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## SCOPING ACTIVITIES

### Proposal to establish a GESAMP marine geoengineering working group

This document provides background information in relation to document GESAMP 42/7 on a proposal to establish a GESAMP Working Group on marine geoengineering.

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# Brief Summary of Marine Geoengineering Techniques

C.M.G. Vivian

## Introduction

This leaflet is a brief summary of marine geoengineering techniques that have been proposed to date together with pointers to more detailed sources of information through hyperlinks to all the references. Due to space limitations, there is limited detail about the techniques and little or no information on the impacts of them. The reader is directed to the references provided for further information. Belter and Seidel (2013) have shown that over the last 5 years there has been a dramatic increase in the number of media and scientific publications on geoengineering/climate engineering. This is also reflected in the number of Google searches on the subject as shown in a graph in David Keith's presentation at an American Meteorological Society meeting in 2011 at 28 minutes 45 seconds.

## Major Types of Marine Geoengineering

Climate-related geoengineering techniques predominantly address carbon dioxide ($CO_2$) and are generally classified into 2 types, namely 'Solar Radiation Management' (SRM) and 'Carbon Dioxide Removal' (CDR). Techniques to address other climate warming substances e.g. methane are very limited and at an early stage of development. Almost all the marine geoengineering techniques fall into the CDR category. For the purposes of the London Convention and Protocol, it is more useful to classify marine geoengineering techniques into:

- Those involving the deposit of wastes or other matter into the ocean, and
- Those involving the deposit of structures or devices into the ocean, whether free floating, floating but tethered to the seabed or directly placed on the seabed.

Because of the uncertainties about both the techniques themselves as well as their effects, it would often not be clear whether such deposits would be dumping or placement under the London Protocol (LP).

It should be noted that a number of schemes have been proposed involving placing substances/wastes or structures in the ocean for purposes other than for climate change mitigation. These schemes can have side-effects that may be very similar to certain types of climate geoengineering and some of them may be considered to be types of marine geoengineering – see Box 1.

## Marine Geoengineering – Deposits of Wastes or Other Matter

**Ocean fertilization** – This involves the deposit of iron, nitrogen or phosphorus compounds intended to stimulate primary productivity and thus through the 'biological pump', increase the carbon flux into deep-ocean where the carbon will remain for a period of from hundreds to several thousand years. This has been the subject of some dozen field experiments and many papers and reports with notable reviews from the CBD (2009), ECOR (2012), NOAA (2010), Wallace *et al.* (2010) and Williamson *et al.* (2012a). The results of natural ocean fertilization events have been reported by Blain *et al.* (2007), Pollard *et al.* (2007), Pollard *et al.* (2009) and Wolff *et al.* (2011) and their effects provide a useful perspective when considering the potential effects of artificially induced ocean fertilization.

**Use of Marine Macroalgae for Carbon Sequestration** – Proposals for sequestering carbon through growing marine macroalgae date back to the early 1990's – see Ritschard (1992). More recently a few papers and reports have looked at the approach anew. Chung *et al.* (2011) critically appraised the approach, finding that it could play a significant role in carbon sequestration and amelioration of greenhouse gas emissions. N'Yeurt *et al.* (2012) proposed that 'Ocean Macroalgal Afforestation' has the potential to reduce atmospheric $CO_2$ levels. These approaches are all at a very early stage of development with much more research needed to explore the possibilities, practicalities and potential problems. There has also been some investigation of the use of marine macroalgae as a fuel e.g. see Roberts and Upham (2012), Hughes *et al.* (2013) and Kelly and Dworjanyn (2008) and as a source of products e.g. see Lewis *et al.* (2011). Aldridge *et al.* (2012) have considered the wider implication of marine macroalgal cultivation.

**Sequestering Additional Carbon in the Refractory Carbon Pool in the Deep Ocean** – The deep ocean contains 700 Gt of dissolved organic carbon and about 95% of this is refractory (unavailable or inedible to marine microbiota) so that it is stored for millennia – Jiao *et al.* (2010). It has been suggested that it might be possible to enhance the amount of carbon stored in this reservoir although there are no specific proposal as yet - Stone (2010).

**Depositing crop wastes on the deep seabed** – Strand and Benford (2009) have proposed depositing bales of terrestrial crop wastes on the deep seabed and this could potentially be extended to include depositing biochar/charcoal or other organic remains. It should be noted that this type of scheme may well be covered by the existing category of wastes 'Organic material of natural origin' in Annex 1 of the Protocol and 'Uncontaminated organic material of natural origin' in Annex I of the Convention. It may therefore be permitted to be disposed of at sea, subject to the other provisions of the Convention and Protocol.

**Enhancing Ocean Alkalinity** – Sequestering $CO_2$ from the atmosphere by increasing the alkalinity (and the pH) of the ocean was first raised by Kheshgi (1995). This is geochemically equivalent to the natural weathering of rocks. It helps to buffer the ocean against decreasing pH and thereby helps to counter ocean acidification. A number of proposals to enhance ocean alkalinity have been brought forward since then utilising different techniques and the ocean-based techniques can be grouped into the following categories:

- Adding calcium oxide, calcium hydroxide or calcium carbonate directly to the ocean. - Kheshgi (1995), Harvey (2008), and the Cquestrate website.
- $CO_2$-rich gases are dissolved in seawater (e.g. from power stations or cement works) to produce carbonic acid that is then reacted with a carbonate mineral to form calcium and bicarbonate ions with the products being released into the sea - Caldeira and Rau (2000), Rau (2011), Rau and Caldeira (1999) and Rau *et al.* (2007).
- Electrochemical splitting of calcium carbonate with the bicarbonate ions produced being released into the ocean – Rau (2008).
- Electrolysis of seawater with the release of the calcium and magnesium chloride salts into the ocean. The hydrogen and chloride ions produced are combined to form hydrochloric acid that is reacted with silicate rocks on land releasing bicarbonate ions into the ocean via rivers – House *et al.* (2007).
- Coastal spreading of olivine or serpentine rock where its natural weathering consumes $CO_2$ and releases bicarbonate ions – Hangx and Spiers (2009), Schuiling and de Boer (2010), Schuiling and de Boer (2011) and Schuiling and Krijgsman (2006). Schuiling's Smart Stones proposal is one of the 11 projects on the Virgin Earth Challenge shortlist. There has also been an analysis by Kohler *et al.* (2013) of the open ocean spreading of finely ground up olivine.

It should be noted that land-based enhanced weathering would also potentially impact on estuaries, coastal waters and the open ocean if the techniques were applied at a climatically significant scale – see section 4.2.1 in Williamson *et al.* (2012b).

**Mineralisation of Rocks in the Seabed** – $CO_2$ can be injected into basalt and peridotite rocks where it reacts with the calcium and magnesium ions in silicate minerals to form stable carbonate minerals – Matter and Kelemen (2009). Basalt rocks are commonly found beneath the oceanic seabed where they may be suitable to sequester $CO_2$ – Goldberg *et al.* (2008), Goldberg and Slagle (2009) and Goldberg *et al.* (2010). This is not the same as Carbon Capture and Storage where the $CO_2$ is physically stored in the pore space of the rock formations. While this activity may be considered to be a form of Carbon Capture and Storage (CCS) and so be covered by the LP, the LP's CCS Specific Guidelines and associated Risk Assessment and Management Framework were not written with this activity in mind and are thus not appropriate for it.

**$CO_2$ Storage in Ocean Waters and Sediments**[1] – There have been proposals for many years to store solid or liquid $CO_2$ within ocean waters or deep ocean sediments. The 2005 IPCC Special Report on Carbon Dioxide Capture and Storage reviewed this subject in some detail. The main variants include placing $CO_2$:

- As a liquid placed in mid to deep ocean waters – Nordhaus (1975), Marchetti (1977), Ormerod *et al.* (2002), Keeling (2009),
- As a liquid placed along with pulverized limestone at depths greater than 500 m – Golomb *et al.* (2004)
- As a liquid placed in depressions on the deep seabed – Marchetti (1977), Nakashiki (1997)
- As solid blocks of $CO_2$ placed that sink to and penetrate the seabed – Murray *et al.* (1996)
- As a liquid placed a few hundred metres into deep-sea sediments – House *et al.* (2006)
- As a liquid placed into methane hydrates in sediments on continental margins and in permafrost regions to displace methane that is captured for energy generation while storing the $CO_2$ – Park *et al.* (2006).

1 This does not include conventional Carbon Capture and Storage in sub-seabed geological formations.

**BOX 1**
**Other Activities in the Ocean with Similar Side-effects to Marine Geoengineering**

**Ocean Thermal Energy Conversion (OTEC)** This uses the temperature difference between cooler deep and warmer shallow or surface ocean waters to run a heat engine and produce electricity. However, that deep water will be rich in nutrients and so its discharge in surface waters will have a fertilizing effect. It will also have the same problems as Artificial Upwelling in bringing water rich in dissolved inorganic carbon to the surface. The technique is described in a Wikipedia article.

**Deep Water Source Cooling** Cool, deep ocean water is being used to cool buildings in tropical areas particularly islands close to the deep ocean. It brings the same problems referred to above for OTEC. The technique is described in a Wikipedia article and by Hou *et al.* (2010). These websites describe the use of the technique in various locations including Hawaii, Bora Bora, Curacao, Stockholm and Bahamas, and its proposed use for the 2018 Winter Olympics. It is also referred to as Seawater Air Conditioning.

**Ocean Fertilisation to Enhance Fish Stocks** This technique has been proposed by the Ocean Nourishment Corporation and Jones (2011) to fertilize the oceans with nitrogen compounds to enhance fish stocks. Green Sea Upwelling, Kirke (2003), Maruyama *et al.* (2004) and Maruyama *et al.* (2011) and Ouchi *et al.* (2005) have also proposed that the artificial upwelling technique could enhance fish stocks.

**Weakening Hurricanes** There has been a proposal by Salter (2009), also reported in Scientific American, using pipes in the ocean to carry warm water down to at least 100 metres thus cooling surface waters to drain hurricanes of some of their energy. Atmocean has also mentioned this concept. This is essentially the reverse of the Artificial Upwelling proposal above.

**Artificially Enhanced Downwelling** – Marchetti (1977) advocated injecting $CO_2$ into suitable downwelling currents to dispose of $CO_2$ in the deep ocean. More recently, Zhou and Flynn (2005) assessed the costs of modifying downwelling ocean currents by either increasing the volume of the currents or their carbon concentration. While some techniques for the former were practical, albeit costly, the latter was not considered practical. They concluded "Modifying downwelling ocean currents is highly unlikely to ever be a competitive method of sequestering carbon in the deep ocean, but may find future application for climate modification".

**Increasing Ocean Albedo (Reflectivity)** – There have been a number of proposals to increase ocean albedo over the years. A report to the US President Johnson's Science Advisory Committee in 1965 proposed that "…a change in ocean albedo could be brought about, for example by spreading very small reflecting particles over large oceanic areas" (PSAC, 1965). Similarly, Morgan (2011) proposes to add 0.1µm latex particles to the ocean to increase ocean albedo to offset current $CO_2$ forcing at a costing of $2 billion per annum. Also, Field (2011) proposes to target polar regions and place high albedo covering material on open water or ice areas in danger of melting - see a presentation in Field (2012).

A proposal by Seitz (2011) known as 'Bright Water' involves the introduction of small bubbles of air into the sea to increase the albedo of the sea so that it reflects a greater amount of radiation. Natural bubbles at or near the surface of the sea already contribute to the Earth's albedo but this contribution is less than 1% of the total. This concept proposes to inject 2 micron sized bubbles into the sea at concentrations of 1 ppm by volume. These bubbles will behave as little mirrors that computer simulations show would double the reflectivity of the water and so help to cool the planet by up to 3°C if the system could be deployed. Robock (2011) critiqued the proposal. An analogous concept put forward by Evans *et al.* (2010) proposes the enhancement of the foam fraction at the sea surface to increase the ocean's albedo.

Natural blooms of some types of phytoplankton can have highly reflective properties e.g. coccolithophores as seen from space-based images as well as at sea level – see NOC (2012). It has been suggested by Isomaki (2011) that it might be possible to grow diatoms or other plankton with reflective properties, treat them to ensure they float and release them to the sea to cover very large areas.

**Methane Capture** – A number of scientists and groups have raised serious concerns about the potential release of vast amounts of methane from the Arctic, particularly the Arctic seabed, as the Arctic warms. A limited amount of information has been published about mitigation and capture methods for methane including that by Salter (2011), Stolaroff *et al.* (2012) and Lockley (2012).

**Miscellaneous Marine Geoengineering** – Isomaki (2011) has compiled a report with 66 ways to absorb carbon and improve earth's reflectivity. The report includes a limited number of marine methods, most of which are covered in this document.

Two reports in the Indian newspaper the Deccan Chronicle in 2010 and 2011, but no longer on the website, reported on research by the Indian National Institute of Ocean Technology that was investigating the use of smelter waste to capture $CO_2$ and then deposit that waste in the deep ocean as "an artificial coral reef"!

## Marine Geoengineering – Deposit of Structures or Devices

**Artificial Upwelling** – This uses pipes suspended in the ocean that use wave action to pump water from several hundred metres depth up to fertilise surface waters. This is a different type of ocean fertilisation. It has been proposed by Atmocean and Lovelock and Rapley (2007) amongst others and some experiments have been carried out by Maruyama *et al.* (2004), Maruyama *et al.* (2011) and White *et al.* (2010) amongst others. However, the deep ocean water proposed to be drawn up to the surface in these schemes contains high levels of dissolved inorganic carbon due to the degradation of sinking organic matter generated in surface waters and would thus greatly reduce if not eliminate, the climate benefits of the schemes as indicated in the papers published by Dutreuil *et al.* (2009), Ikeda *et al.* (2002), Yool *et al.* (2009) and Oschlies *et al.* (2010).

A variation on the artificial upwelling proposal above called Passive Ocean Current Deflectors has been proposed. These are designed to harness the kinetic energy of deep ocean currents to deflect those nutrient rich waters to the euphotic zone using a device moored to the seabed at the bottom end. The intended effect is essential the same as the artificial upwelling proposal above.

A hybrid proposal by Calvin (2011a) involves both upwelling nutrients for fertilization of phytoplankton and downwelling of the products of that fertilization to carry a large fraction of it down to depth where the carbon will be sequestered for hundreds to thousands of years. A shorter version of the proposal in Calvin (2011b) is available as an electronic book.

**Placement of dams across straits either completely or partially** – Johnson (1977) proposed to reduce the deep outflow of salty water from the Mediterranean Sea using a partial dam to affect the water movements in the North Atlantic. This and similar proposals are covered by Cathcart (2006).

Schuttenhelm (2008) proposed to dam the Bering Strait with a 300 km dam. The aim is to reduce the inflow of warm, salty water into the Arctic, thus decreasing the temperature and salinity of Arctic seawater and helping to cool the Artic. This would have knock on effects on the albedo of the Arctic and the thawing of the permafrost but Schuttenhelm recognised that it would have significant side effects.

## Other Types of Geoengineering that could have Direct and/or Indirect Effects on the Ocean

In principle, most types of geoengineering could have implications for the oceans albeit some of the effects would take place over long periods of time through changes in the global cycles of the movement of carbon, nutrients, sediment, etc. However, the SRM techniques, that are designed to reduce the amount of sunlight reaching the Earth's surface, thereby producing a cooling to offset the warming resulting from fossil-fuel burning, are likely to have impacts on the oceans – see section 4.2.1 in Williamson *et al.* (2012b).

Marine Cloud Brightening is one particular type of SRM technique that could have some impacts on the ocean environment as it takes place in the marine environment – see section 4.2.2 in Williamson *et al.* (2012b) and Russell (2012). The concept, originally proposed by Latham, 1990, is to seed low-level, maritime stratocumulus clouds – which cover about 30% of the oceanic surface – with micrometer-sized seawater particles, thereby creating additional droplets inside the clouds, and – for well-established physical reasons – increasing their reflectivity. Ship-tracks from vessels exhaust emissions are a clear example of the reality of this cloud brightening effect. Russell (2012) reported on a field experiment to test this concept. This technique has also been suggested by Latham *et al.* (2012) as a means of weakening hurricanes.

## Reviews of Geoengineering

There have been a number of reviews of geoengineering techniques, including marine ones, from different perspectives including the papers and reports by CRS (2011), GAO (2011), IPCC (2012), Lal (2008), Lenton and Vaughan (2009), McGlashan *et al.* (2012), McLaren (2012), Olson (2011), Royal Society (2009), Stephens and Keith (2008), Vaughan and Lenton (2011) and Williamson *et al.* (2012b). In addition, Bellamy *et al.* (2012a) and Bellamy *et al.* (2012b) have reviewed a number of these and other appraisals.

## Notes:

1. Full access to the references will depend on your access rights to the publications concerned. However, the full texts of some papers are also to be found on the internet by searching for their titles.
2. Hyperlinks checked on 12th February 2013.