

Questioning short-term large-scale deployment of direct air capture as a viable carbon dioxide removal strategy

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Summary

Carbon dioxide removal (CDR) strategies are essential for pursuing worlds “well-below” 2°C and 1.5°C. Among alternatives, DAC differentiates itself due to its theoretical advantage of “no restraint” for deployment. However, capture scales are difficult to grasp by IAM projections and there are significant economic barriers for the technology. This study develops a local/global analysis to estimate constraints for DAC deployment. Our results reveal that DAC coupled with carbon utilization has its advantages but exposes its fragility as a CDR candidate. Global analysis shows that projected values are incompatible with current markets and solar PV coupling with DAC seems unlikely.

Abstract

Carbon dioxide removal (CDR) strategies are key mitigation options to limit global warming to 1.5°C levels by the end of the century [1]. Among those, direct air capture (DAC) of carbon dioxide and its subsequential geological storage is surrounded by uncertainty, mostly due to wide ranges of capture potential (0.5 to 5GtCO₂/year by 2050) and levelized costs (30 to 1000\$/tCO₂ captured) [2].

DAC usage in integrated assessment models (IAMs) is sparse. In the 1.5°C Scenario Explorer, only eight scenarios, in three IAMs, rely on DAC to reach 1.5°C pathways². However, the feasibility of DAC supply chain is unclear, given its immature technology, high levelized costs, and high dependence on consumables for running the capture plant [3]. These requirements add up to reduce its carbon efficiency, when considering life cycle analysis, ranging from 44 to 90% for absorption technologies [4].

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² C-ROADS-5.005 model, “allCDR” scenario. MERGE-ETL 6.0 model, scenarios DAC15_50 and DAC2_66 (50 and 66% probability to stay under 1.5°C up to 2100) and model REMIND 1.7, scenarios for 2°C restraining maximum annual capture rate through CDRs to 8, 12 and 20 GtCO₂/year, and for 1.5°C, with maximum capture rate of 12 and 20, respectively.

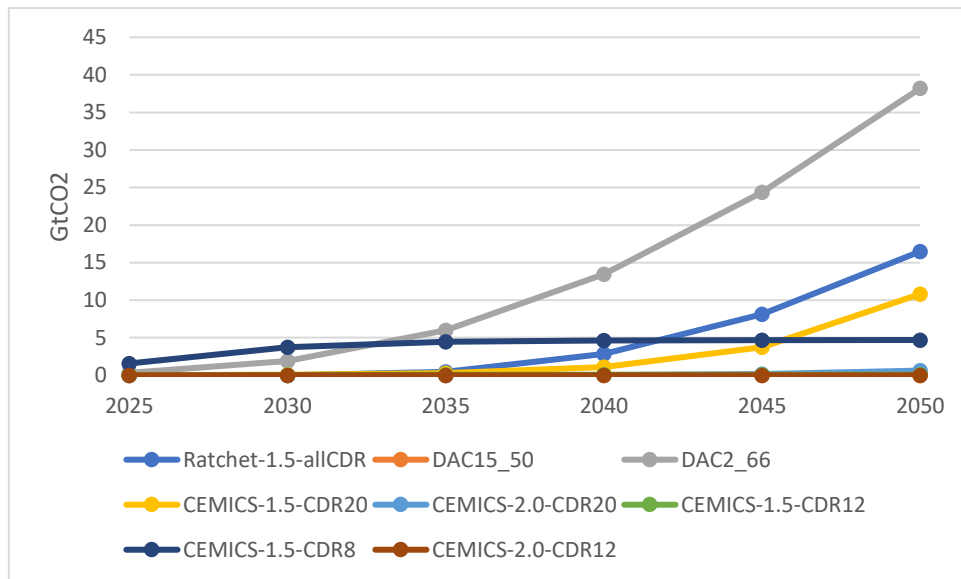


Figure 1 - DAC cumulative capture up to 2050 for selected SR15 scenarios

DAC also raises questions about the scale of the technology. Companies such as Carbon Engineering and Global Thermostat announced DAC projects with 1-2MtCO₂/year capture rate [5][6], but the largest DAC plant in operation has nominal capacity of 4ktCO₂/year [7]. DAC does not have a predominant design and has relative low technology readiness level (TRL, estimation between 5 and 6 [8]). Economical barriers may slow DAC implementation [10], mostly in the short-term where there are no carbon pricing mechanisms. The concept of utilization of the high purity CO₂ stream produced by the chemical unit in existent applications, such as enhanced oil recovery (EOR), instead of the geological storage, may ease these barriers. However, carbon utilization compromises the legitimacy of DAC to deliver negative emissions.

Therefore, a detailed study of DAC implementation is needed for better interpretation of projected capture by IAMs. Understanding what does capture rates translate to in terms of energy, material consumption and net carbon capture, as well as reducing the uncertainty around the levelized costs of capture are pursued. To this end, we develop a methodological framework to assess constrain of DAC deployment at large-scale and applied it to a Brazilian case.

For short-term deployment, we consider a high temperature strong hydroxide solution route, as it uses established chemical process and unit operations derived from the pulp/paper industry [11]–[13]. Although literature reports lower levelized costs for adsorption, solid sorbents need a development of a satellite industry for its production; they also account for more consumption of raw materials [3]; struggle with sorbent degradation and continuous operation, increasing operational expenditure [14].

For the selected strong hydroxide, sodium hydroxide (NaOH) is considered the most suitable option since it does not conflict with fertilizers production (as KOH does)³. For obtaining NaOH there is a mandatory co-production of chlorine, which may flood chlorine markets [3].

This work evaluates DAC by two approaches: (i) locally focused on Brazil, and (ii) globally focused. Firstly, it assesses the DAC deployment in the Northeast region of Brazil, which has idle capacity of NaOH production and mature fields suitable for EOR-CO₂. The levelized cost of capture is calculated with and without additional revenue from crude oil production by EOR. Life cycle analysis is performed for carbon efficiency, considering the utilization of the crude oil produced and a hypothetical case of idealistic geological storage. Secondly, a global scale of 3GtCO₂/year by liquid absorption DAC, based on the works of [17], is investigated. NaOH consumption, Cl₂ co-production and total electricity demand are assessed, alongside utilization of PV solar panels, usually proposed to pair up with DAC aiming at maximum carbon efficiency.

For our hypothetical case study, the idle NaOH production in the Brazilian Northeast region may supply a 0.74MtCO₂ DAC plant yearly with a 50km pipeline for CO₂ injection in mature terrestrial fields for EOR production. An internal rate of return (IRT) of 5.3% p.a. is obtained, with the revenue from the additional oil production reducing the levelized cost of capture from 920\$/tCO₂ to 150\$/tCO₂. However, the combustion of the additional crude oil produced has a positive carbon footprint of 3.6tCO_{2eq}/tCO_{2captured}. Hence, EOR carbon utilization is not a CDR strategy. Even with idealized permanent storage, carbon efficiencies as low as 15% turn DAC a questionable CDR strategy.

Table 1 – Local hypothetical DAC operation in Brazil

	Internal rate of return (IRT)	Carbon footprint (tCO_{2eq}/tCO_{2captured})	Levelized cost of capture (\$/tCO_{2cap})
Idealized permanent storage	N/A	0.85	920
CO ₂ utilization in EOR	5.3%	3.6	150

At global level, for a nominal capture of 3 GtCO₂/year, 3,000 plants of 1MtCO₂/year are needed, consuming 6 times the current global production of NaOH and overflowing the Cl₂ global market with 6 times the current demand. For this scale, 2,000TWh of electricity are needed, accounting the demand for both NaOH production (all destined to DAC) and plant operation, which translates to 45% of current (2019) US electric power consumption. Extrapolating the PV solar panels situation, for supplying the electricity needed for NaOH production and DAC operation, a median value of 16% of all IPCCSR15 PV generation projected

³ KOH is produced by the electrolysis of KCl, which is a basic chemical for fertilizers.

for 2035 is needed. Adding the area for DAC plants construction, 31,000km² are needed, equivalent to the area of Maryland State, USA.

This study reveals that the feasibility of large-scale deployment of liquid absorption DAC is questionable. Although coupling DAC with EOR facilities may reduce the levelized costs, low carbon efficiencies raise the question if the technology is a CDR alternative at all. At global levels, the projected values of DAC large-scale expansion compatible with 1.5°C future scenarios seem unfeasible, due to its dependency on primary resources, high costs, and carbon capture penalty.

References

- [1] IPCC, “Summary for Policymakers. In: 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”, 2018.
- [2] S. Fuss *et al.*, “Negative emissions - Part 2: Costs, potentials and side effects”, *Environ. Res. Lett.*, vol. 13, n° 6, 2018, doi: 10.1088/1748-9326/aabf9f.
- [3] S. Chatterjee e K. Huang, “Unrealistic energy and materials requirement for direct air capture in deep mitigation pathways”, *Nat. Commun.*, vol. 11, p. 10–12, 2020, doi: 10.1038/s41467-020-17203-7.
- [4] P. Taghavi-Moharamli, “Assessing Techno-Economic and Environmental Feasibility of Direct Air Carbon Capture and Storage in the Context of Global Warming of 1.5 °C”, Imperial College London, 2019.
- [5] Carbon Engineering, “Frequently Asked Questions”, 2020. [Online]. Available at: <https://carbonengineering.com/frequently-asked-questions/>.
- [6] Global Thermostat, “The GT Solution”, 2019. [Online]. Available at: <https://globalthermostat.com/the-gt-solution/>. [Acessado: 14-jan-2020].
- [7] Climeworks, “The world’s biggest climate-positive direct air capture plant: Orca!”, 2021. [Online]. Available at: <https://climeworks.com/orca-4000ton-dac-facility>. [Acessado: 02-abr-2021].
- [8] P. Viebahn, A. Scholz, e O. Zelt, “The Potential Role of Direct Air Capture in the German Energy Research Program — Results of a Multi-Dimensional Analysis”, *Energies*, vol. 18, p. 1–27, 2019.
- [9] M. Fasihi, E. Olga, e C. Breyer, “Techno-economic assessment of CO₂ direct air capture plants”, vol. 224, 2019, doi: 10.1016/j.jclepro.2019.03.086.
- [10] H. Coninck *et al.*, “Chapter 4 - Strengthening and implementing the global response. In: Global warming of 1.5°C.”, p. 313–443, 2018.
- [11] R. Socolow *et al.*, “Direct Air Capture of CO₂ with Chemicals, a Technology Assessment for the APS Panel on Public Affairs”, 2011.
- [12] K. Heidel, D. Keith, A. Singh, e G. Holmes, “Process design and costing of an air-contactor for air-capture”, *Energy Procedia*, vol. 4, p. 2861–2868, 2011, doi: 10.1016/j.egypro.2011.02.192.
- [13] D. W. Keith, G. Holmes, D. St. Angelo, e K. Heidel, “A Process for Capturing CO₂ from the Atmosphere”, *Joule*, vol. 2, n° 8, p. 1573–1594, 2018, doi:

10.1016/j.joule.2018.05.006.

- [14] G. Realmonte *et al.*, “An inter-model assessment of the role of direct air capture in deep mitigation pathways”, *Nat. Commun.*, vol. 10, n° 1, p. 1–12, 2019, doi: 10.1038/s41467-019-10842-5.
- [15] W. Moniuk, “KINETICS OF REACTION BETWEEN CARBON DIOXIDE AND IONS IN AQUEOUS ELECTROLYTE SOLUTIONS”, n° 1959, 1988.
- [16] M. Mazzotti, R. Baciocchi, M. J. Desmond, e R. H. Socolow, “Direct air capture of CO₂ with chemicals: Optimization of a two-loop hydroxide carbonate system using a countercurrent air-liquid contactor”, *Clim. Change*, vol. 118, n° 1, p. 119–135, 2013, doi: 10.1007/s10584-012-0679-y.
- [17] J. Fuhrman, H. McJeon, P. Patel, S. C. Doney, W. M. Shobe, e A. F. Clarens, “Food–energy–water implications of negative emissions technologies in a +1.5 °C future”, *Nat. Clim. Chang.*, vol. 10, n° 10, p. 920–927, 2020, doi: 10.1038/s41558-020-0876-z.