Actions required to secure the large-scale deployment of the leading CDR approaches to meet EU climate targets

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CARBON DIOXIDE REMOVAL TECHNOLOGIES (CDR-T): MICROBIAL CO_2 FIXATION (MCO_2)

INTRODUCTION

In the Paris Agreement (United Nations, 2015), the necessary bases were established to address the issue of climate change as urgent, using the highest level of technological and scientific knowledge to contain and address the problem on a global scale. Subsequently, the Intergovernmental Panel on Climate Change (IPCC) announced the results of a rigorous assessment based on scientific, technical, and socio-economic data available in the literature on global warming of 1.5°C and the comparison between global warming of 1.5°C and 2°C above pre-industrial levels. Resulting model pathways with no or limited overshoot of 1.5°C indicate that emissions must decline by 45% to keep warming below 1.5ºC by 2030, and towards net zero by 2050 (IPCC, 2018b).

The C-SINK project funded by Horizon Europe aims to establish the foundations to build a standardized and transparent European CDR market with trustworthy accounting methodologies based on robust Monitoring, Reporting, and Verification (MRV) pre-standards and policy strategies.

WHAT IS CARBON DIOXIDE REMOVAL (CDR)?

Following the IPCC's 8th Assessment Report, CDR refers to activities that remove carbon dioxide (CO_2) from the atmosphere and store it permanently (IPCC, 2018a). They can be grouped into nature-based and technology-based removals (Meyer-Ohlendorf, 2020). Nature-based enhancing biological sinks of CO_2 are, among others, afforestation (AF), reforestation (RF), and soil carbon sequestration (SCS) as a result of BCO_2. Technology-based removals employ chemical engineering to achieve long-term removal and storage. Among others, an example is bioenergy with carbon capture and storage (BECCS), but there are additional approaches including improving soil quality, enhanced weathering, and the production of biochar (Ornelas et al., 2023).

GLOSSARY

Aerobic metabolism: Type of metabolism which occurs in the presence of oxygen.

Anaerobic metabolism: Type of transformation produced with no presence of oxygen.

Autotrophic bacteria: Type of bacteria which synthesizes their own food. They derive energy from light, utilize simple inorganic compounds like CO_2, water, etc., and convert them into organic compounds to supplement their energy requirements.

Biological carbon fixation (BCO_2): A nature-based technology in which living organisms absorb and convert CO_2 into organic matter through biochemical pathways (Berg, 2011). Organic compounds created by BCO_2 are used to store energy and to build other biomolecules. Carbon is primarily fixed through photosynthesis, when sunlight is available, and chemosynthesis, in the absence of sunlight.

Heterotrophic microorganisms: Organisms that obtain their energy and carbon from organic compounds.

Microbial carbon fixation (MCO_2): A sub-term of BCO_2, refers to the fixation of CO_2 by microbes into usable organic substances by means of enzymatic reactions.

Soil microbiota: The abundance and diversity of microbes residing in the soil (bacteria, fungi, archaea, protists, and algae).

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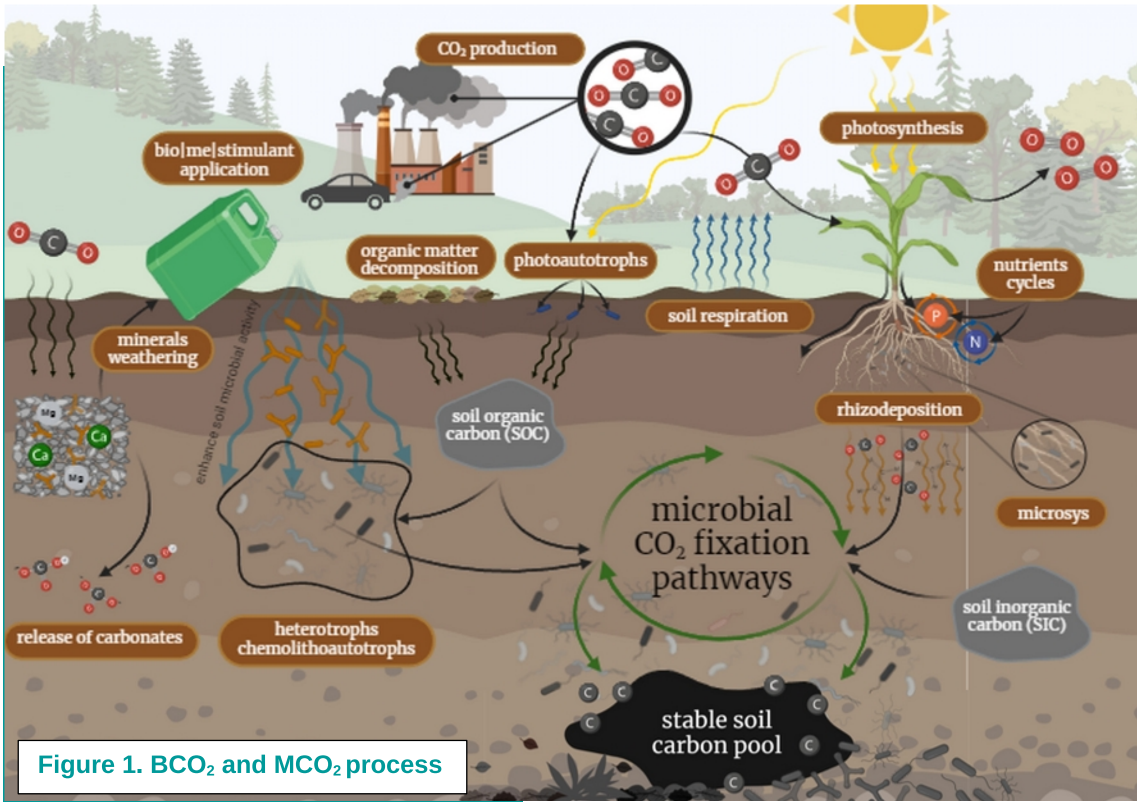

Figure 1. BCO_2 and MCO_2 process

DEFINING CO_2 REMOVAL FROM A MCO_2 STANDPOINT & PROCESS

CO_2 removal by BCO_2 refers to the amount of CO_2 that is consumed and stored by microorganisms in the soil and plants growing in a defined area. When plants photosynthesize, they take CO_2 from the atmosphere and convert it into organic matter, such as wood, leaves, and roots, while releasing oxygen (see Figure 1).

Apart from BCO_2 fixation by plants, MCO_2 occurs in all microorganisms, both autotrophic and heterotrophic. Biological carbon fixation by autotrophs can utilize light or inorganic chemical energy to fix atmospheric CO_2 through evolved carbon fixation pathways (Gong et al., 2018). Autotrophic bacteria synthesize all their constituent cells using CO_2 as a carbon source in that way (Ge et al., 2016).

Importantly, recent studies report significant biological CO_2 fixation by heterotrophic microorganisms. These microorganisms are capable of consuming CO_2 and incorporating it into their metabolism during bioremediation and biofertilization processes (Bräuer et al., 2016); (Chen et al., 2009); (Kimura et al., 2011); (Miltner et al., 2005); (Santoro et al., 2013).

WHAT IS THE CURRENT STATE OF THE TECHNOLOGY?

Various microorganism based biostimulants are commonly applied by farmers to increase yields – however, impact on CO_2 fixation in soil was never the main purpose of their use, consequently monitoring and verification of their impact are lacking.

The major unknowns in MCO_2 technology are the poorly understood related processes involved, the scalability, and the very limited data. There are no clear MRV standards or methodologies. It is very well known that carbon gets sequestered in soil as Soil Organic Carbon (SOC), but there is also a possibility of carbon sequestration in the form of Soil Inorganic Carbon (SIC). Moreover, there is a lack of understanding of biochemical pathways happening in soil microbiota. Furthermore, methodologies

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for the determination of carbon sequestered in soil are not uniform and standardized at the moment. SIC is not taken into account when calculating CO_2 stored in the form of soil carbon.

DEFINITION OF EACH PROCESS-STEP

1. Bioleaching or microbiological weathering for 5 days, in which bacteria multiply and produce metabolites dissolving minerals, to produce 2 types of biostimulants to be used as microbial soil activity enhancers: *ekofertile® plant* and *microfertile® plant – water consumption.*

2. Pumping of biostimulants to plastic canisters – *energy consumption by the pump.*

3. Printing the labels – *energy consumption.*

4. Transport of biostimulants to farmers – *fuel consumption.*

5. The farmer mixes biostimulants with water and applies the solution by spraying – *fuel consumption, water consumption*, or by irrigation system – *electricity and water consumption.*

6. Organic and inorganic carbon monitoring in soil.

7. Harvest and analysis of yield – harvest by tractors, transport to food factories – *fuel consumption*.

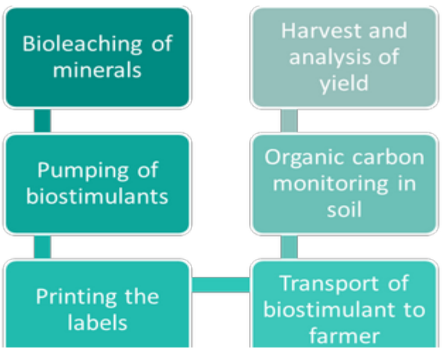

Figure 2. MCO2 step-process.

PERMANENCE

The most common timeframe applied in MCO_2 in the form of SCS is decades to centuries according to IPCC[1]. Regarding the time factor in removing CO_2, soil microbiota communities show significant roles in carbon removal from the atmosphere and fixing it in the soils. However, potential fluctuations during large-scale deployment regarding microbial communities have not been sufficiently studied. Carboxylase reactions are rather immediate reactions and result in the assimilation of CO_2 into organic metabolites by microorganisms. This CO_2 incorporation by chemo-organo-heterotrophic microorganisms has been referred to as "heterotrophic carbon dioxide assimilation" or "heterotrophic carbon dioxide fixation" and can be assumed to have an immediate effect (Braun et al., 2021).

REVERSAL RISK

MCO_2 produces SIC and SOC. Regarding SIC, MCO_2 presents a low risk. Sylvera[2] has ranked mineralized CO_2 (SIC) to have no practical risk of reversal. Microbial carbon fixation of SIC is proven in research done by Liu et al. (2020) where they demonstrated that desert soil microbes are directly involved in fixing atmospheric CO_2 via biomineralisation. Same is proven by Braun et al. (2021) for heterotrophic bacteria's ability to fixate CO_2. However, Sylvera considers that SOC has a high risk of reversal since there is a high range of factors that trigger carbon reversal — flooding, droughts, wildfires, disease, renovation of a pasture, change in soil acidity or change of the soil nutrient content (named "depletion event" in a guide[3] to the estimating sequestration of carbon in soil using default values method).

COSTS, TRL, AND TYPICAL SCALE

Some estimated costs are 1,09 € per litre of biostimulant and it is applied based on the type of crops in rates from 10–200

[1] https://www.ipcc.ch/report/ar6/wg3/downloads/outreach/IPCC_AR6_WGIII_Factsheet_CDR.pdf

[2] https://www.sylvera.com/blog/permanence-carbon-credits

[3] https://cer.gov.au/document/guide-to-estimating-sequestration-carbon-soil-using-default-values-method

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litres per hectare. It is affordable for farmers because the cost return of this novel technology is 10 times higher compared to conventional products due to no diseases, yield increase, proteins increase, and possible reduction on N fertilizer up to 50%. The potential additional profits from carbon credits will be calculated during the field trials within the C-SINK project. Usually, it ranges from an additional 30–300 € per hectare.

TYPICAL SCALE OF CO_2 REMOVAL/LIMITING FACTORS

According to Shimmel (1987), dark fixation of CO_2 in agricultural soil, based on the rate of radiolabelled CO_2 incorporation, varied from 0.2 to 4.8 mg/m^{2}h. Data from Šantrůčková et al. (2005) projected the rate of estimated heterotrophic CO_2 fixation which ranged from 36.5 mg CO_2/m^{2}h, in the soil with pH 7.5, to 2.8 mg CO_2/m^{2}h, in the soil with pH 4.8.

No industrial-scale data is available. Thereby a pilot is essential to study MCO_2 deployment capacity.

C-SINK experts have found that limiting factors to scaling MCO_2 include obtaining import permissions, local registrations, and sales for the biostimulants in the EU[4].

NEGATIVE EFFECTS

High water consumption.

CO-EFFECTS

Benefits for farmers: sugar and protein content increase, faster development of crops, disease resistance, drought resistance, yield and profit increase with low investment per hectare, increased efficiency of agrochemicals.

Benefit for mining companies: new ecological processing technology increases the value and purity of minerals.

The co-effects described above have been verified and measured[5], for instance, if the right dosage of the biostimulant is used. Also, the mentioned co-effects can potentially positively influence the use of biostimulants as MCO_2 CDR-T because farmers are primarily interested in applying it due to agricultural benefits and not specifically CO_2 sequestration potential.

The C-SINK project will allow demonstration of biostimulants' role in MCO_2 CDR-T which will further raise awareness and willingness of, not only farmers, but all land managers to apply this technology. This will enable carbon sequestration and contribute to the goals of the Paris Agreement in tackling climate change by suplementing existing CO_2 mitigation efforts.

MCO_2 PILOTS DEVELOPED WITHIN THE C-SINK PROJECT

Figure 3. C-SINK MCO_2 pilots

Several case studies on farmland with and without crops will be conducted in three countries (Germany, Slovakia, and Croatia). The soil will be inoculated with

[4] In EU countries – in some cases it is a simple two-page declaration, and labels submitted to a relevant authority. In other countries no need for anything, it is automatically mutually recognized. E.g. in Spain, it is on a volunteer basis to prepare this declaration. Only in Switzerland registration is needed, while UK is free to sell without any action.

[5] It is possible to measure yield increase, protein increase etc. to calculate an increase.

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up to 1´000 microbial species of heterotrophic, autotrophic microorganisms and microalgae produced by bioleaching operations. The objective of case studies will be to evaluate the potential and mechanisms by which microorganisms contribute to soil carbon sequestration and retention. Each location is characterised by different climates and different soil types.

Field trials in Slovakia are conducted on raspberries and cereals, on red currants and blueberries in Germany and, in vineyards in Croatia.

Soil samples are taken periodically throughout the growing season to assess the soil sequestration potential. This is done according to ISO 18400-104:2018 Soil Quality – Sampling. Soil samples' collection and application of different concentrations of *ekofertile® plant* and *microfertile® plant* to raspberries by spraying and irrigation are shown in Figure 3. – results can be seen at the farm in Košické Oľšany. Furthermore, soil samples are analysed to obtain parameters of interest: total organic carbon, total inorganic carbon, humus, pH, total nitrogen, phosphorous, potassium, magnesium, copper, C/N ratio, and bulk density.

To process data and determine SCS, a variety of methodologies will be used to evaluate their correctness and suitability such as Microbial Carbon Mineralization (MCM) – Methodology for Quantification and Crediting of Carbon Dioxide Removal from Andes, VM0042 – Methodology for Improved Agricultural Land Management from Verra, Carbon Credits (Carbon Farming Initiative—Estimation of Soil Organic Carbon Sequestration using Measurement & Models) Methodology Determination 2021 from Australian Government & Soil Carbon Measurement Methodology from Carboneg.

Finally, the impact on biological carbon sequestration in the soil will be monitored and compared in sprayed and irrigated areas within the C-SINK project.

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👉 If you want to know more about the C-SINK project, visit our website at ➡️ https://c-sinkproject.eu/

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