

**Gas diffusion
electrodes for
coupled microbial-
electrochemical
syntheses from CO₂**

The project at a glance



Bundesministerium
für Bildung
und Forschung

Title: **Gas diffusion electrodes for coupled microbial electrochemical syntheses from CO₂**

Acronym: **GAMES**

Start: **April 2021**

Duration: **48 month**

Partner:

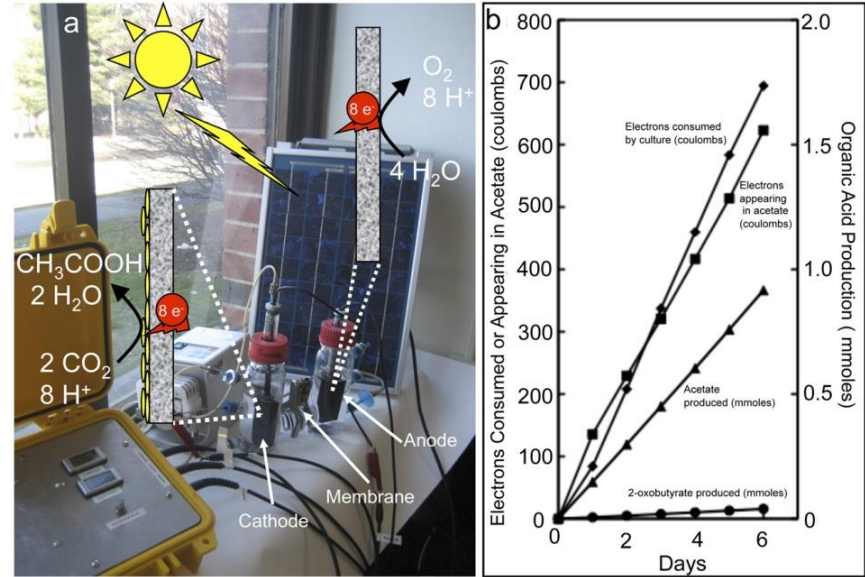
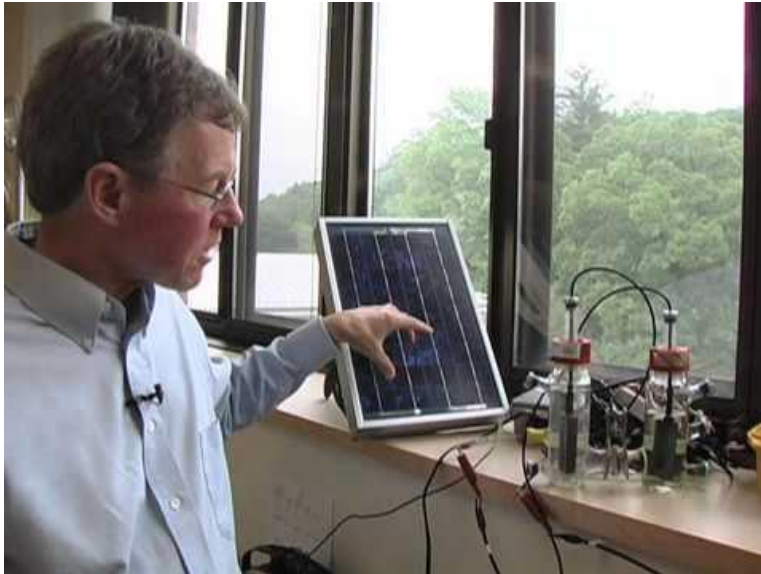


Microbial electrosynthesis – “Start” in 2010



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

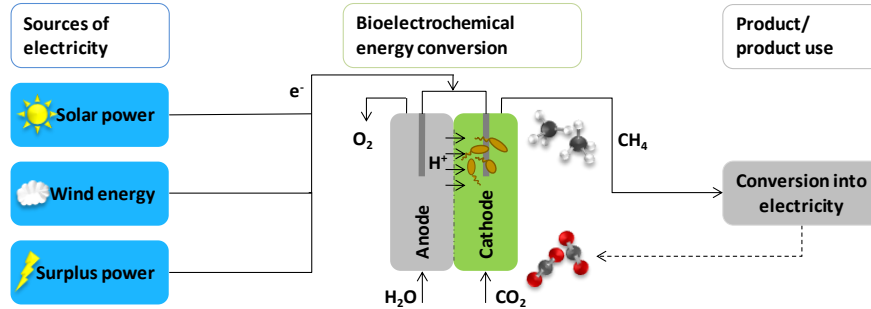
Kelly P. Nevin, Trevor L. Woodard, Ashley E. Franks, Zarath M. Summers, and Derek R. Lovley
Department of Microbiology, University of Massachusetts, Amherst, Massachusetts, USA



Our starting points ... Project MIKE (funded by BMBF CO₂Plus)



Methanation of CO₂ from biogas by microbial electrosynthesis



Research Technology (2016) 12(16)

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Bioresour. Technol.

Journal homepage: www.elsevier.com/locate/biortech

Performance of different methanogenic species for the microbial electro-synthesis of methane from carbon dioxide

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

10/10/16 Available online 10 October 2016

GRAPHICAL ABSTRACT

ARTICLE INFO

ABSTRACT

Microbial electrosynthesis (MES) is a promising technology to convert CO₂ and electricity into the liquid methane using methanogenic DSM 2, and more importantly an electrochemotrophic "species-agnostic" anode. In this paper, different species were experimentally compared to support a first culture optimization. The MES performance was compared to a well-established methanogenic species, Methanospirillum hungatei, and Methanohalobium evestigatum, and Methanohalobium evestigatum, and Methanospirillum hungatei. The results show that Methanospirillum hungatei is the most suitable species for the electro-synthesis of methane from CO₂ and electricity. The results show that Methanospirillum hungatei is the most suitable species for the electro-synthesis of methane from CO₂ and electricity. The results show that Methanospirillum hungatei is the most suitable species for the electro-synthesis of methane from CO₂ and electricity.

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Engineering

in the Sciences

RESEARCH ARTICLE

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

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Abstract

Cathode and anolyte are usually optimized to improve microbial electro-synthesis 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 this 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.

Research Technology (2016) 12(16) Available online 10 October 2016

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Chemical Engineering Journal

Journal homepage: www.elsevier.com/locate/cej

Short communication

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

Franziska Enzmann, Denise Gronemeier, Dirk Holtmann

10/10/16 Available online 10 October 2016

HIGHLIGHTS

- Bioelectromethanogenesis with a pure culture was stable without maintenance for 60 d.
- Bioelectromethanogenesis (substrate gas), temperature and power fluctuations.
- Power gap can be used to be linked to bioelectromethanogenesis.
- Fluctuations in the in-pipe composition can significantly lower the productivity.

ARTICLE INFO

ABSTRACT

The production of chemicals and fuels in bioelectrochemical systems using CO₂ and electrical current as substrate and oxidant presents a new starting point from bio to the fine-plant applications. However, for industrial use, the production of fuels, such as methanol seems to be a reliable process similar against system failures and power fluctuations. Therefore, we briefly show some system failure experiments carried out for bioelectromethanogenesis. It was observed that the bioelectromethanogenesis process is very sensitive (60 d) with a mixture of substrates, suggesting that the technology is viable. During failure of reduced process conditions, the current consumption and methanol production rate increased up to 10% after a shift of all of the optimal process parameters. This study shows that the process will be relatively stable during short-term process failures in industrial applications, which makes it feasible to conduct further research and construct a first pilot plant.

Research Technology (2016) 12(16) Available online 10 October 2016

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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

10/10/16 Available online 10 October 2016

HIGHLIGHTS

- Stability theory used to scale-up a bioelectrochemical system for the first time.
- Energy transfer used for pure culture bioelectromethanogenesis at high CO₂ production.
- Consistency of reactor materials were observed.
- Bioelectromethanogenesis at a high energy efficiency.

GRAPHICAL ABSTRACT

ARTICLE INFO

ABSTRACT

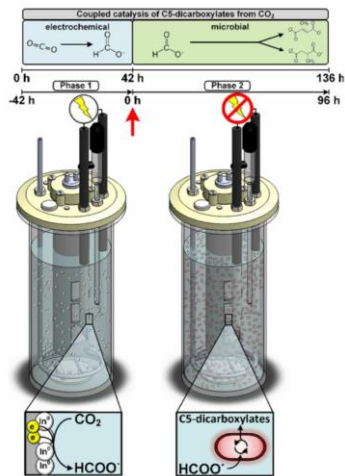
The field of microbial electro-synthesis gained much attention since it allows the conversion of electrical energy into valuable chemicals. The technology is seen as the starting point for bio to the fine-plant applications. However, for industrial use, the production of fuels, such as methanol seems to be a reliable process similar against system failures and power fluctuations. Therefore, we briefly show some system failure experiments carried out for bioelectromethanogenesis. It was observed that the bioelectromethanogenesis process is very sensitive (60 d) with a mixture of substrates, suggesting that the technology is viable. During failure of reduced process conditions, the current consumption and methanol production rate increased up to 10% after a shift of all of the optimal process parameters. This study shows that the process will be relatively stable during short-term process failures in industrial applications, which makes it feasible to conduct further research and construct a first pilot plant.

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 CO₂. Herein, the coupled electrocatalytic and microbial catalysis of the C₅-polymer precursors mesaconate and 25-methylsuccinate from CO₂ 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 CO₂ 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 25-methylsuccinate, respectively. The proof of concept showed an overall conversion efficiency of 0.2% being 0.4% of the theoretical maximum.



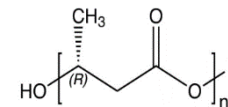
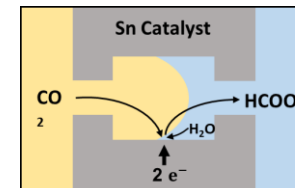
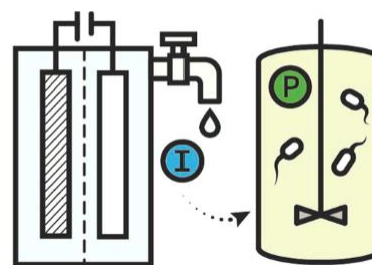
From CO₂ to Bioplastic – Coupling the Electrochemical CO₂ Reduction with a Microbial Product Generation by Drop-in Electrolysis

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

CO₂ 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.

Drop-in electrolysis

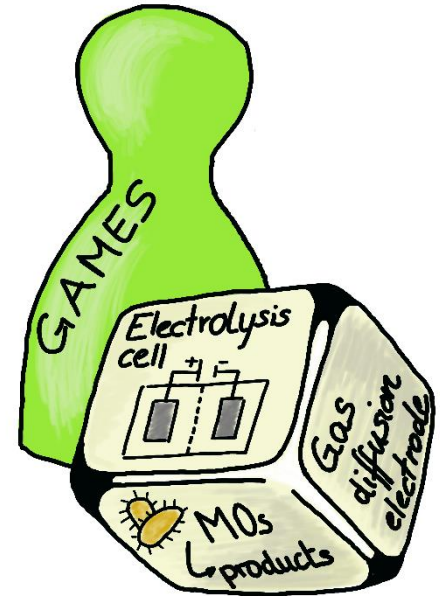


Polyhydroxybutyrate

Motivation and aims

Increasing the application potential of microbial electro syntheses from CO₂ 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

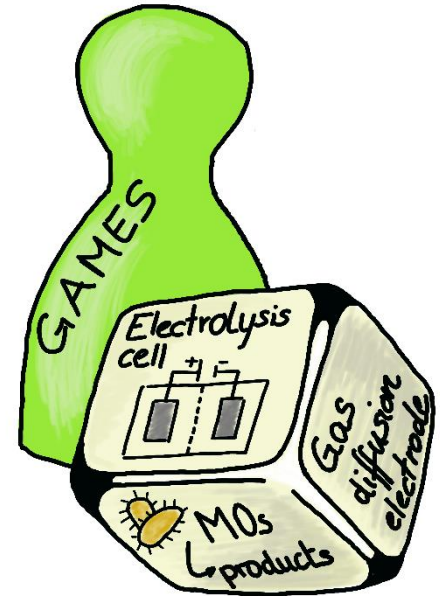


Work packages (selection)

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

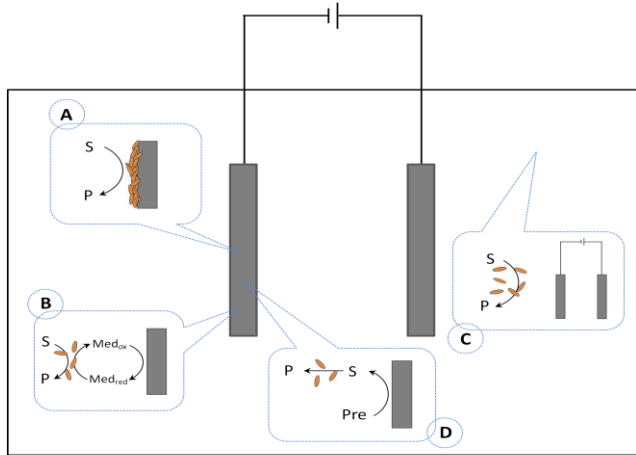
- Electrolysis cell with 100 cm² electrode area
- Development of improved gas diffusion electrodes
- Long-term electrolysis
- Reactors for practical application e.g. biogas plants
- Evaluation in near-industrial conditions

- 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

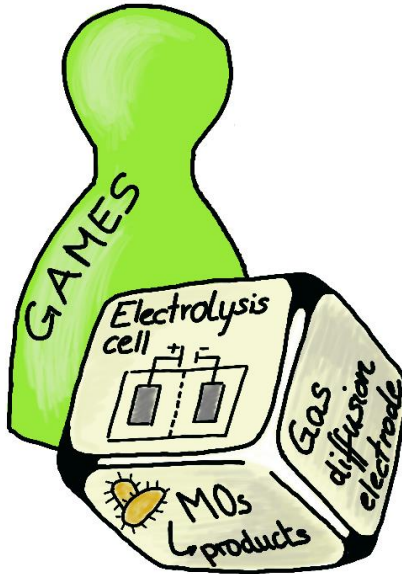


(D) using secondary MET



Take-home message

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.



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