Fall Term - 2013

Woodrow Wilson School 585b

Living in a Greenhouse: Technology and Policy

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Phil Hannam, AI

Week Twelve: December 11, 2013

Geoengineering
Summing up

Lecture 12 Outline

1. Fission weaknesses; fusion (brief, from L 11)

2. Geoengineering

BREAK

3. The road ahead

Fission Power – with Dry Cask Storage

Site: Surry station, James River, VA; 1625 MW since 1972-73,. *Credit*: Domir

After-heat: A fire you can't put out.

Percent of pre-shutdown power

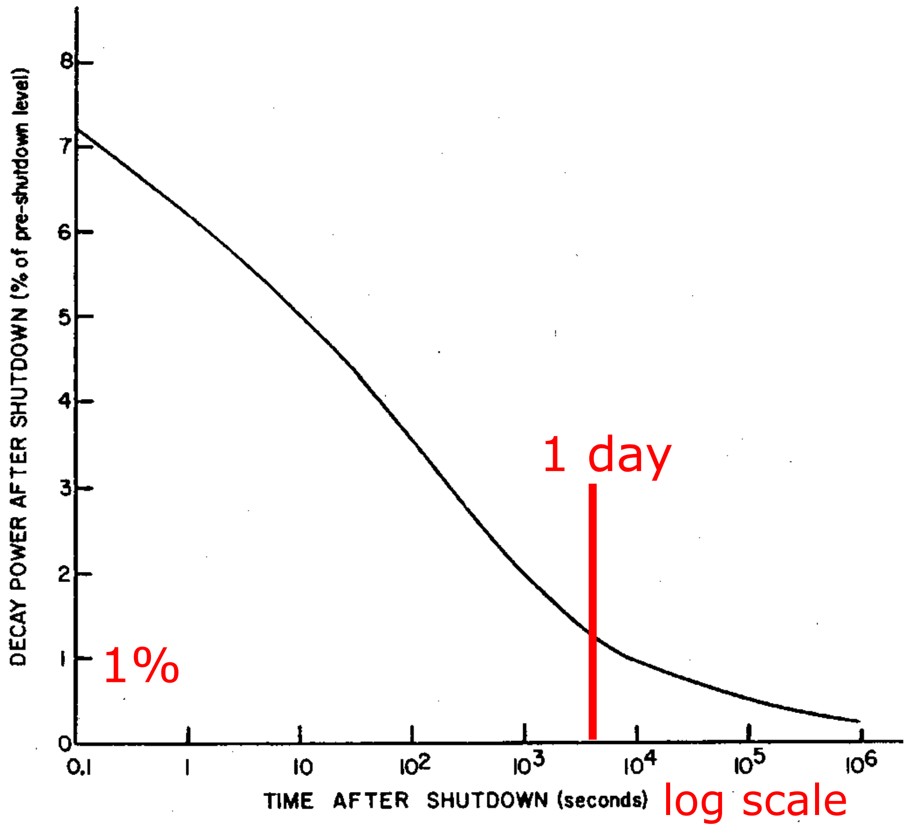


Figure 4-1. THERMAL POWER AFTER REACTOR SHUTDOWN.
After the nuclear chain reaction ceases, radioactivity remaining in the fuel will generate heat as a result of radioactive decay. Assuming that the reactor had been operating for a substantial period, the power generated immediately after shutdown will be approximately 7% of the level before shutdown. For a 3000 MWth reactor, with 1000 MWe capacity, this implies an initial decay power level of about 200 MWth. Due to the rapid decay of short-lived species, this decay heat level decreases rapidly, but is is this heat that imposes the requirement that, in a light-water reactor, cooling water remain available to prevent damage to the fuel.

Source: A. Nero. Jr., *The Guidebook to Nuclear Reactors*, p. 54


A. Q. Khan | The Merchant of Menace
Email this to a friend
Abdul Qadeer Khan stole nuclear designs from the Netherlands, helped Pakistan build a bomb and then created a vast network that traded nuclear secrets and illicit technology across several continents
NETHERLANDS
GERMANY
BRITAIN
SWITZERLAND
ITALY
SPAIN
TURKEY
SYRIA
IRAN
AFGHANISTAN
KAZAKHSTAN
CHINA
NORTH KOREA
MOROCCO
LIBYA
EGYPT
SAUDI ARABIA
U.A.E.
PAKISTAN
NIGER
SUDAN
NIGERIA
MALAYSIA
SINGAPORE
SOUTH AFRICA
KHAN'S DANGERGOUS GAME
Pakistan, Khan's home, where he developed its nuclear-weapons program, then peddled the information and technology
Countries that sought and received Khan's assistance in developing their nuclear-weapons programs
Countries where Khan's network operated
Countries Khan visited for reasons that remain a mystery

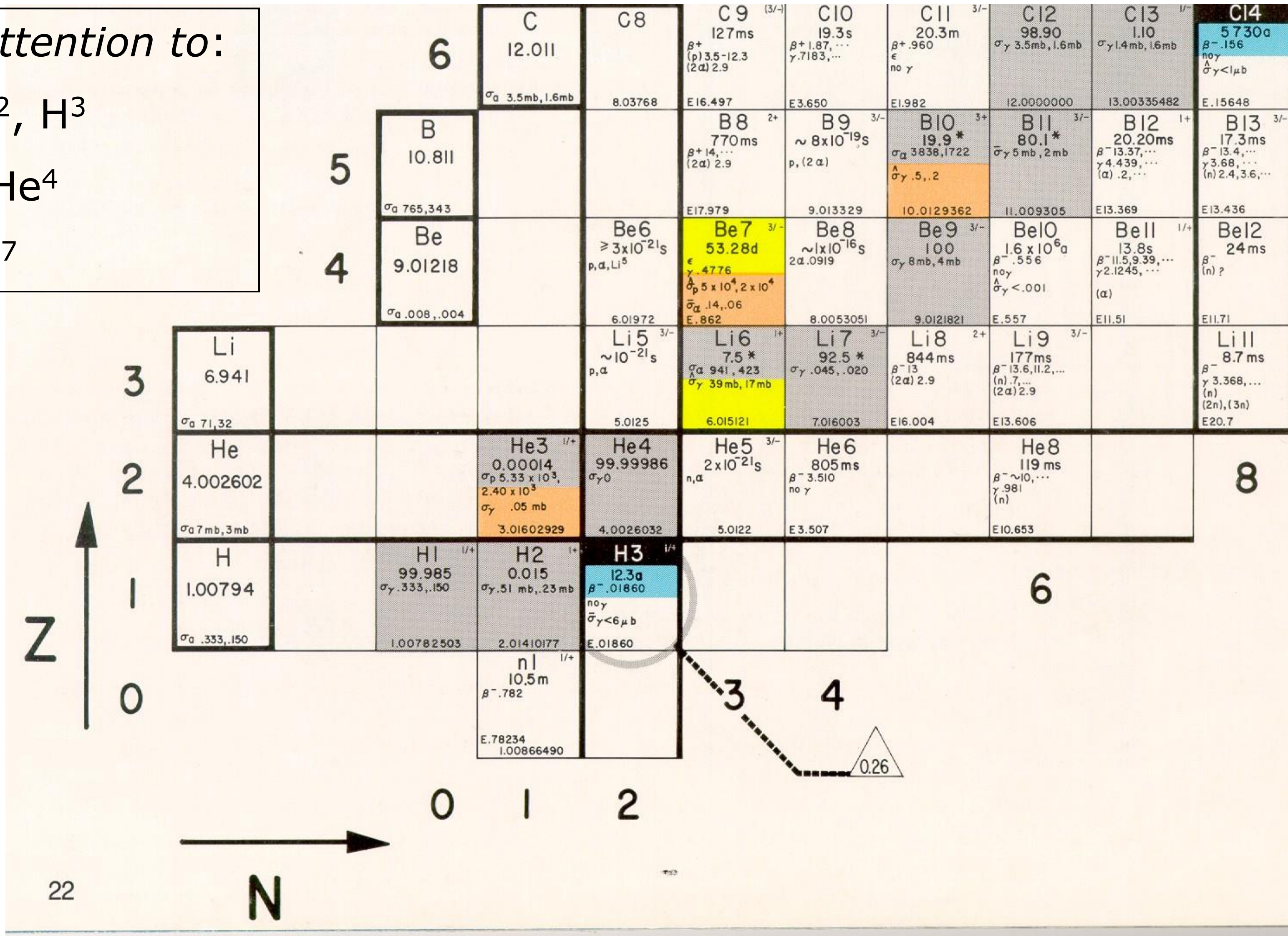
The lightest nuclides

Pay attention to:

H^1, H^2, H^3

He^3, He^4

Li^6, Li^7



Nuclear fusion reactions

I. Deuterium-deuterium (D-D) reaction

D + D → He^3 + n, 50%

→ **T + p**, 50%

Note: T (tritium) is H^3, unstable. Half-life is 12 years.

II. Deuterium-tritium (D-T) reaction.

D + T → He^4 + n.

D-D advantage: D is abundant, T must be manufactured.
D-T advantage: fusion is easier to achieve.

D+T is first-generation fusion. A "lithium blanket" will regenerate T via **Li^6 + n → He^4 + T**.

Li^6 abundance: 7.5%.

Schematic design of a D-T reactor

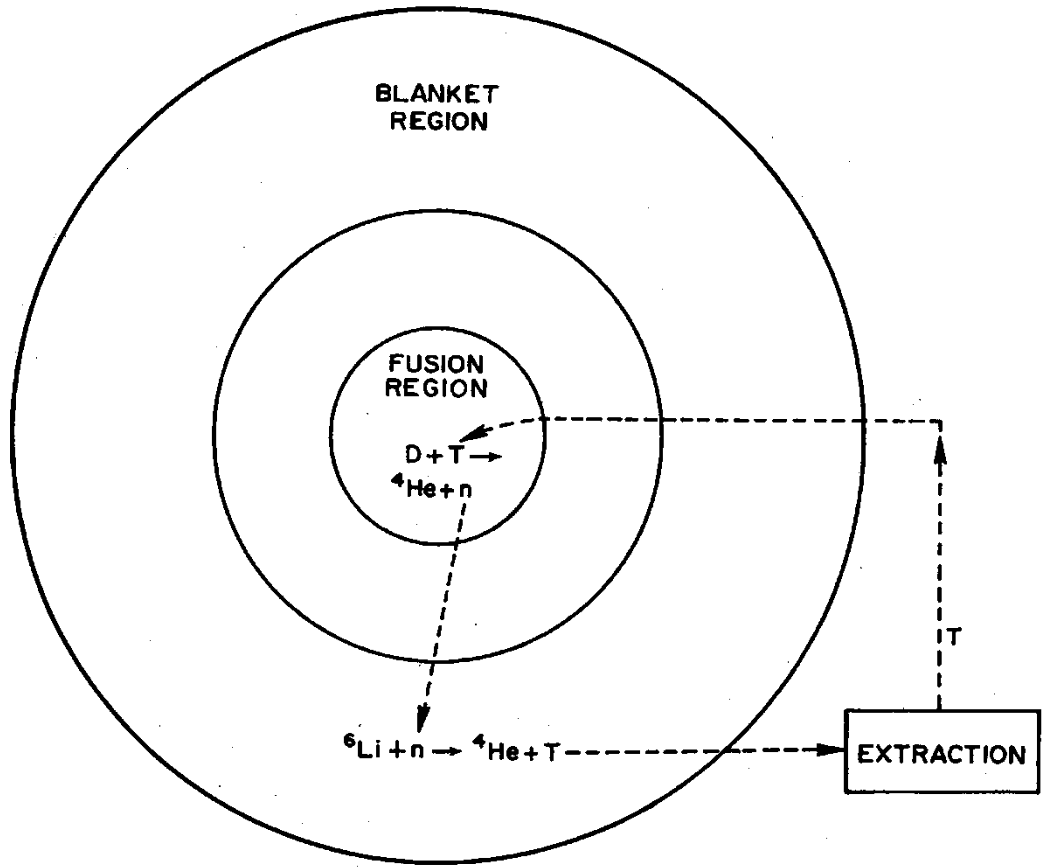


Figure 15-1. SCHEMATIC FUSION REACTOR.
In the fusion region, deuterium and tritium react, producing energetic neutrons. These are stopped in a surrounding blanket. The neutrons react with ^{6}Li to produce tritium for supplying the fusion region; energy is deposited in the blanket, from which heat is removed by a gas or liquid coolant.

A. Nero. Jr., *The Guidebook to Nuclear Reactors*, p. 236

Fusion power requires confinement

Two approaches: Magnetic confinement and inertial confinement.

In *magnetic confinement* a “magnetic bottle” confines a gas of ionized D and T (overall, charge-neutral). The product of confinement time, temperature, and density is the “figure of merit.” High temperature is key to overcoming the electrostatic repulsion between pairs of nuclei. Magnetic confinement improves with reactor size; this has meant large, expensive experiments.

In *inertial confinement* a beam of photons (via a laser) or ions smashes into and heats a “pellet” of D-D or D-T. Large amounts of external energy are required. The coupling to H-bomb design has kept this field partially classified.

Electricity from fusion: When?

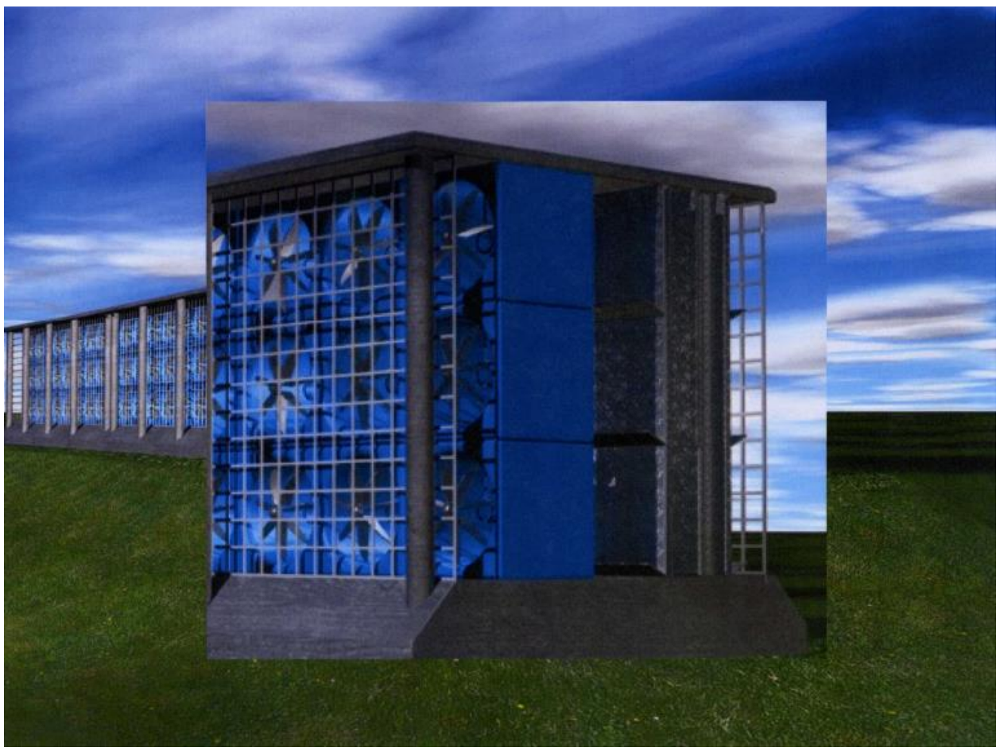
xx

Fusion summary

- Fusion of light nuclides is another route to nuclear energy.
- Fusion promises energy for the very long future. It is difficult, but potentially globally significant.
- Magnetic confinement (via plasmas) and inertial confinement (beam compression of pellets) are two distinct approaches currently being explored via large and very expensive projects. “
- Arguably, fusion power, is better than fission power from the perspectives of safety and waste management.
- Combining fusion power and fission power may have advantages.

Geoengineering: two very different activities

Carbon Dioxide Removal (CDR) from air
Here: air contacting a chemical sorbent. Also, via biology (variants of growing a tree).



Source: David Keith, MIT talk, Sept. 16, 2008

Solar radiation management (SRM)
Here: injection of reflecting particles into the stratosphere

The Case for Carbon Dioxide Removal (CDR)

CDR can counter recalcitrant *decentralized* CO_2 emissions, such as emissions from buildings and vehicles, that prove expensive to reduce by other means.

CDR might someday enable the world to lower the atmospheric CO_2 concentration gradually.

Vocabulary:

Overshoot trajectories (concentrations rise, then fall)
Net negative emissions
Negative emissions
CO_2 removal (CDR) strategies

CO_2 removal (CDR) strategies are all doubtful at scale

Direct air capture (DAC) by chemicals: Capture costs exceed the already high costs of capture from flue gas. Requires socially acceptable large-scale CO_2 storage.

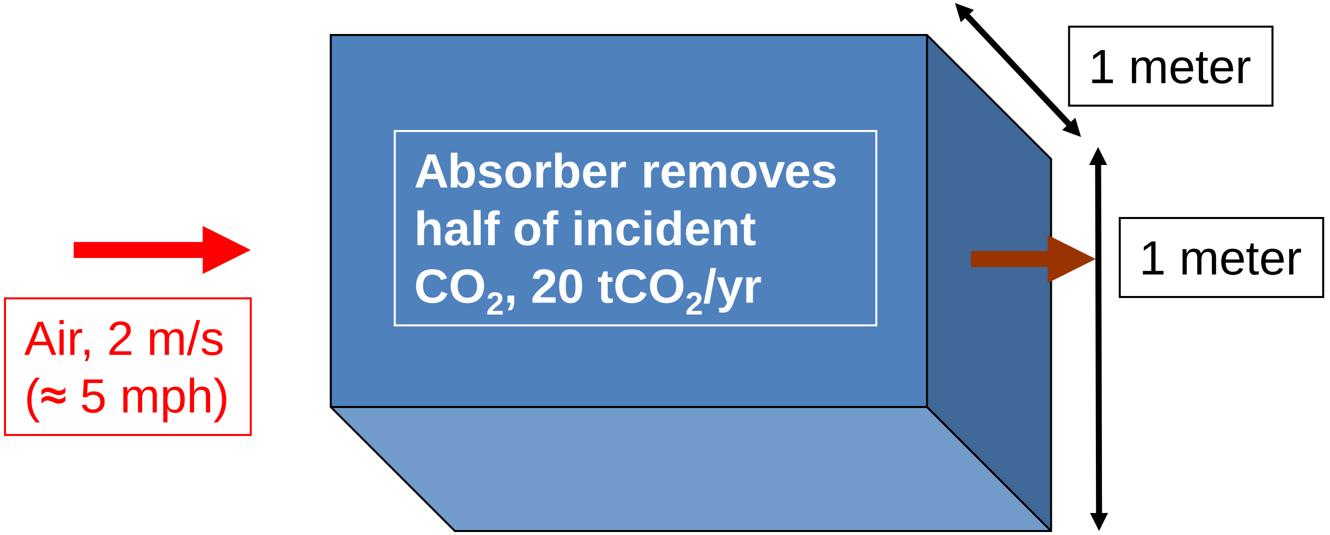
Biopower/biofuels with CCS: Formidable land competition. Requires socially acceptable large-scale CO_2 storage.

Bio-stock augmentation in forests and soils: Even more formidable land competition. Possible restoration benefit.

Ocean fertilization: Not yet established in principle. Attracting rogue behavior.

Enhanced rock weathering: Not yet established in principle.

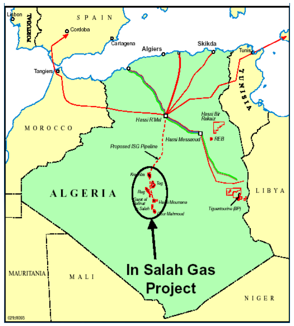
Using DAC to compensate for the average American's emissions requires a contactor with the area of a window



Ambient air flows over a chemical sorbent that selectively removes the CO_2. The CO_2 is then released as a concentrated stream for disposal or reuse, while the sorbent is regenerated and the CO_2-depleted air is returned to the atmosphere.

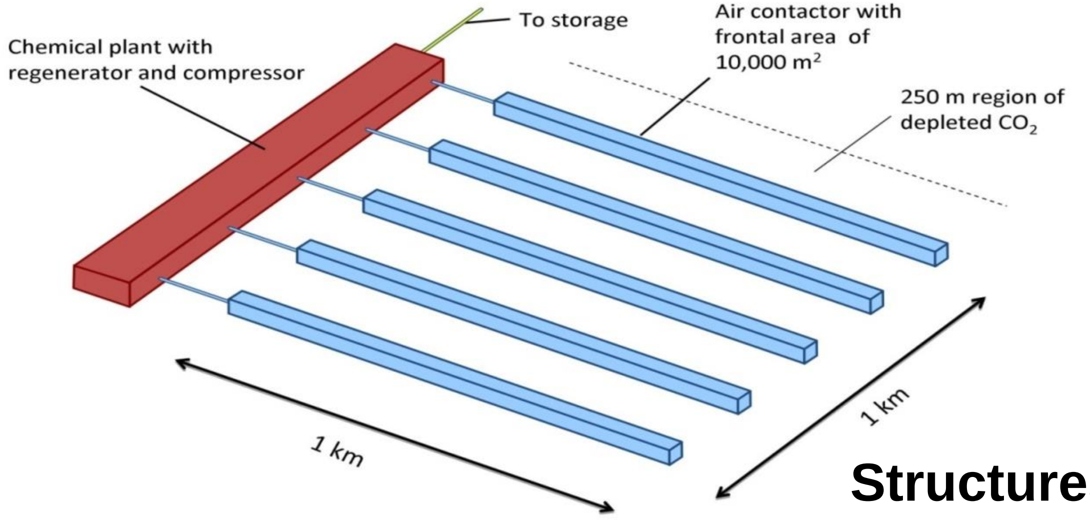
CO_2 sorption and desorption

At In Salah, Algeria, natural gas purification by CO_2 removal plus CO_2 pressurization for nearby injection



Separation at amine contactor towers

Scale for DAC



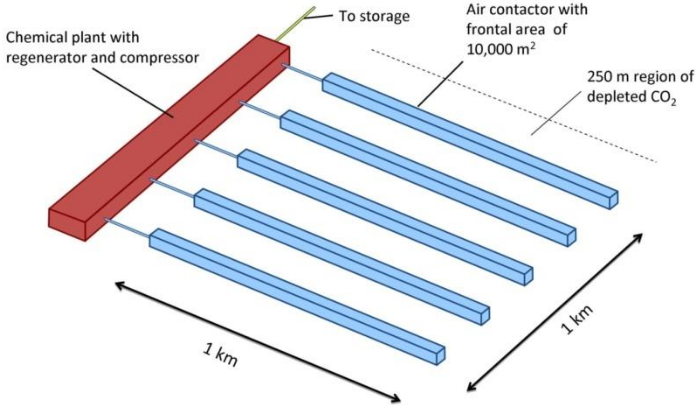
Structures are 10-m high

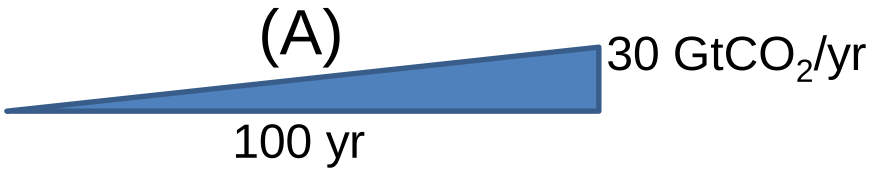
A 1 MtCO_2/yr system (50% capture, 2 m/s air velocity)

Six of these compensate for a 1 GW coal plant. All 30 structures end-to-end make a 30-km Great Wall.

Research frontier: Is 250 meter spacing adequate? The downstream intake must not entrain depleted air.

Remove 100 ppm over 100 years





Add 300 facilities per year for 100 years. Final footprint (30,000 facilities @1.5 km^2 each): 45,000 km^2 (less than area of Nova Scotia).

Biological competitors:

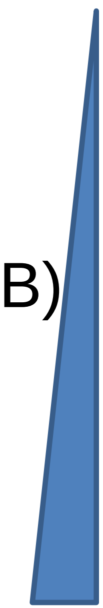
1) *Afforestation*: Not enough land.
2) *Biological energy with capture and storage (BECS)*: land area is hundreds of times larger than for DAC.

CDR: not matched to emergencies

Lower the CO_2 concentration by **100 ppm** (capture **1500 $GtCO_2$**):

A. Over 100 years (e.g., 2050-2150)
B. Over 10 years (e/g., 2050-2060)

1 ppm/yr: plausible build-rate?



10 ppm/yr:
crisis response

"Pace" (slope, rate of increase in removal capability):
(A) 0.30 $GtCO_2/yr^2$; (B) 30 $GtCO_2/yr^2$ (100 times larger).

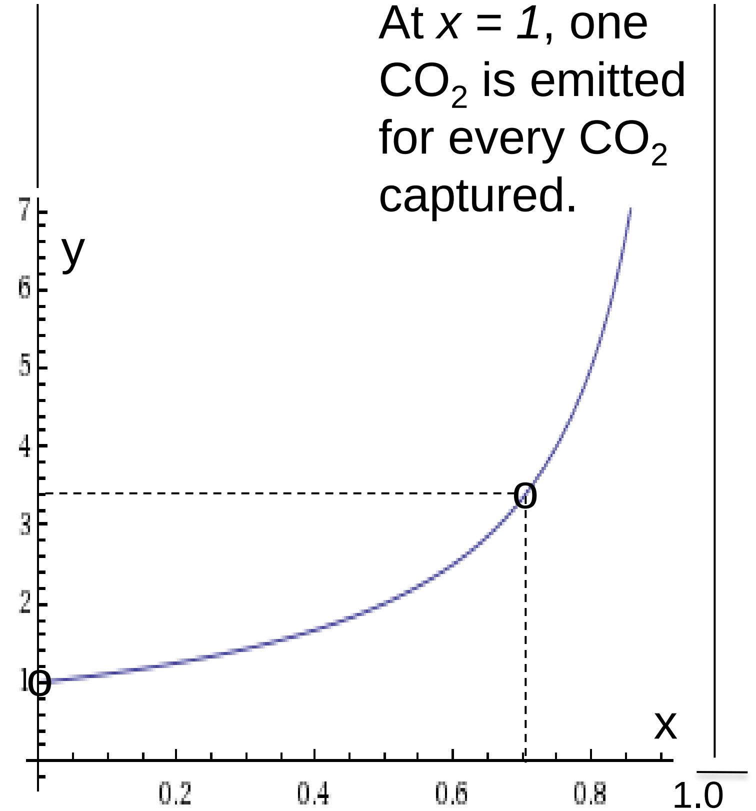
The pace in (B) is far too fast for CDR. It is equivalent to canceling the entire global fossil-fuel system in one year.

"Net-carbon" raises CDR cost $/(tCO$_2$ no longer in the atmosphere)

The cost-multiplier, *y*, is the ratio of avoided cost to capture cost:

$$y = 1/(1 - x),$$

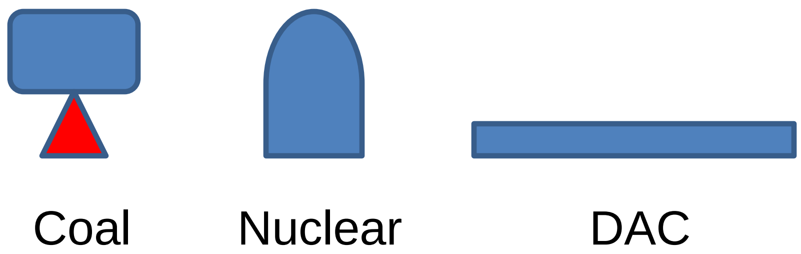
where *x* is the amount of CO_2 emitted per CO_2 captured.



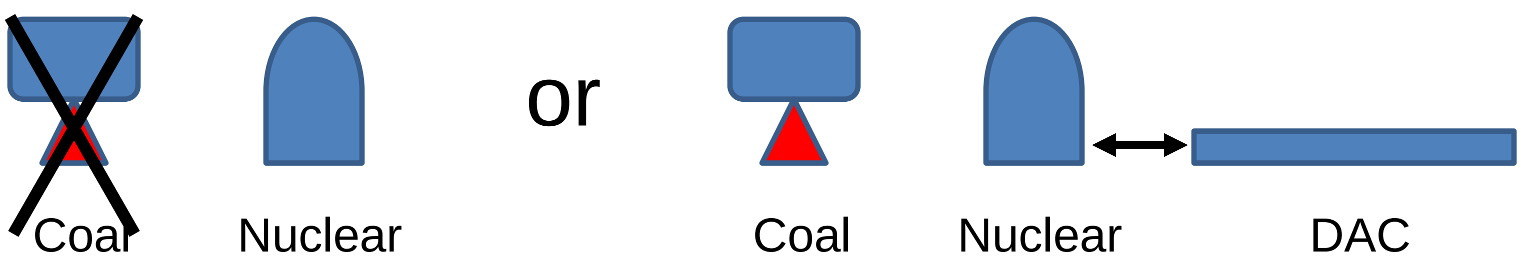
x = CO_2 emitted per CO_2 removed

Example: the APS benchmark system has $x = 0.3$. Grid power runs the fans and compressor, but regeneration heat is provided by natural gas with CCS. Without CCS, $x = 0.7$.

As long as there are high-carbon sources of power and heat, any low-carbon sources should back these out, not run DAC

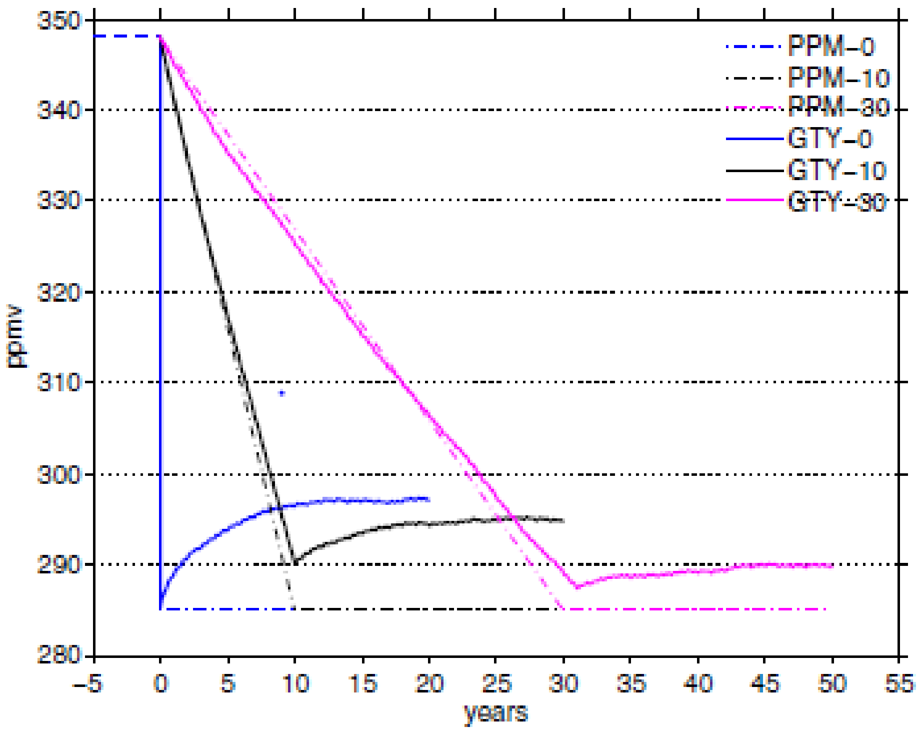


Baseline: A coal plant is running, and a nuclear plant is being built. Which use of the nuclear plant is best for the climate?



Here, “nuclear” is a place-holder for any low-C baseload energy source, e.g., geothermal energy, hydropower, and fossil energy with CCS.

Negative feedbacks for CDR



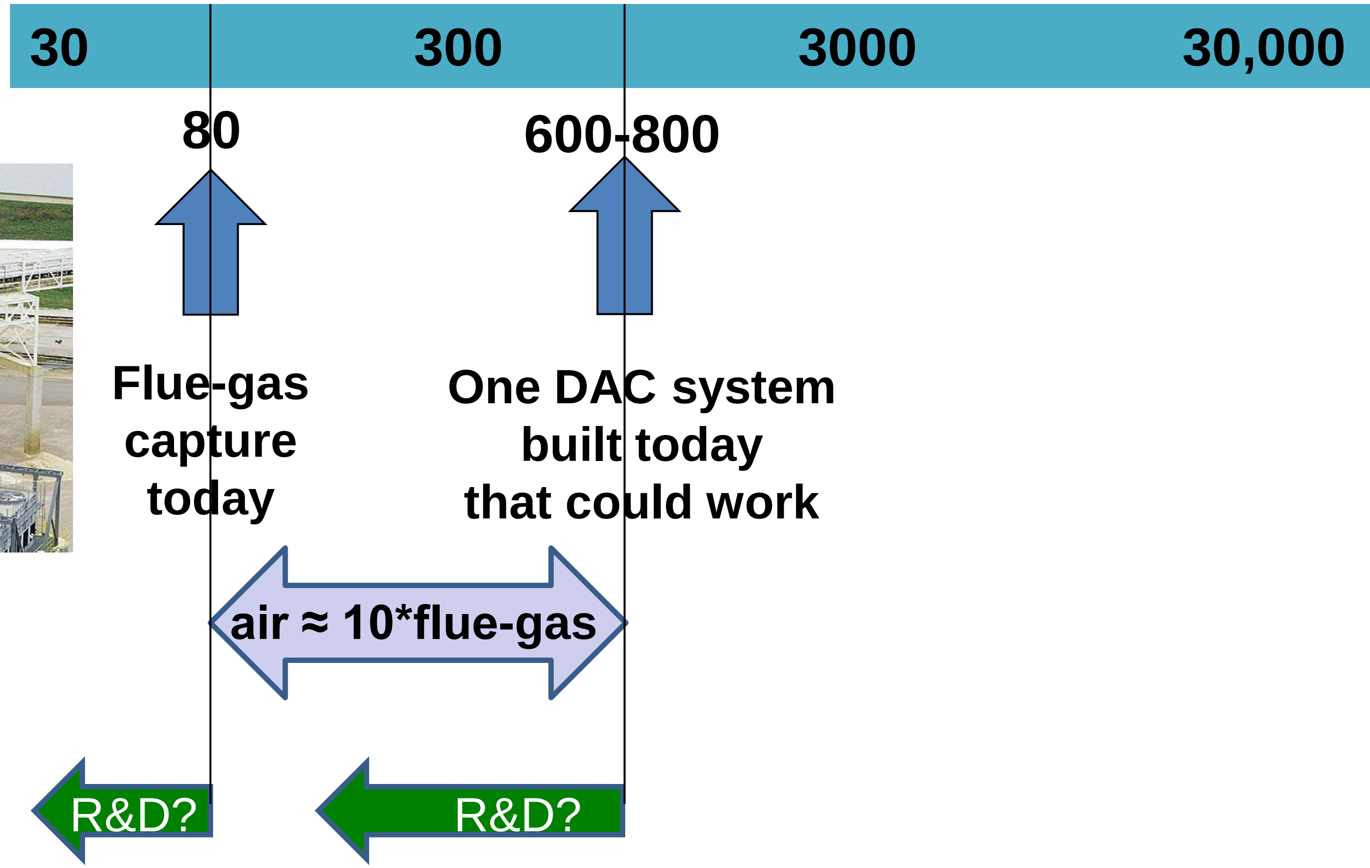
M. Vichi, A. Navarra, P.G. Fogli. 2013."Adjustment of the natural carbon cycle to negative emission rates." *Climatic Change*. http://rd.springer.com/article/10.1007/s10584-012-0677-0

Above: Six scenarios where ocean outgassing accompanies CDR. Expect land feedbacks too (carbon defertilization).

"Takeback": Conservatively, to reduce the mass of CO_2 in the atmosphere by one ton, one must remove ≈2 tons.

Cost domains, in \$/tonCO_2

Mountaineer
AEP, WV



It will almost surely be much cheaper to capture CO_2 from the flue gas of a coal power plant than from ambient air, where it is 300 times more dilute. At a natural gas plant, x100.

Increment from Adding \$600/tCO_2 to Fuel and Power Prices

Natural gas	**\$33/1000scf**
Crude oil	**\$260/barrel**
Coal	**\$1400/U.S. ton**
Gasoline	**\$5.20/gallon**
Electricity from coal	**48¢/kWh**
Electricity from nat. gas	**21¢/kWh**

"Indirect" CO_2 emissions associated with production, transport or transmission, and distribution are not included.

Immense land requirements for Bio-CDR

The bio-CDR strategies, and indeed all versions of bio-mitigation, make immense demands on land.

Side calculation *(see Smith & Torn)*: Land for afforestation to reduce atmospheric CO_2 concentration by 1 ppm/yr (for 50 years). Assume:

10 t biomass/ha-yr (for 50 years), 0.5 tC/t biomass, so **5 tC/ha-yr**

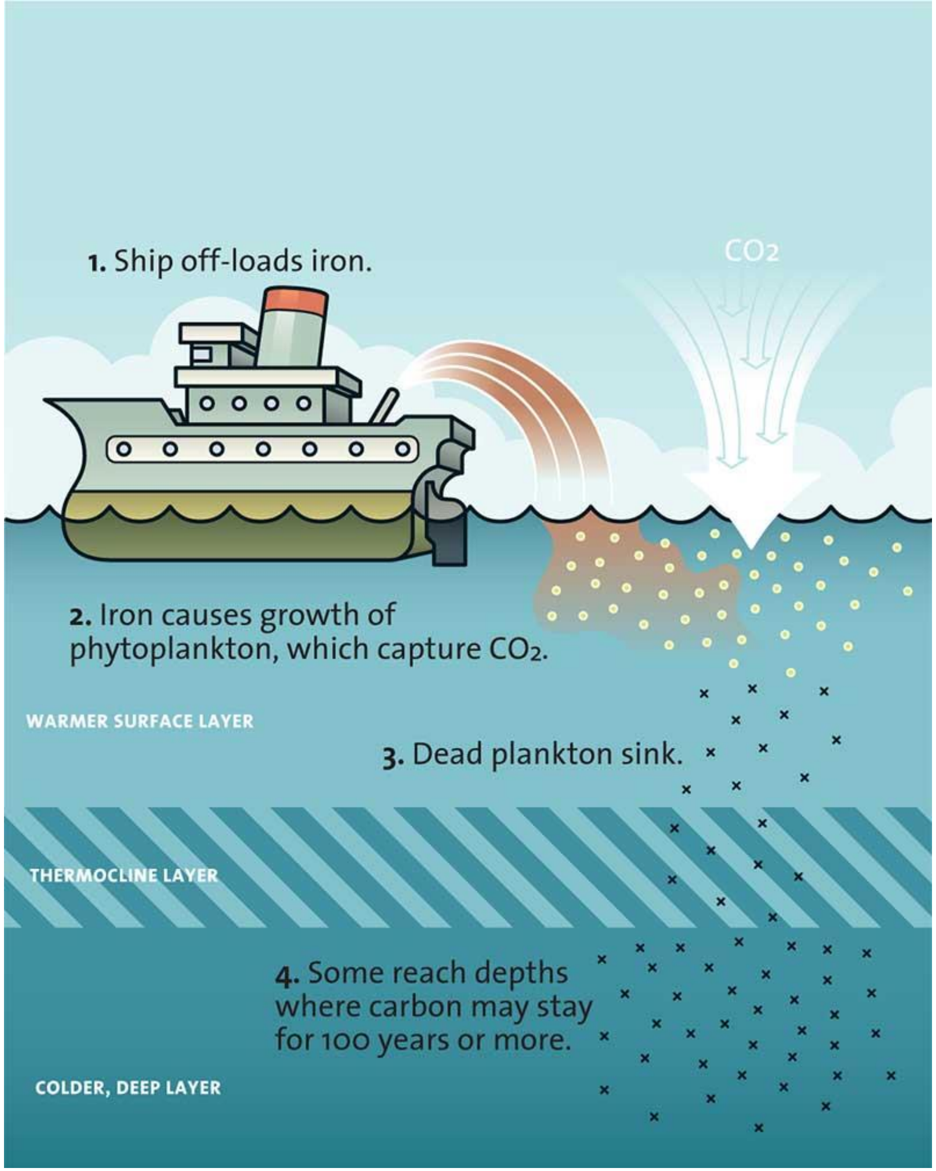
1 ppm = 2 GtC, so must remove **4 GtC/yr** if ocean and land feedback is 50%.

Result: **800 Mha**. (US area: 1000 Mha)

Similar answer for BECCS: Twice the yield (20 t biomass/ha-yr, indefinitely) but, net, only 50% of captured carbon is sequestered.

Compare to 1.5 Mha for DAC (15,000 of the 1 km x 1 km facilities in the earlier slide), neglecting net-carbon issues and land for storage.

Ocean iron fertilization



From Geeta Persad, Oct. 16, 2012

From IPCC AR4:

- Phytoplankton must sink below thermocline layer to sequester CO_2. This is ~10% efficient.

- Could increase methane and nitrous oxide, both GHGs.

- Could cause oxygen depletion, toxic plankton blooms, changes further up food chain.

- Extremely difficult to measure if net effect is actually CO_2 removal.

From 2009 Royal Society Report:

Effectiveness	Low
Affordability	Medium
Timeliness	Low/ Very low
Safety	Very low

California businessman, Russ George, dumps 100 metric tons of iron sulfate off the coast of British Columbia, Canada in order to “enhance salmon stocks” and generate carbon credits.

From Geeta Persad, Oct. 16, 2012

Message about CDR: First things first

Accordingly, aggressive deployment of CDR makes little sense until the world has largely eliminated *centralized and concentrated* sources of CO_2 emissions, especially at coal and natural gas power plants:

- by efficiency gains that make the plants unnecessary
- by substitution of non-fossil alternatives
- by capture of nearly all of the plants' CO_2 emissions.

Solar Radiation Management

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

The Earth's average surface temperature was 0.5^{o}C cooler six months later, then rebounded.

Long-term global cooling can probably be produced by creating the equivalent of a perpetual volcano. Paul Crutzen (in a seminal paper) estimated that maintaining ≈5 MtS in the stratosphere as sulfate aerosols, indefinitely, would cancel the warming due to CO_2 doubling.

Many ways to enhance albedo

Reflection can be enhanced:

- At the surface on land (white roofs)
- At the surface in the ocean (preserve and enhance floating ice)
- In the troposphere (cloud whitening by injecting jets of water vapor)
- In the stratosphere (aerosol injection)
- In outer space (solar shields)

The case for Solar Radiation Management (SRM): What if the current technocratic response is insufficient?

The unfolding technological response to climate change may turn out to be insufficient for two very different reasons:

1. The world cannot implement the necessary changes.
    A. Inertia and habit
    B. Vested interests – incumbent political power
    C. Shortcomings of the available “solutions”

2. The world *does* implement the necessary changes, but low-probability nasty outcomes arrive anyway.

Monsters behind the door

Steve Pacala calls the worst credible climate outcomes "monsters behind the door." The monsters include:

a five-meter rise in sea level by the end of this century

major alterations of the global hydrological cycle

major changes in forest cover

major emissions of greenhouse gases from the tundra.

The monsters open their door in a world of very strong positive feedbacks, a world that spirals out of control.

Today's science cannot predict how much atmospheric change would let these monsters in, nor how quickly they could enter.

Response to an emergency

We may someday need "fast geoengineering," matched to the sudden onset of a crisis. The injection acts quickly.

The analogy here is to the use of epinephrine to treat an acute allergic reaction. It is considered irresponsible for a doctor not to have epinephrine in his or her medicine cabinet.

But geoengineering today is "comparable with 19th century medicine." (James Lovelock).

We need to think hard about how an "emergency" will be identified and how interventions will be implemented.

Novim study group: Steve Koonin (head), David Battisti, Jason Blackstock, Ken Caldeira, Doug Eardley, Jonathan Katz, David Keith, Ari Patrino, Dan Schrag, Robert Socolow.

Acute vs. chronic use

Acute: Hold in reserve for an emergency.

Chronic: Compensate for some fraction of warming, starting soon.

Compensatory S injection: Environmental impact

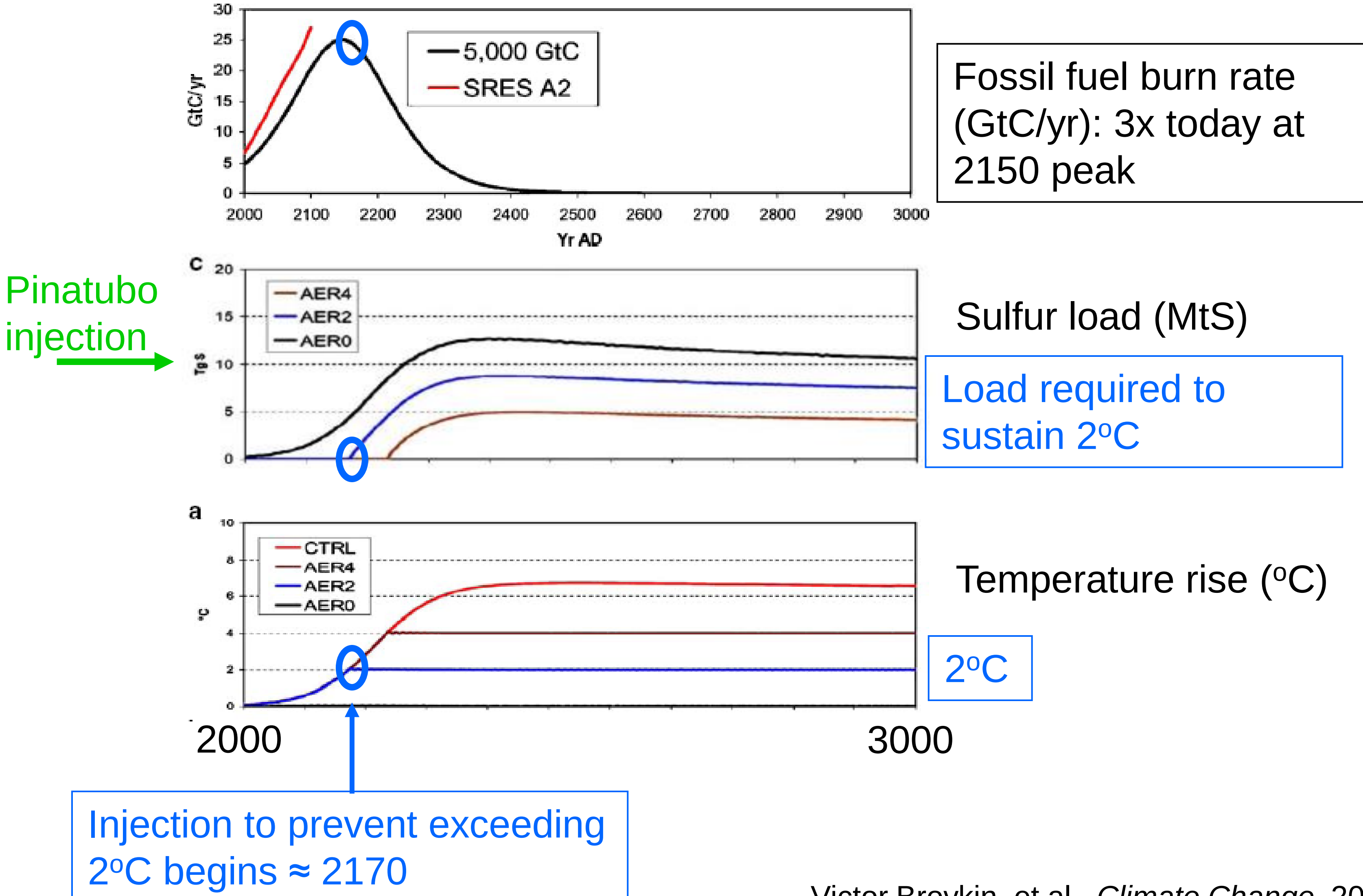
Imperfect cancelation: Even if some desired average surface temperature is achieved exactly, regional precipitation and atmospheric and oceanic circulation may change.

Stratospheric ozone: Adding particles to the stratosphere appears to lead to reduced levels of stratospheric ozone. *Try other chemicals?*

Ocean acidification : Particle injection has no effect.

Acid precipitation: Sulfur emissions from S injection are small relative to emissions from coal power plants and smelters: a 10 MtS/yr increment on 50 MtS/yr.

Compensatory sulfur injection



Victor Brovkin, et al., *Climate Change*, 2008

Rapid disengagement

Rapid disengagement from S-injection might be

a. deliberate: An adverse regional or global side-effect is discovered.

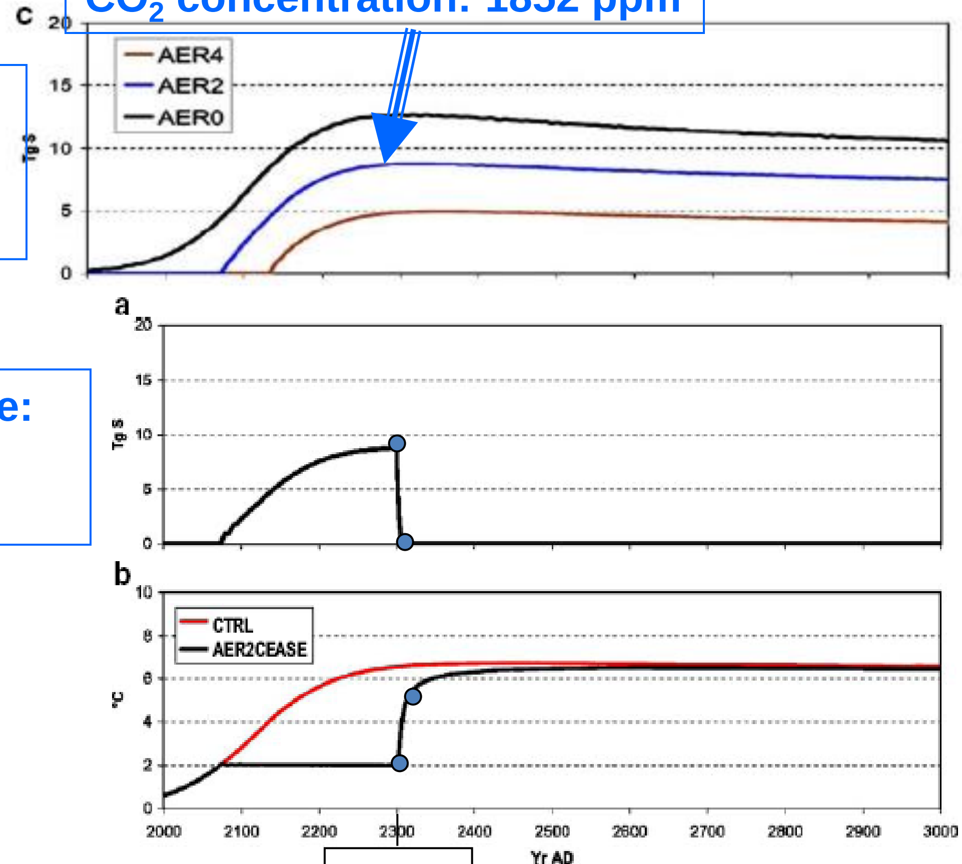
b. unintentional: Loss of capability (e.g., global economic crisis); conflict over who pays to keep the system running (e.g., because local benefits and local harms are reevaluated).

The Sword of Damocles (1)

CO_2 concentration: 1852 ppm

Sulfur injection succeeds in sustaining 2°C

Whoops: System failure: S loading plummets to zero in 2300



Amount of sulfur

Temperature change

2300

Victor Brovkin, et al., *Climate Change*, 2008

The Sword of Damocles (2)

As a consequence of this interruption of injection, "within a few decades, winter warming in the polar regions exceeds 10^{o}C and summer warming in the northern temperate latitudes will be about 6^{o}C."

"Coming generations will have to live with the danger of this 'Sword of Damocles' scenario, the abruptness of which has no precedent in the geologic history of climate."

Victor Brovkin, et al., *Climate Change*, 2008

Watermelon greens

Political conservatives sometimes call environmentalists "watermelon greens": green on the outside, "red" on the inside. One conservative observes that environmentalists generally reject geoengineering. He asserts that this rejection is because geoengineering "does not result in reduction of human appetites for natural resources."* He, like many other conservatives, likes geoengineering.

Question: *Why* do conservatives like geoengineering?

**Source*: based on David Schnare, Thomas Jefferson Institute; A Presentation at the Research Triangle Institute, International. November 18, 2008.

How strongly will SRM be resisted?

There is a widespread assumption that as the public becomes more alarmed, it will acquiesce in CO_2 capture and storage, nuclear power, and geoengineering, probably in that order.

But will rejection dominate? Rejection stems from:

belief in Murphy's Law

unwillingness to cede authority to experts

religious outrage at the prospect of unconstrained human self-determination.

SRM research: at what scale?

Is there a scale large enough so that research can tell us what we need to know but small enough not to trigger the hazards we must avoid?

The testing of therapeutic drugs confronts this question too.

Do we already have sufficient safeguards to embed small-scale SRM research in normal science? How small is “small”?

Can large-scale “research” be forbidden by international agreement?

CDR and SRM

CDR and SRM are very different.

CDR: Slow (think -1 ppm/yr), planetary only, low risk, few deep issues

SRM: Fast, allows regional targets (e.g., arctic), high risk, high leverage, fundamentally new

A global thermostat

“Global Thermostat” (Eisenberger): Tune the CO_2 concentration (and, thereby, the surface temperature) by air capture.

> Drive the concentration as low as desired, e.g., below pre-industrial.
>
> Drive the concentration as high as desired, by storing CO_2 retrievably (parking it) – e.g., to prevent an ice age.

Can the world conceivably negotiate a most desired temperature?

Earth enhancement

If we succeed in developing geoengineering for insurance, it will allow us to enhance the planet.

The analogy is genetic engineering, valuable for the treatment of many diseases, and also providing a capability to enhance the human species.

What will be enhanced?

Genetic engineering now allows enhancement of the human species (prettier, taller, smarter,…)

Geoengineering will allow *enhancement* of the planet – notably, the moderation of extreme events:

warmer winters where people want them
cooler summers where people want them
less severe storms and droughts

sweet spots

An important distinction is that enhancement decisions for genetic engineering can be made by individuals (e.g., parents), with a collective outcome, while geoengineering needs collective decisions.

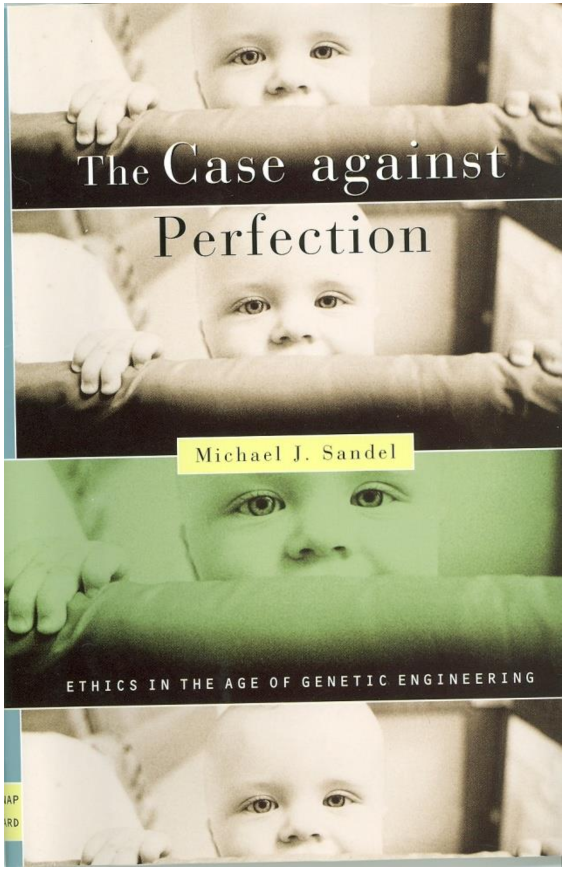
Enhancement is problematic

Analogies to medicine:

Michael Sandel sets up a dichotomy to explore modern medicine:

Cure or restore vs. enhance or perfect.

- Fertility and sex selection
- Eugenics
- Steroids and sports
- Cosmetic surgery
- Hyper-parenting



He argues that enhancement can be pursued to excess. He sees a loss of the ability to savor the life we have been “gifted.” He sees value in randomness, the “unbidden.” See Michael Sandel, T*he Case Against Perfection*.

He has not yet written about geoengineering.

The engineered earth

In a fully engineered world:

Every landscape is simplified

The well-being of every non-human species is subordinated

Instrumental values completely dominate.

Ahead are struggles over goals: levels of risk, inter-generational and intra-generational equity, responsibility for ecosystems and other species.

We will also struggle over processes: Who decides?

Key recommendation

Deliberate manipulation at a planetary scale raises profound issues.

The scrimmage line is *research*: slippery slope vs. mandate.

My principal recommendation: Geoengineering research should be embedded in normal science, not conducted separately.

- This will provide quality control and encourage dual-purpose research.
- It is essential to understand our planet more deeply. To create options to do geoengineering wisely is, for now, a subordinate reason for much stronger planetary science.

In order to know the truth,
it is necessary to imagine
a thousand falsehoods.

Sidney Coleman, ca. 1964, perhaps a quote from H.G. Wells

BREAK

Your “take-aways” from this course?

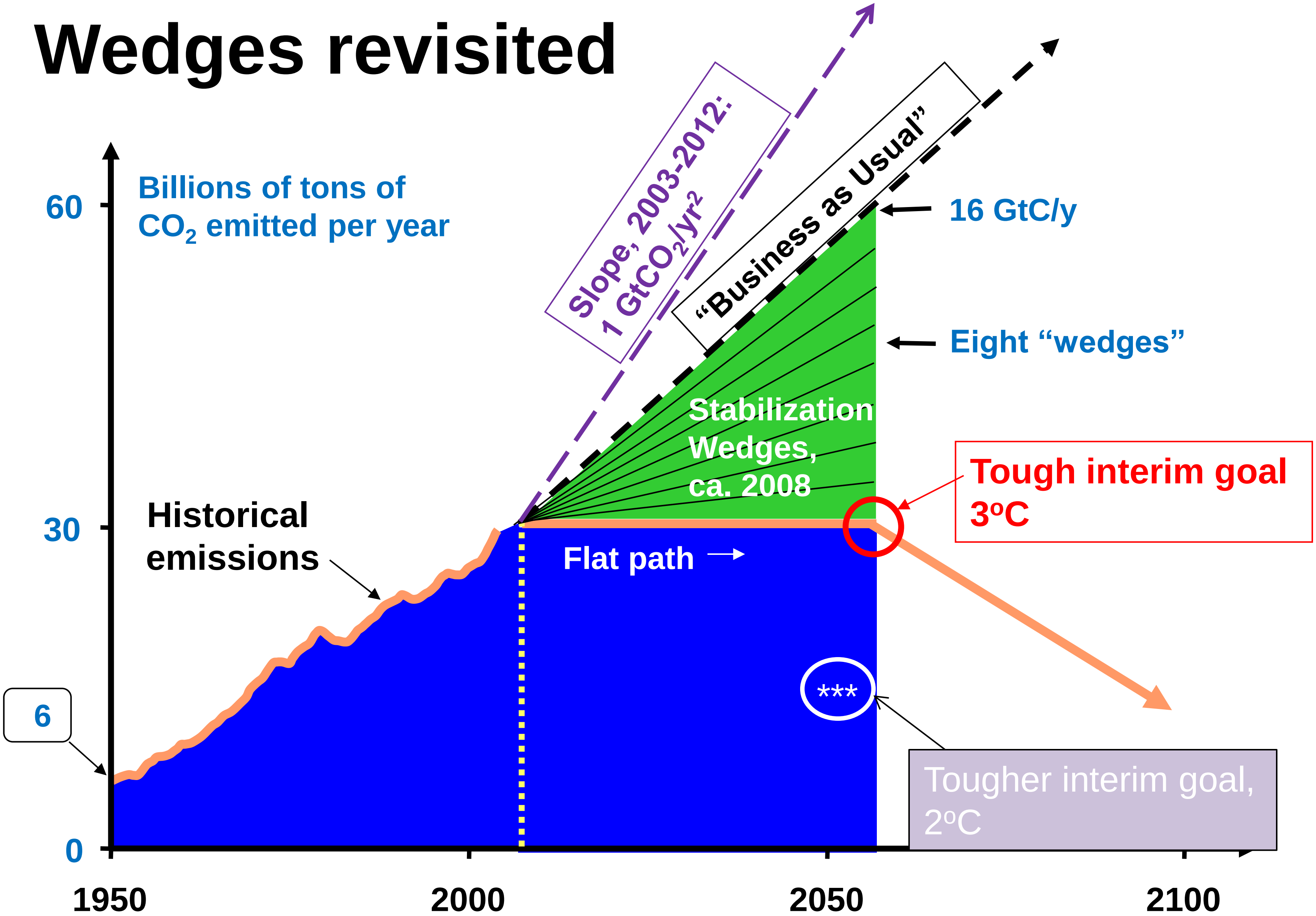
What would you tell a relative today about what you learned from this course?

What is a good example of something that has affected your thinking?

What about something that particularly surprised you or unsettled you?

Let me know.

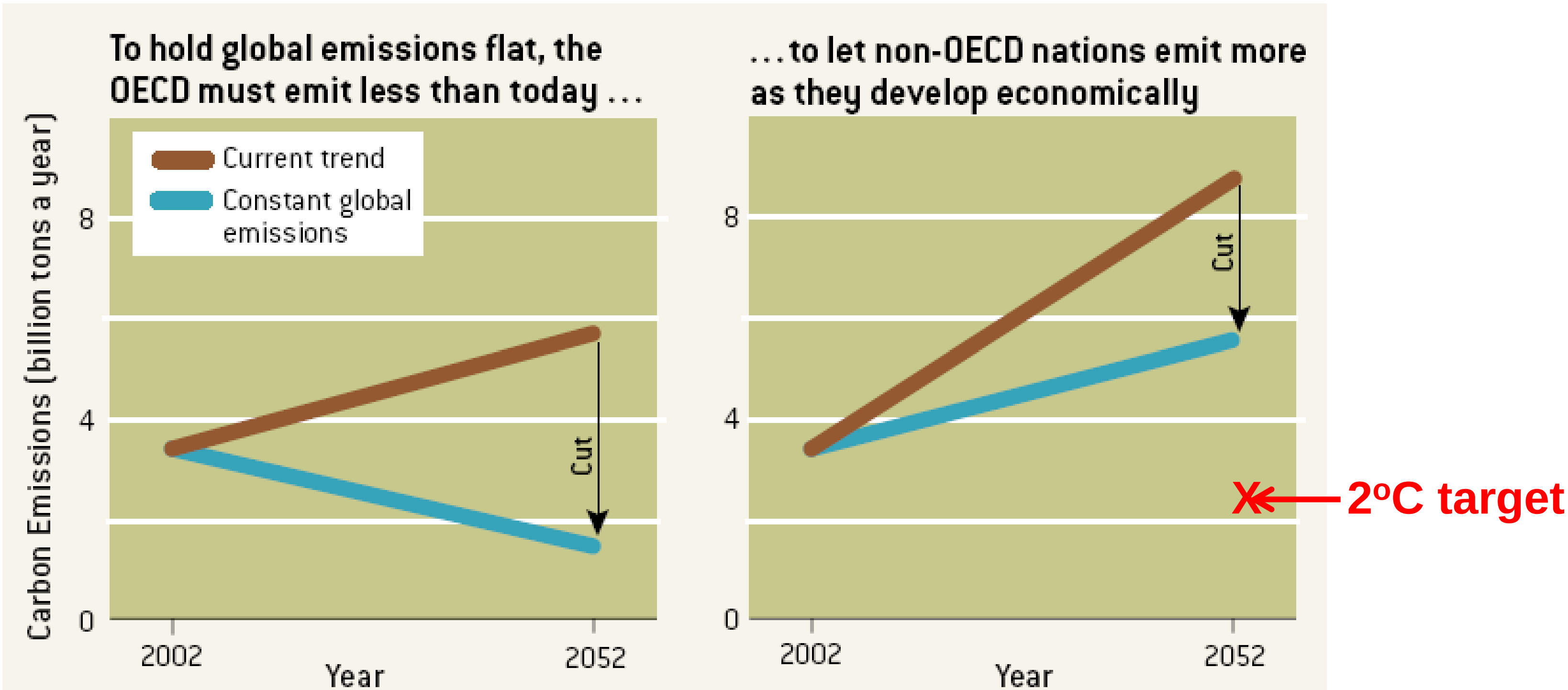
Wedges revisited



Four ways to emit 4 tons CO_2/yr (today's global per-capita average)

Activity	Amount producing 4 ton CO_2/yr emissions
a) Drive	15,000 miles/yr, 45 miles per gallon
b) Fly	15,000 miles/yr
c) Heat home	Natural gas, average house, average climate
d) Lights	300 kWh/month when all coal-power (600 kWh/month, natural-gas-power)

“Flat” vs. “down 50%” is about the developing world’s emissions



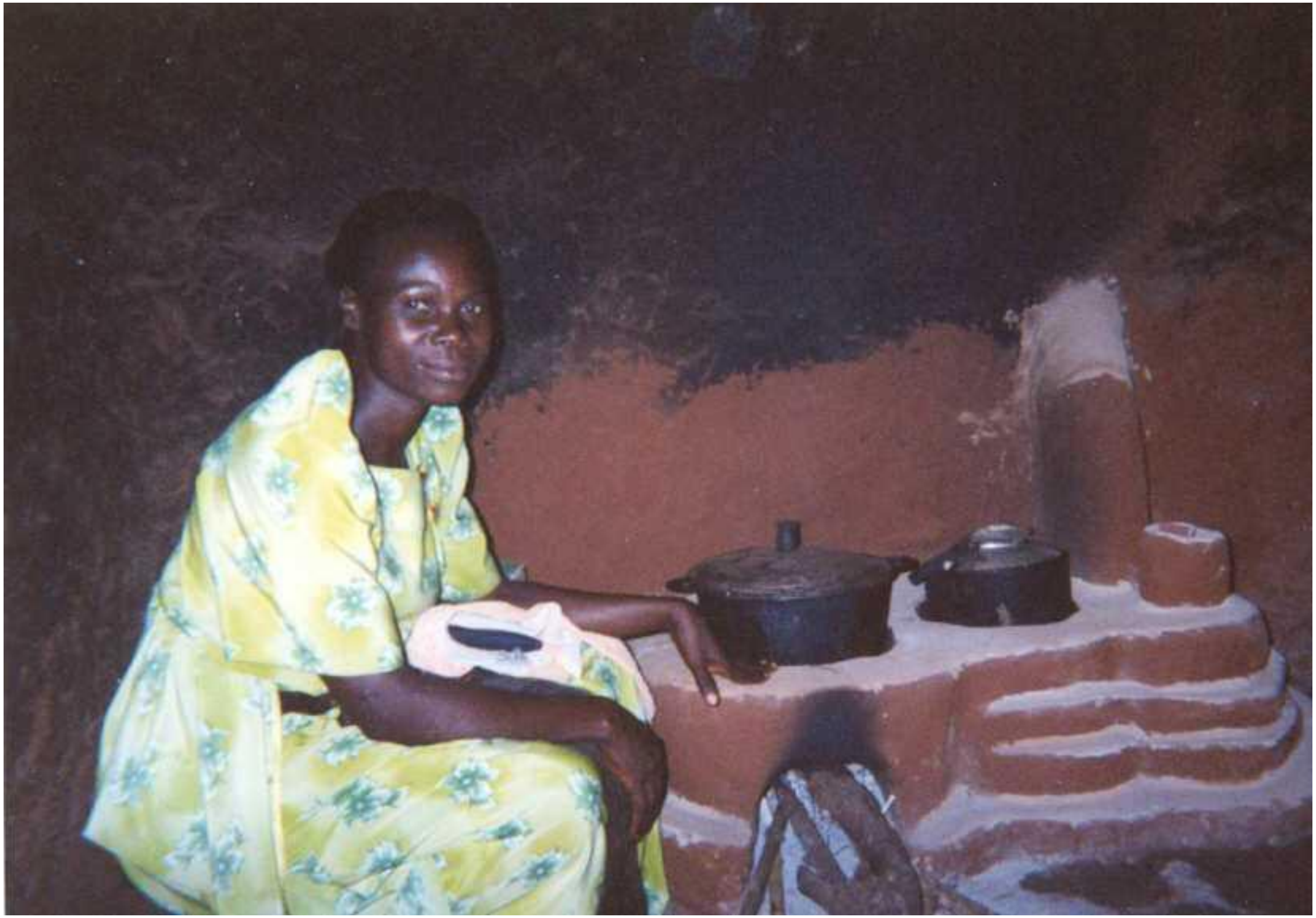
Up 60% or down 60%

Up 140% or up 60%, *or down 40%*

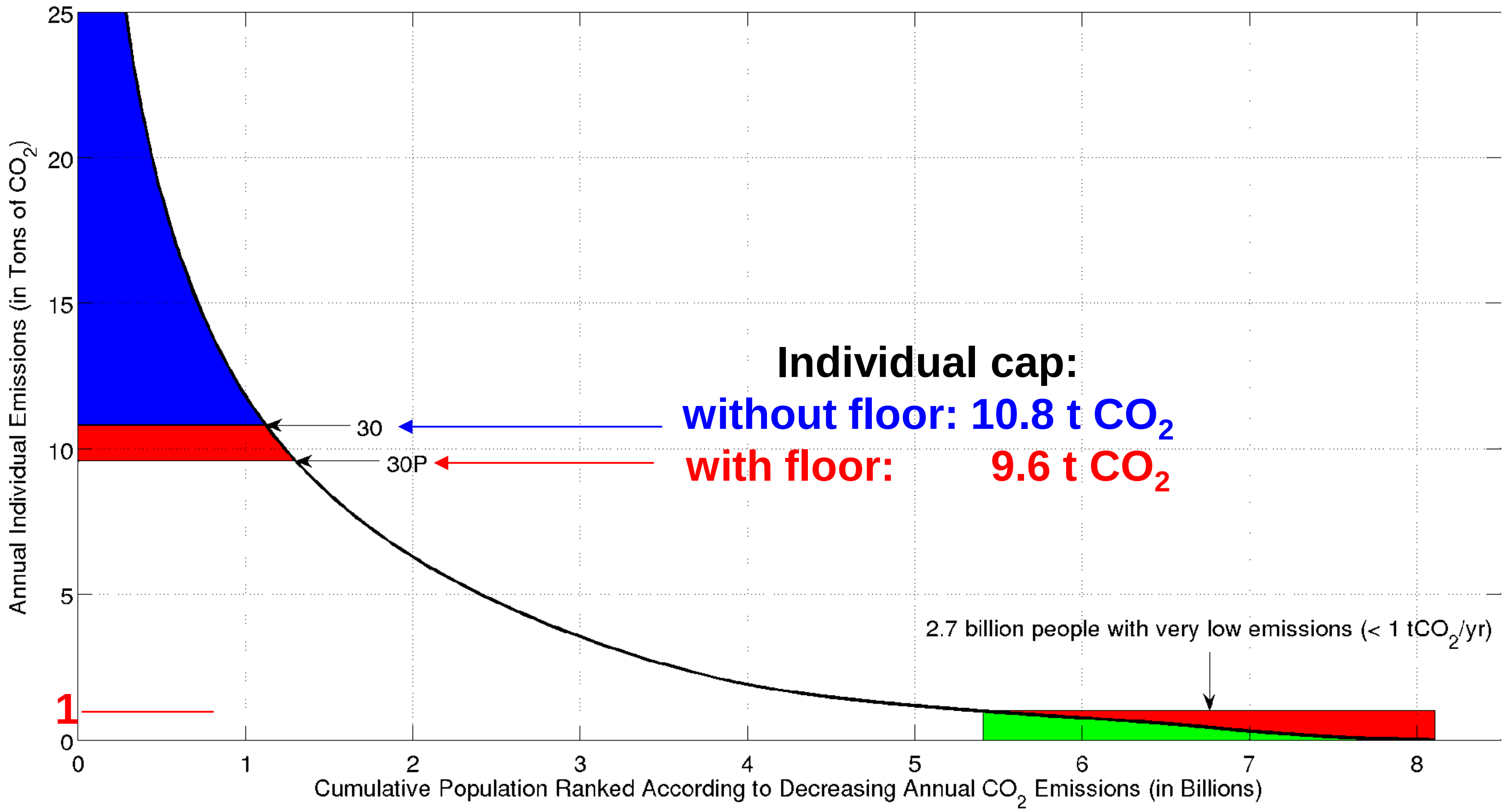
Analysis of low-carbon industrialization has been far too casual relative to its essential role in reaching a 2ºC target.

Source of Figure: Socolow and Pacala, “A plan to keep carbon in check,” *Scientific American*, Sept . 2006.

Sustainability and Health: Indoor Air Quality

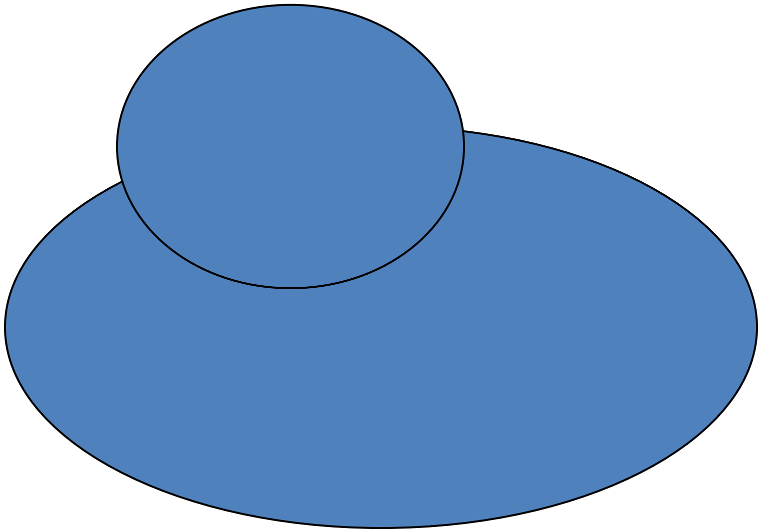


Combine a global-emissions cap and an individual-emissions floor

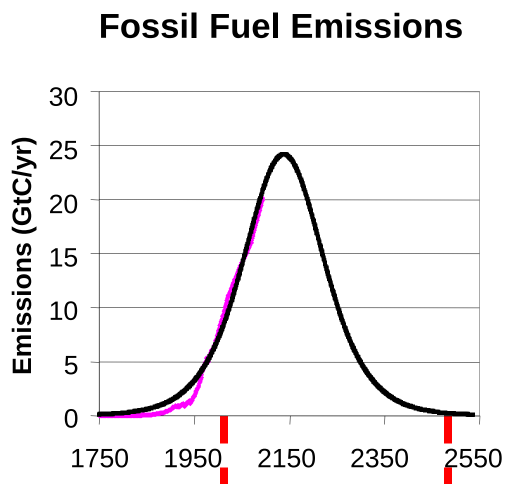


The world's poor do not need to be denied fossil fuels

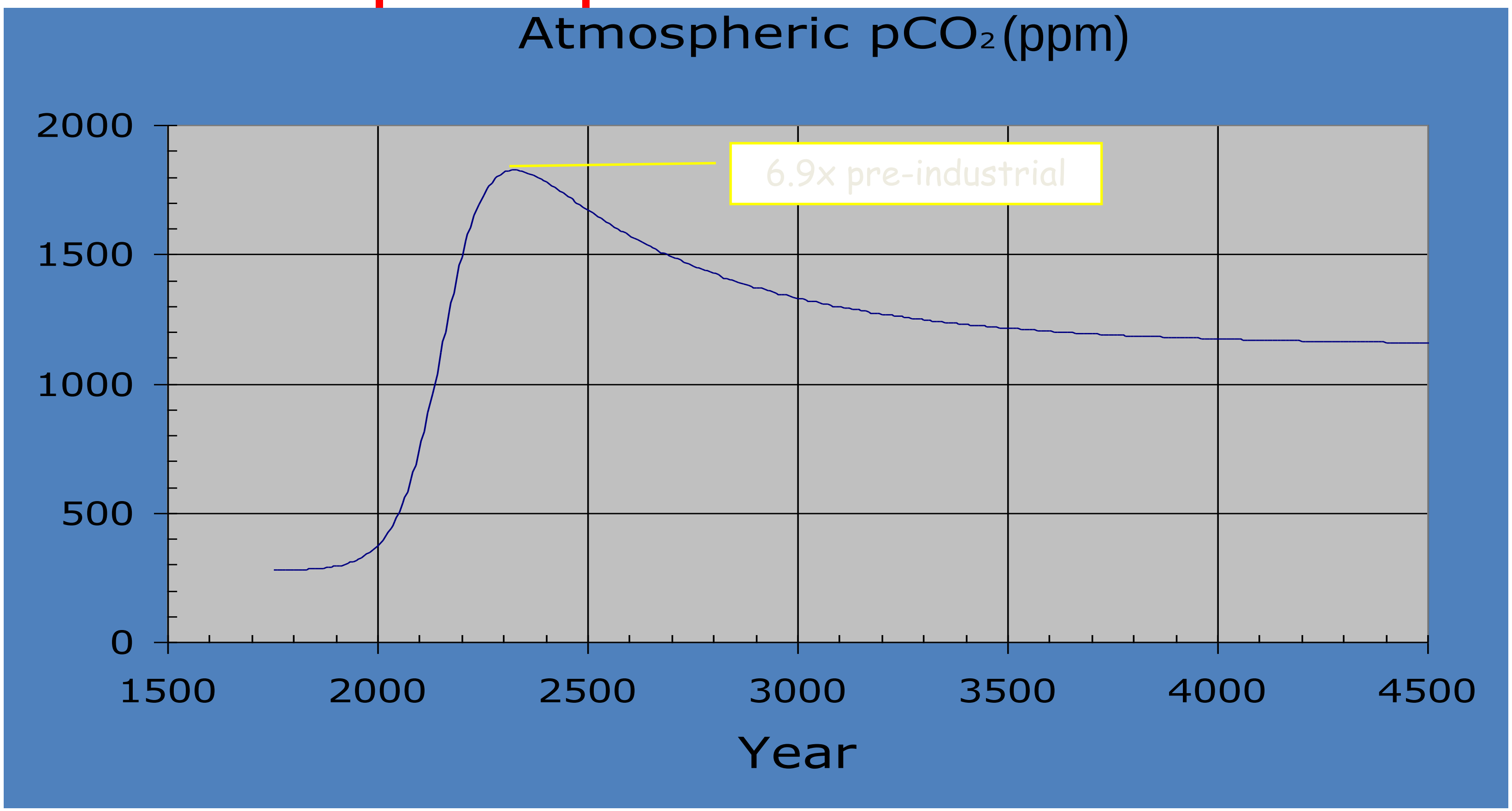
A plan view of the blob



Atmospheric CO_2 with 5600 GtC emissions



Integral ≈ 5,000 GtC ≈ 20,000 $GtCO_2$ → ≈ 10ºC.



Four World Views

		Are fossil fuels hard to displace?	
		NO	YES
Is climate change an urgent matter?	NO	A nuclear or renewables world unmotivated by climate.	Most people in the fuel industries and most of the public are here. **5^{o}C.**
	YES	Environmentalists, nuclear advocates are often here. **2^{o}C.**	OUR WORKING ASSUMPTIONS. **3^{o}C, tough job.**

Every strategy can be implemented well or poorly

Every “solution” has a dark side, generating opposition that thwarts implementation.

Conservation	Regimentation
“Clean coal”	Mining: worker and land impacts
Renewables	Competing uses of land
Nuclear power	Nuclear war
Geoengineering	Technological hegemony

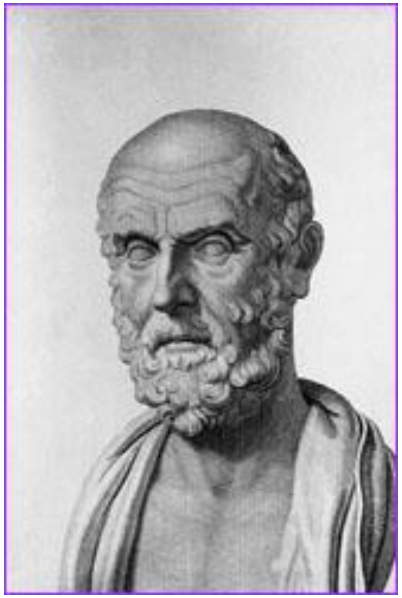
Risk Management: Because mitigation and adaptation are not risk-free, the lowest conceivable greenhouse-concentration targets are not optimal.

The risks of disruption from climate change must be traded against the risks of disruption from “solutions.”

Iterative risk management

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

Hippocrates



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

"Madmen in authority who hear voices in the air are distilling their frenzy from an academic scribbler of a few years back."

John Maynard Keynes

Be very careful.

Never in history has the work of so few led to so much being asked of so many!

The “few” are the climate science researchers.

The “many” are the rest of us.

Understandably, we wish we lived on a larger planet, with a larger atmosphere so that our emissions would be less significant –

and also a planet with larger fisheries, bigger forests, more abundant ground water, so that *all* our actions mattered less.

John Donne, *The First Anniversary*

Published a few months after Galileo's *Starry Messenger* (1610)

And new philosophy calls all in doubt,
The element of fire is quite put out;
The sun is lost, and th'earth, and no man's wit
Can well direct him where to look for it.
And freely men confess that this world's spent,
When in the planets and the firmament
They seek so many new; they see that this
Is crumbled out again t'his atomies.
'Tis all in pieces, all coherence gone,
All just supply, and all relation;
Prince, subject, father, son, are things forgot,
For every man alone thinks he hath got
To be a phoenix, and that there can be
None of that kind, of which he is, but he.
This is the world's condition now…

Copied from David Wootton, *Galileo: Watcher of the Skies*, Yale University Press, 2010, p. 5.

“Shooting the messenger”? No surprise.

The messenger has been shot before.

Galileo argued that the earth wasn’t at the center of the universe and was excommunicated.

Darwin argued that human beings were part of the animal kingdom and was cruelly mocked.

The idea that humans can’t change our planet is as out-of-date and wrong as the earth-centered universe and the separate creation of Man.

But all three ideas have such appeal that they will fade away only very slowly.

Arguments for Delay (1 of 2)

SCIENCE

- We don't know the science. Human activity may be having a negligible effect, swamped by natural variation.
- We may be having an effect, but the impacts are, on balance, favorable.

TECHNOLOGY

- We do not yet have the tools to solve the problem.
- The tools to solve the problem that we have are far inferior to the tools we will have if we conduct R&D for a few decades.
- We have tools that could solve the problem, but they are too dangerous. The cures are worse than the disease.

Arguments for Delay (2 of 2)

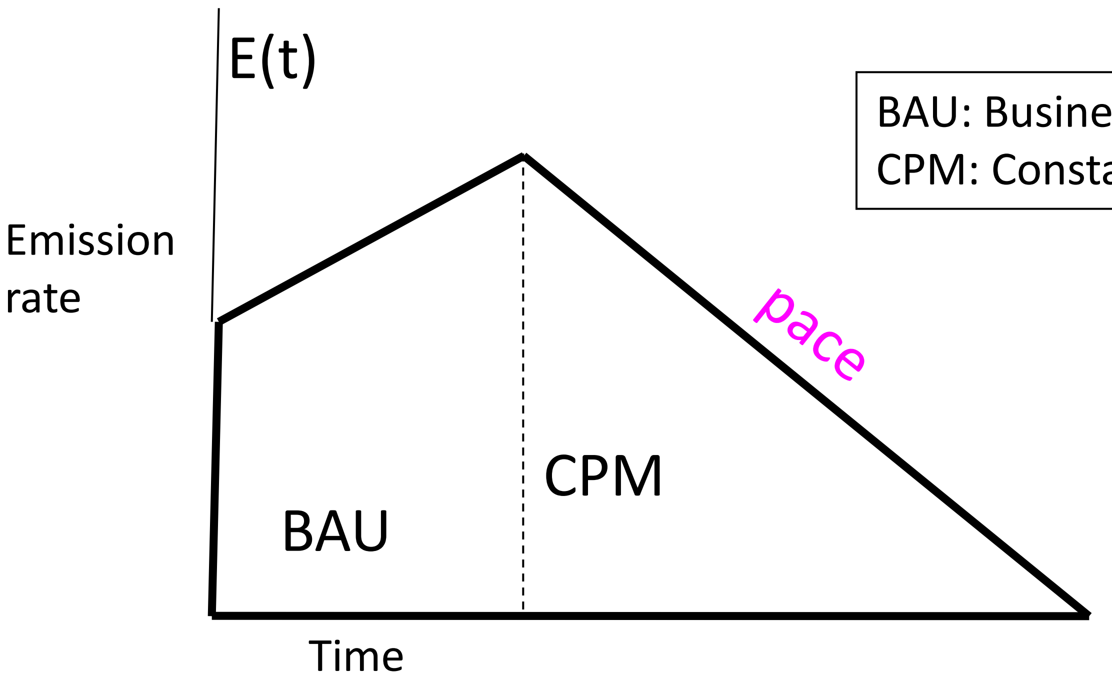
POLITICS, ECONOMICS

- The costs of mitigation are too high, relative to any willingness to pay.
- Government makes a mess of things when it intervenes in the economy.
- The world has more important things to do, notably to deal with world poverty.
- It is wasteful to engage developing countries in mitigation now, given that they will have much greater capacity for implementation later.
- Mitigation will hurt the poor in every country. Wait till we are richer.
- The net result will be to transfer wealth from rich to poor, not good policy.

PHILOSOPHY

- Government should not run our lives.
- People aren’t ready to tackle climate change – the issue is too abstract.
- Whatever the impacts, we can adapt to them.
- We should not play God. We should not control nature.

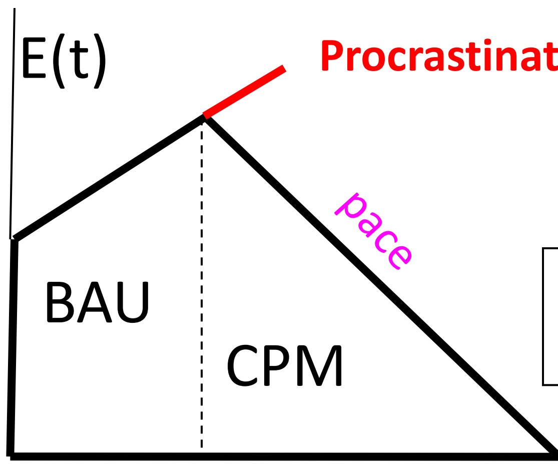
An idealization of mitigation



BAU: Business As Usual
CPM: Constant-Pace Mitigation

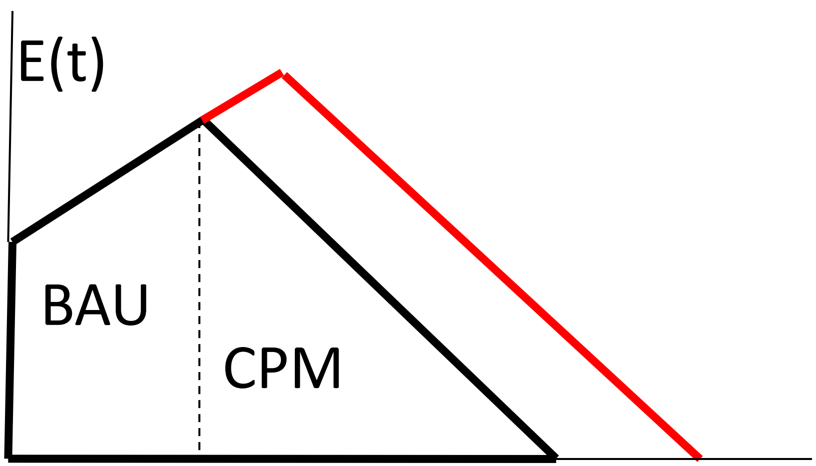
Today, approximately half of emissions are retained in the atmosphere and half move to other reservoirs.

Procrastination and "Pace"

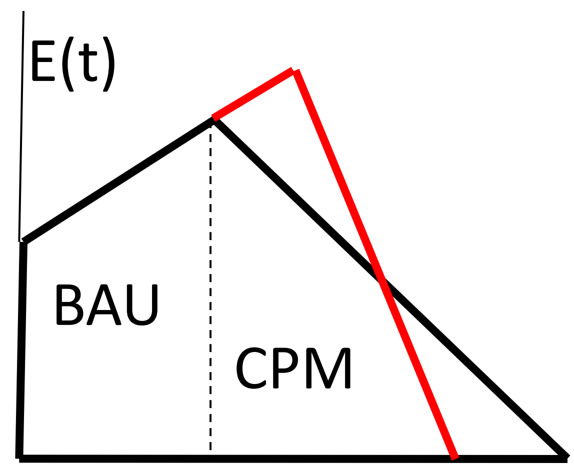


Procrastination can lead to…

BAU: Business As Usual
CPM: Constant-Pace Mitigation



(1) Extra total emissions, because pace cannot be increased,



OR (2) Constant total emissions, with a faster pace.

Surrogate Goals (1 of 3)

Definition of a surrogate goal

A person who holds Goal A strongly and Goal B weakly, but believes that achieving Goal B will also achieve Goal A, can pursue Goal B as a *surrogate* for Goal A.

Usually, Goal A will be revealed only in special circumstances. Recognizing that a multiplicity of surrogate goals is at play has considerable explanatory power.

Surrogate Goals (2 of 3)

Surrogate goals and climate change

In the formulation of policy to deal with climate change, the general objective of slowing the rate of climate change is often a surrogate for more strongly held goals, such as:

- Augmenting financial transfers to developing countries
- Bringing the fossil fuel era to a close
- Curtailing consumerism and human centeredness
- Promoting self-sufficiency, autonomous communities
- Diminishing the power of technological elites
- Promoting environmental science
- Encouraging entrepreneurship

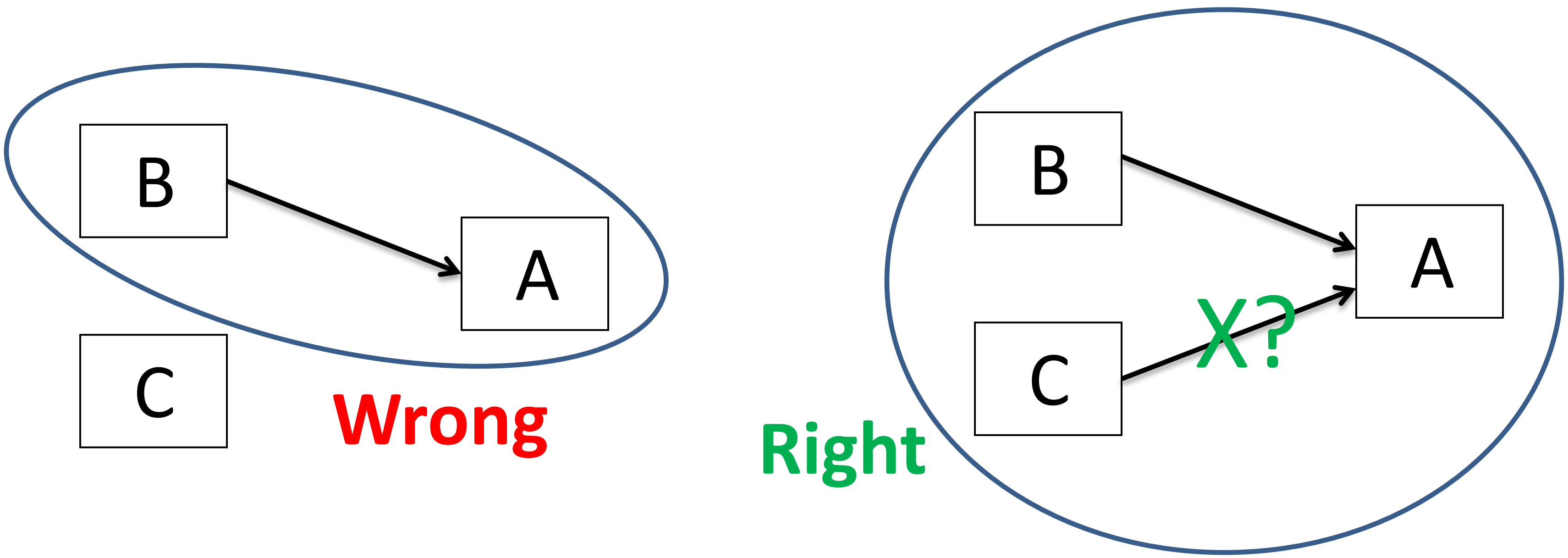
Surrogate Goals (3 of 3)

A problem arises when an action in support of the surrogate goal negates the person's more strongly held goal.

- Capturing and storing CO_2 prolongs the fossil fuel era.
- Large and distant solar arrays and windfarms do not promote local self-reliance.

Be careful how you wish for what you wish for.

Principle: You want A. You figure out that B will get us to A, and you like B. You foster B. But *there is always a C that someone else likes and you don't like at all*, which also gets us to A. Unless you are alert, your efforts enable C.



***Message*: Add conditionality; bargain or walk away.**

Getting to Yes

The more we fear climate change, the less we can allow ourselves to be squeamish about imperfect “solutions.”

We must remember that we want solutions to work. It can’t be enough to identify what’s wrong with a strategy as it is first proposed. We must ask: With what changes would this strategy become acceptable? How might we get from here to there?

Getting to No

However, we may decide, in some situations, to forego an option.

This may be the result of a moral judgment. We will prefer enduring some amount of climate change to the compromises required to avoid it.

Our Collective Future: Can we think systematically about it?

	PAST	FUTURE
INDIVIDUAL		
COLLECTIVE		**NEGLECTED.**

By “collective,” I generally mean the human species.

Three boxes, I presume, are well mapped.

	PAST	FUTURE
INDIVIDUAL	Memory Morality and law (accountability, statutes of limitation)	Death, plain and simple *vs.* after-life stories.
COLLECTIVE	Myth *vs.* science. (Science is not just another myth.)	**Do we even know what the questions are?**

Evidence that we are confused

	PAST	FUTURE
INDIVIDUAL	Memory Morality and law (accountability, statutes of limitation)	Death, plain and simple *vs.* after-life stories.
COLLECTIVE	Myth *vs.* science. (Science is not just another myth.)	**Discount rate.** **Rules for nuclear waste.** **Infrastructure and climate change**

Will universities some day have Destiny Studies departments?

Destiny studies

We have scarcely begun to ask: What are we on Earth to do? What are our goals? What are our responsibilities? *A* new intellectual domain is in view.

In the past 50 years we have become aware of the deep history of our Universe, our Earth, and life. Can we achieve a comparable understanding of future time: 50 years ahead *vs.* 500 *vs.* 5000 *vs.* longer?

We face decisions not only about climate change but also about infrastructure, natural resources, wilderness preservation, reinsurance, endowment management…

We must affirm our collective destiny on Earth.

Fitting on the Earth

Fortunately:

- Our science has discovered threats fairly early;
- We can identify a myriad of helpful technologies;
- We have a moral compass that tells us to care about everyone alive today and also about the collective future of our species.

Planetary identity

In the process of taking climate change seriously, we develop a planetary identity.

We augment our previous loyalties to family, village, tribe, and nation.

Do *you* have a planetary identity?

Will your generation redefine “the good life”?

Many cultures in the history of the world have defined the good life differently than prosperous people do today.

Are serious challenges to the values of the prosperous in view, anywhere in the world?

Can We Do It?

People are becoming increasingly anxious about our limited understanding of the experiments we are performing on the only Earth we have…

…and are learning that there are ways to live more cautiously.

We should anticipate a discontinuity:

What has seemed too hard becomes what simply must be done.

Precedents include abolishing child labor, addressing the needs of the disabled, and mitigating air pollution.

Robert Frost
Two Tramps in Mud Time
(opening stanza)

Out of the mud two strangers came
And caught me splitting wood in the yard.
And one of them put me off my aim
By hailing cheerily "Hit them hard!"
I knew pretty well why he dropped behind
And let the other go on a way.
I knew pretty well what he had in mind:
He wanted to take my job for pay.

Robert Frost
Two Tramps in Mud Time
(penultimate stanza)

Nothing on either side was said.
They knew they had but to stay their stay
And all their logic would fill my head:
As that I had no right to play
With what was another man's work for gain.
My right might be love but theirs was need.
And where the two exist in twain
Theirs was the better right -- agreed.

Robert Frost

Two Tramps in Mud Time

(final stanza)

But yield who will to their separation,
My object in living is to unite
My avocation and my vocation
As my two eyes make one in sight.
Only where love and need are one,
And the work is play for mortal stakes,
Is the deed ever really done
For Heaven and the future's sakes.

Thank you for the privilege of teaching this course.

Group dinner in 150 minutes.