CDR Business models

WP4 - Enabling CDR Uptake

Deliverable D4.1

28 February 2025

Deliverable Title	CDR business models
Deliverable number	D4.1
Brief Description	Report on existing and potential business models for CDR upscaling, including funding sources, capital & ownership structure, and risk management/allocation
WP number	WP4
Lead Beneficiary	REFORM
Author(s)	Karolina Grek, Aneta Stefańczyk, Paweł Wiejski ,Aleksander Śniegocki, Anne Merfort, Sonja Sechi, Eleftheria Zisarou, Sabine Fuss, Friedemann Gruner, Nazlicicek Semercioglu
Deliverable Due Date	28/02/2025
Actual Delivery Date	28/02/2025
Nature of the Deliverable	R — Document, report
Dissemination Level	PU - Public
KeyWords	Communication, Dissemination, Exploitation

Date	Ver.	Contributors	Pages

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521- UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

List of contents

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521- UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

Glossary

Advance market commitment (AMC) – a funding mechanism that facilitates creation of a market for an innovative product or service; it is a binding commitment to buy a product if it is developed successfully offered by governments or private foundators.

Afforestation, reforestation and forest management – afforestation refers to planting forests on land where there was no tree cover, reforestation to planting forest on land where there was recently a forest. Forest management refers to forestry practices that can improve the carbon sink potential of an existing forest.

Biochar – the product of heating waste biomass in a very low-oxygen environment. This process – pyrolysis – can be used as a CDR technology, as it locks the CO_2 away in a solid substance.

Bioenergy with Carbon Capture and Storage (BECCS) – a CDR technology that enables to capture and permanently store CO_2 from biomass; it involves converting biomass into fuels or burning it to generate energy.

Carbon Capture and Storage (CCS) – set of industrial methods for the chemical capture of CO_2, its concentration, and its subsequent geological storage.

Carbon Capture and Utilization (CCU) – set of industrial methods for the capture of CO_2 and its conversion into products

Carbon Dioxide Removal (CDR) – an activity that (1) captures CO_2 from the atmosphere, (2) stores it durably, and (3) is a result of human intervention.

Compliance market – a platform through which different actors finance projects that reduce or remove CO_2 emissions, that is set up in response to legally binding emissions reduction targets set by relevant authorities (local, national, or international).

Direct Air Carbon Capture and Storage (DACCS) – a CDR technology that enables to extract CO_2 directly from the atmosphere at any location and then store it permanently. There are different versions of this technology depending on which specific chemical process is used to capture CO_2.

Enhanced rock weathering (ERW) – a CDR technology that significantly accelerates silicate rock weathering – a natural process of locking CO_2 away permanently. Without enhancement this process takes place at a way too slow pace to facilitate climate change mitigation.

Growth equity – a later-stage funding instrument for relatively mature companies that seek private equity capital in order to expand or restructure operations.

Monitoring, Reporting and Verification (MRV) – a process that enables to track, record, and validate the amount CO_2 emissions reduced by a specific mitigation activity

Ocean alkalinity enhancement (OAE) – a CDR technology that involves adding alkaline substances to seawater to accelerate a naturally occurring process in which the ocean removes CO_2 from the atmosphere.

Seed Funding Round – an early-stage funding round that provides initial capital to startups

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

for market research and product development

Series A Funding Round – an early-stage funding round that follows the seed one, usually utilized to scale the initial operations

Series B Funding Round – a later-stage funding round that follows Series A, aimed at scaling operations and expanding market reach

Soil Carbon Sequestration (SCS) – a set of CDR technologies that aim to increase the rate of capture and the duration of storage of atmospheric CO_2 in soils.

Voluntary Carbon Market (VCM) – a platform through which different actors voluntarily finance projects that reduce or remove CO2 emissions.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521- UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

1 Introduction

The importance of Carbon Dioxide Removal (CDR) for reaching the Paris Agreement goals is well recognized, not least in the IPCC Assessment Reports. In recent years, CDR methods have been rapidly developing at all levels of implementation, from research and development to full-scale projects delivering removals on the ground. Between 2013 and 2023 it is estimated that 2,200 $MtCO_2$ per year was moved into durable storage from the atmosphere as a result of human activity, vast majority (99,9%) of which was achieved using conventional CDR methods. Despite this rapid growth, there is a significant and growing carbon removal gap between announced projects and scenarios compatible with temperature rise limited to 1.5 degrees Celsius. This gap is exacerbated by the failure of the world economies to reduce emissions[1].

CDR deployment is necessary for achieving the Paris Agreement goals, however it cannot replace emission reduction efforts. High overshoot scenarios would require scale of deployment of CDR that may not be feasible due to technical, social or environmental considerations[2].

In all scenarios compatible with the Paris Agreement, the CDR sector needs to rapidly scale up. To that end, it needs to develop sustainable and attractive business models, to attract private investment which can complement state support.

This document aims to **identify and describe existing and emerging business models in** both **novel and conventional CDR methods**. It identifies characteristics of these business models, looking at revenue streams, financing and funding sources, capital structure and risk management. It also analyses policy frameworks to an extent in which they enable specific business models. In a separate chapter it also explores how Monitoring, Reporting and Verification (MRV) frameworks influence the viability and structure of the business models.

The analysis shows a diverse range of possible business models, which vary across and within technologies. The role of carbon credits for business models has been of particular importance. For some technologies, like Bioenergy with Carbon Capture and Storage (BECCS) or Direct Air Carbon Capture and Storage (DACCS), carbon credits are an important revenue stream. For others, they are of limited importance (particularly for conventional CDR methods). Public policy framework is crucial for economic viability of all technologies. Business models also vary due to the differing maturity of specific technologies, as well as required infrastructure and complexity of MRV protocols.

2 Methodology and data sources

The first step in preparing this analysis was an overview of the current literature on the existing and emerging CDR business models. As expected, given how novel the subject is, there were no systematic reviews available. However, *The State of CDR* report[1] gave a comprehensive account of the recent market developments, and these results are often

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

quoted in this work to give a contextual information about the characteristics and relationships of the studied CDR methods. The data in this report come from the Net Zero Insights database, which had been processed to be compatible with the projects assumptions (see Box 3.2 in the publication), so the statistics quoted in this report and repeated here are based on data for 1,000 startups operating in the CDR landscape in the recent years. Another key publication used in preparation phase was *Sewage treatment for the skies: mobilising carbon dioxide removal through public policies and private financing*[3], which examines the main aspects of conducting business activities related to specific CDR technologies.

The analysis of the emerging business models for the novel CDR technologies is based on the CDR.fyi database, which collects and compiles data on companies selling carbon credits in Voluntary Carbon Markets (VCM). The database is an open-source project launched in 2022. It compiles data sourced from public records, direct submissions from market participants through the portal on the website, and integration with other leading registries and marketplaces. It focuses exclusively on durable CDR that last for at least several centuries. It is worth noting that these sales have mostly not been associated with deliveries yet, as they usually concern removals that are expected to be facilitated in the future.

For each technology, the top ten firms by carbon credit sales volume in VCMs were analyzed. This selected approach aims to focus on business models with the highest potential for scalability and profitability, to ensure that the policy-related conclusions align to the most promising solutions.

Subsequently, information on selected companies was collected from their official public communication channels, as well as from media articles and announcements, official websites of governmental bodies and independent research institutions. The analysis focuses on key aspects such as revenue streams, funding sources, ownership structure, and the approaches to MRV and risk allocation of these firms. The collected information was later analyzed collectively in order to recover characteristic features of business models functioning in different CDR fields.

For the conventional CDR methods, data availability is much more limited. Projects participating in the VCM were identified via Verra database, as well as UK-based Peatland Code database. Information about business models has been obtained from literature and the projects' websites.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

For the purposes of this analysis, we combine the definitions of business model that are present in the available literature,[4] [5] to arrive at the following formulation.

Business model - definition

In this paper, **business model** is defined as the manner in which a firm organizes itself to create and distribute value in order to achieve profit. We use the term **business model** to refer to a simplified representation of the elements of an organization, and the interactions between these elements, for the purpose of its systemic analysis.

Along with the business models, the analysis describes also some themes linked to policy support for CDR. It is worth to note though that the sections focused on policy support do not aim to present a full landscape of policy instruments put in place to support the uptake of CDR technologies (which is a subject of another deliverable within the UPTAKE project). In this analysis, the policy support tools are described only to the extent to which they influence the emergence of the described CDR businesses. Since a significant portion of the revenue for CDR companies is directly or indirectly tied to supportive policies, these instruments are important factors in shaping the business models of CDR companies. This fact is reflected in the bulk of scientific literature that is available on the subject so far, as the papers often focus rather on the policy dimension than on the business characteristics while discussing commercialisation of carbon removals[6],[7]. This analysis aims to shift the focus to the business aspects of upscaling the CDR technologies, while also providing the key information on policy support context.

3 Review of business models by technology – novel CDR

3.1 BECCS

3.1.1 Business model characteristics

Based on the number of deals closed (6 deals out of 8160 in the whole CDR start-up space in 2023), Bioenergy with Carbon Capture and Storage (BECCS) is not a CDR technology that receives the attention of numerous investors[1]. This is likely the consequence of a limited number of projects being in the deployment stage, as according to the CDR.fyi[8] database, the number of start-ups that are active on the Voluntary Carbon Markets (VCM) is 13 (with 2 of them not disclosing the details of the orders placed with them). The investment into BECCS projects flows in equal proportions from such types of investors as: private equity, public/quasi-public, angel/family, and venture capital[1]. It is one of the CDR methods that was the most dependent on early-stage financing between 2020 and 2023, with only less than

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

20% of deals being Series A, Series B, or Growth equity, with only enhanced rock weathering receiving fewer deals from later-stage financing.

Even though projects involving BECCS obtain significantly less financing from the capital market than Direct Air Carbon Capture and Storage (DACCS), their declared annual capacity to remove CO_2 through 2029 is about 5 times higher (reaching about 36 Mt). The potential of both technologies to deliver CO_2 removals are expected to even out in 2030 (with each of the technologies contributing about 60 Mt per year, based on data from official announced company plans)[1] This significant near-term potential of BECCS is reflected in the share of carbon credits sold at VCM by BECCS-oriented companies, which in 2023 was 55% of all credits sold by novel CDR start-ups.

The top buyers of BECCS credits are Microsoft and Frontier Buyers – an advance market commitment (AMC) that is created by an alliance of global corporations (Stripe, Alphabet, Shopify, Meta, McKinsey) and numerous businesses using Stripe Climate services. Frontier Buyers pools demand from various market participants and facilitates the process of carbon removal purchase, including managing negotiations, legal and financial processes, as well as verification of suppliers.

Among the top ten BECCS companies that sold carbon credits in the VCM, four are based in North America (three in the USA and one in Canada), while the remaining six are located in Europe (Denmark, Sweden, Switzerland, and the UK).

The currently emerging business models that have been identified include:

- CDR in an existing bioenergy plant (Drax, Ørsted, Red Trail Energy)
- BECCS corporate spin-off (Elimini)
- BECCS project development (CO280, The Carbon Removers)

CDR in an existing bioenergy plant

BECCS projects can be developed by the companies that already operate in the renewable energy space. Examples of firms that use such a business model include: Drax Group, Ørsted, and Red Trail Energy.

Drax Group operates a large biomass-fueled Drax Power Station in Shelby in North England, that provides about 4% of the United Kingdom's electricity supply. Originally the plant was coal-fueled, but in 2012 the company announced its conversion to biomass, which was completed in 2021. This shift in production process was partly financed by subsidies in the form of Renewables Obligation Certificates (RoCs) and Contracts for Difference (CfDs). The total amount of public support for biomass plant cashed in by the company since 2012 was estimated at 7 bn GBP in 2024[9]. The high levels of support were criticized by civil society and Members of Parliament, as the company's business model is considered increasingly less sustainable: the company imports biomass from the USA[10], which requires high

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521- UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

transportation expenses, and there is still more scientific consensus that burning woody biomass for power "is not effective for mitigating climate change"[11]. Despite receiving substantial public subsidies, the company became UK's top CO_2 emitter. In 2024, its profits are expected to rise to 1 bn GBP[12].

Drax applies to the UK government an extension of the subsidy (which is due in 2027) to convert two of its four biomass units to a BECCS project. The project is expected to deliver 8 mln tons of CO_2 removals per year[13] when finalized. In January 2024, The Secretary of State for Energy Security and Net Zero approved the Development Consent Order for the company's plan[14], but the conditions are still under negotiation.

Another company that started its BECCS activity with bioenergy generation is Ørsted. Its main operations focus on the delivery of onshore and offshore wind power, but it has also business in energy trading, electricity retail, sale of grid and energy infrastructure solutions, green gas, and hydrogen. Ørsted flagship BECCS project in Denmark – Kalundborg CO_2 Hub – entails the installation of carbon capture and storage technology at the wood chip-fired Asnæs Power Station. Similar to Drax Power Station, Asnæs plant converted from coal to biomass in 2020. The Kalundborg CO_2 Hub which will be built at Asnæs Power Station site is expected to collect CO_2 also from other Ørsted's Avedøre Power Station, as well as from other emitters potentially in the future, becoming a hub for shipping CO_2 from the region to Norway and generating additional revenue. The shipments will be handled by Ørsted's Norwegian partner Northern Lights, who will deliver the CO_2 to the onshore terminal in Øygarden, Norway, in order to store it eventually in a secured storage complex in Aurora. The Danish Energy Agency provides public financing for building the Kalundborg CO_2 Hub through a 20-year subsidy contract[15] for 8 bn DKK (1 bn EUR).

A slightly different approach is followed by the US company Red Trail Energy (RTE), which produces ethanol (E85) from corn in a facility located near Richardton, North Dakota. Unlike Ørsted and Drax, RTE's business model does not involve bioenergy sales and distribution, but the common feature of the operations of the three companies is adding a CCS unit to a previously operating plant. The CCS process became functional in 2022. Currently RTE captures an estimated annual output of 180,000 tons of CO_2 from its ethanol fermentation process – 100% of total emissions. It is stored in the Broom Creek formation, about 1,6 km below the surface. The total cost of RTE's investment in BECCS – 30 mln USD – was relatively low, as it didn't require high expenditures on transport infrastructure, because the geological storage was available on-site.

Ørsted and Drax Group are the only BECCS-oriented companies that participate in VCMs and are publicly traded. The business model of launching BECCS activity after a company has been able to generate profits from bioenergy production is associated with lower investment risk, not only because other divisions of the company can provide additional liquidity and financing if there are some additional costs or other headwinds for the BECCS project, but

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

also because it already has a functioning management structure which has experience in the bioenergy field. Stable prior financial track record of the company also makes it easier to attract investors in BECCS component and gain trust of the involved stakeholders.

BECCS corporate spin-off

Drax explores also another business model, as it started developing CCS solutions simultaneously both in the UK and the USA. In late 2024, Drax group launched a separate Houston-based, wholly-owned business unit called Elimini, whose role is to develop and construct Drax's new BECCS plants in the USA. Initially, the company plans to focus on the US market, and subsequently also develop international projects if targeted further expansion proves successful.

Elimini announced that it reviews more than 20 potential BECCS sites in North America and looks into additional projects in six other countries. The company has already entered into agreements with 11 companies to develop CO_2 removal projects, and it will manage offtake deals closed earlier by Drax Group. The first facility in the US, and Elimini's currently most advanced project, is expected to produce 2 TWh of renewable energy while capturing 3 Mt of CO_2 annually[16]. The targeted scale of Elimini's operations involves generating more than 1800 GWh of electricity and removing over a 1 mln ton of CO_2 each year.

BECCS project development

Another possible business model in the BECCS space is represented by companies that operate as project developers, rather than owners of the industrial sites that integrate BECCS into their production process. Examples include CO280 and The Carbon Removers.

The first of these enterprises – Canadian CO280 – focuses on the US market, where it is concerned with identifying sites within pulp and paper mills industry across the Gulf Coast that are viable for BECCS installation. The company's aim is to create a network of carbon removal projects that will be able to deliver more than 10 mln tons carbon removals annually. CO280 business model partners with pulp and paper companies to finance, own and operate projects that capture and permanently store biogenic carbon dioxide. The company does not own the carbon removal technology – SLB Capturi will be the supplier of technology for its first facility. CO280's role is to actively manage and execute the investment – provide financing, contract the technology supplier, manage certification and sales of resulting carbon credits, coordinate with energy and utility providers, as well as keep track of the regulatory environment. CO280 has already sold credits for total removals of 224.5 thousand tons of CO_2 to Frontier Buyers, as well as to some of the investors associated with Frontier Buyers.

The Carbon Removers is a Scottish company that originally operated in the UK. Its initial focus was dry ice production, but in 2021 it started operating also as a CCS project developer. The aim of the company's flagship Project Nexus is creating a UK-wide carbon capture,

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

utilization and removal network, in which biogenic CO_2 (mostly from fermentation industries such as whisky distilling) is captured from biogas plants and fermentation industries, and transported to closest utilization and sequestration locations. The range of responsibilities taken on by The Carbon Removers is wider than the other described project developers' – CO280 – as they use proprietary technology. The company recently started to expand its operations overseas, having secured a contract with the Danish Energy Agency to deliver negative emissions from 2026 to 2032.

The strategy of pooling multiple BECCS investments helps mitigate risks associated with individual projects. However, this business model is strongly dependent on the general outlook for BECCS activity, so in that sense it is riskier than one of the previous business models: adding a CDR component to an existing – and already profitable – bioenergy plant.

Two important factors make this business model possible to implement:

- Fungibility of CO_2
- Separateness of different components of the CCU/CCS value chain.

These features make it possible for the two discussed companies and their partners to be flexible in their business models. CO_2 is a highly standardized product, so the specific technologies used by different companies should be compatible with each other, enabling the emergence of networks of business partners, whose involvement in specific projects depends on their location, capacities, other business and market conditions. The companies can also shift between storage and use of CO_2 or combine the two approaches when necessary. Additionally the businesses in this value chain can specialize only in the chosen component of the CCS/CCU process (e.g. they focus only on transport, or capture, or storage, or organization and marketing component), and thus get involved with clients coming from other types of business activities (e.g. company transporting CO_2 can also transport other substances, a firm offering geological storage solutions can use experience in drilling in other areas of business activity). This flexibility can be beneficial for businesses, as they can thus improve their management of risk involved with carbon credit prices and changing policies. The same considerations apply to companies pursuing one of the business models described in the DACCS chapter – namely, DAC component specialization with CCU/CCS components outsourced to partners.

3.1.2 Policy support characteristics

The deployment of BECCS technology at scale and realizing its potential to deliver negative emissions necessary for achieving net zero depends largely on support policies. They should ideally provide clear price signals to market participants, as well as stability of the supportive conditions over the medium term.

There is a remarkable difference between the two geographies leading the BECCS market – North America and Europe – in policy support measures and their role in companies'

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

revenues. Europe-based companies rely heavily on government subsidies and grants. For example, Stockholm Exergi received 180 mln EUR from the European Innovation Fund and is eligible for up to 3 bn EUR from a state aid scheme[17]. Danish Energy Agency provides financing for Ørsted's flagship BECCS project – Ørsted Kalundborg CO_2 Hub – through a 20-year subsidy contract for 8 bn DKK (1 bn EUR), and for BioCirc CO_2 through a NECCS fund contract that provides support amounting to 17 mln EUR annually between 2026 and 2032[18]. The same fund contracted also The Carbon Removers – a Scotland-based company – to capture and store 4,650 tons of biogenic CO_2 annually[19]. The British Drax Group will seek a subsidy for its preliminarily approved BECCS project in its Selby power plant[20]. An exception in Europe is Swiss company CO_2 Energie | Regionalwerke AG Baden, which will add a sequestration component to its BECCU project at the Nesselnbach biogas plant using funds from The Climate Cent Foundation. The Foundation is a voluntary initiative established by the Swiss business community to ensure effective climate protection, so the major source of support for the investment will be provided by a third sector institution, not by the government.

A higher level of involvement in developing BECCS projects of the European authorities is reflected also in the ownership structure of some of the researched firms: 50% of Ørsted is owned by the Danish government, while Stockholm Exergi is in 50% owned by the Municipality of Stockholm.

As far as the US-based enterprises that sell credits on the VCMs are concerned, they mostly rely on carbon credit sales as a major source of revenue and they do not receive funds directly from the US government (with the exception of Arbor, which received a prize from the Department of Energy[21]). The government's involvement in supporting the development of BECCS is realized through financing infrastructural projects that aim to develop CO_2 networks[22], and providing tax incentives that stimulate VCM growth, e.g. via the 45Q tax credit that provided up to 85 USD per ton of CO_2 stored if coming from industrial and power generation facilities. The US government aimed at providing a stimulating environment for the CCS businesses also through the Infrastructure, Investment, and Jobs Act passed in 2021 (also known as the Bipartisan Infrastructure Law (BIL) makes it possible to obtain grants, loans, and loan guarantees (within the total budget of 12 bn USD[23]) for BECCS projects. Another support program The CarbonSAFE Initiative (which followed the Regional Carbon Sequestration Partnerships, operating between 2008 and 2021) allows to fund and develop projects focused on ensuring that carbon storage complexes will be ready for integrated CCU/CCS system deployment in 2025-2030.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

3.2 Biochar

Biochar is a novel CDR method that stores carbon in a stable product resulting from heating up biomass in a low oxygen process. Depending on the choice of process parameters, the resulting product could sequester carbon for up to several hundred years. Biochar as a CDR method is among the most popular in scientific literature. Among the novel CDR methods, it is also the one with highest estimated amount of CO_2 removed from the atmosphere (0.79 $MtCO_2$/year in 2023, over half of all CO_2 absorbed using novel CDR methods)[1].

Even before being considered as a climate change mitigation technology, biochar was already used in agriculture, where it serves as a soil additive, improving crop yields. New applications for biochar are being developed. It can be added to various materials, such as plastics, textiles, concrete or others, potentially improving their characteristics. Biochar companies aiming for CDR contributions are actively marketing their product to the concrete industry, as the construction sector faces inherently hard-to-abate emissions from industrial process emissions due to cement calcination. Studies have found that biochar-concrete composites can reduce cement content in concrete without sacrificing durability or strength of the material[24].

Analysis of the top 10 biggest carbon credit issuers in the CDR.fyi database reveals a variety of business models. Two companies (Douglas County Forest Products and Freres Biochar) produce biochar from waste resulting from wood processing (which is their main revenue stream). Some companies like Carboneers sell carbon credits as a main source of their revenues. For others, the biochar sales for agriculture are the most notable. For some companies, biochar production is one of several activities involving biomass, from producing materials, to burning biomass for energy.

Several biochar manufacturers are well-established companies with proved sustainability of their business models. Major international corporations, such as Arcelor Mittal or Exomad, have biochar producing branches. There are examples of companies at all stages of venture capital funding, from early to late. Some of the biochar also benefit from participation in different accelerator or incubator programs.

Global biochar production is growing, with production estimated at 350,000 metric tons in 2023 and revenues from the biochar sector exceeding 600 mln USD. According to a survey of companies conducted by International Biochar Initiative (IBI) and the US Biochar Initiative (USBI), 51% of surveyed biochar producers reported no revenues from carbon credit issuance. Carbon credit revenues constituted more than half of revenue for only 17% of them. Agriculture was by far the largest end use for the biochar producers, with 70% of companies reporting it as one of the top 3.[25]

The carbon removal potential of biochar varies greatly between potential end-uses. Even sustainably sourced Biochar can later be used as fuel, for example for co-firing in biomass

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

power plants. Carbon stored in the biochar is then released back into the atmosphere. Voluntary certification used by credit issuers, such as the European Biochar Standard, reflect these complexities, as only biochar embedded in long life cycle products can be considered for certification. Greater use of carbon credits can incentivize the uses of biochar that have a higher removal potential.[26]

3.3 DACCS

3.3.1 Business model characteristics

DACCS technology is the top novel technology with respect to the number of deals closed by the investors in CDR start-ups since 2020, with 23% of total deals in the whole CDR space – both novel and conventional (coming second after forestry CDR with 38%)[1]. It is also the type of novel technology with the highest number of start-ups founded since 2020[1]. DACCS is less dependent on early rounds of financing than BECCS, with grant and seed rounds of financing amounting to about 65% of deals. It is also the one CDR method among all that is the most frequent beneficiary of corporate investment flows (obtaining 52% of such funds)[1]. Among the potential reasons why DACCS projects attract a relatively large portion of CDR investment flows are a high quality of DACCS removals, which are easily quantifiable and permanent, as well as small land and water footprint[27].

According to the revealed plans of the companies operating in the space of novel CDR, DACCS's carbon removal potential is expected to be relatively small in the coming years compared to BECCS, and only in 2030 DACCS deployment plans catch up with announced BECCS capacities[1]. This translates to lower share of DACCS carbon credits sold so far in total novel CDR credit sales, which is close to 18%.

DACCS is one of the costliest CDR methods, coming in third place after Ocean Alkalinity Enhancement, Direct Ocean Carbon Capture and Storage (DOCCS), which are technologies still in an earlier stage of development. An estimated average price of DACCS carbon credit was equal to 715 USD in 2023. However, it is worth noting that this price experienced the fastest decline among the CDR methods for which the data exists – dropping by 56% compared to 2022.

Out of the top ten companies that sell the highest amounts of DACCS credits on VCMs, eight were founded in the USA, one in Canada, and one in Switzerland – but the last one has also started its expansion to the USA. The geographical dominance of the USA in developing this CDR method could indicate that the policy measures applied by the US administration from 2020 that aimed at scaling DACCS deployment proved successful.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

In the DACCS space the following business models have been identified as:

- DAC component specialization with CCU/CCS components outsourced to partners (Heirloom)
- DACCS corporate spin-off (1PointFive)
- Technology-neutral DACCS facility (Deep Sky)

DAC component specialization with CCU/CCS components outsourced to partners

A US company from California – Heirloom Carbon – developed a specialized business model, where it delivers the DAC technology and partners with another enterprise that performs the CCS/CCU component to deliver the ordered carbon credits.

Heirloom's DAC solution is based on limestone, which is a low-cost and easy-to-source material. The DAC facilities designed by Heirloom are intended to be modular carbon-absorbing warehouses, which will be mass-manufacturable. Thus, Heirloom attempts to develop a model that involves a clear pathway to driving down costs and scaling quickly, conditional on the success of their first facility in Tracy, California.

In this facility, limestone technology is used to capture CO_2 and then to store it permanently in concrete. This component is handled by the partner company CarbonCure, that produces CO_2-enriched concrete, which is laid in the foundations of buildings and structures. The additional advantage of this process is that resulting concrete is stronger than its non-enriched counterparts. The plant in Tracy became operational in 2023, and its targeted removal capacity is one thousand tons per year contributing to California's goal of achieving carbon neutrality by 2045.

In 2024, Heirloom received a grant from the US Department of Energy Office of Clean Energy Demonstrations (OECD)[Errore. Il segnalibro non è definito.] to develop Project Cypress, in collaboration with Swiss Climeworks Corporation. The project is concerned with creating Direct Air Capture (DAC) Hub in Louisiana, which consists of two separate facilities, each using a different version of DAC technology, provided by one of the contracted companies. Heirloom's facility will become functional in 2027, with capacity of 100 thousand tons, and an additional 200 thousand tons of capacity to come in subsequent years.

Both participating enterprises will be supported by independent nonprofit scientific partner organization Battelle. They also chose the same storage partner – CapturePoint, a carbon management company – who will store the CO_2 captured from project's facilities in underground wells.

Similarly to the third business model described in the BECCS section, this business model is implementable due to fungibility of CO_2 and separateness of different components of the CCU/CCS value chain.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521- UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

DACCS corporate spin-off

The enterprise that sold the most DACCS carbon credits globally so far – 1PointFive, that pledged to remove more than 1.2 mln tons of CO_2 – is a wholly owned subsidiary of Occidental Petroleum. This American petrochemical company is publicly traded, and features in S&P 500 index. It is involved in petrochemical manufacturing in the US, Canada, and Chile, as well as in hydrocarbon exploration in the USA and the Middle East. With launching 1PointFive, Occidental attempts to leverage its experience with hydrocarbons extraction in a new field, while simultaneously advancing decarbonization of its assets.

1PointFive develops currently six projects: four in Texas and two in Louisiana. The first facility in Stratos is expected to be commercially operational in mid-2025. It will capture up to 500 thousand tons of CO_2 per year, thus delivering removals for company's biggest credit buyers – Microsoft (500 thousand tons), Airbus (400 thousand tons) and Amazon (250 thousand tons).

1PointFive receives funding not only from the parent company, but also from the US Department of Energy's OCED, which will provide up to 500 mln USD to support the development of the South Texas Direct Air Capture (DAC) Hub[28]. The subsidy can be potentially increased up to 650 mln USD to fund the development of an expanded regional carbon network in South Texas. The funds were awarded in September 2024, and is expected to be delivered in tranches, depending on the progress of the project. There is no official timeline yet for when the Hub will become operational.

The hub will have an initial removal capacity of 500 thousand. tons of CO_2 per year, but it is planned that it will be expanded to over 1 mln tons in the future. The site has the capacity to expand up to 30 mln tons of removals per year and has a potential to securely store up to 3 bn tons of CO_2 in saline formations.

Technology neutral DACCS facility

Canadian DACCS start-up Deep Sky is a project development company that operates a cross-technology carbon removal innovation and commercialization center in Innisfail, in Canadian Alberta province. Deep Sky provides a space in their facility for developers of novel variants of DACCS technology to run a pilot of their solution. Up to 14 teams can work on their DAC solution simultaneously. Deep Sky provides renewable energy and utilities required to perform the technological tests, as well as facilitates the permitting process, provides supporting engineering teams and crucially – handles CO_2 processing, transport, and sequestration. The intellectual property developed on site belongs to the researchers who were owners of the original idea.

Among the technologies tested by Deep Sky there are carbon capture methods using seawater and electrochemical carbon dioxide removal, both developed in partnership with inventor companies. The former binds atmospheric carbon in seawater as dissolved

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521- UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

bicarbonate ions and as mineral carbonates, producing green hydrogen in the process. The latter removes carbon from ocean water by separating it into acidic and alkaline solutions and then removing carbon separately from each of the solutions.

In two other sites, Thetford Mines and Bécancour, Deep Sky works on refining a technique of in-situ mineralization, in which CO_2 reacts with rocks underground in order to be converted into solid stone.

Deep Sky focuses on the sale of carbon credits as the main source of revenue. Two deals were finalized so far: with Microsoft and the Bank of Canada. The focus on R&D of various technologies is aimed at enhancing the efficiency of current carbon removal and taking advantage of cooperations with other technology developers.

3.3.2 Policy support characteristics

The growth of almost all of the researched companies was supported by the policy measures aimed at scaling DACCS activity provided by the US government – either directly, or indirectly. The major policy instrument for this technology was The Regional Direct Air Capture (DAC) Hubs program. The funding for this program came from the Bipartisan Infrastructure Law and the Inflation Reduction Act (IRA), and amounted to 3.5 bn USD in total. The aim of the program was to create four domestic DAC Hubs, out of which each was supposed to demonstrate a DAC technology (or a bundle of technologies) at a commercial scale. The expected potential of these technologies was at least 1 mln tons of CO_2 captured annually from the atmosphere. This funding was used by the above-described Heirloom Carbon, 1PointFive and Climeworks. In January 2025, the disbursement of the funds from the Bipartisan Infrastructure Law and the Inflation Reduction Act (IRA) was frozen when President D. Trump took office.

Moreover, over 4 bn USD was allocated to enhance geologic sequestration capacity and CO_2 transport infrastructure through the Bipartisan Infrastructure Law[29] in the US. Further initiatives involved the DAC Technology Prize Competition (with a budget of 115 mln USD) and the Carbon Capture Technology Program (total budget of 100 mln USD). There are also other sizeable government programs that targeted storage and utilization of the captured carbon, making them beneficial not only for growth in DACCS/DACCU activity, but also for BECCS/BECCU and other methods of capturing carbon. Among these instruments are the Carbon Utilization Program (310 mln USD) and the Carbon Storage Validation and Testing: 2.5 bn USD).

An indirect policy support was provided by the 45Q tax credit, which was increased with IRA in 2022 to 180 USD per ton of carbon stored permanently that came from DAC activity.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

3.4 Enhanced rock weathering (ERW)

Enhanced rock weathering is a novel method of CDR at an early stage of development. The most advanced companies working with Enhanced Rock Weathering (ERW) method are based in the USA and Europe. Almost all of them are privately owned, with the exception of Vesta, which is a non-profit public benefit corporation.

The funding structure for firms developing ERW technology primarily relies on early-stage venture capital, including seed, Series A, and Series B investment rounds. This highlights a strong dependence on institutional investors and traditional venture capital firms to support initial research, technology development, and scaling operations.

Alongside venture capital, grants have emerged as a vital funding source for ERW initiatives, providing crucial support for project development and commercialization. Both government programs and private philanthropic efforts play an important role in financing these ventures.

For example, the United States Department of Energy has backed CDR through the Carbon Dioxide Removal Purchase Pilot Prize, which aimed to advance market-based approaches to carbon removal. In Phase 1 of this program, 24 semi-finalists were selected, representing various CDR pathways. Five enhanced rock weathering projects were among the semi-finalists. ERW startups have also benefited from funding under the Inflation Reduction Act. For instance, Vesta was part of a initiative that received 1,895,531 USD in funding from the National Oceanic and Atmospheric Administration (NOAA) for a four-year duration project.[30]

Philanthropic support further strengthens ERW funding. The Climate Transformation Fund (CTF), a private charitable initiative managed by Milkywire, a Swedish nonprofit organization. Financed by the private sector, in the last four years, the CTF has distributed more than 14 mln USD to support 49 innovative projects. One of the Fund's three core pillars is durable carbon removal, with 27 CDR projects receiving a total of 2,719,415 USD in funding. Among these, CTF has supported seven ventures focused on geochemical solutions, including enhanced rock weathering.

While debt financing is occasionally utilized, it remains a less common approach, due to the high-risk and capital-intensive nature of the ERW projects. Additionally, alternative funding sources – such as direct community investment and equity crowdfunding – are becoming more relevant, allowing startups to engage more stakeholders while diversifying their capital sources.

Finally, revenues of ERW companies are mostly generated through the sales of carbon removal credits, providing a long-term financial model to sustain and scale operations.

3.5 Ocean alkalinity enhancement (OAE)

Ocean alkalinity enhancement (OAE) is another novel CDR method in its early stage of development. CDR.fyi, the primary database utilized for this research, contains data on only

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521- UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

five companies operating in this technology sector, reflecting its emerging nature and limited market presence. However, despite the small sample size, it is possible to identify common features in the key components of their business models.

Currently some startups operate the alkalinity enhancement method within pit lakes (Aquarry[31]) and rivers (Vycarb[32]) with the prospect of deployment in the ocean at a later stage.

Most of the companies developing an OAE method are privately owned, based in North America and Europe. Funding sources for OAE projects range from venture capital and private equity investments to public grants and philanthropic contributions. The capital structure of OAE startups typically reflects a high reliance on equity financing rather than debt. Given the early-stage nature of OAE technologies and their development timelines before revenue generation, securing traditional loans is challenging.

Private investment, particularly early-stage venture capital, plays a crucial role in the development and commercialization of OAE technologies. Many startups in this sector rely on pre-seed, seed, or series A funding rounds to finance research, prototype development, and initial deployment of their solutions. These investments enable companies to develop their technologies, conduct pilot projects, and scale their operations to demonstrate the feasibility and effectiveness of OAE as a carbon dioxide removal strategy. The growing interest from venture capitalists and private equity firms reflects the increasing recognition of OAE's potential. As private capital continues to flow into the sector, OAE startups are better positioned to accelerate innovation, overcome technical barriers, and move toward larger-scale implementation. One OAE startup was supported by the Climate Transformation Fund. Ebb Carbon and Planetary are among companies deploying OAE that also benefited from IRA funding.

The primary revenue stream for OAE companies is the sale of carbon credits, which are generated based on the estimated amount of CO_2 removed from the atmosphere through ocean alkalinity enhancement. These credits are typically sold to corporations seeking to offset emissions under voluntary carbon markets. However, unlike other CDR methods such as DACCS, BECCS and biochar, where CO_2 removal can be directly measured, OAE's effectiveness remains uncertain.

Additionally, some companies benefit from government subsidies and research grants, particularly those supporting early-stage climate technologies. However, revenue diversification remains limited due to the sector's emerging status.

OAE business models are currently characterized by a reliance on venture capital, philanthropic funding, and carbon credit sales. Companies in this sector continue to navigate challenges related to MRV standardization, financial stability, and regulatory frameworks.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

4 Review of business models by technology – conventional CDR

Conventional methods of CDR analyzed in this document include afforestation and forest management, soil carbon sequestration (SCS), and peatland and wetland management. These methods are currently responsible for a vast majority of human activity-related carbon removals (99,9%).[1] Analysis of business models for conventional CDR methods presents methodological challenges. Many of these methods, while considered as CDR methods in literature, are also considered emission reduction methods (for example SCS, as well as peatland and wetland management). The line between reduction and removal is often blurry, and the removal component is often relatively small. Furthermore, the issue of permanence of nature-based removals adds to the complexity of the analysis. Conventional CDR methods can have significant co-benefits, such as increasing biodiversity, improving soil quality and water retention. These co-benefits obfuscate the analysis of business models even further, as the activities considered as conventional CDR are often undertaken to achieve other ends than carbon removal.

4.1 Afforestation, reforestation and forest management

Appropriate afforestation/reforestation and forest management programs can provide socioeconomic co-benefits and many positive effects related to water management, nature conservation, soil protection and climate resilience. However, there can also be adverse side-effects. For example, grassland afforestation can result in biodiversity loss. Additionally, the mitigation potential of these programs can also be negatively impacted by climate change. Furthermore, the inherent risk of reversibility of the carbon stocks in forests raises serious concerns about equating continued fossil CO_2 emissions with impermanent removals of land-based CDR options such as forests [33] .

Out of all CDR technologies, afforestation, reforestation and forest management are responsible for the vast majority of CO_2 capture from the atmosphere resulting from human activity, with an estimated 1,860 Mt CO_2 per year out of total of 2,200 MtCO_2[1]. Despite growing interest in novel CDR methods, afforestation remains among the most popular CDR methods for investors. An analysis for The State of CDR report 2024 found that forestry startups since 2020 have accounted for 38% of investment deals of all CDR methods[1]. Startups are finding novel ways of reaching customers for their reforestation credits, for example via online apps (Treekly and Pachama). Carbon credits are also being sold to corporate customers. On Voluntary Carbon Markets afforestation and reforestation credits are the most popular type of removal credits[1].

While afforestation, reforestation and forest management constitute a significant part of the VCM, only a small part of planting forests can be attributed to the VCM funding. In 2023, more than 99% of afforestation happened without involvement of carbon markets[1]. Most afforestation projects are developed by national authorities or with direct funding from the

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

state. The state's involvement is also related to the ownership structure of forest land – 73 percent of the world's forests is under public ownership[34]. To summarize, carbon credits constitute a minor part of revenue for forestry CDR companies, which rely mostly on various forms of public funding (public procurement contracts, direct ownership, subsidies).

4.2 Soil carbon sequestration, peatland restoration, wetland coastal restoration

Soil carbon sequestration (SCS)

Soil carbon sequestration (SCS) in croplands and grasslands refers to agricultural practices and land management changes aimed at increasing carbon content in soil. This broad definition includes a wide and growing variety of techniques, including adding nutrients to the soil, changing how the land is used, modifying irrigation, changing crop varieties or mechanically influencing the soil's distribution[35]. Classified as a conventional CDR method, SCS has been receiving a significant part of the grants for CDR research (35% between 2000 and 2022)1.

From a business model perspective, the economic viability of SCS methods depends on their impact on farming productivity. Carbon credits issued by SCS projects are mostly emission reduction ones. Research shows that increasing soil's organic content may increase crop yields[36], especially on poorly managed agricultural land. However, changing land management practices requires investments and upskilling, which currently is financed mostly through subsidies (such as funds under the EU's Common Agricultural Policy). Selling carbon credits on the voluntary carbon market can provide an additional revenue stream for farmers using SCS but would require reliable MRV, which might turn out to be difficult and costly.

Peatland restoration

Peatland restoration projects on the VCM market are rare, with no projects fully registered in the Verra database. In the UK a national certification program for peatland restoration projects (Peatland Code)[37] has been implemented and several projects are under development. However, credits issued under the Peatland Code are classified as avoided emissions, and not removals. Like in other nature-based solutions, peatland restoration projects can be a source of both avoided emissions and of removals. While a healthy peatland acts as carbon sinks, drained peatlands release stored carbon into the atmosphere. Restoring a peatland to its natural state is a gradual process. It initially reduces carbon emissions, and after several years, enables the peatland to function as a carbon sink again. Selling carbon credits could provide a funding source for conservation or nature restoration efforts

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

undertaken by public entities, NGOs or private companies. However, it is highly likely majority of these credits will be for avoided emissions rather than removals.

Wetland coastal restoration

Few wetland coastal restoration projects have been delivering CDR credits, be it on the VCM or in the compliance markets. Assessing the business model potential is challenging, as the existing projects often offer credits for both removals and avoided emissions. For some projects, issuing certificates is described as an additional stream for funding of ongoing conservation methods.38 In the UK a non-governmental research institute UK Centre for Ecology and Hydrology is promoting the establishment of Saltmarsh Code, a certification programme for carbon credits from saltmarsh restoration projects, based on the experiences with existing Peatland and Woodland Codes. The purpose of the programme is to encourage private companies to finance restoration of saltmarshes, which aside from absorbing carbon can provide co-benefits such as improving biodiversity or preventing floods.[39]

5 Monitoring, Reporting and Verification impact for business models

A robust Monitoring, Reporting and Verification (MRV) frameworks for CDR are essential for ensuring integrity and effectiveness for climate change mitigation. It outlines rules for measuring how much carbon is absorbed and retained through different CDR methods and provides procedures for reporting that information to relevant parties (purchasers, regulators, certifying bodies), as well as for independent third-party verification , enhancing transparency and credibility.[1]

The global policy landscape for MRV regulations is at an early stage of development. For conventional methods, the IPCC *Guidelines for National Greenhouse Gas Inventories* [40]contain guidance on MRV. For novel methods IPCC is set to release guidance in 2027, as part of the seventh assessment cycle. While the *Guidelines* are not binding, they influence standards for MRV adopted both by Voluntary Carbon Markets (VCM) and by regulators.[1] Another development in the UNFCCC framework for carbon removals was the standard for requirements for activities involving removals under the Article 6.4 mechanism, adopted COP 29 in Baku.[41]

The most important recent development in public regulation of MRV for carbon removals is the EU Carbon Removal Certification Framework (CRCF).[42] Adopted in 2024, this regulation outlines criteria for carbon removals in the EU. While removal units are currently not accepted in any of EU's compliance mechanisms (like the EU ETS), the regulation is the first step to opening some compliance markets to removal units, potentially opening new revenue streams for CDR businesses. Until 2020 carbon credits (under the UN Clean Development

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

Mechanism) were accepted in the EU ETS, however they have been phased out due to integrity and market stability reasons. Whether or not removal units certified under new EU rules will be introduced into the EU ETS remains to be seen. The regulation is also likely to be used by the VCM as a standard, once the delegated act outlining technical guidance for certification is released by the European Commission.

With public regulations on MRV for carbon removals being at an early stage of development, the CDR businesses use several different MRV protocols. Some standards have been established by non-governmental bodies, like the Integrity Council for the Voluntary Carbon Market (ICVCM) and the Voluntary Carbon Markets Integrity Initiative (VCMI). CDR businesses participating in the VCM develop their own standards or use the ones proposed by certification bodies, such as Verra or Gold Standard. While procedures differ, there is a degree of convergence driven by newly developed standards referencing existing ones. In particular, the IPCC *Guidelines for National Greenhouse Gas Inventories*, the UN Clean Development Mechanism and ISO 14064-2. Serve as key references for ensuring consistency and reliability in carbon accounting and reporting.[43]

Business model considerations

Robust and accurate MRV frameworks are essential for ensuring that CDR methods deliver real world effects in terms of negative emissions. Rapid development of carbon removals is essential for reaching the goals of the Paris Agreement, and MRV frameworks play an important role in accurately estimating the amount of carbon absorbed from the atmosphere. From the perspective of the companies involved in CDR development, the integrity argument is not the only one that matters for their business models. MRV presents several opportunities for business model development. At the same time, it can also be a challenge.

MRV frameworks can build trust from credit purchasers in voluntary carbon markets, as well as from regulators in compliance markets. This is especially important after a series of scandals involving integrity of removal credits. A 2023 study covered extensively in the media found that 90% REDD+ credits certified by Verra – the world's biggest carbon credit certifier – likely do not represent any carbon emissions reductions.[44] While the scandal did not involve removal credits, it significantly impacted trust in the voluntary carbon market as a whole. For companies looking to use carbon credits as a source of revenue it is an important lesson to use robust MRV frameworks. It is also influencing the emerging regulatory frameworks, including the EU CRCF. Opening additional revenue streams in the form of compliance markets will be contingent on the reputation of CDR technologies. It will also be influenced by the public opinion on the integrity of the sector, which also adds pressure to include sustainability criteria in MRV protocols.

While MRV is essential for business It can also be a challenge, as some MRV methods, can significantly increase the cost of the project. Data availability regarding costs of MRV is

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521- UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

limited because of the variety of MRV protocols used and lack of publicly available data. Companies do not generally disclose the costs of MRV publicly. One recent survey regarding MRV costs found significant differences within and between CDR methods. MRV costs can reach up to 75% of the costs of the project. As the sample of companies surveyed was relatively small, these results should not be interpreted as representative. [45]

Especially for nature-based or conventional CDR estimating the amount of removed CO_2 can be technically challenging. For example, for peatland restoration, depending on the state of the peatland at the beginning of the project, for the first several years or even decades it will likely only be a source of emission reductions, and only after that period will it absorb CO_2 from the atmosphere. MRV protocols often do not distinguish between removals and emission reductions, despite the two having different impacts on climate. The challenges also involve proving permanence of the stored carbon, as well as risk assessment of possibility of the stored CO_2 going back into the atmosphere (for example due to a wildfire affecting an afforested land). For some methods, like ocean alkalinity enhancement and enhanced rock weathering, there are large uncertainties regarding the amount of carbon removed from the atmosphere.[1] At the same time, the MRV protocols in these methods are still being developed, and new solutions are emerging for improving MRV accuracy, integrity and costs.[45]

6 Summary and conclusions

The landscape of CDR business models is rapidly developing. Each year, the recognition of the need for CDR development to achieve the Paris Agreement goals continues to grow, from the level of individual companies, through national regulators and policymakers, to international organizations. Emerging business models vary across methods, but several conclusions can be drawn from the analysis.

- **Business models of conventional CDR are distinct from novel CDR.** For conventional CDR carbon credits is an additional, often marginal source of revenue. These projects rely on state support as part of environmental or agricultural policy. The explicit target of these policies is often only partially related to the carbon removal potential, instead focusing on other goals, like conservation, biodiversity, water management or sustainable agriculture. For novel CDR methods carbon removals and associated credits are more important, although state subsidies, research grants, philanthropic funding and venture capital also play a major role.
- Among novel CDR, **BECCS and biochar business models are distinct from other methods**. These technologies can benefit from carbon credits but also have other sources of revenue resulting from the CDR process itself. For BECCS, the product is

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

zero-emission, dispatchable energy. Biochar can be used in agriculture and some industrial processes without releasing the captured CO_2 back into the atmosphere.

- **For BECCS and DACCS** an important consideration for emerging business models **is their place in the CCU and CCS value chain**. Some companies already shift between the use and storage of the captured CO_2, depending on policy setting and market factors. Moreover, companies that act as storage operators for DACCS and BECCS projects can also provide services for partners who want to store carbon coming from other types of activities. This flexibility can be beneficial for the companies which can manage risk involved with carbon credit prices and changing policies.
- **Other novel CDR methods rely on philanthropic funding, venture capital, R&D grants and carbon credit sales**. Their potential for scaling will be closely related to public policy, in particular emergence of compliance markets for CDR and obligations for companies to compensate for their emissions.
- **Robust and accurate MRV frameworks** are key for improving trust in CDR technologies, both for purchasers of carbon credits and for regulators. MRV can be challenging and costly for companies, especially when the frameworks are not fully developed. MRV frameworks stemming from state or international regulation, rather than voluntary market, can be useful in setting a reliable standard for the industry, and potentially reduce the MRV costs for the companies.
- **Data availability on business models in the CDR sphere is limited** and the field is developing rapidly. Business models in evolving, especially for novel CDR methods. For most novel methods, compliance markets for carbon credits or other policy support options will be crucial for scaling up these methods to levels compatible with Paris Agreement pathways.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521- UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

7 Notes and citations

[1] Smith, S. M., Geden, O., Gidden, M. J., Lamb, W. F., Nemet, G. F., Minx, J. C., Buck, H., Burke, J., Cox, E., Edwards, M. R., Fuss, S., Johnstone, I., Müller-Hansen, F., Pongratz, J., Probst, B. S., Roe, S., Schenuit, F., Schulte, I., Vaughan, N. E. (eds.) *The State of Carbon Dioxide Removal 2024 - 2nd Edition.* DOI 10.17605/OSF.IO/F85QJ (2024)

[2] Schleussner, CF., Ganti, G., Lejeune, Q. et al. *Overconfidence in climate overshoot.* Nature 634, 366–373 DOI 10.1038/s41586-024-08020-9 (2024)

[3] Poralla, M., Honegger, M., Ahonen, H., Michaelowa, A., Weber, A., *Sewage treatment for the skies: mobilising carbon dioxide removal through public policies and private financing* (2021)

[4] Geissdoerfer, M., Savaget, P., and Evans S., *The Cambridge Business Model Innovation Process.* DOI 10.1016/j.promfg.2017.02.033 (2017)

[5] Baden-Fuller, C., Morgan, M. S., *Business Models as Models. Long Range Planning*, 43(2-3), pp. 156-171. DOI: 10.1016/j.lrp.2010.02.005 (2010).

[6] Hickey, C., Fankhauser, S., Smith, S.M., Allen M., *A review of commercialisation mechanisms for carbon dioxide removal*, DOI 10.3389/fclim.2022.1101525 (2022)

[7] Torvanger, A., *Business Models for Negative Emissions From Waste-to-Energy Plants*, DOI 10.3389/fclim.2021.709891 (2021)

[8] CDR.FYI, from https:/cdr.fyi [date accessed: 25.02.2025]

[9] EMBER (2024), from https://ember-energy.org/latest-updates/drax-profits-rise-as-electricity-generation-falls-show-new-figures/, [date accessed: 30.01.2025]

[10] EMBER (2024), from https://ember-energy.org/latest-updates/the-uks-largest-emitter-is-looking-for-more-public-money/ [date accessed: 30.01.2025]

[11] EASEC (2021), from https://easac.eu/media-room/press-releases/details/easac-welcomes-that-the-jrc-report-strengthens-the-case-for-shorter-payback-periods-on-woody-biomass/ [date accessed: 30.01.2025]

[12] Proactive (2024), from https://www.proactiveinvestors.co.uk/companies/news/1060391/drax-profits-to-top-1bn-wants-clarity-on-government-plans-1060391.html [date accessed: 30.01.2025]

[13] Drax (2024), from https://www.drax.com/press_release/uk-government-approves-planning-application-for-beccs-at-drax-power-station/ [date accessed: 30.01.2025]

[14] UK Department for Energy Security and Net Zero (2024), from https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010120/EN010120-001660-Drax_BECCS_SoS_Decision_Letter.pdf [date accessed: 30.01.2025]

[15] Ørsted (2024), from https://orsted.com/en/media/news/2024/05/oersted-enters-into-new-major-agreement-on-carbon--13859979 [date accessed: 30.01.2025]

[16] Drax (2024), from https://www.drax.com/ca/press_release/introducing-elimini-new-carbon-removal-leader-launches-at-new-york-climate-week/ [date accessed: 30.01.2025]

[17] European Commission (2024), from

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

https://ec.europa.eu/commission/presscorner/detail/en/ip_24_3583 [date accessed: 30.01.2025]

[18] Ørsted (2024), from https://orsted.com/en/media/news/2024/05/oersted-enters-into-new-major-agreement-on-carbon--13859979

[19] Ministry of Foreign Affairs of Denmark (2024), from https://investindk.com/cases/the-carbon-removers-to-launch-operations-in-denmark-advancing-biogenic-carbon-removal [date accessed: 30.01.2025]

[20] Drax (2024), from https://www.drax.com/press_release/uk-government-approves-planning-application-for-beccs-at-drax-power-station/ [date accessed: 30.01.2025]

[21] US Department of Energy (2024), from https://www.energy.gov/fecm/funding-notice-carbon-dioxide-removal-purchase-pilot-prize [date accessed: 30.01.2025]

[22] US Department of Energy (2021), from https://www.energy.gov/sites/default/files/2021-12/FECM%20Infrastructure%20Factsheet.pdf [date accessed: 30.01.2025]

[23] United States Congress (2021), from https://www.congress.gov/bill/117th-congress/house-bill/3684/text [date accessed: 30.01.2025]

[24] Barbhuiya, S., Das, B. B., & Kanavaris, F. Biochar-concrete: A comprehensive review of properties, production and sustainability. Case Studies in Construction Materials, 20, e02859, DOI 10.1016/j.cscm.2024.e02859 (2024)

[25] IBI, USBI, Global Biochar Market Report 2023 (2024), from http://145249425.hs-sites-eu1.com/2023-global-biochar-market-report [date accessed: 30.01.2025]

[26] EBC (2020), *Certification of the carbon sink potential of biochar, Ithaka Institute* (2021)

[27] IEA, *Direct Air Capture 2022* (2022), from https://www.iea.org/reports/direct-air-capture-2022 [date accessed: 27.02.2025]

[28] Oxy (2021), from https://www.oxy.com/siteassets/documents/news-releases/pr-091224_1pointfives-south-texas-direct-air-capture-hub-awarded-u.s.-department-of-energy-funding.pdf [date accessed: 30.01.2025]

[29] US Department of Energy (2021), from https://www.energy.gov/sites/default/files/2021-12/FECM%20Infrastructure%20Factsheet.pdf [date accessed: 30.01.2025]

[30] National Oceanic and Atmospheric Administration (2021), from https://oceanacidification.noaa.gov/funded-projects/tidal-wetlands-as-a-low-ph-environment-for-accelerated-and-scalable-olivine-dissolution/ [date accessed: 27.02.2025]

[31] Aquarry, from https://www.aquarry.earth/ [date accessed: 27.02.2025]

[32] Vycarb, from https://www.vy-carb.com/ [date accessed: 27.02.2025]

[33] Carton W, Lund JF and Dooley K., *Undoing Equivalence: Rethinking Carbon Accounting for Just Carbon Removal*. Front. Clim. 3:664130. DOI 10.3389/fclim.2021.664130 (2021)

[34] FAO, *Global Forest Resources Assessment 2020: Main report.* DOI 10.4060/ca9825en (2020)

[35] White, R. E., *The Role of Soil Carbon Sequestration as a Climate Change Mitigation Strategy: An Australian Case Study* (2022).

[36] J.-F. Soussana, S. Lutfalla, F. Ehrhardt, T. Rosenstock, C. Lamanna, P. Havlík, M. Richards, E. (L.)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.

Wollenberg, J.-L. Chotte, E. Torquebiau, P. Ciais, P. Smith, R. Lal, *Matching policy and science: Rationale for the '4 per 1000 - soils for food security and climate' initiative*, Soil and Tillage Research, Volume 188, 2019, Pages 3-15, ISSN 0167-1987, DOI 10.1016/j.still.2017.12.002 (2019)

[37] IUCN National Committee UK (2023), from https://www.iucn-uk-peatlandprogramme.org/peatland-code-0?msclkid=d43322a1a6b111ec8ab00b7777b63d66 [date accessed: 30.01.2025]

[38] U.S. Nature4Climate (2022), from https://usnature4climate.org/2022/11/06/virginia-coast-reserve-project/; UKCEH (2024), from https://www.ceh.ac.uk/press/carbon-credits-would-enable-restoration-uk-saltmarshes-say-experts [date accessed: 30.01.2025]

[39] Burden, A., Austin, W., Carter, S., Fitton, R., Garbutt, A., Gupta, S., Hipkiss, A., Mahon, C., McGrath, T., Pontee, N., Reed, M., Skov, van der Meer, S., *Recommendations for development of a UK domestic Saltmarsh Code. Report to the Natural Environment Investment Readiness Fund (NEIRF).* UK Centre for Ecology & Hydrology, Bangor. 59pp (2023)

[40] IPCC, 2006 IPCC Guidelines for National Greenhouse Gas Inventories vol.4 Agriculture, Forestry and Other Land Use, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds) (2006)

[41] UNFCCC, Requirements for activities involving removals under the Article 6.4 mechanism (2024), from https://unfccc.int/sites/default/files/resource/A6.4-STAN-METH-002.pdf [date accessed: 30.01.2025]

[42] EUR-lex, Regulation (EU) 2024/3012 of the European Parliament and of the Council of 27 November 2024 establishing a Union certification framework for permanent carbon removals, carbon farming and carbon storage in products (2024), from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202403012

[43] According to the analysis by the State of the CDR report authors, 67% of standards and protocols reference at least one of the three

[44] The Guardian, 2023, from https://www.theguardian.com/environment/2023/jan/18/revealed-forest-carbon-offsets-biggest-provider-worthless-verra-aoe [date accessed: 30.01.2025]

[45] Mercer, L., Burke, J., Rodway-Dyer, S., *Towards improved cost estimates for monitoring, reporting and verification of carbon dioxide removal*. London: Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science (2024)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081521 - UPTAKE - Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods.