GLOBAL CCS INSTITUTE

Brief

Carbon removal with CCS technologies

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Introduction

Carbon capture and storage (CCS) offers climate change mitigation solutions by removing carbon dioxide (CO_2) from the point sources, or the atmosphere, and storing it underground. CCS being a technological approach to carbon removal, natural methods to remove CO_2 – such as afforestation and reforestation – have been effectively utilised throughout the years. This brief will focus on carbon removal as it pertains to CCS, highlighting the critical role the technology can play in removing CO2 from the atmosphere.

Growing interest in CCS and the emissions reductions and removal it provides is largely steered by international net-zero targets, with the Paris Agreement calling for climate neutrality to be reached in the second half of the century. With the transition to a low-carbon economy steadily underway, CCS is gradually becoming recognised as a tool that complements the wide array of climate approaches being utilised to reach climate neutrality. While there has been major momentum in net zero commitments, policies have been slow to incentivise investment in carbon removal technologies so far. Along with highlighting the varied applications of CCS, this brief will provide a summary of ongoing challenges and opportunities tied to carbon removal related policy development.

1. What is carbon removal?

1.1 The role of carbon removal in climate change mitigation

The Paris Agreement has set a goal to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels[1]. The 1.5 degree mitigation pathways project carbon removal in the order of 100–1000 gigatonnes of CO_2 over the 21st century (IPCC, 2018). Carbon removal would be used to compensate for residual emissions and achieve net negative emissions to limit global warming to 1.5°C. The two elements in the climate change mitigation pathways – emission reductions and removals – are behind the arithmetic of net zero emissions, and net negative emissions thereafter.

The role of emission reductions and removals in the mitigation of climate change will change over time. It is widely agreed that emission reductions should be prioritised on the pathway to net zero. This, however, will change once net zero emissions are achieved; net zero is a point on the journey, not the final destination. Carbon removal will become the main driver of climate ambition in the second half of the century.

1.2 How to define carbon removal?

There is no broadly agreed definition of carbon removal. In this brief, the term “carbon removal” is used to describe approaches that can remove CO_2 from the atmosphere and store it away permanently. Other terms like “greenhouse gas removal” (covers CO_2 and other greenhouse gases) or “negative emissions” (not to be confused with net negative emissions) are often used in the same context.

Negative emission technologies (NETs) are sometimes used interchangeably with carbon removal. Whether a NET delivers carbon removal, depends on the details of how it is used in practice, as described in the list below.

[1] In order to deliver this climate change mitigation goal, countries aim to achieve “*a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century*” (Paris Agreement, 2015). Sinks are defined as “*any process, activity or mechanism which removes a greenhouse gas [...] from the atmosphere*" (United Nations Framework Convention on Climate Change, 1992).

There is a list of four criteria that could be used to determine whether a climate solution or technology can deliver greenhouse gas removal (Tanzer and Ramírez, 2019):

1. Physical greenhouse gases are removed from the atmosphere.

2. The removed gases are stored out of the atmosphere in a manner intended to be permanent.

3. Upstream and downstream greenhouse gas emissions associated with the removal and storage process, such as biomass origin, energy use, gas fate, and co-product fate, are comprehensively estimated and included in the emission balance.

4. The total quantity of atmospheric greenhouse gases removed and permanently stored is greater than the total quantity of greenhouse gases emitted to the atmosphere.

The technological greenhouse gas removal approaches discussed in this paper address one greenhouse gas – CO_2. This is the most important greenhouse gas emitted by human activity (IPCC, 2014). Hence, this paper will focus on carbon dioxide removal (CDR, referred to in this paper as carbon removal) which is the main available greenhouse gas removal option.

1.3 Carbon removal approaches

Carbon removal can be achieved through natural and technological approaches (Figure 1). These offer a wide range of approaches for storing CO_2, ranging from biomass, soils, and oceans to storage in deep geological formations. Certain approaches like biochar and bioenergy with carbon capture and storage (BECCS) can be considered as a mix of natural and technological approaches.

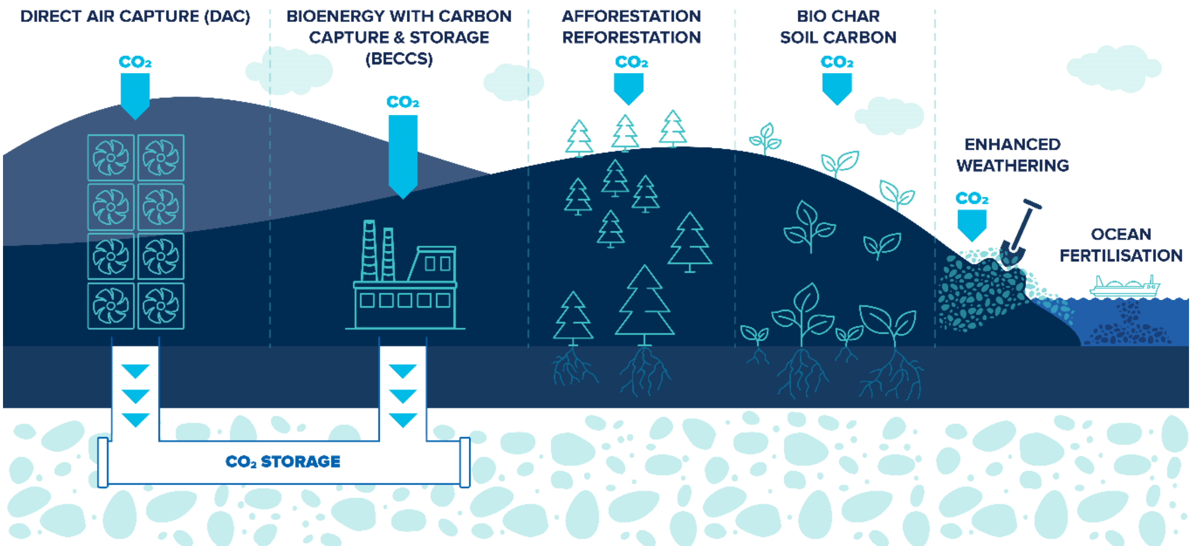

Figure 1. Carbon removal approaches

All carbon removal approaches have different limitations and challenges, be it related to scalability, permanence, cost, impact on land use change and/or biodiversity, or other aspects. It is unlikely that one single approach will be able to sustainably meet the rates of carbon uptake described in integrated assessment pathways consistent with 1.5 ◦C of global warming (Fuss *et al.*, 2018).

This brief focuses on BECCS and direct air capture with carbon storage (DACCS), the technological carbon removal approaches.

2. The dual role of CCS in climate change mitigation

CCS technologies have a dual role in climate change mitigation. First and foremost, CCS technologies can reduce emissions from energy intensive industries and power generation. Secondly, CCS technologies can be used for carbon removal from the atmosphere. The main applications for emission reductions and carbon removal are as follows:

1) Reducing emissions

- **Decarbonisation of heavy industry**, most notably reducing emissions from the production of cement, steel and chemicals. These sectors are amongst the hardest to abate due to their inherent process emissions and high temperature heat requirements. CCS provides one of the most mature and cost-effective options for reducing emissions from these sectors.
- **Clean hydrogen production** by contributing as an enabler of the hydrogen economy via blue hydrogen production.
- **Reducing emissions from recently built power plants**, in particular coal and gas facilities in Asia (Friedmann, Zapantis and Page, 2020).

2) Carbon removal

- CCS provides the foundation for **technology based carbon removal**, including BECCS and DACCS (Global CCS Institute, 2020). BECCS includes the conversion of biogenic Waste-to-Energy with CCS which reduces landfill and methane production and which does not require additional production of biomass.

Figure 2 below highlights the potential contribution of CCS technologies in both reducing emissions and enhancing carbon removal.

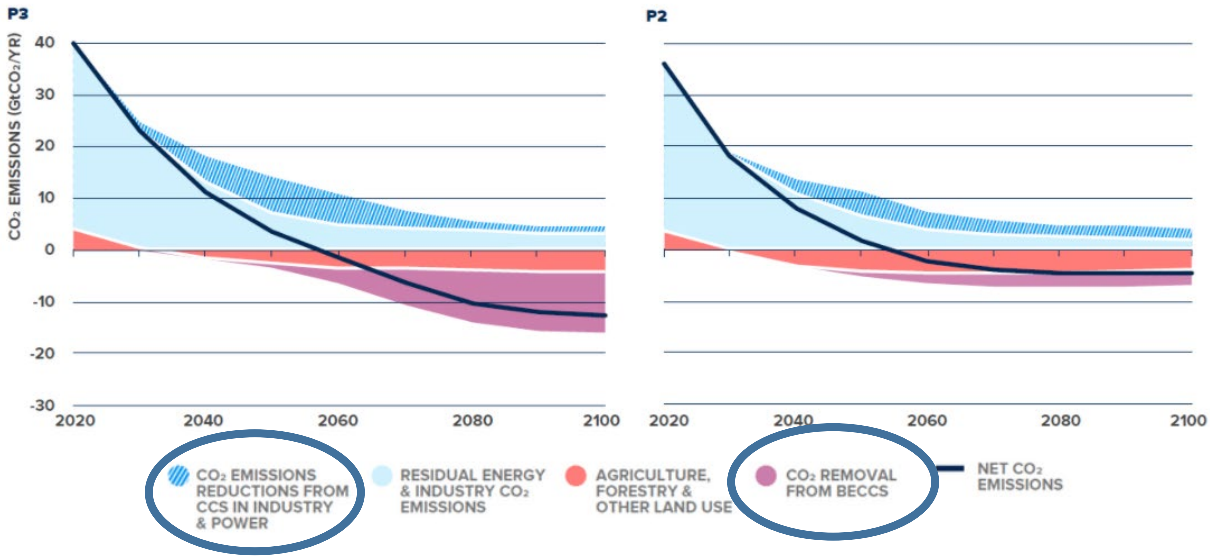

Figure 2. Illustrative mitigation pathways P3 and P2 in the IPCC 1.5 degree report (Global CCS Institute, 2020)

It is the capture part of CCS that makes the difference between achieving emission reductions or carbon removal; the transport and storage of CO_2 always works the same way.

Capturing fossil/end-of-pipe CO_2 can deliver emission reductions, while removing CO_2 from the atmosphere (be it directly or through biomass) can result in carbon removal. It is worth highlighting that geological storage resources for CO_2 are more than sufficient to meet global requirements under any net-zero emissions scenario (Global CCS Institute, 2020).

3. Carbon removal with CCS technologies

While all carbon removal approaches can be complementary, technological approaches like BECCS and DACCS can offer advantages over nature-based solutions, including:

- The verifiability and permanence of underground storage;
- The fact that they are not vulnerable to weather events;
- No risk of fires that can release CO_2 stored in biomass into the atmosphere (IEA, 2020); and,
- In the case of DACCS, much lower land area requirements.

The use of geological CO_2 storage by both approaches can also diversify livelihood for people in areas of geological sequestration; facilitating just transition away from high polluting industry jobs (Buck *et al.*, 2020).

Below is a short overview of both technologies, including their mitigation potential, costs, opportunities and challenges.

3.1 Bioenergy with carbon capture and storage (BECCS)

How it works

BECCS is the most mature of all the carbon removal technologies, as both bioenergy production and CCS have been separately proven at commercial scale. It is also the only negative emission technology currently included in the mitigation pathways in the IPCC 1.5 degree scenarios (IPCC, 2018).

The principle of BECCS is that biomass is grown and used for energy purposes. Biogenic CO_2 is typically counted as a net-zero emission in most greenhouse gas accounting schemes. Therefore, if some of the biogenic CO_2 is captured and stored, this is a net reduction of CO_2 from the atmosphere.

Projects and applications

Most of the world's BECCS facilities involve the capture of fermentation CO_2 from ethanol plants. It is high purity and typically only requires dehydration before it can be compressed for transport and geological storage. An example is the Illinois Industrial CCS facility in the US that has a CCS capacity of one Mt per year. (Global CCS Institute, 2021)

In July 2013, UK based Drax power station converted the first of its six boilers to fire using biomass. Their decision was made in response to the UK Government's 2025 deadline for phasing out coal in the power sector (Global CCS Institute, 2019). This BECCS project is targeting capture of four Mtpa of CO_2 from one of its four power generation units. CO_2 storage will be in the North Sea, with a proposed start date of 2027. This project is part of a larger program to eventually deploy CCS on all four of its bioenergy power units by the mid-2030s. (Global CCS Institute, 2020)

Another example of BECCS is Waste-to-Energy (WtE) with CCS, which is the only way to tackle emissions from a WtE plant. For WtE plants operating on municipal solid waste with a significant biogenic component, CCS can provide a pathway to carbon removal while producing the power and handling the residual waste produced by our growing populations and economies. WtE plants operate at a smaller scale than conventional coal or gas-fired power stations, so their CO_2 capture volumes are also smaller (Kearns, 2019). New technology innovation like oxyfuel combustion WtE plants can make WtE with CCS more economical (Global CCS Institute, 2020).

Mitigation potential and cost

The climate change mitigation potential for bioenergy and BECCS is large, from up to 5 $GtCO_2$ per year (Fuss *et al.*, 2018) to up to 11 $GtCO_2$ per year (IPCC, 2019). However, the effects of bioenergy production on land degradation, food insecurity, water scarcity, greenhouse gas emissions, and other environmental goals are scale- and context-specific (IPCC, 2019).

Integrated assessment models used to develop climate change scenarios generally assume that constraints on biomass production, such as the availability of land, water and fertiliser, do not prevent sufficient biomass supply. A review of the literature identifies that the limiting factor of BECCS is not technology; it is the supply of biomass (Consoli, 2019). Scaling up BECCS will require the development of supply chains for sustainable biomass from the waste products of agriculture and forestry, and potentially significant areas of land for the cultivation of energy crops (Townsend, Raji and Zapantis, 2020).

The cost of implementing BECCS technology varies, the latest estimations put it between US$15-85/ tCO_2 (IEA, 2020). When scaling BECCS beyond a deployment level of 5 $GtCO_2$ per year, the costs are expected to increase as pressures on land and biomass progressively grow with the higher range suggested at US$100-200/ tCO_2 (Fuss *et al.*, 2018).

Accounting challenges

International accounting rules for BECCS are in place[2] but there are certain complications. Different aspects of bioenergy lifecycle (combustion, land use change, transport/conversion, use of fertilisers, removals due to CCS) are reported in different sectors and not linked. As a result, the whole lifecycle effects of bioenergy systems are not captured by the national greenhouse gas inventories. (IPCC, 2019)

3.2 Direct air capture with carbon storage (DACCS)

How it works

Unlike BECCS, DACCS facilities extract CO_2 directly from atmospheric air. This comes with some key advantages:

- Capture plants can be co-located with storage locations, reducing transport costs;
- Plants may be deployed in windy locations reducing the costs of operating fans;
- Plants can be located where they have access to large scale renewable electricity resources.

Capture of CO_2 from the atmosphere is more difficult than capture from other sources because atmospheric CO_2 is very dilute at approximately 400 parts per million. This is just one percent of the CO_2 concentration in flue gas from a gas-fired power station. The energy requirements for concentrating CO_2 from such low levels are considerably higher than those from more concentrated sources. (Global CCS Institute, 2020)

Direct Air Capture (DAC) is a modular technology that can capture CO_2 directly from the atmosphere using chemicals that bind or stick to it. The CO_2 can then be stored or repurposed for CO_2 re-use applications, such as manufacture of construction aggregates, plastics and synthetic fuels.

There are two promising groups of DAC technologies:

- Large infrastructural DAC using water solutions containing hydroxides to extract CO_2 from the air. It requires high temperatures (greater than 800°C) for regeneration, which tends to be provided by burning natural gas.

[2] IPCC Guidelines for National Greenhouse Gas Inventories from 1996, and relevant updates from 2006 and 2019.

- A modular technology based on amine materials bonded to a porous solid support. The process operates at 85°-120°C requiring far less heat energy. There is potential for future cost reductions through mass production. (Global CCS Institute, 2019)

It is important to note the difference between DAC and DACCS, particularly in the context of carbon removal criteria described in chapter 1.2. All elements, including the source of energy for capturing CO_2, and how the captured CO_2 will be stored out of the atmosphere, will define whether the application of this technology delivers carbon removal.

Projects and applications

Combining DAC technology with geological CO_2 storage can deliver carbon removal. While a total of 15 DAC plants are currently operating in Canada, Europe, and the United States, most of them are small-scale pilot and demonstration plants, with the CO_2 diverted to various uses, including for the production of chemicals and fuels, beverage carbonation and in greenhouses, rather than geologically stored (IEA, 2020). One pilot plant, CarbFix in Iceland, is currently storing the captured CO_2 by dissolving CO_2 in water, injecting it into the subsurface and turning it into stone in less than two years through proprietary technology (Carbfix, 2021).

1PointFive, a development company by Oxy Low-Carbon Ventures (a subsidiary of Occidental) and Rusheen Capital Management, plans to finance and deploy Carbon Engineering's large-scale DAC technology in order to develop the world's largest DAC facility. Construction is expected to start in 2022 and when operational, the facility will capture up to one million metric tons of atmospheric CO_2 annually to be used for enhanced oil recovery. Currently, the world's largest individual DAC facilities have the capacity to capture several thousand tons of CO_2 per year (1PointFive, 2021).

Government support

In the US, the Californian low carbon fuel standard (LCFS) enables DACCS projects anywhere in the world to generate LCFS credits (Townsend and Havercroft, 2019). The average price of LCFS credits in 2020 was just under $200 (CARB, 2021). At the end of 2020, the US Congress passed an Energy Act which includes a total authorisation of $447 million for a carbon removal program. DAC is one of the carbon removal approaches to benefit from this funding. (United States Congress, 2021)

The UK government has announced up to £100 million of new research and development funding to help develop direct air capture technologies in the UK (BEIS, 2020).

Mitigation potential and cost

The climate change mitigation potential for DACCS is considered to be large (up to 5 $GtCO_2$ per year) (Fuss *et al.*, 2018). The range of costs for DACCS vary between \$250-\$600/tCO_2 today depending on the chosen technology, low-carbon energy source and the scale of their deployment (Lebling *et al.*, 2021). Depending on the rate of deployment, which can accelerate through supportive policies and market development, costs for DAC could fall to around US\$135-345/tCO_2 though future costs are highly uncertain since this family of technologies is at a comparatively early stage of development (IEA, 2020), making it currently the most expensive carbon removal approach.

Accounting challenges

There are currently no international accounting rules in place for countries to include carbon removal from DACCS in countries' greenhouse gas inventories. Until that changes, carbon removal by DACCS cannot be included under the Nationally Determined Contributions under the Paris Agreement. This is one of the reasons why DAC and DACCS are gaining traction in voluntary carbon markets.

4. Policy developments – why is it complicated?

The massive wave of Net Zero emissions targets in 2020 has helped to explain the "net" in net zero, and the potential role of carbon removal up until the point of net zero and beyond. This has substantially increased interest in BECCS and DACCS among stakeholders.

The policies to incentivise carbon removal have not yet emerged for several reasons. The aspects listed below are strongly interlinked and work will need to progress on all fronts simultaneously to allow for progress. Some of these are relevant for carbon removal in general, others specifically for technological carbon removal approaches.

It is not about the immediate future

The mitigation pathways show the role of carbon removal to start increasing in 2030s, all the way through the 2040s, balancing out all residual emissions at the point of net zero emissions, and seeing carbon removal becoming the main climate change mitigation driver in the world of net negative emissions thereafter.

2050 is still 30 years away (and for perspective, so is 1990) and the pathway to get there will be made up of different phases. The ongoing phase is all about the deep decarbonisation – quick and steep reduction of emissions from all sectors of the economy with the view of getting past global peak emissions as soon as possible. Obviously, technological carbon removal is not the main focus in this phase.

2030s is expected to see continued effort on driving down the emissions but also some growth in technological carbon removal. In order to have policies and incentives in place for 2030s, the preparatory work will have to take place in 2020s. It is especially relevant in the context of BECCS and DACCS projects where deployment relies on access to the CO_2 transport and storage infrastructure which is yet to be developed at scale.

As of early 2020, policymakers have been busy negotiating net zero targets, drafting the necessary legislation and submitting pledges (Nationally Determined Contributions – NDCs) under the Paris Agreement. Aside from the forestry sector, countries have not included carbon removal in their NDCs. Given that the time horizon of NDCs tends to be 2030 (or in some cases only 2025), it is not necessarily surprising.

The specific role of carbon removal

Stakeholders see the role of carbon removal in climate change mitigation differently (Morrow *et al.*, 2020) (Geden and Schenuit, 2020) in the following ways:

- Carbon removal balances out residual emissions from sectors like aviation and agriculture where it is not possible to drive the emissions down to zero (most common interpretation).
  - One possible way of implementing this concept would be to request sectors which have to be allowed residual emissions as a matter of principle, to be responsible for carbon removal, regardless of whether they purchase certificates from other sectors or invest directly in carbon removal methods.
- Carbon removal balances residual emissions while decarbonisation of harder-to-abate sectors such as construction, heavy industry, and heavy transport is being figured out.
- Carbon removal is limited to compensating only for agriculture and land-use emissions or to use it after complete decarbonisation to draw down "legacy carbon" remaining in the atmosphere from past emissions.

Policy design, emission reductions versus carbon removal

There is a concern that if emission reductions are not prioritised, carbon removal as a flexibility mechanism could be used to delay climate action and water down the ambition. In order to address this, there is an overall search for the balance between prioritising emission reductions while already starting to pave the way towards the wider roll-out of carbon removal technologies within the next decade.

While the policymakers are not yet discussing this in any detail, academia has kickstarted their analysis and is suggesting specific thresholds and considerations for setting separate emission reduction and carbon removal targets (Geden and Schenuit, 2020).

Accounting challenges

Designing policies to incentivise technological carbon removal requires robust greenhouse gas accounting rules. On this front, two very different challenges are worth highlighting:

- As mentioned previously, the international accounting rules that countries use to track their emissions are currently only available for BECCS. DACCS is among several new carbon removal approaches where these accounting rules have not yet been developed.
- DAC (and potentially DACCS in the future) has most traction in the setting of voluntary carbon markets. Corporations are looking into DAC in order to achieve their own net zero emissions targets. However, the greenhouse gas accounting by countries and corporations is currently not compatible. As countries are setting more ambitious targets under the Paris agreement, there are bound to be increasing overlaps between the accounting of countries and companies towards net zero. DAC seems to be right in the centre of it.

In Europe, the European Commission is currently preparing a framework for certification for carbon removals, due in 2023. This initiative is poised to tackle all the carbon removal approaches where the accounting challenges loom large, be it related to the amount of carbon removal, permanence of CO_2 storage, life-cycle emissions or other monitoring, reporting and verification challenges. This work could be used later on as an example for other countries to follow, and when discussing international accounting rules on carbon removal (Tamme, 2020).

International cooperation

The potential to reduce greenhouse gas emissions and balance residual emissions with removals is not spread evenly worldwide. After assessing the viability of relying on a portfolio of carbon removal approaches including BECCS, reforestation and DACCS, international cooperation and incentives for the large development of carbon removal seem inevitably necessary (Pozo *et al.*, 2020).

Carbon removal has a long history in international climate negotiations. Carbon sinks (specifically the forestry sector) were inserted in international policy discussions during the negotiation of the Kyoto Protocol in an explicit effort to provide flexibility and low-cost mitigation alternatives for carbon-intensive economies (Jung, 2004). From the intricacies of net accounting to the choices and assumptions by modelers, through to the implementation and governance of specific carbon removal policies, the long history of carbon removal has shown that this is a complicated conversation with differing interests and points of view (Carton *et al.*, 2020).

Conclusion

CCS technologies play two roles in achieving net zero targets – reducing emissions and removing CO_2 from the atmosphere. The two main technological carbon removal approaches – BECCS and DACCS – rely on CCS to permanently store CO_2 out from the atmosphere in deep geological formations.

Both approaches have opportunities and challenges relating to scaling them for carbon removal, and the expected scale of global carbon removal can only be reached when combining a wide range of natural and technological carbon removal solutions.

When designing and implementing policies to deliver net zero targets and net negative emissions thereafter, the main focus so far has justifiably been on emission reductions. However, in order to design appropriate incentives for different carbon removal approaches in time for early 2030s and beyond, it is time to kickstart the policy making process. Carbon removal will need to deliver an increasing amount of climate mitigation action over the coming decades and once the net zero goals have been reached, carbon removal will become the main driver of climate ambition.

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