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Foresight

# International Dimensions of Climate Change

# Discussion paper 1: Climate Change and Geoengineering

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## Abstract

This background paper is based extensively on the results of the Royal Society (2009) study **"Geoengineering the Climate: Science, Governance & Uncertainty"**, for which Geoengineering was taken to be **the deliberate large-scale intervention in the Earth's climate system,** in order to moderate global warming.

## Key Messages

- **Geoengineering is not a magic bullet**: none of the methods proposed provides an easy or immediate solution to the problems of climate change, and geoengineering is not a realistic alternative to emissions reductions.
- **Cutting global emissions of greenhouse gases must remain the highest priority.** However, this is proving to be difficult, and geoengineering may in the future prove to be useful to support mitigation efforts
- **Geoengineering is very likely to be technically possible**. However, there are major uncertainties and thus potential risks with all methods, concerning their effectiveness, costs, and social & environmental impacts
- **Much more research is needed** before geoengineering methods could realistically be considered for deployment, especially on their possible environmental impacts (as well as on technological and socio-economic aspects)
- **Widespread public engagement and debate is also needed**, especially to develop an acceptable national (and where necessary international) **system of governance** & **regulation** (for both eventual deployment and for some research activities)

**Geoengineering comprises a very wide range of methods** which have very different technical bases, environmental impacts and other properties. This range includes

- **Carbon Dioxide Removal (CDR) methods that remove greenhouse gases from atmosphere** (e.g. engineered capture of CO2 from ambient air).
  - These address the root cause of problem, would return the climate to something similar to a former state, and would be generally preferred, but they only **act slowly** and are **likely to be costly**
- **Solar Radiation Management methods that reflect a little sunlight** (e.g. injection of small aerosol particles in the upper atmosphere)
  - **These act quickly**, and would be **relatively cheap**, but only create an artificial, approximate and potentially delicate balance between two opposing anthropogenic forcings

- They would also would have to be maintained for several/many centuries (for as long as greenhouse gases remain in the atmosphere), so they **may not be sustainable** in the long term (and there would a major “termination problem” if one ever had to stop the intervention)
- They also **do nothing for ocean acidification** (the “other CO2 problem”)

**We do not yet have enough information** on any of the possible technologies**,** so it is **too soon to pick winners**, and if geoengineering is ever deployed we are **likely to need a combination of both types of method**. We therefore **need to commence serious research and development** on several of the promising methods, as soon as possible.

Some methods of both types involve **release of materials to the environment**, either to the atmosphere or to the oceans, in areas beyond national jurisdiction. The **intended impacts on climate would in any case affect many or all countries**, possibly to a variable extent. There are therefore **inherent international implications** for deployment of such geoengineering methods (and possibly also for some forms of research) which need early and collaborative consideration, before any deployment or large-scale experiments could be undertaken responsibly.

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## 1) Introduction

It is not yet clear whether, and if so when, it may become necessary to consider deployment of geoengineering to augment conventional efforts to moderate climate change by mitigation, and to adapt to its effects. However, global efforts to reduce emissions have not yet been sufficiently successful to provide confidence that the reductions needed to avoid dangerous climate change will be achieved. There is a serious risk that sufficient mitigation actions will not be introduced in time, despite the fact that the technologies required are both available and affordable (Stern 2007). It is likely that global warming will exceed 2°C this century unless global $CO_2$ emissions are cut by at least 50% by 2050, and by more thereafter (IPCC 2007). There is no credible emissions scenario under which global mean temperature would peak and then start to decline by 2100. Unless future efforts to reduce greenhouse gas emissions are much more successful then they have been so far, additional action such as geoengineering may be required should it become necessary to cool the Earth this century?

Proposals for geoengineering or climate intervention[1] are numerous and diverse, and for our study we deliberately adopted a broad scope in order to provide a wide-ranging review. There has been much discussion in the media and elsewhere about possible methods of geoengineering, and there is much misunderstanding about their feasibility and potential effectiveness and other impacts. The overall aim of study was therefore **to reduce confusion & misinformation, and so to enable a well-informed debate** among scientists & engineers, policy-makers and the wider public on this subject.

The working group which undertook the study was composed of 12 members (listed below). These were mainly scientists & engineers, but also included a sociologist, a lawyer and an economist. The members were mainly from UK but included one member from the USA and one from Canada, and the study itself had an international remit. The WG members were not advocates of geoengineering, and held a wide range of opinions on the subject, ranging from cautious approval to serious scepticism.

The **terms of reference** for the study were **to consider, and so far as possible evaluate,** proposed schemes for moderating climate change by means of geoengineering techniques, and specifically:

1) to consider **what is known, and what is not known**, about the **expected effects, advantages and disadvantages** of such schemes
2) to assess their **feasibility, efficacy, likely environmental impacts**, and any **possible unintended consequences**
3) to identify **further research requirements**, and any specific **policy and legal implications**.

**The scope adopted** included any methods intended to moderate climate change by deliberate large-scale intervention in the working of the Earth's natural climate system, but *excluded*

a) low-carbon energy sources & conventional methods for reducing emissions of greenhouse gases
b) carbon capture & storage (CCS) at the point of emission
c) conventional afforestation and avoided deforestation schemes

because these are either not regarded as geoengineering *per se* and/or they have been extensively considered elsewhere (e.g. IPCC 2005)

[1] The term geoengineering is widely used but the terms *climate intervention, climate engineering, Earth system engineering* and *climate remediation* or *restoration* are preferred by some authors: all are here regarded as synonymous.

## 2) General issues

**The methods considered** fall into two main classes, which differ greatly in many respects, including their modes of action, the timescales over which they are effective, their effects on temperature and on other important aspects of climate, so that they are generally best considered separately. These classes are

1) **Carbon dioxide removal (CDR)** techniques which address the root cause of climate change by removing greenhouse gases from the atmosphere;
2) **Solar Radiation Management (SRM)** techniques that attempt to offset the effects of increased greenhouse gas concentrations by reflecting a small percentage of the sun's light and heat back into space.

**Carbon Dioxide Removal** methods reviewed in the study include:

- Land use management to protect or enhance land carbon sinks;
- The use of biomass for carbon sequestration as well as a carbon neutral energy source ;
- Acceleration of natural geological weathering processes that remove $CO_2$ from the atmosphere;
- Direct engineered capture of $CO_2$ from ambient air;
- The enhancement of oceanic uptake of $CO_2$, for example by fertilisation of the oceans with naturally scarce nutrients, or by increasing upwelling processes.

**Solar Radiation Management** techniques would take only a few years to have an effect on climate once they had been deployed, and could be useful if a rapid response is needed, for example to avoid reaching a climate threshold. Methods considered in the study include:

- Increasing the surface reflectivity of the planet, by brightening human structures (e.g. by painting them white), planting of crops with a high reflectivity, or covering deserts with reflective material;
- Enhancement of marine cloud brightness (reflectivity);
- Mimicking the effects of volcanic eruptions by injecting aerosol particles (e.g. sulphates) into the lower stratosphere;
- Placing shields or deflectors in space to reduce the amount of solar energy reaching the Earth.

**The scale of the impact** required to ameliorate climate change is global, and its magnitude is large. To have a significant effect on man-made global warming by an SRM method one would need to achieve a negative radiative forcing of a few $W/m^2$, and for an effective CDR method one would need to remove several billion tons of carbon per year from the atmosphere for many decades.

**There are many criteria** by which geoengineering proposals need to be evaluated, and some of these are not easily quantified. We undertook a preliminary and semi-quantitative evaluation of the more promising methods according to our judgement of several technical criteria only, namely their **effectiveness, affordability, safety and timeliness**. The cost estimates available are extremely uncertain, and it would be premature to attempt detailed cost-benefit analysis at this time.

## 3) Technical Aspects: feasibility, cost, environmental impacts and side-effects

Our study concluded that geoengineering of the Earth's climate is very likely to be technically possible. However, the technology to do so is barely formed, and there are major uncertainties regarding its effectiveness, costs, and environmental impacts. If these uncertainties can be reduced, geoengineering methods could in the future potentially be useful in future to augment continuing efforts to mitigate climate change by reducing emissions. Given these uncertainties, it would be appropriate to adopt a precautionary approach: to enable potential risks to be assessed and avoided, this requires more and better information. Potentially useful methods should therefore be the subject of more detailed research and analysis, especially on their possible environmental impacts (as well as on technological and socio-economic aspects).

In most respects Carbon Dioxide Removal methods would be preferable to Solar Radiation Management methods, because they effectively return the climate system to a state closer to its natural state, and so involve fewer uncertainties and risks. Of the Carbon Dioxide Removal methods assessed, none has yet been demonstrated to be effective at an affordable cost, with acceptable side effects. In addition, removal of $CO_2$ from the atmosphere only works very slowly to reduce global temperatures (over many decades). If safe and low cost methods can be deployed at an appropriate scale they could eventually make an important contribution to reducing $CO_2$ concentrations and could provide a useful complement to conventional emissions reductions. It is possible that they could even allow future ***reductions*** of atmospheric $CO_2$ concentrations ("negative emissions") and so also address the ocean acidification problem.

Carbon Dioxide Removal methods that remove $CO_2$ from the atmosphere without perturbing natural systems, and without large-scale land-use change requirements, such as $CO_2$ capture from air (and possibly also enhanced geochemical weathering) are likely to have fewer side effects. Techniques that sequester carbon but have land-use implications (such as biochar and soil-based enhanced weathering) may be useful contributors on a small-scale although the circumstances under which they are economically viable and socially and ecologically sustainable remain to be determined. The extent, to which methods involving large-scale manipulation of ecological systems (such as ocean fertilisation) can sequester carbon affordably and reliably without unacceptable environmental side-effects, is not yet clear.

Solar Radiation Management techniques are expected to be relatively cheap and would take only a few years to have an effect on the climate once deployed. However there are considerable uncertainties about their consequences and additional risks. It is possible that in time, assuming that these uncertainties and risks can be reduced, that Solar Radiation Management methods could be used to augment conventional mitigation. However, the large-scale adoption of Solar Radiation Management methods would create an artificial, approximate, and potentially delicate balance between continuing increased greenhouse gas concentrations and reduced solar radiation, which would have to be maintained, potentially for many centuries. It is doubtful that such a balance would really be sustainable for such long periods of time, particularly if emissions of greenhouse gases were allowed to continue or even increase. The implementation of any large-scale Solar Radiation Management method would therefore introduce additional risks and so should only be undertaken for a limited period, and in parallel with conventional emissions reduction and/or Carbon Dioxide Removal methods.

Of the Solar Radiation Management techniques considered, stratospheric aerosol methods have the most potential because they should be capable of producing large and rapid global temperature reductions, because their effects would be more uniformly distributed than for most other methods, and they could be readily implemented. However, there are potentially significant side-effects and risks associated with these methods that would require detailed investigation even before large-scale experiments are undertaken. Cloud brightening methods are likely to be less effective and would produce primarily localised temperature reductions, but they may prove to be readily implementable, and should be testable at small scale with fewer governance issues than other SRM methods. Space based SRM methods would provide a more uniform cooling effect than surface or cloud based methods, and if long-term geoengineering is required, might eventually become a more cost-effective option than the other SRM methods, although development of the necessary technology is likely to take many decades.

## 4) The Human Dimension & International Aspects

The acceptability of geoengineering is likely to be determined as much by social, legal, ethical and political issues as by scientific and technical factors. Geoengineering technologies would modify, by design, the climate of the Earth on a global scale. There are therefore serious and complex national and international governance issues which need to be resolved if geoengineering is ever to become an acceptable method for moderating climate change.

There are no existing international treaties or bodies whose remit covers all the potential methods, but most could probably be handled by the extension of existing treaties, rather than creating wholly new ones. An example of this is the successful extension of the remit of the London Convention & Protocol to cover ocean fertilisation research. It would be highly undesirable for geoengineering methods which involve activities or effects that extend beyond national boundaries (other than simply the removal of greenhouse gases from the atmosphere), to be deployed before appropriate governance mechanisms are in place. Some geoengineering methods could however probably be implemented by just one nation acting independently, and some maybe even by corporations or individuals. The consequences would however affect all nations and all people, so their deployment should be subject to robust governance mechanisms. However, there remains potential for unilateral action by any technologically capable nation or organisation. In the case of CDR methods this could have only an incremental effect, which for ***contained*** methods (e.g air capture, but not ocean fertilisation) could be regarded as non-threatening and requiring little governance; at least until such time as it became possible to ***reduce*** the atmospheric $CO_2$ concentration (after which it would be necessary to reach international agreement on the level to which it should be reduced, e.g. to 350 ppm or 280 ppm or some other level…). However, unilateral action is much more likely to involve precipitate deployment of SRM technology in response to a perceived climate threat, of which loss of Arctic summer sea-ice cover, perceived impacts on equatorial rainfall systems (monsoons), and Mediterranean or Amazonian drying are all obvious and plausible candidates. It is not clear what international mechanisms, if any, would be capable of preventing or managing such an intervention.

The most appropriate way to create effective governance mechanisms (for both R&D and deployment) therefore needs to be determined, and a review of existing bodies, treaties and mechanisms should be initiated as a high priority. Governance issues in relation to geoengineering research were considered recently by a major international conference held at Asilomar, California in March 2010 (see http://www.climateresponsefund.org/index.php?option=com_content&view=article&id=137&Itemid=81 ). In addition, the Royal Society, in partnership with the Academy of Sciences for the Developing World (TWAS) and the Environmental Defense Fund (EDF) recently launched a new Solar Radiation Management Governance Initiative (SRMGI: see http://royalsociety.org/Royal-Society-launches-major-study-on-the-governance-of-geoengineering ) to establish wider international and multi-sectoral consideration of these issues, which arise especially in relation to SRM technologies. Such voluntary efforts are likely to be effective for the time being, but in due course national and international governmental agencies will need to become involved. [Note: the recent report of the House of Commons Select Committee on Science & Technology on *The Regulation of Geoengineering* http://www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/221/22102.htm marks the successful commencement of this process, and the equivalent US House of Representatives committee is also undertaking a related investigation.

## Overall Conclusion

**The safest and most predictable method of moderating climate change is to take early and effective action to reduce emissions of greenhouse gases. No geoengineering method can provide an easy or readily acceptable alternative solution to the problem of climate change.**

**Key recommendations:**

- Parties to the UNFCCC **should make increased efforts towards mitigating and adapting to climate change**, and in particular to agreeing to global emissions reductions of at least 50% by 2050 and more thereafter. **Nothing now known about geoengineering options gives any reason to diminish these efforts.**

- **Further research and development of geoengineering options should be undertaken** to investigate whether low risk methods can be made available if it becomes necessary to reduce the rate of warming this century. This should include **appropriate observations, the development and use of climate models, and carefully planned and executed experiments**. We suggested an expenditure of around £10M per year for ten years as an appropriate initial level for a UK contribution to an international programme, to which we would hope that the USA would also contribute a substantially larger amount.

- The governance challenges posed by geoengineering should be explored in more detail by an international body such as the UN Commission for Sustainable Development, and processes established for the development of policy mechanisms to resolve them.

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## Members of the Royal Society working group

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## Professor John Shepherd FRS: Short biography

Professor John Shepherd MA PhD CMath FIMA FRS is a Professorial Research Fellow in Earth System Science in the School of Ocean and Earth Science, National Oceanography Centre, University of Southampton, UK. He is a physicist by training, and has worked on the transport of pollutants in the atmospheric boundary layer, the dispersion of tracers in the deep ocean, the assessment & control of radioactive waste disposal in the sea, on the assessment and management of marine fish stocks, and most recently on Earth System Modelling and climate change. His current research interests include the natural variability of the climate system on long time-scales, and the development of intermediate complexity models of the Earth climate system for the interpretation of the palaeo-climate record. He graduated (first degree in 1967 and PhD in 1971) from the University of Cambridge. From 1989-1994 he was Deputy Director of the MAFF Fisheries Laboratory at Lowestoft, and the principal scientific adviser to the UK government on fisheries management. From 1994-1999 he was the first Director of the Southampton Oceanography Centre. He has extensive experience of international scientific assessments and advice in the controversial areas of fisheries management, radioactive waste disposal, and climate change, and has recently taken a particular interest in the interaction between science and public policy. He is Deputy Director of the Tyndall Centre for Climate Change Research, and a Fellow of the Institute of Mathematics and its Applications. He was elected a Fellow of the Royal Society in 1999, participated in the Royal Society study on Ocean Acidification published in 2005, and chaired that on Geoengineering the Climate published in 2009.

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