State of the Science FACT SHEET

Climate Intervention

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION • UNITED STATES DEPARTMENT OF COMMERCE

Climate Intervention (CI), also called climate engineering or geoengineering, refers to deliberate, large-scale actions intended to counteract aspects of climate change. This Fact Sheet explains some of the fundamental principles and issues associated with CI *(1)*.

Why Might Climate Intervention Be Considered?

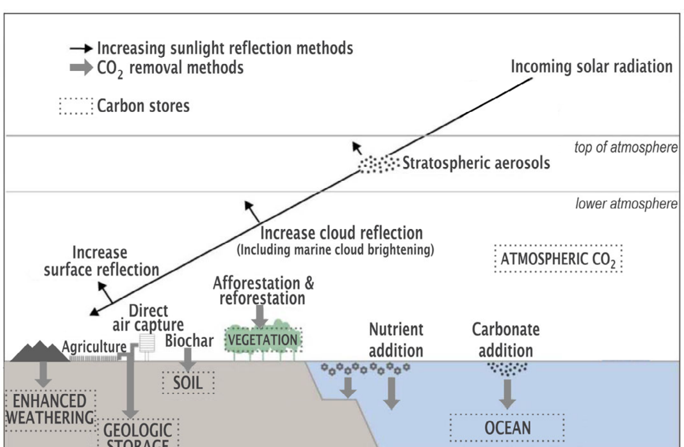
The main driver of climate change over the past century has been anthropogenic emissions of carbon dioxide (CO_2), a greenhouse gas (GHG). Increasing emission rates have caused present-day atmospheric CO_2 to reach the highest value in over a million years based on studies of emissions of atmospheric CO_2 and its accumulation in the atmosphere, ocean, and terrestrial biosphere. The increased emissions of other GHGs, such as methane, nitrous oxide and ozone, also contribute to anthropogenic climate change. The increased accumulation of GHGs has led to warming over much of the globe, to acidification of ocean surface waters (from CO_2) *(2)*, and to many other well-documented climate impacts *(3)*.

As climate change continues, if the world does not make the desired greenhouse gas emissions reductions (4) such as those initiated by the Paris agreement *(5),* governments and other entities might turn to CI to counteract increasing climate change impacts. CI could potentially be implemented by consensus or unilaterally; either way, a thorough understanding of CI methods, and their associated uncertainties and unintended side effects is essential.

Principal CI methods are divided into two general categories (*6*) (see figure):

Carbon dioxide removal (CDR): CDR is a process to remove CO_2 from the atmosphere for long-term storage on land or in the oceans. CDR reduces the accumulation of atmospheric CO_2, thereby directly addressing the major underlying cause of climate change.

Increase in sunlight reflectance: Reflecting more incoming sunlight away from Earth cools the planet. This category of CI methods seeks to counter some global warming by using particles or other materials to lead to an increase in sunlight reflection. Proposed methods would reduce surface temperatures much more quickly than CDR. These methods reduce warming without addressing the fundamental cause, and do not offset the full impact of carbon emissions, which includes, for example, ocean acidification and regional temperature and precipitation changes.



Adapted from Bracmort and Lattanzio, Geoengineering: Governance and technology policy, 2013
Originally from Lenton and Vaughan, Atmos. Chem. Phys., 9, 5539-5561, 2009

Figure. *Illustration of some principal methods proposed for climate intervention.*

How might CDR be accomplished?

Oceanic sequestration: Adding nutrients, such as iron, to "fertilize" the ocean enhances biological growth (e.g., phytoplankton), which removes CO_2 from surface waters and leads to lower atmospheric levels. Large-scale cultivation of macroalgae in the ocean can also remove CO_2. Both methods result in the sinking of biomass into the deep ocean for CO_2 sequestration. Also, increasing the alkalinity of the ocean by adding carbonate, such as limestone, or through electrochemical processes enhances long-term carbon sequestration in the oceans while reducing ocean acidification.

Blue carbon: CO_2 removal from the atmosphere can be increased by management of the world's coastal ocean ecosystems (e.g., salt marshes, mangroves, and seagrasses) through enhanced growth and the resulting accumulation and sedimentation of organic matter to the seafloor.

Accelerated weathering and mineral carbonation: Systematic mining and processing of silicate or carbonate rocks accelerate natural chemical weathering processes that sequester CO_2.

Reforestation and afforestation: Increasing forested areas increases the amount of carbon removed from the atmosphere and sequestered in trees.

Agricultural sequestration: Agricultural waste that would otherwise decompose and release CO_2 to the atmosphere can be turned into solid carbon (biochar), a material that sequesters carbon and can increase soil productivity. Other farm practices can also be changed to reduce CO_2 release from soils (e.g., no-till).

Direct air capture and sequestration: Atmospheric CO_2 can be captured with chemical, biological or physical processes and converted into solids or liquids to be stored on Earth's surface or underground.

A fundamental challenge is to achieve the enormous scale of required carbon removal on a suitably rapid timescale. To have a substantial effect, the amount of CO_2 removed must be a significant fraction of the atmospheric CO_2 increase in the industrial era.

Scientific concerns about CDR include:

• **Unintended side effects**: Large-scale CDR actions may have a variety of unintended side effects. For example, the side effects of fertilizing ocean surface waters on ocean ecosystems are not fully understood and could include depletion of subsurface oxygen and widespread harmful effects on ocean life. Depending on the vegetation they replace, forests planted to absorb CO_2 might reflect less sunlight and so undermine the intended climate cooling effects. Increased nitrogen needs for biochar and afforestation might offset substantial climate gains from CO_2 reduction. Several other CDR methods also may increase nitrous oxide (N_2O) and other greenhouse gases such as methane (CH_4).

• **Storage**: Current options for long-term carbon sequestration may prove unstable and thus undermine goals for long-term removal of atmospheric CO_2. Temporary reservoirs, such as plants and trees, which return CO_2 to the atmosphere when they die, require ongoing management to offset any long-term atmospheric accumulation of CO_2.

How might sunlight reflectance be increased?

Stratospheric injection: Substantially increasing the abundance of particles in the stratosphere by sulfur or sulphate particle injection would cause global surface cooling similar to that which follows explosive volcanic eruptions. Injection of some types of non-sulfate particles may also be effective.

Marine cloud brightening (MCB): Injecting particles into low-level clouds over certain ocean regions could increase sunlight reflection by increasing the number of small cloud droplets.

Implications of increasing sunlight reflectance: These methods applied at a global scale are expected to lower surface temperatures more quickly than CDR methods and for lower initial costs than emissions mitigation. However, scientific understanding of the methods is incomplete and potentially large risks and uncertainties remain. In addition, while surface temperatures respond rapidly to increased sunlight reflection, ocean heat content and sea-level respond substantially slower.

Scientific concerns about increasing sunlight reflectance include:

• **Unintended side effects**: Despite a general understanding of the effects of some of these methods on global temperature, large uncertainties exist for projected changes in other critical variables that accompany the global temperature changes, such as the hydrological cycle and frequency of extreme weather events. Model studies find significant changes in precipitation, including regional extremes, in response to increased sunlight reflection. Explosive volcanic eruptions have demonstrated that short-term effects of stratospheric particles include enhanced depletion of the protective stratospheric ozone layer; while these eruptions are indicative of the type of changes stratospheric particles can cause, they are not representative of the full range of possible impacts of this CI method. Research on low-level clouds has also revealed complex interactions with particles, so the net effect of injecting particles into the lower atmosphere on global and local climate is also difficult to project accurately (*7*).

• **Long-term commitment**: Atmospheric particles are relatively short-lived, lasting a few days in the lower atmosphere and a few years in the stratosphere, so maintaining enhanced reflectivity requires ongoing injections. Once initiated, ceasing actions abruptly, whether due to negative side effects, loss of interest, equipment failure, etc., could lead to more rapid climate change than would otherwise have occurred in the absence of these actions. Such change may be more difficult to adapt to than the change that would have occurred without the CI action.

• **Inability to reverse all changes in climate**: While some effects of climate change may be reversed in some regions, increased sunlight reflection cannot reverse all climate changes everywhere; in fact, it may impact society positively in some locations and negatively in others. This uneven distribution of benefits and consequences introduces potentially significant geopolitical concerns (e.g., who has authority to deploy methods and how to balance the interests of various nations).

Are there other considerations with CI methods?

CI methods are associated with various ethical and legal concerns. Currently, no governance framework (such as required for the biological and medical sciences) provides oversight for general CI research or implementation. International agreements, such as the London Convention and London Protocol (*8*) (covering marine pollution), have addressed specific activities, such as ocean fertilization and storage of CO_2 below the ocean floor, but currently no regulation covers employing or demonstrating most CI methods.

Development, implementation, and monitoring costs of CI methods would likely play a key role in the choice of CI technology to deploy. As technologies advance, different CI methods may gain or lose favor. Currently, there is a wide range in cost, efficacy, unintended side effects, and risk for the various CI methods.

NOAA resources and capabilities

NOAA investigates many complex environmental issues that require assessment and risk/benefit evaluation. NOAA's research programs and scientific integrity policy provide a foundation for developing sound scientific input to environmental decision-making. NOAA's relevant scientific expertise includes atmospheric physics and chemistry, climatology, oceanography, biology, ecology, and economics and social sciences.

References

(1) Lawrence, M.G., et al., 2018. Evaluating climate geoengineering proposals in the context of the Paris Agreement temperature goals, *Nature Comm*., 9, 1-19.

(2) See NOAA State of the Science Fact Sheet on Ocean Acidification (https://pmel.noaa.gov/co2/files/noaa_oa_factsheet.pdf)

(3) IPCC Fifth Assessment Report (2013) (https://www.ipcc.ch/report/ar5), and U.S. National Climate Assessment (2014) (http://nca2014.globalchange.gov/report)

(4) Global Warming of 1.5°C, an IPCC Special Report, 2018 https://www.ipcc.ch/sr15/).

(5) 2015 Paris Climate Conference (https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf)

(6) Sunlight reflection and CDR CI methods have been assessed by the National Academy of Sciences (NAS), 2015 (https://www.nap.edu/)

(7) NOAA State of the Science Fact Sheet on Aerosols & Climate (https://csl.noaa.gov/factsheets/aerosolsandclimatesos.pdf)

(8) https://www.gc.noaa.gov/gcil_geoengineering.html