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Editorial: Insights in negative emission technologies: 2021

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Editorial on the Research Topic
Insights in negative emission technologies: 2021

We are delighted to present *Insights in Negative Emission Technologies: 2021* a Research Topic in *Frontiers in Climate*. These manuscripts showcase new insights, novel developments, current challenges, latest discoveries, recent advances, and future perspectives in the field. Our specific goal was to shed light on the progress made in the past decade in Negative Emission Technologies (NETs), and on its future challenges. We are sure that this article collection will inspire, inform and provide direction and guidance to researchers in the field. We present 9 articles from 36 authors from a wide range of topics including geochemical NETs, ocean-based approaches, biomass energy carbon capture and storage (BECCS), durable carbon utilization, and policy.

The original research piece by Freer et al. use a bespoke model to interrogate the supply chains of three BECCS case-studies, with specific focus on supply-chain emissions from siting BECCS facilities in the United Kingdom.

This is followed by the perspective of Nehler and Fridahl who make the case for improvements to EU regulation for BECCS, particularly allowing member states to use negative emissions from BECCS in their climate obligations, the exemption of leakage of biogenic CO_2, and removing regulatory barriers.

In their review article, Honegger et al. dive deeply into governance principles of carbon dioxide removal to inform policy development. They provide a review of the concept of governance principles, international governance in the context of climate change mitigation (e.g., policy regime of UN Framework Convention on Climate Change), environmental integrity, fair-share efforts, national siting, and public participation/deliberation. They use this deliberation to explore policy considerations for direct air capture, and suggest "a less holistic perspective on CDR policy proposals focusing on techno-economic factors alone would fail to capture such [interlinked governance principles]."

Woodall and McCormick explore the application of the "Aines Principle," proposed previously in a 2020 Lawrence Livermore National Laboratory report (Sandalow et al., 2021), and named after Associate Editor Roger Aines, states that "at some carbon [removal] price, the revenue generated from CO_2 removal will exceed the revenue generated from energy production from a given bioconversion process." In two case studies, that threshold was found to be \$130 tCO_2^{-1} for municipal solid waste, and about \$200–400 tCO_2^{-1} for a range of liquid or hydrogen-based fuel conversion pathways.

While highly ephemeral carbon storage (of say <100 years) might have value for emissions reduction, its utility for negative emissions is limited. It is within this context that actors within the voluntary offset market are navigating, with an apparent need to account for durability within purchases. The prospective from Wenger et al. proposes a ton-year accounting frame work as a tool for comparison.

Storage of CO_2 in mineral-based products within the construction sector offers a scalable, and potentially marketable, vector within existing supply chains, at least this is the basis of the perspective piece by Sick et al.. The authors suggest that multiple gigatonnes of CO_2 may be possible with a market value of around \$1 trillion yr^{-1} by 2050.

The oceans are an important environment within the Earth's climate and offers considerable potential for atmospheric CO_2 removal. This potential was explored by a recent report from the National Academies of Science, Engineering and Medicine (Committee on A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration, Ocean Studies Board, Division on Earth and Life Studies, and National Academies of Sciences, Engineering, and Medicine, 2022), which call for an acceleration of research. Williamson and Gattuso compliment this with a review of the potential of "blue carbon" ecosystems (e.g., mangrove forests, seagrass meadows, and tidal saltmarshes). While blue carbon ecosystems are important habitats for biodiversity, spatially dense long-term carbon sinks, they have reportedly limited scalability (Committee on Developing a Research Agenda for Carbon Dioxide Removal and Reliable Sequestration, Board on Atmospheric Sciences and Climate, Board on Energy and Environmental Systems, Board on Agriculture and Natural Resources, Board on Earth Sciences and Resources, Board on Chemical Sciences and Technology, Ocean Studies Board, Division on Earth and Life Studies, and National Academies of Sciences, Engineering, and Medicine, 2019), Williamson and Gattuso argue that the uncertainty in how these systems accumulate, store, or transport carbon, makes previous cost estimates similarly uncertain.

Finally, a two-part contribution considers the potential of geochemical-based NETs. The topic is reviewed in detail by Campbell et al., presenting an overview of the reaction chemistries, implications for resource availability, kinetics, technology function, novel applications of biotechnology, considerations for life-cycle assessment, and an appraisal of the current state of the field. In Part 2, as perspective, Maesano et al. present a roadmap for the research, development, and large-scale deployment of geochemical NETs. They highlight bottlenecks to progress including the technical readiness, social license to operate, demand and supply, human capital, and infrastructure. They also consider actions and opportunities to overcome these limitations and propose a set of near-term priorities for research and development.

Since 2011, NETs have grown from a fringe interest of the climate change mitigation community, to an integral part of proposals to meet climate targets. Manuscripts contained within this Research Topic, *Insights in Negative Emission Technologies: 2021,* offer a broad snapshot of this growing field.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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