vivaldi
Turns CO_2 emissions into sustainable bioproducts

VIVALDI – Turning CO_2 emissions into sustainable bioproducts

Bio-CO2 Use and Removal 2024
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PUBLIC

The novel CO_2-based industry

Novel carbon capture and utilisation strategies for CO_2 valorisation are needed to achieve the European Union's target of reducing emissions by at least 80 % by 2050

The yearly increasing industrial CO_2 emissions should not only be reduced or mitigated but should also be adopted as a novel feedstock: **the era of the CO_2-based chemicals**

Industries should abandon the conventional linear structure and switch to a circular concept where the wastes are transformed into novel sustainable compounds to be reused in the plant flowchart or to be sold externally

There is urgent need of reliable, sustainable and cost-efficient CO_2 conversion technologies

VIVALDI's solution

Developing innovative biotechnological solution for converting the off-gas emissions of bio-based industries into CO_2-based chemicals

Impact

VIVALDI project develops an innovative, sustainable and cost-efficient biotechnological solution **to convert the off-gas emissions of bio-based industries into CO_2-based chemicals.**

In this way, biorefineries will be able to:

Reduce their greenhouse gas emissions	**Reuse CO_2 emissions as novel feedstock**	**Lower the dependency on fossil fuels import**	**Lower the exploitation of key resources**

Overview

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Turns CO_2 emissions into sustainable bioproducts

Start date: 1.6.2021

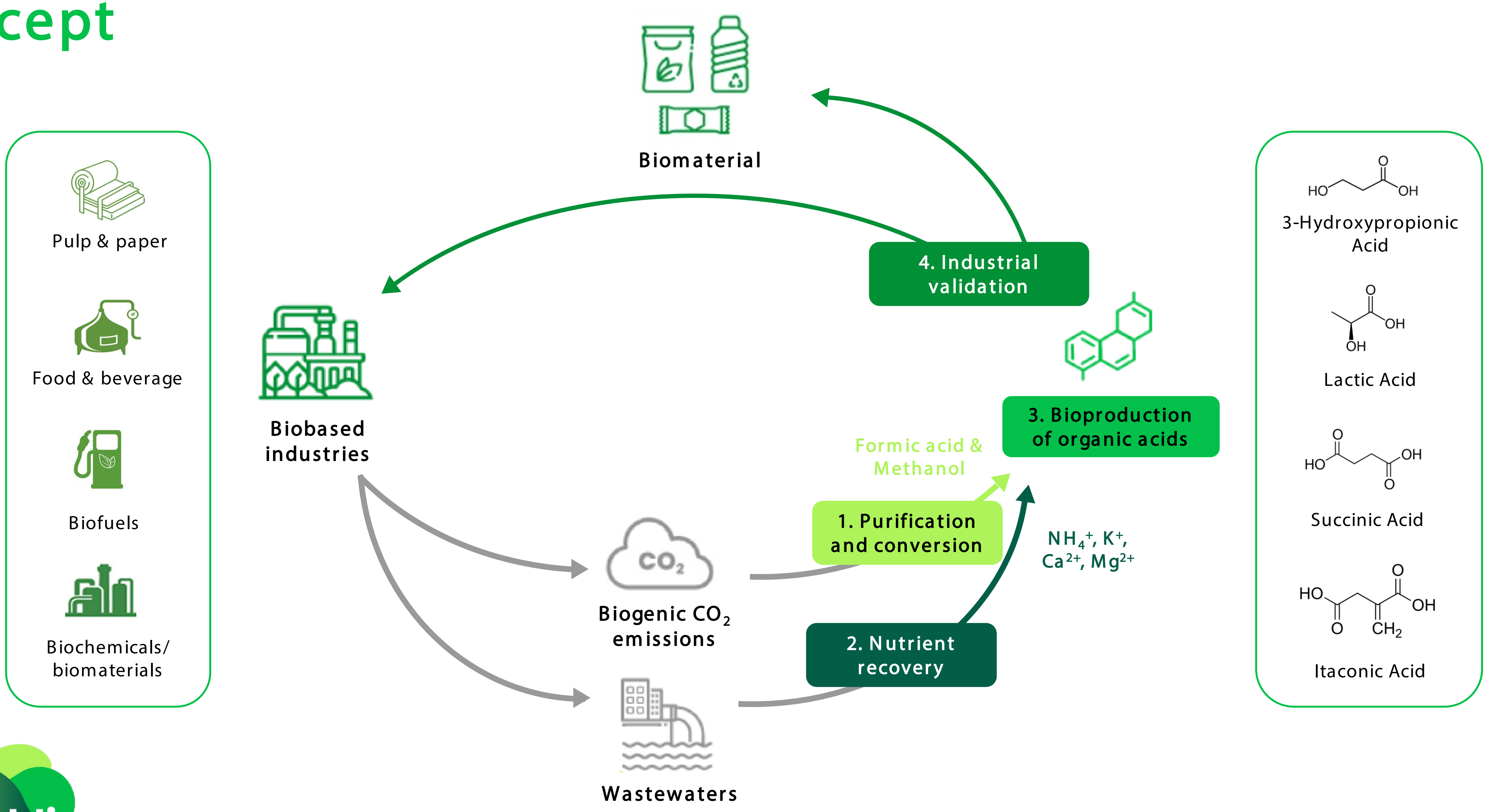
Funded under: H2020-EU 3.2.

Duration: 4 years

16 partners

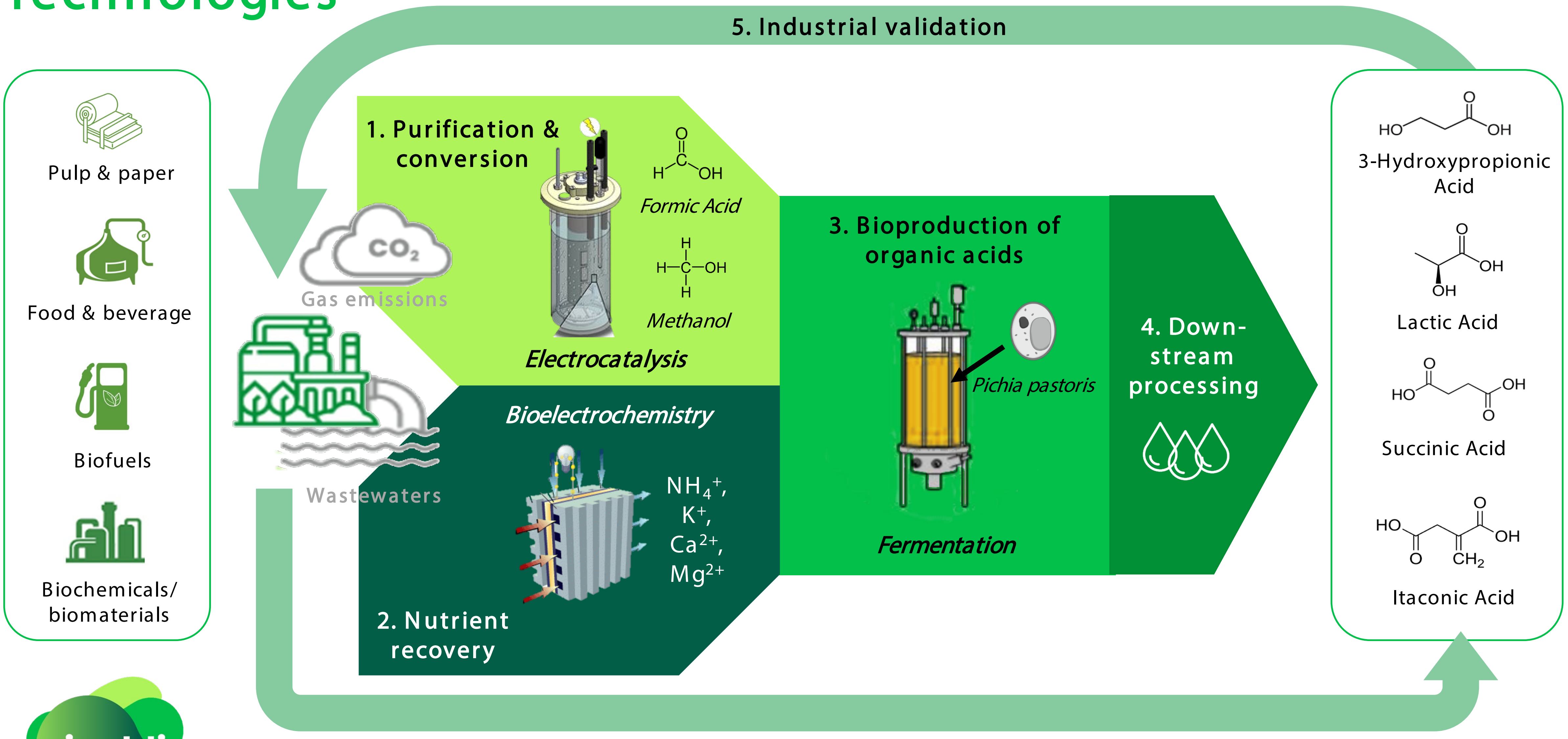
Budget: 7 M€

Concept



Pulp & paper
Food & beverage
Biofuels
Biochemicals/ biomaterials
Biomaterial
Biobased industries
4. Industrial validation
3. Bioproduction of organic acids
Formic acid & Methanol
1. Purification and conversion
NH_4^+, K^+, Ca^{2+}, Mg^{2+}
CO_2
Biogenic CO_2 emissions
2. Nutrient recovery
Wastewaters
HO
OH
O
3-Hydroxypropionic Acid
Lactic Acid
Succinic Acid
CH_2
Itaconic Acid

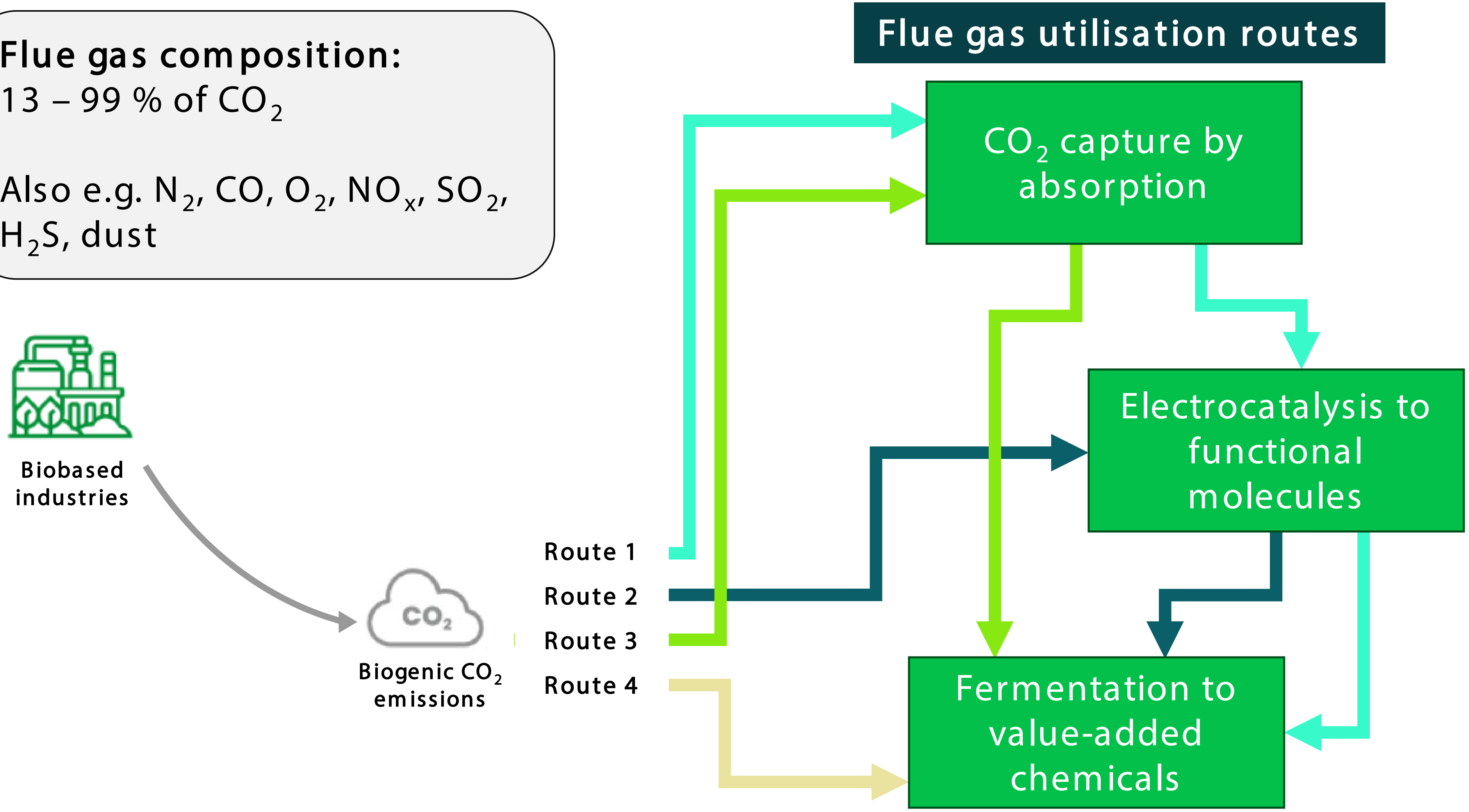
Technologies



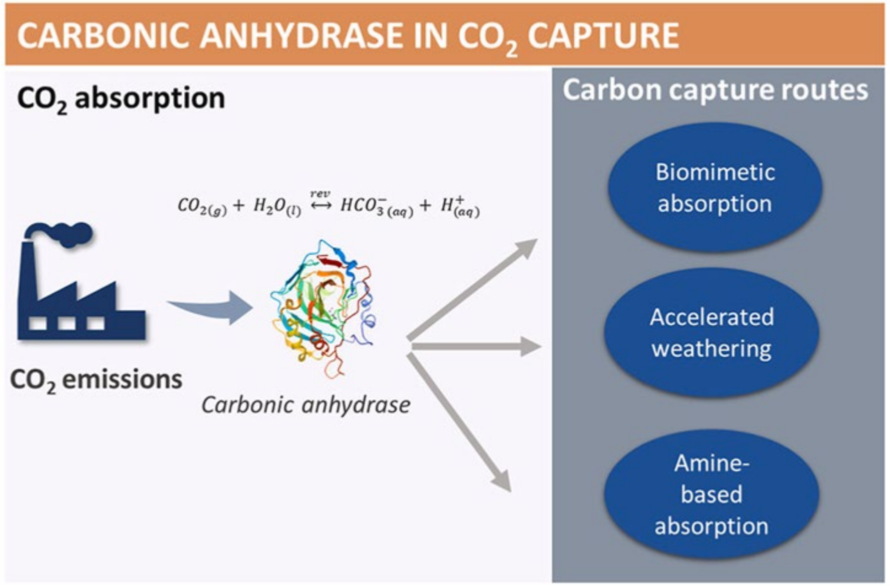
Biobased industries – flue gas utilisation routes in VIVALDI

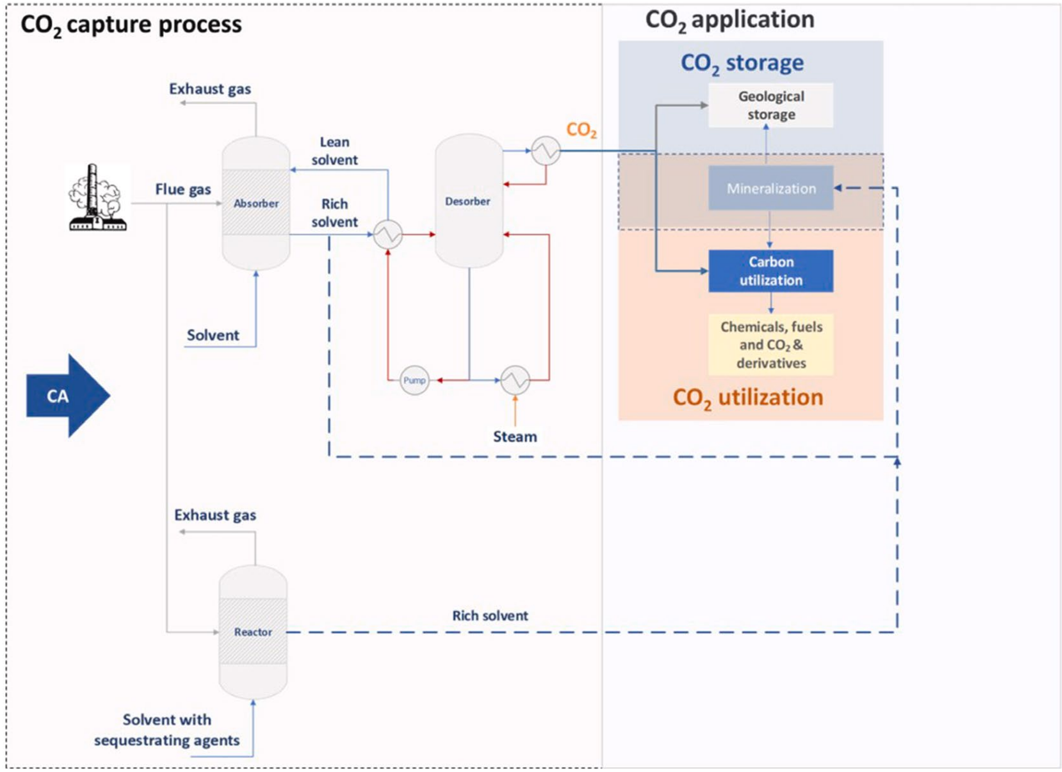
Flue gas composition:
13 – 99 % of CO_2

Also e.g. N_2, CO, O_2, NO_x, SO_2, H_2S, dust



CO_2 capture using carbonic anhydrases



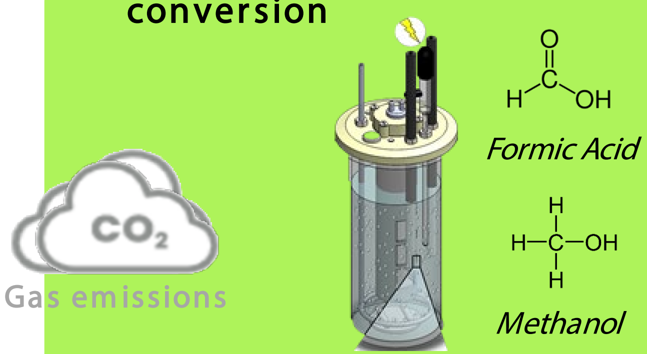


- **Carbonic anhydrase**
  - Enzyme found in several living organisms
  - Accelerates CO_2 hydration to bicarbonate
  - Enhancement of enzyme properties via protein engineering

de Oliveira Maciel, A., Christakopoulos, P., Rova, U., & Antonopoulou, I. (2022). Carbonic anhydrase to boost CO_2 sequestration: Improving carbon capture utilization and storage (CCUS). Chemosphere, 299, 134419. https://doi.org/10.1016/j.chemosphere.2022.134419

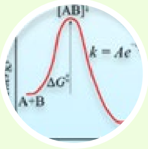
Electrocatalysis

1. Purification & conversion

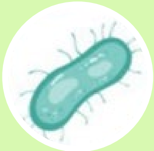


Electrocatalysis

Why electrocatalysis?



CO_2 transformation is limited by thermodynamic and kinetic inertness. To overcome the high energy barriers of CO_2 activation, catalysts are required.



It can be produced at biocompatible conditions (neutral pH, ambient temperature and pressure, physiologic salinity and under presence of components of microbial media).

Depending on the conditions and electrode materials, different products can be obtained. Understanding ECO_2R opens a plethora of novel possibilities of CO_2 valorisation as microbial feedstock.

ECO_2R provides a pathway for the utilization and (temporary) storage of electric energy. Electricity from photovoltaic cells, wind turbines, or off-peak grid power sources can be used to drive CO_2 reduction.

Why Formic Acid (FA) and Methanol (MeOH)?

i. CO_2 reduction to added-value chemicals (i.e. FA) leads to short-term economic feasibility to **a higher market price** and (MWh/tC) among similar **higher energy content** products.

ii. **Biomethanol** from wastes has a higher value (400–450 €/ton) than its cost of production 200 €/ton

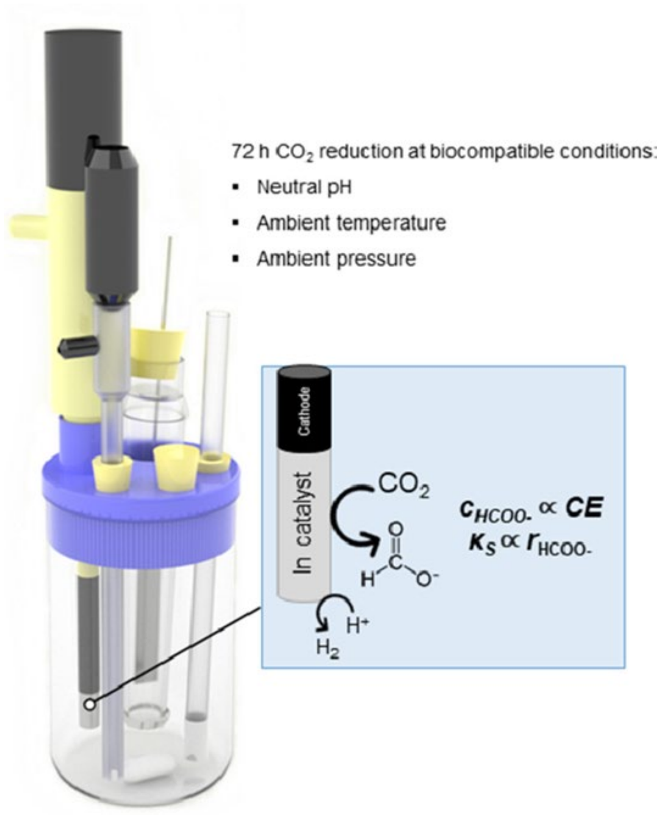
iii. The **energetic efficiency** of converting FA/MeOH into biomass aerobically can reach 50%, while for other C1-feedstocks it lies in a range of 20–40%.

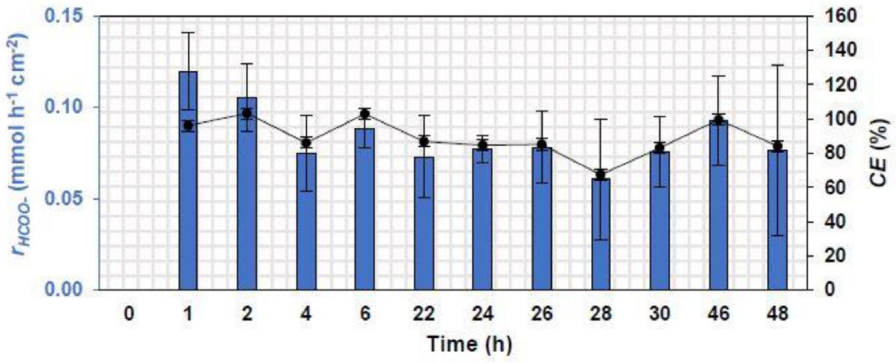
iv. Microbial utilisation of FA and MeOH as C-source needs a **minimal media and simple nitrogen sources**

v. Cultivation of microorganisms on C1-gases (e.g. CH_4, CO, and H_2/CO_2) has several drawbacks: low water solubility, limited mass transfer (due to phase boundaries), issues with storage and transportation, low yield and low microbial productivity.

Electrochemical CO_2 reduction to formate

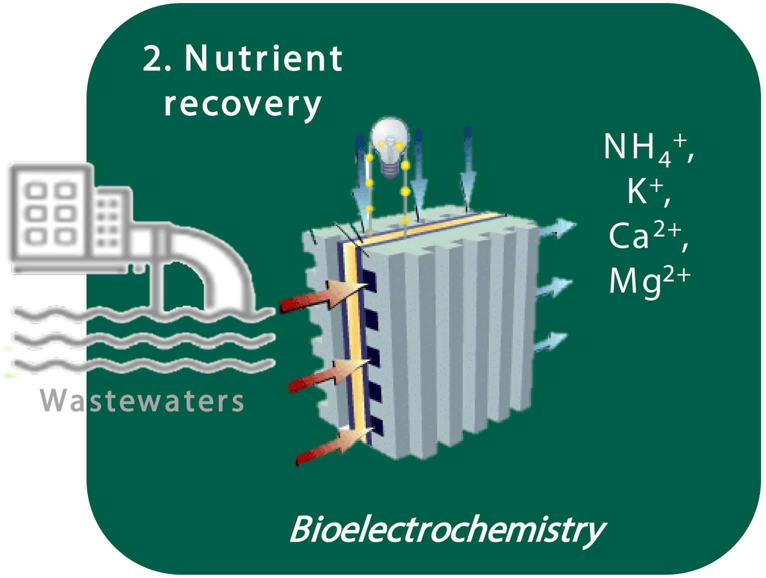
- Enables production of feed for microbial syntheses
- Can be performed in mild biocompatible conditions
- Usually higher production rates than in microbial processes

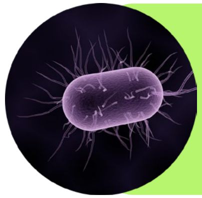




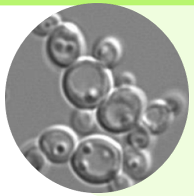
Izadi, P., Kas, A., Haus, P., & Harnisch, F. (2023). On the stability of electrochemical CO_2 reduction reaction to formate at indium electrodes at biocompatible conditions. Electrochimica Acta, 462, 142733. https://doi.org/10.1016/j.electacta.2023.142733

Bioelectrochemical nutrient recovery





Converting the organic compounds in the wastewaters into electricity with the assist electroactive bacteria



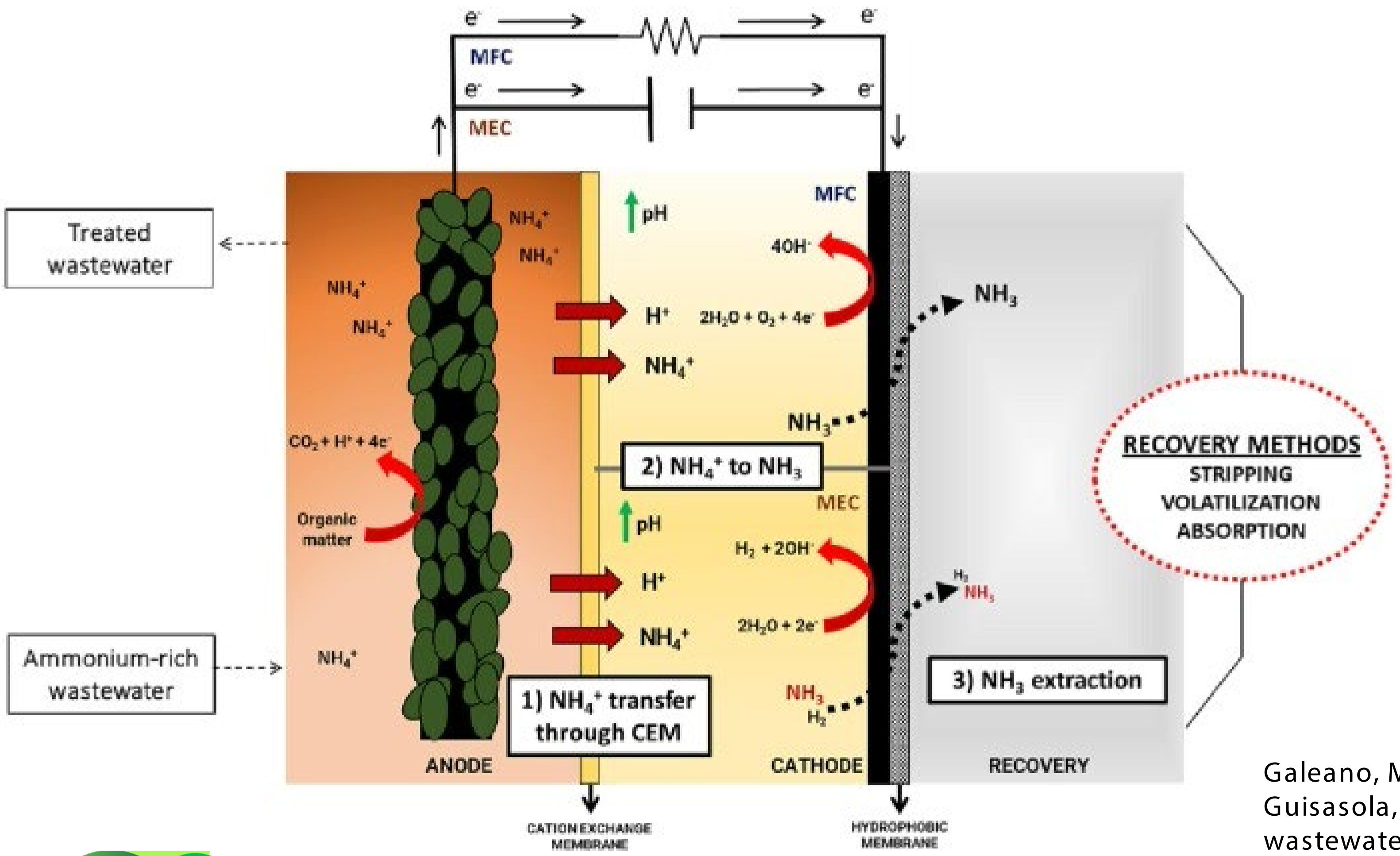
Reduces the need for external addition of nutrients during fermentation

The treated wastewater will be less loaded and thus has less eutrophication potential

Allows abandonment of linear economic models

Provides significant environmental, economic, and energy savings

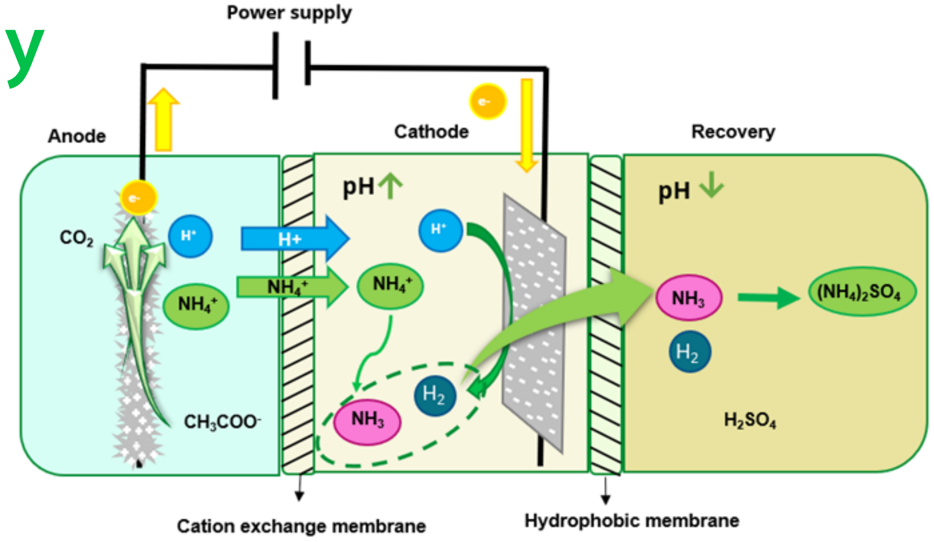
Bioelectrochemical nutrient recovery



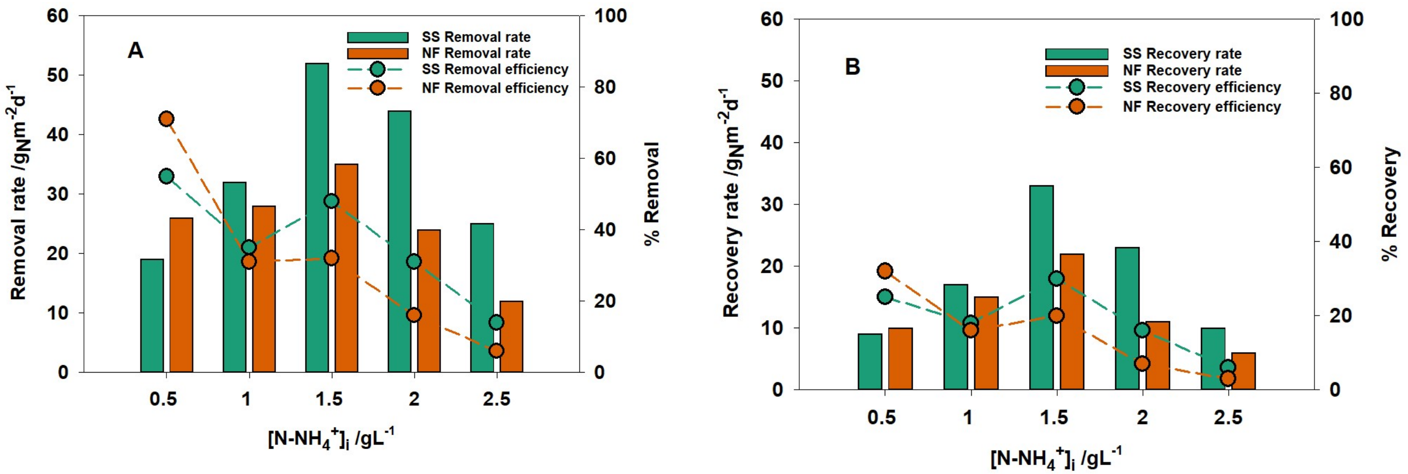
- Organic matter from e.g. industrial wastewaters is oxidised at the anode side and electrons flow from the anode to the cathode
- The charge is balanced by cation transport over the cation exchange membrane to maintain electroneutrality
- Therefore, ammonium and other cations are concentrated in the cathode compartment

Galeano, M. B., Sulonen, M., Ul, Z., Baeza, M., Baeza, J. A., & Guisasola, A. (2023). Bioelectrochemical ammonium recovery from wastewater: A review. Chemical Engineering Journal, 144855. https://doi.org/10.1016/j.cej.2023.144855

Bioelectrochemical nutrient recovery

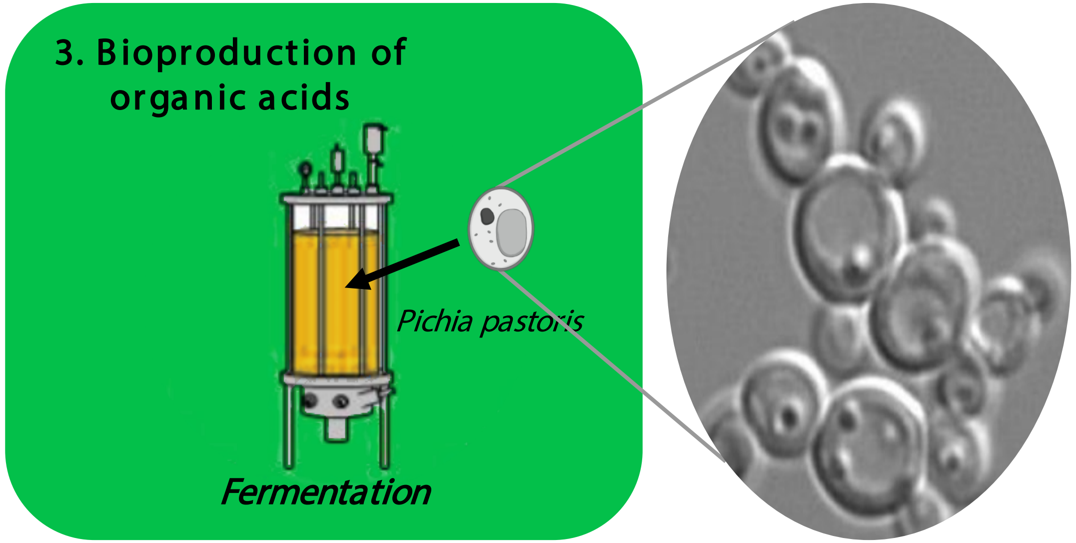


- Nitrogen recovery from synthetic reject water
- Hydrophobic membranes enable energy-efficient N-removal and recovery
- Generated ammonium sulfate can be utilised as a nutrient source (e.g. in fermentation or as a fertiliser)



Ul, Z., Sulonen, M., Baeza, J.A. & Guisasola, A. (2024) Continuous high-purity bioelectrochemical nitrogen recovery from high N-loaded wastewaters *Bioelectrochemistry*. Accepted manuscript.

Biotechnical production of value-added chemicals



Why *Pichia pastoris*?

i. Grows at optimal conditions for recovery of free organic acids: low extracellular pH and high product concentration

ii. Grows on MeOH and can use FA as auxiliary substrate

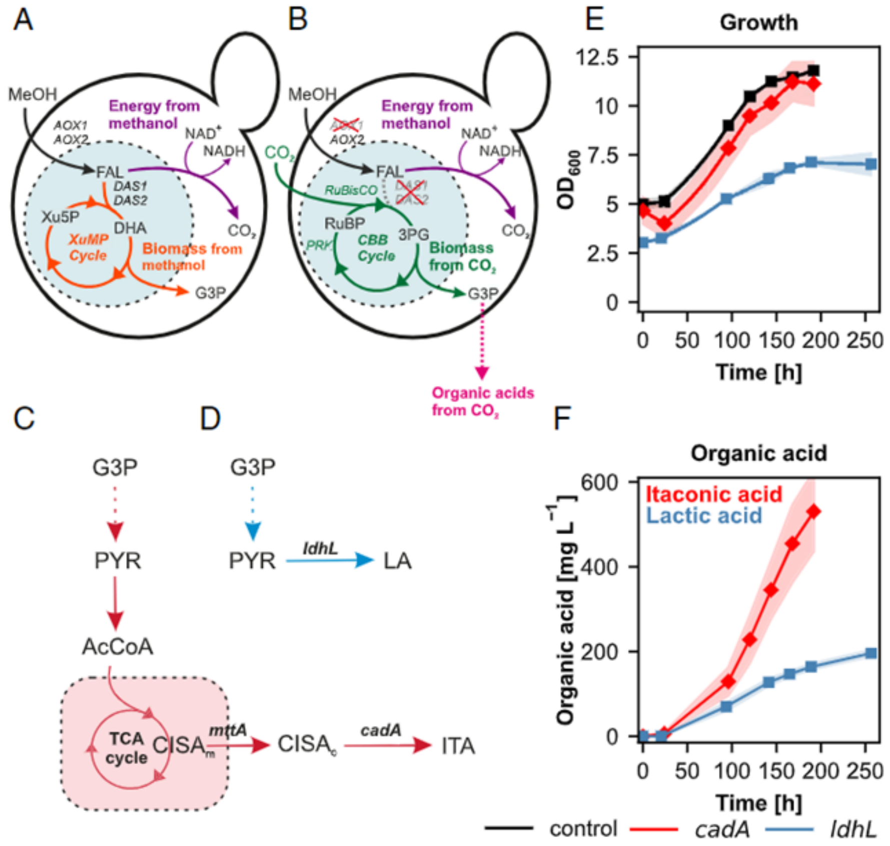
iii. Can grow and produce on simple mineralic media

iv. Industrial scale fermentation is established

v. Genetics and metabolisms are well studied, a genome scale metabolic model and synthetic biology tools are established

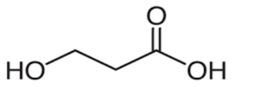
Biotechnical production of value-added chemicals

- Sustainable and cost-effective way for chemical production
- Genetic engineering enables the production of high variety of chemicals
- Single carbon sources are available without competing with food production
  - Serve as the energy and/or the carbon source

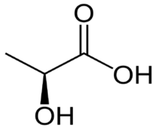


Baumschabl, M., Ata, Ö., Mitic, B. M., Lutz, L., Gassler, T., Troyer, C., ... & Mattanovich, D. (2022). Conversion of CO2 into organic acids by engineered autotrophic yeast. Proceedings of the National Academy of Sciences, 119(47), e2211827119. https://doi.org/10.1073/pnas.2211827119

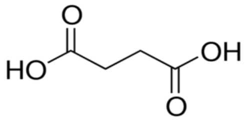
Target compounds



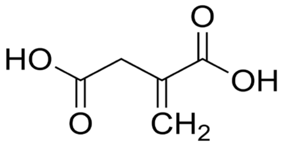
3-Hydroxypropionic Acid



Lactic Acid



Succinic Acid



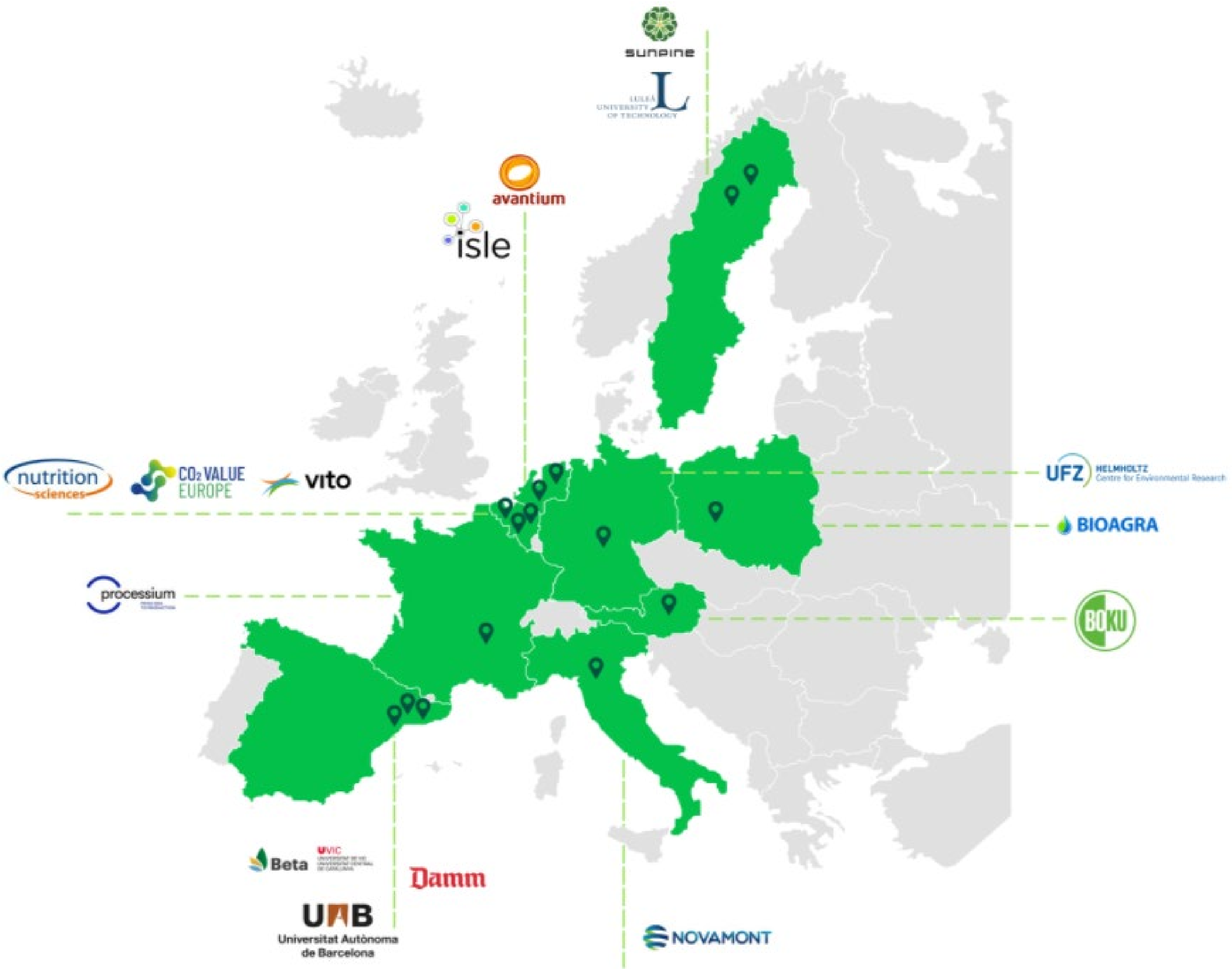
Itaconic Acid

	3-hydroxypropionic acid (3-HP)	Lactic Acid (LA)	Itaconic Acid (IA)	Succinic Acid (SA)
Current synthesis	Microbial/enzymatic production under aerobic conditions with glycerol/glucose as substrate and coenzyme-B12/ NADPH as cofactors	Microbial fermentation from C5-C6 sugars or chemical hydrolysis of lactonitrile by strong acids produces a racemic mixture.	Microbial fermentation with sugar or starch as raw materials. A mixture of IA and derivatives is obtained by reacting succinic anhydride with formaldehyde	Chemical production from maleic acid hydrogenation. Fermentation of sugars by wild strains or genetically engineered well-known industrial microorganisms
Market	3-HPA market is still under development: 40 kt/yr in 2015	800-1200 (2016) kt/yr with expected growth of 1% per year	40 kt/yr (2015). Projection of 50-170-410 kt/ yr in 2025).	50 kt/yr (2014) Projection of 270 kt/yr (2025) at a CAGR 6.8%
€/kg	1.5-2	1.30-2.30	1.5-2	1.8-3
Significance	12 top building-block chemicals that can be produced from biomass[21]	Monomer of PLA (market size was US$1.2 billion in 2018 and a CAGR of 19.8%)	12 top building-block chemicals that can be produced from biomass[21]	Top 10 chemicals that could be produced from renewable resources[21]
	Platform chemical for acrylic acid methylene chloride and 1,3-propanediol	Precursor of propylene glycol, acrylic polymer	Replacement for acrylic acid, maleic anhydride. Precursor of methyl methacrylate. Monomer of polyitaconic acid	Replacement for adipic acid or maleic anhydride. Used in food, pharmaceutical, personal care and chemical sector

Project partners

The multidisciplinary and international consortium is formed by **16 partners**, including:

- biobased Industries
- technology developers
- end-user
- knowledge hubs



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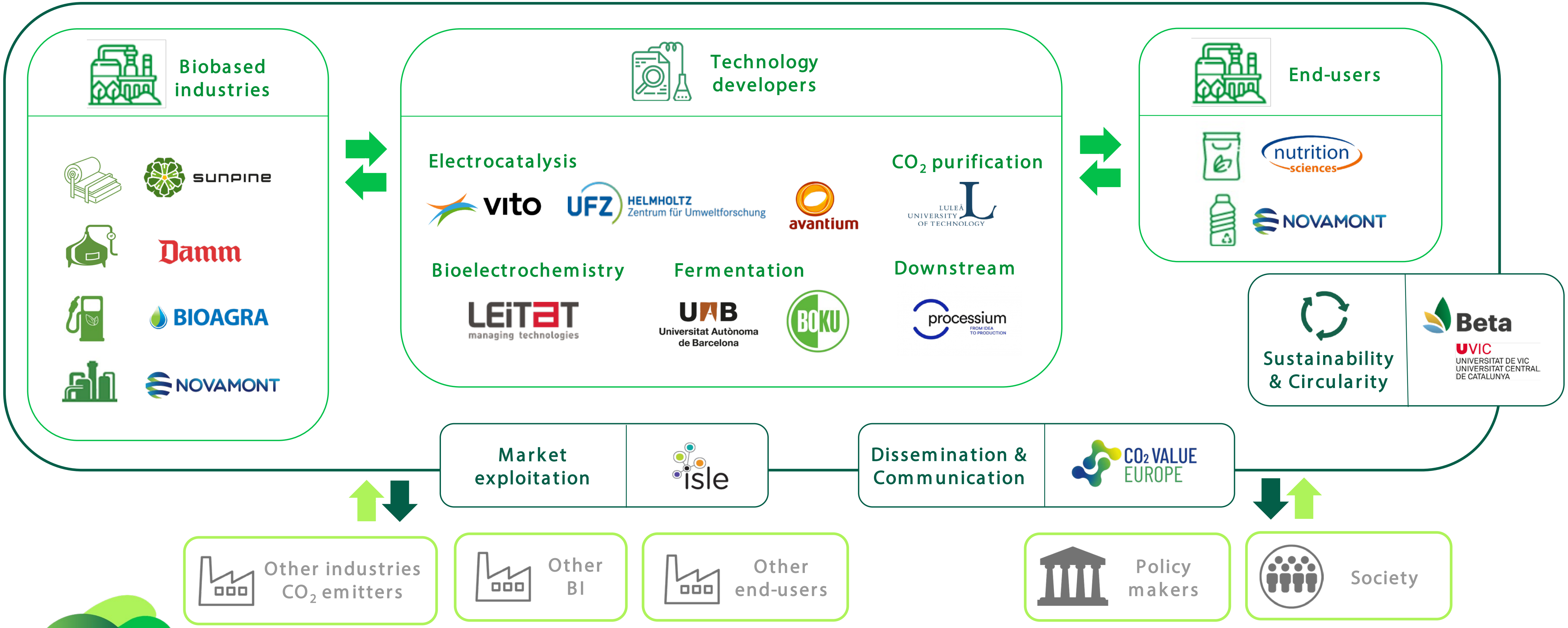
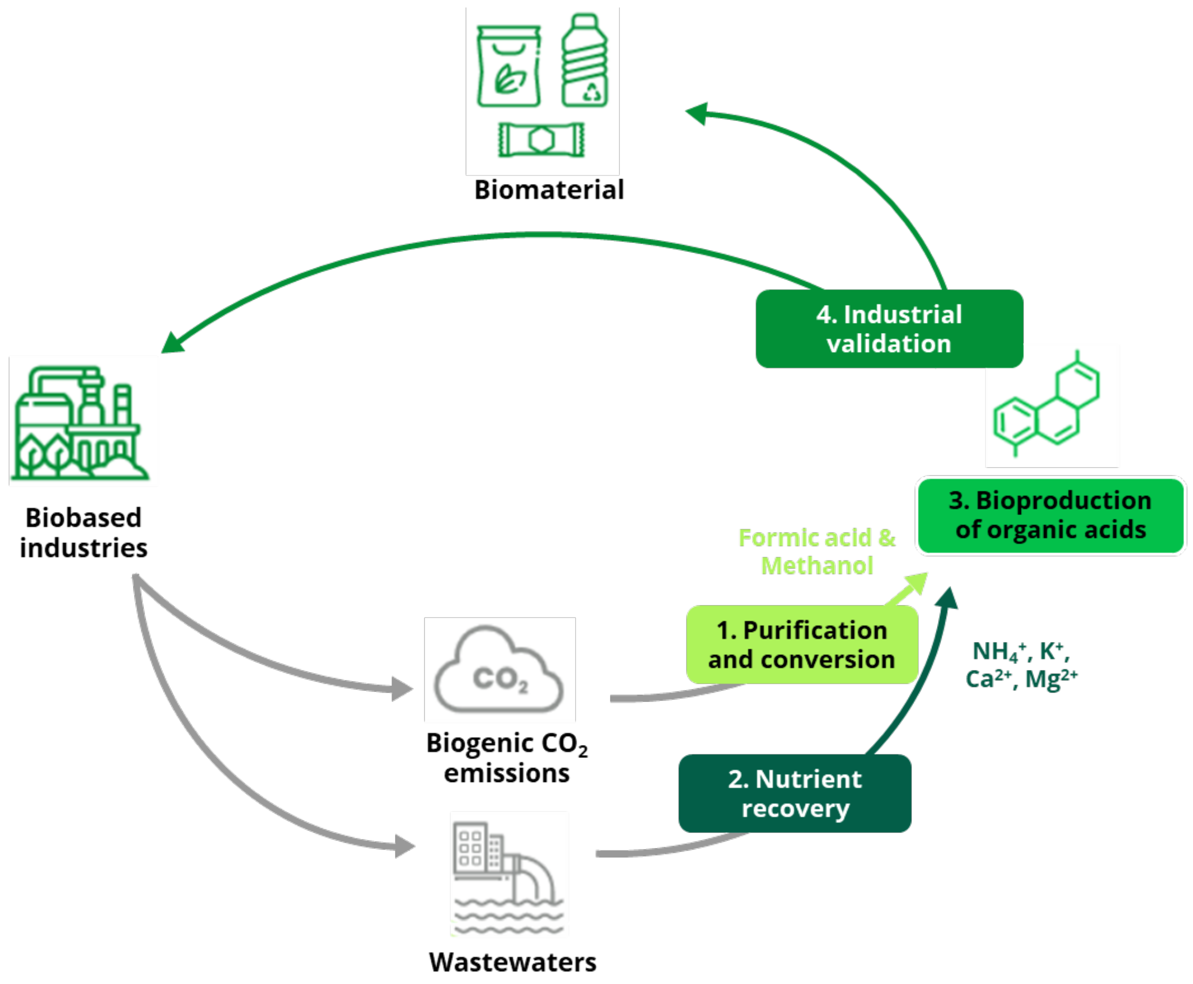
Methodology



VIVALDI's solution in a nutshell

Developing innovative biotechnological solution for converting the off-gas emissions of bio-based industries into CO_2-based chemicals



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THANK YOU

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