Costs and Potentials of Carbon Removals

Most numbers are taken from the State of Carbon Removal Report (https://www.stateofcdr.org) , since it is the most recent and most comprehensive study of literature now, considering > 200 scientific publications and other sources.

			Specific Costs (from)	Specific Costs (to)	Specific Costs (mean)	Potential (from)	Potential (to)	Potential (mean)	Technology Readiness Level (TRL)
Removal Process	**Storage / Product**	**Data Source**	$/tCO2e	$/tCO2e	**$/tCO2e**	GtCO2/yr	GtCO2/yr	**GtCO2/yr**	**1-9**
Direct Air Capturing (DAC)	Geological Injection	CDR_2023	100	300	**200**	5	40	**22,5**	**6**
Enhanced Weathering	Minerals or Biocarbonate	CDR_2023	50	200	**125**	2	4	**3**	**3-4**
Ocean alkalinisation	Minerals or Biocarbonate	CDR_2023	40	260	**150**	1	100	**50,5**	**1-2**
Ocean fertilisation	Marine Sediment	CDR_2023	50	500	**275**	1	3	**2**	**1-2**
Blue Carbon	Aquatic Biomass	CDR_2023 McKinsey_2022	-	-	**66**	0	6	**3**	**2-3**
BECCS	Geological Injection	CDR_2023	15	400	**207,5**	0,5	11	**5,75**	**5-6**
Afforestation/ Reforestation	Trees	CDR_2023	0	240	**120**	0,5	10	**5,25**	**8-9**
Biological capture	Biochar	CDR_2023	10	345	**177,5**	0,3	6,6	**3,45**	**6-7**
Soil carbon sequestration	Soil	CDR_2023	-45	100	**27,5**	0,6	9,3	**4,95**	**8-9**
Peatland and Wetland	Soil	CDR_2023	-	-	-	0,5	2,1	**1,3**	**8-9**
Agroforestry	Trees	CDR_2023	-	-	**100**	0,3	9,4	**4,85**	**8-9**
Biological capture (trees)	Construction Materials	CDR_2023 Puro.earth_2023	80	120	**100**	0,2	1,3	**0,75**	**8-9**
Improved forest management	Trees	CDR_2023	-	-	-	0,1	2,1	**1,1**	**8-9**
Growing Algae	Bioplastic	Wiattrowski_2022 Hepburn_2019	800	1000	**900**	0,2	0,9	**0,55**	**5**
Growing Algae	Construction Materials	Wiattrowski_2022	1200	1200	-	-	-	-	-
Seaweed	Aquatic Biomass	TheSeaweedCompany_2023 Duarte_2017	-	-	**500**	**-**	-	**0,17**	**-**

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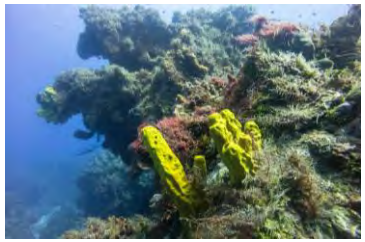
Direct air capturing carbon storage (DACCS) or (DAC) are technologies that extract CO2 directly from the atmosphere by chemical filtering processes. The CO_2 can be permanently stored in deep geological formations, thereby achieving carbon dioxide removal (IEA_2023).

Enhanced Weathering (EW) is a set of theoretical proposals to remove CO_2 by spreading large quantities of finely ground rock material onto extensive land areas, beaches or the ocean. EW aims to mimic and accelerate the natural weathering processes of silicate and carbonate rocks (GEO_2021).

Ocean Alkalinisation is the deposition of alkaline minerals or their dissociation products at the ocean surface. This increases total surface alkalinity and may thus increase ocean CO2 uptake and ameliorate surface ocean acidification as co-benefit. The residence time of dissolved inorganic carbon in the deep ocean lies at around 100,000 years (EU_2022).



Ocean Fertilisation is a carbon removal method that depends on the intentional addition of nutrients to the near-surface ocean with the goal of sequestering further CO2 from the atmosphere through biological production (IPCC_2022).

Blue Carbon is the organic carbon captured and stored by vegetated coastal ecosystems (salt marshes, seagrass meadows, and mangroves). These ecosystems sequester or absorb CO2 from the atmosphere through photosynthesis and trapping carbon-rich sediment particles (NOAA_2014).

Bioenergy with carbon capture and storage (BECCS) involves the biological capture of atmospheric carbon by photosynthetic processes, producing biomass used for electricity or fuel generation before CO_2 is captured and stored into a suitable geological formation (IEA, 2022).

Afforestation is the conversion of abandoned and degraded agricultural lands into forests (SD_2021)

Reforestation is the replantation of trees in deforested land (SD_2021).

Biochar involves pyrolysis or gasification of organic material in low-oxygen conditions from plant waste. The resulting char can be mixed with existing soil, acting as a fertilizer and sequestering carbon with a mean residence time of about 2,000 years (Nature_2009).

Soil Carbon Sequestration is a process in which CO_2 is removed from the atmosphere and stored in the soil carbon pool. This process is primarily mediated by plants through photosynthesis, with carbon stored in soil organic carbon (KP_2012).

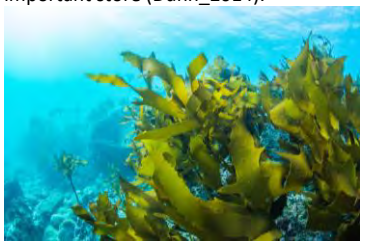
Peatland is generally considered to be a generic term for any freshwater wetland that accumulates partially decayed plant-matter peat (usually to a depth of greater than 40 cm), referred to as peat. Peatlands are the most efficient carbon stores of all terrestrial ecosystems and are second only to oceanic deposits as the Earth's most important store (Dunn_2014).

Agroforestry describes a form of land use intentionally combining the growth of woody perennials with crop production or animal husbandry on the same land area. It is a prime example of integrated land management and likely the mitigation action with benefits in several policy fields (FAO_2015)

Wood in Construction – biomass from sustainably managed forests can be converted to bio-based construction materials used in buildings. They maintain the biomass and carbon sequestered within a long-lived storage, with low likelihood of reversal (Puro_2023).

Improved Forest Management activities which result in increased carbon stocks within forests and/or reduce greenhouse gas emissions from forestry activities when compared to business-as-usual forestry practices (Mongabay_2012).

Micro-Algae Products - Microalgae are very productive biological systems for capturing carbon by generating biomass. They have much a higher efficiency than trees and can grow in industrial reactors, which makes it easier to measure the amount of carbon captured. Algae can be converted to different products (Sayre_2010).



Seaweed (Macro-Algae) could be an important source of the carbon sequestered in marine sediments and the deep ocean. In addition, macroalgae could be transformed into feedstock such as biofuels to reduce reliance on fossil fuel combustion. Land-based macroalgae farming promise to have great potential, too (Krause_2016)

CDR_2023: https://www.stateofcdr.org (table 1.1)

McKinsey_2022: https://www.mckinsey.com/capabilities/sustainability/our-insights/blue-carbon-the-potential-of-coastal-and-oceanic-climate-action

Puro.earth_2023: https://puro.earth/carbon-removal-index-price/

Wiattrowski_2022: https://biotechnologyforbiofuels.biomedcentral.com/articles/10.1186/s13068-021-02098-3

Hepburn_2019: https://www.nature.com/articles/s41586-019-1681-6

TheSeaweedCompany_2023: https://www.theseaweedcompany.com/our-certificates#purchase-certificates

Duarte_2017: https://www.frontiersin.org/articles/10.3389/fmars.2017.00100/full

IEA_2023: https://www.iea.org/reports/direct-air-capture

GEO_2021: https://www.geoengineeringmonitor.org/2021/04/enhanced-weathering-factsheet/

EU_2022: https://data.consilium.europa.eu/doc/document/ST-15557-2022-ADD-5/en/pdf

IPCC_2022: https://data.consilium.europa.eu/doc/document/ST-15557-2022-ADD-5/en/pdf

NOAA_2014: https://oceanservice.noaa.gov/ecosystems/coastal-blue-carbon/

IEA, 2022: https://www.iea.org/reports/bioenergy-with-carbon-capture-and-storage

SD_2021: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/afforestation

Nature_2009: https://www.nature.com/articles/ngeo395

KP_2012: https://www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790/#:~:text=Soil%20carbon%20sequestration%20is%20a,in%20the%20form%20of%20SOC.

Dunn_2014: https://www.tandfonline.com/doi/full/10.4155/cmt.11.23

FAO_2015: https://www.fao.org/3/cb1203en/CB1203EN.pdf

Puro_2023: https://puro.earth/articles/the-role-of-wooden-building-elements-in-achieving-a-net-zero-571

Mongabay_2012: https://rainforests.mongabay.com/carbon-lexicon/Improved-Forest-Management.html

Sayre_2010: https://academic.oup.com/bioscience/article/60/9/722/238034

Krause_2016: https://www.researchgate.net/publication/308036859_Substantial_role_of_macroalgae_in_marine_carbon_sequestration