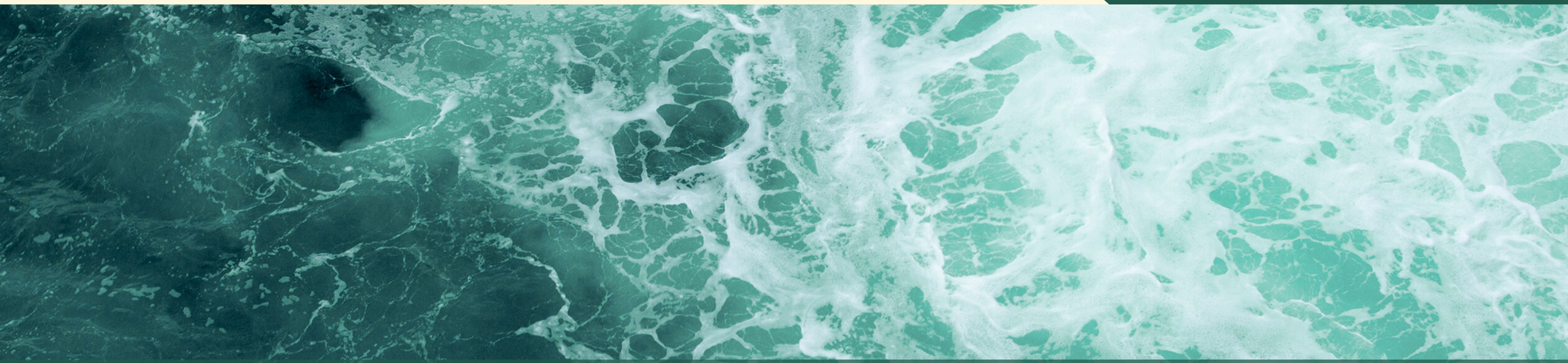

Ocean Alkalinity Enhancement

The ocean is the biggest natural carbon reservoir, holding most of the carbon on Earth (about 90%) in the form of dissolved carbon dioxide (CO_2), organic matter and deep-sea sediments. The rest of the carbon is mainly stored in vegetation and soils, with a small but impactful amount found in the atmosphere as CO_2 and methane.

At least 25% of the CO_2 that humans emit into the atmosphere is absorbed by the ocean every year, as the Earth system attempts to return to equilibrium. Another quarter is taken up by land and the remaining stays in the atmosphere.

The emitted CO_2 is initially absorbed by the ocean's surface and then transported to the deep ocean, where it is stored for centuries, even millennia. Thus, the ocean is crucial in mitigating climate change.

Through a series of chemical reactions, CO_2 dissolves in seawater to form carbonic acid, which then breaks down into bicarbonate and carbonate ions. When the carbonic acid breaks down, it releases hydrogen ions (H+), **causing the water to become more acidic** (i.e. its pH decreases).

This **ocean acidification** affects the life of marine animals, for example by preventing them from forming their shells, disrupting the food chain, and impacting coral reefs.

Furthermore, this increased seawater acidity reduces the amount of carbonate ions available, which help turn CO_2 in the water into a more stable form. **The ocean's ability to absorb more CO_2 from the atmosphere is thus decreasing over time**, as it is proportional to the amount of carbonate ions in seawater. If this acidification continues, it could also accelerate climate change by triggering certain feedback loops.

Carbon dioxide removal (CDR) technologies have the potential to remove and store part of the emitted CO_2. These have traditionally focused on land-based approaches (e.g. afforestation). However, the ocean has the potential to absorb and store even larger amounts of carbon given the right conditions.

Many promising ocean-based CDR approaches are currently explored, such as **ocean alkalinity enhancement** (that we explore in this classroom), blue carbon enhancement and artificial upwelling.

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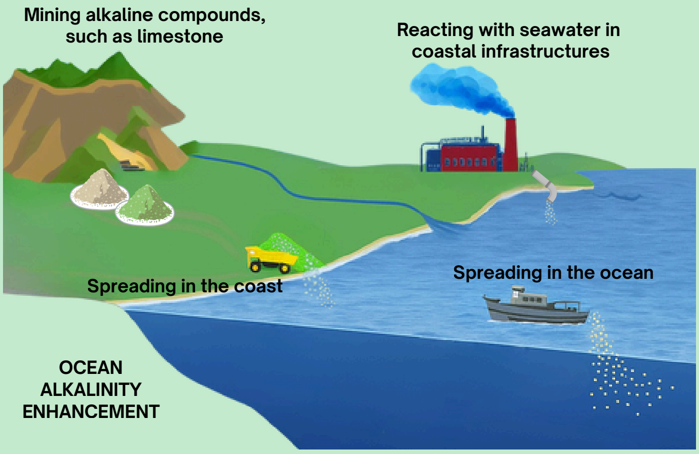
RESCUE

Ocean Alkalinity Enhancement (OAE) is a CDR technique that involves increasing the ocean's alkalinity to enhance its capacity to absorb and store CO_2 from the atmosphere.



How does OAE work?

Natural processes exist that increase the alkalinity of the ocean (i.e. increase the pH) and enhance its ability to take up CO_2. This happens through the natural weathering of minerals and rocks, and run off into the ocean. However, this is a very slow process, which OAE aims to accelerate.

OAE involves adding **alkaline substances added to the ocean**, such as limestone (carbonate rock), olivine (silicate rock) or basalt (volcanic rock). A range of methods are used to increase the alkalinity. For instance, finely ground alkaline substances can be spread on the surface ocean or deposited in coastal areas. Another method involves allowing seawater to react with alkaline minerals in coastal infrastructures, and then releasing it back into the ocean.

As the ocean water becomes more alkaline, it can hold more CO_2 by converting it into stable bicarbonate and carbonate forms. This creates a CO_2 deficit in surface waters. To restore balance, more CO_2 is absorbed from the air and stored in the ocean, decreasing the CO_2 concentration in the atmosphere.

Impacts & challenges of OAE

OAE is a promising CDR solution, as it could increase the uptake and storage of CO_2 in the ocean for long periods of time. At the same time, it could also potentially reduce ocean acidification and its impacts on marine organisms.

Nevertheless, further research is needed to better understand the effects of OAE on the Earth system, climate and marine ecosystems before it can be deployed at a large scale.

In addition, OAE is currently an expensive, energy-intensive technology. Mining, grinding and transporting the alkaline substances come with their own emissions and impact. Thus, its widespread use is currently limited.

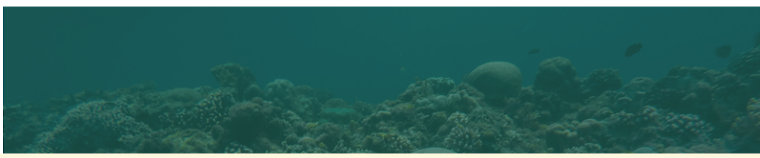
OAE in RESCUE

RESCUE is a European project investigating a number of CDR portfolios within climate neutrality scenarios. OAE is one of the main CDR methods investigated in RESCUE.

In the RESCUE scenarios, OAE is implemented through the onshore production of quicklime (CaO), derived from naturally occurring limestone ($CaCO_3$) using calciners. All the CO_2 that is generated by CaO production is captured, to avoid additional emissions.

The amount of OAE technology that could be potentially deployed in different regions is determined by Integrated Assessment Models (IAMs), based on countries' gross domestic product (GDP), and alkalinity is distributed across countries' exclusive economic zones (EEZs) via ships.

The same IAM-derived allocation of OAE is applied in Earth System Models (ESMs) in RESCUE, but with enhanced resolution of ocean biogeochemical feedbacks that are not fully captured by IAMs.



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