

# Geoengineering and Climate Change: Overview

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One of the most positive developments that emerged from the 15<sup>th</sup> Conference of the Parties to the UNFCCC in 2009 was the recognition in the Copenhagen Accord of the need to keep temperature increases below 2°C (3.6F) relative to pre-industrial levels.

- **Unfortunately**, according to the most recent analyses by Climatic Analytics the post-Copenhagen mitigation reduction pledges made by major GHG States put us on course for temperature increases of between 2.9-3.1°C this century, while the consultancy PWC says we're on a path for a 4C increase by 2100.
  - Study by the World Bank in November 2012 projected that temperatures could increase by as much as 4C by 2060!
- i. A 3-4°C increase in temperatures would be extremely foreboding for human institutions and ecosystems:
  1. For example, a 3°C increase in temperatures could result in the complete melting of the Greenland Ice Sheet over the course of 1000 years, raising sea level an astounding 7 meters
  2. Virtually all coral reefs, which provide habitat for at least one third of all marine species, would be lost under a 3C scenario
  3. A 3-4°C increase in temperatures would threaten 60% of species with extinction
  4. A number of studies project that the thermohaline circulation system could be shut down by temperature increases between 3-4°C, potentially casting much of Europe into Arctic conditions
  5. 3-4°C increase would results in potentially catastrophic declines in agricultural production in developing countries
  6. And once we cross threshold, we're stuck for hundreds to thousand years

The specter of climatic changes of this magnitude has substantially increased interest in geoengineering schemes that might help us avert crossing critical thresholds, or buy us time to develop the will and technology for effective mitigation and adaptation responses

- As defined by the U.S. National Academies of Science geoengineering refers to “options involving large-scale engineering of the environment in order to combat or counteract the effects of changes in atmospheric chemistry” **[SLIDE 2]**
- While such schemes were once considered “taboo” or “forbidden territory” in the context of climate policy making, many members of the scientific and policy community now see a potential role for geoengineering **[SLIDE 3] [SLIDE 4]**

This presentation looks at some of the primary geoengineering options and potential governance options from a policy perspective.

## ROADMAP [SLIDE 5]

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### 1. Overview of Key Geoengineering Options

Geoengineering proposals are generally divided into two categories  
[SLIDE 6]

I will examine a couple of options in each context to seek to demonstrate the potential benefits and risks of such approaches.

#### A. Primary CDR schemes

- a. Ocean Iron Fertilization (OIF) seeks to stimulate production of phytoplankton [SLIDE 7]
  - i. Phytoplankton are microscopic plants found in the world's oceans [SLIDE 8]
  - ii. Phytoplankton obtain energy through the process of photosynthesis, whereby they absorb carbon dioxide from the oceans and convert it to organic carbon, which is stored in the organisms' tissues
    1. Overall, approximately half of the world's photosynthesis occurs in phytoplankton
  - iii. Most of the organic carbon produced in the photosynthetic process is immediately consumed at the surface and converted back to CO<sub>2</sub> and then released into the atmosphere.
    1. However, a small portion of the remainder of the carbon is effectively removed from the system and transported to the deep ocean for storage in the when the organisms die in a process called the "biological pump," or when fecal pellets fall to sea floor [SLIDE 9]
    2. So, some researchers have argued that stimulating the growth of phytoplankton would be great way to reduce concentrations of CO<sub>2</sub> by enhancing sequestration via the biological pump
      - a. Also, some research indicates that increased plankton growth also results in substantial increases in the release of methyl sulfides by the phytoplankton, which would produce more clouds, that could deflect more solar radiation from the Earth

- iv. Where Would It Be Done?:
  - 1. Most researchers who advocate ocean fertilization argue that there are certain areas of the world's oceans, primarily the Southern Ocean, that have high levels of the major macronutrients (especially phosphorous and nitrogen) critical for high levels of phytoplankton productivity, but low levels of a critical micronutrient, iron **[SLIDE 10]**
    - a. This iron deficiency, it's argued, severely limits phytoplankton production in these regions, resulting in the characterization of such ocean areas as "High Nutrient-Low Chlorine" (HNLC) water bodies
  - 2. So, proponents of iron fertilization argue that introducing substantial amounts of iron in these areas to supplement the natural supplies would:
    - a. Stimulate phytoplankton growth, in turn resulting in more uptake of carbon dioxide;
    - b. Ultimately, when the phytoplankton dies, some will drop to the bottom of the ocean below the mixing zone, purportedly sequestering huge amounts of carbon for a century or more **[SLIDE 11]**
- v. Purported Impact of Iron Fertilization:
  - 1. Some proponents claim that iron fertilization could sequester as much as 25% of world's carbon dioxide
  - 2. Argument also made that iron fertilization would be relatively cheap, costing about \$2-\$5 per ton of carbon sequestered
- b. Is Ocean Fertilization Likely to Be Effective?:
  - i. Phytoplankton will only remove CO<sub>2</sub> from air permanently if they die and sink to the bottom of the ocean
    - 1. Evidence does exist that CO<sub>2</sub> concentrations are initially lower where there are large patches of algae **[SLIDE 12]**
    - 2. However, to create permanent reductions in atmospheric concentrations of carbon dioxide, substantial portions of the phytoplankton that are produced by fertilization must die and drop to the bottom.
      - a. But this might not happen:
        - i. Phytoplankton could be eaten by zooplankton, microscopic invertebrate species that feed on algae

1. Zooplankton in turn could be eaten by larger sea creatures, which would release CO<sub>2</sub> back into atmosphere by respiration and excretion
  - a. However, a recent study (2012) did conclude that at least half bloom biomass in one experiment sank far below a depth of 1000 meters, and that a substantial portion is likely to have reached the sea floor.
  - b. Also, much of the organic carbon is remineralized by bacteria back into inorganic carbonate and bicarbonate during the first 500 meters of sinking
- ii. As models of potential for ocean fertilization have become more sophisticated, its prospects have become less hopeful:
  1. Only 3 of 12 iron addition experiments have shown that any sequestration has happened at all;
  2. One study concluded that, at most, the technique would only reduce atmospheric concentrations of CO<sub>2</sub> by 10%
  3. Model developed at Ohio University estimates that even fertilizing the entire 20% of the oceans that are HNLC would only reduce concentrations of CO<sub>2</sub> by about 38ppm
    - a. And another study pegs the decline in atmospheric concentrations to a mere 10ppm because of other limiting factors
  4. Also would require 300,000 ships and 1.6 billion kilograms of iron, obviously can't do it via this distribution mechanism

D. Potential Negative Ramifications of Ocean Fertilization:

- a. Marine systems are very complex; iron fertilization may give rise to a plethora of different phytoplankton species, some of which might be undesirable for food web, or even toxic **[SLIDE 13]**
  1. For example, in one iron fertilization study, the abundance and biomass of one phytoplankton species, *Phaeocystis Antarctica*, was increased; this

species proved unpalatable to mesozooplankton species in the region, which could imperil the trophic web.

2. Overall as a University of Michigan study concluded: “If the wrong species enjoy the most success, the impacts on the marine biosphere could be catastrophic.”
  - b. Fertilization could also result in widespread eutrophication, i.e. proliferation of algae that can choke off light to species and create toxic algae blooms that kill species
    - a. Example in Mediterranean in early 1990s, toxic algae bloom resulted in a massive kill off of dolphins, so called “red tide”
    - b. There was also some speculation that altering plankton growth might alter algae growth which in turn might affect deep ocean iron beds, causing an increase in iron concentrations and further amplifying the effects.
      - a. If this were an unstable scenario, it might reach a scale sufficient to place the Earth back into an ice age.
  - c. Iron fertilization could actually exacerbate climate change:
    1. When phytoplankton begins to die and decay it results in more consumption of oxygen through the respiration process
    2. This could result in anoxic or oxygen-deprived “dead zones”
      - a. Beyond killing lots of species, anoxic environments produce lots of methane and nitrous oxides, two GHGs with much higher global warming potential than CO<sub>2</sub>
        - i. Methane: 21x
        - ii. Nitrous oxides 206x
          1. Believed that the nitrous oxides alone could offset all of the benefits
    3. Recent study of the NAS on potential CDR strategies concluded that “previous studies nearly all agree that deploying ocean iron fertilization at climatically relevant levels poses risks that outweigh potential benefits”
- B. Another approach: Air Capture: [SLIDE 14]**
- a. Would seek to capture carbon dioxide through the use of sorbent materials (e.g. calcium hydroxide or calcium oxide) or a filtering system **[SLIDE 15]**

- b. Proponents argue that we could sequester enough carbon dioxide to return atmospheric concentrations to pre-industrial levels if we wish to
- c. But serious issues with this option also:
  - i. Could cost \$600/ton according recent study of American Physics Society, unless economies of scale arguments correct
    - 1. Proponents contend, however, could bring cost down ultimately to \$25-30 due to economies of scale, and using carbon dioxide to extract oil or to feed algae to produce fuels
  - ii. Also, if need to store the carbon dioxide, need massive infrastructure and adequate storage space
    - 1. NIBMY issues
  - iii. Some efforts to develop markets for CO<sub>2</sub>, which would help on both cost and storage side, but early stages

**C. Another approach: bioenergy carbon capture and sequestration**

**[SLIDE 16]**

- a. Negative emissions are possible
  - i. Cost and storage issues of CCS;
  - ii. Potential social justice issues:
    - 1. Might require up to one-third of croplands for large-scale implementation, so could result in big increases in prices of food, displace agricultural stakeholders

**B. Solar Radiation Management Geoengineering:**

**A. Stratospheric Dispersion of Sulfur Particles: [SLIDE 17]**

- a. One popular proposal is to disperse sulfur dioxide into the stratosphere, which when combined with water vapor, would form sulfate aerosols that would reflect incoming solar radiation back to space **[SLIDE 18]**
- b. In the parlance of climate science, this would reduce “insolation,” i.e. decrease the amount of solar radiation received on Earth’s surfaces
  - i. Study by Caldeira & Wood concluded that we would have to reduce total insolation by 1.84% to restore annual mean temperatures and precipitation to levels seen when concentrations of GHG were approximately 280ppm, i.e. start of Industrial Revolution
- c. A couple of recent studies have concluded that we would need to introduce 5 Tg S year<sup>-1</sup> (5 trillion grams of sulfur) of sulfate aerosols into stratosphere to offset the warming impacts of a doubling of atmospheric carbon dioxide levels **[SLIDE 19]**

- d. Delivery methods:
  - i. Aircraft:
    - 1. Delivery of requisite amount of sulfur aerosols or precursors via aircraft would be formidable task, at minimum would require one million flights of four hours duration
    - 2. Caldeira & Wood have proposed using unmanned airships, e.g. U.S. DOD's High Altitude Airship, with a hose suspended from the ship to disperse aerosols  
**[SLIDE 20]**
  - ii. Artillery shells
  - iii. Weather Balloons
- e. Costs: some studies peg costs very low; for example 2010 study concludes that SRM could offset this century's global average temperature rise 100x more cheaply than emissions cuts
- f. Potential Downsides of this Approach:
  - i. Stratospheric sulfur injection could also result in substantial increases in aridity in some parts of the world
    - 1. Some researchers predict substantial alteration of the hydrologic cycle in the tropics, including large decreases in precipitation (as much as 30% in some studies) over vegetated surfaces as a consequence of reduced evaporation
      - a. Several studies indicated that this could result in the shutdown in some years of the monsoons in Southeast Asia or Africa, threatening the food supply of a billion or more people
        - i. Indeed, after the eruption of Mt. Pinatubo in 1991, with a release of about 5TG of sulfur dioxide, we witnessed the lowest amount of global rainfall in recorded history and the lowest flow rate in history of the Ganges and Amazon rivers
  - ii. Ozone depletion:
    - 1. By cooling stratosphere, the process of breakdown of ozone molecules by ozone-depleting substances would likely be accelerated
    - 2. Estimate is that sulfur dispersion could result in a 40-50 Dobson Unit decline of ozone in Antarctic vortex  
**[SLIDE 21]**
      - a. It could also delay recovery of the ozone layer, devastated by ODSs by 50-70 years!

3. But some argue that increase in UV associated with ozone depletion would be offset by increased light extinction and attenuation by aerosol cloud itself
  - a. A study of impacts of volcanic eruptions show ozone and aerosol effects approximately balanced each other out
- iii. Could reduce effectiveness of solar energy systems, though I don't believe there's been lots of hard research in this context yet
- iv. Could introduce substantial amounts of sulfur dioxide to the troposphere, responsible for acid rain and other maladies:
  1. Ultimately, the particles would drop to the troposphere
  2. One recent study says that the emissions would be around 15% of current sulfur dioxide emissions, which is not unsubstantial
- v. Doesn't address the critical issue of ocean acidification
- vi. Termination effect:
  1. If you ever stop, you get very rapid rises in temperature in the first 10-20 years after ceasing
    - a. Recent study: 3-4C in 11 years, 6-10C in 20 years,
      - i. 20x times more rapidly than in same period of continuous warming under IPCC scenarios
      - ii. Would be very difficult for human and natural ecosystems to adapt to this abrupt change
  2. NAS concluded that such a program would have to continue for up to a MILLENIUM to avoid such effects, until the surplus carbon dioxide is removed from the atmosphere by the ocean and terrestrial ecosystems
- vii. One possible way to ameliorate all these effects: either only regional or limited deployment
  1. However, this assumes that everyone agrees where the thermostat should be set and coordinate responses, big if!

**B. Another SRM Option: Cloud Seeding [SLIDE 22]**

- a. Researchers led by John Latham & Stephen Salter have advocated for dispersing sulfates in the area of low-level maritime clouds:
  - i. This would result in the Twomey effect, i.e., development of extra condensation nuclei for new water drops in such clouds, increasing their albedo, and thus reflecting more incoming radiation back to space
  - ii. Salter et al. proposed using remote controlled, unmanned wind-driven spray vessels to facilitate this [SLIDE 23]

1. Each vessel would be equipped with GPS, allowing it to follow suitable cloud fields, migrate with the seasons, and return to port for maintenance
  2. Salter et al. estimated that a working fleet of 1500 spray vessels would be necessary to keep world temperatures steady with no reductions in carbon dioxide
- b. This approach wouldn't pose threat of ozone depletion for sulfur injection methods, but might alter precipitation patterns also
- C. Another SRM approach: sunshades and deflectors [SLIDE 24]**
- a. The "sunshade" approach:
    - i. Under this proposal, we would launch a rocket with a thin refractive screen, or "sunshade," that would orbit near an in-line point between the sun and Earth, called the Inner Lagrange point **[SLIDE 25]**
  - b. An alternative would be to use a series of smaller flyers in synchronized orbit **[SLIDE 25]**
    - i. Might involve huge amount of small mirrors placed in orbit
    - ii. Object would be to block 1.8% of solar flux and achieve same goal as sulfur dispersion proposals above
  - c. Considered to be most challenging approach:
    - i. Could require 5-16 billion mirrors, which would take a war-like production system and take century to produce
    - ii. Could cost more than \$5 trillion
- D. Overarching concern with all geoengineering approaches: moral hazard

## **2. Governance Implications**

- A. A rationale for establishing an international research program for climate geoengineering:
1. If we do not seek to establish an international geoengineering research program now, several risks:
    - i. We will panic at some point in the future and launch a crash program without having the opportunity to truly assess potential negative impacts certain approaches, or optimal approach
    - ii. Nations may proceed unilaterally without regard for interests of other States
      1. As several commentators have noted, there's a couple of fundamental differences between mitigation

proposals to address climate change and geoengineering proposals:

- a. Whereas mitigation requires concerted action by most major GHG emitting States to make a difference, geoengineering conducted unilaterally could have huge impacts
  - b. And, given the potentially very low cost, there might be a motive for a State to proceed unilaterally and not even pursue cost-sharing, or continue even if others pull out
2. An international research effort might not ultimately stop unilateral deployment by a country, but it would give the international community a chance to develop norms that might prevent more extreme measures at least.
- B. Governance Architecture for Geoengineering Research Program/Potential Deployment:**
- a. Logical for UNFCCC to govern geoengineering research efforts, and perhaps ultimate deployment
    - i. However, it's not clear that UNFCCC has jurisdiction over all forms of geoengineering:
      - 1.** Most likely no argument about CDR geoengineering options because they constitute a form of sink or source of sequestration, and that's clearly contemplated under the treaty **[SLIDE 26]**
      - 2.** But more generally, UNFCCC overarching objective, and focus of commitments is on addressing climate change by reducing emissions and developing adaptation responses **[SLIDE 27]**
        - a.** This does not encompass shortwave radiation management, which would produce its effects independent of the level of atmospheric greenhouse gas concentrations
        - b.** On other hand, Article 3 requires Parties to "protect climate system," so maybe that's the hook for jurisdiction of all geoengineering options
      - 3.** To ensure legitimacy of the UNFCCC's jurisdiction over geoengineering schemes, treaty should be amended to expressly establish treaty purview over such approaches
- C. Architecture for Geoengineering Research:**
- a.** It would probably not be appropriate to call on the Intergovernmental Panel on Climate Change, the primary source of scientific information to the parties to the UNFCCC, to conduct

geoengineering research because its role is primarily to synthesize climate information

**i.** Rather, the optimal approach might be to establish an international research program through a consortium of competent research bodies in a number of different countries

**1.** One model that might provide guidance is the Carbon Sequestration Leadership Forum, a consortium of national research groups seeking to facilitate development of carbon capture and sequestration technologies, including promoting appropriate technical, political and regulatory environments

**2.** The IPCC and the UNFCCC's Subsidiary Body for Scientific and Technological Advice should play an important role in reviewing research results from the consortium and seeking to promulgate such reviews as widely as possible to all UNFCCC parties and the general public

**a.** The IPCC's Subsidiary Body for Implementation also has established a Forum and Work Program on the Impact of Implementation of Response Measures that could play a role in the review process

**3.** The consortium should also embrace relevant principles of adaptive management, including use of the "Blue Team/Red Team" approach, whereby one research team would engage in research to develop highly effective/low risk geoengineering approaches, while another team would try to demonstrate flaws in the research

**b.** Guiding principles for research:

**i.** The research efforts should be focused on preventing temperatures from rising to 2C or more above pre-industrial levels rather than seeking to return temperatures back to pre-industrial levels or totally reversing the potential impact of GHG emissions during this century

**ii.** This would be a beneficial approach for two reasons:

**1.** Could minimize potential side effects of geoengineering schemes.

**a.** For example, Wigley indicates that a sulfur injection scheme that only sought to avert a 2C rise in temperatures by 2050 would have minimal impacts in terms of the ozone layer or regional precipitation

**2.** It would keep pressure on States to develop effective mitigation and adaptation responses, reducing the

“moral hazard” that geo-engineering might otherwise pose

- D. Principles for Potential Deployment of Geoengineering Technologies:
- a. We should develop a protocol under the UNFCCC to govern potential deployment of geoengineering technologies
    - i. We should draw upon pertinent current regimes or soft law documents for provisions, including:
      1. The Convention on Environmental Impact Assessment (Espoo Convention);
      2. The Aarhus Convention;
      3. The ILC Draft Articles on Prevention of Transboundary Harm from Hazardous Activities
  - b. An effort should be made to obtain consensus at the UNFCCC; barring this, a supermajority should be required for deployment of such technologies
  - c. Any scheme should include a provision to compensate those that might be injured by geoengineering schemes, e.g. declines in agricultural production
    - i. UNFCCC provides basis for this with its embrace of the no-harm rule **[SLIDE 28]**
    - ii. Imposing challenges to this approach, however:
      1. Ascribing causality
      2. Funding
      3. Offsets for purported benefits of climate geoengineering protection v. harm via BAU scenario