



***Our Climate:* A Global Challenge**

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Earth's biosphere temperature is controlled
by a very thin layer of atmosphere!



The Greenhouse Effect keeps the planet warm and habitable.

People require food:
requires water and arable land



C HALLENGES ARE WHAT
MAKE LIFE INTERESTING AND OVERCOMING
THEM IS WHAT MAKES LIFE MEANINGFUL.

— JOSHUA J. MARINE

“Climate change does not respect border; it does not respect who you are - rich and poor, small and big. Therefore, this is what we call 'global challenges,' which require global solidarity.”

Ban Ki-moon



‘Geoengineering’ is the deliberate modification of an element of the climate system on a large scale to avoid dangerous impacts of climate change.



AMS, AGU, UK RS

Remember rainmaking?

- Not fringe science
 - Mainstream tool
- Effectiveness a matter of debate
 - NRC: “no convincing scientific proof of its efficacy”
 - less than 30% chance of success

Human hubris: we think we can do anything with impunity

Strategies

Mitigate: intervene to reduce the sources or enhance the sinks of greenhouse gases

Adapt: Adjust in response to actual or expected climatic stimuli or their effects

Climate Intervention:
Plenty of incentive

Increase understanding:

- Research: measure and model
- Technology development

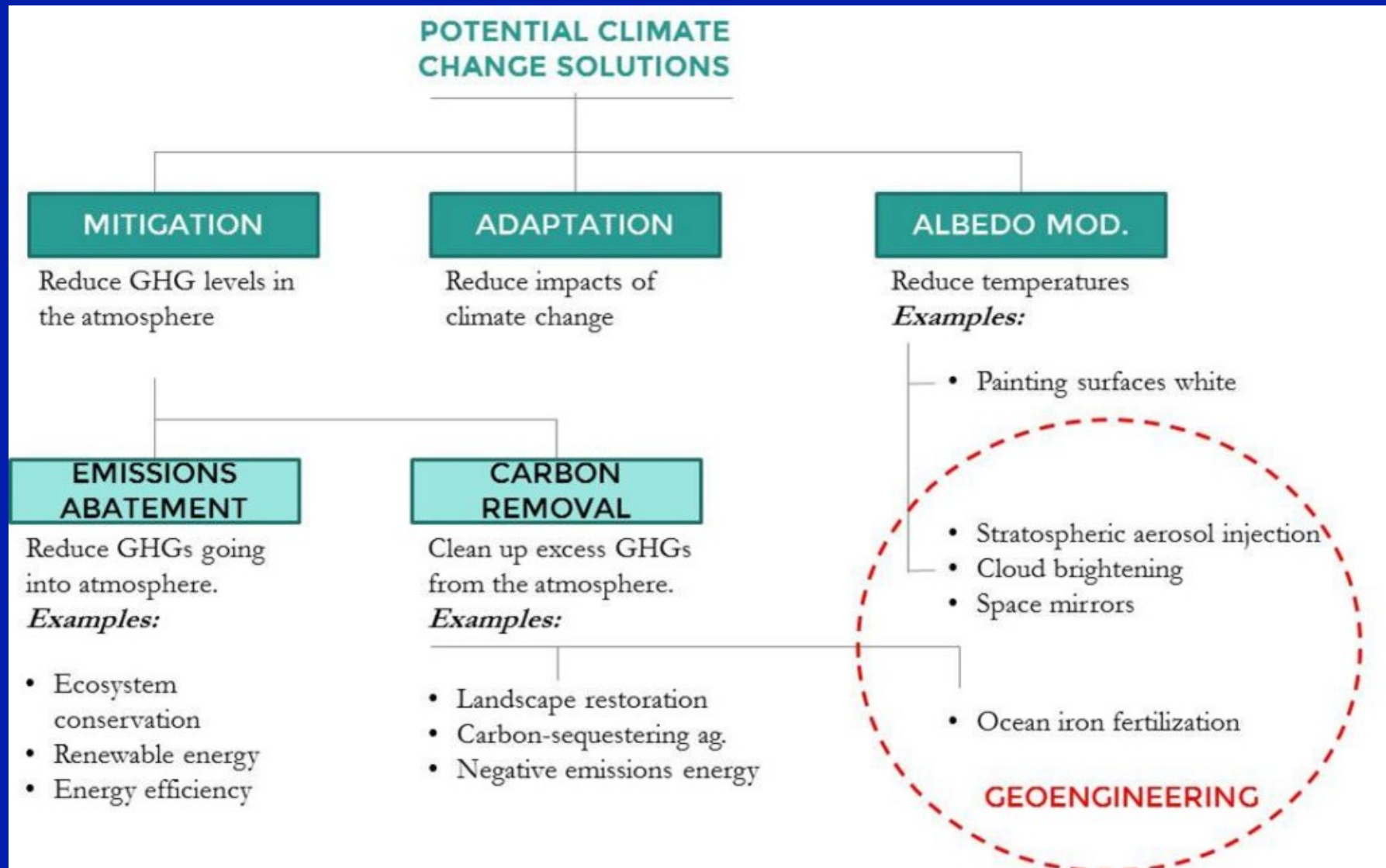
Mitigation

- **Wind energy**
- **Solar cells**
- **Solar power plants**
- **Nuclear power**
- **Energy storage**
- **Geothermal**

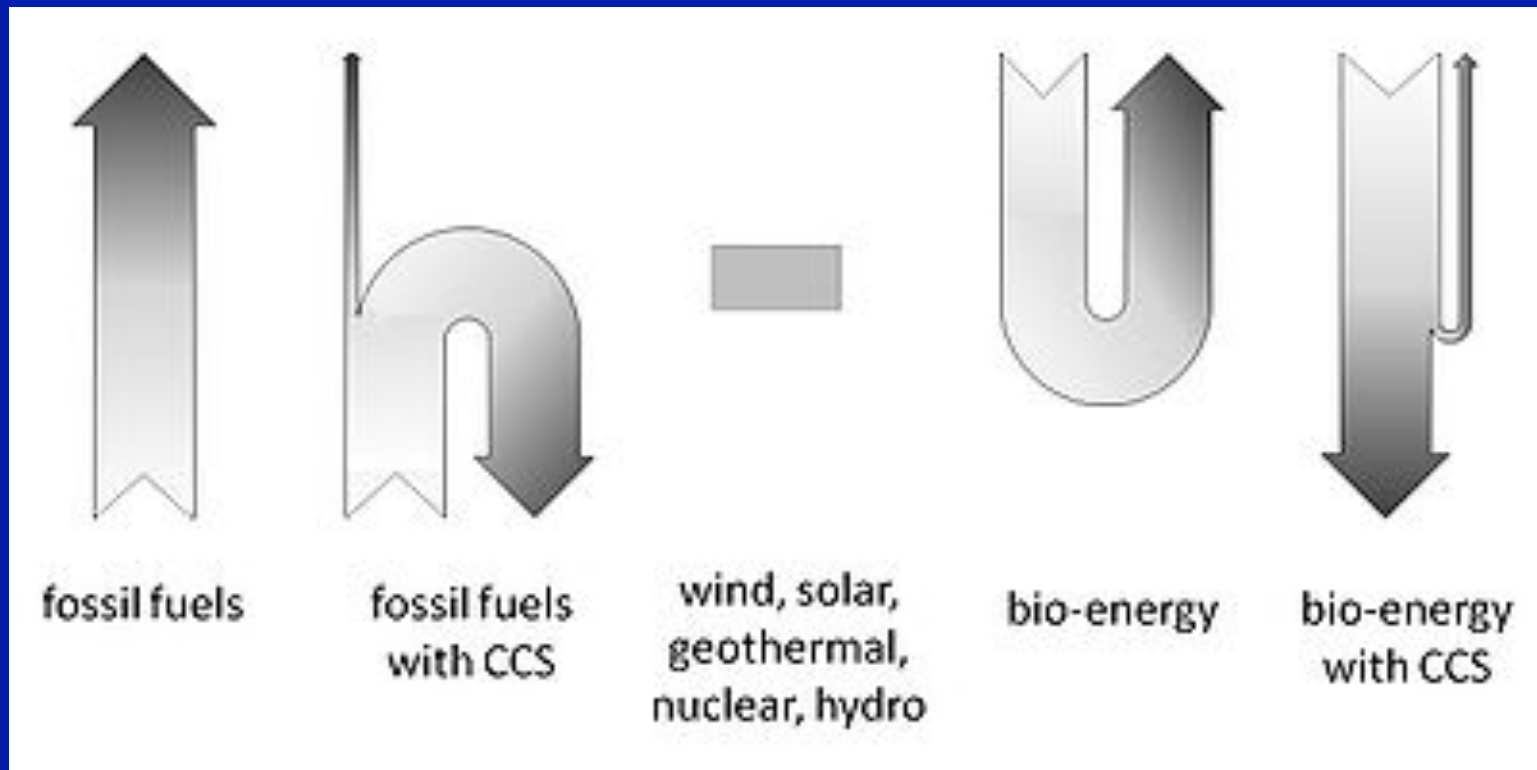
Adaptation

- **Dikes, sea walls, artificial reefs**
- **Electric cars**
- **Paint roofs white**
- **Recycle, recycle, recycle**
- **Buy boat and generator**
- **Move north, buy sweater**

Geoengineering taxonomy



Carbon flow schematic for various energy systems



up arrow implies release of CO₂ to the atmosphere
down arrow implies sequestration in the ground

National Academy of Sciences

Detailed in depth look at ways for humans to cool the planet, which is being increasingly proposed for a variety of reasons

1. & 2. Mitigate and Adapt; first and most important

3. Carbon Capture and removal

4. Albedo Modification

What's In a Name

geo-engineering -> climate intervention

solar radiation management -> albedo modification

engineering implies we know how to do it well (as in bridges)

intervention is done with the intention to improve something (health)

National Academy of Sciences

- Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration (CDR)
- Climate Intervention: Reflecting Sunlight to Cool Earth (SRM)

National Academy Press, 2015



Definitions

- Climate Intervention—purposeful actions intended to produce a targeted change in some aspect of the climate (e.g., global mean or regional temperature); includes actions designed to remove carbon dioxide or other greenhouse gases from the atmosphere or to change Earth's radiation balance (referred to as "albedo modification"), but not efforts to limit emissions of greenhouse gases (i.e., climate mitigation).
- Carbon Dioxide Removal—intentional efforts to remove carbon dioxide from the atmosphere, including land management strategies, accelerated weathering, ocean iron fertilization, bioenergy with carbon capture and sequestration, and direct air capture and sequestration. CDR techniques complement carbon capture and sequestration methods that primarily focus on reducing CO₂ emissions from point sources such as fossil fuel power plants.
- Albedo Modification—intentional efforts to increase the amount of sunlight that is scattered or reflected back to space, thereby reducing the amount of sunlight absorbed by Earth, including injecting aerosols into the stratosphere, marine cloud brightening, and efforts to enhance surface reflectivity.

NAS Recommendations

- Mitigate and Adapt first and foremost
- Albedo modification at scales sufficient to alter climate should not be deployed at this time
- Research of albedo modification should continue (emergency, use by other countries, etc.)
- Carbon capture has more promise, is already in R&D, and has less down side.

Growing UN Attention to soil degradation

The UN has declared 2015 as the International Year of Soils to shine the international spotlight on the challenges.

Threats

Nutrient depletion

Salinization

Erosion

Urbanization

Chemical pollution



A terracing project

Intergovernmental Technical Panel on Soils (ITPS, like IPCC)

24 July, 2014 News release from the UN

World Soils Day, Dec. 4, 2015

<http://www.fao.org/globalsoilpartnership/intergovernmental-technical-panel-on-soils/en/>

One perspective on geoengineering

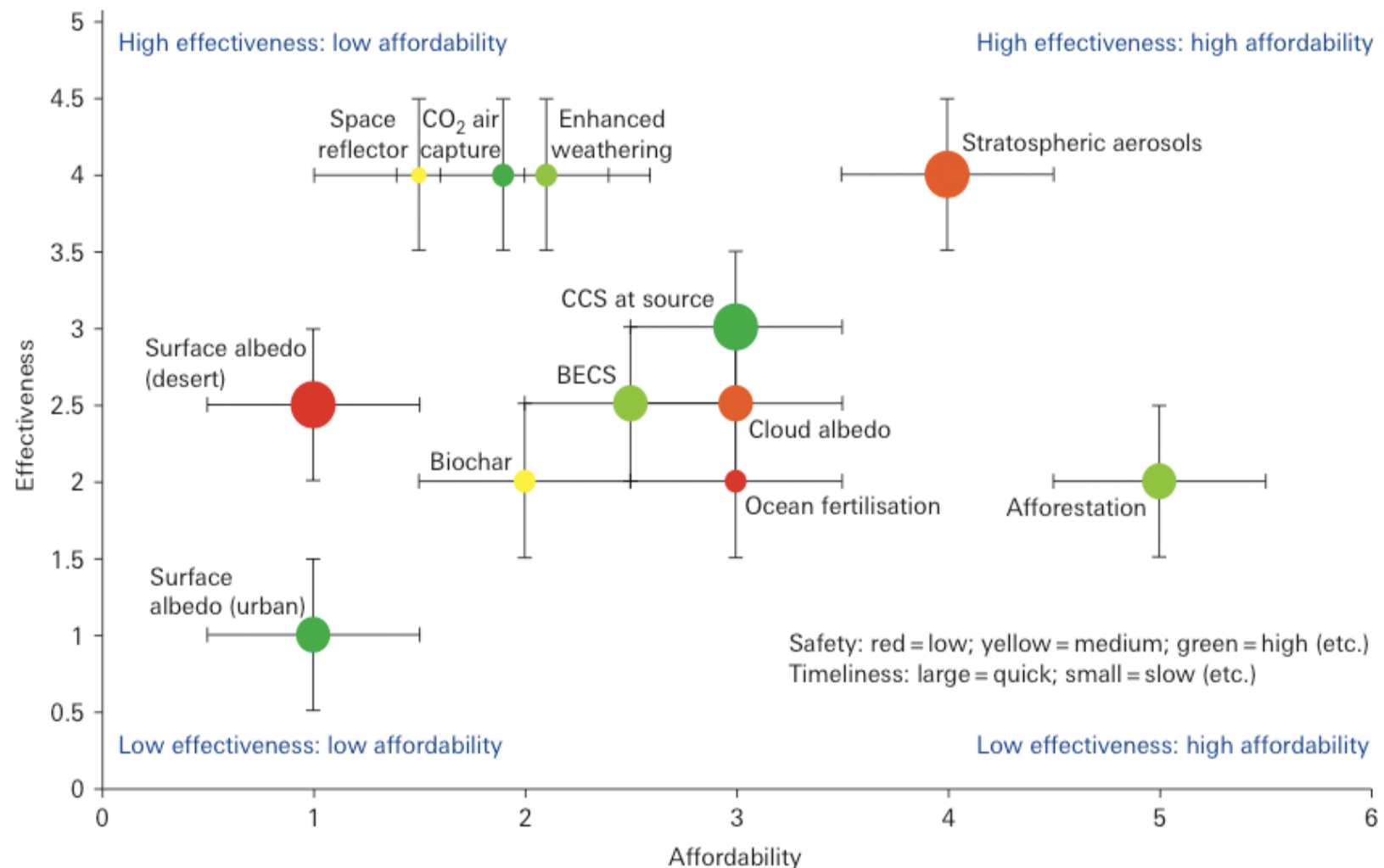
from the Wall Street
Street Journal
15 June, '09

Jamais Cascio

with thanks to
Ron Larson

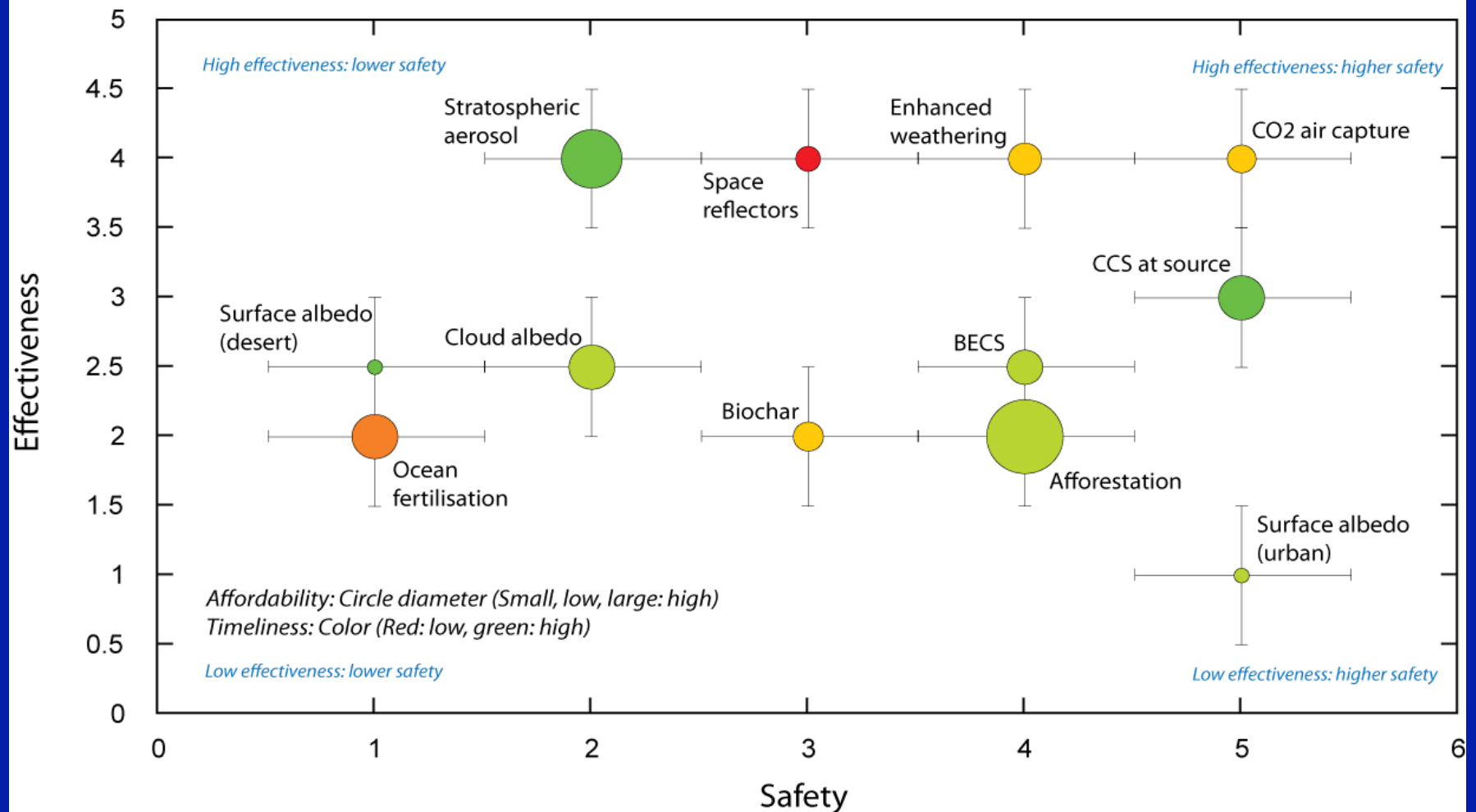


Royal Society, 2009



Geoengineering the Climate

https://royalsociety.org/~media/Royal_Society_Content/policy/publications/2009/8693.pdf



Additional slides for more details

Humans are an incredibly successful species.

- well adapted to the living in the present climate
- able to control/conquer the environment
 - sea walls, control fire (heat), air conditioning
 - agriculture, feeding >7 billion people
 - domesticated animals, can kill dangerous ones
 - conquered disease
 - been everywhere (top of Everest, bottom of sea, moon)
- we should be able to rise to this new challenge



- the Earth's crust is ours to control
 - removing oil and minerals from underground
 - harvesting Nature's bounty (redwoods to fish)
 - controlled rivers



Are we too successful for our own good?

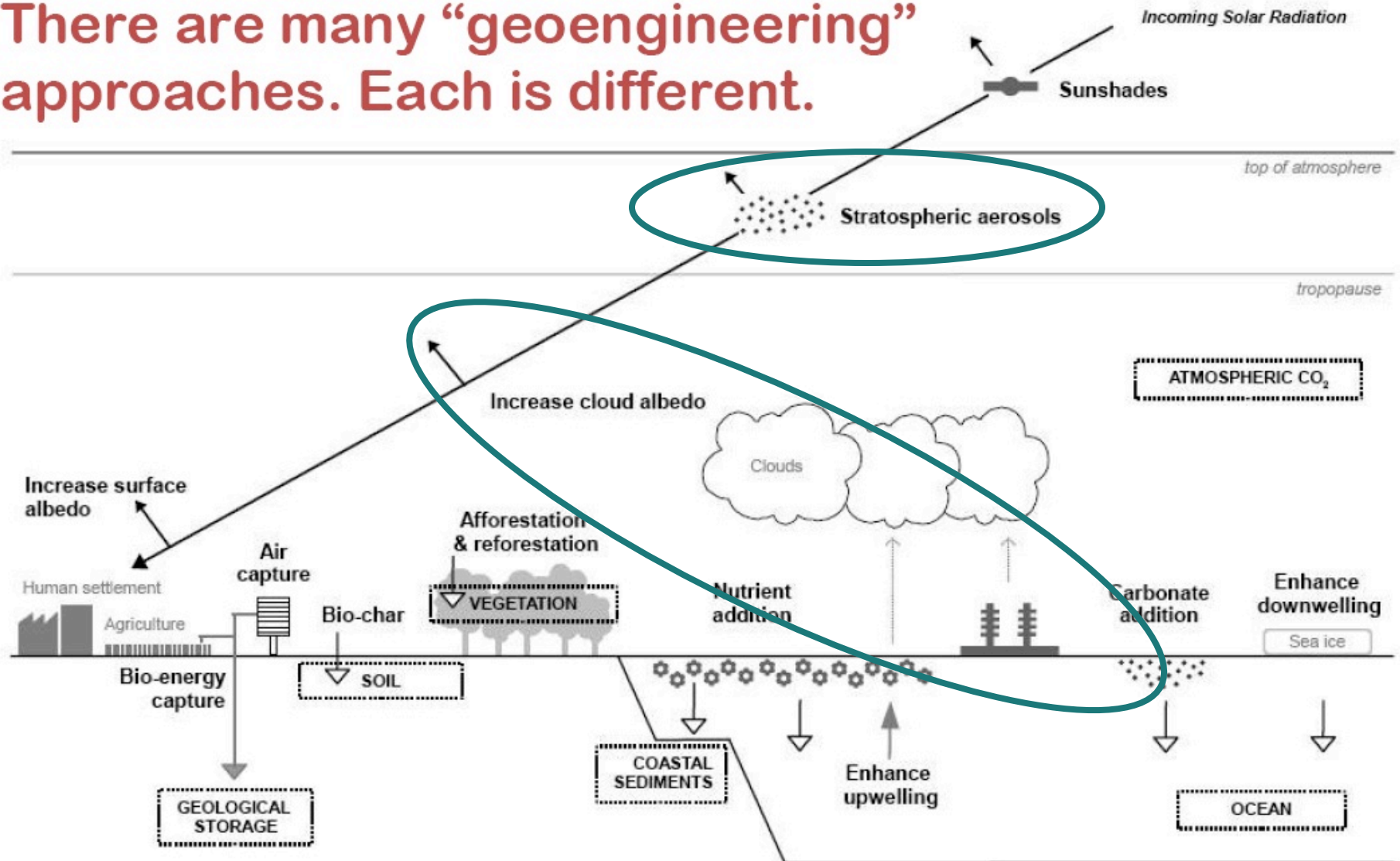
Paul Crutzen advocating research in geo-engineering in 2006



Nobel Prize
Chemistry 1995
Ozone Hole

- Geoengineering discussed for ~50 yr
 - (incl. by Edward Teller in 1990s)
- Terraforming Earth!

There are many “geoengineering” approaches. Each is different.



Credit Warren Wiscombe: NASA, GSFC 2013

Pinatubo eruption June 1991

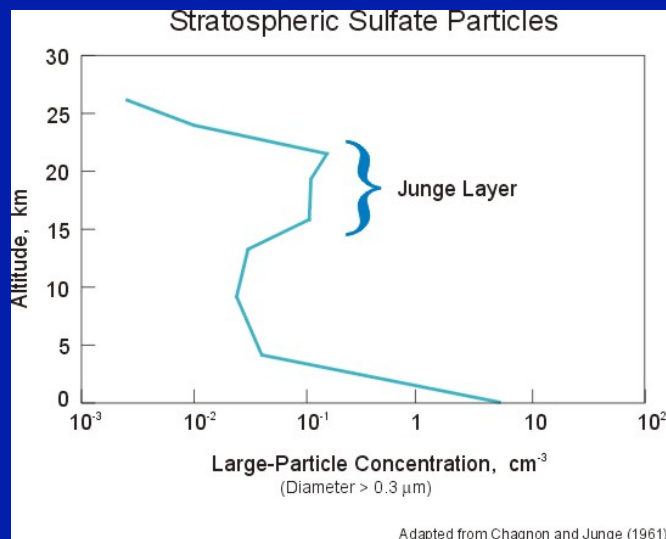


Junge Layer

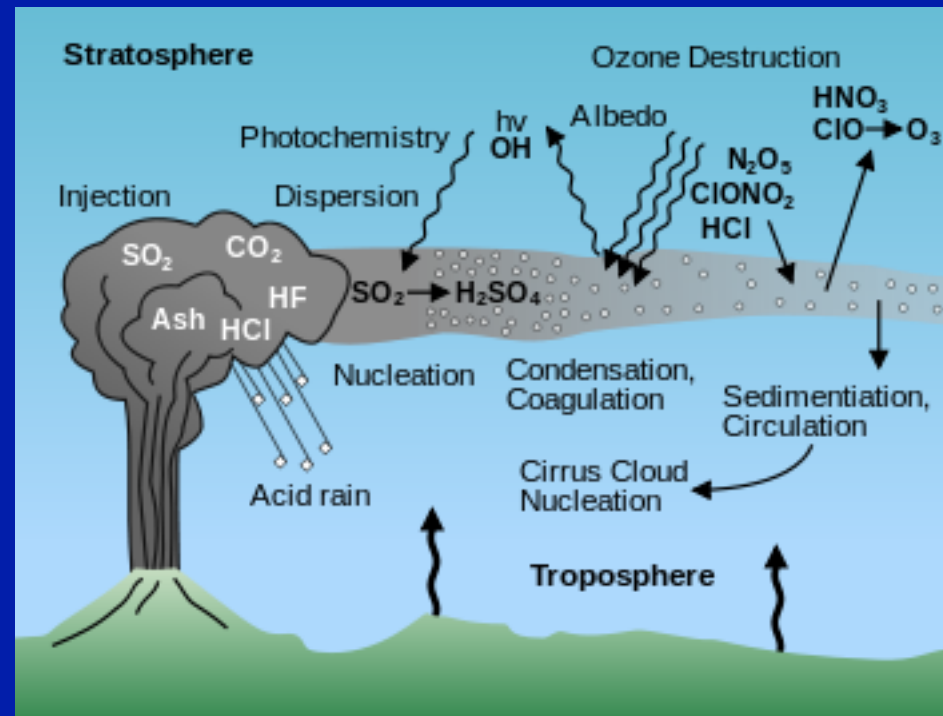
Volcanic sulfates end up here as sulfuric acid droplets and have a strong cooling effect (aka global dimming) on the planet until they fall out over a few years.



Mt. Pinatubo, June 1991



Geo-engineering:
Imitate the natural volcanic action by shooting H₂S and SO₂ into the stratosphere: artillery shells aircraft or stratospheric balloons.



Some of the pros and cons

PRO

- Potent: Could offset all warming from doubling CO₂
- Affordable and feasible
- We know it works – big volcanic eruptions cool Earth this way
- Beautiful sunsets

CON

- Reduces rainfall
- Alters regional climates
 - local famines?
- Cools tropics, not poles
- Won't stop ocean acidification
- Can't stop, else sudden pulse of warming CO₂ takes over
- Will make sky whiter

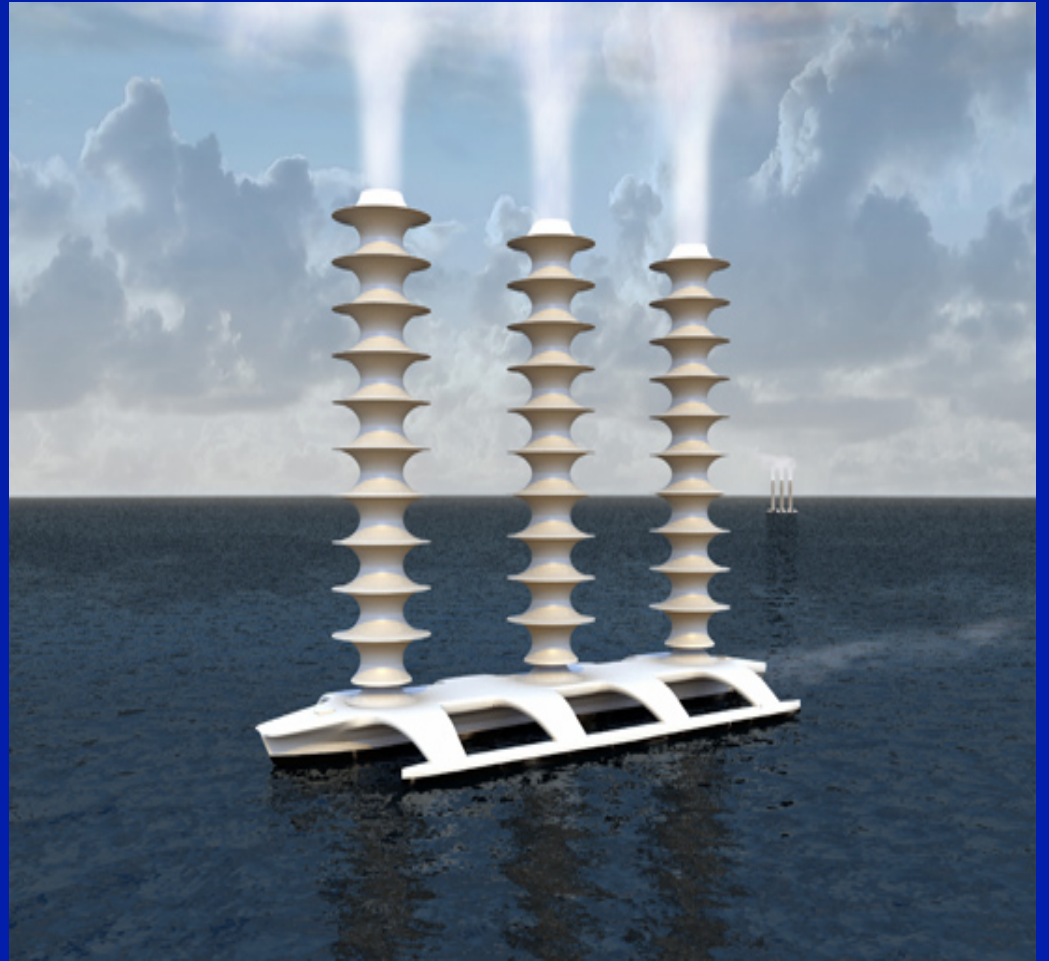
Unintended consequences??

Need to reduce CO₂ emissions anyway.

Should be, and is being, debated.

Modifying low marine clouds (Latham, 1990)

- Flettner rotor ship sprays seawater up
- Resulting salt particles nucleate clouds



You don't need to create clouds to reflect more sunlight,
just modify them to have smaller drops



Credit Warren Wiscombe: NASA, GSFC 2013

Harness the energy in jet stream? (1.5 petawatts) (an aside)

1% would take care of power requirements; 100 times the energy used

- Archer & Caldeira [*Global assessment of high-altitude wind power*, IEEE T. Energy Convers., **2**, 307–319, 2009] claim that the jet streams can generate the total power of 1700 TW, and that the climatic impact will be negligible.

Premature, but humans are an ingenious bunch!

- Miller, Gans, & Kleidon [*Jet stream wind power as a renewable energy resource: little power, big impacts*. Earth Syst. Dynam. Discuss. **2**, 201–212, 2011] claim that the jet streams can generate the total power of only 7.5 TW, and that the climatic impact will be catastrophic.

Cloud reflectivity modification

- Cirrus stripping
 - high cirrus transmits sunlight
 - blocks infrared
- Marine cloud brightening
 - Esp. white clouds with small droplets
 - Twomey effect: small aerosols condense rainless clouds (e.g. contrails)

Seawater spray

- Bursting bubbles of ocean foam
- Ultrasonic excitation of a liquid using a piezo-electric transducer
 - takes lots of energy
- Electrostatic atomization of seawater drops
 - Unmanned spray platforms
 - Cloud seeding yachts
- Ocean sulfur enhancement using iron

Cirrus stripping

It is believed that the synoptic cirrus in the upper troposphere are formed by homogeneous nucleation, resulting in large numbers of small ice crystals. If ice nuclei are introduced into this environment, the cirrus may instead form by heterogeneous nucleation. If the concentration of ice nuclei is tuned such that the resulting cloud particle density is less than for the natural case, the cloud particles should grow larger due to less water vapor competition and attain higher settling velocities. The net effect should be a reduced optical thickness for outgoing infrared radiation and a reduced cloud lifetime. The effects of this modification on the cloud radiative balance operate in different manner from that of the marine stratocumulus cloud brightening scheme. Instead of increasing the incoming shortwave reflectivity and lifetime of the cloud in order to increase the net radiative cooling effect, the outgoing infrared reflectivity and lifetime are reduced thereby decreasing the net radiative heating effect of cirrus. This authors claim that this scheme is sufficient to reverse the warming caused by a doubling of CO₂.

BECCS

burning plants paired with CO₂ capture and burial, aka bioenergy with carbon and capture, or BECCS—might prove vital to restrain global warming. And the U.S. Department of Agriculture provided a \$91-million loan guarantee in October to a company—Cool Planet—looking to build a kind of BECCS facility in Louisiana to make biofuels and biochar, a carbon-rich residual ash that can be used to improve soil fertility, keeping the carbon out of the atmosphere.

Scientific American Article Dec.12, 2014

- Sunlight blocking technologies
 - buy time until energy conversion is complete
 - unless CO₂ is reduced, continual game of catch-up
 - Could be used while CO₂ remains high
 - How to test – takes enormous concentrations
 - unexpected chemistry

http://www.scientificamerican.com/article/fact-or-fiction-geoengineering-can-solve-global-warming/?WT.mc_id=SA_ENGYSUS_20141218