Geo Factsheet

www.curriculum-press.co.uk Number 286

Geoengineering – the ultimate global warming solution?

Introduction

Geoengineering involves humans deliberately altering Earth's environment, on a regional or even global scale, to make the planet more habitable. Today, geoengineering solutions are most often linked to 'solving' the global warming problem but large scale remodelling of the land surface and regional scale river diversions can also be classed as geoengineering (Figure 1).

Figure 1 Types of geoengineering

Climate modification		Other environmental modifications
Solar radiation management Reducing the amount of solar radiation at the earth's surface	**Greenhouse gas remediation (carbon dioxide removal)** Removal of carbon dioxide from the atmosphere	• Regional water transfers • Greening deserts / reversing desertification

For centuries humans have used technology, especially civil engineering (construction), to modify their environment and make it more habitable. Geoengineering differs from traditional civil engineering because it is very large, even global in scale and is as yet theoretical. Using technology to 'engineer the Earth' is controversial. Its use raises a number of issues:

- Why have humans let the global warming problem get so serious in the first place?
- Should humans be inventing yet more technology, to solve problems their technology created?
- Should humans attempt to solve problems with solutions that have unknown risks?

Adaptation, mitigation or geoengineering?

Global warming is now widely accepted by scientists and politicians as a problem that requires a solution. There are three ways the problem could be tackled (Table 1).

Table 1 Options for tackling global warming

Mitigation	Deal with the underlying cause of global warming by reducing emissions of gases which cause the enhanced greenhouse effect (carbon dioxide, methane, nitrogen oxides) aiming to slow or reverse global warming.
Adaptation	Deal with the symptoms of global warming by adapting to a changed climate; human populations would need to use technology to cope with rising sea levels, changes in rainfall patterns and increased temperatures.
Geoengineering	Use new technologies to limit the impact of increased levels of greenhouse gases by reducing the degree of global warming.

Some organisations, such as the UK based Institution of Mechanical Engineers, advocate the 'MAG' approach which combines mitigation, adaptation and geoengineering - rather than relying on one approach only. The MAG approach recognises that:

- Agreement on global mitigation is unlikely to occur quickly enough to prevent some global warming – the most recent climate change summit in Durban in December 2011 delayed significant global action on emissions until 2020.
- Some adaptation will be required whatever happens because global warming is already built into the system.
- Geoengineering, although controversial, has the potential to reduce some of the harmful impacts of global warming relatively quickly.

The MAG approach might have the flexibility to help developing regions adapt to immediate warming threats, while using geoengineering as a short term global response alongside continued efforts to get global agreement on mitigation.

Technological Fix or Attitudinal Fix?

Those in favour of mitigation advocate an attitudinal fix to global warming, arguing that pollution levels need to be reduced by changing human behaviour e.g. using fewer fossil fuels by switching to renewable energy sources. Adaptation, and some geoengineering solutions, involve technological fixes. Rather than prevent pollution, technology is used to solve the problems caused by pollution. This might include higher sea walls, flood defences, drought resistant crops or large scale water diversions. Figure 2 shows differing views on geoengineering.

Figure 2: Views on geoengineering

"Over the past couple of years, it's gone from an outsider thing to something that is increasingly discussed" *(Ken Caldeira, Carnegie Institution for Science at Stanford University)*

"Knowledge that geo-engineering is possible makes the climate impacts look less fearsome. And that makes a weaker commitment to cutting emissions today." *(David Keith , Professor of Applied Physics, Harvard University)*

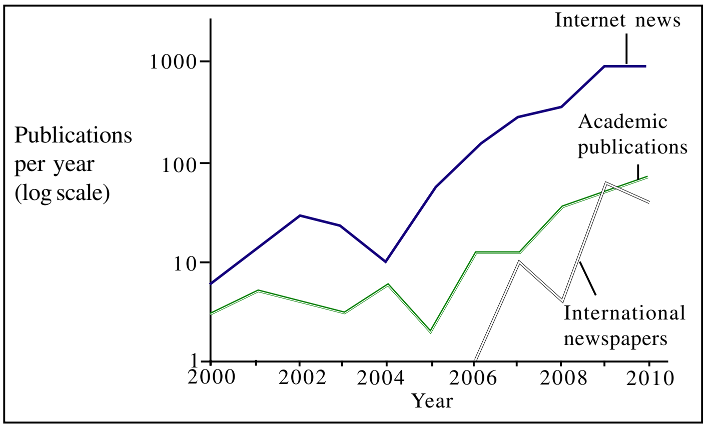
"The reason I think geoengineering should be considered is I don't think we are going to save the planet with the emissions-reduction approaches that are on the table." *(Tom M. L. Wigley , National Center for Atmospheric Research)*

"It's a bad idea whose time has come" (Eli Kintisch, author and science writer)

From science fiction to science fact

Despite the concerns and questions about geoengineering, over the last decade it has moved into the mainstream of the global warming debate. Figure 3 shows that publications on geoengineering, both popular and academic, have grown significantly since 2000.

Figure 3 Growth in publications about geoengineering 2000-2010



(Figure 3 adapted from Environmental Research Letters Vol 6, No4 , Oct-Dec 2011, Public understanding of solar radiation management by AM Mercer, DW Keith and JD Sharp)

Geoengineering to reduce the impacts of global warming falls into two categories:

- **Solar Radiation Management (SRM)** involves reflecting sunlight back into space in order to reduce global temperatures. It does not reduce greenhouse gas levels, and as such is a form of adaptation.
- **Carbon Dioxide Removal (CDR)** involves removing carbon dioxide (and possibly other greenhouse gases) from the atmosphere and storing them. This would reduce greenhouse gas levels and would act in a similar way to mitigation.

CDR is different from **carbon-capture and storage** (CCS). CCS takes place when a large factory or fossil fuel power station removes carbon dioxide from flue gases before it is released into the air. With CCS the polluter is paying to deal with the pollution at source. With CDR, pollutants already in the atmosphere are removed. Table 2 outlines a range of SRM and CDR methods in more detail.

Table 2 SRM and CDR management methods

Solar Radiation Management methods	**How it could work**	**Advantages**	**Disadvantages**
Surface albedo	Change dark, solar energy absorbing surfaces to light, high **albedo** reflective surfaces e.g. painting roofs white in urban areas.	Low-tech and uses existing technology. Minimal impact of people and the environment.	High cost, because large areas would need to be whitened to have any effect. High annual maintenance costs.
Space sunshade	Mirrors or reflectors in orbit to reflect some solar radiation back into space. 1000s or millions would be needed depending on size.	Could be deployed accurately to reflect just the right amount of solar energy based in computer models.	Very costly, financially and in terms of resources. Technically challenging so several decades off.
Cloud whitening	Salt crystals, from the oceans, 'sprayed' onto clouds by aircraft or unmanned drones which increases could albedo.	Would act quickly once begun. Relatively low cost and the technology is simple to deploy.	May increase rainfall in some areas. Unclear how effective it would be and how regularly it would need to be done.
Stratospheric sulphur aerosols	Particles injected into the stratosphere to scatter solar radiation back into space; likely candidates are hydrogen sulphide or sulphur dioxide.	Mimics the natural process of volcanic eruption cooling. Likely to be cost effective.	Could affect wider weather patterns such as monsoons. Possible impacts on the acidity of precipitation.
Carbon Dioxide Removal methods			
Ocean fertilisation	Iron, nitrogen or phosphorus is added to the oceans to stimulate the growth of plankton, sequesting carbon dioxide as it grows.	Basic technology, and many experiments have shown it does work at least partially.	Effectiveness is not clear and it may have unintended consequences on marine ecosystems e.g. marine dead zones.
Artificial trees	Methods to directly remove CO_2 from air and store it, probably underground. 1000s of structures would be needed.	Has minimal negative impacts, beyond the space required to build the structures.Has limitless potential.	Energy would be required to fuel the process e.g. fossil fuels (but wind power could be used). The impact on CO_2 levels would be slow.
Biochar	Plants capture CO_2, then are burnt in a low-oxgyen environment to produce energy + charcoal; the charcoal (carbon) is then buried.	Produces energy as a by-product. The technology is well developed.	Land conflicts with food crops. Unclear how effective it would be and likely to be slow.
Afforestation	Plant large areas of land with trees which slowly grow and sequester carbon dioxide.	Low cost, and natural and could begin immediately. Could enhance biodiversity if well managed.	Very slow to have any impact on CO_2 levels. Huge areas of land are required.

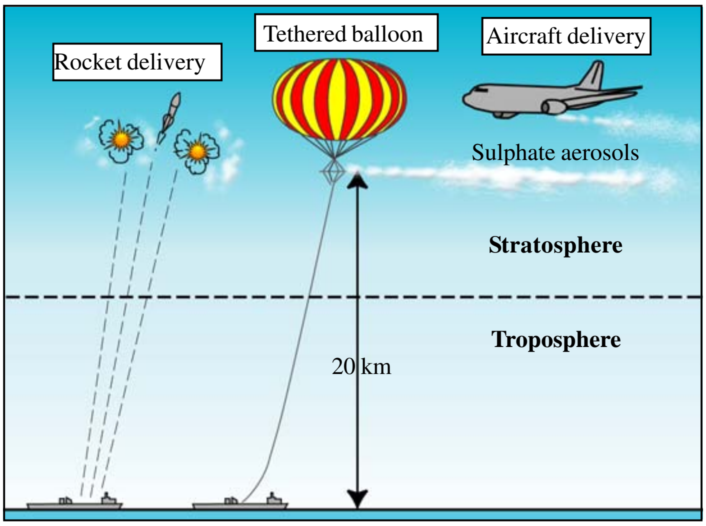
CASE STUDY: Stratospheric aerosols

A widely discussed geoengineering fix is the possibility of using stratospheric particles to reverse global warming by enhancing global dimming. Dimming occurs naturally. The eruption of Mt Pinatubo in 1991 ejected gas (20 million tonnes of SO_2) and dust into the stratosphere with the effect of cooling earth by about 0.5°C for around 6 months. If the right particles were artificially launched into the stratosphere they would reflect incoming solar radiation back into space before it reached the troposphere or surface. Sulphur dioxide gas is the most often suggested aerosol precursor, which would combine with water in the stratosphere to form sulphuric acid aerosols. Research suggests that:

- Sulphate aerosol dimming might cost $10-50 billion per year.
- The effects would persist for 2-3 years if the dimming were stopped.
- An annual sulphur dioxide 'payload' of 1-5 million tonnes could be enough to cause a significant cooling effect.
- Dimming that reduced annual incoming solar radiation by 2% would offset the warming caused by doubling CO_2 levels from pre-industrial levels.

Figure 4 outlines how stratospheric aerosol geoengineering might work using different delivery systems.

Figure 4 Stratospheric aerosol geoengineering



Key term: albedo

Albedo is the reflectivity of a surface. Light coloured surfaces like snow or ice reflect incoming solar radiation whereas dark surfaces (oceans, forests) absorb radiation and warm up. Changing the albedo of a surface will alter the radiation balance.

Which option is best?

Knowing which of the numerous geoengineering options is best is a very challenging question. Most are theoretical, or have been subject to very limited experiment and testing. In 2009 the Royal Society published a major review of geoengineering options. The results of this review are summarised in Table 3.

Table 3 Comparing geoengineering appraoches

Method	Effectiveness (technical feasibility & magnitude of CO_2 reduction)	Timeliness (how ready the technology is and how quickly it would take effect)	Affordability (set up and operating costs)	Safety (predictability of outcome and likelihood of unforeseen consequences)
Surface albedo	Very Poor	Poor	Very Poor	Very Good
Space sunshade	Good	Very Poor	Very Poor	Medium
Cloud whitening	Medium	Medium	Medium	Poor
Sulphate aerosols	Good	Good	Good	Poor
Ocean fertilisation	Poor	Poor	Medium	Very Poor
Artificial trees	Good	Poor	Poor	Very Good
Biochar	Poor	Poor	Poor	Medium
Afforestation	Very Poor	Medium	Very Good	Good

(adapted from Royal Society, 2009, Geoengineering the Climate)

The results of the Royal Society review suggest that:

- Several options are likely to be ineffective (surface albedo, afforestation), too costly (space sunshade) or simply unsafe (ocean fertilisation).
- Biochar and ocean fertilisation score poorly on most measures, and cloud whitening has few no significantly 'good' attributes.
- Sulphate aerosols are likely to be effective, affordable and timely but there are safety concerns; artificial trees score well for effectiveness and safety, but there are cost issues.

These results perhaps help explain why trials of sulphate aerosols, such as the SPICE project (see below) are planned as this method is seen as showing promise. Importantly, none of the SRM methods do anything to counter the problem of **ocean acidification**.

Key term: ocean acidification

As carbon dioxide levels in the atmosphere rise (from the pre-industrial level of 280ppm to 390ppm in 2011 level), some of the excess CO_2 dissolves in the oceans raising their acidity (pH level). In the future this may affect growth of marine organisms such as coral in a negative way.

Geoengineering attempts so far

While geoengineering has not yet been attempted on a large scale, some smaller weather and climate modification experiments have been attempted, with varying degrees of success:

- In 2009, China undertook widespread **cloud-seeding** in order to ease drought in Beijing, which led to disruptive snow fall.
- Experimental ocean fertilisation has been carried out at least 10 times since 1993, seeding the ocean with iron sulphate with variable results.
- Russia successfully unfurled a 20m diameter solar mirror, Znamya II, in space in 1992 although a later attempt at a 25m diameter mirror (Znamya 2.5) in 1999 failed. These experiments at least partially proved the viability of space mirror technology.
- The UK based Stratospheric Particle Injection for Climate Engineering (SPICE project) planned small scale trials of sulphate aerosol deployment via tethered balloon in 2011, although the project was put on hold for further public consultation.

A survey of the public's attitudes to geoengineering conducted in the USA, Canada and UK in 2010 found that 72% of people were in favour of more research into SRM, but that three-quarters of people doubted one method could 'fix' the complex climate system. In general people also believed SRM was not a long-term solution and was an 'easy way out'.

Key term: cloud-seeding

Cloud-seeding is a form of short-term weather modification developed since the 1940s. Tiny silver iodide crystals are spayed into clouds, or shot into clouds via rockets, in order to help promote rain drop or snow-flake formation.

International issues

Geoengineering has the potential to cause international conflict. Imagine a situation where a country, faced with a deteriorating climate due to temperature rise and falling precipitation, acted **unilaterally** to alter the climate by geoengineering. Even if the technology worked for the country in question it could have negative impacts on others. As agreement on climate change mitigation has proved so hard to achieve (e.g. the 1997 Kyoto Protocol and the 2009 Copenhagen Summit), is it any more likely agreement could be reached on geoengineering?

The UN Convention on Biological Diversity (CBD) at Nagoya, Japan in 2010 agreed the following statement:

- *"Climate-related geo-engineering activities should not take place until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts". (UN CBD COP 10 Decision X/33 Biodiversity and climate change)*

This followed a UN ban on large-scale ocean fertilization adopted in 2008 in Bonn, Germany:

- *"ensure that ocean fertilization activities do not take place until there is an adequate scientific basis on which to justify such activities" (UN CBD COP 9 Decision IX/16, Biodiversity and climate change)*

Both of these UN decisions show that there is widespread concern that geoengineering is still an unknown quantity.

Conclusion

Geoengineering is as yet a theoretical solution to the problem of global warming. For any geoengineering option to be considered seriously it will need to be:

- Scalable, so that it will have an impact on a global scale, and thus on global carbon dioxide levels and temperatures.
- Predictable, so that as far as possible any consequences (i.e. degree of cooling, plus impacts on climate patterns or other natural systems such as ecosystems) can be known in advance.
- Reversible, so that if unforeseen consequences begin to occur the geoengineering process can be stopped.

Geoengineering will need to overcome considerable opposition from environmental groups, and will very likely need to be subject to international agreement, before it can be deployed. Nevertheless, unless agreement on meaningful worldwide mitigation is reached the calls for geoengineering to be used to offset the negative impacts of global warming are likely to grow stronger.

References and further research

- Climate Change, have we lost the battle? (2009) Dr. Tim Fox, Environment and Energy Theme Manager, Institution of Mechanical Engineers.
- Public understanding of solar radiation management (2011) by AM Mercer, DW Keith and JD Sharp in Environmental Research Letters Vol 6, No4.
- Geoengineering the climate: Science, governance and uncertainty (2009), Royal Society policy document 10/09.
- Hack the Planet: Science's Best Hope - or Worst Nightmare - for Averting Climate Catastrophe (2010), Eli Kintisch.
- The Parliamentary Office of Science and Technology, Postnote number 327, 2009.
- http://www2.eng.cam.ac.uk/~hemh/SPICE/SPICE.htm website of the SPICE project.

Acknowledgements;

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