Biological methanation processes

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European PowertoGas Platform: Second Meeting 2016

Dr Doris Hafenbradl
CTO
Overview

- Electrochaea company introduction
- Long term energy storage – why should we use biological methanation technologies?
- From the lab to the customer – scaling biological methanation technology
- BioCat project update
About Electrochaea

History
- 2010: founded as a University of Chicago spin-off,
- 2012: establishment of Danish subsidiary
- 2014: Series A financing; move to Munich (Germany)
- 2015: lab and office opening in Planegg
- 2016: first commercial production (Denmark)

Mission
Commercialize biological methanation process for power-to-gas energy storage and biogas upgrading

Partners
Universities, public agencies, grid operators, utilities, gas distributors, technology developers, energy traders, engineering firms, automobile
Who we are

Executive Team

**Mich Hein, PhD, CEO**
- Co-founder and managing partner at Nidus Partners
- Formerly researcher at Scripps, CEO at Chromatin, Founder of Helios and Epicyte Pharmaceutical
- PhD in Plant Physiology, U of Minnesota

**Doris Hafenbradl, PhD, CTO**
- 19 years of experience in biotechnology and pharmaceutical industries
- Formerly with Axxam, BioFocus, Proteros, GPC Biotech, Axxima Pharmaceuticals, GNF, Diversa
- PhD in Microbiology (hyperthermophilic archaea)

**Fernando G. Keuchen, Head of Engineering**
- 16 years of experience in power plant engineering and commissioning
- Formerly with Siemens, Alstom, SENER, FLAGSOL
- B.S. Industrial Engineering, RWTH Aachen

**Markus Forstmeier, PhD VP Business Development**
- 15 years of experience in renewable energy and water treatment space
- Formerly with SGL Group, Siemens AG, and General Electric Global Research
- MBA, Augsburg University, Katz School of Business, Pittsburgh; Diploma in Environmental Engineering and PhD in Process Engineering, TU Berlin

Company

**Electrochaea GmbH**
- Planegg, Germany
- 380 m² reactor development, laboratory and office space
- Staff = 14 FTEs, engineering, technology development, business development and Admin staff

**Electrochaea.dk ApS**
- Avedøre, Denmark
- 1MWe BioCat electrolyzer and methanation reactor, grid injection
- Staff = 3 FTEs, operations and engineering
Long term energy storage – why use biological methanation technology?
Why Electrochaea’s mission matters
Accelerating the carbon cycle to enable a sustainable business

Fossil Carbon Cycle

Oxidation

Reduction
Millions of years

CO₂

CH₄

Energy

Work

Proprietary Biocatalytic System

Oxidation

Reduction
Minutes to days

CO₂

CH₄

Energy

Work

Natural photosynthesis to fossil fuel efficiency (1 to 2%)
Net release of fossil CO₂ to atmosphere

10X compared to natural efficiency
Mitigation of CO₂ release to atmosphere
What would it look like in Germany?

Electricity Storage Requirements and Capacity of Potential Solutions

Storage Volume of Existing Gas Grid (incl. Caverns): 126 TWh*
(incl. Grid Expansion Under Construction/In Planning: 300 TWh)

Future storage capacity required: 20-40 TWh\textsubscript{el}

Current capacity of pumped hydro and batteries:
0.04 TWh\textsubscript{el} (7 GW for 4-8 hrs)

Theoretical capacity of electrified fleet (42m vehicles):
0.42 TWh\textsubscript{el} (70 GW for 6 hrs)
International gas grids – a vast storage capacity
System Design & Chemistry

System Design

- Power: Electrolyzer (off-the-shelf)
- Water: Heat
- CO₂/Biogas: CH₄
- Hydrogen: Oxygen

Chemistry & Biochemistry

Chemical Reactions:
1) Electrolysis: \(4H_2O \rightarrow 4H_2 + 2O_2 + \text{Heat} \) \( \eta=0.80 \)
2) Methanation: \(CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O + \text{Heat} \) \( \eta=0.75 \)
Net Reaction: \(CO_2 + 2H_2O \rightarrow CH_4 + 2O_2 + \text{Heat} \) \( \eta=0.60 \)

Inputs:
- Water
- Low-cost or stranded electricity or H₂
- CO₂ from biogas, fermentation, or other sources
- Electrochaea’s proprietary biological catalyst

Outputs:
- Pipeline-grade methane for direct grid injection
- Oxygen for industrial or medical applications
- Heat for on-site use or district heating grids
## Electrochaea vs. Sabatier

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sabatier</th>
<th>Electrochaea</th>
<th>Electrochaea Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation temperature</td>
<td>300-400°C</td>
<td>60-65°C</td>
<td>Higher complexity, higher dynamics</td>
</tr>
<tr>
<td>Ramp up time (0 → 90%)</td>
<td>~1 hr</td>
<td>Sek/Min</td>
<td>Intermittened operation is possible</td>
</tr>
<tr>
<td>Tolerance against contamination (H₂S, O₂, KOH)</td>
<td>low</td>
<td>high</td>
<td>Raw biogas can be used a CO₂ source</td>
</tr>
<tr>
<td>Product gas</td>
<td>CH₄ + side products (z.B. CO)</td>
<td>CH₄</td>
<td>No upgrading required</td>
</tr>
<tr>
<td>Product purity (%CH₄)</td>
<td>~92%</td>
<td>98-99%</td>
<td>No product purification required</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>~50%</td>
<td>58%</td>
<td>Lower operating costs</td>
</tr>
<tr>
<td>System complexity</td>
<td>High</td>
<td>Low</td>
<td>Lower capital costs, higher flexibility based on modules</td>
</tr>
<tr>
<td>Scalability</td>
<td>low</td>
<td>high</td>
<td>Business cases also positive for smaller units / very large system design possible</td>
</tr>
</tbody>
</table>

Biological methanation is more robust and less cost intensive
Our biocatalyst: methanogenic Archaea

- Methanogenic Archaea:
  - 3.5 billion year-old single-celled organisms
  - Described only 30 years ago by pioneers Prof Carl Woese (Illinois) and Prof Karl Stetter (Regensburg)
  - Specialized „tiny chemical plants“ pre-engineered by nature
  - „Archaeal diet“: CO₂ and H₂ (no other carbon source needed!), 65°C

- **Electrochaea biocatalyst:** proprietary, selectively evolved, highly efficient, optimised Archaea
Profile of Electrochaea's Biocatalyst

Growth Requirements

- Salt water and minerals
- 65°C
- Anaerobic conditions
- Feedgas: CO₂ and H₂

Dynamic Operating Behavior

107-day stability run with intermittent start/stop and mass spec data

Characteristics

**Efficient**  98.6% of carbon goes into product
**Productive**  VVD* of 850, H₂ mass-transfer limited
**Responsive**  Quick return to activity after dormancy
**Selective**  100% methane, no intermediates
**Robust**  Tolerant to oxygen, H₂S, CO, Sulfate, Ammonia, particulates
**Simple**  Moderate temperature range (60-65°C)

*VVD = volumes of gas per volume of reactor per day (24-hr)
From the lab to the customer – scaling of P2G technology
Rapid technology de-risking and scale-up

**Commercial-Scale Field Trial**
Preparing for market entry with a commercial-scale demonstration unit, using an optimized reactor, Copenhagen (DK)

**Pre-Commercial Field Trial**
Process demonstration in stirred tank bioreactor using raw biogas, Foulum (DK) (4500 L)

**Lab-Scale Field Trial**
Biocatalytic capability test with raw biogas

**Basic Research**
In Prof Mets Lab at University of Chicago

**Power Input**
- 1 MW
- 50 kW
- 1 kW
- n/a

**Biological Energy Storage**

2006 - 2010

2011 - 2012

2013

2014 - 2016

http://www.biocat-project.com
1-kW Field Trial Completed
Successful Field Trial at Industrial Anaerobic Digester

Project Cornerstones

- 192 hour operations
- At commercial waste water digester
- Raw biogas upgraded directly from digester
- Stable catalytic activity
- No problems from biological contamination or hydrogen sulfide
- Project report detailing results and 3rd party gas analysis is available
Foullum Project

Danmark (Denmark)

- Biogasanlage
- Labor
- Substrat-Handling
- Gas-Lager
- Reaktorhaus

[Map of Denmark with location of Foullum Project]
Foulum Project: Reactor
Foulum Project: Reactor Internals
Technology Demonstration Project at Foulum, DK
Pre-Commercial Pilot Plant

- Operating Envelope
  - Feedstock: bottled H₂, CO₂ from raw biogas (45-50% vol.) with 500-2,000 ppm H₂S
  - 10,000 L continuous stirred tank reactor with 4,500 L of microbial culture
  - More than 3,300 hours of operation in both continuous and intermittent mode
  - Flow rates of 0.5 – 18.0 Nm³/hr

- Results
  - Demonstrated ability to control system parameters over long periods of time and under different operating conditions
  - Microbes exhibited great robustness, stability, and longevity
  - Demonstrated ability to control cell density and redox potential of microbes
  - CO₂ conversion efficiencies > 90%
BioCat project update
Aerial View of Avedøre WWTP

1) Digesters for biogas production
2) Biogas storage tank
3) Biogas engine, flare and filter
4) Location for BioCat and ENZUP plants

Quelle: gas for energy, DIV Deutscher Industrieverlag GmbH
BioCat Technology Demonstration Project
Scale-Up to Commercial Size

- 1 MW electrical input
- Alkaline electrolysis and biological methanation
- CO$_2$ from biogas
- Injection into 4-bar distribution grid
- Heat used in buildings
- Frequency regulation provision
- Location: Avedøre WWTP, Copenhagen
BioCat Plant Layout (3D)
Impressions from Site: Feb-2016
Installation 2\textsuperscript{nd} Electrolyzer Unit
Status BioCat

- **Biological catalyst** commissioned and working well
- Final steps of plant commissioning ongoing, 98% complete
- Experimental testing of system parameters ongoing
- Expect **natural gas of commercial quality** to be injected into gas grid by **July 2016** (requires completion of HMN injection station)
Impressions from site
Bioreactor and methanation unit

Highlights:
• Operation started within 3 weeks compared to project plan
• 100% conversion rates at 7.5bar operation stably achieved
• High robustness of biocatalyst (O₂ contamination, varying H₂S concentrations etc)
System performance and scaling
The system is envisioned to be scaled up to 50 MWe

Flow rates refer to a system including electrolyzer

- **A 50 Mwe biomethanation system is capable of**
  - Storing 400GWh/a of electrical energy * More than 13000 Households consumption per year
  - Achieving a CO₂ sequestration of 37000 tons/a * Emissions of ~19930 cars per year

*Assumptions:
- Heat and electricity for one year 30.200kWh in a household with 4 person in Germany (2013)
- 132,6 gr/km emission per car and 14.000 km driving average km per year in Germany (2014)
- 8000h/a of operation, electrolysis included
Thank you!

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Opportunities for process integration

Suitable CO$_2$ Source

- Biogas
- Fermentation off-gas
- Oxy combustion flue-gas
- Industrial Processes
- Other (landfill, atmospheric)

Power Grid

- Wind Energy
- Solar Energy
- Low-Carbon Energy Sources

Carbon Dioxide

- Electrolysis
- Gas-Fed Power Plants

Methanation

- Water
- Oxygen

Methane

Gas Grid

- Electricity
- Heat
- Transportation fuel
- Chemical feedstock

Power-to-Gas Energy Storage

Source: Adapted from ZSW, Erneuerbares Methan aus Ökostrom, April 2012