WHITE PAPER

The Global Carbon Dioxide Removal (CDR) Industry

State of Play

August 2025

1. Executive Summary

Carbon Dioxide Removal (CDR) has emerged as a critical pillar of the global climate strategy. While deep emissions reductions remain the foundation of achieving net-zero, leading scientific bodies such as the IPCC make clear that large-scale deployment of CDR will be unavoidable to address residual emissions and remove historical overshoot. By 2035, the CDR industry is expected to evolve from fragmented pilots into a multi-gigaton, multi-billion-dollar sector that underpins climate action alongside renewable energy and electrification.

Technologies and Deployment Readiness

The CDR landscape spans nature-based approaches (reforestation, soil carbon, blue carbon), biomass-based solutions (biochar, BECCS), and engineered technologies (direct air capture, mineralization, enhanced weathering, ocean alkalinity). Today, nature-based and biomass-based methods dominate in volume, while engineered solutions - though high-cost - are rapidly advancing in technical readiness and cost reduction trajectories. By 2035, biochar, BECCS, and DAC are projected to scale most significantly, collectively capable of removing billions of tonnes of CO_2 annually if properly incentivized.

Market Pathways and Monetisation

The CDR market is currently driven by voluntary corporate commitments, with buyers such as Microsoft, Shopify, and Frontier pioneering advance purchase agreements. Compliance and regulatory pathways are beginning to take shape, particularly in Europe and the United States, supported by tax credits, subsidies, and Article 6 mechanisms. The global CDR market, valued in the low billions today, is projected to exceed $100 billion by 2035. Monetisation opportunities extend beyond carbon credits to co-benefits such as soil health, water conservation, and biodiversity credits - especially relevant for nature- and biomass-based approaches.

Bottlenecks to Growth

Despite rapid innovation, the sector faces substantial challenges: high costs for engineered solutions, limited scalability of nature-based projects, feedstock constraints for biochar and BECCS, and persistent uncertainty around measurement, reporting, and verification (MRV). Market integrity is also threatened by concerns over permanence and double-counting. Solutions include digital MRV systems, stronger global standards, blended finance to de-risk early projects, and coordinated policy support through subsidies, procurement, and carbon pricing.

Major Players and Funding Pathways

Key actors include technology developers such as Climeworks, Heirloom, Charm Industrial, Running Tide, and regional innovators like Ecosys.Earth; corporate buyers including Microsoft, Amazon, and Stripe; and coalitions such as Frontier and the First Movers Coalition. Funding is flowing from venture capital, government grants, and philanthropic commitments, with new financial instruments - such as carbon removal ETFs and futures - on the horizon. This evolving ecosystem reflects the growing confidence in CDR as an investable and impactful sector.

The Future of CDR

By 2035, the industry is expected to mature into a mainstream climate solution, shaped by consolidation among technology providers, increasing integration into compliance markets, and expanded participation from the Global South. If successfully scaled, CDR could deliver between 5–10 $GtCO_2$ annually, helping to close the gap to net-zero while generating rural livelihoods, new industrial value chains, and verifiable climate resilience co-benefits.

Key Takeaway

The next decade is pivotal. Without rapid deployment, the world risks locking in overshoot. With coordinated action across technology, markets, finance, and policy, the CDR industry has the potential to transform from a niche innovation into a cornerstone of climate stability by 2035.

2. Introduction

2.1 The Role of Carbon Dioxide Removal in Climate Strategy

As the world pushes toward net-zero emissions by mid-century, it is becoming clear that abatement alone will not suffice. Many sectors - such as aviation, shipping, agriculture, and certain industrial processes - are difficult to fully decarbonise. Moreover, historical emissions have already raised atmospheric concentrations of CO_2, contributing to warming that will persist unless actively reversed. Carbon Dioxide Removal (CDR) thus becomes an essential complement to mitigation: not just managing residual emissions, but drawing down legacy emissions and ensuring long-term climate stability.

This insight is echoed across climate models and scientific assessments: major mitigation pathways assume deployment of CDR at gigaton scales in the second half of the century.

CDR also provides optionality in climate policy: countries and firms may overshoot near-term carbon budgets, but with reliably scaled removal technologies, overshoot can be partially reversed. However, this demands fast scaling over the next decade, not deferred hopes for late-century fixes.

2.2 What Is CDR (and What It Isn't)

To set scope, it is useful to define CDR precisely:

- **Definition & Scope**
  Carbon Dioxide Removal refers to human-driven processes that **remove CO_2 from the atmosphere** and durably store it in geological, terrestrial, oceanic, or product reservoirs. It excludes capture from point sources (i.e. CCS applied to smokestacks or industrial emissions), unless that capture is followed by net negative emissions beyond what would otherwise have been emitted.
  The "durability" criterion is key: CDR typically refers to storage that lasts decades, centuries, or millennia, distinguishing it from ephemeral sequestration.
- **Categories / Taxonomy**
  Common categories of CDR include:
  1. **Nature-based solutions**: afforestation / reforestation, improved forest management, soil carbon enhancement (carbon farming), wetland & peatland restoration, blue carbon (coastal ecosystems).
  2. **Biomass-based removal + storage**: biochar, Bioenergy with Carbon Capture and Storage (BECCS) / Biomass Carbon Removal & Storage (BiCRS).
  3. **Engineered / geochemical**: Direct Air Capture (DAC), enhanced weathering / mineralization, ocean alkalinity enhancement, enhanced rock weathering, olivine dispersion, possibly direct ocean capture, electrochemical sequestration pathways.
  4. **Hybrid / integrative approaches**: combinations of the above, e.g. biomass + mineralization, integrating with industrial processes, or leveraging waste streams.
  5. **Marine / ocean-based**: artificial upwelling, ocean fertilization (though

controversial), alkalinity enhancement, electrochemical methods.

Some categorisations emphasise **storage time horizon** (e.g. durable vs semi-durable) or **scale potential vs risk tradeoffs**.

2.3 The State of the Market & the Role of CDR.fyi

One of the major challenges in the CDR space is transparency: tracking orders, deliveries, pricing, capacities, and performance is complex, given the nascent and fragmented nature of the industry. This is where **CDR.fyi** plays a critical role as a data aggregator and registry for durable carbon removal.

Some key facts from CDR.fyi's public metrics:

- The platform lists **"Total Sales," "Deliveries," and "Price Indices by method"** as core analytics.
- As of the latest data, the platform tracks **666 purchasers**, **611 suppliers**, and **~5,748 orders** in the durable CDR market.
- While the data is not comprehensive (some information is undisclosed or private), CDR.fyi claims to be the largest open registry for high-permanence (≥ 100 year) carbon removal.
- That said, there are limitations: the dataset is drawn from a mix of public sources, community contributions, and private order flow via partnerships, and thus may underrepresent certain transaction types or geographies.

These data are instrumental in tracing market growth, assessing buyer–supplier dynamics, monitoring pricing trends, and benchmarking early-stage firms. In later sections, we will use CDR.fyi data to ground projections and comparisons.

2.4 Objectives & Scope of This White Paper

Given the rapid evolution of the CDR sector and strong interest from investors, policymakers, and climate stakeholders, this white paper aims to:

1. **Survey the technology landscape**: compare readiness, scalability, cost trends, and projected impact by 2035.
2. **Map the market pathways and viability**: assess voluntary, compliance, and corporate demand channels; estimate market size and growth; identify

monetisation models.

3. **Diagnose bottlenecks and propose solutions**: technical, institutional, financial, regulatory barriers and levers.
4. **Profile major players and funding mechanisms**: highlight frontrunners, identify capital flows, and explore future funding innovations.
5. **Forecast the future trajectory and recommendations**: propose what a robust CDR ecosystem might look like in 2035 and what actions are needed now.

This white paper is intended for a broad but informed readership: investors, corporate sustainability strategists, policymakers, climate NGOs, and academic stakeholders. Wherever possible, we aim to bootstrap hard data (e.g. from CDR.fyi and industry reports) while being transparent about uncertainties.

3. CDR Technologies: State of Play and Projections to 2035

This section surveys the major carbon dioxide removal (CDR) pathways, assesses their current readiness (TRLs, pilot/commercial status), and projects their possible scale, costs, and contributions by 2035. Wherever possible we anchor to observed deals and transactions from the durable CDR market (via CDR.fyi) and the broader technical literature.

3.1 Technology Families & Key Characteristics

Here is a quick comparative summary of the major CDR families and their trade-offs:

Technology Family	Core Mechanism	Storage / Sink	Strengths	Key Challenges / Risks
Nature-based (forest, soil, wetland, blue carbon)	Enhanced carbon uptake via photosynthesis / ecosystem restoration	Biomass, soil, sediment, wetlands	Low cost (initially), co-benefits for biodiversity, water, local communities	Reversals (fires, deforestation), saturation limits, competition for land, permanence concerns
Biomass + storage (Biochar, BECCS / BiCRS)	Capture CO_2 in biomass, then convert / store (e.g. pyrolysis, capture +	Stable carbon in soil or geologic	Leverages existing biomass value chains, dual revenue	Feedstock constraints, energy/processing cost, lifecycle

Technology Family	Core Mechanism	Storage / Sink	Strengths	Key Challenges / Risks
	geologic storage)	reservoir	streams (energy, products)	emissions, transport, scale-up
Engineered / geochemical (DAC, mineralisation, enhanced weathering, ocean alkalinity)	Direct removal or facilitation of CO_2 uptake by minerals or ocean chemistry	Geological, mineral, ocean alkalinity sinks	High permanence, can site away from biomass constraints, modular deployment	High energy demand / cost, scaling infrastructure, water/land use, chemical side-effects
Hybrid / integrative	Combinations, e.g. biomass + mineralization, waste streams, industrial integration	Mixed	Potential synergies, flexibility	Complexity of integration, coordination across sectors

In practice, few methods are purely isolated; many paths are hybrid, blending biological and engineered processes.

3.2 Current Readiness (TRLs) & Deployment Status

To understand how far each technology is from scale, we look at technology readiness, pilot/commercial projects, and observed market activity.

3.2.1 TRLs & Technology Assessments

- According to a recent NewClimate review, durable CDR technologies span TRLs from very low (1–2) for certain ocean or electrochemical methods, up to TRL 7–9 for some biomass / BECCS approaches.
- In particular, BECCS is often cited at the higher TRL range (7 to 9) among durable CDRs, meaning it is close to commercial readiness if financing and infrastructure align.
- Other engineered paths (enhanced weathering, ocean alkalinity, novel electrochemical mineralization) are often at earlier TRLs (2–5) and still in research or small pilot phases.

3.2.2 Deployment & Market Activity (CDR.fyi Observations)

- On the durable CDR market tracked by CDR.fyi, as of mid-2025: ~37.9 million tonnes of CO_2 removal have been **sold / contracted** (i.e., forward commitments) across ~5,749 orders, with 666 purchasers and 613 suppliers.
- However, only ~2.5 % of the contracted tonnes have been **delivered** so far, reflecting lead times, project development, and the nascent stage of large-scale deployment.
- Among methods, **BECCS** dominates contracted volumes: in Q2 2025, BECCS accounted for 90 % of contracted durable CDR by volume, while **Biochar Carbon Removal (BCR)** is the dominant method in deliveries and retirements so far.
- For biochar specifically: from 2022 to mid-2025, ~3.04 Mt of BCR credits have been contracted, with ~0.68 Mt delivered to date. The BCR market has been growing at a very high compound rate (e.g. CAGR of ~131 % in 2022–2024) in terms of contracted value.
- Large off-take deals in 2025 reflect confidence in future scale: eg, Microsoft contracted 14.6 Mt in Q2 2025 alone, mostly in BECCS.

These indicators show that while large-scale deployment is still rare, the pipeline (contracted volume) is rapidly ascending, especially for biomass-based routes.

3.3 Projections to 2035: Scale, Cost Declines & Contributions

Below we sketch plausible trajectories (baseline / optimistic) for each major pathway by 2035, and what share they might yield in an integrated CDR portfolio.

3.3.1 Scaling Scenarios & Aggregate Impact

To provide a rough framework, many climate modelling scenarios assume that by mid-century, cumulative CDR in the range of several to ~10 Gt CO_2/yr will be required. By 2035, the sector must begin to ramp meaningfully to reach those higher targets.

A hypothetical (illustrative) trajectory to 2035 might look like:

- **Nature-based approaches**: tens to low hundreds of $MtCO_2$/year (0.1–0.5 Gt)
- **Biochar / BiCRS / BECCS**: 0.5–1.5 Gt CO_2/year, depending on feedstock, policy, and infrastructure
- **Engineered (DAC, mineralization, ocean alkalinity)**: 0.1–0.5 Gt CO_2/year if cost and

energy challenges are mitigated

Thus, by 2035, a well-balanced portfolio might target **1–2 Gt CO_2 annually** from CDR as a realistic mid-term ambition (with continued scaling to 2050).

Note: These are illustrative and depend on policy, cost trajectories, infrastructure, and demand.

3.3.2 Cost Projections and Learning Curves

Cost decline is crucial to viability. Some indicative trends and expectations:

- Biochar / biomass-based methods have already demonstrated lower costs relative to engineered methods in many cases; as scale grows, economies in pyrolysis, logistics, and aggregation could reduce cost further.
- Engineered paths, especially DAC, are expected to see steep cost declines with mass deployment, modular scaling, improved materials, and lower energy intensity. Some projections aim for <$100–$200 per tCO_2 (or lower) by 2030–2035 under favourable assumptions (grid decarbonisation, cheap renewable energy, etc.).
- According to the 2025 CDR Market Survey (by CDR.fyi / Sylvera), suppliers (excluding biochar) expect durable CDR prices to decline in the next five years as much as over the following two decades.
- That said, purchasers expect lower prices than suppliers anticipate receiving - a tension that may compress margins and slow adoption if not resolved.

3.3.3 Method-by-Method Projections & Roles by 2035

Below is a stylised view of how each major pathway might evolve by 2035:

- **Nature-based / Ecosystem-based**
  Likely to continue scaling, but by 2035 constrained by land availability, reversals, and saturation. May contribute 0.1–0.4 Gt CO_2/yr in robust settings (with restoration, agroforestry, peatland rewetting).
- **Biochar / BiCRS**
    - Biochar (BCR) may remain a “delivery leader” in early years because of shorter lead times.
    - As supply chains aggregate and scale, BCR could reach 100s of Mt CO_2

annually.

    - BiCRS / biomass geological storage might grow more gradually, especially where geologic storage infrastructure is available.

- **BECCS (Bioenergy with Carbon Capture & Storage)**
    - Among the more mature durable options, BECCS may scale meaningfully in regions with abundant biomass and CO_2 storage capacity.
    - It could contribute hundreds of Mt to >1 Gt CO_2 per year, depending on policy incentives, energy demand synergies, and logistics.
- **Direct Air Capture (DAC)**
    - In 2035, DAC may still represent a modest share (e.g., tens to low hundreds of Mt CO_2/yr), but cost reductions and modular scaling may push it upward.
    - Regions with low-cost low-carbon electricity, CO_2 transport and storage, and stable policy support will lead.
- **Mineralisation / Enhanced Weathering / Ocean Alkalinity**
    - These methods may still be emerging in 2035, but pilot-to-commercial transitions could yield meaningful volumes (e.g. 10s of Mt CO_2/yr) if technical, ecological, and regulatory hurdles are resolved.
    - Their contribution may grow more in the 2035–2050 window, but early momentum is critical.

When aggregated, a plausible weighted mix by 2035 might look like:

- 40 % biomass-based (BECCS + BiCRS)
- 25 % nature-based / ecosystem
- 20 % DAC / engineered
- 15 % mineral / geochemical / hybrid

The exact mix depends heavily on regional strengths, policy, land constraints, and innovation breakthroughs.

3.4 Key Sensitivities, Risks & Caveats

It is important to highlight several key caveats and risk factors that could dramatically alter trajectories:

1. **Energy & Carbon Intensity**: Many engineered approaches require significant energy input; if that energy is fossil-based or not fully clean, net removal could be eroded.
2. **Feedstock & Land Constraints**: Biomass and nature-based approaches compete with agriculture, biodiversity, and land users; sustainable sourcing is a major limit.
3. **Infrastructure & Transport**: CO_2 transport pipelines, storage facilities, and integration with industrial clusters are nontrivial capital investments and may create bottlenecks.
4. **Permanence & Reversal Risk**: Ecosystem-based methods are vulnerable to disturbance, requiring buffer strategies and insurance.
5. **MRV & Uncertainty**: Accurate measurement, reporting, and verification remain technically and institutionally challenging, especially for emerging pathways.
6. **Policy Uncertainty**: Without stable, long-term policy incentives and carbon removal demand, many projected deployments may stall or fail to attract capital.
7. **Cost & Capital Risk**: The "valley of death" between pilot and commercial scale is wide. If early deployments burn capital without demonstrating credible scale, investor confidence may retreat.

3.5 Summary & Implications for 2035

- The CDR sector is shifting from pilots and small-scale projects toward a growing pipeline of large off-take agreements, especially in biomass-based routes.
- By 2035, we should expect a multi-hundred $MtCO_2$/yr scale for the leading pathways, with the potential to approach 1–2 Gt/yr under aggressive deployment and cost decline assumptions.
- BECCS and biomass-based pathways appear closest to commercial scale in many geographies, but engineered pathways (DAC, mineralization) are essential for scaling removals where biomass or land is constrained.
- The balance among methods will hinge on regional resource endowments,

infrastructure build-out, energy decarbonization, and policy support.

- Successful scale-up will require pushing down costs, creating enabling infrastructure, improving MRV, and aligning demand with supply growth.

4. The CDR Market

The carbon dioxide removal (CDR) market sits at the intersection of climate necessity and economic opportunity. It is both nascent and rapidly scaling, with signals of exponential growth emerging in the last three years. Today, most transactions are concentrated in voluntary markets led by corporate buyers, but compliance mechanisms and public procurement are beginning to play a larger role. This section outlines the pathways, assesses which are most viable, and projects the size and monetisation potential of the market to 2035.

4.1 Market Pathways

CDR demand currently flows through three primary pathways:

1. **Voluntary Carbon Market (VCM)**
    - Dominant channel for durable CDR purchases today.
    - Buyers are primarily corporates with ambitious net-zero or carbon-negative pledges (Microsoft, Shopify, Meta, Stripe, Airbus).
    - Instruments include long-term off-take agreements, advance market commitments (e.g., *Frontier*), and bilateral contracts.
    - VCM buyers value additionality, permanence, and co-benefits, often paying higher-than-average prices to support innovation.
2. **Compliance / Regulatory Markets**
    - Emerging but expected to scale significantly by 2030–2035.
    - Current examples:
        - The **EU ETS** is exploring CDR integration, with removals potentially

eligible under Article 6 of the Paris Agreement.

- The **U.S. Inflation Reduction Act (IRA)** provides subsidies for DAC ($180/t under 45Q), spurring large project announcements.
- Japan, Singapore, and Switzerland are piloting Article 6 bilateral CDR credit schemes.

- Compliance markets tend to favour standardised, high-certainty removals with robust MRV.

3. **Corporate Procurement & Public Procurement**
    - Beyond carbon accounting, corporates are directly contracting CDR to secure supply and de-risk their net-zero commitments.
    - Governments (e.g., U.S. Department of Energy's *Carbon Negative Shot*) are acting as catalytic buyers, offering procurement contracts to build early demand signals.

4.2 Viability of Market Pathways

The viability of each pathway varies with technology type:

- **Most Viable in Short Term (to 2030)**:
    - **Biochar**: rapid deployment, measurable, delivers co-benefits (soil fertility, waste management).
    - **BECCS / BiCRS**: high permanence, scalable where storage sites exist.
    - **Nature-based CDR**: valuable for co-benefits, though permanence concerns limit its role in compliance markets.
- **Emerging Viability (2030–2035)**:
    - **DAC**: policy support and cost declines may shift DAC from niche pilots to hundreds of millions of tonnes annually.
    - **Mineralization / Enhanced Weathering**: promising for permanence but still constrained by TRL and ecological uncertainties.

Overall, a **portfolio approach** is expected: nature-based and biomass pathways dominate near-term, while engineered solutions grow steadily to mid-century.

4.3 Market Size & Growth Projections

Current Market Size (2025)

- According to **CDR.fyi**, the durable CDR market has tracked ~37.9 Mt CO_2 **contracted** across ~5,700 orders, but only ~2.5% delivered to date.
- Contract values are in the low billions of USD, with biochar dominating actual deliveries and BECCS dominating forward contracts.
- Median credit prices:
    - Biochar: $100–$150/t
    - DAC: $600–$1,000/t (with frontier deals often higher)
    - BECCS: $150–$200/t

Projected Growth to 2035

- Multiple analyses (McKinsey, BCG, ICVCM, CDR.fyi) converge on CDR market expansion from <$5 billion today to **$100–200 billion by 2035**.
- **Volume projections**:
    - Baseline: ~0.5–1 Gt CO_2/yr by 2035
    - Optimistic: ~2 Gt CO_2/yr if strong policy support and cost reductions occur

Drivers of Growth

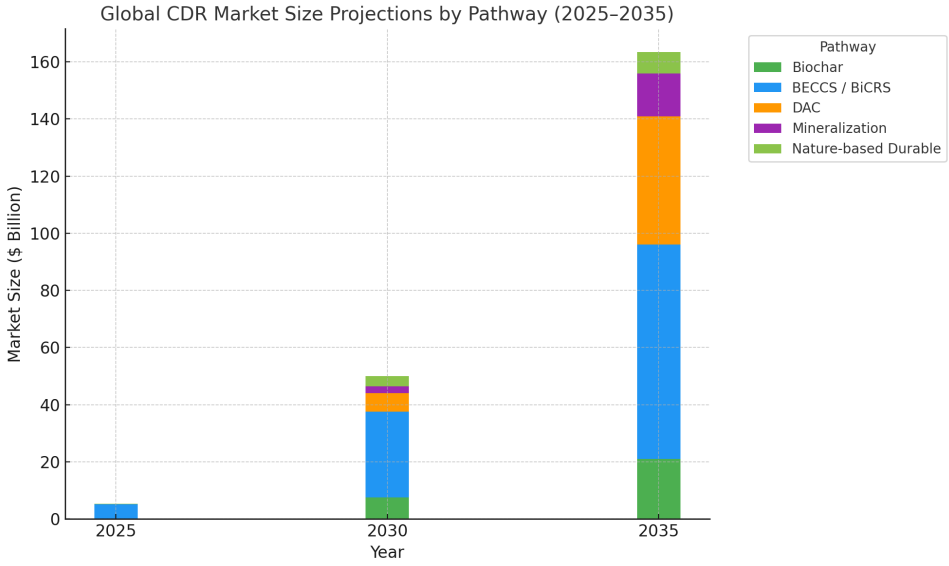
- Corporate net-zero deadlines (2030–2040) drive voluntary demand.
- Compliance integration will add scale and credibility.
- Public funding and procurement programs act as accelerators.
- Financial innovation (futures, securitized carbon removal assets) will deepen liquidity.

Table: Global CDR Market Sizing (Volumes & Value, 2025–2035)

Pathway	2025 Baseline	2030 Projection	2035 Projection
Biochar (BCR)	~3 Mt contracted; ~0.7 Mt delivered; avg $120/t → **$0.1B** market	50–100 Mt/yr; $80–120/t → **$5–10B**	200–400 Mt/yr; $60–100/t → **$12–30B**
BECCS / BiCRS	~30 Mt contracted (future delivery); avg $150–200/t → **$4–6B (forward commitments)**	100–300 Mt/yr; $120–180/t → **$15–45B**	500–800 Mt/yr; $100–150/t → **$50–100B**
Direct Air Capture (DAC)	~0.1 Mt contracted; avg $600–1,000/t → **<$0.1B**	10–30 Mt/yr; $300–500/t → **$3–10B**	100–300 Mt/yr; $150–300/t → **$15–75B**
Mineralization / Enhanced Weathering / Ocean Alkalinity	Pilot stage; <0.1 Mt; $200–400/t → **<$0.05B**	5–20 Mt/yr; $150–250/t → **$1–4B**	50–150 Mt/yr; $100–200/t → **$5–25B**
Nature-based Durable (peatland, mangroves, long-lived soil carbon)	~5 Mt at <$50/t (but quality concerns) → **$0.2B**	50–100 Mt/yr; $30–60/t → **$2–5B**	100–200 Mt/yr; $30–60/t → **$3–12B**

Totals

- **2025 Baseline**: ~$5–6B (dominated by forward BECCS contracts + biochar deliveries)
- **2030 Projection**: ~$25–60B (biochar + BECCS lead; DAC gaining traction)
- **2035 Projection**: ~$85–240B (BECCS + DAC as volume leaders, biochar as steady contributor, minerals/nature adding depth)



Key Insights

- **Biochar is the near-term workhorse**, driving early deliveries thanks to shorter lead times and measurable permanence.
- **BECCS dominates forward contracts**, but actual delivery depends on large-scale infrastructure and policy incentives.
- **DAC's share grows disproportionately post-2030**, once costs fall and compliance markets integrate it.
- **Mineralization and ocean-based methods remain small to 2030 but may ramp strongly in the 2035–2050 window** as technology matures.
- **Nature-based removals remain important but secondary**, mainly for co-benefits and regional adaptation.

4.4 Monetisation Opportunities

The CDR market offers multiple monetisation streams beyond simple credit sales:

1. **Carbon Credits**
    - Traditional model: issue and sell removal credits on voluntary or compliance markets.
    - Premium for durability and verifiable MRV.

2. **Ecosystem Co-benefits (Stacked Credits)**
    - Soil carbon + biodiversity credits + water credits (e.g., regenerative agriculture, wetland restoration).
    - Biochar projects can monetize both carbon credits and improved crop yields.
3. **By-product Value Chains**
    - Biochar as a soil amendment, activated carbon, or construction material.
    - Mineralization by-products as aggregates for cement and concrete.
    - Negative-emissions fuels (BECCS-derived power, bio-oil sequestration).
4. **Data & MRV-as-a-Service**
    - Digital MRV, blockchain registries, and IoT verification systems are emerging as standalone services.
    - Buyers increasingly pay premiums for verified, real-time data streams.
5. **Financial Products**
    - Forward purchase agreements, futures markets, and removal-backed securities (e.g., carbon removal ETFs).
    - Blended finance structures combining grants, concessional debt, and equity to de-risk early projects.

4.5 Summary

The CDR market is rapidly professionalizing, with a steep growth curve projected to 2035. While voluntary markets have catalysed innovation, compliance integration and large-scale corporate/public procurement will define the sector's maturation. The most viable near-term pathways - biochar and BECCS - are scaling now, while engineered approaches will capture increasing market share by the 2030s. Monetisation opportunities are diversifying into co-benefits, by-products, and financial innovation, creating a rich ecosystem around carbon removal.

5. Bottlenecks to Growth & Potential Solutions

Scaling carbon dioxide removal (CDR) from millions of tonnes today to gigaton levels by 2035 requires overcoming a range of technical, market, and policy challenges. This section examines the major bottlenecks holding back growth and outlines potential solutions that can unlock scale.

5.1 Technical Bottlenecks

1. **Measurement, Reporting & Verification (MRV) Gaps**
    - Many pathways, especially nature-based and biomass-based, face challenges in accurately measuring CO_2 removals.
    - Biochar MRV is improving, but soil carbon and ecosystem-based projects struggle with variability, leakage, and permanence risks.
    - Engineered methods like DAC or mineralization offer clearer accounting, but need standardised protocols.

    Solution:

    - Invest in **digital MRV** - combining IoT sensors, satellite imagery, and AI analytics.
    - Standardise methodologies (via ISO, ICVCM, or registries) to reduce uncertainty and increase credit trust.
    - Develop **MRV-as-a-service platforms**, enabling smaller suppliers to access robust verification at low cost.

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2. **Energy & Resource Intensity**
    - DAC and mineralization require high energy inputs; if powered by fossil energy, net removal is undermined.
    - BECCS and biochar depend on sustainable biomass feedstock, constrained by land competition.

Solution:

- **Co-locate engineered CDR** with abundant renewable energy sources and CO_2 storage infrastructure.
- Promote **circular feedstock systems** - e.g., agricultural residues, invasive species (like lantana in India), or waste biomass.
- Incentivize R&D into low-energy sorbents, electrochemical methods, and waste-stream utilization.

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3. **Infrastructure Gaps**
    - Lack of CO_2 transport pipelines, geologic storage hubs, and large pyrolysis facilities delays deployment.
    - Permitting and community opposition often slow down infrastructure projects.

Solution:

- Public–private partnerships to build **CO_2 storage and transport hubs**.
- "Carbon storage as infrastructure" policy framing, similar to electricity grids or highways.
- Streamlined permitting processes with early community engagement.

5.2 Market Bottlenecks

1. **High Costs vs. Buyer Willingness**
    - Most durable CDR today is priced between $100–600 per tonne, far above typical avoidance credits.
    - According to CDR.fyi's 2025 market survey, buyers expect significantly lower prices in the future than suppliers anticipate receiving - a structural tension.

Solution:

- **Blended finance** models (philanthropy + concessional capital + commercial

buyers) to bridge early cost gaps.

- Advance Market Commitments (AMCs) like **Frontier** to guarantee future demand and de-risk investment.
- Government subsidies (e.g., U.S. 45Q tax credit, EU Carbon Removal Certification Framework).

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2. **Credit Quality & Trust Deficit**
    - Market skepticism over permanence, additionality, and double-counting undermines buyer confidence.
    - Low-quality offset controversies spill over into perceptions of removals.

    Solution:

    - Independent standards (ICVCM, SBTi, ISO) for high-integrity removals.
    - Differentiation between **avoidance offsets** and **durable removals** in reporting frameworks.
    - Transparent, open data platforms (like **CDR.fyi**) to track purchases, deliveries, and retirements.

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3. **Fragmented Market Structure**
    - Over 600 suppliers are active (CDR.fyi), but most are small and undercapitalised.
    - Lack of liquidity, secondary markets, and standard contracts makes scaling difficult.

    Solution:

    - Development of **carbon removal exchanges** and standardised contracts (analogous to power purchase agreements).
    - Aggregation platforms to pool small suppliers for bulk corporate buyers.
    - Secondary trading markets for removal credits to improve liquidity.

5.3 Policy Bottlenecks

1. **Uncertain Policy Support**

    - Few governments have set binding CDR targets.
    - Lack of predictable long-term incentives deters investment in capital-intensive projects (e.g., BECCS, DAC).

    Solution:

    - National CDR strategies (e.g., EU, U.S., Japan) with clear deployment targets.
    - Public procurement of durable CDR credits.
    - Integration of removals into compliance markets (ETS, Article 6).

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2. **Global Equity Concerns**

    - Most funding flows into Global North technologies; Global South projects (biochar, afforestation, agroforestry) are underfunded despite co-benefits.

    Solution:

    - Channel climate finance into Global South removal projects via Article 6, development banks, and just transition funds.
    - Prioritise **livelihood-linked CDR models** (e.g., biochar with farmer income, mangrove restoration for coastal resilience).

5.4 Summary

The CDR industry faces a **triple challenge**:

- **Technical**: MRV, energy, infrastructure.
- **Market**: costs, credit quality, fragmentation.
- **Policy**: lack of long-term frameworks and equitable funding.

Solutions exist - from digital MRV and AMCs to CO_2 infrastructure hubs and blended finance. The next decade is less about scientific discovery and more about **deployment,**

scaling, and trust-building. Overcoming these bottlenecks will determine whether the industry can reach the 1–2 Gt/year milestone by 2035.

6. Major Players and Funding Pathways

The CDR industry has grown from a handful of pilot companies to a diverse ecosystem of suppliers, buyers, financiers, and intermediaries. As of mid-2025, **CDR.fyi tracks more than 600 suppliers and over 650 buyers**, reflecting both fragmentation and momentum. This section maps the industry landscape, highlights major players, and explores funding flows and future capital pathways.

6.1 Industry Landscape

The CDR value chain can be divided into four main groups:

1. **Suppliers / Technology Developers**
    - Companies developing CDR technologies and delivering tonnes of CO_2 removal.
    - Examples: Climeworks (DAC), Charm Industrial (bio-oil sequestration), Heirloom (DAC with minerals), Running Tide (ocean), Carbfix (mineralization), Ecosys.Earth (biochar, Global South livelihoods).
2. **Corporate Buyers & Coalitions**
    - Large corporates purchasing removals to meet net-zero targets.
    - Microsoft, Shopify, Amazon, Airbus, JPMorgan Chase are leading buyers.
    - Coalitions such as **Frontier** (Stripe, Alphabet, Shopify, Meta, McKinsey) have committed over **$1B+ in AMCs** to guarantee off-take.
3. **Intermediaries & Registries**
    - Platforms standardising credit issuance, aggregation, and MRV.
    - CDR.fyi (transparency and market data), Puro.earth (biochar registry), Verra and Gold Standard (exploring durable removals), ICVCM (standards),

Carbonfuture (marketplace with MRV).

4. **Public Sector & Philanthropy**
    - U.S. Department of Energy, European Union, and philanthropic foundations (e.g., Chan Zuckerberg Initiative, Gates Foundation) act as catalytic funders.
    - Multilateral development banks are exploring Global South CDR integration.

6.2 Major Players (Representative Profiles)

Climeworks (Switzerland)

- Pioneer of Direct Air Capture, operating the world's largest DAC + storage facility (*Orca*, Iceland).
- High-profile corporate off-take deals (Microsoft, Stripe).
- Raised >$600M (2022), signalling investor confidence.

Charm Industrial (U.S.)

- Converts waste biomass into bio-oil and injects it underground for permanent storage.
- Strong early delivery record; contracted by Microsoft and Shopify.
- Known for innovation in biomass feedstock utilisation.

Heirloom (U.S.)

- DAC startup leveraging accelerated mineralization for lower-cost CO_2 capture.
- Won U.S. DOE funding for DAC hubs; backed by Bill Gates's Breakthrough Energy.

Running Tide (U.S.)

- Ocean-based CDR via sinking biomass in deep sea and enhancing alkalinity.
- Early-stage but controversial; pilot projects with Shopify, Stripe.

Carbfix (Iceland)

- Mineralization company injecting CO_2 into basalt rock formations.

- Partnering with DAC firms for integrated storage.

Carbon Standards International

- Implements **Global Artisan C-Sink** biochar methodology.
- Focus: durable removal + rural livelihoods
- Represents the rise of **Global South innovators** in durable CDR, aligning carbon finance with community development.

Corporate Buyers

- **Microsoft**: Most active corporate CDR buyer (~16 Mt contracted).
- **Shopify**: Early pioneer in advance purchases.
- **Airbus**: Engaged in DAC contracts for future aviation offsets.
- **Amazon / Frontier**: Pooled commitments driving early-stage suppliers.

6.3 Funding Flows

The funding landscape for CDR is increasingly dynamic:

- **Venture Capital & Private Equity**
    - 2021–2024: >$3.5B invested in DAC, biochar, mineralization startups.
    - Climate-focused funds (Lowercarbon Capital, Breakthrough Energy, Sequoia Climate) are heavily invested.
- **Corporate Procurement**
    - Advance Market Commitments (e.g., Frontier's $1B+ pool) de-risk early suppliers.
    - Bilateral off-take deals (e.g., Microsoft with Heirloom, Shopify with Charm).
- **Government Support**
    - U.S. IRA: $3.5B DAC hubs, $180/t 45Q tax credit.
    - EU: Carbon Removal Certification Framework + Innovation Fund grants.

- Japan, Singapore: bilateral Article 6 pilots.

- **Philanthropy & Catalytic Capital**
  - Philanthropic foundations bridging gaps for Global South removals (biochar, mangroves, regenerative agriculture).
  - Effective Altruism-linked funds seeding early science-based startups.

6.4 Future Funding Pathways

Looking ahead, the CDR industry is likely to see:

1. **Aggregated Buyer Clubs**
   - Frontier-style AMCs replicated regionally (e.g., Asia, EU).
2. **Public Procurement at Scale**
   - Governments buying durable CDR for national targets (e.g., EU "Contracts for Difference" for CDR).
3. **Financial Products & Markets**
   - Carbon removal ETFs, securitised portfolios of CDR credits, futures markets.
   - Insurance products for permanence (covering reversal risks).
4. **Global South Finance Integration**
   - NABARD, World Bank, and regional development banks funding livelihood-linked removals.
   - Potential for "ecosystem credits" beyond carbon (soil, water, biodiversity).

6.5 Summary

The CDR industry's landscape is becoming both **crowded and capitalised.** A handful of pioneers (Climeworks, Charm, Heirloom) are scaling engineered solutions, while biochar providers and ecosystem-linked innovators (Carbon Standards International, Puro.earth suppliers) dominate near-term delivery. Corporate buyers and pooled coalitions are de-

risking markets, while governments and philanthropies inject catalytic capital.

The future lies in **blended finance models, stronger compliance integration, and greater Global South participation**. By 2035, the industry is likely to consolidate into a tier of large-scale suppliers with robust funding ecosystems, alongside distributed local providers delivering co-benefits.

7. The Future of the CDR Industry

The next decade will define whether carbon dioxide removal (CDR) becomes a cornerstone of global climate strategy or remains a niche innovation. Current trends point toward rapid industrialisation, with consolidation among suppliers, deeper policy integration, and expansion into new geographies. By 2035, the CDR sector may evolve into a multi-gigaton, $100–200B market, shaping energy systems, land use, and financial flows worldwide.

7.1 Timeline of Key Milestones (2025–2035)

- **2025–2027: Early Commercialisation**
    - Biochar and BECCS projects dominate deliveries.
    - DAC hubs break ground in the U.S. and EU.
    - Article 6 bilateral carbon removal projects emerge.
    - CDR.fyi and similar platforms establish transparency benchmarks.
- **2028–2030: Market Maturation**
    - Compliance markets (EU ETS, U.S. state-level schemes) begin accepting durable CDR.
    - DAC costs fall to ~$300/t as scale and learning curves improve.
    - Consolidation among suppliers: top 20 firms deliver majority of tonnes.
    - Global South innovators expand, leveraging blended finance.
- **2031–2035: Gigaton Scale-Up**

- CDR reaches ~1–2 $GtCO_2$ annually, representing a significant share of climate portfolios.
- DAC and mineralization begin rivalling biomass-based methods in volume.
- Global commodity-style contracts for removals emerge, traded on exchanges.
- Ecosystem credits (carbon + biodiversity + water) become standard in project financing.

7.2 Likely Industry Dynamics

1. **Consolidation & Vertical Integration**
    - Early fragmentation (600+ suppliers today) will consolidate as winners emerge.
    - Integration of capture, storage, MRV, and financing into vertically aligned companies.
    - Strategic alliances between energy majors, agribusiness, and CDR startups.
2. **Global South Emergence**
    - By 2035, Global South projects (biochar, mangrove restoration, regenerative agriculture) will represent a large share of delivery volumes.
    - Livelihood-linked models (e.g., Carbon Standards International's artisan biochar sinks) gain traction as "just transition" CDR models.
    - Development banks and Article 6 funds drive South-South and North-South partnerships.
3. **Financialisation of CDR**
    - Futures markets, ETFs, and securitised carbon removal assets create liquidity.
    - Insurers provide permanence guarantees (covering reversal risk).
    - Carbon removal becomes an investable asset class, attracting institutional

investors.

4. **Technology Evolution**
    - DAC and electrochemical pathways achieve steep cost declines.
    - Mineralization and ocean alkalinity move from pilots to commercial-scale operations.
    - Hybrid models integrating waste management, energy generation, and CDR become widespread.

7.3 Intersection with Other Industries

- **Energy Transition**: BECCS integrates with bioenergy, DAC aligns with hydrogen and storage hubs.
- **Agriculture**: Biochar and soil carbon become part of regenerative agriculture.
- **Construction**: Mineralised aggregates and CO_2-infused materials enter building supply chains.
- **Ocean Economy**: Coastal restoration and ocean alkalinity tie into fisheries, coastal protection, and resilience.

7.4 Scenarios for 2035

- **Baseline Scenario**:
    - 0.5–1 Gt CO_2/yr removal.
    - Market ~$85–100B.
    - Dominated by biochar and BECCS, with DAC just entering scale.
- **Accelerated Scenario**:
    - 1.5–2 Gt CO_2/yr removal.
    - Market ~$200B+.

- DAC and mineralization achieve rapid cost declines, with compliance markets absorbing large volumes.

- **Stalled Scenario**:
  - <0.3 Gt CO_2/yr removal.
  - Market <$50B.
  - Caused by weak policy, slow infrastructure build-out, and loss of investor confidence.

7.5 Outlook

The CDR industry is poised to become a **pillar of global climate mitigation**, on par with renewable energy and electrification. Its trajectory depends on whether the sector can:

- Deliver credible, durable removals at scale.
- Overcome MRV, infrastructure, and financing bottlenecks.
- Build global equity into deployment, ensuring benefits flow to both Global North and South.

If these conditions are met, by 2035 CDR will not only help close the emissions gap but also reshape global value chains, rural economies, and financial markets.

8. Cross-Cutting Considerations

Beyond technology readiness, market growth, and financing, the future of carbon dioxide removal (CDR) will be shaped by systemic factors that cut across the entire industry. These considerations influence trust, adoption, and equity - and will determine whether CDR scales responsibly.

8.1 Ethics and Equity

- **Global North vs. Global South**

Today, most durable CDR projects and financing are concentrated in North America and Europe. Yet the Global South has vast potential for biochar, regenerative agriculture, afforestation, and ocean-based approaches. Without equitable finance flows, the industry risks reproducing historical climate injustices.

Action Point: Develop **just transition models** where Global South CDR delivers removals alongside co-benefits such as rural livelihoods, food security, and biodiversity protection.

- **Indigenous & Local Community Rights**
  Large-scale projects can conflict with land rights, cultural values, and traditional practices. Ensuring **free, prior, and informed consent (FPIC)**, as well as equitable benefit-sharing, is essential.

8.2 Standards and Governance

- **Fragmentation of Standards**
  Currently, multiple bodies are active: Puro.earth (biochar), Verra and Gold Standard (nature-based), ICVCM (Integrity Council for Voluntary Carbon Markets), ISO task forces, and emerging national frameworks (EU Carbon Removal Certification). This creates confusion for buyers and suppliers.
- **Need for Harmonisation**
  By 2030, the industry requires harmonised global standards that:
  - Distinguish **avoidance offsets** from **durable removals**.
  - Define permanence thresholds (e.g., ≥100 years).
  - Set clear MRV protocols across pathways.
- **Role of Transparency Platforms**
  CDR.fyi and similar platforms provide a model for open data. Their transparency reduces greenwashing risk and builds trust in removals.

8.3 Permanence and Risk Management

- **Reversal Risks**

Nature-based solutions face fire, disease, or land-use change; biochar is more stable but requires proper application and tracking; engineered solutions are generally more permanent but not risk-free.

- **Insurance & Buffering**
  The industry is beginning to develop **insurance products** to guarantee permanence (covering reversal risks). Buffer pools, common in carbon markets, may evolve into **risk-adjusted crediting systems** for removals.

8.4 Public Perception and Social License

- **Moral Hazard Concerns**
  Critics argue that CDR may be used as an excuse to delay emissions cuts. Credible governance must emphasise that CDR is a **complement, not a substitute** for decarbonisation.
- **Transparency and Communication**
  To gain legitimacy, the industry must communicate its role clearly - highlighting co-benefits, real deliveries, and limitations. Overhyping speculative technologies risks public backlash.

8.5 Interactions with Nature and Ecosystems

- **Biodiversity Synergies and Risks**
  CDR projects can enhance ecosystems (mangrove restoration, regenerative agriculture) or harm them (monoculture plantations, poorly managed biomass harvest).
- **Ocean Impacts**
  Ocean-based CDR (alkalinity, biomass sinking) carries significant uncertainties. Research and safeguards are required before large-scale deployment.

8.6 Climate Policy Integration

- **Article 6 of the Paris Agreement**

Integration of CDR into global compliance markets could unlock large-scale demand - but only if integrity and transparency are maintained.

- **National Targets**
  Few countries currently have dedicated CDR targets. Setting explicit national deployment goals (as the EU and U.S. have begun) will provide long-term certainty.

8.7 Summary

Cross-cutting factors will decide whether CDR becomes a trusted pillar of climate mitigation or faces backlash.

- **Equity**: Global South participation and community rights.
- **Standards**: Harmonisation and clarity between offsets and removals.
- **Risk**: Permanence insurance and reversal management.
- **Perception**: Maintaining social license through transparency.
- **Ecosystems**: Ensuring ecological co-benefits and avoiding harm.

In short, **trust, equity, and governance** are as important as gigaton-scale deployment. Without them, CDR risks becoming fragmented or delegitimised; with them, it can anchor a fair, effective, and durable global climate response.

9. Policy Recommendations

For carbon dioxide removal (CDR) to scale from today's fragmented pilots to gigaton levels by 2035, strong and coordinated policy frameworks are essential. Market forces and voluntary initiatives alone will not deliver the scale, equity, and trust required. The following recommendations outline priority actions across different stakeholder groups.

9.1 National Governments

1. **Set Explicit CDR Targets**

- Integrate CDR into national climate strategies (NDCs, Long-Term Low Emission Development Strategies).
- Establish annual or decadal deployment goals (e.g., 50–200 $MtCO_2$/yr by 2035 for major economies).

2. **Public Procurement & Demand Signals**
    - Governments should act as **first buyers** of durable CDR credits, similar to renewable energy feed-in tariffs.
    - Use long-term contracts to de-risk early suppliers.
3. **Incentives & Subsidies**
    - Extend or replicate policies like the U.S. 45Q tax credit ($180/t for DAC with storage).
    - Offer production tax credits, capital grants, and low-cost loans for CDR infrastructure (pipelines, storage hubs, pyrolysis plants).
4. **Regulatory Integration**
    - Include durable removals in compliance markets (EU ETS, California ETS, UK ETS).
    - Develop quality criteria distinguishing removals from avoidance offsets.
5. **Infrastructure & R&D Support**
    - Fund regional CO_2 storage hubs and transport networks.
    - Support early-stage R&D for ocean alkalinity, mineralization, and electrochemical CDR.

9.2 Corporates

1. **Advance Market Commitments (AMCs)**
    - Form buyer pools (Frontier-style) to commit long-term financing for CDR suppliers.
    - Secure future supply while helping scale technologies.

2. **Integrate CDR into Net-Zero Strategies**
    - Prioritise emissions reduction, but allocate 5–10% of net-zero budgets to removals.
    - Differentiate between **avoidance offsets** and **durable removals** in disclosures.
3. **Transparency & Leadership**
    - Publicly disclose purchase volumes, prices, and suppliers (as Microsoft, Shopify, and Stripe do).
    - Invest in MRV innovation to raise industry-wide integrity.

9.3 Investors & Financial Institutions

1. **Blended Finance Structures**
    - Combine concessional capital, grants, and commercial equity to de-risk early projects.
    - Deploy catalytic finance in Global South removal initiatives.
2. **Carbon Removal as an Asset Class**
    - Develop securitised portfolios of CDR credits.
    - Create carbon removal funds, ETFs, and futures markets to deepen liquidity.
3. **Risk Management Instruments**
    - Insurance against reversal risks.
    - Standardised credit contracts to reduce counter-party risk.

9.4 International Institutions

1. **Article 6 Operationalisation**
    - Ensure durable removals are eligible under Article 6.4 market mechanisms.

- Set integrity standards to prevent double counting.

2. **Multilateral Development Banks**
    - Fund Global South removal projects, prioritising livelihood-linked models.
    - Provide concessional loans for infrastructure (e.g., biochar hubs, pyrolysis plants, DAC clusters).
3. **Global Standards Harmonisation**
    - Support ISO and ICVCM in establishing unified CDR accounting rules.
    - Promote global registries for removals (analogous to renewable energy certificates).

9.5 Civil Society and NGOs

1. **Watchdog Role**
    - Monitor corporate claims, push for transparency, and expose greenwashing.
    - Advocate for climate justice in CDR deployment.
2. **Community Engagement**
    - Support local communities in co-designing CDR projects.
    - Ensure benefits are equitably shared (jobs, income, resilience).

9.6 Summary

CDR cannot scale without **strong policy scaffolding**. Governments must set targets, provide subsidies, and build infrastructure; corporates must commit long-term demand; investors must innovate financing tools; international institutions must harmonise standards; and civil society must hold the system accountable.

Together, these actions can transform CDR from a fragmented voluntary niche into a robust global industry delivering 1–2 Gt CO_2 removals annually by 2035.

10. Conclusion

Carbon dioxide removal (CDR) is no longer an abstract concept - it is a practical necessity. Scientific consensus is clear: even with aggressive emissions reductions, the world cannot reach net-zero without durable removals. By 2035, the industry has the potential to scale into a multi-gigaton, $100–200 billion global sector that complements decarbonisation, repairs legacy emissions, and supports sustainable development.

This white paper has highlighted:

- **Technological pathways**: from nature-based to engineered, with biochar and BECCS leading near-term deployment, and DAC, mineralization, and ocean-based solutions scaling mid-term.
- **Market evolution**: starting with voluntary corporate commitments, expanding into compliance systems and public procurement, with projected growth to 1–2 Gt CO_2 per year by 2035.
- **Bottlenecks**: technical (MRV, energy, infrastructure), market (cost, credit quality), and policy (uncertainty, equity gaps).
- **Solutions**: digital MRV, blended finance, policy incentives, global standards, and just transition models.
- **Players and finance**: a vibrant ecosystem of startups, corporates, coalitions, governments, and financiers, all shaping the industry's trajectory.
- **Future trajectory**: consolidation, financialisation, and integration with other industries, with Global South participation as both opportunity and imperative.
- **Cross-cutting factors**: equity, governance, risk, and perception - determinants of trust as much as technology or cost.

The opportunity is immense. CDR can:

- Deliver **gigaton-scale removals** by mid-2030s.
- Unlock **co-benefits** for soil, water, biodiversity, and rural livelihoods.
- Create **new industrial value chains** in energy, construction, and agriculture.
- Position nations and companies as leaders in a defining sector of the 21st century.

But the risks are equally real. Without strong governance, equitable finance, and credible delivery, CDR could be undermined by mistrust, greenwashing, or inequity. The difference between a thriving CDR industry and a stalled one is the collective choices made in the next decade.

The call to action is clear:

- Governments must set ambitious CDR targets and back them with procurement, subsidies, and standards.
- Corporates must move from symbolic purchases to strategic portfolios of removals.
- Investors must innovate new finance models to de-risk scale-up.
- International institutions must harmonise standards and channel finance equitably.
- Civil society must ensure that CDR enhances justice, not deepens divides.

If these steps are taken, by 2035 the CDR industry will stand alongside renewable energy and electrification as one of the pillars of climate stabilisation. If they are not, the world risks overshooting its climate goals irreversibly.

The next decade is decisive. CDR is not a silver bullet - but without it, there is no path to a sustainable and just future.

Appendices

Appendix A: Technology Readiness & Durability Matrix

Pathway	Technology Readiness Level (TRL, 2025)	Deployment Status	Typical Cost ($/t CO_2)	Storage Durability
Afforestation / Reforestation	TRL 8–9	Widely deployed	10–50	Decades–centuries (reversal risk)
Soil Carbon Enhancement	TRL 6–8	Pilots, programs scaling	20–50	10–100 years
Biochar	TRL 7–9	Commercial projects active	80–150	Centuries–millennia

Pathway	Technology Readiness Level (TRL, 2025)	Deployment Status	Typical Cost ($/t CO_2)	Storage Durability
BECCS / BiCRS	TRL 7–9	Early commercial, large pilots	120–200	Millennia (geologic storage)
Direct Air Capture (DAC)	TRL 5–7	Demonstration plants	300–600 (falling to 150–300 by 2035)	Millennia
Mineralization / Enhanced Weathering	TRL 3–6	Lab/pilot projects	150–400	Millennia
Ocean Alkalinity Enhancement	TRL 3–5	Early R&D, pilots	200–400	Centuries–millennia
Ocean Biomass Sinking (e.g., kelp)	TRL 2–4	Early pilots	TBD	Uncertain, decades–centuries

Appendix B: Cost Curve Projections (2025–2035)

Indicative cost decline trajectories based on learning curves and scaling assumptions:

Pathway	2025 Cost Range ($/t CO_2)	2030 Projection	2035 Projection
Biochar	80–150	60–100	50–80
BECCS / BiCRS	120–200	100–150	80–120
DAC	600–1000	300–500	150–300
Mineralization	150–400	120–250	80–150
Nature-based (durable)	20–50	20–40	20–40

Appendix C: Market Projections Summary

Global CDR Market by 2035 (Baseline vs. Accelerated Scenario)

Year	Baseline Volume ($GtCO_2$/yr)	Accelerated Volume ($GtCO_2$/yr)	Market Value ($B)
2025	~0.04	~0.04	~5–6
2030	0.5–0.7	1.0–1.2	25–60
2035	1.0	1.5–2.0	85–240

Appendix D: Glossary of Key Terms

- **CDR (Carbon Dioxide Removal):** Processes that remove CO_2 from the atmosphere and store it durably.
- **BECCS (Bioenergy with Carbon Capture and Storage):** Biomass used for energy with captured CO_2 stored geologically.
- **Biochar:** Stable carbon product from pyrolysis of biomass applied to soil or used in materials.
- **DAC (Direct Air Capture):** Engineered technology to chemically capture CO_2 directly from ambient air.
- **MRV (Measurement, Reporting, Verification):** Systems ensuring removals are real, measurable, and permanent.
- **Additionality:** Assurance that carbon removals are above what would have occurred without the project.
- **Permanence:** Duration that CO_2 remains stored without risk of reversal.
- **Advance Market Commitment (AMC):** Buyer coalitions guaranteeing future purchases to stimulate supply.
- **Article 6:** Paris Agreement framework enabling international carbon credit trading.
- **ICVCM:** Integrity Council for the Voluntary Carbon Market, developing global standards for high-quality credits.

Appendix E: Key Data Sources

1. **CDR.fyi** – Largest open registry of durable carbon removal market data, tracking buyers, suppliers, contracts, deliveries, and prices.
   https://www.cdr.fyi
2. **IPCC AR6 (Working Group III – Mitigation of Climate Change)** – Authoritative scientific report outlining mitigation pathways and the role of CDR in limiting warming to 1.5–2°C.
   https://www.ipcc.ch/report/ar6/wg3

3. **IEA Net Zero Roadmap (2023 Update)** – Energy and carbon removal pathways to achieve global net zero by 2050.
   https://www.iea.org/reports/net-zero-roadmap
4. **McKinsey – Carbon Removals: How to Scale a New Gigaton Industry (2023)** – Market outlook, projections, and industry analysis.
   https://www.mckinsey.com/capabilities/sustainability/our-insights/carbon-removals-how-to-scale-a-new-gigaton-industry
5. **BCG – The Time for Carbon Dioxide Removal Has Come (2022)** – Corporate and investor perspective on scaling CDR solutions.
   https://www.bcg.com/publications/2023/the-need-and-market-demand-for-carbon-dioxide-removal
6. **U.S. Department of Energy – Carbon Dioxide Removal (FECM Office)** – Policy framework, funding programs, and R&D initiatives under the Carbon Negative Shot and IRA.
   https://www.energy.gov/fecm/carbon-dioxide-removal
7. **European Commission – Carbon Removal Certification Framework (CRCF)** – EU's proposed framework for certifying removals.
   https://climate.ec.europa.eu/eu-action/carbon-removals-and-carbon-farming_en
8. **ICVCM – Integrity Council for the Voluntary Carbon Market** – Global governance body developing Core Carbon Principles (CCPs) and standards for high-quality credits.
   https://icvcm.org

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