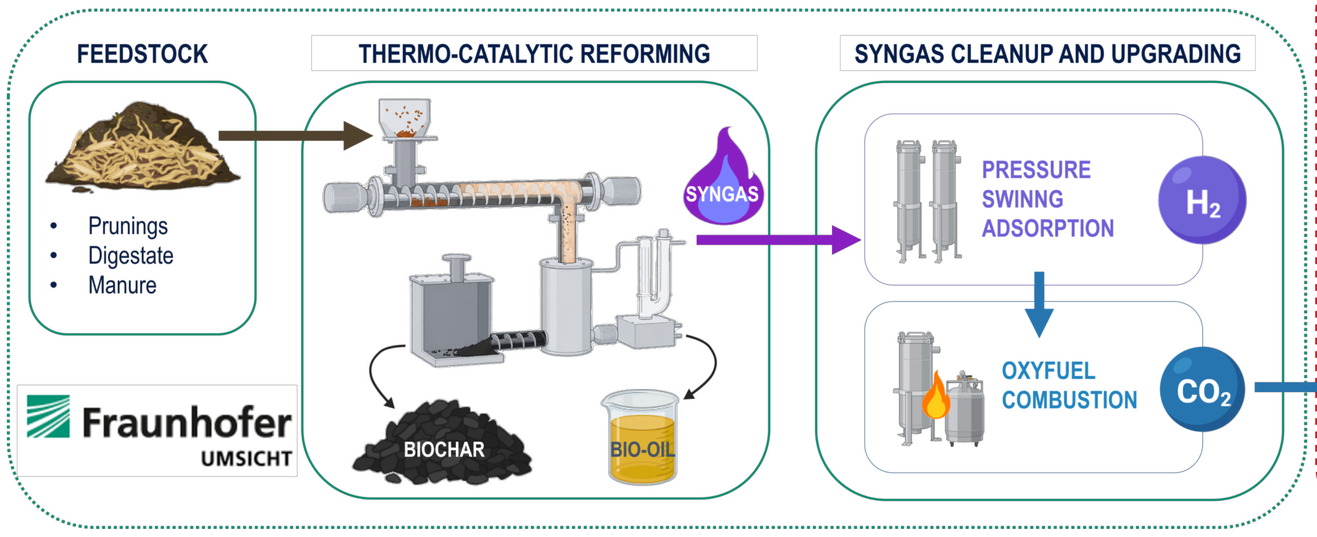
From laboratory to pilot: scale-up of bioelectrochemical methanation for conversion of industrial CO_2 to CH_4

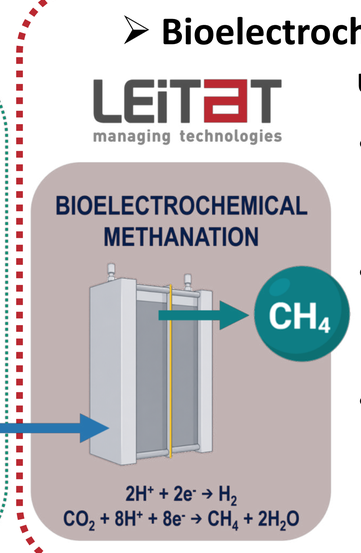
Maria Vega-Paredes[1], Daniele Molognoni[1], Felix Lehner[2], Martin Meiller[2], Sebastià Puig[3,4], Eduard Borràs[1]

[1]Leitat technological center, C/ de la Innovació 2, 08225 Terrassa, Spain
[2]Fraunhofer UMSICHT, Fraunhofer Institute for Environmental, Safety and Energy Technology, An der Maxhütte 1, 92237, Sulzbach-Rosenberg, Germany
[3]LEQUiA, Institute of the Environment, Universitat de Girona, Facultat de Ciències, 69, 17071 Girona, Spain
[4]Pla Serra Húnter, Generalitat de Catalunya. Via Laietana 2, 08003 Barcelona, Spain

eborras@leitat.org

1 Introduction



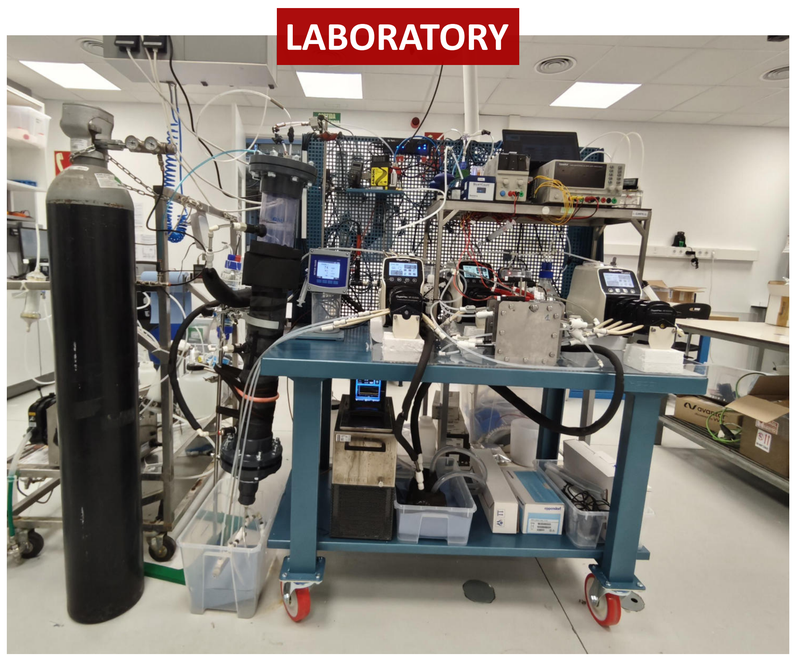


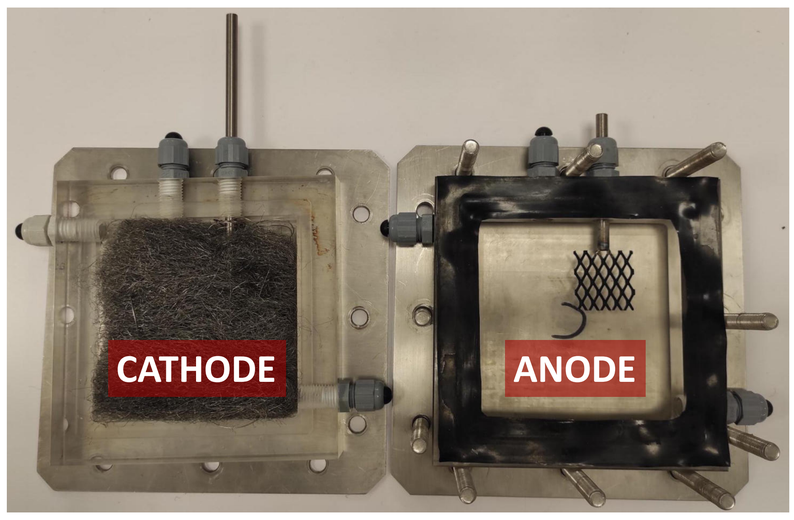
➢ **Bioelectrochemical methanation (BEM)** converts CO_2 into CH_4 using electroactive microorganisms and electricity.

- **Within the NET-Fuels project**, BEM is integrated with a Thermo-Catalytic Reforming (TCR) process to upgrade CO_2-rich off-gases into renewable CH_4.
- **A modular pilot-scale BEM plant (TRL 5)** was designed and built for integration with the TCR process.
- **This study evaluates its long-term performance under real industrial operating conditions**, including process stability, CO_2 conversion efficiency, CH_4 productivity and energy consumption.

2 Materials & Methods

LABORATORY





Stack of **3 double-chamber cells:** • **Cathode:** SS wool (100 cm^2, 12-15 g x cell) • **Anode:** Ti mesh coated with MMO (9 cm^2 x cell) • **Membrane:** RALEX CEM (100 cm^2 x cell)		Stack of **6 double-chamber cells**: • **Cathode:** SS wool (1000 cm^2, 150 g x cell) • **Anode:** Ti mesh coated with MMO (624 cm^2 x cell) • **Membrane:** CMI-700 CEM (1000 cm^2 x cell)
• Cells operated individually, **parallel** connection. • Current density: **12 A m^{-2}**.		• Two electrical branches of 3 cells connected **in series**. • Current density: **5-35 A m^{-2}.**
• **Batch** operation. • **Parallel** cells **recirculation** to common buffer tanks.		• **Batch** operation. • **Parallel** cells **recirculation** to common buffer tanks.
• **14 L catholyte** • **3 L anolyte**		• **120 L catholyte** • **50 L anolyte**
• **CO_2 supplied** through a mass flow controller; **periodic injection controlled by a timer.**		• **CO_2 supplied** through a mass flow controller; **closed-loop PID control** based on dissolved CO_2 saturation (5%).
• **T=35ºC** and **P=200 mbarg** (cathode); • **pH=7-8** (cathode), **1-2** (anode); • **Conductivity=4-6 mS/cm**.		• **T=35ºC** and **P=200-400 mbarg** (cathode); • **pH=7-8** (cathode), **1-2** (anode); • **Conductivity=4-6 mS/cm.**
✓ **TRL 4: laboratory-scale validation** of **CO_2-rich oxy-fuel flue gas.**		✓ **TRL 5: pilot-scale** treatment of approx. **50 L CO_2 d^{-1}** from **CO_2-rich oxy-fuel flue gas**.

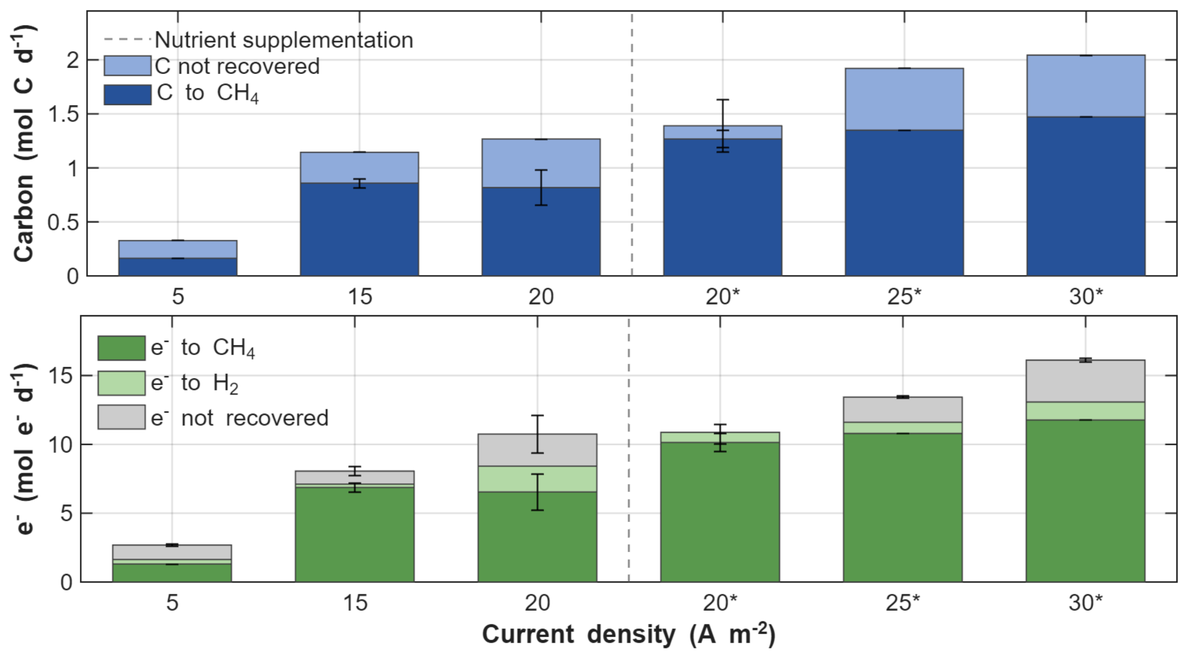
PILOT PLANT

3 Results – Pilot-scale BEM performance

- After 4 months of batch operation, nutrient addition was assessed to investigate potential nutrient limitation at the biocathode at different current densities.

*Table 1. Average values ± SD of the last 3 days of operation. *After nutrient supplementation.*

Current density (A m^{-2})	Cell voltage (V)	CO_2 conversion eff. (%)	CH_4 (%)	CH_4 Prod. rate (m^3-CH_4 m^{-3}_{cat} d^{-1})	Coulombic eff. (%)	Energy cons. (kWh m^{-3} CH_4)
5	3 ± 0	54 ± 2	53 ± 4	0.2 ± 0.0	50 ± 2	49 ± 2
15	4 ± 0	77 ± 5	87 ± 8	1.2 ± 0.1	86 ± 6	40 ± 3
20	5 ± 1	65 ± 13	47 ± 9	1.1 ± 0.2	62 ± 12	69 ± 15
20*	4 ± 1	92 ± 13	78 ± 4	1.7 ± 0.1	94 ± 5	39 ± 3
25*	5 ± 1	71 ± 1	77 ± 2	1.8 ± 0.0	81 ± 1	60 ± 2
30*	6 ± 1	72 ± 1	68 ± 2	2.0 ± 0.0	73 ± 1	78 ± 1



*Graph 1. Carbon (top) and electron (bottom) balances . Average values ± SD of the last 3 days of operation. *After nutrient supplementation.*

4 Conclusions

- ✓ A BEM pilot was successfully designed, constructed, and operated for 2500 hours.
- ✓ Nutrients addition to the catholyte improved CH_4 production and gas quality, highlighting nutrient limitation as a factor to consider during long-term batch operation.
- ✓ Final operation at 30 A m^{-2} provided the highest CH_4 production rate while maintaining a high CH_4 content and Coulombic efficiency, although with an increased energy demand.

5 References

- M. Vega-Paredes et al., Role of electrolytes composition, ionic crossover and CO_2 availability in bioelectrochemical methanation, Journal of CO_2 Utilization 108 (2026) 103460.
- F. Gabler et al., Comparative evaluation of digestate and reject water as nutrient media for syngas biomethanation in thermophilic trickle-bed reactors, Bioresource Technology 435 (2025) 132893.

Funded by the European Union

Acknowledgements: The authors acknowledge financial support from the European Union's Horizon Europe Research and Innovation Programme under the NET-Fuels project (Grant Agreement No. 101083780).
The authors gratefully acknowledge Hiromec Ingeniería y Contratas S.L. for their support in the construction and assembly of the BEM pilot plant.

Congreso Internacional Bioenergía 2026. VALLADOLID 29.30 SEPTIEMBRE

M133NETFUELS112032