Global optimal portfolio for carbon dioxide removal

Inside this report

- Discover Climeworks' optimized model for a CDR portfolio, designed for maximum effectiveness and efficiency.
- Explore the significant cost savings, permanent removal, de-risked deployment, and accelerated scale-up offered by an optimal CDR strategy.
- Understand how an optimal mix of nature-based and engineered CDR solutions will evolve to meet climate targets within planetary boundaries.
- Learn how our advanced CDR modeling and tailored strategies can accelerate your organization's net-zero transition.

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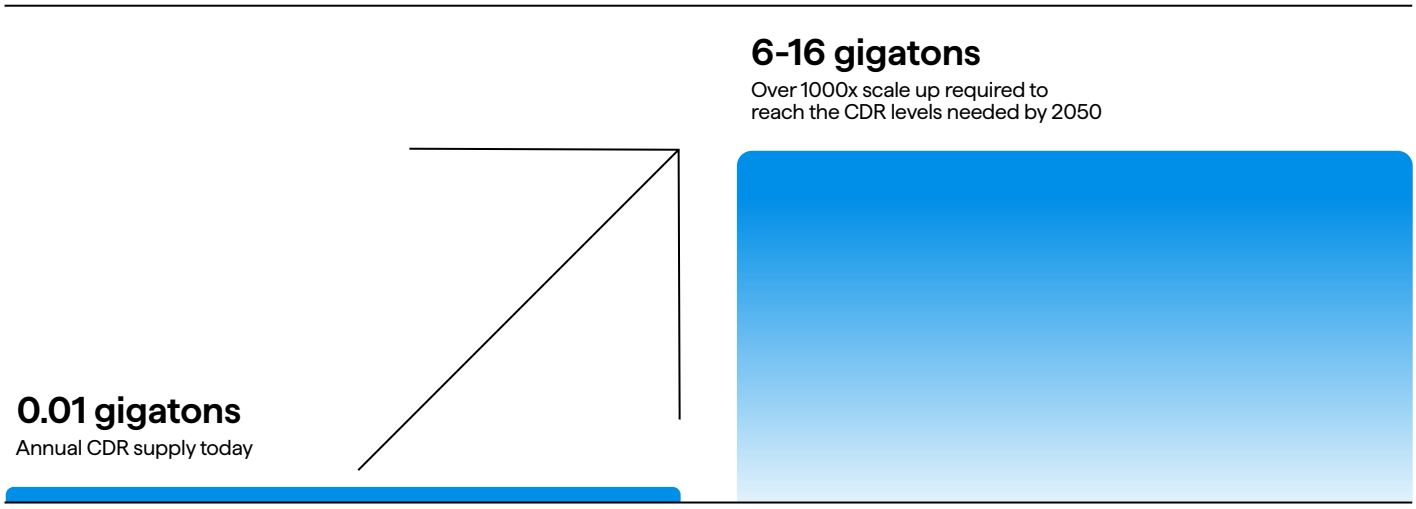
The climate imperative

Our Earth's climate system is undergoing rapid and unprecedented change. Human-induced warming has now reached approximately 1.47°C above pre-industrial levels, with recent analyses showing an increase of roughly 0.26 °C in the last decade, a rate that exceeds any similar period in history and far outpaces natural variability [1, 2]. The implications are stark: without both rapid emissions reduction and active removal of CO_2, the world is poised to exceed 1.5 °C of warming well before mid-century, risking irreparable damage on ecosystems, food security, and human health [3, 4].

In order to limit warming to no higher than 2 °C, carbon removal, in addition to carbon reduction, is required on the order of 6–16 Gt CO_2 annually by 2050, to compensate for residual and historic greenhouse gases in the atmosphere [5, 7]. However, today's global carbon dioxide removal (CDR) capacity amounts to only about 0.01 GT of CO_2 per year across all nature- and engineered-based pathways combined [5, 6]. Achieving a >1,000× expansion of current capacity within 25 years is ambitious, yet entirely feasible, as seen with transformative technologies like solar and wind power.

Navigating this challenge requires strategic action today, and by doing so, unlocks opportunities for economic growth. We must critically respect finite planetary resources (land, water, and materials) and account for the scaling and deployment limits of diverse CDR pathways on the path to net-zero by 2050 [8, 9].



All high-quality solutions, nature-based and engineered, are needed to reach 6-16 Gt CDR scale

Corresponding land, material, or biomass usage for achieving **10 Gt CDR** per year relying on either reforestation (RF), enhanced weathering (EW), or bioenergy with carbon capture and storage (BECCS) alone.

~1.5x

The area of North America covered with trees for reforestation[1]

~90m

Jumbo jets weighing the same as the rock powder used for enhanced weathering[2]

5x

The global municipal solid waste biomass for BECCS utilizing waste incineration[3]

1 Assuming a land-use of up to 4,000 m²/ton CDR. Exact numbers depend on tree species, climate zone, and other climate factors [15].
2 Assuming rock powder mass of 4 tons/ton CDR [16]
3 Assuming global municipal solid waste generation of 2.3 bn tons/year [11] at 50% biogenic fraction [12] and 90% capture rate [13].

Our strategic blueprint:

Building the optimal global CDR portfolio

It's clear that no single CDR pathway can achieve the necessary global scale independently, and a diverse portfolio of CDR solutions is the most practical strategy to meet climate targets. So, what would be the most optimal path to get there—one that's both effective, and efficient?

To answer this, we approached carbon removal as a sophisticated optimization challenge and created a model of the optimal global CDR portfolio, from now through 2050. We included the most advanced CDR solutions available today[4], across reforestation, mangroves, biochar, enhanced weathering (EW), bioenergy carbon capture and storage (BECCS) and direct air capture and storage (DACS) [6], and designed the portfolio mix to evolve over time to optimize cost-effectiveness, while aligning with climate objectives and respecting planetary boundaries. The result is a blueprint for the optimal combination of nature-based and engineered CDR pathways to achieve climate targets on time, and at the lowest cost.

This optimized CDR portfolio is not only essential for limiting global warming, but also unlocks compelling economic advantages:

>$125

per ton in average savings

Through our optimized modeling, average CO_2 removal costs yield savings of >$125 per ton compared to prevailing carbon tax rates [10], translating your CDR investment into immediate financial upside over traditional pay-to-pollute frameworks.

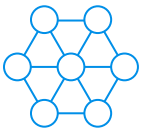
2x

faster delivery trajectory

The optimal portfolio achieves a 2x faster deployment trajectory for novel CDR pathways compared to standard industry forecasts,[5] by harnessing learning-by-doing to drive down unit costs over time.

Up to 20-35%

in estimated risk-adjusted savings[6]



Diversification across CDR pathways cushions against technology failures, resource constraints, or underperformance in any single approach.

2030

permanent removal

By 2030, the portfolio is projected to deliver durable CDR at a cost effectiveness on par with, or even better than, continued investments in reforestation credits.[7]

4 Our analysis focuses on solutions currently offered through Climeworks Solutions portfolios. However, other CDR solutions, such as soil carbon sequestration and ocean-based approaches, will also play a role in achieving global climate goals.
5 Bloomberg, with data from cdr.fyi [14], projects novel CDR removal need to reach 3.5 Gt/yr by 2050. The global optimal portfolio builds over 7.5 Gt/yr in novel CDR by 2050.
6 Assessed against the default and shortfall risks of Climeworks' high quality supplier base – assumptions for high-quality suppliers: i) avg. annual supplier failure risk of ~25%, ii) avg. annual shortfall of ~15%, and iii) avg. tech invalidation risk of ~10%, assumptions for low-quality suppliers: i) ~50%, ii) ~60%, iii) ~20%
7 Repeated investment in an AF/RF credit until 1000 years, every 40 years, discounted with 1%. Price for AF/RF increases by 3% in the first 40 years to mimic reducing supply, then remains constant.

Portfolio evolution over time

Our portfolio model is built on two foundational inputs:

1. The projected evolution of unit prices for each CDR pathway over time (see right)
2. The expected ramp-up curves for their removal volumes (see below)

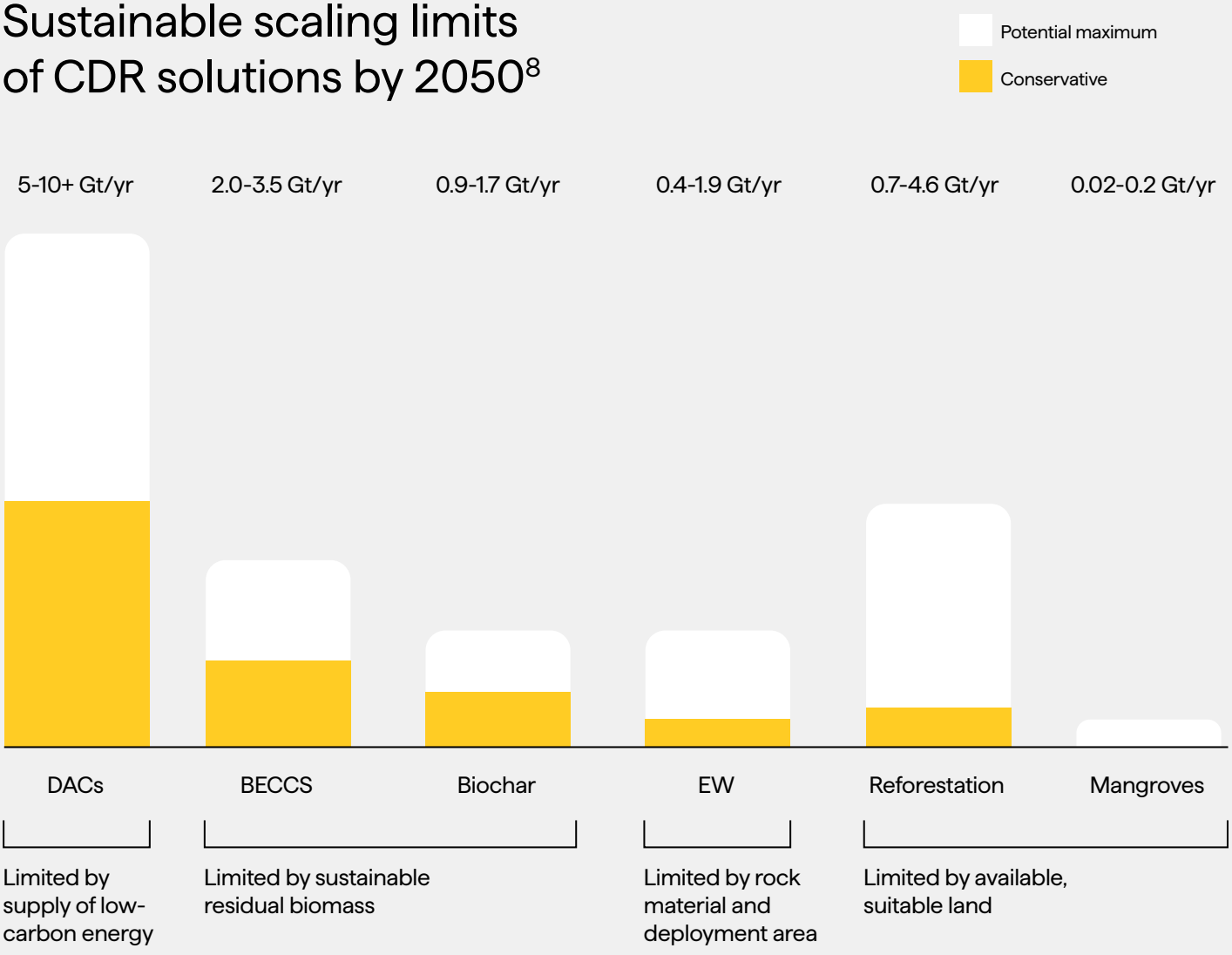
Crucially, every pathway is bound by its own ecological or resource ceiling. Pushing any method past these natural limits not only strains planetary boundaries, threatening biodiversity, water cycles, and food security, but also drives marginal prices exponentially higher. By enforcing these sustainability constraints within our optimization, the blended levelized price of removal across the entire portfolio settles at roughly $225 per ton of CDR.

Expected price evolution by 2050

↓	DACS	Decrease of	~70%
↓	BECCS	Decrease of	~20%
↓	EW	Decrease of	~40%
↑	Biochar	Increase of	~30%
↑	Reforestation	Increase of	~140%
↑	Mangroves	Increase of	~140%

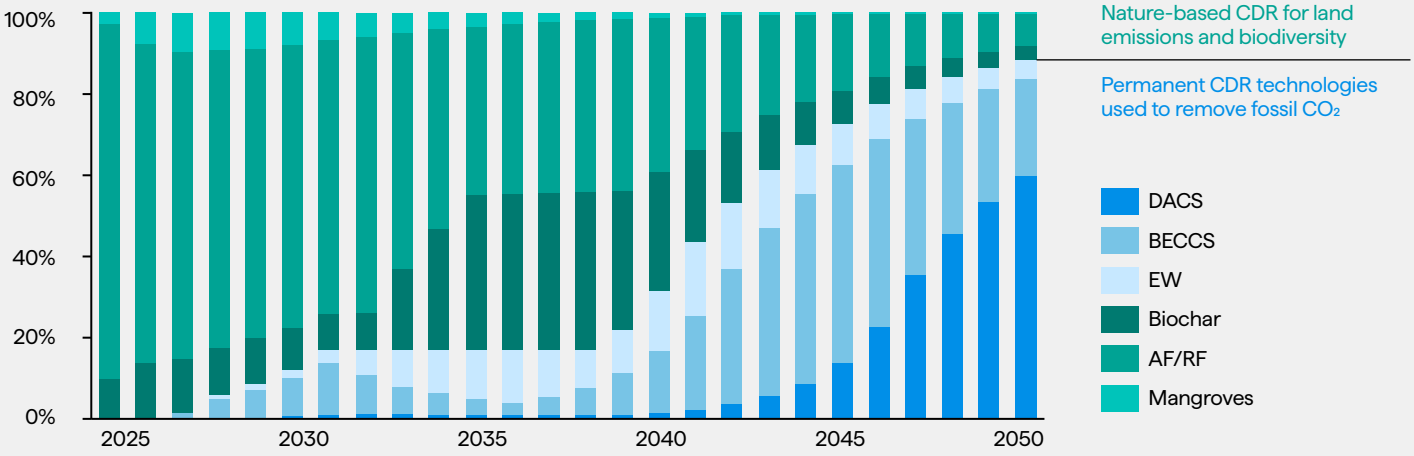
Source: How to scale a new gigaton industry, McKinsey

Sustainable scaling limits of CDR solutions by 2050[8]



8 Climeworks analysis based on available renewable power using [17, 18, 25], available residual biomass and competition between BECCS and biochar using [31, 32, 33, 34], available rock material and deployment land using [16, 19, 20, 21, 24, 26], available land for planting using [26, 27, 28, 29], available coastal regions for planting using [22, 23, 30]

Cost-efficient and high-impact CDR portfolio composition per year to achieve sub-2°C target within natural constraints



Notably, between 2025 and 2040, nature-based solutions[9] are modeled to increase from 10 Mt to nearly 0.7 Gt CDR annually, fully utilizing their wide-spread availability and established effectiveness within ecological boundaries. Simultaneously, initial installations of BECCS, EW, and DACS are forecasted to begin to scale up. By 2040, these engineered methods need to provide approximately 0.3 Gt CO_2 of removal capacity—while this would still be smaller in scale than nature-based approaches, it's a crucial milestone to unlock future growth.

Finally, between 2040 and 2050, we project land-based ceilings will be met, driven by factors such as food security, cultural land rights, and biodiversity, and the portfolio shifts decisively toward engineered CDR. Methods such as DACS and BECCS will need to ramp up dramatically, filling the gap left by saturated natural sinks. By mid-century, engineered approaches need to account for over 70 percent of total carbon removals, with limited remaining nature-based efforts focused on removing shorter-residence greenhouse gases like methane and biodiversity enhancement.

Your net zero roadmap with Climeworks

Our optimized global portfolio for carbon removal establishes key benchmarks for achieving climate targets efficiently. This advanced CDR modelling aligns with established industry standards, including the Science-Based Targets initiative (SBTi) and Oxford Net-Zero Aligned CDR Principles. Applying this optimization framework, we build customized, phased CDR portfolios. We support every step to identify the most effective blend of carbon removal solutions for your organization's specific footprint, timeline, and sustainability objectives.

9 Reforestation, mangroves, and biochar

Learn more about how our team can apply our blueprint for the optimized CDR portfolio to your corporate goals to unlock substantial cost savings, de-risk your strategy, and accelerate your net zero transition.

Together, we can close the climate gap at the speed and scale the planet demands.

↗ Contact our team

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