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Direct Air Capture and Storage: Should we be driving with one foot on the gas and the other on the brake?

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Direct Air Capture (DAC) of carbon dioxide (CO_2) from the atmosphere is one set of Carbon Dioxide Removal (CDR) strategies that may play a role in mitigating climate change, particularly in the mid to latter part of the 21st century. Many hurdles must be overcome for that to happen such as improving methods of capture, new regulatory environments, cost, energy inputs; and the resource requirements of energy, equipment, and chemicals. In addition, sufficient siting of facilities at scale is needed to capture and process the (CO_2), whether the carbon is sequestered underground or put to beneficial use.

Fundamentally, to avoid putting a molecule of CO_2 into the air from the global energy system -- for example switching from fossil fuels to wind or solar -- is far easier than getting that molecule back out. CO_2 makes up less than one percent of the atmosphere by volume. Removing CO_2 requires a massive amount of air flow over a sorbent, a process that utilizes energy and chemicals. This makes a clear argument for rapid deployment of efficiency and clean energy thereby avoiding emissions in the first place, and lowering the need for CDR strategies such as DAC. However, if the rate and extent of the needed mitigation falls short of intended goals such as the Paris Agreement, CDR could possibly make up the difference.

Cost estimates per ton of CO_2 removed have dropped from about \$600 (American Physical Society 2011) by a factor of three or more. One estimate by Keith et al. describing a method used by the company Carbon Engineering, gives a range at \$94-235 per t CO_2 (Keith 2018). Even at these lower costs, without an adequate price on carbon, a market to motivate deployment of DAC at the scale needed will not develop. The IPCC 1.5°C report provided four scenarios (P1-P4 in Figure 1) with increasing roles for negative emissions. All include carbon removal in the form of Agriculture, Forestry, and Other Land Use (AFOLU) scenario P1, and P2-4 also consider varying levels of Bioenergy with Carbon Capture and Sequestration (BECCS). The amount of (CO_2) removal to achieve the 1.5°C goal is greatly affected by how late fossil emissions peak and how steep they decline (IPCC 2018). The amount of carbon capture in P4 is about 20 billion tons of CO_2 (Gt CO_2) per year in 2100 – a massive and costly undertaking.

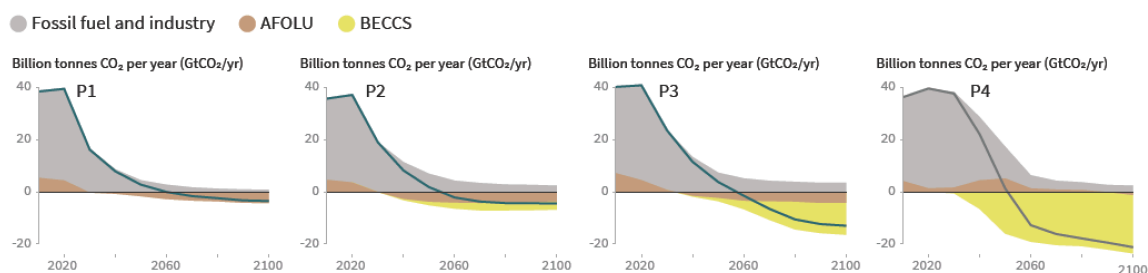


Figure 1. Four scenarios to limit global warming to 1.5°C. Source: IPCC 1.5°C Report

A major report on Negative Emissions Technologies (NETs) lead by Steven Pacala for the National Academy of Sciences provided an overview of a suite of NET technologies close to the 10 to 20 GtCO₂ challenge. Pacala's team included approaches that in their judgment would not adversely affect food availability nor biodiversity but could utilize current or near-term technology and cost less than or equal to \$100/tCO₂. With their criteria, biological and land management strategies made the cut and taken together, provide a possible removal rate of 9.1 to 10.8 GtCO₂ per year. This is only about half of what may be needed for the 1.5°C goal to be met by 2100 in the P4 scenario (NAS 2019). Two technologies with promise – DAC and carbon mineralization -- were listed in the Pacala report but were considered too uncertain for their carbon removal potential to be estimated. BECCS alone accounted for 3.5 – 5.2 GtCO₂ per year in their analysis – an important contribution, but short of the 10 to 20 GtCO₂ per year estimates.

If pushing BECCS and other CDR strategies other than DAC beyond 5 to 10 GtCO₂ per year would have unfavorable environmental impacts as indicated in the Pacala report, is there a role for DAC? A new study in Nature Communications explores the role DAC may play given new estimates of cost and scaling (Realmonde et al. 2019).

The study considered two DAC approaches: one requiring high temperatures (> 800°C) and an aqueous basic solution as a sorbent (DAC1), and the other (DAC2) relying on low process temperatures of 85-120°C with an amine solid sorbent approach. A DAC1 type facility (Carbon Engineering) with an operational pilot plant is shown below on the left alongside an artist rendering of what the facility might look like at scale on the right.



In the Realmonde et al. (2019) analysis of the two approaches, DAC1 is a slightly more mature technology but has the disadvantage of a higher energy input (both electricity and heat). This high-temperature, liquid approach lends itself to larger plant size where 30,000 facilities would be required to remove 30 GtCO₂ per year in 2100. On the other hand, DAC2 takes advantage of lower temperature waste heat from

co-located industry and may be easier to scale via mass produced modular units. To capture the same 30 GtCO₂ per year in 2100 using DAC2, an estimated 30 million units would be deployed. For both DAC1 and 2 these are large numbers of units, but the authors point to other massive production numbers such as the 73 million cars manufactured in 2017. With deployment of DACs by 2100 at this scale, the need for BECCS would be reduced 20 to 37 percent (Realmonte et al. 2019).

The scale needed for CDR is dictated by difficult-to-make estimates of the remaining carbon budget. For example, the remaining carbon budget associated with a reasonable chance (66 percent) of staying below 2°C goal of the Paris agreement is, according to Realmonte, 810 GtCO₂. This stands in contrast to 220 GtCO₂ remaining in order to meet the 1.5°C aspiration, by the same analysis. Note: Actual emissions are now approaching 40 GtCO₂ per year.

Uncertainty exists in these estimates due to the complexities of the carbon cycle and the Earth's response. For example, some published estimates show that we may have already exceeded the carbon budget for 1.5°C while others suggest we still have as many as 15 years at current emission levels (Carbon Brief 2018). While some argue that the need for CDR can be reduced significantly by aggressive deployment of efficiency, clean energy, lifestyle changes, and adequate incentives such as a price on carbon (e.g. van Vuuren 2018), the need for CDR is not reduced to zero in most scenarios.

The Realmonte study offered several cautions. Current expectations of the future feasibility of DAC might relax conventional mitigation efforts in the near term. In this scenario if DAC fails to scale successfully, they estimate an additional 600 to 1200 GtCO₂ would be emitted resulting in an overshoot of 0.15 to 0.8°C by 2100 pushing global temperature over 2°C. On top of the massive amount of expected pollution from the sorbents needed, DAC at scale would use one quarter of the total global energy demand by 2100.

Another consideration is that from 2070 to 2100 between 16 to 30 GtCO₂ is removed from the atmosphere in the Realmonte scenarios. This drawdown of CO₂ from the atmosphere would result in more release of CO₂ from the ocean, perhaps 10 to 19 percent of the carbon removed, because of the shift in gas exchange between the air and ocean. Thus, to make up for the new ocean CO₂ releases, an additional 1.7 to 9.5 GtCO₂ per year would need to be removed by direct air capture.

In summary, Realmonte et al. (2019) conclude that investment in developing DAC to further understand methods, challenges to scaling, and life cycle factors are all merited. Still, they emphasize that near term carbon emission mitigation efforts should not be relaxed on the hope DAC is a viable technology at the scale needed. Other studies offer far more adamant objections. For example, Jacobson offers a suite of arguments against DAC. One example he offers is that if DAC extends the use of fossil fuels betting on future DAC drawdowns, air pollution from fossil fuel emissions will remain unabated extending impacts on human health (see Jacobson 2019 for a full discussion).

Taking the long view, perhaps the ultimate promise of DAC is the potential to dial down the global average temperature beyond what may be achieved by massive deployment of the efficient use of clean energy. For example, if future climate change of even below 2°C is determined to have too many negative impacts, DAC, in combination with other Negative Emission Technologies (NETs) such as afforestation, land management and Bioenergy with Carbon Capture and Storage, could be used to drawdown the concentration of carbon dioxide to a desired concentration and a more favorable climate.

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For a discussion of the remaining carbon budget see the Carbon Brief website:

<https://www.carbonbrief.org/analysis-how-much-carbon-budget-is-left-to-limit-global-warming-to-1-5c>