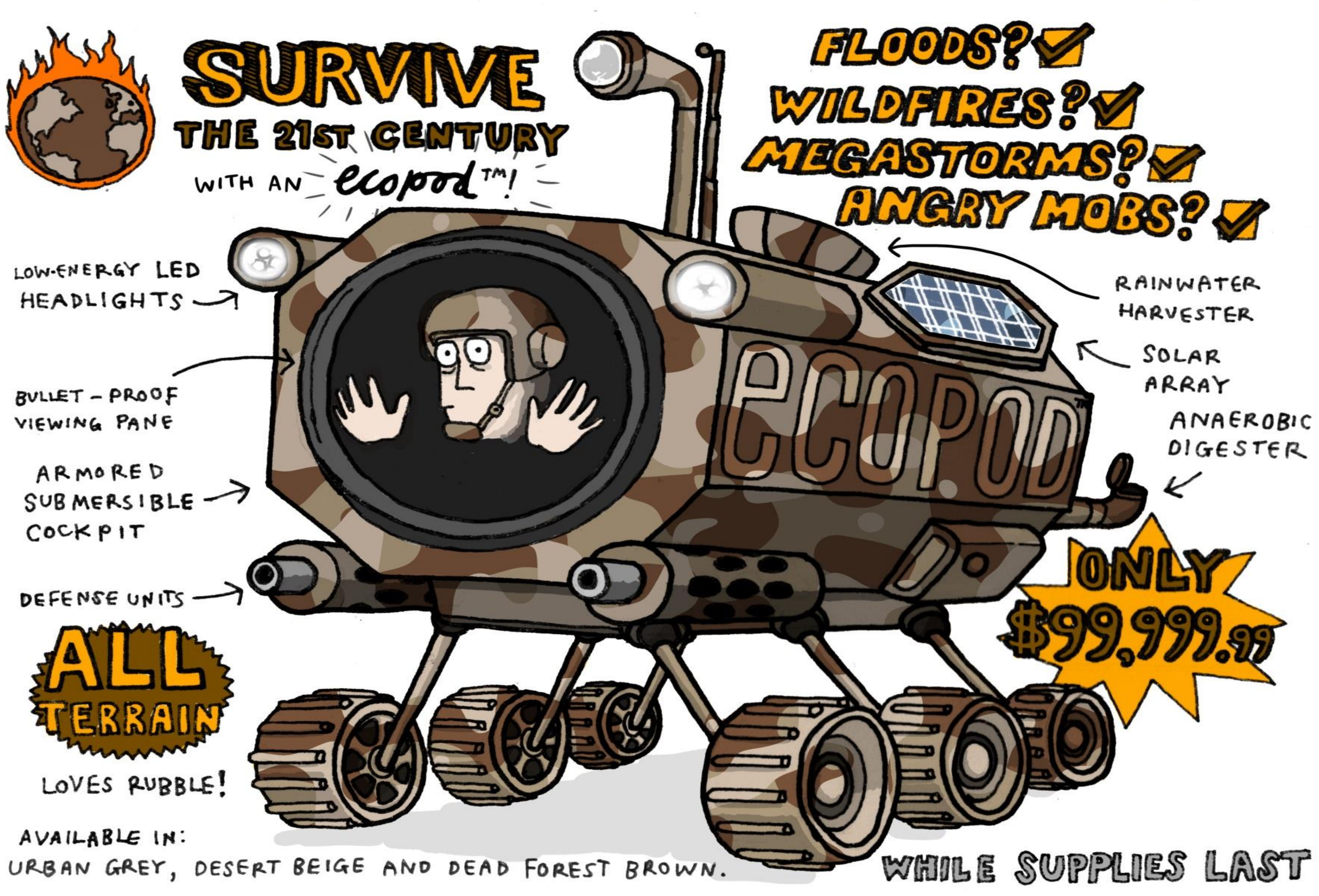
- A **Dutch court has ruled** that the national government has a legal responsibility to protect its citizens against climate change, and ordered faster cuts in greenhouse gases in that nation.
- However, in America, it's different. **Kivalina, Alaska sued Exxon-Mobil** in Federal court over sea-level rise threatening their town. It was dismissed.
- One of the key bases for the law suit was that Exxon-Mobil deliberately lied to the affected people about the science of CO2 and climate. But the court decided to dismiss the case without getting to this interesting question, so it provides no basis for later suits. Such is the System, in the United States.
- **13 U.S. cities are defying Trump** and posting on their own city websites the climate science that was deleted from the EPA's web page at the Trump Takeover of the U.S. Government.

The Extinction Rebellion

- While I don’t believe human extinction is in the cards - the best science doesn’t support that - still…
- …the extinction of a large fraction of Earth’s species, is. And civilization breakdown is a definite possibility or perhaps even probability
- This group is demanding a “WW II Scale Climate Mobilization” to halt what otherwise appears an inevitable descent into a bleak future.

"There's No Fate But What We Make"

Without Radical Change in Human Nature, Techo Efforts Later this Century May Instead End up in This Direction



Is This Going to Be Our Bottom Line?

"Yes, the planet got destroyed. But for a beautiful moment in time we created a lot of value for shareholders."

After the Public Talk: Addendum - Summary on Recommendations

- In order to honor our future generations' planet, and that of all other species – we need to remove essentially all of our CO2 and other direct emissions, replacing civilization energy 100% with renewables.
- And we need to go further. Against steep resistance from Human Nature.
- <u>**Summary Recommendations**</u> - In order to maximally protect Earth's natural surface, and safely re-trace our worsening climate trajectory with minimal hysteresis…

Alternative Energy: Yes

- **Solar PV on existing civilization structures**. Will need much Utility Scale as well, alas. Perhaps in the future, we can perfect clean nuclear power and remove Utility Scale solar from natural habitats
- Deploy wind turbines on utility solar fields when possible
- Will require large improvements, deployment of energy storage, no magic bullets yet.

Alternative Energy: No's…

- Don't deploy new hydroelectric
- Old, light water nuclear reactors should be kept going, but new ones too expensive, uninsurable, hard to permit, Uranium reserves tenuous. Thorium molten salt breeder reactors – the new designs – look very promising and have a low footprint on the neck of Mother Nature.
- **And Forget biofuels**
- Tidal, wave energy too impactful on our precious coastlines, *vs.* the small energy reasonably accessible

Geo-Engineering: YES

- Direct Air Capture (DAC) and pumping underground into safe geological storage. Hardly "GeoEngineering" at all, since it's so safe.
- Do DAC on-site at the geologically prime sequestration locations, to minimize pipelines and related. Use nuclear, or solar or wind turbine farms to pump continuously liquified Air-captured CO2 underground.

BUT - Have We Already Ruined Many of Our Safe Geological Storage Sites?

- Widespread fracking (using high pressure water/chem mixture to crack underground rock) to release natural gas, ruins that formation for being able to safely store pumped CO2.
- Leakage rates of even ½ of 1% per year is a complete killer for sequestering CO2.
- I've not seen numbers quantifying this danger to the long term plan

GeoEngineering: Yes

- Wind-powered bouy-mounted pumps to re-coat winter Arctic Ocean ice thick enough to survive next summer.
- Stop rainforest destruction. Do reforestation (slow, but good long term).

GeoEngineering: Very Iffy

- Stratospheric aerosol injection. Needs much more study, but it's cheap and can be deployed quickly at least. $CaCO_3$ instead of sulfates? But cooling happens differentially, while untouched CO_2 hurts radiant cooling in VERY different pattern. Big rainfall changes likely. Cooler temps encourage more soil carbon sequestration – good.
- Salt water aerosol cloud seeding by ships. Ecosystem damage at suction point? Weather pattern changes look serious, especially induced drought to the Amazon (Jones *et al.* 2009) . Energy cost *vs* Earth cooling? Not very successful tests. Depends sensitively on uncontrollable larger scale weather, so usefulness still in question.

GeoEngineering: NO!

- OTEC pipes, clearly worst of all proposals.
- Trillions of proprietary floating white glass beads spread across the Arctic Ocean (replacing ice). Really?! Ecosystems damage: Didn’t we learn from plastics in the ocean already?
- Park an asteroid or trillions of “butterflys” at L1 Lagrange Point? Expense, danger way too high.
- Mirrors in space. Far too expensive, dangerous if lose control, big climate changes.
- BECCS. Doesn’t work, vast damage to land areas

GeoEngineering: NO!

- **Open ocean Iron Fertilization (OIF).**
- Phytoplankton species which do not produce toxic blooms, do when seeded this way in the open ocean
- A 2019 study (Conway et al.) finds that human-generated iron from fossil fuel burning and deforestation have already been seeding global oceans with far more iron than we'd thought, growing with time – and yet phytoplankton abundances in the oceans have been dropping (Boyce *et al.* 2014).
- This idea has been highly promoted, it now appears because it is cheap and expected funding by carbon offsets, has been projected to produce **big profits**. Yet even in the most favorable site – the Southern Ocean – and even before the Conway study, is expected to sequester at most only 10% of our annual emissions (even if, against evidence, sequestered permanently at all).

GeoEngineering: No

- Plant light-colored reflective crops. In place of what… Natural ecosystems? Light colored crops (think – grains) are in trouble already, in a hot climate. They're above their optimum temperature range in the sunny tropics. And, we have had zero success in decades of trying to GMO' staple crops (wheat, rice…) to handle hotter temperatures.

GeoEngineering: No

- Cover ~France-sized area of the Sahara with natural convection-driven 3,000 ft towers topped by catalyst-coated glass to convert HFC's and methane to (mostly) less harmful chemicals. Huge ecosystem impact. Far from engineering feasibility
- (Find Hugh Hunt talk on YouTube for more on that one)

Policy Changes

Policy: No's

- Cap-and-Trade – only guarantees carbon allowances are maximally used, so maximally emitting CO2, and have never motivated or accomplished lowered CO2 emissions. Instead, provides trading profits while deflecting away from actual carbon emission cutbacks. Don't buy the PR. Read the actual numerical facts, in light of the profit motive.
- Carbon taxes at the consumer level – only succeed in transferring the cost to the poorest among us, and have not accomplished CO2 cuts. (Aldeyn Donnelly talk linked earlier)

Policy: Yes

- 28th Amendment guaranteeing safe commons (oceans, atmosphere, ice caps, great forests) be preserved in undamaged state for all future generations.
- Carbon tax as it enters the country (wellhead, or borders). Proceeds best used to fund direct air capture and sequestration, and other climate-repair actions.