Marine CDR Approaches: Overview and Governance

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1. Introduction

The Paris Climate Agreement, which entered into force in 2016, establishes the salutary objective of keeping temperatures to well below 2°C, and seeking to hold them to 1.5°C

A. Unfortunately, the Nationally Determined Contributions (NDCs) made to date by the Parties to the Paris Agreement put the world on track for temperature increases of around 3.0°C, with temperatures likely to continue to increase for centuries thereafter given the inertia of the climate system.
   a. Could even be an underestimation, as concentrations of GHGs in the past couple of years have risen at a rate of 3ppm
      i. And recent UNEP study indicates that MOST major emitters not even complying with their NDCs

B. Temperature increases of this magnitude could prove disastrous in terms of human institutions and ecosystems **[SLIDE 2]**

   1. For example, a 3ºC increase in temperatures could result in the complete melting of the Greenland Ice Sheet over the course of 1000 years, raising sea level an astounding 7 meters
   2. Virtually all coral reefs, which provide habitat for at least one third of all marine species, would be lost under a 3°C scenario
   3. A 3-4ºC increase in temperatures would threaten 60% of species with extinction
   4. A number of studies project that the thermohaline circulation system could be shut down by temperature increases between 3-4ºC, potentially casting much of Europe into Arctic conditions
   5. 3-4ºC increase would results in potentially catastrophic declines in agricultural production in developing countries
   6. And once we cross threshold, we're stuck for hundreds to thousand years

C. The specter of climatic changes of this magnitude has substantially increased interest in so-called <u>carbon dioxide removal options</u> (sometimes referred to as negative emissions technologies) that might help us avert crossing critical thresholds, or help in overshoot scenarios **[SLIDE 3]**

a. Indeed, in the IPCC's Fifth Assessment Report, 184 of 208 Integrated Assessment Models that were able to effectuate temperature scenarios below 2°C in a cost-efficient manner assume substantial carbon dioxide removal from the atmosphere

1. Recent estimates are that the global community might need to sequester approximately a whopping 13-20 GtCO2e/yr. of carbon dioxide by 2100 **[SLIDE 4]**

a. Today, global CO2-sequestration activities are only sequestering about <0.1 Gt CO2/yr.

2. While the focus up until a few years ago was on terrestrial or atmospheric-based carbon dioxide removal options, there's increasing recognition in recent years that these options may prove too risky, or unsustainable, at very large scales

i. This has resulted in more focus in the past few years on the potential viability of a portfolio that would also include marine-based options CDR options, especially since the world's oceans already naturally remove about 10 gigatons of carbon dioxide

ii. The purpose of this presentation is to provide an overview of marine geoengineering approaches, and some potential venues for governance, with emphasis on international institutions

2. Marine CDR Options

In this section, I'll highlight just a few of those options here that are most often discussed, including potential effectiveness, risks, co-benefits. **[SLIDE 5]**

A. Ocean iron fertilization [SLIDE 6]

i. The essence of understanding the concept of OIF is to the role of microscopic plants found in the world's oceans, phytoplankton, and their role in sequestering carbon **[SLIDE 7]**

1. Phytoplankton obtain energy through the process of photosynthesis, whereby they absorb carbon dioxide from the oceans and convert it to organic carbon, which is stored in the organisms' tissues

a. Overall, approximately half of the world's photosynthesis occurs in phytoplankton

ii. Most of the organic carbon produced in the photosynthetic process is immediately consumed at the surface by other species, and then released into the atmosphere.

1. However, a small portion of the remainder of the carbon is effectively removed from the system and transported to the deep ocean for storage when the organisms die, in a process called the "biological pump" **[SLIDE 8]**
    a. Also effectuated when fecal pellets fall to sea floor
2. So, some researchers have argued that stimulating the growth of phytoplankton would be great way to reduce concentrations of CO_2 by enhancing sequestration via the biological pump

iii. Where Would It Be Done?:

1. Most researchers who advocate ocean fertilization argue that there are certain areas of the world's oceans (about 20-25%, primarily the Southern Ocean), that have high levels of the major macronutrients (especially phosphorous and nitrogen) critical for high levels of phytoplankton productivity, but low levels of a critical micronutrient, iron **[SLIDE 9]**
    a. This iron deficiency, it's argued, severely limits phytoplankton production in these regions, resulting in the characterization of such ocean areas as "High Nutrient-Low Chlorine" (HNLC) water bodies
2. So, proponents of iron fertilization advocate introducing substantial amounts of dissolved iron (usually ferrous sulfates) in these areas to supplement the natural supplies to
    a. Stimulate phytoplankton growth, in turn resulting in more uptake of carbon dioxide
        i. Ultimately, when the phytoplankton dies, some will drop to the bottom of the ocean below the mixing zone, purportedly sequestering huge amounts of carbon for a century or more

iv. Purported Effectiveness of Iron Fertilization:

1. Some proponents claim that iron fertilization could sequester as much as 25% of world's carbon dioxide
2. Argument also made that iron fertilization would be relatively cheap, costing about $2-$5 per ton of carbon sequestered

v. Is Ocean Fertilization Likely to Be Effective?:

1. Studies to date generally show fairly-high proliferation of phytoplankton in patches of ocean fertilized with iron
    a. And research results from OIF field experiments often demonstrate that CO_2 concentrations are lower where there are large patches of algae **[SLIDE 10]**

ii. However, drawdowns in the concentrations of atmospheric carbon dioxide will only occur if phytoplankton are sequestering substantial amounts of CO_2 when they ultimately die and sink to the bottom of the ocean
    1. However, this might not occur:
        i. Phytoplankton can be consumed at the ocean surface by zooplankton, microscopic invertebrate species that feed on algae
            1. Zooplankton, in turn, could be eaten by larger sea creatures, which would release CO_2 back into atmosphere by respiration and excretion
            2. However, a recent study (2012) did conclude that at least half bloom biomass in one experiment sank far below a depth of 1000 meters, and that a substantial portion is likely to have reached the sea floor.
    b. Also, much of the organic carbon is re-mineralized by bacteria back into inorganic carbonate and bicarbonate during the first 500 meters of sinking

iii. As models of potential for ocean fertilization have become more sophisticated, its prospects have become less hopeful:
    1. Only 3 of 12 iron addition experiments have demonstrated substantial sequestration of CO_2
    2. One recent study concluded that, at most, the technique would only reduce atmospheric concentrations of CO_2 by 10%
    3. Model developed at Ohio University estimates that even fertilizing the entire 20% of the oceans that are HNLC would only reduce concentrations of CO_2 by about 38ppm
        a. And, another study pegs the decline in atmospheric concentrations to a mere 10ppm because of other limiting factors
    4. Also, might require 300,000 ships and 1.6 billion kilograms of iron annually

b. However, proponents argue that jury still out:
    i. Some argue that we need larger experiments, longer in length to accurately ascertain full extent of primary productivity that might ultimately occur
    ii. Moreover, proponents argue that even if ultimately only 10-15% carbon drawdown, this would be one of the "wedges" we need to effectively address CC

D. Potential Negative Ramifications of Ocean Fertilization:

a. Marine systems are very complex; iron fertilization may give rise to a plethora of different phytoplankton species, some of which might be undesirable for food web, or even toxic **[SLIDE 11]**
    1. For example, in one iron fertilization study, the abundance and biomass of one phytoplankton species, *Phaeocystis Antarctica,* was increased; this species proved unpalatable to mesozooplankton species in the region, which could imperil the trophic web.
    2. OIF could also privilege fast-growing species of phytoplankton, including *Pseudo-nitzchia,* which produces domoic acid, a neurotoxin that can kill mammals and sea birds
    3. Overall, as a University of Michigan study concluded: “If the wrong species enjoy the most success, the impacts on the marine biosphere could be catastrophic.”

c. By increasing the uptake of nutrients in the region where OIF occurs, downstream ecosystems might be robbed of nutrients
    i. Recent studies indicate that this could occur to a very large extent

d. Fertilization could also result in widespread eutrophication, i.e. proliferation of algae that can choke off light to species and create toxic algae blooms that kill species
    a. Example in Mediterranean in early 1990s, toxic algae bloom resulted in a massive kill off of dolphins, so called “red tide”
    b. There was also some speculation that altering plankton growth might alter algae growth which in turn might affect deep ocean iron beds, causing an increase in iron concentrations and further amplifying the effects.
    a. If this were an unstable scenario, it might reach a scale sufficient to place the Earth back into an ice age.

e. Iron fertilization could actually exacerbate climate change:
    1. When phytoplankton begins to die and decay it results in more consumption of oxygen through the respiration process
    2. This could result in anoxic or oxygen-deprived “dead zones”
        a. Beyond killing lots of species, anoxic environments produce lots of methane and nitrous oxides, two GHGs with much higher global warming potential than CO_2

            i. Methane: 21x
            ii. Nitrous oxides 206x
                1. Believed that the nitrous oxides alone could offset all of the benefits

B. Ocean Alkalinity Enhancement: [SLIDE 12]

- **a.** Overview:
    - i. When carbon dioxide enters the oceans, it reacts with the water, forming carbonic acid.
        1. The acid dissociates into hydrogen ions and bicarbonate ions.
        2. Over time, calcifying organisms convert the bicarbonate ions into calcium carbonate, which forms the basis of their shells and skeletons.
            - a. When the organisms die, they sink to the ocean floor and a portion of the calcium carbonate is buried, effectively resulting in long-term storage of carbon dioxide in mineral form.
    - ii. However, burgeoning uptake of carbon dioxide in the oceans in recent years has limited conversion of CO2 into bicarbonate and carbonate sediments by making the oceans more acidic, limiting ability of oceans to absorb more CO2
    - **iii.** Enhanced Ocean Alkalinization is a process that involves adding alkalinity to the oceans, increasing pH, and thus facilitating more uptake ultimately of CO2
        - **1.** These substances could include silicate-rich minerals, such as olivine or basalt, or artificial substances, such as lime.
            - a. This, in turn, causes the ocean to absorb more CO_2 from the air to restore equilibrium.
        - 2. Another option could be accelerated weathering of limestone, which involves promoting dissolution of limestone dissolution in a reactor with seawater and CO_2 rich gas (e.g., greater than 5000 parts per million by volume).
            - a. This creates a slight increase in the pH and alkalinity of the seawater in the reactor, which is returned to the ocean.
    - **iv.** Could also help with “evil twin” of climate change, ocean acidification, by increasing alkalinity of oceans
    - **v.** A flotilla of ships could be deployed to distribute finely ground limestone or silicates in selected parts of the oceans, or limestone/silicates could be dissolved and pumped to the ocean where local water supplies are readily available.

- **b. Challenges/risks:**

i. Unclear how effective this approach would be, mostly, again, based on modeling: some studies project only a drawdown of 30ppm, others say as much as 166-450ppm by 2100
ii. Large costs: maybe almost $3 trillion annually;
iii. Risks:
    1. The process could potentially disadvantage marine organisms that are not able to concentrate carbon within their cells under conditions of increased alkalinity, e.g. littoral crabs;
    2. AOA could also cause spontaneous precipitation of calcium hydroxide.
        a. This might adversely impact coral reefs, because they are sensitive to high levels of turbidity;
    3. The addition of non-carbon alkaline minerals to the oceans could also alter primary and secondary production, thereby increasing contaminant accumulation in food chains via the release of minerals such as cadmium, nickel, chromium, iron and silicon

C. **Artificial Ocean upwelling:** [SLIDE 13]

a. Artificial upwelling seeks to stimulate primary production in marine environments by drawing nutrient-rich water from beneath the photic zone to the surface.
    i. As is the case with OIF, stimulation of phytoplankton production could lead to a drawdown of atmospheric CO2 through the sinking of a portion of particulate organic carbon to the ocean floor, and sequestration for decades or centuries.
b. Techniques for artificial upwelling involve giant sea pumps powered by offshore wind farms, wave power, or plastic floating tubes that reach hundreds of meters deep.
c. Effectiveness:
    i. Might be relatively modest in terms of carbon drawdown, maybe 1 GtCO2 annually v. 15-20 GtCO2/yr.
    ii. Risks:
        1. The drawdown of CO_2 into marine environments could exacerbate ocean acidification, potentially decreasing ocean pH by 0.15 units beyond present acidification projections.
        2. Artificial upwelling could also substantially restructure ocean ecosystems, including favoring larger phytoplankton, such as diatoms, and resulting in a shift from oligotrophic (nutrient-poor) to eutrophic (nutrient-rich) species

D. Macroalgae Cultivation: [SLIDE 14]

a. Seaweed has been removing carbon dioxide from the atmosphere for at least 500 million years.
   i. Recent studies suggest that wild seaweed sequester 173 million metric tons annually when seaweed drops to the bottom of the ocean and CO_2 is buried in sediments
b. A number of companies are now proposing to amp up this process by farming seaweed for the express purpose of sinking it and locking down its carbon
   i. One company proposes millions of buoys, claiming to be able to sequester gigatons of CO_2, but some other studies say perhaps only a third of gigaton possible
c. Also risks:
   i. Species entanglements in millions of buoys with ropes/lines
   ii. Opportunistic feeding of some species alters ecosystem assemblages
   iii. Potential invasive species catching rides on buoys that drift into coastal areas

3. Marine Geoengineering Governance: International

A. Two international treaty regimes to date have sought to regulate climate geoengineering research, in the context of one specific option: OIF

a. **London Convention Resolution [SLIDE 15]**
   i. Focus on OIF
   ii. Parameters: Case by case with risk assessment framework, only purposed for scientific research currently:
      1. Elements of risk assessment framework established in 2010 **[SLIDE 16]**
         a. Under the framework, scientific research projects will be considered contrary to the aims of the London Convention, unless "conditions are in place to ensure that, as far as practicable, environmental disturbance would be minimized, and the scientific benefits maximized."
      2. Framework doesn't appear to contemplate comparative risk assessment, but would probably be desirable
   iii. Limitations:
      1. Resolutions not legally binding;
      2. Resolution's scope focused on OIF, though it also referred to "other activities that fall within the scope of the London

Convention and the London Protocol and have the potential to cause harm to the marine environment."

3. Would only apply to marine-based options involving placement of matter in oceans, so might not apply to ocean upwelling, for example, where no placement of matter is being conducted

iv. An entity wishing to engage in marine CDR might argue, alternatively, that what's it's planning to do DOES constitute dumping, and if it doesn't involve placing one of the 8 categories of materials prohibited from dumping under the LC into the ocean, could seek a permit
    1. Might permit OIF, OAE, seaweed farming
        a. Note: one of the prohibited categories is persistent plastics and other persistent synthetic materials, for example, netting and ropes, so might encompass seaweed farm, dependent on nature of the operation

b. London Protocol (contemplated successor to LC):

i. Parties passed an amendment in 2013 that would create legally binding regulatory framework, including risk assessment **[SLIDE 17]**
    1. And while restricted to OIF currently, could be expanded in future to other marine geoengineering options

ii. But the amendment's significance is undercut by several facts:
    1. The amendment cannot come into force until two-thirds of the Parties to the London Protocol accept it, which would require 34 Parties to accept.
        a. Currently, only five have accepted
    2. LP only binds 51 States, and doesn't include one key potential actor, the United States
    3. Again, wouldn't encompass all ocean approaches

c. Again, an entity wishing to engage in marine CDR might argue, alternatively, that what's it's planning to do DOES constitute dumping
    i. LC takes a "positive listing" approach, so only things listed may be dumped:
        1. organic material of natural origin, which could include seaweed itself, appear on the list of potentially allowable substances;

d. CBD [SLIDE 18]

i. Subsequently, the parties in 2012 passed a resolution that defined geoengineering very capaciously to encompass any "[d]eliberate intervention in the planetary environment of a nature and scale intended to counteract anthropogenic climate change and its impacts."
ii. Limitations:
   1. Resolutions not legally binding;
   2. Language in geo. resolutions are squishy: merely "invites" countries to "consider" the guidelines provided.
   3. Feckless regime to date

B. Other regimes of pertinence:

a. UNCLOS:

a. Pertinent provisions for research program:
   i. Right to conduct and foster research is cornerstone of UNCLOS, so could help facilitate this research, however, subject to Convention's objectives, including protection of marine environment **[SLIDE 19]**
   ii. Within State's Territorial Seas and EEZs:
      1. Research in territorial or EEZ requires coastal State consent, but good faith requirement to permit if comports with other principles of the Convention **[SLIDE 20]**
   iii. Research beyond EEZs:
      1. Capacious rights **[SLIDE 21]**
      2. But State responsibility and liability for contravention of Convention provisions including pollution impacts **[SLIDE 22]**

b. Potential Deployment of Marine Geoengineering Options:

   i. If serious negative impacts might be manifested by deployment or large-scale research, could run afoul of pollution provisions of UNCLOS **[SLIDE 23]**
      1. Pollution in UNCLOS definition capacious enough to include potential impacts of many of the CDR approaches **[SLIDE 24]**

2. And could give rise to liability, including compensation and full reparation, i.e. return to previous State prior to harm **[SLIDE 25]**
    a. But not absolute liability; if complies with all requirements, including:

B.

a. take all necessary measures to minimize the adverse impacts of the project and ensure that it does not cause damage to other states or their environments;

b. notify affected countries and competent international authorities of any imminent or actual damage from the project;89 and

c. study the risks and effects of the project and publish the results of that study

b. **Emerging Biodiversity Beyond National Jurisdiction treaty could impact deployment of climate geoengineering options on the high seas:**
    i. Might restrict research or deployment in protected areas in open oceans **[SLIDE 26]**
        1. Conversely, might argue that ability to counter climate change or ocean acidification would privilege its use in such areas
        2. EIA requirement **[SLIDE 27]**
            a. Would likely include transboundary EIA requirement for potential impacts on other States in a region where research or deployment might occur

C. Other potentially pertinent regimes:

a. Climate regime: Paris Agreement:

i. Could parties to Paris incorporate marine geoengineering approaches as a way of meeting their nationally determined contributions (NDCs)?
    1. Seems yes in context of CDR:
        a. NDCs require mitigation responses **[SLIDE 28]**

b. While Paris doesn't define term "mitigation," parent agreement does, and OAE would appear to fit under sinks enhancement rubric **[SLIDE 29]**

2. But tougher call in terms of SRM approaches, since they would not reduce emissions or enhance sinks

ii. Either way, there would be other provisions of Paris that could provide authority to regulate marine geoengineering approaches whether claims as part of NDCs or not

1. Paris provides for scrutiny of impact of response measures on axis, e.g. on oceans, and sustainable development, poverty **[SLIDE 30]**
2. Though, note, this is Preambular language, so not legally binding on Parties

iii. Paris has a **Forum on the impacts of the implementation of response measures** that operates under its subsidiary bodies on Science & Technology Assessment, and Implementation

1. Not really designed with this purpose in mind, but could be

2. Can appoint specialized committees of experts to advise, so could do on geoengineering

b. Other treaty regimes:

i. United Nations Fish Stocks Agreement, includes provisions to address threats other than fishing to regulated stocks;

ii. Regional Fisheries Management Organizations, including CCAMLR, particularly in terms of OIF in the Southern Ocean

iii. Marine pollution regimes at regional level

iv. Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD)

c. Customary international law:

i. Precautionary principle;

ii. No-harm rule

iii. Transboundary EIA

D. Of course, domestic law pertinent if conducted within a country's waters, e.g. in US:

a. Marine Protection, Research, and Sanctuaries Act, Clean Water Act, Coastal Zone Management Act, and National Environmental Policy Act