



Editorial: The Role of Ocean-Based Negative Emission Technologies for Climate Mitigation

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Editorial on the Research Topic

The Role of Ocean-Based Negative Emission Technologies for Climate Mitigation

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Mitigating climate change is a massive challenge. Atmospheric carbon dioxide removal (CDR) with negative emission technologies (NETs) is now widely considered a necessary additional action since traditional mitigation measures, such as limiting the use of fossil fuels, have had limited success (Intergovernmental Panel on Climate Change, 2018, United Nations Environment Programme, 2020). Until now, the majority of NETs research and development has focused on land-based options such as bioenergy with carbon capture and storage (BECCS). However, ocean-based NETs can potentially also play a significant CDR role.

Like their terrestrial counterparts, ocean-based NETs seek to accelerate the uptake of atmospheric CO₂ by enhancing natural sinks or by engineering the removal and storage of CO₂. Currently there are too many knowledge gaps to fully assess the potential, effectiveness, efficiency, risks and co-benefits, and economic costs of most approaches. Key elements to facilitate responsible R&D are also lacking, including governance and public acceptance (GESAMP, 2019). The purpose of this topic is to examine ocean-based NETs and the challenges associated with them from a multidisciplinary perspective.

Gattuso et al. introduce an assessment framework for ocean-based NETs in which different criteria are used to group different technologies into three policy clusters: (i) Decisive, (ii) Low Regret, and (iii) Concept Stage. They apply the assessment framework to marine BECCS, restoring and increasing coastal vegetation, enhancing open-ocean productivity, and enhancing weathering and alkalization, comparing these ocean NETs to other (ocean-based) measures. According to their assessment, restoring and increasing coastal vegetation would be a “Low Regret” measure while the other measures are still in the “Concept Stage.” Preliminary application of the framework suggests that ocean-based NETs should be scaled up by prioritizing the implementation of Decisive and Low Regret measures, and urgently improving knowledge on Concept Stage measures.

Cox et al. discuss the importance of public perceptions, decision-making, and the role of discourse for the assessment of ocean-based NETs. They argue that ocean-based NETs will generally face greater public acceptability challenges than terrestrial NETs. In this context, they utilize public acceptability studies on Ocean Iron Fertilization, the only thoroughly investigated open ocean NET, to ask whether further research into iron fertilization is necessary because it is unlikely to ever receive social license. The question added by the Editors is: Will less well-understood methods such as Ocean Alkalinity Enhancement (OAE) follow Iron Fertilization into an “acceptability crises” once more data is available?

Bertram and Merk shed further light on this issue. They identify several key determinants of public acceptability. Ocean-based NETs which appear more “natural” are likely to have a higher degree of acceptability than “engineered” proposals. Proposals that can be contained tend to be more acceptable than those perceived as uncontrollable. Bertram and Merk note that such perceptions could result in ocean-based NETs with limited sequestration capacity being privileged over proposals with far greater capacity. They argue that we need to identify who will be affected and to what degree across the entire process-chain of ocean-based NETs to better understand how public perceptions may affect the feasibility of these proposals.

Several articles focused on OAE as a means of chemical CDR, since this approach has a high theoretical potential (Renforth and Henderson, 2017). By examining the long-term dynamics of adding a constant amount of olivine to a carbon cycle model, which includes sediment and weathering feedbacks, Köhler shows how long it would take for OAE to remove most anthropogenic CO₂ in a high emission climate change scenario. This study also shows that the sequestration efficiency of ocean alkalization has its maximum during the anthropogenic CO₂ emission peak and that altered marine chemistry reverses (after 1–2 kyr) the trend from sedimentary CaCO₃ dissolution to a restrengthened accumulation of CaCO₃ in the sediments.

How OAE might be achieved in practice is the focus of a study by Caserini et al. that investigates the potential of using existing shipping activities and capacities to add lime, Ca(OH)₂, to the ocean. They estimate that the maximum potential discharge of lime from all active vessels worldwide is between 1.7 and 4.0 Gt/year. For the Mediterranean Sea potential discharge of about 186 Mt/year is estimated.

Butenschön et al. use a high resolution (~6 km), physical-biogeochemical model of the Mediterranean Sea to investigate the efficacy and biogeochemical side effects of adding alkalinity along current shipping routes during a moderate emission scenario (RCP 4.5). They find that with a strategic deployment scenario ocean acidification can be stopped and stabilized, while still allowing for efficient CDR.

In a more global context, Burt et al. use an Ocean carbon cycle model to show that the efficacy of OAE varies substantially across different ocean regions over a timescale of 75 years. Within the regions they tested, they found the highest efficacies of OAE when applied in a narrow circumpolar band in the Southern Ocean at (~55°S), while lowest efficacies were observed in the sub-polar North Atlantic. They explain the variable efficacies with regional differences in (i) physical water mass transport and (ii) the ability of the seawater carbonate system to absorb additional CO₂ per amount of alkalinity added to the ocean.

This strong focus on OAE is complemented in a *Frontiers for Young Minds* article by Woodall et al. on enhanced mineral weathering. This article is pitched at school-aged readers, and explains the need for NETs and the potential ways in which carbon mineralization can contribute, including via the ocean. In doing so, it seeks to enhance public understanding and awareness of NETs and inspire the next generation of researchers.

In summary, the articles in this Research Topic add critical knowledge to the small, but rapidly growing body of research on ocean-based NETs. These contributions will be of particular value to guide future work as the field begins to transition from mostly theoretical perspectives to applied research and development of promising NETs. As part of this transition, inter- and trans-disciplinary research will become increasingly important to tackle the multi-dimensional challenges associated with ocean-based NETs. For some NETs this transition is yet to commence, as critical disciplinary knowledge gaps remain. However, for proposals like OAE this transition has begun in earnest, necessitating greater inter-/trans-disciplinary engagement from academia, government organizations and civil society.

AUTHOR CONTRIBUTIONS

DPK wrote the introduction and conclusion sections, as well as paragraphs for each article in the topic that he edited. KB, LTB, and WR wrote paragraphs for each article in the topic that they edited. All authors worked together to edit and improve the final text of the whole article.

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