PUBLIC

CO2SMOS
Solutions for a circular biobased industry

REPORT ON SELECTED EVALUATION INDICATORS

DELIVERABLE 1.3.

[CARTIF]

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Executive Summary

This report - Deliverable 1.3 « *Report on selected evaluation indicators* » is a public document produced in the framework of the CO_2SMOS project. It relates to work conducted under WP1 *« Definition of the full value chain and process requirements »* and more specifically under task 1.4 *« Full process and KPIs definition ».*

This report summarizes a significant part of the contents included in a parallel working document entitled *CO2SMOS D1.3 Confidential Detailed Report*, which actually includes relevant and detailed information provided by the consortium that can be considered sensible data of the project, as well as confidential partners information. This detailed D1.3 report is expected to be submitted by the beginning of 2022 after the approval of the first project amendment that is being prepared in accordance with the Project Officer considerations.

The task 1.4 aims to set up the basis for the development of the full supply chain of the biogenic CO_2/ bio-feedstock to the CO_2-derived chemicals platform and consolidate KPIs for monitoring the outputs of the project.

In the first part, the full process definition from the initial biogenic CO_2/ bio-based feedstock to the CO_2-derived chemicals platform is defined, including a process model that is based on preliminary operation/ performance parameters and mass-energy balance reports obtained from primary data of literature and also from technology providers.

In the second part, the required inputs to calculate KPIs are identified and listed. These inputs have been supplied by industrial biogenic CO_2 emitters, technology providers, innovation and research centers/institutes and final end-users. The data characterize the state of reference of the process proposed by the project.

To facilitate their understanding, they are divided into four different categories related to technical, environmental, economic and social aspects. When necessary, a calculation method is proposed.

The set of KPIs selected during this analysis will enable the assessment of impacts related to the implementation of CO_2SMOS overall concept. All the KPIs and their characteristics have been validated by the CO_2SMOS consortium to have a common basis of evaluation for the project.

Contents

List of abbreviations

2,3-BDO	2,3-butanediol
BBI	Bio-based industries
BTEX	Benzene, Toluene Ethylbenzene and Xylenes
CAPEX	Capital Expenditure
CMR	Catalytic Membrane Reactor
eCMR	Electrocatalytic Membrane Reactor
CSTR	Continuous stirred tank reactor
DSP	Downstream processing
FFAs	Free fatty acids
GHG	Greenhouse gases
GMO	Genetically modified organism
HCAs	Hydroxycarboxylic acids
HT-PEM	High Temperature-Proton Exchange Membrane
KPI	Key Performance Indicator
LCA	Life Cycle Analysis
LcDCA(s)	Long-chain dicarboxilic acid(s)
mcl-PHA	Medium chain length-polyhydroxyalcanoate
MEG	Monoethylene glicol
PET	Polyethylene terephthalate
PHB	Polyhydroxybutyrate
PG	Propylene glycol
PX	Paraxylene
RWGS	Reverse Water-Gas Shift
SEOS	Solid electrolyte O_2 separator
TPA	Terephthalic acid
TFCM	Thin-Film Composite Membrane

1.Introduction

The overall goal of the **CO_2SMOS** project, funded by H2020, is to boost the development of a set of innovative cost competitive CO_2 conversion technologies (gas/liquid fermentation–biorefinery processes, intensified electrocatalytic processes and bio-based/organic catalysed processes) to transform biogenic CO_2 emissions produced by bio-based industries (e.g., in fermentation processes) into a set a of high added-value chemicals with direct use as intermediates for bio-based products within the BBI's value chain.

The project will tackle the development and optimisation of a CO_2 conversion technological toolbox allowing for the production of seven added-value chemicals and polymers (**polyhydroxyalkanoate**s (mcl-PHA and PHB), **2,3-butanediol** (2,3-BDO), **long chain dicarboxylic acids C16-C18** (LcDCAs), **BTEX and para-xylene** (PX), **cyclic carbonates and hydroxycarboxylic acids** (HCAs)) from the primary conversion of CO_2 into two platform bulk chemicals (syngas and acetate). The proposed technologies will be tested and validated from lab (TRL 3-4) to pilot scale (TRL 5), and the obtained molecules will be validated into final applications for the formulation of high-performance biopolymers renewable chemicals.

The **WP1** of the project has several main objectives such as the characterization of the feedstock used (biomass and biogenic CO_2 emissions), the definition of stakeholders and project end-users' requirements (bio-based industries, chemical sector -polymer and renewables chemicals) and specifications, or the study of regulatory barriers for the use of CO_2 in chemicals production or the CO_2SMOS circularity assessment by means of specific methodology developed and its application in user cases.

Within this WP, **Task 1.4** deals with the identification of KPIs for the demonstration of the CO_2SMOS overall concept. Based on these KPIs, data will be collected during the lab scale demonstrations and several assessments will be done at a later stage in the project: the technical energy analysis, the scalability, and replicability analysis. The main output of T1.4 is the **D1.3 – *Report on selected evaluation indicators***. The objective of this deliverable is to establish a list, as exhaustive as possible, of objective criteria in form of KPIs to evaluate the benefits of the CO_2SMOS concept implementation.

2.Full process design

2.1. Main concept of the overall process

The CO_2SMOS concept is focused in a full value chain model in which bio-based industries play the dual role as CO_2 emitters and end-products or technology users, addressing two aspects: a) the development of innovative **CO_2 conversion technologies** and the application of **added-value chemicals** synthetized from biogenic CO_2 streams captured/upgraded from specific industries (bio-based, chemical, other energy intensive sectors), and renewable raw materials/biofeedstock.

CO2SMOS aims to develop breakthrough and cost-effective routes to produce high added-value bio-based chemicals from bio-based industrial CO_2 emissions (especially focused on biogenic CO_2) and renewable sources (green H_2 and biomass), by means of a solution that combines innovative biotechnological and intensified chemical conversion processes, comprising: *a)* a multi-stage gas-liquid-fermentation cascade process, *b)* a co-electrocatalytic technology and a catalytic membrane reactor (CMR) system, and *c)* a biomass conversion process driven by organic/bio-catalysts**.**

In this sense, starting from **biogenic CO_2 emissions** and **bio-based feedstock** as versatile raw materials, CO_2SMOS aims to develop and validate an up-scalable platform of sustainable technologies that can be classified into **primary conversion technologies**, from CO_2 to bulk chemicals (acetate, syngas), and **final conversion technologies**, from bulk chemicals to bio-intermediate products (mcl-PHA and PHB, 2,3-BDO, lcDCAs, BTEX and PX, cyclic carbonates and HCAs). The technologies will be tested and validated from **lab** (TRL 3-4) **to pilot scale** (TRL 5), and the obtained molecules will be evaluated for the formulation of high-performance biopolymers (bio-polyesters, bio-polycarbonates, bio-materials) and renewable chemicals (BTEX, PX) in the last stage.

All the resources involved in these conversion technologies are renewable, including **biogenic CO_2**, **renewable electricity** and **biomass by-products.**

2.1.1. Upstream processing

Purity and specifications of CO_2 streams used: In relation to the biogenic CO_2 emission streams that will be used to carry out the **biotechnological and catalytic conversion processes**, it will be necessary to meet a series of requirements, as these streams may be accompanied by different compounds (O_2, HCN, NH_3, benzene/tars, H_2S) that have an inhibitory effect on the processes. Specific values of most common impurities that can influence the CO_2SMOS technological processes will be determined by means of laboratory tests developed during the project. Other specifications of the target CO_2 streams such as temperature, pressure and the size of the emitting facility (in terms of average flows) are also interesting indicators that will also be studied.

Description of bio-based feedstock used: specially for the synthesis of cyclic carbonates will be vegetable oils and other molecules such as terpenes derived from the agro-food/forestry sectors. These molecules are susceptible to be converted to the corresponding cyclic carbonates through catalysed carbonation reaction on their unsaturated moieties.

2.1.2. Process blocks or technologies

The conversion of CO_2 into bulk chemicals and bio-intermediate products is carried out by means of different technologies. Thus, depending on the technologies and the chemical products obtained, different value chains are developed, which can be generally integrated into the so-called "CO_2 to Chemicals Platform", represented in **Figure 1:**

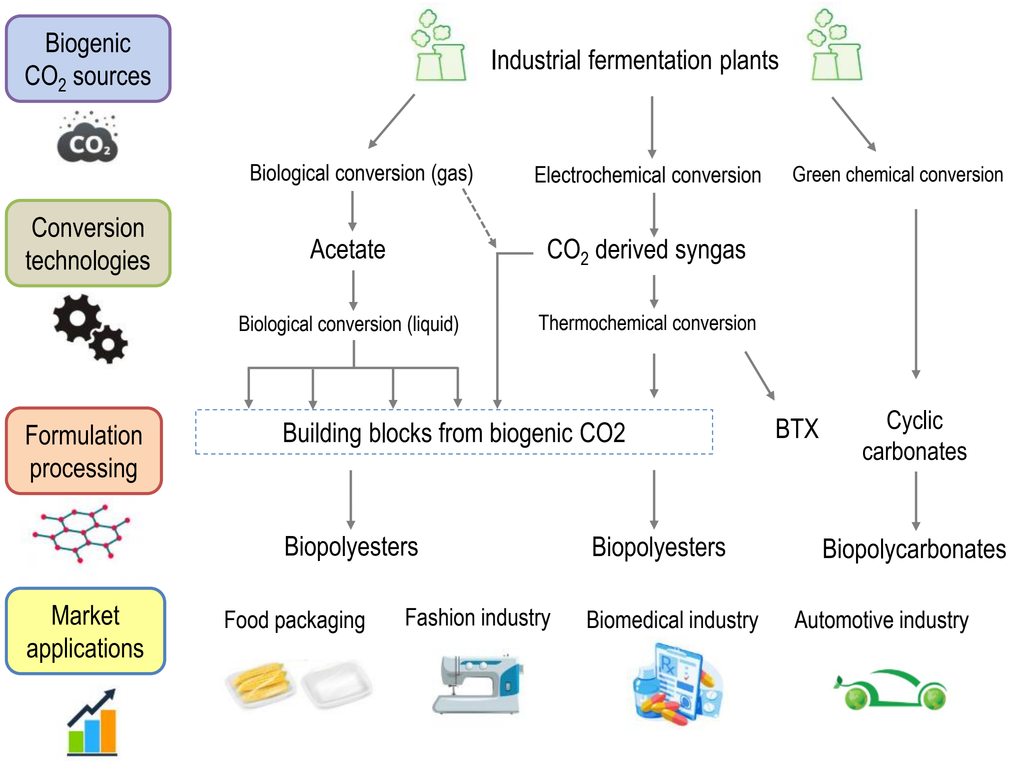

Figure 1: Scheme of the "CO2 to chemicals Platform"

2.1.2.1. Technology 1: Advanced gas-fermentation process for conversion of CO_2/H_2 and green syngas streams into acetate and C4 key bulk-chemicals

Several anaerobic bacteria named as acetogens been shown to ferment single carbon gases such as CO and/or CO_2 plus H_2 into chemicals (acetate, ethanol, lactate, 2,3-BDO, etc.), through the Wood–Ljungdahl pathway. Therefore, depending on the composition of the C1 gases, some bacteria can be more efficient to produce acetate. In this context, metabolic engineering and synthetic biology are powerful tools to increase the acetate production and reduce the spectrum of unwanted by-products. CO_2SMOS proposes two routes to optimize the productivity of the CO_2 to C2-C4 compounds:

- **Technology 1.1: Biological conversion of CO_2/H_2 to bioacetate (Gas fermentation):**

With this technology, **CO_2/H_2 will be converted to acetate** under anaerobic conditions via a gas fermentation biologic process. To increase the transformation efficiency of CO_2/H_2 into acetate, CO_2SMOS propose to genetically modify the acetogenic bacterium. This bacterium is able to use CO_2 as a carbon source and H_2 as energy source to grow and secrete acetate to the culture media. After the identification of target genes responsible of metabolic bottlenecks, a combination of genetic engineering techniques and synthetic biology tools will be used in the selected strains.

- **Technology 1.2: Biological conversion of green syngas to bioacetate or 2,3-BDO (Gas fermentation):**

Syngas fermentation is a bioconversion technology of syngas/waste gas components to produce low-carbon biofuels and various biochemical products. This technology is currently undergoing an intensive research and development phase. A number of laboratory- and demonstration-scale studies have been done on the subject of using different acetogenic bacteria (*Clostridium sp., Morella sp.*) that have the ability to convert various syngas components (CO, CO_2, and H_2) to multicarbon bulk chemicals such as ethanol, 2,3-BDO, acetate, butyrate, butanol, and lactate. The aim of this CO_2SMOS technology is to develop new engineered strain able to produce specifically acetate or 2,3-BDO using the green syngas under anaerobic conditions via a gas fermentation biologic process.

On the one hand, alternative modified strains will be used to increase the **acetate** production and the performance of the syngas fermentation process. On the other hand, modified strains will be tested to produce **2,3-BDO**.

CO_2SMOS will increase the productivity of these gas fermentation processes by carrying trials at moderately elevated pressures (5-10 bar) combined with more controlled operational conditions in specialised pressurised bioreactors and implementing other improvements such as continuous cultivation, reuse of medium components or simple acetate purification processes**.**

2.1.2.2. Technology 2: Electro-catalytic conversion of CO_2/H_2O into green syngas and added-value chemicals

The electrochemical conversion of CO_2 to syngas must compete with syngas from fossil sources, which is yet abundant and can be converted using highly optimised industrial processes. Thus, it is critical to achieve high efficiencies in the electrochemical route.

- **Technology 2.1: Electro-catalytic conversion of CO_2/H_2O into green syngas (co-electrolysis)**

CO_2 will be electrocatalytically reduced to syngas in an intensified electrochemical membrane reactor integrating three components: **(i)** the HT-PEM electrolyser (**Figure 2**), **(ii)** the RWGS catalyst, and **(iii)** the water-selective membrane (TFCM). The architecture of the integrated reactor will enable a more efficient heat and energy management and controlling the flow path and reaction contact time, which allows tuning H_2/CO ratio.

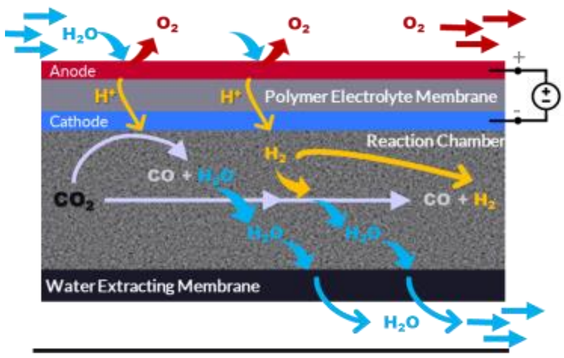

Figure 2: Intensified electrocatalytic CO2 reduction to syngas

- **Technology 2.2: Electro-catalytic conversion of CO_2/H_2O conversion into syngas and HCAs (Paired electrolysis)**

CO_2SMOS also proposes a novel paired electrolysis process to generate value-added chemicals at both electrodes: the co-reduction of CO_2 and H_2O evolution at the cathode produces syngas, whereas the anode reaction is the selective oxidation of bio-based glycols to the value-added HCAs . CO_2SMOS envision that such co-electrolysis will increase the total value of the generated products and make it a price competitive technology.

2.1.2.3. Technology 3: Thermo-catalytic conversion of CO_2 by organic/bio catalysts into cyclic-carbonates

The proposed technology based on heterogeneous and reusable organic catalysts will lead to 100% bio-based cyclic carbonates, serving as potential building blocks in the synthesis of bio-based polycarbonates.

More specifically, CO_2SMOS will combine different bio-based epoxides derived from terpenes or fatty acid esters coming from biomass with metals to provide heterogeneous catalysts with different structures, tuned functionalities and pore diameters. These developed reusable organic catalysts will be tested in the thermo-catalytic conversion using CO_2 as reagent, leading to the synthesis of new bio-polymers.

2.1.2.4. Technology 4: Biotransformation of acetate into different bio-based industrial products (liquid fermentation)

The ability to use acetate as a carbon source is present in numerous microorganisms ranging from eukaryotes to bacteria. CO_2SMOS proposes the use of CO_2-derived acetate as a key-starting material to be transformed in a second stage by means of aerobic liquid-phase fermentations into four high added-value chemicals:

- mcl-PHA
- PHB
- lcDCAs
- 2,3-BDO

Thus, the CO_2-derived bio-acetate produced by the Technology 1 will be used as carbon source by different microorganisms and compete with traditional carbon sources (glucose, sucrose, starch) used commonly in other industrial fermentation processes. The additional help of the synthetic biology tools will allow to increase the efficiency of acetate transformation by modifying wild-type strains of different targeted microorganisms.

2.1.2.5. Technology 5: Catalytic conversion of syngas to aromatics

With this technology, direct conversion of syngas to BTEX and PX will be conducted in a CMR combining catalytic conversion of syngas to BTEX with a ceramic membrane-based separation. The reaction will take place in presence of a tandem catalyst combining metallic oxides to produce specific intermediates from syngas with a zeolite to *in-situ* transform, via acid catalysis, the intermediates into aromatics.

2.1.3. Value chains

Taking advantage of the set of technologies proposed that can be properly integrated and combined, CO_2SMOS will **develop eight innovative CO_2-value chains** towards the production of high value-added and high-quality biopolymers and fine chemicals that can be integrated in the bio-based industries sector will be optimized and implemented to scale-up their production procesess.

2.1.3.1. Value chain 1a: Gas fermentation of CO_2 to bioacetate (CO_2/H_2 or syngas → bioacetate)

In this value chain, CO_2 will be transformed into **acetate** by a gas fermentation process using specific recombinant strains.

2.1.3.2. Value chain 1b: Gas fermentation of syngas to 2,3-BDO (syngas → 2,3-BDO)

In this value chain, the direct conversion of syngas to **2,3-BDO** is carried out by means of a single gas fermentation stage using specific recombinant strains.

2.1.3.3. Value chain 2: Gas to liquid fermentation of CO_2 to mcl-PHA (CO_2/H_2 or syngas → bioacetate → mcl-PHA)

In this value chain, CO_2 will be converted to **mcl-PHA** through a two-stage biochemical route: initially the gas stream will be transformed into acetate by means of an anaerobic gas fermentation process and subsequently the obtained acetate will be transformed into targeted mcl-PHAs by an aerobic liquid fermentation process using specific recombinant strains.

2.1.3.4. Value chain 3: Gas to liquid fermentation of CO_2 to PHB (CO_2/H_2 or syngas → bioacetate → PHB)

In this value chain, CO_2 will be converted to **PHB** following a two-stage biochemical route: initially an anaerobic fermentation of CO_2 to acetate and subsequently an aerobic fermentation to transform the acetate to targeted PHB by an aerobic liquid fermentation process using specific high-performance strains.

2.1.3.5. Value chain 4: Gas to liquid fermentation of CO_2 to lcDCAs (CO_2/H_2 or syngas → bioacetate → lcDCAs)

In this value chain, CO_2 will be converted to **lcDCAs (C16-18)** through a two-stage biochemical route: initially an anaerobic fermentation of CO_2 to acetate and subsequently an aerobic fermentation to transform the acetate to targeted lcDCAs using recombinant strains of the oleaginous yeast.

2.1.3.6. Value chain 5: Gas to liquid fermentation of CO_2 to 2,3-BDO (CO_2/H_2 or syngas → bioacetate → 2,3-BDO)

In this value chain, CO_2 will be converted to **2,3-BDO** through a two-stage biochemical route: initially the gas stream will be transformed into acetate by means of an anaerobic gas fermentation process and subsequently the obtained acetate will be transformed into targeted 2,3-BDO by an aerobic liquid fermentation process using specific recombinant strains.

2.1.3.7. Value chain 6: Co-electrocatalytic conversion of CO_2 to BTEX/PX (CO_2/H_2 → syngas → BTEX/PX)

In this value chain, CO_2 will be transformed into **BTEX and PX** by means of a two-stage conversion process: first, a single-step electrocatalytic process in an eCMR to convert the CO_2 and H_2O gas streams into syngas, and then a catalytic process in a CMR to convert the obtained syngas into valuable aromatics (BTEX and PX).

2.1.3.8. Value chain 7: Paired co-electrocatalytic conversion of CO_2 to HCAs (CO_2/H_2O + MEG/PG → syngas + HCAs)

In this value chain, CO_2 and bio-based glycols will be converted to **syngas** and **HCAs** by means of a paired electrocatalytical process. Since bio-based substrates are generally over-functionalized with hydroxyl groups, the knowledge from this project can be transferred to other valuable oxidation reactions.

2.1.3.9. Value chain 8: Thermo-catalytic conversion of CO_2 to cyclic carbonates (CO_2/biomass → cyclic carbonates)

In this value chain, CO_2 will be used as chemical for the conversion of bio-based feedstocks (vegetable oils, lipid, and terpene-containing fractions) to alternative building blocks such as bio-based cyclic carbonates. These bio-building blocks will be consequently used in the synthesis of green polymers such as polyurethanes and polycarbonates.

2.2. Formulation of the end-products biomaterials.

The final section of the CO_2SMOS concept is the qualification of end-products. In this way, the added-value bio-based chemicals obtained using the different CO_2SMOS technologies will be validated into high-value final applications for the formulation of high-performance and low/negative carbon biomaterials: bio-polyesters , biodegradable and compostable biomaterials band bio-polycarbonates.

2.2.1. Bio-polyesters

Two different value chains are aimed to exploit the building blocks from biogenic CO_2 into polyesters.

From one side, **lcDCAs** obtained from biogenic CO_2 will be validated into the synthesis of biodegradable biopolyesters. These biodegradable biopolyesters will be processed through reactive extrusion technology owned by the CO_2SMOS bio-based industries in combination with other biobased raw materials and additives to obtain novel biomaterials.

In parallel, other CO2SMOS bio-based end-users will aim for making polyesters from **2,3-BDO** and **BTEX**. **BTEX** (specifically p-xylene) is the source for terephthalic acid (TPA), the most commonly used monomer for polyester synthesis (mainly PET). A route to produce BTEX from biogenic CO_2, will be developed within CO_2SMOS in order to find commercially attractive materials.

2.2.2. Biodegradable and compostable bio-materials

Two different opportunities for the valorisation of intermediates from biogenic CO_2 lie in the preparation of biodegradable and compostable biomaterials:

a. **mcl-PHA, PHB** obtained from biogenic CO_2 are biopolymers that need to be properly formulated and processed in combination with other bio-based raw materials and additives to obtain high-performance biomaterials with relevant properties. CO_2SMOS bio-based industries with proprietary reactive extrusion technology will enable the processing of polyhydroxyalkanoates which will be used for the preparation of compostable and biodegradable biomaterials with applications for example in compostable packaging and 3D printing.
b. **Long chain dicarboxylic acids (LcDCAs)** from biogenic CO_2 could be valorised as building block in the synthesis of biodegradable polyesters These novel bio-polyesters could then be processed through CO_2SMOS bio-based industries proprietary reactive extrusion technology in combination

with other bio-based raw materials and additives to obtain novel biodegradable biomaterials with applications in compostable packaging, amongst the other.

2.2.3. Bio-polycarbonates

Cyclic carbonates based on limonene will be used to synthesise bio-polycarbonates, first on lab scale and after recipe development also at litre scale.

2.3. Process model

The modelling of CO_2SMOS processes has been performed using both commercial software and customized spreadsheets to define the process operation/performance parameters and mass-energy balance reports.

2.3.1. Mass balances of each value chain

There is a two-fold approach for product yields estimation in each of the value chains: the ideal yields, based on the complete conversion of the specific reactions that take place in each process step, and the actual targeted yield.

In most of the examined value chains it is aspired to reach up to 67% of the ideal yield.

2.3.2. Energy balances of each value chain

A preliminary analysis of the energy requirements has been conducted, in order to define the relevant KPIs. Regarding the value chains including water electrolysis, the specific power consumption for this process was assumed at 52.29 kWh/kg H_2[1]. In the case of **Tech 2.1** and **Tech 2.2**, the specific power consumption for CO_2 electro-reduction was estimated at 2.56 kWh/kg CO.

Besides, also the energy requirements for the fermentative conversion and DSP are considered. In this preliminary analysis for the estimation of the energy needs at the DSP unit, we assume electricity consumptions equal to 6 kWh per kg of produced CO_2-based chemical, and 10 kWh/kg the heat consumptions for the final product purification. For value chains #6, #7, #8, where no intracellular products are considered, thus the extraction process is not so energy demanding, the electricity and heat consumptions are assumed equal to 3 and 5 kWh/kg, respectively.

In general, CO_2SMOS targets to new value chains for CO_2-based renewable chemicals with total primary energy requirements less than 50 kWh/kg chemical.

2.3.3. CO_2 emissions generated by each value chain

An initial design of eight integrated value chains of CO_2SMOS corresponding to seven intermediate bio-products has been assessed. A preliminary analysis was conducted for the estimation of the CO_2 emissions in these eight value chains.

A CO_2 balance for the direct emissions, emissions derived from DSP and production yields have been also considered in order to normalize the indicators.

[1] S. Siegemund, et al., E-Fuels Study - the Potential of Electricity-based Fuels for Low-emission Transport in the EU, Dtsch. Energ.-Agent. GmbH Dena

The overall process emissions were found to be negative for all targeted value chains with a range from -0.4 to -8.5 kg CO_2/kg biochemical. The net CO_2 conversion rate (percentage of overall biogenic CO_2 effectively converted over the CO_2 input) **ranges from 67% to 99%**, depending on the bio-intermediate molecule considered and the respective value chain.

In addition, a preliminary LCA approach on the GHG emissions has been performed by considering the following categories of indirect emissions. The results indicate that **the utilization of 1 kg of biogenic CO_2 as feedstock contributes to the additional avoidance of 1-10 kg CO_2**, without taking into consideration the avoided CO_2 emissions through the use of renewable electricity. Similarly, in case that the avoided CO_2 emissions are taken into consideration, the 1 kg of biogenic CO_2 used as feedstock contributes to the additional avoidance of 2-15 kg CO_2.

In this sense, **CO_2SMOS integrated processes can be considered as GHG sinks** (having negative GHG emissions). In specific, CO_2 is consumed by advanced acetogenic bacteria (**Tech. 1.1**), as well as in the electrocatalytic process (**Tech. 2**) for the bio-acetate production. The transformation of green syngas to bio-acetate (**Tech 1.2**) will also result in CO_2 emissions avoided, given that green syngas will substitute fossil resources for producing acetate. Furthermore, CO_2 emissions savings are also associated with the transformation of bio-intermediate products to bio-based products (**Techs. 3, 4, 5**).

3.Definition of KPIs

This section includes a set of KPIs related to the most important technical, environmental, economic and social aspects involved in the performance of the principal CO_2SMOS processes.

A **summary** of the main CO2SMOS´s KPIs is described in the table below, in order to provide all information in a nutshell for public information. The KPI's description is much deeply analyzed and extended in a confidential document entitled *CO2SMOS D1.3 Confidential Detailed Report*, including more than detailed KPIs and relevant detailed information provided by the consortium which tackle sensible data of the project, as well as confidential partners information.

Table 1: Summarised KPIs Table description for public D1.3

KPI title	Definition	Expected value
	Technical indicators	
Number of bio-based chemicals	Number of added-value bio-based chemicals that will be produced from CO_2.	7
Acetate titer from CO_2/H_2	Total amount of acetate produced per L reactor volume (from CO_2/H_2).	Confidential info
Acetate titer from syngas	Total amount of acetate that is produced per L reactor volume (from syngas).	Confidential info
Selectivity to catalysts to CO	CO selectivity, a value to know how much CO is formed with respect to the rest of the products of the reaction, and can range from 0 to 100 %.	> 95%
Power consumption	Maximum power that is possible to apply to the electrocatalytic cell before causing destabilisation in the material and components.	Confidential info
Current density of PCEC cell	Activity of electrocatalytic process in current per geometric surface area of electrode.	Confidential info

Number of catalysts tested	Number of different heterogeneous types of catalysts that are effectively tested for the chemical conversion technology.	> 10
Feedstock flexibility	Number of biomass feedstocks effectively tested for chemical conversion technology.	4
PHA titer	Total amount of mcl-PHA that is produced during the process and per L reactor volume.	Confidential info
PHB titer	Total amount of PHB that is produced during the process and per L reactor volume.	Confidential info
LcDCAs titer	Total amount of lcDCAs that is produced during the process and per L reactor volume.	Confidential info
2,3-BDO titer	Total amount of 2,3-BDO that is produced during the process and per L reactor volume.	Confidential info
PX fraction in total xylenes	Amount of para-xylene in the xylenes fraction.	Confidential info
SEOS power	The electrical power that it is possible to apply to the SEOS membrane to pump the oxygen from the water formed inside the reactor.	Confidential info
Environomental indicators		
GHG emissions saving	Net GHG emissions reduction of overall CO_2SMOS processes compared to conventional routes linked to fossil-derived fuels.	up to 60% against the fossil-based counterparts
Life cycle CO_2 emissions	Net CO_2 emissions per produced chemical. GHG emissions from the production of bio-based chemical products, including all the life-cycle stages.	> -37kg CO_2/kg biochemical produced
CO_2 emissions avoided	Kg of CO_2 avoided of transformation processes and biopolymer utilization by each kg of biogenic CO_2 used as feedstock based on LCA approach (without considering the avoided emissions due to renewable energy electricity utilization).	> 1 kg CO_2 / kg biogenic CO_2
Net CO_2 conversion rate	Percentage of overall CO_2 effectively converted into valuable products over the CO_2 input.	> 60%
Cumulative Energy Demand	Direct and indirect energy use throughout the whole life cycle of the production of bio-based chemical products (including the energy requirements for the fermentative conversion and DSP).	< 50 kWh/kg biochemical
Economic indicators		
Specific capital costs (CAPEX)	Costs associated with the main operations of the different processes of CO_2SMOS including electrocatalytic reactors, fermenters, other reactors and peripheral units.	TBD during the project
Total operational costs (OPEX)	Total expenses for operations of the CO_2SMOS processes including labor, maintenance, electricity and consumables per unit of final biochemical product.	TBD during the project
Biopolymer net production cost	Total intended costs including CAPEX+OPEX (raw materials, energy, maintenance, labor, overheads, administrative costs, etc.) per kg of chemical produced.	TBD during the project
Creation of value chains	Number of new value chains created in the CO_2 utilization sector.	7
Bio-based companies reached	Number of bio-based companies reached (through Scale-Up and Replication plans) benefitting the new business models derived from CO_2SMOS.	4
Social indicators		
Incorporation of stakeholders requirements	Unlike other projects, CO_2SMOS will incorporate feedback and requirements of different stakeholders a) from the beginning of the development process and b) both in the design of products and process routes.	TBD during the project
Acceptance of production processes	Knowledge about the social acceptance of production processes is a further criterium for the choice of a process route.	TBD during the project
Acceptance of products	Knowledge about the social acceptance of the intermediate products produced in CO_2SMOS informs which end products are likely to be successful in the market.	TBD during the project
Diversity of stakeholders perspectives	Description of the diverse perspectives of different stakeholder types from the business-to-business and the business-to-stakeholder sector.	TBD during the project

CO2SMOS

Solutions for a circular biobased industry

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