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Chapter 3 | Demonstration and upscaling

Demonstration projects, investment in new firms and expectations of growth are key to scaling up carbon dioxide removal (CDR). There is evidence of increasing activity in all three, albeit with challenges to sustaining that growth for each.

Key insights

- Rapid growth in the number and capacity of demonstration plants is observed. Notably, the US has funded a 1 million ton per year direct air carbon capture and storage demonstration plant, with another currently in negotiations.
- These US direct air capture hubs are by far the most well-funded public demonstration programme. A new initiative from Mission Innovation, the CDR Launchpad, although encompassing less funding, provides a platform for future investment and knowledge-sharing.
- Investment in CDR startups has grown rapidly over the past decade but declined in 2023 alongside a drop in overall climate-tech investment. This highlights the effect of market volatility on investments.
- Growth in novel CDR startups surpasses growth in conventional CDR startups, but CDR startups as a whole report challenges that must be overcome for companies to grow and scale.
- CDR companies and industry groups have announced capacity targets that show ambition to reach significant levels of CDR by mid-century or sooner.
- Current data to track funding – from both public and private sector entities – are sparse and incomplete. Better data are essential to understanding and managing the current CDR research, development and demonstration landscape and its outlook for the future.

The literature on innovation shows that demonstration projects and investment in new firms are central aspects of scaling up technologies from the invention phase (see Chapter 2 – Research and development) to their formative phase – between first commercialization and rapid scale-up – setting the stage for widespread adoption (see Chapter 8 – Paris-consistent CDR scenarios). This chapter tracks progress in the public funding of

demonstration programmes, investment in new startups, and expectations for growth in the coming years and decades.

3.1 Emerging public demonstration programmes

Demonstration plants play a key role in derisking technologies and setting the stage for widespread adoption.

Technology innovation is often described as moving through multiple stages. Between basic and applied research (see Chapter 2 – Research and development) and widespread adoption (see Chapter 8 – Paris-consistent CDR scenarios) are demonstration projects. These projects can demonstrate a technology's performance outside of the lab and provide experimentation and learning opportunities before that technology is widely deployed. Demonstration and pilot projects are typically distinguished by their size, with *demonstration* describing larger projects. At the demonstration stage, government funding is a key component to building plants, given the uncertainties of different technologies at this scale and the opportunities for firms to learn from one another, which provides incentives for firms to follow and observe rather than build first. These projects, therefore, are critical first steps in the pursuit of widespread and effective CDR deployment. This section focuses on existing CDR demonstration plant commitments and on government programmes to fund demonstration plants.

This section also summarizes public funding measures for research, development and demonstration (RD&D). This funding falls into three categories: RD&D funding for carbon capture and storage (CCS); RD&D funding specifically for CDR; and CDR demonstration funding. Although the first category is not explicitly focused on CDR, CCS RD&D may be directly relevant to the development of CDR technologies, such as transport and storage mechanisms.

There is no centralized data source for RD&D funding for CDR methods. This analysis gathers publicly available data on funding for CCS RD&D, CDR RD&D and CDR demonstration projects to identify broad trends and estimate global funding. Although every attempt has been made to gather complete data, these data are sparse. As a result, this is a key information gathering need for the CDR community going forward, and the data gathering conducted for this analysis can serve as an initial step (see Box 3.4). The following analysis is divided into two sections, first focusing on Mission Innovation and then moving to country-specific government demonstration funding.

Mission Innovation

Mission Innovation is a key programme in spurring innovation in low-carbon energy and climate change mitigation technologies. It is an initiative of 23 countries and the EU, with an aim to drive RD&D for these technologies.⁴⁶ Mission Innovation was announced at COP26 in 2021 and includes seven key missions, one of which is CDR. Canada, Saudi Arabia and the US are the three co-leads of the CDR Mission.⁴⁷ The CDR Mission has the primary aim of spurring the development of CDR technologies that will deliver a 100 million ton net reduction in annual global carbon dioxide (CO₂) emissions by 2030. To do so, the mission

focuses on three technologies: direct air carbon capture and storage (DACCS); biomass with carbon removal and storage (including bioenergy with carbon capture and storage (BECCS), bio-oil storage, biochar and other durable products from biomass); and enhanced rock weathering.

A cornerstone of the CDR Mission from Mission Innovation is the CDR Launchpad, a coalition of governments committed to accelerating CDR technology development.⁴⁸ These countries have resolved to work together to invest in CDR demonstration projects, share data and accelerate the CDR technology learning curve. Each country that is part of the CDR Launchpad has committed to:

- Support at least one CDR project with a capacity of at least 1,000 tons of CO₂ removed per year by 2025.
- Provide a portion of the \$100 million in funding for CDR demonstrations and pilot projects by 2025.
- Share data and information on these CDR demonstration projects to enhance knowledge-sharing.
- Support a monitoring, reporting and verification (MRV) working group, mapping of CDR projects, and life cycle analysis case studies of CDR projects.

Mission Innovation is a platform for countries to learn from one another and set parallel goals to increase RD&D and demonstration capacity. Because the CDR Mission is relatively recent, there is not yet comprehensive data on CDR RD&D funding, and not all Mission Innovation countries have made specific commitments for demonstration funding. Estimated country-level CDR demonstration funding is shown in Chapter 3 Technical Appendix and in the country profiles presented in this report.

Five countries (Canada, Iceland, Japan, the UK and the US) and the EU are members of the Mission Innovation CDR Launchpad and have shared data on demonstration projects in their jurisdictions.⁴⁹ This data set includes 22 demonstration projects focused specifically on BECCS, direct air capture (DAC), and enhanced rock weathering (see Figure 3.1).

Mission Innovation CDR Demonstration Projects

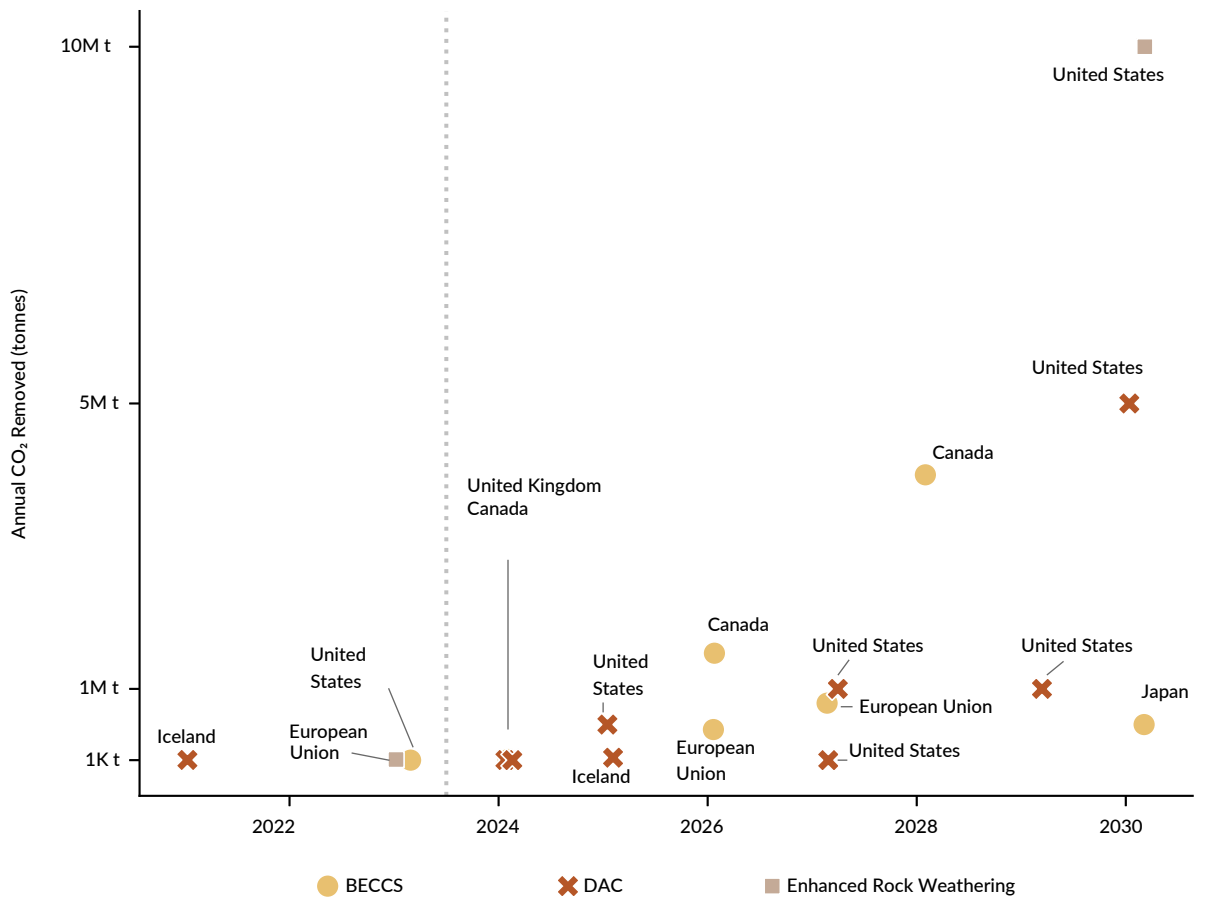


Figure 3.1 Demonstration projects submitted by countries in the Mission Innovation CDR Launchpad. Only includes demonstration projects for which there are complete data (CDR type, annual removal capacity and year of removal capacity). For some projects, there is an initial year and capacity along with future goals. For this figure, the first year and associated capacity level are shown. The points are labelled by the country that submitted the project. These projects have not necessarily received public funding. BECCS = bioenergy with carbon capture and storage; DAC = direct air capture.

Government funding of CDR demonstrations

Governments have approached CDR demonstration funding using diverse strategies. Documented funding for CDR demonstration projects is patchy, in part because these funding programmes include other carbon management approaches, such as carbon capture and sequestration, that are not explicitly CDR but may include CDR components. Some public data on CDR funding also exclude certain countries; for example, International Energy Agency (IEA) data exclude non-member and non-association countries.

Between 1974 and 2023, the global total of public funding for carbon capture and sequestration RD&D, as reported by the IEA, was \$15 billion. However, this data set only includes 33 IEA member and association countries and the EU.⁵⁰ This figure is therefore not exhaustive of all global funding, because it only includes data from these 34 entities. This estimate also includes funding for DAC (not necessarily with storage; therefore, not necessarily CDR) and no other CDR technologies. Australia, Canada, the EU, Germany, Ireland, Japan, Norway, the UK and the US have announced public funding for CDR

RD&D, totalling \$4.2 billion. Within this, Australia, Canada, the EU, Japan, Norway, the UK and the US have all funded demonstration projects, which make up \$3.9 billion of this total, dominated by \$3.5 billion in funding for the US Regional Direct Air Capture Hubs programme (see Box 3.1).

The remainder of this section presents profiles of government entities that have funding programmes specifically to support CDR demonstration projects: Australia, Canada, the EU, Japan, Norway, the UK and the US.¹ This section also highlights demonstration projects with public funding. Many government programmes include funding for CDR, CCS and CCU within the same programme, often under a broader carbon management strategy. Where possible, funding specifically for CDR within these programmes is distinguished.

Australia

In Australia, carbon capture, utilization and sequestration RD&D has been funded for many years through the Carbon Capture Use and Storage Development Fund and the Carbon Capture Technologies Program. The Carbon Capture Use and Storage Development Fund includes funding for up to A\$25 million (US\$17 million) per project for pilot and precommercial projects (demonstrations). This programme is not specifically focused on CDR but can include CDR projects.⁵¹ One of the projects from the Carbon Capture Use and Storage Development Fund is a pilot DACCS demonstration plant operated by AspiraDAC, awarded a A\$4 million (US\$2.7 million) grant with an expected capacity of 365 tCO₂ per year.⁵²

The Carbon Capture Technologies Program funds A\$65 million (US\$43 million) over eight years, from 2023 to 2031.⁵³ The programme specifies priority emerging carbon capture technologies, including DAC, BECCS and CO₂ utilization technologies. Through the Department of Climate Change, Energy, the Environment and Water, the National Soil Carbon Innovation Challenge is focused on measuring soil carbon sequestration.⁵⁴ The funding includes A\$1 million (US\$0.7 million) for 17 feasibility studies and A\$39 million (US\$26 million) for 13 development and demonstration projects. The Clean Energy Finance Corporation, Australia's green bank, has invested A\$15 million (US \$10 million) in Loam Bio, which focuses on enhancing soil carbon sequestration.⁵⁵

Canada

The Canadian government is investing Can\$320 million (US\$240 million) from 2021 to 2028 in carbon capture utilization and storage RD&D through its Energy Innovation Program.⁵⁶ Eligible technologies include DAC, but the final projects are still being evaluated (as of May 2024), so the funding allocated for CDR (as opposed to CCS and CCU) is uncertain.⁵⁷

Beyond the Energy Innovation Program, Canada is funding specific CDR demonstration projects. The Hinton Bioenergy Carbon Capture and Storage Project received Can\$2.5 million (US\$1.9 million) in public funding from Emissions Reduction Alberta, which is funded by the Technology Innovation Emissions Reduction Fund in Alberta.⁵⁸ Through the British Columbia Innovative Clean Energy Fund, a Carbon Engineering (a DAC company) plant that uses DAC technology received Can\$2 million (US\$1.5 million) for engineering

¹ Programme and project funding amounts are converted from national currencies to US dollars as a common currency to calculate an estimate of global funding. Currency exchange rates are from the US Treasury in 2023. Numbers are reported to two significant figures.

and design plans.⁵⁹ This plant does not meet the storage requirement of CDR because the CO₂ is used to produce fuels. Through its Strategic Innovation Fund, the Canadian government has awarded Carbon Engineering Can\$25 million (US\$19 million) to design, construct and operate the Newport Innovation Centre in British Columbia (4.5 tons of CO₂ removed each day via DAC).⁶⁰ Finally, the CARBONITY biochar plant is being built with Can\$11 million (US\$7.8 million) of public funding through two entities: Natural Resources Canada's Investments in Forest Industry Transformation Program and Canada Economic Development for Quebec Regions.⁶¹ This plant will be the largest capacity biochar plant in North America, and larger than any in Europe.

European Union

The EU Innovation Fund includes funding measures for CDR projects.⁶² The fund began in 2020 with a goal to invest an estimated €40 billion (\$44 billion) by 2030 to support the transition towards climate neutrality.

Several CCS and CCU projects have been selected through the Innovation Fund that may inform scale-up of CDR in the future. One project which counts as full CDR – a BECCS plant in Stockholm, Sweden – was awarded public funding and received €180 million (\$200 million).⁶⁴ This demonstration plant is expected to remove an estimated 7 Mt of CO₂ over the first ten years of operation, which is scheduled to begin in 2026. The latest round of funding for net zero technologies opened in late 2023. At the time of writing, no projects had been selected; therefore, no funding estimate is included in this report.

Japan

Japan has invested extensively in CCS technologies, but with less of a focus on CDR.⁶⁵ The primary programme for RD&D is the Moonshot Research and Development Program, which allocates about ¥50 billion (\$350 million) from 2020 to 2030 for climate technologies.^{66,67} Many projects funded under this allocation are focused on methods relevant to CDR, including DAC and enhanced rock weathering. There are no upper or lower bounds for project funding under the Moonshot programme, and as no project-specific investment values are made publicly available, estimating the portion of the total funding going specifically to CDR RD&D is not possible. Beyond the Moonshot programme, the Japan Ministry of Agriculture, Forestry and Fisheries is funding a programme focused on biochar, wood-based carbon sequestration and coastal wetland restoration, up to a total of ¥16 billion (\$110 million).⁶⁸ The Ministry of the Environment has also funded the capture component of the Mikawa BECCS Demonstration Plant.⁶⁹

Norway

Norway has a dedicated national programme related to CCS RD&D, called CLIMIT.⁷⁰ The programme began in 2005 and has primarily been focused on carbon capture, storage and utilization but can also support BECCS and DACCS projects. Many of the previously funded CCS projects may have relevant lessons for CDR, especially those focused on the transport and storage of captured CO₂. Through this programme, Norsk Hydro and Climeworks collaborated on a feasibility study for a DAC plant, either stand-alone or integrated into an aluminium smelter to provide steam to the DAC unit; the study received Nkr 3.5 million (\$0.3 million).⁷¹ The project did not result in a built demonstration plant, however.

The Norway Ministry of Climate and Environment is funding a pilot demonstration DAC unit through Enova, a State-owned enterprise. The demonstration plant, operated by Removr, received Nkr 36 million (\$3.6 million) in grant funding and will capture 300 tons of CO₂ annually beginning in 2024, with a goal of expanding to 1,000 tons captured per year.^{72,73} It is not clear whether the captured CO₂ is stored permanently; thus, the project is categorized as DAC rather than as CDR.

Innovation Norway, a programme of the Norwegian government, has also begun the Bionova programme, which may finance RD&D projects related to conventional CDR methods.⁷⁴ The amount of funding from this source is unclear, as funded projects and results had not been published at the time of writing.

United Kingdom

The UK funds CDR-specific RD&D programmes in addition to programmes on carbon capture utilization and storage. Approximately £32 million (\$40 million) has been granted from UK Research and Innovation, a non-departmental public body, to the Greenhouse Gas Removal Demonstrators Programme, which is funding five demonstration projects encompassing several CDR technologies: biochar, enhanced rock weathering, peatland restoration, perennial biomass crops, and woodland creation and management.⁷⁵

The Net Zero Innovation Portfolio fund, administered by the UK Department for Energy Security and Net Zero, has a programme focused on DAC and greenhouse gas removal. The funding programme is structured as a two-phase competition, with total funding of £70 million (\$89 million). The first phase focused on desk-based feasibility studies. It ended in 2021, with 23 projects funded. The second phase began in 2022 and is focused on demonstration projects, with 15 projects funded. These projects are being built between 2022 and 2025, with demonstration of CDR beginning in 2025. The Department for Energy Security and Net Zero and the Department for Business, Energy and Industrial Strategy have also announced programme funding for hydrogen BECCS technologies totalling £26 million (\$33 million).⁷⁶ While the UK government intends to open up CO₂ transport and geological storage in this decade, the current lack of this infrastructure means that several of these projects are progressing to capture only.

An additional £4.3 million (\$5.5 million) funded six projects to capture carbon through restoration of a range of habitats, starting in 2023, through a partnership led by Natural England, a public body.⁷⁷ Innovate UK, a UK government agency, is also funding the Small Business Research Initiative competition. This competition is focused on tools and techniques for MRV for land-based greenhouse gas removal, with total funding of £1 million (\$1.1 million) over two phases.⁷⁸

United States

The US has several streams of CDR RD&D funding. The flagship CDR demonstration funding is for the Regional Direct Air Capture Hubs programme (see Box 3.1). The Carbon Negative Shot, a cross-departmental initiative of the US government, is focused on CDR and includes funding for pilots and demonstrations. The initiative recently released a Carbon Negative Shot Pilots funding opportunity announcement to complement the DAC hubs and fund small pilots for enhanced rock weathering and BECCS, recognizing that a

portfolio approach is needed. This effort alone will provide \$100 million over five years for demonstration projects. The funding will cover up to five small BECCS pilots, up to ten enhanced rock weathering pilots, up to five CDR testing facilities focused on CDR MRV, and up to five laboratory-scale marine CDR projects.⁷⁹

Box 3.1 US Regional Direct Air Capture Hubs programme

The Regional Direct Air Capture Hubs programme, established in 2022 by the Biden Administration, seeks to fund four research hubs focusing on DAC. To be eligible, companies must demonstrate the ability to construct a DAC facility that can remove 50,000 tons of CO₂ per year, with a plan to scale up to 1 Mt per year.⁸² This programme is funded by resources set aside by the Infrastructure Investment and Jobs Act and the Inflation Reduction Act. It is managed jointly by the Department of Energy's Office of Clean Energy Demonstrations and Office of Fossil Energy and Carbon Management. In total, the Regional Direct Air Capture Hubs programme has been authorized to grant \$3.5 billion (\$700 million per year over five years). The Department of Energy has not yet granted the entire funding amount, noting that it wants to allow earlier-stage companies to reach the maturity needed to become eligible for the programme before granting the entire \$3.5 billion.⁸³

Currently, two DAC hubs have been selected for negotiation, accounting for \$1.2 billion between them.⁸⁴ Both can more accurately be described as DACCS hubs, as they sequester captured carbon in storage sites rather than using it. The first is the South Texas DAC Hub, located in Kleberg County, Texas. Jointly operated by 1PointFive (an Occidental subsidiary), Carbon Engineering and Worley, this DAC hub seeks to remove 1 million tons of CO₂ annually. This hub, in partnership with Gulf Coast Sequestration, plans to sequester this CO₂ in geological formations along the Gulf Coast. To assist the South Texas DAC Hub in its development, the Regional Direct Air Capture Hubs programme is in negotiations regarding the provision of \$600 million in funding.

The second DAC hub is Project Cypress, located in Calcasieu Parish, Louisiana. Operated by Battelle, Climeworks and Heirloom Carbon Technologies, this hub is also working to remove more than 1 million tons of CO₂ annually. It will use a "saline geologic CO₂ storage site" to store carbon captured using DAC. The Regional Direct Air Capture Hubs programme has dedicated \$600 million in funding for this purpose.⁸⁴

Nineteen smaller projects are currently in negotiation with the Department of Energy, for a total of approximately \$100 million. The majority of these projects are seeking funding to study the feasibility of a DAC hub prior to applying for the funding to establish one.⁸²

The US Department of Energy announced \$36 million to fund marine CDR MRV projects through the Advanced Research Projects Agency–Energy. The Department of Commerce and the National Oceanic and Atmospheric Administration announced \$24 million to fund research on marine CDR, in part funded by the Department of Energy through the Office

of Fossil Energy and Carbon Management.^{80,81} The Department of Energy also announced \$17 million to fund 19 early-stage research projects at colleges and universities, which may enable future demonstration projects.

Looking forward

Public demonstration programmes are increasing, both in the number of announced programmes and the capacity of the demonstration plants. However, the timelines for demonstration projects – and their subsequent upscaling phases – are uncertain due to the nascent nature of these technologies. Continued growth relies on production catalysed by the public sector via initiatives such as Mission Innovation. Mission Innovation’s CDR Launchpad could become a key player in this space, serving as a platform for investment and knowledge-sharing. Furthermore, tracking funding – both from public sector entities and private sector investments – is essential to understanding the current CDR RD&D landscape and its outlook for the future. This is another role that Mission Innovation could play moving forward.

3.2 Rapid growth in investment

Investments in CDR startups have grown significantly over the past decade, outpacing the climate-tech sector as a whole.

Startups are a key part of the climate innovation landscape because they can quickly bring new products and services to market. However, they face many challenges in advancing from the demonstration stage to commercial operation and market growth.⁸⁵ Investments from the public and private sector are key to enabling startup success.⁸⁶ This analysis examines the state of investments in CDR startups through 31 December 2023, using the Net Zero Insights database (see Box 3.2).⁸⁷ The database contains 509 CDR startups, defined in this report as startups related to the capture of CO₂ from the atmosphere. Of these, 255 have received at least one investment, with 961 investors participating in 803 deals, totalling \$3.9 billion, during the period 2009–2023.

Investments in CDR startups have grown dramatically in recent years. A decade ago, reported investment in CDR was low: in 2013, three startups received \$4 million in two investment deals. By 2022, when total reported investment in climate-tech peaked, annual investments in CDR startups had reached 131 startups, \$1.5 billion and 207 investment deals (and 2.3% of all climate-tech deals and 1.1% of dollars invested in climate-tech). However, while deals slightly increased in 2023 to 213 (with 145 startups funded), investment in CDR declined to \$856 million. This decline in investment value (43%) was steeper than the decline seen in climate-tech overall (14%).

Box 3.2 Methods: Net Zero Insights database

This report uses the Net Zero Insights database to evaluate early-stage investments in CDR startups. Net Zero Insights monitors a wide range of sources to collect data on climate-tech startups and also accepts submissions from innovators and industry stakeholders. Almost all startups in the database develop climate change mitigation products or services, with a few startups focused on improving the resilience of communities to climate change (i.e. adaptation). Net Zero Insights relies on publicly available information and is published mostly in English, so it may miss some private investments or investments reported in other languages. Startups may also receive funding through instruments not included in this database (e.g. loans). Net Zero Insights shows five CDR startups that have been acquired, one of which (Carbon Engineering) reports its acquisition value as \$1.1 billion.

For the analysis in this report, 1,001 potential CDR or CDR-enabling startups were identified in Net Zero Insights using the following categories: greenhouse gas capture, removal and storage; CDR; carbon capture, utilization and storage; afforestation/reforestation; and forestry. These startups were manually categorized into different CDR methods by reading the pitch and tags to look for descriptions or labels of each method: forestry CDR, DACCS, biochar, biomass burial, marine biomass sinking, enhanced weathering, BECCS, soil carbon, ocean alkalinity enhancement, coastal wetland restoration and direct ocean capture. A total of 218 companies without a specific connection to CDR, such as ordinary timber or agriculture data platforms or generic sustainability business services, were removed.

Companies that mentioned utilization or point source capture of fossil CO₂ in their pitch (or that did not specify the CO₂ source) were also removed and added to the list of enabling startups. Some CDR companies do not specify the destination of the CO₂; these companies were included in the list of CDR startups. Therefore, this analysis may include some companies that do not meet the report's definition of CDR if they use CO₂ but do not report that they do so or if they currently sequester CO₂ but later decide to use it (e.g. Carbon Engineering).

Since 2020, the CDR methods that have received the highest investor attention (based on the number of deals) are forestry CDR (38%), DACCS (23%) and biochar (14%). Enhanced rock weathering and soil carbon sequestration have also experienced rapid growth in deals, with a fourfold and twofold increase since 2020, respectively, but constitute a relatively small share of total deals. Overall, the recent trend in investment is towards more novel forms of CDR, with the share of deals in forestry CDR declining from 49% in 2020 to 30% in 2023. While deals vary in size, and thus do not always reflect trends in the flow of capital, trends in investment dollars since 2020 are similar to the trends seen in deals. For example, as well as having among the highest number of deals, DACCS and biochar are the CDR methods receiving the most funding, with \$808 million to DACCS in 2022 and \$234 million to biochar in 2023.

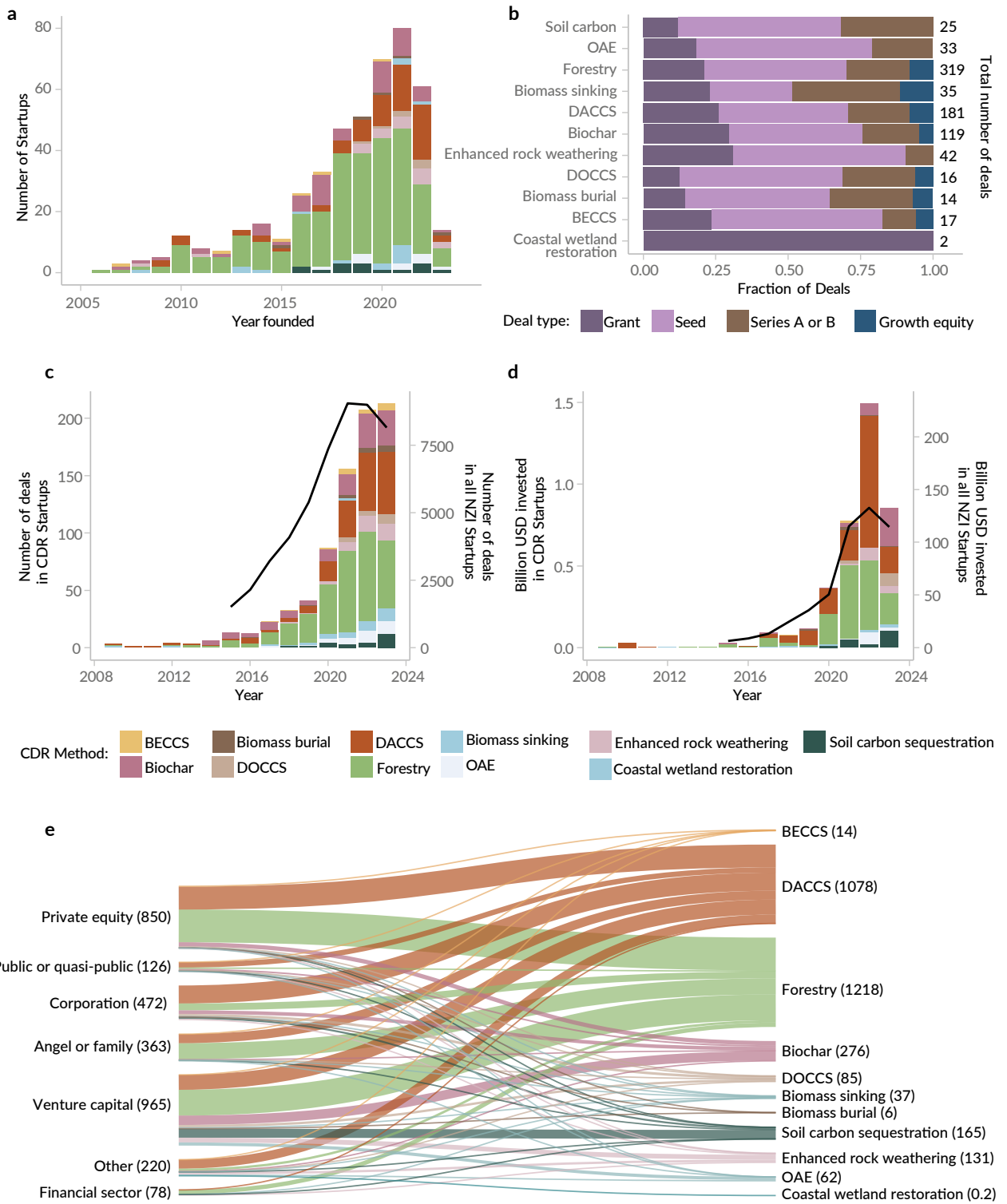


Figure 3.2 Investment trends in carbon dioxide removal (CDR) startups from 2009 to 2023: (a) Number of startups founded in each year (509 total); (b) Proportion of deal types across CDR methods; (c) Number of investment deals in CDR startups each year (255 total startups and 803 deals, bars) and total deals for climate-tech startups (black line); (d) US Dollar value of investments in each year (208 total startups and 511 deals that report a dollar value, bars) and total investment dollars for climate-tech startups (black line); (e) Flow of investments by investor type to CDR method. BECCS = bioenergy with carbon capture and storage; DACCS = direct air carbon capture and storage; DOCCS = direct ocean carbon capture and storage; OAE = ocean alkalinity enhancement. Data source: Net Zero Insights database.⁸⁷

Startups receive funding in sequential rounds, beginning with grant and seed rounds that typically correspond to high technology risk or precommercial stages. They then progress to Series A and B and other equity rounds, where risks are reduced and commercial development has started. They may finally move to the growth equity stage, which tends to involve larger dollar amounts for startups seeking to expand their operations, and investors holding larger shares in these startups.⁷⁷ The distribution of investment rounds across CDR methods reflects a range of maturity (Figure 3.2b). Among CDR methods with at least ten reported deals, enhanced rock weathering is the most dependent on grants (31% of deals). Only forestry, DACCS, biochar and biomass sinking startups have received funding from later-stage growth equity rounds. However, despite the large investments in some CDR methods, such as DACCS and forestry, 71% of deals across all methods since 2020 have been grants and seeds, indicating that many new startups are still entering the space.

The funding for these investment rounds comes from a variety of sources (Figure 3.2e), with funders bringing different motivations, resources and expectations with their investments. These motivations range from financial investment returns for equity investments to strategic interests in maintaining or expanding existing businesses or pivoting to new directions. Based on dollars invested, the largest sources of funds for CDR startups from 2009 to 2023 were venture capital (\$965 million; 25%), private equity (\$850 million; 22%) and corporations (\$472 million; 12%). This is consistent with overall funding patterns for climate-tech startups.⁸⁸ While venture capital is distributed among various CDR methods, corporate investment is largely concentrated in DACCS (52%).

Other startups are also developing technologies that could enable CDR. For example, 80 startups developing conventional CCS technologies participated in 400 investment deals from 2001 to 2023, totalling \$2 billion. About half of these startups specify the destination of the captured carbon: 30 specify sequestration or storage only (68 deals and \$78 million), 12 specify utilization in synthesis of low-carbon fuels or chemicals (44 deals and \$174 million), and six specify utilization in curing cement (33 deals and \$74 million). Five of these CCS startups report a novel carbon capture method – using algae to extract CO₂ from concentrated streams – but no investments are reported. Other enabling startups focus on CO₂ utilization and can provide early markets for captured CO₂.⁸⁹ Thirty-five startups that use a stream of CO₂ to cure cement (104 deals and \$367 million) were identified, as were 92 startups that use captured CO₂ to synthesize fuels, chemicals, plastics or food (295 deals and \$3.6 billion). Investments in these enabling startups follow similar growth trends to those in CDR startups.

CDR startups identify a number of pressing challenges to rapid growth. While there are no comprehensive global surveys of CDR startups, a recent survey of 40 European CDR startups highlighted challenges that are likely to extend to other regions (see Figure 3.3).⁹⁰ The surveyed startups focus mostly on DACCS, enhanced rock weathering and restoring degraded ecosystems and might therefore be less representative for other methods, such as BECCS, biochar and ocean fertilization. The startups rated the importance of bottlenecks (0 = lowest; 5 = highest) across four categories: finance, marketing and sales, product and service, and team. Each of the four categories was further divided into subcategories. The most important subcategory in each main category is shown in grey in Figure 3.3.

The surveyed startups see finance as the central bottleneck. They particularly struggle to access non-dilutive funding (i.e. grants that do not require the selling of ownership stakes in the company); dilutive funding, such as venture capital, tends to be more readily available. The challenges with non-dilutive funding relate to the speed with which funding can be acquired, rather than to availability or conditions. To acquire grants, startups need to put a full-time employee on the task, which often overstretches their budget. In addition, grants often take a year to be approved. During that time, the needs and priorities of the startup often shift, which poses problems if the funds need to be spent as originally intended. The second most pressing bottleneck reported relates to marketing and sales. Startups struggle with converting their leads into actual sales, as many buyers shy away from high prices, uncertainties in the voluntary carbon market (see Chapter 4 – The voluntary carbon market), and scientific uncertainties around MRV (see Chapter 10 – Monitoring, reporting and verification). For instance, less than 1% of companies with a science-based target have bought novel CDR and less than half of novel CDR startups have made a sale to date. These startups perceive challenges related to their product (e.g. business model or supply chains) and hiring (e.g. availability of talent, hiring, and retention) to be less pressing bottlenecks.

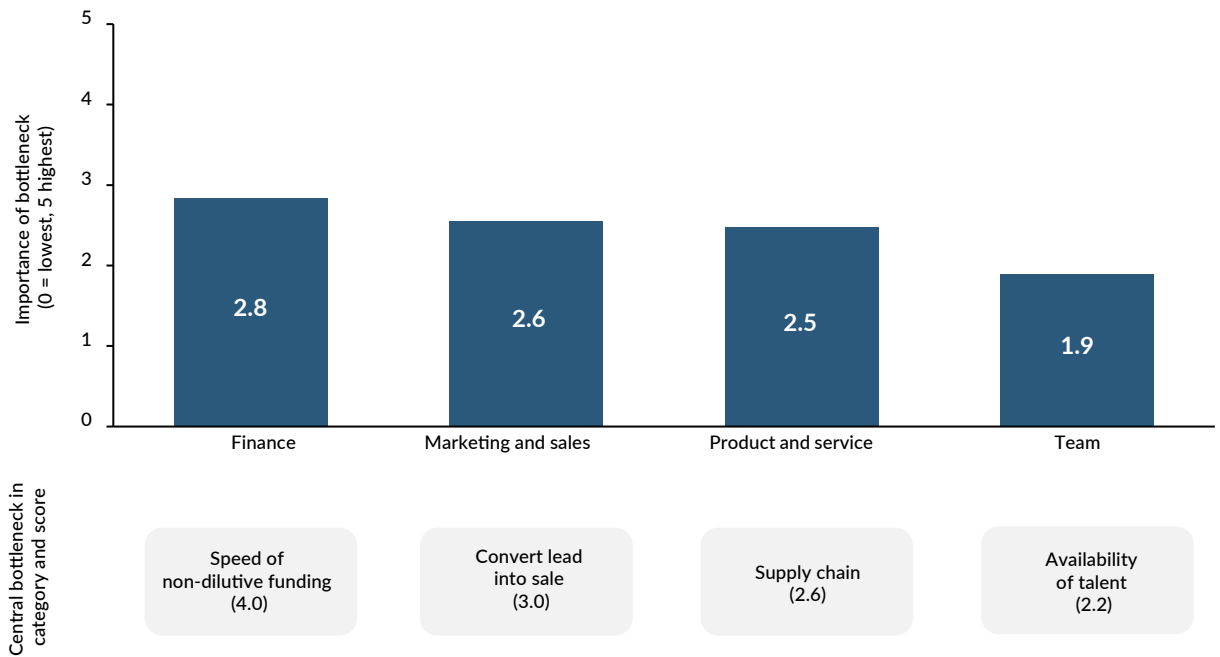


Figure 3.3 Overview of most important bottlenecks reported by a survey of 40 European CDR startups. Data source: Akeret et al., 2023.⁹⁰

Box 3.3 Investment trends

The analysis of reported investments in CDR startups highlights a number of key trends:

High investor interest in DACCS. DACCS has become a primary focus for corporate and other large investors in CDR. Major CDR startups such as Climeworks and Carbon Engineering have received investments from corporations that are looking to offset emissions from their core business (e.g. Microsoft, Airbus, Chevron, J.P. Morgan). Other startups receiving high interest from corporations include those focusing on e-fuels or carbon utilization (e.g. Carbon Engineering, Prometheus, Global Thermostat) or advertising co-benefits such as water security (e.g. Avnos).

Stable interest in forestry CDR. Afforestation, reforestation and forest management – collectively called *forestry CDR* in this analysis – are more established CDR methods. Prior to 2021, forestry CDR startups attracted the majority of CDR investments. In recent years, growth in such investments has stabilized. Compared with other CDR methods, forestry CDR startups have more varied business models, reflecting a higher level of maturity. For example, 39% of forestry CDR startups offer services selling carbon credits on bespoke marketplaces, with the credits either being produced by their own technology or by another startup. These marketplaces enable startups to directly reach customers; for example, Treekly and Pachama verify and sell carbon credits for reforestation.

Emerging interest in other novel CDR. Beyond DACCS and biochar, other novel CDR methods include ocean alkalinity enhancement, enhanced rock weathering, biomass sinking, coastal wetland restoration, direct ocean carbon capture and storage, biomass burial, and BECCS. Together, startups focusing on these seven methods have participated in 52 deals from 2009 to 2023. Examples of recent startups focused on other novel CDR methods include Captura and Deep Sky (which capture gaseous CO₂ from water) as well as Seaforester and the Reef Company (which focus on coastal wetland restoration).

3.3 Company announcements for novel CDR

Announcements by CDR companies and industry groups show their ambition to reach significant levels of CDR by mid-century or sooner.

Companies have made plans and announcements for novel CDR scale-up, both in the near term (2024–2030) and the longer term (2030–2050). The announcements made for these two periods may have different levels of certainty, since companies have more concrete plans in the near term than the longer term, so this report analyses them separately. In both these analyses, the public announcements from companies should not be considered future scenarios, but rather an indication of potential market development. Some companies might not achieve the goals they have announced, some may exceed them, and additional companies will emerge and set new goals.

Projects included in the near-term analysis (2024-2030) are those under construction, in initial stages of deployment, or with publicly announced facility plans or early engineering studies. For the near term, details were gathered for projects under construction and/or in development for DACCS and BECCS (see Box 3.4). Only projects that permanently store the captured carbon or have disclosed that they have plans to do so are included. The near-term analysis is limited to these technology types because of insufficient information on the specific targets set by companies involved in biochar and enhanced rock weathering. Additionally, for emerging technologies such as biomass sinking, it is premature to make near-term predictions using company announcements, as these technologies are currently in the early stages of development.

In total, this report estimates that companies that have announced DACCS and BECCS projects may remove 118 million tons of CO₂ annually by 2030 (see Figure 3.4). BECCS companies may remove nearly 57 million tons of CO₂ annually by 2030; an increase from the current rate of 0.5 million tons per year. DACCS projects may remove 61 million tons of CO₂ annually by 2030.

Near-Term Novel CDR Company Plans

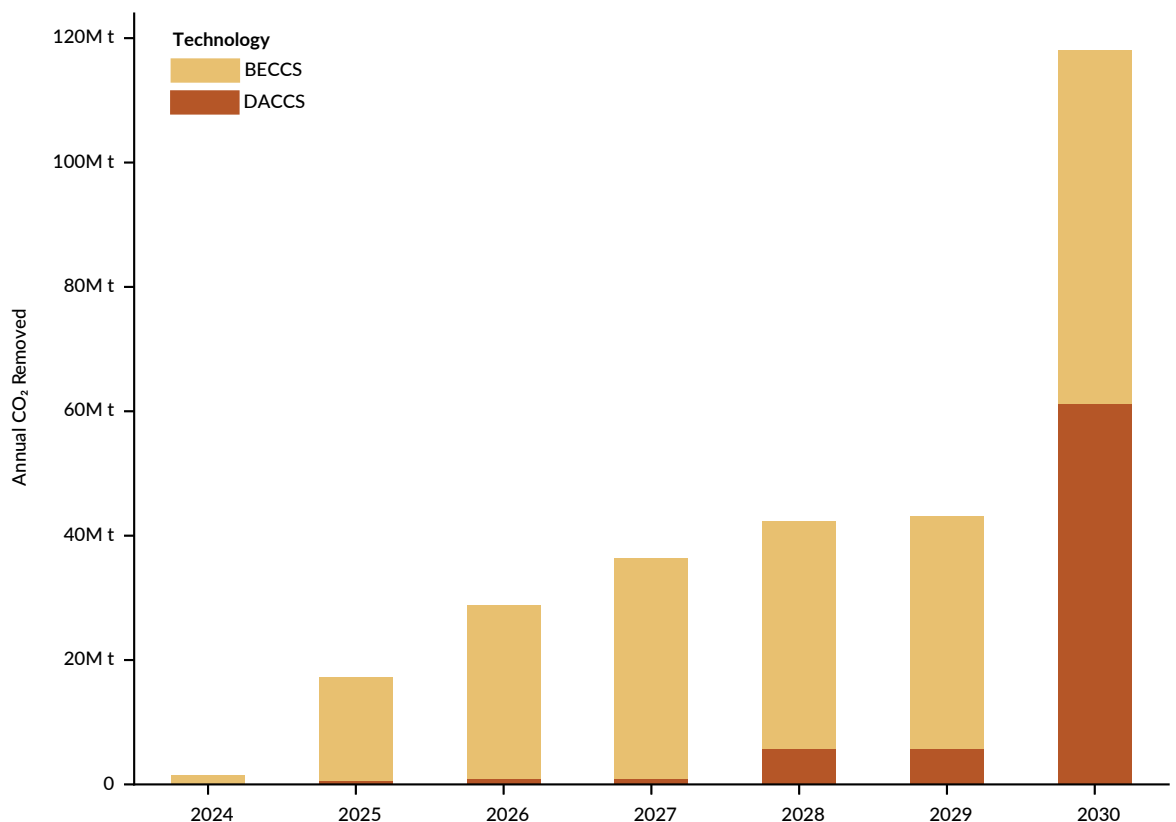


Figure 3.4 Cumulative capacity of direct air carbon capture and storage (DACCS) and bioenergy with carbon capture and storage (BECCS) projects from 2024 to 2030. This report assumes that projects would sustain their announced annual capacities from their operational year through 2030, unless additional extensions at the same plant have been announced for the intervening period. CDR = carbon dioxide removal.

This report supplements the analysis of short-term planned projects with an analysis of company announcements between 2030 and 2050. This longer-term analysis includes any announcement that a company has made publicly that includes both a capacity and a year. These announcements are not filtered by whether the company has begun engineering studies or made plans for specific plants. The announcements were gathered from CDR companies' websites and publicly available industry reports (see Box 3.4). Data were collected for as many companies as possible. However, this data set is not comprehensive of all CDR company plans for a variety of reasons: not all companies disclose their growth goals, and some companies may be missing despite attempts at a comprehensive inventory. Attainment of these announced ambitions is also highly uncertain, and this report includes no assessments of credibility.

Thirty-one company announcements were identified from 24 unique CDR companies and industry groups focused on novel CDR between 2030 and 2050 (Figure 3.5). These announcements span multiple CDR methods, with the majority of the individual announcements coming from DAC companies (65%); the second most prevalent method in the announcements, at 13%, was biochar.

Eleven companies have made plans for 2030, which together total 2 Gt of CO₂ removed annually. Company announcements for 2050 total 11 Gt of CO₂ removed per year, which is mostly driven by a single announcement of 8 Gt per year by 2050. This level of growth in novel CDR, from 1.3 Mt of CDR in 2023 (see Chapter 7 – Current levels of CDR) to 11 Gt in 2050, implies a compound annual growth rate of 40% per year. This growth rate is comparable to other climate-relevant technologies like solar energy and electric vehicles. Between 1975 and 2018, solar photovoltaic grew at a compound annual growth rate of 36% per year in terms of cumulative capacity, and between 2005 and 2019 electric vehicles grew at a compound annual growth rate of 80% per year in terms of cumulative number of vehicles.

Longer-Term Novel CDR Company Announcements

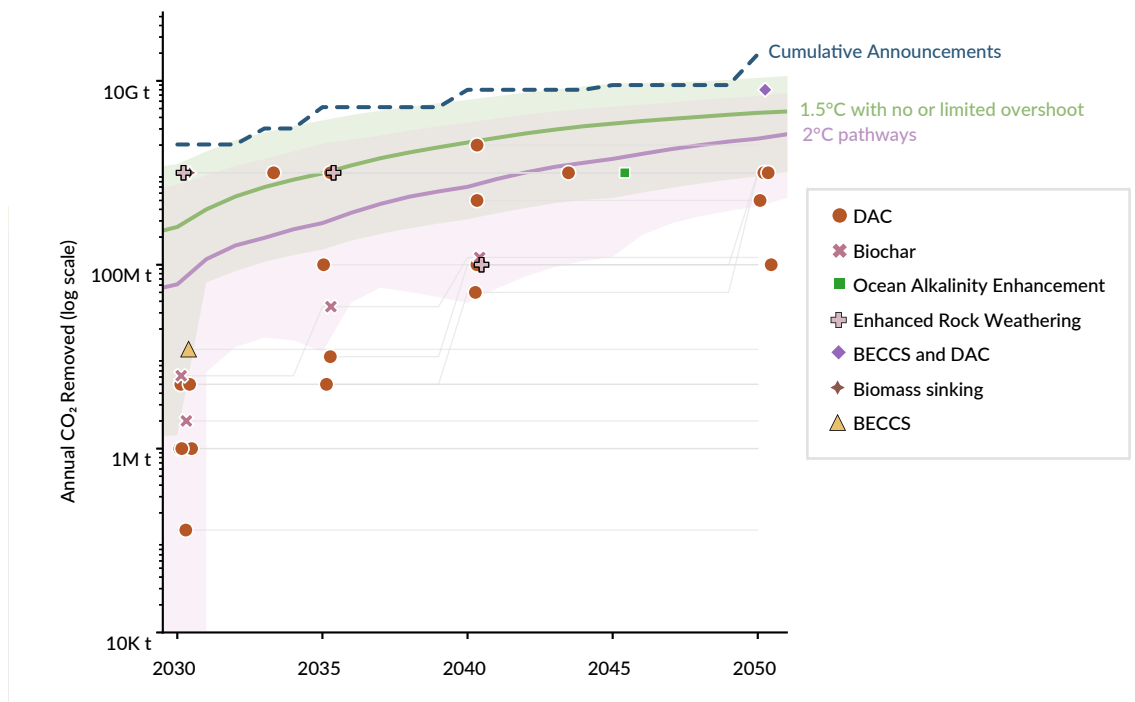


Figure 3.5 Longer-term novel carbon dioxide removal (CDR) company announcements. Dashed lines are cumulative company announcements; points are individual company announcements; each faint grey line is one company’s time series; solid lines show the median amount of novel CDR in two scenario pathways (a 1.5°C with no or limited overshoot pathway and a 2°C pathway). These scenario pathways are constructed between 2010 and 2100, but only those for 2030–2050 are shown in this chart. The shaded areas around each pathway represent the 5th to 95th percentile novel CDR in the scenarios. The companies’ time series are based only on publicly available announcements. It is assumed that each company reaches the capacity of the announcement in the year of that announcement and continues at that capacity until 2050 or until the year of another, intermediate, target set by the same company, at which point their time series increases to capacity and remains flat until 2050 or a new announcement. Company announcements are not filtered by their project status or completion, so whether these announcements will be reached is highly uncertain. DAC = direct air capture; BECCS = bioenergy with carbon capture and storage.

The cumulative amount of novel CDR announced by CDR companies is aligned with the amount of novel CDR required by two temperature scenario pathways: a 1.5°C with no or limited overshoot pathway and a 2°C pathway (see Figure 3.5). The scenarios assessed in this figure are the full set assessed in Chapter 8 (Paris-consistent CDR scenarios); therefore, there is no consideration in this chapter of whether these scenarios meet sustainability goals. Whether companies will achieve the announced amounts of novel CDR by 2050 is uncertain, but the comparison to the novel CDR required by temperature scenario pathways demonstrates the level of ambition in the novel CDR market.

Box 3.4 Methods: Short- and long-term capacity announcements

Data were gathered on near-term plans for BECCS and DACCS projects through several sources. A full accounting of these sources is included in Chapter 7 (Current levels of CDR). Planned BECCS projects include dedicated bioenergy plants, waste-to-energy plants with CCS, and cement production plants with biomass energy inputs. For these latter two types of plant, CDR volumes have been calculated by assuming that the fraction of total captured CO₂ that is attributable to biogenic sources is 50% and 10%, respectively. Together, these two types contribute less than 8% of the total planned BECCS volumes in 2030.

Data on long-term CDR company announcements were gathered by compiling a list of CDR companies and searching each company's website, along with other documents available online, for publicly announced removal levels. The list of companies came from the State of Carbon Dioxide Removal list of deployed projects, Direct Air Capture Coalition company members, companies selected for pre-purchases from Frontier (an advance market commitment funding mechanism), and a list of companies receiving investments compiled from Net Zero Insights.⁷⁹ The companies' activities span different methods of CDR but are focused on novel CDR.

Each company's website was checked for any announcement that included both a capacity and a year for its attainment. If either of these was not available, the announcement was not included. This list was supplemented with announcements found in other company documents, such as year-end presentations and conference videos available publicly online.

A time series was then constructed for each company, in which flat growth (no new capacity built) is assumed for that company unless and until a new ambition level is announced. A cumulative level for the total novel CDR capacity announcements in the market was then calculated by summing each company's time series – assuming each announcement is successfully reached by each company.

Data were gathered from as many companies as possible; however, this data set is not entirely comprehensive because not all companies disclose their CDR growth ambitions. Attainment of the targets in these announcements is also highly uncertain, and this report includes no assessments of credibility.

Box 3.5 Limitations and knowledge gaps

This report has identified areas on which future assessments can build, including:

- Conducting annual surveys of national governments' public investments in CDR RD&D for several categories of CDR technology, including MRV, would be important to assess support for CDR over time. The IEA has done this successfully for energy technologies.
- Startups are often reticent to share detailed information, resulting in gaps in both investment data and technology details. Access to more detailed information about investment amounts and technology development could allow for more specific analysis of technology development trajectories and their implications.
- Company announcements, both near term and long term, can provide a useful early indicator of progress being made to close the CDR gap described in Chapter 9 (The CDR gap). Adding probabilistic information for each stage and timing can help establish a more credible range of progress.



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