Moving toward Net-Zero Emissions Requires New Alliances for Carbon Dioxide Removal

Citation for the original published paper (version of record):
Fuss, S., Canadell, J., Ciais, P. et al (2020). Moving toward Net-Zero Emissions Requires New Alliances for Carbon Dioxide Removal. One Earth, 3(2): 145-149.
http://dx.doi.org/10.1016/j.oneear.2020.08.002

(article starts on next page)

One Earth

CellPress

Commentary

Moving toward Net-Zero Emissions Requires New Alliances for Carbon Dioxide Removal

Sabine Fuss,[1,2,*] Josep G. Canadell,[3] Philippe Ciais,[4] Robert B. Jackson,[5] Chris D. Jones,[6] Anders Lyngfelt,[7] Glen P. Peters,[8] and Detlef P. Van Vuuren[9]
[1]Mercator Research Institute on Global Commons and Climate Change, Berlin, Germany
[2]Institute of Geography, Humboldt University of Berlin, Germany
[3]CSIRO Oceans and Atmosphere Flagship, Canberra, Australia
[4]Laboratoire des Sciences du Climat et de l'Environnement, Institut Pierre-Simon Laplace, CEA-CNRS-UVSQ, Gif sur Yvette Cedex, France
[5]Department of Earth System Science, Woods Institute for the Environment, and Precourt Institute for Energy, Stanford University, Stanford, CA, USA
[6]Met Office Hadley Centre, Exeter, UK
[7]Energy Technology, Department of Space, Earth, and Environment, Chalmers University of Technology, Gothenburg, Sweden
[8]CICERO Center for International Climate Research, Oslo, Norway
[9]PBL Netherlands Environmental Assessment Agency, the Hague, the Netherlands
*Correspondence: fuss@mcc-berlin.net
https://doi.org/10.1016/j.oneear.2020.08.002

The 1.5°C target will require removing at least some of the carbon dioxide (CO_2) previously emitted. Knowledge on how this can be done has been increasing, though barriers remain concerning governance, policy, and acceptability. For the 26th session of the Conference of the Parties (COP26) to move beyond an academic debate on CO_2 removal (CDR), a broader alliance of research and policy communities, industry, and the public is needed.

Three decades ago, we could still gradually reduce emissions to avoid the strongest effects of global warming. Today, however, continued growth in emissions and stringent climate targets through the Paris Agreement require a new type of mitigation pathway: moving beyond zero emissions to net-negative emissions by removing more greenhouse gases (GHGs), specifically carbon dioxide (CO_2), from the air than are emitted. Because temperatures generally stabilize when CO_2 emissions reach net zero but emissions are unlikely to be comprehensively reduced to zero, net-negative emissions are required in most emission pathways consistent with 1.5°C or 2°C warming.[1] Not only can CO_2 removal (CDR) offset residual emissions, but it can also be used to bring temperatures down after an overshoot of the target (Figure 1).

Even after the Paris Agreement in 2015, much of the debate on CDR has taken place within academia and only minimally entered policy discussions, despite its prevalence in commonly discussed scenarios. However, the Intergovernmental Panel on Climate Change (IPCC)'s Special Report on 1.5°C Global Warming[1] and growing public pressure to pursue ambitious climate targets have increased the visibility of CDR as a way of reaching net-zero emissions. For instance, the European Commission's Green Deal aims at net-zero emissions by 2050, and many (also non-European) countries have their own net-zero plans.

Policymakers now face the unprecedented challenge of reaching net-zero emissions within the first half of the century at a time when global cumulative CO_2 emissions reached a record high of ~43 billion metric tons in 2019 for fossil and land-use-change emissions,[2] and current climate policies remain insufficient to meet the 1.5°C target, potentially leading to twice this amount of global warming.[1] Emissions of methane—a GHG with high global-warming potential—have also steadily risen over the last decade.[3]

Diverse factors, including current and proposed energy infrastructure, which will emit enough CO_2 through its potential lifetime to exhaust the remaining budget for 1.5°C,[4] are placing additional pressures on the carbon budget (the amount of CO_2 that can still be emitted for a given temperature target; see Figure 1). Moreover, the innovation gap remains large: questions remain about (1) the maturity of CDR technologies, where experience with afforestation is ample, but direct air capture (DAC) technologies, for example, still feature much higher costs;[5] (2) the socio-economic attractiveness and realism of using them, where technology-specific knowledge concerning public acceptance, for example, remains sparse;[6] and (3) the large magnitude of deployment required and possible unintended consequences, for example, in terms of competition for land, which is an important input for some CDR options such as afforestation but will also be key to feeding a growing population.[5]

Decision makers are turning to the international research and development (R&D) community for answers, requiring inter- and transdisciplinary initiatives by science, industry, governments, and the public to discuss the social license to operate CDR, i.e., the acceptance of removing CO_2 in the first place (CDR demand) and the actual operation of specific CDR technologies within the mitigation portfolio. Here, we describe new research avenues and partnerships that are needed to fill the knowledge gaps to enable sustainable CDR deployment while actively managing CDR demand. In a nutshell, societal choice defines the temperature target, physical science then determines the corresponding CO_2 budget, and multiple pathways (Figure 1) can then be carved out for emission

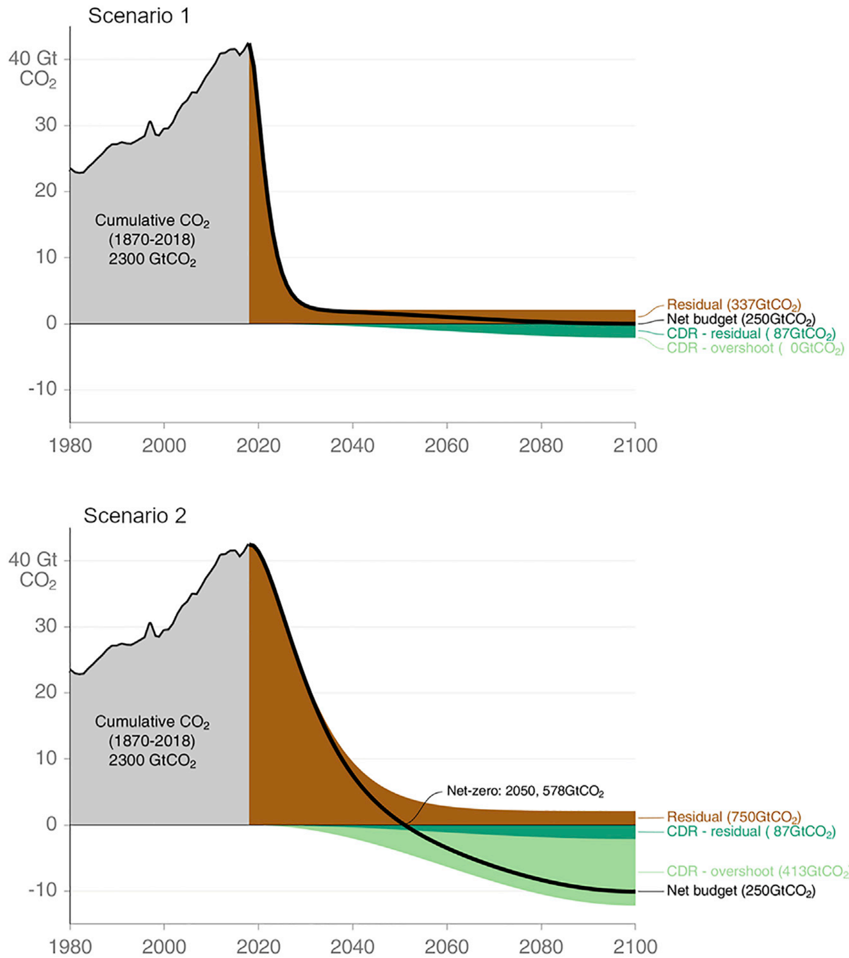

Figure 1. Historical Emissions and Stylized Pathways that Emit Less Than 250 Gt CO_2 between 2019 and 2100 to Limit the Temperature Increase to 1.5°C in 2100

Scenario 1: negative emissions offset residual (positive) emissions, resulting in little CDR and drastic and immediate emission reductions.

Scenario 2: greater (positive) emissions result in larger CDR and higher overshoot before the temperature increase declines to 1.3°C–1.4°C in 2100, still with drastic CO_2 emission reductions in the next two decades.

Both scenarios reach 1.3°C–1.4°C in 2100, but temperature diverges beforehand. Data sources: historical emissions from the Global Carbon Project; scenarios based on stylized functions with cumulative emissions consistent with scenarios from the IPCC SR1.5 scenario database.

reductions to comply with this budget (Figure 2).

Closing the Gaps

Building on the promising recent developments identified below, closing the remaining gaps pertaining to the demand for CDR and the contribution of particular technologies and practices will be key to reaching ambitious temperature goals sustainably. In terms of Figure 2, gap (1) addresses the question of how much CDR will be required after more drastic emission reductions, whereas gaps (2)–(4) are concerned with how this can be achieved.

(1) *Demand-side reductions in emissions.* Many climate-stabilization pathways rely on drastic and rapid emission reductions through changes in human behavior by, for example, reducing energy demand,[1] cutting meat consumption and replacing it with alternative protein sources,[7] and accelerating education to constrain global peak population.[8] These scenarios call for early action and suggest it will be possible to reduce the demand for CDR by a factor of 10 for pathways with limited or no overshoot.[1] Whether such demand-side mitigation scenarios to *reduce* the need for CDR are any more feasible than scenarios requiring massive CDR deployment requires further scrutiny—both are likely to be required.

(2) *Natural climate solutions.* CDR options already used in models such as afforestation, reforestation, and restoration are more mature in terms of experience and costs and might have larger carbon-capture potentials than previously estimated.[1] These biomass-based pathways benefit most from high carbon density in tree biomass and soil carbon storage accomplished through a range of practices, from conservation agriculture to biochar applications or agroforestry. These practices often feature large potentials and—if implemented to adhere to sustainability criteria—co-benefits for ecosystems and local livelihoods.[5] They could be scaled up more effectively now, though with lower long-term potentials and permanence.

(3) *Biomass energy with carbon capture and storage (BECCS).* Although there appears to be broader public support for natural climate solutions, hybrid sequestration technologies incorporating BECCS could be more efficient in the use of land than afforestation in standard cases and could thus reduce some impacts on food production and pricing. BECCS also has the additional co-benefit of producing energy for electricity and transportation fuels[9] and can replace fossil fuels. Yield increases, different feedstocks (including biogenic waste), and advances in technology (e.g., improving efficiency and reducing energy penalties) can further improve the negative emission balance of BECCS and counteract adverse side effects on land requirements, food security, water demands, and other ecosystem services that could be altered.

(4) *Engineering options for GHG removal.* Recent cost reductions in the DAC of CO_2 and the first commercial attempts to remove CO_2

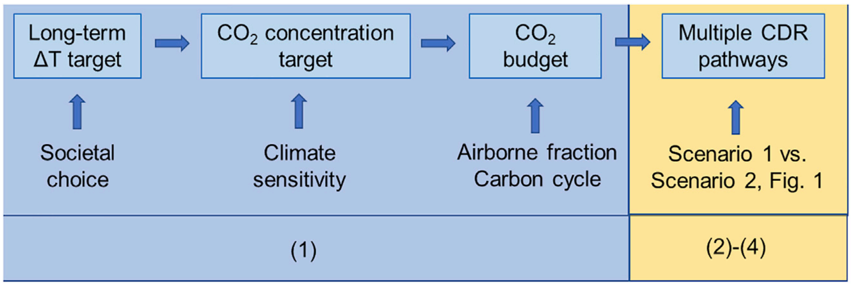

Figure 2. Relating CDR Requirements to Feasibility

The long-term target for global warming (ΔT) is a societal choice informed by science about, e.g., climate impacts of different temperature increases. How sensitive the climate is to higher CO_2 concentrations implies a concentration target, which can be translated into the remaining allowance of CO_2 emissions (CO_2 budget). Science can then offer multiple pathways (cf. scenarios 1 and 2 in Figure 1) for societal deliberation and policymaking. Parenthetical numbers refer to the gaps listed in Closing the Gaps.

directly from the air are steps toward making DAC a scalable alternative to other CDR options.[10] The spotlight is now also on less-explored options with large potentials, including enhancing natural weathering by adding silicate minerals to soils, which does not compete with other land uses.[10] Recent studies have also suggested evaluating DAC or conversion for other GHGs, such as nitrous oxide (N_2O) and methane (CH_4).[11] Such removals are challenging because the atmospheric GHG concentrations are lower than those for CO_2. However, unlike for the DAC of CO_2, oxidizing CH_4 to CO_2 is an energy-generating reaction that could restore the atmosphere to preindustrial levels of ~3 billion metric tons of CH_4, far lower than quantities needed for DAC.[11] This conversion would reduce temperature forcing by approximately one-sixth while generating only a few months' worth of additional CO_2 emissions. Absorbing aerosols, such as black carbon (soot), also represents an anthropogenic warming of the climate system. Because of the aerosols' short lifetimes, it is not necessary to remove them; merely reducing their emissions is sufficient.

Focusing on Solutions

It becomes clear that all CDR technologies and practices come with their respective strengths and tradeoffs; thus, depending solely on large-scale deployment of single CDR options is a risky strategy. Key to reducing this dependence is to decrease emissions more drastically in the short term while promoting a portfolio of CDR options for the longer term, i.e., minimizing the demand for CDR while maximizing the amount of sustainably scalable CDR (see Figure 2). As an entry point into a temporally diversified portfolio of CDR options, it is possible to first focus on the lower-cost, high-co-benefit, and technologically more mature and tested options, particularly natural climate solutions. These solutions can be complemented with low-cost and ready-to-be-deployed practices for short-term emission reductions, such as scaling carbon capture and storage (CCS) at power plants and industrial facilities.

Path to Commercialization and Large-Scale Deployment

Most of the research to date has focused on the early stages of the innovation chain (R&D), whereas demand pull, niche markets, and public acceptance remain under-researched.[6] Different CDR options will have very different requirements for successful commercialization. The flexibility of thermochemical conversion in the case of biomass, with or without CCS, makes it especially attractive for energy and chemical applications with a broad spectrum of applications and commercialization pathways.[12] Established industries could exploit new opportunities for removing CO_2 by using alkaline materials from certain types of waste,[10] which would also open up opportunities to go into the direction of making our economies more circular—a core element of the European Union's Green Deal strategy. An exploration of these pathways, most often regionally dependent, should become a focus of research in combination with experimental and full demonstration projects.

More Integrated R&D Approaches

More cooperation is needed among different disciplines to account for uncertainty and advances in our knowledge base. Although integrated assessment models (IAMs) are the main tool for combining multiple CDR technologies for scenarios consistent with low warming, bottom-up studies are needed on the spatial details of regional CDR potentials and possible bottlenecks, including conflicts of land use and infrastructure needs for transport and storage of the removed CO_2. Comparisons of IAMs, dynamic (global) vegetation models, and Earth system models have highlighted substantial uncertainties in socio-economic scenarios and climate responses to them.[13] Increased coordinated use of these models is needed if we are to better understand the diverse outcomes and the full climate consequences and collateral effects of CDR on water, nutrients needed by plants for growth, and energy budgets. These studies will need validation by observations and field studies. Policies and plans regarding the deployment of CDR need to be adaptive given that emerging evidence could change the demand for, or feasibility of, CDR.

Building the Social License to Operate

Demand-side solutions will also bear social costs. Countries with lower-quality diets, for instance, still need to raise their protein levels, which needs to be factored into decarbonization pathways.[7] Nevertheless, the motivation of improved health through less carbon-intensive diets in industrialized countries has great mitigation potential, and healthier diets can free land for CDR. Another example is improved energy efficiency, which would reduce final demand without giving up the goal of universal energy access.[14] Enhanced understanding is needed for consumption, including distributional implications of wider mitigation portfolios, household behavior, and potential rebound effects leading to increases in consumption in response to efficiency gains.[1] More broadly, the *potential* ability to remove CO_2 raises the ethical concern of moral hazard, such as delaying the phasing out of fossil fuels. Slow mitigation progress in the past is hardly attributable to this effect given that political economy, non-binding national commitments, barriers in renewable roll-out, and many other factors have all played their role independently of the opportunity to remove carbon from the atmosphere. However, we acknowledge the importance of avoiding moral hazard in the future. Building a social license to operate CDR will require closing these knowledge gaps and addressing the resulting challenges in close deliberation with society.

Exploring New Contexts of Governance

Emerging legislation around the world on net-zero targets—including in several EU countries, California, and New Zealand, to name a few—has seen progress in pathways to decarbonization. The Paris Agreement also explicitly calls for a balance of emissions and removals between 2050 and 2100. However, a diverse range of concepts has been applied: climate neutrality (EU), CO_2 neutrality,[1] and GHG neutrality (UK) are examples. Within each of these, a variety of alternative definitions can be applied.[15] There will most likely be a range of additional aspects, including new carbon-accounting approaches and the use of emission trading. Addressing these and other governance challenges, such as monitoring, reporting, and comprehensively verifying, will be critical for policy success.

Net Zero as a Framework for Policy

It remains unclear what are the best incentives to encourage CDR deployment. In the early stages, direct government interventions can push innovation. In the longer term, net zero could provide a framework for policy: because every metric ton emitted would need to be offset by a metric ton sequestered, there is a symmetric case for pricing emissions and financing removals such that each unit price charged for emissions will be turned into financial support for CDR. The ideal implementation route for this—whether comprehensive emission trading with a zero cap has advantages over taxing emissions and using the revenues to finance CDR—remains unclear. Others have proposed direct mandates for CDR to introduce an "emitter liability," i.e., to make all emitters pay for the removal of the CO_2 emitted to the atmosphere.[16] Acknowledging that there might be good reasons for at least temporarily allowing some residual emissions, particularly those related to food systems, we recognize that there could be a case for governments to use other revenues to balance these emissions. Evidently, the ultimate choice of policy instruments and distributional mechanisms will also depend on a society's norms and values—as does the role of CDR in the wider mitigation strategy. No matter what the context-specific policy approach eventually will be, however, reaching net zero as rapidly as possible remains the overarching policy priority.

Conclusion

It emerges very clearly from the latest research that the combination of more ambitious temperature targets and continued delay in stringent mitigation policy has increased the dependence on CDR, which requires us to urgently close knowledge gaps to move on with implementation, which until now has been far removed from what we see in pathways reaching the 1.5°C target, implying a need for exponential upscaling.[6] Governing CDR will require policy frameworks managing both the demand and the feasibility of CDR. Greater transparency in the treatment and consideration of CDR within a mitigation portfolio is required. With an increasingly solid science base for further CDR planning, we believe social factors, barriers and inertia, policy volatility, and governance uncertainties remain the largest challenges to early action. Therefore, we need a broader alliance to move toward net-zero targets, which brings together the research and policy communities, industry, and the broader public to explore and find the common ground to push climate solutions forward. In the run-up to the 26th session of the Conference of the Parties (COP26), it will be key to develop nationally vetted CDR agendas that consider both how much CDR is wanted and how this will be achieved. Nationally determined contributions have been found to fall short of the ambitious Paris targets,[1] and CDR still remains on the sideline in current debates. Yet, there is vast scope for including not only deeper emission reductions through conventional mitigation but also more targeted action for the rollout of CDR in plans for national emission reductions.

ACKNOWLEDGMENTS

This commentary has benefited from discussions at the First International Conference on Negative Emissions at Chalmers University of Technology in Gothenburg, Sweden, in May 2018 and during S.F.'s Jubilee Professorship stay at Chalmers University in 2019. S.F. acknowledges funding by the RESTORE+ project (http://www.restoreplus.org/), part of the International Climate Initiative, supported by the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU) on the basis of a decision adopted by the German Bundestag. G.P.P. was supported by the European Commission Horizon 2020 project Paris Reinforce (grant no. 820846). C.D.J. was supported by the joint UK BEIS/Defra Met Office Hadley Centre Climate Programme (GA01101).

REFERENCES

1. (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, sustainable development, and efforts to eradicate poverty, V. Masson-Delmotte, P. Zhai, H.O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, and R. Pidcock, et al., eds., Intergovernmental Panel on Climate Change. https://www.ipcc.ch/sr15/
2. Friedlingstein, P., Jones, M.W., O'Sullivan, M., Andrew, R.M., Hauck, J., Peters, G.P., Peters, W., Pongratz, J., Sitch, S., Le Quéré, C., et al. (2019). Global carbon budget 2019. Earth Syst. Sci. Data *11*, 1783–1838.
3. Saunois, M., Stavert, A.R., Poulter, B., Bousquet, P., Canadell, J.G., Jackson, R.B., Raymond, P.A., Dlugokencky, E.J., Houweling, S., Patra, P.K., et al. (2020). The global methane budget 2000–2017. Earth Syst. Sci. Data *12*, 1561–1623.
4. Tong, D., Zhang, Q., Zheng, Y., Caldeira, K., Shearer, C., Hong, C., Qin, Y., and Davis, S.J. (2019). Committed emissions from existing energy infrastructure jeopardize 1.5c°C climate target. Nature *572*, 373–377.
5. Fuss, S., Lamb, W.F., Callaghan, M.W., Hilaire, J., Creutzig, F., Amann, T., Beringer, T., de Oliveira Garcia, W., Hartmann, J., Khanna, T., et al. (2018). Negative emissions - part 2: costs, potentials and side effects. Environ. Res. Lett. *13*, 063002.
6. Nemet, G.F., Callaghan, M.W., Creutzig, F., Fuss, S., Hartmann, J., Hilaire, J., Lamb, W.F., Minx, J.C., Rogers, S., and Smith, P. (2018). Negative emissions - part 3: innovation and upscaling. Environ. Res. Lett. *13*, 063003.
7. Van Vuuren, D.P., Stehfest, E., Gernaat, D.E.H.J., Van Den Berg, M., Bijl, D.L., De Boer, H.S., Daioglou, V., Doelman, J.C., Edelenbosch, O.Y., Harmsen, M., et al. (2018). Alternative pathways to the 1.5 °C target reduce the need for negative emission technologies. Nat. Clim. Change *8*, 391–397.
8. Bongaarts, J., and O'Neill, B.C. (2018). Global warming policy: Is population left out in the cold? Science *361*, 650–652.
9. Bauer, N., Calvin, K., Emmerling, J., Fricko, O., Fujimori, S., Hilaire, J., Eom, J., Krey, V., Kriegler, E., Mouratiadou, I., et al. (2017). Shared socio-economic pathways of the

energy sector – quantifying the narratives. Glob. Environ. Change *42*, 316–330.

10. National Academies of Sciences, Engineering, and Medicine (2019). Negative Emissions Technologies and Reliable Sequestration: A Research Agenda (National Academies Press).
11. Jackson, R.B., Solomon, E.I., Canadell, J.G., Cargnello, M., and Field, C.B. (2019). Methane removal and atmospheric restoration. Nat. Sustain. *2*, 436–438.
12. Patrizio, P., Leduc, S., Kraxner, F., Fuss, S., Kindermann, G., Mesfun, S., Spokas, K., Mendoza, A., MacDowell, N., Wetterlund, E., et al. (2018). Reducing US coal emissions can boost employment. Joule. *2*, 2633–2648.
13. Jones, C.D., Ciais, P., Davis, S.J., Friedlingstein, P., Gasser, T., Peters, G.P., Rogelj, J., van Vuuren, D.P., Canadell, J.G., Cowie, A., et al. (2016). Simulating the Earth system response to negative emissions. Environ. Res. Lett. *11*, 095012.
14. Grubler, A., Wilson, C., Bento, N., Boza-Kiss, B., Krey, V., McCollum, D.L., Rao, N.D., Riahi, K., Rogelj, J., De Stercke, S., et al. (2018). A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies. Nat. Energy *3*, 515–527.
15. Fuglestvedt, J., Rogelj, J., Millar, R.J., Allen, M., Boucher, O., Cain, M., Forster, P.M., Kriegler, E., and Shindell, D. (2018). Implications of possible interpretations of 'greenhouse gas balance' in the Paris Agreement. Philos. Trans. R Soc. A Math Phys. Eng. Sci. *376*, 20160445.
16. Allen, M.R., Frame, D.J., and Mason, C.F. (2009). The case for mandatory sequestration. Nat. Geosci. *2*, 813, https://doi.org/10.1038/ngeo709.