THM
TECHNISCHE HOCHSCHULE MITTELHESSEN

IBPT
Institut für Bioverfahrenstechnik
und Pharmazeutische Technologie

ZEuUS
Kompetenzzentrum für
nachhaltiges Engineering und UmweltSysteme

# Gas diffusion electrodes for coupled microbial-electrochemical syntheses from $CO_2$

# The project at a glance

Bundesministerium
für Bildung
und Forschung

Title: **Gas diffusion electrodes for coupled microbial electrochemical syntheses from $CO_2$**

Acronym: **GAMES**

Start: **April 2021**

Duration: **48 month**

Partner:

UFZ HELMHOLTZ Centre for Environmental Research

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ifn FTZ GmbH innovation forschung nachhaltigkeit

gaskatel

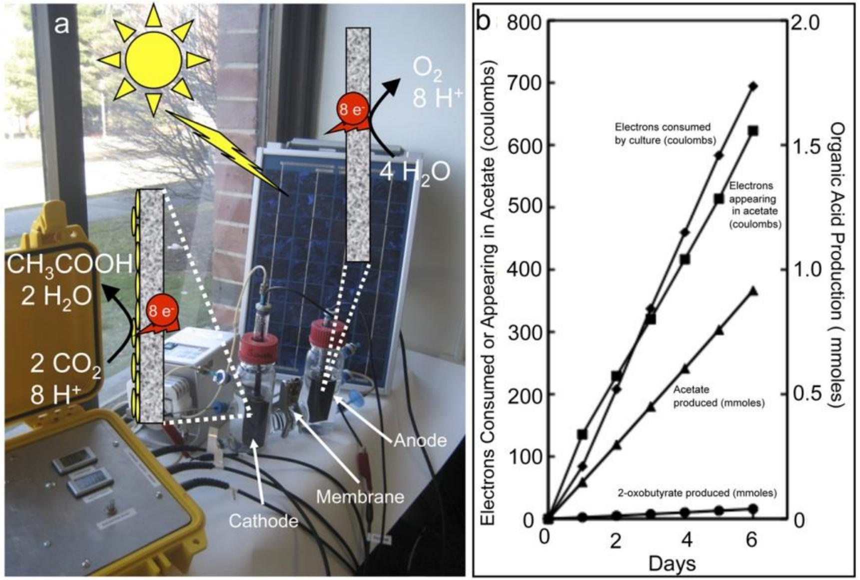
# Microbial electrosynthesis – “Start” in 2010

FUTURE

## Microbial Electrosynthesis: Feeding Microbes Electricity To Convert Carbon Dioxide and Water to Multicarbon Extracellular Organic Compounds

**Kelly P. Nevin, Trevor L. Woodard, Ashley E. Franks, Zarath M. Summers, and Derek R. Lovley**

Department of Microbiology, University of Massachusetts, Amherst, Massachusetts, USA

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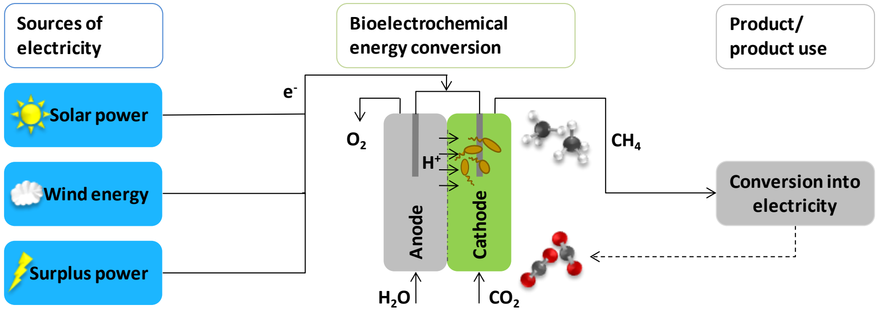
# Our starting points … Project MIKE (funded by BMBF $CO_2$Plus)

FUTURE

## Methanation of $CO_2$ from biogas by microbial electrosynthesis

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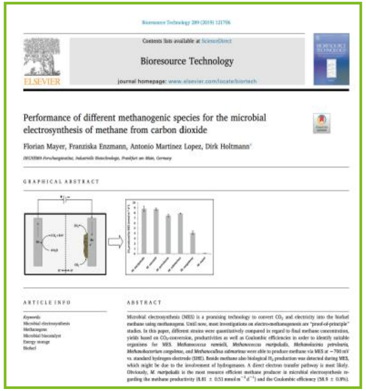

Bioresource Technology 289 (2019) 121706
Contents lists available at ScienceDirect
Bioresource Technology
journal homepage: www.elsevier.com/locate/biortech

Performance of different methanogenic species for the microbial electrosynthesis of methane from carbon dioxide

Florian Mayer, Franziska Enzmann, Antonio Martinez Lopez, Dirk Holtmann

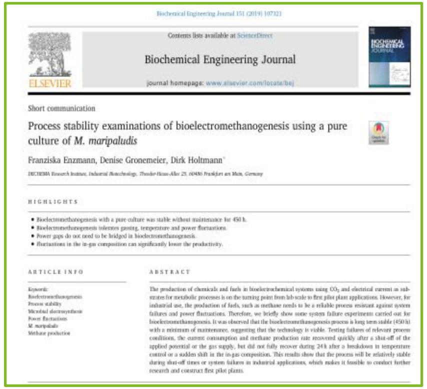

Received: 23 July 2019 | Revised: 18 August 2019 | Accepted: 10 September 2019
DOI: 10.1002/elsc.201900126
Engineering in Life Sciences

RESEARCH ARTICLE

Insights in the anode chamber influences on cathodic bioelectromethanogenesis – systematic comparison of anode materials and anolytes

Franziska Enzmann[1] | Markus Stöckl[2] | Denise Gronemeier[3] | Dirk Holtmann[3,4]

Abstract
Cathode and catholyte are usually optimized to improve microbial electrosynthesis process, whereas the anodic counter reaction was not systematically investigated and optimized for these applications yet. Nevertheless, the anolyte and especially the anode material can limit the cathodic bioelectrochemical process. This paper compares for the first time the performance of different anode materials as counter electrodes for a cathodic bioelectrochemical process, the bioelectromethanogenesis. It was observed that depending on the anode material the cathodic methane production varies from 0.96 μmol/d with a carbon fabric anode to 25.44 μmol/d with a carbon felt anode of the same geometrical surface area. The used anolyte also affected the methane production rate at the cathode. Especially, the pH of the anolyte showed an impact on the system; an anolyte with pH 5 produced up to 2.0 times more methane compared to one with pH 8.5. The proton availability is discussed as one reason for this effect. Although some of the measured effects cannot be explained completely so far this study advises researchers to strongly consider the anode impact during process development and optimization of a cathodic bioelectrochemical synthesis process.


Biochemical Engineering Journal 151 (2019) 107321
Contents lists available at ScienceDirect
Biochemical Engineering Journal
journal homepage: www.elsevier.com/locate/bej

Short communication

Process stability examinations of bioelectromethanogenesis using a pure culture of *M. maripaludis*

Franziska Enzmann, Denise Gronemeier, Dirk Holtmann


Chemical Engineering Science
journal homepage: www.elsevier.com/locate/ces

Rational Scale-Up of a methane producing bioelectrochemical reactor to 50 L pilot scale

Franziska Enzmann, Dirk Holtmann

# Our starting points … Proof of principle studies

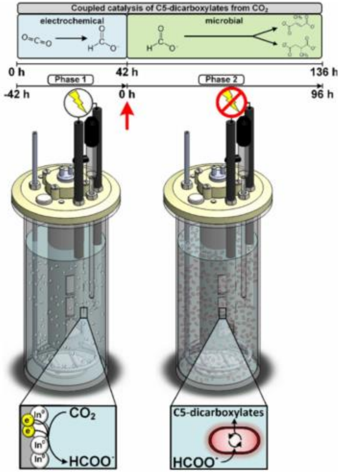
PRESENT

ChemSusChem | Full Papers doi.org/10.1002/cssc.202001272 | Chemistry Europe European Chemical Societies Publishing

## Coupled Electrochemical and Microbial Catalysis for the Production of Polymer Bricks

Richard Hegner,[a] Katharina Neubert,[a] Cora Kroner,[b] Dirk Holtmann,*[b, c] and Falk Harnisch*[a]

Power-to-X technologies have the potential to pave the way towards a future resource-secure bioeconomy as they enable the exploitation of renewable resources and $CO_2$. Herein, the coupled electrocatalytic and microbial catalysis of the $C_5$-polymer precursors mesaconate and 2S-methylsuccinate from $CO_2$ and electric energy by in situ coupling electrochemical and microbial catalysis at 1 L-scale was developed. In the first phase, 6.1 ± 2.5 mM formate was produced by electrochemical $CO_2$ reduction. In the second phase, formate served as the substrate for microbial catalysis by an engineered strain of *Methylobacterium extorquens* AM-1 producing 7 ± 2 µM and 10 ± 5 µM of mesaconate and 2S-methylsuccinate, respectively. The proof of concept showed an overall conversion efficiency of 0.2% being 0.4% of the theoretical maximum.

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ChemSusChem | Full Papers doi.org/10.1002/cssc.202001235 | Chemistry Europe European Chemical Societies Publishing

## From $CO_2$ to Bioplastic – Coupling the Electrochemical $CO_2$ Reduction with a Microbial Product Generation by Drop-in Electrolysis

Markus Stöckl,[a] Svenja Harms,[a] Ida Dinges,[a, b] Steliyana Dimitrova,[a] and Dirk Holtmann*[a, c]

$CO_2$ has been electrochemically reduced to the intermediate formate, which was subsequently used as sole substrate for the production of the polymer polyhydroxybutyrate (PHB) by the microorganism *Cupriavidus necator*. Faradaic efficiencies (FE) up to 54% have been reached with Sn-based gas-diffusion electrodes in physiological electrolyte. The formate containing electrolyte can be used directly as drop-in solution in the following biological polymer production by resting cells. 56 mg PHB $L^{-1}$ and a ratio of 34% PHB per cell dry weight were achieved. The calculated overall FE for the process was as high as 4%. The direct use of the electrolyte as drop-in media in the bioconversion enables simplified processes with a minimum of intermediate purification effort. Thus, an optimal coupling between electrochemical and biotechnological processes can be realized.

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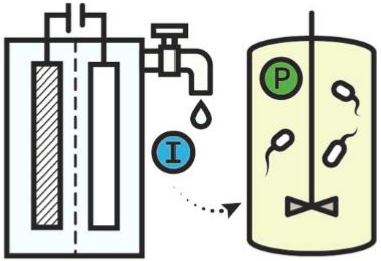
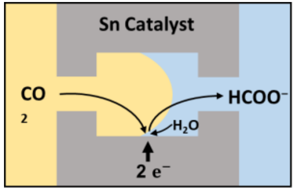
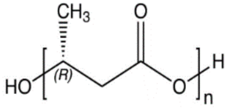
**Drop-in electrolysis**



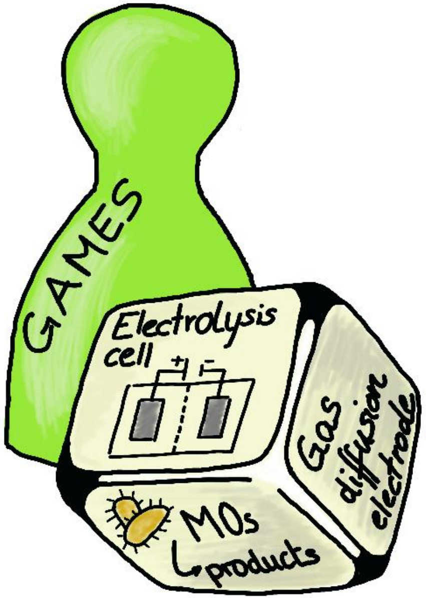




**P**oly**h**ydroxy**b**utyrate

# Motivation and aims

Increasing the application potential of microbial electro syntheses from $CO_2$ based on gas diffusion electrodes and formate as a central intermediate

- Optimization of process performance
- Broadening the process window of GDE-based processes
  - Electrochemical conditions (temperature, osmolarity)
  - Organisms
- Stability and reproducibility
  - Electrodes
  - Electrolysis cell
- Evaluation and modelling

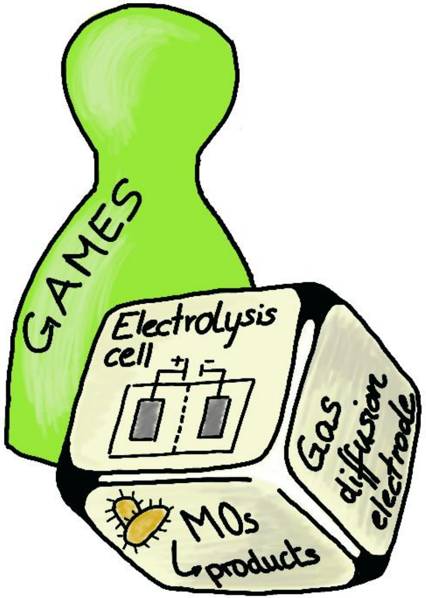


## Work packages (selection)

- Use of mixed cultures in formate-based production
- Comparison of mesophilic vs. thermophilic processes
- Halophilic production strains
- Production of methane, PHB, isopropanol, ectoine, ...

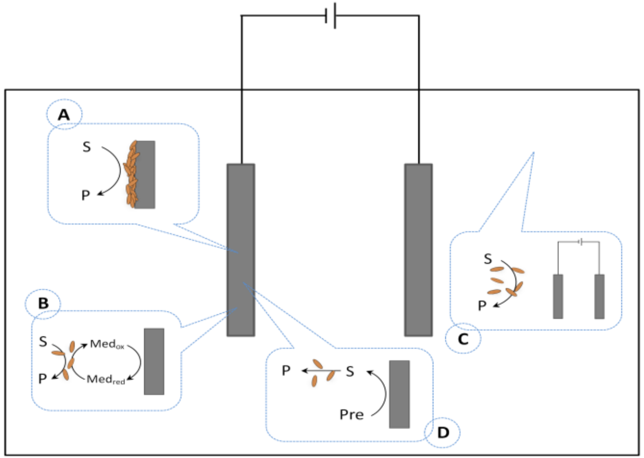
- Electrolysis cell with 100 cm$^2$ electrode area
- Development of improved gas diffusion electrodes
- Long-term electrolysis
- Reactors for practical application e.g. biogas plants
- Evaluation in near-industrial conditions

- Optimization of the reactors on the basis of CFD
- Mass and energy balances
- Process design using SuperProDesigner



## Take-home message

**The different types of MES processes offer options for today's industrial use, as well as an exciting and future-oriented technology that can be applied in a medium-term perspective.**




(A) MES based on biofilms


(B) MES based on soluble mediators


(C) Electro-fermentations


(D) using secondary MET


# Take-home message

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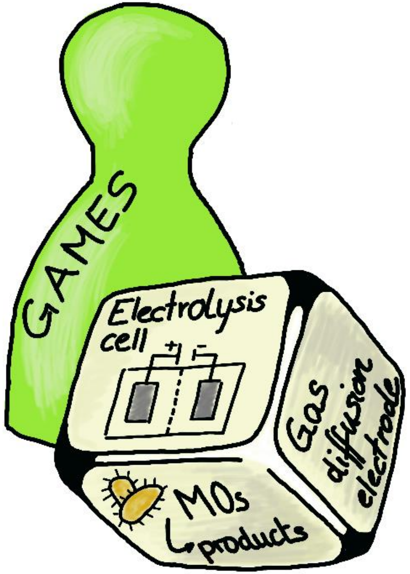


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