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GEOENGINEERING

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Geoengineering is a controversial strategy to tackle global warming. It has recently attracted the interest of scientists and policy-makers around the world as we continue to rely on fossil fuels like coal and oil for energy, with limited cuts to global greenhouse gas emissions. There is currently little governance of geoengineering, and any action taken by individual countries or companies could have far-reaching implications for the entire planet. This paper provides an overview of the science behind some of the better-studied geoengineering strategies.

Overview

Geoengineering is an attempt to combat global warming independently of reducing greenhouse gas emissions from human activities. There are serious risks associated with some geoengineering methods and they remain unproven.

Geoengineering strategies fall into two broad categories:

- ▶ Carbon dioxide (CO₂) removal techniques reduce the CO₂ concentration in the atmosphere by locking away carbon in places where it cannot contribute to global warming. For example, ocean fertilisation would aim to increase the transfer of carbon from the atmosphere to the deep ocean.
- ▶ Solar radiation management aims to reflect some sunlight back into space, reducing the amount of heat reaching the Earth's surface from the sun. Placing sulphate particles (aerosols) high in the atmosphere is one example of a strategy to reflect sunlight away from Earth.

Background

Naturally occurring greenhouse gases in the atmosphere keep the Earth at a temperature warm enough to sustain life¹. With the burning of fossil fuels in modern industrial times, the concentration of these gases has increased significantly (about 40% above pre-industrial levels^{2,3}). Great concerns exist about the extra warming caused by increased concentrations of greenhouse gases.

Fossil fuel-derived greenhouse gases, mainly carbon dioxide (CO₂), have given rise to much of the human-induced global warming already observed⁴. Elevated CO₂ levels have also increased ocean acidification, whereby CO₂ dissolving in the ocean alters the environment for ocean plant and animal life⁵. While CO₂ is an essential component of life on Earth, the increased concentration and rate of increase (far above any experienced in the past million years or so⁶) in the atmosphere and oceans are cause for concern⁷.

One approach to tackle human-induced global warming is to reduce the production of greenhouse gases. Another approach is termed geoengineering - also referred to as climate remediation⁸.

Geoengineering is defined here as the deliberate manipulation of physical, chemical, or biological aspects of the Earth system to counter global warming⁹. It focuses on tackling the effects of greenhouse gases, or removing the gases, after they have been emitted. The methods discussed may counter global warming, but they do not mitigate the underlying causes, namely greenhouse gas emissions. Further, they introduce their own risks and uncertainties¹⁰.

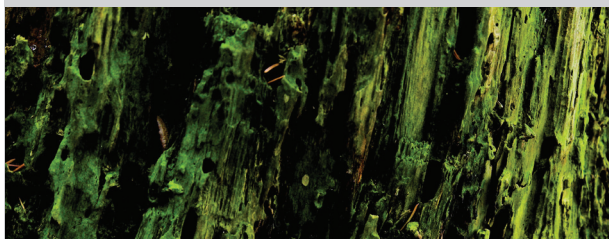
In the following sections we review two geoengineering strategies under current discussion⁸: 1) carbon dioxide removal and 2) solar radiation management.

Carbon dioxide removal

Carbon moves between various natural systems, including the atmosphere, land and ocean. This is known as the global carbon cycle. Land and ocean systems play an important role in the global carbon cycle and have absorbed from the atmosphere about half of all fossil-fuel CO₂ emissions to date². When carbon is stored in land or ocean systems, it cannot contribute to global warming, leading to consideration of ways to enhance these carbon stores to reduce atmospheric CO₂.

Box 1 | Carbon dioxide removal

Here are some examples of proposed carbon dioxide removal techniques. Some are relatively well-tested and low-risk, while others are untested and carry higher levels of uncertainty and risk (see Further Reading).



- Afforestation – the planting of forests to store carbon.
- Biochar – in the absence of oxygen, burning plant and other waste can result in solid carbon that is locked away for long periods.
- Agricultural management to increase carbon storage in the soil – e.g. no-till cropping.
- Carbon capture and storage – collecting CO₂ from the atmosphere or a high-CO₂ source (e.g. power plant) for long-term storage.
- Silicate weathering – silicate rocks react with CO₂, removing it from the atmosphere as a natural process. This reaction can be accelerated by artificial means.
- Ocean fertilisation – see main text.
- Increasing ocean alkalinity – introducing alkaline materials into the oceans may increase CO₂ absorption.

Geoengineering strategies that use this approach are termed *carbon dioxide removal*⁹. Some of these strategies are discussed here; see Box 1 for other examples.

On the land, planting forests has already been implemented as a means of building carbon stores¹¹. This approach can reduce atmospheric CO₂ and also provides benefits to ecosystems, such as improvements to land and water quality¹¹. The amount of carbon that can be stored by planting forests is limited by many factors, including the availability of suitable land, water and nutrients. Estimates suggest that, at best, about 2 to 4 per cent of greenhouse gas emissions from human activities could be offset in this way⁹.

The Earth's oceans store CO₂ through a variety of naturally occurring processes¹². One way to increase oceanic CO₂ uptake is to promote the biological transfer of carbon from the surface into the deep ocean¹³. This strategy, known as ocean fertilisation, focuses on accelerating algae growth at the ocean surface^{14,15}. Algae are simple plants that can convert CO₂ into organic carbon, using energy from the sun. A lot of the carbon absorbed this way is soon converted back to CO₂, through a process called respiration, and is released back to the atmosphere (Box 2). However, some of the carbon (in the cells of dead algae and other particles) can sink to the deep ocean¹⁶. Carbon in the deep ocean may remain there for very long periods, thus not contributing to global warming.

The conversion of CO₂ is limited by the availability of nutrients for the algae. The aim of ocean fertilisation then, is to increase nutrient availability to stimulate algal growth¹⁷. Stimulating CO₂ consumption by algae in the ocean would possibly increase its storage in the deep ocean.

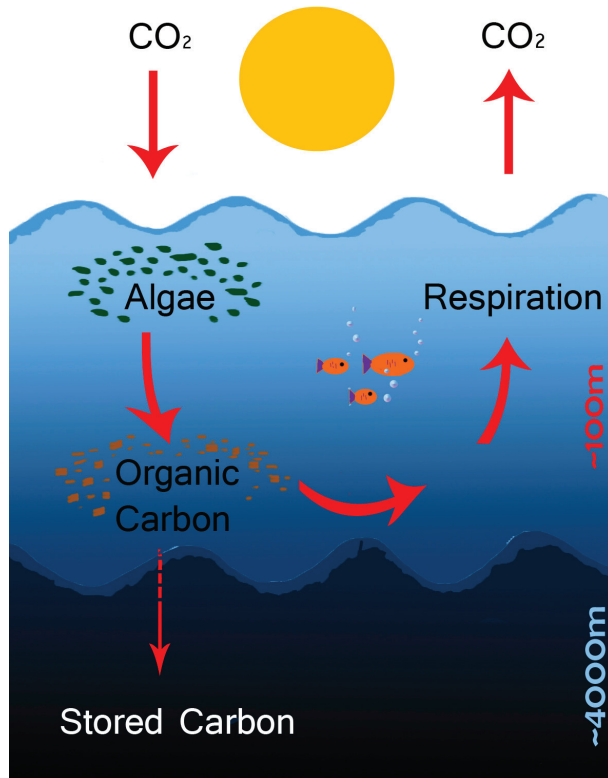
Depending on the location within the ocean, the nutrients required for increased algae growth will vary¹⁷. Nitrogen and phosphorous are nutrients required in large amounts by algae, and are the limiting factor for algae growth in most of the ocean. Increasing algae growth within these areas would require very large inputs of nitrogen and phosphorous¹⁷.

Some areas, like the Southern Ocean, have abundant nitrogen and phosphorous, but are lacking in micronutrients (nutrients required only in small amounts). One such micronutrient is iron, required by algae in significantly smaller amounts than nitrogen or phosphorous¹⁷. Large-scale experiments have shown that fertilising ocean regions with iron where micronutrients are low increases algae growth and CO₂ uptake¹⁸.

Ocean fertilisation would only be effective at tackling global warming if significant amounts of carbon were to sink very deep into the ocean (more than around 1km deep) and remain there for long periods (at least 100 years)¹⁶.

Box 2

Like plants on land, algae convert CO_2 to organic carbon, most of which is converted back into CO_2 via respiration. However, some of the carbon sinks to the deep ocean where it may remain for long periods. One geoengineering approach, ocean fertilisation, aims to promote the growth of algae at the ocean surface, which may in turn promote the storage of carbon in the deep ocean.



This is in question, since most of the CO_2 absorbed by algae is returned to the atmosphere by marine organisms that feed on the algae¹⁹. Ocean mixing would also promote CO_2 transfer back to the atmosphere²⁰. Another limitation is that the fertilisation process would have to be continued indefinitely to achieve ongoing CO_2 removal. Estimates of the maximum benefit possible through large-scale and sustained ocean fertilisation suggest that, at most, only a few per cent of human emissions could be offset in this way⁹.

Side effects of fertilisation could include the production of oxygen-starved deep waters where fish cannot survive²¹. Low-oxygen water can also stimulate production of nitrous oxide, itself a greenhouse gas. Similarly, fertilisation may increase calcium carbonate production, a process that could offset the additional CO_2 uptake²¹. Fertilisation of one ocean area may also deprive other ocean areas of nutrients and reduce their productivity. Marine ecosystems may be altered, with still poorly-understood effects on fisheries. Surface ocean acidification may be reduced as carbon is transferred to deeper water, but acidification would be amplified at those depths²².

Solar radiation management with sulphate aerosols

Solar radiation management (SRM) aims to counter global warming by reflecting some sunlight back into space, reducing the amount of heat reaching the Earth's surface⁹. Box 3 lists some SRM methods currently under consideration.

The most commonly discussed method of SRM is the release of sulphate aerosols (sulphur-containing particles suspended in the air) high into the atmosphere to a region called the stratosphere (see Box 4). The sulphate aerosols would make the stratosphere more reflective, scattering sunlight away from Earth. This happens occasionally by natural means: when a volcanic eruption releases a large amount of sulphates into the stratosphere, a cooling effect is observed for a few years²³. Injections of sulphate aerosols into the stratosphere would mimic this process and could induce cooling^{24,25}.

Techniques for getting sulphate aerosols to the upper atmosphere include weather balloons, high altitude planes, or long tubes supported by balloons connected to a sulphate source^{9,26}. The latter strategy appears to be the most technologically and financially feasible method of SRM^{9,10}.

The major benefit of reflecting sunlight away from Earth is that it would operate quickly to reduce surface temperatures²⁷. However, SRM would not reverse the underlying cause of global warming: growing emissions of greenhouse gases. Also, other emissions-associated impacts like ocean acidification would remain. Since greenhouse gases from human activities tend to accumulate in the atmosphere, SRM options would have to be continued indefinitely to have a long-term effect. If they failed or were stopped, temperatures would increase within a few years. On the other hand, the quick reversal of temperature once SRM is stopped could act as a failsafe if undesired consequences develop.

Box 3 | Solar radiation management

Here are some examples of proposed SRM techniques. These are largely untested and carry high levels of uncertainty and risk. See Further Reading for more information.

- Increasing earth surface reflectivity – painting urban structures (e.g. roofs) white, cultivating highly reflective plants or placing reflective materials in deserts or on the ocean.
- Space mirrors – reducing the amount of sunlight that reaches the earth by putting reflective materials in space.
- Cloud whitening – increasing the reflectivity and amount of clouds.
- Sulphate aerosols – see main text.

Risks of SRM include possible unintended consequences to climate patterns. For example, there is some evidence SRM may reduce precipitation on land and contribute to drought risk²⁷. Sulphates already released into the atmosphere by burning fossil fuels may have partly masked global warming²⁸, but have also led to the occurrence of acid rain. SRM using sulphate aerosols could potentially increase the incidence of acid rain (although only slightly, as the amount of sulphates required is much lower than current releases from fossil fuel burning, and the release is aimed at a much higher altitude)²⁹. Sulphate aerosols can also impede ozone formation, potentially hampering ozone layer regeneration²⁸. Other impacts that are less certain include reduced solar energy for power generation, effects on agricultural production, and whitening of the sky³⁰.

Governance

There is currently little governance of geoengineering at national or international levels. However, various international bodies have expressed concerns over the associated risks. The UN Convention on Biological Diversity called for governments to ensure “that no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities...with the exception of small scale scientific research studies”³¹. The European Parliament similarly expressed its opposition to large-scale geoengineering³². In 2008 a non-binding resolution to the London Protocol on Ocean Dumping classed ocean fertilisation activities, other than for legitimate scientific research, as contrary to the aims of

the convention³³. At this stage these resolutions are the only international instruments dealing intentionally and specifically with geoengineering.

Conclusion

Given the difficulty in implementing global action to reduce CO₂ emissions from human activities and their continued growth^{2,3}, geoengineering is one possible approach to combat global warming. Geoengineering would not moderate all the effects of rising emissions, and will introduce its own risks and uncertainties¹⁰. The UK Royal Society, while recommending research into geoengineering options, notes “all of the geoengineering methods assessed have major uncertainties in their likely costs, effectiveness or associated risks and are unlikely to be ready for deployment in the short to medium term.”⁹ The US Task Force on Climate Remediation Research similarly has “not recommended deployment of climate remediation technologies, because far more research is needed to understand the potential impacts, risks, and costs associated with specific technologies.”⁸ Scientific research into the usefulness and safety of geoengineering needs to proceed so that the best information is available for policy discussions.

Further Reading

[Royal Society \(2009\), Geoengineering the Climate: Science, Governance and Uncertainty.](#)

[Task Force on Climate Remediation Research \(2011\), Geoengineering](#)

[Olson, R. L. \(2011\) Geoengineering for Decision Makers.](#)

References & Acknowledgements

The reference list is available at:
chiefscientist.gov.au/2012/04/ops1/

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