Chemical methods

Minerals for enhanced carbon dioxide uptake by the ocean

The amount of carbon dioxide that the ocean can absorb without becoming highly acidic depends on the alkalinity of its surface water. This term refers to the amount of acid-binding mineral components of mineral origin that were previously dissolved from weathered rock and washed into the ocean. The question now is: could a targeted input of such minerals help to increase the marine carbon dioxide uptake without unbalancing the chemistry and life in the ocean? This approach does work in simple model calculations. However, field experiments are still lacking, as are realistic simulations and detailed knowledge about the consequences and risks of an increase in alkalinity. The research mission CDRmare investigates the potentials, feasibility and side effects of the various methods.

The big climate goal: a net zero of carbon dioxide emissions

> Even with an ambitious climate policy, Germany is still expected to release **10 to 20 per cent** of its current greenhouse gas emissions in three decades, further driving climate change. One possible way out: **offset the remaining emissions** – for example by increasing carbon dioxide uptake and storage by the ocean.

> There is a constant exchange of carbon dioxide between the ocean surface and the atmosphere, which equalises any pressure differences between the carbon dioxide dissolved in the seawater and the carbon dioxide in the atmosphere. If the carbon dioxide concentration in the atmosphere increases, the ocean also absorbs more carbon dioxide.

> In recent decades, the **world ocean** has absorbed about 25 per cent of anthropogenic carbon dioxide emissions from the atmosphere, thus significantly **slowing down global warming**.

The laws of marine chemistry

> When carbon dioxide dissolves in seawater, some of the gas undergoes a **series of chemical reactions** during which it is chemically bound as hydrogen carbonate so that the ocean can absorb new carbon dioxide. However, this reaction chain also releases protons that **acidify the ocean**. The extent to which this happens depends on the amount of acid-binding minerals in solution in the

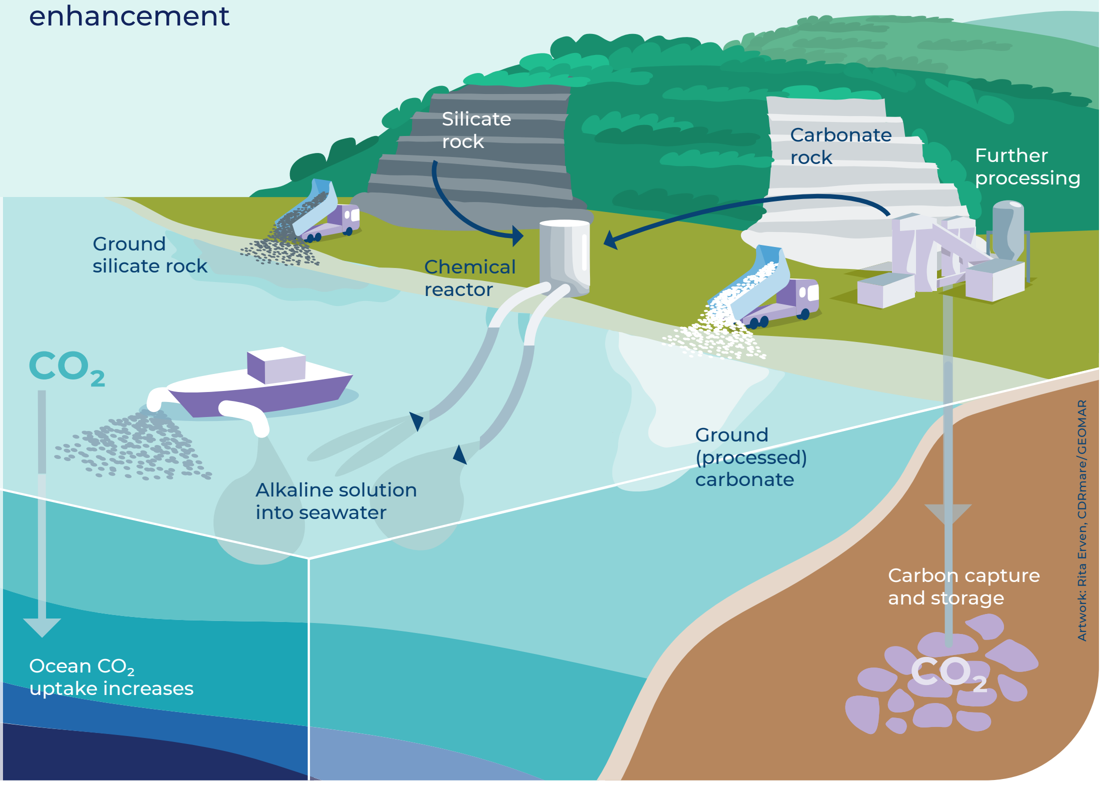
Costs: Estimates range from **US$40 to US$260 per tonne of carbon dioxide**

Scalability: **Carbon dioxide extraction on an industrial scale is theoretically possible.**

Duration of storage: **Many hundreds to hundreds of thousands of years**

Technical state of development: For the ocean, the method has so far **only been simulated in computer models and tested in individual laboratory experiments**. Extensive **laboratory and field tests** as well as **knowledge on risks and side effects for humans and the environment are lacking.**

Marine alkalinity enhancement



water, which were previously dissolved from weathered rock and washed into the ocean. Experts speak of the degree of alkalinity as a measure of the **acid-binding capacity** of seawater.

> Rock weathering on land and the subsequent storage of the acid-binding solution products in the ocean are comparatively slow natural processes. Nevertheless, they remove about **1 billion tonnes of carbon dioxide** from the atmosphere annually. On a long-term average, this amount corresponds roughly to the amount of carbon dioxide that enters the atmosphere through volcanic activity and mineralisation processes in the Earth's mantle and in the ocean.

> In order to fully compensate for man-made residual emissions from 2050 onwards, the **ocean's natural carbon uptake would have to increase fivefold**.

The idea: an acceleration of natural weathering

> According to modelling studies, an increase in oceanic carbon uptake would be entirely possible if mankind were to accelerate the natural weathering of mineral-bearing rocks and deliberately increase the alkalinity of seawater.

> Such an intervention in ocean chemistry would have the advantage that **the ocean could absorb more carbon dioxide without acidifying**. At the same time, an increase in alkalinity in highly acidified ocean regions would lead to free protons being bound, thereby decreasing their acidifying effect. This in turn would facilitate the **protection and restoration** of coral reefs, mussel beds and other important marine habitats.

Alkalinity enhancement: A method in its infancy

> **Various processes** are currently being developed that could accelerate the natural weathering of mineral-bearing rocks and increase the alkalinity of seawater.

> However, most knowledge about the chemical and biological consequences of alkalinity enhancement has so far come from model studies (computer simulations). **Conclusive laboratory or field studies** on local, regional and global impacts of industrial-scale mineral inputs on the environment and humans are **still largely lacking**.

> It is also not clear in which marine regions the appropriate techniques would have to be used in order to achieve the greatest possible benefit and whether alkalinity enhancement methods are ultimately more effective and expedient than other marine or land-based processes that increase carbon dioxide removal from the atmosphere.

CDRmare provides answers

> In the interdisciplinary research mission CDRmare, scientists for the first time comprehensively investigate the **carbon dioxide removal potential, feasibility and possible ecological and social side effects** of the various methods of marine alkalinity enhancement.

> They combine local laboratory and mesocosm experiments with model studies for selected regions as well as the world ocean. They review the legal framework, consider social aspects and the compatibility of a deployment with the UN's sustainability goals, and analyse whether the benefits that might be achieved could justify the effort, the costs and any environmental impacts that might arise.

> They also address the question of how permanent an ocean carbon dioxide removal achieved through alkalinity enhancement would be and how it could be measured, monitored and attributed to specific measures.

> Its aim is to provide policy-makers and society with **scientifically sound information** on whether and in what form marine alkalinity enhancement can be a viable method to permanently remove significant amounts of carbon dioxide from the atmosphere in an environmentally safe and socially responsible manner.

All research activities described here are carried out within the CDRmare consortium »RETAKE – CO_2 removal by alkalinity enhancement: potential, benefits and risks«.

RETAKE retake.cdrmare.de

twitter.com/cdrmare

linkedin.com/company/cdrmare/

CDRmare Knowledge Transfer
transfer@cdrmare.de

DAM GERMAN MARINE RESEARCH ALLIANCE

SPONSORED BY THE Federal Ministry of Education and Research

IMPRINT GEOMAR Helmholtz Centre for Ocean Research Kiel // Wischhofstr. 1-3 // 24148 Kiel // Germany // **Responsible for content:** Andreas Oschlies, Gregor Rehder, Achim Kopf, Ulf Riebesell, Klaus Wallmann, Martin Zimmer // **Editorial office:** Ulrike Bernitt (ubernitt@geomar.de) // **Text:** Sina Löschke (schneehohl.net) // **Design:** Rita Erven // **Translation:** Anja Wenzel // June 2023