Biomass for Power-to-Gas: Direct Methanation of Biogas

Biosweet Conference, 05.09.2017
Power-to-Gas (PtG) Scheme

\[ \text{Electrolysis} \]

\[ \text{Methanation} \]

\[ \text{Application} \]

\[ \text{Gas Grid} \]

\[ \text{Storage} \]

Air, Water, Sun

\[ \text{CO}_2 \rightarrow \text{H}_2 \rightarrow \text{H}_2\text{O} \rightarrow \text{CH}_4 + 2 \text{H}_2\text{O} \]
More Bio-Methane with PtG

Conventional Biomethane Production

Biomass → Digestion → Biogas (60% CH₄ and 40% CO₂) → CO₂ Scrubbing → Biomethane

Power-to-Gas Biomethane Production

Biomass → Digestion → Biogas (CH₄ and CO₂) → Methanation (CO₂ + 4 H₂ ⇌ CH₄ + 2 H₂O) → Biomethane

Electricity + H₂O → Electrolysis → H₂ → Methanation → Biomethane

60% more Biomethane with PtG
Biomethane Potential in Switzerland

• 180 GWh: Modification with PtG technology of existing biogas plants with injection into gas grid

• 955 GWh: Modification with PtG technology of electricity producing biogas plants close to the gas grid

Total Bio-Methane Potential: 1397 GWh (4.3% of total gas consumption in CH)
Overview Methanation Technologies

Methanation Technologies

- Biological
- Stirred Tank
- Fixed Bed
- Bubbling Fluidized Bed

Methanation Technologies Overview
## Comparison of Methanation Technologies

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Cooled Fixed bed (Hitachi Zosen)</th>
<th>Bubbling Fluidised Bed (PSI)</th>
<th>Biological (electrochaea, Microbenergy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat integration/ process heat &gt;100°C</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Further upgrading after methanation necessary (&lt; 2% H₂)</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Advanced sulphur removal necessary</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Reactor size (high GHSV possible)</td>
<td>+</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>Alkenes and aromatics in feed (C₂H₄, C₆H₆), advanced gas cleaning</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Technical readiness level (TRL)</td>
<td>8</td>
<td>6-7</td>
<td>7, [8]</td>
</tr>
<tr>
<td>Demonstration Plants</td>
<td>Werle (3 MW&lt;sub&gt;SNG&lt;/sub&gt;)</td>
<td>GanyMeth (200 kW&lt;sub&gt;SNG&lt;/sub&gt;) Güssing (1 MW&lt;sub&gt;SNG&lt;/sub&gt;)</td>
<td>BioCat (500 kW&lt;sub&gt;SNG&lt;/sub&gt;) [Solothurn, Dietikon]</td>
</tr>
</tbody>
</table>
Process Design and Evaluation

**Process I**
- Biogas
- \( \text{H}_2 \), from Electr

- **Main Methanation** (fluid. bed)

- Condensation

- Water

- Drying

- Water

- Bio-Methane

**Process II & III**

- Biogas
- \( \text{H}_2 \), from Electr

- **Main Methanation** (fluid. bed)

- **Main Methanation** (fixed bed)

- **OR**

- Condensation

- Water

- \( \text{H}_2 \)-Membrane

- Bio-Methane

- \( \text{H}_2 \)-rich Recycle

Gas Grid Requirements:
- \( \text{CH}_4 \geq 96 \text{ vol\%} \)
- \( \text{H}_2 \leq 2 \text{ vol\%} \)
Key Points of evaluated Processes

- Detailed process models

- Processes are modelled and simulated in large scale

- All processes produce biomethane which is injectable into the gas grid without restrictions

- Process II with fluidised bed and H₂-membrane is favoured

200 Nm³/h biogas

\[ BFB \text{ Meth} \rightarrow H₂\text{-Membr} \]
Transport of the Demonstration Plant COSYMA from PSI to the Biogas Plant in Zürich, Jan. 2017

Energy System Integration (ESI) Platform

PAUL SCHERRER INSTITUT

PSI
At the Biogas Plant in Zürich

- Demonstration plant 1-2 Nm³/h gas production
- Catalytic methanation via fluidised bed technology
- Over 1000 hours of experiments with real biogas
- Injection into the gas grid
Demonstration Plant COSYMA

Electrolysis

Electricity → Water → Biogas

Compressor | Gas Cleaning | Heating | Fluidized Bed Reactor | Water | Filter | Condenser | H₂, Membrane | Injection

Reaction Equation Methane Synthesis: \( \text{CO}_2 + 4 \text{H}_2 \rightarrow \text{CH}_4 + 2 \text{H}_2\text{O} \)
Conditions and Behaviour of COSYMA Set-Up

\[
\begin{align*}
CH_4/CO_2 &= 62/38 \text{ (Biogas = 100\%)} \\
H_2/CO_2 &= 4.05 \\
\end{align*}
\]

Due to kinetic and thermodynamic limitations, a maximum for the yield of methane is formed

\[
CO_2 + 4 H_2 \leftrightarrow CH_4 + 2 H_2O
\]

\[p = 6 \text{ bar}\]

Graph showing yield of methane as a function of temperature.
Conditions and Behaviour of COSYMA Set-Up

\[ \text{CH}_4/\text{CO}_2 = 62/38 \text{ (Biogas = 100%)} \]

\[ \text{H}_2/\text{CO}_2 = 4.05 \]

Yield$_{\text{CH}_4}$ = 95%

9% H$_2$

90% CH$_4$

1% CO$_2$

\[ \text{CO}_2 + 4 \text{ H}_2 \leftrightarrow \text{CH}_4 + 2 \text{ H}_2\text{O} \]
Long-term experiment with real biogas in Zürich, Werdhölzli

- Long-duration experiment successfully completed with one batch of catalyst material
- Predicted gas composition is equivalent to measured results
- Due to a partial deactivation of the catalyst, 150g of new catalyst was added
Gas Cleaning Unit with two Stages

- 1. Bed: H₂S was removed sufficiently
- 2. Bed: Mainly dimethyl sulphide (DMS) and dimethyl disulphide (DMDS) removed.
Sulphur Poisoning and Catalyst Activity

![Graph showing molar fraction and yield over operational hours]

- After reactor
- After second sorption bed
- After reactor
Every process unit was simulated for a plant size of 200 Nm$^3$/h biogas and evaluated regarding the technical and economic feasibility.

The experimental and simulation results of fluidised bed methanation and gas cleaning allow an up-scaling from ‘COSYMA size’ to an industrial size of 200 Nm$^3$/h.

Next step for realisation is a pre-engineering study for a specific site.
Key Notes

• App. 60% more biomethane with the same amount of raw materials

• Five times bigger biomethane production possible with current biogas production

• Fluidised bed methanation technology successfully tested in long-duration experiment

• All evaluated PtG-process concepts reach gas grid requirements

• Fluidised bed technology ready for up-scaling to industrial size
Thank you for your Attention!

We acknowledge support by:
- TCP Group
- energie360°
- Forschungs-, Entwicklungs- und Förderungsfonds der Schweizer Gaswirtschaft (FOGA)
- Swiss Federal Office of Energy (SFOE)
- Swiss Competence Center of Energy Research - BIOSWEET