State of the Science FACT SHEET

Climate Engineering

Climate engineering, also called geoengineering, refers to deliberate, large-scale manipulation of Earth's climate intended to counteract human-caused climate change.

As a world leader in climate science, NOAA has expertise to assess the state of the science and the potential efficacy and consequences of climate engineering proposals. This Fact Sheet explains the basic science of, but does not endorse, climate engineering.

Why discuss 'engineering' the climate?

Some well-established facts and serious global trends motivate climate engineering discussions:

- Increases in atmospheric greenhouse gases (particularly CO_2) at rates and to levels not experienced over at least the past half-million years
- Very slow (thousands of years) natural removal of industrial CO_2 from the atmosphere and oceans
- Ineffective efforts to slow greenhouse gas emissions
- Observed and projected climate warming and associated environmental and societal impacts
- Acidification of ocean surface waters[1] by CO_2

Growing interest in potential climate engineering options necessitates a more complete understanding of the proposed actions and their possible impacts. However, scientific research on climate engineering is in its infancy, with most relevant research published only in the past few years. Studies have just begun to explore the potential environmental and societal consequences of any climate engineering proposals.

Two different climate engineering approaches are most commonly considered:

- Removing some CO_2 from the atmosphere to reduce its greenhouse effect
- Increasing the reflection of sunlight away from Earth back to space, thus cooling the planet

This Fact Sheet describes these approaches. It does not treat the full spectrum of proposals, including capture and storage of industrially emitted CO_2 before it mixes with air.

How might CO_2 be deliberately removed from the atmosphere to reduce climate change?

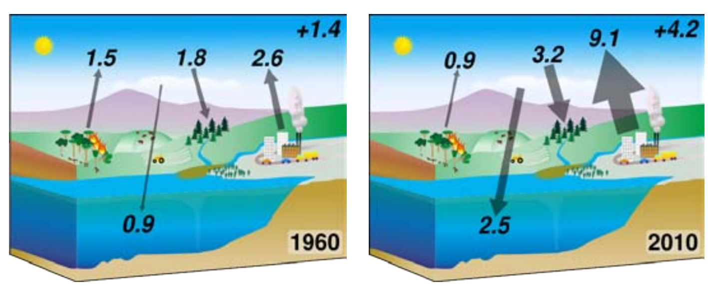
The main greenhouse gas contributing to climate change over the past century is CO_2. Studies have tracked sources of atmospheric CO_2 and its accumulation in the atmosphere, ocean and biosphere (as illustrated). CO_2 emissions and the rate of atmospheric accumulation have grown by about a factor of three over the past half century.

Because fossil fuel use dominates other CO_2 sources, reducing those emissions is the most direct way to influence future atmospheric increases. One class of climate engineering proposals seeks instead to concentrate and remove some CO_2 from the atmosphere and store it on land or in the ocean. Proposals are numerous, but the main categories are:

- Adding nutrients, such as iron, to the ocean to enhance the growth of phytoplankton that remove CO_2 from surface waters (ocean fertilization)
- Capturing atmospheric CO_2 via chemical processes involving specially designed solids or liquids
- Mining and processing silicate or carbonate rocks to accelerate natural chemical weathering processes that involve reaction with CO_2
- Modifying land ecosystems to store more carbon by increasing forested areas
- Turning agricultural wastes that would otherwise decompose and release CO_2 into solid carbon (biochar) or changing farm practices to avoid CO_2 release from soils (no-till)

Basic challenges involve the scale of potential carbon removal activity. To be effective, the amount of CO_2 removed must be enormous, comparable to the emissions of the global energy industry. Removing dilute CO_2 from the global atmosphere requires energy, which may be costly and create additional pollution. Other scientific concerns include:

- Effects of fertilizing ocean surface waters on ocean ecosystems are poorly understood.
- "Permanent" storage options may prove unstable and so undermine long-term removal of atmospheric CO_2.
- Storage in temporary reservoirs (such as plants that return CO_2 to the atmosphere when they die) would require ongoing management.
- Depending on the vegetation they replace, forests planted to absorb CO_2 might reflect less sunlight and so undermine the intended climate cooling effects.



Illustrations show sources of CO_2 (upward arrows) and its accumulation in the atmosphere, oceans, and biosphere (downward arrows), in gigatons of carbon per year, and large increases from 1960 (at left) to 2010 (at right).

[1] NOAA State of the Science Fact Sheet on Ocean Acidification http://nrc.noaa.gov/plans_docs/2008/Ocean_AcidificationFINAL.pdf

How might deliberately reflecting sunlight away from Earth reduce climate change?

Our climate's energy source is the Sun, but not all sunlight warms the Earth. About one third is reflected back to space by the atmosphere (clouds and particles), land (deserts and snow), and ice-covered ocean. A class of proposals seeks to counter some global warming by increasing reflection of sunlight (as illustrated). These include:

- Placing mirrors between Earth and Sun, either in the atmosphere or in space
- Injecting reflective particles into the stratosphere, to mimic the process leading to global surface cooling following explosive volcanic eruptions
- Brightening low-level clouds over oceans by injecting particles to increase concentrations of smaller, more reflective cloud droplets

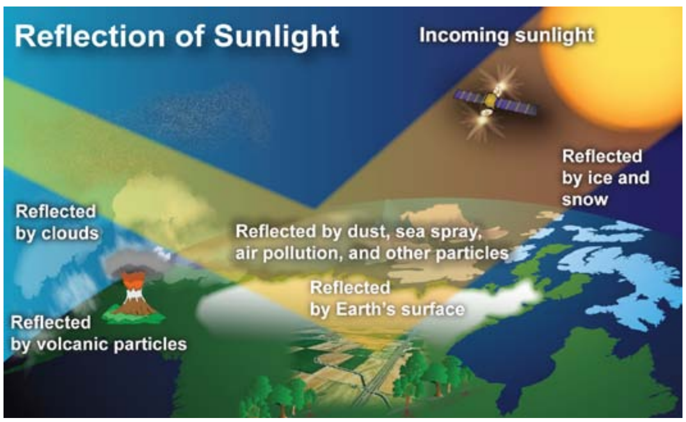


Illustration of the main ways sunlight is reflected away from Earth

Scientific understanding of these reflection processes and their effects on climate varies. The effect of mirrors can be more readily estimated, because interactions with other aspects of the environment are limited. Explosive volcanic eruptions have provided some opportunity to study short-term effects of stratospheric particles on atmospheric temperature (stratospheric warming and surface cooling) and ozone (depletion of the protective stratospheric ozone layer). Cloud research has revealed complex interactions between particles and clouds, so net effects of injected particles on global or local climate are difficult to predict.[2]

Other scientific concerns are:

- Increasing reflection of sunlight does not address atmospheric CO_2 increase and related environmental impacts, such as ocean acidification and changes in land and ocean food chains and ecosystems.
- Atmospheric particles are relatively short-lived (lasting a few days in the lower atmosphere and a few years in the stratosphere), so maintaining their brightening effect would require ongoing injections.
- Once initiated, ceasing actions to increase reflection of sunlight could lead to more rapid climate changes than would otherwise have occurred.

Legal, Ethical and Societal Concerns

In addition to scientific challenges, climate engineering proposals have serious and complex ethical and legal dimensions and raise social, political and economic questions, including:

- What standards should constrain climate engineering research or dissemination of results that could be used to do harm?
- If climate engineering would benefit some people and harm others, how could gains and losses be weighed?
- Would it be fair to adopt technologies that involve commitments by future generations to maintain them?
- Pursuing climate engineering may undermine efforts to reduce emissions or be more resilient to climate change. Are the resulting avoidable risks justifiable?
- How can societies and political institutions organize themselves to best address such questions?

Currently, no regulatory, legal or ethical framework (such as those required for the biological and medical sciences) provides oversight of climate engineering research or implementation. Internationally, no legal framework exists to comprehensively govern climate engineering. However, certain international agreements, such as the London Convention/Protocol (covering dumping wastes at sea), have addressed specific activities, such as ocean fertilization and storage of CO_2 below the ocean floor.

Because fully controlled experiments (with and without an intervention) cannot be undertaken in the real world, it is difficult to verify that a modification achieves its goal and to gauge risks of unintended, possibly harmful, consequences. Experience with weather modification, a somewhat analogous issue, has demonstrated these challenges, which are especially relevant to climate engineering.

NOAA Resources and Capabilities

NOAA science investigates and informs many complex and controversial environmental issues, such as ozone depletion and ocean acidification. Its research programs and scientific integrity policies provide a foundation for sound scientific input to decision-making. NOAA scientific expertise relevant to climate engineering includes atmospheric physics and chemistry, climatology, oceanography, biology, ecology, economics and social sciences. NOAA participates in international and domestic ocean fertilization policy discussions.

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[2] NOAA State of the Science Fact Sheet on Aerosols & Climate http://nrc.noaa.gov/plans_docs/SOSFactSheet_AerosolsandClimate_October2011.pdf