Removing carbon *responsibly*

A guide for business on carbon removal adoption

Photo credit: Climeworks

World Business Council *for Sustainable Development*

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Acronyms and abbreviations

AR	afforestation and reforestation
BECCS	bioenergy with carbon capture and storage
BECCS exp.	bioenergy with carbon capture and storage, with agricultural expansion
BECCS no exp.	bioenergy with carbon capture and storage, without agricultural expansion
BECCU	bioenergy carbon capture and utilization
BiCRS	biomass carbon removal and storage
BVCM	beyond value chain mitigation
CCS	carbon capture and storage
CCU	carbon capture and utilization
CDR	carbon dioxide removal/carbon removal/removals
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
°C	degrees Celsius
DAC	direct air capture
DACCS	direct air carbon capture and storage
DACCU	direct air carbon capture and utilization
FLAG	forest, land and agriculture
GHG	greenhouse gas
Gt	gigatonne
IPCC	Intergovernmental Panel on Climate Change
MCDA	multi-criteria decision-analysis
MRV	measurement, reporting and verification
NCS	natural climate solutions
NET	negative-emissions technology
SBTi	Science Based Targets initiative
SCS	soil carbon sequestration
t	metric tonne
TRL	technology readiness level
USD	United States dollar
VCM	voluntary carbon market

Executive summary

The science is irrefutable – drastic and urgent greenhouse gas emissions (GHG) reductions are needed to limit global warming to 1.5°C.

It is becoming increasingly clear that simply reducing emissions will not be sufficient. It is also necessary to remove significant quantities of carbon dioxide (CO_2) from the atmosphere to complement short-term climate mitigation, neutralize any residual emissions at net zero and potentially mitigate the effects of a global temperature overshoot through carbon negativity.[1] Most residual emissions at net zero will be from hard-to-abate sectors, such as aviation and heavy industry. Estimates of the scale of carbon dioxide removal (CDR) needed in 2050 vary widely from between 5 and 15 $GtCO_2e$/year.[2] This will largely be dictated by the level of decarbonization achieved over the next two decades.

CDR will be core to achieving net zero as companies use it to neutralize any residual emissions. However, if companies wait until close to the point of them achieving net zero emissions to invest in CDR, the various methods will not be able to materially contribute to mitigation in the short-term and will not be available at scale to achieve net zero emissions by 2050. Hence, the World Business Council for Sustainable Development (WBCSD) recommends that companies also begin investing in CDR during the transition to net zero in parallel with in-value chain emissions reductions. Guardrails, such as those required by the Science Based Targets Initiative (SBTi) Corporate Net Zero Standard, ensure CDR investments complement, but do not come at the cost of emissions reduction activities.[3]

There are a range of promising conventional land-based and novel CDR methods in various states of development, although deployment has been limited to date for a variety of reasons. These reasons include a continued lack of awareness of the broader need for CDR, lack of investment incentives, high costs and scrutiny over the integrity of corporate claims and the projects themselves. Fortunately, much work is underway to improve CDR governance and market integrity. For example, the rules for the trading of CDR between countries are being defined by the Supervisory Body of the UNFCCC Article 6.4 mechanism and supply-side integrity benchmarks for the voluntary carbon market (VCM) are being developed by the Integrity Council for the Voluntary Carbon Market (ICVCM).

Despite this progress, many companies remain unclear on the business case for early CDR investment and lack guidance on the different roles conventional land-based and technological methods could take in their climate strategies. WBCSD aims to help companies navigate these complexities and to bridge the common divide between nature and technology in the CDR landscape. This document provides practical guidance to help sustainability professionals develop ambitious CDR investment strategies – that include and embrace the differences between the various methods and support their corporate climate strategies.

Box 1: Key principles for responsible CDR investment

- Minimize the need for CDR
- Ensure that CDR investments are not priotizied ahead of emissions reduction
- Ensure the timely deployment of CDR
- Understand the differences and wider implications of CDR
- Proactively develop a diverse portfolio of methods
- Conduct due diligence to ensure removals are of high quality and integrity
- Consider managing permanence differences

We introduce seven key principles for responsible CDR investment – shown in Box 1. These will help companies understand how to maximize the climate and broader sustainability benefits of CDR while minimizing associated risks and trade-offs.These principles broadly apply to all forms of investments, though this guidance is primarily targeted at investments made beyond the value chain.

There are various promising CDR methods, such as reforestation, biochar and Direct Air Carbon Capture and Storage (DACCS). Well-designed, high-integrity CDR projects should materially mitigate climate change. They can provide broad contributions to Sustainable Development Goals (SDGs) and apply safeguards to mitigate any potential negative side impacts. However, each CDR method exhibits distinct climate impacts, feasibility considerations and potential side effects. Due to the fundamental differences between the different CDR methods, making decisions about which of them to invest in can be challenging. To address this complexity, this document provides a detailed overview of a short-listed set of promising CDR methods and presents a decision framework that enables companies to compare them holistically. The decision framework uses a standardized set of criteria based on climate mitigation effectiveness, feasibility and side impacts.

This, combined with analysis of different methods based on available scientific literature, will allow companies to prioritize methods based on different corporate preferences.

Companies that develop portfolios with a diverse array of both conventional land-based and novel methods can maximize climate advantages and reap various core benefits. This approach also helps to balance out any trade-offs and spread any investment risks across the portfolio. In addition, companies that proactively plan a CDR portfolio can provide strong demand signals to the market and facilitate access to those methods with currently very limited supply.

To assist companies in developing a diverse portfolio, we introduce a multi-step approach using the decision framework created to inform the optimal mix of CDR methods while also accounting for future market mandates, different purchasing approaches and project-specific considerations.

We hope this guide will help companies overcome the barriers on the way to investing in CDR that fit their business and sustainability strategies and ultimately increase the uptake of CDR in the short- and medium-term, and help the world to stay in reach of a 1.5°C scenario.

An introduction to *carbon removal*

01.

01. An introduction to carbon removal

Climate context

Global temperatures have already risen by more than 1°C – caused mainly by ever-increasing concentrations of atmospheric CO_2. The remaining carbon budget of about 500 gigatonnes (Gt) (2021 figure) is dwindling rapidly. The window to limit global warming to 1.5°C is closing fast and can only be achieved through unprecedented emissions reductions globally. However, even the most ambitious decarbonization pathways consistent with a greater than 50% chance of limiting global warming to 1.5°C, with no or limited overshoot, often rely on carbon removal to varying degrees. [4]

Carbon dioxide removal (CDR) can provide three key benefits:

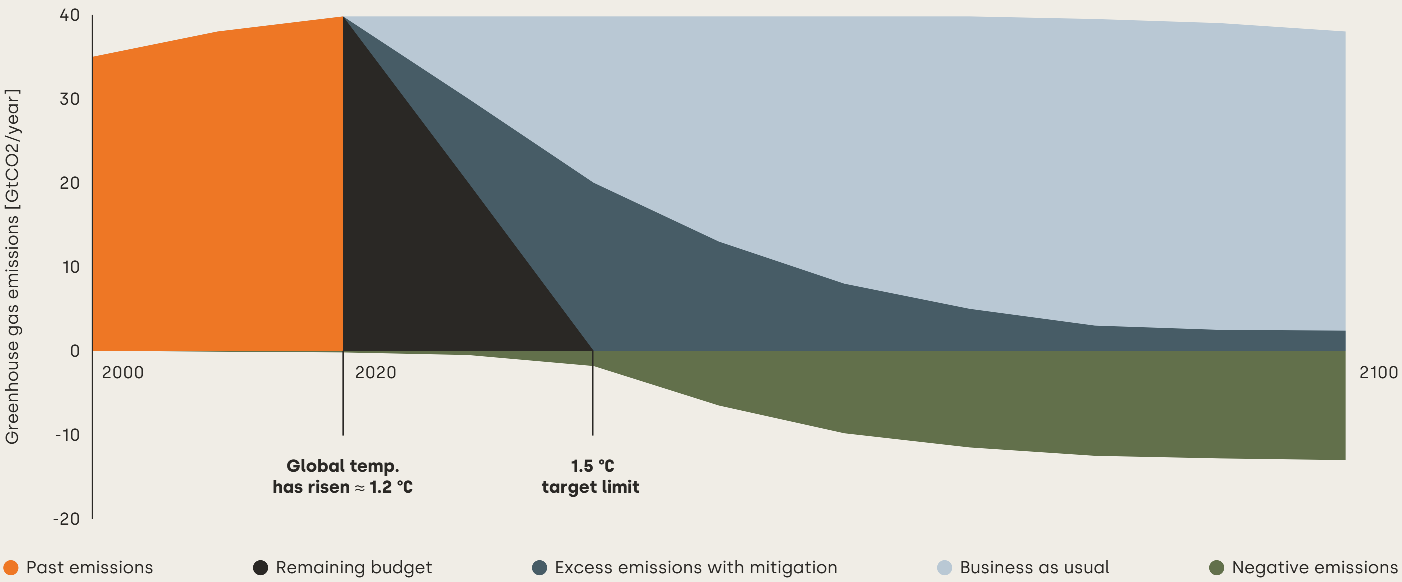
1. Complement emissions reductions to accelerate short-term climate mitigation to avoid a dangerous temperature overshoot over 1.5°C.
2. Neutralize any remaining unabated or residual emissions at the point of net zero from the hard-to-abate sectors.
3. Help the world to recover from a potential temperature overshoot.[6]

Climate experts generally agree that carbon removal of around 200–1,000 $GtCO_2e$ (gigatonnes of carbon dioxide equivalent) throughout the century will be needed to limit global warming to a safe limit.[7,8] Estimates of the scale of CDR required in 2050 vary widely from between 5 and 15 $GtCO_2e$/year. This corresponds to approximately 10-30% of annual global emissions in 2022. [2]

Despite their critical role in tackling climate change, overreliance on CDR could decelerate other decarbonization efforts. It may also pose a heavy burden on economies, societies and natural ecosystems because of high resource requirements, such as energy, materials and land.

Overreliance may also be much more expensive. The marginal abatement cost of reducing emissions is generally significantly lower than the cost of removing equivalent quantities from the atmosphere permanently until emissions have reached a minimum, as many of the technologies available for emissions reductions are more mature than those for permanent removal.[9] Therefore, CDR cannot be a substitute for drastic emissions reductions in the near term. Nevertheless, it is necessary to invest in removals in parallel to ensure they can meaningfully contribute to climate mitigation.

Figure 1: CO_2 removal (negative emissions) in a stylized climate mitigation pathway



Source: Based on[5]

Defining carbon removal

The Intergovernmental Panel on Climate Change (IPCC) defines CDR as an activity initiated by humans that removes CO_2 from the atmosphere and durably stores it in geological, terrestrial, or ocean reservoirs or in products.[1] The two defining elements of CDR are the carbon capture mechanism and storage medium. Ultimately, all carbon is removed from the atmosphere, although different capture methods involve taking carbon directly from either the atmosphere or indirectly through biomass. The most fundamental characteristic that defines the climate impact of a removal solution is durability. This is a measure of the permanence of storage and is largely dictated by the storage medium. Figure 2 provides an overview of the most common CDR methods under development.

Carbon capture, utilization and storage (CCUS) and CDR are frequently confused. CCUS is an important suite of technologies that can reduce fossil emissions from hard-to-abate sectors or lead to a net removal if the captured carbon is atmospheric. CCS-based removals are typically differentiated into direct air carbon capture and storage (DACCS) or bioenergy carbon capture and storage (BECCS) based on whether the captured carbon is sourced from the atmosphere directly or indirectly through biomass.

Figure 3 shows the different climate outcomes that can result from CCUS.

Figure 2: A descriptive taxonomy of different removal solutions

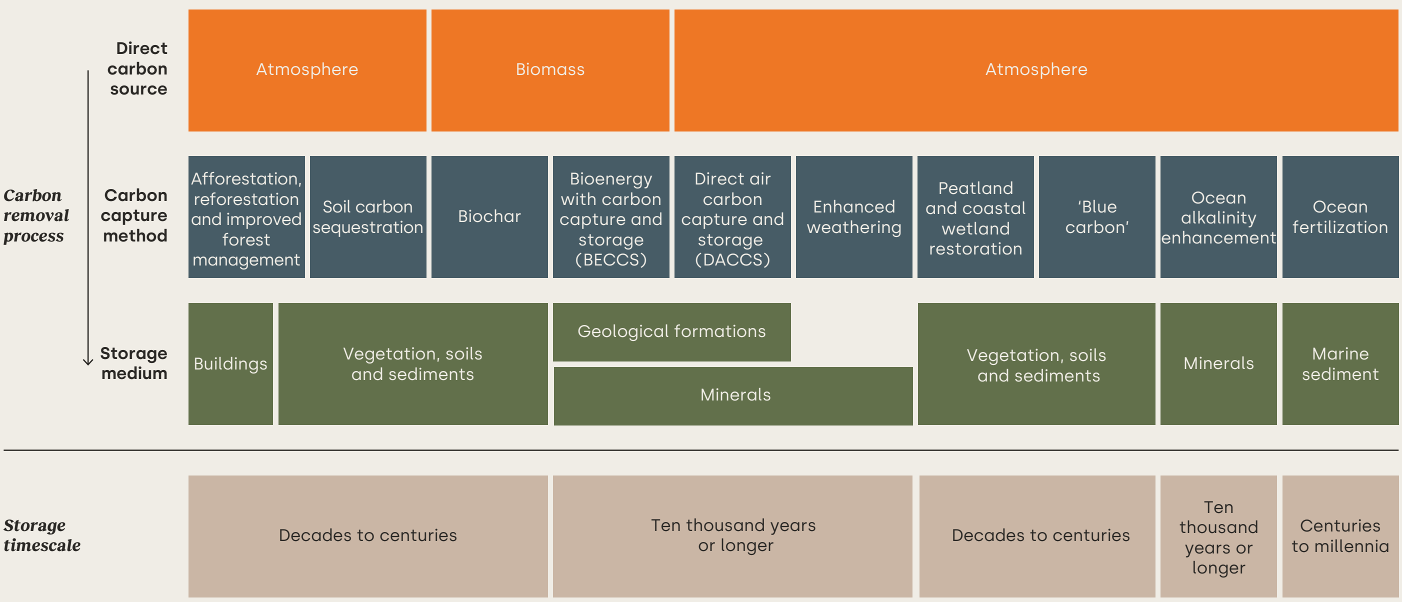


Figure 3: Overview of the different applications of CCUS and the resulting climate impacts

Storage medium	*Direct carbon source*		
	Fossil emissions	**Atmosphere**	**Biomass**
Geologic (e.g., depleted oil and gas reservoirs and aquifers)	Fossil/point source CCS	Direct air carbon capture and storage (DACCS)	Bioenergy carbon capture and storage (BECCS)
Long-term products (e.g., cement)	Fossil carbon capture and utilization (CCU)	Direct air carbon capture and utilization (DACCU)**	Bioenergy carbon capture and utilization (BECCU)**
Short-term products (e.g., synthetic fuels)	Fossil carbon capture and utilization (CCU)*	Direct air carbon capture and utilization (DACCU)**	Bioenergy carbon capture and utilization (BECCU)**

● Carbon reduction ● Carbon removal

* Synthetic fuels made from fossil-based CCU can only ever result in partial emissions reductions from increased carbon efficiency.
** Biogenic CCU can result in removals for long-lived products, for use in synthetic fuels, but the best outcome that can be achieved is net-zero emissions.

Carbon removals in corporate climate strategies

The backbone of a company's climate strategy will be a reduction of emissions in its own operations (known as Scope 1 or 2) as well as in the rest of its value chain (known as Scope 3). However, unless they can fully eliminate all emissions, companies that commit to achieving net-zero emissions are effectively committing to investing in CDR to some degree.

Companies will need to eliminate any remaining unabated emissions at the point of net zero with an equivalent quantity of CDR. This is also known as neutralizing residual emissions under the Science Based Target initiative's (SBTi) *Corporate Net Zero Standard.*[3] Irrespective of the type of carbon removal, these investments can take place in the value chain or beyond the value chain - by directly investing in projects or purchasing and retiring removal credits from the VCM.

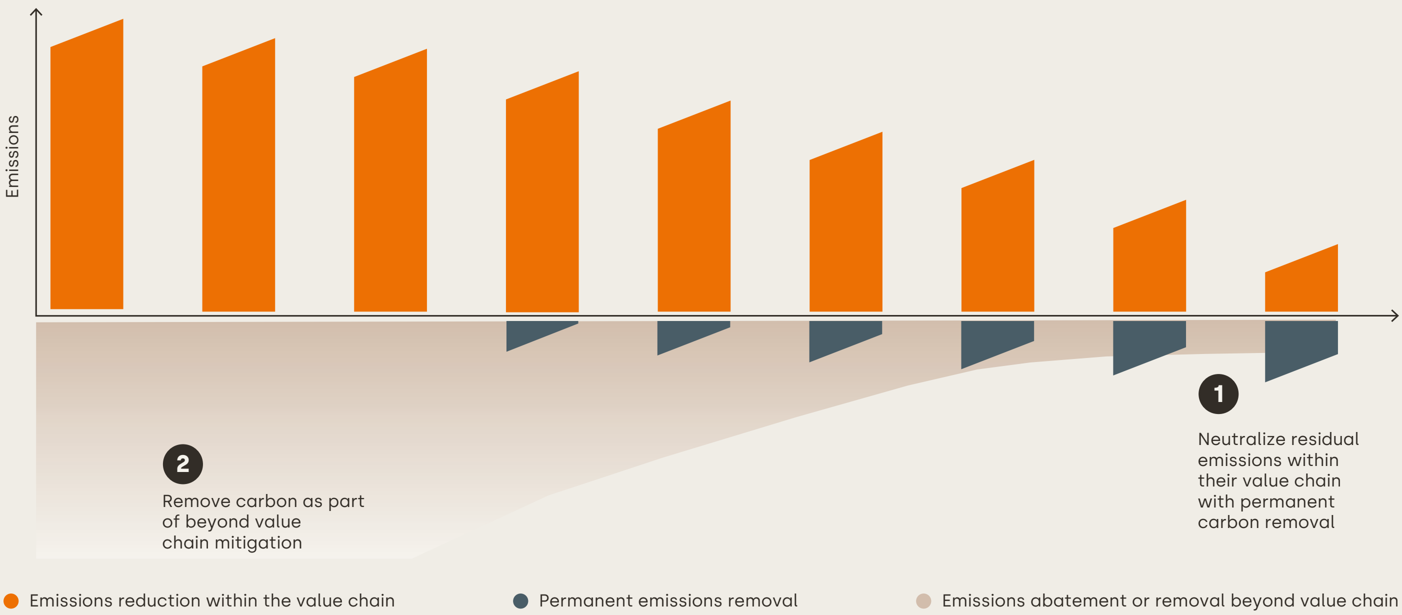
Three main variables dictate the neutralization strategy at net-zero emissions:

1. The quantity of residual emissions when a company claims to have achieved net zero emissions;
2. The sources of residual emissions may dictate the level of permanence of the storage mechanism required. Different organizations are working to define permanence levels across the VCM and compliance markets, though they have reached no definitive position at present. There is a growing movement to neutralize residual fossil emissions with only the most durable technological methods to attain permanent climate stabilization and avoid putting undue pressure on land use.[10]
3. The overall climate ambition – whether companies are aiming to go beyond net zero emissions and become carbon negative (or climate positive) with a view to remove all historical emissions. Note that there is no standardized approach to measure and claim progress against such targets at present.

If every company waits until the point of net zero emissions to start investing in CDR, the methods may not be mature and will not be available at the right scale for them to make a meaningful contribution to global climate mitigation. In addition, there may be a limited supply of CDR methods available for neutralization if early-mover companies have secured access early-on. Companies can help mitigate this by creating clear demand signals and starting to invest in CDR in increasing quantities during the transition to net zero emissions, in parallel with emissions reduction activities. SBTi's *Corporate Net Zero Standard* places guardrails on these investments to ensure they don't come at the cost of a company's absolute emissions reduction objectives.

Under this standard, companies can only make claims with CDR investments at the point of net zero emissions and cannot use them to claim progress against interim decarbonization targets. Instead, investments during the transition to net zero can only be made outside the value chain – not in the value chain. This is what SBTi refers to as "beyond value chain mitigation" (BVCM).[3] Due to dependences and impacts on land, unlike companies in other sectors, in-value chain investments are more strategically important to companies in the Forest, Land and Agriculture

Figure 4: An example of a non-FLAG sector corporate net-zero pathway



Source: Science Based Targets initiative[3]

(FLAG) sector. As such, SBTi provides standalone guidance for companies in this sector – as described in Box 2.[11]

BVCM activities include buying and retiring carbon credits from the VCM, though work is still ongoing by SBTi to fully define what other activities may be counted.[12] Buying and retiring carbon credits may allow companies to make with additional claims, such as those developed by the Voluntary Carbon Market Integrity Initiative (**VCMI**).[13] To be able to make the highest level of claim (Platinum) under the VCMI Claim Code of Practice, companies that satisfy the pre-requisites will need to fully counterbalance all unabated emissions on the path to net-zero emissions by buying and retiring an equivalent number of high-integrity carbon credits. The *Integrity Matters* report from the UN High-Level Expert Group (HLEG) calls upon ambitious companies to do this.[14]

Carbon credits can either be associated with activities that lead to a reduction of emissions or removal of carbon from the atmosphere. We recommend that companies develop a portfolio of quality carbon credits that includes both. There is limited formal guidance on the relative proportions of the different mitigation types in a portfolio at present. SBTi recommends initially prioritizing projects that restore and enhance natural carbon sinks to protect remaining intact ecosystems in the near term. However, portfolios that include gradually increasing proportions of technological removal will help these still-nascent technologies overcome the significant techno-economic challenges preventing their deployment at scale. Innovation and learning-while-doing will help ensure technological methods are available for companies to achieve net-zero emissions at the stated target date.[15]

WBCSD is currently developing guidance for beyond value chain mitigation, focusing on the business case and a how-to guide for overarching carbon credit portfolio construction. Companies can use this CDR-specific guide to complement the forthcoming publications.

Box 2: CDR in the forest, land and agriculture (FLAG) sector

CDR plays a different role in the climate strategies of the FLAG sector. Due to dependencies and impacts on land, enhancing terrestial carbon sinks is a key part of a net-zero emissions pathway for companies in the FLAG value chain. As such, activities such as agroforestry, soil carbon sequestration and biochar within the value chain are permitted to contribute to near-term climate targets under SBTi guidance.

Key principles for *carbon removal investments*

02.

02. Key principles for carbon removal investments

We introduce seven science-aligned key principles for companies to adopt CDR responsibly. These will help ensure companies can maximize the environmental, social and economic benefits of CDR while mitigating any associated risks (such as financial risks to the company and potential physical side impacts of the removal) as much as possible.

2.1 Minimize the need for CDR

The quantity of residual emissions at the point of net-zero emissions will drive the overall global need for CDR. As per SBTi's net-zero standard, companies should minimize residual emissions to as low a level as possible.[3]

This will ensure the most cost-effective deployment of removals and will help drive the overall system transformation needed to mitigate climate change fully, rather than prolonging dependence on fossil fuels where not truly needed.

2.2 Ensure that CDR investments are not prioritized ahead of emissions reduction

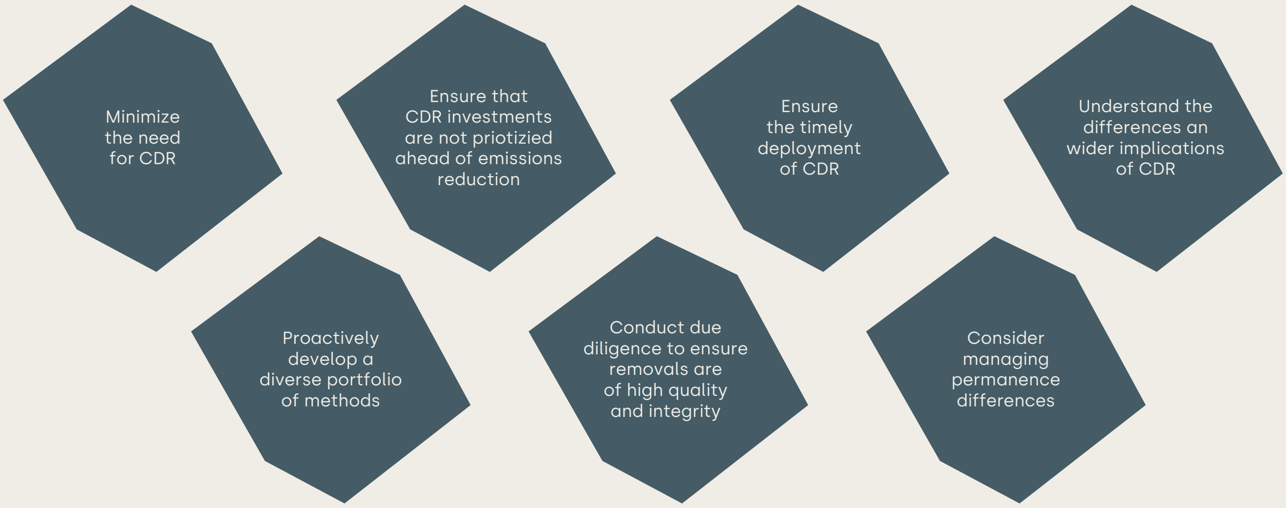
CDR should never be a substitute for in-value chain decarbonization activities. For companies outside the FLAG sector, SBTi's net-zero standard does not allow companies to use any form of CDR investment (in or out of the value chain) to contribute to near-term emissions reduction targets. Instead, CDR investments can only made as a BVCM activity Companies are encouraged to develop a portfolio of climate mitigation solutions beyond the value chain that includes both emissions reduction and removal activities, with reduction activities initially prioritized.[3]

2.3 Ensure the timely deployment of CDR

CDR methods have a narrow window of opportunity to help stabilize the climate safely. Most will take time to start achieving material removal from when companies make the investments. Novel technological methods like direct air carbon capture and storage (DACCS) and bioenergy carbon capture storage (BECCS) involve long planning periods (e.g., to develop geological storage sites). Conventional land-based methods, like reforestation, have non-linear sequestration rates and need rapid deployment to fulfil their full potential this century.[16]

In addition, novel technological methods typically have very high costs because of the early stage of technological development. Investment into first-of-a-kind projects and strong demand signals for novel methods can help reduce costs through innovation and learning while doing. Therefore, we recommend that companies start investing in a diverse range of promising CDR methods as soon as possible and gradually increase the proportion of novel methods over time. This will help companies contribute to short-term climate mitigation ambition and ensure they can neutralize residual emissions at net zero – ultimately helping to stabilize the climate safely.

Figure 5: Key principles for CDR investment



2.4 Understand the differences between and the wider implications of different CDR methods

Deciding on which CDR methods to invest in can be daunting. There are many different CDR methods in varying stages of development. They all come with a wide array of attributes. Different methods can also have a variety of positive or potentially negative side impacts. Examples include competition for resources and consequences for biodiversity and local communities. Many projects are specifically designed with many positive side impacts that contribute to the Sustainable Development Goals (SDG's), which are labeled as core benefits for Natural Climate Solutions (NCS). These can be essential for companies aiming to develop a CDR portfolio that contributes to their broader sustainability agenda, including e.g. nature positivity.

To make informed purchasing decisions, it is critical to understand the attributes, ramifications and particular investment needs of different methods. This is also needed to justify different price points. We provide a decision framework in section 4 to help companies fully assess and prioritize methods across a common set of attributes.

2.5 Proactively develop a diverse CDR portfolio

Rather than investing in a single or limited set of methods, a portfolio of different methods will allow for synergies and will counteract the trade-offs between the different solutions. There are clear benefits for companies and the climate as a whole:

- Companies can fulfil their climate strategies and maximize the short and longer-term global climate benefits by developing a portfolio of both more scalable conventional land-based and more nascent technological methods.
- Companies can maximize the various core benefits across the different solutions which will help companies contribute to their broader corporate sustainability targets.
- Methods that emerge to meet the requirements of future compliance markets will be sufficiently well-developed to be more commercially viable. This will ensure companies can access sufficient supply of removals to satisfy compliance market demands.
- Companies can spread the potential investment risks and potential trade-offs, such as land and energy requirements, of different methods across the portfolio.

Section 5 provides practical guidance for companies on developing a diverse CDR portfolio.

2.6 Conduct due diligence to ensure removals are of high integrity and quality

We recommend that companies ensure any removals projects they invested in satisfy minimum quality and integrity criteria and conduct sufficient due-diligence assessments. This will ensure that companies maximize broader sustainability benefits and minimize the following risks:[18]

- The reputational risk from "greenwashing" accusations caused by investing in low-quality projects;
- The financial risk associated with projects being able to withstand future price and demand fluctuation;
- The operational risk associated with the removal not happening as planned;
- The risk that could result from political uncertainty.[18]

Quality criteria

While CDR investments will not exclusively be purchases of credits from the VCM, most of the "Core Carbon Principles" set out by the ICVCM for high-integrity carbon credits provide a useful framing of the key criteria that could apply to any type of investment.[17] If a company purchases a CDR credit, the independent validation and verification of CDR projects by credible carbon crediting programs should ensure the project satisfies minimum quality criteria. If companies directly invest in a CDR project outside of a crediting program, companies will need to ensure the project satisfies these criteria themselves.

Due to significant variation in the potential for core benefits and negative impacts across different methods, it is particularly important to ensure that sufficient safeguards are put in place to mitigate any associated risk and that projects maximize contribution to sustainable development benefits.

We strongly recommend that companies apply additional, more stringent quality criteria emphasizing the importance of biodiversity gains, community engagement and benefits to people. More comprehensive resources are available on this topic, such as the NCS Alliance's *A Buyers' Guide to Natural Climate Solutions Carbon Credits*, which focuses on nature-based emission reductions and carbon removal credits.[18]

Due diligence

Due diligence is key to ensuring selected CDR projects satisfy the criteria set out for high-quality removals. Companies are encouraged to conduct due diligence in addition to any independent verification of the specific project provided by a crediting program. They can do this internally or via third parties, if needed. Purchasing platforms that provide vetted CDR portfolios or consultancies may conduct this degree of due diligence. Refer to section 5 for more details and examples. The NCS Alliance's *A Buyer's Guide to Natural Climate Solutions Carbon Credits* details the steps that companies can follow to develop their own due diligence approaches.[18]

2.7 Understand and manage permanence differences

Ensuring permanence is key to a high integrity CDR project. High integrity crediting schemes put measures in place to ensure that all high integrity removal projects remove carbon from the atmosphere 'permanently'– that is potentially up to 100 years. This is key to ensuring CDR projects provide material removal for a climate relevant duration.[17]

However, this does not reflect the orders of magnitude of permanence differences between different methods. These differences may dictate the future different roles that the different CDR methods may have in neutralizing emissions. For example, fossil emissions may only be fully neutralized by a removal if the carbon is stored for geological timescales – greater than 100,000 years.[20] A net zero emission state without this storage permanence would result in unsustainable continued carbon flows into the atmosphere.[10] Only the most durable methods will be able to achieve this equivalence. Neutralization of a fossil emission with a more temporary removal would effectively just delay the emission. This may still delay climate impacts and reduce peak warming but will ultimately not lead to permanent climate stabilization.[21]

Permanence rules for neutralizing residual emissions across voluntary and compliance markets have yet to be defined. As such, companies that seek and claim to actively neutralize any fossil emission through a CDR investment may wish to consider proactive voluntary approaches to managing the permanence equivalence of different methods. This therefore may not be relevant to companies not actively making fossil emission neutralization claims from CDR investments, such as those making CDR investments to complement short-term climate mitigation on the transition to net zero as a beyond value chain activity.

There are three approaches to managing permanence equivalence when considering neutralizing a fossil emission.[22]

Box 3: ICVCM Core Carbon Principles relevant to companies investing in CDR. [17]

Additionality. "The greenhouse gas (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. "The 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."

Robust quantification of emission reduction and removals. "The GHG emission reductions or removals from the mitigation activity shall be robustly quantified, based on conservative approaches, completeness and scientific methods."

No double counting. "The 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. "The carbon-crediting program shall 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 toward net-zero transition. "The 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."

There are also principles of **effective governance, tracking and transparency**, but these are mostly specific to crediting programs.

1 Horizontal stacking

This involves sequentially purchasing another "temporary" removal every time a credit expires – or at the end of the estimated storage duration. This simplistic approach could be more cost-effective due to the significantly lower costs of less permanent methods compared to the most permanent, novel methods. However, it may place undue demand for land availability and relies on a company continuing this approach indefinitely. This places a significant administrative burden on a company and the renewal is at risk of stopping if a company goes out of business at some point in the future.

2 Vertical stacking

This involves purchasing multiple temporary credits upfront to permanently neutralize an emission. While this supplies significant up-front climate benefits, it ultimately leads to a delayed spike in emissions. This approach is more complicated than horizontal stacking and requires companies to weigh short-term climate benefits with long-term climate impacts. It also may be difficult to meet short-term supply to achieve the over-purchase in the near-term.

3 Like-for-like neutralization

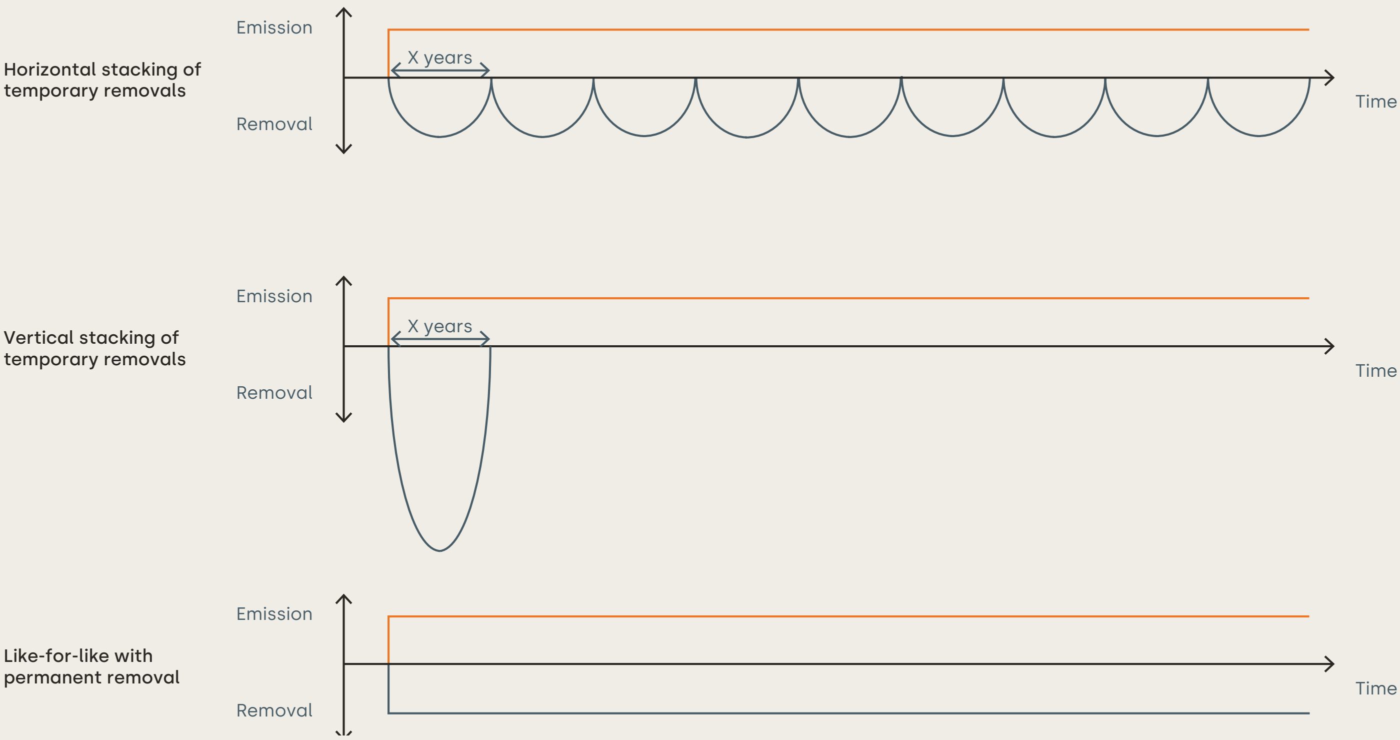
This entails investing only in the most durable CDR methods to neutralize fossil emissions. This can apply regardless of the investment approach and may be a key consideration for in-value chain investments and direct investments into projects. While this is the simplest and most effective approach, it is mostly prohibitive at this time due to the high costs and lack of available novel, highly permanent, CDR methods.

Box 4: How do crediting schemes manage permanence?

The ICVCM Core Carbon Principle of permanence requires that any crediting scheme puts in place measures to address the risk of non-permanence and compensate reversals. [(17)] Crediting schemes need to guarantee permanence for a climate-relevant duration (initially for 40 years but potentially up to 100 years). This can only be achieved by continued monitoring for reversal after the crediting period is over.

Unplanned re-emission may occur due to events such as forest fires and extreme weather. Carbon crediting programs have buffer pools to account for this. This requires project developers to hold some of the supplied credits in a buffer pool that they surrender in the event of premature re-emission. This is factored into the credit pricing.[19]

Figure 6: Overview of different approaches to managing permanence



Note: Not to scale

The stacking approaches are likely to only be possible for CDR investments made through purchasing and retiring carbon credits due to the administrative complexities of stacking multiple investments.

Developments in voluntary or compliance frameworks may require companies to use specific approaches in time. We do not intend for this guide to provide a comprehensive overview of permanence equivalence but rather a high-level overview of critical considerations and approaches. Additional tools, such as Carbon Plan's permanence calculator, provide further guidance.[23]

Overview of common *CDR methods*

03.

03. Overview of common CDR methods

In this section, we present a synopsis of some of the most promising CDR methods to help companies understand some of the main differences among them. The methods are categorized into "conventional CDR methods" and "novel CDR methods".[24] They all hold the potential to achieve CO_2 removal at the gigaton scale ($GtCO_2$/y), though, as Figure 8 shows, there are wide variations in the estimated potentials.

Figure 7: Overview of selected CDR methods

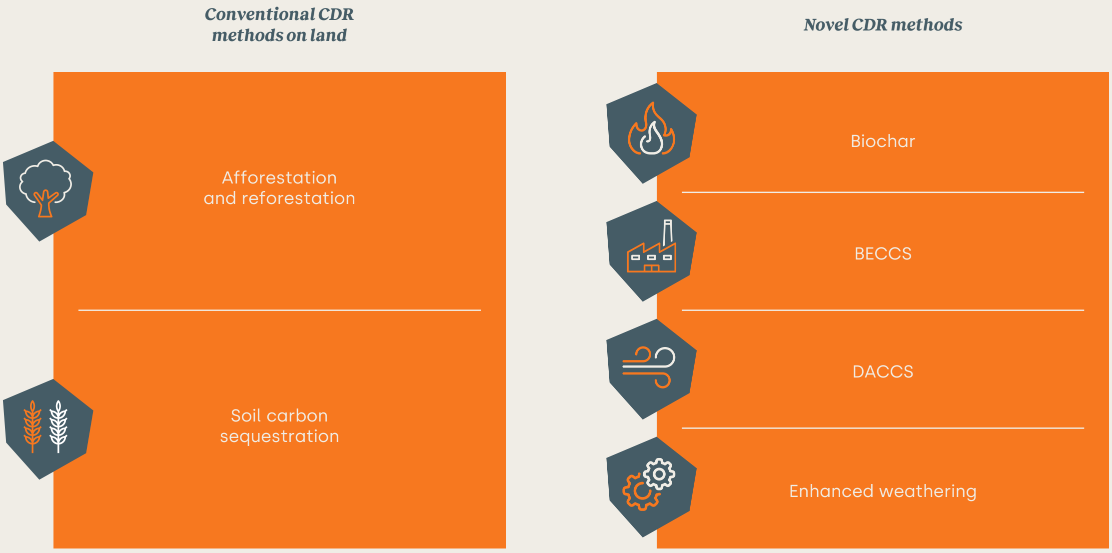
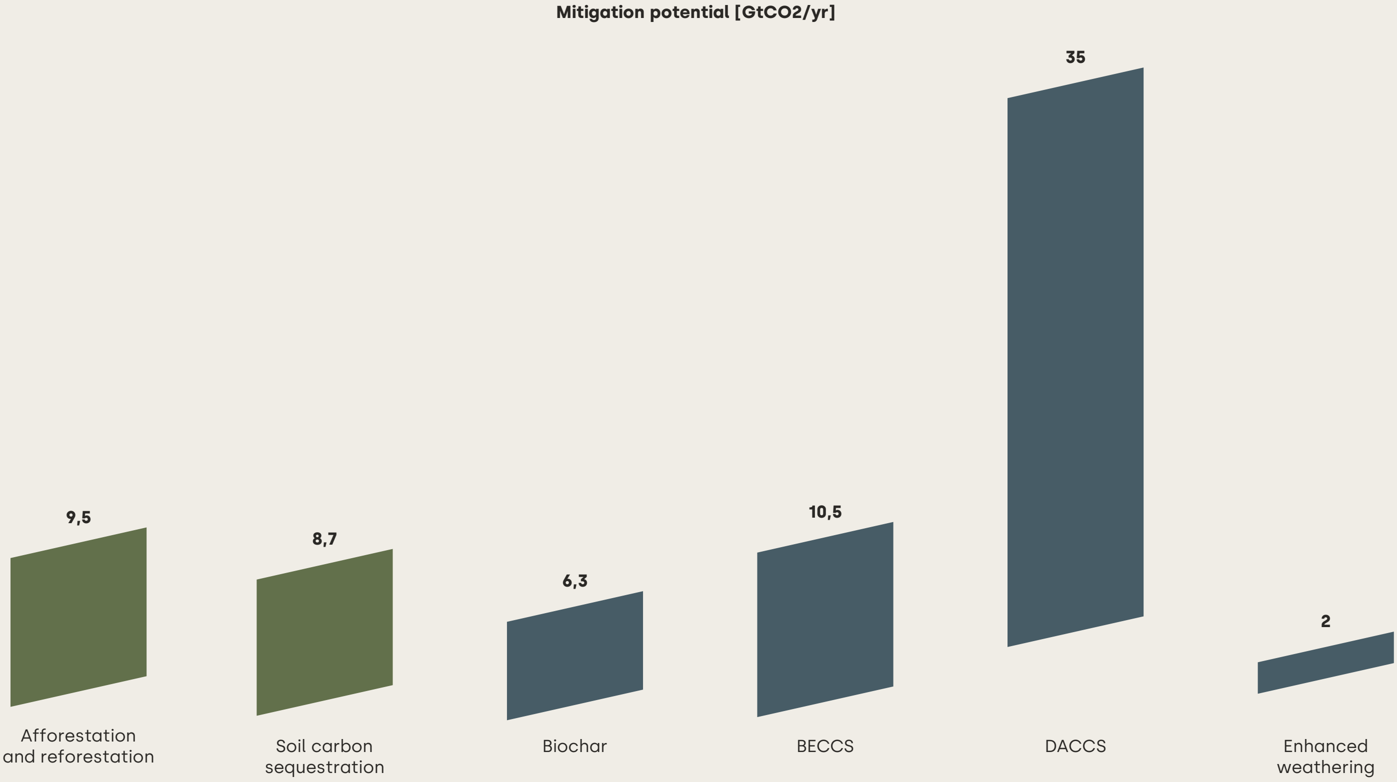


Figure 8: Mitigation potentials of selected CDR methods



Source: IPCC WGIII AR6[1]

3.1 Conventional CDR methods on land

Afforestation and reforestation

The IPCC defines afforestation as the "conversion to forest of land that historically has not contained forests" and reforestation as the replanting of trees in "previously forested land".[25] They involve planting trees to remove carbon dioxide from the atmosphere through photosynthesis and storing it as carbon in their leaves, stems and roots. Afforestation and reforestation are often grouped together, although it is important to distinguish one from the other.

> ***Box 5: What are Natural Climate Solutions (NCS)?***
>
> NCS are Nature-based Solutions (NbS) that address climate change. NbS are "actions to protect, conserve, restore, sustainably use and manage natural or modifies terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits…".[26]
>
> These can be activities that lead to emissions reductions, or removal of carbon from the atmosphere. Conventional, land-based removal methods can be classified as NCS, if projects are sufficiently designed to provide the benefits described above.

Relative to other CDR methods, both are low-cost and low-tech with many potential core benefits. Reforestation, in particular, can help protect and recover biodiversity, improve water supply and quality, and reduce the risk of soil erosion and floods.[25, 27] Reforestation can also have substantial social benefits,such as providing sustainable incomes for local populations, improving climate adaptation and water security and reducing the risk of floods.[25] Unlike reforestation, according to the IPPC, "afforestation of naturally unforested land [..] can compound climate-related risks to biodiversity, water and food security, and livelihoods".[25]

Afforestation and reforestation have characteristic carbon storage durations in the order decades to centuries and have relatively high risks of reversal from effects such as extreme weather. Reforestation projects are typically more effective at storing carbon and increasing resilience than other forms of tree-planting, as natural forests are typically more climate-resilient.[27] Any reforestation or afforestation project that involves non-native native species, or insufficient species diversity, can be more vulnerable to reversals as these ecosystems can become less climate-resilient.[1]

These variations show the importance of careful project design and planning in maximizing carbon removal and climate resilience, while ensuring a positive impact on people and ecosystems. Effective strategies must acknowledge local socio-ecological aspects by integrating effective landscape planning and informing, engaging and getting consent from local communities.

Soil carbon sequestration

Soil carbon sequestration (SCS) involves a range of agricultural and land management practices to increase soil organic carbon content. This results in the removal of CO_2 from the atmosphere. Measures include improved crop rotations with reduced fallow, the addition of organic materials like compost and other cropland, and grazing management measures.[2]

These agricultural and land management practices are generally well-known and immediately deployable, though the method only represents a small portion of the CDR market at present.[2] As such, there is limited available data to analyse actual performance. Based on available research, SCS measures can improve soil health and increase agriculture's climate resilience, in addition to removing carbon. Costs can be very location-specific, though initial estimates suggest relatively low cost compared to other methods, generally in the range of 0-100 USD $/t.[2] In some cases, projects may even result in net profits if productivity gains exceed implementation costs – though in other cases, productivity losses could occur without adequate safeguards. The practices require zero additional land footprint and negligible water and energy use.[28]

However, SCS projects can be highly vulnerable to reversal: if the agricultural practices cease, the carbon can be re-released back into the atmosphere. The removal timeline is also uncertain because it depends heavily on environmental factors. Measurement, reporting and verification (MRV) can be difficult because its effect is difficult to quantify. Also, implementation can be challenging as is requires multiple, and diverse stakeholders across the agricultural value chain to be aligned. Assessing additionality may also become a challenge due to the potential for profit creation and emerging supportive regulations.

Despite these challenges, SCS can provide significant global potential for a more temporary removal method with relatively low costs, while potentially providing a number of core benefits. Due to the strong association with agriculture, these methods may be particularly suitable for achieving in-value chain removal targets in the FLAG sector.

Box 6: Key considerations for conventional[2] CDR methods on land:

- → These methods broadly have lower techno-economic risk than novel methods.
- → These methods, particularly when classed as NCS, can provide strong contribution to numerous SDGs by bringing many social, economic and biodiversity (core) benefits.
- → Projects need to be planned and designed carefully to ensure removal potential, climate adaption potential and core benefits are realized, without introducing any negative impacts.
- → Given the typically higher reversal risk, robust MRV and systems to compensate for any reversals are needed to guarantee permanence for a climate-relevant duration – such as those provided by a high-integrity carbon crediting scheme.

3.2 Novel CDR methods

Biochar

Biochar is a biomass-based CDR method that helps build soil organic carbon stocks. Biomass stores CO_2 removed from the atmosphere by photosynthesis. It is converted to charcoal via pyrolysis (thermal decomposition). The char is then added to the soil during the crop-sowing process to store the carbon in the soil.[29]

Biochar is still fairly nascent, although there are established and growing market offerings. As such, there is still significant uncertainty over the potential permanence of storage, though current literature suggests a range from hundreds to thousands of years.[30, 31] The numerous system configurations that exist for producing biochar impact storage duration. Influencing factors include:

- → **Feedstock**, such as woody residues, crop straw, animal manures, sewage sludge, and food waste;
- → **Maximum pyrolysis temperature.** This commonly ranges from around 350°C to over 750°C;
- → **Residence time** at maximum temperature during pyrolysis;
- → **Treatment** of the biomass and/ or the char after pyrolysis;[32]
- → **Soil type**, such as clay content.[33]

Biochar produced above 500°C has the potential to achieve longer storage times, with up to thousands of years estimated.[29, 34] Biochar produced at higher temperatures is typically more expensive, with prices of over USD $300/t$CO_2$ seen to date, compared to prices below USD $200/t$CO_2$ for lower-temperature biochar.[35]

Biochar can have an immediate removal effect and market trends suggest it may be possible to have a quick adoption rate. Biochar can also have positive economic side impacts, for instance by improving agricultural yields by 10%–42%.[29]

Negative environmental side impacts are possible, although long-term effects remain uncertain. Avoiding agricultural expansion to produce feedstock biomass is essential to prevent negative impacts from land-use change. Instead of dedicated biomass crops, biochar systems can use waste and residues from forests, crops, sewage and manure.

The many possible biochar configurations mean that they can be tailored for specific applications, such as maximizing the duration of storage and the delivery of co-products or reducing costs. In some situations, this method may also be able to lead to a reduction of soil GHG emissions along with a removal of CO_2 from the atmosphere.

BECCS

Bioenergy carbon capture and storage (BECCS) involves producing energy carriers from biomass, through combustion, gasification or other processes. The resultant biogenic CO_2 emissions are then captured and stored geologically for tens of thousands of years. BECCS achieves net CO_2 removals from the atmosphere if the amount of stored CO_2 exceeds the total emissions along its supply chain. In principle, BECCS is a subset of biomass carbon removal and storage (BiCRS).

In practice, however, BiCRS prioritizes carbon removal and BECCS prioritizes energy production. Hence, BECCS suppliers are increasingly referring to their projects as BiCRS. The main variations include:

- → **Biogenic carbon source**. This most commonly biomass. Alternative sources include dedicated energy crops, agricultural by-products, forestry residues and organic municipal waste.
- → **Energy product**. These can include electricity, heat, hydrogen and synthetic fuels.
- → **Capture method**. A range of technological solutions exist with varying efficiencies and applications. Common differentiation includes pre-combustion and post-combustion.
- → **CO_2 transport options**. Common examples include pipelines and shipping and road tankers.
- → **CO_2 storage medium**. Saline aquifers or depleted oil and gas fields are the most common. The CO_2 can also be stored in basaltic rock through mineralization and other long-life products. Additional detail on mineralization is available under DACCS.

All these factors significantly impact the full life cycle emissions and therefore the level of net removals. For example, one type of BECCS involves the capture of CO_2 produced during the fermentation of biomass to produce biogas or bio-ethanol. The net removal will be significantly impacted by the downstream emissions from the combustion of produced biofuels.[36]

As another example, the capture processes involved in BECCS provide a source of bio-CO_2, that may be able to replace non-biogenic CO_2 sources for the chemicals, food and emerging e-fuel sectors. These utilization cases may be key to reducing emissions from certain sectors, but will not achieve permanent removal due to the transient nature of carbon storage in the products. The demand for these products may ultimately limit the potential for BECCS, where the carbon is stored geologically.

BECCS could provide substantial energy supplies globally while durably removing CO_2 from the atmosphere for durations of tens of thousands of years or longer. Electricity and hydrogen production are particularly promising for BECCS.[(37)] [(38)] Costs vary largely, depending on the technology and feedstock, and supply chain complexities such as the transport of biomass and CO_2. The average market price is USD $300/t$CO_2$.[35]

Sustainable biomass sourcing is critical to safely harnessing the removal potential of BECCS. If biomass production results in agricultural expansion (directly or indirectly), the impacts on ecosystems would compromise environmental integrity. The resulting competition for land with food crops may compromise food security and increase food prices. If bioenergy crops directly or indirectly replace highly biodiverse ecosystems, the impacts on biodiversity could outweigh any climate mitigation value. BECCS with agricultural expansion could, in theory, achieve net removals even if it involves substantial land-use change emissions. However, the upfront land-use change emissions and long breakeven time to achieve net removals mean it could not mitigate climate change in a timely manner.

The greenfield application of BECCS could also place additional pressures on biomass supply chains and be more likely to lead to agricultural expansion. Additional transparency is required to ensure feedstock biomass sustainability for greenfield projects.

Sourcing biomass from residues and waste is the most certain way to avoid adverse impacts from land-use change. Dedicated bioenergy crops on existing agricultural land do not directly result in agricultural expansion (i.e., land-use change); nonetheless, it is difficult to ensure they would not result in agricultural expansion elsewhere. Sound governance and transparent supply chain processes can help guarantee environmental integrity. In addition to ensuring environmental integrity, such processes can help increase public engagement and acceptance.

DACCS

Direct air carbon capture and storage (DACCS) involves the removal of CO_2 directly from the atmosphere using a diverse range of technologies. Promising DACCS technologies include solid adsorbents like calcium hydroxide and liquid solvents like amines.[2] Once the carbon has been captured, the transportation and storage processes can be identical to BECCS. The captured carbon can be stored geologically for tens of thousands of years in aquifers or depleted oil and gas reservoirs. An emerging solution is to store carbon in basalts to achieve rapid mineralization. Although both options are considered safe, storage in basalts may be more acceptable – even if more expensive and technically immature – thanks to the possibility of rapid mineralization, which would practically eliminate the risk of leakage. As with BECCS, the captured atmospheric CO_2 can also be used as a feedstock for other processes. All DACCS systems require large amounts of electricity to run the fans and heat to release the captured CO_2 from the chemical absorbent or solid adsorbent. DACCS is less efficient than CCS applied to point-source emissions such as power station flues because the CO_2 is highly diluted in the atmosphere. Maximizing net CO_2 removals from DACCS requires renewable energy to satisfy its substantial energy requirements.[2, 28] However, displacement impacts can be avoided if projects can demonstrate additionality in the renewable energy they use. Although DACCS also requires land, and some variants may require water, the requirements are generally substantially lower than for afforestation, reforestation and BECCS.[40]

Despite high current costs of USD $320 to USD $1800/t$CO_2$, technical immaturity and large energy requirements, DACCS can be a highly effective CDR method.[16] There is significant scope for cost reductions through innovation, with USD $100 to USD $300/t$CO_2$ possible by 2050.[16] The carbon removal created through DACCS is also more easily accounted for, tracked and controlled than other CDR methods.

DACCS can achieve the largest potential among all CDR methods because it is less constrained by biophysical limits.[2] DACCS is also one of the most scalable, fast acting and theoretically location-flexible CDR methods. In practice though, DACCS projects will most likely be located where there is significant other carbon transportation and storage infrastructure due to economies of scale and shared costs.[7]

Enhanced weathering

Weathering is a natural process that erodes rocks and sequesters atmospheric CO_2 over tens of thousands of years into minerals. Enhanced weathering speeds up the natural chemical and physical processes through increasing temperatures, reactive surface area, and interactions with water.[2] A promising method involves pulverizing silicate rocks such as basalt. The resulting powder is then spread on large areas of agricultural land where plant roots and microbes in the soil speed up the chemical reactions.[41] A significant portion of these products will ultimately end up in the ocean.[42]

Enhanced weathering could store CO_2 for the longest duration among the evaluated methods. It also may help increase crop yields if spread on farmland[2] and can help counteract acidification of the ocean caused by increased CO_2 absorption.[42] As an emergent method, it is technologically immature and still faces some uncertainties regarding the timeliness and side impacts (both positive and negative). Moreover, the feasibility of MRV is low at present.[24]
More details can be found in the **appendix**.

Enhanced weathering is possibly the most nascent of all of the selected methods and is not widely commercially available. As such, cost projections are uncertain, though there has been evidence of costs below USD $100/t$CO_2$ being possible.[35] Despite its challenges and uncertainties, enhanced weathering may emerge as a highly promising CDR method.

3.3 Other CDR methods

There are other potential promising CDR methods that are in development, such as ocean-based methods, blue carbon management, agroforestry, and bio-oil sequestration. There are also forms of CCU that lead to a net removal when the product storage is of sufficiently high durability. These include emerging forms of concrete mineralization. All these forms are attracting investment into research and development, as well as pilot projects. However, for the purposes of this guidance we have excluded them. This is mainly due to the lack of readily available data to make a comparison based on scientific consensus.

Box 7: Key considerations for novel CDR methods:

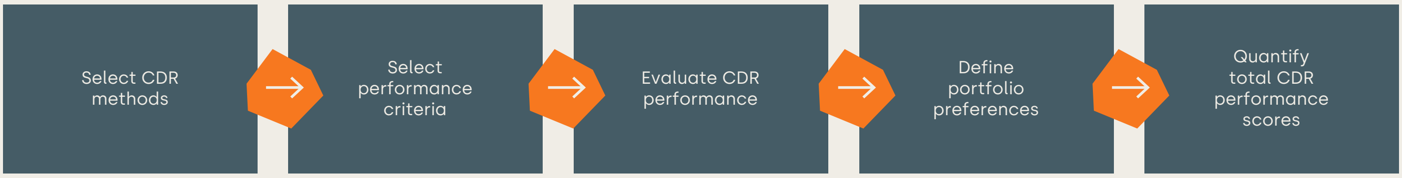
- → Enhanced weathering, DACCS and BECCS offer the most durable CO2 storage with very low risk of reversal. Hence, they offer the closest like-for-like compensation for residual fossil emissions and are ultimately essential for achieving "durable" net-zero emissions. Biochar can be a valuable method with greater durabilities than conventional land-based methods with possible core-benefits.
- → The timeliness and potential scale of novel CDR methods may become vital in mitigating climate change. Although conventional land-use methods have a key mitigation role, their timeliness and potential would likely be insufficient to meet climate targets alone.
- → The high costs and low technology readiness level (TRL) of some options show the opportunities for improvement. Early support of pilot projects can help improve the prospects of emerging CDR methods.
- → The sustainability of key inputs to novel methods, such as energy for DACCS and biomass for biochar and BECCS, will have significant bearing on the overall climate impact and side impacts.

Framework to compare *CDR methods*

04.

04. Framework to compare CDR methods

Figure 9: Decision framework to evaluate different CDR methods



Source: Based on[43]

CDR methods vary greatly across a wide range of attributes. As such, it can be challenging for companies to assess and compare the different methods on a like-for-like basis – especially when comparing conventional land-based with novel CDR methods.

We present a comprehensive yet intuitive framework in the form of a multi-criteria decision analysis (MCDA) process to help companies compare and prioritize different CDR methods on a net removal basis – that is the full life cycle emissions are accounted for outside the framework. As a result, companies will be better equipped to define diversified CDR portfolios that reflect their priorities. The framework was originally developed and published in a peer-reviewed journal by O. Rueda et al. (2021). The IPCC has acknowledged it as a rare case looking beyond least-cost pathways to define CDR portfolios.[1, 43]

We discuss how companies can apply each step of the framework sequentially below. We then apply the framework to selected methods for illustration based on a wide variety of scientific resources.

The performance scores calculated under this process for any CDR method can vary under diverse conditions, such as location or technology-specific applications. **Rather than providing definitive performance scores for CDR methods, the analysis in this guidance aims to show the main differences between the methods and illustrate how companies could use the framework to understand how to prioritize different solutions based on corporate preferences.**

An editable version of the framework is available as a complementary **tool** alongside this guide.

4.1 Select carbon removal methods

Table 1: Selected CO_2 removal methods

Category	*Option*	*Option definition*
Conventional methods on land	Afforestation	The planting of trees on naturally unforested land [25]
	Reforestation	The planting or regrowth of trees on previously forested land using native and non-monoculture species.[25, 44]
	Soil carbon sequestration	The removal and storage of CO_2 in soils via the improved management of land.[45]
Novel methods	Low-temperature biochar	The decomposition of biomass residues at temperatures below 450°C and applying the resulting char to soil.[46]
	High-temperature biochar	The decomposition of biomass residues at temperatures over 600°C and applying the resulting char to soil.[46]
	BECCS involving agricultural expansion	The production of heat, electricity or biofuels with biomass, followed by the capture and storage of exhaust CO_2 underground; the biomass comes from agricultural land that involves land-use change.[47]
	BECCS without agricultural expansion	The production of heat, electricity or biofuels with biomass residues, followed by the capture and storage of exhaust CO_2 underground.[47]
	Direct air capture with storage in saline aquifers	The capture of CO_2 directly from ambient air via the use of chemical reactions with geological storage in saline aquifers.[48]
	Direct air capture with storage into basalts for mineralization	The capture of CO_2 directly from ambient air via the use of chemical reactions with geological storage into basaltic rock through mineralization.[48]
	Enhanced weathering	The acceleration of the process by which minerals absorb CO_2 via, for example, the pulverization and spread of basalt on soil.[49]

The first step is to select the CDR methods for comparison and prioritization.

We have short listed the 10 methods, shown in Table 1. These are based on the 6 CDR categories introduced in section 3.

These 10 methods have been selected to illustrate the following main differences:

- The contrasting impacts of afforestation and reforestation.
- The different storage duration and costs for biochar produced at different temperatures.
- The importance of sustainable biomass sourcing for BECCS.
- The different storage technologies currently being applied to DACCS projects. These could, in theory, apply to BECCS projects although not analyzed here.

Another possible variation was to differentiate DACCS on energy supply that is based on additional renewable energy against energy supplied from local grids. The carbon intensity of the energy supply is key to defining the net removal quantity.

This differentiation was not used here as the framework compares the net removal of the different methods and side impacts are hugely variable based on local energy systems.

Companies can expand the framework to include some of the more nascent methods as data becomes more widely available. They can also amend the selected methods to provide additional granularity between different configurations – for example different types of BECCS projects.

Companies can even use this **tool** to compare removals at the project level, although comparing a specific project or method with very high granularity to high-level CDR methods may result in skewed results. Companies must take care to ensure they are comparing removals on a **like-for-like basis**, such as only different CDR projects or only CDR methods with similar levels of granularity.

4.2 Select CDR performance criteria

The second step is to define performance criteria to evaluate different CDR methods. We recommend the nine criteria shown in figure 10. The selection of the criteria and their evaluation was based on a variety of scientific references.[2, 24, 7, 25, 50, 51]

There may, in theory, be additional criteria, such as capacity potentials and geographical considerations. As shown in Figure 8, all selected methods have the potential to achieve greater than gigatonne level of removal and due to the wide variation in potentials, it would be challenging to compare methods objectively. Geographical considerations are also important for deciding on which projects to invest in, rather than only assessing on a method level.

Feasibility

These criteria assess the **technical**, **economic** and **governance** barriers that can hinder the adoption of each method.

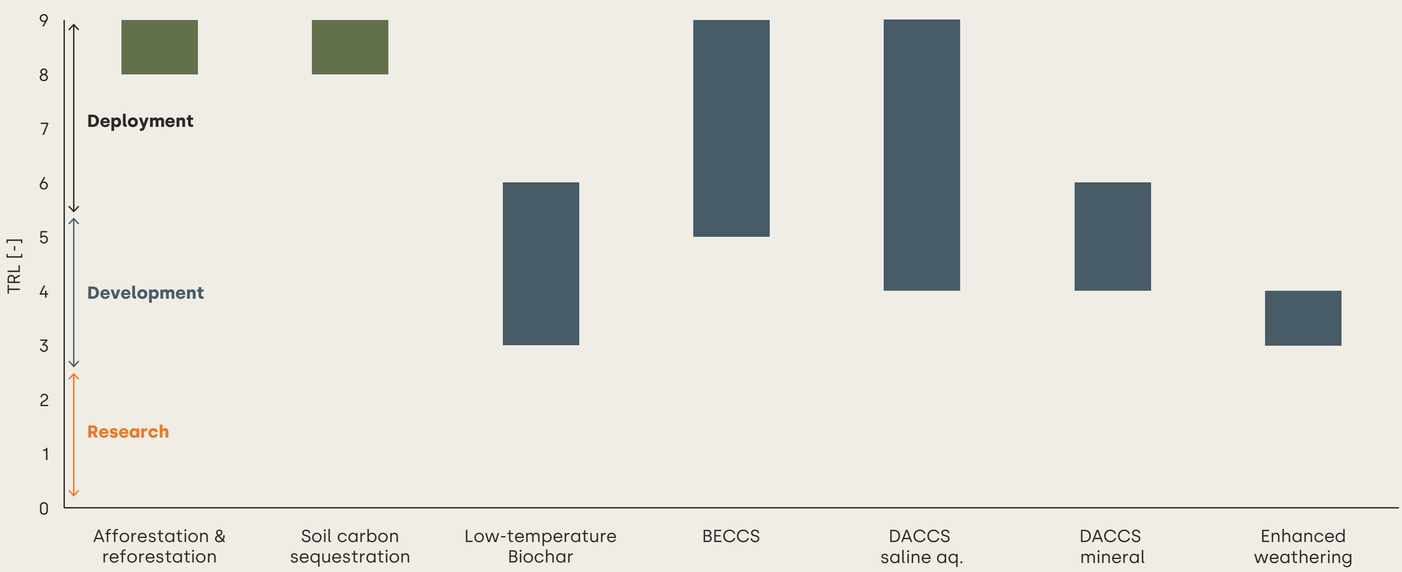
→ **Technical feasibility** is a measure of the technological maturity. TRL is used as a proxy in the absence of clear data for a probability to overcome technical limitations. Figure 11 illustrates the wide variation in **TRL** across CDR methods.

→ **Economic feasibility** is a measure of the market price of removal in relation to the social cost of CO_2. Given the current lack of economic incentives to invest in removals, the social cost of CO_2 provides a useful reference point to contextualize the affordability of different methods. The social cost of CO_2 is an indication of the value of damages from emissions. The reference value of USD $185/t is based on a robust peer-reviewed study.[53]

Figure 10: Performance criteria for evaluation framework

Source: Based on[43]

Figure 11: Technology readiness level (TRL) ranges for novel (blue) and conventional land-based methods (green)



Source: data provided in Table 6 in the Appendix.

→ **Governance feasibility** is a measure of the incentives and barriers to deployment, apart from techno-economic feasibility. It considers the feasibility of MRV, public acceptance, governance, and other implementation barriers (evaluation details in the **appendix**).

Climate change effectiveness

This is an evaluation of the effectiveness of a CDR method in mitigating climate change on a net removal basis. This considers the mitigation **effect**, **timeliness** and **durability** of storage.

→ **Effect** assesses net effect on the climate, considering the likelihood of realizing emissions removals and the reversal risk once the method is implemented. It also includes other climate effects (beyond emissions removals), where applicable, such as albedo (surface reflectivity) change.

→ **Timeliness** evaluates the ability of the methods to remove carbon within the necessary timeframe to materially contribute to mitigating climate change. It considers flexibility, controllability and the speed at which the method can be scaled up. Flexibility and scalability can help avoid a dangerous temperature overshoot. Controllability can help stop unexpected negative impacts that may arise.

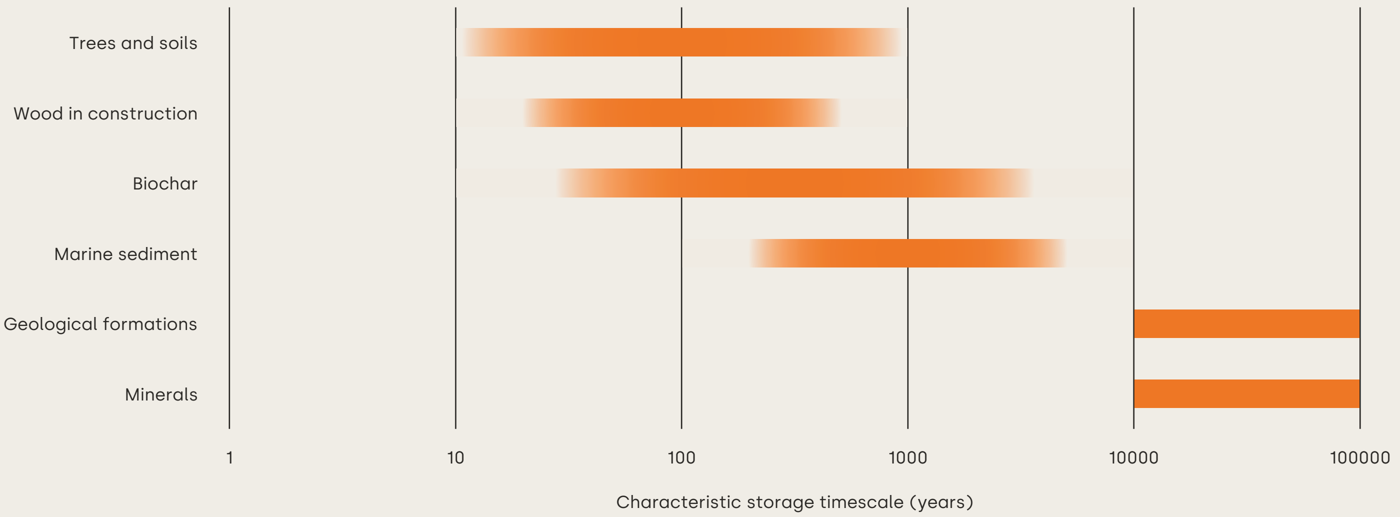
→ **Durability** evaluates the characteristic timescale for storge, assuming no premature disturbance– refer to earlier definition. CDR methods differ widely in duration of storage, from centuries to tens of thousands of years (Figure 1; Figure 13).

The integrity principles for carbon crediting schemes may put in place measures to try to manage some of the differences in climate impacts, though we recommend companies to be fully aware of these different characteristics.

Figure 12: Average and indicative market price ranges and averages for novel (blue) and conventional land-based (green) methods relative to an approximate social cost of carbon of UDS $185/tonne[53]

Source: data provided in Table 8 in the **Appendix**.
Note: No price range data is available for BECCS – only average price.
Note: Market price can change significantly with quantity of purchased removals. Cited price ranges have been based on purchases of greater than 100 tonnes, apart from biochar which is based on 1000 tonnes.

Figure 13: Characteristic storage timescales of different storage types



Source: The State of Carbon Dioxide Removal[24] and IPCC[1]

Side impacts

This is an assessment of the collateral **environmental**, **economic** and **social** effects of CDR. They can be positive or negative. Positive side impacts are referred to as **core-benefits** for Natural Climate Solutions (NCS).

→ **Environmental side impacts** exclude climate change mitigation. They include impacts related to land-use change, such as for BECCS, afforestation and reforestation, which may affect biodiversity (both positively and negatively).

→ **Economic side impacts** exclude costs. They may include by-products, energy generation, new market opportunities, and economic diversification. BECCS, for example, has positive side impacts – energy market opportunities and economic diversification from energy generation, and possible negative side impacts, such as impact on food prices if the biomass supply competes for food production.

→ **Social side impacts** include positive and negative effects on societies, such as economic factors, impacts on climate adaptation and food and energy security. For instance, although soil carbon sequestration is expected to produce economic benefits through higher agricultural yields and income, its social benefits are even higher because benefits could be more evenly distributed to smallholder farmers.

4.3 CDR evaluation

The third step is to evaluate the performance of the selected methods across the selected criteria. The main steps are the following:

1. Source quality data to analyze the performance of each method against each criteria;
2. Score each method against each criteria;
3. Normalize the performance scores against each criteria from 0 (worst) to 10 (best) to ease comparison across the methods.

Table 2 presents the evaluation of the selected CDR methods based on analysis of a variety of scientific references and our judgment where necessary. The **appendix** details the methodologies, sources, assumptions and judgements. **As stated, this is not intended to be a definitive performance ranking of different CDR methods – companies should come to their own conclusions based on additional data and regional-specific considerations.**

Table 2: CDR evaluation score heatmap, from worst (0-2, red) to best (8-10, dark green) performance.

CDR option	*Feasibility*			*Climate change effectiveness*			*Side impacts*		
	Technical	Economic	Governance	Effect	Timeliness	Durability	Environ.	Economic	Social
Afforestation	9.4	10.0	6.0	2.0	1.5	2.0	1.7	5.0	5.0
Reforestation	9.4	10.0	6.0	4.0	1.5	2.0	10.0	6.7	8.3
Soil carbon sequestration	9.4	10.0	5.0	3.0	2.0	2.0	6.7	8.3	10
Low-temperature biochar	7.2	9.0	6.0	5.0	10	3.0	6.7	6.7	6.7
High-temperature biochar	7.2	6.0	6.0	6.0	10	6.0	6.7	6.7	6.7
BECCS no exp.	8.0	7.0	6.0	8.0	8.0	9.0	3.3	8.3	6.7
BECCS exp.	8.0	7.0	5.0	7.0	1.0	9.0	0.0	5.0	1.7
DACCS saline aq.	8.3	1.0	8.0	8.0	10	9.0	3.3	3.3	5.0
DACCS mineralization	5.5	1.0	8.0	10	10	9.0	3.3	3.3	5.0
Enhanced weathering	3.9	6.0	6.0	10	3.5	9.0	3.3	6.7	3.3

Conventional land-based methods stand out for their techno-economic feasibility and novel solutions for their climate change effectiveness. Side impacts and climate change effectiveness show a stark trade-off as the methods with the most favorable side impacts may typically be the least effective for climate change mitigation. The governance scores reinforce the fact that the most cost-effective methods are not necessarily the easiest to implement.[43]

Novel methods typically have much greater durability, although biochar may exhibits a similar duration of storage to conventional land-based methods. The biochar variants mainly differ in economic feasibility and duration of storage. BECCS without agricultural expansion and both DACCS variants show the overall highest effectiveness to mitigate climate change thanks to high duration of storage, climate change effectiveness and timeliness. Enhanced weathering also has high climate change effectiveness thanks to its superior duration of storage and low risk of reversal, although its timeliness is the lowest of the novel solutions due to the uncertainty of environmental impacts and low controllability.

The granularity shown by differentiating between the methods illustrates that each solution category has individual considerations that significantly impact the performance. With the assumptions used for this assessment, afforestation on non-naturally forested land and BECCS with agricultural expansion stand out for their potentially adverse environmental impacts. BECCS with agricultural expansion obtained the lowest score in environmental side impacts and its climate change effectiveness is much lower than BECCS without agricultural expansion due to large upfront land-use emissions before generating net removals.

4.4 Define portfolio preferences

The fourth step is to define preferred weighting factors for the evaluation criteria. These must be between zero to one and the sum must equal one.

We have defined weighting factors based on four hypothetical portfolio preferences and one using data collected for the analysis, as shown in Table 3.

→ **Equal weighting** is the most common weighting method for decision-making; it requires minimal knowledge of different internal and external stakeholder preferences and ensures all criteria are accounted for.[55]

→ **Climate change effectiveness** is a hypothetical weighting prioritizing the three climate change effectiveness attributes.

→ **Economy** is a hypothetical weighting prioritizing the economic feasibility attribute.

→ **Sustainability** is a hypothetical weighting prioritizing sustainability more broadly across environmental, economic and social core benefits.

→ **Average stakeholder preference** is based on data collected from a diverse range of stakeholders across multiple companies, NGOs and academic institutions. See **appendix** for more details.

The weighting factors for the average stakeholder preference and equal weights scenarios are very similar. As such, these are used in preference to equal weights for the analysis in the next section.

4.5 Quantify total CDR performance score

Finally, the total performance score for each CDR method is calculated as a sum of the weighted individual criteria scores based on the weighting factors and evaluation scores from the previous steps.

Under the average stakeholder preference scenarios, BECCS with no agricultural expansion ranks highest thanks to its high effectiveness in mitigating climate change and positive side impacts from its energy supply benefit. The DACCS variants also scored highly despite low economic feasibility. Reforestation, soil carbon sequestration, and both biochar variants obtained similar good scores overall, but for different reasons. On the one hand, the lower-cost options of soil carbon sequestration and reforestation offer attractive positive side benefits at the expense of effectiveness in mitigating climate change. On the other hand, both biochar variants offer more balanced qualities across performance areas. Enhanced weathering performed below average mainly due to its low techno-economic feasibility, side impacts, and timeliness. Nonetheless, the evaluation of enhanced weathering is also the most uncertain due to its low maturity level compared to other methods. Afforestation and BECCS with agricultural expansion rank lowest due to their potential negative side impacts.

Table 3: Example weighting scenarios for portfolio preferences

Portfolio scenarios	*Feasibility*			*Climate change effectiveness*			*Side impacts*		
	Technical	Economic	Governance	Effect	Timeliness	Durability	Environmental	Economic	Social
Equal weights	**0.111**	**0.111**	**0.111**	**0.111**	**0.111**	**0.111**	**0.111**	**0.111**	**0.111**
Economy	0.013	**0.900**	0.013	0.013	0.013	0.013	0.013	0.013	0.013
Climate change effectiveness	0.017	0.017	0.017	**0.300**	**0.300**	**0.300**	0.017	0.017	0.017
Sustainability	0.017	0.017	0.017	0.017	0.017	0.017	**0.300**	**0.300**	**0.300**
Average stakeholder preference	0.117	0.124	0.110	0.117	0.123	**0.127**	0.115	0.080	0.088

Source: Based on[43]

Figure 15 shows how the overall scores of the different methods change drastically based on the different portfolio preference scenarios. This demonstrates the critical role of incorporating decision-maker preferences into the CDR procurement process. If stakeholders prioritize minimizing costs, conventional land-based methods would be the preferred option.

If stakeholders prioritize climate change mitigation effectiveness, the novel solutions of DACCS and BECCS with no agricultural expansion would be prioritized. If stakeholders prioritize side impacts over effectiveness in mitigating climate change, soil carbon sequestration and reforestation would be prioritized.

Figure 14: Example CDR scores based on average stakeholder portfolio preference scenario

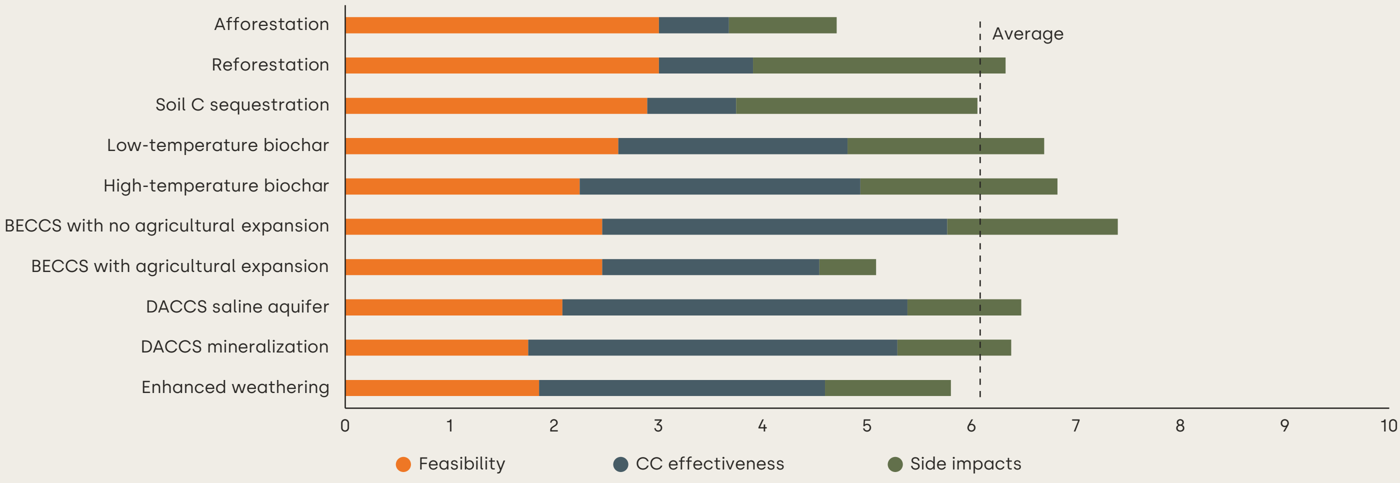
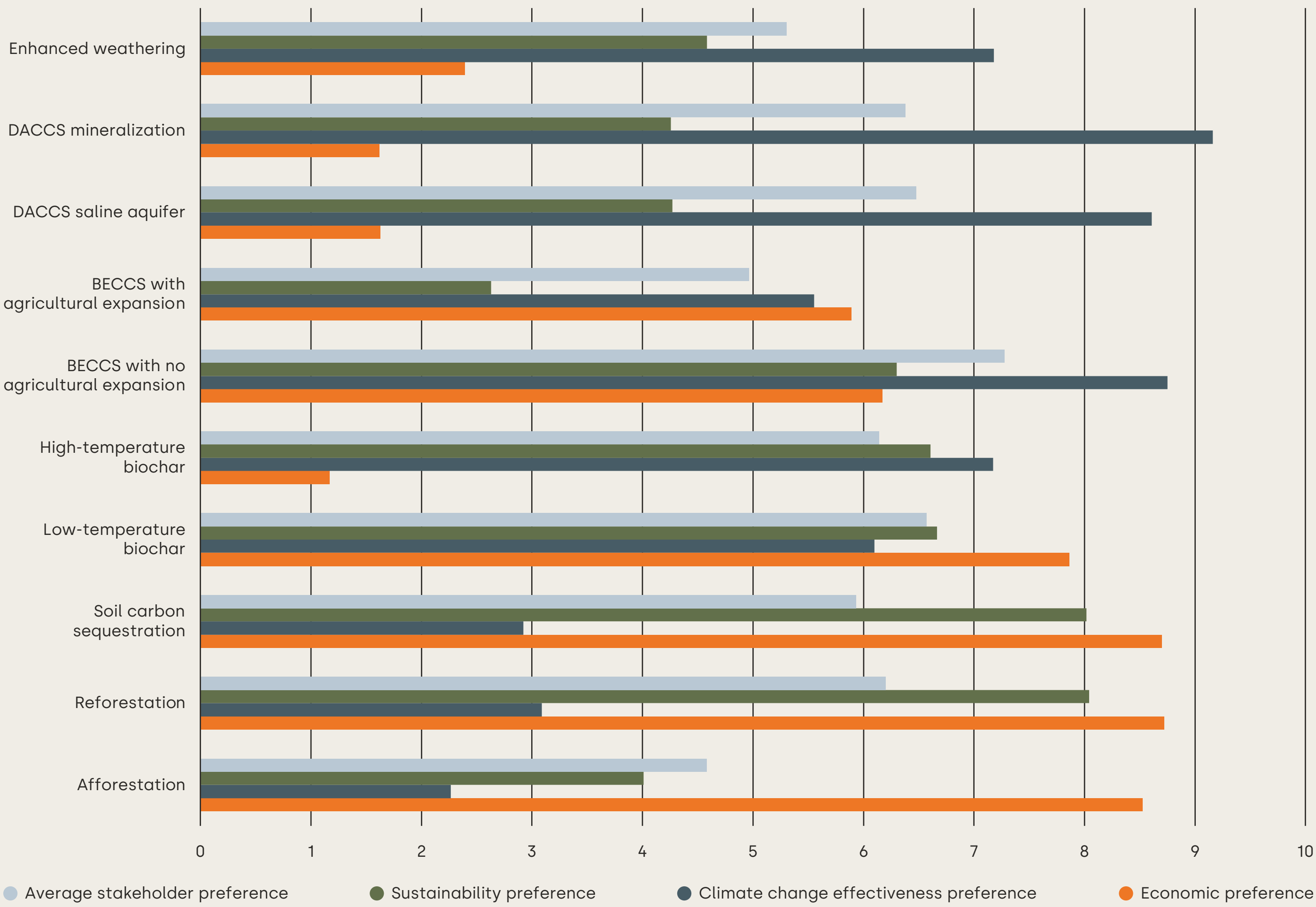


Figure 15: CDR scores for different portfolio preference scenarios, defined in Table 3



Planning and *development of a CDR portfolio*

05.

05. Planning and development of a CDR portfolio

The primary considerations associated with planning a CDR portfolio are:

1. Proactively planning for potential market and policy changes that may influence portfolio design;
2. Determining the quantity of CDR investments;
3. Selecting the mix of CDR methods based on a holistic decision process;
4. Planning the purchasing approaches for the selected CDR methods;
5. Selecting the projects to invest in.

5.1 Plan for potential policy and market changes

The frameworks and markets that govern CDR are rapidly evolving. While most companies are making removal investments as purely voluntary actions, there are several market and policy developments that may influence a company's approach to developing a portfolio of removals. Companies should monitor developments closely and expect to factor potential changes into long-term portfolio planning.

Compliance markets

→ The integration of CDR into compliance markets may add additional incentives to invest in removals earlier than required under voluntary frameworks;

→ Compliance markets may place limitations on the CDR projects allowed under the scheme. Limitations may be based on permanence criteria, accounting methodologies and eligibility under countries' Nationally Determined Contributions (NDCs).

Rules for managing permanence differences

As introduced in section 2, there are specific requirements to proactively account for fundamental permanence differences for emissions neutralization under voluntary or compliance frameworks. This is a rapidly developing space, and it is possible there will be rules for managing permanence in the coming years. This may ultimately impact a company's portfolio structure if, for example, compliance markets or voluntary frameworks mandate certain requirements for like-for-like emissions neutralization. These requirements may be established as a benchmark for a CDR portfolio, as described in the following sub-section on defining the CDR mix.

5.2 Determining the quantity of CDR investments

We recommend that companies start proactively planning the quantities of CDR investments needed throughout the transition to and at net zero as soon as possible. These may be dictated by the following:

→ The opportunities for in-value chain CDR investments for the FLAG sector.

→ The mix of CDR and emission reduction activities in a total portfolio of mitigation actions beyond the value chain. WBCSD's forthcoming How-to guide on carbon credit portfolio construction" will provide further guidance on this topic.

→ The quantity of emissions needed to neutralize residual emissions at net zero.

5.3 Defining the CDR mix

There are many different ways for companies to define the mix of CDR methods in a portfolio. We present a structured approach that uses the decision framework introduced in section 4 to evaluate different methods, as detailed in Figure 16.

Figure 16: Process to define CDR mix in a portfolio

Define any portfolio benchmarks

Define any benchmarks for a portfolio based on broader sustainability goals or requirements from voluntary/compliance frameworks.

↓

Identify CDR methods needed to satisfy benchmarks

Methods with particular attributes may be needed to satisfy a benchmark.

↓

Complete CDR evaluation

Use decision framework to determine performance scores for different CDR methods using portfolio preference weighting factors.

↓

Optimize CDR mix to achieve benchmarks

Compare different CDR mixes that satify benchmarks and select portfolio with highest overall portfolio scores.

1 Define any portfolio benchmarks

Benchmarks are key requirements or objectives for a CDR portfolio. These can be based on a company's own sustainability objectives or requirements from voluntary or compliance frameworks. Examples include:

- A target for a certain proportion of conventional (land-based, nature-based) or novel (technology-based) CDR methods (for example as defined in WBCSD's forthcoming How-to guide on carbon credit portfolio construction).
- Using a certain proportion of methods with minimum durabilities (potentially set by future framework requirements).

2 Identify CDR methods needed to satisfy benchmarks

Select CDR methods that satisfy benchmarks. If a benchmark is based on a certain proportion of a portfolio, the remainder of the portfolio does not need to be limited to these select CDR methods. If no benchmarks have been set, the methods can be shortlisted without needing to satisfy a particular benchmark. As previously described, portfolios with a wide array of methods provide multiple benefits to companies and we recommend companies consider selecting each of the CDR categories introduced in Figure 7 as a starting point.

3 Complete CDR evaluation

- Use the decision framework established in section 4 to calculate performance scores for the selected CDR methods.

4 Optimize CDR mix to achieve benchmarks

Companies can select a CDR mix optimized to their own portfolio preferences by calculating the percentage of each method as a direct proportion of the individual method score under each benchmark. This is shown in the example below.

Alternatively, another approach is the following:

- Qualitatively construct a number of different portfolios or receive pre-designed options for portfolios;
- Calculate overall performance scores for each portfolio as a weighted total of each method;
- Select the portfolio with the highest overall score.

Example:

A company has defined a benchmark of 20% of purchased removals achieving storage durations of geological timescales. The methods that satisfy this benchmark are the following:

- → DACCS
- → BECCS
- → Enhanced weathering

The CDR evaluation framework is then applied to evaluate the following shortlisted methods, using the sustainability preference weighting factors introduced in Table 3. For simplicity, only one category each is used from tree planting, biochar, BECCS and DACCS.

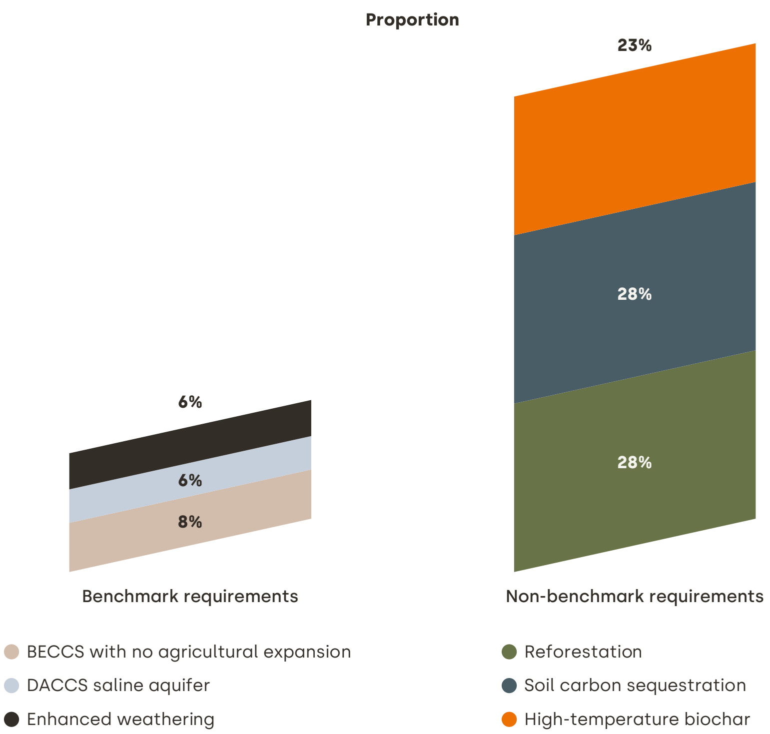
- → Reforestation
- → Soil carbon sequestration
- → High-temperature biochar
- → BECCS with no agricultural expansion
- → DACCS with aquifer storage
- → Enhanced weathering

The proportions of each method are then calculated as a direct proportion of the individual performance score to the total proportion of methods that satisfy the benchmark. The results are shown below in Table 4.

Table 4: Results of example portfolio CDR mix that satisfies defined benchmark

Methods that satisfy benchmark	*Performance score*	*Portfolio proportion*
BECCS with no agricultural expansion	6.3	8%
DACCS with aquifer storage	4.3	6%
Enhanced weathering	4.6	6%
Total		20%
Methods that don't satisfy benchmark	*Performance score*	*Portfolio proportion*
Reforestation	8	28%
Soil carbon sequestration	8	28%
High-temperature biochar	6.7	24%
Total		80%

Figure 17: CDR mix of a hypothetical portfolio



5.4 Planning CDR purchasing approaches

For non-in-value chain investments, companies need to consider which purchasing approaches are needed for the different CDR methods when planning a portfolio. Conventional land-based CDR methods are more prevalent and have more purchasing channels than novel removal methods. Companies may require specific purchasing approaches, such as long-term purchase agreements and equity purchases, to secure access to novel methods.

Those involved with procuring CDR need to take into account in-house resource and expertise constraints, selected CDR mix and overall corporate strategy when deciding on purchasing approaches. Figure 18 provides an overview of the decision-making process.

Purchase type

The purchase of removal credits from a credible crediting program has the benefit of having independent verification and validation of quality, which can simplify the due diligence process.

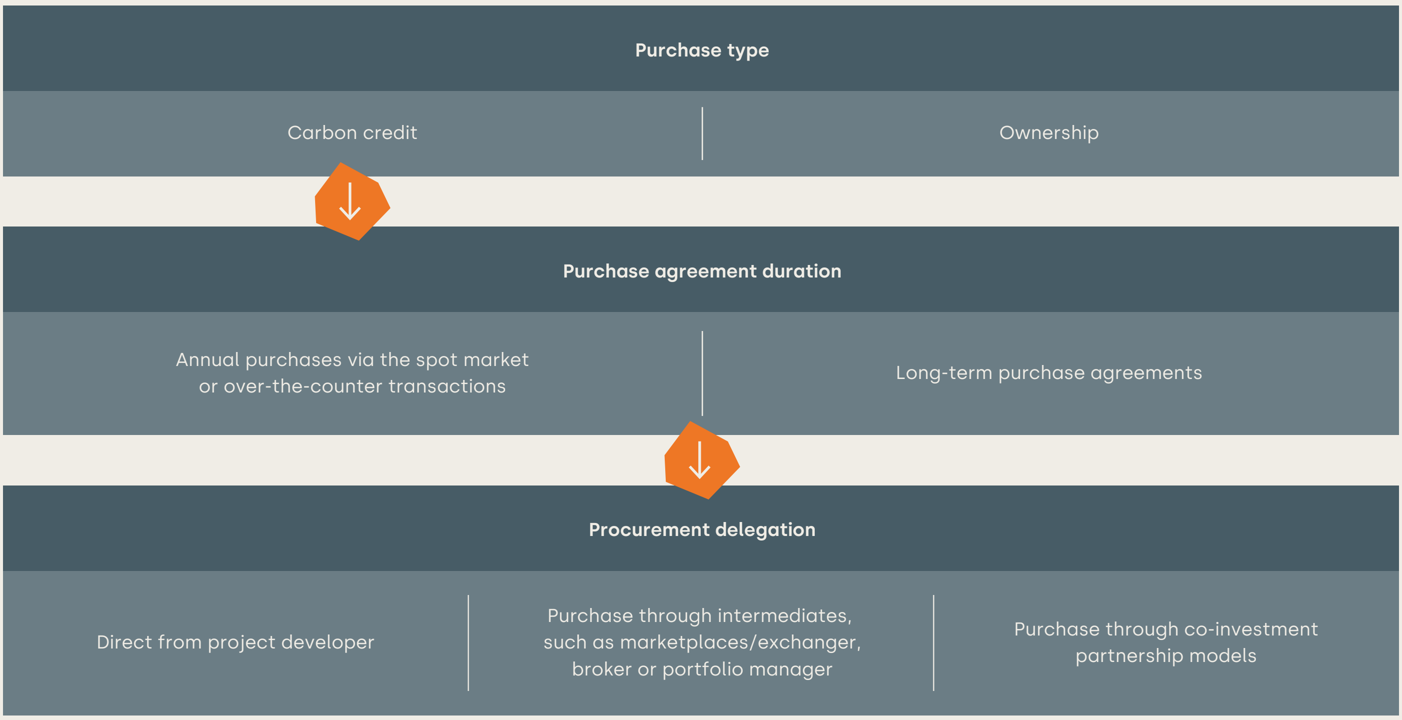
Unlike purchased credits, the ownership of part of a CDR project through equity investments will allow for the inclusion of the associated removal into the corporate greenhouse gas inventory under the Greenhouse Gas Protocol (unless the company sells the associated credits to a third party where they surrender the claim to the removal). Therefore, the decision to invest in the equity of a project will depend on the strategic value of CDR for a company. Equity purchases will ensure long-term access rights to a removal and are key to helping early-stage projects receive up-front funding to progress. It will also help lock in demand in a supply-limited market. This approach may be particularly well-suited to more nascent novel removal projects. However, companies that make equity purchases may be exposed to risks, such as the lack of a standard definition of a removal, technological risks and merchant risks. Correspondingly, companies will require greater levels of in-house expertise to conduct due diligence.

Purchase agreement duration

Annual credit purchasing can provide greater flexibility and potentially allow for finding lower priced methods and allows the purchasing of removals that have already happened. This may, however, add a significant administrative burden and may not secure reliable access to the desired methods.

Long-term agreements are a means for companies to ensure security in the supply of credits and secure access to projects yet to be developed. This then provides project developers with sufficient demand confidence to proceed with a project. Unlike annual credit purchasing, this approach is for removals that have not happened yet. This, therefore, carries a potential risk of failure to deliver the credits, although third-party insurance can offset this.

Figure 18: CDR purchasing decisions



Source: National Climate Solutions Alliance[18] and McKinsey[56]

Procurement delegation

Companies that purchase directly from project developers may enter a competitive bidding process but can more closely influence the characteristics of the removals project. This may only be suited to companies investing large quantities and to those that have sufficient internal experience and resources to do so.

Purchasing through intermediaries, such as carbon credit marketplaces, exchanges, brokers or portfolio managers, may be more appropriate for companies that purchase lower volumes and are less experienced. These intermediates can help conduct some of the due-diligence assessments.

Purchasing through partnership models, such as buyers' clubs, can provide a means for different companies to pool resources to source, conduct due diligence assessments and purchase CDR. These are emerging as promising models, especially for novel removal methods, as they provide advanced market commitments - strong market signals to promote continued investment in more nascent methods and promote broader awareness of the importance of CDR through strong media attention. In addition, buyers' clubs like Frontier and NextGen aggregate supply and demand to leverage economies of scale and reduce risks.[57, 58]

5.5 Selecting the CDR projects to invest in

The last step is to decide on the projects that satisfy the targeted mix of CDR methods. As introduced in section 2, a key principle for investing in CDR responsibly is to ensure that all CDR investments are made only into high-quality and integrity projects. Beyond this requirement, additional factors that influence project selection include, but not limited to:

→ Budget;

→ Geographical considerations;

→ Requirements for projects that use certain carbon accounting methodologies or certification schemes.

Detailed guidance on this is beyond the scope of this document. For further information, refer to WBCSD's forthcoming How-to-Guide on carbon credit portfolio construction.

Conclusion

06.

06. Conclusion

Widespread carbon dioxide removal is now likely unavoidable as a measure to limit global warming to 1.5°C. Society will have to deploy a wide range of methods to achieve global CDR targets and companies have a key role in scaling them up.

CDR will be core to achieving net zero as companies use these methods to neutralize any residual emissions. It is crucial that companies do not delay their investments in CDR. Waiting too long could hinder the material climate contributions of CDR in the short term and compromise the scalability of novel, technological methods for achieving net-zero emissions by 2050. To optimize the impact of CDR, we recommend that companies integrate CDR investments into their short-term climate strategies, adhering to guardrails such as those set by SBTi's Corporate Net Zero Standard.[3]

CDR investment must never come at the cost of carbon emissions reduction ambitions, as over-reliance on carbon removal may make achieving climate goals more difficult while introducing additional environmental, social and economic burdens. As such, we recommend the following science-aligned principles for CDR investment, based on the consensus of the scientific community:

→ Minimize the overall need for CDR by reducing value chain emissions as much as possible;

→ Ensure that CDR investments are not prioritized ahead of emissions reduction;

→ Ensure the timely deployment of removals so they can achieve their full potential to neutralize residual emissions at net zero;

→ Identify and account for the wider implications when prioritizing different CDR methods;

→ Proactively plan and develop a portfolio of removals that includes a diverse array of both conventional land-based and novel technological methods;

→ Conduct due diligence to ensure purchased removals are of high quality;

→ Consider approaches to manage durability differences.

By adhering to these principles, companies can adopt CDR in a responsible manner, maximizing the benefits for the environment, the economy and society while minimizing all associated risks. The decision framework and guidance introduced in this document can help companies develop a CDR investment strategy that includes an ambitious CDR portfolio. The right portfolio of CDR methods and accompanying investment strategies can empower companies to meet their climate targets and support their organizational mission.

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A wide range of members of the CCS & Removals workstream have reviewed the material, thereby ensuring that the document broadly represents a majority view. It does not mean, however, that every company within the workstream agrees with every word.

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