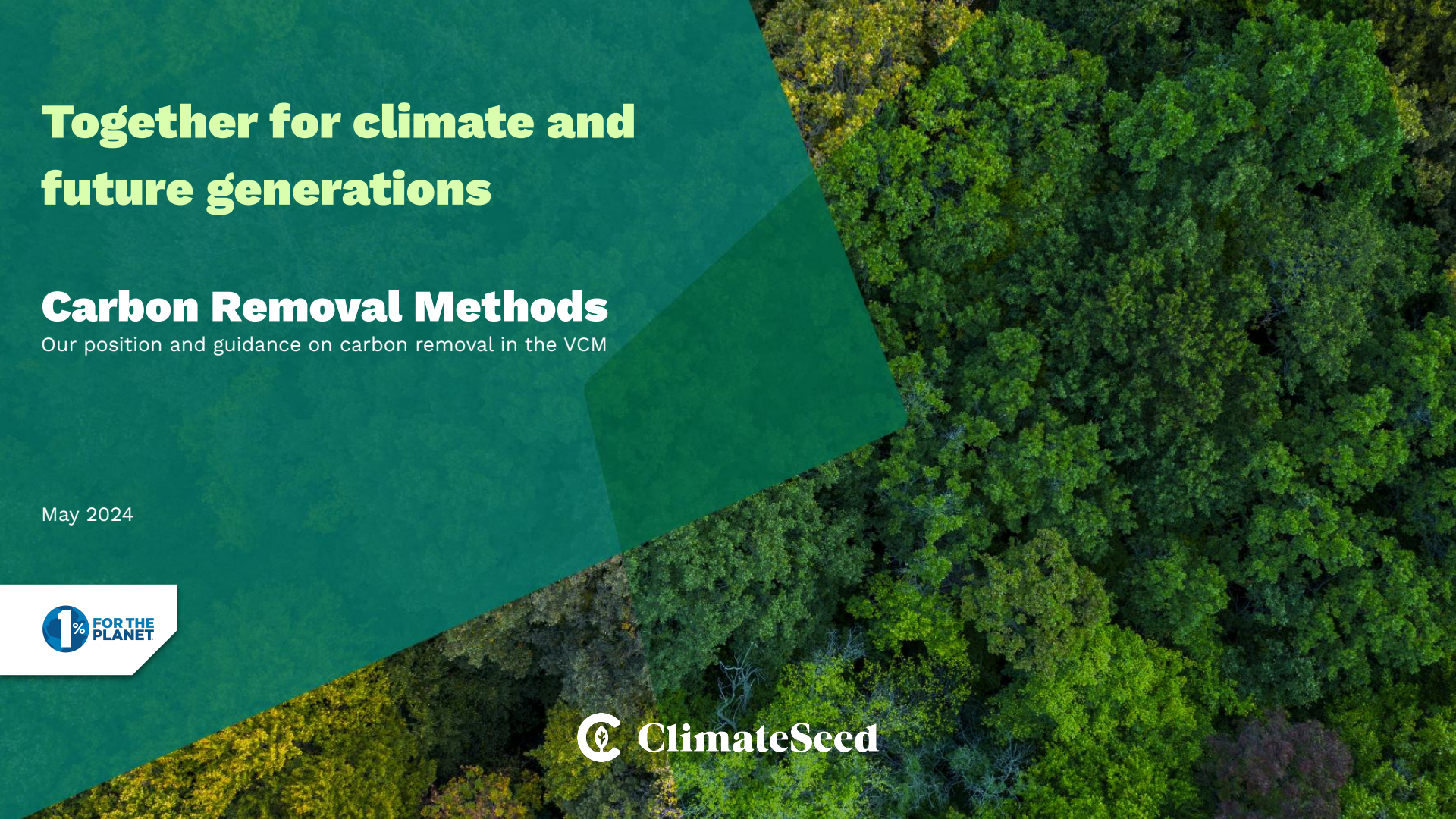
Together for climate and future generations

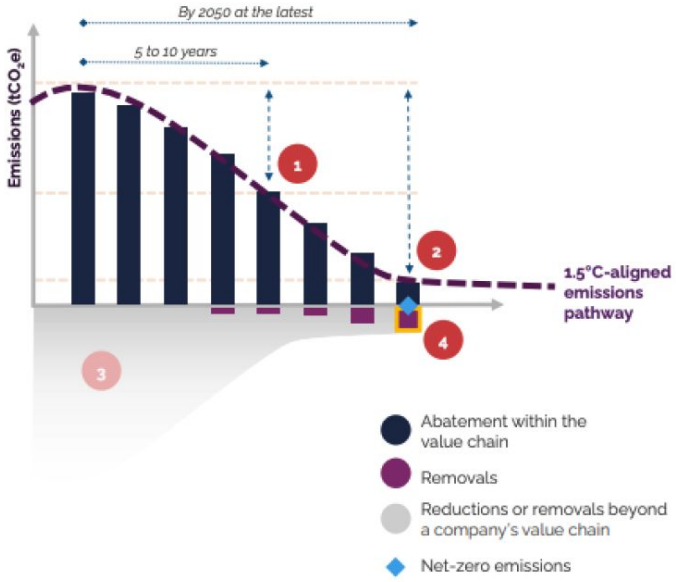
Carbon Removal Methods

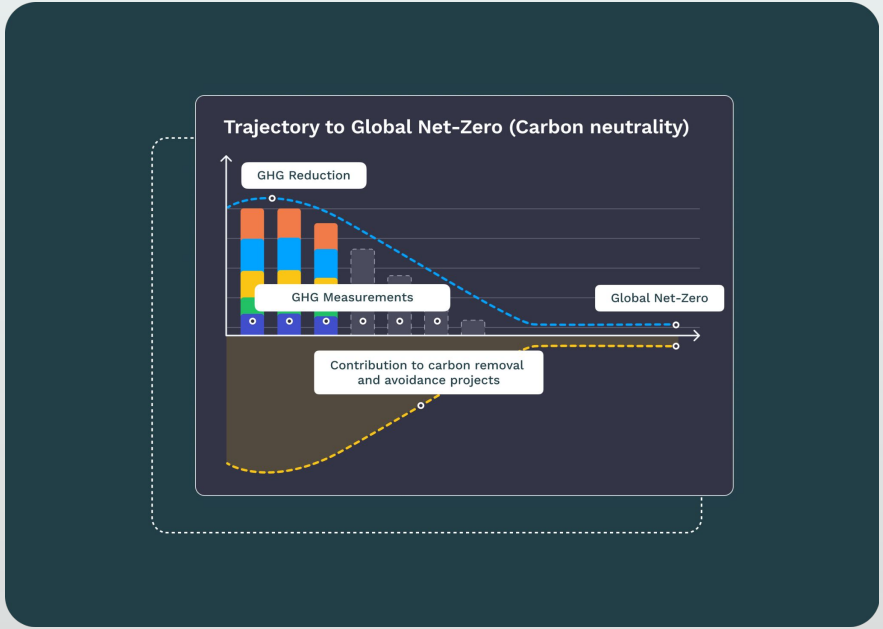
Our position and guidance on carbon removal in the VCM

May 2024



The importance of carbon removal





Source: SBTi, IPCC

CCU & CCS

Carbon Capture & Utilization (CCU)

The primary goal of CCU is not only to **remove CO_2** from the atmosphere but also to find **novel** and **practical** uses of **carbon as raw material.**

CCU can take several forms, including the **production of chemicals**, **biofuels**, **plastics**, or **construction materials** from CO_2 emissions.

Carbon Capture & Storage (CCS)

CCS technologies capture CO_2 emissions from industrial processes, power plants, or other sources and **stores** them **underground** in **geological formations** to **prevent their release** into the atmosphere.

CCS aims to **permanently store** captured CO_2 and help create **net negative** greenhouse gas emissions.

Carbon Removal Methods

Afforestation/Reforestation

Agriculture

Mangroves

Seagrass and Seaweed Farming

CO_2

Biochar

Enhanced Rock Weathering

Carbonated Materials

Woody Biomass

CO_2

Direct Air Capture and Storage (DACCS)

Bioenergy with Carbon Capture and Storage (BECCS)

CO_2

Nature-based Solutions (NbS) **Hybrid Solutions** **Engineered Solutions (ES)**

Nature-based Solutions (NbS)

Nature-based Solutions (NbS) leverage the natural capacity of ecosystems —such as **forests**, **wetlands**, **grasslands**, and other **natural habitats**— to **absorb and retain CO_2** from the atmosphere over time, contributing to both carbon dioxide removal and ecosystem restoration.

These solutions include projects like reforestation, afforestation, wetland restoration, and sustainable land management practices. NbS projects promote biodiversity, are **community-oriented** and aim to enhance both **carbon sequestration** and increase **ecological benefits**.

- Low capital investment
- Large volumes
- High co-benefits
- €15–€50 price range
- *Ex-post* and *ex-ante* credits
- Higher risk of reversal

Afforestation, Reforestation & Revegetation (ARR)

Agriculture

Mangroves

Seagrass and Seaweed Farming

Nature-based Solutions at a glance

Afforestation Reforestation Revegetation (ARR)	Agriculture	Mangroves	Seagrass & Seaweed
Permanence: Decades to centuries **Price range:** €15–€40	**Permanence:** Years to decades **Price range:** €30–€100	**Permanence:** Decades to centuries **Price range:** €25–€40	**Permanence:** TBD **Price range:** TBD
ARR projects involve planting trees on lands that have been deforested or degraded. These projects aim to restore ecosystems, sequester carbon dioxide, and provide numerous co-benefits such as biodiversity enhancement and soil protection. They are critical in combating climate change by capturing CO_2 and restoring natural habitats.	Agricultural carbon projects implement sustainable farming practices that increase soil carbon sequestration. These practices include no-till farming, cover cropping, and agroforestry, among others, which enhance soil health and productivity. Such projects also reduce greenhouse gas emissions from agricultural activities.	Mangrove restoration projects involve the replanting and protection of mangrove forests in coastal areas. These projects sequester carbon, protect coastlines from erosion, and provide critical habitats for marine life. Mangroves are highly efficient at carbon sequestration due to their dense biomass and sediment trapping capabilities.	Seagrass restoration projects involve planting and protecting seagrass meadows in marine environments. These underwater plants sequester carbon efficiently, stabilize sediments, and support marine biodiversity. Seagrass meadows are crucial for maintaining healthy coastal ecosystems and mitigating climate change.

Afforestation, Reforestation & Revegetation (ARR)

Afforestation, Reforestation and Revegetation (ARR) projects focus on planting trees on lands that were previously forested but have since been cleared or degraded. This process helps in sequestering atmospheric carbon dioxide as the new trees grow and mature.

ARR projects often include **selecting appropriate native species to restore ecological balance and improve biodiversity.** The projects may **involve community engagement** and provide **social benefits by creating jobs and enhancing local livelihoods.** Additionally, ARR projects can **improve water cycles** and **prevent soil erosion.** These efforts contribute significantly to **mitigating climate change** while also **addressing environmental and social issues.**

BENEFITS OF BIOCHAR

- Restored forests provide habitats for wildlife, promoting biodiversity.
- Prevents of erosion and and enhances soil fertility.
- Improves water cycle quality, and retention.
- Creation of local jobs and community engagement.

Agriculture

Agricultural carbon projects aim to reduce greenhouse gas emissions and sequester carbon in agricultural landscapes through improved land management practices. Techniques such as **no-till farming, cover cropping, crop rotation, and agroforestry** are employed to enhance soil organic carbon levels. These practices not only sequester carbon but also improve soil health, leading to increased agricultural productivity and resilience to climate change.

Projects often involve **training and supporting farmers to adopt sustainable practices.** By improving soil structure and fertility, these projects also **reduce the need for chemical fertilizers**, further lowering emissions. Overall, they **promote sustainable agriculture and enhance food security.**

BENEFITS OF BIOCHAR

- Increases soil carbon storage, reducing atmospheric CO_2 levels.
- Improves water retention and reduces runoff.
- Enhances soil structure and fertility, boosting crop yields.
- Reduces input costs and increases resilience for farmers.

Mangrove

Mangrove restoration projects focus on replanting and conserving mangrove forests along coastlines. Mangroves are unique ecosystems that sequester significant amounts of carbon both i**n their biomass and in the soil they stabilize.** These projects typically involve **community participation and can enhance local fisheries by providing nursery habitats for marine species.**

Mangroves also act as **natural barriers** against storm surges and coastal erosion, protecting human settlements and infrastructure. Additionally, they i**mprove water quality** by filtering pollutants and trapping sediments. **The combination of these benefits makes mangrove restoration a highly effective nature-based solution for climate mitigation and adaptation.**

BENEFITS OF BIOCHAR

- Mangroves store large amounts of carbon in biomass and soil.
- Reduce erosion and protect against storm surges.
- Provide habitats for numerous marine and terrestrial species.
- Enhance local fisheries by providing breeding grounds.
- Protect coastal communities and support livelihoods.

Seagrass & Seaweed

Seagrass restoration projects focus on planting and conserving seagrass meadows in shallow coastal waters. Seagrasses are highly effective at sequestering carbon due to their fast growth rates and the large amounts of organic carbon stored in the sediments they trap. These projects often involve **scientific monitoring and community engagement** to ensure successful restoration. Seagrass meadows provide critical habitats for a variety of marine species, including fish, shellfish, and sea turtles. They also play a vital role in maintaining water quality by stabilizing sediments and filtering nutrients. Overall, seagrass restoration contributes to carbon sequestration, biodiversity conservation, and the health of marine ecosystems.

BENEFITS OF BIOCHAR

- Prevent erosion and maintain coastal integrity.
- Support diverse marine life and ecosystems.
- Enhance local fisheries through habitat provision.
- Strengthen resilience of coastal areas to climate impacts.

Hybrid Solutions

Hybrid solutions represent an **innovative** approach of **integrating** both **Nature-based** and **Engineered solutions** to maximize CO_2 removal from the atmosphere. These projects recognize the **complementary** nature of **ecological** and **technological** interventions. The objective of hybrid removal projects is to **maximize carbon removal efficiency** and **environmental benefits** through a **synergistic** approach.

- Medium to high capital investment
- Small volumes
- Low co-benefits
- €100–€600 price range
- *Ex-ante* credits
- Low risk of reversal

Biochar | Enhanced Rock Weathering | Carbonated Materials | Woody Biomass Burial

Hybrid Solutions at a glance

Biochar	Enhanced Rock Weathering	Woody Biomass Burial	Carbonated building elements
Permanence: +100 years **Price range:** €70–€170	**Permanence:** +1000 years **Price range:** €200–€500	**Permanence:** +100 years **Price range: TBD**	**Permanence:** +1000 years **Price range: TBD**
A very stable, solid form of carbon that can endure in soil for hundreds of years. It is produced from biomass through pyrolysis (heated in the absence of oxygen) and can be used for agricultural and industrial purposes, such as to enhance the quality of soils or remove pollutants from wastewater.	Natural rock weathering is a geological process that removes around 1.1 Gt of CO_2 from the atmosphere per year. As silicate rocks weather, they capture carbon from the atmosphere permanently, but it happens at extremely slow rates over tens of thousands of years. Enhanced rock weathering is a process that fast-tracks the natural process of carbon removal.	Buried or covered biomass can be preserved over time for thousands of years as observed in many natural examples. This engineered method offers a large scale, affordable and fully additional carbon removal solution. It covers activities that inhibit decomposition of buried woody biomass and where this can be maintained for at least 100 years.	Manufactured concrete-like building elements from steel slag (waste material from steel industry) instead of traditional cement. CO_2 negative concrete that removes more CO_2 than its production emits.

Biochar

Biochar is obtained from **heating biomass** (wood, leaves, straw, or other biosolids) at **high temperatures without oxygen**. This process, known as **pyrolysis**, concentrates carbon in a form that is very resistant to biological **decomposition**.

Biochar can be used for **agricultural** and **industrial purposes**, such as to **enhance** the quality of **soils** or **remove pollutants** from **wastewater**. Biochar is a powerful tool for removing carbon dioxide from the atmosphere and has many **social** and **environmental** benefits.

BENEFITS OF BIOCHAR

- Improves agricultural productivity, by helping soils retain water and nutrients, and restoring degraded soils
- Can be used for remediation of contaminated sites or as a sorbent for water treatment
- Generates renewable energy from the pyrolysis process
- Avoids air pollution caused by biomass burning and diverts organic waste from landfill

Enhanced Rock Weathering

Rock weathering is a **natural process** that removes carbon from the atmosphere and usually takes thousands of years. **Enhanced Rock Weathering (ERW) fast-tracks** the carbon removal process by **spreading crushed silicate rocks** on **surfaces**, such as agricultural lands.

The CO_2 is removed, locking it for thousands of years, when the **carbon in soil moisture and rainwater reacts** with the surface area of the **silicate rocks.**

BENEFITS OF ENHANCED ROCK WEATHERING

Increase crop yield and enhance agricultural productivity

Amend degraded soils and reduces the need for fertilizers

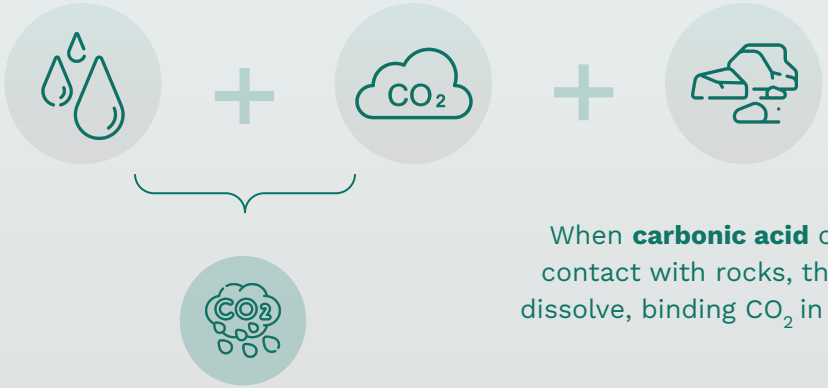
Build plant resistance against pests and diseases Improve crop water retention, potentially increasing crop resilience to drought

Enhanced Rock Weathering

How does it work?

ERW is the chemical reaction between 3 main ingredients: **rocks**, **water** and **CO_2**.

Through this chemical reaction, finely crushed rocks dissolve into the water, binding CO_2 in the process and storing it.



When water and CO_2 come into contact, **carbonic acid** is produced.

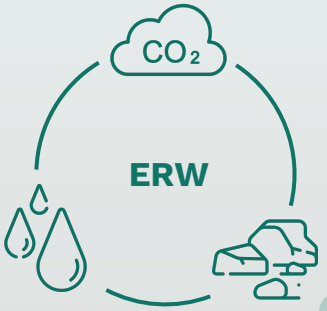
When **carbonic acid** comes into contact with rocks, they begin to dissolve, binding CO_2 in the process.

Enhanced Rock Weathering

How does it work?

CO_2 is emitted into the atmosphere through **natural processes** (i.e., venting volcanoes, natural wildfires, decomposing biomass, etc.) or through **anthropogenic activities** (i.e., fossil fuel extraction and burning, mining, industrial processes, etc.)

The water needed comes from naturally occurring **rainfall** or through the **irrigation** systems typically used in **agricultural fields**. Due to the large concentration of CO_2 in soils combined with the ample surface area, it makes sense to combine ERW projects with agriculture.



For the CO_2 weathering reaction, rocks must contain easily weatherable minerals such as olivine, which reacts fast with water and CO_2, one the most effective minerals. **Basalt** is a type of volcanic **rock** that is abundantly present and high in **olivine** thus making it a good first choice for ERW.

Engineered Solutions (ES)

Engineered solutions (ES) involve the use of **human-made technologies** and **innovative processes** to capture and store GHG emissions from the atmosphere. These solutions are more focused on mitigating emissions directly, rather than relying on natural ecosystems.

Examples of engineered solutions include carbon capture and storage (CCS) technologies, direct air capture (DAC) systems, and technologies that reduce emissions from industrial processes or energy production.

- Very high capital investment
- Small volumes
- Low co-benefits
- €160–€1,600 price range
- *Ex-ante* credits
- Low risk of reversal

Direct Air Capture and Storage (DACCS)

Bioenergy with Carbon Capture and Storage (BECCS)

Direct Air Capture and Storage (DACCS)

Geologically Stored Carbon involves the carbon sequestration and **geo-storage**, where CO_2 is captured from the atmosphere and **stored permanently** into **deep geological rock formations** where the CO_2 **cannot escape** back into the **atmosphere**.

Direct Air Capture and Storage (DACCS) focuses on **directly** capturing CO_2 from the **ambient air** and **storing** it **underground**. It uses engineered **technologies** to remove carbon from the atmosphere, usually through chemical or physical processes.

BENEFITS OF DACCS

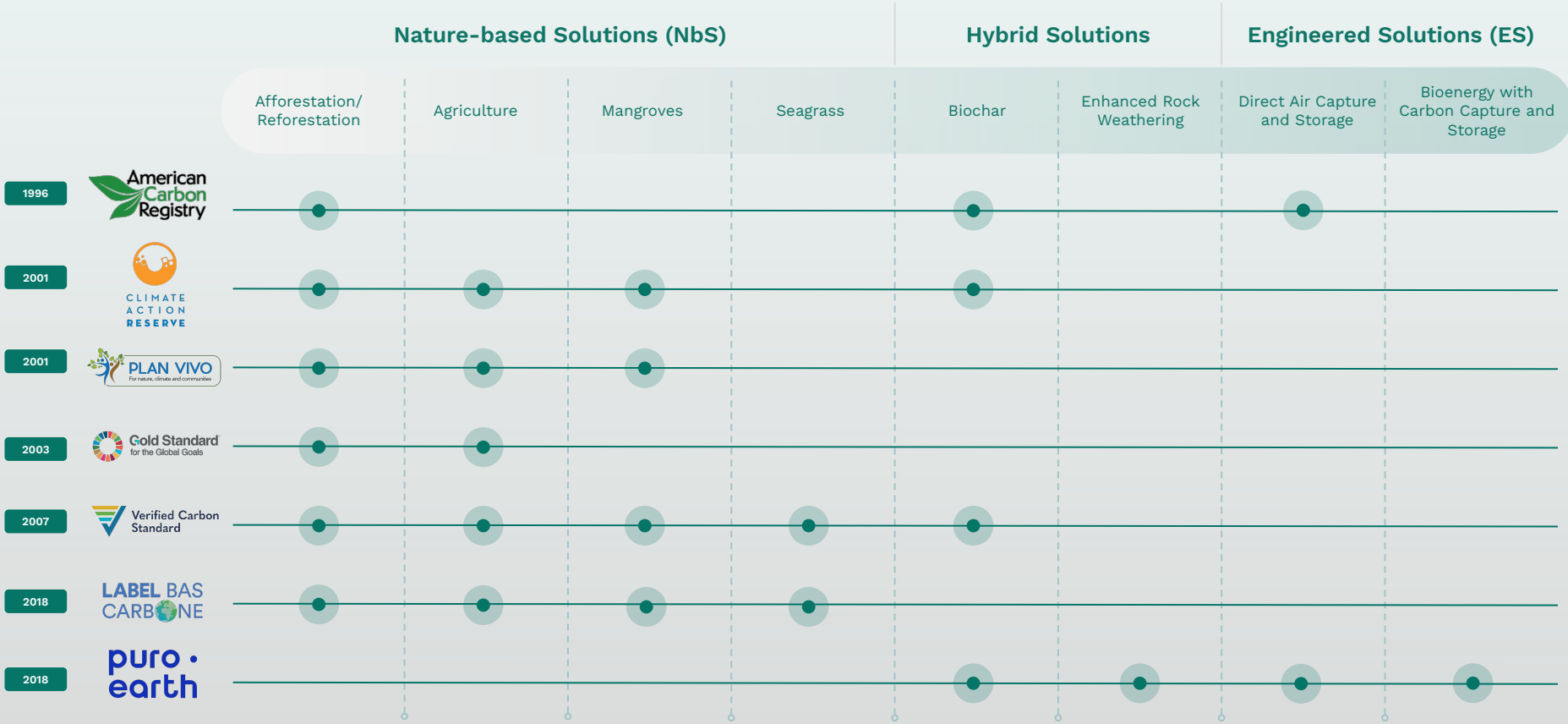
DACCS contribute to air quality, as it removes not only CO_2 but also other pollutants and particulate matter from the air.

DACCS projects can create employment opportunities in R&D and the deployment of carbon capture technologies, fostering innovation and providing jobs and financial benefits.

DACCS can recycle CO2 into valuable products like synthetic fuels or construction materials, reducing the need for fossil fuel extraction and the associated environmental impacts.

How do they compare?

Factor	Nature-based Solutions	Hybrid Solutions	Engineered Solutions
Capital Investment	Low		High
Operational & Maintenance Costs	Low		High
Co-benefits	High		Low
Volume	Large		Small
Risk of reversal	High		Low
Price range	€15–€50	€100–€600	€160–€1,600
Procurement type	*Ex-post & ex-ante*	*Ex-post & ex-ante*	*Ex-post & ex-ante*



*Some methodologies might still be under development

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