OCEAN ALKALINIZATION

WHAT IS OCEAN ALKALINIZATION?

Ocean alkalinization is an approach to carbon removal that involves adding alkaline substances to seawater to enhance the ocean's natural carbon sink. These substances could include minerals, such as olivine, or artificial substances, such as lime or some industrial byproducts. Adding alkalinity to the ocean removes carbon dioxide (CO_2) from the atmosphere through a series of reactions that convert dissolved CO_2 into stable bicarbonate and carbonate molecules, which in turn causes the ocean to absorb more CO_2 from the air to restore equilibrium.

There are several ways to add alkalinity to the ocean. These include spreading finely ground alkaline substances over the open ocean, depositing alkaline sand or gravel on beaches or coastal seabeds, and reacting seawater with alkaline minerals inside specialized fuel cells before releasing it back into the ocean.

CO-BENEFITS AND CONCERNS

+ **Countering ocean acidification:** ocean alkalinization would directly counteract ocean acidification, protecting marine ecosystems.

+ **Co-production of hydrogen:** some "electrochemical weathering" methods, which use fuel cells to enhance alkalinity, would produce hydrogen, which could be used for energy.

± **Ocean fertilization:** using silicate minerals like olivine would release iron and silica, which could fertilize oceans; this might remove CO_2 but would have uncertain and controversial impacts.

− **Possible biogeochemical side effects:** other effects on ocean chemistry and marine ecosystems, especially local effects, remain uncertain.

− **Trace metals:** many alkaline materials contain small amounts of heavy metals that could accumulate in marine food chains.

− **Concerns associated with mining:** most approaches to ocean alkalinization require extensive mining and processing of raw materials, which raises local environmental and health concerns.

− **Energy use:** most approaches require large amounts of energy (e.g., for grinding rocks).

POTENTIAL SCALE AND COSTS

The oceans already hold roughly 38,000 billion tons of carbon; their capacity to store additional carbon is, for practical purposes, unlimited. In theory, ocean alkalinization could remove **many billions of tons of CO_2 per year**, limited mainly by the extraction, processing, and application of alkaline substances: each ton of removal through ocean alkalinization requires processing roughly 1–3.5 tons of material. Cost estimates vary for different approaches. **Estimated costs for the various methods, while highly uncertain, generally range from $70–160 per ton of CO_2**, but net costs may be as low as $3 per ton for methods that produce hydrogen as a byproduct.

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TECHNOLOGICAL READINESS

Although the basic chemistry of ocean alkalinization is well understood and the individual components of most approaches are well developed, **ocean alkalinization itself remains in the early stages of research and development**. That is, the technologies to extract, process, and transport minerals are all mature, but research on ocean alkalinization remains mostly at the level of theoretical work and laboratory experiments, with a few coastal experiments in development. Much research remains to be done to assess the efficacy and side effects of various approaches.

GOVERNANCE CONSIDERATIONS

- □ **Promoting research and development:** in the near term, research and development are needed to assess the viability, acceptability, and sustainability of various approaches.
- □ **Complex regulatory environment:** activities in international waters operate under a complex web of legal institutions, including the UN Convention on the Law of the Sea, the London Convention/London Protocol, and national legislation.
- □ **Ensuring environmental and social sustainability:** policies are needed to ensure the environmental and social sustainability of mining, processing, transport, and application of minerals across complex supply chains.
- □ For **cross-cutting considerations,** see the What Is Carbon Removal? fact sheet on our website.

FURTHER READING

Renforth, P. & G. Henderson. 2017. "Assessing Ocean Alkalinity for Carbon Sequestration," *Reviews of Geophysics* 55: 636–74, doi 10.1002/2016rg000533.

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Meysman, F.J.R. & F. Montserrat. 2017. "Negative CO_2 Emissions via Enhanced Silicate Weathering in Coastal Environments." *Biology Letters* 13: 20160905. doi 10.1098/rsbl.2016.0905.

Rau, G.H., H.D. Willauer & Z.J. Ren. 2018. "The Global Potential for Converting Renewable Electricity to Negative-CO_2-Emissions Hydrogen." *Nature Climate Change* 8: 621–25. doi 10.1038/s41558-018-0203-0.

Renforth, P., B.G. Jenkins & T. Kruger. 2013. "Engineering Challenges of Ocean Liming." *Energy* 60: 442–52. doi 10.1016/j.energy.2013.08.006.

For more fact sheets on carbon removal, visit https://carbonremoval.info/factsheets.

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