

CARBON MARKET-DRIVEN EXPERIMENTS IN THE OPEN OCEAN ENDANGER THE MARINE ENVIRONMENT

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*This update on Marine Geoengineering through Ocean Alkalinity Enhancement (OAE) summarises the latest developments on the Geoengineering Monitor Map, highlighting new trends for civil society and climate justice movements to follow in their efforts to oppose geoengineering globally. This update is Part One of a three-part update on Marine Geoengineering. It was researched and written by **Anja Chalmin**, and published with the support of the Geoengineering Monitor team.*

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Critical developments in Marine Geoengineering through Ocean Alkalinity Enhancement (OAE)

- OAE experiments and commercial-scale projects aiming to remove CO₂ from the atmosphere by reducing the acidity

of seawater are proliferating in open ocean, coastal and nearshore areas globally.

- The promise of generating revenue through the sale of carbon credits is the driving force behind many OAE projects, and pre-purchase agreements for offsets have already been signed, including with Boeing.
- Companies with commercial interests in OAE include Equatic, which is currently testing its OAE technology in Los Angeles and Singapore, and “wants to generate tens of millions of dollars in revenue [...] by selling carbon offset credits to corporate buyers”, and Limenet, which has demonstration sites in Italy and Latvia and claims that no long-term monitoring of its CO₂ capture scheme is necessary.
- The impacts of OAE on the carbon cycle and biodiversity are highly unpredictable due to the complexity of the marine environment and carbon exchange processes, and may, for example, threaten marine food chains.
- Older OAE approaches which require large quantities of ground-up rock are gradually being replaced by newer electrochemical approaches, which usually involve removing seawater and treating it before returning it to the ocean.

The different approaches to OAE currently being developed

OAE aims to remove CO₂ from the atmosphere by increasing the alkalinity of seawater. As a result of the increased alkalinity, the surface water is able to absorb more CO₂, which is then chemically bound and stored primarily as hydrogen carbonate. There are several types of OAE that generally fall into the following and sometimes-overlapping categories:

- *Ground minerals*: These approaches aim to mimic natural weathering processes by adding ground-up alkaline minerals such as limestone, olivine, magnesite or brucite directly into the ocean or onto beaches, where they are washed into the ocean by wave action.
- *Electrochemical*: These processes extract seawater from the ocean and return it in a more alkaline state, or remove CO₂ from seawater to increase the ocean’s ability to absorb atmospheric CO₂.
- *Photochemical*: Alkalinity enhancement can be triggered by the absorption of light, whereby a molecule will become acidic when exposed to sunlight and revert to its original neutral form in the dark.

Whilst these three OAE approaches differ technologically, they face a number of common challenges and potential impacts, which include the following:

- CO₂-depleted water can only absorb atmospheric CO₂ when it rises to the surface and comes into contact with air, which can take hundreds of years.
- Research undertaken on Tasmanian beaches has shown that OAE can significantly reduce natural alkalinity production by slowing natural weathering through increasing the carbonate saturation of seawater.
- Italian researchers have shown that OAE can cause temporarily high pH values that can be dangerous to marine life.
- The International Maritime Organisation (IMO) states that marine geoengineering technologies, including OAE, “have the potential to cause deleterious effects that are widespread, long-lasting or severe” and highlights that “there is considerable uncertainty regarding the effects on the marine environment, human health, and on other uses of the ocean”.
- OAE approaches which aim to mimic the process of natural weathering would require the addition of **several gigatonnes** of mined alkaline minerals to the ocean per year in order to enhance ocean alkalinity on a climate-relevant scale. This would **require vast quantities of minerals** to be mined, milled, transported and distributed, which would have a large environmental footprint.

OAE with alkaline materials

There are a number of companies and projects currently seeking to increase ocean alkalinity using alkaline rocks and other alkaline substances. Most of the companies are based in the United States, and a number of research projects are also looking to conduct experiments in the open ocean.

Vycarb (USA): Open-ocean experiments building towards carbon credit sales

Vycarb plans to conduct two small-scale experiments off the coast of New York and Massachusetts in 2024 involving the addition of ground minerals such as dunite and silicates to seawater. The trials follow a four-hour demonstration trial undertaken off the coast of New York in 2023 to test deployment technology. Vycarb expects to “generate millions of dollars in profit annually” through selling carbon credits.

Limenet S.r.l. (Italy, Latvia): More open-ocean experiments building towards carbon credit sales

This OAE approach is based on the Italian DESARC-MARESANUS research project and requires CO₂, limestone, seawater and energy. Firstly, calcium hydroxide is produced from limestone in several very energy-intensive processes. The next step is the conversion of calcium hydroxide, CO₂ and seawater into calcium bicarbonate with CO₂ and seawater in a reactor. The CO₂ used can be captured in the calcium hydroxide production process, or could come from another source such as Direct Air Capture (DAC). After these energy-intensive processes, the alkaline solution is then mixed with seawater and discharged into the ocean. The company has already tested a prototype on the coast of the Gulf of La Spezia in Liguria, Italy, and another pilot project is underway in Latvia. Limenet S.r.l. also has plans to build and begin operating a commercial-scale plant in Taranto, Italy, by the end of 2024, and to sell carbon credits generated by the process. The company claims that its OAE approach results in the long-term and stable storage of CO₂ in seawater for 10,000 to 100,000 years, and that no long-term monitoring is required.

Carbon Blue Ltd. (Israel): Using calcium to mineralise dissolved CO₂

This OAE process involves using calcium to mineralise the CO₂ dissolved in seawater by pumping it through a closed-loop system. The mineralised CO₂ is then removed and the sea water is returned to the sea. The company intends to sell the captured CO₂ for use in consumer products. The process has already been tested on a laboratory scale and is currently being tested in a seawater pool at Kibbutz Maagan Michael, Israel.

Planetary Technology Inc (Canada, UK and USA): Open-ocean experiments trigger protests

The company is developing and commercialising its SeaOH2 technology which combines an energy-intensive electrolysis process with the addition of a mineral salt derived from alkaline rock tailings to produce magnesium hydroxide. In 2022, the company conducted a first open-ocean OAE trial in St. Yves Bay, UK. Local residents found out about the trial after it had happened, and responded with vigorous protests against continued experiments. Planetary Technology is proposing to introduce alkaline magnesium hydroxide into the wastewater outlet pipe at the Hayle Wastewater Treatment plant in St Ives Bay, where it would be discharged 2.4 kilometres offshore. The Environment Agency published a pre-trial audit of the proposal in February 2024.

In late 2023, Planetary Technology released up to 300 tonnes of magnesium hydroxide into the Halifax harbour area, Canada. The company now proposes to mix the alkaline substance into an existing water outflow at the Tufts Cove power plant in the Halifax harbour area in 2024. The company raised US\$ 10 million in funding in February 2024.

Planetary Technology Inc also plans to conduct OAE experiments at the mouth of the Elizabeth River in the southern Chesapeake Bay, Virginia, in collaboration with the University of Maryland Center for Environmental Science and the University of Delaware. The publicly-funded experiments will take place at a wastewater treatment plant, where alkaline substances will be added to treated wastewater to enhance the alkalinity of coastal waters. The project also plans to evaluate the feasibility, cost and environmental and biological impacts of various alkaline substances. A one-week trial will take place in the river mouth in 2024, followed by a four-week trial the following year.

LOC-NESS research project: OAE trials off Martha’s Vineyard (USA)

The four-year Locking away Ocean Carbon in the Northeast Shelf and Slope (LOC-NESS) research project, funded by the Additional Ventures Carbon to Sea Initiative, is conducting four open-ocean experiments off the coast of Martha’s Vineyard, an island in the Gulf of Maine, Massachusetts. Alkaline substances are to be released into seawater between summer 2023 and summer 2025.

University of Rhode Island: Coastal alkalinity enhancement at Winnapaug Pond (USA)

The University of Rhode Island and collaborators are planning to conduct an OAE trial at Winnapaug Pond, a shallow salt lake that exchanges water with the ocean, in the southern coastal region of Rhode Island. The goal of the publicly-funded project is to apply alkaline minerals to a coastal zone and study the effects on the coastal environment. Crushed limestone will be applied to a golf course on the shores of the salt lake and inorganic and organic parameters will be measured in the lake’s waters. Researchers will also explore the scalability of the approach (referred to as “terrestrial liming”) in coastal environments along the US East Coast.

Ocean Alk-align Consortium: OAE trial in Kiel Fjord (Canada, Germany)

The Ocean Alk-align Consortium, funded by the Additional Ventures Carbon to Sea Initiative and led by Dalhousie University, Canada, aims to evaluate the efficiency and environmental risks of different alkaline OAE feedstocks through laboratory and open-ocean experiments. The consortium is currently conducting an OAE study in the Kiel Fjord, Germany, in mesocosms, which are large, free-floating test tubes, to investigate the impact of mineral-based OAE on the plankton community and the uptake of CO₂ in seawater.

Equatic (USA, Canada, Singapore): Energy-intensive OAE approach targets lucrative carbon credit sales

The company is commercialising an OAE technology developed at the University of California that requires seawater, air, rock and electricity. Seawater is split into hydrogen and oxygen through electrolysis, and then exposed to ambient air to convert CO₂ into solid calcium carbonate and dissolved bicarbonate. This makes the seawater more acidic, so alkaline rocks are then dissolved in it to restore the pH of the seawater, and the seawater and carbonates are returned to the ocean. Hydrogen is captured as a by-product for use as fuel. Since 2023, Equatic has been testing its technology in Singapore and Los Angeles. A third test site in Quebec, in cooperation with Deep Sky, is in the pipeline. Equatic *“wants to generate tens of millions of dollars in revenue within a few years by selling carbon offset credits to corporate buyers”* and has already signed a pre-purchase agreement for carbon credits with Boeing.

Vesta (USA, Dominican Republic): Ongoing and planned open-air experiments

Vesta is testing and commercialising OAE with crushed olivine, a soft, green volcanic rock, along beaches, in a tidal wetland and in nearshore waters. Ongoing test sites include North Sea Beach on Long Island, east of New York, two bays northwest of Puerto Plata in the Dominican Republic and a tidal wetland in the Herring River estuary on Cape Cod, Massachusetts. Vesta is also preparing to demonstrate OAE in the nearshore waters off Duck, North Carolina, and has announced joint research projects in cooperation with the Canadian Council of The Lakes Region and Great Lakes Dredge & Dock.

In a recent press report, academics questioned Vesta’s approach, including the half-life of olivine dissolution that Vesta used to calculate CO₂ sequestration rates. They also pointed to possible poorly-understood effects of olivine on coastal ecosystems, for example due to the fact that olivine often contains toxic metals such as nickel and chromium. In addition, crushed olivine could affect smaller creatures at the bottom of the food chain by blocking light, with other unintended consequences for marine life.

OAE based on electrochemical processes

SeaO2 (the Netherlands): Electrochemical OAE with CC(U)S

SeaO2’s electrochemical process involves extracting seawater from a depth of 50 to 100 metres. A small amount of this seawater is filtered and passed through a bipolar membrane, splitting it into an acid (HCl) and a base (NaOH). The acid produced is mixed back into the seawater, which lowers its pH and carbon absorption capacity, forcing CO₂ to bubble out of it. This CO₂ is captured, compressed and transported for injection into geological formations or for use in products such as chemicals or fuels. The basic (NaOH) and (now mildly) acidic (HCl) parts of the extracted seawater are mixed with more seawater and returned to the ocean. SeaO2 developed a prototype of its technology and demonstrated it at a laboratory scale in 2023, and is now preparing to build a demonstration plant on the Dutch North Sea coast, probably near its R&D facility in Breezanddijk.

Pronoe (France): Using waste treatment plants to generate carbon credits

Pronoe’s electrochemical process can be applied to water treatment plants or industrial effluents near the coast. The technology produces an alkaline effluent for discharge into coastal waters, and the company is currently in the process of building a laboratory-scale prototype, with the next step being to demonstrate the technology and sell carbon credits.

Capture6 Corp. (USA, South Korea, Australia): OAE with DAC

Capture6 combines OAE with DAC through an electrochemical process that produces a liquid solvent that reacts with atmospheric CO₂ to form an alkaline solution. The company proposes to disperse the alkaline solution into surface ocean waters to increase ocean alkalinity and the ocean’s ability to absorb atmospheric CO₂. The company intends to apply its technology to existing seawater desalination and water purification plants and has announced three demonstration projects. Project Monarch, in Los Angeles County, California, is a collaboration with the Palmdale Water District, and has received US\$ eight million of funding from the California Energy Commission. Project Octopus is a collaboration with K-water and BKT/Tomorrow Water, and will be located at a seawater desalination plant in the Daesan Industrial Complex in South Korea. Project Wallaby is a

collaboration with Pilot Energy Ltd, and will be located in Arrowsmith, Western Australia. In 2023, Capture6 signed pre-purchase agreements for carbon credits with several carbon markets, including Terraset, Respira and Kakao Impact.

Massachusetts Institute of Technology (USA): Electrochemical OAE with multiple applications

The private research university is proposing the coupling of an electrochemical CO₂ removal process with existing infrastructure, such as seawater desalination plants. Other potential applications include ships, which could process seawater while travelling, as well as offshore drilling platforms and aquaculture farms.

Ebb Carbon/PNNL (USA): Selling hydrochloric acid and carbon credits

The company is commercialising an electrochemical OAE process developed as part of the SEA MATE research project. Hydrochloric acid (HCl) is separated from seawater, making it more alkaline, and it is then returned to the ocean to increase atmospheric CO₂ absorption rates. Ebb Carbon plans to sell the HCl as an industrial byproduct and to install its technology in facilities that already treat seawater, such as desalination plants and aquaculture farms. The company has raised over US\$ 20 million in funding and is looking to sell carbon credits, having already made an initial sale to the Stripe carbon market. In 2023, Ebb Carbon partnered with the US Department of Energy's (US-DOE) Pacific Northwest National Laboratory (PNNL) to test its approach at PNNL's marine laboratories in Sequim, Washington. PNNL is also conducting modelling and tank-based laboratory experiments to evaluate OAE as part of the US-DOE SEA-CO₂ programme.

Captura Corp. (USA, Canada, Norway): Electrochemical OAE with CCS

The California Institute of Technology spin-off Captura Corp. is commercialising an electrochemical OAE process which starts with pre-treating seawater to remove dissolved calcium and magnesium, in order to soften it. In the next step, an electrochemical process is used to split some of the softened seawater into an acid (HCl) and a base (NaOH). The pH of the seawater is then lowered with the HCl, and the CO₂ released as a result is captured. Calcium, magnesium and NaOH are then added to the seawater to neutralise its acidity and it is returned to the ocean. The captured CO₂ is to be injected into geological formations in collaboration with partners such as the Norwegian Northern Lights CCS project.

Captura is currently running two pilot projects in California, at the Kerckhoff Marine Lab in Newport Beach, and at AltaSea at the Port of Los Angeles, San Pedro. Captura's third pilot will take place in Quebec, Canada, in partnership with Deep Sky in 2024. For the fourth pilot, Captura has partnered with Equinor and plans to install a unit at Equinor's Kårstø natural gas processing plant in Norway. In its latest funding round in early 2024 Captura raised US\$ 21.5 million.

OAE based on photochemical processes

Banyu Carbon Inc. (USA): Using a photoacid to extract carbon from seawater

This process uses sunlight to activate a synthetic molecule (called a photoacid) that becomes acidic in sunlight and reverts to its original neutral form in the dark. When the molecule comes into contact with seawater, its acidity causes the release of dissolved CO₂. The decarbonised seawater is then returned to the ocean. The company proposes to use the captured CO₂ as a feedstock for industry (CCUS) or for injection into geological formations (CCS). The composition and toxicity of the photoacid has not yet been revealed, but according to Banyu Carbon it is capable of switching between neutral and acidic states 14,000 times before it loses its effectiveness. The approach is based on technology developed and patented at the University of Washington, where the company is based. Banyu Carbon developed a prototype of the technology in 2023, and plans to implement a pilot project in 2024 and a demonstration project in 2026. It also has a contract with the Frontier carbon market for over 360 tonnes of CO₂.