

REPORT

ADVANCING CARBON DIOXIDE REMOVAL BEYOND THE HYPE CYCLE

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FOREWORDS

Reaching net-zero emissions is essential to stabilising our climate—and Carbon Dioxide Removal (CDR) represents the ‘net’ in net-zero. While the exact amount of durable carbon removal needed by mid-century remains uncertain, projections estimate it will be in the billions of tons annually by 2050, compared to just over a million tons today. Achieving this scale within a single generation is an unprecedented challenge, particularly given the current lack of economic incentives associated with carbon removal. Yet, it is a challenge we must overcome—because we have no other choice.

Over the past decade, CDR has transformed from a little-known concept into a burgeoning field that has attracted billions of dollars in investment and grant funding for early-stage start-ups and initiatives. However, the hardest work lies ahead: navigating the cycles of innovation, development, and deployment while simultaneously creating a viable market. The speed at which this sector must evolve to become a critical climate solution is without historical precedent, making this journey as daunting as it is exciting.

The term ‘CDR’ encompasses a wide range of techniques, each with unique potentials and externalities. This diversity calls for a portfolio approach—there will be no ‘winner takes all’ solution. Progress will require advancing multiple options in parallel while fostering the demand for high-integrity carbon removal. Along the way, failures are inevitable, and managing these setbacks will be critical to sustaining the credibility of the sector.

This report explores the current state of the CDR industry, its opportunities, and the barriers it faces. It highlights the pathways necessary to transform CDR into a mature, scalable industry capable of delivering the climate impact we so urgently need. I am pleased Quadrature Climate Foundation has supported this work, and I hope it serves as a valuable resource for anyone committed to accelerating climate solutions.

Greg De Temmerman, Deputy CEO and Chief Science Officer, Quadrature Climate Foundation

This report “*Advancing Carbon Dioxide Removal Beyond the Hype Cycle*” arrives at a critical moment. The carbon dioxide removal (CDR) industry has seen unprecedented growth since the late 2010s, evolving from academic concepts to attract large funding by the 2020s. Now at a time of peak expectations, we face a choice: risk falling into disillusionment or take decisive action toward meaningful scale.

Warning signs are clear – funding is declining as sales remain concentrated among few buyers, offset market scandals have eroded trust, and geopolitical tensions have deprioritised climate action. We face dual challenges: securing government support to reduce costs and establish compliance markets, while breaking out of our technical echo chamber to achieve gigatonne-scale deployment by 2050.

Despite these challenges, I remain hopeful. The report’s framework for addressing both ambition and action gaps provides a practical way forward. As we navigate this critical period, the industry must build robust social, political and economic infrastructure for large-scale deployment through broader engagement.

The path ahead demands unprecedented collaboration. While the challenges are formidable, this report offers a roadmap for a mature, systems-level approach to CDR. I urge all climate action stakeholders to embrace these insights and ensure CDR fulfills its crucial role in addressing climate change. The time for action is now.

Christoph Beuttler, CEO Carbon Gap

EXECUTIVE SUMMARY

1 Since its inclusion in the 2018 IPCC report, the carbon dioxide removal (CDR) industry has ridden a hype tailwind with high dynamics and an increased level of sophistication.

However, the momentum is fragile, challenges are emerging, and the industry is encountering significant barriers to further growth and advancement. Slower technological breakthroughs and lower deliveries than previously promised, exacerbated by high political, geopolitical, and economic instability are driving prudence. Investments are becoming scarcer, government support outside the US remains timid. Corporate purchases in the voluntary carbon market (VCM) are growing slower than the magnitude of growth required and still limited to very few players. **CDR is at an inflection point**, with cracks in the hype trend appearing at several levels:

➤ **Increasing – yet still insufficient – public support and private demand:** Current support is focused in the US (Inflation Reduction Act, Bipartisan Infrastructure Law), the Denmark incentive programme, large deployment announcements (e.g., Climeworks' Mammoth project, Project Bison, Ørsted), and significant VCM corporate deals (e.g., Airbus-Ipoint5, Microsoft-Ørsted, Microsoft-Heirloom, few over 100k tCO₂).

➤ **Funding flows, yet uncertainty looms:** CDR investments reached \$3.5bn in 2023, doubling compared to the previous year. Yet a 30% contraction in broader climate tech funding and decreasing deal sizes signal potential challenges from economic pressures and geopolitical instability. H1'24 saw the continued gradual downtick in climate tech deal counts and funding according to a CTVC report¹.

➤ **The market is flimsy, struggling to expand beyond innovators, with hyper-concentrated yet still limited demand, fragmented supply, and even more limited deliveries:** In 2023, the top three deals represented 72% of total tons sold, and in June 2024 Microsoft alone accounted for 83% of the top three buyers, including the largest CDR deal (June 2024) and two deals over 1 Mt (May 2024). Compared to 2022, sales continue to grow faster than deliveries: 55% more companies have made at least one sale, versus 35% for deliveries. The delivery time remains stable at 35 months (one month less than in 2022). Biochar based CDR deliveries dominated (94% of tons delivered and eight of the top ten suppliers).

➤ **Mounting obstacles:** Political turbulence, economic headwinds, geopolitical tensions and the escalating consequences of climate change across the globe collectively require immediate attention and hence pose formidable threats to the industry's upward trajectory.

2 Expert interviews unanimously confirm two phenomena that are stalling broader industry growth: 1) that CDR awareness is limited to a bubble and predominantly confined within industry circles, and 2) the industry is grappling with a discursive struggle that creates an echo chamber. The broader public remains largely unaware of CDR and its current challenges and opportunities. The insularity, characterised by jargon and silo mindsets, impedes the industry from attracting the critical buyers, funders, partners, and supply chain integrators required for scaling at this pivotal juncture. Engaging with the broad chain of actors necessary for a functioning industry is equally important as demonstrating technological progress.

¹ CTVC Report: A weak \$11.3bn start to 2024.

3. The current stage of the industry is a critical yet natural transition point, close to the peak of inflated expectations on the hype cycle and ahead of the adopter phase on the S-curve. There is a requirement and an opportunity for the industry to stand up.

Taking the right actions can soften the depth and length of the 'trough of disillusionment' and accelerate progress on the S-curve from being an innovators' centre of interest to an 'early adopter diffusion status'. Preparing for integration at a systems level would enable substantial advances towards realising climate impact potential.

4. There is a large belief that accelerating industry maturation via parallel technological breakthroughs and advocacy-driven engagement is both necessary and still possible. Two objectives must be pursued by all actors:

➤ **Focus on creating a positive ambition loop² by addressing a double gap:** 1) an ambition gap where more companies and countries must commit to supporting CDR as part of a serious climate action plan and 2) an action gap where deployment needs to be supported via funding and tangible mechanisms.

➤ **Unlock the wait-and-see attitude:** Urgent priorities will require parallel action: 1) decrease costs to secure buyers' offtakes and investor support and 2) increase public support for large demand via direct procurement, indirect support and perspective on upcoming regulation.

5. The industry's long-term potential requires large, sustained demand unlocked by a robust compliance market. This prospect is more likely to materialise when CDR is treated as a limited but vital public utility (vs. a commodity);

Establishing clear public demand mechanisms and commitments to drive social diffusion will be a key part of national and European climate plans. Until then, the industry must grow by relying mostly on innovators (both on the supply and demand side) and a voluntary ecosystem.

² We have the technology, but where is the ambition? [RMI](#), 2021

6. The industry must chart the course and have an active role in overcoming the current inflection point CDR is facing on the S-curve. Driving more aligned expectations across the systems and developing creative approaches will be key to minimising a 'CDR winter' period. This momentum can be achieved via:

➤ **Publicly acknowledging the critical state of the industry:** open acceptance could include facing the current challenges and regulatory limitations head-on, diving deeper into growth triggers and avoiding surface-level 'business-as-usual' conversations on the over-discussed requirements (e.g. moving from 'CDR needs more support' to 'developers face huge barriers to creating FOAK plants' and illustrate these conversations with concrete challenges faced in the field.

➤ **Reinforcing credibility and trust via transparency and balanced views:** eliminate inflated claims and over-promises that undermine credibility, and focus on tangible near-term benefits like job creation, workforce upskilling, and economic stimulation, while acknowledging the substantial challenges.

➤ **Adhering to radical transparency processes and high-integrity standards:** supporting independent platforms free of potential conflicts of interest will help facilitate data sharing on projects, technologies, obstacles and setbacks.

➤ **Developing and experiment with innovative financing stacks and deployment-focused partnerships:** These partnerships, like the one involving Microsoft, Aker, carbon capture, and co280, as well as systems that can favour companies able to embed cdr into system-wide operations and supply chains, can fast-track the adoption of CDR into existing infrastructure for expedited adoption.

7 The most potent levers for catalytic action ● should focus either on tools currently missing, or on under-developed areas that could accelerate CDR adoption. These loci act as a complement to the current focus that is almost solely based on technology and distribution (e.g. marketplaces):

➤ **Accelerate legislation adoption:** fund policy listening and research initiatives to devise robust mechanisms for policymakers collaborating with NGO research (like Carbon Gap). There is a particular gap for these types of initiative in Europe (equivalent to ClearPath in the US). Action towards these objectives could include advocating for non-financial support, such as the US DOE VCM principles released in May 2024, or demand mechanisms for low-carbon products via procurement criteria similar to NYC local Law 971 including requirements on GHG for buildings over 25k square feet. Additionally, it would be worthwhile to explore dedicated integration mechanisms inspired from the utility sector given CDR delivers a public benefit similar to wastewater treatment.

➤ **Drive trust:** establish independent science-based standards and frameworks to drive transparency by facilitating objective technology comparisons to drive cost down and channel actions from the voluntary carbon market (both purchases and investments). Examples could include standards, registries or neutral frameworks like a levelised cost of CDR template to drive transparent reporting across companies and different CDR pathways. These actions would better enable cross-comparisons and establish a learning loop to help new buyers or financiers as they enter the industry.

➤ **Fast track the technology funnel:** catalyse the proof-of-concept stage of technology development and accelerate real-world deployment. For example, capital could be provided for FOAK projects in exchange for high levels of transparency in key metrics, to be collected on a selected trusted platform or by providing support to real-world deployment labs similar to [Deep Sky Climate projects](#).

➤ **Attract new entrants:** This critical priority can be accomplished by selecting from the following toolkit:

- 1) Conduct research to better understand the drivers behind the corporate 'say-do gap' and generate impactful insights to encourage companies to sign offtakes and engage effectively with the VCM;
- 2) Develop CDR industry education messaging and content that can be made available centrally to a wide range of industry players (as such also aligning messaging and avoiding dilution of resources across the industry);
- 3) Establish a multi-stakeholder, tailored initiative consisting of experienced champions from the energy and industry space, crafting messages dedicated to audiences unfamiliar with CDR with a focus on building public confidence in CDR. This programme could be hosted at a recognised NGO with an established science background, high recognition of neutrality and strong credibility to industry players.

➤ **Support public outreach:** foster community engagement to enable project acceptance well ahead of the critical deployment stage. The best channel for such outreach would be a technology-neutral non-profit platform to drive CDR acceptance and neutralise 'nimbyism'.

➤ **Support high-integrity, market-shaping initiatives:** focusing on messaging, tailored content and critical multi-stakeholder dialogue. The Clinton Health Access Initiative allowed funders to engage with then-seemingly insurmountable goals like eradicating polio or malaria; a similar coordinated approach could align the diverse actors needed to catalyse scaled action and growth required for CDR.

About Carbon Dioxide Removal (CDR)

- Carbon Dioxide Removal (CDR) – taking out CO₂ from the atmosphere – has been identified as a crucial component in the suite of strategies required to address climate change on top of drastic emissions reductions.
- The Intergovernmental Panel on Climate Change (IPCC)³ – the leading international body established by the UN to assess the scientific knowledge related to climate change, states that 6 to 10 gigatons (Gt) of CDR will be required annually by mid-century to reach net zero and, after that, to realise negative emissions to reduce the global overshoot and minimise the effects of global warming.
- Carbon removal is an emerging industry. Today it encompasses a wide variety of technologies and processes designed to remove CO₂ from the atmosphere and securely store it in geological, terrestrial or oceanic reservoirs. Techniques such as direct air capture (DAC), bioenergy with carbon capture and storage (BECCS), and enhanced rock weathering (ERW) are among the many approaches contributing to this effort.
- In February 2024, the revised Oxford net zero principles⁴ stressed the need to transition to carbon removal as a means of offsetting any residual emissions (away from emissions avoidance or reduction) by the global net zero target date. As such, those carbon removal solutions with the lowest risk of reversal should steadily be increased to represent 100% of the removals by 2050. This goal would be in line with the long and short carbon cycles, where fossil-based CO₂ should be durably eliminated via a permanent method.

LANDSCAPE STATUS

In the last two decades, CDR has grown from a research and academic area into a real, burgeoning industry. Over the last years, bolstered by its recognition and inclusion in the 2018 IPCC Report³, the industry has capitalised on a hype tailwind propelling a surge in visibility, development and funding, albeit with variability across pathways and geographies.

- **Exponential ascent:** bolstered by its recognition in the 2018 IPCC report, the industry's momentum has catalysed an exponential increase in:
 - **Research:** the last years have seen a steep increase in funding, patent activity and number of labs, as well as the integration of CDR in large corporations' incubation programmes or joint-venture structures (Airbus, Siemens, Suez etc.)
 - **Funding:** CDR investments have been steadily increasing and reached 3.5bn\$ in 2023 (excluding DAC Hubs), doubling from 2022. That money was mostly spent on Series A and early-stage companies despite a general slowdown in climate tech investment overall.
- **Awareness:** CDR companies have achieved international recognition in mainstream platforms. For instance, Fast Company rankings included Heirloom and Climeworks as 'most innovative companies'. In addition, several high-profile prizes have recently generated public visibility and financial support for CDR companies (e.g., X prize, Earthshot prize, etc.).
- **Entrepreneurship:** the creation of numerous companies in this field has attracted high-profile founders from the tech and entrepreneurship world (e.g. Charm Industrial, Heirloom or Deep Sky). Starting in the late 2000s, the ecosystem has evolved today into a diverse ecosystem, which now includes a wide range of sophisticated players across various sectors, including insurance, rating agencies, carbon registries and portfolio management firms.
- **Market:** early signs show that the voluntary market signs is also increasing, with pioneering customers like Shopify, Stripe and Microsoft engaging in the VCM since 2020 and a drive towards increasing diversity and sophistication on the buying side, most notably with Frontier the first advanced market commitment established in 2022.

³ IPCC Carbon Dioxide Removal Factsheet

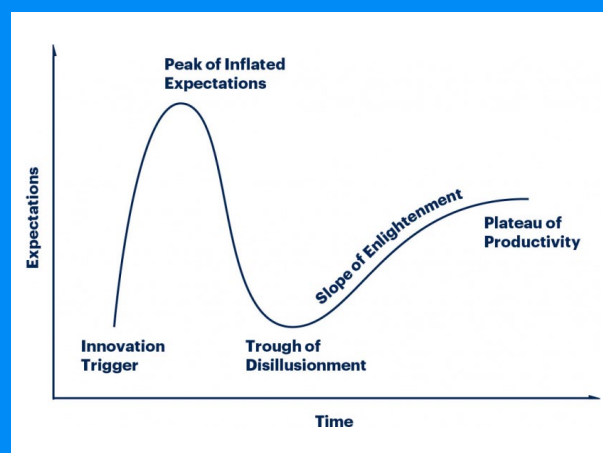
⁴ Revised Oxford Net Zero Principles, February 2024

⁵ IPCC Report

About the Gartner hype cycle

The hype cycle model was created and popularised by Gartner⁶ and provides a graphic representation of the maturity and adoption of technologies and applications. It identifies 5 key phases:

- **Innovation Trigger:** a potential technology breakthrough kicks things off. Early proof-of-concept stories and media interest trigger high publicity. Often, no usable products exist, and commercial viability is unproven.
- **Peak of Inflated Expectations:** early publicity produces several success stories, often accompanied by scores of failures. Some companies take action, while many do not.
- **Trough of Disillusionment:** interest wanes as experiments and implementations fail to deliver. Producers of the technology shake out or fail. Investments continue only if the surviving providers improve their products to the satisfaction of early adopters.
- **Slope of Enlightenment:** more instances of how technology can benefit the enterprise start to crystallise and become more widely understood. Second -and third-generation products appear from technology providers. More enterprises fund pilots while conservative companies remain cautious.
- **Plateau of Productivity:** mainstream adoption starts to take off. Criteria for assessing provider viability are more clearly defined. The technology's broad market applicability and relevance are paying off.



The hype stage refers to the combination of the media attention to a new technology combined with its net expectations (positive minus negative). It starts with increased media attention coupled with net positive expectations, in turn followed by a possible peak with decreased media attention, or decreased level of net positive expectations (decrease of positive expectations or rise of negative expectations). 'Over-hype' refers to a possible negative impact if momentum leads to shallow due diligence and drives disconnects between expectations and possibilities, for example in magnitude or speed of development.

Along the curve, there are **inflection points** that arise when there is a palpable disconnect between the expectations portrayed in the media and the real-world possibilities generally. This disconnect generally appears at an early stage due to failure, delays in giving proof of concept, or later failing to deliver on the fast growth objectives or lower/ slower high returns.

- **Nuanced support for different CDR pathways:** in recent years, support from public investments in the US has largely favoured DAC, but there is emerging support for ocean-based CDR methods. However, financial assistance can vary as illustrated by biochar which received limited support to date despite producing over 90% of CDR deliveries in 2023.

- **Geographic currents:** in terms of geographies, the US has long dominated innovation in the domain, housing active research centres and pioneering companies. The UK (Oxford University, Heriott-Watt University) and Switzerland (ETH Zürich) have emerged as secondary hubs. Recently, several Nordic countries and Canada are catching up to the global trend, joined by notable interest from Japan and strong signs from Singapore, Kenya and China (particularly in biochar research).

⁶ Introduction to the Gartner Hype Cycle, [bmc](#)

The industry is now showing some positive signs of maturity and the sophistication necessary to reach the large scale required. Such signals in turn fuel expectations on the industry's ability to fulfil the stated ambitions.

Among the main ones:

- Governments are stepping up and providing a clear sign of the maturity of an industry that needs both support and regulation. The role of government is multiple, as they act as:
 - **Funders:** mostly in US with Inflation Reduction Act and Bipartisan Infrastructure Law, bringing large amounts of tax incentives and deployment grants as well as subsequent guidelines and procurement programmes.
 - **Buyers:** piloting single purchases or future procurement programmes like those in the US, Canada and Denmark; similar programmes are under investigation in Germany.
 - **Regulators:** such as with the call for high integrity in projects from the US government⁷ or the EU CRCF certification framework.
 - Players are reaching key milestones on the scaling journey with the announcement of large deployments, making projects like Climeworks' Mammoth⁸ (unveiled on May 8th, 2024) a tangible reality.
 - Very large deals in the voluntary carbon market are regularly exceeding the 100 ktCO₂ mark including Airbus and Ipoint5, Microsoft and Ørsted, Microsoft and Heirloom. These offtakes serve as a guarantee from funders and enable the financing of key infrastructure projects.
 - MRV (monitoring, reporting and verification) and certification efforts are expanding beyond specialists, with the first CDR and storage methodology approved by the renowned Gold Standard organisation in April 2024⁹.
 - The ecosystem is ramping up, with more partnerships being created across players, as illustrated by the Deep Sky DAC innovation hub in Québec, Canada or Deep Sky Labs, the 'world's first cross-technology carbon removal innovation and commercialization center', based in Alberta, Canada.
- The challenging global context is hastening the emergence of significant barriers to growth for CDR, pushing the industry towards a critical turning point. First, exogenous factors are combining into a perfect storm to increase scrutiny and decrease support:
- An overall instable global context disproportionately affects CDR as a nascent industry, especially regarding investments. The geopolitical situations and conflicts around the globe including, but not limited to, the Ukraine-Russia war and the Middle East conflict, stall or limit focus and financial support from many financial actors as well as states around the world.
 - The tense economic context characterised by rising inflation across the globe and partially driven by energy prices, leads to certain countries focusing more fully on local situations. These tensions put pressure on the availability of capital from corporates (offtake), supply chain players (R&D investments), and funders (VCs, growth investors and banks).
 - In 2024, more than 50% of the global population will elect new leaders in key countries and regions (India, the UK, Europe, and the USA) and stall political decision-making in key spheres for extended periods both before and after elections.
 - There is a general negative bias towards carbon offsets which are often perceived as a 'villainous cousin'. 2023 has been described as a 'horror year' for the carbon offset market with the lowest ever trust, particularly given the negative coverage of REDD+ projects that is still muddying the current perceptions of CDR credits. This distrust has resulted in the VCM shrinking for the first time in the last 7 years.
 - The market is still warm, yet it shows strong signs of slowing down for climate tech¹⁰:
 - Total funding for 2020-2023 was \$142bn. 2023 saw a 29% increase in the cumulative total, even though the compound annual growth rate (CAGR) cooled; for 2020-2023, CAGR was 23%, versus 32% for 2020-2022.
 - Venture and growth investment decreased by 30% to \$32bn between 2022-23 (despite a high CAGR of 23% over the 2020-23 period as a whole); fewer companies advanced to later-stage rounds, average deal size fell by 28%, and overall deal activity dropped by 3% compared to the previous year.

⁷ US unveils policy to boost carbon offset market integrity, [Reuters](#)

⁸ Climeworks unveils Mammoth plant, [Climeworks](#)

⁹ First carbon removal and storage certification approved by Gold Standard, [Summit Carbon Solutions](#)

¹⁰ [Sightline Climate](#)

- Late-stage and growth investments continue to decline amid higher expectations for milestones achieved and clear pathways toward profitability. The later the stage, the higher the drop-off, with series C and growth deals both falling by ~30%. Rising interest rates and increased supply chain costs make it harder for companies to build early plants and projects, which may further deter investors from deploying late-stage capital.
- At a time when deployment is critical for CDR, the climate tech trend shows that deals for physical-based / hardware technologies decline faster than software, with hardware deal count declining 6% versus 3% for software).
- For the first time, there was a decrease in VC dollar value in the VCM in 2023¹¹; VC investment in VCMs grew from less than \$100 million from 2017 to 2019 to a peak of \$1.8 billion in 2022, with deal count growing every year from 2017 to 2022. As of December 2023, while deal count was close to that of 2022 (101 deals, versus 104 in 2022), deal value dropped 17% to \$1.5 billion from 2022's \$1.8 billion, likely due to a decline in total VC dollars invested, an increased uncertainty in VCMs, and the effects of these trends on carbon-credit buyer confidence.
- Qualitative feedback from suppliers and funders highlights the limited budget available for project finance which is critical to deploying and scaling CDR operations. While this constraint might be driven mostly by a large proportion of early-stage companies, there is a growing need to finance real-world projects that have the potential to scale exponentially but are facing a project finance bottleneck.
- The pessimism around carbon capture and storage (CCS) negatively impacts CDR with which it is often conflated in the public opinion. This confusion is based on the fear of mitigation deterrence raised by many climate actors (see Al Gore's Ted Talk¹²) and the perception of possible malicious intentions or technical inability to deploy the solution at scale.
- The risk of irrelevance increases next to unmoving global GHG emissions. Insurers and civilians alike are becoming increasingly clear; since emissions reductions are not happening at the required pace and climate change consequences are costly, carbon removal might be perceived as marginal or unable to make a difference, thereby negatively impacting the willingness to invest in its development.

Despite high growth, CDR is still niche, representing ~7% of the wider carbon market¹³, with very concentrated buyers and over-reliant suppliers. The endogenous signs below started appearing over the last months, based on data from CDR.fyi¹⁴:

- There is a concentrated market of deals and few buyers. In 2023, the top 3 deals represented 72% of volume contracted and in May 2024, Microsoft represented 83% of the top 3 buyers. Microsoft has three deals over 1Mt, out of which the largest BECCS deal to date at 3.3Mt and its deal with Heirloom, was the 2nd largest DAC deal at 315kt.
- The market for large deals is limited to a few buyers. As of May 2024, only 6 companies have ever bought over 100kt, and only 14 over 10kt. Additionally, 55% of customers are from the financial and professional services industries.
- The market grew sevenfold between 2022 and 2023, adding 3.885Mt in sales (which has since largely been surpassed by the Microsoft-Stockholm Exergi and Microsoft-Ørsted deals at 3.3Mt and 1Mt respectively), yet the top 3 deals represent 83% of that growth. Overall, the top 10 buyers represent 95% of commitments.
- 1point5, the 4th largest seller, relies on only 2 buyers (Amazon and Airbus) for 85% of their sales; 92% of Heirloom's total volumes sold are based on one 315Kt deal with Microsoft in 2023.
- Biochar has been under-hyped while leading the delivery board with 87% of Top 10 deliveries (in volume) and 8 out of the top 10 suppliers along with Running Tide ranked #4 (biomass removal) and Charm Industrial ranked #9 (bio-oil).

The over-exposure of social media generates visibility for any company or technology regardless of its stage of readiness. Over a series of interviews, several experts noted that 'there is still a certain amount of nonsense in the magnitude of the claims and the actual technology readiness'. CDR credits are not a commodity but rather are closer to a utility like waste or water treatment. In a voluntary carbon market system, the power of the market is limited to driving winning technologies or aggregate supply chains.

¹¹ Pitchbook, Emerging Tech research Voluntary Carbon Markets

¹² What the fossil industry does not want you to know, TED

¹³ Allied Offsets 2023 Carbon Market Insights Report

¹⁴ CDR.fyi Trending on track? 2023 Year in review

The perception of any 'over-hype' is still limited and mostly prevalent in the financing world, where, after a couple of years with limited scrutiny, CDR projects and companies are now judged on the same criteria as other climate tech projects. This perspective is mainly due to the

increased number of projects, the growing sophistication of funders and their dedicated science team, and the contracting global macroeconomic environment leading to more stringent due diligence across projects. Some experts noted the 'incompatibility of the ambitious promises and hopes with the current, yet legitimate, speed of tech development and performance.'

Additionally, expert interviews unanimously confirmed that CDR awareness is confined to a bubble that self-reinforces, limiting the potential to welcome new entrants.

- The broader public remains largely unaware of both the issues and the opportunities presented by carbon removal. Uncoordinated, repeated use of the same messages creates more noise to the outside world and the general push for a single method instead of a portfolio approach undermines the credibility of the entire industry. Additionally, it reinforces an insular mindset and leads to the creation of an echo chamber.
- This phenomenon is particularly prevalent today as suppliers are experiencing a critical inflection point in both purchases and funding. This insularity, with its jargon and community mindset, can blind the key stakeholders and restrict the industry's ability to attract new buyers, funders and partners, including those in supply chain development and operations who are critical to the deployment stage.
- This discursive struggle in both content and outreach is a key headwind to broader industry growth. Ensuring advocacy efforts target the right and profound legitimisation strategy at national and community levels is becoming as important as developing tech strategies.

THE RISKS

CDR currently confronts a complex set of interconnected challenges that are hindering its growth and development.

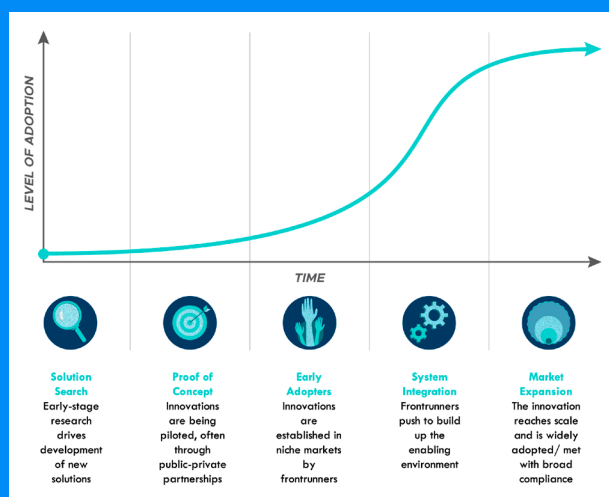
Diverse obstacles, ranging from technological limitations to regulatory hurdles and market uncertainties, collectively impede CDR's ability to evolve and reach its full potential. The accumulation of those endogenous and exogenous factors favours a wait-and-see reaction; only innovators keep buying CDR credits, and only a few suppliers get limited funding. We see the emergence of several disconnects that trigger negative tipping points toward 'the trough of disillusionment':

- **A growing unbalance in purchase-deliveries:** in 2023, a tiny 2.8% of the volumes purchased were delivered, with 94% of the deliveries provided by biochar. For most purchases, competition takes place on expectations of future performance rather than on actual performance.
- **Funding crunch:** there is a disconnect between the investment level required, the currently available of funds, and the willingness to invest at current technological readiness levels (TRL) and associated risk levels. Current levels are hardly acceptable for VC funds, especially after decades of high-returns-low capex-fast growth software projects.
- **Internal fights:** in a tense funding and purchasing context, different methods and players are advocating to get an 'individual' share instead of collectively driving to grow the 'pie' and overall funding for the CDR industry.
- **Deployment disconnects:** while some CDR players are ready to deploy their technology modules, they are sometimes limited by the availability of the existing infrastructure such as upstream renewable energy capacities, grid requirements, transportation pipelines and downstream storage, and facilities or permitting for storage.
- **Pressure on leading players:** for some methods, there is a high reliance on key players. This dependence is especially true for DAC with project Stratos (1point5), Mammoth (Climeworks) or Cypress Hub (Battelle, Climeworks, Heirloom). These projects, including Running Tide which recently shut down¹⁵, are emblematic of the industry's perceived progress; their successes or setbacks could drive or stall positive perception.
- **Disconnect expectations/readiness:** hype cycles do not align with actual tech readiness. An overly optimistic outlook, combined with a lack of realistic assessments of the challenges in large-scale CDR deployment, has led to inflated expectations. Additionally, innovators tend to present ambitious projections to attract discerning investors. These factors have resulted in declared capacity estimates that are significantly disconnected from what is realistically achievable. This pattern of disconnect between expectations and technical readiness is typical for emerging industries, yet it ultimately fuels more caution among stakeholders.
- **Limited shared expectations among supply chain actors:** in early phases, shared expectations play an important role in mobilising resources by reducing the perceived uncertainty and stimulating the fulfilment of other key processes. In the case of CDR, this thinking applies to storage, CO₂ transportation, the sorbent supply chain etc.

¹⁵ Running Tide Shuts Down Citing Lack of Demand From The Voluntary Market, [Carbon Herald](#)

About the S-curve

- The S-curve represents the adoption pattern of innovations—beginning slowly, rising quickly, and then levelling off at market saturation¹⁶. This model has been observed in various historical transitions, such as the adoption of cars over horses and electric lighting over gas lighting, and more recently in renewable energy technologies such as solar and wind. The S-curve's shape is influenced by factors such as learning curves, economies of scale, technological reinforcement and social diffusion.



- According to RMI¹⁷, the main dynamics that drive S-curve growth are learning curves (improved productivity and reduced costs with increased experience), economies of scale (lower costs with higher production volumes), technological reinforcement (supporting technologies that enhance the main innovation), and social diffusion (adoption spreading as more people use the innovation).
- The transition through an S-curve is segmented into five phases:
 - 1. Solution search** – visionaries conceptualise new solutions.
 - 2. Proof of concept** – innovators develop working prototypes.
 - 3. Early adopters** – niche markets emerge as the innovation shows promise.
 - 4. System integration** – innovation reaches the mass market, offering better performance at lower costs.
 - 5. Market expansion** – growth slows as the market saturates and the focus shifts to new markets/ innovation.

For instance, today, the traction to produce solid sorbents is limited among giant chemicals companies who hesitate to start expensive multi-year R&D programmes before a clear winning technology is identified. This problem is replicated along most components of the supply chain.

The CDR industry is at a critical juncture in the early adopter's phase as modeled in the S-curve.

- The proof-of-concept phase is focused on taking the most promising innovative concepts and proving their real-world technical and commercial viability through pilots and prototypes before transitioning to an early commercial market. This stage is still valid for some innovations such as low energy DAC or Direct Ocean Capture (DOC) while more advanced players – both on the supply and demand side, like Microsoft – are driving the market and leading the early-adopters phase by catalysing early niche markets and overcoming barriers to make the innovation more accessible and viable beyond just innovators and early enthusiasts.

- The next stage is to prepare for system integration at which point the innovation can reach a broader scale. Key activities include building out supporting infrastructure, workforce development and developing regulatory standards. This phase requires coordination across the value chain to create an enabling environment for mainstream integration of the innovation and adequate supporting policies.

The CDR industry's success hinges on rapidly reaching a scale that can significantly impact climate change. Lingering in hype cycles and delays risks undermining crucial progress toward exponential growth. With global climate challenges and consequences increasingly visible, an urgent window of opportunity has emerged to propel the CDR industry along an exponential growth trajectory. This pivotal moment demands a decisive response from the industry – harnessing the mounting urgency to supercharge scaling efforts and maximise its potential for lasting impact.

¹⁶ Harnessing the Power of S-Curves, RMI

¹⁷ Ibid.

Table 1: Overview of the roles expectations play in creating an industry

Role of expectations	Status	Risk
Legitimising action	While legitimisation has been formally achieved via scientific consensus at the inclusion of carbon removal in the IPCC report in 2018, further work remains to be done with actors that enable CDR via strong awareness and education programs.	High
Providing direction	High-level direction is clear and provided by a macro breakdown of the IPCC goals. Yet, 'Gigaton by 2050' is still very challenging and rarely broken down.	Medium
Coordinating efforts	The emergence at scale of such an industry requires heavy lifting from a broad network of actors of companies, institutions, and research groups. With the high fragmentation due to a high number of entrants, high competition to attract funding, and individual focus on one's technology progress, coordination is informal and rare.	High

THE NEED TO MANAGE EXPECTATIONS

The CDR industry has a great responsibility and role to play in managing expectations, driving healthier dynamics, higher credibility and triggering a positive circle.

- Expectations are a great lever for action as they highly influence the development of an industry and can be defined as real-time representations of future capabilities. Hype trends typically do not mirror field technical readiness but rather collective expectations of future performance¹⁸. In a natural trend, they build up and move from generic to more short-term and specific over time¹⁹. Expectations shape the process instead of simply reflecting them and drive a self-fulfilling prophecy dynamic. As such, it is critical to manage the formal and informal expectations associated with CDR to channel the efforts towards the most needed areas.
- Different pieces of research have detailed the role of expectations in the creation of an industry. Schoen et al. (2011) and Val Lente (2012)²⁰ detail the three stages of the role of expectations play (see table 1). The biggest risk for the CDR industry is its lack of coordination, made inherently difficult due to its protean nature across pathways, stages of maturity, scalability potentials, speed of deployment, and need for layered innovation the supply chain (building of low-carbon energy capacities, standardisation efforts, supply chain build etc).



Despite current challenges of slowing market demand and stalling investments creating a negative feedback loop for CDR, there's a potential to reverse this trend. Experts

agree that stimulating market demand is key, as it drives innovation investments and technology diffusion and leads to cost reductions that further boost demand. To reverse this negative loop, fostering a positive sentiment towards the CDR industry is crucial. Three main action areas have been identified to promote a healthy and positive perception of the CDR industry:

¹⁸ Hype cycles during socio-technical transitions: the dynamics of collective expectations about renewable energy in Germany, [Kriechbaum et al. 2021](#)

¹⁹ Borup et Al. 2006

²⁰ Navigating foresight in a sea of expectations: Lessons from the sociology of expectations, [Van Lente 2012](#)

1) Address the perceived ideas that are negatively affecting CDR's image and deployment and steer the right conversations toward driving a favourable context for the scientific role of CDR. While CDR is scientifically supported, some informal public beliefs create negative frame expectations and hinder progress. Despite scientific consensus, 'perception is reality'; whether it be fully grounded or not, these negative perceptions should be proactively addressed to align public perception with science and reality. The main ones are:

- CDR is needed, however only after full completion of reduction work;
- CCS is not working – why would CDR work?
- CDR is another fig leaf by the oil and gas industry to delay climate action²¹;
- Nature is sufficient to deliver on the CDR goals;
- Costs are not competitive yet, 100\$ or 200\$ needs to be achieved before scaling;
- CDR is a shady market like offsets.

2) Eliminate seeds of disconnect and inflated expectations from the CDR industry itself. Experts stressed that 'there is still a great deal of nonsense in the claims made by some CDR players', contributing to confusion and self-fed inflated expectations. This misperception is driven by 1) challenges in scaling up novel CDR technologies, 2) overly optimistic outlooks from inexperienced new players, and 3) the need for companies to sound confident when attracting investors seeking high returns akin to successful tech startups. It is important to **synergise efforts to increase positive sentiment and refresh expectations based on tangible elements instead of optimistic promises.** That means:

- Publicly address the status of the CDR industry and inherent current natural limitations by:
 - **Normalising failures and celebrating learnings.** The players in the industry should get ready for natural downturns. In the words of several experts – 'there will be few winners and many losers as the industry matures', yet 'it is possible that most companies we know today will go bankrupt; until 2030, it is about selecting what needs to be scaled'. In a phase where most companies go from lab to field, public opinion and key players need to be reminded that project setbacks should be interpreted rather as proof of progress toward implementation instead of as a sector's general inability to deliver.

- **Treat CDR as a utility.** CDR is a utility, not a commodity, despite the existence of great business opportunities. Without regulations, the market's typical Darwinist survival-of-the-fittest dynamic does not apply. Among investors and corporates, a fear of the winner-takes-it-all drives snowflake-like funding and purchasing that slows overall advancement.

- **Remember the non-linear path to technological breakthroughs.** As one expert said, "success and failures are equally needed; no tech had an unobstructed path to growth'. Even today's tech and innovation had struggles and a long path to maturity from solar and wind to electric vehicles.

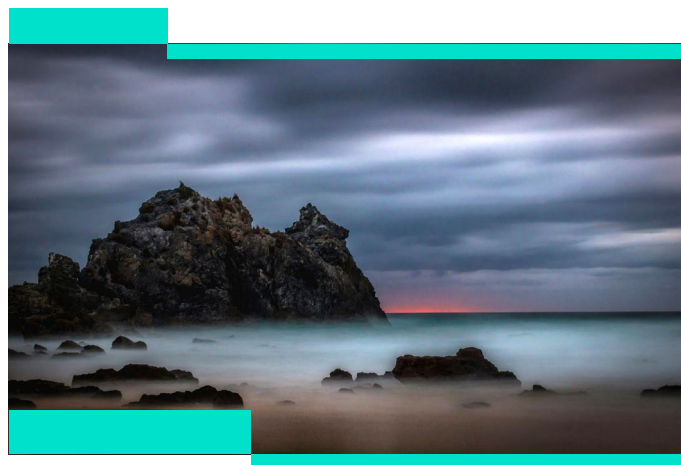
- **Realign financial expectations.** Unlike recent benchmarks set by tech investments with high and rapid returns, CDR requires high CAPEX and an infrastructure-heavy reality.

- Share tangible examples to decrease rampant scepticism and help experts assess and form relative expectations. Action requires transparency and coordination. Some approaches include:

- **Transparent field-reporting:** share facts and learnings through pilots, both for tech-specific features (such as performance or cost development) and field-related impact (such as job creation).

- **High standards:** accept to abide by robust due diligence from a tech and investment standpoint.

- **Responsible public relations:** acknowledge limitations inherent to a nascent infrastructure-led industry and right-size announcements to limit inflated claims of reaching a gigatone and the subsequent delays, which can negatively impact the entire industry (e.g. CarbonCapture Inc. project Bison delays or Running Tide closure of operations).



²¹ Al Gore [TedTalk](#), What the fossil fuel industry doesn't want you to know

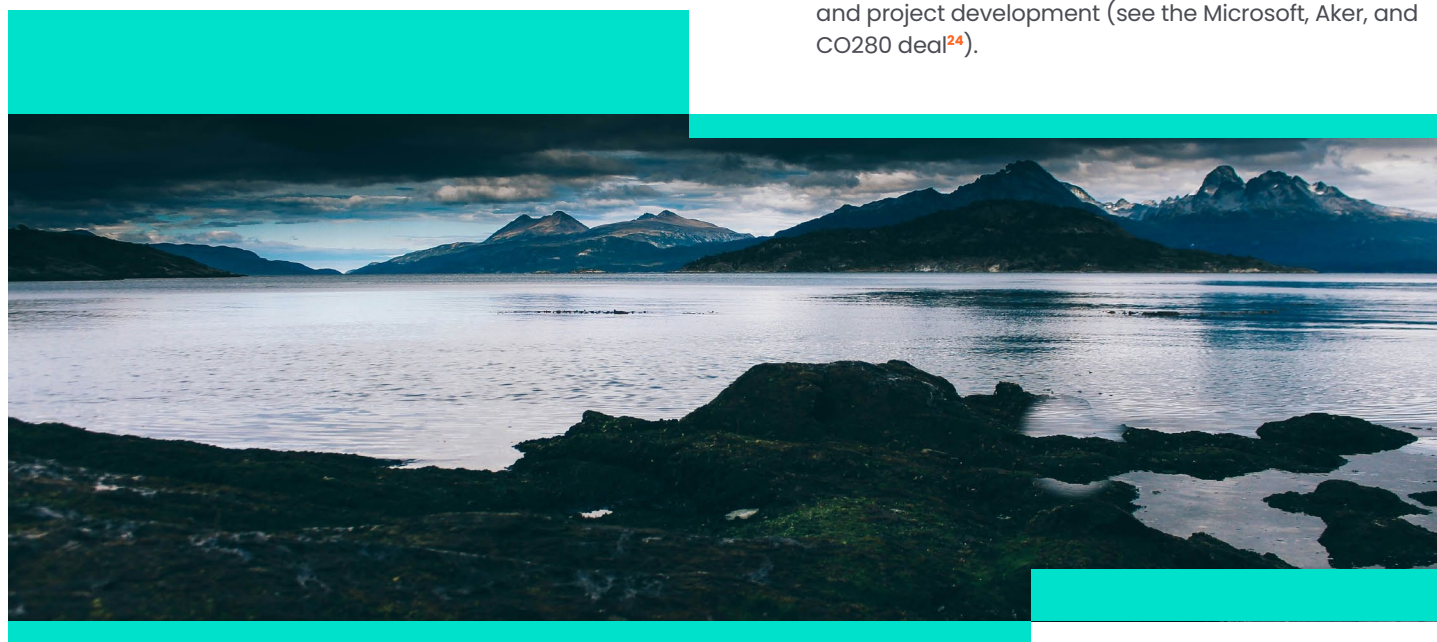
3) Focus on the short-term benefits. Most stakeholders cannot relate to abstract 2050 timelines which are disconnected from their current reality. **Given the current breadth of variables, breaking down the vision into short-term steps to micromanage expectations** will help engage new stakeholders. As one expert put it, 'one way to drive positive maturity of the hype is to proactively address what needs to be done now'.

- **Highlight tangible short-term benefits.** Job creation, workforce upskilling, community safeguarding, and economic growth were key drivers in the success of the USA IRA and Bipartisan Infrastructure Law adoption.
- **Map the branches of action required.** It would be useful to have an overview of general actions required, from energy sourcing to grid upgrades, from permitting to delegating authority and decision making. Such an overview would include highlighting the long-term actions (like engineer training and state investments) that all are required to enable a key project to break ground.
- **Update the narratives.** Carbon sovereignty, industrial competitiveness, and infrastructure as a competitive advantage are key narratives that can positively feed into supporting carbon removal but are currently underutilised. Most advanced countries in the energy and climate transition are those who invested early in infrastructure (US, DK, Iceland etc.). With long lead times, having the **most potent** narratives should be a focus.

• **Outsmart the system via an 'embedding approach'.**

Embed carbon removal seamlessly into today's existing life and systems for faster adoption.

- **Favour technologies** that leverage existing infrastructure, enable rapid deployment, lower CAPEX, and facilitate buy-in, including from communities. For example, CREW's carbon technology improves the performance of water treatment facilities while reducing their net carbon footprints.
- **Integrate CDR directly into supply chains** as a value-adding 'side benefit', e.g. the NetZero and ECOM pioneering biochar deal that uses coffee waste to improve soils and provides 6kt/ y of CDR for Nespresso. In the absence of aligned high standards to define high quality, co-benefits, even if sometimes intangible, will become a stronger key argument for the voluntary carbon markets.
- **Embed CDR into regulations**, such as CORSIA²², by requiring airlines to offset emissions exceeding 2020 levels and promoting sustainable aviation fuels. Another example is NYC's Local Law 97²³ which requires most buildings over 25,000 square feet to meet greenhouse gas emissions limits by 2024, with stricter limits coming into effect in 2030. These regulations encourage companies in the construction sector, including those involving cement, to consider their carbon footprint and energy efficiency.
- **Innovate beyond tech**, especially for financing stack and project development (see the Microsoft, Aker, and CO280 deal²⁴).



²² Corsia (Carbon Offsetting and Reduction Scheme for International Aviation) offset scheme

²³ NYC Local Law 97

²⁴ Scaling removal markets, [ESG today](#)

RECOMMENDATIONS

After years of organic growth and the emergence of multiple players, it is time for the CDR industry to stand up and proactively drive alignment of expectations. The four essential levers necessary for CDR to timely scale highlighted collectively are:

- Rapidly establishing large and sustainable demand from private markets and from public institutions;
- Accelerating technology de-risking of projects including for first-of-a-kind (FOAK) projects and driving cost down;
- Enabling funding for sustainable capital expenditure;
- Fostering public acceptance as the base of public action and project deployment.

There are 4 main areas of needs and opportunities to drive catalytic action:

1. Stimulate public demand and establish a clear action plan for regulations and incentives:

- **Enable policy listening** to retrofit proposals and increase chances of applications, for instance by strengthening the great work of Carbon Gap via a dedicated engagement strategy complementing the research and report work.
- **Support policy research** and build up proposals to pilot demand mechanisms (especially in Europe) and build evidence banks as illustrated by a recent Nature article²⁵ or by Clear Path's work in the US.
- **Increase available science support** and reinforce the scientific foundation for carbon removal, possibly via 1) further research within the IPCC report dedicated to implementing carbon removal recommendations including an outline of strategic planning for CDR at country level (possibly in the NDCs) and 2) available data at national level on the roadmap for renewable energy sourcing, storage and procurement programmes.
- **Ensure intentional international coordination** across local structures in Europe and internationally, and kick start it in other regions where private players currently have the lead (DAC in Japan, geothermal and mineralisation in Kenya).
- **Disproportionately drive mechanisms that encourage private-public partnerships**, for example, through the US public CDR purchase prize which drives matching from large corporations.

2. Propel rapid progress by prioritising TRL increase and rapid cost reduction via:

- **Financing R&D** at universities and institutions to advance innovative climate solutions.
- **Providing funding for FOAK** and demonstration pilot projects and requiring transparency on results will help identify both the potential and hurdles of these technologies and accelerate the selection of viable solutions for further development.
- **Ensuring robust foundations** by enhancing the development of standards and systems for transparency maintained by neutral entities free from potential conflicts of interest. Currently, most registries operate as both standard-setters and certifiers, which may not be sustainable in the long term.
- **Supporting comparative platforms that create fair benchmarking of technologies** like Deep Sky for DAC, while providing infrastructure for energy inputs and CO₂ storage.

3. Increase trust and objectivise the industry by driving transparency:

- **Create norms** and benchmarks for comparable key points, for instance via levelising costs of CDR.
- **Track projects** and report updates, setbacks and learnings. Doing so would limit unrealistic goals by driving accountability and promoting collaborative transparency on results and challenges to accelerate problem-solving across the ecosystem.
- **Prepare the general opinion** on natural trends of technology development: project failures, company bankruptcies, suppliers' consolidation as well as technological breakthroughs.



²⁵ What's the best way to tackle climate change? An 'evidence bank' could help scientists find answers, [Nature](#), Jun 2024

4. Create a non-profit, multi-stakeholder engagement platform to implode the bubble before it explodes:

Unlike, hydrogen, LNG, or health care issues like vaccines²⁶, Malaria, or AIDS, CDR does not benefit from a dedicated international platform. A great example is the Clinton Health Access Initiative which, by aggregating demand for AIDS vaccines and collaborating with the government infrastructures, highly contributed to bringing down vaccine costs and enabling general access.

The objectives would be to:

- **Provide insights on market entry barriers** focusing on buyers, OEMs and funders for infrastructure as well as communities; here, only limited research has been done for DAC in the context of DAC Hubs in the US.
- **Consolidate and renew current interaction formats with a focus on buyers and policymakers targeting big players** (e.g. largest market caps, Nvidia, Eli Lilly, Walmart, Visa, Mastercard, Oracle, Merck, or the CEOs of LVMH, AstraZeneca, GSK, Roche, Nestlé or L'Oréal etc.) through educational programmes, roundtables and high-level workshops (including decision-makers).
- **Coordinate and disseminate digestible educational content** about CDR to various stakeholder groups like the public, media, corporates, funders, and policymakers in order to limit diluting current efforts (everyone working on the same content and news across the sector) and, as such, reducing the resulting cacophony. Better outreach would require current CDR players to let go of individual communication and coordinate among themselves, representing an opportunity to be more efficient with their own resources.
- **Find the right advocates and high-level champions** that can unite behind the need for CDR. Here, the diversity of representatives matters for creating strong legitimacy and should ideally include government figures (past or present); stronger diversity drives strong legitimacy and public faces have a disproportionate weight when expressing or rallying expectations.

About the author and acknowledgements

Julie Gosalvez is a recognised CDR leader with a strong background in business. She is a seasoned business executive with over 15 years of international background in leadership positions across large corporations like Procter & Gamble and LVMH. As the former Chief Marketing Officer of Climeworks, she played a pivotal role in establishing carbon dioxide removal (CDR) as a critical component of credible climate strategies worldwide. Now serving as the President of the 'Association Française pour les Emissions Négatives' (AFEN), she is building France's premier carbon removal trade association. She is also a co-founder of the SheChangesClimate France non-profit and the Climate House, the first physical space dedicated to climate action and its related ecosystem in Paris. With a unique blend of marketing expertise and strategic thinking and deep climate tech and carbon removal knowledge, Julie is dedicated to accelerating the transition to a sustainable, low-carbon future.

The analysis in this report is based on the contributions of many experts from inside and outside the industry stemming from a wide range of stakeholders. Insights were gathered from authoritative voices among suppliers, developers, policy analysts, academics, researchers, economists, funders, and other entities with experience in science, climate technologies and heavy-industry development. Organisations represented include influential bodies such as RMI, Columbia Business School, the U.S. Department of Energy, JP Morgan, Stripe, BCG, McKinsey & Company, early-stage and growth investors as well as key CDR suppliers across pathways, climate-tech marketplaces and asset managers.

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²⁶ Through GAVI - Global Alliance for Vaccines and Immunization

About Us

Carbon Gap is an independent, Brussels and UK-based non-profit **organisation** supporting Europe's unique opportunity to lead the responsible deployment of carbon dioxide removal (CDR) to fight climate change through independent and science-led advice.

The logo for Carbon Gap, featuring the word "Carbon" in a dark grey sans-serif font and "Gap" in a white sans-serif font inside a blue square.

Carbon Gap

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