Geoengineering the climate: Science, governance and uncertainty

Responses to call for evidence

Part V

2 PER CENT FOR THE PLANET

Richard Mountford
2% For The Planet
37 Greenview Crescent
Hildenborough
Tonbridge
Kent
TN11 9DR
Tel: 01732 833170
Mob: 07743 918677

Dear Sir or Madam

Thank you to the Royal Society for taking on this vital project. My feedback for some of your questions is as follows:

Question 2
Ideally, governments and international organisations with access to large amounts of money such as the EU should be researching into climate geoengineering as a matter of urgency. As they are not doing so, the Royal Society is right to take on the work.

Question 4
Individuals, organisations and national governments are unilaterally emitting carbon. It is therefore difficult to see why they are not also entitled unilaterally to remove it. Of course, before a government implements any climate geoengineering project, they would ideally take into account the views of other governments as well as general scientific opinion. However, the dangers of not taking action are likely to be far greater than the dangers of implementing any project to remove carbon or mitigate its consequences.

Question 6
I consider climate geoengineering to be the most important thing to do now. Despite all the international meetings and treaties, carbon emissions per year are actually higher this decade than last decade. Energy efficiency and reductions in certain types of carbon-emitting activities would only be effective if they meant that oil and coal stayed in the ground. The reality is that we look set to keep emitting more carbon, so we need to remove it again.

Yours sincerely

Richard Mountford
Founder
twopercentfortheplanet.org

ANTARCTIC CLIMATE AND ECOSYSTEMS COOPERATIVE

Author: Ian Allison

Geoengineering Climate: call for submissions

The Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC), together with its partner agencies, is the key Australian research body dealing with climate change and the Southern Ocean. Ocean fertilization is an important area of research within both the Ocean Control of Carbon Dioxide and Policy programs of the ACE CRC.
The ACE CRC would like to make the attached submissions in relation to iron fertilization.
The ACE CRC has recently released a Position Analysis on Ocean Fertilization which elaborates on, and substantiates, the points made in this submission. It is attached for your information.
The ACE CRC, together with its partner agencies, is continuing its research into iron fertilization and would welcome any further requests for information The Royal Society may have.
Yours sincerely

Dr Ian Allison
Acting CEO

Response to The Royal Society study on geoengineering, October 2008 from the Antarctic Climate & Ecosystems Cooperative Research Centre

Further information:
Associate Professor Tom Trull
Program Leader, Ocean Control of Carbon Dioxide
Tel: (03) 6226 7888
E: enquiries@acecrc.org.au
W: www.acecrc.org.au

Question1: What do you consider to be the current state of knowledge regarding the feasibility, efficacy and predicted impacts of climate engineering schemes?
Proposals have been made to add iron in areas where this is in short supply – such as the Southern Ocean – to increase the growth of microscopic marine plants (phytoplankton). Phytoplankton consume CO_2 during photosynthesis. While promoting phytoplankton growth has been proposed as a method to increase sequestration of carbon in the deep sea and several ocean experiments have been undertaken to test this scientists are not yet able to measure how much carbon is transferred to the deep ocean as a result of ocean fertilization.
Satellite remote sensing can identify increased phytoplankton presence but there is scientific uncertainty about how that increase impacts on the food web and how carbon is exported into the deep ocean.
Only three of the 12 iron fertilization experiments conducted to date demonstrated that there was a temporary increase in the drawdown of atmospheric CO_2 into the surface layer of the ocean (~100 m depth). Insofar as carbon penetration to deeper waters is concerned – which is where it matters from a climate change point of view – the results of the experiments were inconclusive.
An important factor in assessing the suitability of any carbon sequestration process is the duration for which the carbon will remain out of contact with the atmosphere. It appears that much of the sinking CO_2, in fact, returns to surface waters within decades. Only a small fraction remains in the deep ocean for centuries.
Large scale ocean fertilization may cause harmful changes in marine ecosystem structure and biodiversity. These may include:

- changes in the food chain as iron fertilization boosts larger phytoplankton at the expense of smaller species;
- increased phytoplankton blocking sunlight needed by deeper corals or kelp;
- depletion of oxygen in deep waters, creating 'dead zones' where fish could not survive;
- increased acidification of the oceans, which would reduce the ability of corals and marine organisms to form hard carbonate shells in the waters into which CO_2 is sequestered;
- more potent greenhouse gases, such as nitrous oxide and methane may be produced by the altered phytoplankton communities; and

- changes to global ocean circulation as increased phytoplankton increases heat absorption by the surface ocean.

In conclusion, the impact of iron fertilization is uncertain, both in terms of measurable benefits for the increased drawdown of atmospheric CO_2 and effects on marine food webs.

Question 2: How do you think research into climate geoengineering should be taken forward, and by whom?

Larger experiments and more ambitious measurement programs will be necessary to reduce the significant uncertainties that currently exist about iron fertilization, in particular with respect to risk. Experiments to date have not been designed to address risk, and future research will require expanding the types of observations made and the specialists involved, e.g. to include toxicology and formal risk assessment procedures.

In addition, to understand longer term ecological changes from iron fertilization, it may be useful to study regions that receive natural nutrient inputs, for example regions where large amounts of iron-containing soils are blown to sea or where upwelling of deep waters brings it on to the surface.

Question 4: What do you consider to be the most important political, social, legal or ethical issues raised by climate geoengineering?

Specific international regulatory frameworks for geoengineering, and iron fertilization in particular, do not exist. Governments need to address this gap as a matter of urgency.

In so far as iron fertilization is concerned the most useful effort, to date, has been by the International Maritime Organization. Its London Convention/Protocol requires a precautionary approach to the deposition of any material into the oceans (Art.3.1 Protocol). It also asks parties to protect and preserve the marine environment from all sources of pollution (Convention Art. 1/Protocol Art.2).

In October 2008, the Conference of Parties to the London Convention/Protocol adopted a Resolution stating that ocean fertilization operations should only be allowed for research purposes. The question of whether or not this becomes binding will be considered at the next Conference of Parties in 2009.

On this basis, insofar as ocean fertilization is concerned, governments should be urged to take a precautionary approach to authorizing the deposition of foreign material into the ocean until such time as its efficacy can be quantified and its environmental impact assessed and found to be within acceptable limits.

ATMOCEAN INC

Author: Phil Kithil

In Response To The Royal Society Call For Submissions: "Geoengineering Climate"

Oceanic Recycling Of CO_2 By Enhancing Natural Biological Processes

Philip W. Kithil, CEO
Atmocean, Inc.
802 Early St.
Santa Fe, NM 87505
505-2310-2294
pkithil@atmocean.com
www.atmocean.com

Summary. The need to continue using fossil fuels for air and ground transportation and coal infrastructure requires some way to offset the resulting carbon in the decades ahead, since widespread (>60% for example) adoption of non-fossil energy by 2050 likely would absorb an unacceptable (and probably unachievable) percentage of all available public and private investment capital.

Therefore, any practical approach that effectively deals with CO_2-induced climate change must necessarily pursue concurrent geoengineering efforts to address previous as well as future emissions. 350.org advocates getting us back to 350 ppm CO_2 and to do that we must pull carbon out of the atmosphere and back into the earth and the oceans where it
came from.

No reasonable approach should be off the table, and every reasonable idea should be given full consideration and adequately funded until proven to not be viable. Most particularly, we must include oceanic solutions since they dominate the carbon cycle and provide the ultimate repository for carbon. Finally, natural biological processes to recycle CO_2 are orders of magnitude more cost-effective than man-made techniques, with reasonable environmental consequences over ~3 billion years of evolution.

Our responses to specific questions follow.

1. What do you consider to be the current state of knowledge regarding the feasibility, efficacy and predicted impacts of climate geoengineering schemes [with respect to the above topic]?

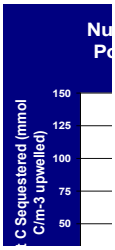
First of all, from an overall perspective, it is important to realize that we have already geo-engineered our climate over the past two centuries, with the UK actually taking the lead over the US in total carbon emissions since 200 years ago. Our societies have done an incredible job of geoengineering, actually increasing the CO_2 levels to the point where global climate change is occurring. What we are talking about is **reverse geo-engineering:** taking the changes that Man has accrued and reversing them so the natural state is restored. That inherently means pulling carbon dioxide out of the atmosphere and putting it back into the land and the oceans where it originally came from. It so happens that the oceans have a much greater capacity to recycle CO_2 than the forests and the soils of the land, both because there is 10 times more ocean area to work with than all the arable land of the Earth and also because the oceans do not compete for real estate and farmland as does reforestation.

Feasibility. The conventional wisdom regarding oceanic recycling of CO_2 is that Redfield-ratio limitations on biological productivity imply that the upwelled water would contain as much, or more, dissolved CO_2 as could be potentially absorbed by the upwelled nutrients – therefore typically it is a zero sum game.

Contrary to this conventional wisdom is the hypothesis put forth by Professors David Karl (University of Hawaii) and Ricardo Letelier (Oregon State University) which proposes that residual phosphate from a primary bloom in waters with a <16:1 N:P ratio can incite a secondary diazotrophic bloom that results in significantly more absorbed pCO_2 than that which is upwelled.

Efficacy ("the capacity to produce a desired size of an effect under ideal or optimal conditions"- Wikipedia). Within low-nitrate, low-chlorophyll (LNLC) ocean regions, namely the tropical and subtropical oceans between 30ºN and 30ºS, the Karl-Letelier hypothesis proposes that net carbon export is substantially determined by the nutrient ratios at different depths. Assuming those nutrients are brought up to the euphotic zone, the potential net carbon export volume per cubic meter of upwelled water can be accurately estimated. Based on nutrient ratios measured over many years at Station ALOHA north of Hawaii, Karl-Letelier would expect to see these amounts net sequestration of carbon:

For nutrients measured at 300m depth, net export is expected to be 32.7 mmol C per cubic meter upwelled. To convert this to annual potential net CO_2 sequestered per upwelling pump, we first must assume pump size and average wave conditions. With a 3m diameter pump operating year-round with 2m average waves at 10 second intervals, this value of 32.7 mmol C net export translates to the equivalent of 64 metric tonnes of CO_2 per year.[1]



Predicted Impacts. The long-term impact of wave-driven upwelling must consider numerous elements, some of which are listed below.

- Warming of the global oceans causes more stratification, less delivery of deep-ocean nutrients, and less primary production. Reversing this unwanted stratification should help restore historic levels of nutrient upwelling and help the ecosystem.
- Since wave height and period are inherently variable and sporadic, perturbation using wave-driven upwelling pumps also will be variable and sporadic, as will the resulting net export. This is advantageous with respect to any unintended ecological effects since natural variability is intact, just slightly amplified. What happens today throughout the LNLC ocean regions, without wave-driven upwelling, will be very similar to what will happen in the future, with wave-driven upwelling.
- Upwelling of nutrients will increase primary production – the base of the ocean food chain. This is good news for every trophic level, up to and including large carnivorous fish, sea mammals, and marine avian species.
- Some argue that upwelling may increase toxic blooms, increase the existing low-oxygen regions of the mid-ocean, and other countervailing effects. We counter that the modest volume of upwelled nutrients from wave-driven upwelling pumps is orders of magnitude less than common natural events such as El Nino, hurricanes, or natural variability; and that mixing of deep water quickly dissipates the modestly greater concentration of deep nutrients brought upward. Also the work of the pumps is done in the central ocean aquatic deserts. The toxic blooms that affect human activities occur near the shore. The nutrients from the pumps are consumed far before they can travel from the central ocean to the shorelines, thus not contributing to shoreline toxic blooms that people observe from time to time.
- More testing is needed to measure and verify the effects. Thus far the main difficulty has been in measuring the changes induced by wave driven upwelling – barely above background levels except right at the pump outlet.

2. How do you think research into climate geoengineering [using wave driven upwelling pumps] should be taken forward, and by whom?

How. The global environmental situation with respect to CO_2 is so dire that precious little time remains before one or more climate tipping points are reached. Therefore, we cannot immediately answer every possible question that the scientific community might ask, but instead need to work with the scientific community to quantify effects as well as to monitor potential side effects and respond accordingly.

It is a matter of risk-avoidance: is it riskier to undertake wave-driven upwelling - soon - even though there is a small possibility of some side effects, or is it riskier to spend decades getting 99.9% confidence there will not be any undue harmful side effects from upwelling?

A low risk strategy is to quickly implement reverse geo-engineering approaches such as upwelling on a small scale and observe the results. When upwelling is stopped, the harmful effects would stop as well. There is no scenario of a runaway situation with upwelling, since Nature shows us that it happens naturally all the time. We are simply restoring more of what is a natural process that is being impeded by oceanic surface warming.

Other geoengineering schemes that are difficult or impossible to undo would require a very cautionary approach. Examples of such schemes are the introduction of new species into isolated ecosystems that otherwise would remain isolated.
By Whom. It is very important for academic research to partner with non-governmental enterprises in the research effort.

- First, the amount of funding needed to evaluate all reasonable reverse geo-engineering proposals, is not within the reach of already-strapped governmental R&D budgets.
- Second, the choices of which reverse geo-engineering schemes to evaluate must involve the private sector, because the private sector factors in "risk versus reward". Bad ideas get put in the trash much sooner when private money is in the game. Conversely, governmental agencies are poor decision-makers when it comes to which technology to fund (Synfuel, and ethanol, as two examples).
- Third, the evaluation time frame is much quicker when private money is involved. Government-sponsored research inherently takes longer and costs more, by the very nature of the process.

3. What factors need to be considered before deploying any climate geoengineering schemes [such as wave driven upwelling]? Who should be responsible for any deployment?

Factors To Consider. Where will it work best? How much will it cost, and what is the cost-benefit? Do these costs and benefits fully account for intangibles and downstream effects? Is the magnitude marginal or significant, when fully implemented? How large are the ancilliary benefits, such as restoring collapsed fisheries, resulting in more fish or other food supply, etc.? Are there truly any significant (not just by armchair naysayers) side effects of low-intensity upwelling in the deep ocean? What is the practicality of the scheme in today's socio-political-economic environment?

Who Is Responsible: The entities that do the reverse geo-engineering should accrue the benefits and assume the responsibility for their actions. Regretfully, as we have seen with the IPCC Reports in which the forecast outcomes even under the worst case assumptions are turning out to be significantly understated, when you ask for scientific consensus and a high level of certainty, you get overly conservative results. The scientific community has an important role to play in observing the process and reporting on results.

4. What do you consider to be the most important political, social, legal or ethical issues raised by climate geoengineering [using wave driven upwelling]?

Political Issues: Though not precisely political, climate reverse geo-engineering ultimately involves both economic and environmental tradeoffs. If there was no risk of side effects, the issue would be moot. A combined analysis of environmental + economic tradeoffs is needed, incorporating all possible tangible and intangible costs and benefits. Policymakers need the benefit of this analysis to make informed decisions.

Social Issues: Equalizing the effects on economically well-developed vs. less-developed countries should flow from the above analysis.

Legal: Legal drafting of policy decisions should follow – not lead – the above political and social processes.

Ethical: To achieve a truly sustainable environment, we must accept painful and/or expensive tradeoffs. For example, achieving a sustainable food supply from the oceans will require rigorous & expensive enforcement of fishing limits, likely with decade-long catch restrictions, higher prices for ocean protein, and the need to supplement the food supply in poor countries.

5. What do you see as the main barriers to, and opportunities offered by, climate geoengineering?

Barriers: 1) NIMBY: not in my back yard. Many scientists don't want to see a climate solution in their field because they might be held responsible if side effects occur and they didn't foresee them. 2) Those who refuse to adopt 100% accounting (eg. Fail to consider all aspects of the problem), rather see the issue through a narrow lens.

Opportunities: If the reality is that our global economy cannot afford to adopt non-fossil energy without catastrophic reductions in standards of living, anytime soon, then the opportunity offered by reverse geo-engineering is to make up for this reality.

6. Where do you feel that climate geoengineering fits in the greater scheme of climate research and action to mitigate and adapt to climate change?

How It Fits. Climate reverse geo-engineering should be in the lead, since the economic transition to non-fossil energy is impractical in the short term. Effectively, we have to reverse geo-engineer the geo-engineering that has been done by our society for the past 200 years in the emission of greenhouse gases and also the collapse of the ocean fisheries by overfishing and nutrient runoff adjacent to shorelines.

Mitigate and Adapt. Mitigation/adaptation simply defers the catastrophic outcome for a few years or decades. A three-foot seawall around all the coastal cities won't stop four feet of ocean.

7. Are there any other issues related to climate geoengineering that you consider to be important?

- Delay in confronting climate change could be worse for the environment, than taking action on a hundred measures of which half will fail.
- To expedite the international decision-making process, negotiators should start at the desired end result and work backwards to the present, beginning at a high level then drilling down to details. This will elucidate the decision pathway and quickly highlight the real benefits and costs. Current negotiations start from each party's present situation and horsetrade inch by painful inch to the desired end game.
- New issues and new potential solutions will arise, so there must by a dynamic, flexible process embedded in final political agreements.
- This effort by The Royal Society adds great value by broadening the debate and legitimizing fresh thinking.

[1]Adopted from Table 1, "Nitrogen fixation-enhanced carbon sequestration in low-nitrate, low-chlorophyll seascapes". David M. Karl, Ricardo M. Letelier. Marine Ecology Progress Series M 7547, 19 June 2008.

BIOFUELWATCH

Author: Deepak Rughani

Submission to Royal Society study on Climate Geo-engineering

Biofuelwatch

Dear Andrew Parker,

In our submission we focus on proposals for terrestrial bio-geoenginering. However, much of our concern relates to the impact which those proposals would have on biodiversity, without which ecosystems would collapse and no longer be able to regulate the climate, nor sustain the lives and livelihoods of people. The same concerns apply to other geo-engineering proposals, all of which have unquantified but potentially very serious impacts on biodiversity (and thus long-term climate stability) and on communities. Ocean-fertilisation or artificial ocean mixing, for example, threatens major negative impacts on marine biodiversity which plays an essential role in the carbon cycle. Any schemes to induce global dimming would impact on photosynthesis and thus also post a new threat to the carbon cycle. We therefore believe that geo-engineering should not be pursued as a policy option.

We focus primarily on proposals to use so-called 'carbon negative' bio-energy as means of reducing atmospheric carbon dioxide, i.e. falling within the first category of Greenhouse Gas Reduction Schemes. Those encompass Bioenergy with Carbon Capture and Storage (BECS) and biochar as a means of drawing down CO2 from the atmosphere.

Summary:

The 'carbon-negative' bioenergy proposals involve manipulating the carbon cycle by greatly increasing the burning of biomass and then attempting to sequester the carbon dioxide. There are serious questions as to whether the proposed sequestration of CO2, particularly in the case of biochar, will be possible.

Supporters of 'carbon-negative' bioenergy have claimed that up to 9.5Gt of carbon per year could be sequestered, specifically through biochar – which is more than the carbon contained in all fossil fuels burnt per year at present. [Biochar sequestration in terrestrial ecosystems", Johannes Lehmann et al, Mitigation and Adaptation Strategies for Global Change (2006) 11: 403–427]. Such a major increase in global biomass burning would require land conversion on a scale which far outstrips all the land-use change that has taken place for current agrofuel use – possibly 20-25 fold, if not more. Peter Read, one of the leading supporters of carbon-negative bioenergy and of biochar in particular, for example, has spoken of a need to convert an area the size of France in the tropics and sub-tropics, plus an area the size of Germany in temperate zones every year (Peter Read, "Biosphere carbon stock management: addressing the threat of abrupt
climate change in the next few decades." [Peter Read; An editorial comment", Climatic
Change, Volume 87, Numbers 3-4 / April, 2008]. Such large-scale land conversion would put major pressures on global ecosystems and biodiversity and thus on climate stability, on communities and food securities, on freshwater and soils. We believe that this could threaten essential global life-support systems on which we depend for our survival.

<u>1. What do you consider to be the current state of knowledge regarding the feasibility, efficacy and predicted impacts of climate geoengineering schemes?</u>

BECS relies on carbon capture and storage which has not so far been proven to be commercially viable. According to the IPCC, with regards to CCS there are still uncertainties relating to "proving the technologies, anticipating environmental impacts and how governments should incentivise uptake" (Assessment Report 4, Working Group 3 report, Chapter 4). Furthermore, the IPCC has stated that at best, 60% of CO2 emissions from power production and 40% from industry could be captured and sequestered by 2050 (IPCC Special Report, Carbon Dioxide Capture and Storage, 2005). The large-scale

commercial deployment of BECS thus does not appear likely in the short term. In the medium and long term, BECS would compete with CCS linked to coal power stations and other fossil fuel burning. If BECS ended up leading to more carbon emissions from fossil fuel burning, that would render any notion of 'carbon negativity' or even 'carbon neutrality' invalid.

Biochar has not so far been proven to result in long-term carbon sequestration in soil. It is true that ancient high-carbon soils have been found, most notably terra preta in Central Amazonia. Pyrogenic carbon from incomplete biomass burning is understood to have played part in such soil formation and the carbon contained in the ancient charcoal has indeed been highly stable for centuries or millennia. A paper which looks at such soil in North America, Germany and Brazil found that out of six such cases which have been found, three cannot be dated, and three are between 7500 and 2700 years old. ("Potential of pyrolyzed organic matter in soil amelioration", Bruno Glaser et al, International Soil Conservation Conference, Beijing, 26031 May 2002). Whilst that paper refers to the North American soils in question as being of unknown age, another study notes that they have all been under prairie or oak savannah vegetation where fire has been prevalent for 5,000 years. There is as yet no evidence that those ancient charcoal-rich soils can be recreated over a short period, or that they can be recreated at all through reliance on biochar, rather than the adoption of far more complex sustainable farming strategies. Amongst the different charcoal-enriched ancient soils, the Brazilian terra preta has been studied in most detail. The Food and Agriculture Organisation summarises the findings as follows: "Diverse organic nutrient sources were identified such as fish residues, turtle shells, weeds and sediment from the rivers, manures, and kitchen waste other than fish. It appears that the 'Terra Preta management' which produced the Amazonian Dark Earths was a sophisticated combination of organic soil management and burning, using locally available nutrient and carbon sources" (http://www.fao.org/sd/giahs/other_brazil_desc.asp).

There are no studies to prove that use of modern biochar will result in long-term carbon sequestration. We contacted Johannes Lehmann, one of the leading scientists working on biochar, and he advised us: "So far, there are no longer-term studies looking at the retention of carbon and nutrients from biochar in soil. One four year experiment was abandoned and another four-year old study is still ongoing, however neither of those has been published. There appears to be no other study older than about two years" (Email to Biofuelwatch, 27th March 2008). In a peer reviewed paper, Johannes Lehmann concluded that the half-life of biochar was unknown, I
i.e. that we do not know how long the carbon and nutrients will remain in the soil and that nobody knows how to incorporate biochar in soil without aggravating soil erosion and soil depletion (resulting in soil organic carbon loses). (Bioenergy in the black, J. Lehmann, Front Ecol Environ 2007; 5(7): 381–387, www.css.cornell.edu/faculty/lehmann/publ/FrontiersEcolEnv%205,%20381-387,%202007%20Lehmann.pdf). Furthermore, a recent peer-reviewed study by David Wardle et al (Fire-Derived Charcoal Causes Loss of Forest Humus, David A. Wardle et al, Science 2
May 2008: Vol. 320. no. 5876, p. 629) found that when biochar was mixed with boreal forest soil, it substantially increased decomposition of existing soil organic carbon by soil bacteria and fungi, resulting in very substantial soil organic carbon losses through leaching or respiration. Although those findings are specific to soils rich in soil organic carbon, the findings were unexpected and show how premature it would be to rely on biochar to sequester carbon in the absence of long-term field trials.

These represent our concerns about the feasibility of sequestering any carbon through BECS or biochar. Even more serious, however, are the implications of the scale of biomass use required for climate geo-engineering with so-called 'carbon negative' bioenergy.

The German Government's Advisory Council for Sustainable Development, WGBU, has spoken out against biomass with CCS for climate change mitigation because of the large amounts of additional biomass which would be required (www.pik-potsdam.de/members/edenh/publications-1/reccs-short-version-engl). Adopting bioenergy with CCS as a climate mitigation strategy would require the conversion of hundreds of millions of hectares to bioenergy plantations

Scientific understanding of both methodologies, and particularly bioenergy with biochar are in their infancy. As serious concerns about dangerously high GHG levels is prompting exploration of geo-engineering options, we appear not to be taking account of the wider risks of associated collapse of other life-support systems. Both methodologies are currently being promoted by industry at the UNFCCC, and at the US, EU and UK government levels. Yet the scientific basis is questionable and there is no serious critique of the risks and wide- scale impacts.

2. How do you think research into climate geoengineering should be taken forward, and by whom?

The full impacts of any climate geoengineering strategy can only be known if such a scheme was adopted on a large scale. This would mean engaging in a planetary experiment with unknown consequences which, particularly if they were to trigger rapid collapse of ecosystems or biodiversity, could turn out to be irreversible. We believe that the risks are so high, that such research should not be pursued. In the case of biochar, we can see merit in further research into the potential use of charcoal as one amongst many soil conservation methods in sustainable farming, provided that the results of such research were freely and publicly available and not patented, but this would not be linked to geo-engineering because, as we have discussed above, biochar use on a scale that amounts to geo-engineering would be inherently unsustainable.

3. What factors need to be considered before deploying any climate geoengineering schemes? Who should be responsible for any deployment?

4. What do you consider to be the most important political, social, legal or ethical issues raised by climate geoengineering?

We discuss 3 serious risks associated with BECS and bioenergy with biochar.

A. Ecosystems and Climate

James Hansen and several other proponents advocate large-scale bioenergy production based on low-input, high-biodiversity cultivation methods and on the use of forestry and agricultural 'waste', although Hansen has recently indicated in the media that he may also be looking at tree plantations. There are markedly different estimates of the energy return from biomass. A recent study by Christopher Field et al, estimates one-eighth of the returns compared to the OECD estimate (CB Field et al, Biomass energy: the scale of the potential resource, Trends in Ecology andEvolution Vol.23 No.2, 2008). Field identifies 'abandoned cropland' larger than the sub-continent of India as the source. Abandoned crop land usually means seasonal pasture land, land left fallow for restoration purposes and semi-natural forest, savannah and scrubland used for hunting and gathering. Even without accounting for this dramatic overestimate in yields, Van Zwieten concludes at the IBI Conference presentation (2008) that there is "not enough infrastructure and biomass, so we need to grow energy crops fast to produce enough feedstock" (http://www.biochar-international.org/images/IBI_2008_Conference_Parallel_Discussion_Session_D.pdf).

The scale and speed of bioenergy expansion required for the purpose of trying to reduce atmospheric carbon dioxide levels is fundamentally incompatible with sustainable production. It will inevitably put greater pressure on food production and ecosystems just as agrofuels has done. It will also require policies that favour short-term high yields per hectare, which are ecologically the most damaging. Any policies aimed at the scale of bioenergy use proposed will result in a dramatic expansion of industrial monocultures, even if this is not the intention of those scientists. We note that the key study on which proponents rely for the concept of 'low input, high biodiversity' bioenergy presumes a major intensification of high-input, low-biodiversity industrial agriculture in all other sectors.

Large-scale bioenergy expansion, regardless of the mode of production, will accelerate ecosystem and biodiversity destruction which in turn will accelerate climate change. WGBU (mentioned above) estimate that 428GtC are stored in tropical forests and soils. Losing the Amazon rainforest because a critical tipping point has been crossed, for example, would release 120GtC, nullifying the projected gains from nearly 50 years of bio-geoengineering sequestration. With droughts now an annual occurance in the Amazon, long-term stability is already threatened. Tropical grassland is also a key repository, containing 330GtC, indicative of the large amounts of carbon stored in undisturbed soils.

It will further deplete freshwater and soil and will inevitably compete with food production, threatening the livelihoods of large numbers of people, primarily in the global South. Bioenergy figures used by proponents of these schemes rely on calculations by other scientists which suggest that at least 500 million hectares worldwide would have to be dedicated to bioenergy production. This represents 1.5 times the entire land area of India, and 20 to 25 times the land area currently used for agrofuel

production. Conversely studies show that there is no productive land which is not either natural habitat or already under cultivation.

Misleading terms such as ‘degraded’ and ‘marginal’ lands are used to describe, for example, semi-arid and community lands slated for conversion to bioenergy. We would also argue that large-scale removal of so-called agricultural and forest ‘waste’ or residues will deplete soils, greatly speed up soil erosion and soil carbon emissions, as well as trigger chains of biodiversity loss.

The term 'carbon negative' bioenergy is shown (see link to paper below) to be a misleading term. Industrial agriculture and forestry are already one of the leading causes of climate change, as a result of large-scale ecosystem destruction, soil carbon losses, nitrous oxide emissions from fertiliser use, and high energy inputs. Calling them 'carbon negative' or even 'carbon neutral' is misleading and unjustifiable.

B. Communities
Indigenous peoples, small-scale farmers and other communities
in the global South, including many who practice truly low-carbon and sustainable or near-sustainable living, are likely to pay the price for any large-scale bioenergy expansion. The number of people who will be displaced could be of an order of magnitude greater than those currently being displaced by agrofuels, given the scale of land-use change advocated by proponents of such policies.

C. Life Support Systems
We wish to put the question; Is it correct to speak about the 'climate crisis' or should we be even more concerned about the 'convergence of crises', which include not just climate change, but also species extinctions and ecosystem destruction, soil losses and freshwater depletion, as well as myriad forms of pollution. We suggest that it is dangerously reductionist to view those crises in isolation from eachother. Not only does each crisis threaten the very foundations of life on earth, but they interact and compound each other. This is illustrated with the wide-scale collapse and extinction of amphibian populations which is currently occurring. The causes include the converging impacts of agri-chemical pollution, loss of vegetation cover, ozone depletion, the introduction of invasive species as well as climate change. Reptiles and insect pollinator species (essential for crop production) are also collapsing. Such large biodiversity losses can degrade ecosystems to the point of collapse. Throughout the planet's history, ecosystems have both maintained a stable climate and prevented runaway warming. Their role cannot be measured in terms of carbon storage alone. Natural forests, for example, help to regulate the global carbon and nitrogen cycles, the freshwater cycle and cloud formation, thus increasing the planet's reflectivity. Via the production of the chemical, hydroxyl, they also play an important role in breaking down the powerful greenhouse gas methane. Globally, key ecosystems act as a 'heat pumps' regulating rainfall and storm tracks. Without biodiverse ecosystems, the conditions amenable to life could not be sustained and true runaway warming – a ‘Planet Venus’ scenario - would be the likely outcome.

5. What do you see as the main barriers to, and opportunities offered by, climate geoengineering?

6. Where do you feel that climate geoengineering fits in the greater scheme of climate research and action to mitigate and adapt to climate change?

7. Are there any other issues related to climate geoengineering that you consider to be important? Submissions are welcomed on any of the issues mentioned in the project scope and terms of reference.

Responses which address only one aspect of the crisis – for example fossil fuel burning, whilst ignoring or even aggravating others, offer no realistic hope of avoiding runaway warming and a mass extinction event. The UN Framework Convention on Climate Change makes clear these twin objectives. Both BECS and biochar threaten emissions reduction, ecosystem protection and social justice. Regarding social justice, the burden would predominantly fall on countries in the global South which have contributed the least to global warming but which have the highest photosynthetic rates.

Our hope of survival depends on ending any further destruction and giving the biosphere the best possible chance of maintaining and, if possible, increasing its resilience through ecosystem restoration.
.

References

For all assertions unsupported by a reference please see the following report: *Climate Geo-engineering with 'Carbon Negative' Bioenergy; Climate Saviour or Climate Endgame?*
http://www.biofuelwatch.org.uk/docs/cnbe/climate_geoengineering_web241108.pdf

Authors:
Almuth Ernsting, almuthbernstinguk@yahoo.co.uk
Deepak Rughani, dee.rughani@btinternet.com

CARBFIX PROJECT

Author: Hólmfríður Sigurðardóttir and Sigurdur Gislason

Reykjavik, 11 December 2008

Royal Society study on geo-engineering

Following is a response on the Royal Society study on geo-engineering given personally by:

Holmfridur Sigurdardottir
Head of Innovation and development & Project Manager for CarbFix
Reykjavik Energy
Baejarhals 1
110 Reykjavik
Iceland
E-mail: holmfridur.sigurdardottir@or.is
Phone: +354 516 6908
Mobile: +354 617 6908
www.carbfix.is
www.or.is

Dr Sigurdur Reynir Gislason
Research professor in Geochemistry & Chairman for Scientific Steering Committee for CarbFix
Institute of Earth Sciences, University of Iceland
Building of Natural Sciences, Askja, room 236
Sturlugata 7
101 Reykjavík
Iceland
E-mail: sigrg@raunvis.is
Phone: +354 525 4497 / 525 4625
www.earthice.hi.is/

Summary

- The current stage of knowledge in climate geoengineering and public interest is increasing and the media has been focusing on the issue the past few years, but the current state of knowledge is still in its infancy.
- It needs to be clarified how long the climate geoengineering schemes will last, i.e. whether they will keep up with increasing levels of GHGs and whether they will be reversible.
- The main barrier is the cost and possible objection from the general public.
- The size of this problem provides an opportunity; it will force large groups of scientist, engineers, etc. to work together towards a common goal.
- The solution will be multidisciplinary.

1. What do you consider to be the current state of knowledge regarding the feasibility, efficacy and predicted impacts of climate geoengineering schemes?

Geoengineering has often been seen as a science fiction. However, the past few years scientists, the industry and policymakers have been looking seriously into large scale projects like CO2 sequestration projects (CCS) [1,2,8].The current stage of knowledge and public interest is increasing and the media has been focusing on the issue the past few years [3,4,5]. At this stage answer to number of questions need to be addressed. Questions like whether these schemes may work, how long it will take to implement them, what their impact might be, whether the impacts will be reversible, are they going to last etc. Their feasibility (cost, time, risk and impact) needs to be clarified. Will it for example be more efficient to cut GHGs emission? Furthermore it needs to be clarified how long these schemes will last, i.e. whether they will keep up with increasing levels of GHGs. In short; the current state of knowledge is in its infancy.

2. How do you think research into climate geoengineering should be taken forward, and by whom?

A group of leading and outstanding scientists needs to be put together, scientists who have a unique overview of the subject as well as scientist with specific skills that are needed. Many countries need to support the topic financially. The scientists would be responsible for the research with the support from chief executives of various states. Dr Wallace Broecker at Columbia University has suggested that similar effort has to be put forward as the Manhattan Plan during the World War Two and the more recent CERN project recently [5].

3. What factors need to be considered before deploying any climate geoengineering schemes? Who should be responsible for any deployment?

It is very important to predict and test the efficacy, i.e. how rationale they are. The cost needs to be estimated. The system complexity needs to be taken into account as well as possible side effects. The risk needs to be assessed and the schemes need to be verificated. Possible mitigation measures need to be assessed. The authorities should be responsible.

4. What do you consider to be the most important political, social, legal or ethical issues raised by climate geoengineering?

The issue whether the climate geoegineering schemes will keep up with the increasing GHGs accumulation is most important. Equally important is the issue whether it will be possible to stop once the course has been set. And finally it is very important that the implementation of these schemes does not result in that the general public will become inactive towards the climate change issue.

5. What do you see as the main barriers to, and opportunities offered by, climate geoengineering?

The main barrier is the cost and possible objection from the general public. It will be very expensive to execute these large scale projects and the cost is likely to rise into the future. At the same time the GHGs accumulation will be increasing. Therefore, it is vital at the same time to put a strong effort in informing and training the public and thereby attempt to reducing GHGs emissions so the demand for these schemes will diminish with time. The most pragmatic solution is to put a price tag on the carbon emission. The size of this problem provides an opportunity; it will force large groups of scientist, engineers, etc. to work together towards a common goal. And in the process, we need to produce fundamental science that will be employed in the overall solution (e.g.8)

6. Where do you feel that climate geoengineering fits in the greater scheme of climate research and action to mitigate and adapt to climate change?

Climate geoengineering needs to be placed above the individual research field such as climate sciences, engineering or geology. The solution will be multidisciplinary.

7. Are there any other issues related to climate geoengineering that you consider to be important?

No.

References:

1. Proposal for a Directive on the geological storage of carbon dioxide: http://ec.europa.eu/environment/climat/ccs/eccp1_en.htm
2. IPCC, 2005. Carbon Dioxide Capture and Storage. Bert Metz, Ogunlade Davidson, Heleen de Coninck, Manuela Loos and Leo Meyer (Eds.)Cambridge University Press, UK. pp 431.
3. Five Ways To Save The World. http://video.google.com/videoplay?docid=286000425078890061
4. Iceland tests carbon capture. http://news.bbc.co.uk/2/hi/programmes/newsnight/7662561.stm
5. Kunzig, l. and Broecker W. Fixing climate. The story of climate science – and how to stop global warming. Green Profile in association with Sort of Books, London, 2008.
6. Holmfridur Sigurdardottir 2008. Nature Imitated in Permanent CO2 Storage Project in Basalts in Iceland. Greenhouse Issues Number 90, June 2008. p.15-17
7. www.carbfix.is
8. Cole D. R. and Oelkers E. H. 2008. Carbon dioxide sequestration. Elements, volume 4, October 2008.

CLIMOS

Author: Kevin Whilden

Submission to the Royal Society on Geoengineering CLIMOS

Summary of Key Points

In our answers, we will focus on Ocean Iron Fertilization (OIF), which enhances the natural CO2 removal process of the biological pump in the oceans.

1. The state of scientific research on OIF is more advanced than any other geoengineering scheme, and suggests significant potential as large scale carbon mitigation technique.
2. Continued research including field trials of moderate scale (>~100 km x100 km) is needed to assess the technical potential for CO2 sequestration, the potential environmental effects, and develop a regulatory framework that can effectively govern large scale deployment.
3. Unintended consequences of OIF could be minor. Paleo-oceanographic and paleo-climate evidence shows that natural increases in iron fertilization occurred repeatedly during glacial cycles, with correspondingly higher biological productivity and lower atmospheric CO2 levels.
4. Funding for continued research could come from a combination of government grants and contracts, private foundations, private capital, and the carbon market.
5. The carbon market is an appropriate source of research funding if independent scientists measure carbon sequestration, and the rigorous protocols of the carbon market are followed.
6. OIF should be the first geoengineering scheme considered for deployment on a large scale, because it is the closest to reaching a state where it can be governed effectively and funded by private capital.

Response to Individual Questions

1. *What do you consider to be the current state of knowledge regarding the feasibility, efficacy and predicted impacts of climate geoengineering schemes?*

OIF has by far the largest body of scientific research of any potential geoengineering scheme, with 20+ years of research into the underlying science, feasibility, efficacy, and potential impacts. There have been twelve field trials, and nearly 500 papers have been published on the science related to this technique and the experiments. Recent scientific results suggest that CO2 export by the "biological pump" is greater than previously thought and that carbon sequestration from OIF might therefore be greater than previously estimated. The most recent field trial which was both longer and larger (EIFEX [*Smetacek et al.*, Submitted]), as well as recent observations of natural phytoplankton blooms (e.g. KEOPS [*Blain et al.*, 2007], VERTIGO [*Buesseler et al.*, 2007]), show very high rates of carbon export. Newer models that use an explicit iron cycle coupled with a GCM, biochemical and ecological components in a realistic CO2 atmosphere also suggest high rates of sequestration – For example [*Aumont and Bopp*, 2006] simulated global OIF and found a 2-4 GtC/yr net increase in carbon export from surface waters throughout a 100 year period of fertilization, resulting in a net removal of 33 ppm atmospheric CO2.
Negative environmental impacts from individual short-term experiments have not been observed, and are not likely for carefully designed experiments given the natural process which is being stimulated. One experiment observed an increase in juvenile mackerel inside the fertilized patch [*Takeda and Tsuda*, 2005].
The risk of unintended consequences from small-scale, short-term experiments is extremely low with careful experimental design. Questions still remain about the efficacy and impacts of a long term, large scale program of OIF as a climate change mitigation technique and require further research.
The paleo record provides import insights into larger scale OIF. The supply of dust to the ocean was 2-20x greater during glacial periods [*Jickells et al.*, 2005] and the additional Fe supply has been associated with increased biological productivity [*Bender*, 2003; *Winckler et al.*, 2008]. The resulting naturally enhanced iron fertilization may have resulted in a net drawdown of 40ppm CO2 during the last glacial cycle [*Cassar et al.*, 2007]. The evidence from these periods of substantially greater iron flux indicates that the additional iron was *not* associated with species extinctions or permanent shifts in ocean ecosystems. Glacial plankton assemblages were different from interglacial assemblages based on microfossil records, but these would have been affected by changes in temperature, salinity, water column structure and circulation, and CO2 as well as Fe flux.
Moderate scale experiments (>~100x100km) are the next crucial step toward analyzing the questions on

feasibility, efficacy, and impacts [*Boyd et al.*, 2007; *Buesseler et al.*, 2008; *IOC*, 2008; *Lampitt et al.*, 2008; *Smetecek and Naqvi*, 2008]. These experiments can improve upon prior OIF research by focusing on quantification of carbon sequestration potential, measuring environmental effects (e.g. oxygen depletion, biogenic gases, DMS, ecological changes), and improving the predictive capabilities of models.

2. How do you think research into climate geoengineering should be taken forward, and by whom?

Research should be conducted by the scientific community, and in the case of OIF, by oceanographers. All researchers should make data on experimental design, environmental impact assessment, and research results publicly available. Both observational studies and modeling will be necessary to understand the sequestration and environmental impact.
While OIF research can certainly be funded by research funding agencies and not-for-profit entities, we believe there is a role for the private sector in helping to finance and organize larger scale projects which have a significant capital requirements and a heavier logistical demand. This also makes sense given the tradition of private sector investment in development of scientific techniques after initial public funding. If research results indicate that carbon has been sequestered with acceptable environmental impacts, and if this sequestration can meet the rigorous standards and protocols of the carbon market (including 3rd party verification against a publicly available methodology document), then it is appropriate to generate funding for further research and development through the sale of carbon credits on the voluntary carbon market.
These carbon credits would be of high quality in terms of important carbon market metrics such as additionality and permanence [*Whilden et al.*, 2007].
We believe strong international oversight is appropriate for OIF and other geoengineering techniques. For OIF, international governance comes under the London Convention/London Protocol (LC/LP). The LC/LP has moved quickly to educate themselves on this issue, and to deliberate carefully on the promise as well as the concerns voiced. In November 2008, the LC/LP resolved to allow 'legitimate scientific research' to take place and has directed its Scientific Group to identify assessment guidelines for potential OIF projects by signatory countries to the LC/LP.
It is noteworthy that OIF is the first geoengineering technique to have active development of international regulatory framework, with 90+ member countries participating under the auspices of the United Nations.
(The LC/LP also resolved to allow subseafloor sequestration of CO2 after a similar period of discussion and evaluation by scientific and technical experts.) As a result, OIF will serve as a model for dealing with the complex issues of regulating geoengineering. It is important to note that further moderate scale research is clearly needed in order to design an effective regulatory framework for larger scale implementation that serves the dual goal of both sequestering CO2 and protecting the environment. The regulatory framework must also be flexible to incorporate the results of ongoing scientific research as OIF is deployed on larger scales.

3. What factors need to be considered before deploying any climate geoengineering schemes? Who should be responsible for any deployment?

The experience gained from the twelve prior small scale (~10x10km) OIF experiments strongly suggest that OIF research is ready to deploy at moderate scales (~100x100km). Moderate scale OIF research should only be conducted in the deep, open ocean far from land. This will minimize the risk of concentrating the organic matter and/or carbon in shallow waters, of algal blooms including harmful species characteristic of the nearshore and continental margin environments. Deploying OIF outside of equatorial oceans will also minimize the generation of N2O [*Jin and Gruber*, 2003; *Walter et al.*, 2005].
Before deploying OIF at a large scale in order to sequester CO2, more research is needed to study effects on ecology, biodiversity, oxygen, nutrient levels, the production of "GHG-active" gases (e.g. N2O, CH4, DMS), changes to ocean pH (both surface and deep ocean), and particularly the magnitude and permanence of CO2 drawdown from the atmosphere.
Modeling of the sequestration and environmental impact of OIF will also need to be actively encouraged and improved. Because the remineralization of organic material exported by OIF takes place and at depth and undergoes mixing and transport, modeling will be necessary to fully quantify these effects. Likewise the longer term impact on downstream regions will require modeling.
In order to assess the potential for unintended consequences from large scale deployment of OIF, it will be important to consider the degree to which the technique mimics natural processes, the degree to which these processes have occurred at large scale throughout geologic time, and the degree to which we understand the effects and impacts during these historical conditions The risk of unintended

consequences from OIF should also be compared to the risk of consequences from global climate change on the oceans (e.g. ocean acidification, and changes to ocean circulation – including those that alter oxygen [*Stramma et al.*, 2008], nutrient levels [*Polovina et al.*, 2008], and ecology), and weighed against the carbon reduction benefit of OIF.
Deployment could be undertaken by governments, by companies under contract from government, or by companies under some regulatory framework. The technique of deployment (dissolving iron sulfate in sea water) is straightforward and has been used successfully in the prior twelve experiments, although further experiments may result in improvements to the form in which the iron is added or the distribution method.

4. What do you consider to be the most important political, social, legal or ethical issues raised by climate geoengineering?

Politically, there is concern that geoengineering is a distraction to emissions reductions at the source, and that efforts to develop geoengineering will only delay necessary emissions reductions. However, the CO2 reduction potential of OIF is too small to replace emission reductions, and there must be a strong regulatory commitment to maximize emissions reductions in parallel. However as the political challenges to emissions reductions magnify in parallel with accelerating global warming impacts, ocean iron fertilization can potentially be a rapid complimentary response to the global warming threat.
Socially, there is a lack of understanding of the natural constraints on OIF and of the natural analogues for OIF in the present and past ocean. For climate geoengineering in general, there is also a lack of public familiarity with the amount of change that has happened in the Earth system with time, the resilience of the ocean, as well as the substantial threat of non-linear climate change posed by the current slow pace of progress on emissions reduction. Acceptance is also complicated by the lack of understanding of the natural analogues to many geoengineering approaches (e.g. volcanoes for stratospheric aerosols, and dust storms for OIF).
Legally, there are no appropriate international governance bodies for virtually all geoengineering activities, except for the emerging framework around ocean fertilization under the London Convention and the London Protocol (LC/LP).
A significant ethical issue has been the lack of knowledge on the part of scientists and the public about the role of ethics in science. In other words the focus has been on moral questions, "should mankind meddle with mother nature", rather than on ethical frameworks, "how do we understand the risks of the various kinds of geoengineering versus the benefits". An effort towards forming a unified ethical framework around geoengineering is paramount, perhaps like the work which was done at the Asilomar conference for recombinant DNA experimentation in the early 1970s.

5. What do you see as the main barriers to, and opportunities offered by, climate geoengineering?

There are many barriers to the acceptance and implementation of OIF, including a general lack of understanding that the pace and extent of climate change are faster than predicted, and that there is a high potential for non-linear feedbacks – especially Arctic sea ice – that could accelerate climate change. Geoengineering may be necessary to avert these feedback loops, but research may not happen quickly enough for implementation to begin because calls for research have only been voiced in the last few years.
The lack of funding sources for research is a major barrier, particularly a lack of funding sources that can work at the speed at which the problem is presenting itself. Finally, a lack of existing international legal framework reduces the rate at which geoengineering can be studied and implemented, although OIF appears to be the first geoengineering technique with an emerging regulatory framework.
The primary opportunity for OIF is to accelerate the sequestration of CO2 in a natural manner into the single largest carbon reservoir in the carbon cycle. The technical potential for sequestration is large, and the costs are likely much smaller than other sequestration techniques ($5-10 / tCO2e). After safety and efficacy have been proven, a regulatory framework is in place, and together with a tight cap on overall emissions, OIF can help society meet the CO2 mitigation challenge more quickly and at a lower overall cost. Another opportunity is that active removal of CO2 could prevent more extensive climate change than will occur under an emissions-reductions-only scheme. Given the serious and real threats to ocean and terrestrial ecosystems from higher CO2 concentrations, OIF could quickly help to reduce atmospheric CO2. This would buy time for radical changes in the energy economy necessary to dramatically reduce GHG emissions.

Citations

Aumont, O., and L. Bopp (2006), Globalizing results from ocean in situ iron fertilization studies, *Global Biogeochem. Cycles*, *20*.
Bender, M. (2003), Climate-biosphere interactions on glacial-interglacial timescales, *Global Biogeochem. Cycles*, *17*(3), 1082.
Blain, S., et al. (2007), Effect of natural iron fertilization on carbon sequestration in the Southern Ocean, *Nature*, *446*(26 April), 1070-1074.
Boyd, P. W., et al. (2007), Mesoscale Iron Enrichment Experiments 1993-2005: Synthesis and Future Directions, *Science*, *315*(5812), 612-617.
Buesseler, K. O., et al. (2007), Revisiting Carbon Flux Through the Ocean's Twilight Zone, *Science*, *316*(5824), 567-570.
Buesseler, K. O., et al. (2008), ENVIRONMENT: Ocean Iron Fertilization--Moving Forward in a Sea of Uncertainty, *Science*, *319*(5860), 162.
Cassar, N., et al. (2007), The Southern Ocean Biological Response to Aeolian Iron Deposition, *Science*, *317*(5841), 1067-1070.
IOC (2008), STATEMENT OF THE IOC AD HOC CONSULTATIVE GROUP ON OCEAN FERTILIZATION.
Jickells, T. D., et al. (2005), Global Iron Connections Between Desert Dust, Ocean Biogeochemistry, and Climate, *Science*, *308*(5718), 67-71.
Jin, X., and N. Gruber (2003), Offsetting the radiative benefit of ocean fertilization by enhancing N2O emissions, *Geophysical Research Letters*, *30*(24).
Lampitt, R. S., et al. (2008), Ocean Fertilisation: a potential means of geo-engineering?, *Philosophical Transactions of the Royal Society A*, *366*(1882), 3919-3945.
Polovina, J. J., et al. (2008), Ocean's least productive waters are expanding, *Geophys. Res. Lett*, *35*.
Smetacek, V., et al. (Submitted), Massive carbon flux to the deep sea from an iron-fertilized phytoplankton bloom in the Southern Ocean, *Submitted*.
Smetecek, V., and S. W. A. Naqvi (2008), The next generation of iron fertilization fertilization experiments in the Southern Ocean, *Philosophical Transactions of the Royal Society A*.
Stramma, L., et al. (2008), Expanding Oxygen-Minimum Zones in the Tropical Oceans, *Science*, *320*(5876), 655-658.
Takeda, S., and A. Tsuda (2005), An in situ iron-enrichment experiment in the western subarctic Pacific (SEEDS): Introduction and summary, *Progress in Oceanography*, *64*(2-4), 95-109.
Walter, S., et al. (2005), Nitrous oxide measurements during EIFEX, the European Iron Fertilization Experiment in the subpolar South Atlantic Ocean, *GEOPHYSICAL RESEARCH LETTERS*, *32*(L23613).
Whilden, K., et al. (2007), Ocean Fertilization as an Effective Tool for Climate Change Mitigation, in *Greenhouse Gas Market Report 2007*, edited by D. Lunsford, pp. 136-141, International Emissions Trading Association.
Winckler, G., et al. (2008), Covariant Glacial-Interglacial Dust Fluxes in the Equatorial Pacific and Antarctica, *Science*, 1150595v1150591.

CQUESTRATE
Tim Kruger

Submission to the Royal Society report on Geoengineering the Earth's Climate

Increasing the alkalinity of the ocean to enhance its capacity to act as a carbon sink and to counteract the effect of ocean acidification

Executive Summary

The addition of calcium hydroxide to seawater as a way of sequestering carbon dioxide from the atmosphere was first put forward by Haroon Kheshgi in a paper in *Energy* in 1995. Recently this approach has been re-examined and current indications are that it may be a feasible 'carbon negative' technology and one which can simultaneously tackle ocean acidification.
Positive aspects of the process include:

The process is an adaptation of a naturally occurring process, which utilises the oceans' capacity to buffer atmospheric carbon dioxide levels

The process counteracts ocean acidification, so it might actually have a beneficial effect on marine ecosystems

If done on a large enough scale this process could return atmospheric levels of carbon dioxide back to what they were before the Industrial Revolution

Potential weaknesses of the process include:

The impact on marine ecosystems of the process is currently unknown

The alkalinity needs to be mixed across a large part of the ocean

The process is energy intensive

Research is currently underway to determine the economics of the process.

Introduction

A number of schemes involving altering ocean alkalinity as means to counteract the effects of anthropogenic carbon dioxide emissions have been proposed. (KHESHGI (1995), RAU and CALDERA (1999), RAU et al (2007), HOUSE at al (2007) and HARVEY (2008))
This submission focuses on a method first proposed by Kheshgi. In his paper in *Energy* in 1995 he outlined an approach which involved the calcination of limestone and subsequent addition of hydrated lime (Ca(OH)2) to seawater. In his conclusion he stated "Increasing ocean alkalinity is a means by which CO2 might be sequestered from the atmosphere, but not without significant consumption of energy resources and significant cost. Nevertheless, this approach appears to be limited only by the availability of energy."
In the past year, this approach has been re-examined and current indications are that it may be a feasible 'carbon negative' technology and one which can simultaneously tackle ocean acidification. Attached to this submission are two reports on this process – one from the Department of Earth Sciences at the University of Oxford (HENDERSON et al, 2008) and the other from Plymouth Marine Laboratory (ALLEN et al, 2008) which consider the potential impact on the biology and chemistry of the ocean. The Oxford report concludes "Overall, there appears to be no serious flaw in the oceanic aspect" of the process, but calls for more research.

The Process

The first step of the process involves the calcination of limestone ($CaCO_3$) into lime (CaO) and carbon dioxide. This first step is counter-intuitive – it generates carbon dioxide and consumes a large amount of energy. However, it is possible to produce lime from limestone in such a way that the carbon dioxide that is generated is pure and thus easy to sequester.
In the second step, the lime is hydrated to form calcium hydroxide. This calcium hydroxide is then added to seawater. This increases ocean alkalinity by two moles of alkalinity per mole of calcium hydroxide

added. In turn this shifts the series of equilibria which govern the relative concentration of species of dissolved inorganic carbon in the ocean over to the right (see Fig 1)
This results in a decrease in the amount of carbon dioxide dissolved in the seawater as it is converted into bicarbonate and carbonate ions. Each mol of calcium hydroxide will reduce the amount of carbon dioxide dissolved in the seawater by between 1.6 and 1.8 moles, dependent primarily on the temperature of the seawater (see Fig 2)

Carbon Footprint and Energy Balance

Fig 3 considers the carbon footprint and energy requirements of the process for a tonne of $CaCO_3$. The amounts of carbon dioxide generated in the quarrying and transport of the materials are small in comparison with the energy required for calcination. Each tonne of lime requires 45kg of methane to provide the energy for calcining the lime. In addition a further 15kg of methane is required to generate oxygen sufficient to oxy-combust both amounts of methane for the calcinations and the power generation (this is necessary so that the carbon dioxide generated both from the calcinations and the power generation is pure and thus easy to sequester). Overall the processing of each tonne of limestone is sufficient to sequester between 633 and 724kg of carbon dioxide – or to put it another way, in order to sequester a tonne of carbon dioxide approximately 1.5 tonnes of limestone are required. The energy requirement is approximately 5GJ per tonne of carbon dioxide sequestered.
There are several things to note about this carbon and energy balance: firstly, it is very high-level and work is currently underway to refine the numbers; secondly, the calculations have been performed using calcium carbonate as the source of alkalinity – if magnesite ($MgCO_3$) or dolomite ($MgCa(CO_3)_2$) are used instead the quantity of material and energy required is slightly reduced; and thirdly, the energy requirement is high.
Since this analysis was undertaken, another route for obtaining alkalinity has been considered and is being investigated. This involves the treatment of magnesium silicates with hydrochloric acid to yield magnesium chloride. This magnesium chloride can be reacted with steam to yield magnesium oxide and hydrochloric acid. This process (the Magnifin Process) is performed industrially by RHI, an Austrian company, for the production of high grade magnesium oxide.

$Mg_2SiO4 + 4HCl \rightarrow 2MgCl_2 + SiO_2 + 2H_2O$
$2MgCl_2 + 2H_2O \rightarrow 2MgO + 4HCl$

Whether this magnesium oxide can be made in such a way as to be sufficiently soluble in seawater is the subject of research currently underway. The advantage of using silicates as a source of alkalinity is that there is no requirement to sequester carbon dioxide from the process that generates the alkalinity.

Energy and Location

As noted by Kheshgi, the availability of energy is likely to be the limiting factor for this approach. The cost of energy is extremely location dependent. As shown in Fig 4 the cost of natural gas varies dramatically depending on its location. The wholesale price of natural gas delivered to markets in Europe and North America is typically in the range of USD5-10 per MMBtu – yet in many locations around the world the cost of extracting the gas from the ground can be as little as USD0.05-0.10 per MMBtu. The reason that this very cheap gas is not extracted is that the cost of transporting the gas from these locations to a market exceeds the price that can be achieved in that market – the gas is 'stranded' – it has no economic value. If this stranded energy can be utilised in this process then carbon dioxide can be removed from the atmosphere at a relatively low cost.

Scale and Availability of Limestone

To sequester 15 billion tonnes of carbon dioxide (equivalent to the approximately 2ppmv of carbon dioxide, by which atmospheric levels of the gas are increasing each year) would require the processing of some 10 km^3 of limestone per year. This is equivalent to over twenty times the scale of annual US extraction of limestone, which, whilst large, is not outside the bounds of current quarrying and calcining technology. There are ample quantities of limestone available in the world – the Nullarbor Plain in Australia contains some 10,000km3 of limestone - and that is just one of many large deposits of limestone available around the world.

Current Work

Three pieces of work are currently underway:

1. Analysis to create a detailed energy balance, carbon footprint and economic cost per tonne of carbon dioxide sequestered, broken down by each step of the process.
2. Analysis of the rate at which the alkalinity can be added to seawater. If the alkalinity is added too rapidly then it will result in a spike in pH which could lead to calcite being precipitated, undoing the purpose of the process. If the alkalinity has to be added at a very slow rate it would negatively effect the economic viability of the process.
3. Analysis of alternative routes for obtaining alkalinity – using magnesium silicates as a source of alkalinity and the use of emerging technology in the area of lime calcinations.

Each of these pieces of work is expected to produce a report by September 2009.

For further details of the process please see www.cquestrate.com. Cquestrate is conducting this project in an open source way and is not seeking to generate intellectual property (IP) in the core process. Cquestrate has received funding from Shell through their GameChanger programme. Cquestrate is independent of Shell and Shell has agreed to the open source approach and is not gaining any IP from the research.
For more information please contact Tim Kruger at tim@cquestrate.com or call +447740282549

References:
Allen, I., Richardson, K., Robins, D., Nightingale, P., Whitfield, M., Turley, C., Blackford, J., Hattam, C., Lowe, D., Wheeler, G. and Gilbert, J., 2008. An assessment of Questions Posed to Plymouth Marine Laboratory (PML) by Cquestrate Regarding a Concept Process for the Oceanic Sequestration of Carbon Dioxide and the Mitigation of Ocean Acidification. PML Applications Ltd
Dickson, A. and Millero F., 1987 A comparison of the equilibrium constants for the dissociation of carbonic acid in seawater media. *Deep-Sea Res.* **34**, 1733-1743. (Corrigenda. *Deep-Sea Res.* **36**, 983).
Harvey, L. D. D., 2008. Mitigating the atmospheric CO2 increase and ocean acidification by adding limestone powder to upwelling regions. *Journal of Geophysical Research-Oceans* **113**.
Henderson, G., Rickaby, R. and Bouman, H., 2008. Decreasing atmospheric CO2 by increasing ocean alkalinity. The ocean dimension: would the concept work and what would be the environmental consequences, University of Oxford, Department of Earth Sciences and The James Martin 21st Century Ocean Institute.
House, K. Z., House, C. H., Schrag, D. P., and Aziz, M. J., 2007. Electrochemical acceleration of chemical weathering as an energetically feasible approach to mitigating anthropogenic climate change. *Environmental Science & Technology* **41**, 8464-8470.
Kheshgi, H. S., 1995. Sequestering atmospheric carbon dioxide by increasing ocean alkalinity. *Energy* **20**, 915-922.
Kruger, T. and Henderson, G., 2008. Sequestering carbon dioxide from the atmosphere by enhancing the capacity of the oceans to act as a carbon sink. Presentation to Shell GameChanger.
Lewis, E. and Wallace, D. W. R., 1998. Program developed for CO2 system calculations. *http://cdiac.ornl.gov/oceans/co2rprt.html*.
Magnifin Process: http://www.magnifin.com/process.htm
Rau, G. H. and Caldeira, K., 1999. Enhanced carbonate dissolution: a means of sequestering waste CO2 as ocean bicarbonate. *Energy Conversion and Management* **40**, 1803-1813.
Rau, G. H., Knauss, K. G., Langer, W. H., and Caldeira, K., 2007. Reducing energy-related CO2 emissions using accelerated weathering of limestone. *Energy* **32**, 1471-1477.
Zeus Development Corp., 2003. Stranded Gas Locations and Statistics. World LNG/GTL Review.

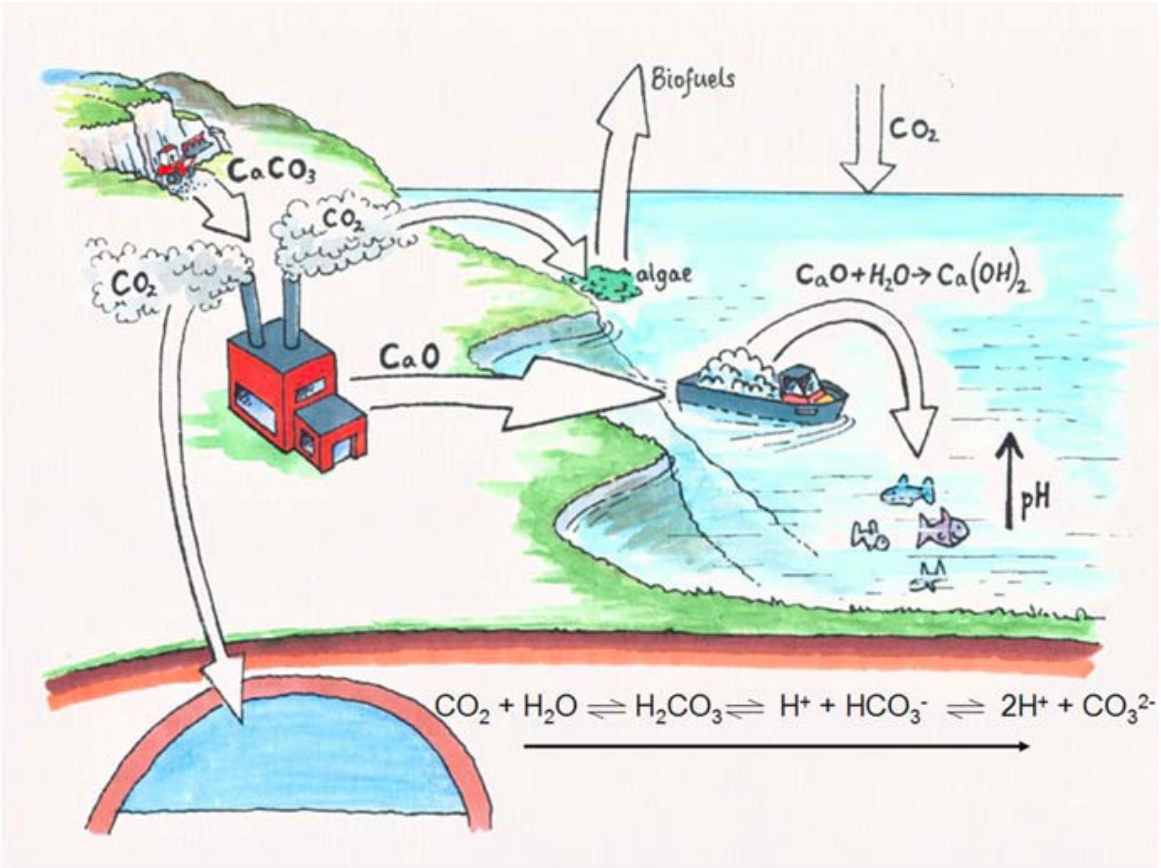


Fig 1: A simplified schematic of the process

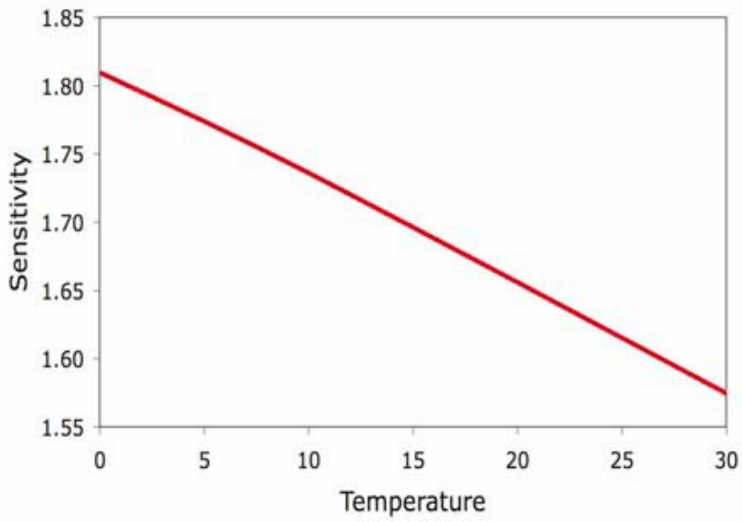


Fig .2: Sensitivity (=mole of atmospheric carbon uptake per mole of added $Ca(OH)_2$) versus temperature at an atmospheric pCO_2 of 390 ppmV. Calculated using the equilibrium coefficients of DICKSON and MILLERO 1987 and the *CO_2Sys* programme of LEWIS and WALLACE (1998). (From HENDERSON et al 2008)

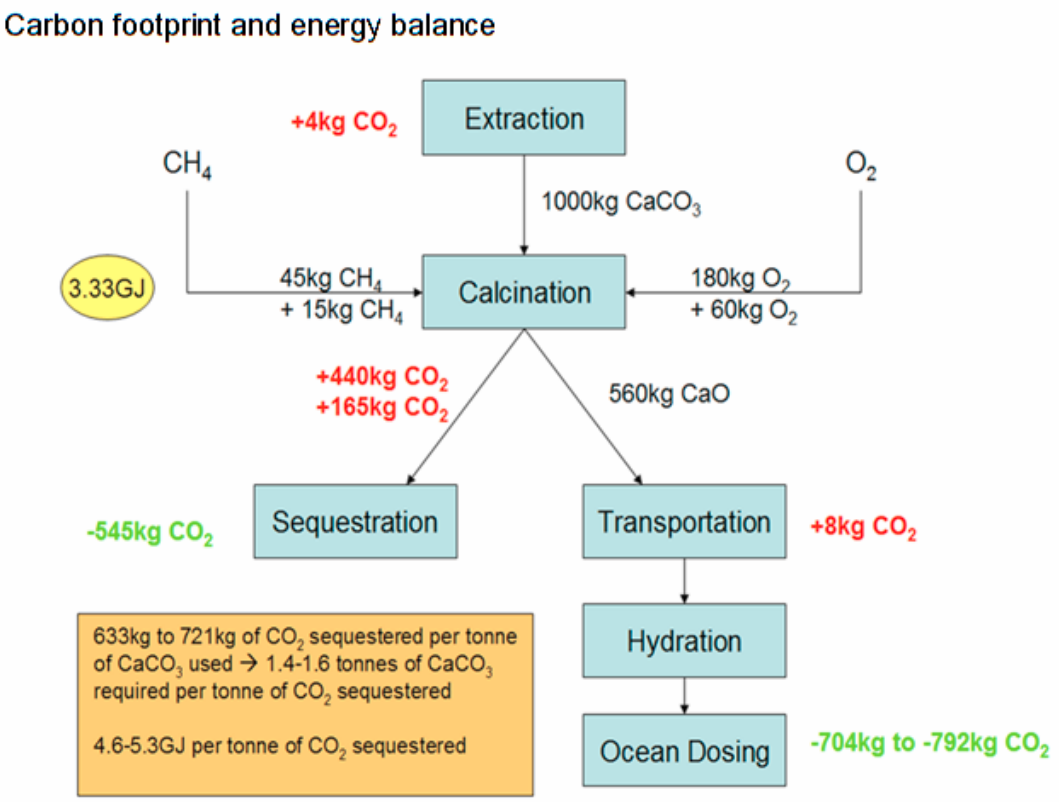


Fig 3: The carbon footprint and energy requirements for a tonne of CaCO3 used in the process (from KRUGER and HENDERSON, 2008)

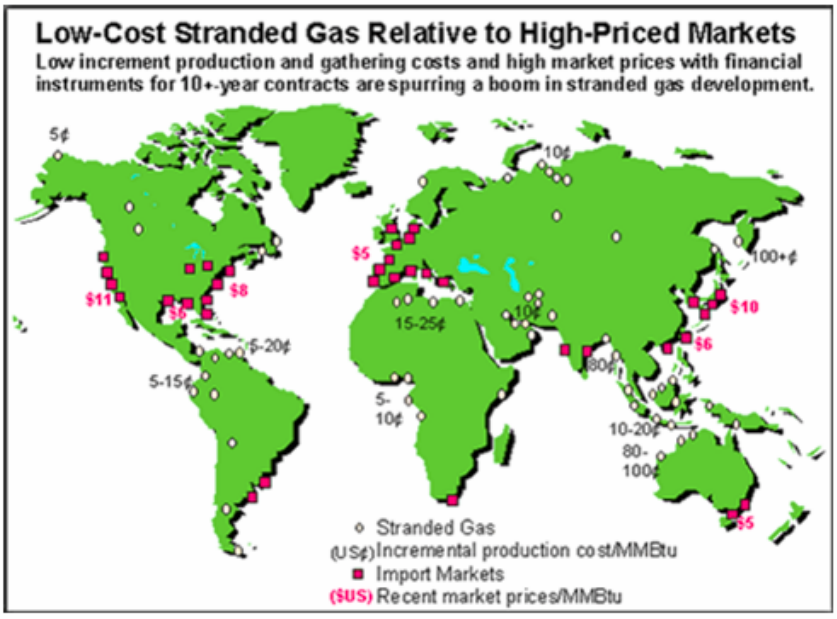


Fig 4: Map showing stranded gas deposits (ZEUS DEVELOPMENT CORP., 2003)

CONVENTION ON BIOLOGICAL DIVERSITY

From: David Cooper, CBD Secretariat[1][1]

MAIN POINTS

Biodiversity conservation and the maintenance and restoration of ecosystems are essential components of climate change mitigation and adaptation responses, yet currently these approaches are underutilized. Ecosystems need to be managed according to an ecosystem approach that is holistic and recognizes the complexity of ecosystems.
Geo-engineering technologies are generally poorly understood and if implemented may have serious negative impacts on biodiversity and ecosystem functioning.
Some geo-engineering technologies are inherently risky because they involve essentially irreversible steps. There are designed, by defination, to be implemented at large scale, thereby accentuating risks. Less inherently risky technologies that may be categorized as geo-engineering, may lead to increased net greenhouse gas emission when implemented on a large scale, in addition to other negative impacts on biodiversity and ecosystems.
While the Convention on Biological Diversity has not addressed geo-engineering directly in a comprehensive manner, where it has addressed aspects of the issue, it has called for a precautionary approach. It has called upon Parties to ensure that ocean fertilization activities do not take place.

CONSIDERATION OF THE ISSUE BY THE CBD
Consideration of the issue of geo-engineering by the CBD Conference of the Parties and the its Subsidiary Body on Scientific, Technical and Technological Advice has been limited to date. The issue has not so far been addressed directly in a comprehensive manner. However, COP did address the issue of Ocean fertilization at its last meeting. Reports of technical bodies have also touched on this issue as well as oceanic storage by deep sea injection, and LULUCF activities. In addition, the CBD has drawn upon and/or developed a body of principles and guidance, notably the ecosystem approach and the precautionary approach, that may bear on the issue of geo-engineering.

Decision IX-16.C on Ocean fertilization.
At its ninth meeting, the CBD Conference of the Parties, addressed the issue of ocean fertilization and *requested* Parties (…) in accordance with the precautionary approach, to ensure that ocean fertilization activities do not take place until there is an adequate scientific basis on which to justify such activities (…) and a global, transparent and effective control and regulatory mechanism is in place for these activities; with the exception of small scale scientific research studies (….) . The decision also referred to work of the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972) and the 1996 London Protocol on this issue. The full decision is provided in the annex.

Technical Studies
Some of the issues of geo-engineering have been examined by various Ad hoc technical expert groups on biodiversity and climate change. These groups comprise government-nominated scientists working in their individual expert capacity. The first group, in its report: "Interlinkages between biological diversity and climate change" (CBD, October 2003; http://www.cbd.int/doc/publications/cbd-ts-10.pdf) noted that "all proposed oceanic CO2 storage schemes have the potential to cause ecosystem disturbance" (p.69) and, referring to coean fertilization, noted that "the consequences of larger and longer term introductions of iron remain unknown" (p70). A more recent expert group (2008) noted in the first part of its report (www.cbd.int/doc/meetings/cc/ahteg-bdcc-01/other/ahteg-bdcc-01-findings-en.pdf) noted that:
Artificial ocean fertilization has been promoted and exposed to early testing as a technique to increase the uptake of atmospheric carbon dioxide, but it is increasingly thought to be of limited potential and may have adverse environmental consequences. The potential of ocean fertilization to increase the sequestration of carbon dioxide with limiting nutrients such as iron or nitrogen, is highly uncertain and increasingly thought to be quite limited, and there are potential negative environmental effects including increased production of methane and nitrous oxide, de-oxygenation of intermediate waters and changes in phytoplankton community composition, which may lead to toxic algae blooms and/or promote further changes along the food chain.

---

[1][1] Note the views expressed here are those of the authour and do not necessarily reflect the views of Parties to the Convention, unless explicitly so stated.

The biological and chemical implications of deep sea injection of carbon dioxide, associated with carbon capture and storage, are at present largely unknown, but could have significant adverse consequences for marine organisms and ecosystems in the deep sea. Leakage from carbon storage on the sea bed could increase ocean acidification, which could have large-scale effects on marine ecosystems, including coral reefs.
In addition to direct impacts of mitigation activities (LULUCF, renewable energy technologies and geo-engineering) on biodiversity there may be significant indirect impacts which require further research. There is also potential for new mitigation technologies to be developed with either positive, neutral or negative impacts on biodiversity.

GENERAL CBD PRINCIPLES AND GUIDANCE

State responsibility
According to the third article of the Convention (Principle): "States have, in accordance with the Charter of the United Nations and the principles of international law, (…) the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction."

The Ecosystem Approach.
The Conference of the Parties has determined that the Ecosystem Approach is the primary framework for action under the Convention. A description, principles and operation al guidance on the Ecosystem Approach are contained in decision V/6. (http://www.cbd.int/decision/cop/?id=7148). The ecosystem approach is a holistic approach for the integrated management of land, water and living resources. It recognizes that ecosystems are complex and that full understanding of their functioning is rare, and that therefore adaptive management must be followed. The Convention seeks to promote its objectives through the ecosystem approach rather than through single simple approaches.
Some of the relevant principles include the following:
Principle 3: Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.
Principle 5: Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.
Principle 6: Ecosystems must be managed within the limits of their functioning.
Principle 7: The ecosystem approach should be undertaken at the appropriate spatial and temporal scales

Precautionary approach.
The precautionary approach is contained in the preamble of CBD (ninth preambular paragraph):
"Noting also that where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat."
The CBD has referred to the precautionary approach, in a number of cases including in reference to ocean fertilization (see above).
Many irreversible.

FURTHER OBSERVATIONS

ENGINEERING COMMITTEE ON OCEANIC RESOURCES

Author: Martin Renilson

RS Geo-engineering Review

Carbon Storage in the Ocean

December, 2008

Summary
Nations are finding it difficult to limit the generation of carbon dioxide and as a consequence the concentration of CO2 in the atmosphere is rising. This increase is causing both heating of the Earth and acidification of the surface ocean. The ocean, occupying 70% of the surface of the globe, is a promising place to store the liberated carbon dioxide away from the atmosphere. The issues involved have recently been reviewed by a Working Group of the Engineering Committee for Oceanic Resources, an ICSU affiliated body. The report of this group will be released in 2009.
The ocean already stores much carbon and the addition of all the estimated reserves of fossil carbon would increase the carbon content of the ocean by only 10%. If the fossil fuel generated carbon dioxide is left in the atmosphere, much of it will end up in the ocean, if it is not stored elsewhere by processes such as carbon capture and geological storage. The ocean has lots of capacity to store additional carbon and unlike the densely populated land, storage in the ocean has a low opportunity cost.
The ECOR Report considers three main categories of storage of carbon. They are direct injection, changes in alkalinity and ocean fertilisation. None have been commercialised at this time but all could be demonstrated at pilot plant scale in the near future.
Direct injection relies on capturing carbon dioxide, usually from intense sources, and injecting the concentrated CO2 into the deep ocean. At mid depth the carbon dissolves in the sea water and can be stored for long time. Alternatively liquid carbon dioxide can be injected in deep topographical depressions in the sea floor to form a carbon dioxide lake.
Changing the alkalinity by increasing the bicarbonate content of the ocean allows carbon to be stored indefinitely. Most proposals involve using carbonic acid formed from carbon dioxide, to dissolve calcium carbonate either in ambient sea water or in reactors at elevated pressure and temperature.
Ocean fertilisation exploits the fact that the biological carbon pump is limited by one or more nutrients in the surface ocean. These can be either micronutrients, e.g. iron, or macronutrients, e.g. nitrogen and phosphorous. Nitrogen can be provided to the surface ocean either by pumping up nutrient rich waters from the thermocline, by generating nitrogen using the Haber Bosch process or by encouraging cyanobacteria to fix nitrogen.
Direct injection of carbon dioxide involves capture of carbon dioxide and its compression. Changing the alkalinity needs carbon dioxide rich mixture to be economic. Ocean fertilisation does not require carbon capture and so can store already emitted CO2.
With varying rainfall patterns as the climate changes, agricultural costs can be expected to rise creating a serious problem for the many subsistence farmers worldwide. A technology such as ocean fertilisation holds out the promise of a significant increase in the supply of economical marine protein as well as storage of carbon away from the atmosphere for thousands of years. More protein will be needed over the next 30 years to satisfy the demands of the presently malnourished people as well as the expected additional 2 billion people. The collateral benefit of increasing the marine food web may be of greater value to humanity than the cost of providing the nutrients. This is known as a *no regrets* option.
Ocean storage of carbon is a somewhat neglected opportunity that deserves further development. The costs are less than or comparable with other large capacity options to reduce net emissions of carbon dioxide to the atmosphere. The environmental risks, while uncertain, do not appear unacceptable.
The price at which carbon can be stored is a critical factor, when market mechanisms are used to limited net emissions, in determining which technologies are adopted. There are many factors contributing to the estimate of the cost of avoiding the equivalent of releasing one tonne of carbon dioxide into the atmosphere. Not all of the carbon dioxide emitted will remain in the atmosphere. Some will be taken up by plants and some will flux into the ocean. Input prices fluctuate with time. The overheated economies of the first years of the 21st century have sharply cooled in the 2008 American recession. These changes lead to fluctuations in construction and feed stock prices in addition to varying interest rates. This report tries to express costs in US dollars of the year 2000, before the sustained period of unusual global economic growth. Representative inflation rate between 2000 and 2008 for the US is 20%. Those prices

that have a wide range of possible values and are quoted in dollars near the year 2000 have not been adjusted. Prices for the three technologies are shown in Table 1.

Table 1 Carbon dioxide capture and storage costs

Category	Type	Cost,US$ per tonne CO2 avoided	Capacity CO2
CCS	IPCC (2005)	30 – 70	2000Gt
Direct Injection	Lake	13-15*	large
Midwater	11-13*	large	
Alkalinity shift	CCOS	30 (70)	Small (large)
Ocean fertilisation	Iron	5 (for 100 yr)	medium
Macronutrient	20-30	50-500Gt?	
Cyanobacteria	10 -20	50-500Gt?	

*capture only, IPCC (2005)

International discussions of climate change need to keep in mind that the UNFCCC commitment deals with sinks of greenhouse gases in the ocean as well as other terrestrial, coastal and marine ecosystems. The subsequent protocols should not exclude potentially lower cost emerging technologies designed to store carbon in the ocean.

Reference:
IPCC (2005) IPCC Special Report on Carbon Dioxide Capture and Storage….ISBN 13978-0-521-68551-1, 442pp.

ENVIRONMENTAL DEFENDER'S OFFICE (NSW)

Author: EDO and Professor Rosemary Rayfuse (University of New South Wales)

Submission to the Royal Society –'Geoengineering climate'

The EDO Mission Statement
To empower the community to protect the environment through law, recognising: the importance of public participation in environmental decision making in achieving environmental protection the importance of fostering close links with the community that the EDO has an obligation to provide representation in important matters in response to community needs as well as areas the EDO considers to be important for law reform.

Contact Us
Environmental Defender's
Office Ltd
Level 1, 89 York St
SYDNEY NSW 2000
freecall 1800 626 239
tel (02) 9262 6989
fax (02) 9262 6998
email: edonsw@edo.org.au
website: www.edo.org.au

For inquiries on this matter contact international@edo.org.au

SUMMARY
This report is submitted by the *NSW Environmental Defenders Office* and *Professor Rosemary Rayfuse of the University of New South Wales* in response to the Royal Society's call for submissions to inform its study on geoengineering the Earth's climate. It addresses terms of reference (3) and (4) which are:

3) To identify further research requirements, and any specific legal and policy implications, and
4) To provide guidance to policymakers by which options can be evaluated.

We have identified international environmental law that imposes limitations on the potential for geoengineering projects and set a framework for the way in which they must be conducted. These general limitations are:
- The duty not to cause transboundary harm,
- The precautionary principle,
- The principle of intergenerational equity,
- The duty to cooperate, and
- The procedural duties to undertake environmental impact assessments, to provide prior and timely notification, to undertake good faith consultation and to obtain prior informed consent.

We have also identified relevant treaties. These are:
- UN Framework Convention on Climate Change 1992,
- Convention on Long Range Transboundary Air Pollution 1979,
- Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (the London Convention) and Protocol 1996,
- UN Convention on the Law of the Sea 1982, and
- UN Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques 1976.

To provide guidance for policymakers, we have considered how the law would be relevant in two case studies. These are:
- Sulfur-based aerosols, and
- Ocean iron fertilization.

Overarching recommendation
The EDO recommends that an international body, such as a subsidiary body of the UNFCCC, be established to:

- Coordinate research and exchange of information on geoengineering,
- Ensure that risks are properly identified and assessed, and
- Ensure that obligations under international law are complied with.

A new protocol should be drafted to consolidate all relevant law and establish appropriate procedures and commitments to ensure compliance.

Term of Reference 3: Legal implications of geoengineering – International law applicable to geo-engineering projects
Duty not to cause transboundary harm
A fundamental element of international environmental law is the general obligation of States not to use or allow others to use their territory in a way that can harm the interests of another State. It is established in numerous international treaties and declarations including the UN Convention on the Law of the Sea (UNCLOS), the Rio Declaration and the UNEP Environmental Guidelines[1] and it has been affirmed several times by the International Court of Justice.[2] Parties to the UN Framework Convention on Climate Change (UNFCCC) are specifically committed to minimising the adverse effects of projects undertaken to mitigate climate change.[3] As geoengineering is intended to have global impacts, this duty suggests that any geoengineering projects which could have adverse effects should not be undertaken.

Precautionary principle
The precautionary principle applies where science is uncertain, placing the burden of proof on those advocating an action that might cause severe or irreversible harm to human health, the economy or the environment. It is established in international instruments such as the Convention on Biological Diversity (CBD), the UNFCCC, the Protocol to the London Convention on the Prevention of Marine Pollution and the Stockholm Convention on Persistent Organic Pollutants.[4] Given the significant scientific concern about geoengineering proposals, the precautionary principle requires that geoengineering projects be delayed until research demonstrates that such concerns are not serious.

Intergenerational equity
This principle highlights the need to consider, and minimize, the impact of activities on future generations. It is established in several environmental instruments including the UNFCCC and the Millennium Declaration,[5] and has been applied in the Philippines Supreme Court and noted in a Canadian court. This principle requires that geoengineering projects likely to have long-term or irreversible effects be avoided.

Duty to Cooperate
The duty to cooperate is a key element of international law, highlighted in Article 1 of the UN Charter.[6] States have the duty to co-operate with one another in order to maintain international peace and security and to promote international economic stability and progress and the general welfare of nations.[7] Given the global effects of geoengineering projects, the duty to cooperate requires States contemplating such activities not to act unilaterally.

Procedural duties
Environmental impact assessments (EIAs) are required under numerous international instruments[8] and in the domestic legislation of over 150 states.[9] The UNFCCC specifically suggests that parties undertake EIAs to minimise the effects of climate change mitigation activities.
The duties to provide prior and timely notification and to undertake good faith consultation with all potentially affected states are established in numerous international instruments.[10] States are also under an obligation to obtain free, prior informed consent from Indigenous communities for activities affecting them.[11] The UNFCCC specifically requires parties to promote and cooperate in the undertaking of research and exchange of information related to the consequences of climate change response strategies.[12] As the impacts of geoengineering are likely to be long term, wide reaching and unpredictable, these duties require states to ensure that research and broad consultation are undertaken before any geoengineering projects are commenced.

Key treaties

UN Framework Convention on Climate Change 1992 (UNFCCC). Parties are committed to minimising the adverse effects of projects undertaken to mitigate climate change.[13]
UN Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques 1976 (ENMOD). Parties are prohibited from modifying the environment to cause damage or injury to other states. ENMOD highlights the need for precaution in considering geo-engineering proposals and may prohibit any such project that causes adverse effects.[14]

Term of reference 4: Guidance for policymakers – Application of legal principles to two case studies

Case Study 1: Sulphur based aerosols

Following observations of the cooling effects of major volcanic eruptions,[15] one climate geoengineering proposal that has been discussed is to inject sulphate aerosols into the stratosphere to increase the planetary albedo.[16] This would be done by burning sulphur (S2) or dihydrogen sulphide (H2S), or a sulphur containing gas such as carbonyl sulphide (COS), carried into the tropical or arctic stratosphere on balloons and by artillery guns, to produce sulphur dioxide (SO2). Chemical and micro-physical processes will then convert the SO2 into sub-micrometer sulphate particle to act as condensation nuclei and increase cloud albedo, thereby backscattering solar radiation into space.[17]

Duty not to cause transboundary harm

The use of sulphur based aerosols to geoengineer the climate has the potential to have impacts on the entire world, therefore the likelihood of causing transboundary harm through experimentation or use of this process must be considered. Potential transboundary harms that may be caused include;

- Unintended modification of the climate system, beyond what is intended by using or experimenting with the technique. There is currently insufficient understanding of how aerosols interact with the climate system,[18] particularly how aerosols interact with cirrus clouds[19] and radiations through the depth of the atmosphere.[20]
- Adverse human health impacts of sulphate particles may occur in transboundary jurisdictions.[21] It is *hoped,* however not known, that releasing sulphur into the stratosphere, rather than the troposphere, will avoid these risks.[22]
- Ecological damage through increased acid precipitation and deposition may affect pristine areas significantly.[23]
- Alteration of regional hydrologic cycles, with tropical and arctic SO2 injection potentially disrupting the Asian and African monsoon season, reducing precipitation necessary for food supply.[24]
- Ozone depletion has also been raised as a potential side effect of tropical and arctic SO2 injection.[25] Ozone depletion has impacts on human health and biodiversity.[26]

Precautionary principle

Given the considerable scientific uncertainty on unintended or unknown consequences of using sulphur based aerosols to geoengineer the climate,[27] and given the disastrous consequences if some of these unintended side effects were to occur, the precautionary principle suggests that with the current level of scientific knowledge, experimentation or use of these techniques should not proceed.

Intergenerational equity

Using sulphur based aerosols to geoengineer the climate is likely to be a relatively short term solution, with sulphur needing to be continuously deployed to modify the climate permanently.[28] As the technique only modifies the earth's temperature and not the atmospheric CO2 concentration, consequences of increased atmospheric CO2 such as ocean acidification[29] and changes in ecological systems[30] would still occur and require action by future generations.
Although the consequences of using sulphur based aerosols to geoengineer the climate has relatively short term effect (1-2 years),[31] by taking this approach, the longer term consequences of ocean acidification and altered ecological systems as a result of CO2 concentration are left unmitigated, maintaining the problem for future generations.

Duty to cooperate

This duty suggests that states should not proceed with using sulphur based aerosols to modify the climate unilaterally, and any decision made to further experiment with the method should be made cooperatively to ensure the use of the technique would be beneficial to nations and international peace and security.

Procedural duties

Due to the broad reaching impacts as well as potential disagreement between states about using sulphur aerosols for climate modification, extensive consultation and environmental impact assessment covering, as a minimum, the potential issues raised in this submission should be undertaken before even experimentation of this technique is undertaken. There is also the potential for disagreement between states on how extensively to use this technique and others to cool the climate, given the different preferences of counties at different latitudes for temperature ranges,[32] highlighting the need for extensive consultation with parties fully aware of potential consequences.

Key treaties
Convention on Long Range Transboundary Air Pollution 1979. Parties to LRTAP have agreed to limit and, as far as possible, gradually reduce and prevent air pollution.
Specific actions have been agreed under protocols to the Convention, including reductions in sulphur emissions.[33] Deliberately injecting sulphur into the atmosphere would directly contravene these protocols.

Case Study 2: Ocean Iron Fertilisation

Ocean iron fertilization (OIF) is one of several ocean methods proposed for mitigating climate change. It involves stimulating phytoplankton growth by releasing dissolved iron in certain parts of the open ocean, which then absorbs carbon dioxide (CO2) from the atmosphere. For the method to work, the phytoplankton must sink to ocean depths.[34] OIF has been studied since 1993 in 12 small-scale experiments.[35]
However, the effectiveness of OIF as a carbon mitigation strategy remains uncertain and there are a number of unresolved questions about its impact on the marine environment.[36]

Duty not to cause transboundary harm
Previous OIF experiments have been conducted over relatively small areas (about 100 km2). However, large-scale experiments (involving the fertilization of ocean patches of about 40,000 km2, which will cause algal blooms over much larger areas)[37] are now being pursued. The effects of OIF will be spread over large areas by ocean circulation,[38] making it a transboundary issue. OIF has the potential to cause transboundary harm in a number of ways, including due to: toxological impacts of the addition of iron to the ocean; generation of greenhouse gases (in particular dimethylsulphide, nitrous oxide, and methane); creation of low oxygen zones (or dead zones); creation of harmful (toxic) algal blooms; and changes to marine food chains.[39]

Precautionary principle
There is significant scientific uncertainty in relation to both the effectiveness of OIF as a carbon mitigation strategy and its potential impacts on the marine environment.[40] Some scientists argue that large-scale experiments are required to resolve key questions.[41] However, because the effects of OIF will be spread over large areas, conducting experiments to address key uncertainties will be difficult.[42] The precautionary principle suggests a need to keep the size of experiments to a minimum, to control the number of experiments being conducted (eg. Through permits), to ensure detailed assessment of potential impacts and risks (including consideration of the sensitivity of the location of experiments), and to ensure extensive monitoring, reporting, and peer-review to enable better predictions of impacts in the future.

Intergenerational equity
There is significant scientific uncertainty in relation to the effectiveness of OIF as a carbon mitigation strategy and, as a number of complex interacting factors are involved, determining the amount of carbon sequestered through experiments is likely to be difficult to do accurately.[43] In addition, there is uncertainty over how long the carbon will be stored in the oceans, although it will be stored over relatively short periods (eg. a few hundred years) rather than geological time scales.[44] These points raise two issues in terms of intergenerational equity: 1) OIF may only make a partial contribution to reducing atmospheric CO2 levels, and 2) OIF only provides a temporary offset (ie. further mitigation will be required by future generations).

Duty to cooperate
In relation to OIF, the duty to cooperate requires states not to undertake large scale experiments unilaterally and to cooperate to ensure that any use of OIF would benefit nations rather than be detrimental.

Procedural duties
OIF carries potential risks and benefits and has the potential to cause unforeseen impacts. Before OIF is undertaken on a large-scale, its impacts on the marine environment must be determined with a reasonable level of certainty and must be communicated to, and acceptable to, society. Society must also be willing to acknowledge and accept unforseen risks. This requires detailed assessment of potential impacts, monitoring and reporting, and extensive community consultation.

Key treaties
Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (the London Convention) and Protocol 1996. OIF would require a permit under the London Convention and Protocol.[45] States determining whether to issue such permits would be required to take a precautionary approach "even when there is no conclusive evidence to prove a causal relation between inputs and their effects," and to follow procedures including consultation with other states.[46] In October 2008, Parties to the London Convention and Protocol resolved that marine fertilization activities other than legitimate scientific research projects should not be allowed.[47]
UN Convention on the Law of the Sea 1982 (UNCLOS). Parties have a general duty to protect and preserve the marine environment.[48] Parties to UNCLOS have a duty to cooperate to eliminate effects of pollution and to prevent or minimize damage and, when taking measures to prevent, reduce and control pollution of the marine environment, to ensure that they do not transfer damage or hazards from one area to another or transform one type of pollution into another.[49] At a minimum, parties to UNCLOS would be required to undertake EIAs for OIF, to monitor activities and to share this information.[50] UNCLOS may preclude OIF altogether, however, as transferring excessive greenhouse gases from the atmosphere to the ocean would arguably constitute the transfer of damage and/or hazards.

---

[1] UNCLOS, Art. 194(2); Rio Declaration 1992, Principle 2; UNEP Principle 3. See also Stockholm Declaration 1972, Art. 21; IUCN Draft International Covenant on Environment and Development 2004, Art. 11.
[2] *Trail Smelter* Arbitration 1941; *Corfu Channel* case (UK v Albania) 1949; *Advisory Opinion on the Legality of the Threat or Use of Nuclear Weapons* 1996
[3] UNFCCC Art. 4(1)(f).
[4] Rio Declaration, Principle 15; World Charter for Nature 1982, Principle 11; CBD, Preamble; UNFCCC, Art 3.3; Stockholm Convention 2001 Arts. 1 and 8; Protocol to the London Convention 1996, Art. 3(1).
[5] UNFCCC, Art 3.1; Millennium Declaration, paragraphs 6, 11 and 21, Stockholm Declaration, Principles 1 and 2; Rio Declaration, Principle 3; UN A/RES/35/8 1980 "Historical Responsibility for States for the Protection of Nature for the Benefit of Present and Future Generations".
[6] See also UN Charter Arts. 55 and 56; Moon Treaty Art. 2; Rio Declaration, Principle 7.
[7] UN Declaration on Principles of International Law Concerning Friendly Relations and Cooperation among States in Accordance with the Charter of the United Nations, 2625 (XXV), 24 October 1970.
[8] EIAs are required in UNCLOS, Art. 204; ILC Draft Article on the Prevention of Transbounary Harm for Hazardous Activities 2001, Art. 7; UNEP Principles on Shared Natural Resources 1978, Principle 4; Espoo Convention on EIA in a Transboundary Context 1991.
[9] Hunter, Salzman and Zaelke (2007) *International Environmental Law and Policy*, p. 533.
[10] Espoo Convention, Arts. 3, 5, 8; ILC Draft Principles on the Prevention of Transboundary Harm from Hazardous Activities 2001; Rio Declaration, Principle 19; OECD Council Recommendation on Principles Concerning Transfrontier Pollution; London Guidelines for the Exchange of Information on Chemicals in International Trade 1989; Montreal Rules of International Law Applicable to Transfrontier Pollution, Art. 8; UNEP Principles of Conduct in the Field of the Environment for the Guidance of States in the Conservation and Harmonious Utilisation of Natural Resources Shared by Two or More States 1978, Principles 6 and 7.
[11] UN Declaration on the Rights of Indigenous Peoples; ILO Convention 169 concerning Indigenous and Tribal Peoples in Independent Countries www.ilo.org/ilolex/english/convdisp1.htm.
[12] UNFCCC Art. 4(1)(g) and (h).
[13] UNFCCC Art. 4(1)(f).
[14] See, eg, Alan Robcock "20 Reasons Why Geoengineering May be a Bad Idea" 64(2) Bulletin of the Atomic Scientists 14 (2008), at 17.
[15] Hansen, J., Lacis, A., Ruedy, R. & Sato, M. (1992) 'Potential climate impact of Mount Pinatubo eruption', *Geophysics Research Letter*, 19, 215-218
[16] Most recently by Crutzen, P.J. (2006) 'Albedo enhancement by stratospheric sulfur injections: A contribution to resolve a policy dilemma?' *Climactic Change*, 77, 211-219; Wigley, T. (2006) 'A combined mitigation/geoengineering approach to climate mitigation' *Science*, 314, 452-454.

[17] Rosenfeld, D. (2000) 'Suppression of rain and snow by urban and industrial air pollution', *Science*, 287, 1793-1796; Ramanathan, V., Crutzen, P.J., Kiehl, J.T. and Rosenfeld, D. (2001) 'Aerosols, climate and the hydrological cycle' *Science*, 294, 2119-2124.
[18] Rodhe, H., Charlson, R.J., & Anderson, T.L. (2000) 'Avoiding circular logic in climate modeling', *Climate Change*, 44, 419-422.
[19] Robock, A. (2008) '20 reasons why geoengineering may be a bad idea', *Bulletin of the atomic scientists*, 64 (2) 14-18.
[20] Bengtsson, L., Semenov, V. & Johannessen, O.M. (2004) 'The early 20th century warming in the Arctic- a possible mechanism', *Journal of Climate Oct.*, 2004, 4045-4057.
[21] Nel, A. (2005) 'Air pollution-related illness: effects of particles', *Science*, 308, 804.
[22] Crutzen, P.J. (2006) 'Albedo enhancement by stratospheric sulfur injections: A contribution to resolve a policy dilemma?' *Climactic Change*, 77, 211-219.
[23] Robock, A. (2008) '20 reasons why geoengineering may be a bad idea', *Bulletin of the atomic scientists*, 64 (2) 14-18.
[24] Oman, L.A., Robock, A. , Stenchikov, G.L. & Thordarson, T. (2006) 'High-latitude eruptions cast shadow over the African monsoon and the flow of the Nile', *Geophysics Research Letters*, 33, L18711; Robock, A. (2008) '20 reasons why geoengineering may be a bad idea', *Bulletin of the atomic scientists*, 64 (2) 14-18.
[25] Tilmes, S., Muller, R. & Salawitch, R. (2008) 'The sensitivity of polar ozone depletion to proposed geo-engineering schemes', *Science*, in revision.
[26] Rasch, P.J., Tilmes, S., Turco, R.P., Robock, A., Oman, L. Chen, C.C., Stenchikov, G.L. (2008) 'An overview of geoengineering of climate using stratospheric sulfate aerosols' *Philosphical Transactions of the Royal Society*, 366, 4007-4037
[27] Rodhe, H., Charlson, R.J., & Anderson, T.L. (2000) 'Avoiding circular logic in climate modeling', *Climate Change*, 44, 419-422; Bengtsson, L., Semenov, V. & Johannessen, O.M. (2004) 'The early 20th century warming in the Arctic- a possible mechanism', *Journal of Climate Oct.*, 2004, 4045-4057; Oman, L.A., Robock, A. , Stenchikov, G.L. & Thordarson, T. (2006) 'High-latitude eruptions cast shadow over the African monsoon and the flow of the Nile', *Geophysics Research Letters*, 33, L18711; Tilmes, S., Muller, R. & Salawitch, R. (2008) 'The sensitivity of polar ozone depletion to proposed geo-engineering schemes', *Science*, in revision; Rasch, P.J., Tilmes, S., Turco, R.P., Robock, A., Oman, L. Chen, C.C., Stenchikov, G.L. (2008) 'An overview of geoengineering of climate using stratospheric sulfate aerosols' *Philosphical Transactions of the Royal Society*, 366, 4007-4037; Robock, A. (2008) '20 reasons why geoengineering may be a bad idea', *Bulletin of the atomic scientists*, 64 (2) 14-18.
[28] Crutzen, P.J. (2006) 'Albedo enhancement by stratospheric sulfur injections: A contribution to resolve a policy dilemma?' *Climactic Change*, 77, 211-219.
[29] Caldeira, K. and Wickett, M.E. (2003) 'Anthropoenic carbon and ocean pH', *Nature*, 425, 365; Doney, S.C. (2006) 'The dangers of ocean acidification', *Scientific American*, 294 (3), 38-45.
[30] Bala, G, Caldeira, K., Mirin, A., Wickett, M., Delire, C. & Philips, T.J. (2006) 'Biogeophysical effects of CO2 fertilization on global climate', *Tellus Ser B*, 58, 620-627.
[31] Archer, D., Khesgi, H., and Maier-Reimer, E. (1997) 'Multiple timescales for neutralization of fossil fuel CO2', *Geophysics Research Letter*, 24, 405-408.
[32] Robock, A. (2008) '20 reasons why geoengineering may be a bad idea', *Bulletin of the atomic scientists*, 64 (2) 14-18
[33] 1994 Protocol on Further Reduction of Sulphur Emissions; 1985 Protocol on the Reduction of Sulphur Emissions or their Transboundary Fluxes.
[34] E. Kintisch (2007) *Science* 318 1368-1370.
[35] P. Boyd et al (2007) *Science* 315 612-617.
[36] K. Buesseler (2008) *Science* 319 162; International Maritime Organization (2008) Scientific Group of the London Convention – 31st meeting and Scientific Group of the London Protocol – 2nd meeting, 19-23 May, 2008: 'Ocean fertilization: background and literature review addressing main elements in the LC/LP scientific groups' statement of concern on ocean fertilization'.
[37] International Maritime Organization (2008) Scientific Group of the London Convention – 31st meeting and Scientific Group of the London Protocol – 2nd meeting, 19-23 May, 2008: 'Ocean fertilization: background and literature review addressing main elements in the LC/LP scientific groups' statement of concern on ocean fertilization'.
[38] K. Buesseler (2008) *Science* 319 162.
[39] International Maritime Organization (2008) Scientific Group of the London Convention – 31st meeting and Scientific Group of the London Protocol – 2nd meeting, 19-23 May, 2008: 'Ocean fertilization: background and literature review addressing main elements in the LC/LP scientific groups' statement of concern on ocean fertilization'.
[40] K. Buesseler (2008) *Science* 319 162; International Maritime Organization (2008) Scientific Group of the London Convention – 31st meeting and Scientific Group of the London Protocol – 2nd meeting, 19-23 May, 2008: 'Ocean fertilization: background and literature review addressing main elements in the LC/LP scientific groups' statement of concern on ocean fertilization'.

[41] K. Buesseler (2008) *Science* 319 162.
[42] International Maritime Organization (2008) Scientific Group of the London Convention – 31st meeting and Scientific Group of the London Protocol – 2nd meeting, 19-23 May, 2008: 'Ocean fertilization: background and literature review addressing main elements in the LC/LP scientific groups' statement of concern on ocean fertilization'.
[43] K. Buesseler (2008) *Science* 319 162; International Maritime Organization (2008) Scientific Group of the London Convention – 31st meeting and Scientific Group of the London Protocol – 2nd meeting, 19-23 May, 2008: 'Ocean fertilization: background and literature review addressing main elements in the LC/LP scientific groups' statement of concern on ocean fertilization'.
[44] International Maritime Organization (2008) Scientific Group of the London Convention – 31st meeting and Scientific Group of the London Protocol – 2nd meeting, 19-23 May, 2008: 'Ocean fertilization: background and literature review addressing main elements in the LC/LP scientific groups' statement of concern on ocean fertilization'.
[45] Protocol, Art. 2.
[46] Protocol, Art. 3(1).
[47] LC-LP.1(2008), Adopted at the 30th Meeting of Parties to the London Convention and Protocol, October 27-31.
[48] Art. 192.
[49] Art. 199; Art. 195.
[50] Arts. 204-206.