

Deep Ocean Climate Intervention Impacts Ocean Alkalinity Enhancement

The Concept:

The ocean contains 50 times as much carbon as the atmosphere and acts as a natural thermostat. Based on natural weathering that occurs on geological time scales, ocean alkalinity enhancement is intended to speed the process of removing CO₂ from the atmosphere and reducing ocean acidification by increasing seawater alkalinity, the capacity of a solution to neutralize acid. This approach transforms CO₂ into bicarbonate (HCO₃⁻), carbonate (CO₃²⁻) and to a much smaller extent hydroxide (OH⁻) anions. The former are charge balanced by cations other than H⁺ (GESAMP, 2019), increasing pH and causing more drawdown of CO₂ from the atmosphere (Gagern et al., 2019; Fig. 2; NASEM, 2021; Fig. 1). Ocean alkalinity enhancement aims to increase the alkalinity of the oceans by either:

- adding calcium carbonate (CaCO₃) to the ocean from limestone rocks (Renforth and Henderson, 2017); calcium silicates (Ca₂O₄Si) from rocks, construction waste or desalination waste, slaked lime (calcium hydroxide Ca(OH)₂; e.g., Caserini et al., 2021; Butenschön et al., 2021) as well as magnesium hydroxide (Mg(OH)₂) (Ocean Visions Road Map - <https://www2.oceanvisions.org/roadmaps/ocean-alkalinity-enhancement/>) or
- using electrochemistry - technologies for carbon dioxide removal from seawater, sometimes called “direct ocean capture” (House et al., 2007; Rau, 2008; Rau et al., 2013; Lu et al., 2015; La Plante et al., 2021). These techniques capture and remove dissolved inorganic carbon from seawater (either as CO₂ gas or as calcium carbonate), and/or produce a CO₂-reactive chemical base, e.g., sodium hydroxide (NaOH), that can be distributed in the surface ocean to ultimately consume atmospheric CO₂ and convert it to long-lived, dissolved, alkaline bicarbonate (Ocean Visions Road Map - <https://www2.oceanvisions.org/roadmaps/electrochemical-cdr/>).

Alkalinity enhancement approaches will likely start in coastal areas more affected with ocean acidification, and will capture and store carbon dioxide predominantly in the form of bicarbonate. This will result in increases in pH and alkalinity as well as the aragonite saturation state.

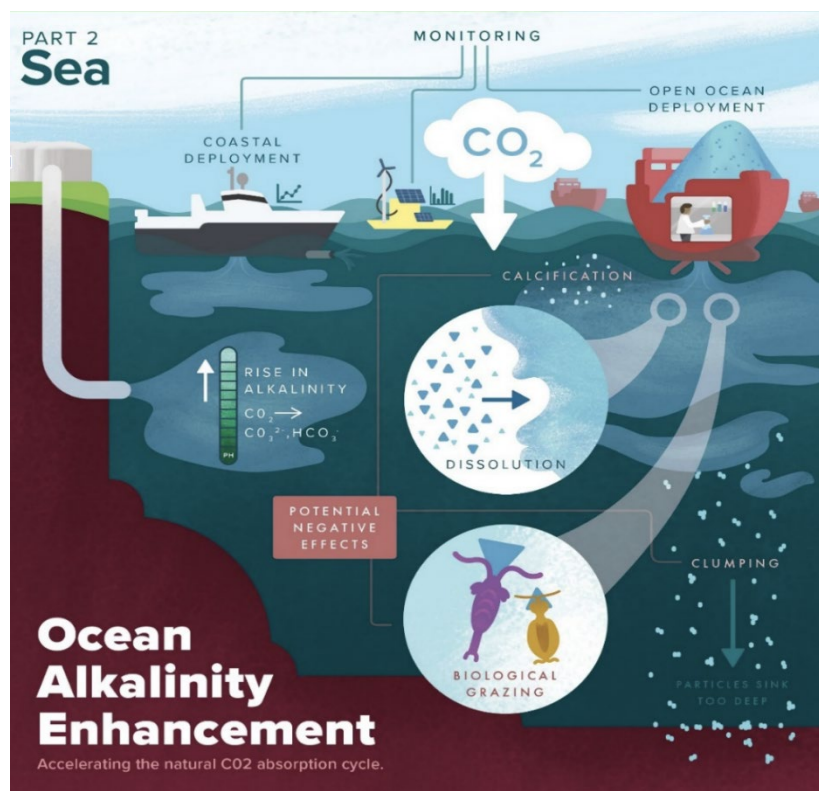


Fig. 1. Approach and impact of ocean alkalinity addition. From NASEM, 2021

Key Points

- Using silicate or carbonate minerals to achieve gigatonne scale CO₂ removal would require very large quantities of these materials to be mined, crushed and distributed across the ocean.
- While mineral-induced changes in the form and flux of surface production might be reflected at the deep-sea floor, effects on the deep sea would mainly be in the long-term due to the ocean overturning circulation unless materials were directly placed in the deep sea. However, deep-sea biota that have near-surface-dwelling larval stages could be adversely affected.
- The environmental effects of electrochemical alkalization techniques on the deep sea is unclear except where acid material would be discharged directly into the deep sea. This could result in potential lethal and sub-lethal effects on organisms close to the discharge zone.
- Deposition of alkaline material into the ocean could be governed by the London Protocol.

Deep-sea Impacts

There are a limited number of papers on the potential impact of ocean alkalinity enhancement (e.g., Gim et al., 2018, Bach et al., 2019, Gore et al., 2019 and Ferderer et al., 2022). There have been a few small-scale or mesocosm studies (e.g., Albright et al., 2016, 2018) including on-going studies under the CDRmare research project in Germany (<https://cdrmare.de/en/>) and the recently initiated RECAP project (<https://www.cima.ualg.pt/en/research/projects-in-execution/recap>).

If conducted at a large scale or near a conduit to the deep ocean such as canyons, ocean alkalinity enhancement will increase the alkalinity of the deep ocean in the long-term due to cascading or overturning ocean circulation. The potential for sedimentation of the particulate alkaline material sinking to the deep sea may be a relatively minor issue as these materials would be designed to dissolve in the surface mixed layer in order to have the effect of drawing down CO₂ from the atmosphere (e.g., Caserini et al., 2021). However aggregation and export to deep water could occur. If silicate materials are used, they may release associated trace elements (e.g., cadmium, nickel, chromium) that could be harmful to the biota (Bach et al., 2019) and, depending on the scale of the activity and location, these could end up in deeper waters, and affect deep-sea biota.

Increased pH resulting from artificial ocean alkalinity enhancement experiments or implementations may only have a short-term and localized effect in surface waters due to dilution and dispersion, and so will be unlikely to affect the deep sea. Introduced particles that may partly sink to the deep sea may be consumed by biota and may also provide substrate for attached

microbes, resulting in potential change in microbial concentrations and composition in the deep water column or on the deep-sea floor and eventually changing POC flux to deeper waters. However, there are currently no studies on the potential impact of artificial ocean alkalinity enhancement in the deep sea. There is a recent proposal for a technique for enhancing surface ocean alkalinity by electrochemical means that would affect the deep ocean as it involves discharging the acid component from the procedure into the deep ocean (Tyka et al., 2022) with potential deleterious effects on calcified organisms and seafloor biota. However, there is no indication at present that this concept is under active development.

Depending on minerals used (silica-rich olivine or carbonate-rich quicklime), alkalinity enhancement could modify the relative representation of siliceous (e.g., diatoms) and calcareous plankton (e.g., coccoliths) in surface waters (Bach et al., 2019), altering the amount and composition of organic matter flux to the seafloor and its seasonality, potentially affecting the food supply to the deep-sea benthos and consequently their faunal composition and diversity (Nomaki et al., 2021). Some deep-sea biota, such as bivalve molluscs from methane seeps, have larval stages that develop in surface waters (e.g., Arellano et al., 2014) and they would potentially be affected by ocean alkalization activities alongside biota that live in surface waters permanently. These larvae may experience changes in light, primary productivity, suspended particles and metal exposure with as yet unknown consequences to their ability to function and survive.

Scaling Up and Effectiveness

Effective massive dumping of alkaline rock material into the ocean would be required to achieve significant CO₂ removal. Feng et al. (2016) estimate that the regional addition of 1-10 Gt of lime per year may be able to reverse pH decline in the Great Barrier Reef, Caribbean Sea, or South China Sea. Feng et al. (2017) modeled coastal alkalinization in ice-free waters of the global ocean and their results indicated that with a large-scale deployment of 10-µm particles, atmospheric CO₂ could be reduced by more than 800 Gt by 2100. Paquay and Zeebe (2013) assess the alkalinity requirements on a global level and estimate that an annual input of 5-26 Gt of lime would be required to keep ocean surface pH above 8.0. The effects of mining this much alkaline rock material on the land would be massive, as would the logistics of distributing it across the oceans. Careful selection of discharge methods and rates (e.g., Caserini et al., 2021) and monitoring of areas receiving alkaline material would be required to avoid excessive dosing that could lead to pH and alkalinity above the desired range. An evaluation of global capacity of electrochemical techniques suggested that 100's of Gt CO₂ removal and 1000's of EJ of energy generation per year might be technically possible (Rau et al., 2018).

Governance

Ocean depositions for the purpose of marine geoengineering are proposed to be governed under the London Dumping Protocol, an international treaty which was amended to provide a permitting mechanism for enumerated forms of marine geoengineering research. The London Protocol Parties could add alkalinity enhancement to the new Annex 4 of the 2013 London Protocol amendments that could permit their regulation, in a manner similar to ocean fertilization (Ginzky and Frost, 2014; Ginzky, 2018; GESAMP, 2019).

The amendments to the Protocol have yet to enter into force. The US is not a party to the London Protocol but is a party to the London Dumping Convention. Some countries are not party to either.

Where materials are deposited within national jurisdiction or from vessels flagged to the state, or where material is loaded in the state, each state's designated regulatory body for the London Convention/London Protocol (the Environmental Protection Agency in the US) would be responsible for permitting such activities. Note that the London Convention/ London Protocol covers all waters up to the baselines used to measure the territorial sea and the EEZ. For activities under US jurisdiction, the London Convention is implemented through the Marine Protection, Research and Sanctuaries Act (MPRSA). While a proposed biodiversity treaty under negotiation at the United Nations (International Legally Binding Instrument on Marine Biodiversity of Areas Beyond National Jurisdiction) may influence the details of EIAs for such activities, the proposed treaty is not supposed to override existing institutions' powers e.g., the London Convention/London Protocol.

Exploratory Practitioners and Research

Groups exploring ocean alkalinity include: Planetary Hydrogen – <https://www.planetaryhydrogen.com/>, OceanNETs (<https://www.oceannets.eu/>), Project Vesta (<https://www.projectvesta.org/>), SEA MATE (<https://www.oceanvisions.org/post/ocean-visions-to-advise-and-evaluate-innovation-in-electrochemical-carbon-dioxide-removal>), Cquestr8 (<https://cquestr8.com/>), SeaQuesterTM (<http://www.prdd.net/> and <http://www.prdd.net/co2-capture-repurpose.html>), Additional Ventures (<https://www.additionalventures.org/>) and SeaChange (<https://pubs.acs.org/doi/10.1021/acssuschemeng.0c08561> and <https://www.gaiadiscovery.com/planet/sea-change-s1million-prize>)

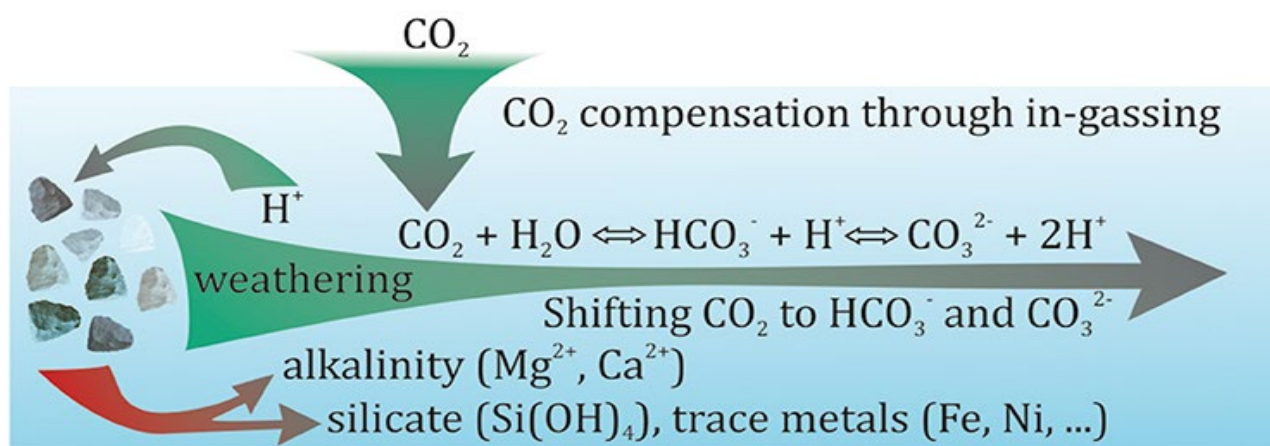


Fig. 2. Depiction of how alkalinity carbon dioxide removal works. When relevant minerals (e.g., quicklime or olivine) dissolve they consume protons, which shifts the carbonate chemistry equilibrium away from CO₂ to HCO₃⁻ and CO₃²⁻. Additional CO₂ can subsequently be absorbed by the aqueous media because the shift can cause CO₂ undersaturation relative to the surrounding atmosphere. From Bach et al., 2019

ABOUT DOSI

The Deep-Ocean Stewardship Initiative seeks to integrate science, technology, policy, law and economics to advise on ecosystem-based management of resource use in the deep ocean and strategies to maintain the integrity of deep-ocean ecosystems within and beyond national jurisdiction.

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