



## OPEN ACCESS

EDITED AND REVIEWED BY  
Matthew Collins,  
University of Exeter, United Kingdom

\*CORRESPONDENCE  
Phil Renforth  
✉ p.renforth@hw.ac.uk

RECEIVED 17 August 2023  
ACCEPTED 25 August 2023  
PUBLISHED 18 September 2023

CITATION  
Renforth P, Bellamy R, Beerling D, Boettcher M,  
Bonalumi D, Brandão M, Fridahl M, Fuss S,  
Hansson A, Heyward C, Kolosz B, Lamers P,  
McLaren D, Pomi R, Sanchez DL, Shayegh S,  
Sick V, Van der Spek M, Vishal V and Wilcox J  
(2023) Specialty grand challenge: renaming our  
section to “Carbon Dioxide Removal”.  
*Front. Clim.* 5:1279109.  
doi: 10.3389/fclim.2023.1279109

COPYRIGHT  
© 2023 Renforth, Bellamy, Beerling, Boettcher,  
Bonalumi, Brandão, Fridahl, Fuss, Hansson,  
Heyward, Kolosz, Lamers, McLaren, Pomi,  
Sanchez, Shayegh, Sick, Van der Spek, Vishal  
and Wilcox. This is an open-access article  
distributed under the terms of the [Creative  
Commons Attribution License \(CC BY\)](#). The use,  
distribution or reproduction in other forums is  
permitted, provided the original author(s) and  
the copyright owner(s) are credited and that  
the original publication in this journal is cited, in  
accordance with accepted academic practice.  
No use, distribution or reproduction is  
permitted which does not comply with these  
terms.

# Specialty grand challenge: renaming our section to “Carbon Dioxide Removal”

Phil Renforth<sup>1\*</sup>, Rob Bellamy<sup>2</sup>, David Beerling<sup>3</sup>,  
Miranda Boettcher<sup>4</sup>, Davide Bonalumi<sup>5</sup>, Miguel Brandão<sup>6</sup>,  
Mathias Fridahl<sup>7</sup>, Sabine Fuss<sup>8,9</sup>, Anders Hansson<sup>7</sup>,  
Clare Heyward<sup>10</sup>, Ben Kolosz<sup>11</sup>, Patrick Lamers<sup>12</sup>,  
Duncan McLaren<sup>13</sup>, Raffaella Pomi<sup>14</sup>, Daniel L. Sanchez<sup>15</sup>,  
Soheil Shayegh<sup>16</sup>, Volker Sick<sup>17</sup>, Mijndert Van der Spek<sup>1</sup>,  
Vikram Vishal<sup>18</sup> and Jennifer Wilcox<sup>19</sup>

<sup>1</sup>Research Center for Carbon Solutions, Heriot-Watt University, Edinburgh, United Kingdom, <sup>2</sup>Department of Geography, University of Manchester, Manchester, United Kingdom, <sup>3</sup>Department of Animal and Plant Sciences, University of Sheffield, Sheffield, United Kingdom, <sup>4</sup>Research Cluster Climate Policy and Politics, German Institute for International and Security Affairs, Berlin, Germany, <sup>5</sup>Department of Energy, Politecnico di Milano, Milano, Italy, <sup>6</sup>Department of Sustainable Development, Environmental Science and Engineering, KTH Royal Institute of Technology, Stockholm, Sweden, <sup>7</sup>Department of Thematic Studies, Unit of Environmental Change, The Centre for Climate Science and Policy Research (CSPR), Linköping University, Linköping, Sweden, <sup>8</sup>Mercator Research Institute on Global Commons and Climate Change, Berlin, Germany, <sup>9</sup>Department of Geography, Humboldt-Universität zu Berlin, Berlin, Germany, <sup>10</sup>Institute for Philosophy, UiT The Arctic University of Norway, Tromsø, Norway, <sup>11</sup>Energy and Environment Institute, University of Hull, Hull, United Kingdom, <sup>12</sup>National Renewable Energy Laboratory, Strategic Energy Analysis Center, Golden, CO, United States, <sup>13</sup>The Emmett Institute, School of Law, University of California, Los Angeles, Los Angeles, CA, United States, <sup>14</sup>Department of Civil and Environmental Engineering, University of Rome “La Sapienza”, Rome, Italy, <sup>15</sup>University of California, Berkeley, Berkeley, CA, United States, <sup>16</sup>RFF-CMCC European Institute on Economics and the Environment (EIEE), Centro Euro-Mediterraneo sui Cambiamenti Climatici, Lecce, Italy, <sup>17</sup>Department of Mechanical Engineering, Global CO2 Initiative, University of Michigan, Ann Arbor, MI, United States, <sup>18</sup>Department of Earth Sciences, Indian Institute of Technology Bombay, Mumbai, India, <sup>19</sup>Department of Chemical and Biomolecular Engineering, University of Pennsylvania, Philadelphia, PA, United States

## KEYWORDS

Carbon Dioxide Removal (CDR), Negative Emission Technologies (NETs), climate change, Greenhouse Gas Removal (GGR), nomenclature

While the concept of removing carbon dioxide (CO<sub>2</sub>) from the atmosphere to help prevent climate change has been around for decades, it is only relatively recently that its importance within climate policy has moved into mainstream discussions. As such, conventions for nomenclature are widely debated (for examples, see [Table 1](#)). The proposed methods of removing CO<sub>2</sub> from the atmosphere to restore a level that ensures a stable climate, are diverse and often share little in their form and function beyond their impact on atmospheric CO<sub>2</sub>. However, for this reason alone, it is useful to refer to these within an umbrella term. In this editorial, we outline why the editorial board has decided to rename this section of Frontiers in Climate to “Carbon Dioxide Removal”.

The original title for the section “Negative Emission Technologies” (NETs) was first used in a paper title by [Lemoine et al. \(2012\)](#), although “negative emissions” seems to have been used perfunctorily in the climate modeling community (e.g., [Harvey, 2004](#)) as a useful driver to a desired atmospheric CO<sub>2</sub> concentration, and the “technologies” for achieving this were implicit ([Azar et al., 2006](#)), and finally explicitly referred to as NETs ([Azar et al., 2010](#)) specifically for biomass energy carbon capture and storage. It similarly has been used within life-cycle analysis (LCA) to describe emissions reduction approaches that result in a net negative value on LCA emissions balance sheets (e.g., [Brinck et al., 2011](#)). [McLaren \(2012\)](#), responding to the use of “negative emissions” terminology by the UK Climate Change

**TABLE 1** The use of terminology to describe the removal of CO<sub>2</sub> from the atmosphere from IPCC 1.5 degree report and the 6<sup>th</sup> Assessment Report.

Carbon Dioxide Removal	“Anthropogenic activities removing CO <sub>2</sub> from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO <sub>2</sub> uptake not directly caused by human activities.”
Negative Emissions	“Removal of greenhouse gases (GHGs) from the atmosphere by deliberate human activities, i.e., in addition to the removal that would occur via natural carbon cycle processes.”
Net negative emissions (IPCC 1.5 degree) Net negative greenhouse gas emissions (AR6)	“A situation of net negative [greenhouse gas] emissions is achieved when, as result of human activities, more greenhouse gases are removed from the atmosphere than are emitted into it. [when metric weighted anthropogenic greenhouse gas (GHG) removals exceed metric-weighted anthropogenic GHG emissions]. Where multiple greenhouse gases are involved, the quantification of negative emissions depends on the climate metric chosen to compare emissions of different gases (such as global warming potential, global temperature change potential, and others, as well as the chosen time horizon).”
Greenhouse gas removal	“Withdrawal of a GHG and/or a precursor from the atmosphere by a sink.”

Committee, was the first to connect negative emissions with the broader set of technologies that perform the function (although with a preference for “techniques”) and encompassing non-CO<sub>2</sub> greenhouse gasses. NETs has subsequently been used in high level reports by the [Committee on Developing a Research Agenda for Carbon Dioxide Removal Reliable Sequestration \(2019\)](#) and the European Academies’ Science Advisory Council, [EASAC \(Courvoisier and European Academies Science Advisory Council, 2018\)](#), and it was within this context that the name was chosen for this section ([Renforth and Wilcox, 2020](#)).

“Carbon Dioxide Removal” (CDR) has been used extensively (e.g., an early example specifically referring to removal from the atmosphere is [Spector and Dodge, 1946](#)). CDR was also the preferred sub categorization within the emerging discussion on “Geoengineering” ([Keith, 2000](#); [The Royal Society Shepherd, 2009](#); [NASEM, 2015](#)). The term appears to be favored within the IPCC’s 6th Assessment Report (AR6), referenced in both Chapter 3, 4, 7 and 12 of working group III to specifically refer to the approaches that remove CO<sub>2</sub> from the atmosphere ([Babiker et al., 2022](#); [Lecocq et al., 2022](#); [Nabuurs, 2022](#); [Riahi et al., 2022](#)). “Negative emissions” is used by AR6 to refer to outcome of applying CDR at a systems level, rather than the removal approach. The “technologies” within NET is almost entirely omitted from use within AR6, and follows concerns about the drawing of arbitrary lines between “natural” and “technological” CDR ([Bellamy and Osaka, 2020](#)). Likewise, within international, European and US governance policy landscapes, the terms “carbon removal” and “CDR” are now consistently used (see for example negotiations around Article 6.4 of the Paris Agreement ([UNFCCC Secretariat, 2015](#)), the EU legislative process on the certification of carbon removals ([European Commission, 2022](#)), the proposed US Federal Carbon Dioxide Removal Leadership Act

([US Congress, 2022](#)) and other policy spheres ([Schenuit et al., 2021](#); [Schenuit and Geden, 2023](#)). Finally, the term has been the preferred choice in the influential Carbon Dioxide Removal Primer ([Wilcox et al., 2021](#)).

An initial reason for the choice of NETs for the section was that CDR can easily be confused with processes that remove CO<sub>2</sub> from other gases, especially carbon capture and storage (CCS) which was first suggested in 1977 (under the moniker “geoengineering” [Marchetti, 1977](#)), and developed throughout the 1990s and 2000s—therefore long before CDR came into policy debates. More recently, there have been advances in using the captured carbon (carbon capture and utilization CCU). The confusion between CCS and CDR is highly problematic given their similar names but different climate policy purposes (the former helping to reduce emissions, the latter compensating for residual emissions or contributing to net negative emission pathways). Careful consideration of locating CDR within the landscape of climate change responses is well established academically ([Heyward, 2013](#)), and the differentiation for policy has also been well articulated ([Schenuit et al., 2023](#)). While the risk of confusion remains, the possible impact is less than in 2018 and CDR has since become a well-established term.

The use of “Greenhouse Gas Removal” (GGR) followed early use of CDR in a categorization review by [Boucher et al. \(2014\)](#), and has been used almost exclusively in Europe, and especially in the UK ([Royal Society, 2018](#)). It was included in the glossary of the IPCC’s Special Report on Global Warming of 1.5°C ([Masson-Delmotte et al., 2022](#)), but omitted from the glossary of AR6 and considered only as a previously used term. Research considering the removal of other, short-lived, greenhouse gases (e.g., methane) from the atmosphere is still at a relatively early stage, with the direct comparison with CO<sub>2</sub> removal not being particularly helpful given that the removal of short-lived gases has a similar impact on climate as reducing their emissions. It is of equal relevance that CDR approaches do not only differ in the processes that captures the CO<sub>2</sub> from air or bodies of water, but also in the fate of the CO<sub>2</sub> and how long it remains removed from the environment.

Academic journals play a vital role in disseminating scientific knowledge and fostering scholarly communication. They serve as platforms for researchers to share their findings, exchange ideas, and catalyze scientific progress. CDR is a field of interdisciplinary research, and it is essential for our section in *Frontiers in Climate* to embrace the broadest appeal to accommodate the needs of the scientific community. Furthermore, the use of “Negative Emission Technologies” can impose an unnecessary restriction to the potential authorship and readership of the journal as non-technical aspects such as policy, legal, and social implications are not limited to individual technologies. On the contrary, “Carbon Dioxide Removal” has a greater potential of engaging audience from a broader field of Social Sciences and Humanities. We believe that renaming the section to Carbon Dioxide Removal uses the most widely used terminology for what the section publishes.

## Author contributions

PR: Conceptualization, Writing—original draft, Writing—review and editing. RB: Writing—original draft, Writing—review

and editing. DB: Writing—review and editing. MB: Writing—review and editing. DB: Writing—review and editing. MB: Writing—review and editing. MF: Writing—review and editing. SF: Writing—review and editing. AH: Writing—review and editing. CH: Writing—review and editing. BK: Writing—review and editing. PL: Writing—review and editing. DM: Writing—review and editing. RP: Writing—review and editing. DS: Writing—review and editing. SS: Writing—original draft. VS: Writing—review and editing. MV: Writing—review and editing. VV: Writing—review and editing. JW: Conceptualization, Writing—review and editing.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships

## References

- Azar, C., Lindgren, K., Obersteiner, M., Riahi, K., van Vuuren, D. P., den Elzen, K. M. G. J., et al. (2010). The feasibility of low CO<sub>2</sub> concentration targets and the role of bio-energy with carbon capture and storage (BECCS). *Clim. Change* 100, 195–202. doi: 10.1007/s10584-010-9832-7
- Azar, C. A., Lindgren, K., Larson, E., and Möllersten, K. (2006). Carbon capture and storage from fossil fuels and biomass—costs and potential role in stabilizing the atmosphere. *Clim. Change* 74, 47–79. doi: 10.1007/s10584-005-3484-7
- Babiker, M., Berndes, G., Blok, K., Cohen, B., Cowie, A., Geden, O., et al. (2022). *Cross-Sectoral Perspectives*. Cambridge: Cambridge University Press.
- Bellamy, R., and Osaka, S. (2020). Unnatural climate solutions? *Nat. Clim. Change* 10, 98–99. doi: 10.1038/s41558-019-0661-z
- Boucher, O., Forster, P. M., Gruber, N., Ha-Duong, M., Lawrence, M. G., Lenton, T. M., et al. (2014). Rethinking climate engineering categorization in the context of climate change mitigation and adaptation. *Wiley Interdiscip. Rev. 5*, 23–35. doi: 10.1002/wcc.261
- Brinck, K., Poulsen, T. G., and Skov, H. (2011). Energy and greenhouse gas balances for a solid waste incineration plant: a case study. *Waste Manag. Res.* 29, S13–S19. doi: 10.1177/0734242X11413803
- 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, et al. (2019). *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda*. Washington, DC: National Academies Press.
- Courvoisier, T. J., European Academies Science Advisory Council, and Deutsche Akademie der Naturforscher Leopoldina. (2018). *Negative emission technologies: what role in meeting Paris Agreement targets?* EASAC policy report. EASAC Secretariat, Deutsche Akademie der Naturforscher Leopoldina, Halle (Saale).
- European Commission (2022). *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a Union certification framework for carbon removals* (No. COM/2022/672). Brussels: European Commission.
- Harvey, L. D. D. (2004). Declining temporal effectiveness of carbon sequestration: implications for compliance with the united national framework convention on climate change. *Clim. Change* 63, 259–290. doi: 10.1023/B:CLIM.0000018511.36935.e0
- Heyward, C. (2013). Situating and abandoning geoengineering: a typology of five responses to dangerous climate change. *APSC* 46, 23–27. doi: 10.1017/S1049096512001436
- Keith, D. W. (2000). Geoengineering the climate: history and prospect. *Ann. Rev. Energy Environ.* 25:245–284. doi: 10.1146/annurev.energy.25.1.245
- Lecocq, F., Winkler, H., Daka, J., Fu, S., Gerber, J., Kartha, S., et al. (2022). “Mitigation and development pathways in the near-to mid-term,” in *IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*.
- Lemoine, D. M., Fuss, S., Szolgayova, J., Obersteiner, M., and Kammen, D. M. (2012). The influence of negative emission technologies and technology policies on the optimal climate mitigation portfolio. *Clim. Change* 113, 141–162. doi: 10.1007/s10584-011-0269-4
- Marchetti, C. (1977). On geoengineering and the CO<sub>2</sub> problem. *Clim. Change* 1, 59–68. doi: 10.1007/BF00162777
- Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., and Shukla, P. R. (2022). *Global Warming of 1.5°C: IPCC Special Report on Impacts of Global Warming of 1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*. Cambridge: Cambridge University Press.
- McLaren, D. (2012). A comparative global assessment of potential negative emissions technologies. *Process Saf. Environ. Protect.* 90, 489–500. doi: 10.1016/j.psep.2012.10.005
- Nabuurs, G.-J. (2022). “Agriculture, forestry and other land uses (AFOLU),” in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. O., Edenhofer, R., Pichs-Madruga, Y., Sokona, E., Farahani, S., Kadner, K., Seyboth, et al. (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press).
- NASEM (2015). *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration*. Washington, DC: National Academies Press.
- 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
- Riahi, K., Schaeffer, R., Arango, J., Calvin, K., Guivarch, C., Hasegawa, T., et al. (2022). “Mitigation pathways compatible with long-term goals,” in *IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. P. R. Shukla, J. Skea, R. Slade, A. Al Khouradjaie, R. van Diemen, D. McCollum, et al. (Cambridge, UK and New York, NY, USA: Cambridge University Press).
- Royal Society (2018). *Greenhouse Gas Removal*. Royal Society (Great Britain).
- Schenuit, F., Boettcher, M., and Geden, O. (2023). “Carbon Management”: Opportunities and risks for ambitious climate policy (No. SWP Comment 2023/C 29). Stiftung Wissenschaft und Politik.
- Schenuit, F., Colvin, R., Fridahl, M., McMullin, B., Reisinger, A., Sanchez, D. L., et al. (2021). Carbon dioxide removal policy in the making: assessing developments in 9 OECD cases. *Front. Clim.* 3, 638805. doi: 10.3389/fclim.2021.638805
- Schenuit, F., and Geden, O. (2023). “Chapter 22: Carbon dioxide removal: climbing up the EU climate policy agenda,” in *Handbook on European Union Climate Change Policy and Politics*, eds. T., Rayner, K., Szulecki, A. J., Jordan, S., Oberthür (Cheltenham, UK: Edward Elgar Publishing) 322–336. doi: 10.4337/9781789906981.00037
- Spector, N. A., and Dodge, B. F. (1946). Removal of carbon dioxide from atmospheric air. *Trans. of Am. Inst. Chem. Eng.* 42, 827–848.
- The Royal Society and Shepherd, J. (2009). *Geoengineering the Climate: Science, Governance and Uncertainty*. London: The Royal Society.
- UNFCCC Secretariat (2015). *Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015 Addendum*. Part two: Action taken by the Conference of the Parties at its twenty-first session. (Session and meeting reports No. FCCC/CP/2015/10/Add.1). United Nations - Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA), Paris Climate Change Conference - November, 2015.
- US Congress (2022). *Federal Carbon Dioxide Removal Leadership Act of 2022* (No. S. 4280). 117th Congress (2021–2022).
- Wilcox, J., Kolosz, B., and Freeman, J. (2021). *Carbon Dioxide Removal Primer*. Available online at: <https://cdrprimer.org>

that could be construed as a potential conflict of interest.

The authors declared that they were an editorial board member of *Frontiers*, at the time of submission. This had no impact on the peer review process and the final decision.

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.