

Curing the Climate?

"...wild ideas like mirrors in Space, we're going to consider all of them." This was a member of the UK parliament describing a select committee investigation planned for 2009 on using engineering to mitigate climate change. It's becoming a hot topic in the journal *Nature*, the Royal Society is jumping in with a working group and it's even in the Natural Environment Research Council's top 10 things most likely to affect UK biodiversity between now and 2050 [1].

So what's the fuss about? Since the industrial revolution, we humans have been pumping vast quantities of greenhouse gasses in general, and carbon dioxide(CO₂) in particular, into the atmosphere. This amounts to a vast, if inadvertent, experiment in atmospheric physics. Had this experiment been intentional (and schemes for inducing global warming have been around for a while [2]), it might have been termed 'Geo-engineering'- manipulating the atmosphere in a way that will affect climate, in this case, globally. The results of this experiment are only now unfolding, but include substantial and highly damaging global warming. CO₂ is a long lived gas in the atmosphere, so even if we stopped emitting it entirely tomorrow, the sort of scenario that could only ever be implemented in a computer simulation, global warming would continue and even increase for years, with all the concomitant effects of rising sea levels on low-lying countries and islands, desertification, modification of arctic habitats and the rest. So is our only option to learn to live with a warmer world- adapt ourselves, our crops, and, to the limited extent of our ability, assist that process for the rest of the natural world? Well, perhaps not. If the problem was a geo-engineering experiment in atmospheric physics, perhaps the solution could be one too...

There's no lack of ideas. Prominent among them are plans to 'fertilise' oceans so as to encourage algae to absorb more CO₂. Other options for capturing CO₂ include artificial trees to collect the gas from the atmosphere followed by sequestering it underground or in deep ocean currents. Carbon CO₂ may be the cause, but the effect we care about most is global warming. Geo-engineering could therefore focus, not on CO₂, but on warming itself. The greenhouse effect, causing the warming, is an issue with the energy budget- our energy 'expenditure' into space is not high enough- the CO₂ is keeping the energy in. There's more than one way to balance a budget, so instead of attacking the 'expenditure' side, we could tackle the 'income', i.e. the energy the Earth receives from the Sun. If less of the energy coming from the Sun were caught by the Earth, we'd have less to worry about causing global warming, even with higher levels of CO₂. There are various ideas for how this could be done, most of which involve reflecting more Sunlight back into space [3].

Reducing global warming by reflecting more Sunlight

The Earth, like all objects that are neither perfectly black nor perfectly white, absorbs a proportion of light and other electromagnetic radiation hitting it and reflects the rest. The extent to which the Earth diffusively reflects radiation coming from the Sun is termed its 'albedo'. The Earth's albedo is about 0.3, i.e. about 30% of the radiation from the Sun is reflected straight back out into space. However, this average figure comes from a mixture of the different surfaces with very different individual albedos. The sea, which covers most of the Earth has a low albedo, and forest is not much

higher, at 0.09-0.18. On the other hand, snow and ice can have an albedo up to 0.9. With such a range of different albedos making up the global average, the balance of the different albedo surfaces is crucial to the overall amount of energy coming from the Sun that is absorbed and so can result in global warming. Thus, for instance, melting arctic ice gives a reduction in average albedo and hence increase in the potential for global warming. Geo-engineering approaches to reduce global warming by changing albedo therefore focus on increasing the proportion of the Earth with high albedo, or increasing the albedo of particular elements. Clouds are an ideal candidate in this direction, being relatively easily influenced and potentially having an albedo of over 0.7. Even schemes that enhance the albedo of existing clouds, rather than create new ones, could have a substantial effect. For instance a recent paper proposes a scheme at sea whereby “Wind-driven spray vessels will [...]release micron-sized drops of seawater into the [...] layer beneath marine stratocumulus clouds. [...] When residues left after drop evaporation reach cloud level they will provide many new cloud condensation nuclei, giving more but smaller drops and so will increase the cloud albedo to reflect solar energy back out to space.” [4]. See Fig. 1.

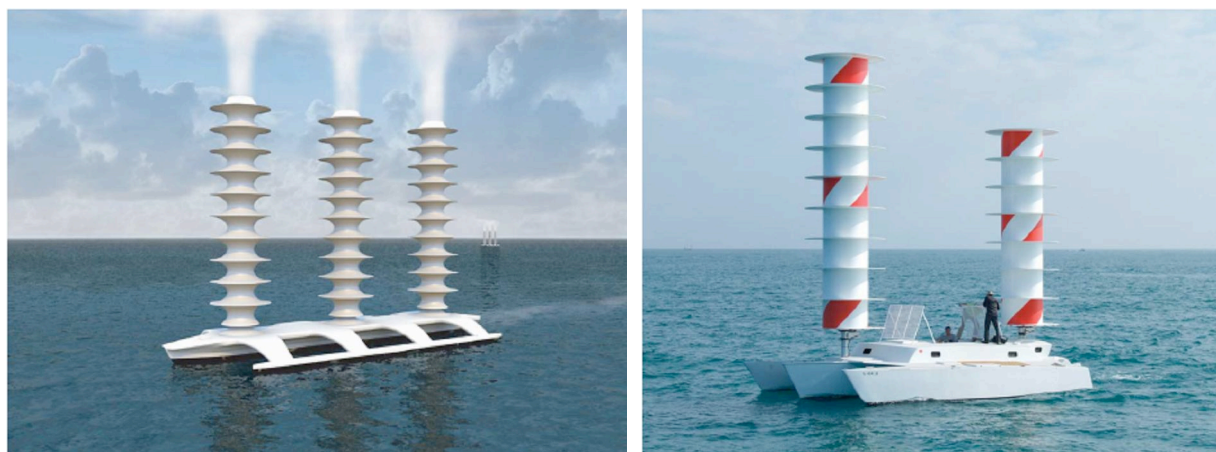


Fig. 1. Wind-driven spray vessels for enhancing cloud albedo to reduce global warming. **Left** an artist's impression of what such a final vessel would look like. **Right** 'Clodia', an existing vessel working on the same principle. Both pictures taken from [4], copyright J. MacNeill and Discovery Channel respectively.

Many other possible schemes are based on the same principle of reflecting back the radiation that would otherwise be causing global warming. These include putting carefully chosen particles higher into the atmosphere (e.g. [5]) and extend to the sort of thing highlighted by the MP quoted earlier, what the eminent Stanford climate scientist Stephen Schneider has described as 'Buck Rogers schemes in space' [6]. One particularly carefully calculated scheme would create a cloud of tiny spacecraft to act as a Sunshade. As they put it “The concept builds on existing technologies. It seems feasible that it could be developed and deployed in ~25 years at a cost of a few trillion dollars, <0.5% of world gross domestic product (GDP) over that time.” [7]

Schemes that actively reduce atmospheric CO₂

Once the Sun's radiation has made it here and not been reflected straight back into space, there may still be ways of helping it escape again more quickly and hence reduce global warming. Much of the current slowing in radiation loss comes down to the CO₂ humans have been pumping into the atmosphere, so the most direct route to increasing the radiation loss is actively removing some of this CO₂. One of the most successful strategies for removing CO₂ from the atmosphere is employed by plants, where, in the course of photosynthesis they capture CO₂ from the atmosphere into more complex chemicals in their own cells. This occurs most extensively in some of the simplest plants- marine algae. Proposals therefore focus on giving these tiny plants a helping hand in their CO₂ capture. A principal thing limiting their activity is the availability of nutrients necessary to growth but generally rare in the ocean. Foremost among these is iron. If iron is added to the oceans ('iron fertilization') it can produce great algal blooms, which capture large amounts of CO₂. Experiments both deliberate and natural have demonstrated that this process does indeed occur, with up to hundreds of thousands of carbon atoms captured for every iron atom added [8]. Similar ideas with less experimental backing include large pipes to draw up nutrient-rich water from lower in the ocean to the surface [9].

Ultimately these schemes aim to transfer CO₂ from the atmosphere to the deep ocean. There may be means other than algae of extracting it (such as artificial trees [10]) and there may be other means of sequestering the CO₂ in places where it cannot have its deleterious atmospheric effects, such as in geological formations, including those from which the carbon (in the form of oil and gas) originally came. Indeed the process of sequestering CO₂ may just as well start directly at the power stations that produce it, an idea finally beginning to receive serious consideration in the power industry [11].

Personal reflections

So far we have considered a subset of current ideas for using an understanding of environmental physics to alter the human effects on our physical environment, specifically global warming. Very little has been said about whether these ideas are likely to work or even if they did, whether they'd be a good idea.

There is no doubt that the challenge is serious –the political process for the reduction of carbon emissions is slow, perhaps hopelessly so, with a focus on scenarios (notably 2°C global warming) that may prove wildly optimistic [12]. There is a strong motivation for politicians to grab whatever tools are to hand, and some of the geo-engineering options mentioned could seem very attractive routes to avoid the thorny issues of CO₂ emission reductions and get a technological 'quick fix'. There is a serious worry that if, like the British MP quoted at the start, politicians get geo-engineering ideas, their eye may stray from the ball of global CO₂ reductions, from which we may all suffer: the schemes mentioned are finite- a limited amount of albedo enhancement with a finite lifetime, a definite amount of CO₂ sequestered somewhere out of the way, yet human CO₂ emissions are indefinite- it is only in the computer simulation that it is possible to stop them entirely- unless emissions are actively cut, the problem does not go away, indeed unless something drastic is done to emissions *as well as* any geo-engineering, CO₂ will continue to grow (latest figures suggest

greenhouse gasses rising at an equivalent to ~2.4% per annum increase in CO₂ emissions [12]) and result in an even worse state at the end of any geo-engineering scheme than the beginning.

There is then the question of whether these schemes will work- many have received little research. Undoubtedly calls for more research cash are important. However even for those areas that are being researched, neither efficacy nor desirability is obvious. For instance, some of the most direct experimental research relates to ocean fertilization. While some efficacy has been demonstrated , albeit not for the complete process [8-9], iron fertilization has received a rather bad press. Most criticism at the level of it being 'tampering with nature' a level applicable to most geo-engineering. Given the degree of 'tampering with nature' evident in the original problem (human CO₂ emissions), this seems a weak argument. Nonetheless the public is well to be wary- there are real down-sides. The idea of turning low productivity areas into high by means of fertilizers has echoes of the 'green revolution' in 20th century agriculture, a process that undoubtedly had huge impact, much of it positive, but being reliant on fertilizers and pesticides, transformed many terrestrial ecosystems into 'green deserts' and associated fresh-water habitats into precisely the sort of environments, dominated by algal blooms and toxic to anything else, envisaged in iron fertilization projects. In the UK, low productivity ecosystems like lowland heath or chalk downland were 'improved' by the green revolution and are now, along with many of their specialist species, highly threatened. These systems are well studied, the ocean ecosystems that are candidates for fertilization are far less known and the deep ocean being considered as a location for long-term sequestration of CO₂ is one of the least-known habitats on Earth.

However, while scientific scepticism is justified, a generalised rejection is no better than a generalised enthusiasm among the multiplicity of ideas currently mooted in geo-engineering. Lovelock has likened geo-engineering to pre 1940s medicine, a period with limited medical tools [13]. It remains to be discovered which geoengineering tools resemble which medical tools. Crude interventions into biological systems, as in iron fertilization, may have most in common with trepanning - brain surgery with a chisel. Other options, such as developing means to capture and sequester CO₂ may have more in common with equally ancient common-sense first-aid, such as stopping a bleeding artery. Others again may be like the basic interventions available in the early 20th century, such as aspirin, that can only tackle a few symptoms, for instance albedo enhancement, which may temporarily reduce global warming, but leaves the underlying cause (raised atmospheric CO₂) and its other symptoms (e.g. ocean acidification) untouched. Whatever the putative merits of the medicines, the ailment is real and, unlike in much pre-1940s medicine, we have a fair idea of the cause, in CO₂ emissions, and the ultimate cure, in reducing those emissions. Geo-engineering may soon have a vital role in maintaining the patient without excessive damage though the treatment. However, the 'medics' are politicians, not physicists. Healthy debate and sound science are vital among the scientists to uncover and develop the best 'medicines' amid the multiplicity of ideas if the 'medics' are to be given their tools. The question is whether this can be done without getting distracted from the treatment itself.

Notes

- [1] For the most recent discussion in Nature see <http://www.nature.com/news/2008/081217/full/news.2008.1319.html> . For the most tangible output from the Royal Society so far, see the November 2008 edition of the Philosophical Transactions of the Royal Society A 'Geoscale engineering to avert dangerous climate change', on which this essay draws heavily. For the NERC 'Top 25 Challenges to UK biodiversity' see <http://www.nerc.ac.uk/research/highlights/2008/biodiversity.asp>
- [2] Russian schemes have been particularly notable, see Rusin and Flit 1966. **Man versus climate**. Central Books Ltd (Translator Rottenberg)
- [3] The alternative of moving the Earth's orbit to a position where it receives less Sunlight in the first place has been mooted. Even if making nuclear explosions in space could be done in a way that did the job, there are mercifully few who believe it would be a good idea.
- [4] Salter et al. (2008) **Sea-going hardware for the cloud albedo method of reversing global warming** *Phil. Trans. R. Soc. A* 366: 3989-4006
- [5] Caldeira and Wood (2008) **Global and Arctic climate engineering: numerical model studies** *Phil. Trans. R. Soc. A* 366: 4039-4056
- [6] Schneider (2008) **Geoengineering: could we or should we make it work?** *Phil. Trans. R. Soc. A* 366: 3843-3862
- [7] Angel (2006) **Feasibility of cooling the Earth with a cloud of small spacecraft near the inner Lagrange point (L1)** *Proc. Natl. Acad. Sci. USA* 103: 17184-17189
- [8] For a review of current and future use of experimental work with iron fertilization see Smetacek and Naqvi (2008) **The next generation of iron fertilization experiments in the Southern Ocean** *Phil. Trans. R. Soc. A* 366: 3947-3967 For a natural experiment and the source of the Iron:Carbon ratio figure quoted see: Blain et al. (2007) **Effect of natural iron fertilization on carbon sequestration in the Southern Ocean** *Nature* 446: 1070-1074
- [9] Lovelock and Rapley (2007) **Ocean pipes could help the Earth cure itself** *Nature* 449: 443 Also see the arising correspondence: Shepherd et al. (2007) **Geo-engineering might cause, not cure, problems** *Nature* 449: 781
- [10] 'Artificial trees' as an idea are largely associated with Klaus Lackner, while it has been widespread in the media there is a lack of formal references, an exception being Lackner et al. (1999) **Carbon dioxide extraction from air: Is it an option?** Proceedings of the 24th. International Conference on Coal Utilization and Fuel Systems. Clearwater, 885-896, Florida, USA.
- [11] For the logic behind why carbon sequestration and storage is a potentially useful strategy see Breeze (2008) **Coping with carbon: a near-term strategy to limit carbon dioxide emissions from power stations** *Phil. Trans. R. Soc. A* 366: 3891-3900

[12] Anderson and Bows (2008) **Reframing the climate change challenge in light of post-2000 emission trends** *Phil.Trans. R. Soc. A* 366: 3863-3882

[13] Lovelock(2008) **A geophysiolologist's thoughts on geoengineering** *Phil.Trans. R. Soc. A* 366: 3883-3890