Bioelectrochemical reduction of CO_2 to alternative fuels

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Outline

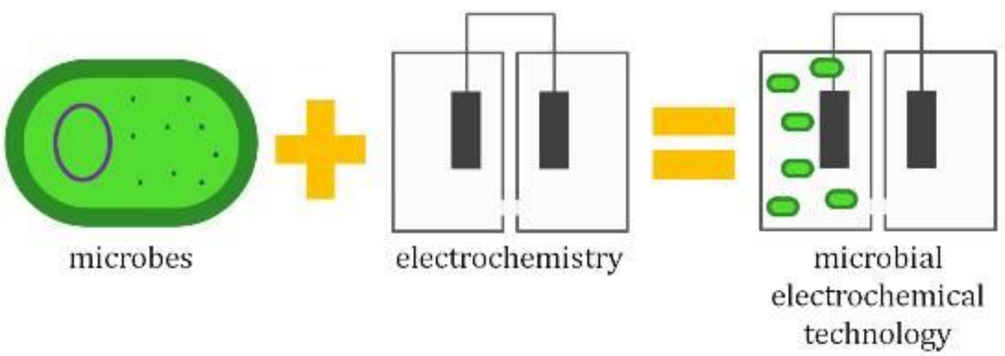
- Introduction
- Biofilm on electrodes
- Results
- Summary and Outlook

Introduction

Bioelectrochemical systems

Microbial electrochemical technologies (METs)
link a microbial metabolism to an electrochemical system

- Interaction between biocatalysts and electrodes
- Microorganisms are attached on electrode surface
  "catalysts" for reactions on electrodes



http://www.is-met.org

METs for CO_2 conversion

- Methanogenic cultures
  - Methane as product
  - First report on MEC use for CO_2 reduction in 2009 by Cheng[1] et al.
  - Literature reports claim coulombic efficiencies between 60 – 100% [1,2,3,4]

- Acetogenic cultures
  - Products are organic acids, ethanol, butanol, acetone,…
  - Literature reports claim coulombic efficiencies of around 86% [5,6,7]

1 Cheng S., Xing D., Call D.F., Logan B.E., 2009;Environ. Sci. Technol. 43, 3953-3958
2 M. Villano, G. Monacor, F. Aulenta,, M. Majone, 2011, Journal of Power Sources, 196, 9467-9472
3 Y. Jiang, M. Su, Y. Zhang, G. Zhan, Y. Toa, D. Li, 2013, Int. J. of Hydrogen Energy Volume 38, Issue 8, Pages 3497–3502
4 M.C.A.A. Van Eerten-Jansen, A.T. Heinjne, C. J.N. Buisman, H. V.M. Hamelers, 2011, Int. J. Energy Res., 2011
5 K. P. Nevin, T. L. Woodard, A. E. Franks, Z. M. Summers, D. R. Lovley, mBio, 1(2), 2010, doi:10.1128/mBio.00103-10
6 T. Zhang, H. Nie, Ti. S. Bain, H. Lu, Mengmeng Cui, O. L. Snoeyenbos-West, A. E. Franks, K. P. Nevin, T. P. Russelland D. R. Lovley, *Energy Environ. Sci., 6,2013,217*
7 P. Nevin, S. A. Hensley, A. E. Franks, Z. M. Summers, J. Ou, T. L. Woodard, O. L. Snoeyenbos-West, D. R. Lovley, *Appl Environ Mircobiol, 77(9), 2011, 2882-2886*

CO_2 reduction with methanogens

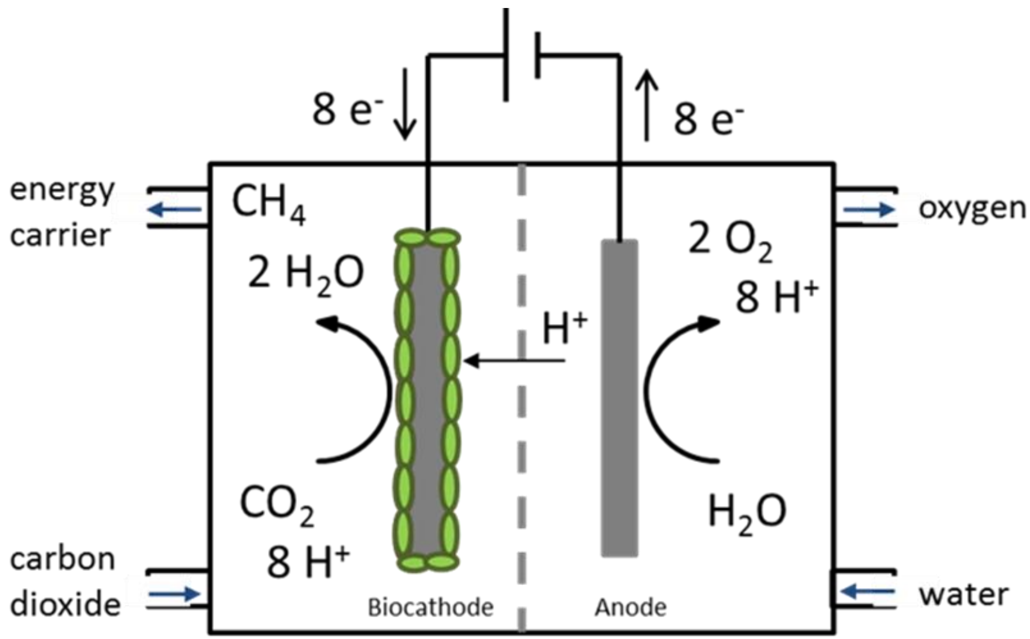
- Microorganism metabolism:

  $CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$

- Adaption of microorganisms to electrode

  $CO_2 + 8H^+ + 8e^- \rightarrow CH_4 + 2\ H_2O$

CO_2 reduction in a microbial electrolysis cell (MEC)

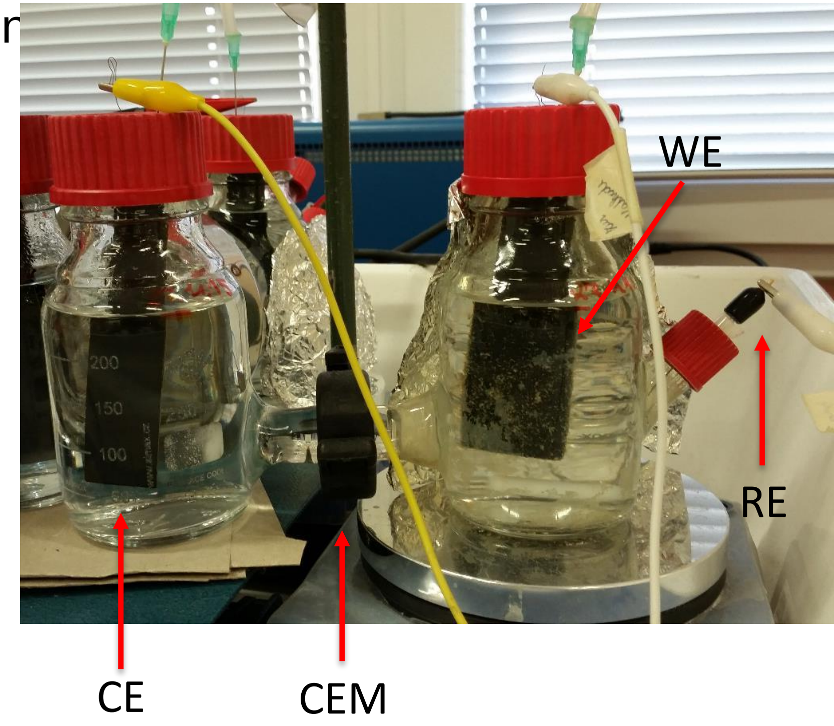


Biofilm on electrodes

Two-Chamber MEC with mixed cultures

Setup

- Cation-exchange membrane (CEM): Nafion 324
- Working electrode (WE):
  Carbon or stainless steel material
- Counter electrode (CE):
  Dimensionally stable anode (DSA)
- Reference electrode (RE): Ag/AgCl
- const. temp., stirred, anaerobic
- Anode chamber
  - Phosphate buffer
- Cathode chamber
  - Nutrient medium enriched with vitamins, trace elements and 5 g/l $NaHCO_3$

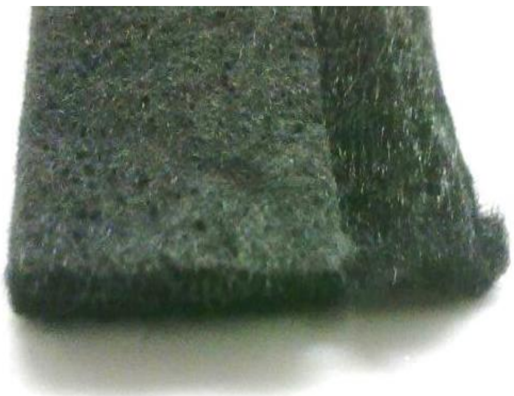


Inoculum: sewage sludge

Biofilm on Electrodes

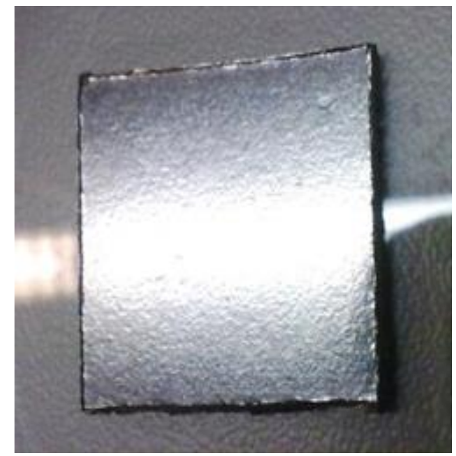
- three different carbon materials were investigated

Carbon felt



Carbon rod

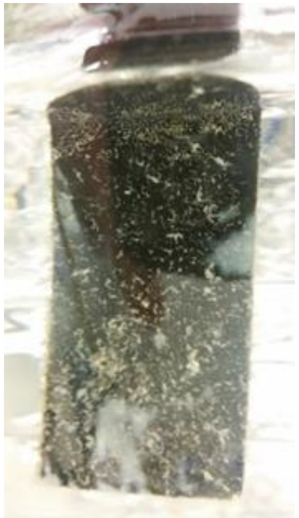
Carbon plate



Results

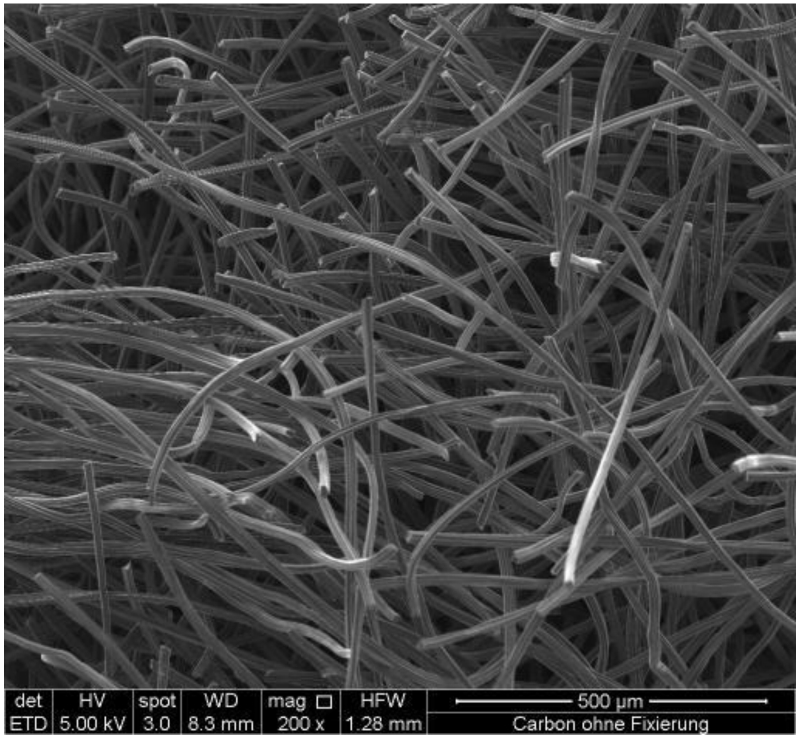
Biofilm on Electrodes

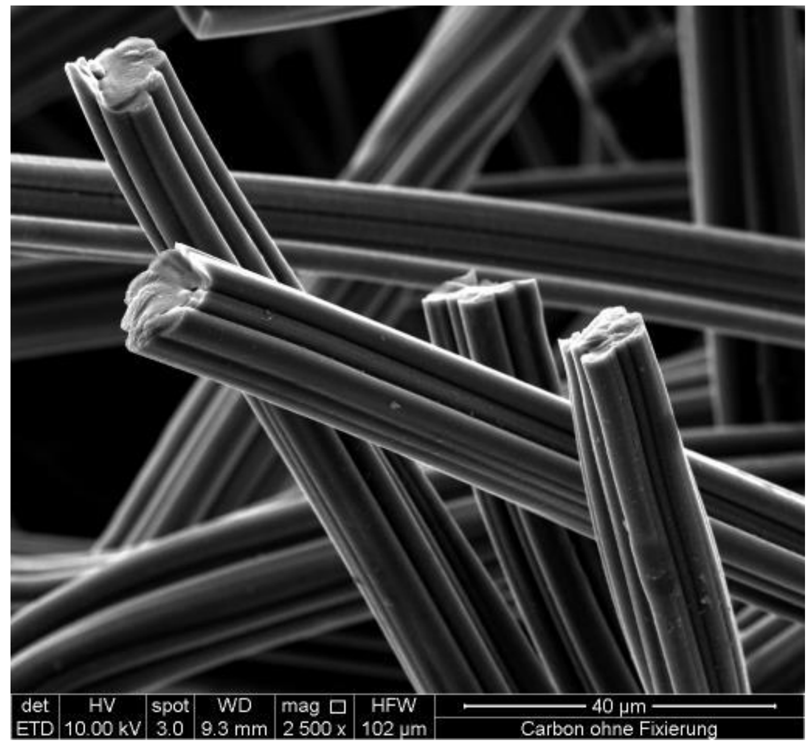
- Best results with carbon felt as electrode material
- -800mV vs Ag/AgCl
- Methane was detected



biocathode

Carbon felt- SEM analysis

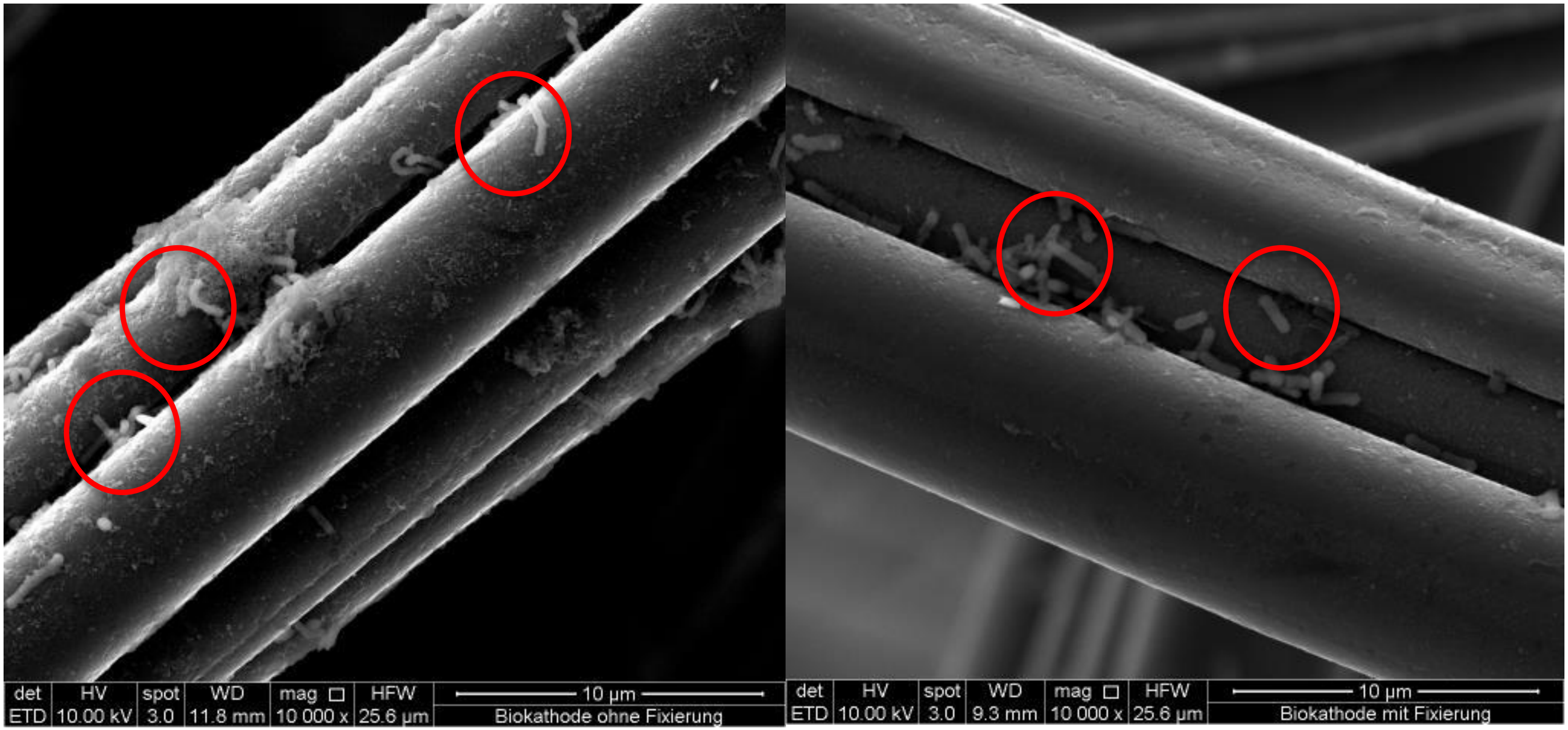




regular structure of single stranded fibers with superficial longitudinal side groove structure (along its entire length)

SEM analysis was done by S. Weiss ESEM Quanta FEG 250

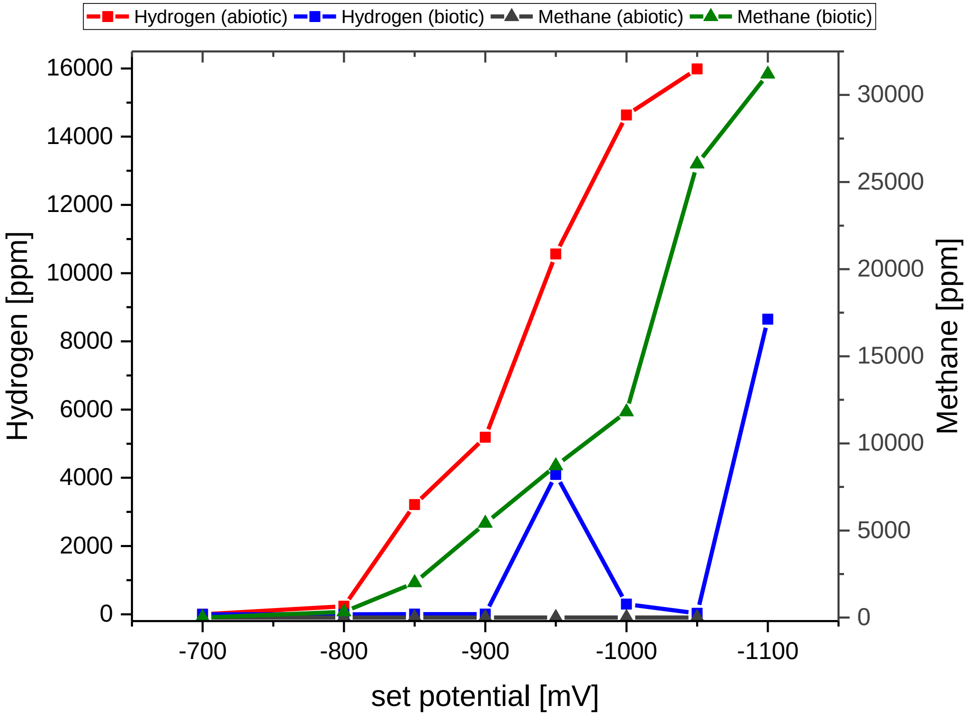
Biocathode - SEM analysis



Microorganisms (rods) were found on biocathode

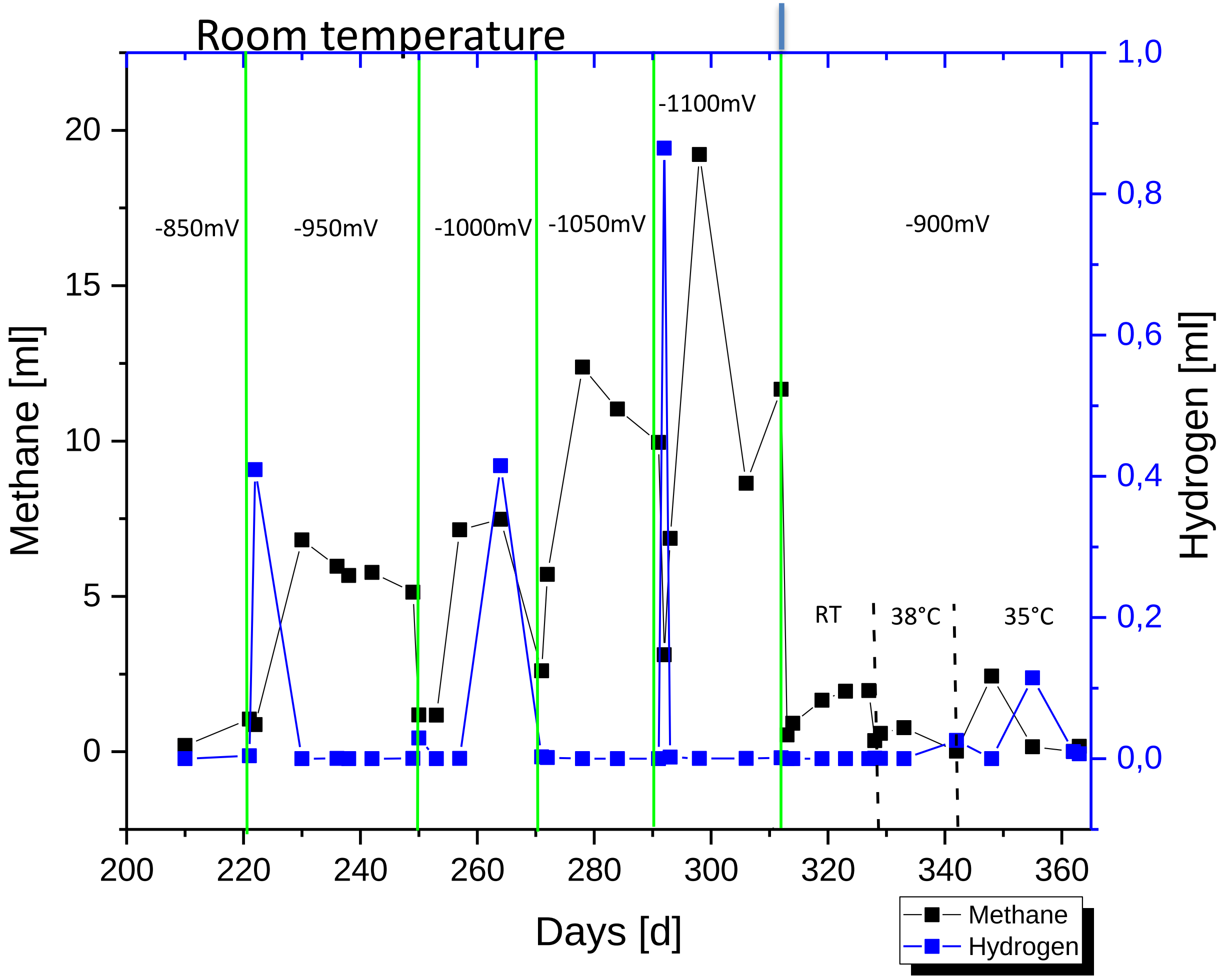
SEM analysis was done by S. Weiss   ESEM Quanta FEG 250

Comparison biocathode/abiotic cathode



electrolysis (24 hours)

Long-term experiment MEC

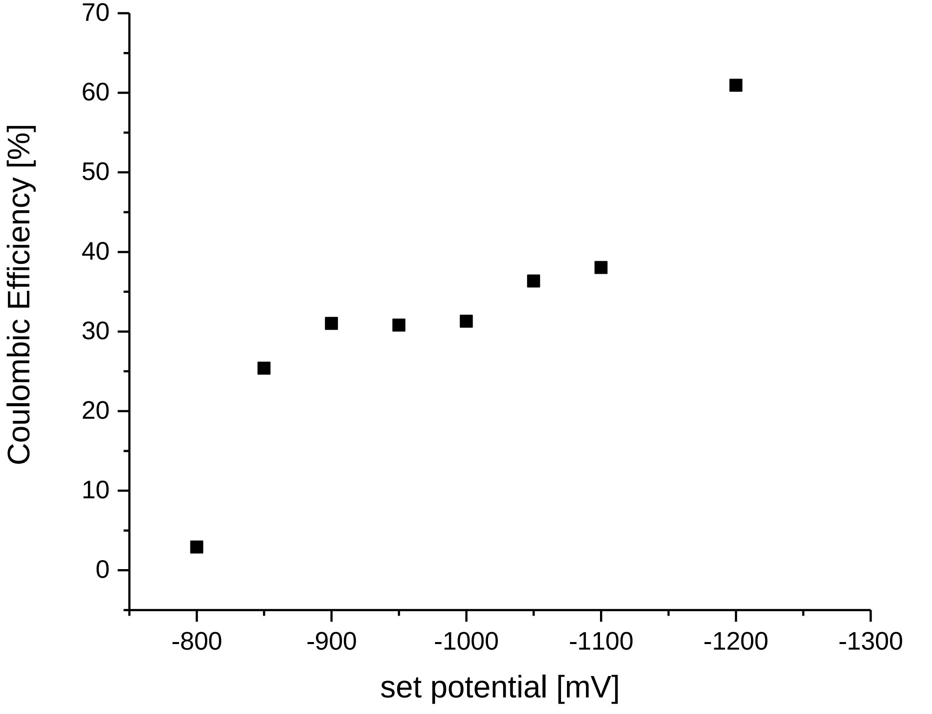


potential vs. Ag/AgCl

Long-term experiment MEC

Coulombic Efficiency (CE)

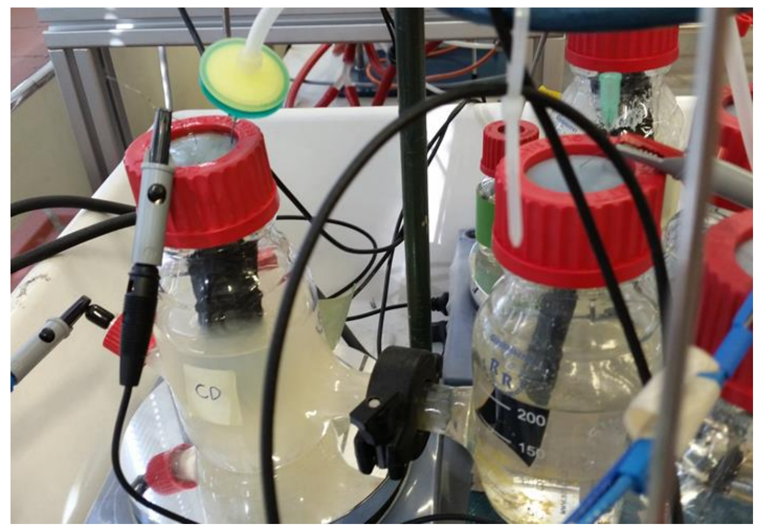
$$\eta_{CE} = \frac{V_{\mathrm{CH_4}} \cdot \mathrm{F} \cdot n}{V_{\mathrm{m}} \cdot \int_{t=0}^{t} I \mathrm{d}t}$$



V_{CH4}: cumulative gas production (m^3 CH_4)
F: Faradays constant (96485 C/mole e^-)
n: mol of electrons per mole of methane
(8 moles e-/mol CH_4)
V_m: molar volume (0,02447 m^3/mole)
I: current (A)
t: time (s)

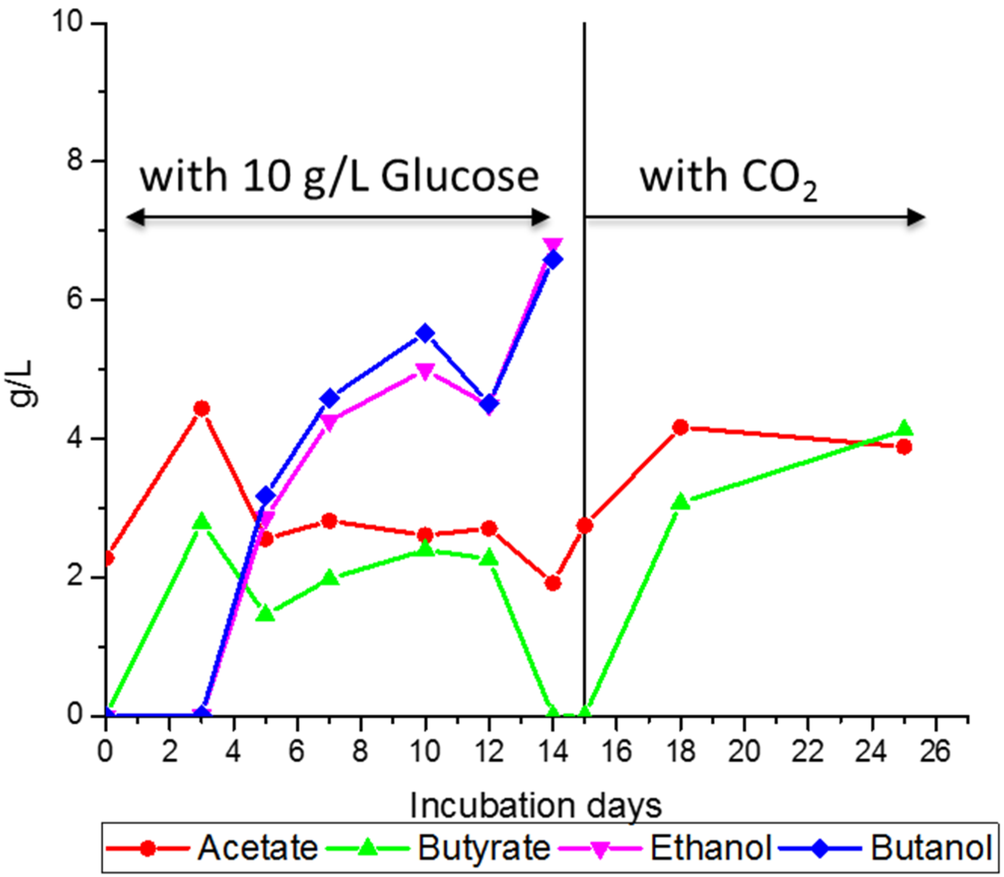
Experiments with pure cultures

- -900 mV vs. Ag/AgCl
- 30°C/37°C depending on the MO
- 70 rpm
- 2-bromoethanosulfonic acid (to prevent methane production)
- 2 phases
  - Glucose-feeding
  - CO_2



Microbial electrolysis cell

Results with pure cultures

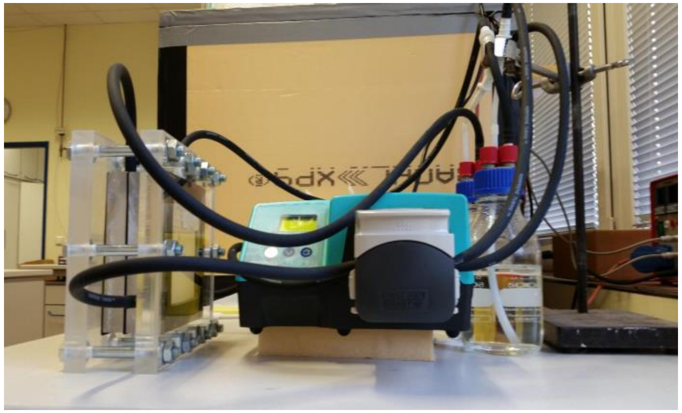


Summary and Outlook

- Adaption of mixed and pure cultures to e^- successful
- Coulombic efficiency depends on applied potential
- H_2 may be a key pathway for methane formation
- Longterm MEC operation successful (nearly three years)
- Pure cultures in MEC reduce CO_2 to acetate and butyrate

MECs are a promising tool for the reduction of CO_2 to liquid and gaseous energy carriers

Optimization of operating conditions
(flow, pH control,…)



Thank you for your attention!

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