frontiers in Climate

EDITORIAL
published: 28 January 2020
doi: 10.3389/fclim.2020.00001

Editorial: The Role of Negative Emission Technologies in Addressing Our Climate Goals

Phil Renforth[1]* and *Jennifer Wilcox*[2]

[1] *School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, United Kingdom,* [2] *Department of Chemical Engineering, Worcester Polytechnic Institute, Worcester, MA, United States*

Keywords: negative emission technology (NET), climate change, greenhous gases, net zero, 1.5°C agenda

Editorial on the Research Topic

The Role of Negative Emission Technologies in Addressing Our Climate Goals

Imagining ourselves in the mid-1700s with perfect foresight of the impending technological revolution, how might our decisions be guided? Would we have done anything different? It is tempting to think that we would skip fossil fuels altogether and that the industrial revolution would have been powered largely by renewables. We may have also avoided obvious environmental failures like the prolific use of asbestos, lead-based paint, and unregulated chlorofluorocarbon use. However, it is likely that we still would have used some fossil fuels. While we may have pushed for quicker deployment of carbon capture and storage, we probably would have afforded ourselves the luxury of unmitigated CO_2 emission into the atmosphere.

If our 1,700 selves had a trillion-ton emission budget, how would we have spent it? We have not entirely squandered that resource. It has raised billions out of poverty, extended our lives and improved living conditions, fuelled exploration and scientific progress, and created opportunities for human connection that have never previously existed in the history of our species. The travesty is that not everyone has benefited from the value of this budget, nor was the transition cost factored into its exhaustion. However, the era of unabated CO_2 emission to the atmosphere must end, and we are now called upon to implement a rapid transition to net-zero greenhouse gas emissions. Most pathways for limiting climate change contain rapid and deep emissions reduction combined with large amounts of CO_2 removal from the atmosphere facilitated by Negative Emission Technologies (NETs).

While NETs have long been part of the climate change conversation, their unique importance has emerged following the 2015 Paris Agreement, and subsequently crystallized by high level reports from the European Academies' Science Advisory Council (2018), The Royal Society Royal Academy of Engineering (2018), National Academy of Sciences Engineering and Medicine (2019), and Intergovernmental Panel on Climate Change (2018). They all acknowledge that NETs are not a replacement for reducing emissions, and that there is an unsettling gap between the assumptions made about the potential of NETs (e.g., in model scenarios) and what is currently known about their feasibility of operating at a global scale. These reports are a call to action for researchers to fill this knowledge gap. In 2019 we launched *Frontiers in Climate: Negative Emission Technologies* as a dedicated home for research in this field, and welcome submissions from any discipline considering the feasibility or implications of NETs. We are delighted to present the collection of articles in our first Research Topic.

Scale is important, not just because it frames the contribution of an approach to solving the problem, but also constrains what might be possible. When an industry operates at a global scale it potentially runs up against hard immovable geophysical limits. Arguably, humanity has surpassed

Edited and reviewed by:
Sabine Fuss,
Mercator Research Institute on Global Commons and Climate Change (MCC), Germany

****Correspondence:***
Phil Renforth
p.renforth@hw.ac.uk

Specialty section:
This article was submitted to Negative Emission Technologies, a section of the journal Frontiers in Climate

Received: *02 December 2019*
Accepted: *09 January 2020*
Published: *28 January 2020*

Citation:
Renforth P and Wilcox J (2020) Editorial: The Role of Negative Emission Technologies in Addressing Our Climate Goals. Front. Clim. 2:1. doi: 10.3389/fclim.2020.00001

several of these limits already (Steffen et al., 2011) and is rapidly approaching the limit of cumulative atmospheric CO_2.

Unquestionably, we have been able to innovate our way out of complicated problems. The story of our species is tethered to that of technological change. This story is also marked by enormous social transformation. Climate change challenges us to innovate and transform further still. However, we postulate that the risk of failing to meet our climate targets depends not only on questions of whether technological or social transformation can occur fast enough, but that ideological conflict between techno-driven or socio-driven approaches may ultimately prevent either from occurring. The perspectives piece from Friedmann makes this point by borrowing from *The Wizard and the Prophet* by Mann (2018).

> "Mann asserts that 'wizards' [those that favor technical solutions] and 'prophets' [those that favor social solutions] represent distinct approaches and tribes, commonly with very different world views and value systems. Understanding this axis of contention is essential to acknowledging the difficulty of the task of climate restoration… Despite their common goals, wizards, and prophets sometimes view each other with contempt."

This "axis of contention" can be a positive reflective force in a world driven by technological change but is essential when confronted by the geophysical limits of global technologies. An early manifestation of this is the potential for new or even hypothetical NETs to act as deterrents to emissions reduction (or "moral hazard"). Within this context McLaren et al. argue for separate targets for emissions reduction and negative emissions. This approach may limit the moral hazard but requires separation of target-setting, incentivization, monitoring, and evaluation regimes.

The perspective of a company developing systems for directly removing CO_2 from the atmosphere is described by Beuttler et al. Switzerland based Climeworks have been operating for a decade, and here they provide an overview of their direct air capture approach, how it was developed, and the current disconnect between markets for CO_2 and what may eventually form part of a global effort to remove billions of tons of CO_2 from the atmosphere. Current policies are not adequate so opportunities that capture CO_2 from air are presently coupled with approaches that help to offset the costs of capture, with most re-releasing CO_2 back into air, whether it be through food (e.g., CO_2 use in greenhouses), carbonated beverages, or synthetic fuels.

Many of the negative emissions approaches create enriched CO_2 gas for storage, and by mid-century about 10 billion tons will need to be stored (e.g., under the "middle of the road" 1.5°C scenario, Intergovernmental Panel on Climate Change, 2018). Kelemen et al. provide a comprehensive review of storage options. This includes sequestration in deep saline aquifers and mineralization. The annual storage potential together with approximate costs are reported. Geological storage of CO_2 has considerable capacity at global scale, and storage in sedimentary basins has been carried out in practice since the early 1970's (e.g., in the Permian Basin).

Over the next 50 years and beyond, our energy transition must reduce fossil fuel use and increase renewables. It is unlikely that fossil fuels will disappear completely, and certainly decarbonizing fossil fuel energy will be an important part of the technology transition. "Enhanced oil recovery" (EOR), the method by which CO_2 is injected into the subsurface to extract oil from depleting reservoirs, has long been acknowledged as releasing more CO_2 than it sequesters. Núñez-López and Moskal challenge us to think again. If optimized for CO_2 storage rather than oil production, an EOR scheme may operate with a net negative carbon balance for a limited period. This potential is further extended if additional process CO_2 is injected lower in the rock formation ("stacked storage"). The finite capacity of an EOR project to be net carbon negative together with constrained scalable potential (Kolster et al., 2017), make carbon storage in EOR a precious resource, which we should take care in using as part of a longer-term transition to decarbonize fossil fuels. Managing the transition to net-zero carbon emissions may include technologies and processes that are incompatible with the goal but otherwise take us several steps closer. For instance, swapping unabated coal for unabated gas lowers emissions from energy generation, but further emissions reduction will be needed to reach our climate targets. Similarly, the feasibility of several NETs (e.g., direct air capture) is sensitive to the emission intensity of the energy supply and are thus inextricably linked to the energy transition.

The oceans play a vital role in the Earth's climate. Marine ecosystems are becoming increasingly stressed by elevated atmospheric CO_2 concentrations. The oceans are becoming more acidic, which makes it harder for some shell forming organisms to grow. Bach et al. explore the possibility of increasing ocean alkalinity through mineral addition. Such proposals plan to remove CO_2 from the atmosphere while also partially ameliorating the impacts of acidification. The potential environmental impact on pelagic marine ecosystems is mapped out here, and they constrain the changes in surface ocean alkalinity, silica, iron, and other metals as a consequence of a range of mineral addition scenarios.

It may surprise many that the two-meter sliver of soil that covers much of our planet contains more carbon than vegetation and the atmosphere combined. Paustian et al. review existing best management practices and frontier technologies for managing and maximizing this resource. They call for a two-stage strategy. First, strong policy that could be enacted immediately to incentivize existing technologies and approaches. Furthermore, continued and leveled-up research and development could be used to create new crop varieties for additional negative emissions mid-century.

Emerging within NET's discourse is the integration of land-based approaches with agricultural reform policy platforms. Within this context, Jacobson and Sanchez review agricultural relevant NETs in the context of the US public administration. They recommend the establishment of a new research agency and technology commercialization program within US Department of Agriculture, improved coordination agencies and foundations and congressional action to establish and fund new NETs programs. The work is valuable insight into how public administration may be shaped by the challenge of balancing residual emissions using NETs.

Considering the global potential of NETs has been an important first step in understanding what options may be available at scale. However, their deployment will undoubtably be on national and regional scales. The perspective article by Fajardy et al. examines the national and regional barriers to a range of approaches including land and water, access to low carbon energy, CO_2 storage, socio-economic issues, and finance.

While the journal is always open to new submissions, future Research Topics will include technology-specific approaches (ocean-based, direct air capture), system-level assessment and rationalization, social sciences, policy and governance. We also welcome suggestions for future Research Topics, and look forward to working with you as editors, reviewers and authors in bridging the NETs knowledge and policy gap.

AUTHOR CONTRIBUTIONS

PR and JW wrote the manuscript.

ACKNOWLEDGMENTS

The editors would like to thank all the authors, reviewers, and associate editors who contributed to the first Research Topic of Frontiers in Climate.

REFERENCES

European Academies' Science Advisory Council (2018). *Negative Emission Technologies*. Available online at: https://easac.eu/publications/details/easac-net/ (accessed January 14, 2020).

Intergovernmental Panel on Climate Change (2018). *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change.*

Kolster, C., Masnadi, M. S., Krevor, S., Dowell, N. M., and Brandt, A. R. (2017). CO_2 enhanced oil recovery: a catalyst for gigatonne-scale carbon capture and storage deployment? *Energy Environ. Sci.* 10, 2594–2608. doi: 10.1039/C7EE02102J

Mann, C. C. (2018). *The Wizard and the Prophet: Two Remarkable Scientists and their Dueling Visions to Shape Tomorrow's World*. New York, NY: Knopf.

National Academy of Sciences Engineering and Medicine (2019). *Negative Emissions Technologies and Reliable Sequestration*. Washington, DC: National Academies Press. doi: 10.17226/25259

Steffen, W., Persson, A., Deutsch, L., Zalasiewicz, J., Williams, M., Richardson, K., et al. (2011). The anthropocene: from global change to planetary stewardship. *Ambio* 40, 739–761. doi: 10.1007/s13280-011-0185-x

The Royal Society and Royal Academy of Engineering (2018). *Greenhouse Gas Removal*.

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.