A Briefing on Marine Geoengineering

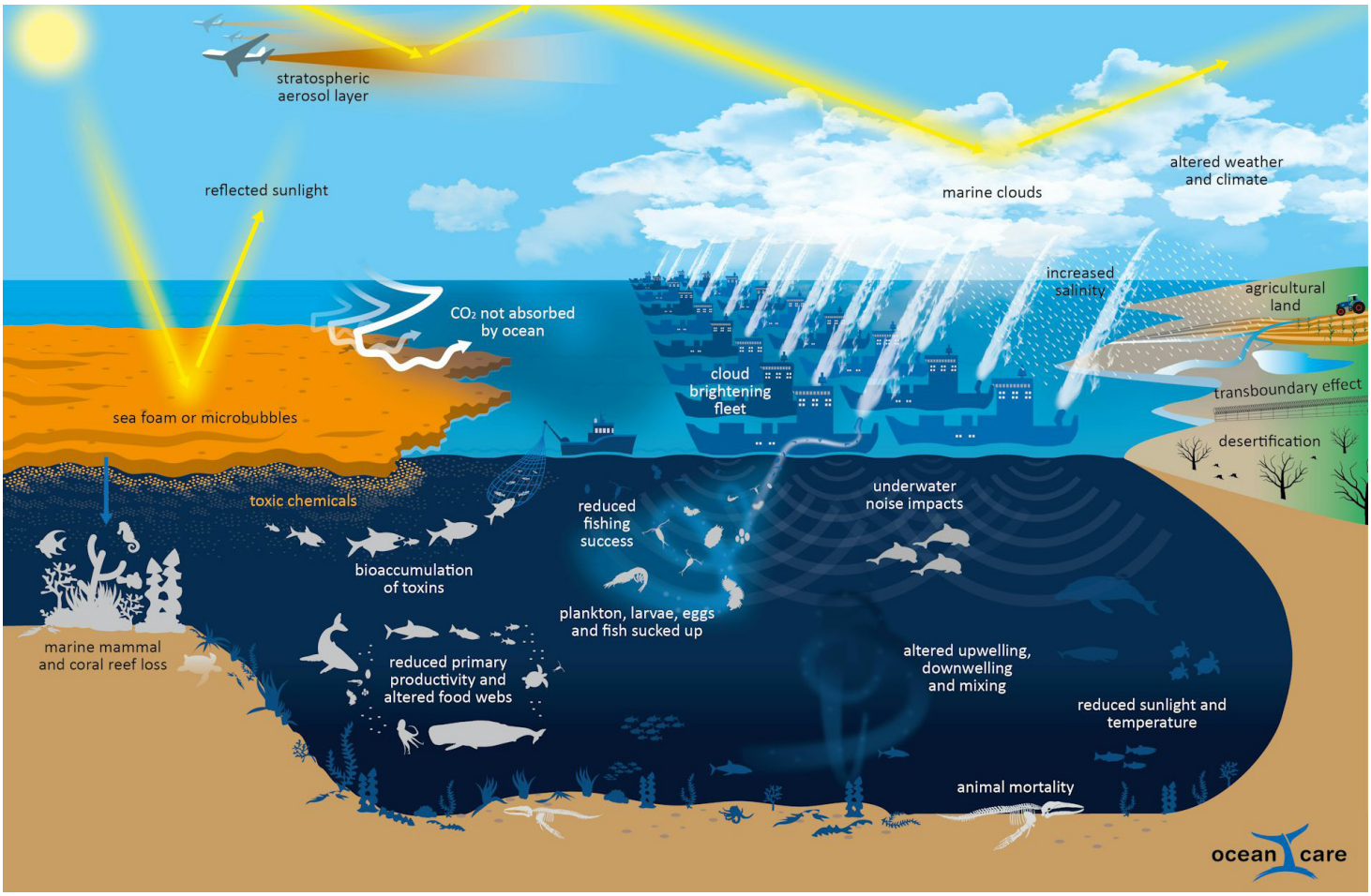
1 WHAT IS MARINE GEOENGINEERING?

To effectively address the climate crisis, it is crucial to urgently reduce greenhouse gas emissions in a just and equitable manner.

However, in the context of the failure of high-emitting governments and corporations to take action to tackle the root causes of the crisis, there is a growing trend of integrating highly speculative marine geoengineering technologies into climate policy and forums. Marine geoengineering (mGE) involves efforts to alter the Earth's oceans in order to mitigate some of the impacts of climate change but does not tackle the root causes of climate change.

Most of these speculative proposals focus on removing carbon dioxide (CO2) from the atmosphere and storing it in the ocean, a process often referred to as "marine Carbon Dioxide Removal" (mCDR) or "ocean-based Carbon Dioxide Removal." Other approaches attempt to manipulate ocean surfaces to increase the amount of sunlight reflected back into space in an attempt to cool the planet. For these technologies to have a significant impact on the climate, they would need to be deployed on an enormous scale, with serious adverse effects. Potential harmful impacts include ecosystem disruption, marine food chain disruption, loss of biodiversity, changes in ocean chemistry, concerns about governance, socio-economic losses, and violations of human rights including those of vulnerable populations and the inherent collective rights of Indigenous Peoples. Marine geoengineering methods, such as large-scale seaweed plantations, could also devastate coastal communities by disrupting local ecosystems, food systems, and livelihoods, raising ethical concerns about their long-term consequences for future generations.

Additionally, market-based mechanisms and carbon offsetting are significant drivers of many of these speculative technologies, perpetuating harm in already vulnerable populations and biodiversity.



Marine Geoengineering Methods

1 Ocean Fertilization

Ocean fertilization is a method in which iron or nutrients such as nitrogen are added to parts of the ocean to stimulate plant growth. The idea is that by "fertilizing" ocean regions with lower biological productivity, minute plants called "phytoplankton" which grow more readily. As these plants proliferate, they absorb carbon dioxide (CO2) from the atmosphere. Upon the demise of the phytoplankton, some descend to the ocean floor, although it is unclear what proportion of CO2 is locked away and for how long. In previous trials, ocean fertilization experiments did stimulate phytoplankton blooms, but also resulted in toxic outbreaks that released potent greenhouse gases like nitrous oxide and methane, which exacerbates global warming. Additionally, studies suggest most of the carbon initially absorbed by phytoplankton is released back into the environment through the food chain, likely making long-term carbon sequestration ineffective.

2 Macroalgae Cultivation and Sinking

Seaweed, also known as macroalgae, absorbs CO_2 and converts it into a form of carbon that living organisms store via photosynthesis. Proponents of large-scale industrial seaweed cultivation for geoengineering claim that this process could sequester carbon dioxide in three main ways. One method involves seaweed breaking away from farms and sinking, taking the stored carbon with it. Another approach is to use harvested seaweed to create materials like biochar or bioplastics. Lastly, seaweed biomass can be gathered, pressed, and submerged into the deep ocean. However, the massive scale of cultivation required would significantly disrupt marine ecosystems and affect the livelihoods of coastal communities - some 10% of the ocean surface has been suggested. [2] Seaweeds release bioaerosols that can act as potent greenhouse gases and their growth will rob nutrients from phytoplankton that are a significant component of the biological carbon pump. [3] Additionally, the idea of artificial upwelling—pumping nutrient-rich deep water to the surface to stimulate seaweed growth—has been proposed despite concerns that it could disrupt natural ocean processes and ecosystems and bring up CO_2 stored in deeper waters. [4] The large-scale sinking of organic matter over vast areas can have significant environmental impacts, such as releasing dissolved organic materials and chemicals during their descent and at the seafloor. This process can lead to smothering and create low-oxygen conditions (anoxia), which may produce harmful hydrogen sulfide. A meta-analysis showed that under hypoxic conditions, the survival rate of benthic communities decreases by an average of 30%. [5] These conditions can result in the mass die-off of seafloor organisms at the disposal site, with potentially cascading impacts on marine ecosystems. [6]

3 Ocean Alkalinity Enhancement

The method involves attempting to increase the ocean's alkalinity to enable it to drawdown more CO_2 from the atmosphere. There are two primary methods suggested for achieving this: adding ground alkaline rocks or alkaline liquids to the ocean or coastline (enhanced weathering) and using electrochemical techniques. Massive dumping of alkaline rock into the ocean would be necessary for any significant CO_2 removal; on a global scale, 5-26 gigatons would be needed each year to maintain ocean surface pH. This would lead to devastating environmental impacts from the large-scale mining, processing, and transportation of alkaline materials. While designed to increase CO_2 absorption by altering ocean chemistry, OAE could unintentionally affect marine ecosystems. If silicate materials are used at scale, they would likely release harmful trace elements like cadmium, nickel, and chromium, which could negatively impact deep-sea organisms. Increased pH from OAE would have harmful short-term impacts on marine life in surface waters, but particles sinking to deeper waters could alter microbial communities and affect the food supply for deep-sea life. [7] Electrochemical ocean alkalinity methods pose risks to marine ecosystems by releasing toxic by-products like chlorine gas and trace metals, which could lead to ecotoxicological effects on marine life. The processes are highly inefficient, processing large amounts of seawater for a small quantity of CO_2 removal, this would damage and kill marine life and also require large quantities of renewable energy that should instead prevent further CO_2 from being released into the atmosphere. [8]

4 Carbon Capture and Storage (CCS)

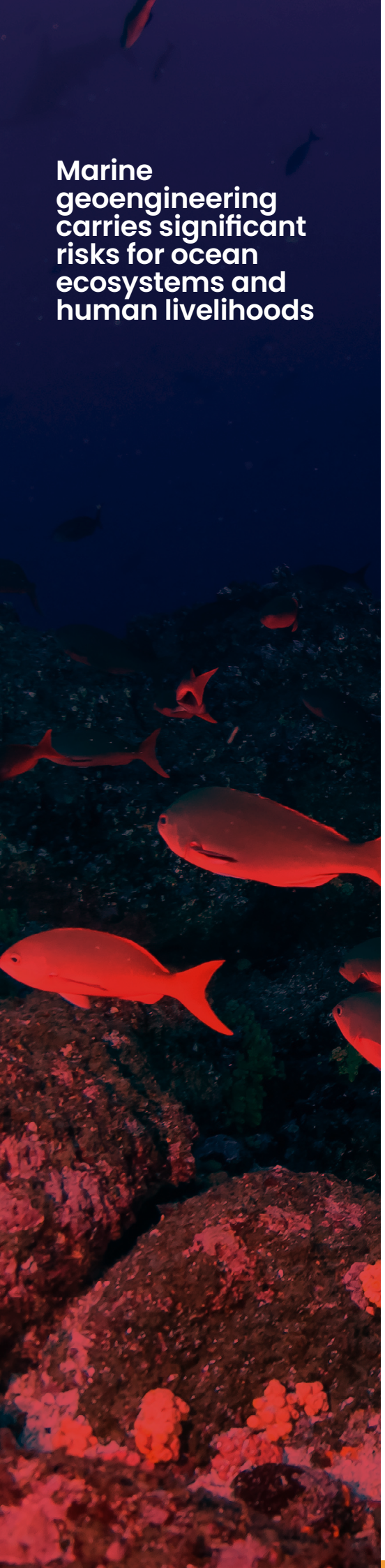
This method involves capturing CO_2 emissions from power plants or industrial facilities, typically by using a sorbent chemical to trap the CO_2 before it exits a smokestack. The captured CO_2 is subsequently converted into a liquefied or carbonated state and then introduced into geological formations, typically within nearly depleted oil wells or sub-seabed locations, as a means of long-term storage. However, concentrated liquefied CO_2 is highly toxic. [9] When CO_2 is stored in deep ocean waters or on the seafloor, there are concerns about potential direct exposure of deep-sea animals and ecosystems to the CO_2 or CO_2-hydrate, as well as the possibility of a plume of carbon dioxide spreading from the storage site and affecting surrounding waters. Further marine impacts may arise from noise pollution and physical disturbance caused by the construction of extensive pipelines for transporting and storing CO_2. Additionally, there is an increased risk of seismic activity due to raised sub-surface pressure. [10]

5 Marine Cloud Brightening

This proposed solar geoengineering technique aims to increase the brightness of clouds in order to reflect more sunlight back into space. The idea is to enhance cloud reflectivity by injecting tiny particles–such as sea salt aerosols–into marine clouds, creating smaller and more concentrated droplets. While some models suggest that this technique could lower global temperatures, they also predict uneven and potentially harmful effects in different regions. For example, if deployed at a scale large enough to affect temperature, global rainfall is expected to decrease. One study suggests a potential 2.3% reduction in precipitation. This could have severe consequences, such as making South America warmer and drier, leading to devastating ecological impacts, particularly in the Amazon rainforest. In contrast, another study forecasts a 7.5% increase in runoff over land, especially in the tropics, due to uneven changes in precipitation patterns. [11] Additional salt loads returning to the ocean surface will slow air-sea gas exchange and, therefore CO_2 uptake by the oceans, reducing light and temperature levels that could affect ocean circulation and mixing. On land, increased salt deposition could corrode coastal infrastructure, pollute waterways, and harm agricultural productivity. Lastly, large-scale seawater pumping and filtration will ingest and kill significant numbers of marine organisms.

6 Ocean Reflectivity Enhancement

The technique involves using microbubbles and sea foam on ocean surfaces, including sea ice, as a proposed method of solar geoengineering. The aim is to increase the reflectivity of water surfaces (albedo) to reflect more sunlight and reduce heat absorption. This can theoretically be achieved by creating brighter water surfaces, such as whitecaps or foamy waves, which naturally reflect more sunlight. There are two proposed methods to extend the lifespan of these bubbles: using ships equipped with special nozzles to produce microbubbles or using chemicals called surfactants to stabilize the bubbles. Artificial foam can also be created using foaming agents like cellulose ethers. However, it's important to consider the potential negative effects of large-scale use of microbubbles. This method could disrupt marine ecosystems by reducing the sunlight that phytoplankton–the foundation of the marine food web–need for photosynthesis. It could also hinder gas exchange, leading to lower oxygen levels in the water, which would negatively affect marine biodiversity and productivity. Additionally, the surfactants used to stabilize bubbles would most likely be toxic to marine life. [12]



Marine geoengineering carries significant risks for ocean ecosystems and human livelihoods

2 NEGATIVE IMPACTS OF MARINE GEOENGINEERING

Large-scale interventions can lead to unintended and irreversible consequences in natural ocean processes. The GESAMP high-level review of a wide range of proposed marine geoengineering techniques suggests that technologies such as ocean fertilization and ocean alkalinity enhancement would need to be deployed across roughly 10% of the world's oceans to be effective. [13]

The extensive deployment of these technologies raises serious concerns about long-term environmental sustainability and global equity.

1 Ecosystem Disruption

Interventions, such as ocean fertilization or artificial upwelling, can have a significant impact on marine ecosystems. For example, stimulating the growth of phytoplankton through ocean iron fertilization may increase short-term carbon uptake, but it could also result in harmful algal blooms that deplete oxygen levels in the water. [14] These oxygen-depleted zones can be fatal to marine life, causing the collapse of plankton communities, which are crucial to the marine food chain. This disruption could have far-reaching effects on fish, marine mammals, and other species that rely on these foundational organisms. [15]

2 Biodiversity Loss

Marine geoengineering would inevitably result in a loss of biodiversity. The introduction of artificial substances or alteration of ocean conditions inevitably leads to the favoring of certain species, ultimately causing a significant shift in species dominance. For example, enhancing one type of plankton through fertilization could hinder the growth of other types, resulting in a less diverse ecosystem. Large-scale algae monoculture cultivation would displace other species and could spread pathogens to natural algae and artisanal cultivation. [16] This loss of biodiversity could drive some species to extinction, especially those already vulnerable to environmental stressors, and could fundamentally change the balance of marine ecosystems. Similarly, another concern with storing CO_2 in deep ocean waters or on the seabed is that it could expose deep-sea creatures to harmful levels of CO_2, which can dissolve into the water and affect marine life. Storing CO_2 under the seabed also carries the risk of leaks, which could change the water's chemistry by altering pH and increasing metals or salinity, all of which can harm ocean ecosystems. [17]

3 Ocean Chemistry Alteration

The modification of ocean chemistry through marine geoengineering is a significant cause for concern. Methods such as Ocean Alkalinity Enhancement and Ocean Fertilization can unpredictably alter the chemical composition of seawater. While these techniques are intended to boost the ocean's ability to absorb carbon dioxide, they may lead to unintended consequences such as increased acidification or the creation of dead zones with dangerously low oxygen levels. Many marine species are highly sensitive to changes in pH, and even slight alterations can disrupt ecosystems and harm biodiversity. The long-term effects of these chemical changes are poorly understood, and there is a significant risk of triggering chain reactions that could be difficult or impossible to reverse. [18]

4 Social, Cultural, and Economic Impacts

Marine geoengineering could have significant social and economic impacts, especially on coastal communities that depend on healthy oceans for their livelihoods. Fisheries, which provide food and income for millions of people worldwide, could be disrupted by changes in fish populations or shifts in marine food webs. Likewise, for coastal and Indigenous communities that have worked for centuries on artisanal fisheries and small-scale algae cultivation. Coastal communities could face unintended consequences, such as increased storm surges or changes in coastal erosion patterns, which could be worsened by large-scale geoengineering projects. [19] Tourism, particularly in areas reliant on clean waters and thriving marine life, could suffer if geoengineering results in ecosystem degradation. Large-scale infrastructure built near Indigenous Peoples' territories has been shown to increase violence against and murder of Indigenous Peoples. [20] Indigenous Peoples' territories continue to be targeted by marine geoengineering researchers. [21] Further, marine geoengineering experiments and projects disrupt Indigenous Peoples' cultural practices. Researchers fail to implement free, prior, and informed consent (FPIC) or uphold the Rights of the Indigenous Peoples as enshrined in the UNDRIP. [22]

Protest on the beach against Planetary Technologies' experiments. Photo by James Warbey

3 MARINE GEOENGINEERING IS NOT A SOLUTION TO CLIMATE CHANGE

False Solutions vs Tackling Root Causes

Marine geoengineering is often presented as a technological solution, but it fails to address the root cause of climate change: greenhouse gas emissions from using and burning fossil fuels. Even if methods like ocean fertilization or artificial upwelling could theoretically temporarily capture small amounts of carbon, they do not stop the ongoing release of CO_2 into the atmosphere.

The only real, long-term solution is to rapidly and justly phase out all extraction and production of fossil fuels, and equitably cut all greenhouse gas emissions at the source.

Risk of Moral Hazard

Marine geoengineering risks to present a false sense of security. This is sometimes called "moral hazard," where relying on future technological solutions to tackle the climate crisis might shift resources away from proven emissions reduction methods. Governments and industries might delay or avoid tough decisions, such as transitioning away from fossil fuels because they think geoengineering will buy them more time. In reality, the more we rely on these risky technologies, the harder it will be to mitigate climate change in the future and prevent its worst impacts.

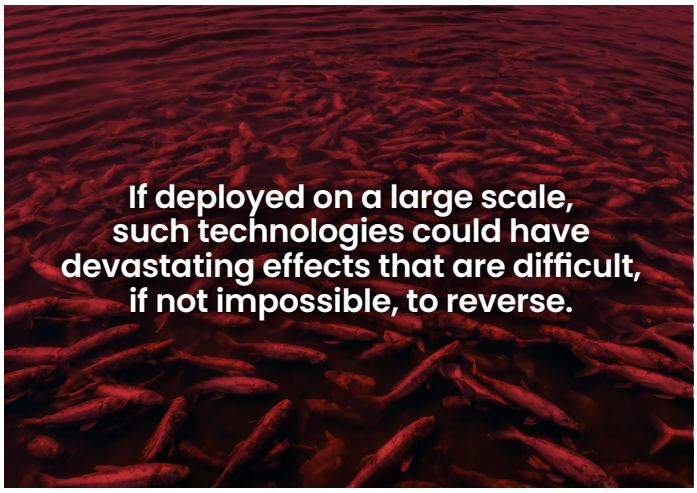
Financial Drivers of Marine Geoengineering Expansion

The rapid development of marine geoengineering projects is being fueled in part by substantial venture capital investments and the lucrative potential of generating profit from carbon credits. With financial incentives tied to carbon markets, a surge of initiatives aimed at manipulating ocean processes to remove CO_2 is emerging, often without sufficient consideration of the long-term environmental consequences. Carbon markets, both in the voluntary and regulated sectors, convert the CO_2. These units are then sold onto a market and bought by polluters, allowing them to falsely claim that they have reduced or removed their emissions. Ultimately, carbon markets allow polluters to continue to pollute while making money in the carbon markets by buying and selling these units when the market values fluctuate. Carbon markets are a lose-lose process on both sides because marine geoengineering is claimed to be a solution to reducing or removing CO_2, and extractive industries can continue to pollute, worsening climate change.

While these projects are marketed as climate solutions, they present severe risks by focusing on profit-driven technological interventions rather than addressing the underlying cause of climate change—greenhouse gas emissions from fossil fuels. This reliance on financial mechanisms encourages speculative projects that divert attention from sustainable solutions and further intensifies the moral hazard by delaying the much-needed transition to renewable energy sources.

The Precautionary Principle

The long-term consequences of marine geoengineering (mGE) remain poorly understood. Techniques such as ocean fertilization and adding alkaline substances to seawater carry potential risks, as they may lead to unintended side effects that could exacerbate climate change. For instance, while these methods are intended to enhance carbon storage in the ocean, they could instead disrupt marine ecosystems or alter ocean chemistry in unpredictable ways. Given the complexity of ocean systems, even minor interventions can have far-reaching negative impacts on marine life and human communities.



Compromising the Ocean's Natural Carbon Storage Role

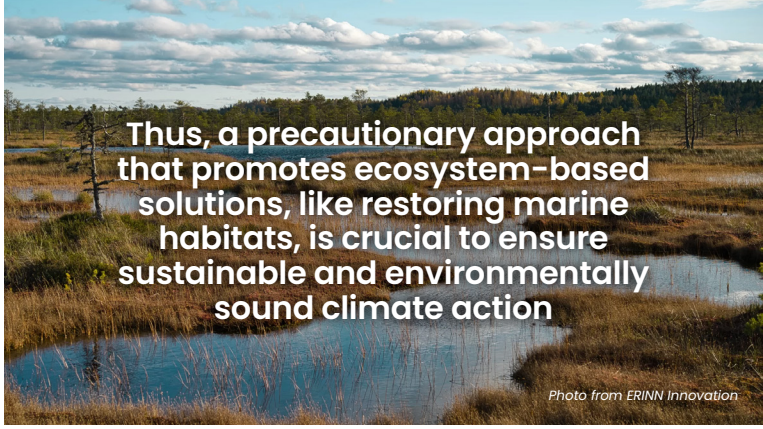
Beyond uncertain climate impacts, these marine geoengineering techniques could compromise the ocean's existing role as a natural carbon sink. By adding stress to marine ecosystems, mGE could reduce the ocean's natural capacity to sequester carbon. This would not only counteract the intended benefits of mGE but could also exacerbate the climate crisis by reducing the ocean's ability to regulate atmospheric CO_2 levels. The ocean's carbon cycle is intricately linked with global climate stability,[23] and additional interventions might destabilize this balance, bringing serious risks to both marine ecosystems and human communities.

Risk of Temperature Overshoot and Irreversible Tipping Points

While mGE may seem like a promising tool to mitigate climate impacts, reliance on these technologies brings significant risks. If global temperatures temporarily overshoot the 1.5°C threshold, it could trigger tipping points and feedback loops that accelerate climate change. [24] Once such processes start, they might be impossible to reverse, even with carbon dioxide removal methods like mCDR. Relying heavily on geoengineering could also reduce the urgency to cut emissions at their source, potentially locking us into a path that results in catastrophic climate impacts over the long term. [25]

4 GOVERNANCE AND REGULATION

The field of marine geoengineering (mGE) intersects with various international and regional frameworks, each offering different regulatory perspectives and challenges. As interest in mGE grows, there is a greater recognition of the necessity for strong governance to prevent potential ecological harm and to ensure that mGE does not undermine existing climate and biodiversity goals. This section delves into the roles of key conventions, protocols, and treaties in regulating mGE.



Convention on Biological Diversity

In 2008, CBD made a landmark decision, calling for a precautionary approach to ocean fertilization, urging countries to halt such activities until there is sufficient scientific evidence to assess their risks and establish global, transparent regulatory mechanisms. Exceptions were made only for small-scale scientific studies in coastal waters, provided they undergo thorough environmental assessments and are not for commercial purposes. In 2010, CBD extended its caution to all climate-related geoengineering activities, calling for a moratorium on large-scale deployment until global, multilateral and transparent governance mechanisms are in place, with no risk of transboundary harm and sufficient scientific backing to ensure these activities don't threaten biodiversity or social and cultural values. [26]

The Convention on Biological Diversity (CBD) has taken significant steps in regulating marine carbon dioxide removal (mCDR) activities.

LC&P
LONDON CONVENTION AND PROTOCOL

Adopted in 1972, the LC prohibits dumping of certain harmful substances, while the 1996 LP, which is more restrictive, prohibits all dumping except for a few listed substances. [27] The London Protocol and Convention (LC/LP) regulate marine geoengineering, primarily focusing on activities like ocean fertilization, which is only permitted for legitimate scientific research, that was very strictly defined in 2010. In 2013, the LP.4(8) amendment was introduced, prohibiting ocean iron fertilization except for legitimate scientific research. This amendment also establishes a framework to govern future marine geoengineering activities. Although it has not yet entered into force, this is the first attempt at creating legally binding rules for geoengineering under international law, marking a significant step towards future governance. [28]

In October 2023, during the 45th meeting of the governing parties of the London Convention and the 18th meeting of the parties to the London Protocol, a cautionary statement was issued regarding marine geoengineering technologies. The parties highlighted that these technologies have the "potential for deleterious effects that are widespread, long-lasting, or severe" and noted the "considerable uncertainty regarding their effects on the marine environment, human health, and other uses of the ocean. [29] This underscores the importance of a precautionary approach in regulating these emerging technologies.

The London Convention (LC) and London Protocol (LP) provide important international rules for regulating ocean dumping, building on UNCLOS' general obligations.

United Nations Framework Convention on Climate Change

Article 6 is the carbon markets Article of the Paris Agreement. Specifically, Article 6.4 replaces the Kyoto Protocol's Clean Development Mechanism and is positioned to become the largest global carbon offsets platform. This market-based mechanism would allow countries to trade credits from emission reduction and removal projects, where one nation's carbon offsets can be used by another to meet its Nationally Determined Contribution (NDC) in the Article 6.2 registry database. [30] While presented as a cost-effective approach to achieving climate goals, Article 6 risks prioritizing technological fixes over direct emissions reductions and phasing out fossil fuels at source. Governing rules regarding methodologies for removals will be negotiated at the upcoming UNFCCC COP 29, and if agreed upon, Article 6 could pave the way for marine geoengineering (mGE) to be included as a form of greenhouse gas removal. Such a move would fundamentally shift carbon markets globally, potentially legitimizing mGE despite its risks to marine ecosystems, biodiversity, and coastal communities. Although Article 6.4 Supervisory Body claims to ensure transparency and effectiveness, the growing emphasis on speculative technologies like mGE would divert resources from essential climate solutions, like phasing out fossil fuels to technofixes and false solutions.

United Nations Framework Convention on Climate Change (UNFCCC)

THE LAW OF THE SEA

Although it does not explicitly address marine geoengineering activities, UNCLOS may still influence their regulation. Key provisions, such as those defining countries' jurisdiction over ocean areas and responsibilities to protect the marine environment, could shape how nations govern mGE. For example, coastal states have sovereign rights over their territorial waters and exclusive economic zones, allowing them to regulate ocean-based activities, including mGE. However, ocean CDR could also be classified as marine pollution under UNCLOS, depending on its impacts on marine ecosystems. The convention also integrates international rules and standards from other treaties, meaning that future mGE activities will need to align with both UNCLOS and global climate agreements like the Paris Agreement. [31]

The United Nations Convention on the Law of the Sea (UNCLOS) provides a wide legal framework for regulating ocean-based activities.

OSPAR

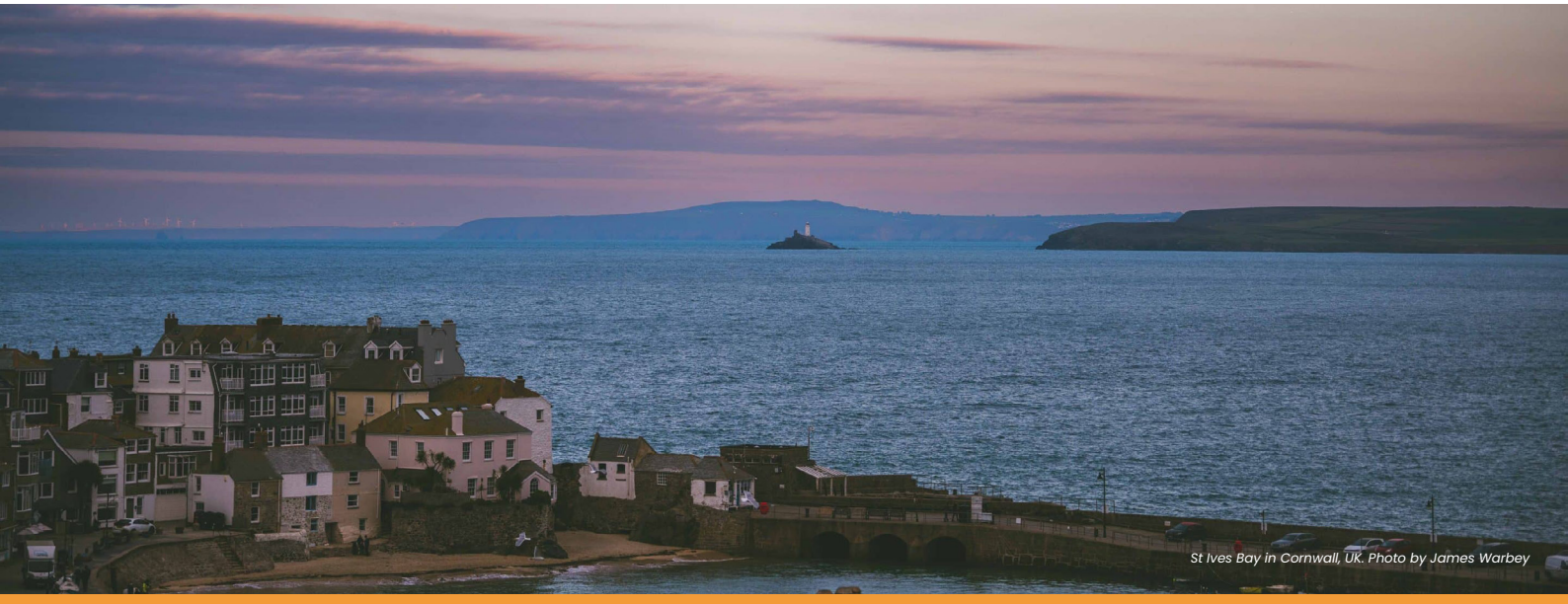
OSPAR brings together various nations to address issues like marine pollution, biodiversity conservation, and sustainable use of ocean resources. The Commission emphasizes a precautionary approach, ensuring that activities, such as carbon capture and storage (CCS), are rigorously assessed to prevent harm to marine ecosystems in the North-East Atlantic. OSPAR also highlights the need for clear regulations and monitoring frameworks for CCS, addressing concerns about unintended consequences, such as ocean acidification, disruption of ecosystems, and leakage from sub-seabed storage sites. By adhering to international environmental principles like the precautionary principle, OSPAR seeks to balance technological innovation with the protection of marine biodiversity. [32]

The OSPAR (Oslo-Paris) Convention is an international body dedicated to protecting the marine environment of the North-East Atlantic.

The UN High Seas Treaty

It is a framework established for the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction, such as the high seas. Though it does not specifically address marine geoengineering, it could be used to regulate these activities, based on the precautionary principle, through its tools for area-based management and environmental impact assessments. The treaty allows for the creation of protected marine areas where harmful activities like mGE could be restricted or monitored. Additionally, it requires countries to assess the environmental and other impacts of ocean-based activities, ensuring that mGE projects undergo thorough evaluations. The treaty emphasizes transparency, stakeholder consultation, and the use of scientific evidence, creating an opportunity for balanced assessments of mGE activities, considering both risks and potential climate benefits. However, its effectiveness will depend on how well countries implement its provisions, and it will take time for the treaty to come into force. [33]

The High Seas Treaty, also known as the Agreement on Biodiversity Beyond National Jurisdiction or 'BBNJ', was adopted in June 2023.



St Ives Bay in Cornwall, UK. Photo by James Warbey

Protest against false solutions at Bonn climate negotiations. Photo by Tamra Gilbertson/IEN

5 RECOMMENDATIONS FOR UNFCCC COP29

At COP29, Parties should reinforce a precautionary approach to Article 6 mechanisms, particularly regarding marine geoengineering (mGE) projects. As global carbon markets expand under Article 6, it is vital to prevent mGE from gaining acceptance as a legitimate carbon removal solution. Due to its significant environmental risks, mGE should be explicitly excluded from qualifying as a removal method under Article 6.4 mechanisms. Recognizing the biodiversity threats associated with mGE, the UNFCCC should also coordinate closely with the Convention on Biological Diversity (CBD), the London Convention and Protocol (LC/LP), and other relevant organizations to ensure that Article 6 mechanisms uphold existing biodiversity safeguards and reinforce global environmental protections.

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