MELISSA
MICRO-ECOLOGICAL
LIFE SUPPORT SYSTEM
ALTERNATIVE

2022 MELISSA CONFERENCE
8-9-10 NOVEMBER 2022

CREATING
A CIRCULAR
FUTURE

Indoor CO_2 Direct Air Capture (iCO_2-DAC): CO_2 As Renewable Carbon Source

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UdG lequia ECO-INNOVATIVE ENVIRONMENTAL SOLUTIONS
Universitat de Girona
$MiCrO_2$-Bio
Marie Skłodowska-Curie Actions
UCA

Grant Agreement no. 101018274cc

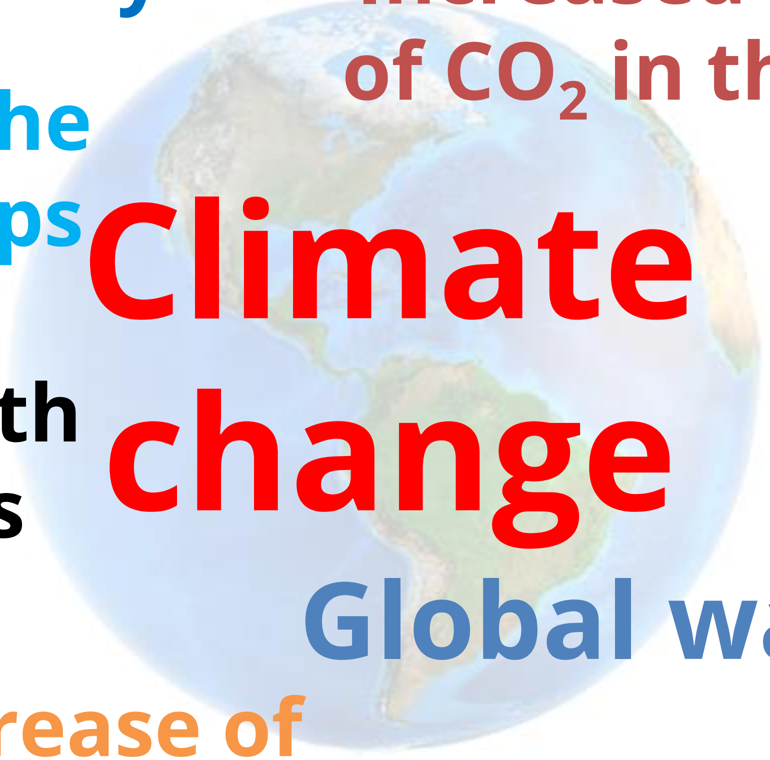
Indoor CO_2 Direct Air Capture (i CO_2 -DAC): CO_2 As Renewable Carbon Source

Presentation content

- Research Motivation
- Circular economy
- CO_2 Direct Air Capture (CO_2 -DAC)
  - Sources
  - Types of indoor environments
  - Mitigation strategies
- Case Study: “The MICRO-BIO process”
  - CO_2 concentrator module
  - Microbial Electrosynthesis module
- Summary

MiCrO$_2$-Bio

Research motivation



Decreased life expectancy

Increased concentration of CO_2 in the atmosphere

Melting of the polar ice caps

Climate change

Forced geographic displacement

Increased length of dry periods

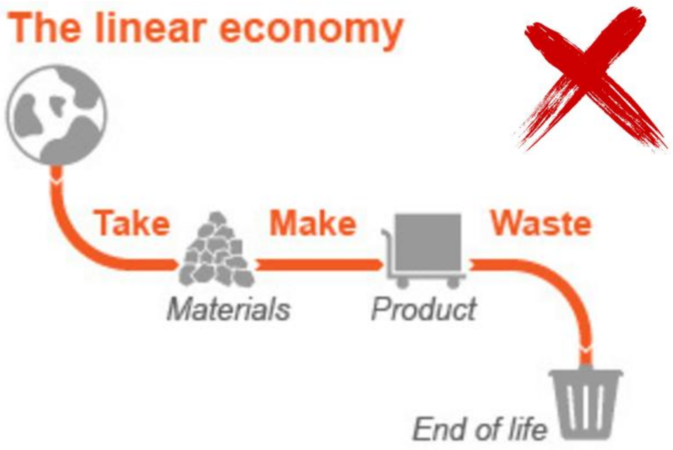
Global warming

Increase of sea level

Wars

¿How can we fight climate change effectively?

Replacing the current economic model based on **“take-make-waste”** for a model based on **circular economy.**



✓

Circular economy: regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops.

(Geissdoerfer et al., 2017)

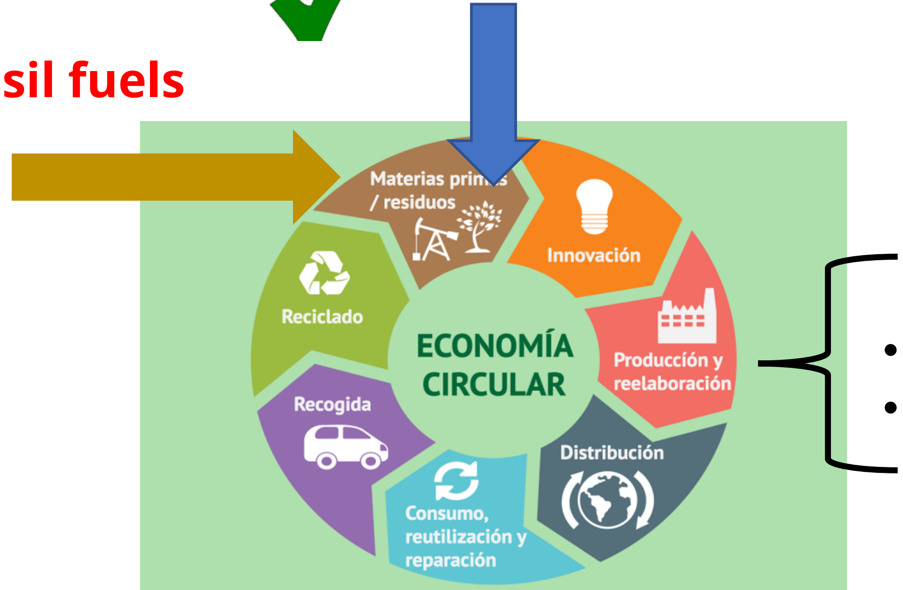
Circular economy

Eliminate the use of fossil fuels

✓ **Renewable carbon sources**

- CO_2 capture (large emissions and Atmospheric CO_2)
- Plastic materials recycling
- Biomass

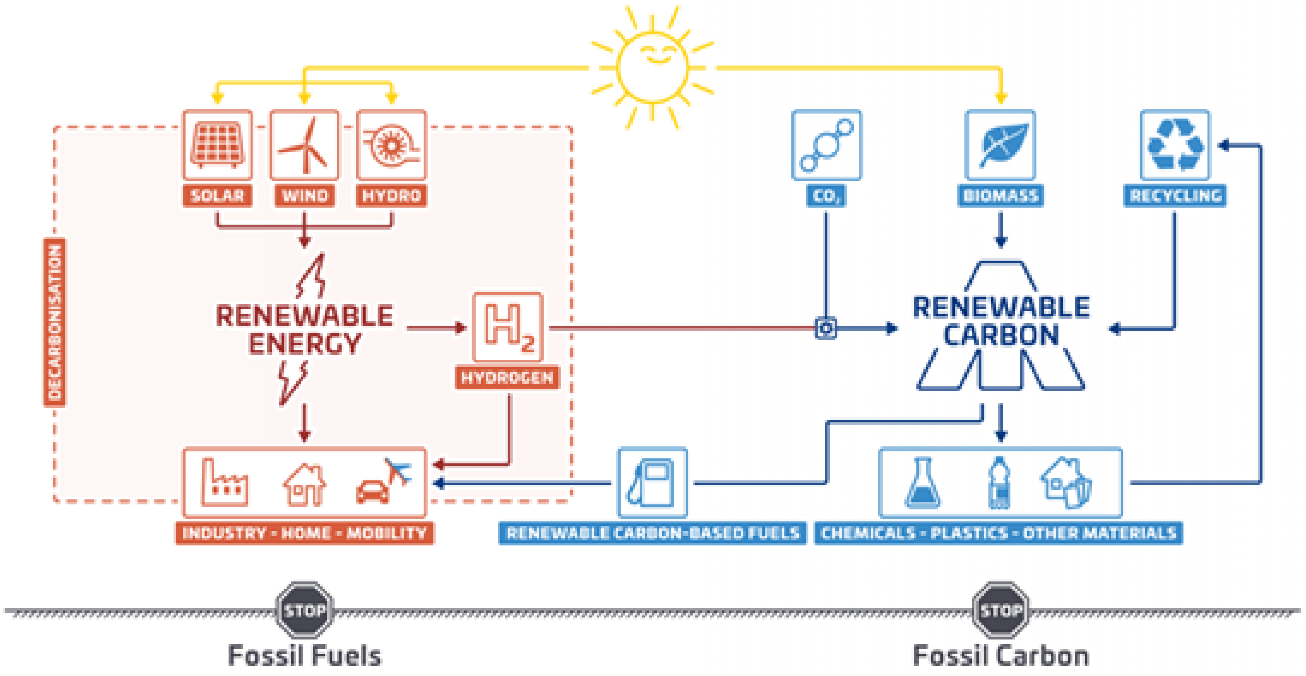
Carbon from fossil fuels ✗



- **Energy**
- **Raw materials for the Chemical industry**

Circular economy

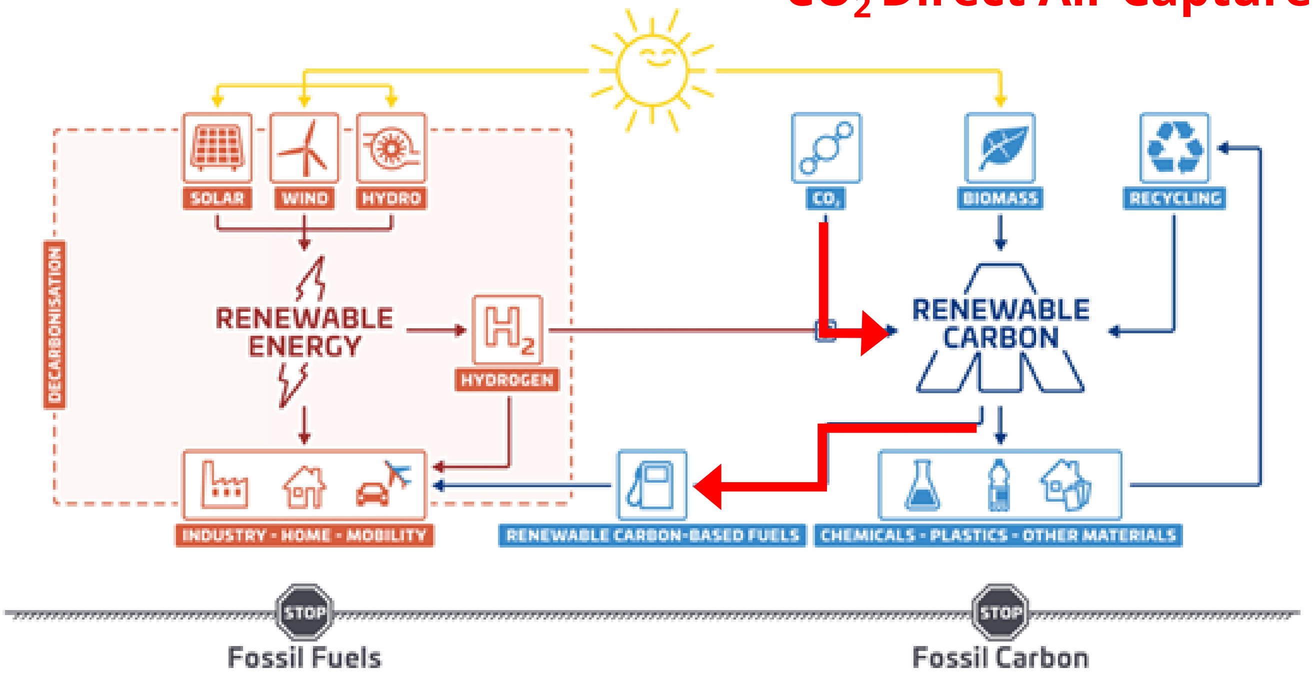
Sources of renewable energy and renewable carbon



Source: http://nova-institute.eu/

Circular economy

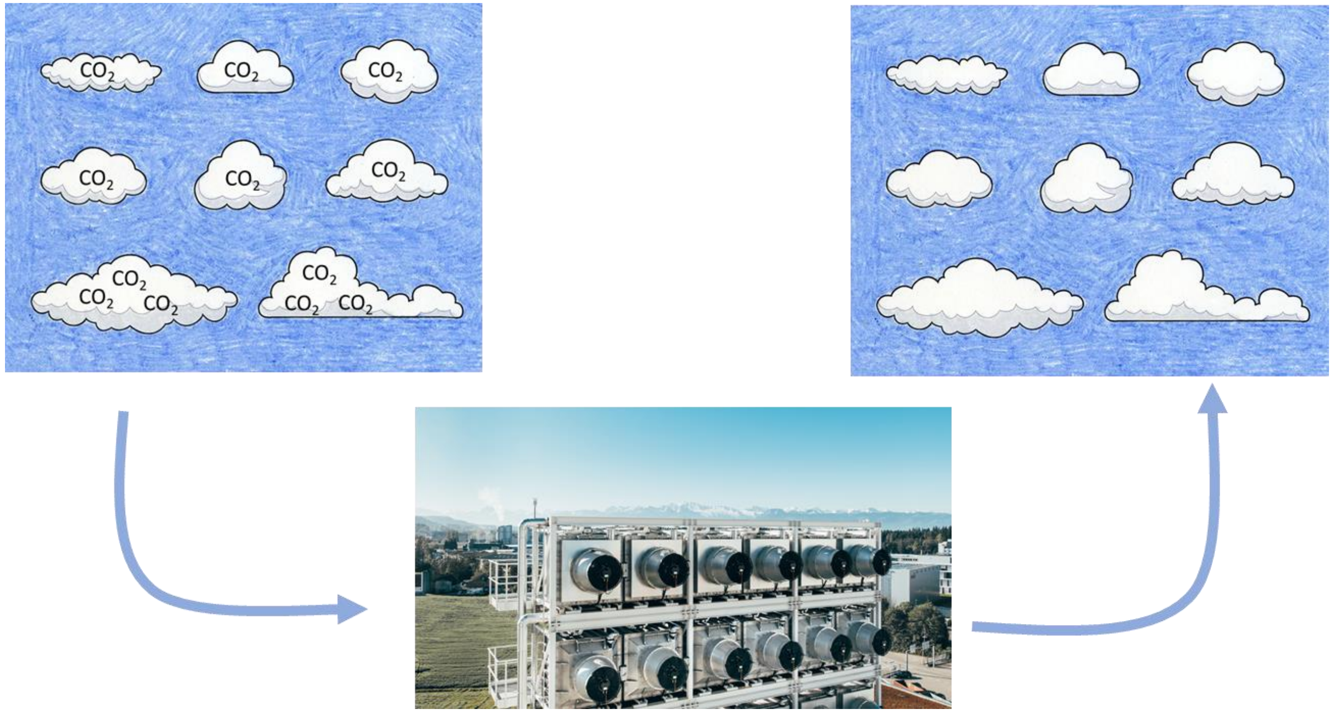
Sources of renewable energy and renewable carbon



CO_2 Direct Air Capture (CO_2-DAC)

Source: http://nova-institute.eu/

CO_2 Direct Air Capture (CO_2 -DAC)

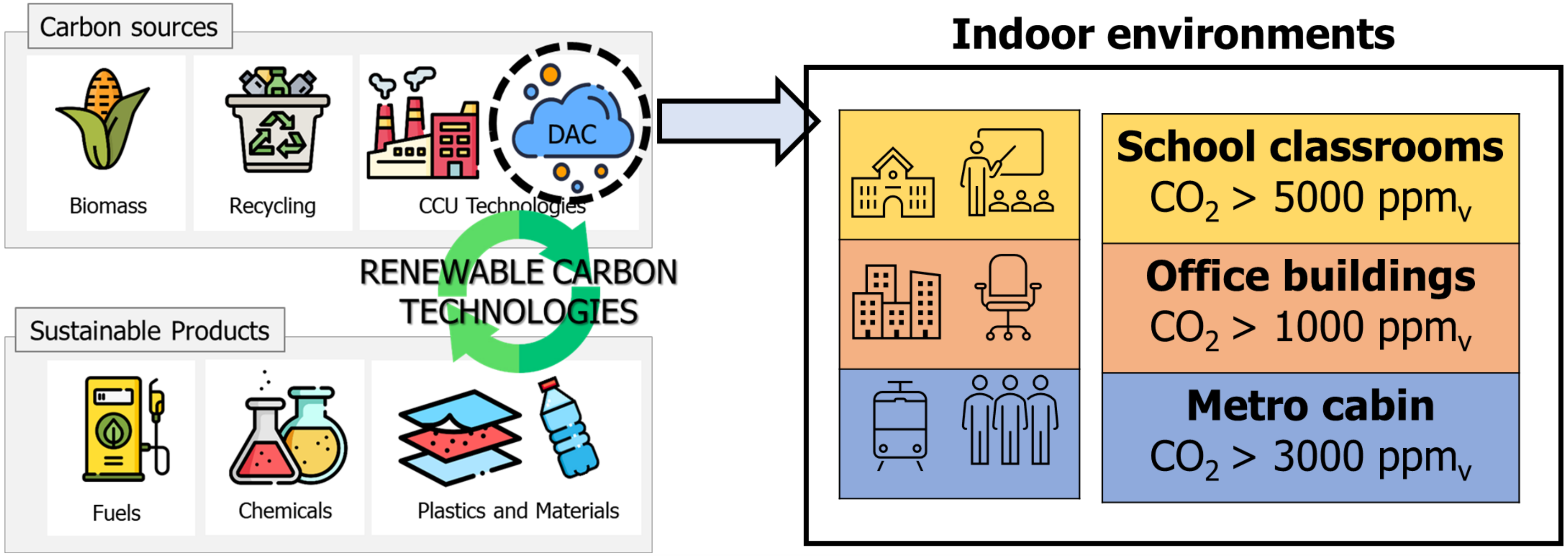


CO_2 DAC: a range of technological solutions to extract CO_2 from ambient air at any location on the planet

(Beuttler et al., 2019)

Capture and bioconversion of CO_2 from indoor environments

Sources of renewable carbon



Carbon sources

Biomass

Recycling

CCU Technologies

DAC

RENEWABLE CARBON TECHNOLOGIES

Sustainable Products

Fuels

Chemicals

Plastics and Materials

Indoor environments

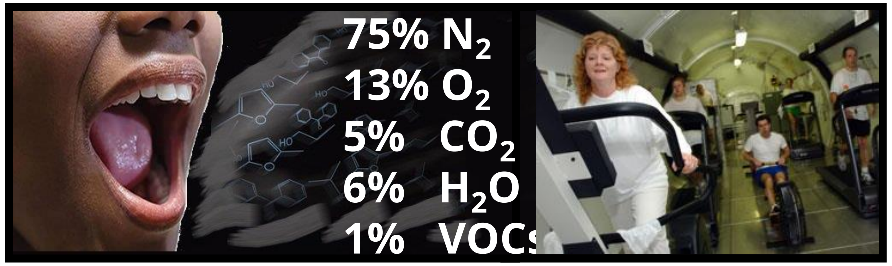
School classrooms
$CO_2 > 5000$ ppm_v

Office buildings
$CO_2 > 1000$ ppm_v

Metro cabin
$CO_2 > 3000$ ppm_v

Indoor CO_2 represents a potential/unexplored source of renewable carbon

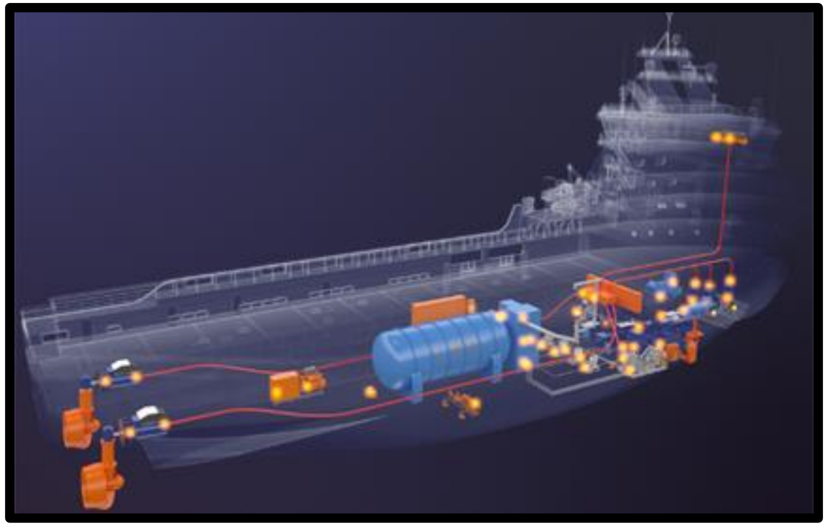
Sources of emission of CO_2 in indoor environments (civilian)



75% N_2
13% O_2
5% CO_2
6% H_2O
1% VOC

Human metabolism

Combustion and tobacco smoke

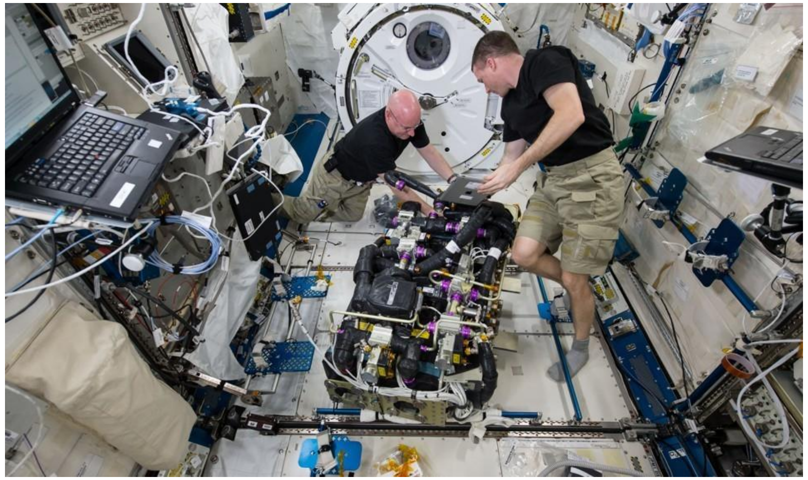


Engine emissions/instrumentation

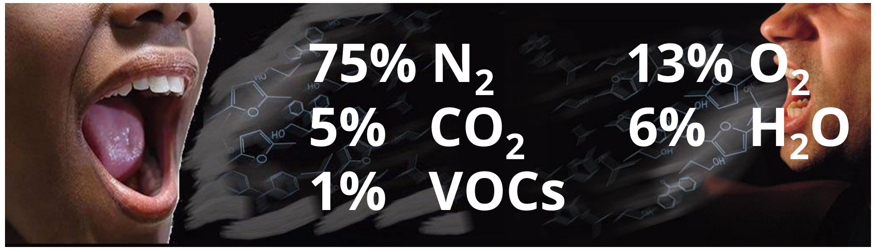
Outdoor air infiltration

Sources of emission of CO_2 in indoor environments (non-civilian)

Indoor air quality can be very poor in closed or semi-closed environments



Human metabolism



75% N_2 13% O_2
5% CO_2 6% H_2O
1% VOCs

Analytical instrumentation emissions
Fuel and engines emissions
Consumer products / materials

Representative indoor environments

School classrooms

Recommended value
1000-1500 $ppm_v < CO_2$

Average values
3200-5800 ppm_v CO_2

Office buildings

Recommended value
1000-1500 $ppm_v < CO_2$

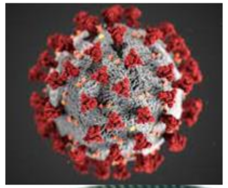
Average values
850-1300 ppm_v CO_2

Metro cabins

Recommended value
1000-1500 $ppm_v < CO_2$

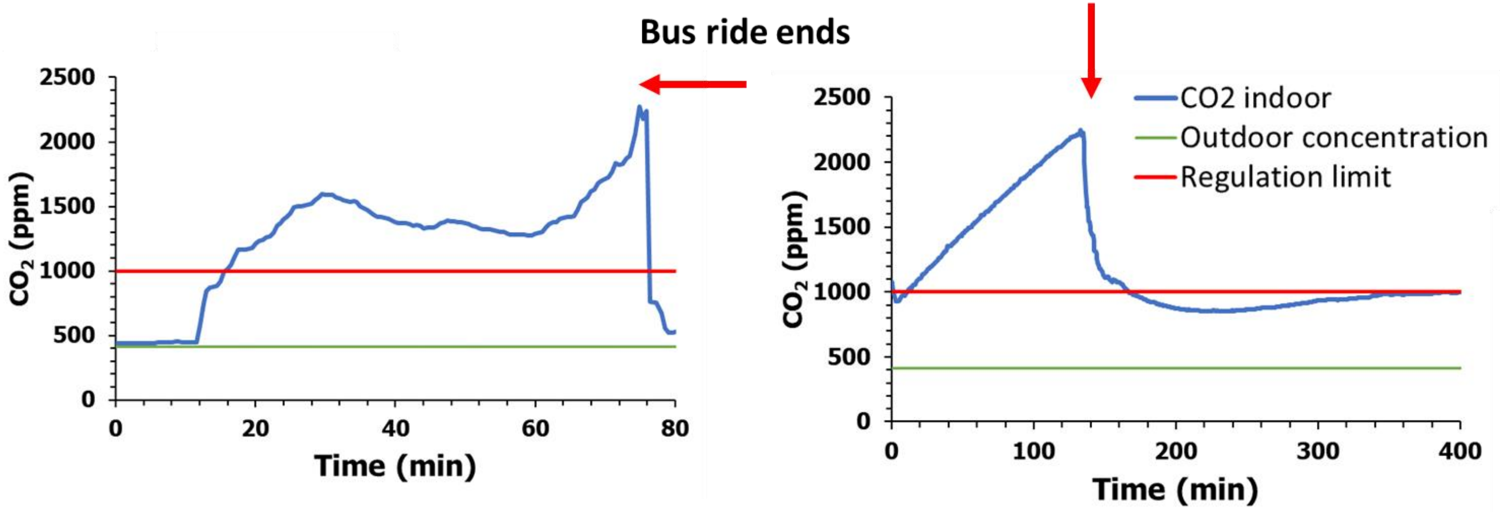
Average values
650 and 5525 ppm_v CO_2

Indoor environments with low “air exch rate” → **Bad Indoor Air Quality**



Higher risk of bioaerosols transmission (COVID-19) ←

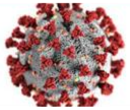
Sources of CO_2 emission in indoor environments



1 hour bus ride
30 passengers, sensor at 3rd row
Reached máximum values near 2500 ppm

Study room at home
2 hours no ventilation-1 person **Linearly increasing CO_2 concentration for 2 hours.**

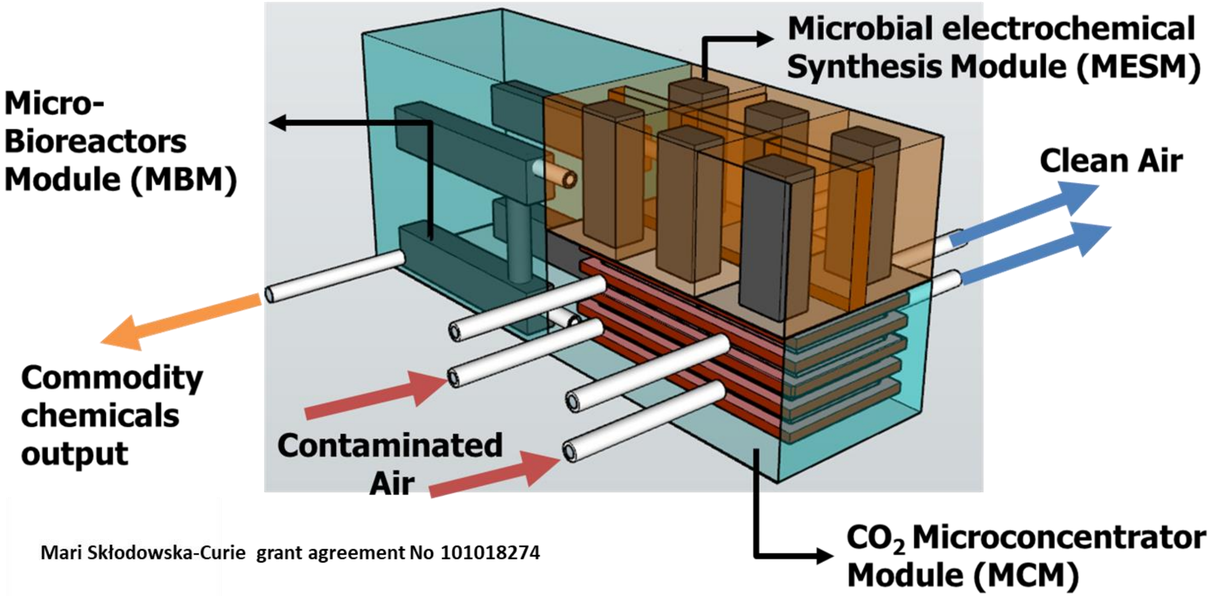
High indoors CO_2 concentration → **BAD IAQ & high risk of infection**



Case study

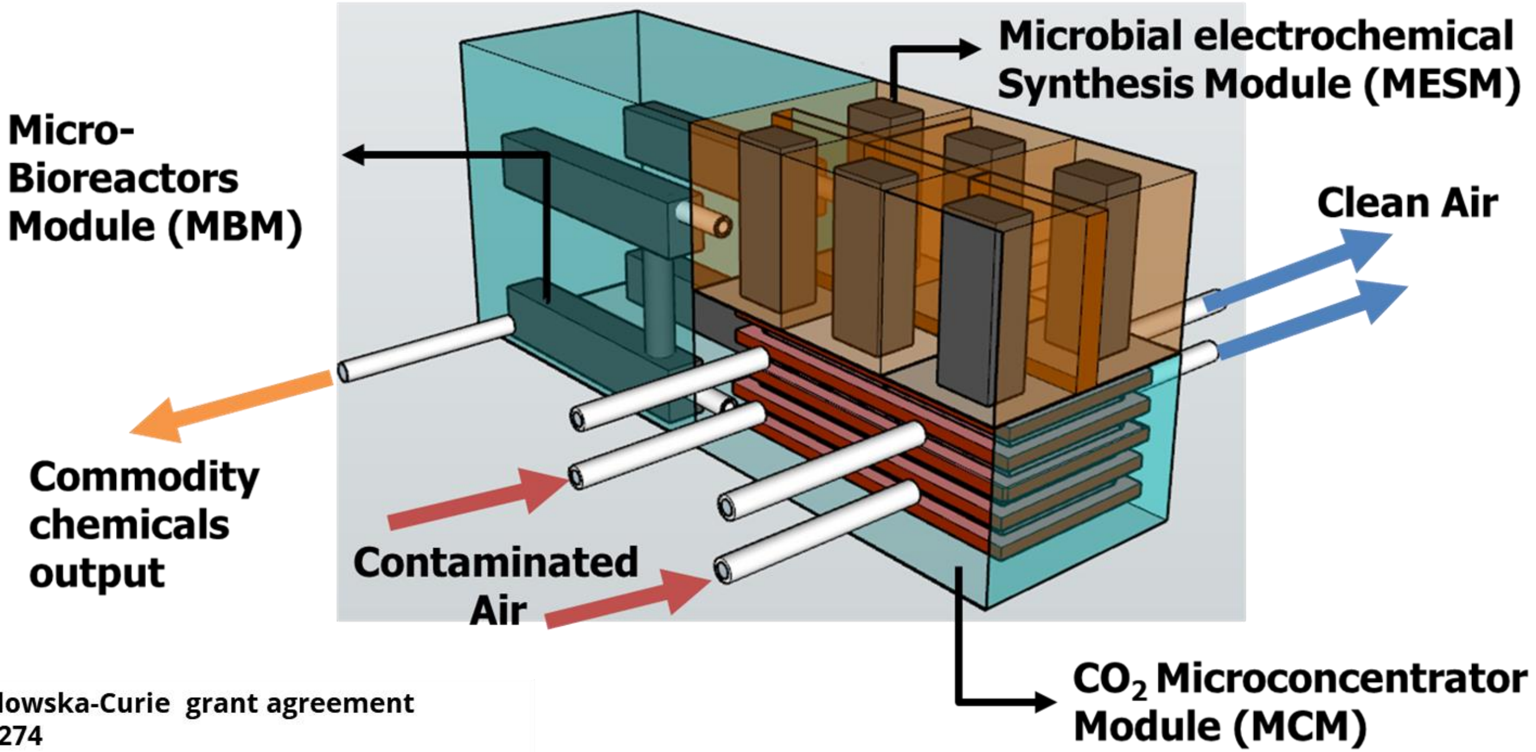
Case study: “The MICRO-BIO process” transforming indoor air pollutants into valuable compounds

MiCrO$_2$-Bio



Mari Skłodowska-Curie grant agreement No 101018274

Capture and bioconversion of CO_2 from indoor air: "The MICRO-BIO process"



Mari Skłodowska-Curie grant agreement No 101018274

Circular Economy:

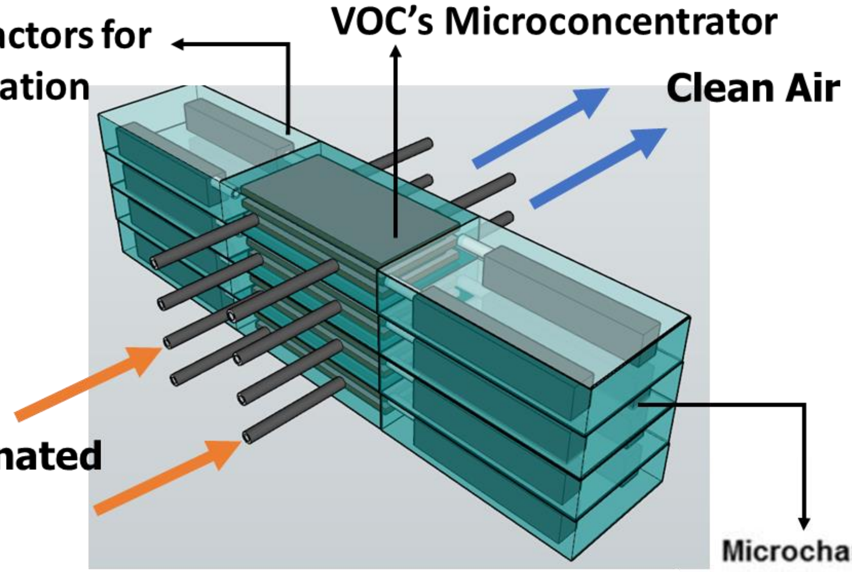
Transform an indoor pollutant (Waste) into renewable carbon source (Resource)

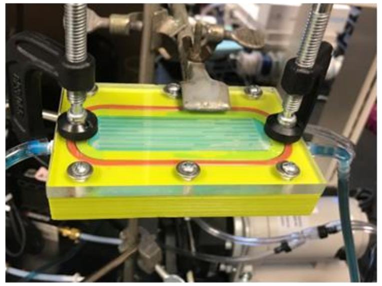
MELiSSA

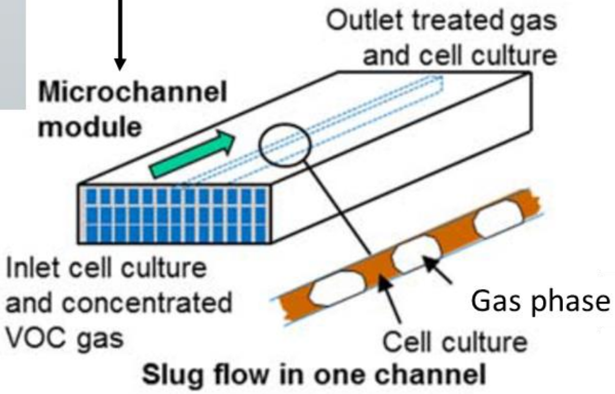
MICRO-BIO process: Learning from space applications

14,000 µg/m³ TVOC

67,000 µg/m³ TVOC







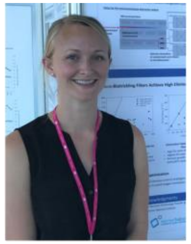
DARPA

warner babcock institute for green chemistry

Duke PRATT SCHOOL of ENGINEERING

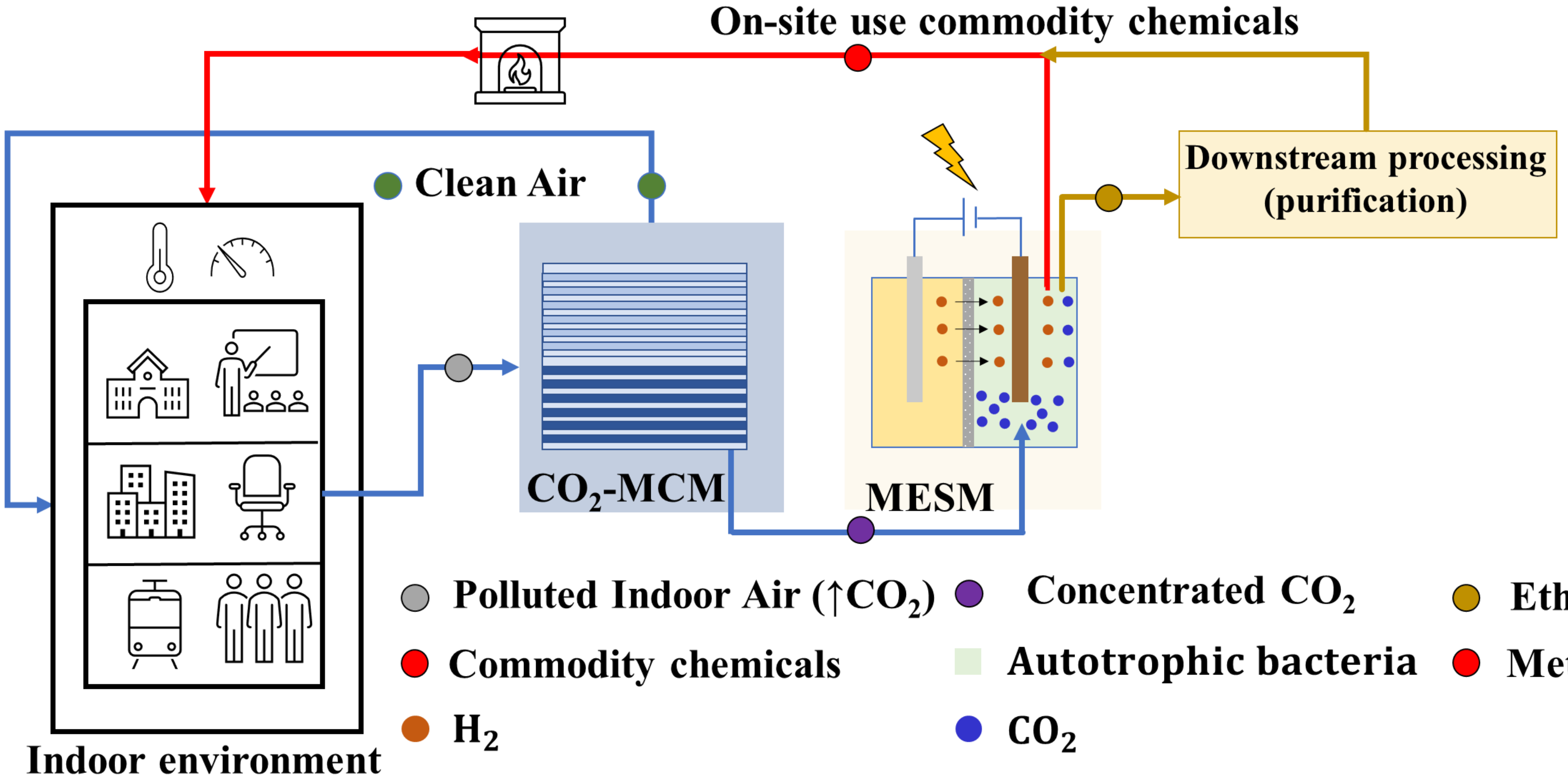
2016-2020 project

Dr. Marc Deshusses
Professor
Duke University



Kelsey E. Deaton
Graduate student
Duke University

Capture and bioconversion of CO_2 from indoor air: "The MICRO-BIO process"



● Polluted Indoor Air (↑CO_2)

● Concentrated CO_2

● Ethanol

● Commodity chemicals

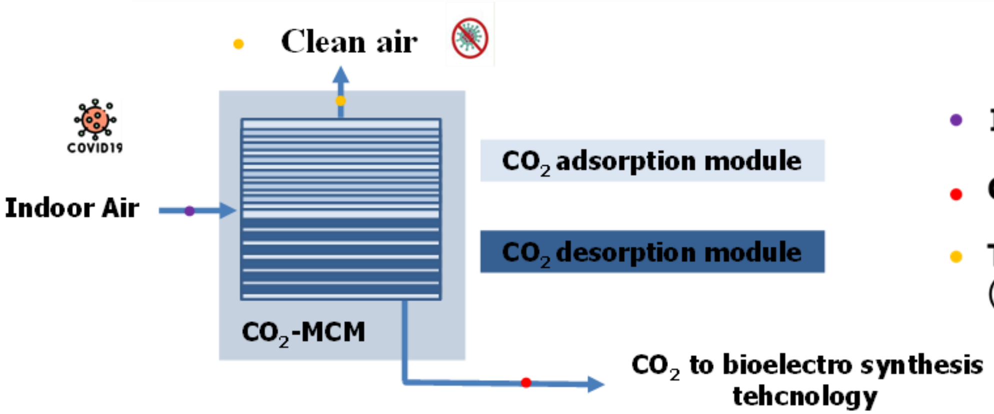
🟩 Autotrophic bacteria

● Methane

● H_2

● CO_2

“The MICRO-BIO process: CO_2 Microconcentrator module”



- **Indoor Air Stream**(↓↓ CO_2)≈ 800-5000 ppm_v
- **CO_2 concentrated stream** (↑↑↑CO_2) ≈ 15 % CO_2 - 90%
- **Treated/clean indoor**/(free of COVID-19) and low CO_2 concentration (↓ CO_2)≈ 0-100 ppm_v

Key operational parameters for the CO_2 Microconcentrator module

- **CO_2-MCM:** Glass columns filled with a porous solid adsorbent material impregnated with polyethylenimine (PEI)
- **Adsorption material regeneration:** CO_2 desorption cycles at mild temperatures **(70-100 ºC)**[1].
- Heat applied during desorption cycles helps to disactivate viruses such as CODI-19 if:

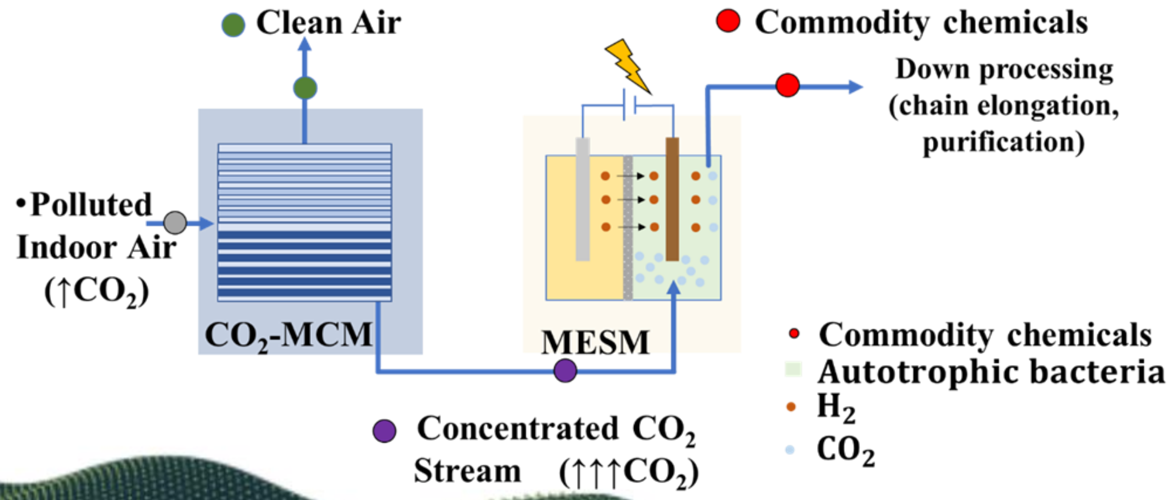
T> 75 ºC ,3 min.	T> 65 ºC, 5 min.	T> 60 ºC, 60 mins.

Capture and bioconversion of CO_2 from indoor air: “The MICRO-BIO process”

School classrooms

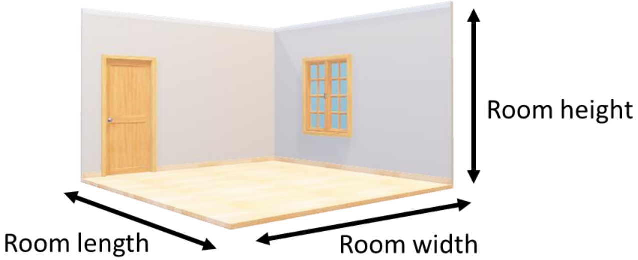
Office buildings

Metro cabins

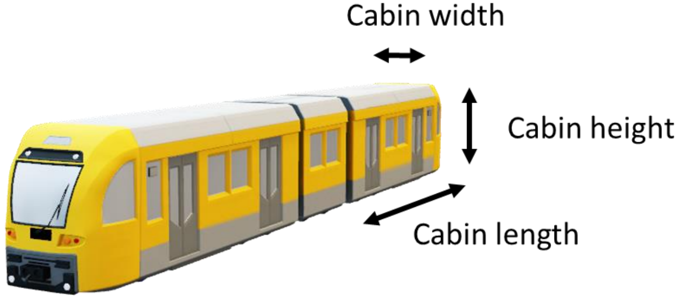


Methane
Ethanol

Capture and bioconversion of CO_2 from indoor air: “The MICRO-BIO process”

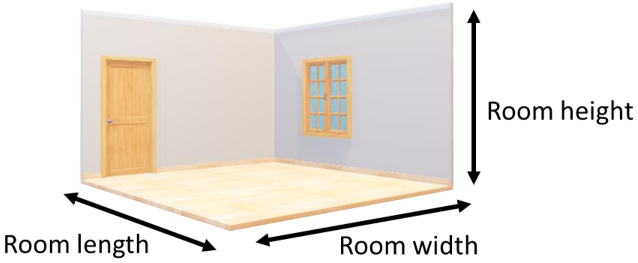


- # External walls
- # Window size
- External temperature
- Required temperature



Parameter	Scenario		
	High school	**Office**	**Metro cabin**
Room height	3	3.5	3
Room length	8	8	20
Room width	8	8	3
Window size (m^2)	2	2	1.2
External walls[a]	2	2	6
Windows	2	1	6
External temperature (°C)	10	10	10
Required temperature (°C)	20	20	20

Capture and bioconversion of CO_2 from indoor air: “The MICRO-BIO process”



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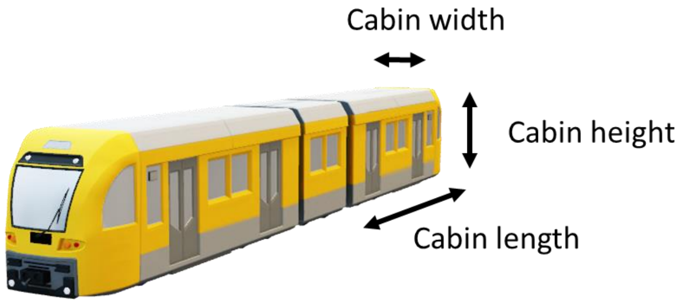

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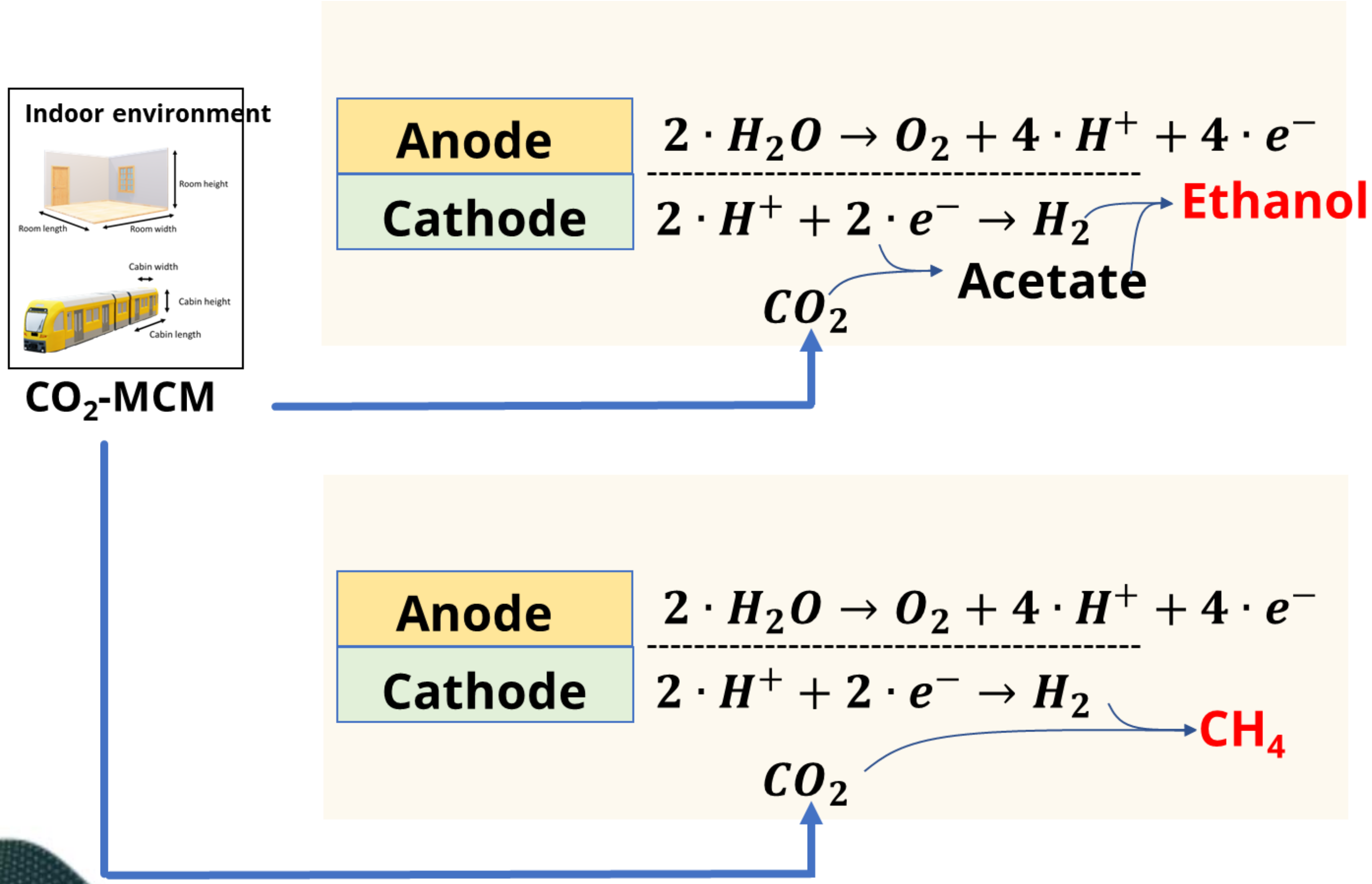
Required temperature (°C)	20	20	20

Microbial Electrosynthesis of biofuels

Microbial electrosynthesis reactors



CO_2-MCM

Anode $2 \cdot H_2O \rightarrow O_2 + 4 \cdot H^+ + 4 \cdot e^-$

Cathode $2 \cdot H^+ + 2 \cdot e^- \rightarrow H_2$

CO_2

Acetate

Ethanol

Anode $2 \cdot H_2O \rightarrow O_2 + 4 \cdot H^+ + 4 \cdot e^-$

Cathode $2 \cdot H^+ + 2 \cdot e^- \rightarrow H_2$

CO_2

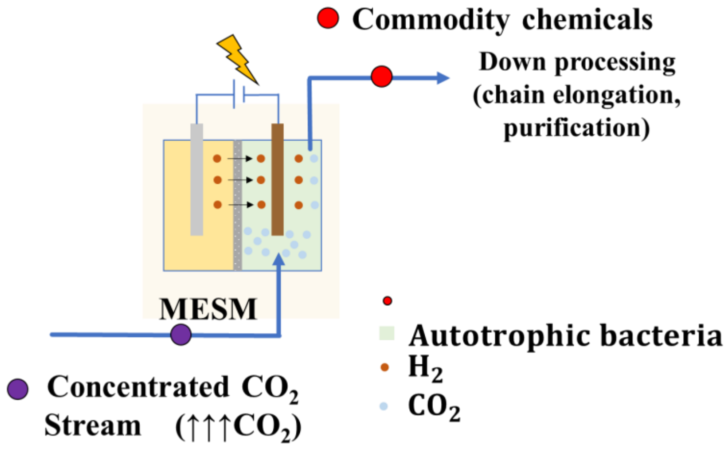
CH_4

Microbial Electrosynthesis Technology Module

Microbial electrosynthesis reactors

Parameter	**Scenario methane**			**Scenario ethanol**		
	High school	Office	Metro cabin	High school	Office	Metro cabin
Fuel required for temperature control (kg/h)	0.05	0.03	0.57	0.10	0.07	1.06
CO_2 required for fuel production (kg/h)	0.15	0.10	1.61	0.19	0.13	2.03
Cathode electrode required (m^2)	9.4	6.3	102.6	233.0	157.1	2552.5
Cell volume required (m^3)	1.7	1.2	18.9	25.9	17.5	283.7
Power consumed (kWh/d)	75.6	51.0	828.2	249.0	73.7	2726.6

Smaller cathode size and smaller cell volume is needed in the **methane scenario** when **compared to the ethanol scenario**



“The MICRO-BIO process: CO_2 Microconcentrator module”

Automated CO_2 Microconcentrator prototype roadmap

1. **Process design: 3D printed CO_2 microconcentrator prototype**
    - 1.1. Optimization of adsorbent material
    - 1.2. Prototype design for 3D printing
2. **Prototype automation**
    - 2.1. Design of control loops (acquisition of instrumentation, coding)
    - 2.2. Coupling of automation instrumentation with CO_2 microconcentrator prototype

“The MICRO-BIO process: CO_2 Microconcentrator module”

1. Process design: 3D printed CO_2 microconcentrator prototype

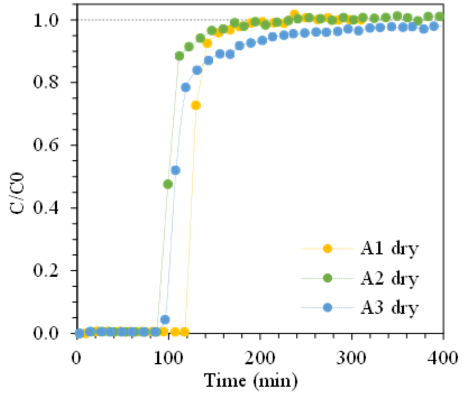
1.1. Optimization of adsorbent material

Main Support Material	Acronym
Fumed Silica	FS

+

Amines
Low Molecular Weight **(LMW)** Polyethylenimine **(PEI)**
High Molecular Weight **(HMW)** Polyethylenimine **(PEI)**

Test	Material code	Support Material	PEI MW (g/mol)	PEI Loading (%)
1	A1	Fumed Silica	800	20
2	A2	Fumed Silica	800	30
3	A3	Fumed Silica	800	50
4	A4	Fumed Silica	800	70
5	A5	Fumed Silica	25,000	20
6	A6	Fumed Silica	25,000	30
7	A7	Fumed Silica	25,000	50
8	A8	Fumed Silica	25,000	70



Characterization of breakthrough time and adsorption capacity to select the best formulation (% FS, % PEI and type of PEI)

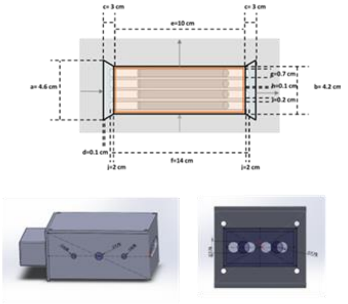
“The MICRO-BIO process: CO_2 Microconcentrator module”

1. Process design: 3D printed CO_2 microconcentrator prototype

1.2. Prototype design for 3D printing

Start 02/2022

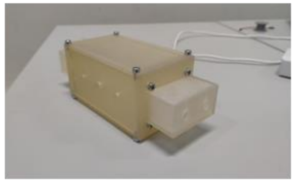
03/2022



Preliminary design

07/2022

Final design



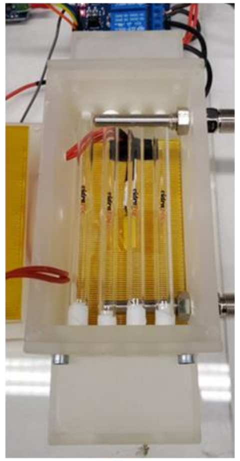
3D printed prototype

09/2022

Fabrication of of glass columns

10/2022

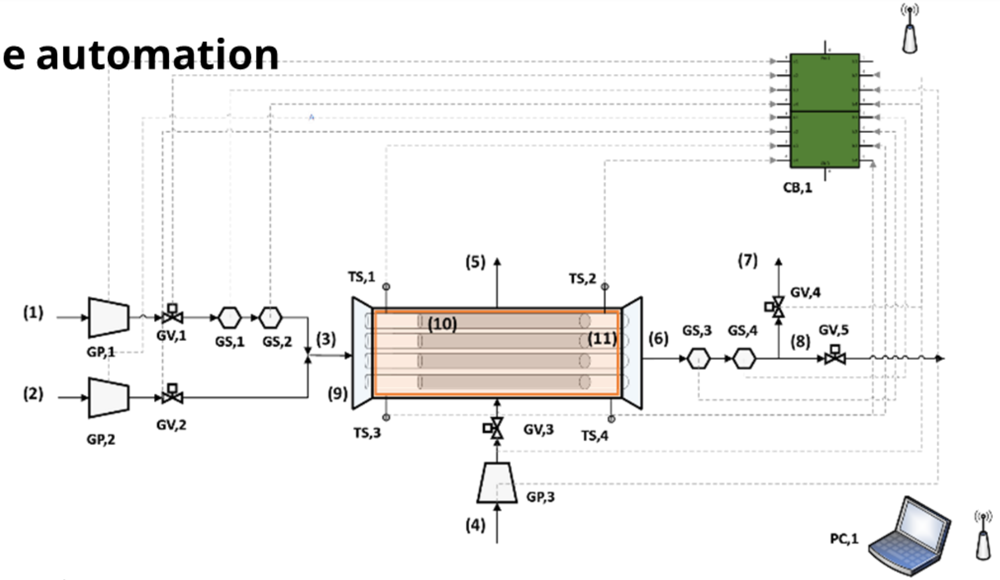
Integration of glass columns and 3D printed prototype



Integration w. Automation

“The MICRO-BIO process: CO_2 Microconcentrator module”

2. Prototype automation



Main elements of the automated prototype

- Temperature, humidity and CO_2 microsensors (inlet and outlet)
- Automated air flow control (inlet and outlet)
- Temperature controlled heating of the prototype for CO_2 desorption
- Temperature controlled cooling for switching from desorption/adsorption cycle

“The MICRO-BIO process: CO_2 Microconcentrator module”

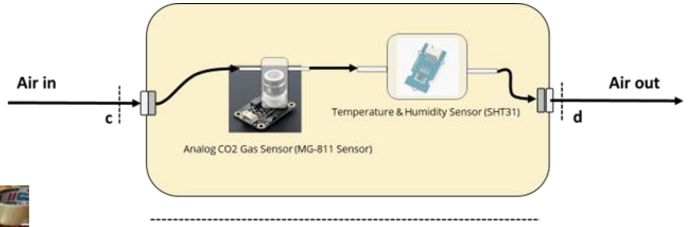
2. Prototype automation

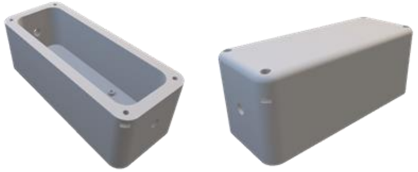
2.1. Design of control loops (acquisition of instrumentation, coding)

Start 02/2022

Instrumentation acquisition: microsensors

06/2022





Design of 3D printed sensors case

07/2022

Fabrication of 3D printed sensors case

10/2022

Integration w. prototype

“The MICRO-BIO process: CO_2 Microconcentrator module”

2. Prototype automation

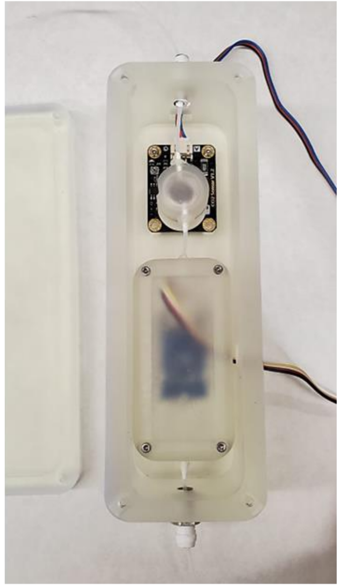
2.1. Design of control loops (acquisition of instrumentation, coding)

Arduino CO_2 sensor

3D model of CO_2 sensor case

3D model of Arduino sensor

3D model of sensors case



3D printed sensor case

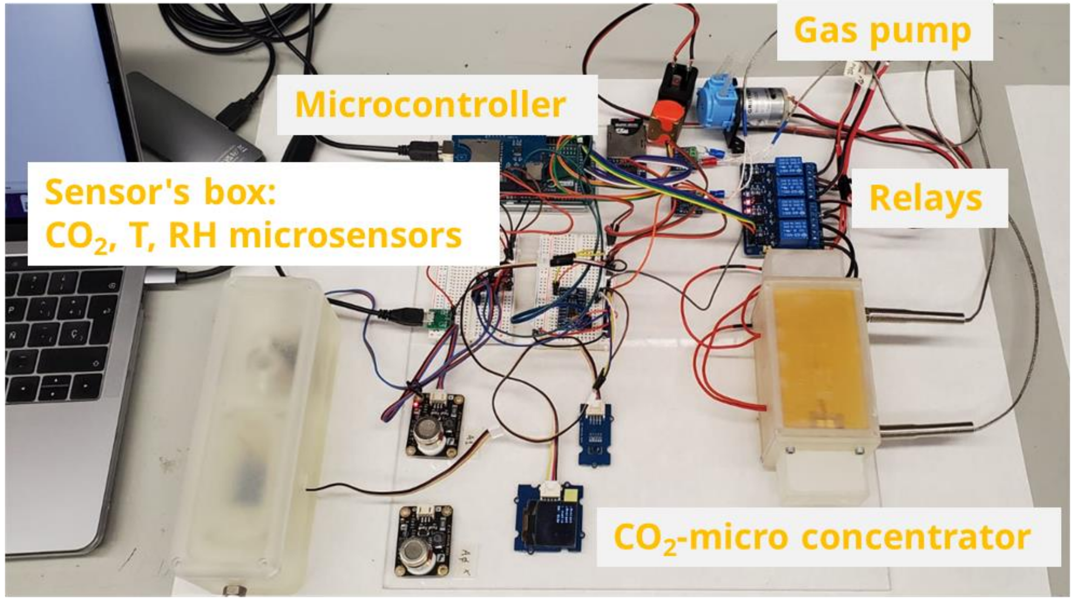
“The MICRO-BIO process: CO_2 Microconcentrator module”

2.2. Coupling of automation instrumentation (control loops with instrumentation)

Prototype

Integration

Automation instrumentation



Single column test:

1 single column test, 1 g material x 1 column = 1 g ~ 20,000 ppmv CO_2 (2 %) released

Prototype: expected results

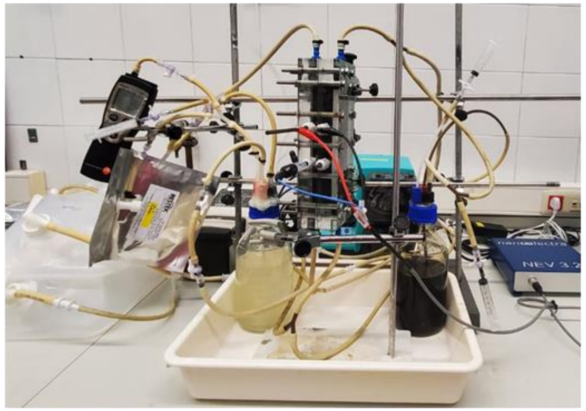
4 columns prototype, 5 g material x 4 columns= 20 g ~ 400,000 ppmv CO_2 (40 %) released

Preliminary results: Microbial Electrosynthesis Technology Module

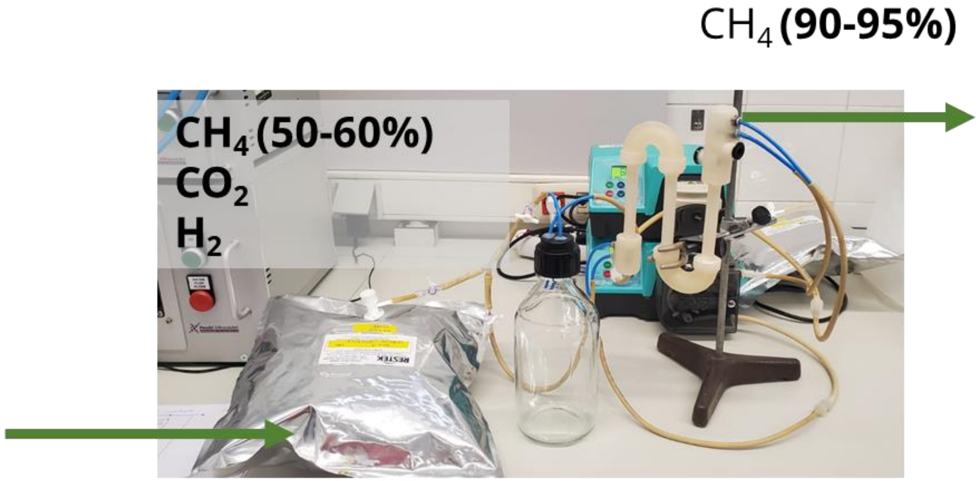
Module 2 start-up: bioelectrochemical system for CH_4 production

Research goal:

- To produce high purity CH_4 stream (90-95 % V/V)



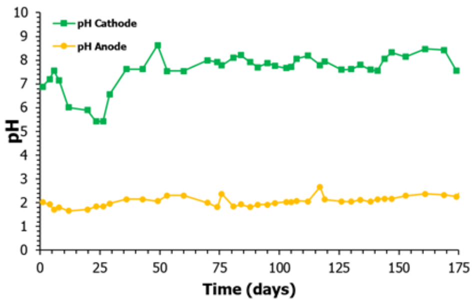
Flat plate BES
Cathode: carbon cloth
Anode: granular graphite

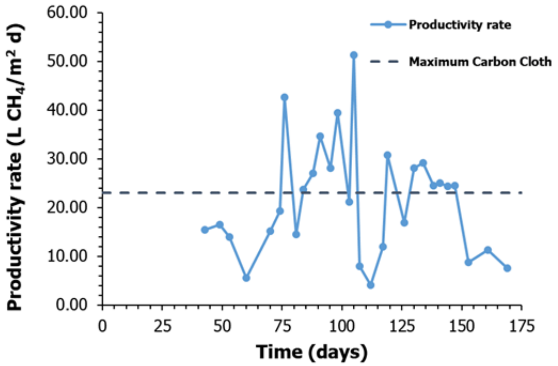


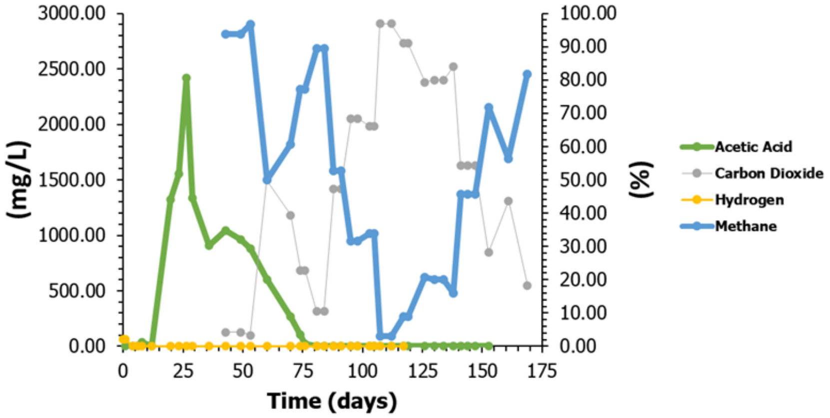
3D printed capillary channels
Internal diameter = 1.1 mm
channel length= 10 cm

Preliminary results: Microbial Electrosynthesis Technology Module

Module 2 start-up: bioelectrochemical system for CH_4 production



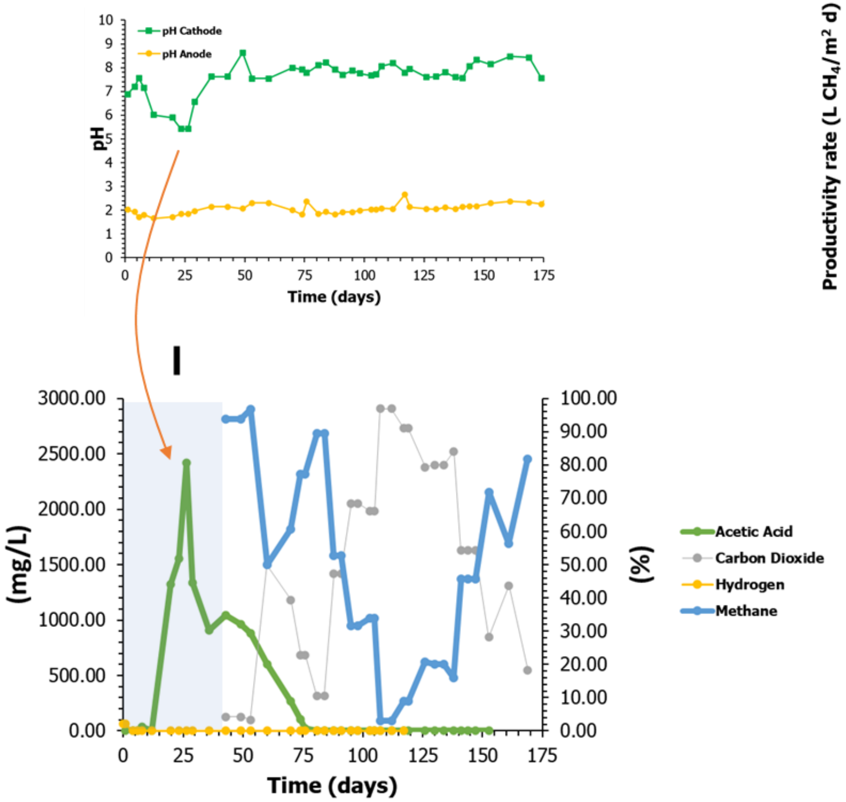


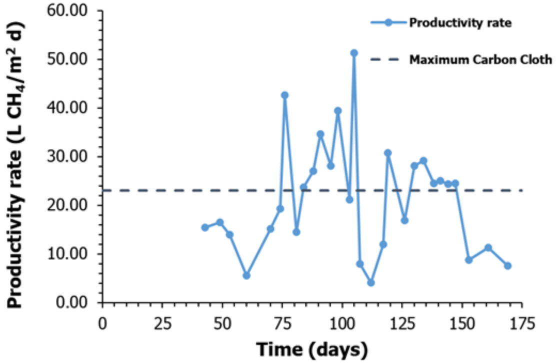


Preliminary results: Microbial Electrosynthesis Technology Module

Module 2 start-up: bioelectrochemical system for CH_4 production

pH control to neutral values helped to select hydrogenotrophic methanogens

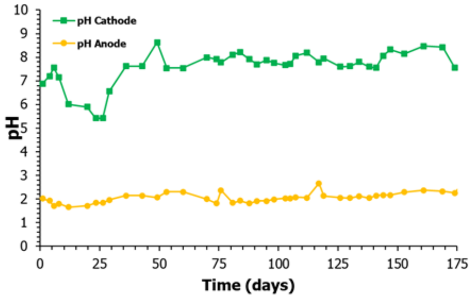


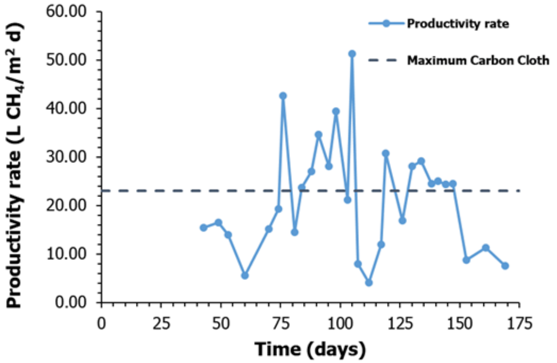


I: Start-up period

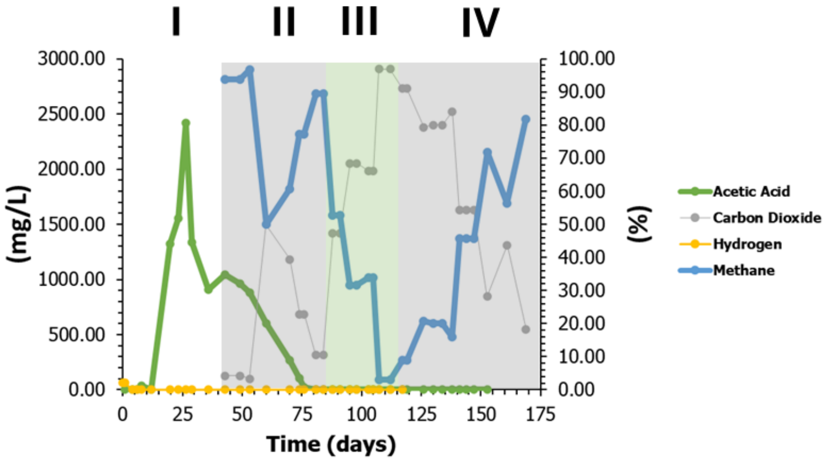
Preliminary results: Microbial Electrosynthesis Technology Module

Module 2 start-up: bioelectrochemical system for CH_4 production





Bioreactor managed to recover after electrode damage (biofilm loss)

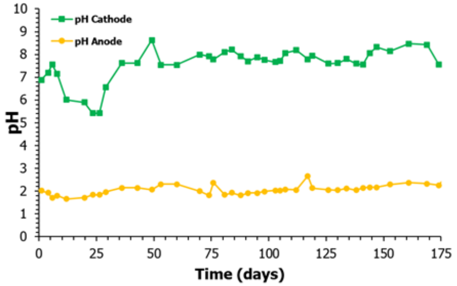


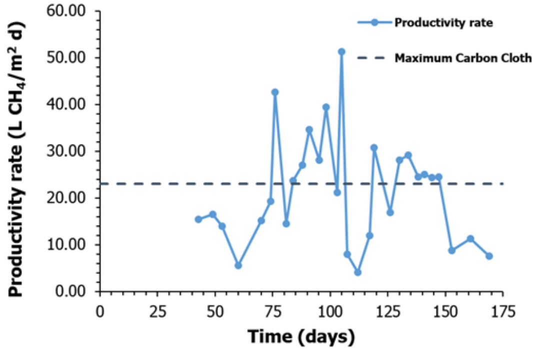
I: Start-up period
II: CH_4 production ~90 % v/v
III: electrode broke
IV: reactor recovery

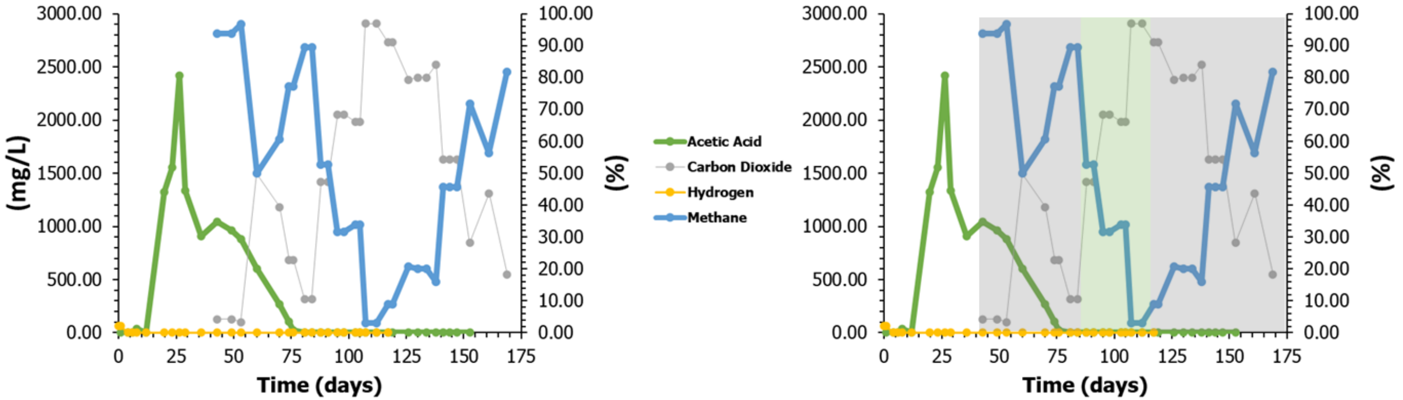
Preliminary results: Microbial Electrosynthesis Technology Module

Module 2 start-up: bioelectrochemical system for CH_4 production

Methane productivity was above maximum rates reported in the literature for similar operating conditions and cathode material







Summary

- The **capture of CO_2 from indoor environments** stands as an unexplored **source of renewable carbon**, but also as a strategy to improve **indoor air quality**.

- The combination of **indoor CO_2 Direct Air Capture** (iCO_2-DAC) and Microbial Electrosynthesis Technologies stands as an environmentally friendly technological solution to minimize the climate change effects.

- This technology would be suitable to be used within circular life support systems such as space missions, helping to improve IAQ by handling IAPs and producing new starting materials for the crew.

THANK YOU.

Luis R. López de León
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