“Energy Storage Technologies: Focus on Power-to-Gas Technology”

Environmental aspects of Power-to-Gas concept systems.

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Objectives

• The major objective is to assess the environmental and energetic performance of a “base case” scenario, involving assumptions regarding the CO₂ input feed and the generation mix of the electricity demand.

• The analysis refers to a “cradle-to-gate” approach, modelling the upstream energy/material flows which lead to the production of 1 m³ of Synthetic Natural Gas (SNG).
Major assumptions

- No emissions from system operation (environmental impact assigned to upstream processes)
- The CO₂ input will be treated as a resource (incorporation of benefits and burdens all along its “supply chain”) equivalent O₂ production from a reference system.

- Functional unit: 1 m³ (NTP) of SNG
- Timeframe: 2020-2050
- Geographical context: Germany
- Grid electric supply (re-evaluated in order to represent mid-term and long-term German generation mixes, featuring RE contribution up to 100%)
- CO₂ from Biogas facility (including purification stage)
- The O₂ outflow will replace the equivalent O₂ production from a reference system.
Definition of “Base Case” system

Main criteria of choosing between alternatives:

• Estimated techno-economic feasibility
• Estimated environmental advantage
• Current practice in PtG demonstrators

Issues to be defined:

• Electricity supply
• CO₂ supply
• SNG output
• Nominal output power of concept system
• Utilization of produced O₂
PtG system “Base Case” options

Issue 1: Electricity supply

Options:
A. Connected to el. grid  B. Attached to Wind/PV power plant

Continuous operation  Intermittent operation

“Base Case” selection: A

- High utilization
- Less starts/stops
- Lower SOEC degradation
- CO₂ supply and SNG grid injection near Wind/PV plants?

However… Electricity input only partially renewable
PtG system “Base Case” options

Issue 2: CO₂ supply

Options:

A. Fossil power plant
   i. NG (Flue gas)
   ii. Coal (Flue gas)

B. Bioenergy facility
   i. Biogas (biochemical)
   ii. Biomass combustion/gasification (thermochemical)

C. Industrial source
   i. Clinker/Cement
   ii. Fertilizers

“Development of a methanation process for PtG appliances”
Siegfried Bajohr (KIT), Manuel Götz (DVGW)
EDGaR/DVGW Conference

Pictures:
www.bbfm.de
www.repotec.at
www.skwp.de
PtG system “Base Case” options

Issue 2: CO₂ supply

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A. Fossil power plant  B. Bioenergy facility  C. Industrial source

- i. NG (Flue gas)
- ii. Coal (Flue gas)

- i. Biogas (biochemical)
- ii. Biomass combustion/gasification (thermochemical)

- i. Clinker/Cement
- ii. Fertilizers

“Base Case” selection: B-i

- Biogenic carbon input
- High CO₂ content compared to flue gas
- Preferred CO₂ source in ALL running P-to-G research projects (According to “Global screening of projects and technologies for Power-to-Gas and Bio-SNG”, Nov. 2013, Danish Gas Technology Centre)

However... NG grid proximity is not certain.
PtG system “Base Case” options

Issue 3: SNG output
Options:

A. Proximity to NG grid  
   i. Injection

B. Away from NG grid  
   i. Compression/Liquefaction/Storage/Transportation

“Base Case” selection: A

- Injection of NG is a core issue in HELMETH
- NG grid proximity will be assumed in all cases examined
PtG system “Base Case” options

**Issue 4: Nominal output power**

**Options:**

A. ~10 MW of converted el.  
B. ~100 MW of converted el.

- i. Existing techs: NaS; Flywheels
- ii. Existing techs: PHES; CAES

IEC: Electrical Energy Storage; White Paper
PtG system “Base Case” options

Issue 4: Nominal output power
Options:

A. ~10 MW of converted el.
   i. Existing techs: NaS; Flywheels

B. ~100 MW of converted el.
   ii. Existing techs: PHES; CAES

“Base Case” selection: A

- Straight connection to the CO₂ availability

Pictures:
www.bbfm.de
www.repotec.at
www.skwp.de
PtG system “Base Case” options

Issue 5: Utilization of produced O2

ISO 14044: “allocation should be avoided by expanding the product system to include the additional functions related to the co-products”

The O₂ outflow will replace the equivalent O₂ production from a reference system.

The impact of producing O₂ with the reference system is avoided.

<table>
<thead>
<tr>
<th>Technology &amp; development stage</th>
<th>O₂ purity %</th>
<th>Capacity, tons per day</th>
<th>Possible by-products, Their quality</th>
<th>Driving force</th>
<th>Start-up time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryogenic Matured</td>
<td>99 +</td>
<td>up to 4 000*</td>
<td>Nitrogen, Argon, Krypton, Xenon, Very good</td>
<td>Electricity</td>
<td>hours/days</td>
</tr>
<tr>
<td>Adsorption Matured</td>
<td>95 +</td>
<td>up to 300</td>
<td>Nitrogen, Bad, ca. 11% O₂</td>
<td>Electricity</td>
<td>minutes/hours</td>
</tr>
<tr>
<td>Membrane (polymer) Matured</td>
<td>~ 40</td>
<td>up to 20</td>
<td>Nitrogen Bad</td>
<td>Electricity</td>
<td>minutes</td>
</tr>
</tbody>
</table>

Pressure Switch Adsorption (PSA) is selected as the reference O₂ production system (gaseous phase, purity)

LCA Methodology

Life Cycle Assessment is a methodology aiming:
(a) to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment and
(b) to identify and evaluate opportunities to bring about environmental improvements

Examined system boundaries

Cultivation of biomass feedstock
- Biogas production
- Separation
- Compression

Bio-CH₄

Production of de-ionized water
- Avoided production of O₂

German electricity generation projections for 2020/2050

Electrolysis
- Methanation

PtG system boundaries
Grid Electric Supply

Objective: Estimation of environmental impact “inherited” from the electric input to the HELMETH “Base Case”

- Scenarios 1-3
  Achieving the NREAP targets by featuring a renewable share of ca. 40%.

- Scenarios 4-6
  The renewable share lies between 80% and 100%.

Corresponding inventories built and incorporated in LCA software

- VDE-ETG. Energiespeicher fuer die Energiewende. 2012
- OEKO Ins. – FhG-ISI. Klimaschutzszenario 2050. 2014.
CO₂ supply from biogas facility

1. Cultivation of biomass feedstock
2. Biogas production
3. Separation stage
4. Compression up to 30 bars

The diagram shows the following steps:

- Cultivation of biomass feedstock
- Biogas production
- Separation stage
- Compression up to 30 bars

The process involves:
- Electrolysis: Water (H₂O) is split into hydrogen (H₂) and oxygen (O₂)
- Methanation: CO₂ is converted into methane (CH₄)
- Electricity storage
CO$_2$ supply from biogas facility

Energy consumption & Emissions due to:

Production / extraction / transportation of Pesticides, Fertilizers, Diesel fuel

Electricity, Transportation of feedstock, Application of digestate

Electricity

Cultivation of biomass feedstock (Maize silage)

Biogas production

Separation stage (Pressure Switch Adsorption) → Bio-CH$_4$

CO$_2$ supply
CO₂ supply from biogas facility

Energy consumption & Emissions due to:

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- Electricity, Transportation of feedstock, Application of digestate
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Biogas production

Separation stage (Pressure Switch Adsorption)

CO₂ supply

Avoided Energy consumption & Emissions due to:

Displacing NG imports to DE from RU

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CO₂ supply from biogas facility

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Biogas production

Separation stage (Pressure Switch Adsorption)

- Ecoinvent LCA Database, v3.0
LCA Modelling

Concept system mass/energy balance
Simulated system efficiency 85%

Input | Output
--- | ---
Electricity : 12.5 kWh el | SNG : 1 m$^3$ (NTP)
CO$_2$ : ~1.9 kg | O$_2$ : ~2.8 kg
H$_2$O : ~4 kg
LCA Results

- Fossil CO$_2$ emissions caused/abated by the input/output flows considered (Electricity, CO$_2$, O$_2$ and water)

- The Fossil Primary Energy Demand (PED) of the respective flows, distinguished according to its origin (renewable: wind, solar, biomass, geothermal and non-renewable: fossil and nuclear).
LCA Results

Input of CO₂ from biomethane plant is associated to avoiding from 3.7 to 4.7 kg of emissions per produced m³ of SNG.

The O₂ utilization can have a noteworthy positive contribution, saving up to 13-14% of the CO₂ emitted for the overall electricity consumption (scenarios 1-3).

In the scenarios 4-6, the “carbon-sink” effect is observed.

Fossil CO₂ emissions of extracting, producing, transporting and burning 1 m³ of natural gas from Russia to Germany is estimated at **2.3 kg CO₂/m³ NG**.
LCA Results

More fossil PED is avoided than consumed, leading to a negative value of the corresponding index.

The “fossil PED sink effect” is increased in the scenarios 4-6, due to less fossil fuel combustion share in the generation mix.

Fossil PED of extracting, producing and transporting 1 m³ of natural gas from Russia to Germany is estimated at 50 MJ-eq/m³ NG.
Conclusions

• Provided that there will be no emissions expected from the operation stage, the environmental impacts are located in the upstream processes of supplying/utilizing the input/output flows: electricity, CO₂, water and O₂.

• In the “base case” formulated for the present analysis, the contribution of water supply proved insignificant. On the contrary, the electric generation mix is decisive towards minimizing the indirect impact and PED of the PtG concept system.

• Significant amounts of fossil emissions and primary energy are saved, by:
  • displacing fossil NG with bio-CH₄ and
  • secondly by avoiding conventional O₂ production

• Assuming a strong trend towards renewable generation and the utilization of CO₂ output of a biomethane plant showed a clear environmental advantage: the potential of a “fossil CO₂ and PED sink effect”, since more fossil emissions and PED are avoided than emitted/consumed.

• The enhanced efficiency potential of integrating high-temp electrolysis and methanation is capable to provide less life cycle CO₂ emissions compared to fossil NG, even when actual (non-fully renewable) generation mixes are considered.
Questions?

www.helmeth.eu

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