Barriers and enablers of two development pathways for Direct Air Capture

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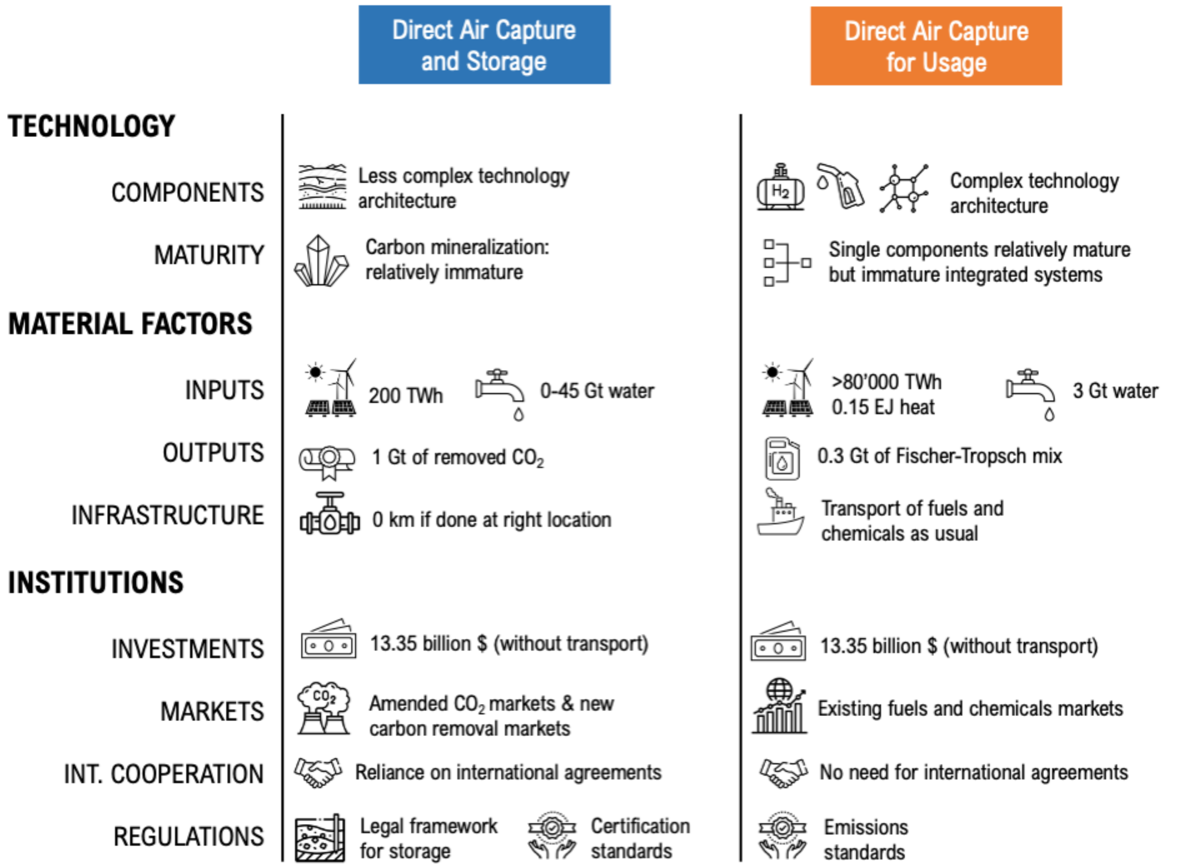
Abstract
Carbon dioxide removal is likely to be unavoidable to achieve ambitious climate goals. Deploying Direct Air Capture (DAC) might be necessary, in the long-term, to avoid conflicts for land-surface, biomass, and water usage [1–6]. Currently, only a handful of commercial-scale DAC plants exist, with costs ranging from at least 600 to 1000 USD/tCO_2 removed [7–9]. To reduce theses costs through technological learning and economies of scale[10], governments will need to adopt policies encouraging the development and deployment of DAC plants. Using the multi-level perspective on technological transition as theoretical framework[11,12], we investigate two possible development pathways for DAC: its explicit deployment for carbon removal (the *DAC Direct* pathway), or its deployment for CO_2 utilization e.g., for synthetic fuels, chemicals, and plastics (the *DAC Spillover* pathway). In particular, we assess the differences between these pathways in terms of what they require to deploy the first gigaton of air-captured CO_2. We thereby identify barriers and opportunities for the creation of new socio-technical regimes along three dimensions: (1) technology, (2) material factors and infrastructure, and (3) immaterial factors and institutions.



Our results concerning the different needs along the two development pathways are summarized in Figure 1. We find that the use of DAC-based CO_2 fuels and chemicals in the *Spillover* pathway requires a more complex technological architecture, more resources, and larger investments than simply storing the captured CO_2 underground. However, the institutional framework needed to govern the production of CO_2-based fuels and chemicals largely overlaps with the existing set-up, highlighting the lower societal barriers to their adoption. The *Direct* pathway, conversely, relies on less energy and capital, yet it faces the challenge of having to set up a whole new industry with new markets, user practices, and socio-cultural meanings.

Finally, we identify policy mixes to overcome the barriers in the short-term development of DAC-based CO_2 products. The lack of existing institutions to enable DACCS requires a series of substantive policies to enable the *Direct* pathway, notably the creation of new markets, of legal and regulatory structures to enable underground storage, and of international governance agreements. The *Spillover* pathway is, on the opposite, largely aligned with existing institutional infrastructures, and its policies consist of incentives to facilitate its access to these institutions.

We conclude that initially supporting spillover-technologies i.e., CO_2-based fuels and chemicals, could face less barriers than directly scaling up DACCS while having co-benefits for the decarbonization of different sectors of the economy. Yet, due to this pathway's higher costs and energy use, this is only true as long as volumes of CO_2-based fuels and chemicals are small. On the longer-term, however, as the institutional framework enabling carbon removal starts materializing, DACCS-supporting policies could become more politically feasible. Yet, since the advantages of each pathway are counterbalanced by trade-offs that might affect the local deployment differently, the suitability of each pathway is heavily context dependent.

References

1. Fuhrman, J. *et al.* Food–energy–water implications of negative emissions technologies in a +1.5 °C future. *Nat. Clim. Chang.* **10**, 920–927 (2020).
2. Nolan, C. J., Field, C. B. & Mach, K. J. Constraints and enablers for increasing carbon storage in the terrestrial biosphere. *Nat Rev Earth Environ* **2**, 436–446 (2021).
3. Smith, P. *et al.* Biophysical and economic limits to negative CO2 emissions. *Nature Clim Change* **6**, 42–50 (2016).
4. Strefler, J. *et al.* Carbon dioxide removal technologies are not born equal. *Environ. Res. Lett.* **16**, 074021 (2021).
5. Low, S. & Schäfer, S. Is bio-energy carbon capture and storage (BECCS) feasible? The contested authority of integrated assessment modeling. *Energy Research & Social Science* **60**, 101326 (2020).
6. Dooley, K., Christoff, P. & Nicholas, K. A. Co-producing climate policy and negative emissions: trade-offs for sustainable land-use. *Global Sustainability* **1**, (2018).
7. Ishimoto, Y. *et al.* Putting Costs of Direct Air Capture in Context. *SSRN Journal* (2017) doi:10.2139/ssrn.2982422.
8. Lackner, K. S. & Azarabadi, H. Buying down the Cost of Direct Air Capture. *Ind. Eng. Chem. Res.* (2021) doi:10.1021/acs.iecr.0c04839.
9. Young, R., Yu, L. & Li, J. Cost Assessment of Direct Air Capture: Based on Learning Curve and Net Present Value. SSRN Scholarly Paper at https://doi.org/10.2139/ssrn.4108848 (2022).

10. Nemet, G. F. *et al.* Negative emissions—Part 3: Innovation and upscaling. *Environmental Research Letters* **13**, 063003 (2018).
11. Geels, F. W. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy* **31**, 1257–1274 (2002).
12. Geels, F. W. & Kemp, R. Dynamics in socio-technical systems: Typology of change processes and contrasting case studies. *Technology in Society* **29**, 441–455 (2007).