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Developing Direct Ocean Capture (DOC) for a Net-Zero Future

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Outline

- Global demand for DOC in a net-zero future
- Direct Ocean Capture (DOC) fundamentals
- VTT and Mitsubishi Electric’s rapid development and scale-up efforts for DOC

Global demand for DOC in a net-zero future

A 1.5 °C pathway is virtually impossible to reach with mitigation efforts alone

Since the 1850s, we've emitted 1.6 trillion tons of CO_2, driving up atmospheric concentrations, warming the planet, acidifying the oceans, and disrupting the climate system. According to IPCC models, limiting warming to 1.5 °C will require carbon dioxide removal (CDR) of 100–1000 Gt of CO_2 from the atmosphere by the end of the century.

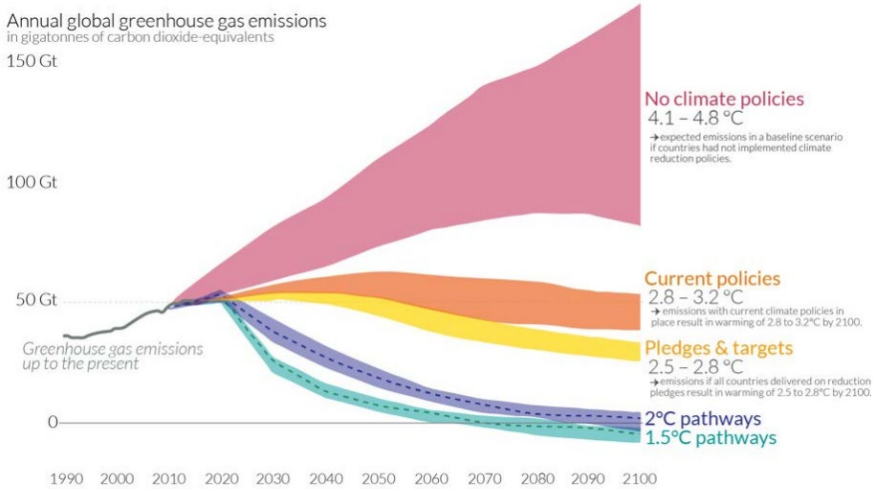


Figure 1: Global GHG emissions and warming scenarios.
Source: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

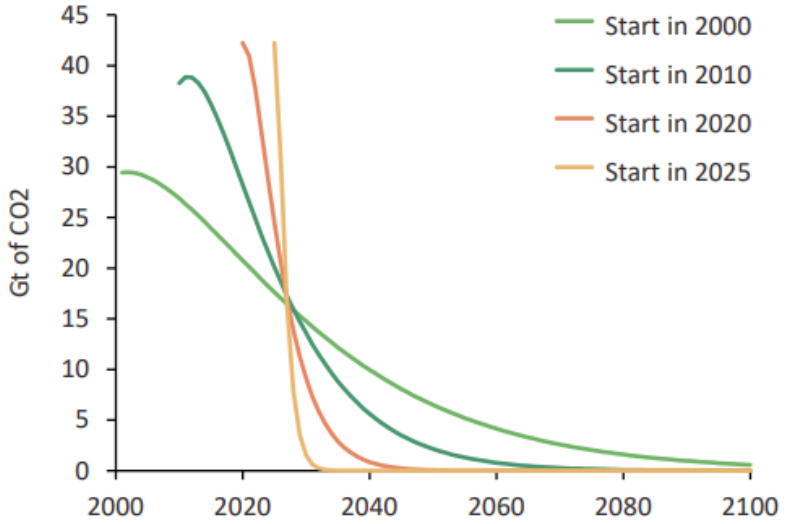


Figure 2: CO_2 reductions needed to keep temperature rise below 1.5 °C by 2100.
Source: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

There is no single silver bullet for CDR, and land-based methods alone may be infeasible at the required scale

- Removing hundreds of billions of tons of CO_2 from the atmosphere is an enormous challenge.
- Commonly discussed CDR approaches include direct air capture (DAC), bioenergy with carbon capture and storage (BECCS), reforestation and afforestation, and agricultural practices that enhance the burial of organic carbon.
- While these methods hold significant promise, their rapid scale-up faces critical barriers such as high costs, substantial energy demands, limited biomass availability, and land and water use constraints.

The **ocean** cannot be overlooked given its role as one of Earth's largest carbon sinks. Utilizing the ocean for CDR offers several key advantages:

1. Vast, virtually unlimited CO_2 storage capacity
2. No competition with land-based uses
3. Leverages and enhances natural oceanic carbon sequestration processes
4. Some methods can counteract ocean acidification

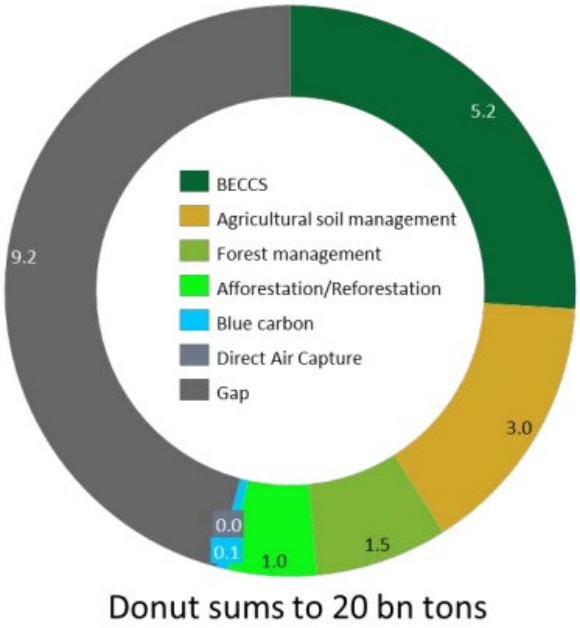


Figure 1: Estimated CO_2 removal potential based on current technologies and scientific understanding.

Sources: NASEM 2019. The National Academies Press. https://doi.org/10.17226/25259; https://physicsworld.com/a/carbon-removal-requires-multiple-technologies/

Direct ocean capture (DOC) fundamentals

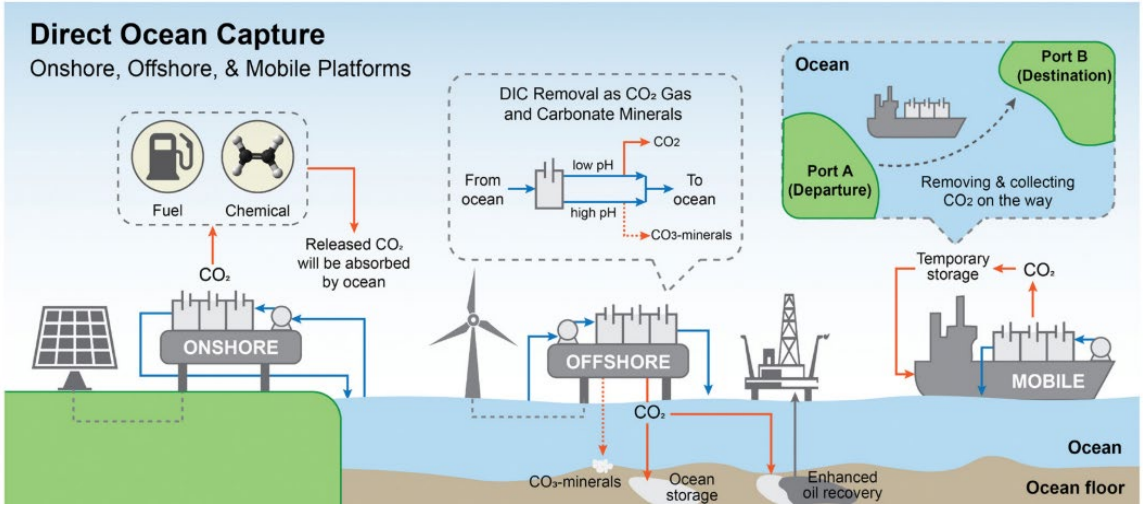
Direct Ocean Capture (DOC)

Oceans serve as a natural carbon sink, currently storing 38,000 Gt C (vs. 860 Gt C in the atmosphere)

~25% (~9 Gt) of antrophogenic CO_2 is absorbed into oceans each year

Oceans contain 130 times more CO_2 than the atmosphere (on mass/volume basis)

Increased CO_2 levels decrease ocean pH, causing acidification



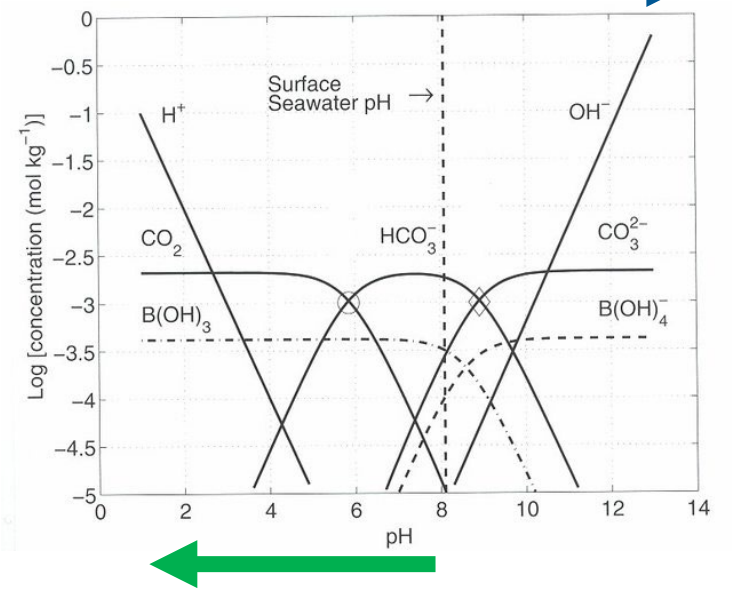
Source: Aleta et al., (2023), *Energy Environ. Sci.*, 16, 4944

DOC is an emerging negative emissions technology (NET) that removes CO_2 directly from seawater using electrochemical methods. By splitting water (H_2O) with an electric current, these systems generate acidic (H^+-rich) and alkaline (OH^--rich) effluent streams to alter seawater pH. Depending on the process design, CO_2 can be extracted either in gaseous form or as solid mineral carbonates. DOC is still in the early stages of development, with several companies and research institutions actively piloting technologies and exploring various implementation pathways.

Operating through electrochemical processes powered by green electricity rather than fossil heat, DOC offers advantages for sustainable integration into existing infrastructure and scalable deployment. However, significant challenges remain, including the need to reduce costs, improve energy efficiency, and address practical barriers to widespread adoption. If successfully scaled, DOC could contribute meaningfully to global net-zero targets and climate mitigation efforts.

DOC: Two fundamental routes

Natural ocean action
(absorbs CO_2)



"Base-DOC" via alkalinization

- Increase the pH of seawater
- Enable controlled release of pre-absorbed CO_2 through mineral precipitation in solid form

Both routes rely on an electrochemical system to induce a **"pH swing"**

"Acid-DOC" via acidification

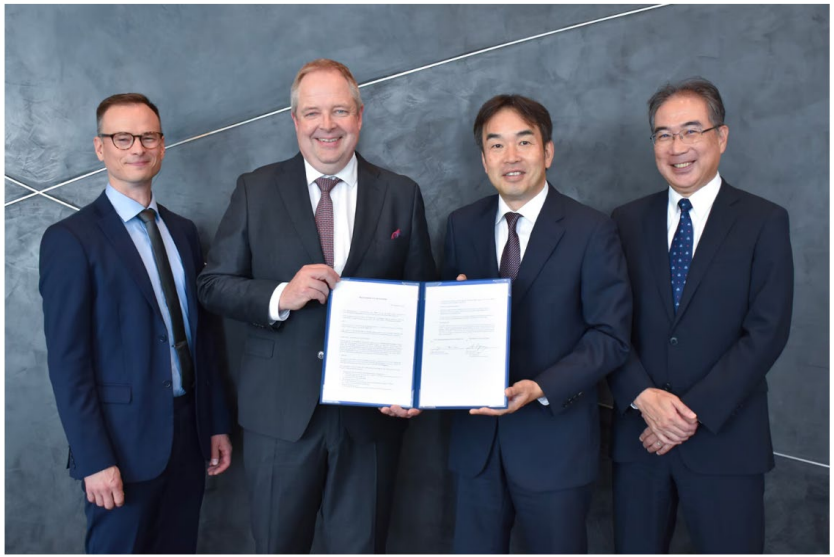
- Lower the pH of seawater
- Enable controlled release of pre-absorbed CO_2 as gaseous CO_2, e.g., through a membrane contactor

VTT and Mitsubishi Electric's rapid development and scale-up efforts for DOC

News

Mitsubishi Electric and VTT of Finland to Develop Technology for Direct Capturing of CO2 from Oceans

Direct-ocean-capture technology will contribute to nature-positive initiatives



From left: DSc Antti Arasto, Vice President, VTT; PhD Jussi Manninen, Executive Vice President, VTT; Seiji Oguro, Executive Officer and Vice President, Sustainability Innovation Group, Mitsubishi Electric; Akihiko Watanabe, Deputy Vice President, Sustainability Innovation Group, Mitsubishi Electric.

- VTT and Mitsubishi Electric Corporation have signed a memorandum of understanding (MOU) to initiate a long-term research collaboration aimed at developing *nature-positive technologies* to address global challenges in marine ecosystems.
- The collaborative DOC R&D project aims to accelerate the commercialization through piloting and demonstration of the technology.
- Further information from this project will be shared as results become available.

Thank you for your attention!