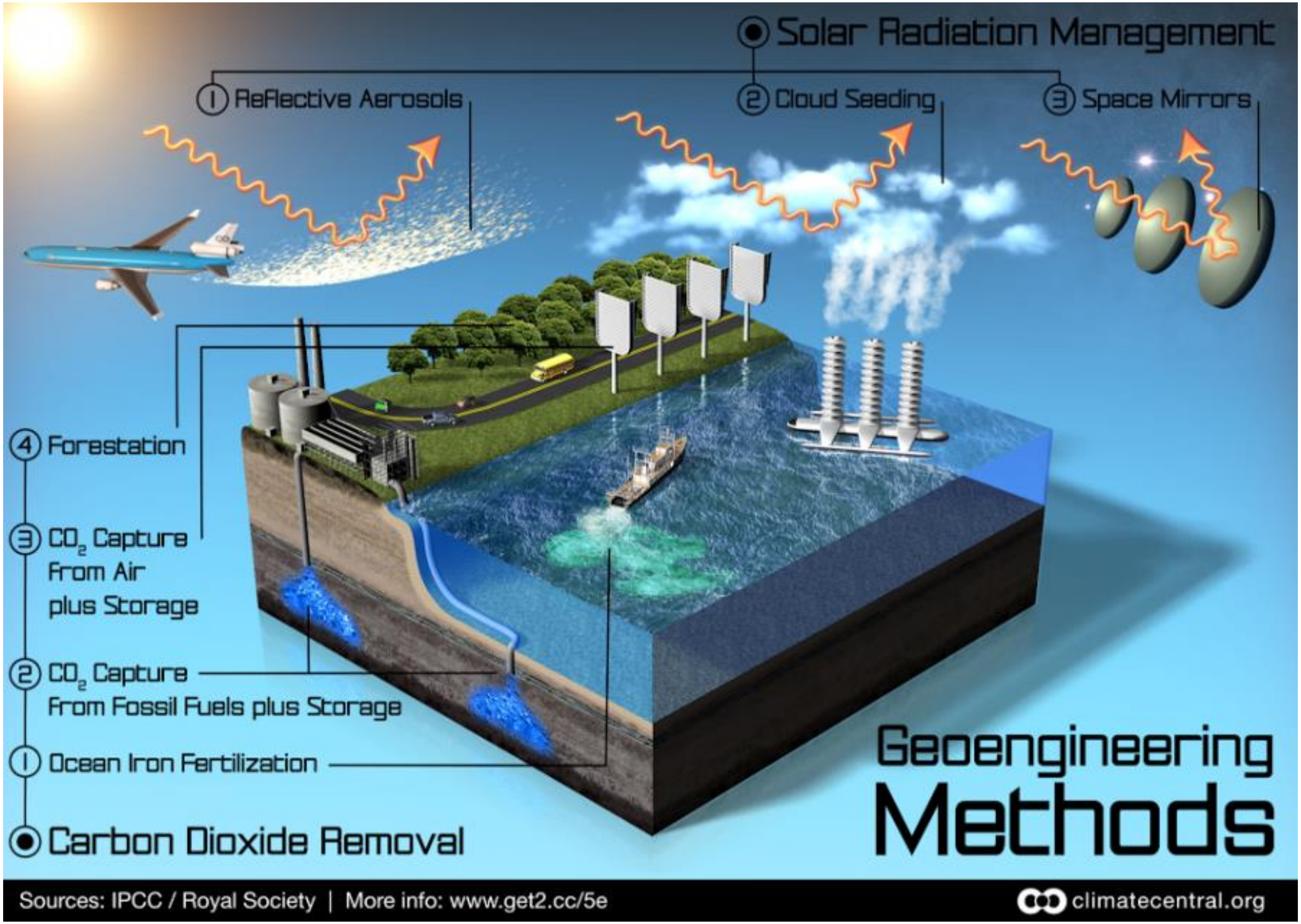
Alternative to the Wedges Approach: Geo-engineering?

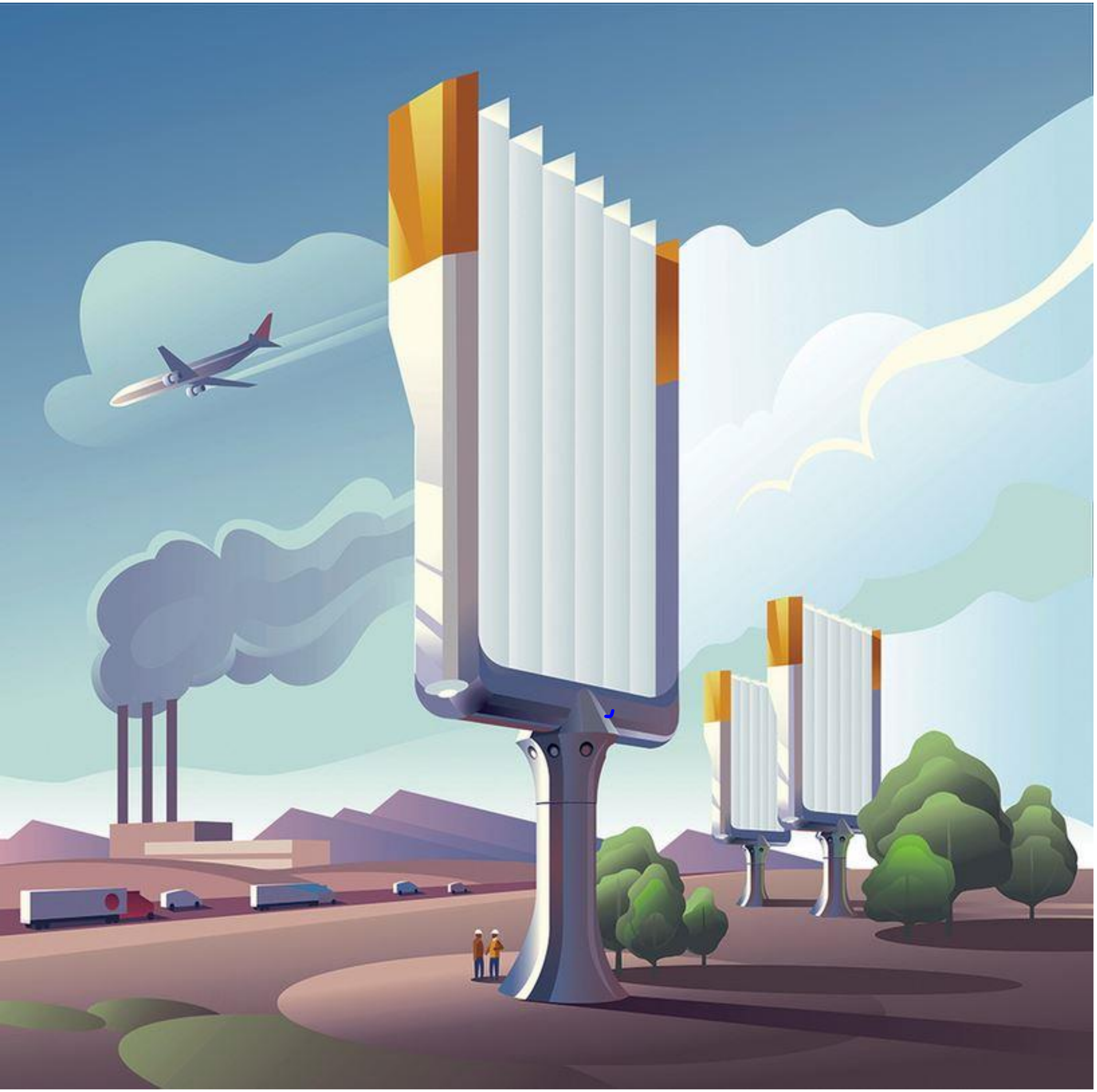
Solar Radiation Management
--increase albedo to offset GHG warming

Carbon Dioxide Removal (CDR)
--actively scrub CO_2 from the atmosphere

Proposed Geo-engineering Schemes



Negative Emissions Strategy: Carbon Dioxide Removal (CDR)



Scrubbing CO_2 from air

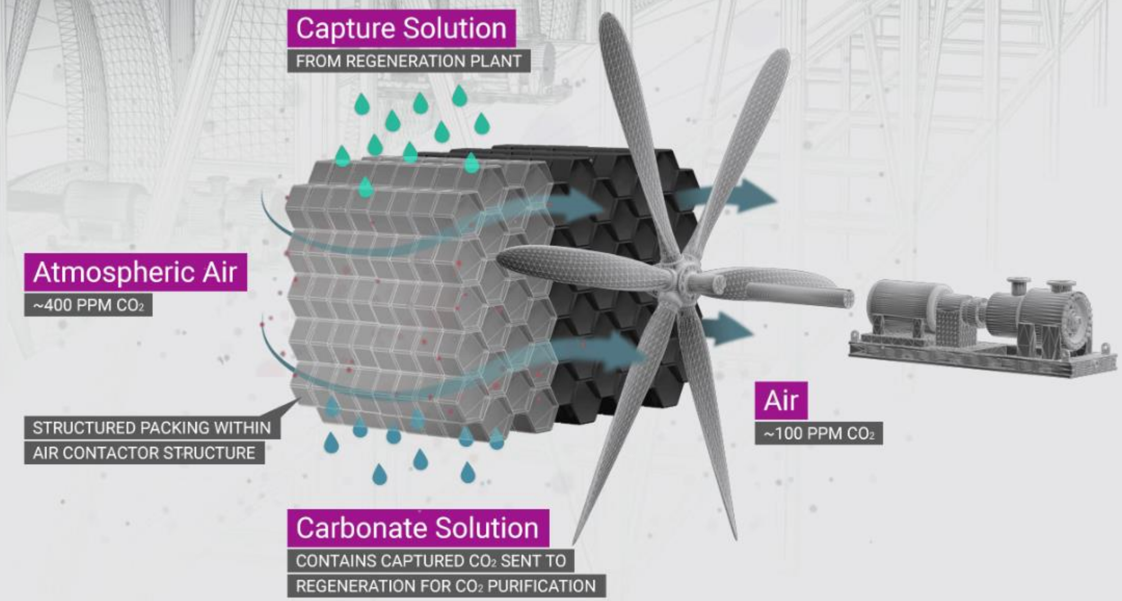
New technologies needed (being tried)

Current costs are estimated at \$100-\$200 per ton

Typical installation 20-500 tons/year/m^2


Global Thermostat
A carbon negative solution

Carbon Engineering



Direct Air Capture

CE has proudly developed an industrially scalable Direct Air Capture (DAC) technology, which can remove CO_2 directly from the atmosphere at an affordable price point.

Our technology does this in a closed loop where the only major inputs are water and energy, and the output is a stream of pure, compressed CO_2. This CO_2 can be stored underground to compensate for emissions too costly or challenging to eliminate at source, or can be converted into fuels using our AIR TO FUELS™ technology.

Individual DAC facilities can be built to capture one million tons of CO_2 per year each, which is equivalent to the annual emissions of 250,000 average cars.

2015: Pilot demonstration of DAC

In 2015, CE constructed an end-

2017: Pilot demonstration of AIR TO FUELS™ technology

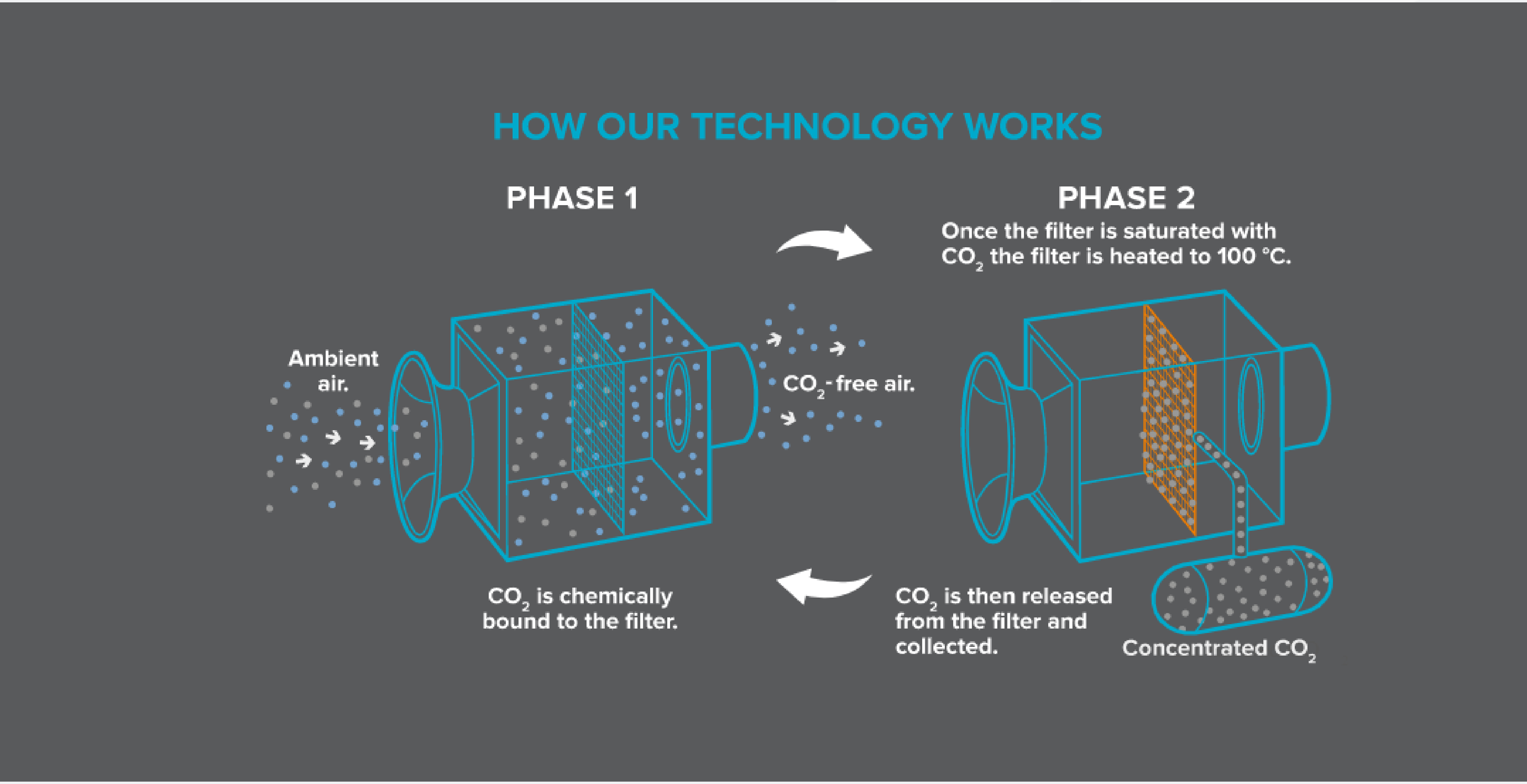
2018-2021: Commercial validation

Today, CE is running a

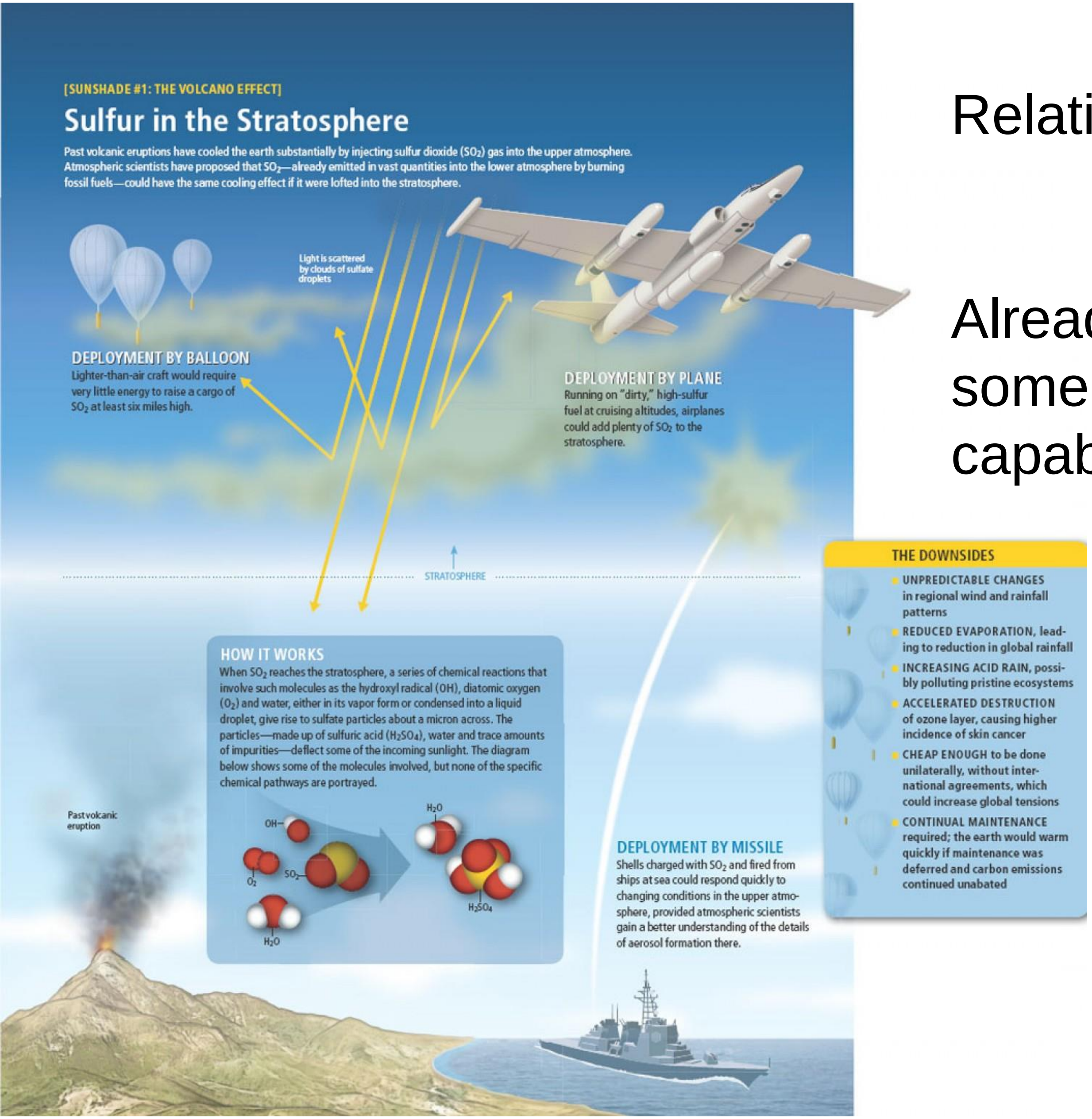
2021: Broad commercial deployment

In 2021, following commercial

Climeworks.com



Stratospheric Aerosol Injection (Enhancement)



Relatively low cost

$2-3 billion / year

Already technically feasible – some debate about aircraft capability

Environmental Research Letters

LETTER

Stratospheric aerosol injection tactics and costs in the first 15 years of deployment

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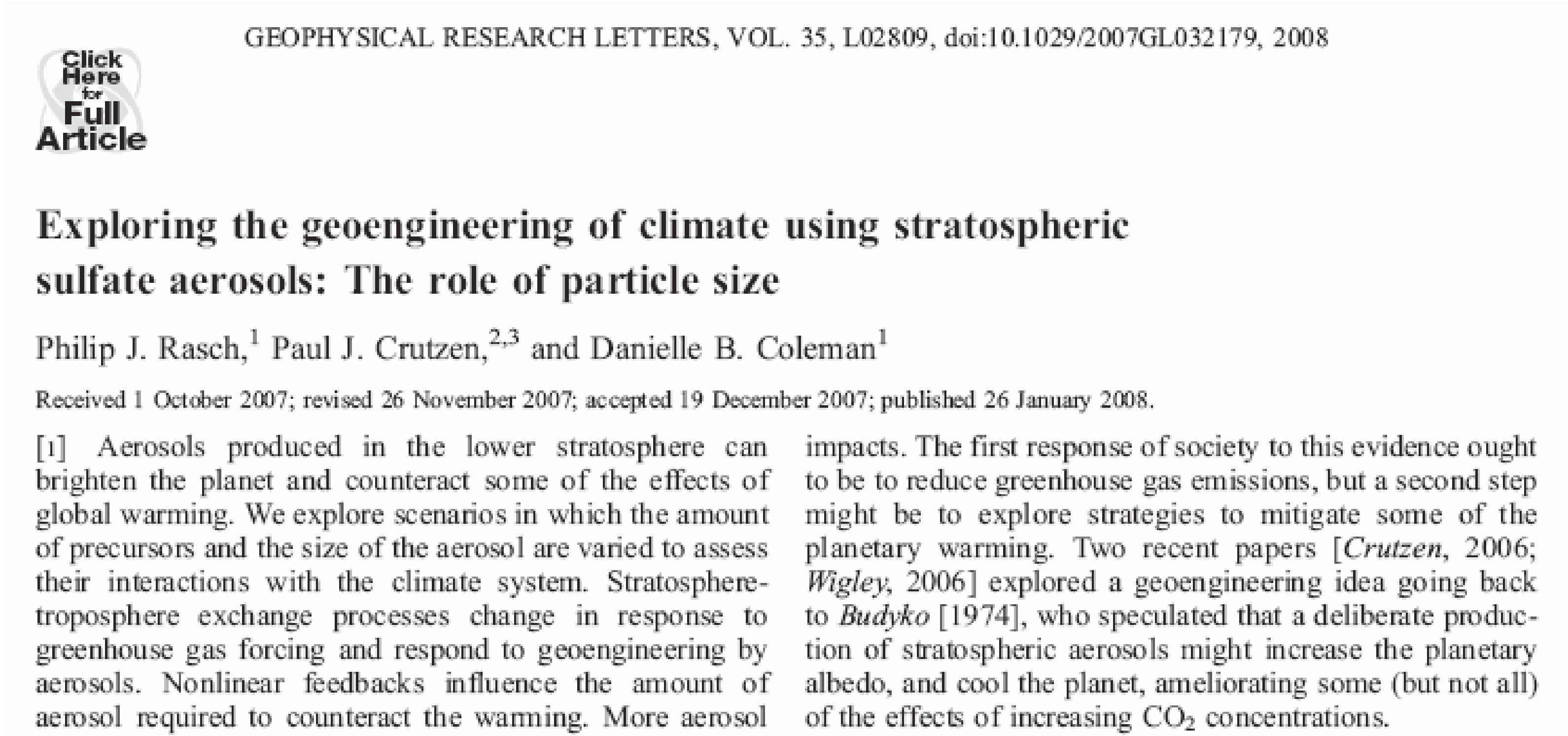
Keywords: solar geoengineering, albedo modification, solar radiation management, high-altitude aircraft

Abstract

We review the capabilities and costs of various lofting methods intended to deliver sulfates into the lower stratosphere. We lay out a future solar geoengineering deployment scenario of halving the increase in anthropogenic radiative forcing beginning 15 years hence, by deploying material to altitudes as high as ~20 km. After surveying an exhaustive list of potential deployment techniques, we settle upon an aircraft-based delivery system. Unlike the one prior comprehensive study on the topic (McClellan *et al* 2012 *Environ. Res. Lett.* **7** 034019), we conclude that no existing aircraft design—even with extensive modifications—can reasonably fulfill this mission. However, we also conclude that developing a new, purpose-built high-altitude tanker with substantial payload capabilities would neither be technologically difficult nor prohibitively expensive. We calculate early-year costs of ~\$1500 ton^{-1} of material deployed, resulting in average costs of ~\$2.25 billion yr^{-1} over the first 15 years of deployment. We further calculate the number of flights at ~4000 in year one, linearly increasing by ~4000 yr^{-1}. We conclude by arguing that, while cheap, such an aircraft-based program would unlikely be a secret, given the need for thousands of flights annually by airliner-sized aircraft operating from an international array of bases.

Geo-engineering: Particles in Stratosphere



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GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L02809, doi:10.1029/2007GL032179, 2008

Exploring the geoengineering of climate using stratospheric sulfate aerosols: The role of particle size

Philip J. Rasch,[1] Paul J. Crutzen,[2,3] and Danielle B. Coleman[1]

Received 1 October 2007; revised 26 November 2007; accepted 19 December 2007; published 26 January 2008.

[1] Aerosols produced in the lower stratosphere can brighten the planet and counteract some of the effects of global warming. We explore scenarios in which the amount of precursors and the size of the aerosol are varied to assess their interactions with the climate system. Stratosphere-troposphere exchange processes change in response to greenhouse gas forcing and respond to geoengineering by aerosols. Nonlinear feedbacks influence the amount of aerosol required to counteract the warming. More aerosol

impacts. The first response of society to this evidence ought to be to reduce greenhouse gas emissions, but a second step might be to explore strategies to mitigate some of the planetary warming. Two recent papers [*Crutzen*, 2006; *Wigley*, 2006] explored a geoengineering idea going back to *Budyko* [1974], who speculated that a deliberate production of stratospheric aerosols might increase the planetary albedo, and cool the planet, ameliorating some (but not all) of the effects of increasing CO_2 concentrations.

Estimates: Need 1 – 5 Tg S/yr to negate doubled CO_2

Geo-engineering: Particles in Stratosphere

~20 Tg S in stratosphere

↓

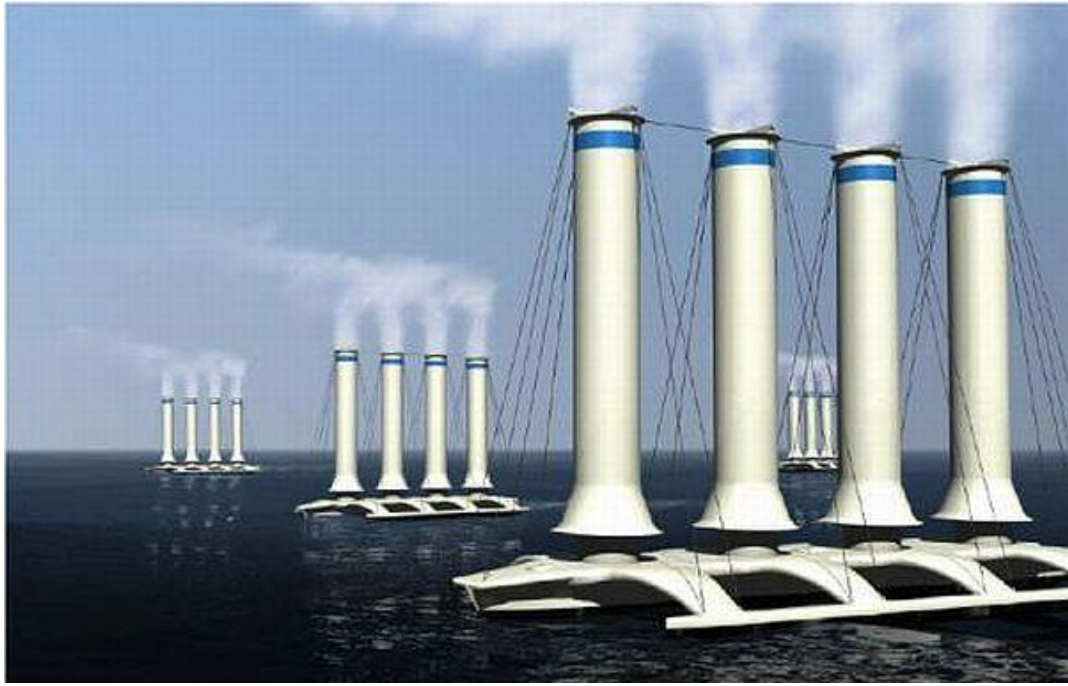
Need Mt. Pinatubo every 2-4 years…

Marine Cloud Brightening

- https://twitter.com/i/status/1121455609465974786

- **Lifetime of aerosol in air near surface much shorter (1 week or less) → need bigger source, but more natural (sea spray)**

- **Effect of brightening clouds on energy balance potentially stronger effect than stratospheric aerosol**



Suppose you are a UNFCCC negotiator, and the international community is considering the implementation of geo-engineering schemes. For which do you advocate?

Visual settings
Activate
Show results
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Poll locked. Responses not accepted.

- Stratospheric aerosol injection, for its low cost and technical feasibility, despite uncertainties about effects on ecosystem/crop productivity
- Large scale CO2 removal, in spite of its lack of proven technology and cost
- Marine cloud brightening, for its more natural and potentially strong impact, in spite of not knowing effects on circulation and precipitation

Next
Previous

Total Results: 0

What should the goals of geo-engineering of climate be?

Poll locked. Responses not accepted.

- Stable climate with global average T similar to pre-industrial value
- Optimized global crop productivity and stable climate with global average T within 2 degrees of pre-industrial value
- Stable climate with global average T less than 2 degrees for the lowest cost
- Carbon dioxide removal only, regardless of time or cost

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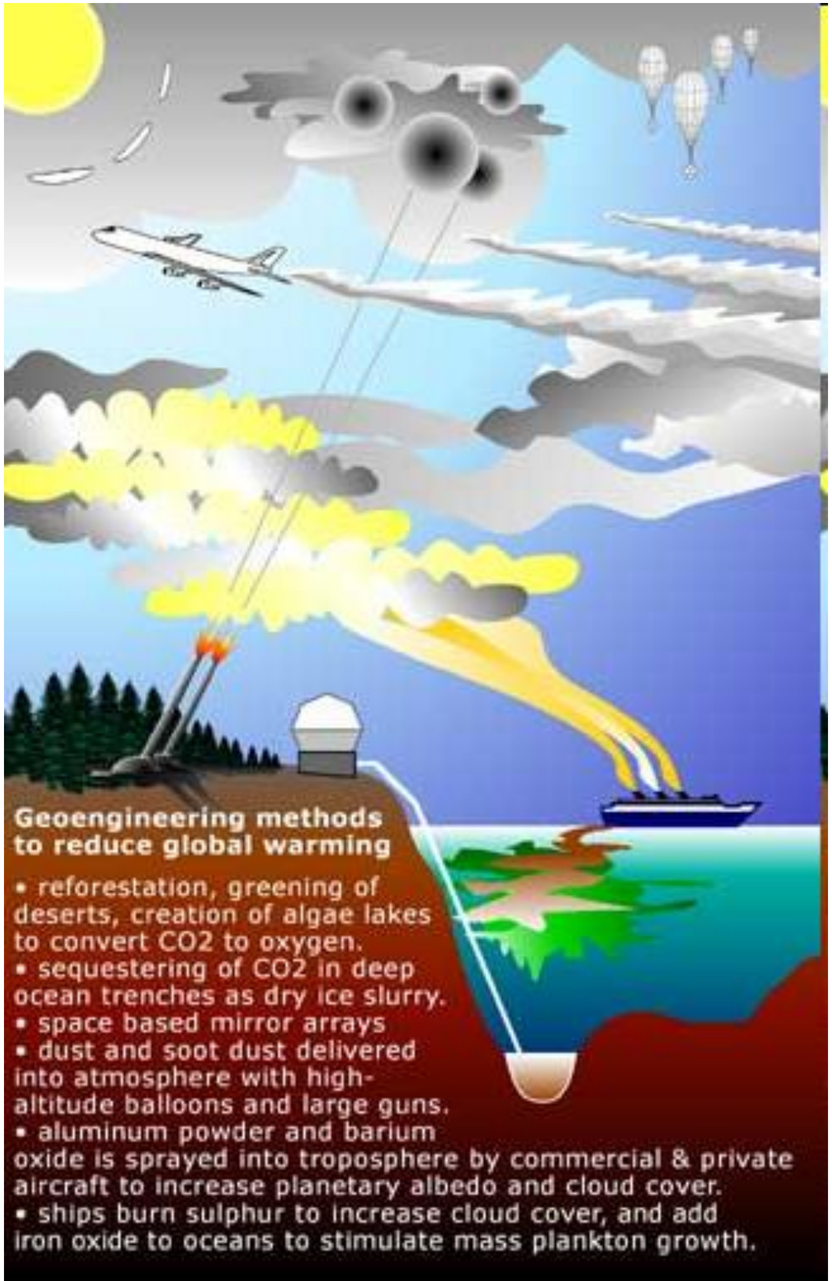
Total Results: 0

Geo-engineering Issues



What laws and treaties exist or are needed?

Who will control the desired climate?

How will these affect regional climates?

What happens if there is an interruption in the scheme or faulty storage, etc.?

Global average T is not the only problem associated with increasing CO_2, what about those?

International Agreements are Voluntary

While free-riding is pervasive, it is particularly difficult to overcome for global public goods. Global public goods differ from national market failures because no mechanisms—either market or governmental—can deal with them effectively. Arrangements to secure an international climate treaty are hampered by the Westphalian dilemma. The 1648 Treaty of Westphalia established the central principles of modern international law. First, nations are sovereign and have the fundamental right of political self-determination; second, states are legally equal; and third, states are free to manage their internal affairs without the intervention of other states. The current Westphalian system requires that countries consent to joining international agreements, and all agreements are therefore essentially voluntary (Treaty of Vienna 1969, article 34).

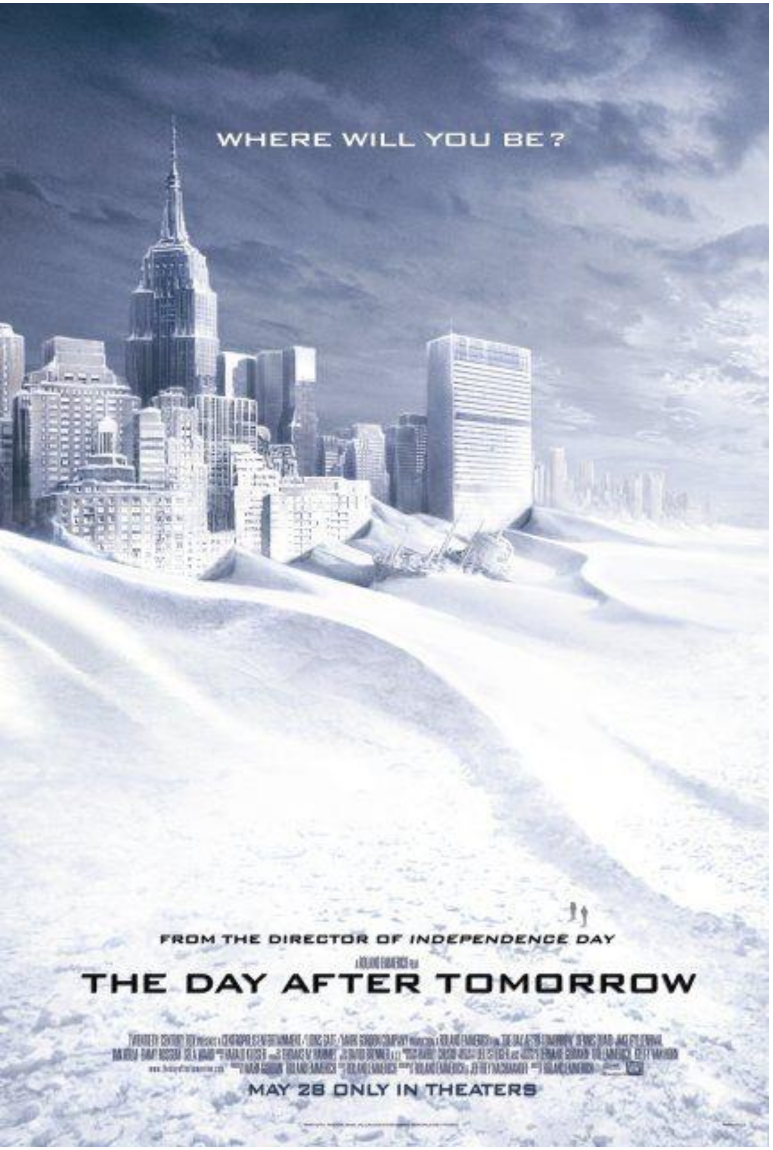
Climate Club Example

The theory of clubs is a little-known but important corner of the social sciences. (For an early analysis, see Buchanan 1965, while for a fine survey, see Sandler and Tschirhart 1980.) The major conditions for a successful club include the following: (i) that there is a public-good-type resource that can be shared (whether the benefits from a military alliance or the enjoyment of a golf course); (ii) that the cooperative arrangement, including the dues, is beneficial for each of the members; (iii) that non-members can be excluded or penalized at relatively low cost to members; and (iv) that the membership is stable in the sense that no one wants to leave. For the current international-trade system, the advantages are the access to other countries' markets with low trade barriers. For military alliances, the benefits are peace and survival. In all cases, countries must contribute dues—these being low trade barriers for trade or burden sharing in defense treaties. If we look at successful international clubs, we might see the seeds of an effective international system to deal with climate change.

"Club" of countries agree to emissions reductions

Countries not agreeing (and not meeting targets) are penalized via tariffs on imports

It isn’t “rocket science”

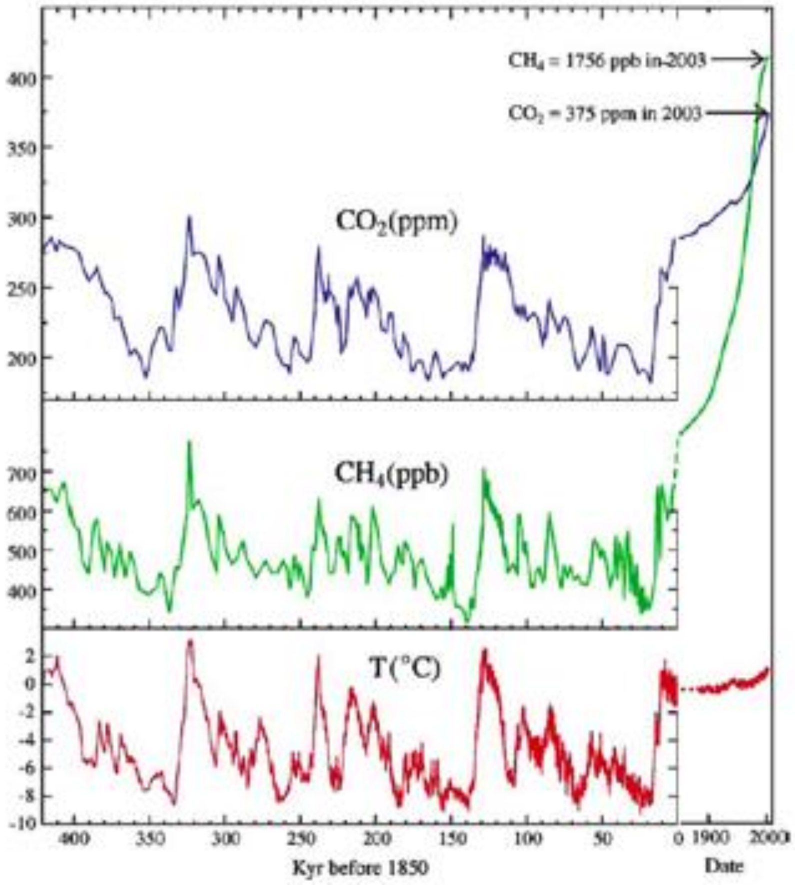


1. **Increasing greenhouse gases is a positive radiative forcing.**

2. **Temperature should increase (1880’s physics): natural positive feedbacks amplify warming**

3. **Impacts of increased temperature: ice melts, sea water expands, soil moisture evaporates faster, more water vapor means heavier rains**

Course Goals



1. Introduce you to climate science and the scientific method

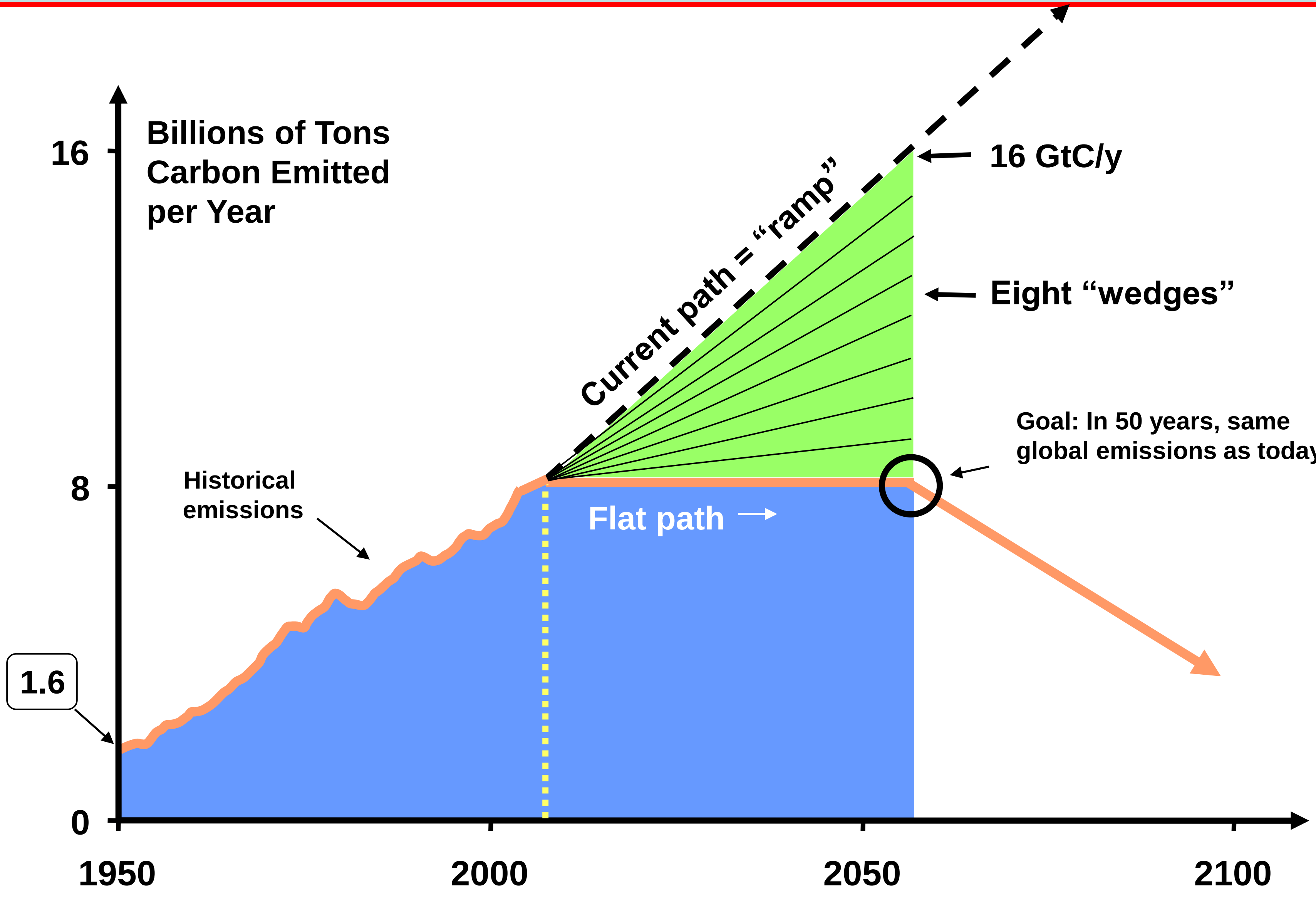
2. Give you tools to understand and <u>critically evaluate</u> modern environmental problems

https://uw.iasystem.org/survey/209394

Enjoy your summer!*

**But first study for your final exam*

Stabilization Wedges



An Economic Approach

American Economic Review 2015, 105(4): 1339–1370
http://dx.doi.org/10.1257/aer.15000001

Climate Clubs: Overcoming Free-riding in International Climate Policy†

By William Nordhaus*

Notwithstanding great progress in scientific and economic understanding of climate change, it has proven difficult to forge international agreements because of free-riding, as seen in the defunct Kyoto Protocol. This study examines the club as a model for international climate policy. Based on economic theory and empirical modeling, it finds that without sanctions against non-participants there are no stable coalitions other than those with minimal abatement. By contrast, a regime with small trade penalties on non-participants, a Climate Club, can induce a large stable coalition with high levels of abatement. (*JEL* Q54, Q58, K32, K33)

Climate Clubs

New York Times: Climate Deal Needs a Big Stick, Eduardo Porter

June 2, 2015

According to calculations by William Nordhaus, an expert on the economics of climate change at Yale, the United States, on net, would gain $8 billion a year by benefiting from everybody else's efforts to slow down the Earth's warming without having to exert any effort itself.

But if the other advanced nations had a stick — a tariff of 4 percent on the imports from countries not in the "climate club" — the cost-benefit calculation for the United States would flip. Not participating in the club would cost Americans $44 billion a year.

Some opinions (not necessarily endorsed by me)

http://thedailyshow.cc.com/videos/8q3nmm/burn-noticed

https://www.youtube.com/watch?v=3E0a_60PMR8

https://www.youtube.com/watch?v=YDL4Bs3NbB0