

The Time for Carbon Removal Has Come

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A consortium of CDR organizations, venture capital funds, and philanthropic organizations have commissioned this report, with a subset having provided input on the contents. While representatives from these organizations were interviewed as part of the research for this study and provided input on technical, regulatory, and customer aspects of the CDR market, the findings from this report represent the views of the authors, backed by both primary and secondary research.

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Executive Summary

Broad scientific consensus supports the tenet that Carbon Dioxide Removal (CDR) will play a crucial role in supporting global decarbonization, with analysis pointing to a significant role in slowing of “net” global emissions in the short term and removing historical emissions in the longer term. “High quality” removals (for example, those with *permanence*, *verifiability*, and *additionality*) are of particular importance, as any reversal in CDR limits expected benefits.

Ensuring the emergence of a robust supply for high-quality removals will require action across all stakeholders, including governments, buyers, suppliers, standard-setters, and investors. Namely, buyers interested in purchasing durable CDR will need to act now given the limited announced supply in 2030.¹ Similarly, investors will need to invest now in a portfolio of durable CDR, as successful CDR suppliers will be determined in the coming years.

This report is an independent study by the Boston Consulting Group (BCG) to assess the market opportunity, across both voluntary and non-voluntary markets, for a select set of CDR methods in the 2030–2040 timeframe, leveraging select interviews and a survey of 100+ current and potential buyers as well as BCG IP and analysis.² The results are informed by how the future markets may evolve based on today’s information (for example, stated buyers’ preferences, current view on policy and its trajectory). The results aren’t meant to emulate global decarbonization scenarios (for example, International Energy Agency (IEA) scenarios) or incorporate supply considerations into demand outlook.

This report provides a holistic, baseline view of global demand for these technologies.³ Here is a summary of what we have learned:

1 Durable CDR Demand Offers a Significant Market Opportunity

- **Our analysis estimates an annual demand of ~40 million–200 million tons (Mt CO₂) for durable CDR in 2030, which is very likely to far outstrip the announced supply of ~15–32 Mt CO₂.**^{4,5} The 2030 demand will come primarily from the voluntary market (~90%), driven by early purchases from industries with climate commitments and the highest willingness to pay for durable CDR (for example, software, professional services). As further developments lead to increased scale and lowered costs, the demand from buyers with historically lower willingness to pay (for example, manufacturing) can be unlocked, filling up the upper end of this market opportunity.
- **While the estimated demand for durable CDR is meaningful, it is below the volume that would be expected if companies are to hit their stated Net Zero targets with ~10% removals (~1.1–1.6 Gt CO₂ in 2030).** Additionally, it is well below what is needed to achieve global decarbonization (5–16 Gt CO₂e p.a.).⁶ Given the climate urgency and changing market dynamics, several upside scenarios can lead to further growth in the market opportunity: (1) compliance markets move to integrate removals, which can accelerate uptake, with the current example of the UK Emissions Trading Scheme, (2) voluntary demand is unlocked from all industries through either reduction in durable CDR cost due to scaling factors or increase in companies’ willingness to pay due to customer pressure or regulatory changes.⁷
- **There is an opportunity for investors given today’s gap in durable CDR investments.** Current investment in durable CDR (~\$1.7 billion in 2022) reflects less than 10% of investments in other climate technologies such as solar in the same early stages.^{8,9,10} Private investment today can further scale durable CDR and lower associated costs. If done right, serving as early investors could be

1. In this report, we include four CDR methods within the category of “durable,” namely direct air capture, biomass with carbon removal and storage, enhanced weathering/CO₂ mineralization, and ocean alkalinity enhancement.

2. Commissioned by a consortium of CDR organizations, venture capital funds, and philanthropic institutions. See the Disclaimer and Acknowledgement section for more details.

3. Includes geographies with highest emissions, namely North America, EU/UK, APAC, and LATAM.

4. Includes US, Europe, LatAm, and APAC and excludes China and India.

5. DACCS and EW technology supplier project announcements; Energy Futures Initiative, Global CCS Institute.

6. IPCC AR6 Mitigation of Climate Change.

7. Developing the UK Emissions Trading Scheme: Main Response, June 2023.

8. Primarily consists of VC, PE, CVC, and institutional equity investments and not including purchase agreements.

9. Pitchbook; BCG Greentech portal; Center for Growth & innovation Analytics.

10. BloombergNEF Clean Energy Investment Trends 2019; includes solar PV and CSP.

beneficial, as winning suppliers of 2030 are being determined today.

2 Buyers Take a Portfolio Approach to Accomplish Their Quality, Cost, and Risk Thresholds

- **Buyers are willing to pay a premium for durable removals, citing quality as the primary reason.** Companies with climate commitments indicate a willingness to pay up to a ~3.5x price premium for higher-quality removal credits (those with *permanence, verifiability, additionality*) in 2030. The price premium associated with each removal method is influenced by the growing significance buyers are placing on quality (~77% of buyers indicate that they first optimize for credit quality versus quantity).¹¹
- **Multiple CDR methods are needed to achieve required CDR scale for global decarbonization; companies are already taking a portfolio approach to balance cost, ensure overall quality, and hedge associated risks.** On average, buyers would like durable CDR to comprise a larger percentage of their carbon credit portfolio over time (~34% in 2030 up to ~48% in 2040), provided they are priced in line with average portfolio cost expectations.¹¹ Diversifying purchases across suppliers and types of durable CDR is preferred in order to control costs and manage financial and technological risks (as removal methods advance in commercialization). This is also a market necessity, as no single CDR solution could meet projected demand by 2030.

3 All Stakeholders Play a Critical Role in Realizing This Market Opportunity

- **Investors, standards-setters, buyers, suppliers, and governments all play a role in advancing durable CDR and would benefit immensely if they acted today.** Patient capital from investors across both early- and late-stage development will drive the markets; early-stage investors must become more comfortable with large infrastructure expenses and longer-term timeframes. Carbon accounting and standards organizations must clarify the need for removals in Net Zero pathways and incorporate meaningful guidelines for companies to invest in high-quality removals. Corporations should spend toward their climate commitments across both reduction and removals. To prepare for regulatory requirements, they need to act now to secure limited 2030 supply of removals. Governments can continue to accelerate removal scale-up and cost reductions through both supply- and demand-side policies.

Specific challenges in creating the durable CDR demand estimates can be summarized across data gaps and regulatory uncertainties, including the following:

- **Data gaps result in a partial view of the total demand.** When assessing removal demand within voluntary markets, a key identifier is the total emissions by companies that have announced Net Zero commitments. However, only a portion of public companies report their emissions, with only ~15% of direct corporate greenhouse gas (GHG) emissions disclosed to the Carbon Disclosure Project (CDP), and emissions from private companies are typically not accessible.¹¹ Additionally, many companies are just beginning to understand and define the role of removals in their broader plans.
- **Inherent limitations with survey insights into corporate behavior and market dynamics.** Our study utilizes information on companies' willingness to pay for durable CDR today. However, companies may adjust their willingness to pay as knowledge of the market improves, Net Zero standards evolve, and supply constraints manifest in the market.
- **Limited uniformity among compliance schemes under development.** While there is no uniform approach to compliance markets, there are a number of regimes being proposed and debated around the globe. These range from integrating removals into trading schemes to pushing emitters to purchase removals. This drives a broad range of possible outcomes, and this report accommodates for this range through a scenario-based approach to represent a realistic view informed by today's policy conversations.

¹¹ Approximately 1,200 publicly traded companies globally have some form of Net Zero pledge, representing ~13 Gt CO₂ in annual global emissions; emissions as reported to CDP, supplemented with emissions data from Refinitiv.



Objectives of This Report

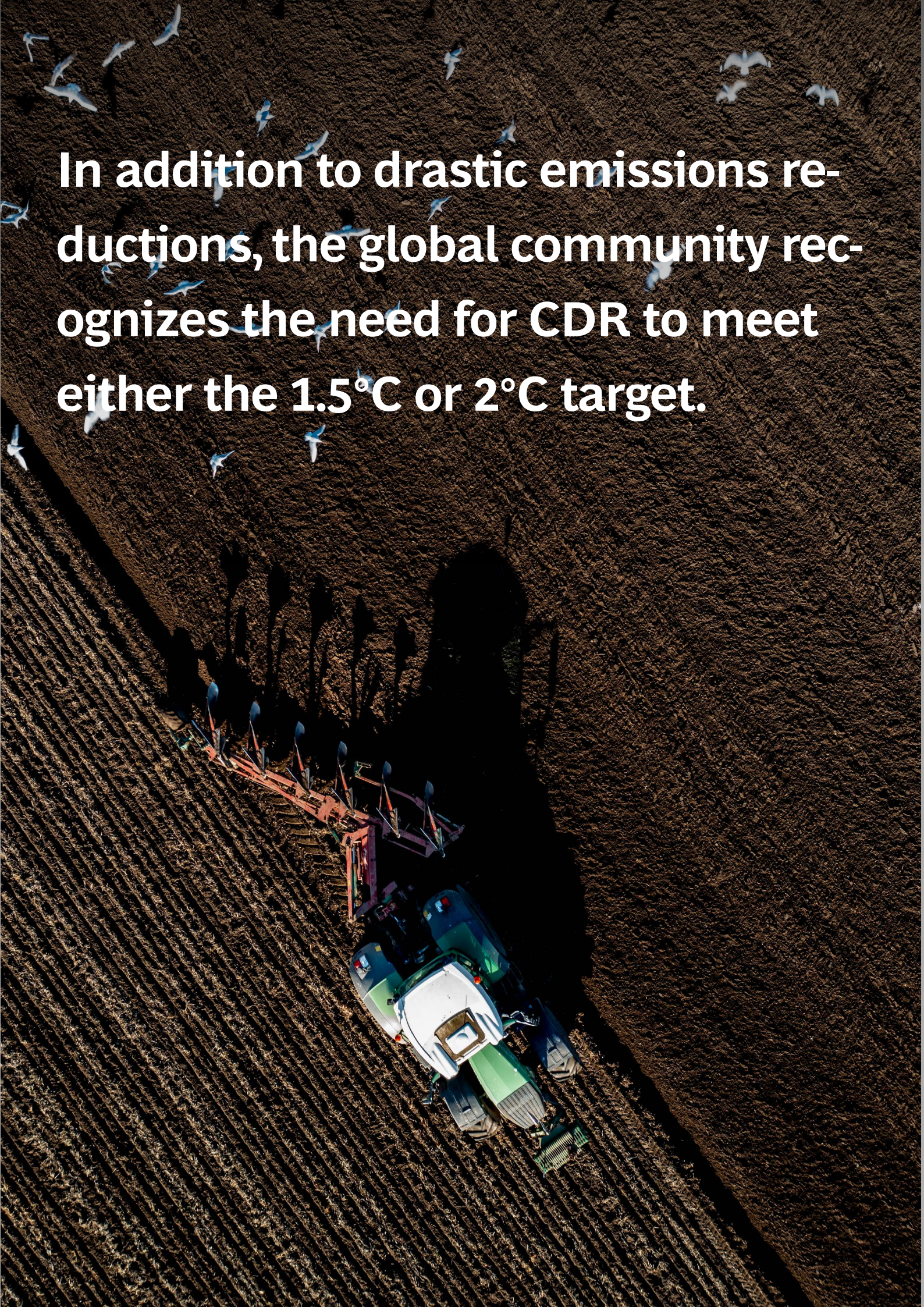
Today, there is a significant shortfall in investments for durable CDR. Given the urgency of climate change, this must be remedied. This report aims to support this transition with the three following goals:

1. Demonstrate the market viability of durable CDR methods by estimating demand outlook in 2030–2040
2. Synthesize and articulate buyers' approaches to CDR purchase decisions
3. Identify meaningful actions that can help further the growth of the durable CDR market

Historically, there have been reports of supply and cost estimates for a subset of CDR methods, with specific focus on direct air capture. These reports have typically covered the challenges associated with scaling these technologies and the resulting high costs. We see the need to showcase the other side of this narrative: the fact that estimated demand for CDR technologies is far greater than the projected supply in the 2030–2040 timeframe (across announced projects), providing a significant market opportunity for participants across diverse CDR solutions.

This study is not trying to estimate the size of the market under specific decarbonization scenarios (for example, IEA's Net Zero Emissions by 2050). Rather, we are forecasting demand based on stated buyer preferences coupled with expected policy over the next 10–20 years. We hope this report supports stakeholders in building a broader view of buyers' thinking about the CDR market.

In addition to drastic emissions reductions, the global community recognizes the need for CDR to meet either the 1.5°C or 2°C target.





Role of CDR in Global Decarbonization

What is CDR? Carbon Dioxide Removal (CDR) methods capture and sequester CO₂ from the atmosphere through a range of mechanisms and are currently at varying levels of technology readiness. CDR is intended to capture and durably store the CO₂ in geological, terrestrial, and ocean reservoirs, or in products.¹² The scope of CDR methods spans nature-based (for example, afforestation), technology-based (for example, direct air capture), and hybrids of the two (for example, bioenergy with carbon capture and storage, and most forms of ocean alkalinity enhancement).

Reducing emissions is not enough. In addition to drastic emissions reductions, the global community recognizes the need for CDR to meet either the 1.5°C or 2°C target, backed by science. Over the years, several key research and/or government bodies, including but not limited to IPCC and the National Academy of Sciences, have highlighted the necessity of CDR in global decarbonization. However, the required amount of carbon removal depends on how quickly the world reduces GHG emissions. Current estimates for the needed amount of CDR range from 5–16 Gt CO₂e per year by mid-century.¹³

¹² IPCC AR6 Mitigation of Climate Change.

¹³ Luthi, D., et al., 2008; Etheridge, D.M., et al., 2010; Vostok ice core data/J.R. Petit et al.; NOAA Mauna Loa CO₂ record. Some descriptions were adapted from the Scripps CO₂ Program website, “Keeling Curve Lessons.”

CDR is crucial for Net Zero. CDR helps deliver the “net” in Net Zero by removing emissions where mitigation and reduction measures aren’t readily available. CO₂ has been collecting in the atmosphere for the last 70 years, from ~300 parts per million (ppm) to ~420 ppm compared with pre-industrial times.¹³ CDR will help reduce this gap. More specifically, as shown in Figure 1, CDR methods enable the world to do the following:¹⁴

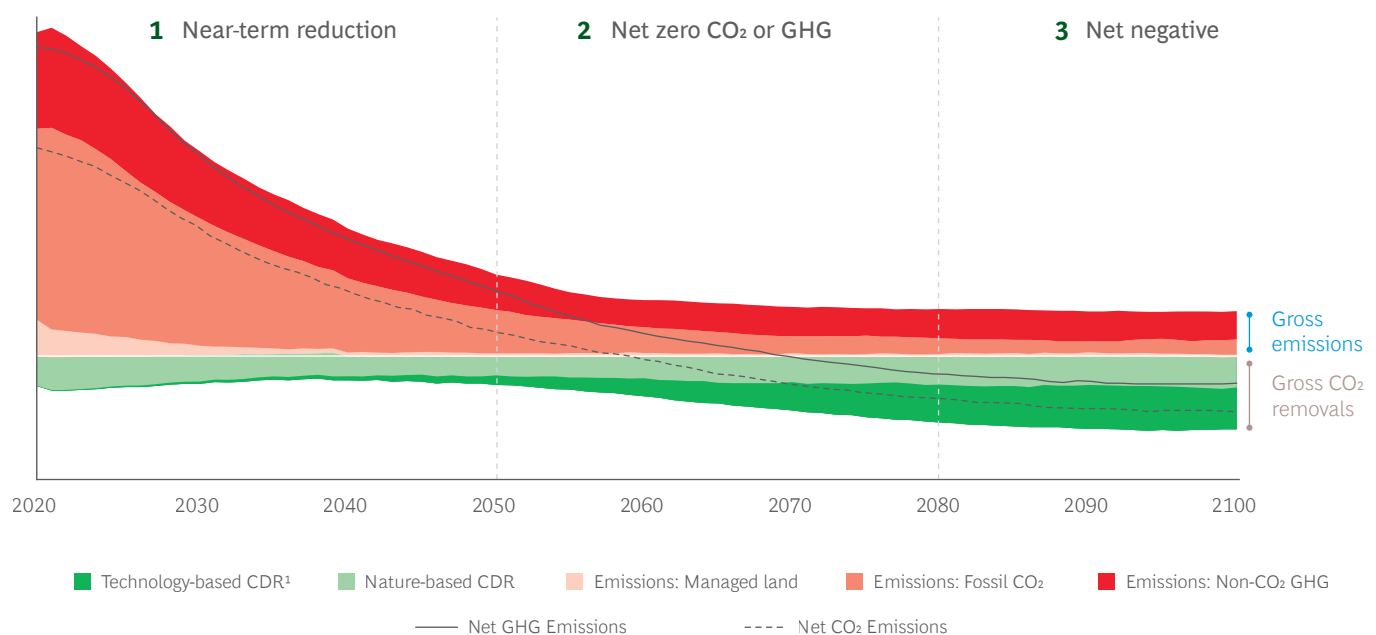
1. Reduce GHG emissions in the near term, especially in hard-to-abate sectors where reduction measures may require more time to implement
2. Counterbalance residual emissions to help reach Net Zero in the medium term
3. Achieve net-negative emissions in the long term

Nomenclature: Defining CDR Methods

Today, there is a lack of consensus on the nomenclature for types of removals. In this report, we distinguish them based on quality, as it is the primary driver for buyers’ higher willingness to pay. The most influential quality dimensions include permanence of carbon sequestration; ease of monitoring, reporting, and verifiability (MRV); and additionality of carbon capture.

Figure 1 - IPCC’s assessment of CDR shows its three functions in different phases of an ambitious pathway

(stylized graph, do not interpret shape or timing)¹



Sources: IPCC AR6 Mitigation of Climate Change; BCG analysis

¹Including biochar, BiCRS, DACCS, enhanced weathering, and ocean alkalinity enhancement.

CDR methods can be categorized across the following:

- **Lower durability** solutions that generally sequester carbon for <100 years, with less maturity on quality dimensions (examples include forestry and soil approaches)
- **Medium durability** solutions that sequester carbon for 100–1,000 years (such as biochar)
- **Higher durability** solutions that sequester carbon for >1,000 years, with highest maturity on quality dimensions (examples include Direct Air Capture and Carbon Storage (DACCS), Bioenergy with Carbon Capture and Storage (BECCS), and Ocean Alkalinity Enhancement (OAE))¹⁵

We acknowledge the global need for removals of all types to address the climate urgency, but define the scope of this report around removals with medium and high durability. We use the term “durable CDR” throughout the report to refer to both medium- and high-durability CDR.

This report specifically explores the market opportunity associated with the four solutions listed below:

- **DACCS** uses a chemical process to absorb CO₂ from ambient air, and either stores the captured CO₂ underground or utilizes it in a product for long-term storage.¹⁶
- **BiCRS** refers to land-based biological methods that involve processing biomass for CO₂ removal, and can have variations depending on their storage methodology, for example (*note, not a comprehensive list*):¹⁷
 - **BECCS** if the CO₂ is stored geologically as part of bioenergy production from biomass
 - **Biochar** if the CO₂ is stored as an addition to soil carbon stocks

- **Enhanced Weathering/CO₂ Mineralization** utilizes the natural chemical mineralization of CO₂ to capture CO₂ from the atmosphere. This process can be accelerated by treating material on site at active industrial mines (for example, ultramafic mine waste) or through distribution of minerals (for example, basalt) over forests or cropland. Rainwater dissolves the minerals and the aqueous solution reacts with CO₂ from the atmosphere, mineralizing the CO₂ and storing it permanently as solid carbonate minerals.¹⁸
- **Ocean Alkalinity Enhancement** accelerates the natural process of sequestering carbon in the ocean by increasing the alkalinity of seawater to enhance its capacity to absorb and store CO₂ from the atmosphere.¹⁹

Why a portfolio? Due to the strengths and limitations of each solution, a portfolio of CDR methods is necessary to achieve global temperature rise limits. This allows buyers to optimize their selections based on preferences, including the project timeline and cost, geographic characteristics (for example, energy, water, and land availability), capital availability, and political incentives or limitations (for example, ability to build needed infrastructure).

These methods are at varying technology readiness levels (TRLs), ranging from pilot stage through near commercial readiness.²⁰ The specific nuances in these variations will likely drive differences in willingness to pay from one technology to another, or from one supplier to another.

The Opportunity: CDR Investments Lag Behind Other Climate Investments

Climate mitigation investments, including CDR, will need to be at least three to six times higher by 2030 to limit warming to below 2°C.²² Nature-based removals require time to capture CO₂—newly planted trees require ~10 years to maximize their rate of CO₂ capture—and many durable CDR methods are only at a pilot stage (TRL 5-6).²¹ Early investment in durable CDR is essential to accelerate growth in the supply of durable removals. Today’s investments can support the much-needed scale to drive cost reductions and broader market adoption.

15. NOAA 2023.

16. IPCC Special Report: Global Warming of 1.5°C.

17. Biomass Carbon Removal and Storage (BiCRS) Roadmap, Lawrence Livermore National Lab 2021.

18. BCG Report - Negative Emission Technologies: Introduction.

19. IPCC AR6 Mitigation of Climate Change.

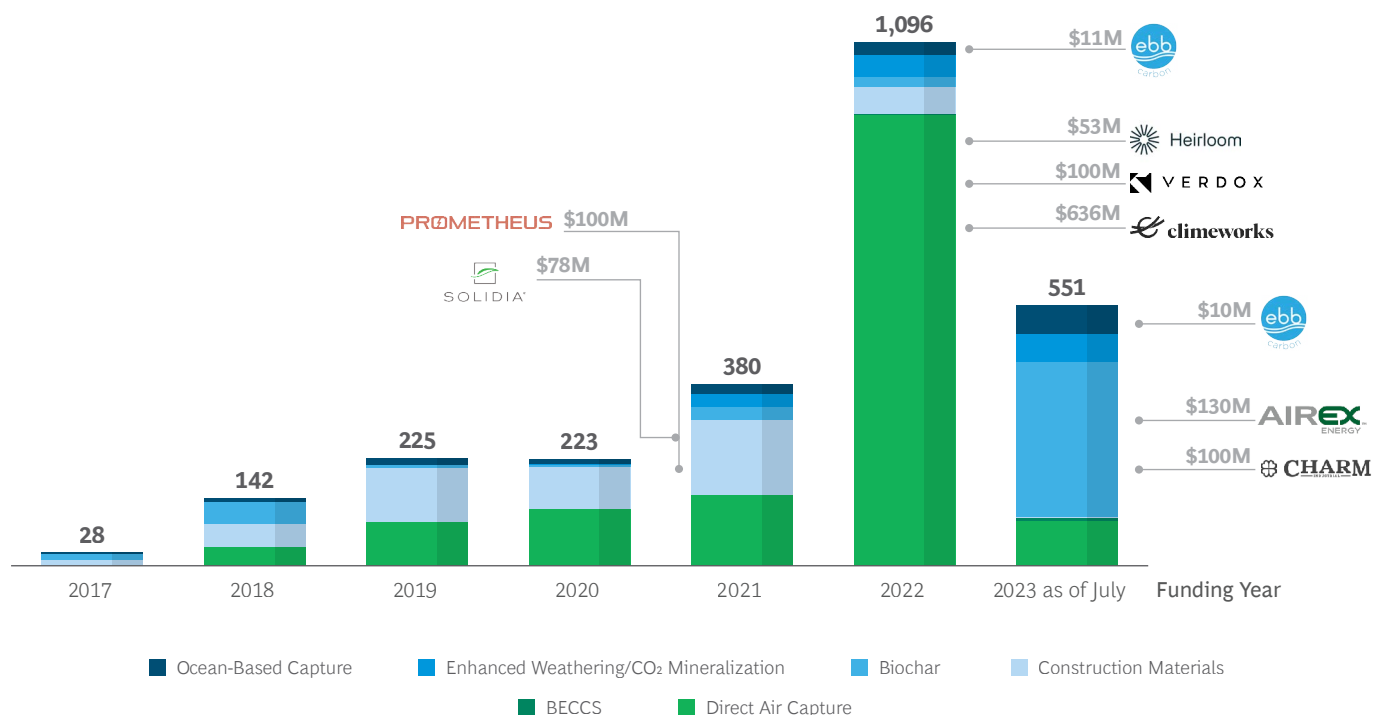
20. National Academies of Sciences, Engineering, and Medicine 2019: Negative Emissions Technologies and Reliable Sequestration: A Research Agenda.

21. BCG Report - Negative Emission Technologies: Introduction.

Figure 2 - Private investments in durable CDR 2017-2023 in million USD

Private investments in durable CDR (\$M)¹

Not exhaustive



Sources: Pitchbook; BCG Greentech portal; Center for Growth & innovation Analytics; BCG analysis.

Note: Analysis focused on carbon removal tech companies receiving private investments since 2017.

¹23% investments undisclosed; private investments refer to investments by VC/PE, corporate venture, financial institutions.



Why Invest Today? Demand Outlook for Durable CDR

Early adoption has been voluntary. To date, durable CDR demand has been led by voluntary purchases from a few corporations. In 2022, the size of the market was relatively small at just ~600 kt CO₂, but has accelerated in 2023 with large recent purchases from Microsoft, J.P. Morgan, and NextGen, as well as significant advanced market commitments from buyer groups such as Frontier Climate.²²

Coming adoption will also include compliance and government procurement. Our 2030–2040 demand estimate will span across voluntary markets, compliance schemes (including removal mandates), and direct government procurement. In this outlook,

voluntary demand is built on emissions covered by the ~1,200 publicly traded companies globally that have some form of Net Zero pledges, representing ~13 Gt CO₂ in annual global emissions.^{23,24} Compliance market forecasts are largely based on carbon tax and emissions trading schemes (ETS) worldwide.²⁵ Given the evolving nature of the compliance markets, our estimates do not consider their potential overlap with voluntary markets. However, we anticipate some overlap between the voluntary and compliance markets (for example, in the EU) that will likely lead to a size reduction in the voluntary market and will instead be absorbed by the compliance market for in-scope industries.

²² CDR.fyi; Frontier Climate website.

²³ As disclosed to Climate Disclosure Program (CDP).

²⁴ Includes full scope 1, 2 emissions and 50% of scope 3 emissions for all industries besides Energy; emissions as reported to CDP, supplemented with emissions data from Refinitiv.

²⁵ Currently, only the US government has indicated pursuit of a direct procurement program.

1 Demand Sizing Assumptions

Throughout our forecasting exercise, we have relied on a set of core assumptions that are important for context, including the following:

- **Voluntary demand for CDR will grow, driven by increase in Net Zero pledges.** There has been significant growth in voluntary demand for CDR over the past year, with the market growing from 437 kt CO₂ in 2022 and picking up in 2023, with large recent purchases from Microsoft (~2 Mt CO₂), JPM (~800 kt CO₂) and NextGen (~200 kt CO₂).²⁶ Between June 2020 and 2023, total sales of CDR on the market grew at ~800% compound annual growth rate (CAGR).²⁸ We assume that demand will continue growing as more companies make Net Zero pledges and companies with Net Zero pledges buy more durable CDR as supply grows and costs decline.
- **Companies make Net Zero pledges in good faith.** Many companies with climate commitments have faced scrutiny for greenwashing. They have been criticized for failing to provide concrete plans that deliver tangible climate impact, which has in some cases led to direct customer and/or employee pressure.^{27,28,29} These recent events may suggest that, going forward, corporations will be more likely to deliver on their claims with measurable actions. Our forecast assumes that companies will abide by their pledges, provided that they are financially and operationally capable of doing so.
- **No major global disruptions will occur.** We assume that there will be no significant global events that will lead to a complete shift in corporations' behavior and potential future outcomes.

2 Forecasting Demand for Durable CDR

Estimate demand in 2030–2040 timeframe. Demand for durable CDR is projected at ~40–200 Mt CO₂ (\$10 billion–\$40 billion) in 2030, growing significantly to ~80–870 Mt CO₂ (\$20 billion–\$135 billion) in 2040. This spread reflects uncertainty in future prices, corporations' willingness to pay, and the pace of change in compliance markets. Figure 3 provides a summary view of scenarios and associated removal estimates broken down by voluntary, compliance, and government procurement markets. At a high level, our estimates show the following:

- **The low scenario leads to a demand of ~40–80 Mt CO₂ p.a. in 2030–2040, with a market size of ~\$10 billion–\$20 billion.** We assume limited growth in Net Zero pledges across industries and regions, with ~40% of global emissions falling under Net Zero pledges by 2030 and a limited portion of those emissions accounted for with removals. The average voluntary durable CDR portfolio price in the voluntary market is assumed at ~\$300/t CO₂ in 2030 and ~\$250/t CO₂ in 2040.
- **The medium scenario yields a demand of ~70–230 Mt CO₂ p.a. in 2030–2040, with a market size of ~\$15 billion–\$45 billion.** We assume moderate growth in Net Zero pledges across industries and regions, with around 50% of global emissions covered by Net Zero pledges by 2030 and a limited portion of those emissions accounted for with removals. The average voluntary durable CDR portfolio price is assumed at ~\$250/t CO₂ in 2030 and ~\$200/t CO₂ in 2040.
- **The high scenario leads to a demand of ~200–870 Mt CO₂ p.a. in 2030–2040, with a market size of ~\$40 billion–\$135 billion.** We assume higher growth in Net Zero pledges across industries and regions, with around 60% of global emissions covered by Net Zero pledges by 2030 and a limited portion of those emissions accounted for with removals. The average voluntary durable CDR portfolio price is assumed at ~\$200/t CO₂ in 2030 and ~\$150/t CO₂ in 2040.

Price down, demand up. Across scenarios, the wide variations in both demand and market size are due to a sharp increase in demand as price declines. Demand significantly increases as the average durable CDR price goes down from ~\$300/t CO₂ to ~\$150/t CO₂. The low scenario represents what we believe is most likely the lower bound of the market, but it could be higher if the average price of durable CDR falls below \$300/t CO₂; this is unlikely given current average reported transaction prices of \$350/t CO₂.^{30,31}

26. CDR.fyi; note that purchases represent future deliveries over multiple years.

27. Guardian, "Drop carbon offsetting-based environmental claims, companies urged," July 2023.

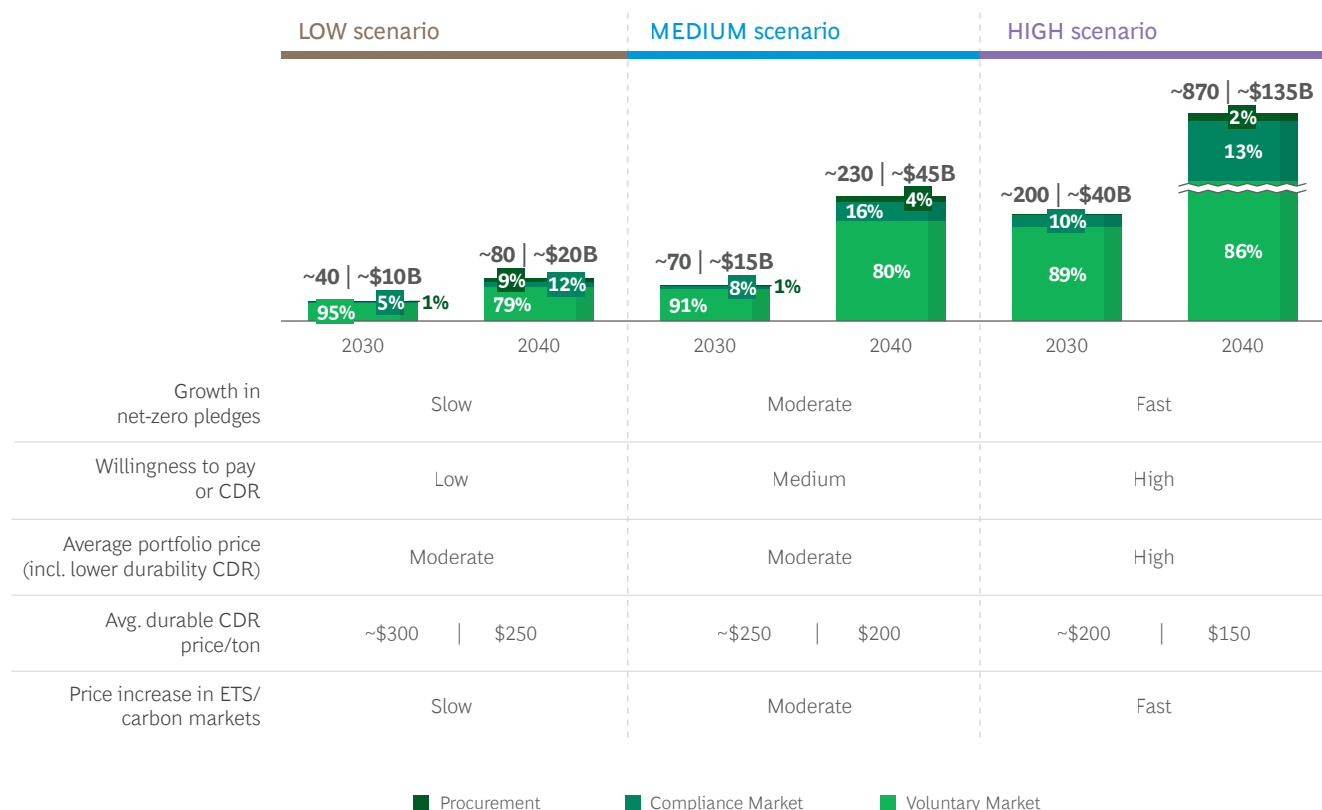
28. Guardian, "Toyota accused of greenwashing in Greenpeace complaint filed to ACCC," March 2023.

29. Seattle Times, "Hundreds of Amazon workers walk out to protest return to office, climate."

30. Average price in market today driven primarily by large-scale purchases of BECCSs.

31. CDR.fyi; calculated as total price paid divided by total price purchased for all orders where volume and price are reported.

Figure 3 - 2030-2040 durable CDR demand (Mt CO₂) and market size (\$B) across scenarios



Source: BCG analysis, June 2023.

Compliance demand rises. While the voluntary market is expected to make up the majority of durable CDR demand, the share of compliance demand grows across scenarios, reaching ~15% in 2040. The limiting factors for compliance schemes include (1) carbon prices are too low in most places to incentivize durable CDR; (2) removals are only likely to be eligible for a relatively small percentage of emissions under ETS and carbon taxes; and (3) other carbon credits may be preferred over durable CDR based on price, if compliance markets do not strictly define quality standards.

3 Voluntary Demand: Quality as the Main Purchase Driver

Choosing quality. When choosing which carbon credits to purchase, buyers prioritize quality, which they define as permanence of CO₂ removal as well as MRV. Driven by increasing quality standards of carbon markets and public pressure on companies to pursue verifiable impact, ~77% of buyers indicate that they first optimize for quality over quantity.³¹ While buyers often take an approach that considers the nuances of each specific CDR project, they consistently rank the permanence of CO₂ removal (~78% of buyers ranked in top 5) and measurement, and reporting and verification (~77% of buyers ranked in top 5) as top indicators of quality.³² One buyer in the airlines industry articulated, “Permanence, additionality, and MRV are important criteria when determining quality.”³³

32. BCG Durable CDR Buyer Survey, July 2023 (N=113).

33. Interviews with select survey respondents (opt-in).

**The quality of the carbon credit is
the main purchase driver for the
majority of buyers.**

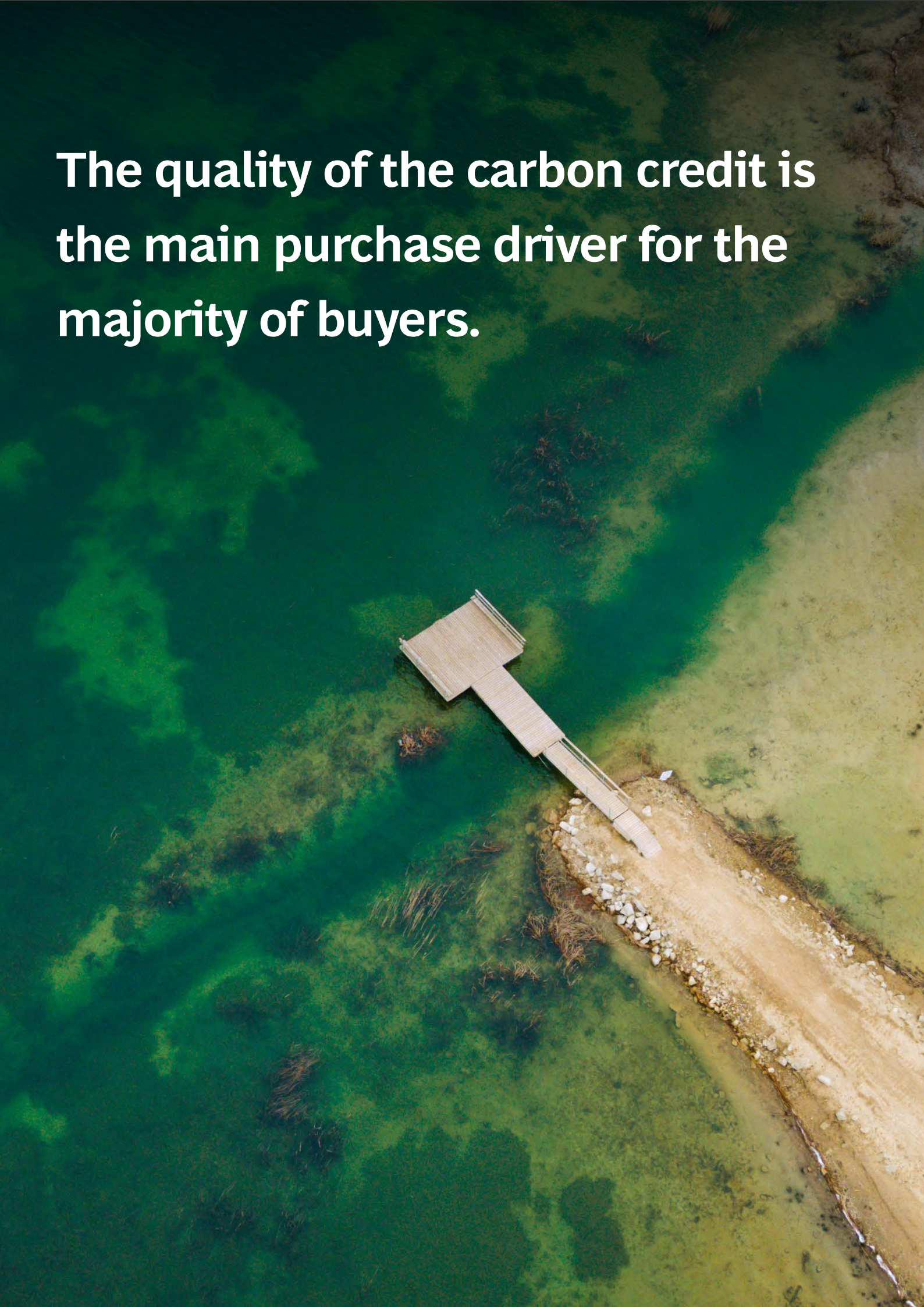
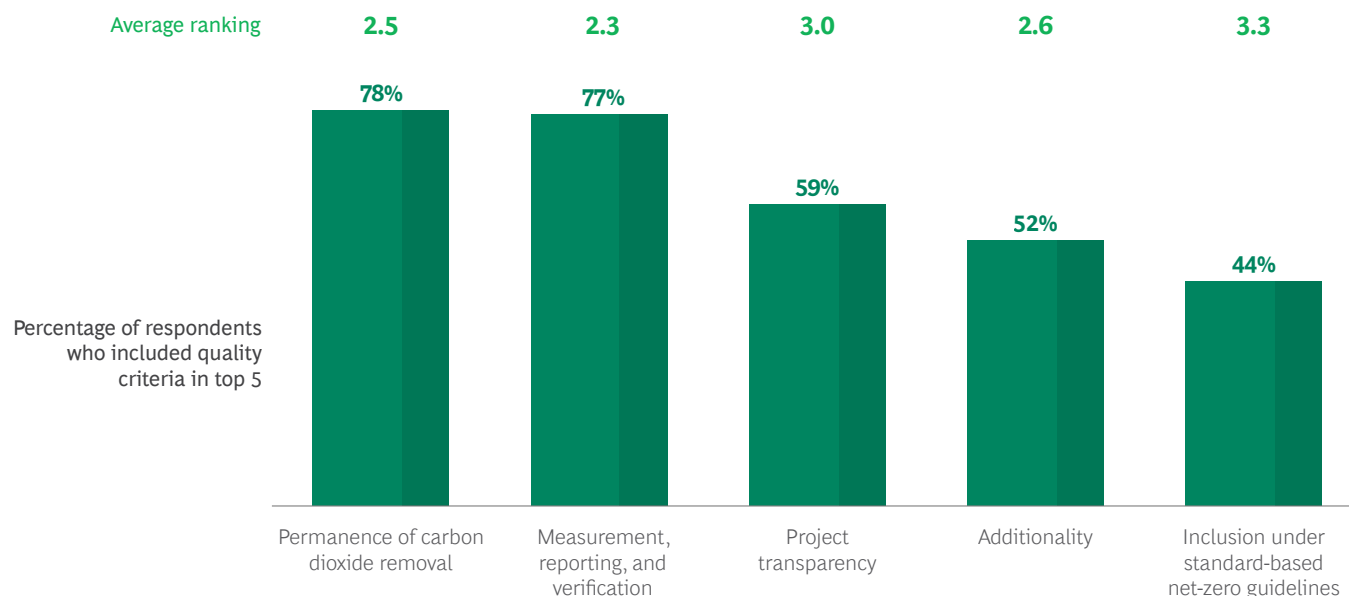


Figure 4 - Buyer's reported ranking of most important criteria when evaluating carbon credit quality

(buyers where asked to rank their top 5 criteria from a select set of options)¹¹



Source: BCG Durable CDR Market Study Buyer Survey (July 2023, N=113).

Portfolios make sense. Across all buyer archetypes, there is a preference for a portfolio of CDR methods, both to diversify technology and economic risk and to balance total cost. Buyers indicate a likelihood to purchase a portfolio of solutions across reduction credits and removals, with the average percentage of durable removals in the overall portfolio increasing to ~35% in 2030 and up to ~47% in 2040 (Figure 5).³⁴ One buyer in the technology sector explained that “we want a mix of technologies in our portfolio, and within each technology a mix of companies that use different design methodologies. That way, we diversify the risk of one company or technology not working out because of scientific, economic, or political reasons.”³⁸

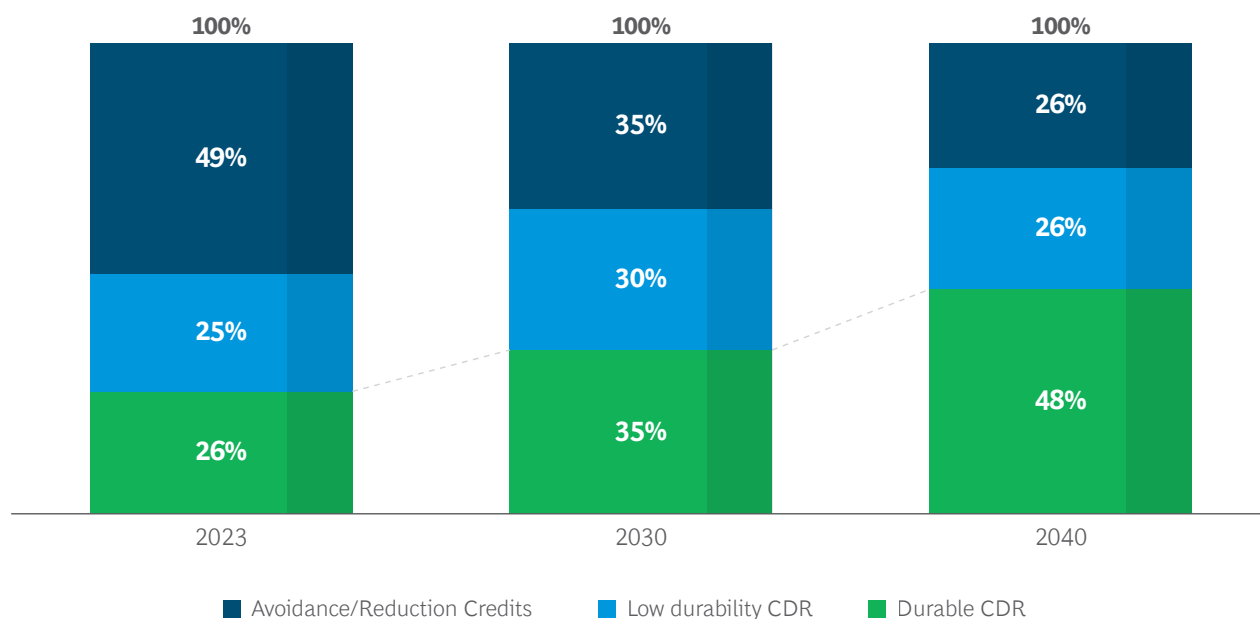
Voluntary Demand Across Industries

Low demand among high emitters. Today, demand for durable CDR is largely driven by early buyers with progressive climate commitments across industries such as software and professional services, with predominantly Scope 3 emissions.³⁴ Though the largest emitting sectors (industrials and manufacturing) are those with the largest total potential emissions for removal, companies with lower emissions but higher profit margins tend to be the earliest potential buyers of durable CDR. This is because these early buyers leverage removals to address Scope 3 emissions where alternatives are currently limited today, and public purchase prices of durable CDR are significantly higher than other carbon credits: ~\$240–\$1,600/t CO₂ for durable CDR, versus ~\$8–\$50/t CO₂ for low durability removals, and ~\$5–\$30/t CO₂ for reduction credits.^{35,36}

³⁴ Early buyer categorization is informed by purchases to date. These industries include Financial Services, Health, Insurance, Professional services, Retail and Technology/Software.

³⁵ Interviews with select survey respondents (opt-in).

Figure 5 - Buyer's reported projection for their carbon credit portfolio mix in 2030-2040¹¹



Source: BCG Durable CDR Market Study Buyer Survey (July 2023, N=113).

More diverse buyers as price declines. By 2030–2040, the market is likely to move beyond these early buyers to a wider range of industry buyers if the average prices decline. Industries such as consumer goods and industrials have indicated willingness to pay for durable CDR at average prices below \$200–\$250/t CO₂. The consumer goods sector, which has a focus on building a strong public-facing brand, is likely to see growth in durable CDR purchases, with early commitments from companies such as H&M leading the way.³⁷ While emissions of consumer goods are about half of industrials, the sector is expected to make up ~33% of demand in 2030 because of a higher reported willingness to pay for durable CDR. Additionally, despite lower early adoption rates, industrials and manufacturing will drive a significant share of removals given their emission intensity (~22% and 17%, respectively, in 2030).

Big picture costs may matter. A portion of demand from industrials and other high emitters could be driven by how removal costs compare with other abatement levers. Our estimates show that some high emitters with large Scope 1 emissions tend to have marginal abatement costs that are higher than \$250/t CO₂ for ~10% of their emissions in 2030. Depending on the rate of advancement for durable CDR compared with other abatement levers, durable CDR could be an efficient and cost-effective complement to the significant reduction of value chain emissions, especially for residual hard-to-abate emissions.

³⁶. Abatable. Data as of August 2022.

³⁷. H&M Joins Frontier Initiative for Carbon Removal Commitments, April 2023.

Voluntary Demand by Region

North America leads. On a regional level, the largest market in 2030 will likely be in North America (~36% of market), followed by Europe and Asia-Pacific (APAC). While APAC is only beginning to see early purchase commitments from buyers, this market represents ~28% of the market, largely driven by a higher concentration of heavy-emitting industries. One recent example of this is Mitsui O.S.K. Lines' commitment as a buyer in NextGen, a South Pole and Mitsubishi Corporation joint venture to establish a diversified portfolio of carbon removals.³⁸

4 Compliance Demand: Nascent But Fast-Moving Global Compliance Landscape

Regulatory landscape on a positive trajectory. To date, existing regulations have focused on supporting durable CDR through supply-side policies, the opportunity to expand demand-side policies, and eligibility of other quality carbon removals. Supply-side policies that have helped lower costs tend to benefit

development specifically. These include the Inflation Reduction Act's expansion of section 45Q tax credits in the US and the DACCS Removal Competition grants in the UK. As the landscape evolves, particularly in high-income countries, new measures could include technology-neutral demand-side policies. Proposals to this effect are currently under consideration in the US; by 2030, federal and state-level regulations could promote as much as \$100 million p.a. in direct procurement demand.

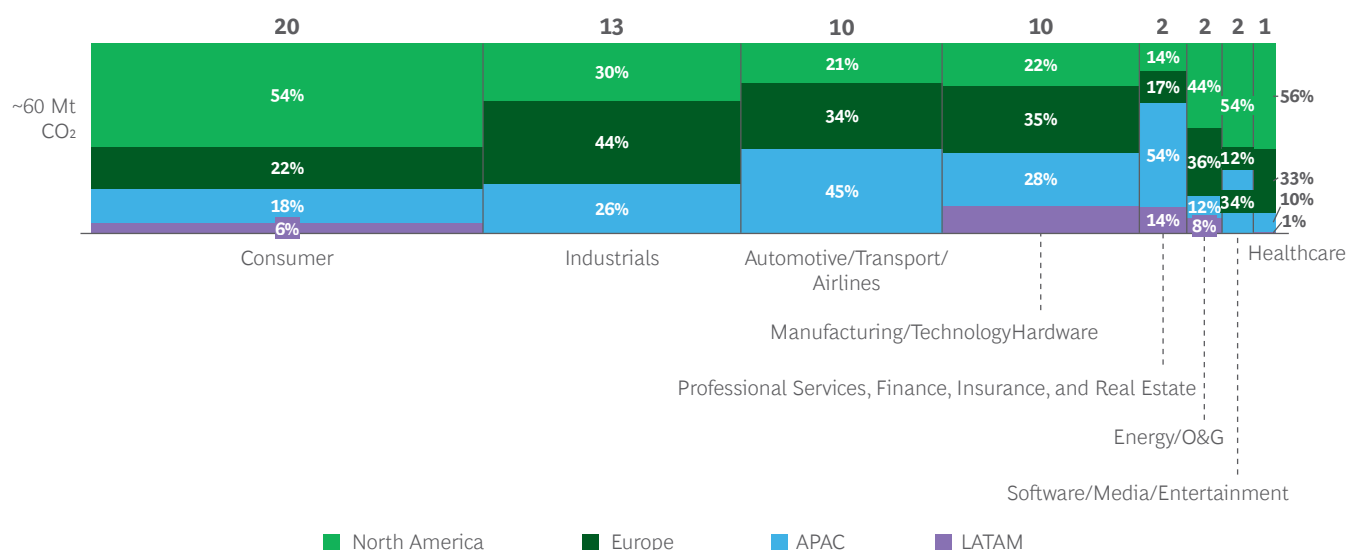
Removal integration can improve market adoption.

Eligibility of durable CDR in global compliance markets is a key enabler.

Today, only a few small compliance markets (for example, South Africa's Carbon Tax) allow for durable CDR to account for some portion of emissions.³⁹ However, there is increasing policy momentum that could impact long-term durable CDR demand through integration in compliance schemes (for example, UK ETS), standard-setting regulations (for example, EU Carbon Removal Framework), policies that require emitters to pay for durable CDR (for example, CA SB 308), and guidelines (for example, Paris Agreement Article 6).

Figure 6 - Durable CDR demand, broken down by industry/region in 2030, in the medium scenario (Mt CO₂)¹

(Mt CO₂, 2030 medium scenario)



Sources: CDP emissions data; Refinitiv emissions data; BCG survey and analysis.

¹Food & beverage and apparel industries, both of which rely on agriculture, are contained within "Consumer." Both industries make up ~3% of consumer emissions in North America, ~9% in Europe, ~3% in APAC, and ~5% in LATAM.

³⁸. NextGen—a South Pole/Mitsubishi Corporation joint venture—establishes world's largest diversified portfolio of permanent carbon dioxide removals to scale the market.

³⁹. Only applies to Direct Air Capture.

Compliance market prices need to grow. Beyond the eligibility of removals, compliance market prices are expected to grow to make market adoption of durable removals feasible. To date, most compliance schemes (representing ~85% of emissions covered under these schemes) have carbon prices of less than \$50/t CO₂.⁴⁰ While there are select leading markets where prices are reaching \$100+, prices in existing schemes will need to grow ~10% annually to make compliance adoption financially feasible in the most advanced markets.^{41,42} For example, California's Low Carbon Fuel Standards (LCFS) currently allows for DACCS projects to generate credits; however, LCFS is only likely to drive DACCS purchases if the price of DACCS is competitive with alternative credit generation methods (e.g., renewable fuels) and makes financial sense after accounting for IRA 45Q tax credits.

5 Demand and Supply Imbalance

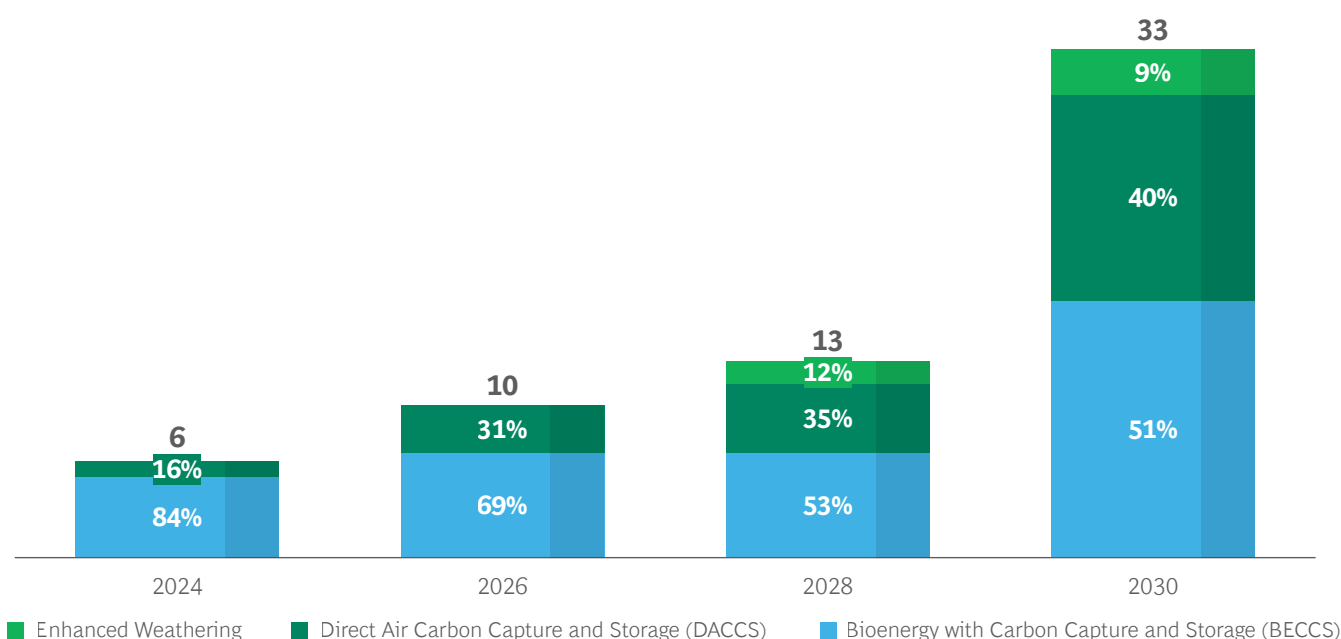
The challenge of limited supply. As of today, projected available supply in 2030 is limited to ~15–32 Mt CO₂

across a few announced large-scale projects made up primarily of BECCS, DACCS, and enhanced weathering (Figure 7).⁴³ While suppliers have announced targets at higher ranges, specific project announcements have lagged significantly behind stated goals. Similarly, while there is ongoing research and pilots of other forms of durable removals, there have not yet been large-scale projects announced outside enhanced weathering, BECCS, and DACCS.

As a result of few announced projects, the 2030 market is likely to be supply constrained and heavily influenced by buyers willing to pay >\$300/t CO₂.

The small-scale supply in the market has already resulted in an outsized impact of early buyers who are willing to pay a premium price, such as Microsoft, BCG, and Airbus. As such, public purchase prices for durable CDR have averaged ~\$350/t-CO₂.⁴⁴ In a likely supply-constrained market, the 2030 market price will continue to be heavily influenced by these early adopters at the top of the demand curve.

Figure 7 - Cumulative durable CDR online capacity (supply) based on public project announcements in Mt CO₂/yr, as of June 2023



Sources: DAC and EW technology suppliers; Energy Futures Initiative, Global CCS Institute.

⁴⁰. International Carbon Action Partnership; World Bank Carbon Pricing Dashboard.

⁴¹. Estimated based on ETS/carbon price data from ICAP.

⁴². Financially feasible defined as ETS/carbon tax prices >\$100/ton.

⁴³. DACCS and EW technology supplier project announcements; Energy Futures Initiative; Global CCS Institute.

⁴⁴. CDR.fyi.

However, with cost declines, heavy-emitting sectors such as manufacturing and industrial goods could drive significant additional demand. Cost declines will rely on public and private sector investments in R&D and infrastructure support to increase scale. Without such investments, the market could remain supply constrained.

6 Potential Alternative Outcomes

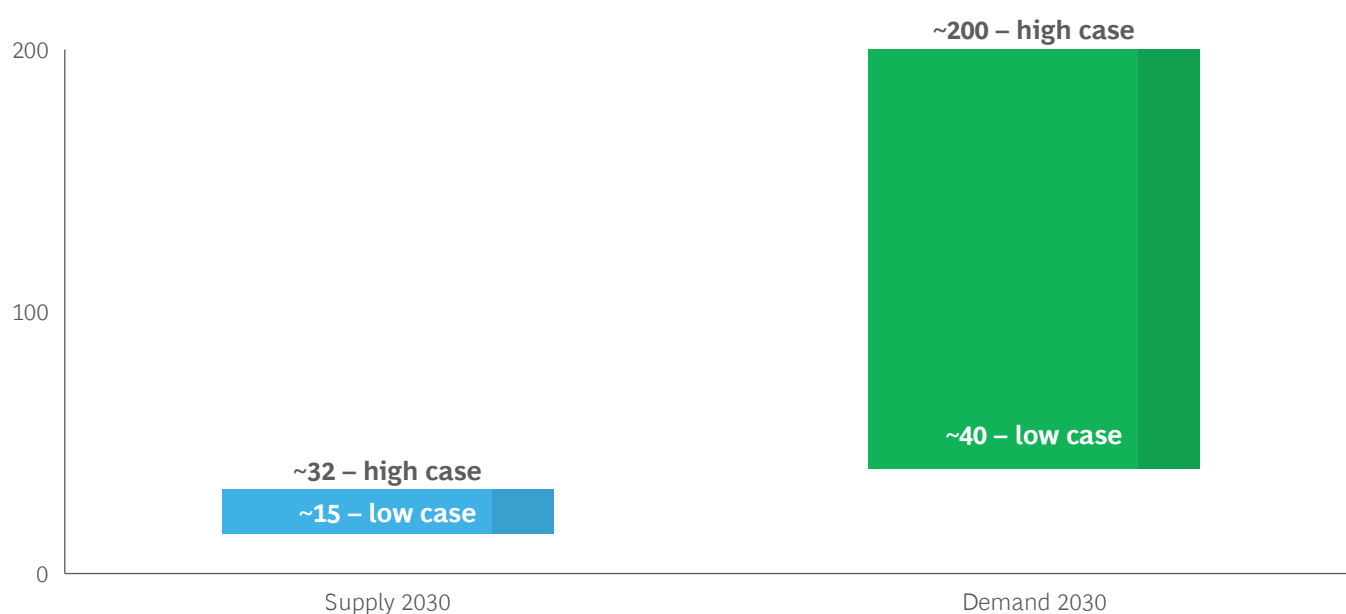
While the report's forecast demand is meaningful, it still falls well below what is needed to achieve global decarbonization in line with IPPC's removal estimates of 5–16 Gt CO₂e p.a.⁴⁵ The presented demand outlook reflects perspectives across today's buyers and current policy discussions; however, there are several factors that could help drive demand upward in the next decade, driven by climate change, regulations, and customer pressure.

- **Removal purchases in line with Net Zero targets:** If companies are to remove up to 10% of their emissions toward their Net Zero commitments, as opposed to following through with their stated willingness to pay for available removals, there could be an additional upside

for demand up to ~1.1–1.6 Gt CO₂ in 2030 and 1.5–2.1 Gt CO₂ in 2040.

- **Advancement in regulations:** Today, the compliance carbon market covers almost 20% of global emissions, far more than the volume of credits in the voluntary market.⁵¹ However, little to none of this market is currently driven by durable CDR due to legislations that limit the role of credits to a select number of compliance schemes. Legislations globally could change demand significantly through increased carbon prices and broader integration of durable removals, reflecting the true cost of carbon in the market.
- **Changing buyers' purchase patterns due to customer pressure and avoidance of legal risk:** While the surveyed buyers indicated willingness to pay of <\$300 ranges for durable CDR, we know that today some companies are already paying higher-than-average market prices (for example, ~3.2 kt CO₂ purchased at \$1,000+ since 2020) and may still do so in the 2030–2040 timeframe. If such behavior change were to occur at a broader scale in a continued supply constrained market, one could expect to see higher purchase prices.⁴⁶

Figure 8 - Supply and demand range (Mt CO₂ per annum) for 2030 and 2040 market as of June 2023



Sources: CDR.fyi; BCG Survey and Analysis, 2023.

Note: While we recognize significant uncertainty in the carbon removals future market, the low scenario represents what we believe is the most likely lower bound. The market is potentially lower if the price of CDR does not go below \$300 by 2030, or if net-zero pledges are not addressed.

⁴⁵ The Untapped Power of the Carbon Markets, BloombergNEF.

⁴⁶ CDR.fyi.

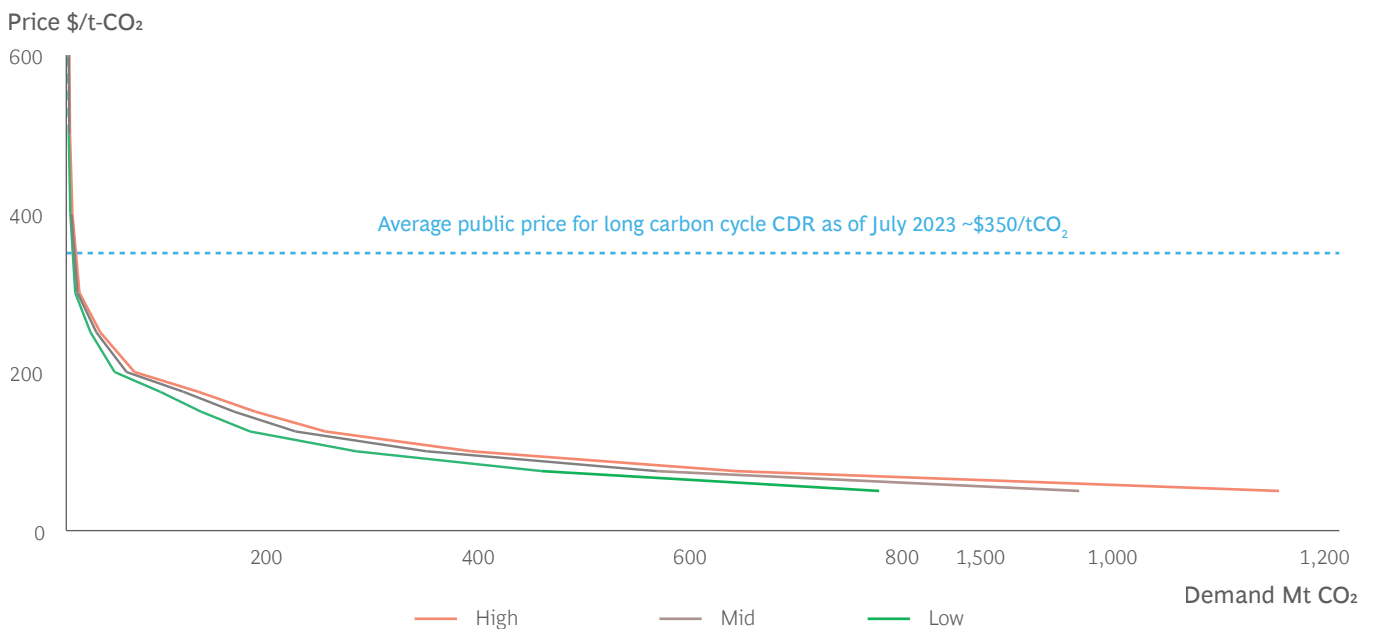
7 Conclusion

As durable CDR costs decline, there will be a large and growing market for associated carbon credits

that is very likely to exceed the announced supply substantially (by ~10–180 Mt CO₂ per year in 2030). Initially, this market will be driven predominantly by buyers who seek out removals or who are willing to pay a premium for quality. Figure 9 showcases the demand curve informed by willingness-to-pay data across different industries; there are two takeaways from this view: (1) demand is very inelastic at upper prices above an average price of \$250/t CO₂, and (2) it becomes significantly more elastic as prices decline in increments of \$50/t CO₂. A decline in average price below \$200/t CO₂ has the potential to unlock significant demand in emissions-intensive industries with high relative marginal abatement costs.

There is a significant opportunity for private funders to invest in durable CDR to meet demand from early high willingness-to-pay segments of the market in meeting their climate commitments and drive down prices of durable removals now so as to be able to capitalize on broader voluntary and compliance market demand as it evolves over time. While private investments in durable CDR have grown over the past several years (by 360% from 2021–2022 alone), there is still a significant lack of investment in removals (\$0.4 billion in 2021) as compared with other decarbonization technologies (\$170 billion in 2021).^{47,48}

Figure 9 - Volume of durable CDR demand (Mt CO₂) at given price points, 2030 projections



Source: BCG Carbon Credits Survey 2022.

⁴⁷. Pitchbook; BCG Greentech portal; Center for Growth & innovation Analytics.

⁴⁸. The State of Carbon Dioxide Removal, the Carbon Gap.



Enabling Markets to Realize the Opportunity

Several market forces need to be in place to support realization of the forecast demand beyond the 2030 supply—and to levels needed for global decarbonization. This is mainly driven by price reductions but is also impacted by external factors such as regulations and industry standards.

Government incentives work. Regulations or various forms of government incentives can be a significant purchase driver for many corporations. In BCG's survey of current and potential CDR buyers, ~80% indicated that their CDR spend would increase with government incentives, with ~60% increasing their spend considering CDR inclusion in compliance markets. Access to a broader universe of durable CDR credits may well improve for these buyers if CDR is favorably included in Article 6.4 of the Paris Agreement, since CDR credits from jurisdictions worldwide could begin to count toward compliance obligations under a different jurisdiction's ETS.

“If governments subsidized CDR, that would impact our spending. Government subsidies are one of the reasons we are optimistic that costs will come down.”

— Managing Director of Sustainable Investing, financial services⁴⁹

The importance of standards. Standard setters such as SBTi and VCMi can also shape the purchase behavior across voluntary markets by providing guidance on inclusion of CDR in companies’ Net Zero pathways.

Approximately 70% of survey respondents indicated that they would increase their durable CDR spend if guidance were available from scientific or NGO bodies, since most companies (77% of survey respondents) prioritize quality of carbon credits in their CDR purchases. Clear guidelines and standards can contribute to shorter project lead times for issuance of carbon credits through leaner registration processes.

“We have contracts in place, but volumes are flexible. We would change our spending if there were updated guidance from science-based communities or regulatory changes that encouraged or discouraged certain CDR methods.”

— Sustainability Lead, financial services⁵²

The power of market shaping. Finally, advanced market commitments can be catalytic in building confidence in CDR demand. Another recent BCG study highlights the power of market-shaping in securing demand for climate technologies, through mechanisms such as advance market commitments, concessional capital, offtakes and volume guarantees, and coalitions. For example, the Frontier coalition has committed \$925 million in funds toward development of carbon removal technologies between 2022 and 2030.⁵⁰

⁴⁹. Interviews with select survey respondents (opt-in).

⁵⁰. Ushering in the Next Generation of Climate Technology, BCG.



An Opportunity Not to Miss: What Must Be Done

Today, there are significant opportunities to unlock the potential of the CDR market in support of global decarbonization. Considering it took solar more than five decades to reach competitive costs and widespread adoption, immediate action allows for acceleration of CDR developments while capturing a significant market opportunity for its contributors.⁵¹ Actions across ecosystem stakeholders take varying forms, specifically the following:

Investors must act now to capitalize on a growing market opportunity (~\$10 billion–\$135 billion), in which demand for durable CDR is estimated to exceed supply, creating competitive market dynamics likely to benefit investors of early market suppliers over the 2030–2040 timeframe. While these investments are perceived as high risk, the demand and supply forecast demonstrate the potential for high returns. Today's CDR purchases by early buyers, along with government incentives, send positive signals for investors to get in early and identify the winning suppliers. There may also be additional opportunities beyond investing in the suppliers—for example, supporting CDR buyers across various industries by providing financing options—given that there are at least thousands of companies with Net Zero commitments.

⁵¹. How Solar Energy Became Cheap, Gregory F. Nemet.

Carbon accounting and standard-setting organizations

such as the GHG Protocol and SBTi must encourage the procurement of high-quality carbon credits in tandem with meaningful emissions reduction measures (for example, through counting removals toward companies' Net Zero commitments). This emphasis on quality is even more important in an emerging market such as CDR, where standard setters are heavily relied upon to provide third-party guidance, thereby influencing the overall voluntary market.

CDR credit buyers must act now to secure durable CDR credits to ensure their access in 2030. Projections show limited available supply, and those contracting today are negotiating preferential rates and access to future projects. Buyers that limit or delay their credit purchases today may have to pay a premium for credits in the future, or risk not being able to meet their climate commitments. One approach to establishing commitments to the purchase of durable CDR credits can be through contribution claims set out in 2023 by VCMi's Claims Code, in which companies commit a portion of their financial gains toward global efforts to mitigate climate change. These commitments will have a secondary benefit of increasing company carbon credit budgets, many of which are currently underinvested. Almost no company is currently investing more than 0.1% of its EBITDA on carbon removal credits.⁵² SBTi has also suggested "allocation of responsibility" approaches in its Beyond Value Chain Mitigation publication. Companies with the ability to sign early offtakes for durable removals can help stimulate the market to increase scale and decrease costs.

CDR suppliers must share learnings in technological scale-up and cost reduction to accelerate overall development of the durable CDR ecosystem, particularly in less-competitive areas. Collaborating on the procurement of commercial assets (for example, blowers, minerals such as limestone) can increase economies of scale and decrease costs without sharing intellectual property. Active collaboration in developing consistent MRV standards is also required to streamline the credit assurance process and make credits more accessible to buyers.

Governments must accelerate support for durable CDR to enable further cost reductions and market development, including supply-side (for example, subsidies, innovation funds) and demand-side mechanisms (for example, direct government procurement, compliance regulations). Governments should view removing carbon from the air as analogous to cleaning up municipal solid waste, where various forms of financial and commercial guarantees have been used and compliance with removal obligations has been put in place.⁵³ Governments can build confidence in the consistency and continuity of incentives by providing clarity in implementation timelines, specific budgets, and their projections to the greatest extent possible. Finally, there is a clear opportunity for governments to support setting the standard for high-quality credits by advancing public science, resourcing government agencies, or supporting NGOs to adequately contribute to the development of robust MRV methods.

52. CDR.fyi; CapIQ.

53. Shifting the Direct Air Capture Paradigm, BCG.

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