

GEOENGINEERING – CHALLENGES AND GLOBAL IMPACTS

Geoengineering provides a set of options in which the Earth's climate is deliberately manipulated to offset the effects of global warming due to increasing levels of greenhouse gases in the atmosphere. The Institute of Physics, the Royal Society of Chemistry and The Royal Academy of Engineering held a joint seminar at the House of Commons in July 2009, chaired by Dr Brian Iddon MP, to explore approaches to managing climate change based on strategic engineering of the environment on a global scale. The seminar has been summarised and placed into context by science writer Nina Hall.

Most climate experts now agree that rising emissions of CO₂ are causing global warming and if they are not brought down considerably they will lead to unacceptable levels of climate change. Before the Industrial Revolution, the atmospheric concentration of CO₂ was about 280 parts per million (ppm) but it has now risen to 385 ppm. With industrialisation and energy consumption in developing countries set to increase, CO₂ levels could rise much further – to as much as 1,000 ppm by the end of the century, leading to an increase in global surface temperatures of up to 7°C. Although there are uncertainties in climate models, they predict that concentrations above 550 ppm would result in massive, irreversible changes in the climate and the global

environment. Most of the Greenland ice sheet would melt and sea levels would rise, with low-lying coastal countries such as Bangladesh becoming permanently flooded. How should we respond? The most important and obvious solution is to reduce and manage energy use, so that much less CO₂ is emitted. The second is to control CO₂ emissions into the atmosphere through industrial carbon management and CO₂ storage. A third, pragmatic approach is to look at ways of adapting to the impact of climate change.

The fourth possibility is to engineer the environment to counteract global warming. While this last option may seem drastic, it is likely that implementing the first and second approaches will not slow

down the underlying processes driving climate change quickly enough. Even the most radical emissions reduction – in the order of 80% over the next 30 years – will still leave atmospheric CO₂ at about 450 ppm. This is the EU's target (which many consider to be unrealistic) and would limit warming to 2°C above pre-industrial levels.

Climate change might happen even more rapidly than computer models have predicted: the melting of ice sheets would reveal darker surfaces beneath, which would warm up more quickly by absorbing sunlight. In addition, melting of the Arctic permafrost could release large amounts of methane, a much more powerful greenhouse gas than CO₂. Thus, in the short term, geoengineering solutions that can be implemented swiftly

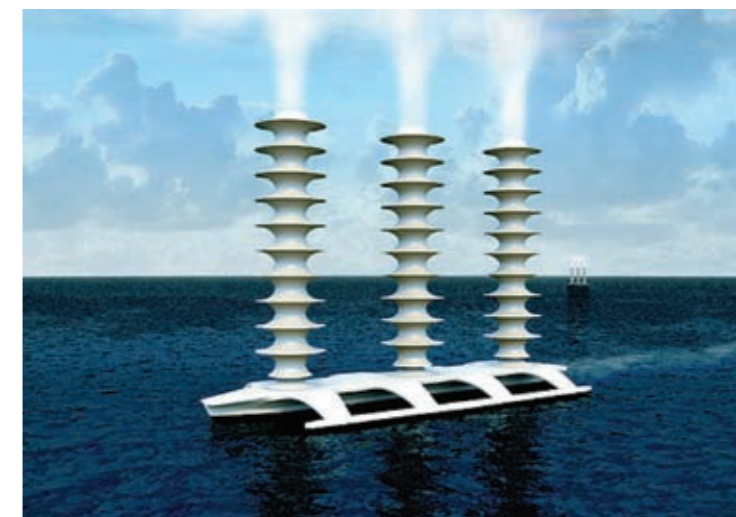
and effectively over periods from a few years to decades, could provide the necessary breathing space to allow the longer-timescale CO₂ reduction efforts to take effect.

There are two main considerations to apply with these approaches: the first is to manage the amount of solar radiation reaching the Earth's atmosphere; and the second is to reduce atmospheric CO₂, particularly by engineering the global carbon cycle. During the seminar session three specific geoengineering schemes were outlined.

CLOUD ALBEDO MODIFICATION

Stratocumulus clouds cover more than 30% of the ocean and have high reflectivity dependent on the number and size of the water droplets they contain. Physics tells us that the greater number of smaller droplets in a cloud system the greater the whiteness, and thus its reflectivity, or 'albedo' – more of the sunlight is therefore reflected back into space.

Dr Alan Gadian, from the University of Leeds' School of Earth and Earth Environment department, described a system developed by a team of UK and US scientists to increase the albedo of stratocumulus clouds



A visualisation of a spray vessel that would be used to carry out cloud albedo modification © J MacNeill and S Salter/University of Edinburgh

by spraying droplets of seawater into the atmosphere from purpose-designed ships. Small droplets, ideally less than one micrometre (µm) in diameter, would rise to cloud-base levels via thermals and turbulence. They would dissipate, spreading sea-salt particles that act as nuclei for cloud condensation. The system would have the advantage of being an enhancement of a natural ocean process produced by breaking waves. When it is switched off, the effects would disappear within a few weeks.

Such a spray mechanism has been designed by University of Edinburgh engineer Professor Stephen Salter. His team's proposal is to build a fleet of wind-powered remote-controlled ships that would operate continuously with low ecological impact.

The technology and concept has already undergone preliminary trials. Computer simulations have been carried out for a range of spray rates, which have shown that a cooling of 1.2 watts per square metre (W m⁻²) could be achieved over about 20 years. This figure, when compared with the predicted increase in radiative heating of 3.7 W m⁻² for a doubling of CO₂ concentrations, suggests that cloud albedo modification could be a viable option.

Current climate models are not accurate enough, particularly relating to rainfall, and so more modeling is needed, as well as more atmospheric studies and field experiments. Dr Gadian highlighted the fact that the UK is one of the leaders in atmospheric science, and a timeline of two years to build an experimental spray system and two years to carry out the field experiment is needed.

SUNSHADE ENGINEERING

A more ambitious engineering option is to place a giant reflector system between the Sun and the Earth. Roger Angel, a British astronomer at the University of Arizona in the United States, has proposed launching a 100,000 km long cloud of 15 trillion reflective discs, each 60–70 cm across, to shade the Earth. The sunshade would be positioned at the Lagrange, L1 point (the orbit 1.5 million km out in space where an object sits in a gravitationally stable, fixed position between the Sun and the Earth). It could be done within 25 years and would cost several trillion dollars, according to Dr Dan Lunt, from the University of Bristol's School of Geographical Sciences.

Taking a climate model developed by the Met Office, Dr Lunt's team carried out a

EXAMPLES OF GEOENGINEERING APPROACHES

Solar-radiation management
Injection of sulphate particles into the stratosphere to reflect or absorb solar radiation.

Pros:

- Known to work: the eruption of Mount Pinatubo in the Philippines threw up particulate matter into the atmosphere, which lowered global temperatures.
- Has a short lead time, three to five years.
- Relatively cheap.

Cons:

- Requires international agreement.
- There is a potential difficulty in gaining public acceptability.
- Could cause ozone depletion.

Cloud albedo modification

Pros:

- Has quite a short lead time; 20 years.
- Quick to turn off.
- Cheap.
- Natural process.

Cons:

- Effectiveness is uncertain.
- Needs to be carried out continuously.

Sunshade engineering

Pros:

- Would work immediately.
- Would be effective.

Cons:

- Expensive.
- Could be weaponised.
- Requires international agreement.

Painting rooftops of buildings with reflective paint

Pros:

- Cheap.

Cons:

- Would work only on a local scale, in cities that are usually hotter than the surrounding environment.

Selecting or engineering varieties of food crops to be more reflective

Pros:

- Much of Europe and North America could be cooled by

up to 1°C during the summer growing season, equivalent to an annual global cooling of more than 0.1°C.

Cons:

- Would have limited efficacy on a global scale.

CO₂ reduction

Iron fertilisation of oceans to increase photosynthesis.

Pros:

- Enhancement of a natural process.
- Cheap.

Cons:

- The efficacy is uncertain because of the limited uptake capacity of the oceans.
- Potential deleterious effects such as the release of nitrogen oxides.
- Possibility that the ocean nutrient balance would be disrupted.

Adding lime or other alkalis to oceans to lower the acidity and allow more CO₂ to be absorbed

Pros:

- Calculations indicate that it could be effective.

Cons:

- The material is energy-intensive to produce.
- Potential disruption to the ocean balance.

Direct extraction of CO₂ from the air using absorbents

Pros:

- Shown to be technically feasible.
- The equipment can be switched on and turned off at will.
- The amount of carbon captured can be measured accurately for the carbon-trading market.
- The technology can be located anywhere.

Cons:

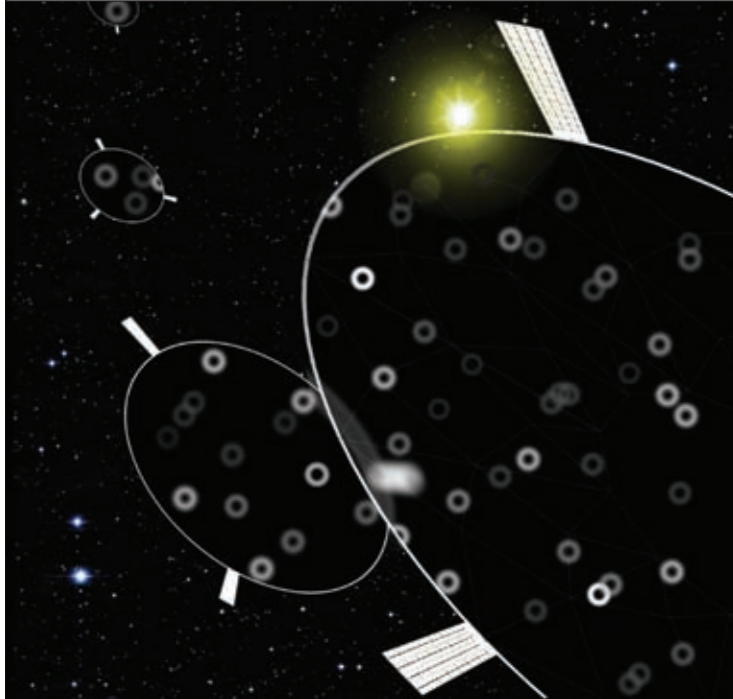
- Might be socially unacceptable if the installations are large.
- The economics of large-scale use is not known.
- The time and effectiveness in mitigating climate change is uncertain.

series of simulations to assess what happens when the amount of solar energy reaching the Earth is reduced by a sunshade. A control simulation was run with pre-industrial levels of atmospheric CO₂, with which a second simulation, with four times the amount of CO₂, could be compared. For the same CO₂ concentration, a third simulation introduced a lower level of solar radiation, as achieved with a

sunshade. This showed that a reduction in radiation of 4.2% would be enough to eliminate global warming.

Closer examination revealed that the effects would be uneven, with warming in the polar regions and cooling in the tropics. However, reducing the shade strength to 75% brought the anomalous variations down to an acceptable level. Dr Lunt feels that more research is

Sunshade engineering: light reflectors stationed at Lagrange point 1. Lagrange points are locations in space where gravitational forces and the orbital motion of a body balance each other. There are five Lagrangian points in the Sun-Earth system and such points also exist in the Earth-Moon system. © R Angel/Steward Observatory, University of Arizona



Ocean fertilisation: phytoplankton bloom off the coast of south-west Africa © NASA

needed to look at the unforeseen effects of geoengineering. Reducing CO₂ emissions should always remain the focus of efforts to deal with global warming but he felt that Sunshade engineering is definitely a contender for plan B.

OCEAN FERTILISATION

Curtailing the sunlight reaching the Earth's surface does not, of course, reduce the amount of atmospheric CO₂. A more direct approach, first proposed at the beginning of the 1990s, is to engineer the natural turnover of carbon in the biogeochemical cycle via ocean fertilisation. The idea is to stimulate the growth of marine algae by adding nutrients such as iron, or nitrogen and phosphorus. The resulting algal bloom then takes up and fixes increased amounts of CO₂ via photosynthesis. Eventually, the biomass sinks to the bottom of the ocean explained Professor Andrew Watson, from the University of East Anglia's School of Environmental Sciences.

Experiments with iron fertilisation have already been carried out in iron-starved ocean regions, the Equatorial Pacific, North Pacific and Southern Ocean, and have been shown to stimulate blooms of phytoplankton. The amount of carbon sequestered is variable and unpredictable.

Because the CO₂ is taken from the surface ocean rather than directly from the atmosphere, the net atmospheric carbon fixed is difficult to assess. Furthermore, the effectiveness depends on how much of the biomass sinks, how far it sinks and whether the material is eaten – all depends on the alga species. The efficiency of iron fertilisation also seems to depend on location, working well in the Southern Ocean but not in the Equatorial Pacific.

Adding nitrogen and phosphorus, which are limiting nutrients over large areas of the oceans, would be effective anywhere – and proponents claim that they have the added bonus of increasing fish stocks. However, these materials are much more expensive than iron, and much more of them would be needed: whereas one atom each of nitrogen and phosphorus will fix six and 100 atoms of carbon respectively, 100,000 atoms of carbon are fixed by one atom of iron. Furthermore, their application to the oceans would compete with their essential land use as agricultural fertilisers. A negative feedback mechanism could also come into play as adding nitrogen would slow down the ongoing natural fixation of nitrogen in the oceans.

Professor Watson added that the capacity of ocean fertilisation to sequester atmospheric CO₂ is quite limited. Models for the ocean's carbon cycle suggest that it would be difficult to

increase carbon fixation by more than 10 to 20%. Estimates show that a few hundred million tonnes of carbon could be fixed a year, which is small compared with the annual emission rates of 7–8 billion tonnes. In addition, undesirable changes in the marine ecosystem cannot be ruled out, and there are also ethical and legal issues to be considered. He concluded that iron fertilisation could be carried out on a small, commercially based scale and would have a similar impact on reforestation programmes. Land-based engineering schemes to capture CO₂, he suggested, were more promising and these are laid out in the section *Examples of Geoengineering Approaches*.

PRACTICAL, SOCIAL AND ETHICAL IMPLICATIONS

Professor Steve Rayner, director of the James Martin Institute at the University of Oxford, told the seminar that the concept of geoengineering was highly politicised and was an approach that policy makers found difficult to talk about. The view had been that geoengineering solutions create a potential hazard by providing a 'get-out-of-jail card' that permits society to continue to emit CO₂ with impunity. There are concerns about interfering with large-scale Earth systems. It is especially difficult to make policy and

management decisions about technologies that are largely undeveloped, and for which the consequences of implementation are far from understood. Geoengineering should be considered for two reasons: the first to buy time or to shave off the peaks from the rising CO₂ emissions profile – these may not fall as originally predicted due to the rapid economic growth of China and India. The second is as an insurance policy against a climatic emergency.

Geoengineering concepts can be divided into two categories: those involving tuning large-scale Earth systems and encapsulated, hard-engineering solutions. Each of the concepts have their pros and cons, according to Professor Rayner – see *Examples of Geoengineering Approaches*. There is also the question of international law. For the ocean treatments there are already two treaties that might claim jurisdiction, the Convention

on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (commonly called the London Convention) and the UN Convention on Biological Diversity.

Hard-engineering solutions also have challenges. Space-based reflectors would require expensive launch facilities and might raise public concerns about weaponisation. Schemes involving carbon-capture machines that absorb CO₂ from the air and then store it in spent oil wells or saline aquifers are less controversial, and would not involve issues of international law. The technology has the advantage of enabling accurate measurement of the carbon captured, as required for claiming carbon credits in the carbon-trading market. However, the economics of implementing any of these technologies is not known accurately when scaled up to the levels proposed.

To formulate a policy on geoengineering also requires

taking into account the timeframes over which they would be effective. Sulphate aerosols offer an emergency response, whereas air capture offers emission shaving over the medium term. Professor Rayner reiterated the views of the other speakers that, based on the precautionary principle, more research must be done, adding that the ethical, political, economic and legal aspects must also be considered. "We have a choice, we must exercise it wisely," he said.

View the full text from the seminar at: www.iop.org/activity/policy/Events/Seminars/file_37088.pdf

BIOGRAPHY – Nina Hall

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UK PROGRESS ON GEOENGINEERING

The UK Government has not yet put in place a policy for geoengineering, either as a way of gaining a 'grace period' of two or three decades, or as a plan B to deal with the possibility that climate sensitivity turns out to be greater than expected. Two UK research councils, the Engineering and Physical Sciences Research Council (EPSRC) and the Natural Environment Research Council (NERC), fund research relevant to geoengineering, mostly in terms of modelling Earth and climate systems.

NERC has allocated £2 million to a consortium studying cloud seeding and cloud formation and related albedo effects. In addition, the research councils' Energy Programme has recently announced that it plans to provide funding support for geoengineering research, and will hold a scoping workshop, led by EPSRC, to identify the major challenges and potential research themes for future activity.

The Institution of Mechanical Engineers published a report in August 2009 titled *Geoengineering – Giving us the time to act?* which assessed three more possible geoengineering approaches – artificial trees, algae-coated buildings and reflective buildings. The report stressed the need for a balanced assessment of the full range of proposals with regard to their climatic effectiveness, likely environmental and ecological impacts and possible unintended side-effects.

The Royal Society published a comprehensive report, *Geoengineering the climate: Science, governance and uncertainty* in September 2009. Among the recommendations was a call for relevant UK Government departments in association with the UK Research Councils to fund a 10-year geoengineering research programme at a level of around £10 million a year. This should actively contribute to an international programme and be closely linked to climate research programmes.