

# Processos bioelectroquímics

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## Acknowledgements (selected):

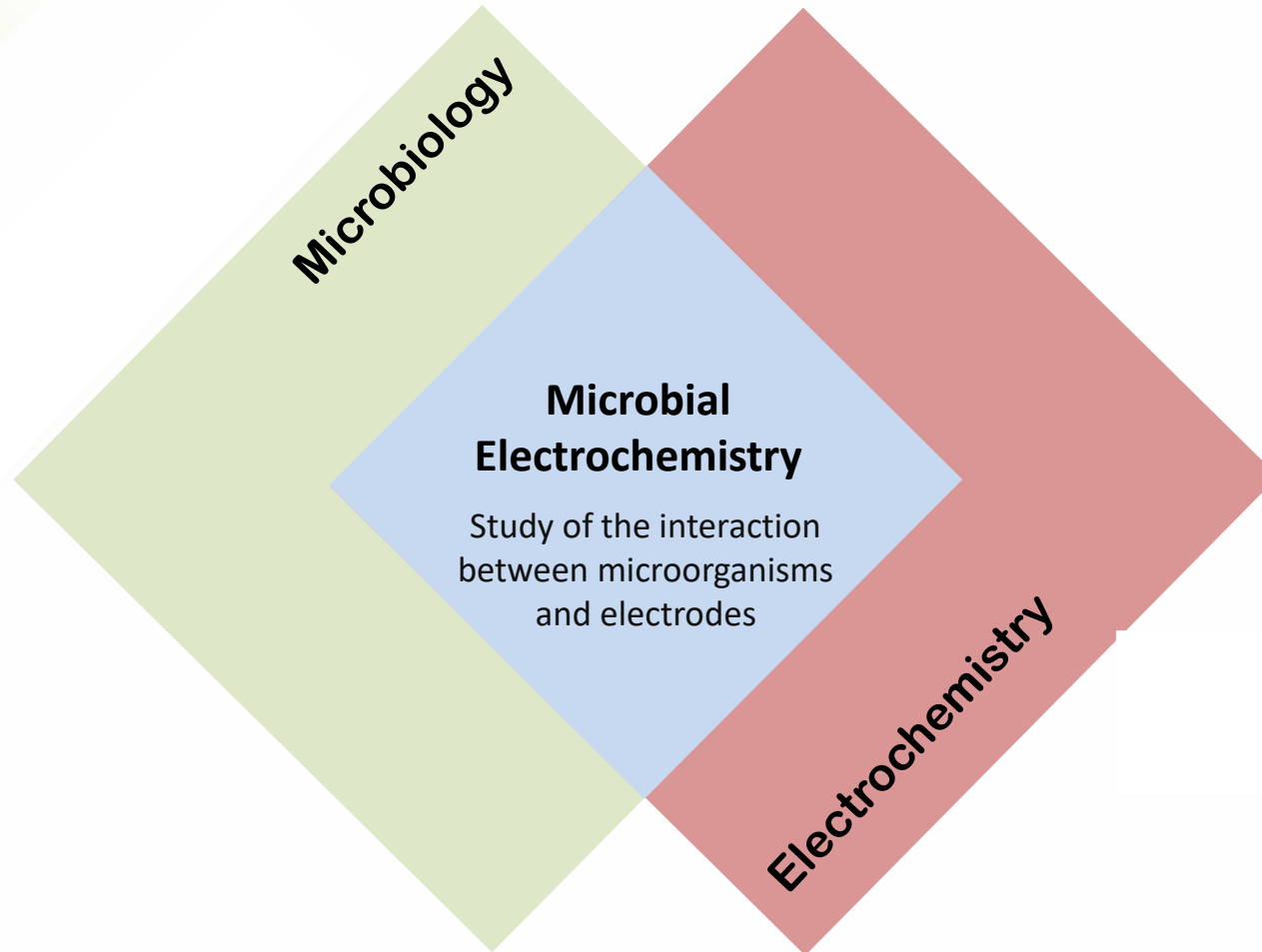
# Microbial Electrosynthesis

**CO<sub>2</sub> Recycling** **Bioremediation** **Bioelectrochemistry**

**Wastewater Treatment** **Circular Economy** **Resource Recovery** **Biofuels**

**Nitrate Removal** **Pattern Discovery** **Microbial Proteins** **Machine Learning** **Electromicrobiology**

**Methane Production**



**Microbial Electrochemical Technologies  
METs**

Courtesy of Abraham Nuñez-Esteve

J Solid State Electrochem (2011) 15:1481–1486  
DOI 10.1007/s10008-011-1395-7

REVIEW

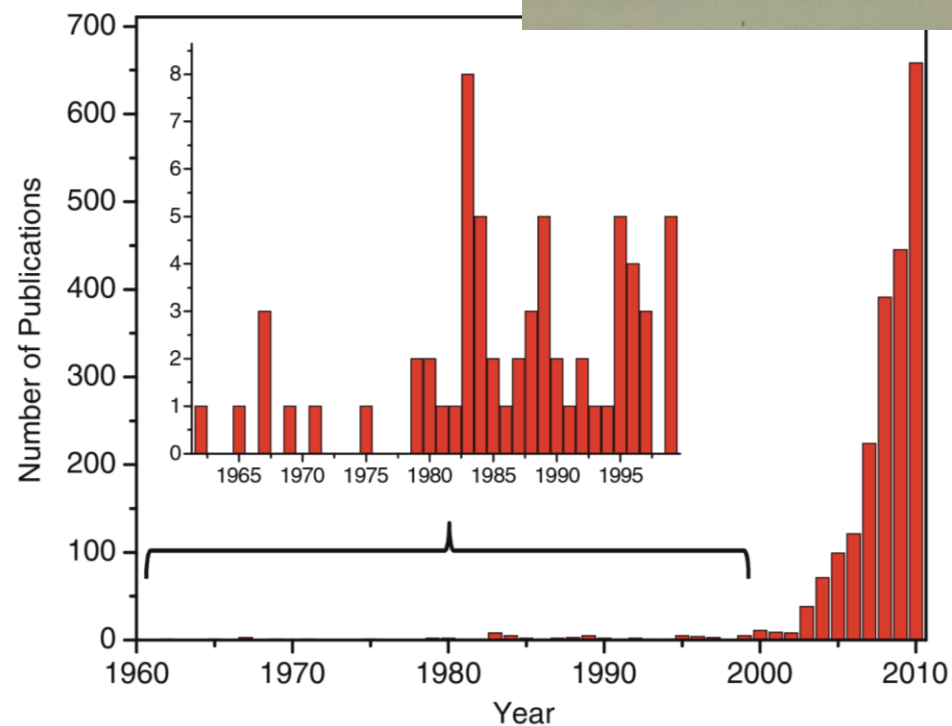
## Discover the possibilities: microbial bioelectrochemical systems and the revival of a 100-year-old discovery

Uwe Schröder

*Electrical Effects accompanying the Decomposition of Organic Compounds.*

By M. C. POTTER, Sc.D., M.A., Professor of Botany in the University of Durham.

(Communicated by Dr. A. D. Waller, F.R.S. Received July 14, 1911.)



**Fig. 1** Number of publications from 1960 to 2010 containing the phrase “microbial fuel cell” (SciFinderScholar, February 2011)

Bioresource Technology 347 (2022) 126705



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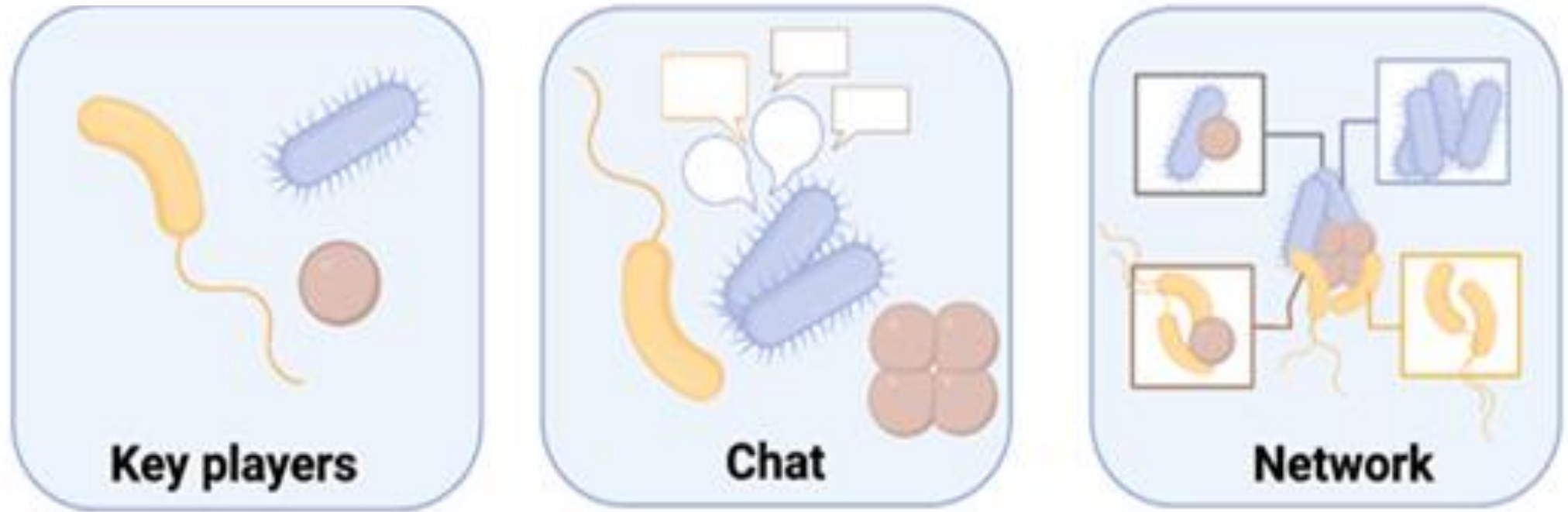
Bioresource Technology

journal homepage: [www.elsevier.com/locate/biortech](http://www.elsevier.com/locate/biortech)

Review

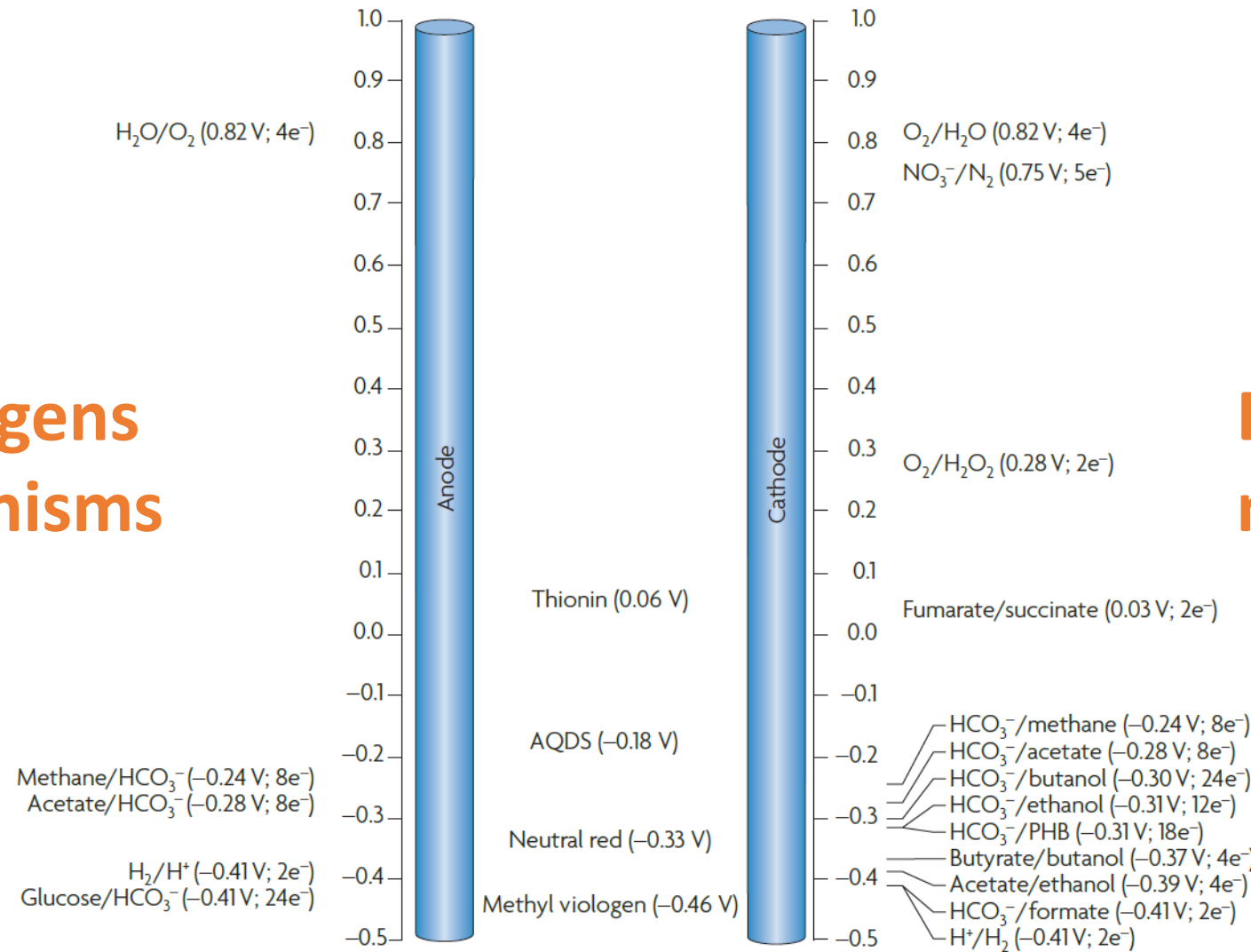
### Let's chat: Communication between electroactive microorganisms

Catarina M. Paquete<sup>a</sup>, Miriam A. Rosenbaum<sup>b,c</sup>, Lluís Bañeras<sup>d</sup>, Amelia-Elena Rotaru<sup>e</sup>,  
Sebastià Puig<sup>f,\*</sup>



# Exoelectrogens microorganisms

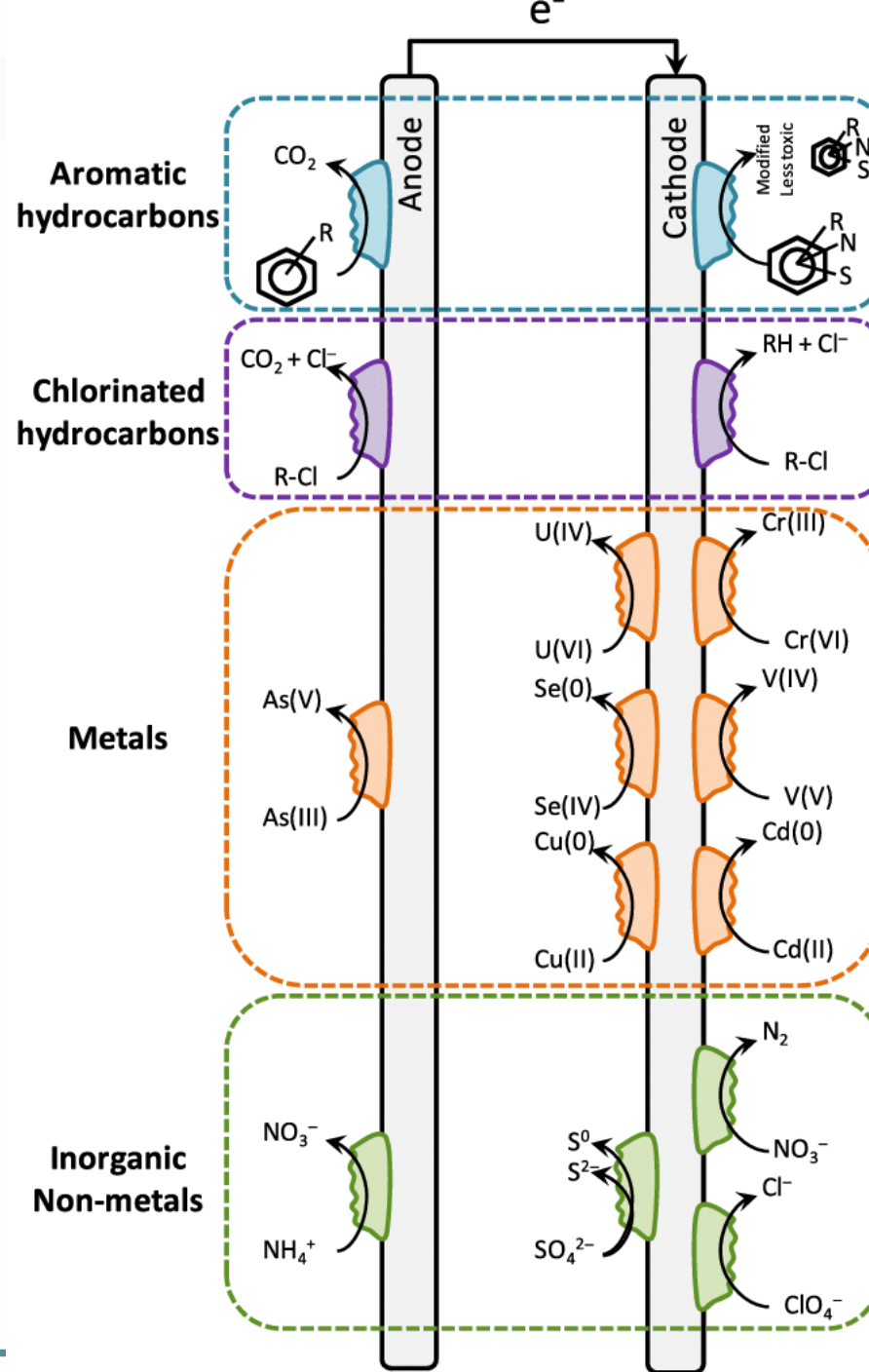
# Electrotrophs microorganisms



PHB, poly-β-hydroxybutyrate. \*The electrode potentials of all electron donor and acceptor couples are calculated from Gibbs free energy data, from REFS 99, 117, according to the methods described in REF. 13. The E<sub>0</sub> values of the electron mediators are from REFS 83, 118.

[Key players]

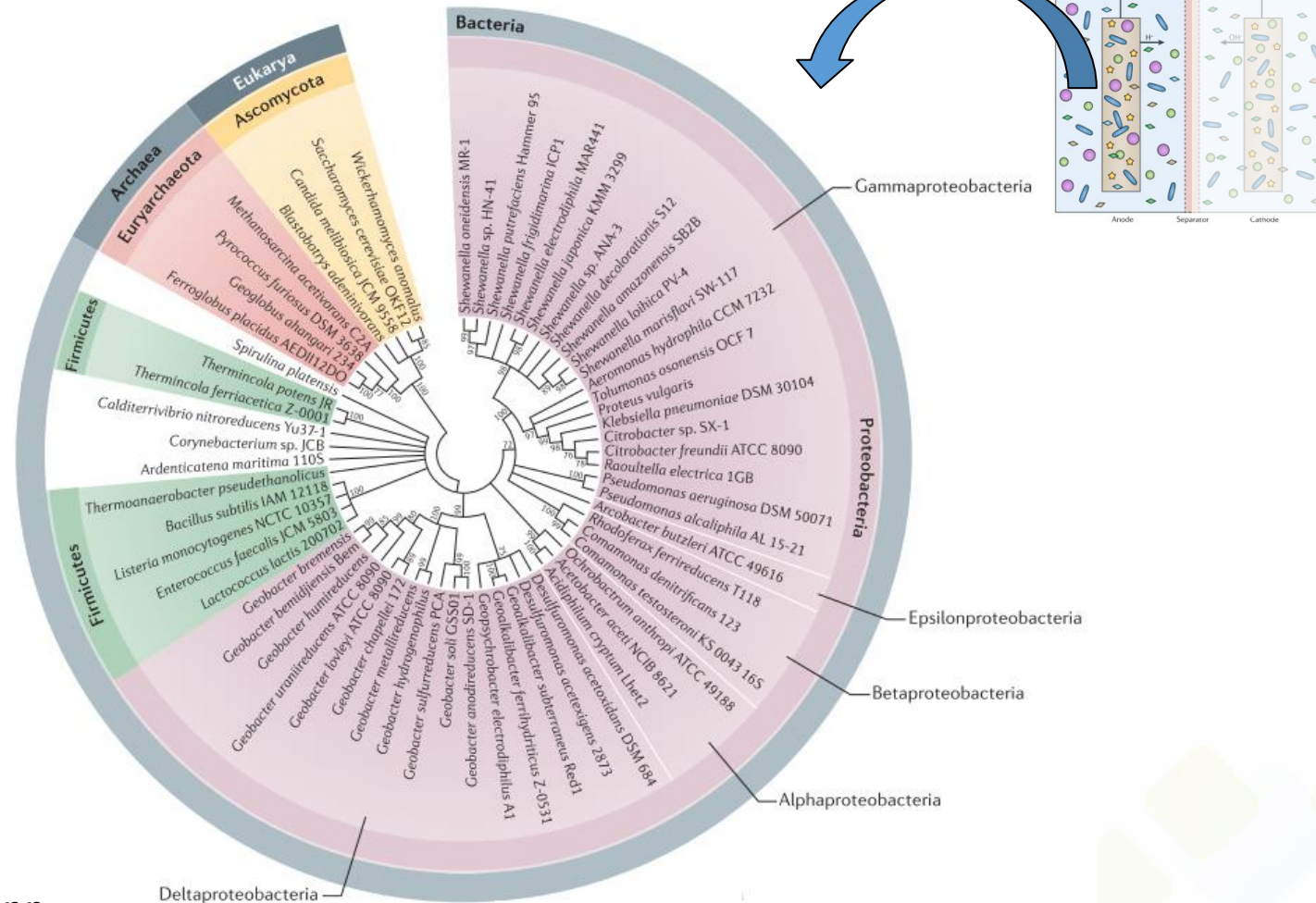
Exoelectrogens  
microorganisms



Electrotrophs  
microorganisms

Pous *et al.* (2018). Microbial Biotechnology 11(1), 119.

# Exo-electrogenic



## Bacteria

- *Geobacter* spp.
- *Shewanella* spp.

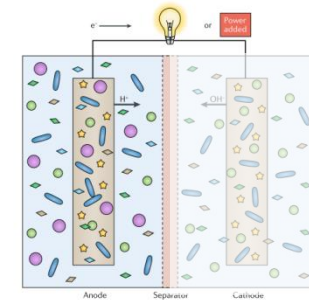
## Archaea

- *Methanosarcina* spp.

Logan et al., 2019. Nature Reviews Microbiology

## Exo-electrogenic – Organic matter oxidizers

Biochar

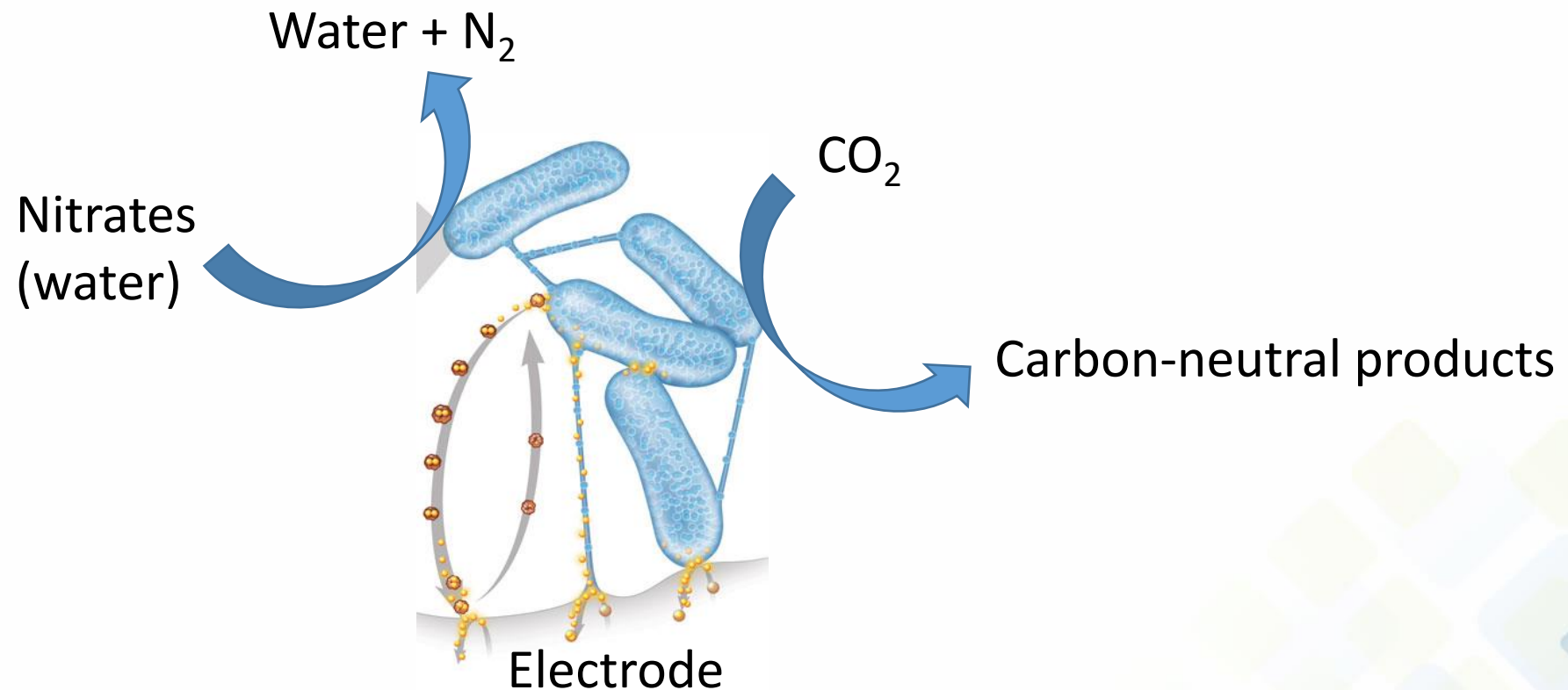


<https://www.carbongold.com/>



<https://www.gardenista.com>

An **electrotroph** is a microorganism which can receive electrons necessary for its growth from an electrode (power supply) terminal.





## Electrotrophs – Nitrate reducers

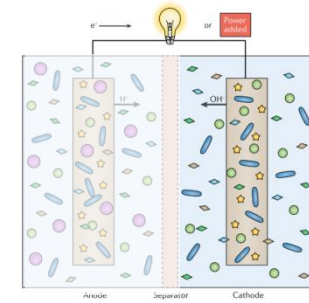
- Groundwater wells



shutterstock.com • 1061041094

## Electrotrophs - Methanogens

Ruminant gut  
Paddy soils  
Rice field



shutterstock.com • 1383828836



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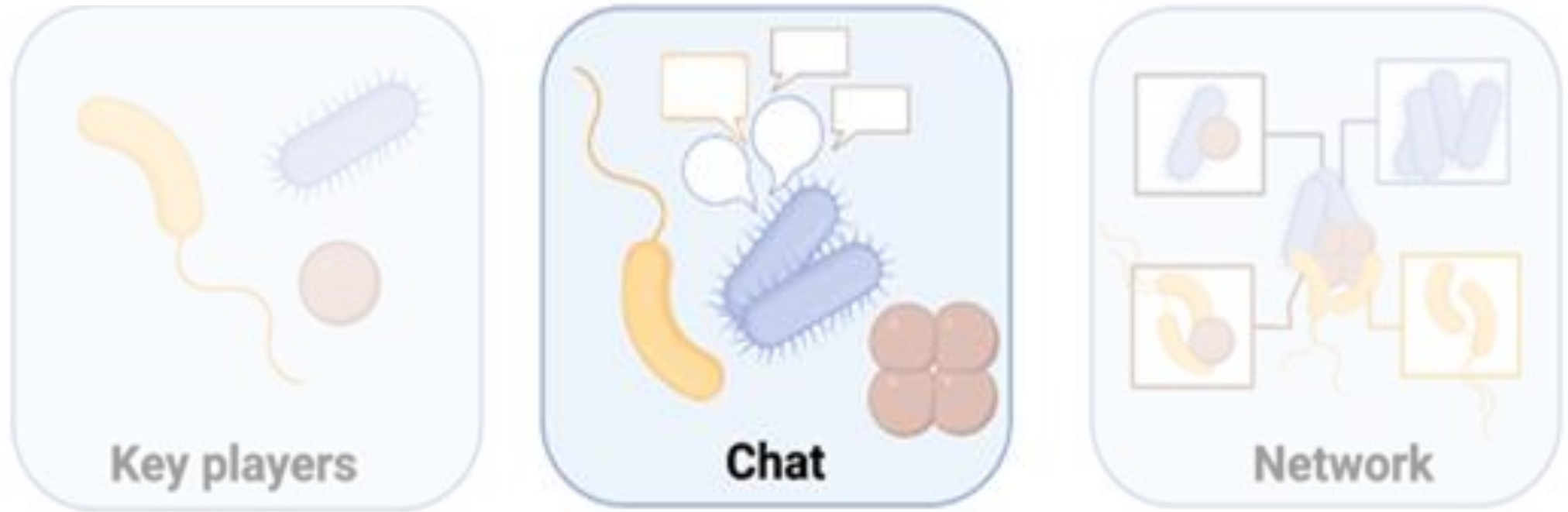
Bioresource Technology

journal homepage: [www.elsevier.com/locate/biortech](http://www.elsevier.com/locate/biortech)

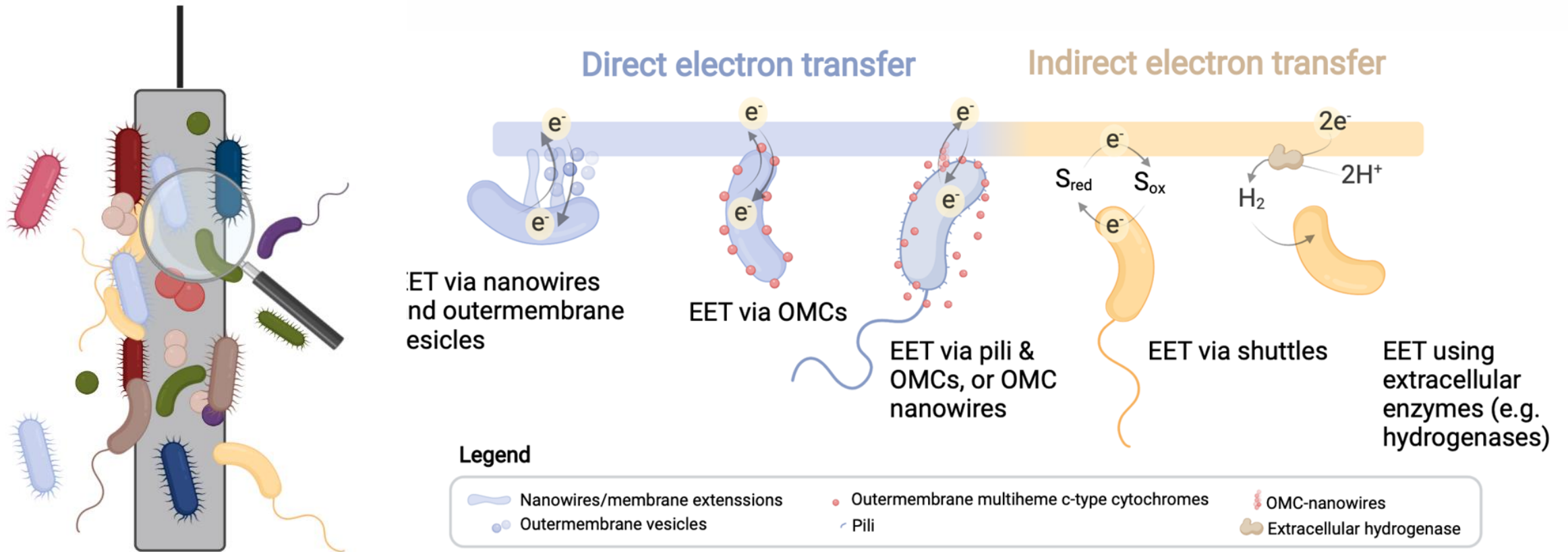
Review

### Let's chat: Communication between electroactive microorganisms

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# KEY PLAYERS AND THEIR EXTRACELLULAR ELECTRON TRANSFER PROCESSES

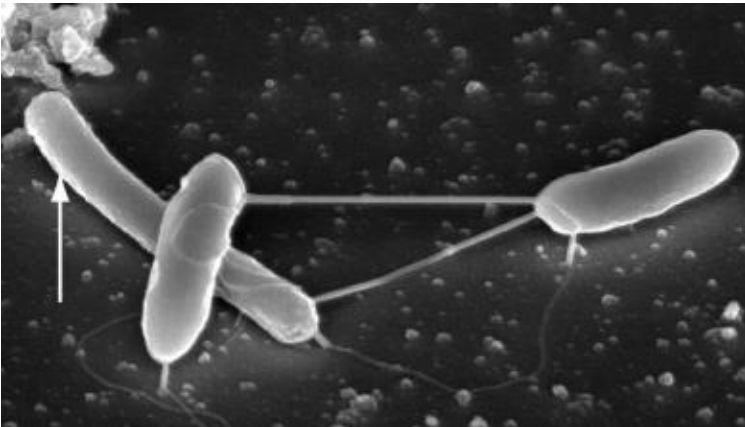


Paquete *et al.* (2022). *Bioresource Technology* 347, 126705

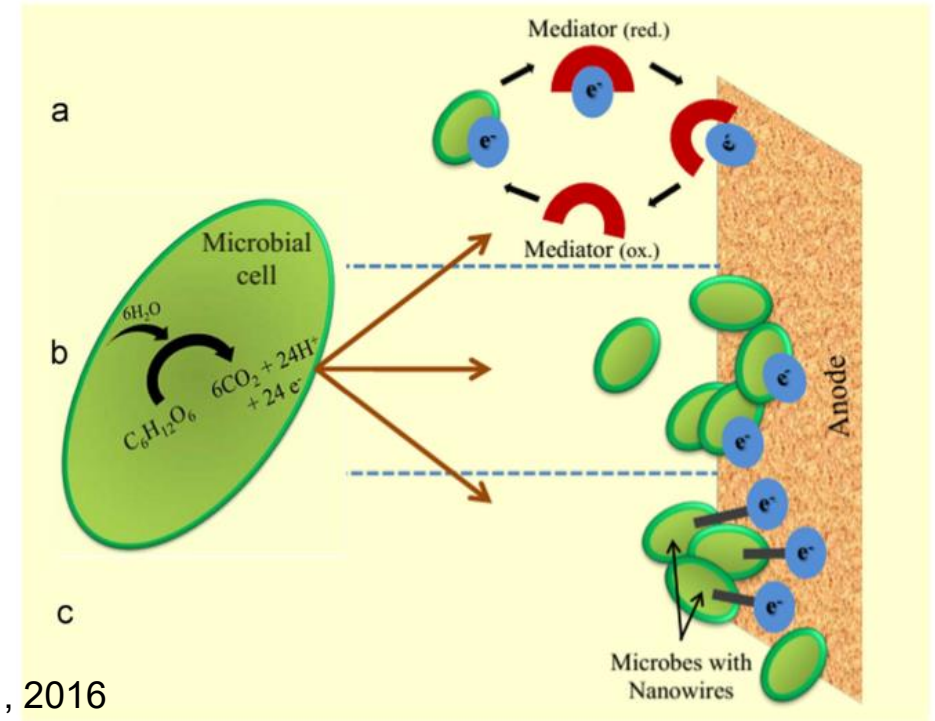
# The microbe-electrode interaction

## Electron transfer mechanisms

- Mediated electron transfer (a)
- Short-range electron transfer (b)
- Long-range electron transfer (c)



Yuri Gorby, Rensselaer Polytechnic Institute, Troy, New York



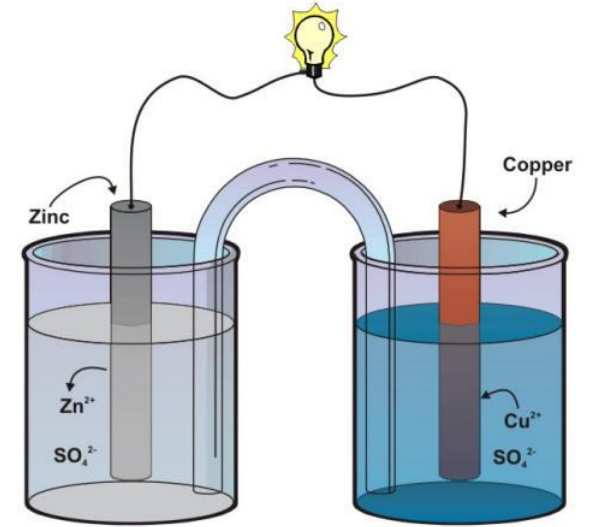
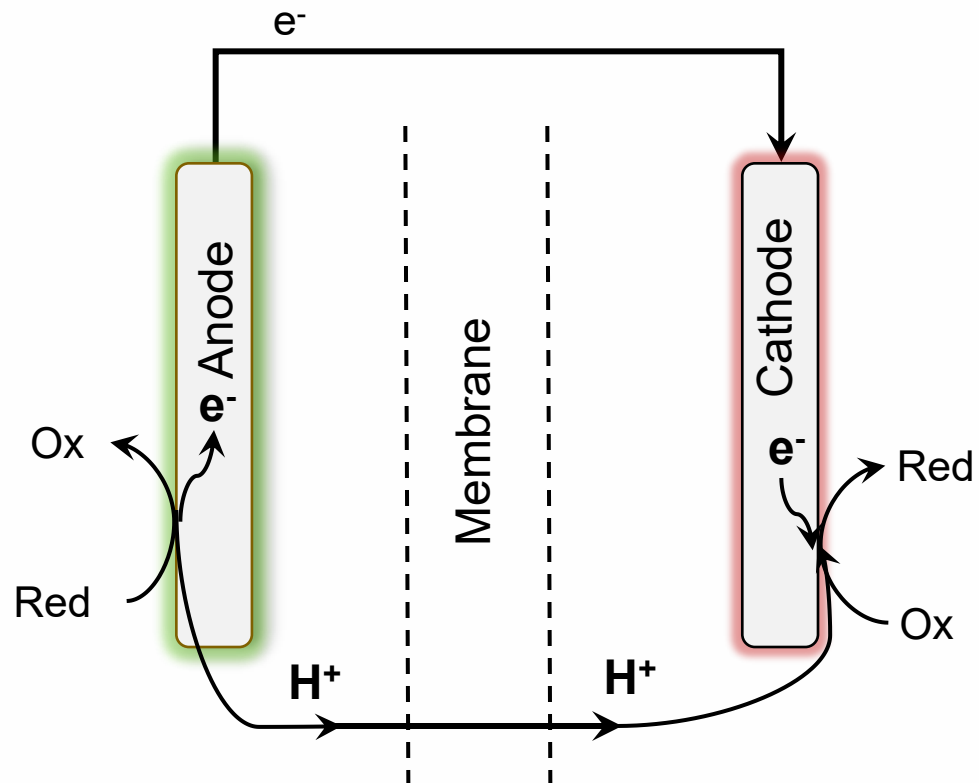
Butti et al., 2016

## Exoelectrogenic microorganisms (give electrons)

- *Geobacter*, *Shewanella*, *Thermincola*

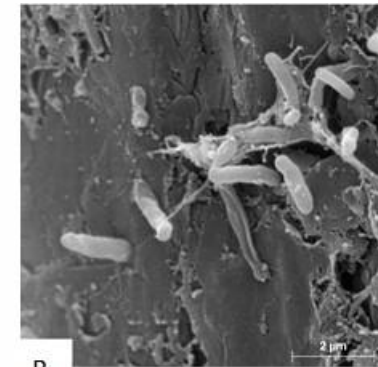
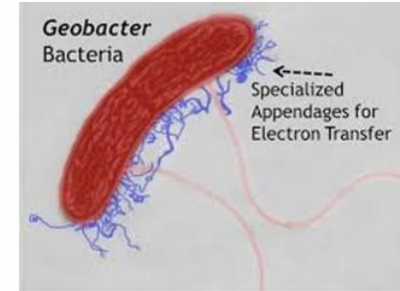
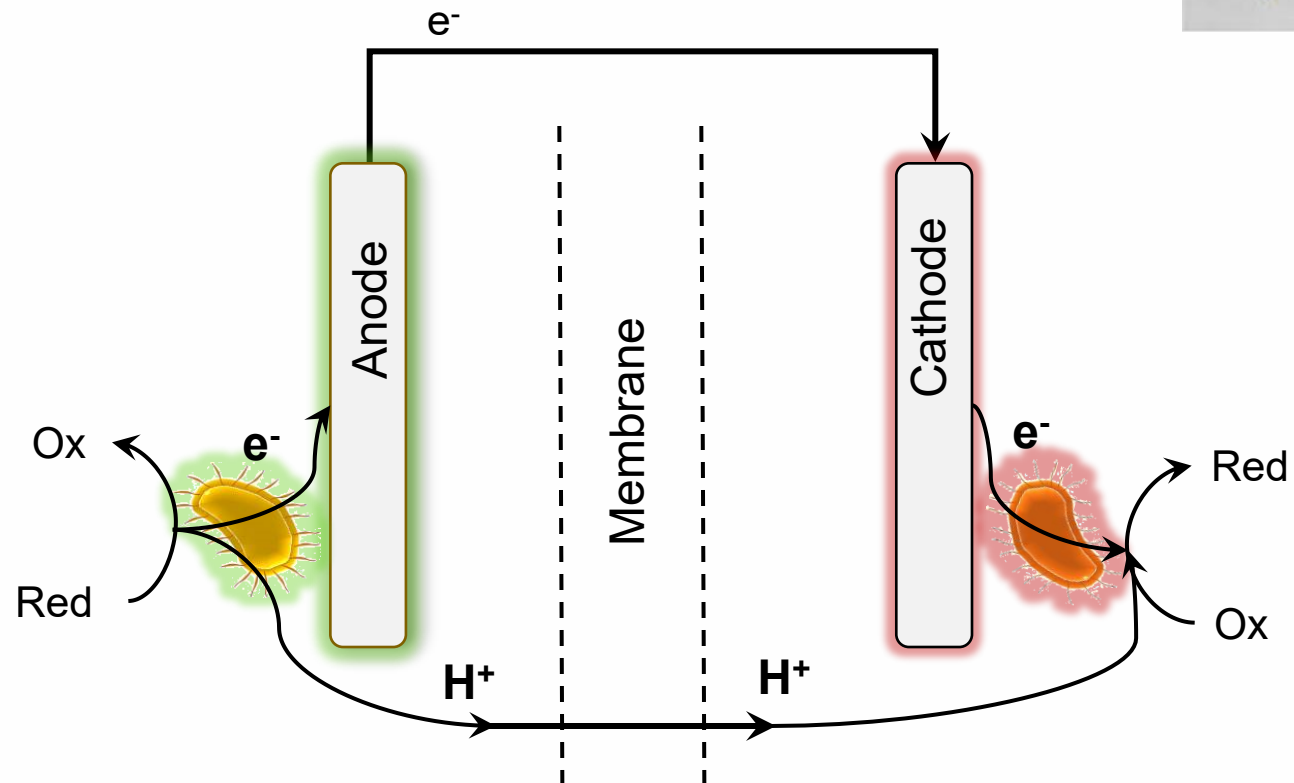
## Electrotrophic microorganisms (uptake electrons)

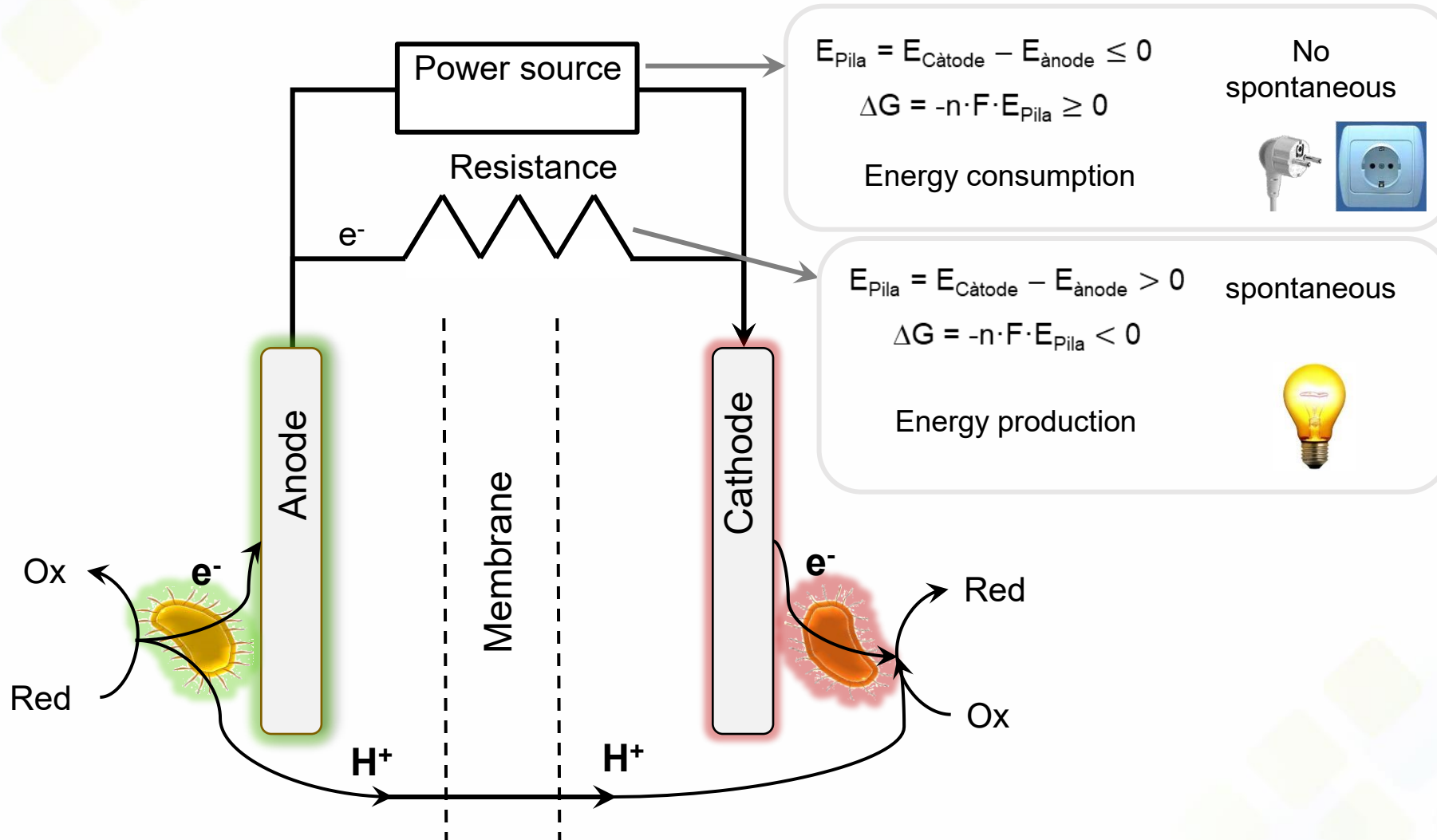
- *Desulfovibrio*, *Sporomusa*, *Clostridium*



Daniel Cell







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Review

### Let's chat: Communication between electroactive microorganisms

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## BIOREMEDIATION

### Electro-Bioremediation

Restoring water quality through the bio-electro-remediation of **nitrates** and **microplastics** in contaminated aquifers or wastewater.



## SUSTAINABLE FUELS

### Microbial Electrosynthesis

Synthesis of **methane** from (indoor) CO<sub>2</sub>, **Aviation Fuel (SAF)** from solar, and **bioethanol** from recycled carbon.

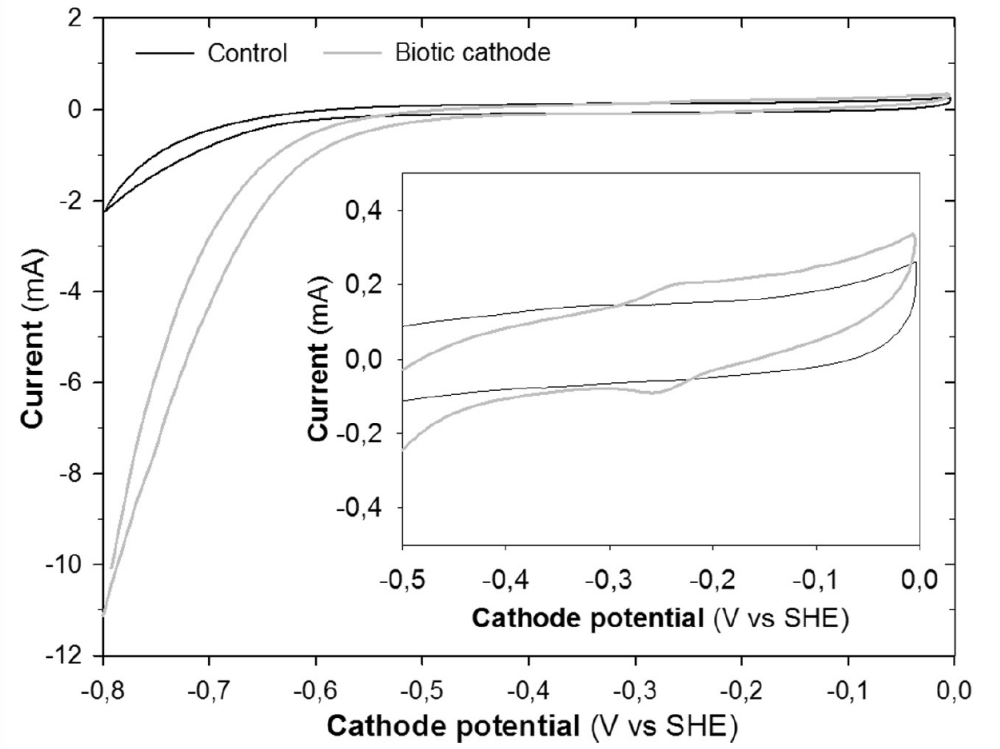
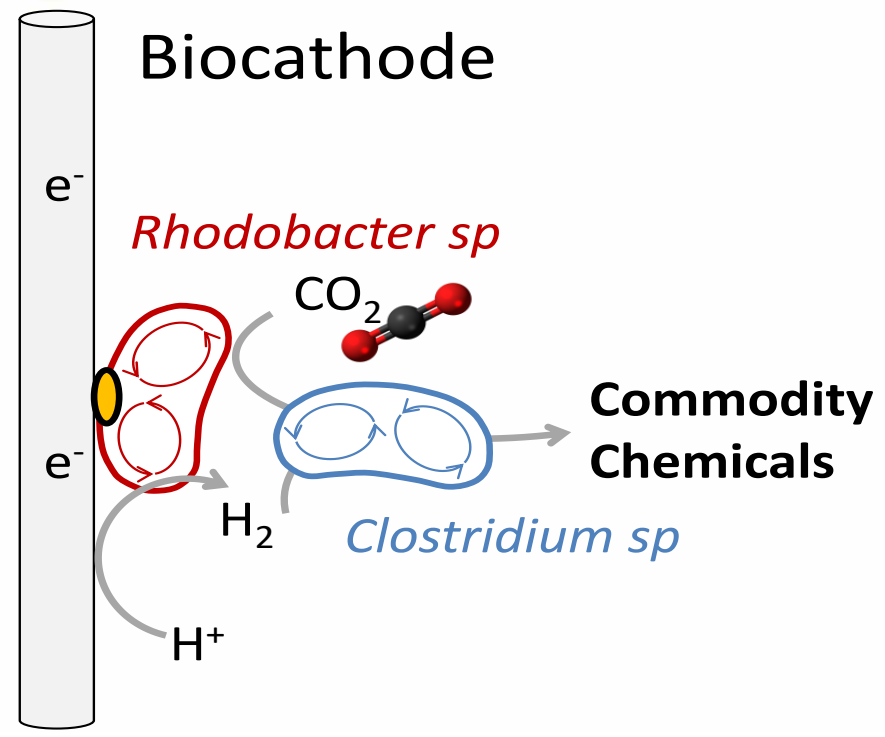


## NOVEL PRODUCTS

### Microbial Proteins

Empowering land-free protein production via continuous fermentation of **H<sub>2</sub>-oxidizing bacteria** using water, urea and electricity.

[Carbon recycling – Air recovery]



### Abiotic vs. **Biotic** mediated H<sub>2</sub> production

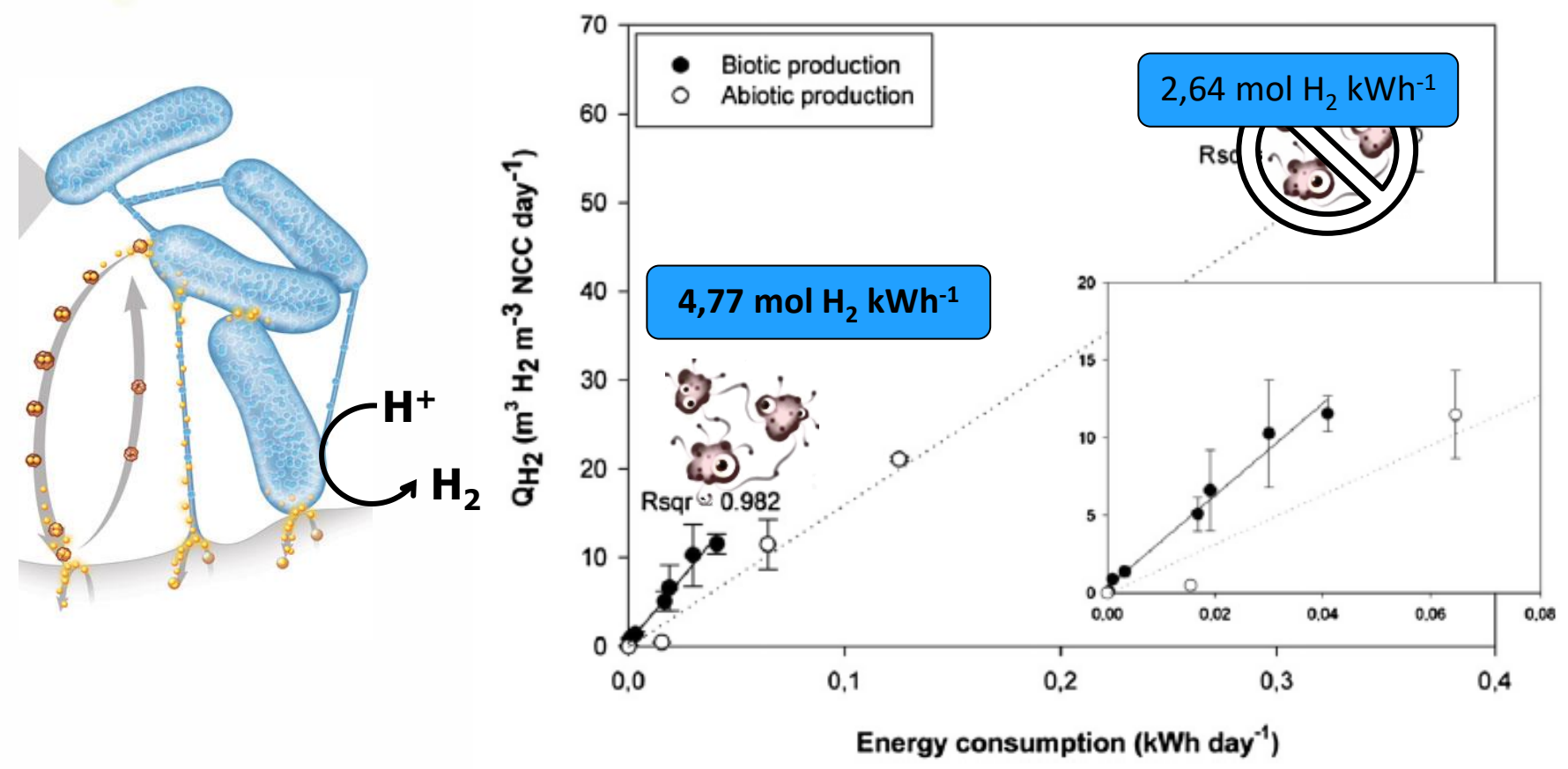
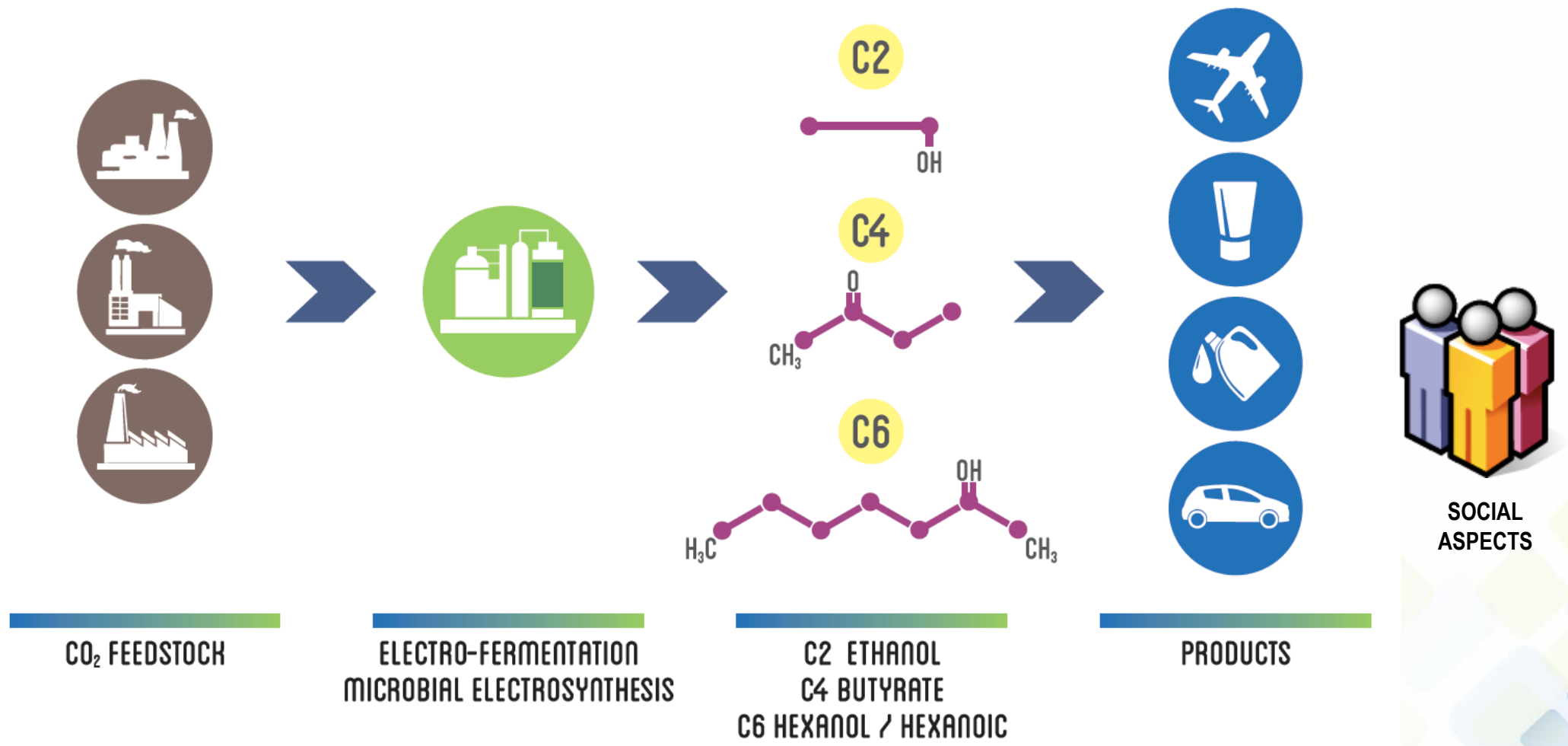
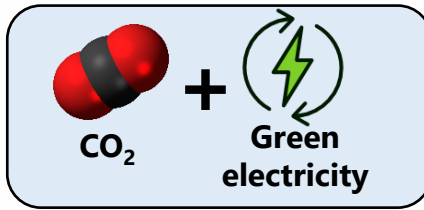


Fig. 2 – Hydrogen production rate versus energy consumed (linear regression fitted) in the biotic and abiotic MEC.

[Carbon recycling – Air recovery]



# [Carbon recycling – Air recovery]



**Hydrogen**

Assessment of biotic and abiotic graphite cathodes for hydrogen production in microbial electrolysis cells

Modelling the simultaneous production and separation of acetic acid from CO<sub>2</sub> using an anion exchange membrane microbial electrosynthesis system

Bioelectrochemical transformation of carbon dioxide to target compounds through microbial electrosynthesis

**Acetate**

**Butyrate**

Microbial Community Pathways for the Production of Volatile Fatty Acids From CO<sub>2</sub> and Electricity

Bio-electrorecycling of carbon dioxide into bioplastics.

**Bioplastics (PHA)**

**Microbial Protein**

**Butyrate**

Deciphering the electron transfer mechanisms for biogas upgrading to biomethane within a mixed culture biocathode

Microbial electrosynthesis of butyrate from carbon dioxide

Continuous acetate production through microbial electrosynthesis from CO<sub>2</sub> with microbial mixed culture

**Methane**

**Acetate**

Tracking H<sub>2</sub>-mediated microbial electrosynthesis of commodity chemicals from carbon dioxide

On the edge of research and technological application: a critical review on electromethanogenesis

Microbial electrosynthesis of butyrate from carbon dioxide: production and extraction

**Hydrogen**

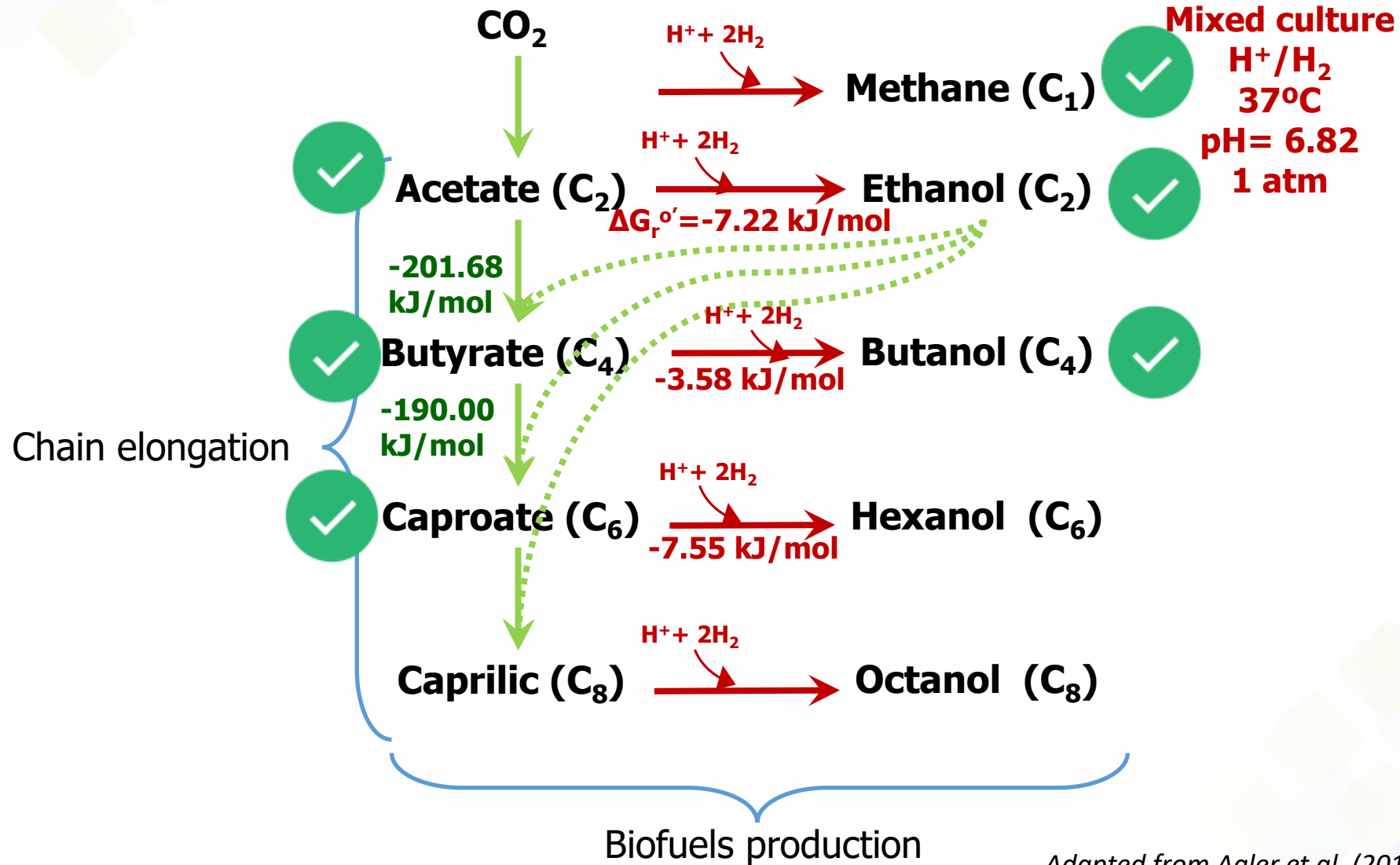
**Methane**

**Butyrate**

Unravelling the factors that influence the bio-electrorecycling of carbon dioxide towards biofuels

**Ethanol**

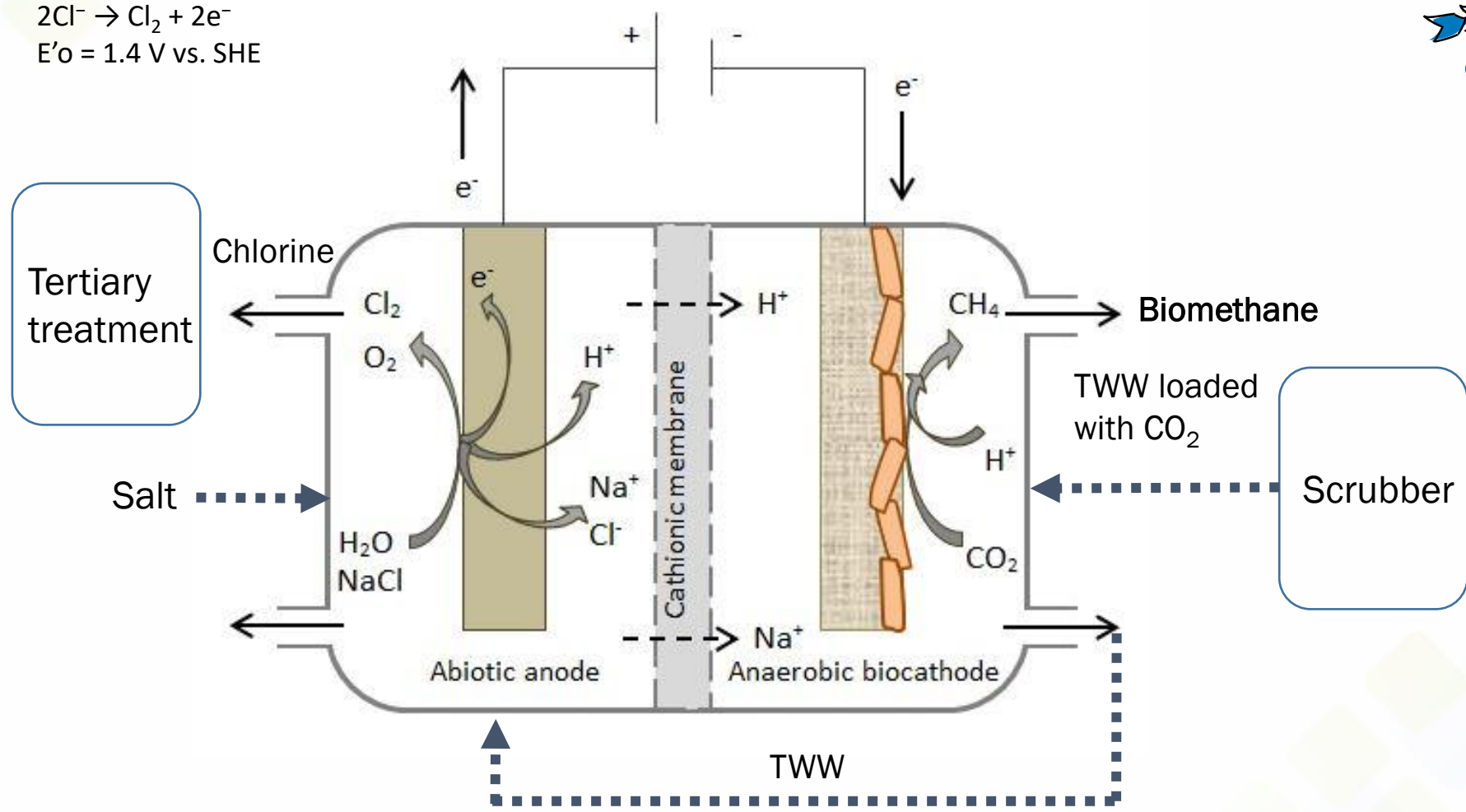
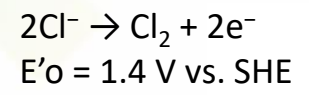
## Thermodynamics analyses



Adapted from Agler et al. (2011). Trends in Biotechnology

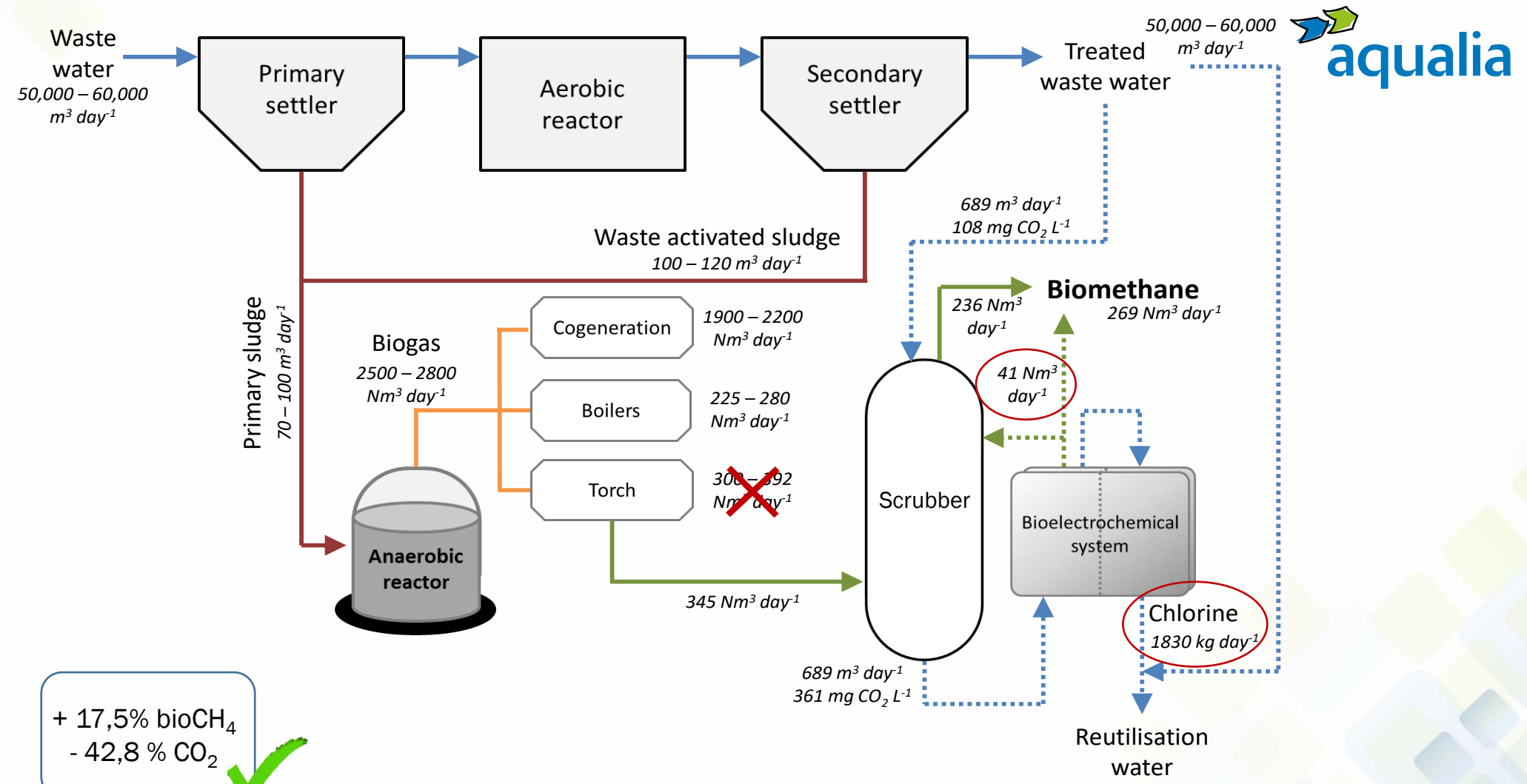
[Carbon recycling – Air recovery]

Simultaneous CH<sub>4</sub> and Cl<sub>2</sub> production



Batlle-Vilanova et al. (2019). *Science of The Total Environ.* 690, 352-360  
EP3527538A1. (2018)

# Case scenario



+ 17,5% bioCH<sub>4</sub>  
- 42,8 % CO<sub>2</sub>



## Advancing Anaerobic Digestion



### Improved Kinetics

Integrating bioelectrochemical systems directly into anaerobic digestion fundamentally accelerates the biological pathways. This synergy yields over a **40% increase in the specific methane production rate** compared to conventional methods.

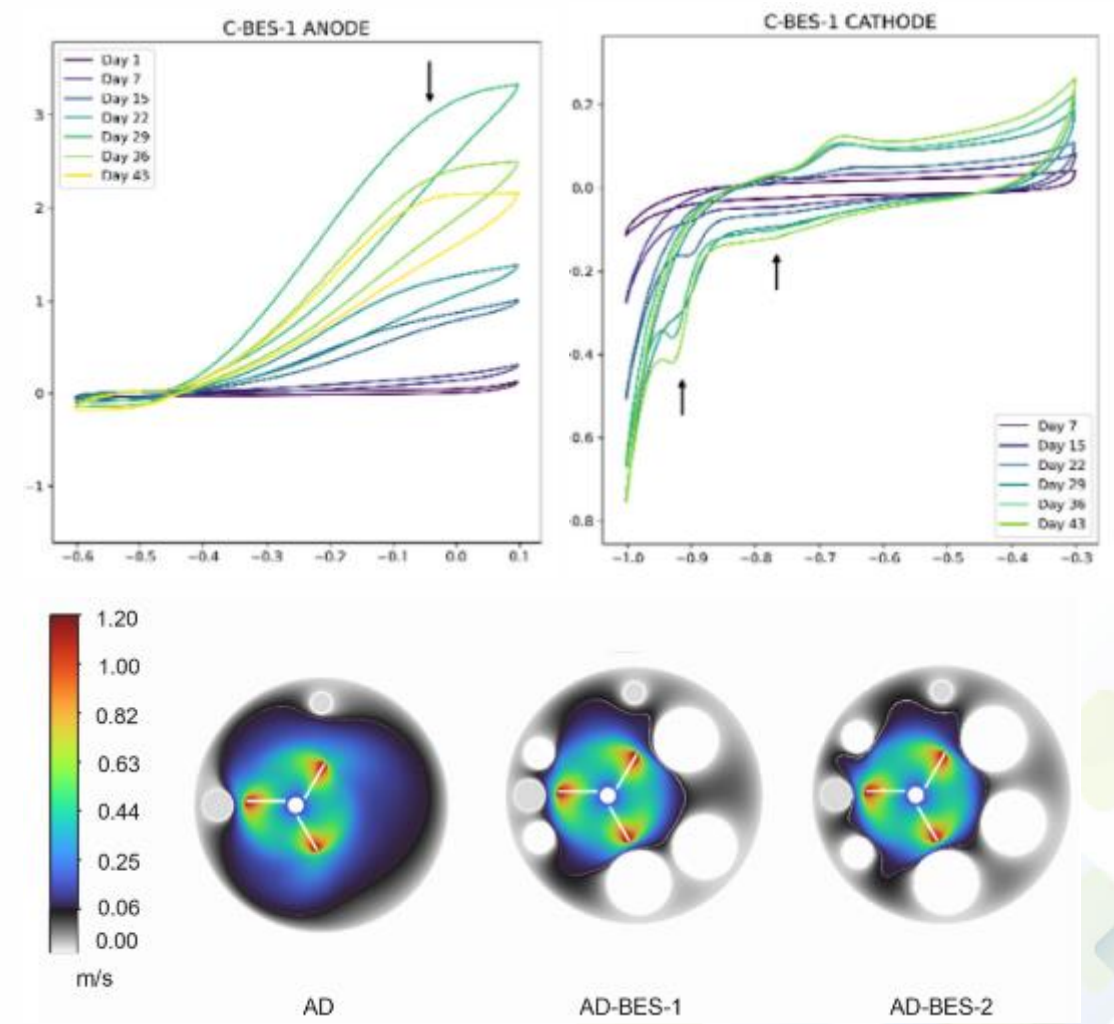
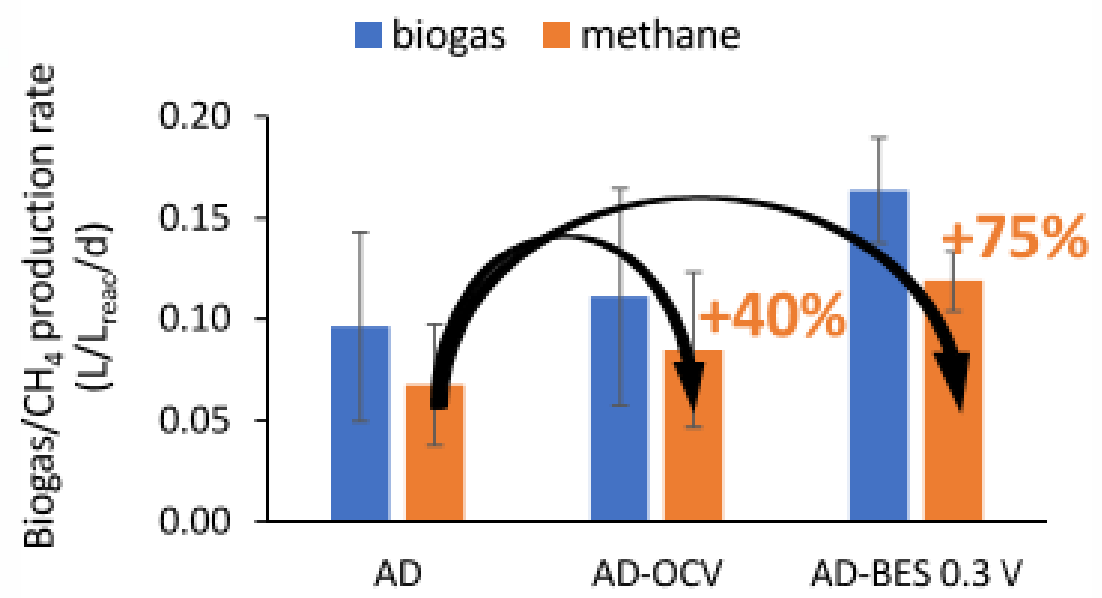
### Enhanced Stability & Quality

The system consistently produces high-quality biogas (75-80%  $CH_4$ ) with significantly reduced  $H_2S$ . Additionally, the process demonstrates superior resilience against organic overloads and mitigates severe acid regression.

### Advancing Anaerobic Digestion



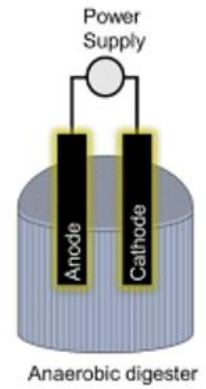
## Biogas production rate



Molognoni D, Garcia M, Sánchez-Cueto P, Bosch-Jimenez P, Borràs E, Lladó S, et al. **Electrochemical optimization of bioelectrochemically improved anaerobic digestion for agricultural digestates' valorisation to biomethane.** Journal of Environmental Management 2025;373:123898.

S. Feilner, M. Espejo, M. Garcia, D. Molognoni, E. Borràs, K. Herkendell, **CFD simulation for optimizing flow dynamics in a bioelectrochemically enhanced single-chamber anaerobic digester.** International Journal of Thermofluids (2025) 101432.

[Carbon recycling – Air recovery]



**LEITAT**  
managing technologies

In-situ BES  
Integration in AD



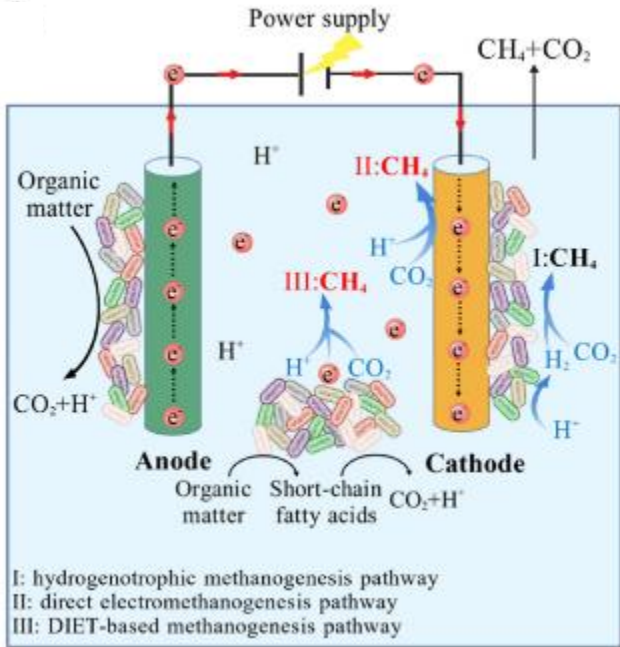
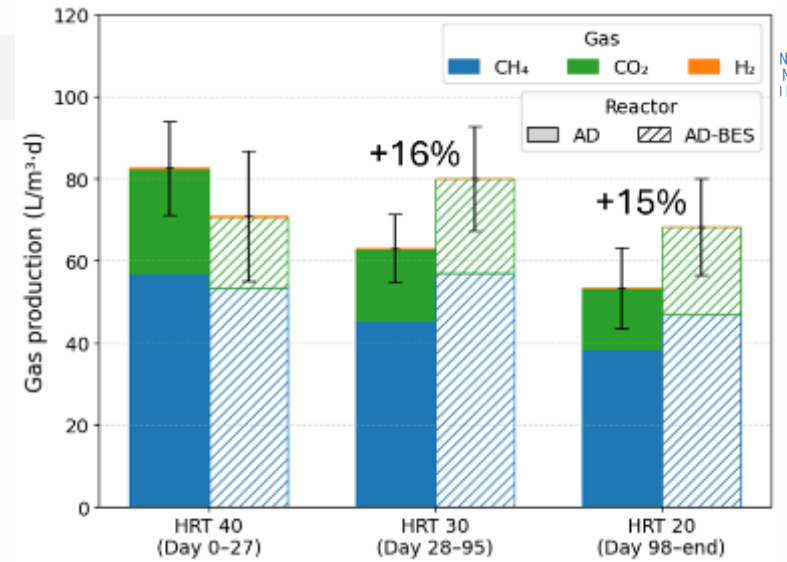
innovations in the  
**BIOMETHANE**  
uni**VERSE**

Relevant partners:



# ◆ [How does AD-BES work?]

- Promotion of VFAs oxidation reactions, H<sub>2</sub> production, and hydrogenotrophic methanogenesis
- Favoring Direct Interspecies Electron Transfer (DIET)
- Electro-Fermentation process, with improved hydrolytic and acidogenic phases due to better redox balance
- Leitat validated AD-BES from lab to pilot scale (TRL 7)



innovations in the  
**BIOMETHANE**  
uni**VERSE**

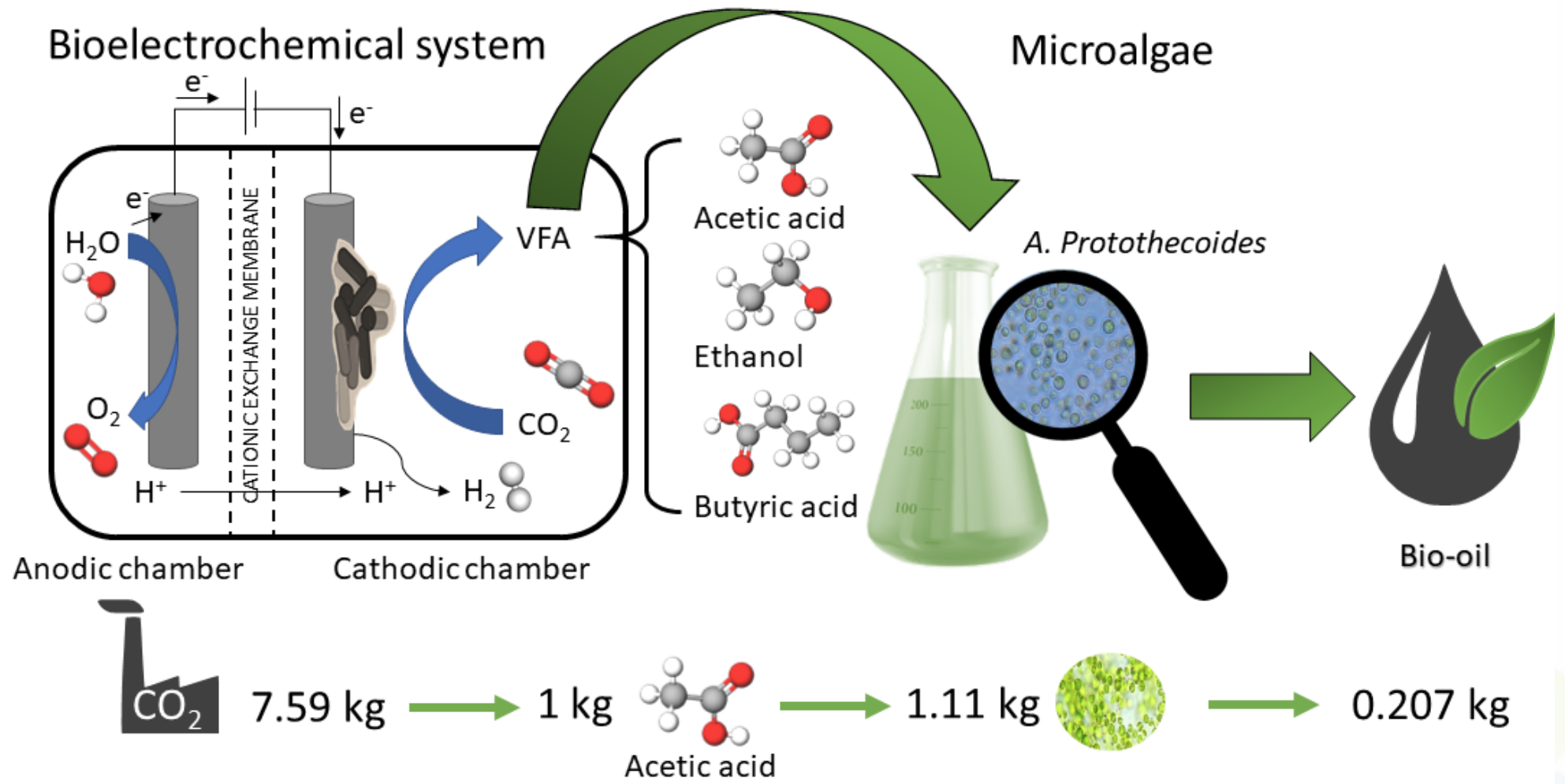


- HRT  
40 → 30 → 20 days
- +25% CH<sub>4</sub> at HRT 30
- Stable microbial community for AD-BES

<sup>1</sup>S. Tan, L. Li, S. Liu, L. Han, C. Duan, Y. Liu, X. Wang, **Biogas upgrading via microbial electrolysis cell-integrated anaerobic digestion: A critical review of stabilization strategies towards practical application**, *Journal of Environmental Management* 2026.

<sup>2</sup>Garcia-Montolio M. et al. **Bioelectrochemical stimulation enhances methane production and microbial stability in anaerobic digestion**. *Bioelectrochemistry*, under review

[Carbon recycling – Air recovery]

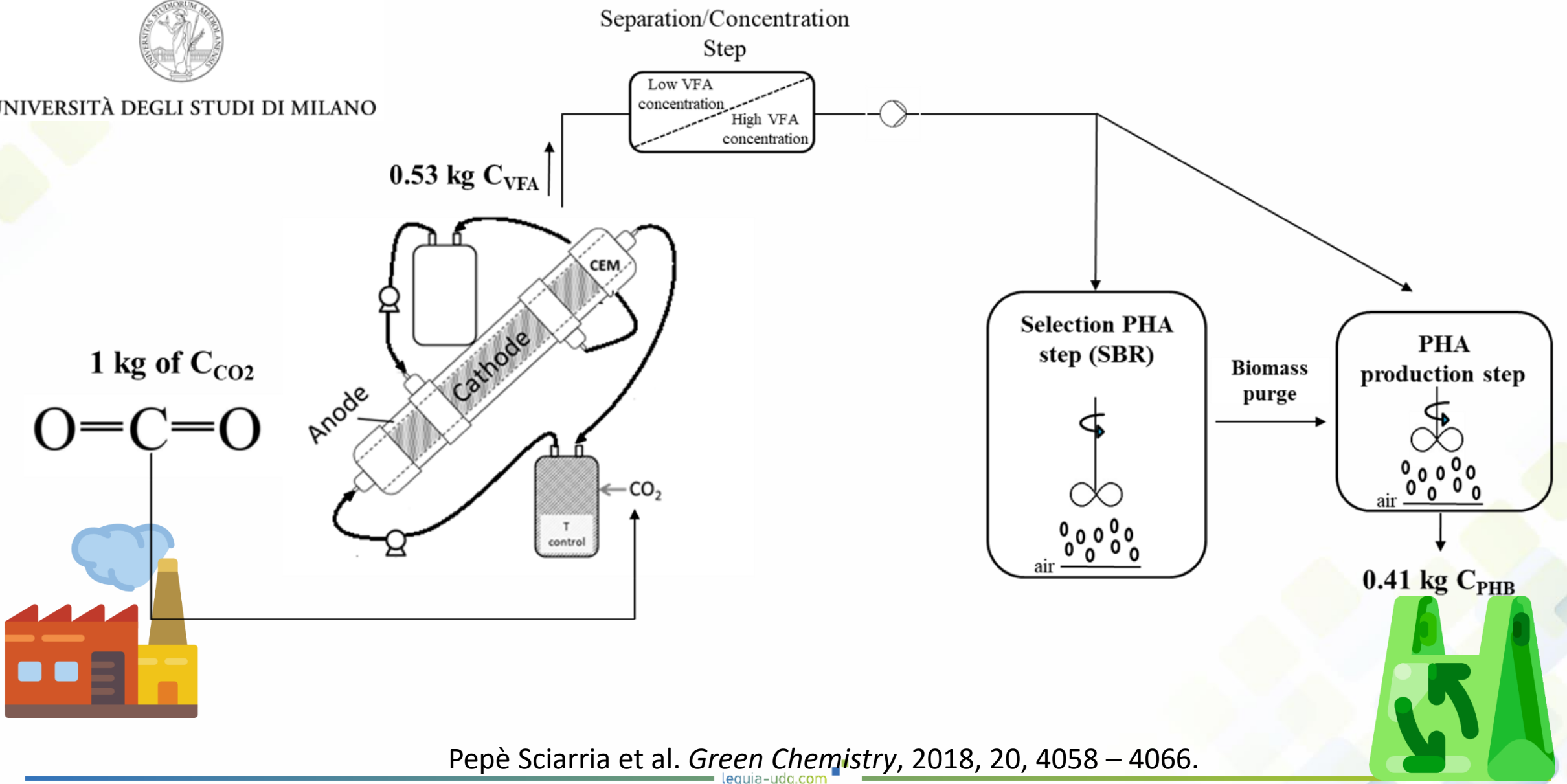


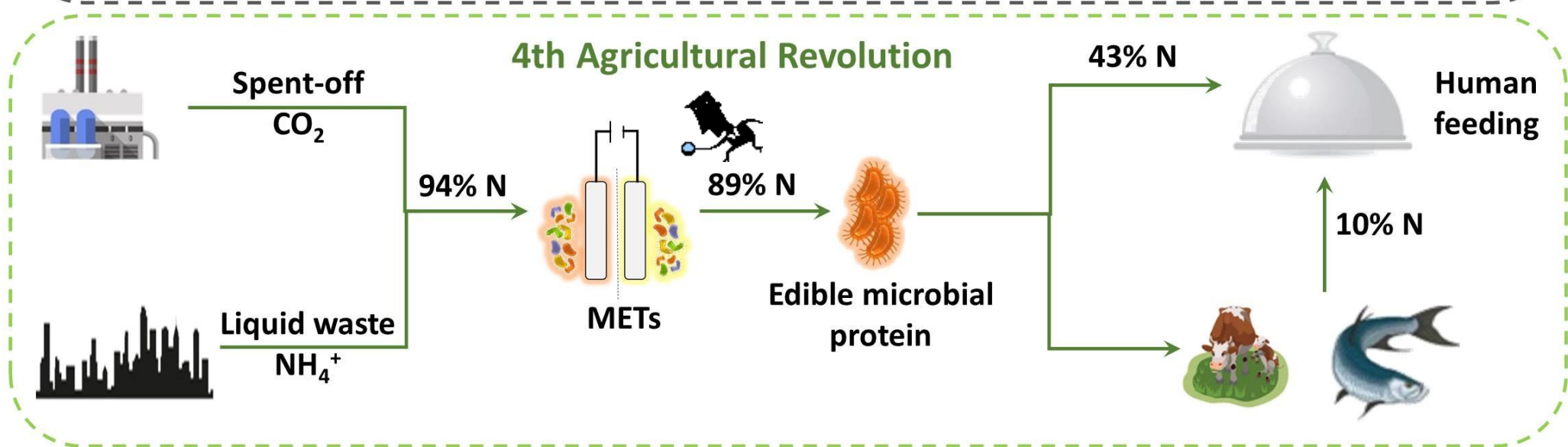
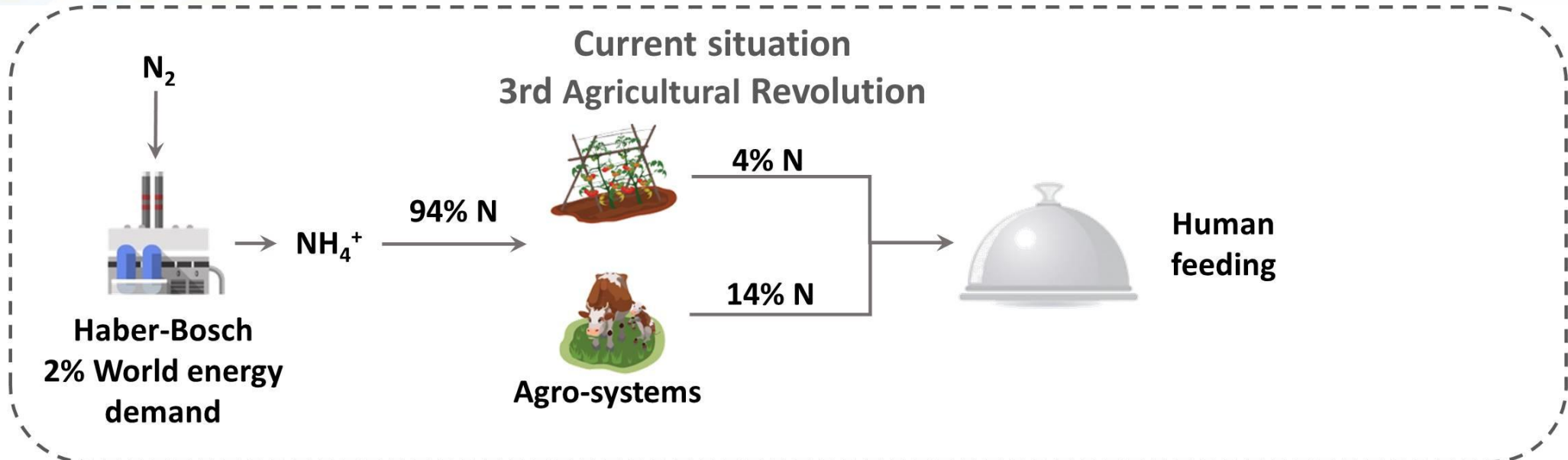
Bolognesi et al., 2022. Carbon dioxide to bio-oil in a bioelectrochemical system-assisted microalgae biorefinery process. Sustainable Energy & Fuels 6(1), 150-161. <https://doi.org/10.1039/D1SE01701B>

[Carbon recycling – Air recovery]

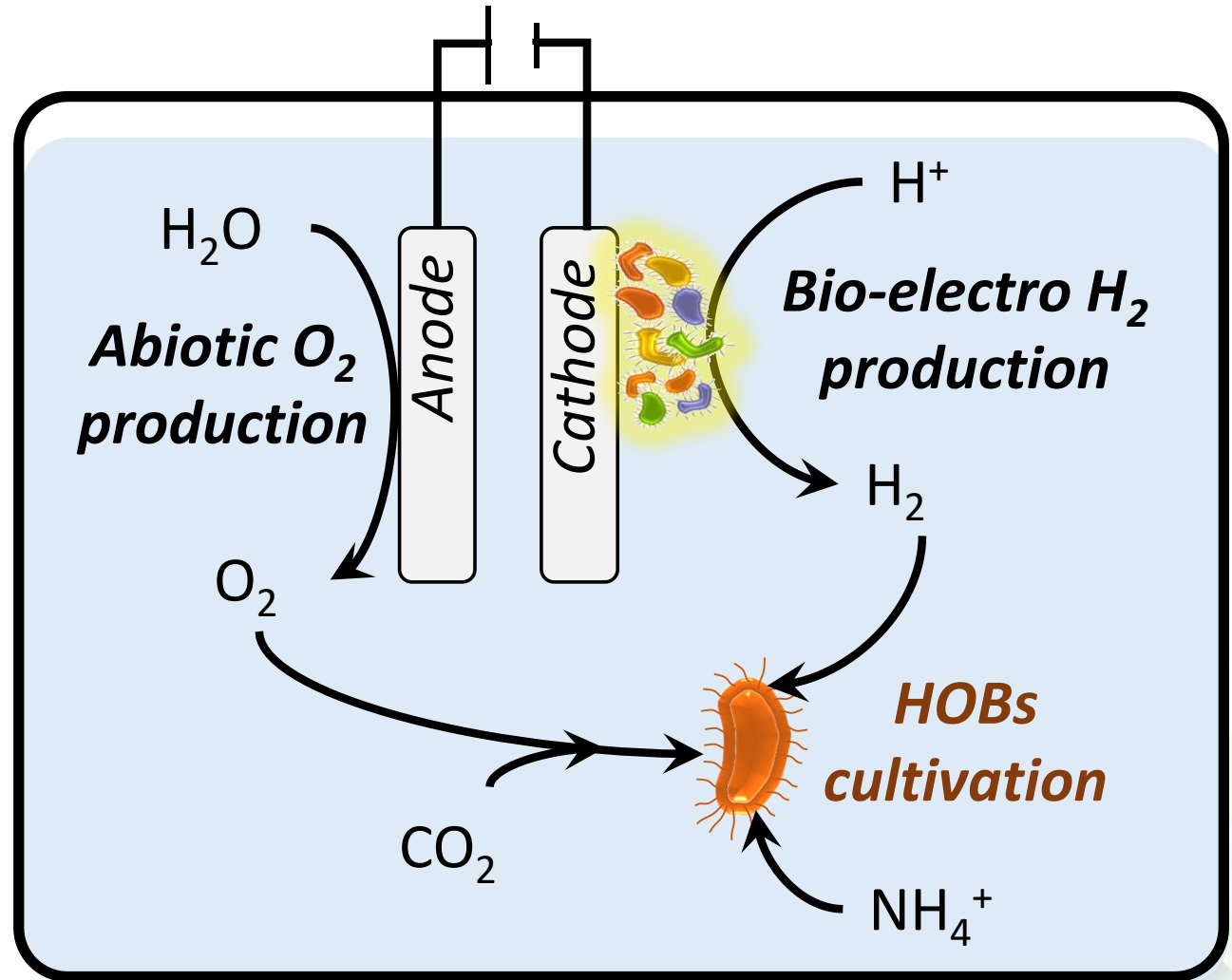
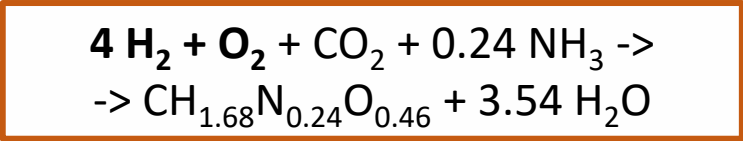
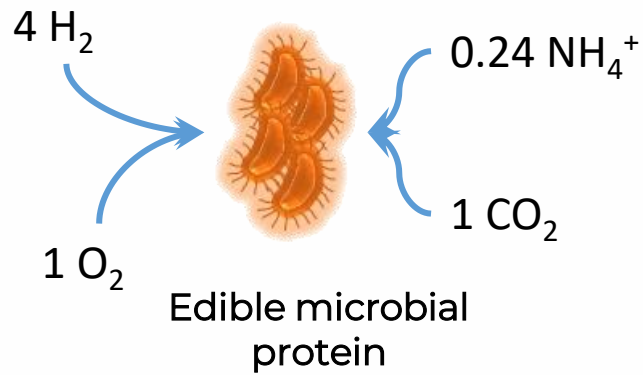


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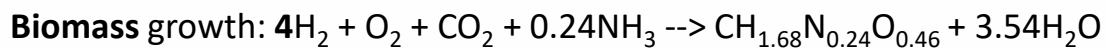
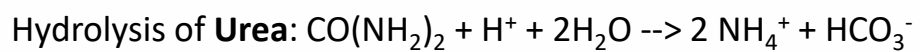
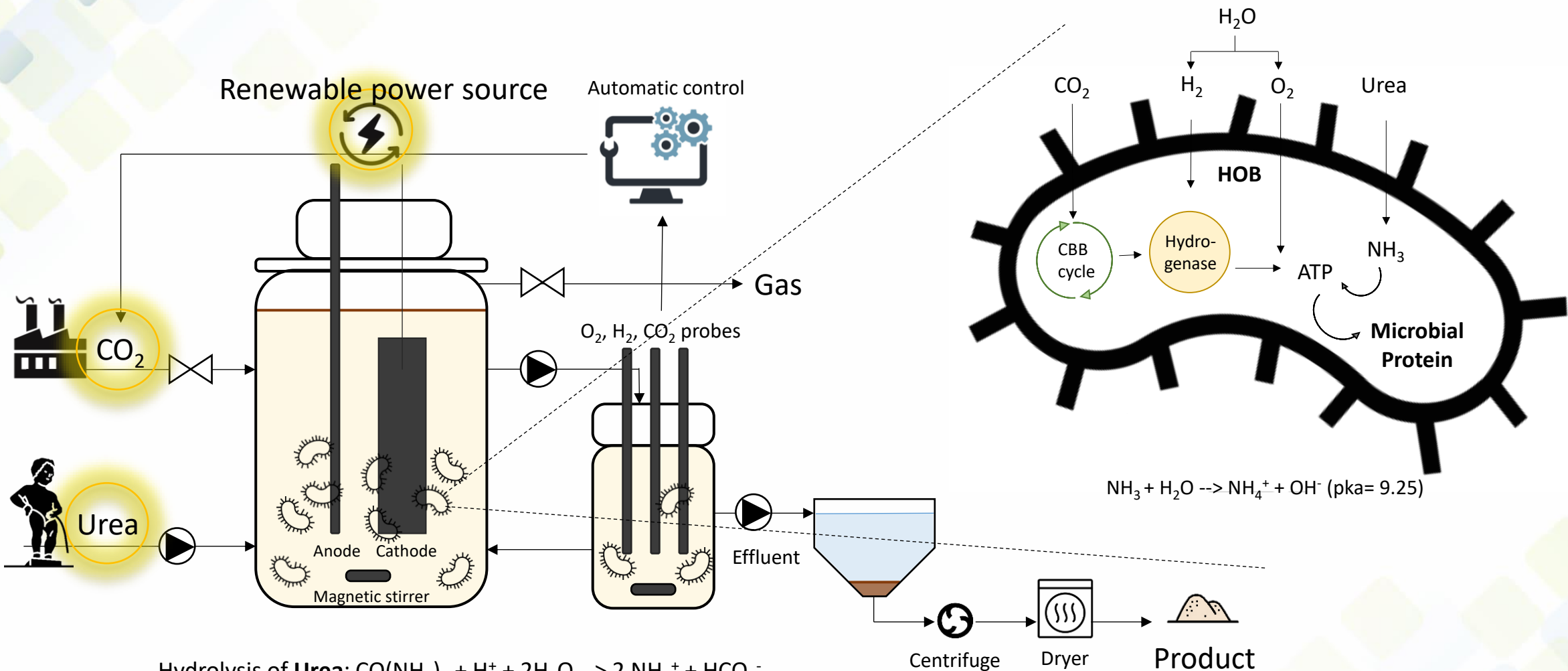


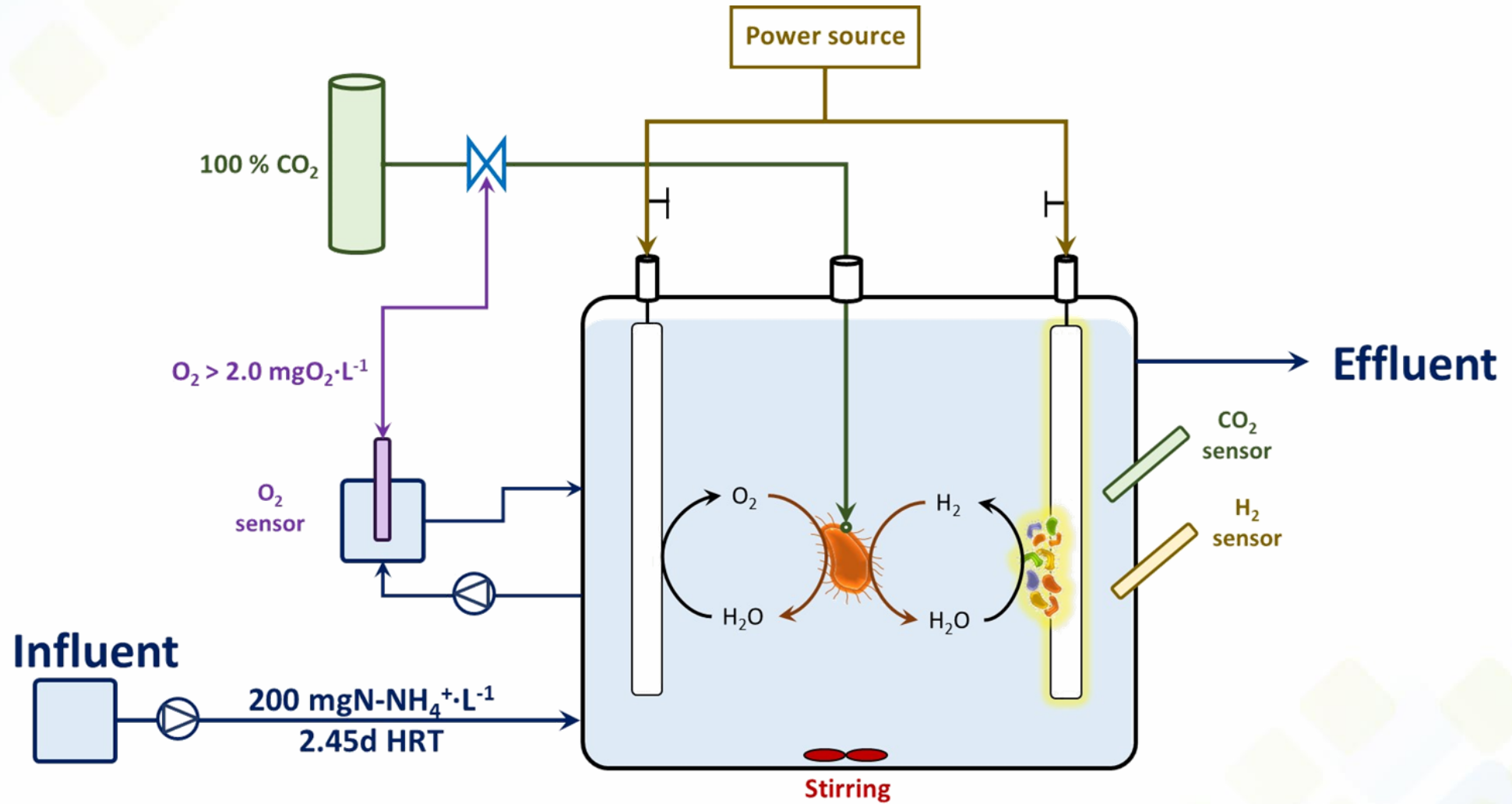
Hydrogen-oxidizing bacteria (HOB)

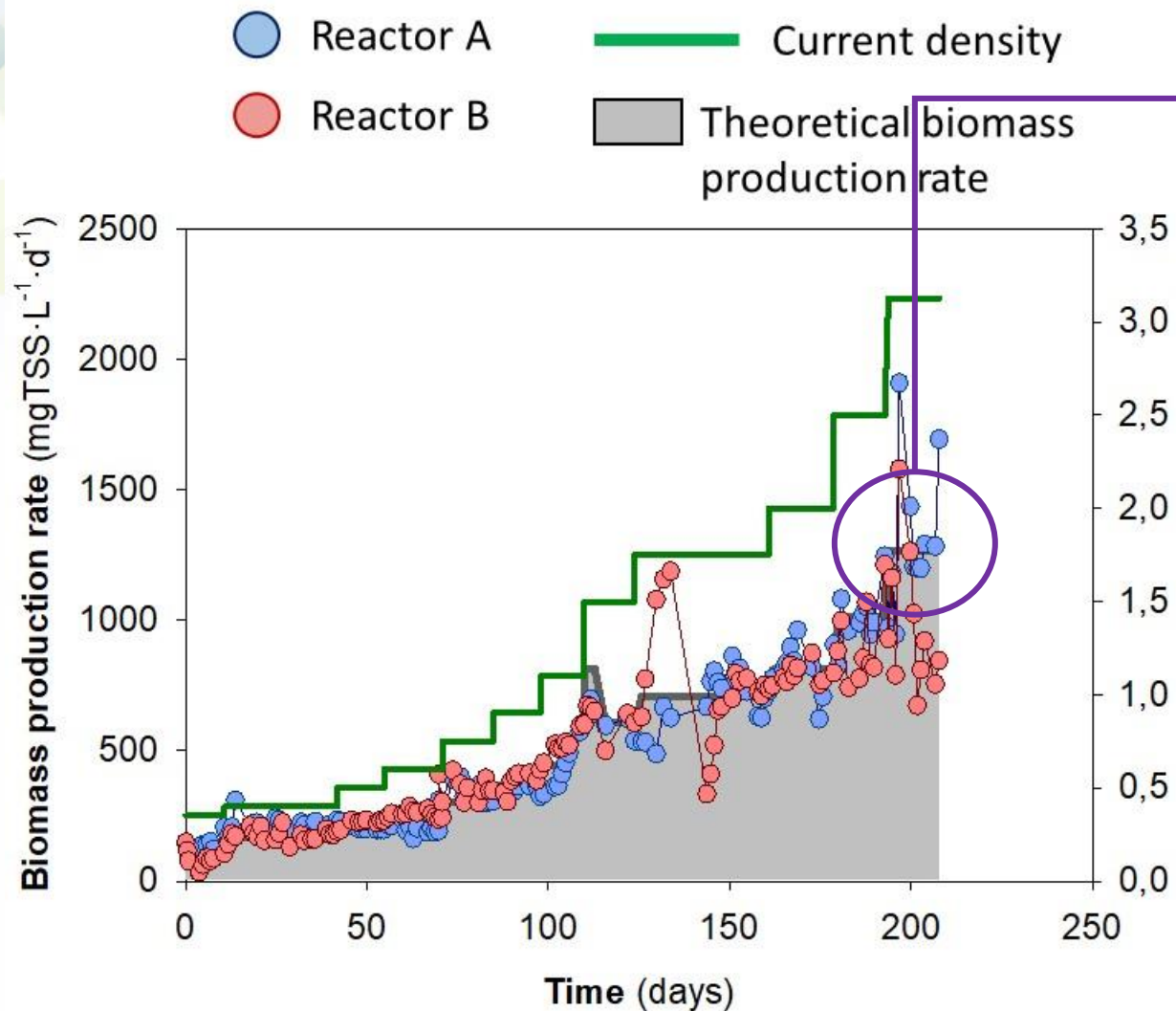


Pous et al., 2022. Bioresource Technology Reports 18, 101010

[Power-to-Protein: Our approach]



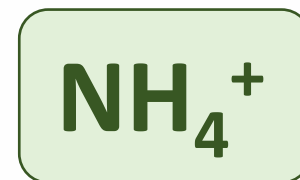




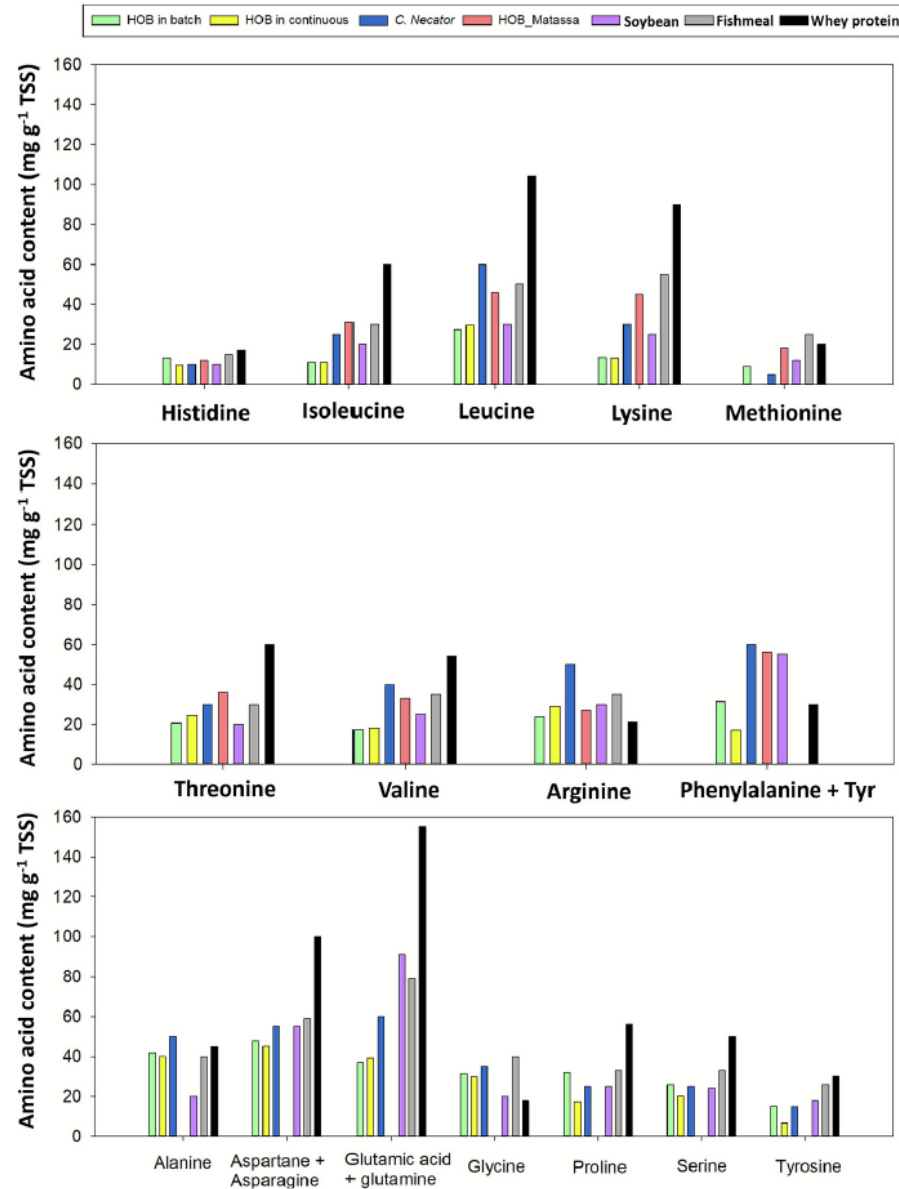
Production rate	1236 ± 47 mgTSS·L <sup>-1</sup> ·d <sup>-1</sup>
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Protein content  
60 – 70 %



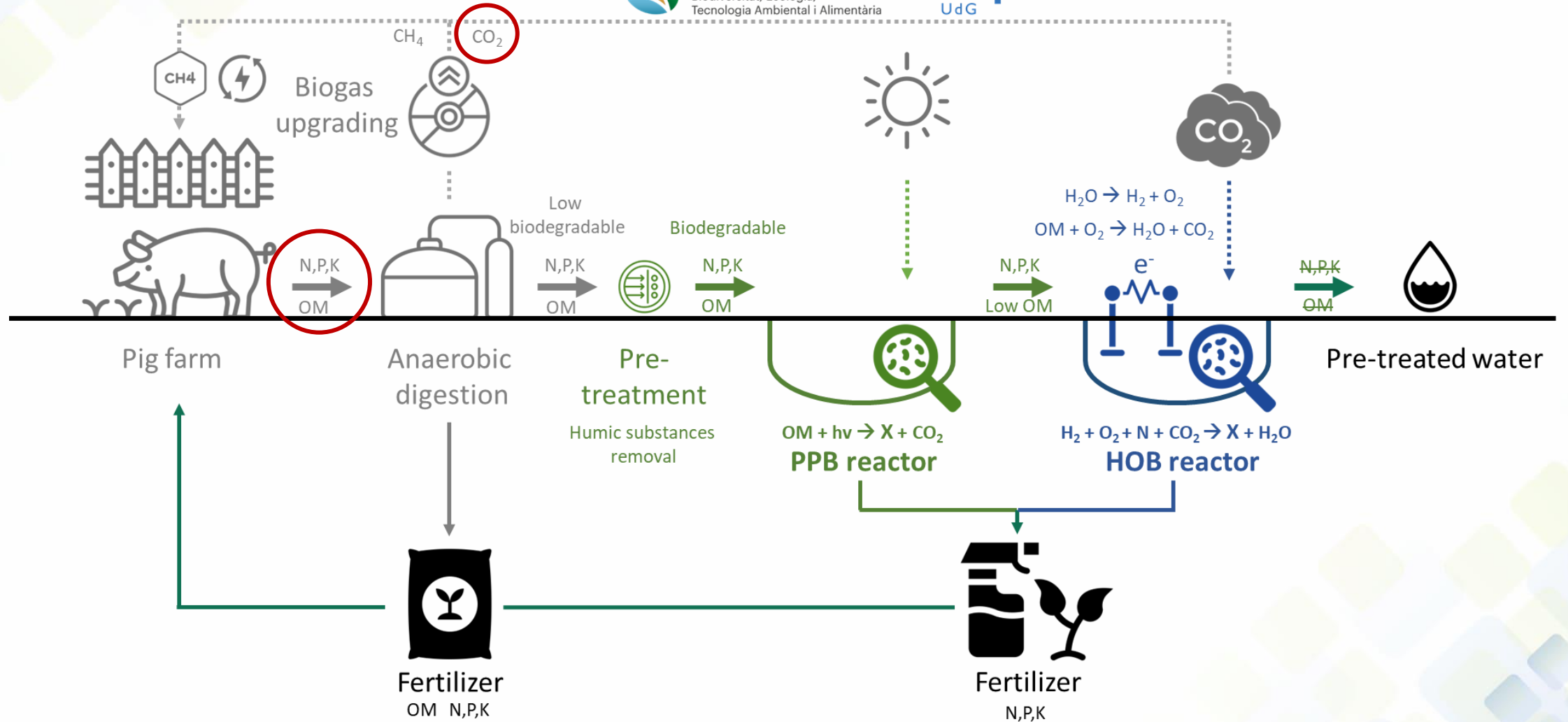
N-NH <sub>4</sub> <sup>+</sup> consumption rate	62 ± 5 mgN·L <sup>-1</sup> ·d <sup>-1</sup>
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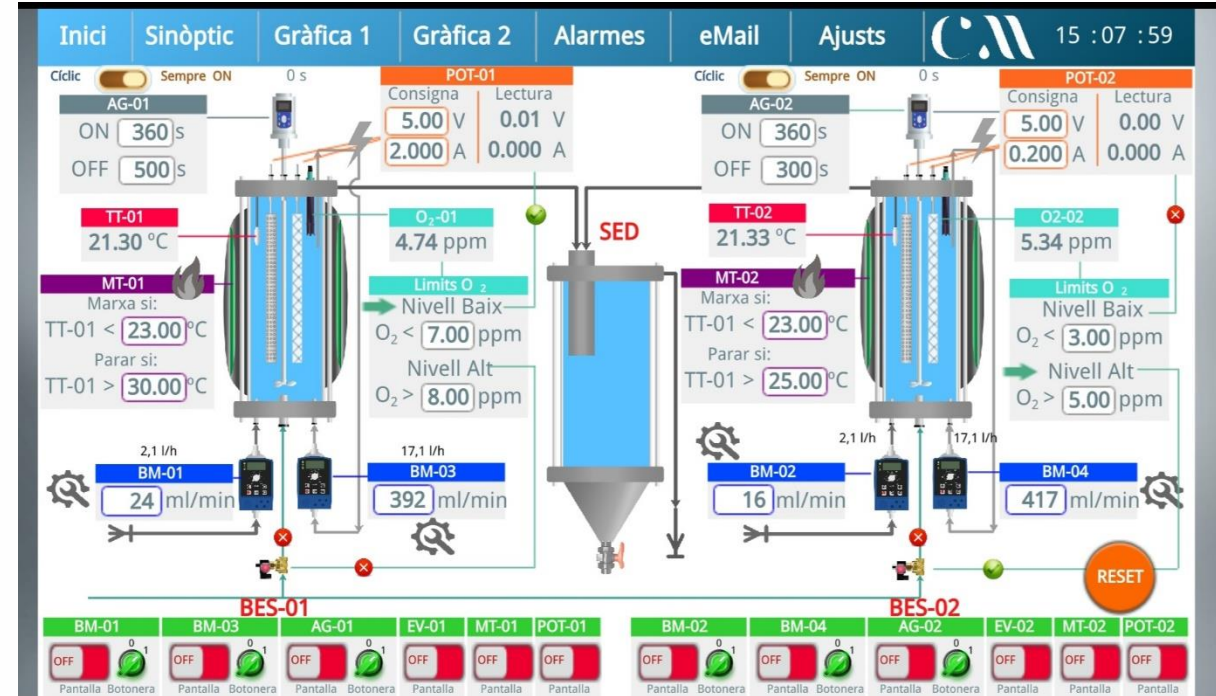


**Composition of freeze-dried microbial biomass**

Protein (%)	65.17 ± 0.55
Fat (%)	7.20 ± 0.77
Carbohydrate (%)	13.58 <sup>a</sup>
Moisture (%)	2.16 ± 0.23
Ash (%)	11.89 ± 0.06

<sup>a</sup> estimation by difference





TRL  
3

TRL  
4

TRL  
5

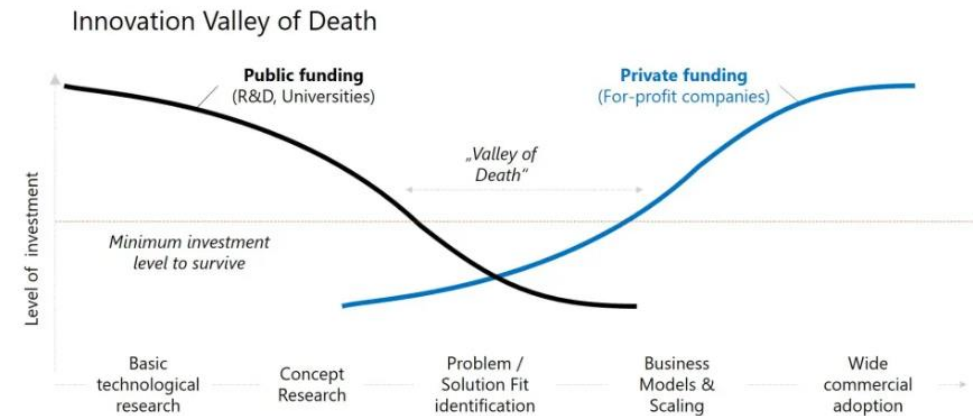




- ✓ **Resource recovery** would become a new niche for the MET platform
- ✓ Zero-chemical-input technology
- ✓ Minimization of intermediates
- ✓ Lab-to-pilot scaling achieved



- Move towards upscaling METs
- Move from synthetic to real water streams
- Keep in mind the counter electrode
- Pathway for regulatory approval of microbial proteins



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## Acknowledgements (selected):