



Carbon Dioxide Removal
Driving Systems Change with
Breakthroughs in Carbon
Dioxide Removal by 2030

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Foreword

Carbon dioxide removal (CDR) represents a cornerstone of every pathway to limit average global surface temperature rise to 1.5°C in line with the goals of the Paris Agreement. At COP27 in Egypt, **the UN Climate Change High-Level Champions** launched the CDR 2030 Breakthrough, a suite of ambitious CDR goals to achieve before 2030. **As part of the Race to Zero**, this Breakthrough sets out what must be done, by whom and when, to deliver the comprehensive change needed to achieve a resilient, zero carbon world.

This report can be seen as a 'companion' to the [CDR 2030 Breakthrough](#), providing further detail and depth to the goals. It describes how and why CDR can be scaled-up responsibly on a global level. The CDR 2030 Breakthrough depends on a responsible approach centred around five levers of change: supply, demand, finance, policy and civil society.

Here the latest developments in the CDR sector are described, identifying the signals of progress and direction forward. We must ensure that solutions for carbon removal are rolled out in a way that minimises the rise in average global surface temperature while maximising co-benefits. These include increased resilience to the impacts associated with climate change, providing security for local communities, and benefits to ecosystems.

Deloitte has produced this report in collaboration with the Climate Champions Team and the Race to Zero. We thank them for their invaluable role in showcasing this most crucial of topics.



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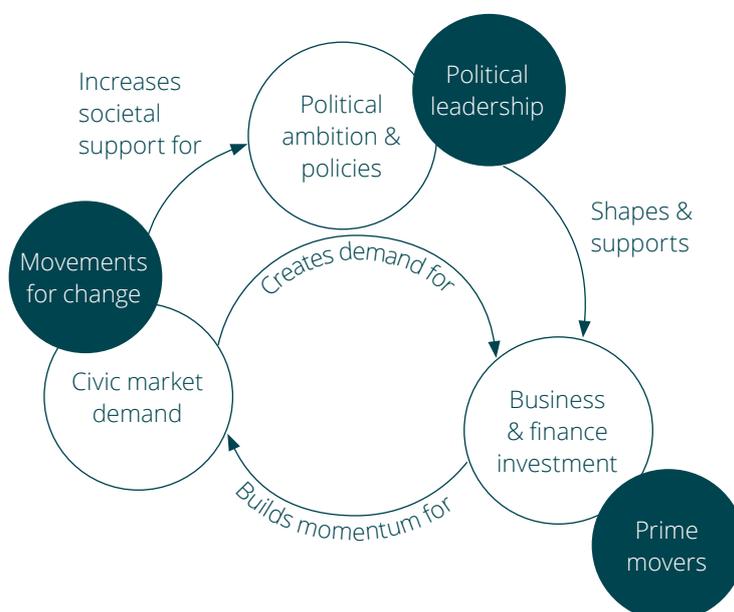
The 2030 Breakthrough

Led by the High-Level Champions, the Race to Zero campaign provides ambitious goals for multiple sectors in the form of the 2030 Breakthroughs.¹ These Breakthroughs – of which the CDR Breakthrough is one – create a shared vision to help multiple actors accelerate progress, and clarify how everyone’s efforts contribute to the whole.

This lends increasing confidence to the system. It’s easier to create new and innovative solutions when consumers are providing clear demand signals, governments are putting supportive policy in place and financiers are providing much needed capital investment. This creates positive feedback between different actors in the form of an **‘ambition loop’**.^{2,3} As all actors increase their ambition, it encourages others to do the same. By providing a ‘headline’ breakthrough followed by individual goals across five levers of change (**supply, demand, finance, policy, and civil society**), the 2030 breakthroughs unlock opportunities to ensure we achieve our net-zero goals.

The 2030 Breakthroughs represent convergence and consensus across a multi-stakeholder system, including academia, civil society, business, and government. They are the result of in-depth consultation with experts and partners. The CDR Breakthrough is estimated to set sufficiently ambitious, yet practically achievable, targets that act as a direction of travel and guiding star for climate action.⁴

This report explores the CDR Breakthrough and assumes a foundational knowledge of CDR what it is and how it can be achieved. If you’re unfamiliar with CDR, please see our report **‘Carbon Dioxide Removal: An Introduction’**.



Ambition Loop

Source: Future Stewards, 2021: 10 tools for systems change to a net zero carbon world

The 2023 Breakthrough for carbon dioxide removal

“By 2030, carbon dioxide removals are responsibly scaled to remove 3.5 billion tonnes of carbon dioxide per year. 500 million tonnes of this must be stored for at least 100 years.”

2022 was a significant year for CDR, with advancements occurring in all five levers of change (**supply, demand, finance, policy, and civil society**). For example, total sales of durable carbon removal credits increased more than 500 per cent in just one year, between 2021 and 2022, reaching over 700,000 tonnes by December 2022.⁵ CDR was written into Finnish law⁶ and Tasmania became the world’s third carbon negative region.⁷ Increased action has led to an even more ambitious 2030 Breakthrough target for CDR.

Here, we explore how we can achieve the headline Breakthrough target by understanding what needs to happen to scale up, and what leaders are already doing across our five levers of action.



How to achieve the Breakthrough using the five levers of action



Supply



Demand



Finance



Policy



Civil Society



Supply

This lever depends on responsibly scaling a diverse portfolio of CDR options. This should be across regions and solutions to cumulatively remove 3.5 billion tonnes of carbon each year from 2030 onwards. This should be made up of 3 billion tonnes of lower durability carbon removal, storing it from *up to* 100 years, and 500 millions tonnes of higher durability carbon removal, storing it for *over* 100 years. In parallel, the Breakthrough calls for the price of durable removals to decrease to approximately US\$100 per tonne of CO₂ removed. To entrench the “responsible” element of this change lever, the solutions used and the process of scaling them must be carried out in tandem with local contexts, the needs of communities and with consideration of the co-benefits of such solutions.

Breakthrough targets:

By 2030 we are responsibly scaling our removals to 3 billion tonnes of CO₂ from the atmosphere each year and storing it for *up to* 100 years.

To reach 3 billion tonnes per annum of lower durability carbon removal (i.e., carbon that is stored for a duration of decades to centuries and has a higher risk of reversal) we focus on solutions where carbon is predominantly stored in the biosphere. This can be achieved through restoration or management activities. Restoration includes returning degraded, abandoned, or agricultural lands to their original natural ecosystem, or creating forestation on land that has not seen trees for centuries. Management activities include increasing the carbon sequestration ability of land without changing its current use, such as shifting to regenerative agriculture or climate smart forestry. For example, Reduced-Impact Logging for Climate (RIL-C) shifts plantations to more species-diverse, multi-age plantations or simply extends the average age of trees before harvest, so that they can have a significant impact on carbon uptake.

It’s crucial that these activities occur on marginal and degraded land (especially in the tropics) to ensure land required for people’s livelihoods and food security is not taken away. This is where the **responsibility** part of the target comes in.



It's also important that afforestation/reforestation is predominantly focused on the tropics, due to the higher sequestration density, lower risk of forest fire (due to higher humidity) and the albedo effect.

The albedo effect is the ability of a surface to reflect heat. Lighter, flat surfaces reflect heat while dark, rugged ones absorb and retain heat. As such, it's best to leave a snowy plain unforested, as afforesting this area could have a net warming effect, even though the trees would absorb carbon dioxide.

According to the Energy Transitions Commission,⁸ if 320 million hectares of ecosystems were restored (including tropical forests, mangroves and peatlands) and 900 million hectares of forest and cultivated land (approximately 12-15%) came under improved management, we could remove 3.2 billion tonnes of CO₂ per year by 2030.

By 2030 we are removing another 500 million tonnes of CO₂ from the atmosphere each year and storing it for more than 100 years.

This subset of the **Supply** lever of the 2030 Breakthrough focuses on scaling higher durability carbon removal (solutions that can store carbon dioxide for centuries to millennia with a low risk of reversal). Today, we're only durably removing a few thousand tonnes of CO₂ per year. Recently however, we've seen significant strides in durable CDR deployment with many suppliers exhibiting exponential growth.

One of the higher durability solutions receiving a lot of attention and action is Direct Air Carbon Capture and Storage (DACCS). A clear 'Signal of Change' identified by the CDR 2030 Breakthrough, is Climeworks. DACCS start-up Climeworks launched Orca, the world's first industrial scale DACCS plant in Iceland in 2021 with a capacity to remove 4,000 tonnes of CO₂ per year.⁹ A new plant is expected to be operational in 2024 with a capacity to remove 36,000 tonnes of CO₂ per year.¹⁰ This would constitute a nearly 10x increase in capacity in less than three years.¹¹

Another DACCS supplier, Carbon Capture Inc, has ambitions to roll out what could become the biggest single atmospheric carbon removal project in the world by 2030. Project Bison, a three-phase plan (starting in 2023) is scheduled to roll out a 500 million tonne per year facility in Wyoming by 2030.¹¹

Another of the larger DACCS suppliers is also employing exponential growth to reach its targets. This DACCS supplier has plans to see 70 million tonnes CO₂ per year of DACCS operational across the globe by 2035. If successful, this would represent an approximate 34 fold increase in global DACCS supply. This may rise to 135 million tonnes per year if global governments and markets increase support for climate action. These strides in capacity demonstrate how quickly we're growing our ability to sequester large amounts of CO₂ durably.

In addition to these companies focusing on DACCS, other high-durability solutions are scaling at pace. Although not a definitive list, we have outlined examples of these innovative CDR solutions to provide a sense of the variety of operations from across the globe. UK based start-up, Brilliant Planet,¹² grows algae at unprecedented rates in sea water to remove CO₂ from the atmosphere in coastal deserts and stores it underground, while de-acidifying the ocean water at the same time. InterEarth is another start-up that works with nature to store carbon for centuries. It has developed a solution where woody biomass is buried in saline soil in Australia.¹³ This effectively stores and locks up carbon in the wood. InterEarth's method also improves soil quality in degraded agricultural land and reduces desertification.

These signals of progress show that while a target of 500 million tonnes of CDR per year is ambitious, the rapid growth of these solutions and their equally ambitious supply targets demonstrate that, with continued perseverance, it is a Breakthrough we can achieve.

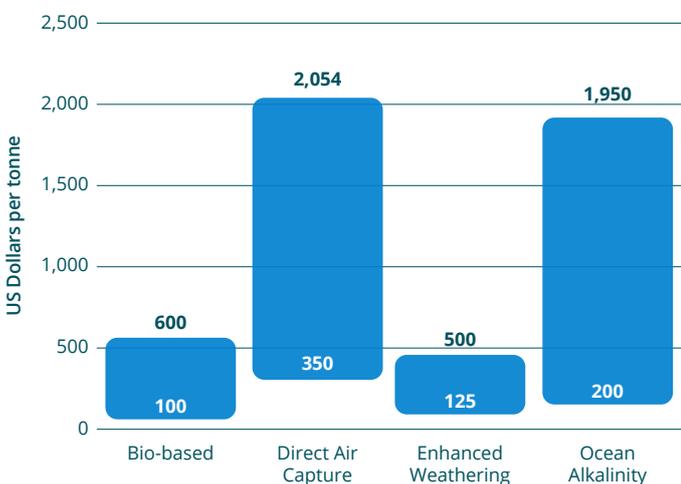


Carbon removal at the gigatonne scale costs less than US\$100/net metric tonne of CO₂ equivalent by 2030.

To achieve the 2030 Breakthrough and further scale CDR, it is imperative that carbon removal is affordable.¹⁴ This target is focused specifically on higher durability carbon removals solutions. At present, the costs associated can vary considerably. From US\$100 for bio-based carbon removal (including biochar, Bionergy with Carbon Capture and Storage (BECCS), Bio-oil, or preservation) to more than US\$2,000 for direct air capture.¹⁵ The price drivers include the cost of capture and storage itself as well as contractual terms, e.g., the size of orders, delivery year, pre-payment level etc. The solutions at the higher range tend to be more expensive due to their relative nascency and higher capital intensity. Furthermore the range within the solutions themselves reflects the maturity across projects.

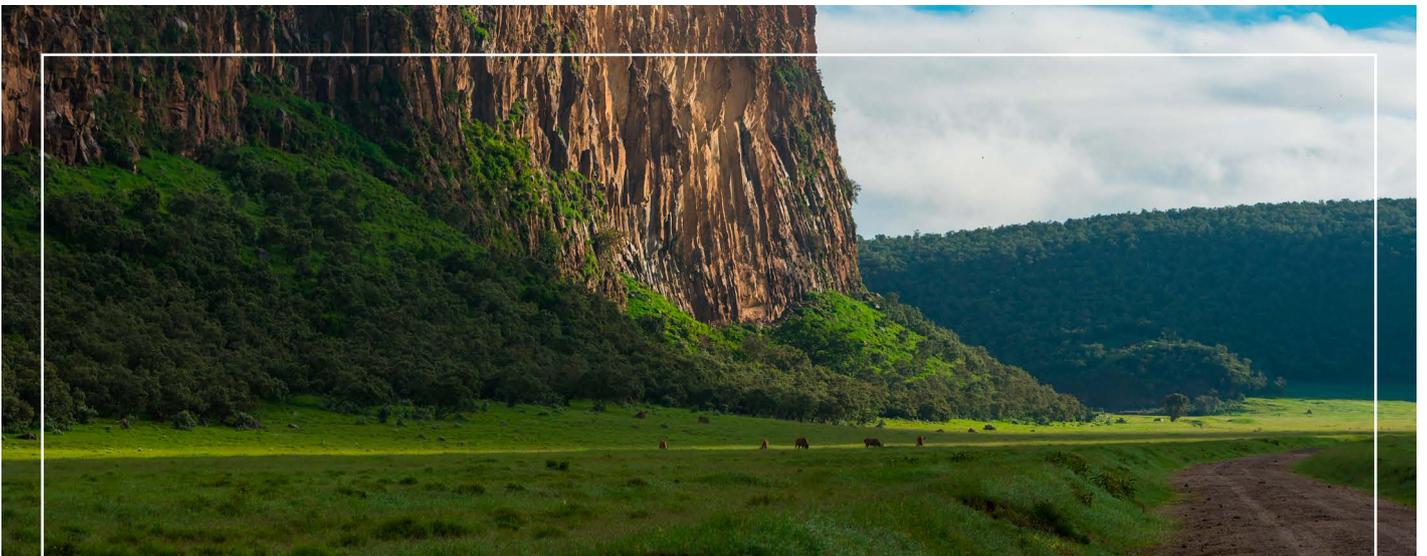
Similarly to how the cost of solar photovoltaics (PV) decreased by 82 per cent between 2010 and 2019¹⁶ as the technology grew and economies of scale were achieved, CDR is expected to follow a comparable trajectory as uptake grows.

Figure 1. Price ranges per durable CDR category



Source: CarbonX, 2023: CDR Market Overview





Case study: Scaling carbon removals responsibly in Kenya

'The Great Carbon Valley' in Kenya¹⁷ is a concept conceived by James Mwangi, Founder of Climate Action Platform – Africa. Under this concept, by scaling DACCS and other energy-intensive climate technology in places like the Rift Valley in Kenya, we could increase carbon removal capacity in places with the *right geology* and plenty of renewable energy potential, while creating the basis for investment in expanding the country's renewable energy potential. This would create a business case to provide millions of people with affordable clean energy, improve their standard of living, and encourage more businesses to take advantage of this renewable energy by stimulating job creation and sustainable development. Introducing new technologies in Africa can also encourage more entrepreneurship and further growth.

This is just one example of how in-depth systems-level understanding of local contexts, in tandem with the careful design and deployment of carbon removal solutions, can have wide-ranging positive impacts and far-reaching effects beyond simply removing carbon dioxide from the atmosphere. This is also an example of how CDR can be a part of the just transition and provide opportunities for sustainable development in the Global South.



Demand

Breakthrough targets:

Public and private payments for CDR reach approximately US\$200 billion per annum by 2030. 20x more than the estimated US\$10 billion per year supporting removals today.

To support a CDR ecosystem sequestering 3.5 billion tonnes of carbon dioxide per year, it's estimated that annual payments of approximately US\$200 billion are required.⁸ This is based upon an analysis performed by the Energy Transitions Commission where removals are purchased at the following estimated costs; lower durability carbon removal solutions in a range of US\$5 to US\$50 per tonne but rising over time, while the costs of higher durability removals are estimated between US\$300-600 per tonne of CO₂ removed but fall to around US\$100 over time. This implies an average of US\$55/tonne of CO₂ sequestered, based on a weighted average between the high and low estimates of the different CDR methods.

An analysis conducted by an independent researcher on behalf of the Climate Champions (using aggregated data) found that while a 20x increase in annual payments is a significant increase, the demand for CDR is already on an exponential path. The 2021 market demand for CDR of approximately 8 million tonnes represents a 93x growth or 10-year Compound Annual Growth Rate (CAGR) of 57.3 per cent from a 2011 total of approximately 86,200 tonnes.¹⁸ Reaching the 2030 Breakthrough will require a 96.5 per cent CAGR from 2021 market demand levels.

Focusing solely on CDR with high durability, the outlook is more favourable. Examining demand using an 'exponential mindset', demand for high durability removals doubled approximately twenty times from 2020-2022 (from close to zero to over 700,000 tonnes). In May 2023, a large tech firm bumped this number to nearly 4 million tonnes when it agreed to purchase 2.76 million tonnes over the next 11 years. This is one of the largest carbon removal offtake agreements by volume, to date.¹⁹ To reach our 2030 goal (of 500 million tonnes) we need to double every year for the next seven years.

In addition to changes seen in the voluntary carbon market, there's also been significant support for demand-led initiatives. Here we describe some of the more well known initiatives as cited in the CDR 2030 breakthroughs 'Signals of Change'. In 2022, the Frontier Fund²⁰ was launched. Frontier is an advanced market commitment (AMC) to buy over US\$1 billion in high durability CDR between 2022 and 2030. It is the first and largest fund of its kind. AMCs were first used a decade ago to accelerate the development of pneumococcal vaccines for low-income countries, saving an estimated 700,000 lives. Here, the concept is being borrowed to send a strong demand signal whilst remaining CDR solution agnostic. The World Economic Forum (WEF) has added CDR to its First Movers Coalition programme²¹ – with companies pledging to buy at least US\$500 million of carbon removal by 2030.

Meanwhile, a number of companies have signed decade-long pre-purchase agreements for carbon removal from suppliers.²² These activities are crucial in providing strong demand signals, confidence to the market and revenues for carbon removal suppliers and start-ups to continue their work.



Finance

Breakthrough targets:

Capital investment in CDR (i.e., in project demonstration, deployment and infrastructure development) averages at least US\$100 billion/year by 2030.

The financial backing of CDR is fundamental to its widespread uptake through economies of scale and cost decreases. Therefore, it's vital to build capital investment in CDR, which might be directed towards infrastructure development, project demonstration or deployment. While this annual US\$100 billion target is sizeable, when put into a wider context, it's a fraction of the estimated investment required for the broader net-zero transition. For example, according to the International Energy Agency (IEA), to achieve net-zero by 2050, the global energy sector will need a total annual energy investment of US\$5 trillion by 2030.²³

Reaching US\$100 billion per year will require both private and public investment. Private investors are already focusing on carbon removal both from a profit generating and philanthropic perspective. Some of the biggest technology companies have launched climate funds (representing approximately US\$3 billion in Assets Under Management) which are explicitly investing in CDR. Venture capitalists are also beginning to invest in early stage CDR solutions.

Notable investors include Lowercarbon Capital (US\$1.2 billion AUM with US\$350 million for CDR)²⁴ and Counteract²⁵ (which invests exclusively in CDR).

The public sector can provide additional and different forms of funding, including activity and results-oriented subsidies.²⁶ For example, research and development (activity-oriented) subsidies can push removals solutions towards their subsequent maturity level and are best-placed for investigating and demonstrating new solutions, and further encouraging innovation outcomes.²⁷ This type of funding takes a long-term view as opposed to it being allocated based on current cost-effectiveness of the solutions. For example, the EU Innovation Fund adopts this model.

Results-oriented subsidies can also be deployed in the form of grants, tax credits or concessional loans, and are allocated based on the volume of actual CO₂ removed. For example, the USA's Inflation Reduction Act includes an extension of the 45Q tax credit. This credit provides US\$180 for every tonne of CO₂ sequestered through geologic storage (higher durability).²⁸ This change catalyses the deployment of DACCS by adjusting the feasibility of new projects. Altogether, diverse funding instruments for CDR are available for solutions across the maturity curve. This is especially important for solutions that aren't yet able to access funding or be self-sustaining.²⁶





Policy

Breakthrough targets:

- Policies provide **robust governance and regulatory support frameworks** through:
 - **Accounting and Methods:** Formalised and widely applied approaches to robust quantification of Greenhouse Gases (GHGs) removed at individual project and regional levels by a particular project, and reporting these results to a larger emissions accounting framework
 - **Inventories:** National governments adopt clear methodologies and rules to account for CDR in their national inventories and Nationally Determined Contributions (NDCs). Guidance from the UN has been developed to start bringing these methodologies into interoperability and cohesion
 - **National and International Regulatory Standards:** Standards on the overall integrity and quality of removals including definitions of additionality, permanence, and environmental integrity of CDR solutions
 - **Claims enforcement:** Guardrails and regulation of environmental claims made to consumers and the use of carbon credits for compensation claims
 - **Liability Rules:** Industry-wide insurance schemes, liability caps, and clear liability guidance for reversals or re-release of stored CO₂
 - **Planning Rules:** Rules which govern the location of CDR facilities/projects, rights of local stakeholders and mitigation of local impacts.
- National policies and public funding provide support for **CDR research, development, and demonstration** through:
 - Research and pilot grants
 - Feasibility studies
 - Demonstration studies.
- National policies support **CDR deployment** through:
 - Public funding to reduce the cost of capital or operations for contractors or suppliers. Tax credits and/or subsidies for CDR.
- Policies provide **infrastructure support** through:
 - The development of industry clusters (to share infrastructure and efficiency gains) or publicly provided infrastructure (such as CO₂ transport and storage infrastructure and networks).
- National policies support **market development** and the **creation of CDR demand**. These may include:
 - Direct purchase and offtake agreements
 - Feed-in tariffs
 - Contracts for difference
 - Reverse auctions
 - Advanced market commitments
 - Demand subsidies.



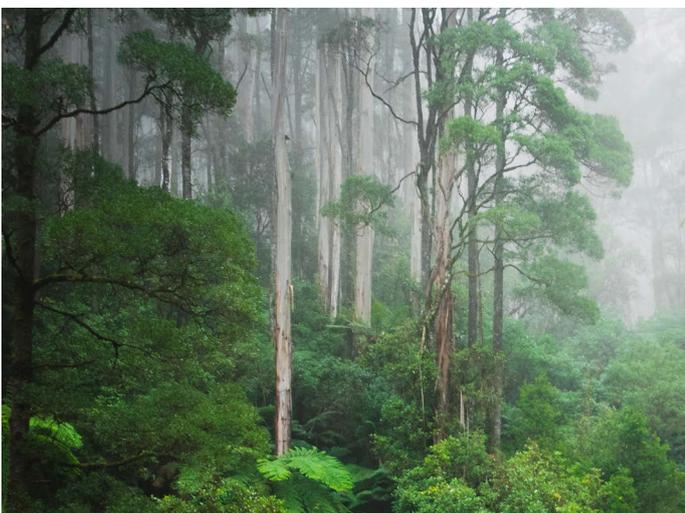
As perhaps the most wide-reaching single lever of change, policy has the potential to influence other levers and rapidly accelerate carbon removal. The policy-related breakthrough target covers a lot of ground due to the nascence of the sector, alongside the fact that policy priorities will differ according to different CDR methods and their maturity levels.

Progress across several policy lever targets is already underway. From foundational regulatory frameworks and support for research, demonstration, and deployment to subsidies for scaling efforts and financial support to increase demand. In November 2022, the European Commission adopted a proposal for the first EU-wide voluntary framework to reliably certify high-quality carbon removals. The proposal also includes rules to monitor, report and verify the authenticity of the removals.²⁹ This helps set the foundation for further MRV and certification across the globe.

We're now seeing increased financing into CDR Research, Development, and Demonstration (RD&D) in more countries. We outline a variety of cross-country initiatives to demonstrate some signals of change in this area. One example of this is the UK's Greenhouse Gas Removal Demonstrators programme with five projects (biochar, enhanced weathering, peatland restoration, perennial biomass crops and woodland creation and management).³⁰

The USA's new Inflation Reduction Act³¹ and the Creating Helpful Incentives to Produce Semiconductors (CHIPS) Act,³² includes over US\$1 billion in funding for CDR-relevant RD&D. New Zealand's One Billion Trees Fund³³ is further supporting reforestation in the country. Sweden is set to hold the world's first reverse auction for Bio-CCS (i.e., BECCS) in 2023. Here, the Swedish Energy Agency will hold the position of auctioneer to provide state funding to organisations that can capture and store CO₂ at the lowest cost.³⁴

In addition to actions which target specific outcomes, states are beginning to set ambitious targets for CDR. Finland has committed to being carbon negative by 2040, becoming the first country to make carbon removal legally binding.³⁵ Meanwhile, the UK government has released a net-zero strategy which includes a target of at least 5 million tonnes of CO₂ removal per year by 2030, 23Mt by 2033 and 75-81Mt by 2050.³⁶





Civil Society

Breakthrough targets:

- Civil society organisations take a leading role in describing **how best to incentivise, govern, and undertake carbon dioxide removals** by focusing on societal values, interests and needs in local contexts. For instance, describe how to do removals responsibly³⁷ while focusing on climate justice and equity
- Civil society organisations **responsibly create knowledge, awareness and demand** for increasing CDR capacity across all key stakeholders
- Civil society organisations **accelerate CDR innovation** through R&D funding and support
- Civil society organisations **draw critical attention** to instances where CDR is being used as a substitute for reductions, or worse as predatory delay,³⁸ rather than complementary to rapid decarbonisation
- Civil society organisations lead the way in the development of a **recognised standard for CDR**, certifying its responsible use and upholding the highest quality and integrity standards.

This lever explores how individuals and organisations can spur change and mobilise carbon removal while maintaining their focus on **climate justice and equity**. This lever can best encompass the needs of local communities and direct the scaling of carbon removals so they can offer co-benefits suited to the environment they are located in.

Similarly to the **policy** lever, civil society organisations are well-placed to effect change across the levers. The 2030 Breakthroughs call for civil society to engage in activities such as investing time in unpacking issues around quality, additionally, durability and setting out how to incentivise, govern and deploy carbon removals while maintaining focus on societal values and needs in local contexts.

Some notable examples of civil society action are highlighted as 'Signals of Change' in the CDR 2030 Breakthrough. For example, at the TED Countdown in 2022, Rethinking Removals³⁹ ran workshops with expert stakeholders to unpack these issues. Civil society can responsibly build knowledge, awareness, and demand for carbon removal capacity through engagement with a wide variety of stakeholders. The Foundation for Climate Restoration,⁴⁰ one of the organisations that the Climate Champions Team acknowledges as working towards the CDR breakthrough, provides education in schools and at a policy-level to tackle this. As has already been outlined, funding is crucial to scale CDR, support research and development, and catalyse carbon removal innovations. As such, some notable philanthropies have begun to focus on CDR, while the Carbon Dioxide Removals Accelerator⁴¹ is supporting early-stage start-ups.

Civil society organisations are uniquely placed to call out cases of CDR being used as a substitute for emission reductions, or as justification for delaying emission reductions. In coordination with the policy lever, civil society can also assist in the development of a recognised standard for carbon removal which upholds the highest quality and integrity standards and endorse its use. The Integrity Council for the Voluntary Carbon Market⁴² has begun such work already, with the aim of achieving a just transition to 1.5°C. As engagement in CDR increases throughout the decade, the support of civil society will become increasingly important.

Conclusion: Adopting an exponential mindset

It's clear from examining these levers of change that a lot must be done quickly to achieve the Breakthrough and limit the average global surface temperature increase to 1.5°C. To do this we will need to adopt an exponential mindset and ask ourselves questions such as: how often do we need to double our efforts to reach our goals?

The 2030 Breakthroughs direct our attention to the **solutions** and how we can bring them into existence with innovations, rather than incremental changes to existing solutions. We've seen how much change can take place when we settle on a single approach. This allows us to move along a curve of change. For example, when technology improves efficiency and effectiveness, this can also lower costs and encourage adoption by society.³ The changes in demand and supply for durable CDR already show this exponential mindset in action. From 2020-2022, demand doubled approximately 20x (from near zero to over 700,000 tonnes) and the supply of a single DACCS provider has increased by 10x in approximately two years.

While we scale our ambitions it's crucial that we do so in a responsible and conscientious manner. This means ensuring we avoid damaging our global ecosystems and local communities while removing significant volumes of CO₂. But it also means that we do not decelerate our ambition and progress on rapid and deep emission reductions now.

Carbon Removal is a crucial pillar of climate action that can be used to further restore balance to our planet and support thriving communities.



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