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GEO-ENGINEERING RESEARCH

There is evidence that efforts to reduce emissions of greenhouse gases may be insufficient to avert unacceptable levels of climate change; global emission levels are currently higher than even the highest scenario produced by the Intergovernmental Panel on Climate Change (2001). Geo-engineering seeks to use global scale engineering to offset the effects of greenhouse gas emissions. This POSTnote summarises the arguments relating to research funding for geo-engineering.

Background

Increasing awareness of the threat that climate change represents has propelled many respected scientists, including Nobel Laureate Professor Paul Crutzen and former UK Government Chief Scientist Professor Sir David King to call for a significant research programme into geo-engineering to combat climate change directly. This briefing focuses on two areas of such research:

- Solar Radiation Management (SRM) – cooling the Earth by reducing the amount of the Sun's energy absorbed by the climate system, by altering terrestrial albedo (Box 1).
- Carbon Capture from Air – capturing CO_2 from air with the intent of storing it in the long term.

Current Funding of Geo-engineering Research

There is currently very little public funding specifically earmarked for geo-engineering. Despite a US Department of Energy White Paper (Unpublished) that in 2001 recommended a $64M, five year programme, less than $1M of public money is currently directly funding geo-engineering research in the USA. In the UK, the Engineering and Physical Sciences Research Council (EPSRC) has proposed a £3M 'Ideas Factory' commencing in 2010. To date, therefore, most research has been either funded using existing climate science grants or has been unfunded, performed in researchers' spare time. Researchers in the field believe that an international research programme of around $100M could advance the scientific and engineering knowledge significantly, of which the suggested UK contribution could be £10-20M[1]. One priority would be to gain a greater understanding of the risks associated with interfering with the climate system.

Box 1 – The Earth's Albedo

The term terrestrial albedo refers to the fraction of the Sun's energy that is reflected back into space by the Earth's surface or atmosphere. The albedo of an object is generally quoted as a number between one and zero, one indicating that all radiation is reflected, zero that all is absorbed.

Different parts of the Earth's surface can have radically different albedos. Sea ice generally has a value of 0.5-0.7, whereas the open ocean can be as low as 0.06 with 94% of the Sun's energy being absorbed as heat. Any changes in the albedo of the Earth would have dramatic consequences for global temperatures.

Climate Change

The extent of the threat that climate change represents is documented in detail elsewhere (POSTnote 295, 245). Several key risks give the context in which geo-engineering research is advocated:

- CO_2 levels may need to be brought down to below 350ppm (parts per million, CO_2 in the atmosphere) from current levels of 385ppm, within decades, to avoid significant climate change[2].
- Without a step change in mitigation efforts, especially in the developing world, green house gas, (GHG), concentrations of 1000ppm CO_2 equivalent (POSTnote 318) may be passed by the end of this century[3].
- Above 1000ppm, catastrophic and irreversible changes to the climate system may occur, including the loss of the majority of the Greenland ice sheet and sea level rise that would threaten coastal cities.

Runaway Climate Change

As Arctic sea ice melts, more open ocean is exposed to sunlight. Less sunlight is therefore reflected back into space (see Box 1) leading the ocean to warm, melting more ice. A similar effect can be seen in Arctic permafrost regions where melting releases methane, a significant GHG. This causes further warming and methane release. There is a risk that, past a certain temperature threshold, these processes take over as the main driver of climate change. After this point, no level of emissions cuts would prevent continued warming and runaway climate change.

Emissions Cuts and Geo-engineering

According to a recent survey by the *Independent*[4] a small majority of climate scientists believes that these risks justify research into geo-engineering as a potential 'plan B' or 'insurance policy'. There is scientific consensus that the risks justify a massive global effort to reduce greenhouse emissions, above and beyond what is already under way. There is also a widely held view[5] that geo-engineering should not reduce efforts to reduce GHG emissions, either by sapping research funding, occupying significant numbers of climate scientists or by reducing the political pressure for action. Some environmental NGOs, politicians[6] and climate scientists, have even argued that geo-engineering should not even be explored while politicians are attempting to negotiate binding commitments to cut GHG emissions.

Geo-engineering

Carbon Capture from Air

These proposals are similar to carbon capture and storage (CCS) technologies (see POSTnote 238). However, instead of removing CO_2 from fossil fuel power station emissions, CO_2 would be extracted directly from atmosphere for storage.

Geological

Industrial processes for achieving this have received media attention, for example "Artificial Trees"[7]. A chemical is used to scrub CO_2 from the atmosphere. This is then treated to yield pure CO_2. As with CCS, once the CO_2 is collected, sites where it could be stored on geological timescales must be found, such as depleted oil wells. Energy would be required to produce the scrubbing chemical, to recycle it and to release the CO_2, as well as to transport it to the storage location.

Biological

Biological mechanisms could be used to remove CO_2 from the air. For example, biological material can be heated to high temperatures in the absence of oxygen to produce charcoal (biochar). This is then mixed into the soil of agricultural land, sequestering the carbon in the charcoal for centuries and also improving soil quality. Further research is required to determine the geographic and economic scale at which such processes would need to be implemented to be effective.

More controversial are proposals to fertilise areas of ocean to encourage the growth of algae. In large areas of the world's oceans the factor limiting algal growth is a lack of the nutrient iron. Ocean Iron Fertilisation (OIF) – spreading this nutrient from ships – has been shown to cause algal blooms which will consume CO_2 as they grow. When the algae die, a fraction of them will sink to the deep ocean, sequestering the carbon. There is, however, debate surrounding both how much of the carbon absorbed is permanently removed in this way, and potential effects on marine eco-systems. Several private companies have attempted to commercialise OIF, seeking to claim carbon credits from emissions trading schemes (POSTnote 318). At present, there is an international moratorium on the commercialisation of OIF (Box 4). The biggest challenges for OIF are:

- assessing whether carbon has been sequestered in the long term,
- proving that any damage to ecosystems would be limited to an acceptable level.

Summary

Both forms of geo-engineering by air capture address the root cause of the problem – atmospheric CO_2 and could, therefore, be used to return its presence in the atmosphere to pre-industrial levels. The economics and logistics of CO_2 capture from air are significant issues, given the volumes of CO_2 – of the order of hundreds of cubic kilometres – that would need to be extracted to have an effect. Further research is required to establish the likely costs of implementing these technologies on such a scale. In principle, the deployment of carbon capture and storage from air could be funded by inclusion in an emissions trading scheme. However, even if these issues were resolved, it is difficult to imagine a system that could be deployed rapidly in response to a climate emergency.

Solar Radiation Management

SRM attempts to offset global warming by increasing the amount of solar radiation reflected back into space, for example by increasing the Earth's albedo (Box 1). A

Figure 1 – Predicted temperature changes at 880 ppm without (A) and with (B) solar radiation management

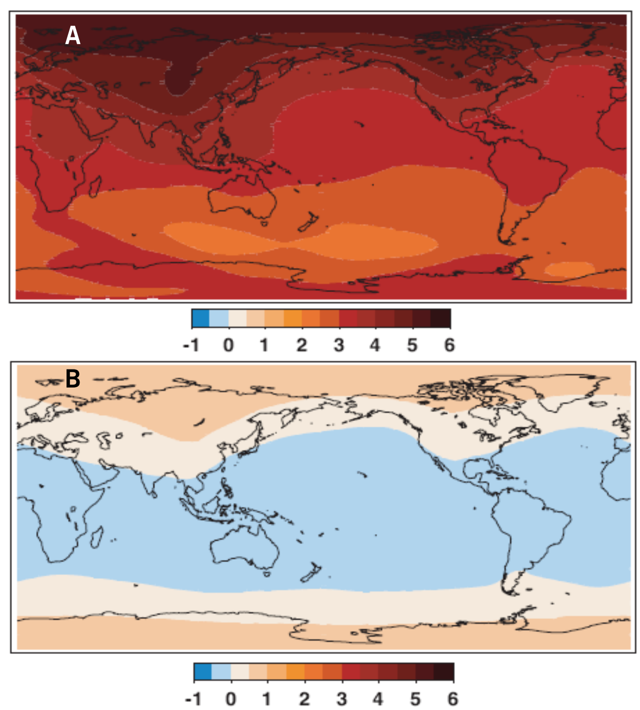

Figure 1 (Scales in degrees Celsius): Climate model predictions of average local surface temperatures for the year 2100, compared with those of 1900. Figure A shows temperature change for a 'business as usual' scenario (IPCC A2) where emissions cuts are not made to the required extent and greenhouse gas levels reach 880 ppm by 2100. Figure B represents the same scenario where simplified, uniform solar radiation management is used to maintain average global temperature at pre-industrial levels.[8]

reduction in the amount of solar radiation absorbed by the climate system will result in a corresponding cooling effect (Figure 1). Simulations performed by Dr Dan Lunt, a glaciologist at the University of Bristol, have also suggested SRM has the potential to avert the collapse of the Greenland ice sheet. Important factors, including scalability, negative effects, reversibility, costs and uncertainty (Box 2) influence the potential of SRM techniques.

Stratospheric Aerosols

The geo-engineering proposal that has received the most attention[9] is SRM by the introduction of aerosols into the upper atmosphere (Box 3). Initial research has suggested that the technique could exert a cooling effect at a lower cost than other geo-engineering proposals. The lead time for deployment of some form of stratospheric sulphate scheme could be very short, 3-5 years. It is suggested that a research effort, backed up by small scale tests, could quantify the risks involved and the likely costs.

Box 2 – Key Factors for SRM

Scalability – Simulations suggest that approximately 2% more solar energy would need to be reflected back into space to maintain average global temperatures with GHGs at double their pre-industrial levels. To have a significant effect, therefore, SRM must increase the albedo of the Earth on a continental scale.

Negative Effects – SRM proposals generally aim to increase reflection of wavelengths shorter than those absorbed by greenhouse gases. The spatial distribution of the cooling effect is also likely to be different from that of greenhouse gas warming. These effects add up to give a climate that is not equivalent to that were GHG levels to be reduced. One significant concern is that precipitation will be affected as evaporation of water is more sensitive to levels of direct sunlight than to temperature. The Meteorological Office has performed simulations of SRM that result in a dieback of the South American rain forest and changes in the El Niño weather cycle[10]. Proponents of SRM argue that this work was not representative of their proposals, and that while resultant climatic patterns may not be equivalent to those for the pre-industrial, they would be more similar than those arising without any attempt to compensate for the warming.

Uncertainty – As with all climate predictions, there is significant uncertainty involved with the models used to predict the effects of SRM. The complexities of the climate system mean that, while this uncertainty can be reduced, it can not be eliminated. Were a system implemented, it is likely that there would be climate consequences not foreseen by modelling.

Reversibility – Given such uncertainty, it is critical that any SRM project can be reversed quickly.

Tropospheric Cloud Seeding

Proposals have also been made to alter the albedo of clouds in the troposphere (lower atmosphere). In large areas of the oceans, overall cloud reflectivity is limited by absence of airborne particles on which water droplets can form. Professors Stephen Salter of the University of Edinburgh, and John Latham of the US National Center for Atmospheric Research have produced plans for a prototype ship that would inject a fine spay of salt water into the lower atmosphere This would evaporate to form such seeding particles. The resulting greater cloud cover would increase the local albedo, yielding a cooling local effect.

Proponents claim that, initially, a fleet of 50 ships would need to be deployed continuously to yield the desired global cooling effect. The potential also exists for local cooling to be achieved over sensitive areas such as the Arctic or coral reefs. The key advantage of this mechanism is that the process would be, in terms of pollution, largely environmentally benign. However, if an adverse climate impact were observed and seeding terminated, the effects should dissipate in a matter of days.

Box 3 – Stratospheric Aerosols

In 1991, Mt Pinatubo, a volcano in the Philippines, erupted, discharging ~20 million tonnes of sulphur dioxide, (SO_2), into the stratosphere. Much greater volcanic releases of SO_2 have occurred throughout geological history. The resultant sulphate particles from Pinatubo increased global albedo, reflecting enough solar energy back into space to cool the global climate by an average of 0.5˚C over the following 1-2 years. Paul Crutzen, recipient of the Nobel Prize in chemistry for his work on the atmospheric chemistry of ozone, argued in the journal *Climate Change*[11] that this effect could be used to counteract climate change.

There are various ways in which the aerosol precursors could, in principle, be launched into the atmosphere including using aircraft, rockets or heavy lift balloons. The particles could also be tuned to reflect as much sunlight as possible per gram. More sophisticated particles than sulphates are proposed that could potentially have greater residence times in the atmosphere or that could preferentially absorb harmful UV radiation.

Observations suggest that geo-engineering based on sulphate aerosols would have lower costs relative to other geo-engineering proposals. Professor David Keith, director of the Energy and Environmental Systems Group at the University of Calgary, has suggested that for as little as 0.01% of global GDP temperatures could be lowered to the extent of initiating an ice age using this technique[12]. Sulphate emissions from industry (mainly coal power plants in the USA, China and India) already counteract the warming effect of approximately 100ppm of CO_2. Estimates of the costs of implementing this form of geo-engineering are in the region of $10-50 billion a year to return to 'pre-industrial' average global temperatures.

If particle injection were suspended due to unforeseen consequences, the effects would dissipate over 2-3 years. It is, however, known that increased sulphate aerosol concentrations in the stratosphere would catalyse ozone destruction, and an increase in levels of acid rain would occur. The greatest harm, however, is thought to be the effect on precipitation levels (Box 2). There is considerable debate on the extent of this effect, with different simulations producing outcomes varying from a minimal effect to a significant drop-off in rainfall.

Mirrors in Space

A proposal to place an array of mirrors in space between the Earth and the Sun has received significant press attention. In principle, the climate could be cooled by such a scheme but it is thought that the costs (estimated in the range of 1 US $trillion) and reliance on as yet undeveloped technologies mean that this proposal is unlikely to be taken further.

Surface Based SRM

There are also proposals to change the albedo of the Earth's surface, for example, by genetically modifying crops to reflect more sunlight or by painting human made surfaces with reflective paint. It is possible that this latter could help to alleviate local problems such as the urban heat island effect, whereby cities are significantly warmer than the surrounding countryside. It would, therefore, reduce the need for air conditioning in cities (POSTnote 315), and any associated CO_2 emissions. At this stage, however, such techniques do not appear be able to be deployed on a scale large enough to affect global temperatures significantly.

Objections to SRM
It is sometimes suggested that SRM could lead to less effort in cutting emissions as the issue of climate change would appear less urgent. Prominent climate scientists, including Dr Vicky Pope, head of climate change advice at the Meteorological Office Hadley Centre, and Raymond Pierrehumbert, Professor of Geophysical Sciences at the University of Chicago, have argued that by reducing the climate impacts of greenhouse gases in the short term, SRM may store up larger longer term climate impacts for the future. Given that there is uncertainty as to how sensitive the climate is to greenhouse gas and temperature levels, were the SRM to be halted for any reason, such as a conflict or economic crisis, the climate would heat rapidly to an unknown level. Such a rate of warming could overwhelm any attempt at adaptation.

SRM also has no effect on the other consequences of elevated CO_2 levels such as ocean acidification. This has the potential to decimate plankton and coral reefs by further acidifying the ocean. This would have significant consequences for global biodiversity and food production.

Box 4 – International Law
In recent years, parties to the treaties that together comprise international environmental law have been active in dealing with geo-engineering proposals. From Carbon Capture and Storage to Ocean Iron Fertilisation (OIF), existing treaties have been interpreted to provide a legal framework for research. In the case of OIF, parties to the London Convention/Protocol (an international legal framework covering dumping at sea) agreed in October 2008, to place a moratorium on commercial OIF but to allow experiments for legitimate scientific research.

Field trials of atmospheric albedo modification should also be placed within an appropriate international legal framework. This would provide guidance for nations when considering funding or authorising any experiments that might have consequences for ‘downwind’ nations. The most applicable specific treaty would vary from proposal to proposal. For field trials of sulphate aerosol injection, the Convention on Long-range Transboundary Air Pollution (LRTAP), which deals with sulphur dioxide pollution, and the Vienna Convention for the Protection of the Ozone Layer are likely to be relevant.

If a policy decision to deploy any form of geo-engineering proposal were in consideration, the international legal situation would be complicated and problematic. Detailed analysis of this issue is beyond the scope of this briefing. Universal consensus between nations is unlikely to be achieved. This is because the benefits and harms of any project would not be shared equally between countries.

International Aspects
Any efforts to geo-engineer the planet would raise major international legal (Box 4) and geopolitical issues. Many prominent scientists, including DEFRA Chief Scientist Professor Bob Watson and Professor John Shepherd, the chairman of a current Royal Society enquiry into geo-engineering argue that research in the area should be as international as possible. This would give all governments greater confidence in the results and allow costs to be shared. In addition, perceptions of international research will not be affected by the policy aims of any specific country. Were the current modelling efforts expanded to include pilot scale experiments and consideration of deployment, there would be a pressing need for a suitable international legal, political and research framework.

Ongoing Reviews
The Royal Society and the House of Commons Select Committee on Innovation, University, Science and Skills (IUSS) are currently studying geo-engineering. The Royal Society is aiming to deliver a rigorous comparison of the various geo-engineering proposals, while the committee is addressing specifically the UK context. Both reports are planned to be published by summer 2009. This will lead to a significant increase in information available to policy makers.

Overview
- There is growing evidence that efforts to reduce emissions of greenhouse gases may not be sufficient within the timescales required to avert unacceptable levels of climate change.
- Computer simulations and observations of the climate system show that there are engineering projects that have the potential to cool the climate dramatically though not enough information exists for a policy decision on implementation to be made.
- Solar radiation management techniques can do nothing except buy time for efforts to reduce atmospheric CO_2 to succeed as they do not address the root causes of climate change.
- Carbon capture from air could return atmospheric CO_2 to pre-industrial levels. The economics and reliability of such processes are, however, currently unclear.
- A relatively modest research programme, with a UK contribution of £10-20M,could advance relevant knowledge significantly.

Endnotes
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POST is an office of both Houses of Parliament, charged with providing independent and balanced analysis of public policy issues that have a basis in science and technology. POST is grateful to Dan Bradley for preparing this briefing, and to the Royal Society of Chemistry for supporting his fellowship at POST. For further information on this briefing, please contact Dr Jonathan Wentworth at POST.

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