WORLD ECONOMIC FORUM

What Companies Can Learn from First Movers

# Carbon Dioxide Removal: Best-Practice Guidelines

**WHITE PAPER**

JANUARY 2024

**Images:** Unsplash, Getty Images

# Contents

# Preface

**Nasim Pour**
Lead, Carbon Removals
and Market Innovation,
World Economic Forum

So far in 2023, the average global temperature on one-third of days has been at least 1.5°C higher than pre-industrial levels.[1] At the end of October, scientists warned that within just five or six years, humanity would exceed the remaining carbon budget required for an evens chance of keeping warming to 1.5°C.[2] Yet despite repeated warnings and the commitment of 195 nations in Paris in 2015 to reverse this unfolding climate catastrophe, greenhouse gas emissions continue to rise, not fall.

Decarbonizing the global economy is the primary and most critical challenge. But hot on its heels is an equally pressing priority: to accelerate the rate at which we are removing excess carbon dioxide from the atmosphere. Even if every country and every company achieves net zero by 2050, it won't be enough. We will need to keep removing $CO_2$ for decades afterwards – to reverse the accumulation of historic emissions, to balance out the hardest-to-abate emissions and to safeguard us against Earth's own feedback loops from a warmer world.

The scale of the challenge is, for want of a better word, mind-blowing. Up to 687 billion tonnes of $CO_2$ will need removing by the end of the century – with around 10 billion tonnes a year required by 2050.[3] Currently we are removing around 2 billion tonnes of $CO_2$ a year through natural climate solutions such as afforestation. But we can't just rely on trees, soils and oceans to do our dirty work for us – not least because wildfires and degradation risk releasing the carbon captured by nature.

New solutions are needed urgently – technologies that can deliver additional, permanent and quantifiable impacts at the speed and scale required to make a difference. This white paper examines the promising potential of several of these "engineered" carbon dioxide removal (CDR) technologies, including biochar, bioenergy with carbon capture and storage (BECCS), direct air capture with carbon storage (DACCS) and enhanced rock weathering (ERW). Each solution aims to clear the high bar of the World Economic Forum's First Movers Coalition (FMC) – to demonstrate it can capture and store carbon at scale and with high durability.

The FMC leverages the collective purchasing power of companies to send a clear demand signal to scale up emerging decarbonization technologies that are critical to the net-zero transition. By stimulating sufficient demand, the FMC aims to help accelerate the commercialization of these technologies and ultimately drive down their cost.

Members of the FMC have committed to contract for at least 50,000 tonnes – or $25 million worth – of durable and scalable CDR by 2030. We need more corporate leaders such as these to step up right now and demonstrate demand to the pioneers of engineered CDR, so they can gain the confidence and lines of credit needed to invest in these potentially life-saving technologies.

We have interviewed eight FMC members from different industry sectors to gain their insights into why it's so important to start now, why "wait and see" is not an option, and how best to navigate through this nascent market. This paper charts their experience and calls on every company to make advance purchases of engineered CDR as part of their wider climate strategy.

# Executive summary

In 2022, global emissions were 2 billion tonnes more than in 2015 – a 5% rise. Yet achieving the Paris climate goals requires a decline in emissions of 40–60% by 2030. Decarbonizing 90% of the global economy is the priority according to the Science Based Targets initiative. The remaining 10% will need to come from "negative emissions" – capturing $CO_2$ from the atmosphere and storing it permanently, known as carbon dioxide removal (CDR).

CDR is required for three reasons: 1) to compensate for those last 10% of "hard-to-abate" emissions; 2) to draw down Earth's own emissions from natural feedback loops exacerbated by global warming (e.g. forest fires); and 3) to reverse the accumulation of historic emissions.

By 2050, global emissions must reach net zero, which means removing up to 10 billion tonnes (or "gigatonnes", Gt) of $CO_2$ from the atmosphere every year. Throughout the second half of the century, global emissions have to stay net-negative (where more $CO_2$ is removed than emitted).

This report is aimed at sustainability professionals. It makes the case for engineered CDR solutions and presents guidelines on how to enter the nascent removals market. It draws on interviews with members of the First Movers Coalition (FMC), who have each committed to contract for 50,000 tonnes – or $25 million worth – of durable, scalable carbon removal by 2030.

## The engineered CDR landscape

**Biochar carbon removal (BCR):** creates charcoal when biomass is heated without oxygen, enabling the carbon in the biomass to resist decay. Biochar is more affordable than other engineered CDR but is limited by the availability of sustainable biomass.

**Bioenergy with carbon capture and storage (BECCS):** burns sustainable biomass to produce power and heat or processes biomass. The resulting $CO_2$ is stripped from the flue gas, compressed and stored permanently. Carbon capture is performed by the biomass through photosynthesis.

**Direct air capture with carbon storage (DACCS):** uses filters to trap $CO_2$, which is compressed and stored underground. It uses a small land footprint and offers permanent geological storage, but costs are very high ($600–$1,000/tonne), due to the clean energy required.

**Enhanced rock weathering (ERW):** involves spreading forest soils, croplands and beaches with minerals that dissolve in water and absorb $CO_2$, binding it for hundreds of years. Uncertainty remains about the cost, side effects, permanence and scalability.

To remove 10 Gt of $CO_2$ a year by 2050 requires ramping up all solutions, whether engineered or nature-based. Success depends on **integrity** (delivering an additional, permanent and quantifiable impact) and **scalability** (fast enough to make a difference).

Engineered CDR scores highly on integrity. DACCS and BECCS are clearly additional since the technology is dedicated to removals and would not exist otherwise. Both can store carbon underground for millennia, whereas natural climate solutions (NCS) risk releasing carbon through forest fires or degradation. Engineered CDR solutions, executed in industrial installations, are simpler to quantify.

Current CDR totals 2 Gt $CO_2$/yr, of which 99.9% comes from NCS (e.g. afforestation, reforestation). While only 0.1% results from engineered CDR, it has more potential to scale up, because the space required for NCS is limited by other land uses. The United Nations estimates that the mitigation potential of engineered CDR by 2050 could total 62 Gt $CO_2$/yr, compared to 33 Gt $CO_2$/yr for NCS. The main constraint to scaling up engineered CDR is the high cost, which is where private-sector leaders have an important role to play.

## Why should a company engage in engineered CDR now?

**Corporate climate strategy:** engineered CDR's quality and scalability offers companies greater certainty in meeting climate targets and making credible claims for offsetting residual emissions. Taking a lead in engineered CDR can protect companies from accusations of greenwashing, while improving reputation and competitive edge.

**Business opportunities:** companies can use existing expertise to develop new CDR-related business models, including infrastructure development, equipment manufacturing, plant operations, consulting or trading CDR certificates ("removals").

**Co-benefits:** can contribute to a just transition. Existing fossil fuel infrastructure (e.g. depleted oil and gas fields, pipelines, industrial clusters) can be repurposed for engineered CDR, preventing redundancies or leading to new jobs.

**Leadership:** the world cannot afford to "wait and see" if new CDR technologies will fall in price. Developers of engineered CDR need early adopters with offtake agreements that guarantee future revenue, enabling developers to raise money to scale up.

**Keep overall cost of removals down:** investing in engineered CDR now will make it less expensive in the long term, whereas favouring cheaper NCS today will deplete nature-based solutions, increasing their price.

## How to access the nascent market for engineered CDR

**Secure the budget with an internal carbon price:** Several FMC members have set an internal carbon price based on what they are prepared to pay for the duration of the CDR engagement period. Disclosed prices range from \$80 to \$200/t$CO_2$ by 2030. This strategy has advantages: it removes the uncertainty of annual budget requests; transparency on price sends a clear demand signal to CDR developers; it allows the company to enter long-term offtake agreements; and, importantly, the higher the internal carbon price, the more a company will prioritize emission reductions over CDR. Other FMC members have set a goal that combines a target budget and volume of removals per year.

Choose the right market access model:

- **Direct deal-making with CDR developers:** allows buyers to negotiate the exact contract terms, but comes with substantial transactional effort. Suited to large companies with big offtake volumes looking to build in-house competency and relationships with strategic partners.
- **Buyers' club:** aggregates demand from individual buyers into a managed portfolio of engineered CDR. Members sign one contract with the intermediary and secure diversified removals at competitive prices. Suitable for companies sourcing smaller volumes through long-term offtakes.
- **Over-the-counter purchases:** where engineered CDR certificates are traded among suppliers, brokers and buyers. Prices per tonne are often fixed and carry heavy overheads, but transactions are fast, low-effort and flexible.
- **Consultants:** for companies with limited experience of CDR, who can seek support from a specialist consultant to provide technical advice on access routes and help build a meaningful strategy.

**Communication strategy:** The paper presents examples of how FMC members have communicated their CDR actions in-house and externally, underlining the importance of seeking the broadest buy-in.

# 1 Overview of the challenge

Net zero by 2050 is not the final destination. Thereafter, global emissions will need to become net-negative – and carbon removals offer the only pathway to that goal.

## 1.1 Why carbon removal is essential to achieving the Paris goal

By 2050, nearly **10 billion** tonnes of $CO_2$ may have to be removed from the atmosphere annually

The speed at which the planet is warming is currently greater than the speed at which the global economy is reducing its emissions. Since December 2015 – the date when 195 nations signed the legally binding Paris Agreement to pursue "efforts to limit the temperature increase to 1.5°C above pre-industrial levels"[4] – net greenhouse gas emissions have not fallen but risen, despite a COVID-19-induced blip. Last year, total estimated emissions were nearly 2 billion tonnes more than in 2015 – an increase of roughly 5%.[5]

According to the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC), achieving the goal envisioned in the Paris agreement will require a decline in global net anthropogenic $CO_2$ emissions of 40–60% by 2030 (compared to 2010), en route to net zero by 2050.[6] To achieve this 2030 target means reducing emissions by the pandemic-level equivalent of a 7% drop every year (see Figure 1).

Decarbonizing the way humanity lives, travels, makes things and consumes them is the top priority. According to the Science Based Targets initiative (SBTi), companies need to reduce the absolute emissions of their value chains by at least 90%. Remaining emissions must be removed or "neutralized" through permanent carbon dioxide removal (CDR), not through conventional carbon avoidance certificates. As per SBTi's Corporate Net-Zero Standard, "a company is only considered to have reached net-zero when it has achieved its long-term science-based target and neutralized any residual emissions".[7]

Each of the four "model pathways" presented by the IPCC in its 2018 special report *Global Warming of 1.5ºC* depends upon some degree of CDR.[8] This process is also known as "negative emissions" and it takes the world beyond net zero to a point where more $CO_2$ needs to be removed than is being emitted.

The predicted volumes of CDR that will be needed are eye-watering. Even for the two more moderate IPCC scenarios, cumulative carbon capture and storage (CCS) in the realm of 348–687 billion tonnes will be needed by the end of the century.[9] By 2050, nearly 10 billion tonnes of $CO_2$ may have to be removed from the atmosphere annually, according to the median estimates of several of the IPCC's net-zero scenarios.[10]

CDR is required for three reasons:

- To compensate for "hard-to-abate" emissions (the last 10% in SBTi's Corporate Net-Zero Standard) necessary to deliver authentic net zero
- To draw down the Earth's own emissions resulting from the natural feedback loops of a warming planet, such as forest fires or methane escaping from melting permafrost
- To reverse the accumulation of historic emissions

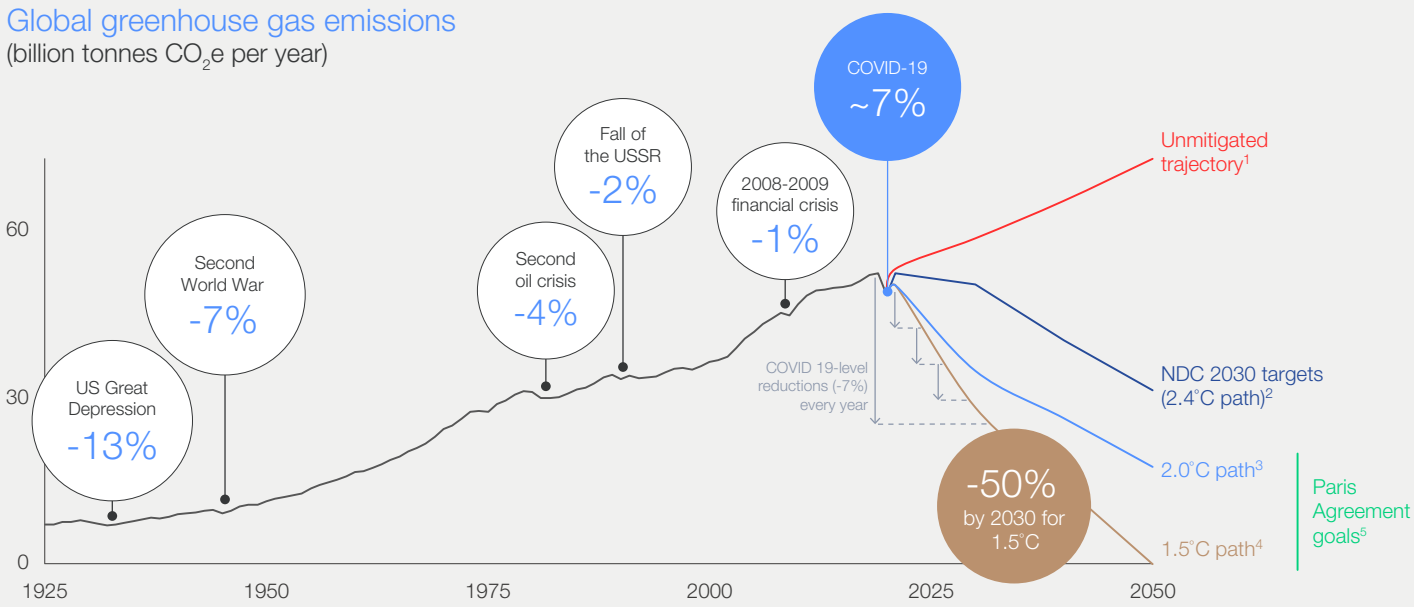
This last case is significant. Since 1990, the year when the IPCC published its first report, humanity has emitted more greenhouse gases than in all recorded history before that date.[11] To begin to restore the climate, these accumulated emissions need to be removed – permanently. That means net zero by 2050 is not the final destination. From mid-century onwards, global emissions will need to become net-negative – and CDR offers the only pathway to that goal (see Figure 2).

> **Since 1990, humanity has emitted more greenhouse gases than in all recorded history before that date.**
>
> Institute for European Environmental Policy

Figures 1 and 2 summarize what needs to happen to achieve the Paris Agreement goals:

- Halve emissions by 2030
- Net-zero emissions by 2050
- Net-negative emissions after 2050

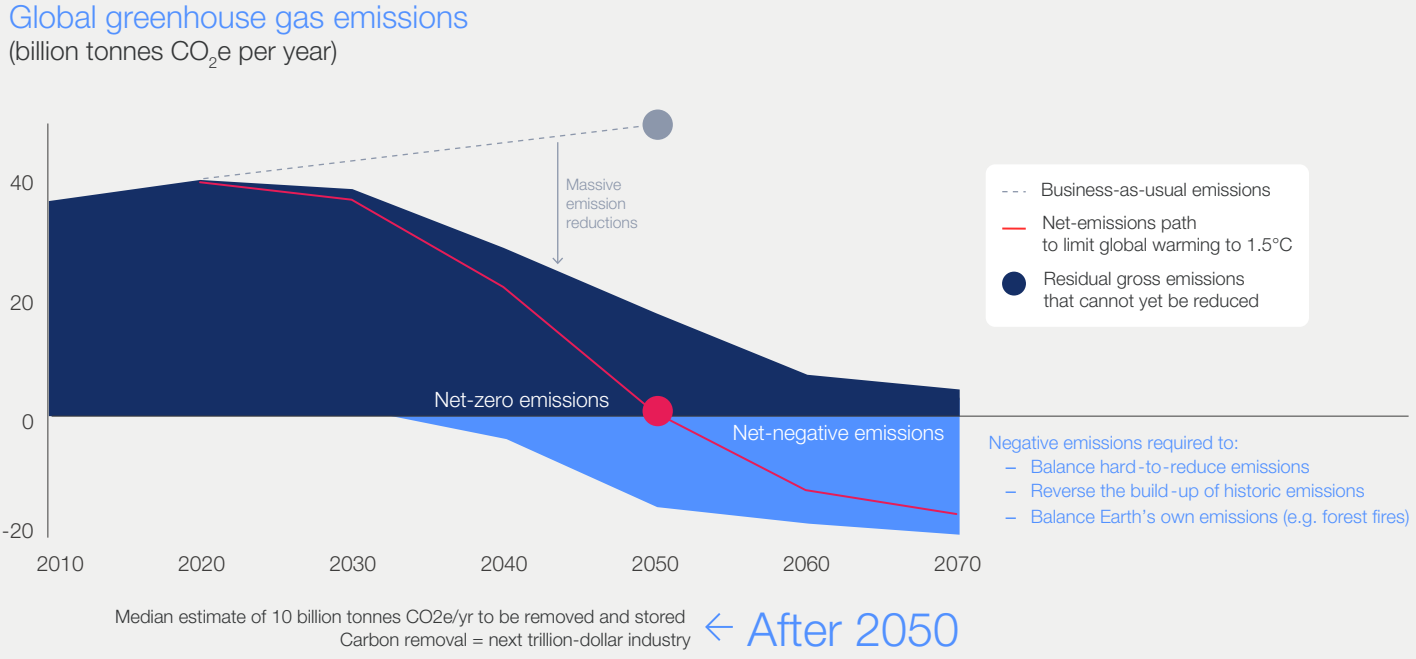
FIGURE 1 **The emissions trajectory needed to deliver the goals of the Paris Agreement**




**Notes:** 1. Assumes GHG emissions rebound and grow from 2020 at the same rate as the current policies scenario in UNEP 2019 Gap report to 2050 (1.1% CAGR); 2. Assumes countries decarbonize further at the same rate required to achieve their Nationally Determined Contribution (NDC) between 2020 and 2030; 3. Assumes 25% reduction by 2030 and net zero by 2070; 4. Assumes 45% reduction by 2030 and net zero by 2050; 5. Paris Agreement goals are to limit global warming to 2.0°C, preferably 1.5°C. Figures exclude land use, land-use changes and forestry.

**Source:** World Economic Forum[12]

FIGURE 2 **Beyond net zero – negative emissions required through carbon removals**




**Note:** Different emissions scenarios require different quantities of carbon dioxide removal based on timing and quantity of gross emissions reductions.

**Source:** World Economic Forum[13]

## 1.2 Status of carbon removal technologies

Today, CDR is still in its infancy. Few companies have successfully engaged with it and there are many roadblocks for those that have begun the process. The current focus is on natural climate solutions (NCS) to remove carbon since they are affordable and ready to use. It is inherently important to support NCS, owing to their co-benefits, such as to biodiversity, ecosystem services, natural catastrophe resilience and so on.

The other family of carbon removal solutions is called engineered CDR (or technological CDR), where engineering tools – instead of plants and soils – are used to capture and store atmospheric $CO_2$. Today, these technologies are barely developed, despite the expectation that they will deliver the majority of the carbon removal capacity the world needs over the long run.

Thus, not only are emission reductions a gargantuan task that allows no further delays but so too is the build-up of a carbon removal industry capable of delivering enough negative emissions at scale and on time. To be aligned to global climate goals, a company's climate strategy needs to address both sides of the challenge immediately.

## 1.3 Purpose of this report

This report is for sustainability professionals who are in the process of adding CDR to their companies' climate strategy. It makes the case particularly for engineered CDR solutions and seeks to lower the entry barriers to the nascent removals market.

The report shares lessons learned by members of the World Economic Forum's First Movers Coalition (FMC and provides best-practice guidelines for companies looking to enter the engineered carbon removal space. Many companies are asking legitimate questions such as: Why enter the engineered CDR market when the technologies are so unproven? Why not wait and see if the prices come down before committing?

This report involved interviewing eight leading members of the FMC that have committed to the coalition's CDR target: to contract for either 50,000 tonnes – or at least $25 million worth of – durable, scalable net carbon removal by the end of 2030 (see Box 1).

BOX 1 **FMC commitment to carbon dioxide removal**

"Members commit to contract for durable and scalable net carbon dioxide removal to be achieved by the end of 2030, in addition to their maximal direct emission reduction efforts.

Members may choose to contract for at least 50,000 tonnes of durable and scalable net carbon dioxide removals to be achieved by the end of 2030, or as an alternative may choose to contract for at least $25 million of durable and scalable net carbon dioxide removals to be achieved by the end of 2030."

The FMC's criteria for "durable and scalable" are solutions that demonstrably store captured carbon for 1,000 years and solutions that can potentially store at least 1 million tonnes (Mt) of carbon by 2030 and 1 billion tonnes (Gt) by 2050.

**Source:** World Economic Forum, First Movers Coalition[14]

This white paper is organized as follows:

**Part 1** provides an overview of the carbon removal challenge.

**Part 2** provides an introduction to engineered CDR and its nascent market.

**Part 3** focuses on why companies should engage in engineered CDR now and provides arguments that interviewed FMC members have brought forward to make the case to their decision-makers.

**Part 4** provides insights from FMC members regarding how to access the market for engineered CDR, including securing the budget, choosing a market access model and communicating CDR actions in-house and externally.

The **Appendix** outlines the questions each interviewee company was asked during research for this report.

# 2 The engineered CDR landscape

Engineered CDR technologies are still underdeveloped, despite their quality features. Investing in them now can help ensure they are available at scale and on time.

## 2.1 Carbon removal technologies available in the market

Methods to remove carbon dioxide from the planet's atmosphere are typically divided into NCS[15] and engineered CDR.

Engineered CDR solutions include biochar, bioenergy with carbon capture and storage (BECCS), direct air capture with carbon storage (DACCS) and enhanced weathering. Data on cost per tonne and mitigation potential in this section are all long-term estimates for 2050, sourced from the IPCC's 2022 Sixth Assessment Report.[16]

> In the IEA's net zero by 2050 scenario, DACCS needs to capture almost 60 Mt $CO_2$/yr by 2030.

**Biochar carbon removal (BCR):** based on a type of charcoal created when biomass from crop residues, grass, trees or other plants is combusted at high temperatures without oxygen. This process, known as pyrolysis, enables the carbon in the biomass to resist decay.[17] When mixed with existing soil, most biochar options are expected to have a durability of less than 500 years.[18] However, some recent studies suggest that biochar could last 1,000+ years, depending on the feedstock and temperature of pyrolysis used.[19] Biochar also improves soil fertility.

Making biochar is a more affordable process than other engineered CDR solutions. The IPCC estimates the cost of biochar at $10–$345 per tonne of $CO_2$ removed, with a mitigation potential of 0.3–6.6 Gt $CO_2$/year by 2050.[20] Given its relative affordability, biochar currently represents about 80% of all engineered removals.[21] It can therefore be scaled up both rapidly and immediately.[22] Its removal potential, however, is limited by the availability of sustainable biomass (typically crop and forestry residues), for which there are competing uses.

**Bioenergy with carbon capture and storage (BECCS):** a technology that burns biomass to create energy or processes it to produce biofuel. The resulting $CO_2$ is stripped from the flue gas using technology developed for carbon capture at large point sources (e.g. post-combustion, pre-combustion or oxyfuel). The effectiveness of the carbon removal relies on two separate processes. First, the amount of carbon sequestered by the biomass during its organic growth through photosynthesis must exceed the amount of $CO_2$ emitted through planting it, harvesting it and transporting it to the BECCS facility. Second, the captured $CO_2$ must be stored permanently; for example, by compressing and pumping it deep underground into geological storage formations (porous rock layers that are sealed with an impermeable caprock) or into depleted oil reservoirs. One noteworthy BECCS use case is to burn waste (e.g. municipal solid waste). In this waste-to-energy process, the biogenic fraction of the waste being burnt results in negative emissions if the $CO_2$ in the flue gas is captured and stored. The main advantage of BECCS is the renewable energy that is "co-generated" while producing negative emissions.

The IPCC estimates the cost of BECCS at $15–$400 per tonne of $CO_2$ removed, with a mitigation potential of 0.5–11 Gt $CO_2$/year by 2050.[23] As of September 2022, around 2 million tonnes (Mt) of biogenic $CO_2$ were being captured per year. In the net zero emissions by 2050 scenario of the International Energy Agency (IEA), BECCS needs to capture around 250 Mt $CO_2$/yr by 2030. Momentum is building, however, with plans announced for more than 50 new BECCS facilities with a combined capacity of around 20 Mt $CO_2$/yr, according to the IEA.[24] As is the case with biochar, the limited availability of sustainable biomass will eventually curtail BECCS' removal potential.

**Enhanced rock weathering (ERW):** mimics the natural $CO_2$ cycle where minerals slowly dissolve in surface waters, which allows these waters to absorb more atmospheric $CO_2$ and bind it for hundreds of years if left undisturbed. Minerals that naturally absorb carbon dioxide, such as dunite or basalt, are ground up and spread across forest soils, cropland and beaches. Atmospheric $CO_2$ and water react with these finely ground silicate rocks to form bicarbonate ions that then precipitate in soils and drainage waters as solid carbonates or remain dissolved and increase alkalinity levels in the ocean when the water reaches the sea. This engineered process accelerates the natural capacity of minerals to sequester carbon from geologic to human timescales and can result in permanent sequestration of 1,000+ years.

Uncertainty remains regarding cost, side effects, durability and scalability. However, unlike other engineered CDR options, ERW does not require new infrastructure or technology. In 2022, the IPCC put the costs of enhanced weathering at $50–$200 per tonne of $CO_2$ removed, with a mitigation potential of 2–4 Gt $CO_2$/year.[25]

**Direct air capture with carbon storage (DACCS):** this technology uses banks of fans to pass ambient air through physical or chemical filters that selectively trap the $CO_2$ molecules. As with BECCS, the captured $CO_2$ can then be compressed or stored in deep geological formations for thousands of years. The benefits of DACCS as a CDR option include high storage permanence (when stored geologically) and a limited land and water footprint. Alternatively, instead of producing negative emissions, the captured $CO_2$ can be combined with hydrogen to produce synthetic fuels.

The IPCC estimates that the cost of DACCS will fall by 2050 to around $100–$300 per tonne of $CO_2$ removed, with a mitigation potential of 5–40 Gt $CO_2$/year.[26] Today, however, the cost is far higher, caused mainly by the large amount of clean energy used in its air filters. Data from the Boston Consulting Group (BCG) published in June 2023 suggests the end-to-end cost of $CO_2$ removal using direct air capture including final storage is between $600 and $1,000 per tonne today. BCG believes that reducing the costs of DACCS to $150–$200 per tonne by 2050 is possible, but this would require "a massive step up in investments, government support, collaboration models and broader industry engagement".[27]

The scalability of DACCS is therefore limited by its cost, which is primarily driven by the large amount of clean energy used in the air filters. As a result, there are currently only 18 direct air capture plants operating worldwide, capturing just 0.01 Mt $CO_2$/yr – although a 1 million tonne/yr plant is in advanced development in the US. According to BCG, even if capacity were to scale up to 100–400 million tonnes of deployment per year, the cost is likely to remain at around $300–$400 per tonne – unless the technology sees a step change in deployment rates, access to low-cost capital, supportive infrastructure and energy prices and actions that accelerate collaborative learning.

In the IEA's net zero by 2050 scenario, DACCS needs to capture almost 60 Mt $CO_2$/yr by 2030. "This level of deployment is within reach, but will require several more large-scale demonstration plants to refine the technology and reduce capture costs," notes the IEA.[28]

**"As part of its Inflation Reduction Act, the US government offers a tax credit of $180 for every tonne of permanently stored $CO_2$.**

**“ To make DAC cost-effective, the industry will need to scale up to one gigatonne per year, which will take $200 billion of investment.**

The challenge of getting DACCS to scale is similar to the challenge facing BECCS. It takes more than just building the direct air carbon capture plant. An entire infrastructure is required around transporting the captured $CO_2$ and storing it underground. This raises some important questions: To what extent is the whole supply chain supporting these innovations? Who will build and operate the infrastructure for transporting and storing the $CO_2$? And who should pay for it?

While recent analysis by BCG[29] suggests that the high costs of DAC could come down considerably, possibly to as little as $100–$200 per tonne, it will take the right combination of factors. Stronger demand signals are needed from buyers committing to advance purchases, which in turn lead to accelerated levels of deployment. Technology developers need greater access to low-cost renewable energy and affordable capital. There also needs to be more knowledge-sharing and collaboration, as currently “companies are carrying out development within walled gardens to protect their intellectual property,” according to BCG. And governments need to frame a favourable policy environment (see Figure 3) – for example, as a result of last year’s Inflation Reduction Act, the US government offers a tax credit of $180 for every tonne of permanently stored $CO_2$.

As an industry scales up, capital expenditure (capex) and unit costs typically come down. For example, the successful scaling up of the solar industry has led to an impressive fall in prices per megawatt hour (MWh) in recent decades. However, BCG argues that the gas industry is a closer analogue to DAC. Capex costs for gas turbines have fallen by 15% for every doubling in production capacity. To make DAC cost-effective, the industry will need to scale up to one gigatonne of annual capacity, which in turn will take about $200 billion of additional capex and operating expenses (opex) investment.

FIGURE 3 **Three scenarios to drive down the cost of direct air capture (DAC)**

| Cost/$tCO_2$ | Description | DAC capacity/yr |
|---|---|---|
| $300–$400/tonne (policy-as-usual) | DAC plays limited role as premium credit in voluntary market<br>Development enabled by isolated cases of supportive policy and philanthropy | 100–400 Mtpa |
| <$200/tonne | Favourable policy encourages deployment<br>Low collaboration on technology development given competition between players for market share | 1,000–2,000 Mtpa |
| <$100/tonne | Favourable policy encourages deployment<br>High collaboration enables knowledge spillover effects<br>Synergies from dedicated low-carbon infrastructure further reduces cost | 2,000–3,000 Mtpa |

DAC plays a substantial role in the path to net zero

**Note:** Mtpa = million tonnes per year.

**Source:** Boston Consulting Group (BCG)

# 2.2 Quality features of engineered CDR

**Two overarching criteria will determine the success of carbon removals: integrity and scalability.**

As noted earlier, according to the IPCC, at a global scale up to 10 billion tonnes (10 Gt) of carbon dioxide must be removed from the atmosphere every year from 2050. To achieve that requires ramping up all available solutions, whether NCS or engineered CDR.

Two overarching criteria will determine the success of this venture: **integrity** and **scalability**. Any high-integrity carbon removal solution must make an additional, permanent and quantifiable impact on reducing emissions. It must also be capable of scaling up at the speed and volume required to make a difference. This section looks at the relative advantages of engineered CDR against some of these criteria.

## Integrity

The Integrity Council for the Voluntary Carbon Market (ICVCM) has framed 10 Core Carbon Principles that define when carbon credits are "high-integrity", under three broad headings: governance, emissions impact and sustainable development (see Figure 4).

Below, three of ICVCM's high-integrity carbon credit principles related to emissions impact – additionality, permanence/durability and quantification – are examined. These principles will prove vital in the quest to cut the amount of $CO_2$ in the atmosphere to levels consistent with a 1.5–2.0°C pathway. They are also areas where NCS have been challenged in recent years. While NCS will remain a critical tool to tame climate change – as well as offering multiple co-benefits – engineered removals score particularly highly against these principles.

TABLE 1 **The ICVCM's Core Carbon Principles**

| 10 Core Carbon Principles – to ensure carbon credits are "high-integrity" | | |
|---|---|---|
| **Governance** | Effective governance | Have effective programme governance to ensure transparency, accountability, continuous improvement and the overall quality of carbon credits. |
| | Tracking | Operate or make use of a registry to uniquely identify, record and track mitigation activities and carbon credits issued to ensure credits can be identified securely and unambiguously. |
| | Transparency | Provide comprehensive and transparent information on all credited mitigation activities. The information shall be publicly available in electronic format and shall be accessible to non-specialized audiences, to enable scrutiny of mitigation activities. |
| | Verification | Have programme-level requirements for robust independent third-party validation and verification of mitigation activities. |
| **Emissions impact** | Additionality | GHG emission reductions or removals from the mitigation activity shall be additional, i.e. they would not have occurred in the absence of the incentive created by carbon credit revenues. |
| | Permanence | GHG emission reductions or removals from the mitigation activity shall be permanent or, where there is a risk of reversal, there shall be measures in place to address those risks and compensate reversals. |
| | Quantification | GHG emission reductions or removals from the mitigation activity shall be robustly quantified, based on conservative approaches, completeness and scientific methods. |
| | No double counting | GHG emission reductions or removals from the mitigation activity shall not be double counted, i.e., they shall only be counted once towards achieving mitigation targets or goals. Double counting covers double issuance, double claiming and double use. |
| **Sustainable development** | Benefits and safeguards | Have clear guidance, tools and compliance procedures to ensure mitigation activities conform with or go beyond widely established industry best practices on social and environmental safeguards while delivering positive sustainable development impacts. |
| | Contribution to net-zero transition | Mitigation activity shall avoid locking-in levels of GHG emissions, technologies or carbon-intensive practices that are incompatible with the objective of achieving net zero GHG emissions by mid-century. |

**Source:** Integrity Council for the Voluntary Carbon Market (ICVCM)[30]

❝ The IPCC's top-end estimates for the mitigation potential of engineered CDR by 2050 total 62 Gt $CO_2$/yr, compared to 33 Gt $CO_2$/yr for nature-based removals.

**Additionality:** According to ICVCM: "The GHG emission reductions or removals from the mitigation activity shall be additional, i.e. they would not have occurred in the absence of the incentive created by carbon credit revenues." Put another way, these emissions would not have been reduced or removed unless the project had been implemented. Engineered solutions such as DACCS can easily be defined as additional, since the technology is dedicated solely for the purpose of CDR.

**Permanence/durability:** It is important to know that any carbon captured for the sake of producing negative emissions is locked away for the foreseeable future. Engineered solutions score very highly on durability. They are not prone to the risks of wildfires or droughts that can reverse NCS – risks that will increase in a warming world. Carbon captured through engineered CDR, either directly from the air using DACCS or from flue gases using BECCS, can be compressed and stored underground for centuries to millennia.

**Quantification:** Engineered solutions such as DACCS are contained within industrial processes and installations that are more amenable to measurement and quantification than NCS. While this may be something of an oversimplification, it is frequently said that with engineered CDR all that is needed is a flowmeter.

## Scalability

The current scale of carbon dioxide removals is nothing like sufficient, considering the IPCC's estimate that around 10 Gt $CO_2$/yr will be needed by mid-century and possibly even more throughout the second half of the century. According to *The State of Carbon Dioxide Removal*, published in 2023 by a team of researchers led by the University of Oxford, current CDR totals 2 Gt $CO_2$/yr, of which 99.9% comes from NCS, primarily via afforestation and reforestation.[31] Just 0.1% results from what the researchers call "novel CDR methods" (e.g. DACCS, BECCS and biochar). The authors note that the levels of CDR required in the second half of this century will be feasible only if there are substantial new deployments of novel CDR in the next decade.

While NCS are limited by other land uses (e.g. food and feed production, infrastructure, Indigenous ownership, etc.), an important advantage of engineered CDR is that far less physical space is required. In principle, there is no limit to the scalability of engineered solutions such as DACCS when it comes to space. However, the current prohibitively high cost of engineered CDR is a major hurdle to scalability. The requirement for additional infrastructure (e.g. clean energy, pipelines, storage sites, etc.) are also significant constraints.

Top-end estimates for the mitigation potential of engineered CDR by 2050 total 62 Gt $CO_2$/yr, compared to 33 Gt $CO_2$/yr for nature-based removals.[32] While it is tricky to predict near-term demand for engineered CDR by 2030, researchers at Dartmouth College in the US have estimated demand for certified technical removals in 2030 at between 31 Mt $CO_2$ and 623 Mt $CO_2$ per year, depending on the adoption by various compliance markets.[33]

## Standards and criteria

One of the main challenges with engineered CDR is the lack of mature quality standards. In a 2022 report on DAC published by the IEA, one of the six priorities for direct air capture deployment is standards: "Develop internationally agreed approaches to DAC certification and accounting. Robust, transparent and standardised international certification and accounting methodologies for DAC are needed to facilitate its recognition in carbon markets and IPCC greenhouse gas inventory reporting."[34]

The International Carbon Reduction and Offset Alliance (ICROA) offers an accreditation programme, "recognised since 2008 as the industry standard for VCM [voluntary carbon market] organisations promoting GHG emission reductions and offsetting to the highest standards of environmental integrity". ICROA published version 2.1 of its *Code of Best Practice* in July 2023.[35]

NextGen, a buyers' club for carbon removals, requires all CDR projects from which it purchases credits to go through an ICROA-endorsed certification process to provide a degree of independent verification and public transparency on quality. NextGen is also working on methodologies to support the third-party verification of engineered CDR.

# 3 Why engage in engineered CDR now?

For some companies, engineered CDR solutions offer greater certainty around delivering on net zero. For others, they could become a core business opportunity. Either way, they are here to stay.

The overarching challenge facing engineered carbon removal is cost. The FMC[36] of the World Economic Forum has set a CDR target for its members to contract for at least 50,000 tonnes – or at least $25 million worth – of "durable and scalable net carbon dioxide removal to be achieved by the end of 2030".[37] The arithmetic of this target acknowledges a mean cost today of $500 per tonne of CDR. How is it possible to convince the board about such an apparently costly engagement? This chapter sheds light on the most pertinent arguments in favour of engaging in engineered CDR now.

## 3.1 It's good for corporate climate strategy

Engineered CDR provides companies with the credible, scalable carbon removals required for net zero. Companies that have committed to net-zero goals need a reliable portfolio of carbon removal services to deliver on the "net" in net zero. As outlined in the previous section, engineered CDR scores particularly highly in terms of both the integrity and the scalability of the underlying climate change mitigation outcome. While NCS remain a vital tool in combatting climate change – and are uniquely valuable given their nature-positive co-benefits – engineered removals bring a level of additionality and durability that NCS find hard to match.

Accordingly, the most compelling and widely cited argument for engineered removals among the FMC members interviewed is that they can help protect against the potential integrity shortcomings frequently associated with NCS.

Reputational risk arising from negative publicity is also a growing concern. Some companies face the allegation that they are hiding the slow pace of their carbon abatement behind a net-zero "fig leaf".[38] Others have encountered legal challenges to their carbon neutrality claims,[39] plunging many companies into uncertainty, inaction or attempts to hide their participation in carbon markets ("greenhushing").

One interviewee put it this way: "Carbon offsetting is so difficult to manage in the face of public opinion that we're looking at ways to avoid offsetting altogether."

Expectations regarding what companies can and cannot claim in relation to carbon certificates are becoming more stringent. In June 2023, the Voluntary Carbon Markets Integrity Initiative (VCMI) released its *Claims Code of Practice* – a rulebook that moves the debate from "offsets" to "contribution claims" and states: "carbon credits cannot be counted towards the achievement of within-value chain emission reduction targets, but instead represent a contribution to both the company's climate goals and global efforts to mitigate climate change".[40]

When it comes to scalability, companies are worried that – due to constraints on the land area available for planting trees and other nature-based solutions – there simply will not be enough NCS to go round.

"There is a limitation of supply in high-quality nature-based removals," says Kazura Koda, General Manager of the Carbon Desk for Mitsui O.S.K. Lines (MOL), a global shipping company based in Japan.

MOL is targeting a total of 2.2 million tonnes of carbon removals by 2030 as a part of its mitigation actions beyond the value chain. “So if we want to neutralize our emissions in the year of achieving net zero and we cannot just rely on natural climate solutions, then we have to support and scale up the CDR market.”

> **There is a limitation of supply in high-quality nature-based removals. So if we want to neutralize our emissions in the year of achieving net zero and we cannot just rely on natural climate solutions, then we have to support and scale up the CDR market.**
>
> Kazura Koda, General Manager of the Carbon Desk, Mitsui O.S.K. Lines (MOL)


## 3.2 It provides business opportunities

Engineered CDR offers commercial opportunities. The technology, or a link in its value chain, could become part of some companies’ day-to-day business activities. An emerging industry such as engineered CDR that combines highly innovative technology, considerable capital risk and very little commercial track record will require many dimensions of expertise in financing, infrastructure development, de-risking and operations.

The size of the potential pie – commentators often refer to CDR becoming the next trillion-dollar industry – invites all players in the economy to study the CDR value chain and anticipate where to slice into it. Put another way: they are looking at where they can use their existing corporate expertise and expand their business activities, or develop new business models that either support or are directly integrated into the new CDR value chain.

One interviewee characterized the opportunity this way: “Don’t just write a cheque. Look at investments that complement your existing business processes and environment. And think of your reputation and aspirations, too – just writing a cheque doesn’t make you a leader.”

Below are the perspectives of two global companies that have committed to FMC’s CDR target and are looking to make carbon removal part of their core business. Each story brings a unique angle, one from the viewpoint of the international commodity trader, the other from a global energy major.

## **Perspective #1:** The international commodity trader

Trafigura is a multinational commodity trading company that is approaching the carbon removal sector from the perspective of developing carbon assets like any other natural resource. Hannah Hauman, Global Head of Carbon Trading at Trafigura, explains the opportunity: "Trading exists to solve the natural mismatch between production and consumption requirements, be it physical commodities or the carbon balance. Wherever there are gaps and inefficiencies between supply and demand, whether it's related to time, technology or policy, there is value in closing those gaps."

Trafigura's aim is to fuse the worlds of the institutional investor and the technology developer to create bankable projects. "There's a reason that carbon dioxide removal today is not successfully scaling: projects are not yet seen as bankable," says Hauman, who adds: "To bridge the worlds of the project and the investor, what's needed is a combination of technical and policy understanding, price risk management and what's effectively venture capital funding – that's a huge ask for one organization."

To date, Trafigura has deployed hundreds of millions of dollars "to scale removals that wouldn't otherwise exist". Although customers will not need these removals until 2026–2027, "unless we start now, they won't be ready," says Hauman. Trafigura's aim is to "progress from a carbon finance world driven by philanthropy to a carbon accounting market focused on net-zero claims". In turn, this means reframing the opportunity to buyers to suit a procurement stance, "where buyers know what they want to buy and can have surety on the number of tonnes delivered, when and at what price".

> **Our aim is to progress from a carbon finance world driven by philanthropy to a carbon accounting market focused on net-zero claims.**
>
> Hannah Hauman, Global Head of Carbon Trading, Trafigura

One of the main limitations in attracting capital for carbon removal projects is the lack of a track record. Trafigura's approach is therefore to work with a developer or project owner to make their project bankable. This means de-risking the project finance by taking it onto Trafigura's balance sheet initially, demonstrating performance, then inviting others to get involved – from banks and insurers to alternative investment funds and pension funds. "Incubating and scaling is one of the things that we do best," says Hauman.

## **Perspective #2:** The global energy major

The AES Corporation is a Fortune 500 energy company that aims to lead the industry in the responsible transition to low-carbon and zero-carbon sources of energy. Michael Baute, AES's Entrepreneur-in-Residence for Carbon Removal, believes there is a critical gap in the CDR sector. "I'm not seeing the project developer at the table," he says, adding: "The question is: Who's going to own these assets?" Baute wants to leverage AES's expertise as a project developer to support project management and commercialization of the sector – raising the finance, securing offtake deals, acquiring land, securing permits, site management, consolidating commercial standards and scaling up CDR technologies into a viable, large-scale industry. Technology developers can then focus on getting the technology working at the right price for the market.

Baute is evaluating development opportunities in everything from DACCS and BECCS to other as-yet-unproven technologies. "Our interest is in infrastructure development – we're talking megatonnes and beyond," says Baute, "but until we can secure offtake at large volumes, it's challenging to find the project finance for what we want to do."

So how could money be raised for this type of infrastructure? "Capital markets are answering the call," says Baute. "They want to participate, but they're looking for ways to de-risk." Government incentives are certainly helping, especially President Biden's Inflation Reduction Act (IRA), signed into law in August 2022. "At this time, the projects don't pencil without the 45Q," says Baute, referring to the clause in the IRA that deals with tax credits for carbon capture, utilization and storage. "We also need support for a greater degree of tech agnosticism, beyond simply DACCS and BECCS," he adds.

> **Let's start with $150 a tonne by 2040. That won't materially impact global GDP, but anything higher and we don't think it'll scale.**
>
> Michael Baute, Entrepreneur-in-Residence for Carbon Removal, The AES Corporation

One additional concern is over how long such government tax credits will last. Baute is tracking the CDR policy landscape in other countries, as well, to assess their appetite for state support for the sector. That said, he is open about AES's working assumption on price per tonne for removed carbon. "We don't know if we'll get there, but let's start with $150 a tonne by 2040," he says, adding: "That won't materially impact global GDP, but anything higher and we don't think it'll scale."

## 3.3 Leadership is essential – 'wait and see' is not an option

Whatever the rationale for investing in CDR, if a company plans on using removals to balance residual emissions by its net-zero target year, say 2050, it cannot wait until 2049 before starting to think about where to get them from. Simply hoping that others will step up and pay the first-mover price that allows costs to come down is a behaviour described in economics as the "freerider problem".

None of the companies interviewed envisages a rapid uptake of engineered CDR among buyers of carbon certificates. But they all agree that for engineered CDR solutions to be commercially viable and operational at the required scales by the 2030s, 2050s and beyond, it is imperative to start investing now. Put another way, leadership is essential.

One interviewee company, Salesforce, used the Forum's May 2022 annual meeting in Davos to announce a commitment to invest $100 million to scale up and commercialize durable carbon removal technologies. According to Jamila Yamani, Salesforce's director for climate and energy, one of the Forum's unique contributions has been to create a critical mass of companies aligned around the shared goal of carbon removals. "The FMC elevated this topic to our leadership," she says. "We know we can't move the market alone, but if we can align our targets and KPIs on scaling durable CDR with our peers, it builds trust and de-risks the process," she adds: "Then we can better optimize our resources."

The commitments made by FMC members today can send a valuable demand signal to the future market for CDR. But more than that, the technology developers and suppliers can go to their banks with binding offtake agreements for 50,000 or more tonnes of engineered removals as a proof of their future cashflow. "Suppliers of carbon removals need real loans; they can't scale up out of their equity pocket. They need a guaranteed income from creditworthy offtakers to get the project finance," says Mischa Repmann, Senior Risk Manager in the sustainability team of multinational reinsurance firm Swiss Re.

> **Suppliers of carbon removals need real loans; they can't scale up out of their equity pocket. They need a guaranteed income from creditworthy offtakers to get the project finance.**
>
> Mischa Repmann, Senior Sustainability Risk Manager, Swiss Re

Taking a proactive position today gives CDR developers the capacity to ramp up supply and bring down the costs of their removals more quickly. According to MOL's Kazura Koda, waiting for the price of CDR to drop is not an option. "A lot of people would like to be a freerider while the CDR market develops, waiting to see if the technological CDR cost reduces," she says. "But instead of sitting on the side, we decided to be a forerunner and help bring down the cost of the technology faster."

Leadership can provide companies with an edge over their peers. According to Koda, MOL's top management sees the FMC's position on engineered CDR as a leadership opportunity to stand out from the crowd. "Having a net-zero target is normal now," she says. "It doesn't give you a competitive edge." MOL takes leadership seriously. It's the first company from the Asia-Pacific region to commit to the FMC's carbon removal goal. It is also the first company from the hard-to-abate shipping sector to commit. And it hopes others will follow. "We want to make the CDR market more reachable for our industrial partners and customers, especially in the hard-to-abate sectors," says Koda.

## 3.4 Engineered CDR brings co-benefits, too

The co-benefits to engineered CDR are less pronounced than for NCS and of a different nature.

For example, biochar and the minerals used for ERW, when spread on agricultural fields, have been shown to enhance soil health and plant fertility, thereby improving crop yields. Biochar can also help protect native plants by absorbing toxic substances secreted by invasive plant species.[41] Furthermore, when applied to oceans, the minerals used for ERW can reverse acidification and reduce algal blooms.[42]

Many technologies and processes deployed in engineered CDR solutions resemble those used in today's fossil fuel and heavy industries. Existing infrastructure, such as depleted oil and gas fields, pipelines and industrial clusters, can be reused or repurposed. This could prevent layoffs of workers, or eventually lead to new jobs in communities confronted with a decline in more traditional, emissions-intensive industries.

There is also an opportunity for emerging markets to position themselves early and prominently in the engineered CDR space – wherever untapped clean energy resources and good storage options are co-located. Thus, the main co-benefits of engineered CDR are addressing decent work and economic growth (United Nations Sustainable Development Goal #8), which speak to the need for a just transition.

Companies interviewed had differing positions on the co-benefits of engineered CDR. For Rafael Broze, Senior Program Manager, Carbon Removal, Microsoft, any co-benefits should be a secondary consideration, with carbon sequestration the clear priority. "We focus first on the carbon. If after passing through that test we then see other co-benefits, then we might choose the solution with co-benefits. But we don't weigh the co-benefits and carbon at the same time – that confounds the calculus."

However, Salesforce's Jamila Yamani points out a significant challenge facing these emerging technologies: "In our CDR portfolio, we will be buying largely unregistered tonnes at a high cost, with a high risk of non-delivery." Because the goal of this forward purchase strategy is to scale new, early markets, Yamani is considering novel key performance indicators (KPIs) to track impact, many of which are inspired by, but look very different from, the co-benefits companies are used to in the world of NCS. "Our $100 million commitment likely won't buy much in terms of volumes of $CO_2$ removed, so it's important that we look at KPIs other than tonnes of carbon in the ground to drive the most impact," she says.

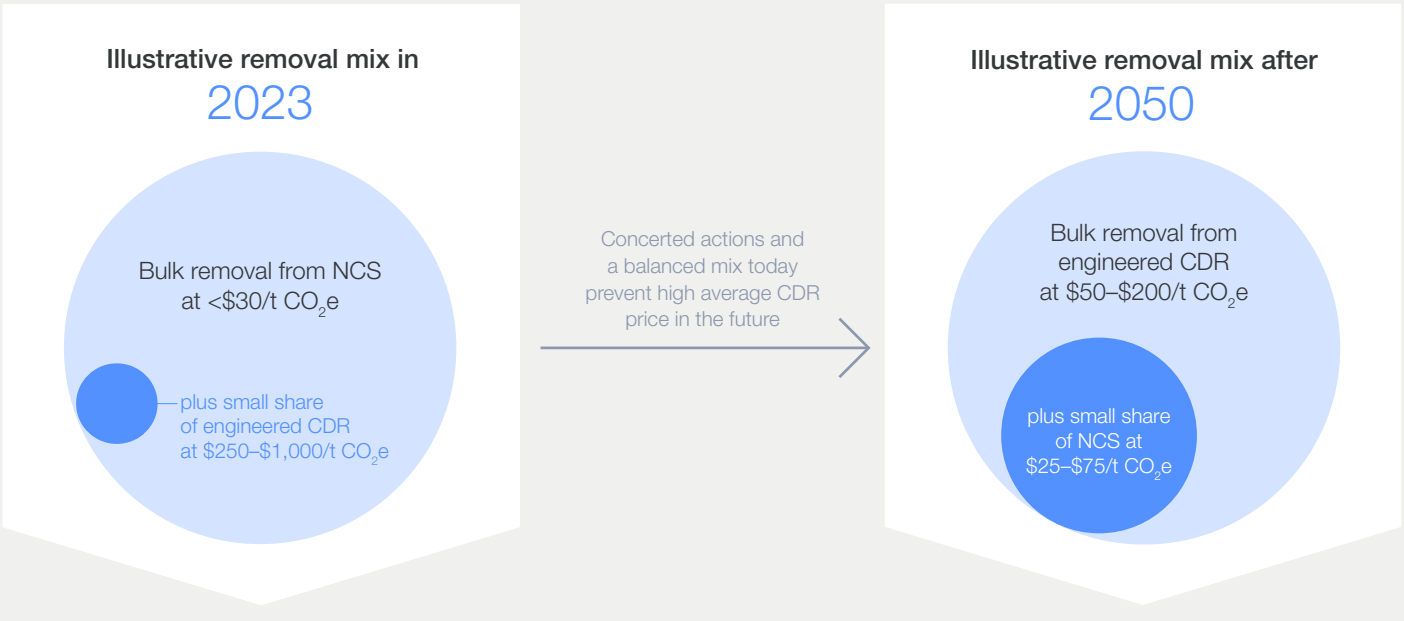
> **Our $100 million commitment likely won't buy much in terms of volumes of $CO_2$ removed, so it's important that we look at KPIs other than tonnes of carbon in the ground to drive the most impact.**
>
> Jamila Yamani, Director, Climate & Energy, Salesforce

These KPIs could include the following: By how many years did we help accelerate the viability of the technology? How many new methodologies did our purchases help to develop? How many tonnes of carbon removal were catalysed by our forward purchase? How many new jobs or repurposed workers does our investment support in communities where traditional fossil fuel economies are winding down?

## 3.5 A mix of natural climate solutions and engineered CDR is needed

Beyond the FMC community, potential buyers of carbon removal certificates may be easily scared off by the high first-mover price of engineered CDR, with little appetite to take a leadership position. To circumvent this, they could be tempted to focus on much cheaper and more readily available NCS removals. This strategy, however, can make the price situation for other market participants even worse: a company spending all of its removals budget on NCS will cause the overall CDR price (averaged over all engineered and NCS solutions) to go up over time rather than helping it to come down. The NCS will deplete faster, their price will increase, while the underinvested engineered solutions remain expensive. Rafael Broze from Microsoft puts it this way: "We need to consider equity if big corporations are buying up all the relatively inexpensive nature-based removals."

FIGURE 4 **How can companies use removals smartly?**




This mix today can keep **average removal price well below $100/t $CO_2$e** and…

… prevent a price rise mid-century to keep **average removal price to around $100/t $CO_2$e**

**Notes:** NCS = natural climate solutions, CDR = carbon dioxide removals, t $CO_2$e = tonne of carbon dioxide equivalent.

**Source:** Boston Consulting Group[43]

If, instead, companies were to spend part of their removals budget on engineered CDR today, these technologies would start coming down the cost curve while pressure on the limited supply of quality NCS is reduced. In this way, the average CDR price would become cheaper for all market participants – ideally in time for when the world needs CDR at the gigatonne scale.

Trafigura's Hannah Hauman argues that, while the 2020s will be an essential "decade for nature" with pledges to end deforestation and restore habitats by 2030, it is vital to put weight behind commercializing engineered CDR solutions today, because they will not be ready at the scale required in the 2040s unless companies start now. So while nature needs to be supported in its own right, engineered CDR is indispensable over the mid to long term.

Reflecting on the mix of NCS and engineered CDR in his company's portfolio, Antoine Poulallion, Director of Sustainability, Boston Consulting Group (BCG), says: "We had to find a balance between removal types. Aiming for exclusively mainstream credits, for example afforestation or reforestation, would not help unlock the potential of more pioneering and permanent technological solutions, which we know the world will also need. On the other hand, covering our full footprint using only these new technologies was not feasible either given their nascency." So, the company decided on a mix of CDR options, encompassing both nature-based and engineered solutions.

# 4 How to access the nascent market for engineered CDR

## Securing the budget, deciding on the right market access model and communicating corporate CDR engagement both in-house and externally are all key priorities.

In order to engage in the engineered CDR space, a number of questions need to be worked through and answered upfront (see Box 2). There are certainly additional questions and case-by-case nuances. This chapter aims to cover the essentials: how to secure the budget, choosing the right market access model, and good communications about the engagement in-house and externally.

BOX 2 **Questions to consider when deciding how to access the engineered CDR market**

- What is the company's climate strategy and does it (already) embrace the role of CDR?
- What is the company's business strategy and can the CDR engagement be linked to it?
- Who is the executive sponsor and are they onboard with the CDR narrative?
- Which corporate functions are to be involved (e.g. procurement, finance, legal, sustainability, business) and who are the potential allies therein?
- What's my own level of expertise or that of colleagues/allies? Can I make the case to pay a consultant?
- How far into the future – and thus how impactful – can the engagement be planned?
- What is the budget and how can it be secured for as long as the engagement is planned to last?
- How can the market be practically accessed so that it suits the climate and business strategy and fits the available human resources and budget?
- What partners are needed and available for which market access route?
- What should be communicated to whom and when?

## 4.1 How to secure the budget

### Internal carbon price model

When a company buys carbon certificates, it often already knows both the volume (given by its current emissions that it plans to match with the equivalent number of certificates) and the price per tonne (based on current market offers it has solicited). Then a budget request is filed and this process repeats year after year. The cost can be assumed by the company budget, or collected from the actual emitters within the company (e.g. air travellers). The latter can then be communicated as an internal carbon price, which differs from year to year based on the market price of the selected certificates.

Several FMC members have adopted a different strategy to secure the budget for their engineered CDR certificates. They ask themselves upfront: what is the company willing to pay for CDR today and in the future? Then they implement this figure as an internal carbon pricing policy for as long as the CDR engagement period is planned. Every year, the price per tonne that the emitters within the company have to pay is thus preset. The sourcing team can then enter offtake agreements for as long as the carbon pricing policy is in place, thereby ensuring that the average price of the various deliveries in a given year matches that year's internal carbon price level.

There are several advantages to this strategy:

- It removes the uncertainty of whether annual budget requests will be granted or not
- Transparency on price sends a clear demand signal to technology developers and suppliers, which builds confidence and helps the market develop
- It enables the company to enter long-term offtake agreements, so providing the CDR developers with the future revenue stream they need to obtain finance
- Most importantly, the higher the predefined and openly communicated internal carbon price, the more a company will prioritize emission reductions over the purchase of CDR

Given that setting an internal carbon price is currently a voluntary exercise, actual prices vary considerably from company to company. Among the interviewee companies, disclosed prices ranged from $80 to $200 per tonne of carbon by 2030.

FMC member Swiss Re pioneered the idea that a stringent internal carbon pricing policy could secure the budget for high-quality CDR. In 2021, the company launched its $CO_2$NetZero programme, which introduced a real internal carbon price of $100 per tonne of $CO_2$. This "carbon steering levy", as Swiss Re calls it, applies to the company's Scope 1, Scope 2 and material upstream Scope 3 emissions, including business travel. The funds collected are spent on a mix of high-quality carbon avoidance and carbon removal certificates to compensate for these emissions. Between 2021 and 2030, the carbon price will increase incrementally from $100 to $200 per tonne of $CO_2$ and at the same time the share of removals in the certificate mix will grow from 10% in 2021 to 100% by 2030. In other words, by 2030, Swiss Re aims to neutralize all its in-scope residual emissions through high-quality removals that can cost on average $200 per tonne.

How did the company arrive at this price? The starting point of $100 is the UN Global Compact's minimum recommendation for internal carbon pricing.[44] The final price of $200 is what Swiss Re expects to pay on average for safe and durable carbon removal by the end of the decade. "The $200 figure is also our marginal abatement cost in 2030 – so any abatement measure cheaper than $200 per tonne should come before paying for removals," explains Mischa Repmann, who adds: "The higher the price, the more reductions are prioritized over removals, which is how setting an internal carbon price can connect the two."

Securing funding for carbon certificates through a 10-year carbon pricing policy – as opposed to filing budget requests year after year – comes with an important advantage: it enables Swiss Re to enter long-term offtake agreements for removal certificates. In 2021, for example, the company entered the world's first carbon removal purchase agreement with Swiss direct air capture provider Climeworks, worth $10 million over 10 years. Such contracts provide project developers with the future income they need to raise the finance for the next step-up in scale.

> **Our internal carbon price of $200 is also our marginal abatement cost in 2030 – so any abatement measure cheaper than $200 per tonne should come before paying for removals. The higher the price, the more reductions are prioritized over removals.**
>
> Mischa Repmann, Senior Sustainability Risk Manager, Swiss Re

Another example of a company using the internal carbon price model is BCG, which has committed to reach net-zero climate impact by 2030. To achieve this, the firm set science-based targets to halve emissions intensity by 2025 and remove any unabated emissions with high-quality carbon removals by the end of the decade. In May 2022, BCG pledged to purchase 100,000 tonnes of permanent carbon removals by 2030 – double the bar set by FMC.[45] To achieve this, BCG then established a clear dollar per tonne carbon price expectation – to reduce, avoid and remove emissions – that ramps up between 2022 and 2030. "In 2022, we spent an average $16 per tonne," says Antoine Poulallion. "This is higher than the market average, reflecting our deliberate positioning as premium buyers." By 2025, BCG expects that amount to rise to $35, climbing further

to $80 per tonne by 2030. In reality, this means the firm has paid and will continue to pay more to fly its consultants around the world. It is important to realize that $80 per tonne would be an average price point. Some nature-based removals may cost much less. Some engineered removals may cost a lot more.

## Setting a goal by budget and tonnes of $CO_2$ removed

An alternative approach taken by several FMC members is to set a time-bound goal with a defined budget and/or a target number of tonnes of carbon removals per year.

For Salesforce, it was important to make a top-end commitment of $100 million to scale up and commercialize durable CDR technologies. When it comes to spending the money, Jamila Yamani anticipates building a portfolio that puts impact first, positioning the company to make CDR purchases in areas best aligned with the company's targets and KPIs. "This $100 million is giving us the space to get it right, and put in the early resources, so that when the time comes, CDR is available at scale to help Salesforce meet its commitments and the world to meet its climate goals," she says.

In 2020, Microsoft committed to make its own operations and its entire supply chain carbon-negative within a decade. Its pathway to achieving this goal is a 55% reduction in absolute carbon emissions plus carbon removals. That same year, it phased out its avoided emissions offsets and began to embrace CDR. More ambitious still, Microsoft pledged to remove from the environment all the carbon the company has ever emitted, both directly and through its electricity consumption since it was founded in 1975.

Microsoft's finance and sustainability teams have strict parameters of success for the deals they sign up to. The company's target is 5.5 million tonnes of carbon removals per year by 2030. "We have a budget and a tonnes goal," explains Broze, "that drives discipline, focus and risk management." KPIs include tonnes delivered over the following 12 months (for CDR approaches up and running), tonnes delivered up to 2030, average price per tonne across the portfolio, the price of any given deal and the risks of any given deal. The contracts they seek strike a balance between long-term surety of delivery for Microsoft and surety of revenue for the supplier and financiers. "The banks won't invest and underwrite a contract with a supplier if Microsoft could exit any time, so we look at reasonably restricting our options to walk away," says Broze.

> **Microsoft's rules of thumb for carbon removal are simple: contract for a mix of technologies, suppliers and countries.**
>
> Rafael Broze, Senior Program Manager, Carbon Removal, Microsoft

When it comes to deciding which CDR projects to invest in, Broze counsels in favour of spreading the risk. He notes that investing in emerging economies is challenging. Zimbabwe recently signalled a move to nationalize all of its carbon credits and last year an Indian minister said the country would halt all extra-national carbon transfers. "Microsoft's rules of thumb for carbon removal are simple," says Broze: "contract for a mix of technologies, suppliers and countries."

# 4.2 Choosing the right market access model

Next, companies need to find a way to access the engineered CDR market, which requires a purchasing strategy that speaks to their appetite for direct deal-making, capacity to manage transactions, and expectations in terms of quality, price, volume and delivery schedule. There are three common access routes:

– Direct deal-making

– Participation in a buyers' club

– Over-the-counter purchases

For each of these access models, there are implementation partners. Those working with FMC include the following: Carbon Direct[46] acts as a consultant for every access model, but particularly for direct deal-making; Frontier[47] and NextGen[48] are buyers' clubs; while Carbonfuture[49] and Patch[50] specialize in over-the-counter purchases.

## Direct deal-making

Direct deal-making with selected removals developers enables buyers to get to know the developer and negotiate the exact contract terms. This comes with substantial transactional effort, such as soliciting offers, due diligence on short-listed suppliers and contract negotiations. Therefore, the direct deal-making model is usually feasible only for large companies with bigger offtake volumes. These companies also profit by avoiding fees for intermediaries, and – more importantly – because the direct exchange with developers helps them to build up in-house competency and relationships with strategic partners in the engineered CDR space.

Carbon Direct aims to enable organizations to reduce, remove and use their emissions using carbon science. Their clients currently represent more than 100 million tonnes of carbon removal demand. In the largest engineered CDR deal of its kind to date, Carbon Direct acted as technical adviser in Microsoft's recent purchase of around 2.7 million tonnes of BECCS-driven carbon removal credits from Danish energy giant Ørsted's power facilities over an 11-year period.[51]

In a separate deal, Microsoft signed a long-term contract to purchase up to 315,000 tonnes of CDR over a multi-year period from Heirloom, representing one of the largest DAC deals to date and providing predictable cash flows for Heirloom to enable project financing of their upcoming facilities.

"We use Carbon Direct as a technical adviser, as we value their deep expertise and ability to look around corners. Then we do all our deals direct because we think it's important to have disinterested advisers," says Rafael Broze. "We do a lot of digging into individual projects to be able to believe in them, and every project has to clear our quality bar before we start discussing prices and partners," he adds.

Trafigura, which is taking the risk onto its balance sheet, also works directly with tech developers and project owners to create viable and resilient carbon removal businesses.

## Participation in a buyers' club

A buyers' club is where several buyers come together, pool their individual demand for removals and have it placed collectively on the market through an intermediary, the buyers' club manager. The manager takes care of all transactional and administrative duties, such as building a project pipeline from different technologies, suppliers, project sizes and geographies. Members need only one contract with the intermediary, as opposed to a separate contract per project in the direct deal-making model above. They commit to participate in the club with a particular dollar or volume amount and gain access to a managed portfolio of engineered CDR.

Over time, members receive their corresponding share of the resulting removals mix – at a lower average price for a more diversified portfolio than they could have purchased independently. The buyers' club model is particularly suitable for companies with smaller offtake volumes and less tolerance for transactional efforts, but who still want to source removals through impactful longer-term offtakes.

Frontier acts on behalf of both buyers and sellers, and aims to secure the purchase of $1 billion of permanent carbon removal credits between 2022 and 2030. Buyers decide how much they want to spend on carbon removal each year until 2030. Frontier then aggregates those commitments to set a total annual demand pool, vets carbon removal suppliers and invites them to apply for purchases via regular requests for proposals (RFPs). Frontier can facilitate both low-volume pre-purchases and long-term offtake agreements to purchase future tonnes of carbon removal at an agreed price, if and when delivered. Suppliers are paid only when the tonnes of carbon are removed.

NextGen aims to build a market for credible, scalable CDR by committing to 1 million certified long-term carbon removals by 2025 for delivery by 2030, at an average price of $200 per tonne. All removals purchased through NextGen must be certified under ICROA standards[52] to ensure quality, transparency and credibility; and all will be retired by buyers in a public registry to avoid double counting.[53]

## Over-the-counter purchases

Emerging marketplaces, such as Carbonfuture and Patch, offer over-the-counter purchases in which engineered CDR certificates are traded among suppliers, brokers and buyers. Since these purchases are usually one-offs, they send a weaker market signal compared to longer-term offtakes that are arranged directly or via a buyers' club. Prices per tonne are often fixed (unless the offtake volume exceeds a certain threshold) and accommodate a potentially heavy overhead from brokers and marketplace operators.

For the buyers, transactions are fast, low-effort and add flexibility to any sourcing strategy. For instance, potential gaps between actual demand and what is contracted through direct offtakes or membership of a buyers' club can be closed quickly at year-end.

## Standardized offtake agreements hold the key to scaling up the sector

Swiss Re's Mischa Repmann explains how NextGen came into being. The reinsurer's first long-term offtake agreement with Climeworks took six months to close, given the complexity of negotiating a contract from scratch that had to specify the schedule, volume, delivery and price per tonne of removals. The contract became known as a carbon removals purchase agreement (CRPA) and acted as a template for future deals.

"We couldn't do that with 30 more projects," says Repmann. "Instead, we looked for an intermediary that had a pipeline of projects all falling under the same long-term offtake model." Not finding a suitable intermediary, from 2020 Swiss Re helped establish NextGen as a buyers' club and joined it in 2022 alongside fellow FMC founder buyers BCG and MOL.

For Swiss Re, partnering with a global consolidator of carbon removals such as NextGen – using a standardized CRPA – is critical to scaling up the sector. Intermediaries not only save companies time by standardizing and accelerating deal-making, they also serve a vital function in consolidating and building demand. "We see a lack of demand rather than a shortage of supply. In helping to establish NextGen, we're helping build demand by making it easier for more buyers to access the removals market," says Repmann.

> **We see a lack of demand rather than a shortage of supply. In helping to establish NextGen, we help to build demand by making it easier for more buyers to access the removals market.**
>
> Mischa Repmann, Senior Sustainability Risk Manager, Swiss Re

Michael Baute of AES agrees that structuring a standard type of contract – for example, one based on the energy industry's existing power purchase agreements (PPAs) – is critical to growing the CDR sector. AES, recognized for two years running as the top developer worldwide at signing renewable PPAs with corporate offtakers, is looking to use the company's expertise in the CDR sector. Baute is concerned, however, that tech developers and suppliers of credit are asking buyers to take too much risk by paying upfront for CDR. "To get more buyers in, the industry cannot continue asking customers for upfront cash. In the renewable energy industry, a customer agrees to offtake over, say, a 10–12-year term and you pay when you get the power, or in this case, the carbon removals," he says.

## If you're just starting out – hire a consultant!

FMC members use all three access routes to various degrees – in parallel or in sequence – in combinations that best suit their needs, ambitions and level of experience. For most companies, experience is limited or absent, given the novelty of engineered CDR and its nascent market. Therefore, it can make good sense to get support from an external specialist.

Consultants can brief clients on the up-to-date intricacies of carbon markets, related standards, regulations and claims, and provide a market overview of engineered CDR. They can offer technical advice on any of the three market access routes described above, particularly on direct offtakes and how to combine them into an impactful, workable purchasing strategy. Consultants can also accompany the actual purchasing process: soliciting offers, performing due diligence on vendors and projects and contracting and handling carbon certificates upon delivery.

# 4.3 Communicating CDR performance in-house and outside the company

## In-house communication

Commitment to a company's planned engagement in engineered CDR is a prerequisite from the very top. But to get to the top requires taking the case to the chain of decision-makers who will be the door openers to that level. At the end of this process, ideally, the CEO themself signs off the engagement in engineered CDR; for example, via the FMC commitment. Once leadership is signed up, it is important to communicate the company's CDR story to the wider workforce.

At AES, Michael Baute has already initiated widespread internal information campaigns. But as he makes clear: "This is not just another procurement approval – we're exploring the creation of a new business around carbon removal with the potential for exponential value creation. That brings with it a new level of business scrutiny." So Baute's primary communication priority is to create a strategy that can secure a "big buy-in from everybody".

When it comes to communicating with employees, Trafigura has found there are many carbon removal enthusiasts across its 16,000-strong workforce who are volunteering to get involved. "As a result, we've rolled out a programme for each department and desk to have a window into what we're doing – from introductory webinars through to company-wide updates in addition to our public communications," says Hannah Hauman, who adds: "There's a lot of thirst for knowledge."

Swiss Re engages its employees in its net-zero implementation strategy through the dedicated app-based "NetZeroYou2" programme. Launched in 2021, it seeks to encourage individual action and inspire employees across the group to adopt the motto: "Do our best, remove the rest." To support the "do our best" component, Swiss Re helps employees calculate their private carbon footprint and offers various climate challenges, practical climate actions and events. To support the "remove the rest" component, employees can access Swiss Re's carbon certificate purchasing campaign, which includes engineered CDR through long-term offtakes that could not usually be accessed by individuals. To date, more than 5,000 of the company's 14,000 employees have participated in the programme, securing 2,200 tonnes of carbon certificates.[54]

## Third-party communication

There are many reasons why companies may seek to communicate with third parties and the wider public about their carbon removal initiatives and achievements. Some arising from the interviews conducted for this report are recounted below.

Publicly listed companies such as MOL are required to disclose how they are going to deliver on their 2.2 million tonne carbon removal commitment. "First we have to ensure we disclose the progress of CDR credit retirement and demonstrate if we are on track to hit our target," says Kazura Koda. For MOL, the priority is about "taking robust steps and being proud and transparent with stakeholders," she adds.

For companies such as AES seeking to make a business out of this, communicating with the market is a sales opportunity. “We want to be the deployment partner of choice for tech developers as well as companies looking to purchase removals,” says Baute, adding: “It should give trust to both suppliers and buyers that an experienced infrastructure developer like AES is exploring how best to bring scale to the table.”

Microsoft publicizes whatever carbon removals it is buying and issues regular lessons-learned papers. “We’re eager to talk to other buyers and sellers to provide them with any advice we can, as well as looking to collaborate,” says Rafael Broze. “We want other buyers to be aware of good opportunities – with engineered removals, there is no competition among buyers for now,” he adds.

Meanwhile for Trafigura, with its very large client base and Scope 3 impact, Hauman notes: “We have the ability to speak on behalf of our customers and the market.” The company does this through white papers, videos and occasional podcasts.

Being open in advance about the price a company is prepared to pay for engineered removals can send the all-important demand signal to the market that this is a sector worth investing in. This form of communication lies at the core of the rationale informing the FMC.

For example, BCG’s Antoine Poulallion says: “We are proud of our transparency around the price per tonne we are paying for carbon removals. We’ve heard it’s helpful for project developers and their funding partners because they know there will be buyers at those levels.”

**We are proud of our transparency around the price per tonne we are paying for carbon removals. We’ve heard it’s helpful for project developers and their funding partners because they know there will be buyers at those levels.**

Antoine Poulallion, Director of Sustainability, Boston Consulting Group

In addition, transparency serves a purpose both for internal cost control and for building trust with the wider public. Poulallion puts it this way: “On the internal side, it’s helpful for management because it helps to anchor the overall cost. And we hope it’s helpful for the public because they can see that we are doing our best to buy high-quality removals.”

# Conclusion

## By committing to engineered CDR today, companies can drive value for money while demonstrating climate leadership.

This white paper presents the case for every company to make its own commitment to invest in engineered carbon dioxide removal without delay. The technologies are still too expensive for sure, but only if companies send demand signals to the market will prices come down – for everyone.

Engineered CDR solutions – such as biochar, BECCS, DACCS and ERW – offer additional, durable and quantifiable removals that can help companies deliver on their climate targets and guard against accusations of greenwashing. They can also build the credibility of a company's broader climate strategy, sharpening its reputation in the eyes of employees, clients and investors.

No company can yet afford to spend all its carbon mitigation budget on engineered CDR alone. A mix of natural climate solutions and engineered CDR is needed. But unless companies commit to engineered solutions today, the prices for engineered CDR will stay high, the supply of nature-based solutions will diminish, and the average cost of carbon removals will rise for all.

The best way to commit to engineered CDR is through a long-term offtake agreement that guarantees suppliers an income stream they can use to leverage lines of credit to invest in their chosen technology. This paper has described how companies can secure such agreements tailored to their size and budget, whether by direct deal-making, through a buyers' club or via over-the-counter purchases.

The bottom line is that the world cannot limit global temperatures to 1.5°C or even 2.0°C – and maintain them at that level – without some degree of engineered carbon removals. The sooner companies can demonstrate demand for these solutions, the quicker the industry will scale up and the faster prices will fall. The need of the hour is not to wait and see. Now is a time for leadership.

# Appendix

## Questions for companies interviewed for this report:

1. Why did your company get involved in engineered CDR? How did you convince leadership? Are the rationales mainly strategic or financial?

2. How are you executing your engineered CDR strategy in terms of budget? What is the mix between engineered and natural solutions? Where does the financing come from – an internal carbon price or budget? Is CDR part of your business model?

3. How have you found and worked with implementing partners? How do you vet them? How do you choose the optimal engagement or offtake model? What criteria or standards do you apply and how do you measure these?

4. How do you manage your ongoing communication, whether with the board, management or the wider market? How do you view your role as a buyer in helping stimulate market development through communicating project outcomes?

# Contributors

## World Economic Forum

**Nasim Pour**
Lead, Carbon Removals and Market Innovation

**Jonathan Walter**
Freelance writer

# Acknowledgements

The World Economic Forum would like to thank the following individuals for their generous and insightful contributions to this publication:

**Michael Baute**
Entrepreneur-in-Residence for Carbon Removal, The AES Corporation

**Rafael Broze**
Senior Program Manager, Carbon Removal, Microsoft

**Katherine Duff**
Principal, Boston Consulting Group

**Jane Flegal**
Climate advisor, Stripe

**Lucy Hargreaves**
Corporate Affairs & Climate Policy, Patch

**Hannah Hauman**
Global Head of Carbon Trading, Trafigura

**Kazura Koda**
General Manager, Carbon Desk, Mitsui O.S.K. Lines (MOL)

**Philip Moss**
Chairman, NextGen CDR Facility

**Henry Mumford**
Consultant, Boston Consulting Group

**Antoine Poulallion**
Director of Sustainability, Boston Consulting Group

**Mischa Repmann**
Senior Sustainability Risk Manager, Swiss Re

**Tom Spencer**
Environmental Management Specialist, Swiss Re

**Leila Toplic**
Chief Communications & Trust Officer, Carbonfuture

**Sumit Verma**
Consultant, Boston Consulting Group

**Jamila Yamani**
Director, Climate & Energy, Salesforce

# Content and design

**Bianca Gay-Fulconis**
Designer, 1-Pact Edition

**Alison Moore**
Editor, Astra Content

**Charles Phillips**
Editor, Astra Content

# Endnotes


1. McGrath, M. et al., "World Breaches Key 1.5C Warming Mark for Record Number of Days", BBC News, 7 October 2023: https://www.bbc.co.uk/news/science-environment-66857354.
2. Lamboll, R. et al., "Assessing the Size and Uncertainty of Remaining Carbon Budgets", *Nature Climate Change*, 30 October 2023: https://www.nature.com/articles/s41558-023-01848-5.
3. Intergovernmental Panel on Climate Change (IPCC), *Special Report: Global Warming of 1.5°C, Summary for Policymakers*, 2018, p.14: https://www.ipcc.ch/sr15/chapter/spm/.
4. Intergovernmental Panel on Climate Change (IPCC), *Special Report: Global Warming of 1.5°C: FAQ Chapter 1*, 2018: https://www.ipcc.ch/sr15/faq/faq-chapter-1/.
5. Statista, "Annual Carbon Dioxide ($CO_2$) Emissions Worldwide from 1940 to 2022 (*in Billion Metric Tonnes*)", November 2022: https://www.statista.com/statistics/276629/global-co$_2$-emissions/. Data as follows: 2015: 35.56 billion tonnes (Gt); 2016: 35.52 Gt; 2017: 36.1 Gt; 2018: 36.83 Gt; 2019: 37.08 Gt; 2020: 35.26 Gt; 2021: 37.12 Gt; 2022: 37.49 Gt (projection).
6. Intergovernmental Panel on Climate Change (IPCC), *Special Report: Global Warming of 1.5°C: Headline Statements from the Summary for Policymakers*, 2018: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Headline-statements.pdf.
7. Science Based Targets Initiative (SBTi), "The Corporate Net-Zero Standard": https://sciencebasedtargets.org/net-zero.
8. Intergovernmental Panel on Climate Change (IPCC), *Special Report: Global Warming of 1.5°C: Summary for Policymakers*, 2018: https://www.ipcc.ch/sr15/chapter/spm/.
9. Ibid. p. 14: https://www.ipcc.ch/sr15/chapter/spm/.
10. Azarabadi, H. et al., "Shifting the Direct Air Capture Paradigm", Boston Consulting Group (BCG), 5 June 2023: https://www.bcg.com/publications/2023/solving-direct-air-carbon-capture-challenge.
11. Stainford, T. and Brzezinski, B., "More Than Half of All $CO_2$ Emissions Since 1751 Emitted in the Last 30 Years", Institute for European Environmental Policy (IEEP), 29 April 2020: https://ieep.eu/news/more-than-half-of-all-co$_2$-emissions-since-1751-emitted-in-the-last-30-years/.
12. World Economic Forum, *On the Critical Role of Carbon Removal and How Companies Can Use It Smartly*, Alliance of CEO Climate Leaders' Carbon Removal Action Group, with contributions from members of the Forum's Global Future Council on Net-Zero Transition, November 2021: https://www3.weforum.org/docs/WEF_Carbon_Removal_for_CEOs_read.pdf.
13. Ibid.
14. World Economic Forum, First Movers Coalition: https://www.weforum.org/first-movers-coalition/sectors.
15. Natural climate solutions (NCS) include: forestation – either planting new trees on previously woodless land or restoring forests to preserve their capacity to act as natural carbon sinks; soil sequestration – increasing the carbon content of soil, through changes in land management, such as no-till agriculture and use of cover crops; blue carbon – wetland and marine ecosystems, such as mangroves and kelp, which can lock away carbon when managed properly.
16. Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2022: Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, 2022, Table 12.6, pp. 1275–1276: https://www.ipcc.ch/report/ar6/wg3/.
17. American University, Washington, DC, "Carbon Removal Fact Sheet: Soil Carbon & Biochar", 2018: https://www.american.edu/sis/centers/carbon-removal/upload/icrlp_fact_sheet_soil_carbon_biochar_181006.pdf.
18. Chiquier, S. et al., "A Comparative Analysis of the Efficiency, Timing and Permanence of $CO_2$ Removal Pathways", *Energy & Environmental Science*, Issue 10, 2022: https://pubs.rsc.org/en/content/articlelanding/2022/ee/d2ee01021f.
19. Petersen, H. I. et al., "Carbon Stability and Morphotype Composition of Biochars from Feedstocks in the Mekong Delta, Vietnam", *International Journal of Coal Geology*, Vol. 271, 15 April 2023: https://www.sciencedirect.com/science/article/pii/S0166516223000514#t0010.
20. Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2022: Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, 2022, Table 12.6, pp. 1275–1276: https://www.ipcc.ch/report/ar6/wg3/.
21. Cdr.fyi, "Key Metrics": https://www.cdr.fyi/.
22. Glaser, B. et al., "Biochar is Carbon Negative", *Nature Geoscience*, January 2009: https://www.nature.com/articles/ngeo395#:~:text=Carbon%20sequestration%20through%20biochar%20involves,of%20about%202%2C000%20years5.
23. Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2022: Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, 2022, Table 12.6, pp. 1275–1276: https://www.ipcc.ch/report/ar6/wg3/.

24. International Energy Agency (IEA), "Bioenergy with Carbon Capture and Storage: Tracking – September 2022": https://www.iea.org/reports/bioenergy-with-carbon-capture-and-storage.
25. Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2022: Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, 2022, Table 12.6, pp. 1275–1276: https://www.ipcc.ch/report/ar6/wg3/.
26. Ibid.
27. Azarabadi, H. et al, "Shifting the Direct Air Capture Paradigm", Boston Consulting Group (BCG), 5 June 2023: https://www.bcg.com/publications/2023/solving-direct-air-carbon-capture-challenge.
28. International Energy Agency (IEA), "Direct Air Capture: Tracking – September 2022": https://www.iea.org/reports/direct-air-capture.
29. Azarabadi, H. et al, "Shifting the Direct Air Capture Paradigm", Boston Consulting Group (BCG), 5 June 2023: https://www.bcg.com/publications/2023/solving-direct-air-carbon-capture-challenge.
30. The Integrity Council for the Voluntary Carbon Market, "The Core Carbon Principles", 2023: https://icvcm.org/the-core-carbon-principles/.
31. Smith, S. et al., *The State of Carbon Dioxide Removal – 1st Edition*, University of Oxford, 2023: https://www.stateofcdr.org/home/#key.
32. Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2022: Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, 2022, Table 12.6, pp. 1275–1276: https://www.ipcc.ch/report/ar6/wg3/. The data is calculated using the IPCC's upper estimates of mitigation potential for: engineered CDR (taken as the sum of: DACCS, enhanced rock weathering, BECCS and biochar); natural climate solutions (taken as the sum of afforestation/reforestation, soil carbon sequestration in croplands and grasslands, peatland and coastal wetland restoration, agroforestry and improved forest management); solutions with a low technology readiness level (TRL) are not counted.
33. Kalra, G. et al., *Technical $CO_2$ Removals Market: Present and Future*, Tuck School of Business, Dartmouth College, May 2022: https://www.tuck.dartmouth.edu/uploads/content/Technical$CO_2$RemovalsMarketvF1.pdf.
34. International Energy Agency (IEA), *Direct Air Capture 2022*, April 2022: https://www.iea.org/reports/direct-air-capture-2022.
35. International Carbon Reduction and Offset Alliance (ICROA), "ICROA Code of Best Practice", July 2023: https://icroa.org/icroa-code-of-best-practice/.
36. First Movers Coalition (FMC): https://www.weforum.org/first-movers-coalition/sectors.
37. CDR technologies considered to be within the scope of the FMC's commitment must satisfy the following thresholds: permanence – solutions that demonstrably store captured carbon for 1,000+ years; and scalability – solutions that can potentially store at least 1Mt of carbon by 2030 and 1Gt by 2050.
38. Tyson, J., "Large Companies Hide Behind Net Zero 'Fig Leaf': Report", CFO Dive, 21 February 2023: https://www.cfodive.com/news/large-companies-hide-behind-net-zero-fig-leaf-ESG-GHG-sustainability/643215/.
39. Rives, K., "Companies Face 'Massive Growth' in Litigation over Climate Claims", S&P Global Market Intelligence, 6 July 2023: https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/companies-face-massive-growth-in-litigation-over-climate-claims-76429935#:~:text=In%20May%2C%20a%20class%2Daction,on%20allegedly%20questionable%20carbon%20offsets.
40. Voluntary Carbon Markets Integrity Initiative (VCMI), *VCMI Claims Code of Practice*, June 2023: https://vcmintegrity.org/vcmi-claims-code-of-practice/.
41. Adams, M. et al., "The Effect of Biochar on Native and Invasive Prairie Plant Species", *Invasive Plant Science and Management*, Vol. 6, Issue 2, pp. 197–207, June 2013: https://doi.org/10.1614/IPSM-D-12-00058.1.
42. Vakilifard, N. et al., "The Role of Enhanced Rock Weathering Deployment with Agriculture in Limiting Future Warming and Protecting Coral Reefs", *Environmental Research Letters*, Vol. 6, No. 9, 12 August 2021: https://doi.org/10.1088/1748-9326/ac1818.
43. World Economic Forum, *On the Critical Role of Carbon Removal and How Companies Can Use It Smartly*, Alliance of CEO Climate Leaders' Carbon Removal Action Group, with contributions from members of the Forum's Global Future Council on Net-Zero Transition, November 2021: https://www3.weforum.org/docs/WEF_Carbon_Removal_for_CEOs_read.pdf.
44. United Nations Global Compact, "Carbon Pricing", 2023: https://unglobalcompact.org/take-action/action/carbon.
45. Boston Consulting Group (BCG), "BCG Commits to Remove 100,000 Tonnes of Carbon by 2030 as Expanded First Mover Coalition Sends Powerful Signal to Market to Commercialize Zero-Carbon Tech", 25 May 2022: https://www.bcg.com/press/25may2022-bcg-expanded-first-mover-coalition-zero-carbon-tech.
46. Carbon Direct: https://www.carbon-direct.com/.
47. Frontier: https://frontierclimate.com/.
48. NextGen: https://www.nextgencdr.com/.
49. Carbonfuture: https://www.carbonfuture.earth/.

50. Patch: https://www.patch.io/.

51. Gordon, O., “Ørsted Launches Landmark CCS Project in Denmark”, *Energy Monitor*, 23 May 2023: https://www.energymonitor.ai/tech/carbon-removal/orsted-launches-landmark-ccs-project-in-denmark/.

52. International Carbon Reduction and Offset Alliance (ICROA), “Accrediting Best Practice in Carbon Offsetting”: https://icroa.org/.

53. NextGen CDR Facility: https://www.nextgencdr.com/.

54. Swiss Re, “It’s Time to Start Engaging Your Employees and Customers as Part of Your Sustainability Strategy”: https://www.swissre.com/sustainability/sustainable-operations/net-zero-you2-app.html.

WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

The World Economic Forum, committed to improving the state of the world, is the International Organization for Public-Private Cooperation.

The Forum engages the foremost political, business and other leaders of society to shape global, regional and industry agendas.

World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744
contact@weforum.org
www.weforum.org