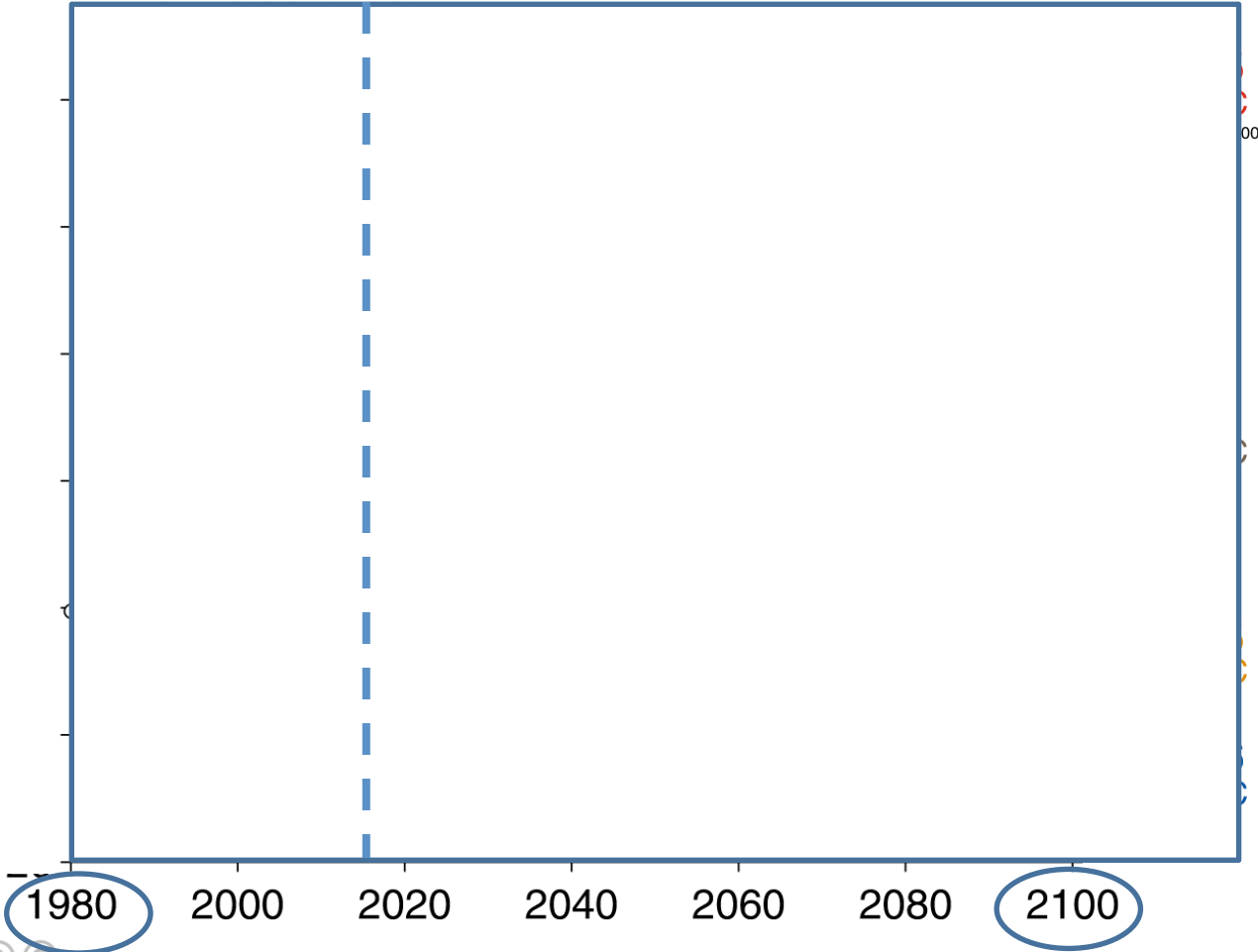


Truths we must tell ourselves to manage climate change

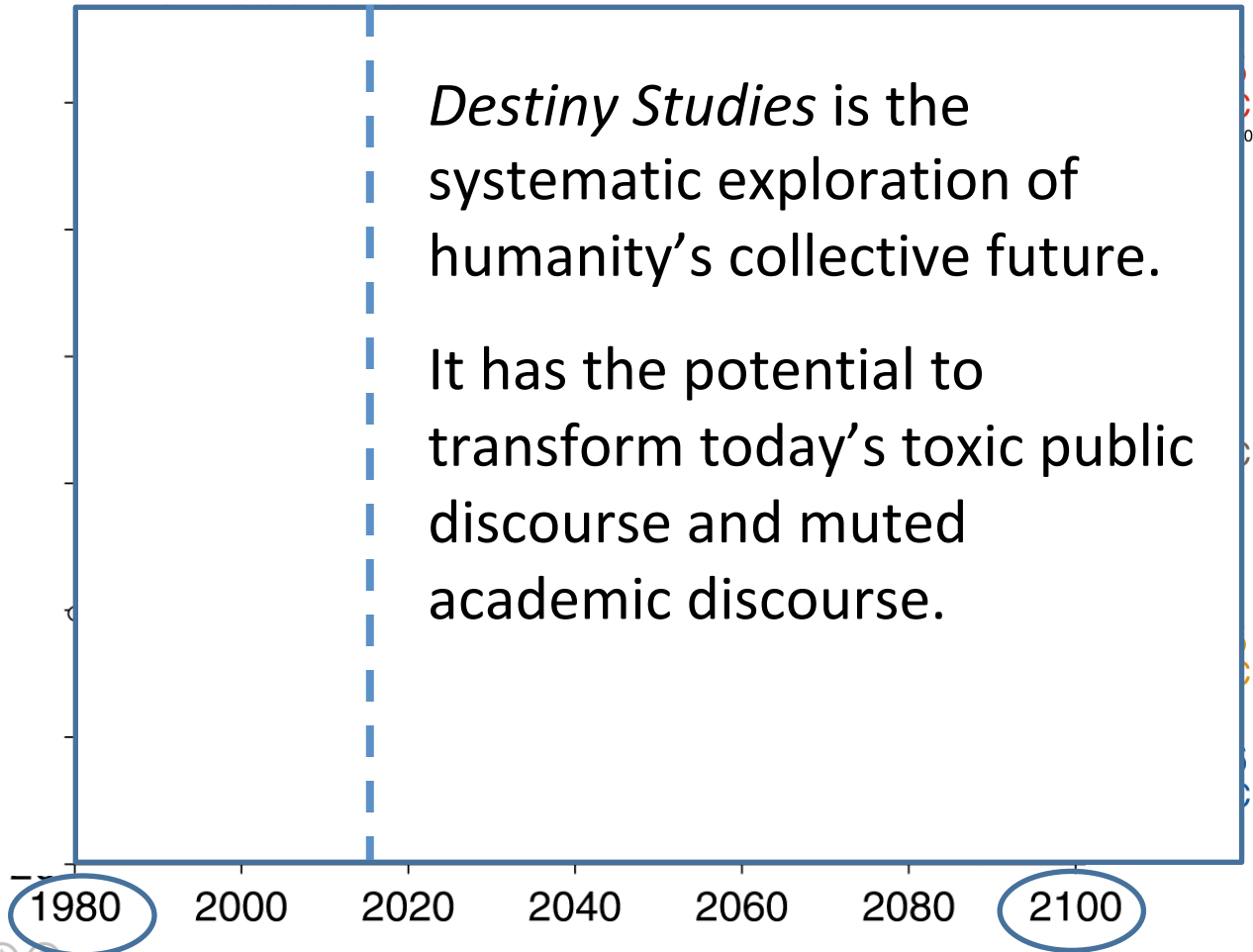
Robert Socolow

Energy Technologies Area Seminar
Lawrence Berkeley National Laboratory
February 15, 2018

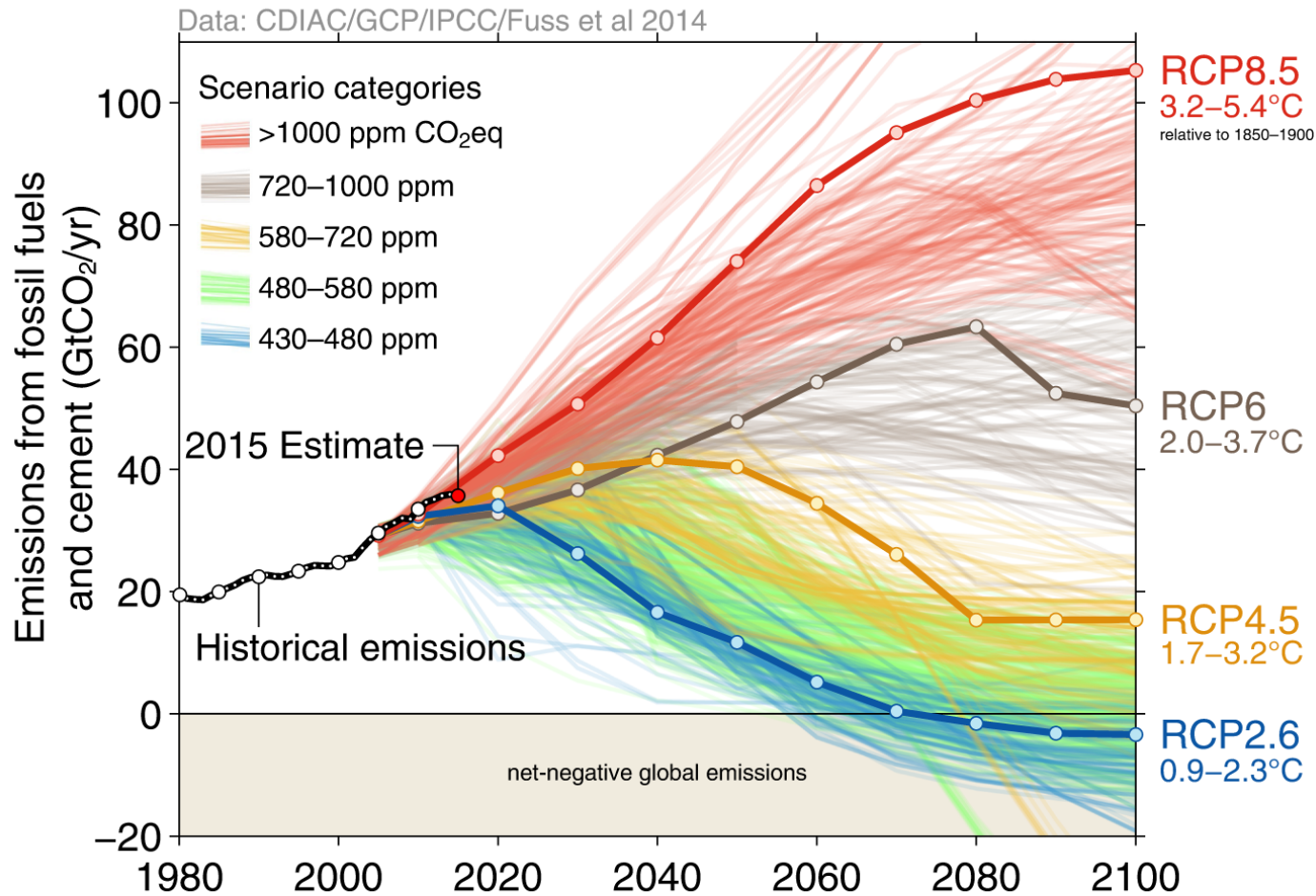
What we project, and how far



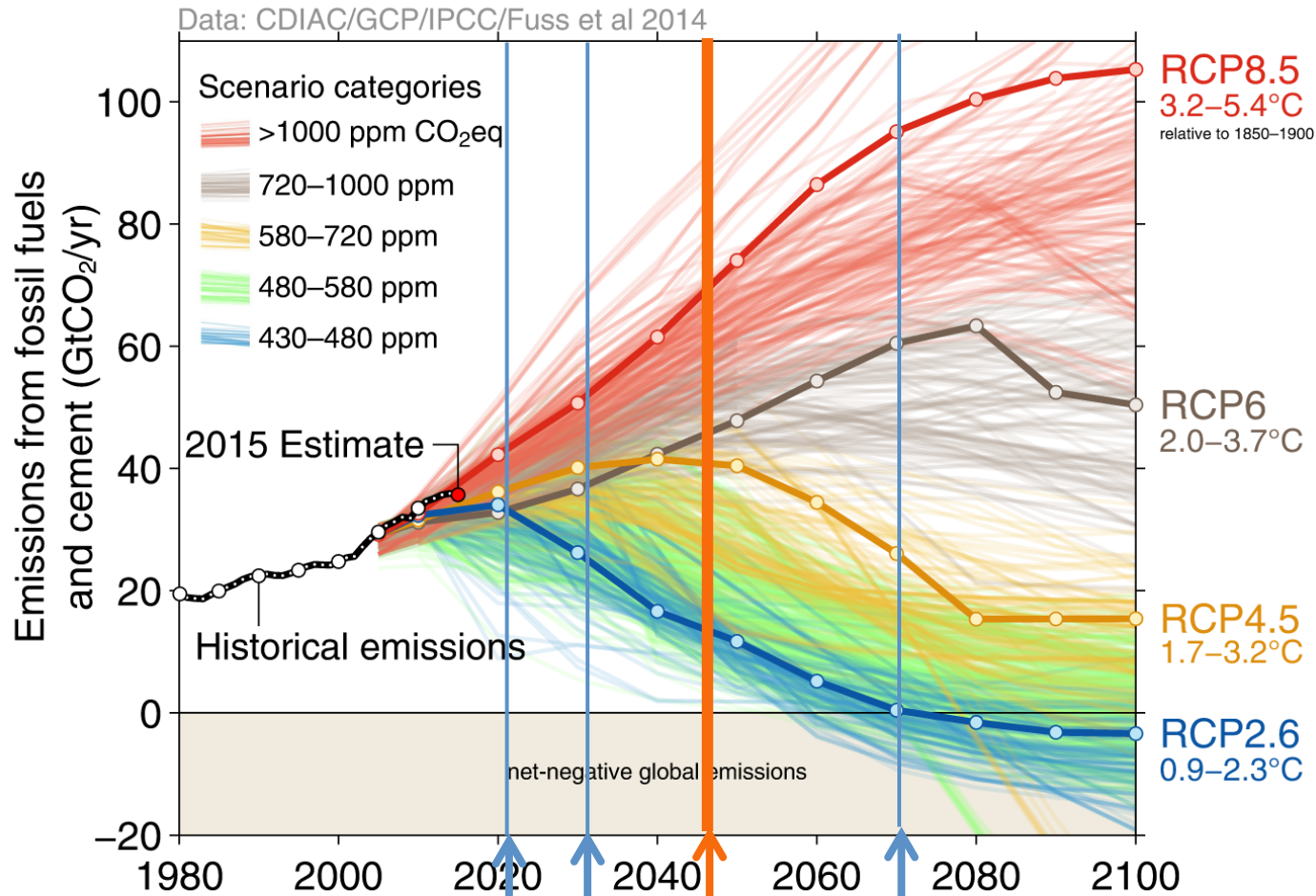
What we project, and how far



CO₂ emissions scenarios



The Freshman Seminar 151 capsules



Reunions: 0 10 25 50

2046 is also PU #300.

“Time capsules for climate change, to be opened at your reunions”

Student's topics:

Sea level rise and cities
Solar radiation management
Carbon dioxide removal

Solar power
Batteries
Electric Cars



Photo credit: Denise Applewhite

Each student wrote about two alternative futures: *Will the electric car dominate or find only niches?* They interviewed people with a range of views: *How will the Catholic Church deal with geoengineering?*

“It’s up to us.”

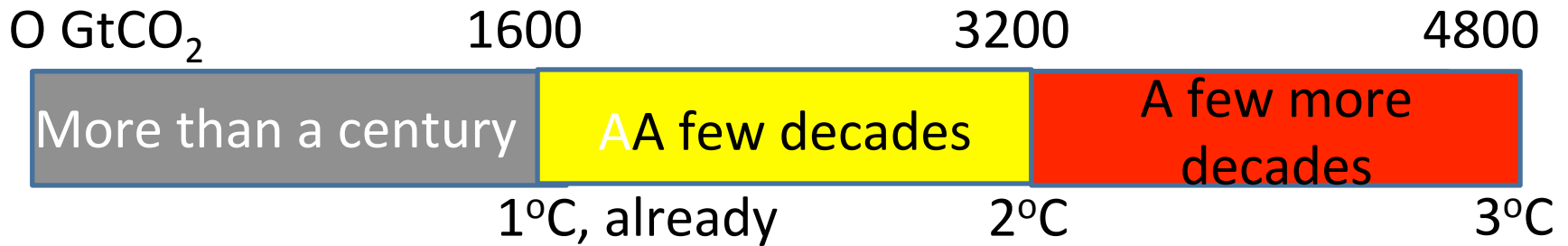
The climate change problem

Doing ordinary things, we are changing the planet.

Because our climate science is so unsettled, the best and worst outcomes of what we are doing are dramatically different.

High-carbon industrialization in the developing countries is the Number One problem. (*Note: politically charged.*)

Our small planet



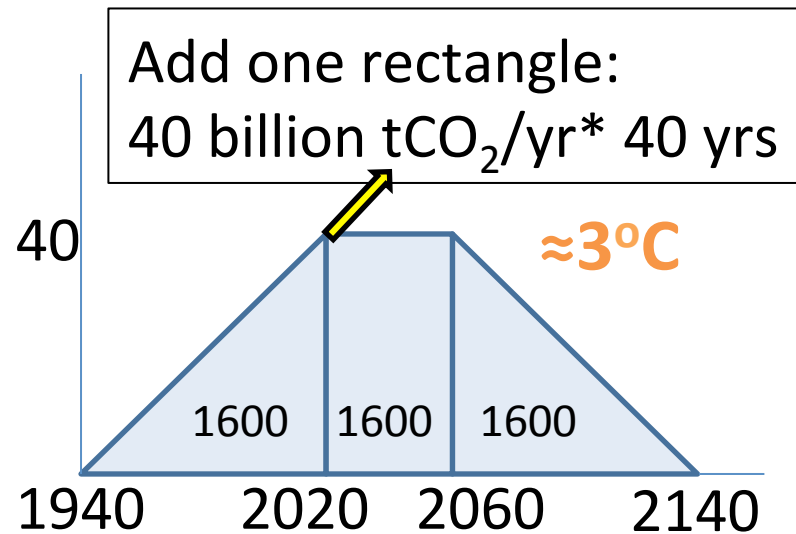
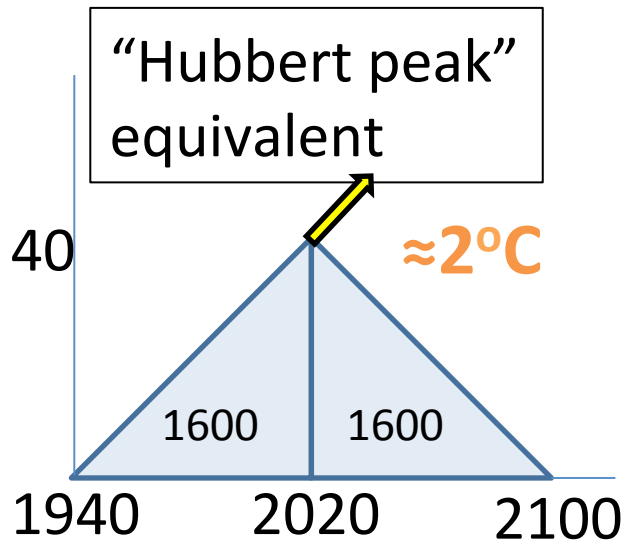
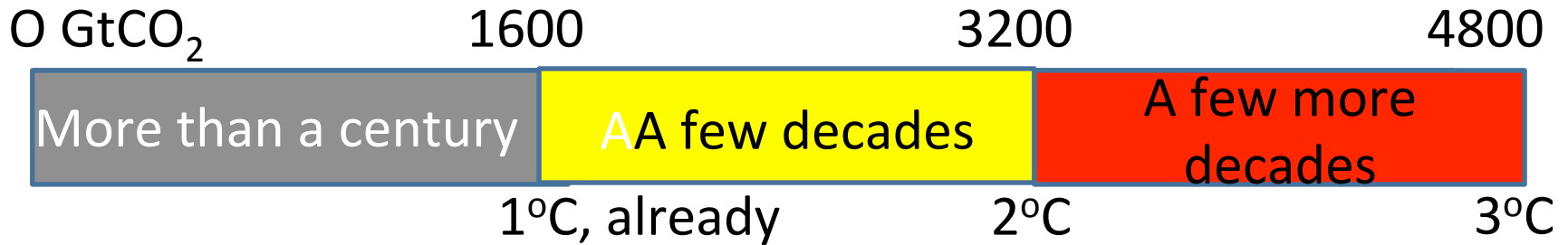
A useful approximation: The long-term average temperature rise on the Earth's surface is proportional to the cumulative global emissions of CO₂. 2°C is the most discussed target. $G = 10^9$.

The multiplier from emissions to temperature rise reveals that our planet is small. When we as a species do ordinary things* globally with the technologies we have, we harm ourselves.

**Examples of ordinary things:* eating hamburgers, commuting to work, building with concrete, going skiing.

1. We wish Earth were larger.

Carbon budgets



↗ If we were not confronting climate change, the era of fossil fuels (coal, oil, and gas) could last hundreds of years.

What if, in 2018, we had still not figured out CO₂?

Budgets demand choices

The budget concept leads inexorably to choices about which fossil fuels to extract and which to consider “unburnable”:

When?

Better options someday?

Whose?

Geopolitical stability

Used where?

“Fairness”

For what purpose?

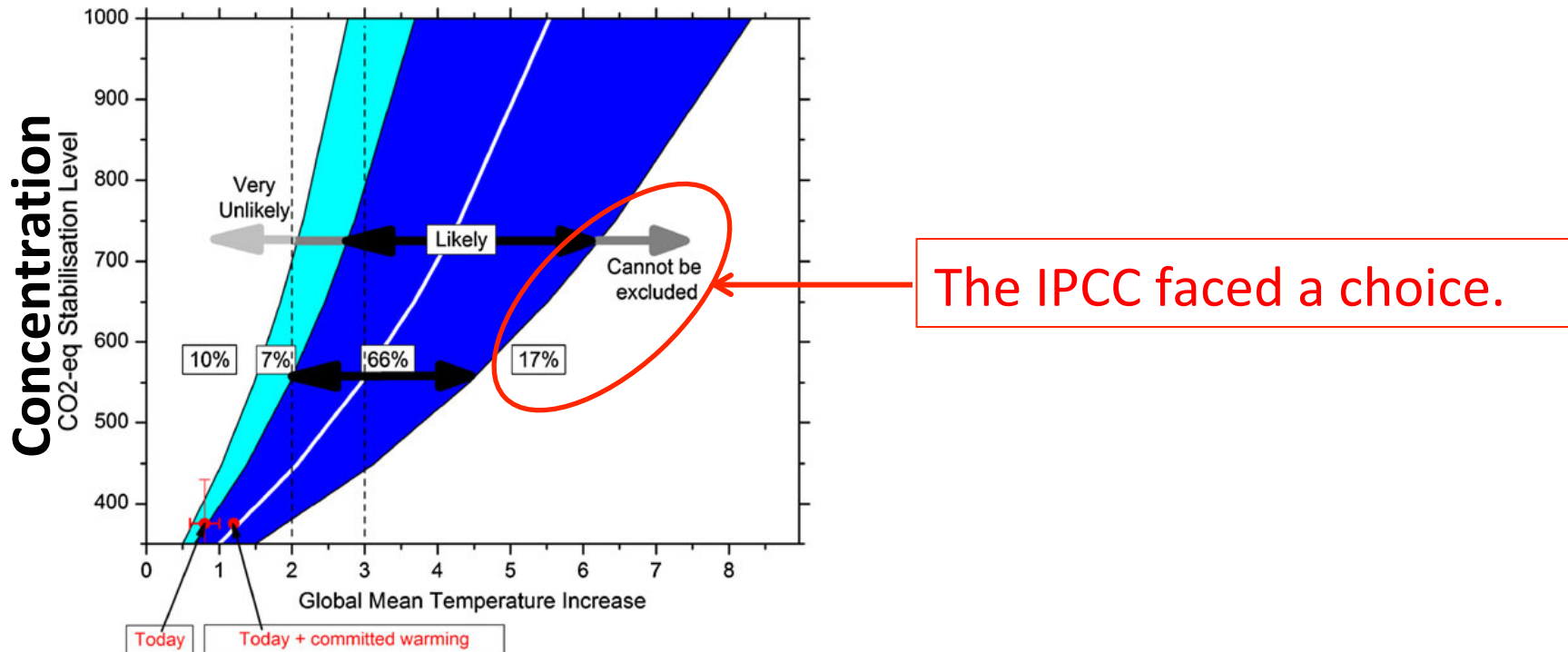
Who judges?

Which fossil fuels?

Those with the highest H/C ratio?

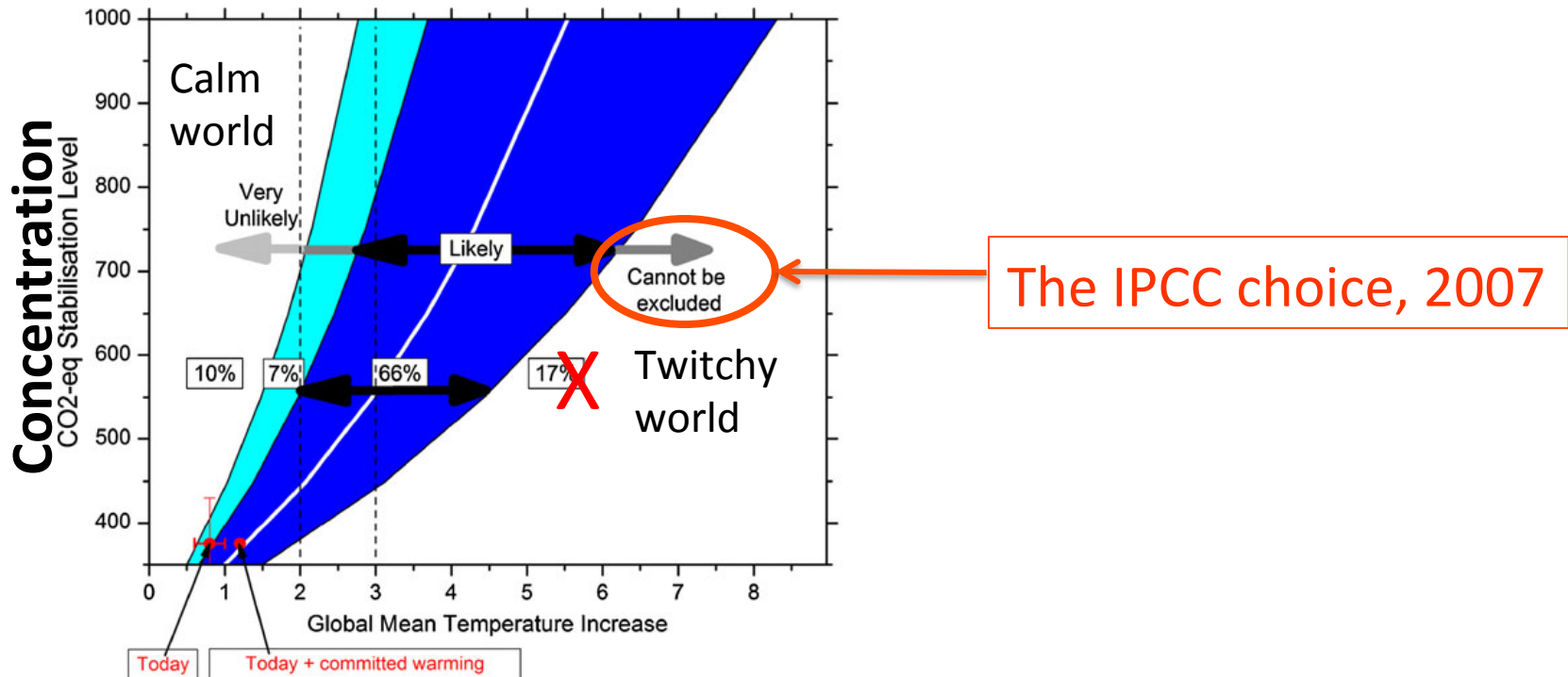
2. Judgments about which fossil fuels are “unburnable” have no precedents.

Climate change has uncertain “tails”



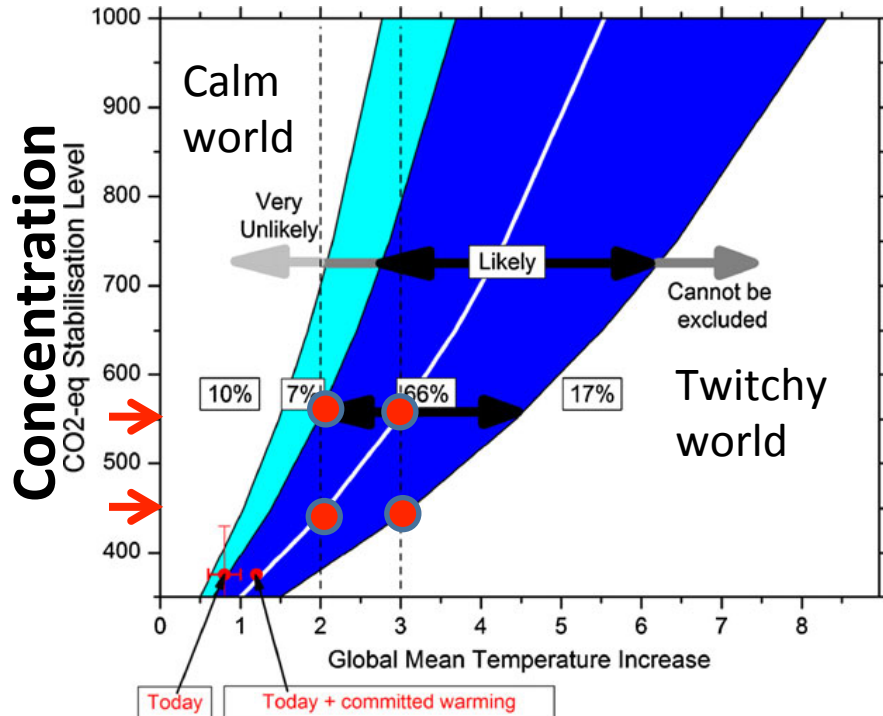
This Figure was prepared by Martin Manning for Working Group 1 during the preparation of the IPCC *Fourth Assessment Report* (2007), but the IPCC did not publish it. I did, with Manning's permission, in *Climatic Change*, 2011.

The uncertain twitchiness of the climate



Later, in the *Fifth Assessment Report* (2012), the lack of consensus was not disguised: “No best estimate for equilibrium climate sensitivity can now be given because of a lack of agreement on values across assessed lines of evidence and studies.”

We could be lucky...or unlucky



The four red dots:

550 ppm: 50% chance of 3°C, but 1/6 chance of 2°C. **Lucky!**

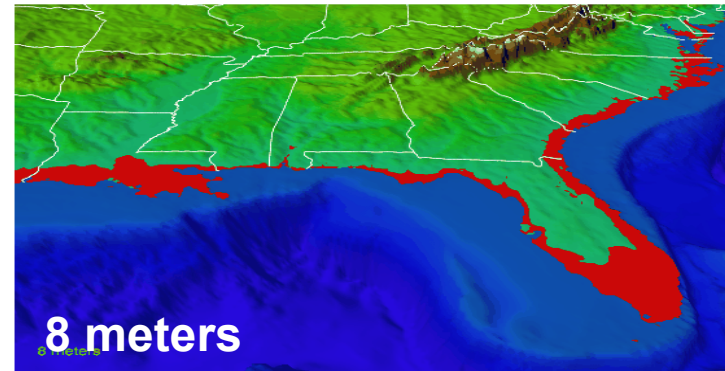
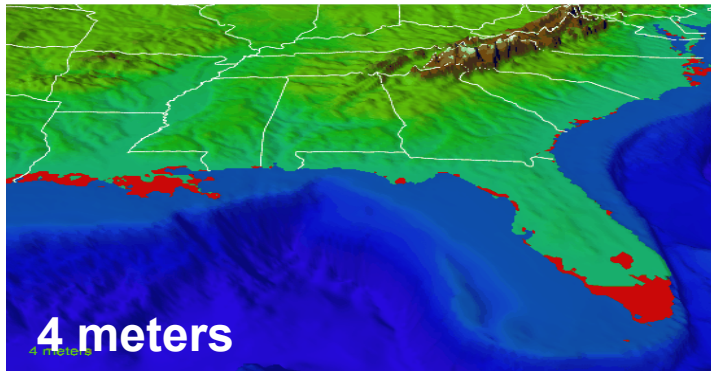
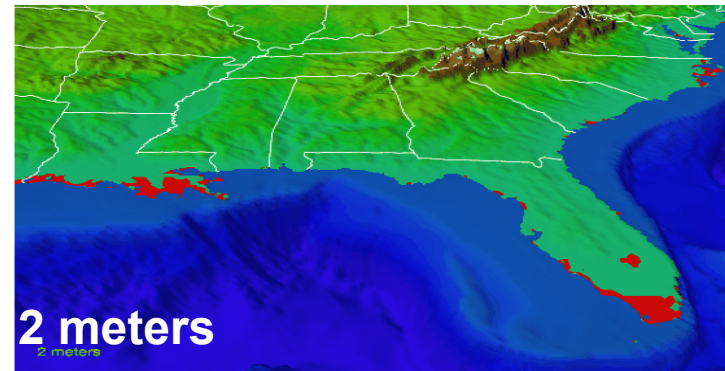
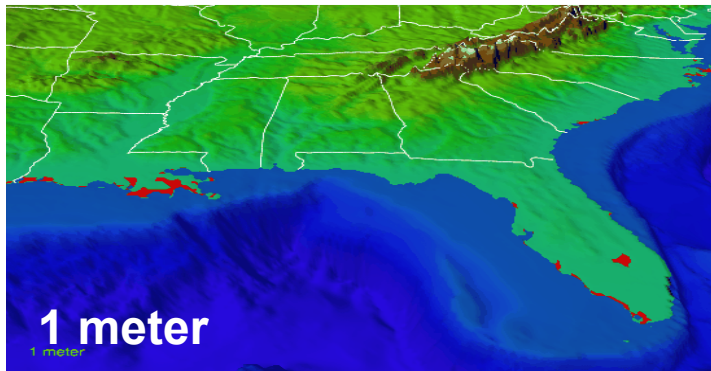
450 ppm: 50% chance of 2°C, but 1/6 chance of 3°C. **Unlucky!**

The best and worst outcomes of our emissions are very different. However, a well known climate science leader, when I said, “We could be lucky,” replied: “You must never say that.”

***3. “Tails Science” must get greater priority.**

Sea level rise: When?

Sea Level Rise



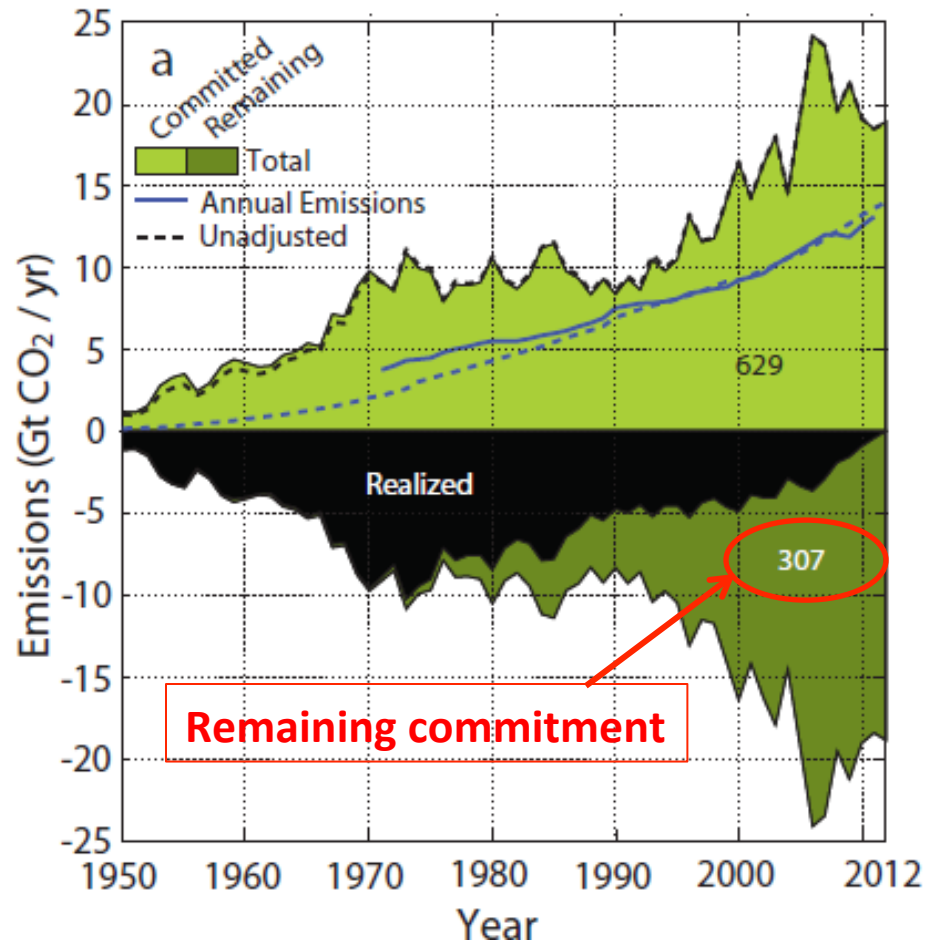
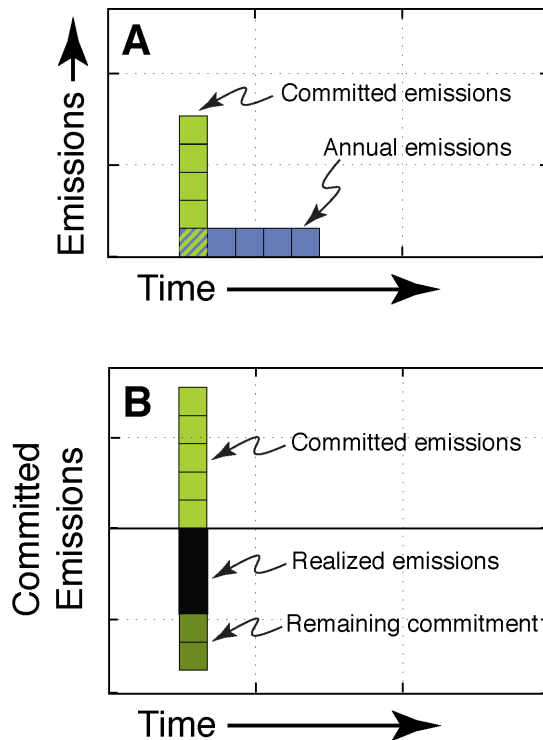
Greenland ice sheet: 7 meters

West Antarctic Ice Sheet: 5 meters

Reference pace for sea-level: +1 meter/century

“Committed emissions”

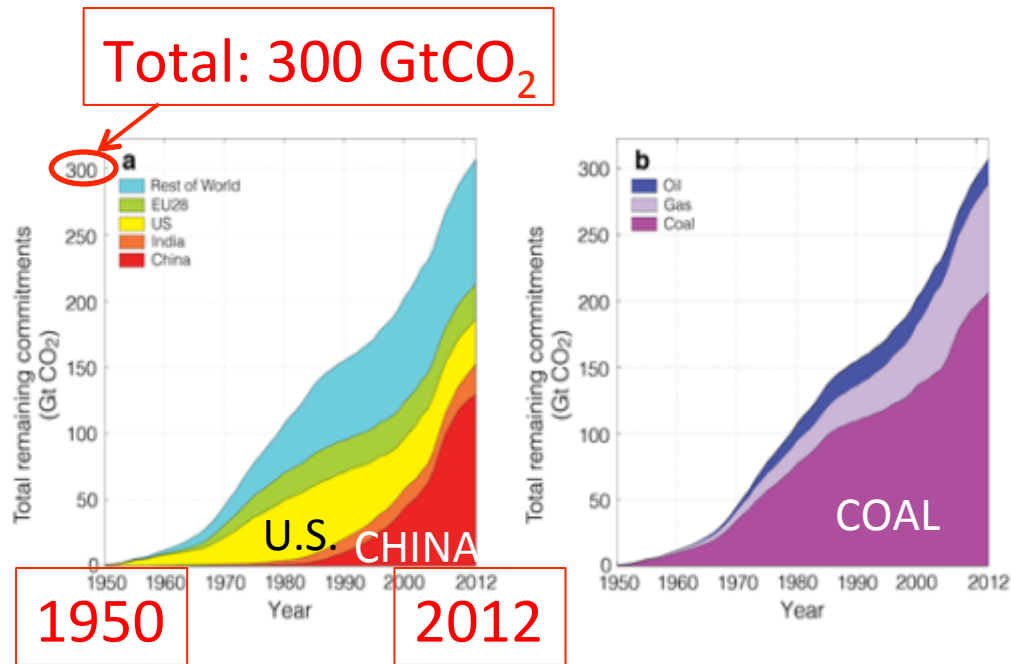
Future emissions inherent in current investments



Collaborator: Steve Davis.
Source: Davis and Socolow,
Env. Research Letters, 2014

Global view of electric power from 2012.
Assumes 40-year life for power plants, updated
for retirements and plant-life extensions.

Remaining emissions, year by year



Global remaining “committed emissions” from then-operating power plants, 1950 – 2012. (Assumes a 40-year lifetime.)

A *preliminary* analysis updated by four years (to 2016) shows 355 GtCO₂ of remaining commitments, thus a continued 4%/year growth (Dan Tong, unpublished).

Committed emissions from new buildings



Shown: Yanjiao, China

Most power-plant electrons go to buildings. Less demand for heating, cooling, and appliances – fewer power plants.

***4. “Committed emissions” prioritizes low-carbon industrialization.**

Leapfrogging



Developing countries used to be unwilling to do something before it was proven in the industrialized countries. They didn't want to be guinea pigs. This is changing. For example, China is leapfrogging over the rest of the world with high-voltage transmission.

5. The developing world will decide what kind of planet we live on.

One billion high emitters



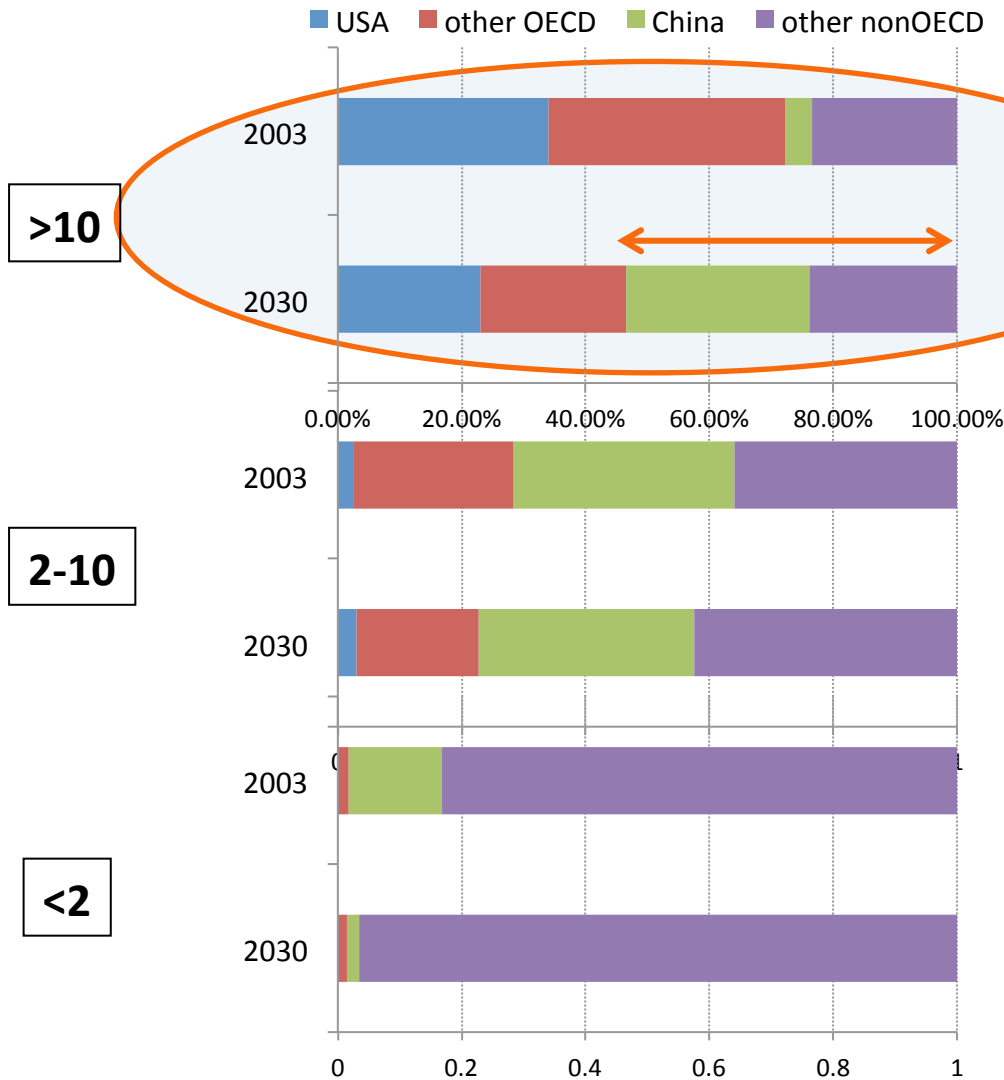
1.2 billion “high emitters” in 2030.

Bin boundaries at 2 tCO₂/yr and 10 tCO₂/yr are the 2003 per capita values for Brazil and EU. *Most high emitters are not “rich.”*

Collaborators: Shoibal Chakravarty and Massimo Tavoni.

Source: <http://www.climatescienceandpolicy.eu/2009/11/afocus-on-individuals-can-guide-nations-towards-a-low-carbon-world/>

Where do the high emitters live?



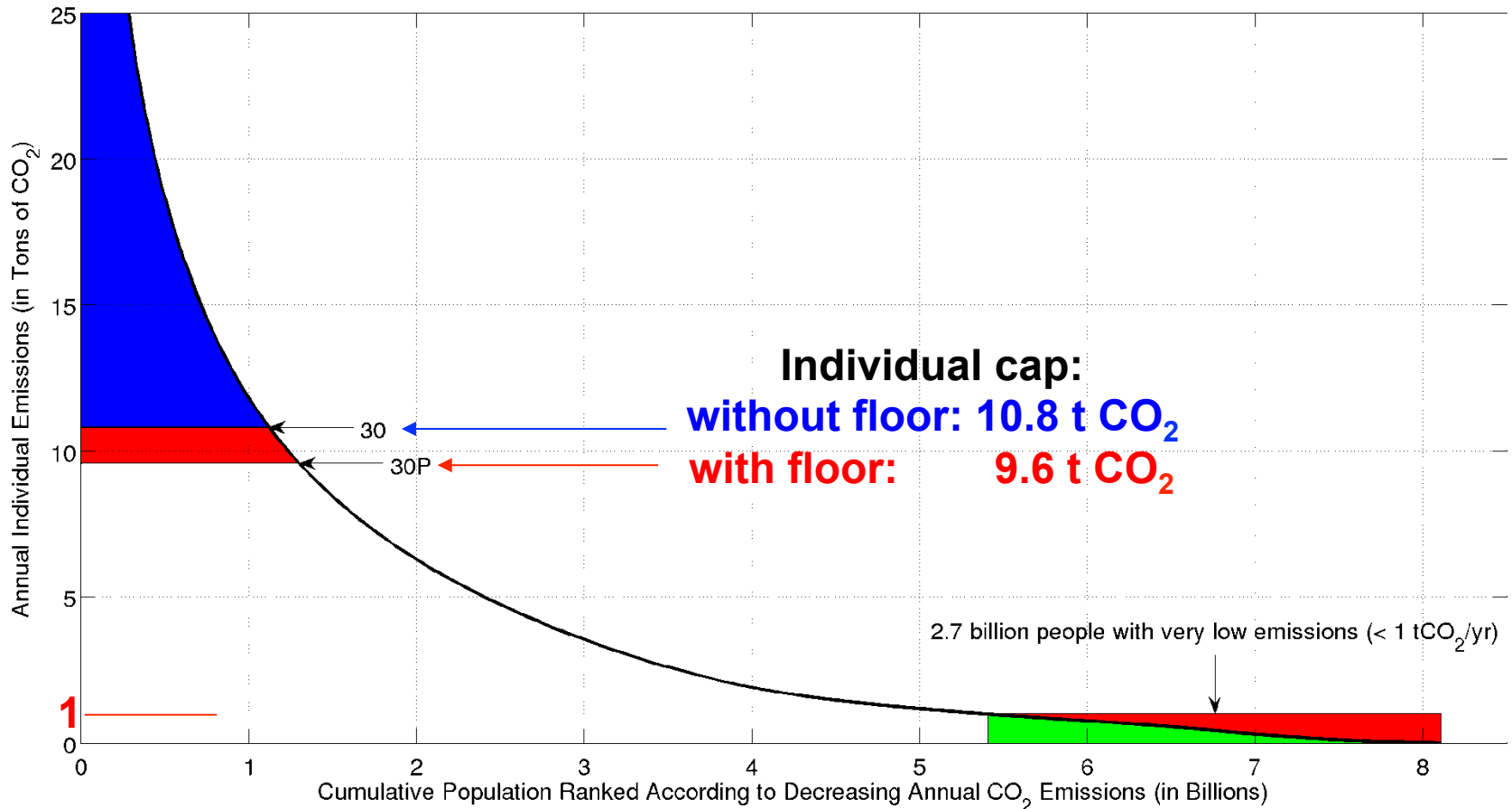
More than half of the 2030 high emitters are projected to live outside the OECD.

The high-emitter lifestyle is similar across the world. Best practices pioneered in one country can spread.

The “Paris” process can help: participants show off their best dishes.

6. “Paris,” a potluck dinner, can help drive a race to the top.

High emitters and abject poverty



The world's poor do not need to be denied fossil fuels.

“Solutions”

There are still many options. Is it already time to declare a winner?

Options can be more dangerous than climate change.

Stabilization wedges... in 2004



2011 Kentucky Derby, AP Photo/Matt Slocum. <https://www.cbsnews.com/pictures/2011-kentucky-derby/7>

Slide pair: courtesy of Greta Shum, Andlinger Center, Princeton University

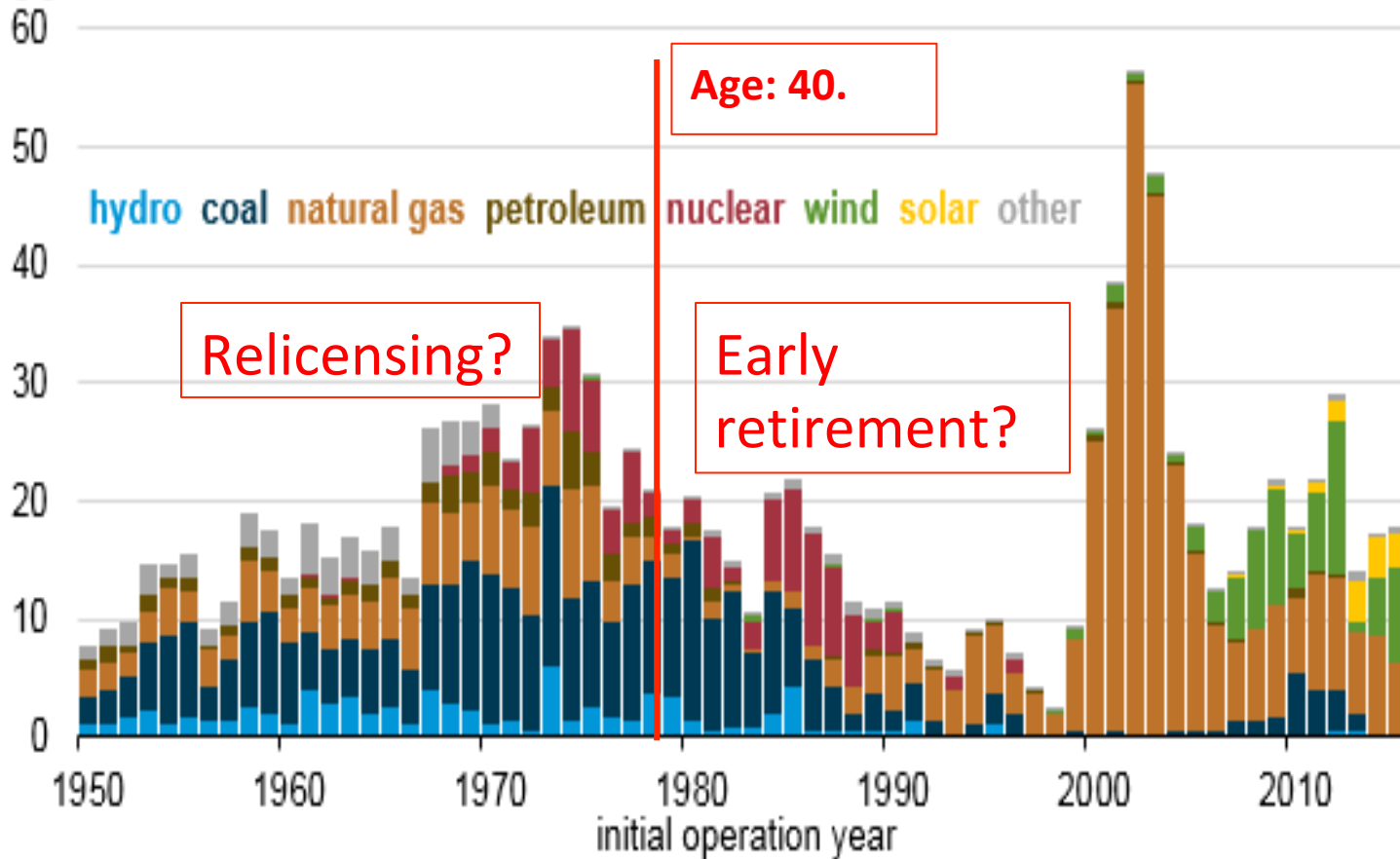
Stabilization wedges... in 2018



U.S. power plants: Replaced by what? When?

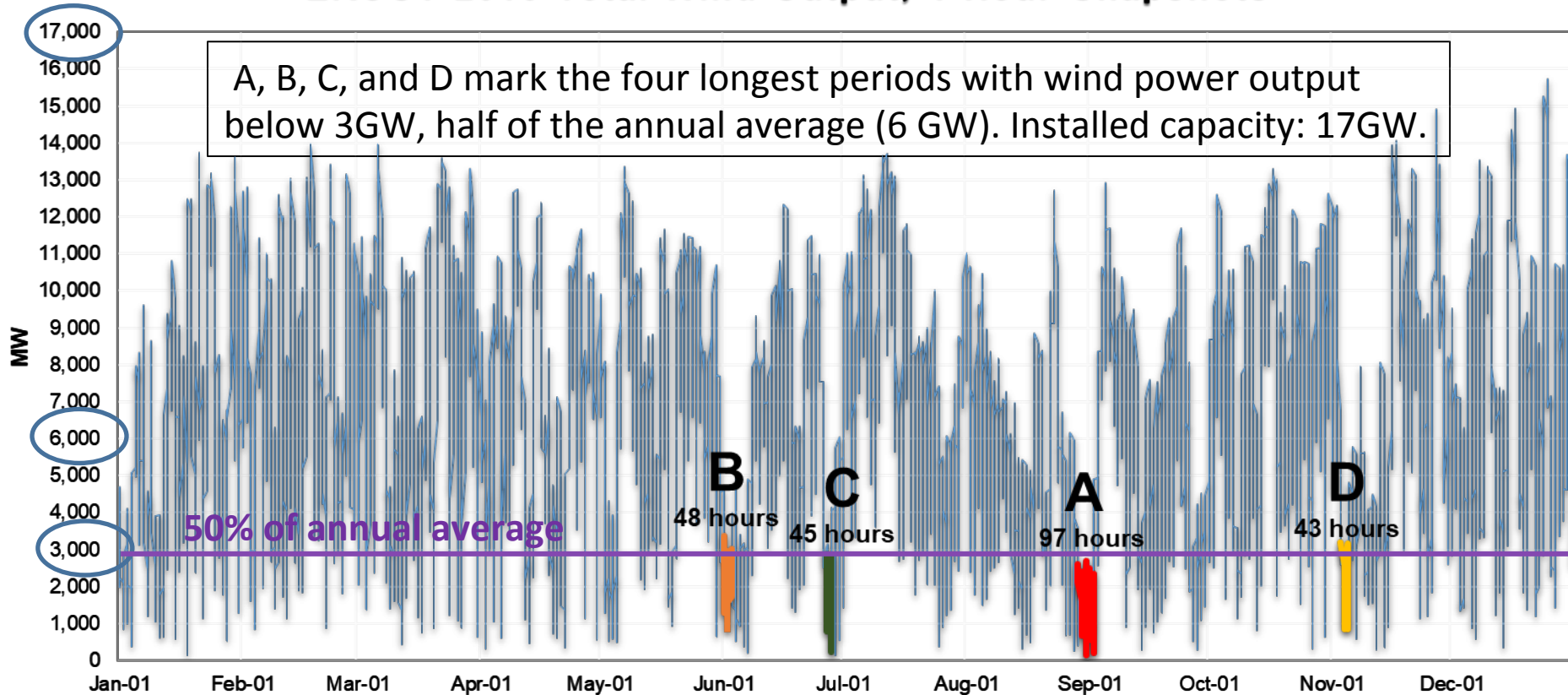
Electric generation capacity additions by technology (1950-2015)

gigawatts



Wind Power: Low-Output Analysis (LOA)

ERCOT 2016 Total Wind Output, 1-Hour Snapshots

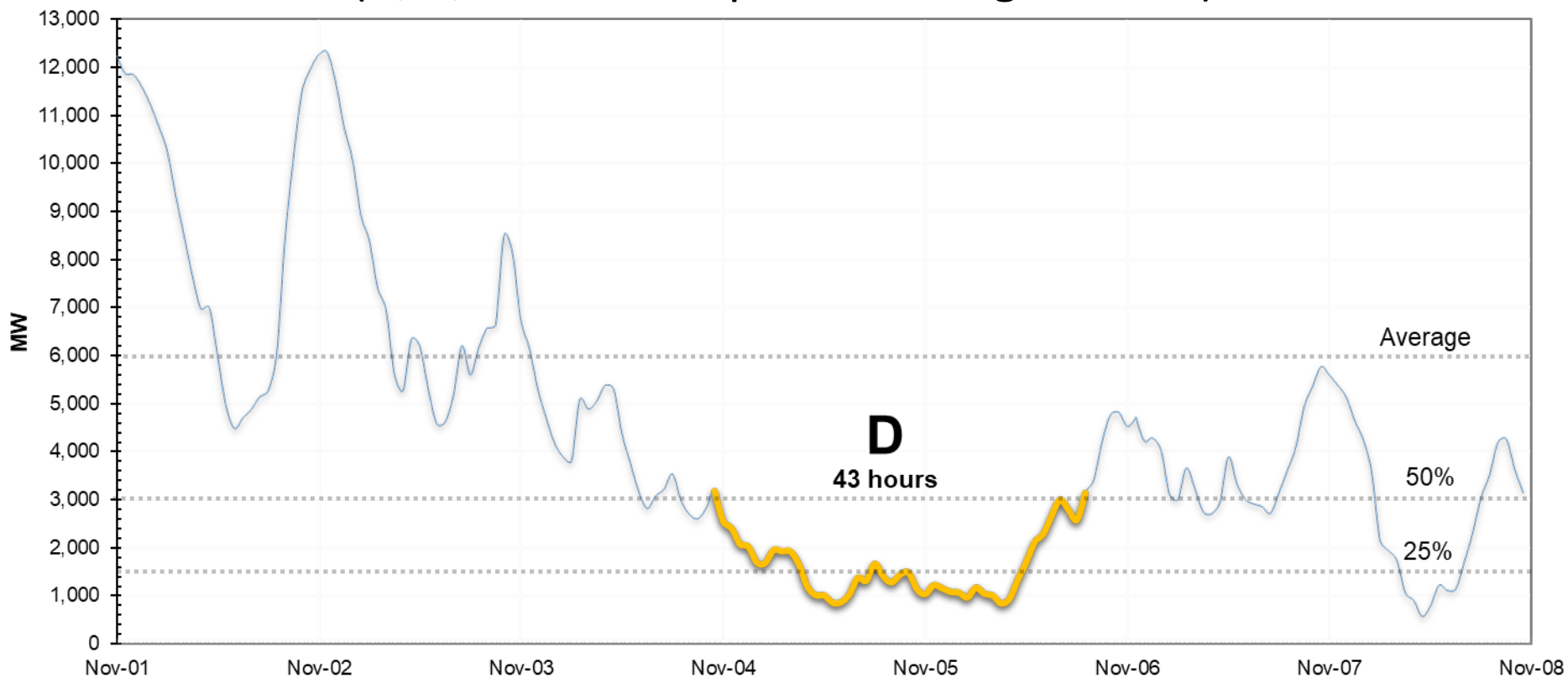


Wind accounted for 15% of 2016 ERCOT (roughly, Texas) electricity production. Wind expansion could be thwarted by events like A-D.

Figure and analysis courtesy of Pedro Haro.

Only D is a long lull.

(A, B, or C are responses to high winds.)



Wind speed
(San Marcos, TX)

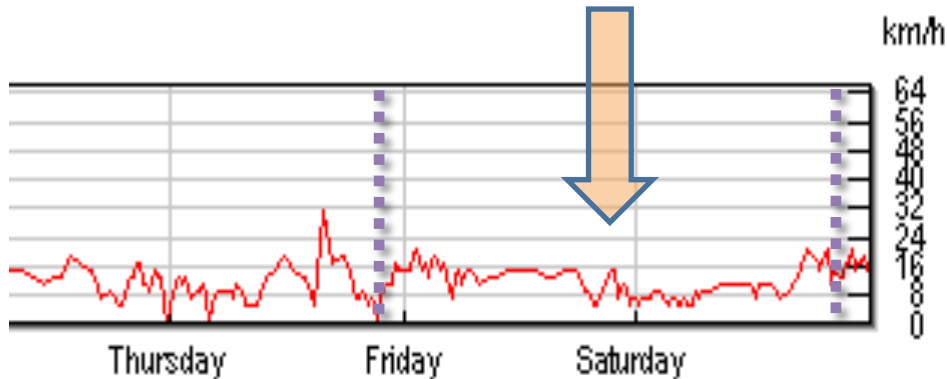
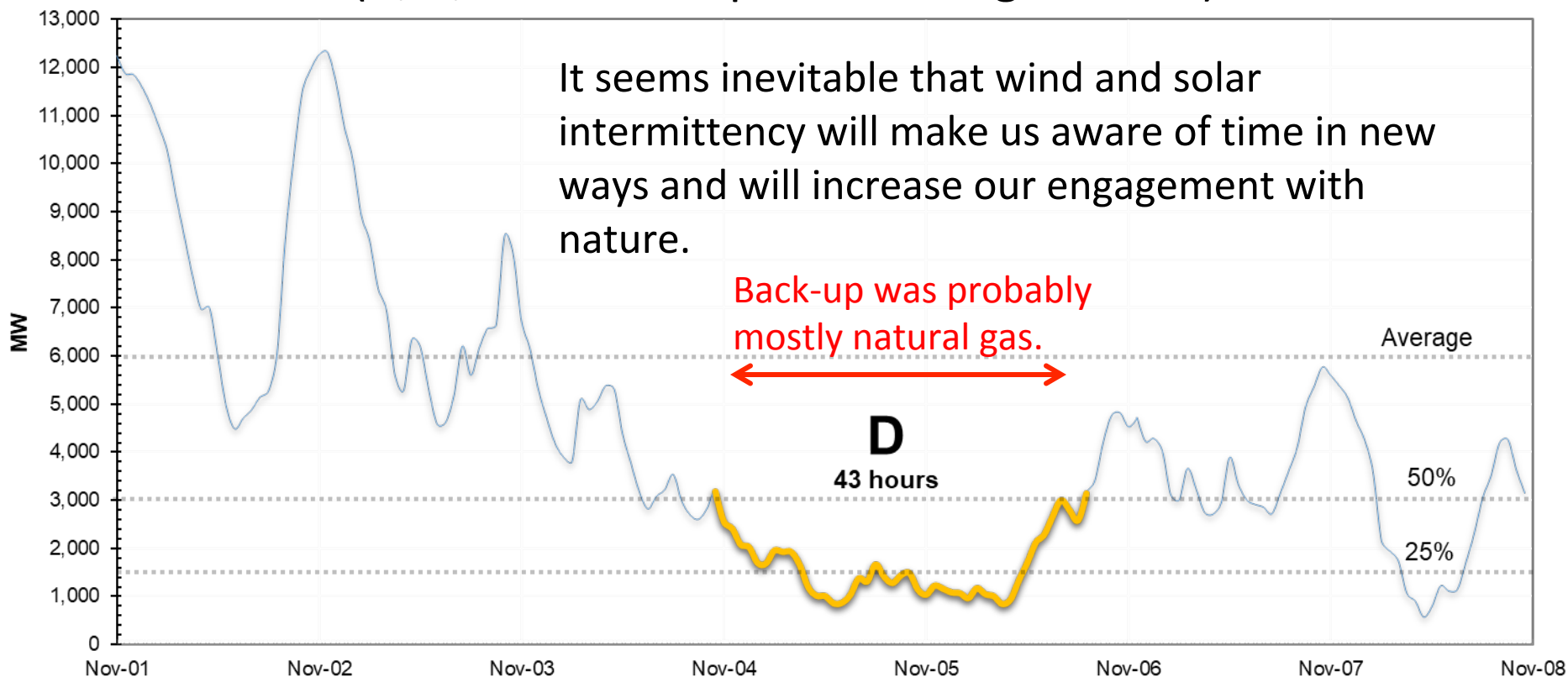


Figure and analysis
courtesy of Pedro Haro.

Only D is a long lull.

(A, B, or C are responses to high winds.)



***7. Solar-fossil and wind-fossil packages would reduce the intermittency challenge. Zero-carbon ideology is in the way.**

Rapid Switch:

How quickly can change occur?

How quickly can solar and wind gain market share?
How quickly can coal lose market share?

What limits how quickly social norms can change?

Wind and solar intermittency will make us aware of time in new ways and increase our engagement with nature.

How strongly will we resist?

History is useful: How quickly did automobiles displace horses? Why neither faster nor slower?

What goes wrong when change is attempted too quickly?



8. “Rapid Switch” (the pace of change) is ripe for academic inquiry.

Every “solution” is dangerous*.

* I choose the word with Rio in mind.

Every strategy can be implemented well or poorly

Nuclear power

Nuclear war

Biocarbon

Competing uses of land

Geoengineering

Technological hegemony

“Clean coal”

Mining: worker and land impacts

Wind and solar

Unreliability

Conservation

Regimentation

It is essential to identify the “conditionalities” that make a solution less dangerous.

Risk management reappears: It is possible to achieve 2°C and regret doing so. “Two-sided reasoning” weighs both the threat and the “solutions.”

Conditionality for nuclear power

Nuclear power is coupled inevitably to nuclear weapons. Alas, in the past two decades, nuclear weapons have become more desired. Thus, a condition for the deployment of nuclear power to address climate change needs to be that it leads away from, not toward, national nuclear weapons programs.

The Iran deal shows the extent to which sovereignty must be compromised to sever the connection between nuclear power and nuclear weapons. The logic of the Iran deal points toward the internationalization of nuclear power – especially the “fuel cycle” – including for the U.S.

9. A nuclear war is a poor trade for the slowing of climate change.

Conditionality for biocarbon

What will go wrong if we move headlong to maximize global biocarbon stocks without conditionalities?

Suppose you were a forester or an agronomist in a world where the carbon price was very high. You were told that storing carbon was your only objective. What would you do? Establish a monocrop? Pour on fertilizer? Be inventive....

Conditionality for biocarbon

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Now, change roles. You are the policy maker in the same world. What conditionalities would you place on the carbon market for biostocks in the interest of eliciting actions you would welcome and deterring outcomes you would decry?

10. The biosphere is at risk at \$100/tCO₂.

Geoengineering by imitating volcanoes



On June 15, 1991 (three days after this photo), Mt. Pinatubo injected 10 million tons of sulfur into the stratosphere.

The Earth's average surface temperature was 0.5°C cooler six months later, then rebounded.

Cooling the Earth deliberately by perpetually injecting sulfur particles into the stratosphere is an example of “geoengineering” (also called “solar radiation management”).

Engineered Earth



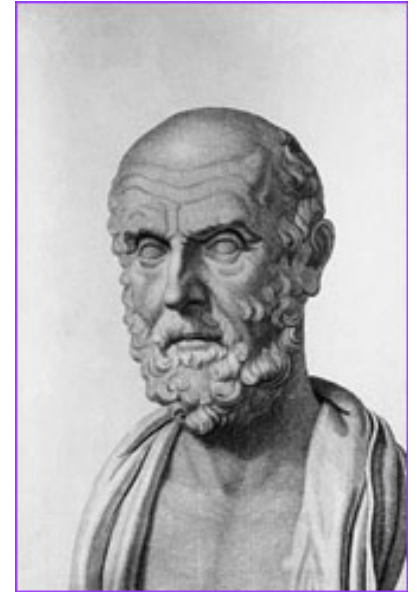
In a fully engineered planet:

- There may be no way back.
- There is no obvious political process that will reconcile contending goals.
- Taking other species into account will create conflict; many species depend on the extreme events we find unpleasant and costly.

11. Beware of using geoengineering to remove highs and lows; it will eradicate the evolutionary niches of countless species.

Patient Earth

“I will apply, for the benefit of the sick, all measures that are required, avoiding those twin traps of overtreatment and therapeutic nihilism.”



Hippocrates

***12. The lowest conceivable greenhouse targets, achievable only by casting caution to the winds, are not optimal.**

* Modern version of the Hippocratic oath, Louis Lasagna, 1964,
http://www.pbs.org/wgbh/nova/doctors/oath_modern.html

Twelve truths

1. We wish Earth were larger.
2. Judgments about which fossil fuels are “unburnable” have no precedents.
3. * “Tails Science” must get greater priority.
4. * “Committed emissions” prioritizes low-carbon industrialization.
5. The developing world will decide what kind of planet we live on.
6. “Paris,” a potluck dinner, can help drive a race to the top.
7. * Solar-fossil and wind-fossil packages would reduce the intermittency challenge. Zero-carbon ideology is in the way.
8. “Rapid Switch” (the pace of change) is ripe for academic inquiry.
9. A nuclear war is a poor trade for the slowing of climate change.
10. The biosphere is at risk at \$100/tCO₂.
11. Beware of using geoengineering to remove highs and lows; it will eradicate the evolutionary niches of countless species.
12. * The lowest conceivable greenhouse targets, achievable only by casting caution to the winds, are not optimal.

Can such points of departure – and many comparable ones – enable a more constructive conversation about climate change?

Remember what supporting science in America looked like?



1st WH Astronomy Night for Kids



Mathletes in the Oval Office



1st WH Science Fair



Honoring outstanding K-12 science teachers



Visiting MIT's Energy Lab

Homage to the research community

Its values: Rigor, engagement, independence, global reach, collegiality, irreverence, moral compass.

Its scholar-friends: John Harte, Marc Ross, Art Rosenfeld, Frank von Hippel, Bob Williams, Steve Pacala, and many more.

Its homes for me: Harvard, LBNL, CERN, Yale, Princeton

Its young people: undergrads, graduate students, post-docs. They replenish the spirit (“it’s up to us”). They take the baton.

What will be in *their* talks in 2068?