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

Environmental aspects of Power-to-Gas concept systems.

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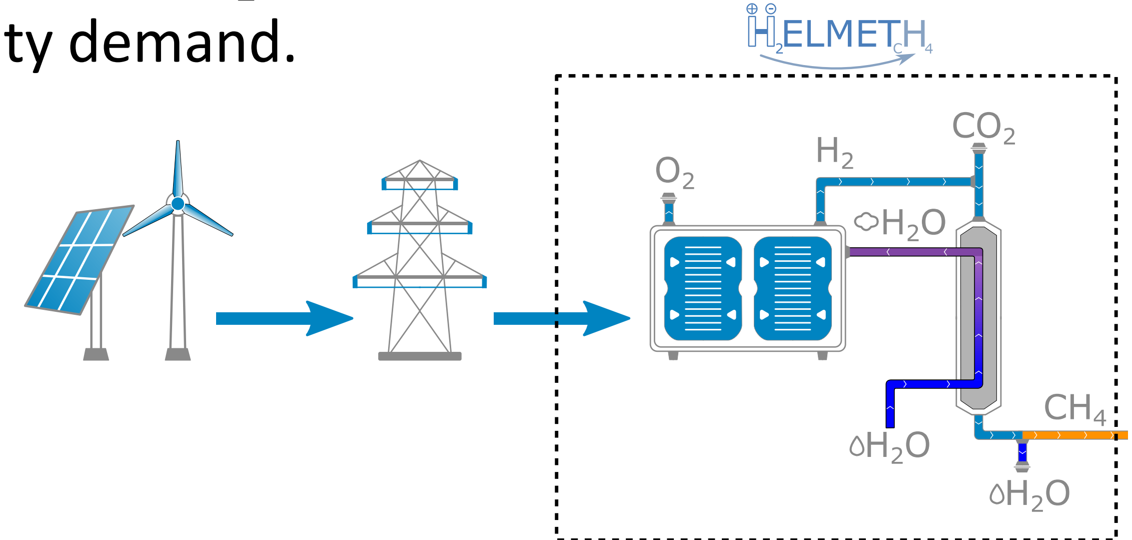
Objectives

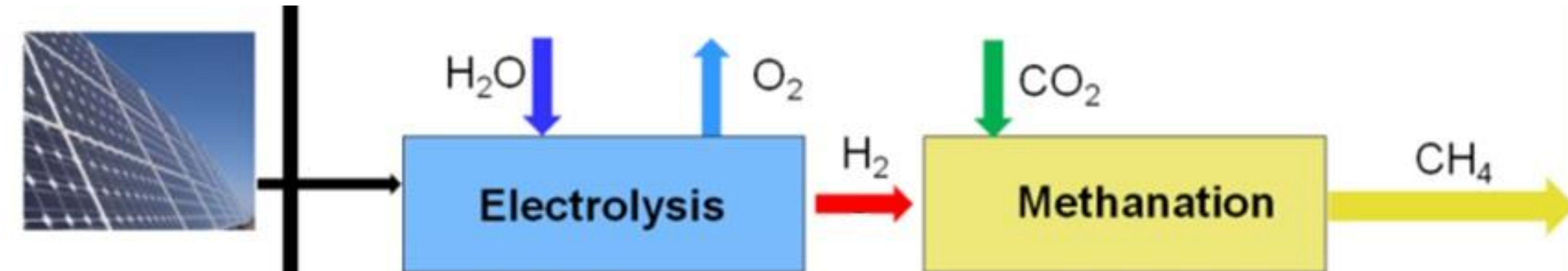
- The major objective is to assess the environmental and energetic performance of a “base case” scenario, involving assumptions regarding the CO_2 input feed and the generation mix of the electricity demand.



- The analysis refers to a “cradle-to-gate” approach, modelling the upstream energy/material flows which lead to the production of 1 m^3 of Synthetic Natural Gas (SNG).

Major assumptions

- No emissions from system operation (environmental impact assigned to upstream processes)
- The CO_2 input will be treated as a resource (incorporation of benefits and burdens all along its "supply chain") equivalent O_2 production from a reference system.



- Functional unit: 1 m^3 (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%)
- CO_2 from Biogas facility (including purification stage)
- The O_2 outflow will replace the equivalent O_2 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
- CO_2 supply
- SNG output
- Nominal output power of concept system
- Utilization of produced O_2

PtG system “Base Case” options

Issue 1: Electricity supply

Options:

A. Connected to el. grid → Continuous operation

B. Attached to Wind/PV power plant → Intermittent operation

“Base Case” selection: A

- High utilization
- Less starts/stops
- Lower SOEC degradation
- CO_2 supply and SNG grid injection near Wind/PV plants?

However… Electricity input only partially renewable

PtG system "Base Case" options

Issue 2: CO_2 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

small: biogas plants | medium: BM-gasification | big: industry (NH_3 etc.)

small: biogas plants
- ≈ 500 m³/h CO_2
- ⇨ ≈ 2 000 m³/h H_2 necessary
- „bio methane" 500 m³/h
- product gas (bio methane + SNG): **1 000 m³/h CH_4** ≈ 11 MW (chem.)

medium: BM-gasification
- ≈ 2 100 m³/h CO_2
- ≈ 1 400 m³/h CO
- ⇨ ≈ 12 600 m³/h H_2 (8 100 m³/h from electrolysis)
- product gas: **3 500** (4 500) **m³/h CH_4** ≈ **40** (50) MW (chem.)

(...) = incl. 1 000 m³/h CH_4 in the rawgas

big: industry (NH_3 etc.)
- ≈ 30 000 m³/h CO_2
- ⇨ ≈ 120 000 m³/h H_2 necessary
- NH_3-Anlage: CO_2 is byproduct
- product gas: **30 000 m³/h CH_4** ≈ 332 MW (chem.)

Pictures:
www.bbfm.de
www.repotec.at
www.skwp.de

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

PtG system "Base Case" options

Issue 2: CO_2 supply

Options:

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

B. Bioenergy facility
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C. Industrial source
- i. Clinker/Cement
- ii. Fertilizers

"Base Case" selection: B-i

- Biogenic carbon input
- High CO_2 content compared to flue gas
- Preferred CO_2 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 → ii. 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

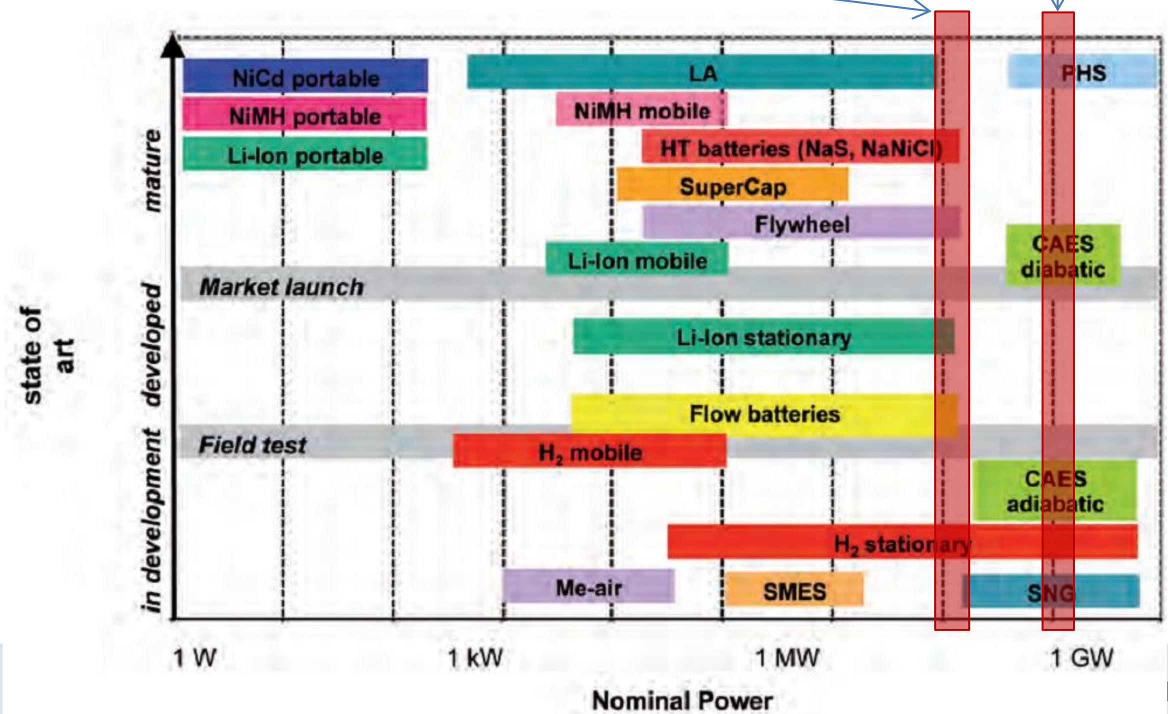
PtG system "Base Case" options

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. **B.** ~100 MW of converted el.

i. Existing techs: NaS; Flywheels

ii. Existing techs: PHES; CAES

"Base Case" selection: A

- Straight connection to the CO_2 availability

Pictures:
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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 O_2 outflow will replace the equivalent O_2 production from a reference system.

The impact of producing O_2 with the reference system is avoided.

Technology & development stage	O_2 purity %	Capacity, tons per day	Possible by-products, Their quality	Driving force	Start-up time
Cryogenic Matured	99 +	up to 4 000*	Nitrogen, Argon, Krypton, Xenon, Very good	Electricity	hours/ days
Adsorption Matured	95 +	up to 300	Nitrogen, Bad, ca. 11% O_2	Electricity Heat (70-90 °C)	minutes/ hours
Membrane (polymer) Matured	~ 40	up to 20	Nitrogen Bad	Electricity	minutes

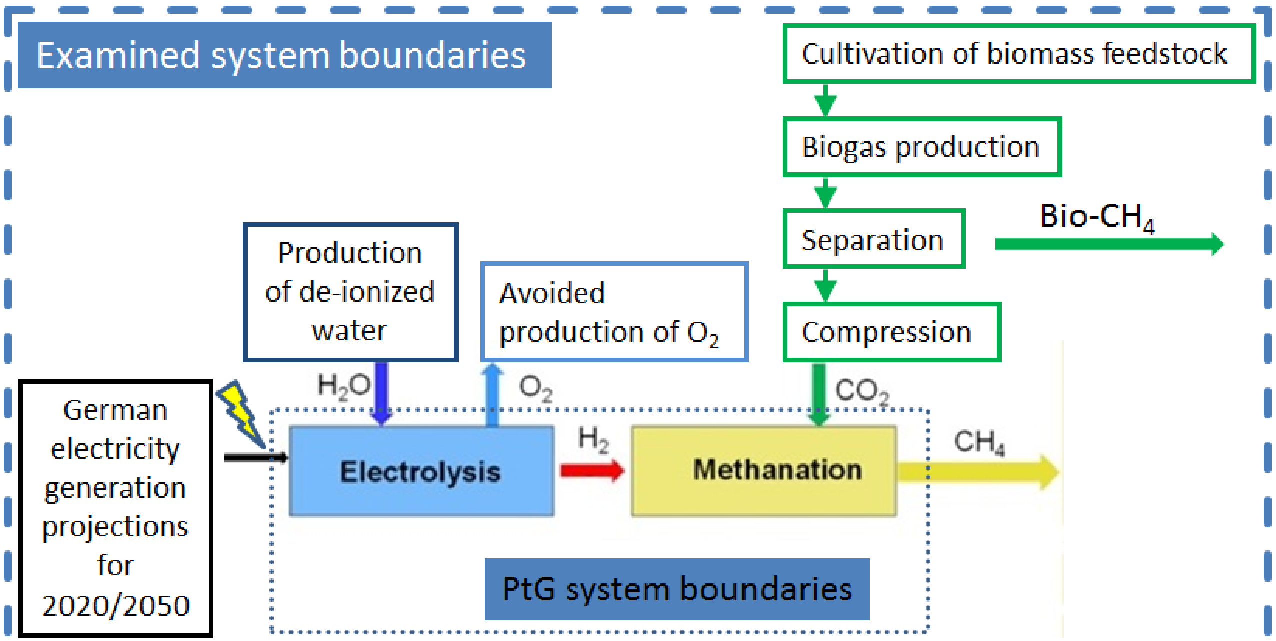
Pressure Switch Adsorption (PSA) is selected as the reference O_2 production system (gaseous phase, purity)

*Banaszkiewicz et al. "Comparative analysis of oxygen production for oxy-combustion application". Energy Procedia 51 (2014) 127 – 134

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

http://www.solidworks.com/sustainability



Grid Electric Supply

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

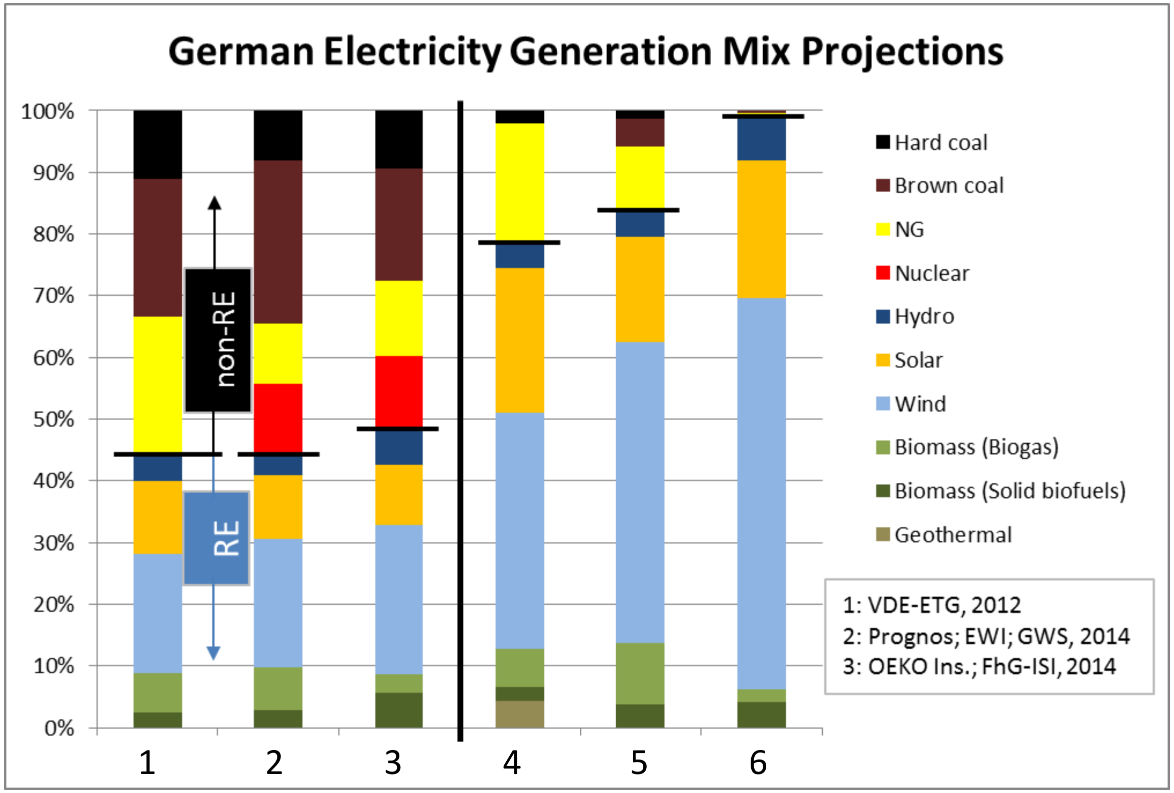
- Scenarios 1-3

Achieving the NREAP targets by featuring a renewable share of ca. 40%.

- Scenarios 4-6

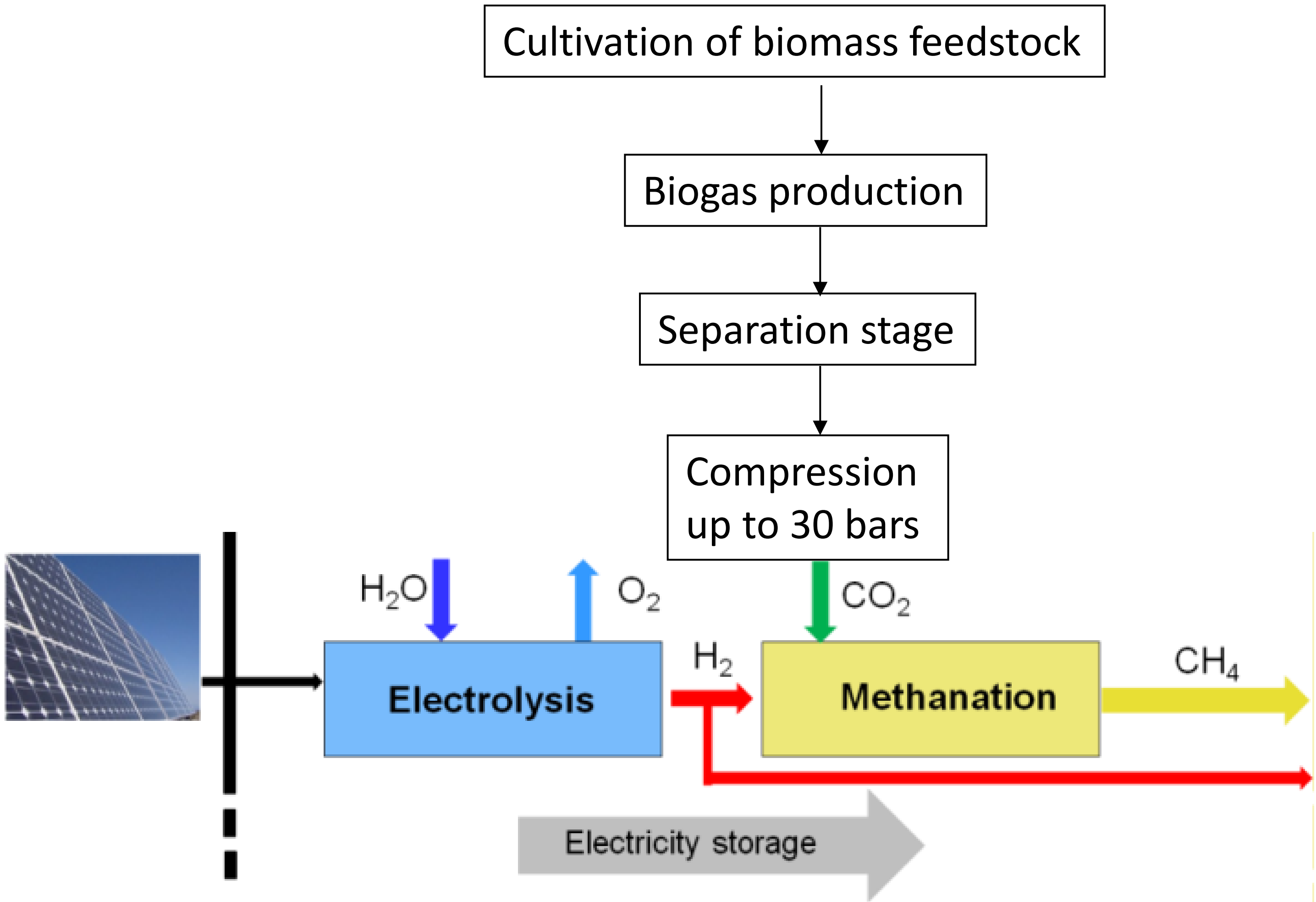
The renewable share lies between 80% and 100%.

Corresponding inventories built and incorporated in LCA software



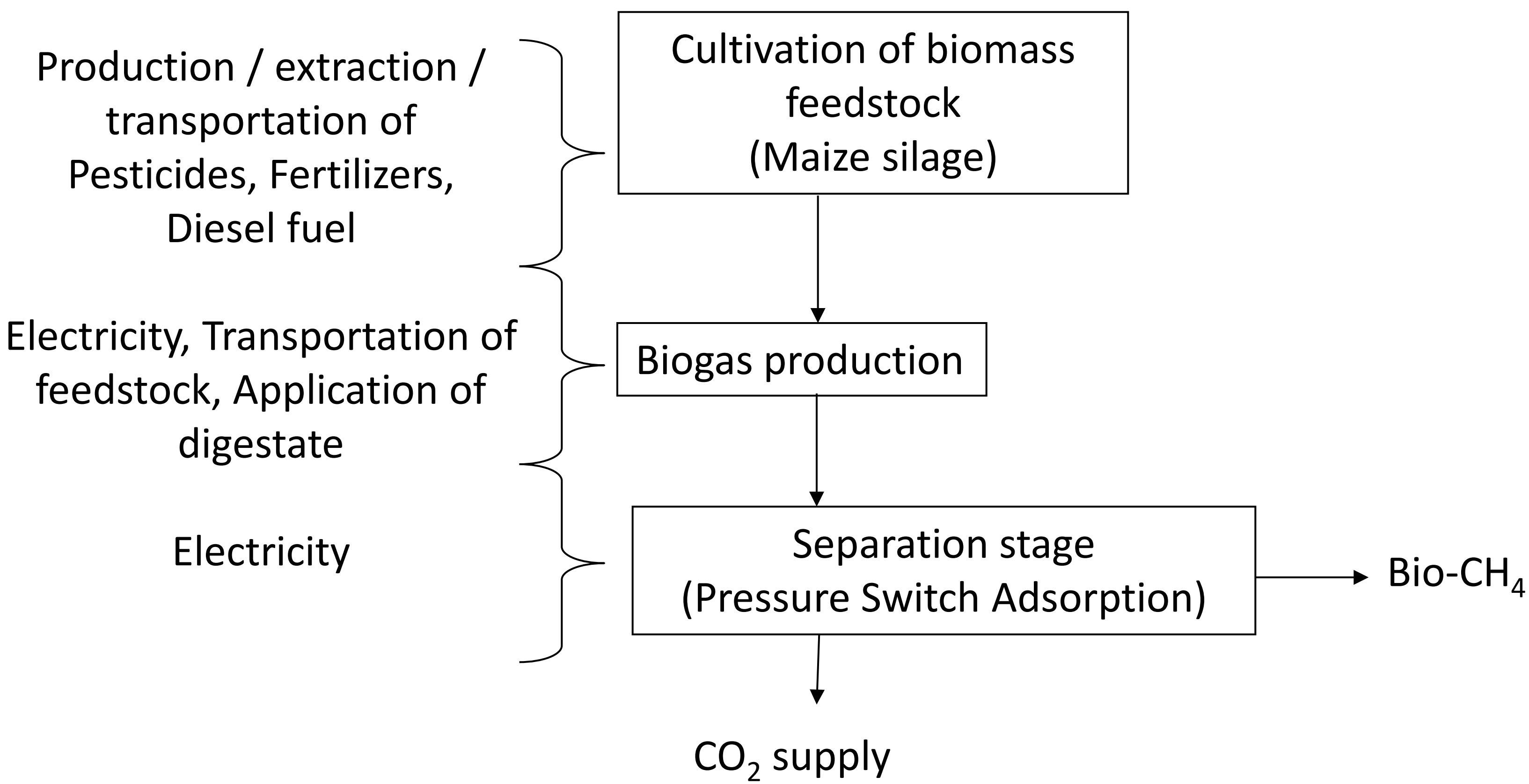
- VDE-ETG. Energiespeicher fuer die Energiewende. 2012
- PROGNOS-EWI-GWS. Entwicklung der Energiemaerkte – Energiereferenzprognose. Project Nr. 57/12. 2014
- OEKO Ins. – FhG-ISI. Klimaschutzszenario 2050. 2014.

CO_2 supply from biogas facility



CO_2 supply from biogas facility

Energy consumption & Emissions due to:



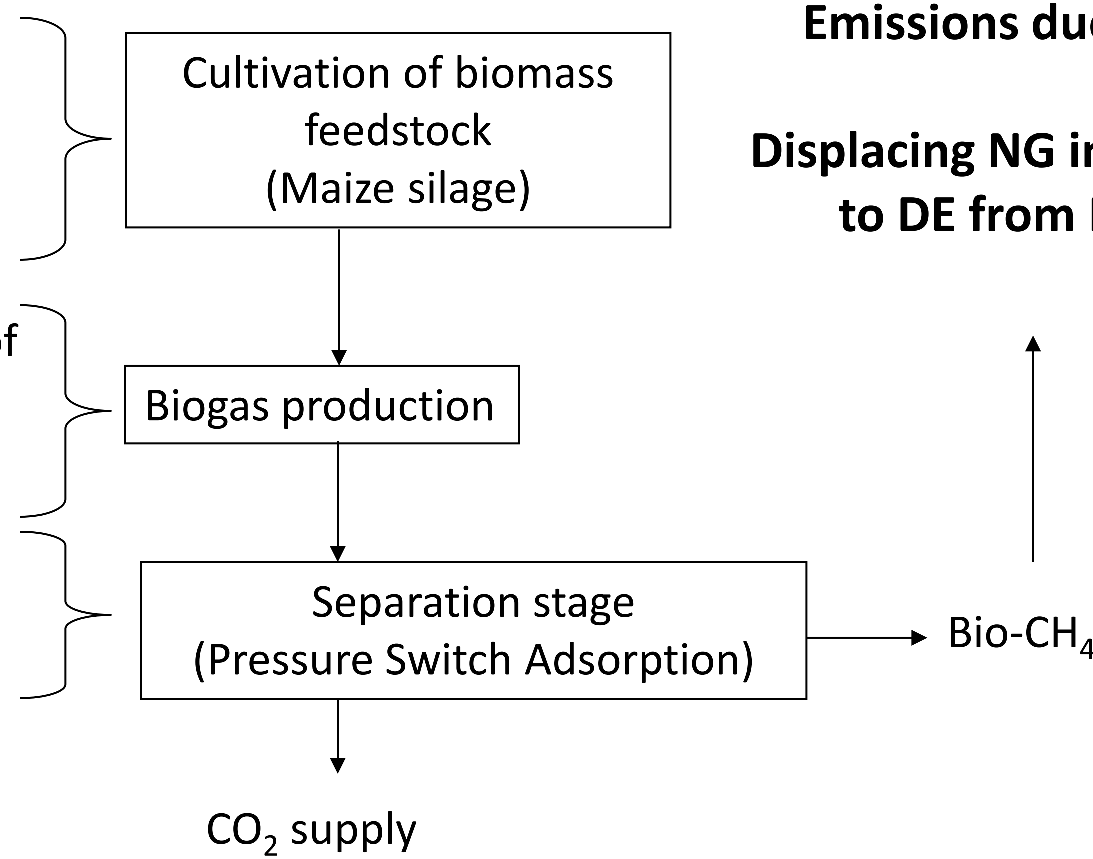
CO_2 supply from biogas facility

Energy consumption & Emissions due to:

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

Electricity, Transportation of feedstock, Application of digestate

Electricity

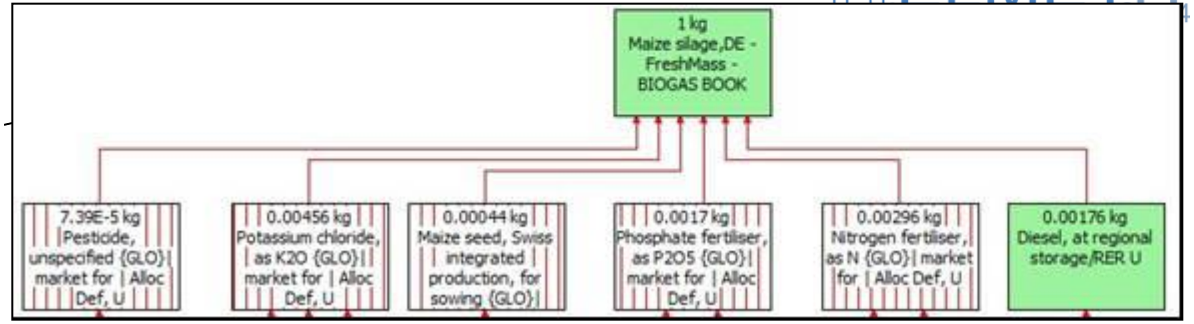


Avoided Energy consumption & Emissions due to:

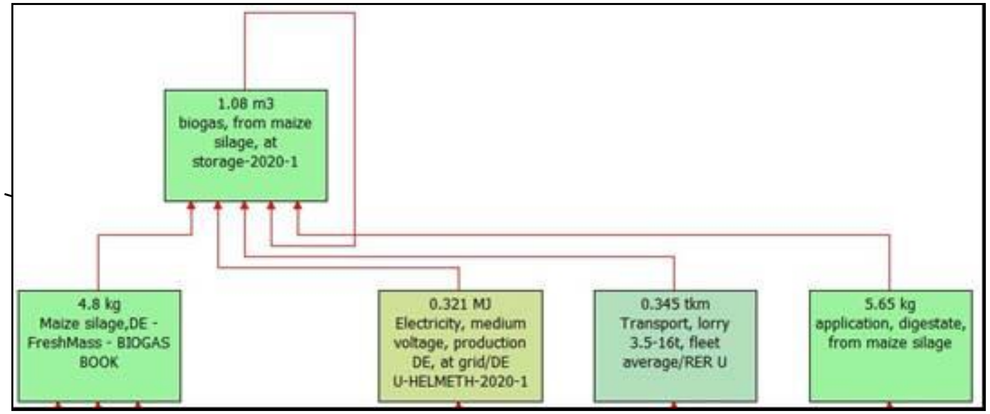
Displacing NG imports to DE from RU

CO_2 supply from biogas facility

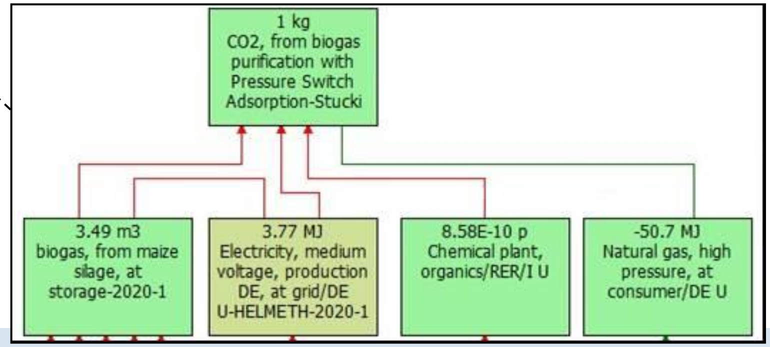
Cultivation of biomass feedstock (Maize silage)



Biogas production



Separation stage (Pressure Switch Adsorption)

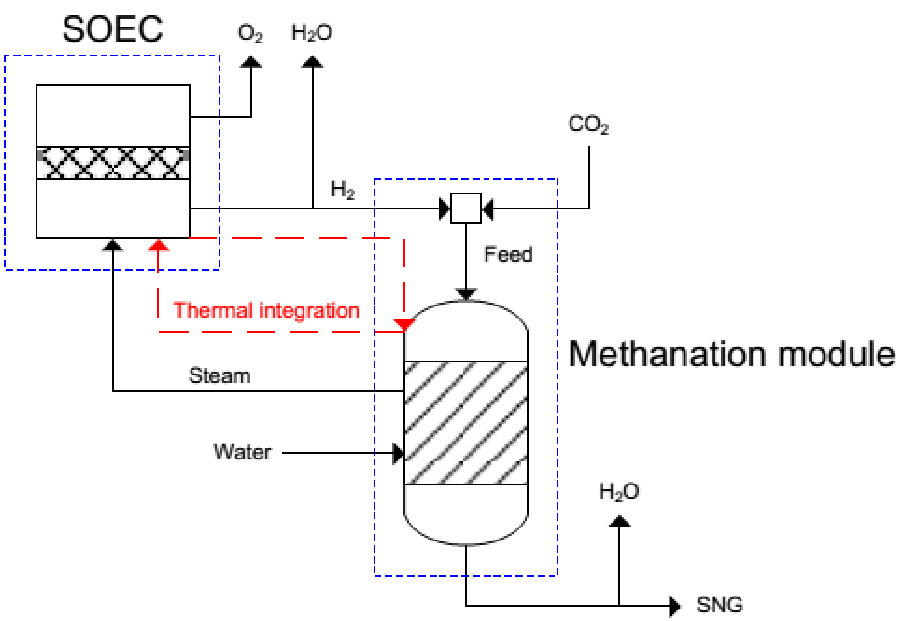


- Stucki M. et al., "*Life Cycle Assessment of Biogas Production from Different Substrates*", ESU-services Ltd., Bundesamt für Energie BFE Forschungsprogramm Biomasse.
- Graf, F. and Bajohr, Z. Biogas. Erzeugung, Aufbereitung, Enspeisung. 2. Auflage. Deutscher Industrieverlag GmbH. 2013
- Ecoinvent LCA 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	
H_2O : ~4 kg	O_2 : ~2.8 kg

LCA Results

- Fossil CO_2 emissions caused/abated by the input/output flows considered (Electricity, CO_2 , O_2 and water)

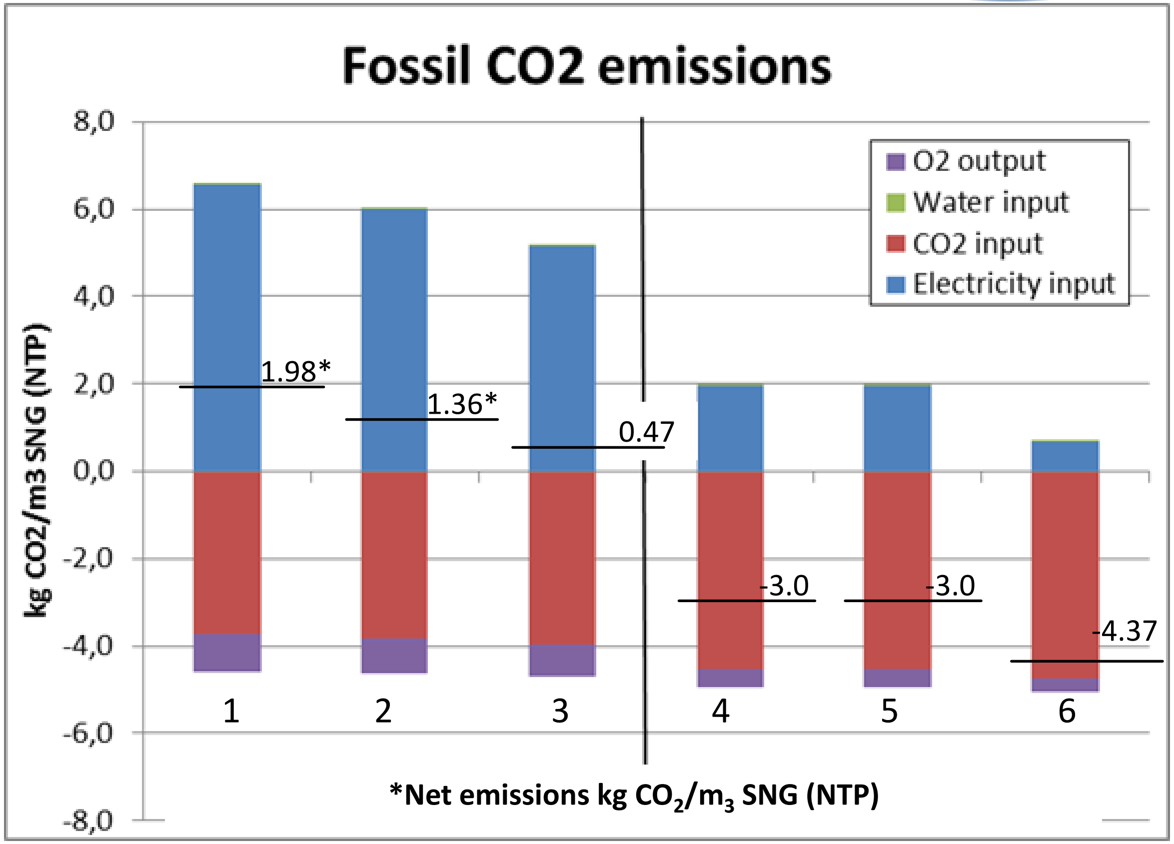
- The Fossil Primary Energy Demand (PED) of the respective flows, distinguished according to its origin (renewable: wind, solar, biomass, geothermal and non-renewable: fossil and nuclear).

LCA Results

Input of CO_2 from biomethane plant is associated to avoiding from 3.7 to 4.7 kg of emissions per produced m^3 of SNG.

The O_2 utilization can have a noteworthy positive contribution, saving up to 13-14% of the CO_2 emitted for the overall electricity consumption (scenarios 1-3).

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

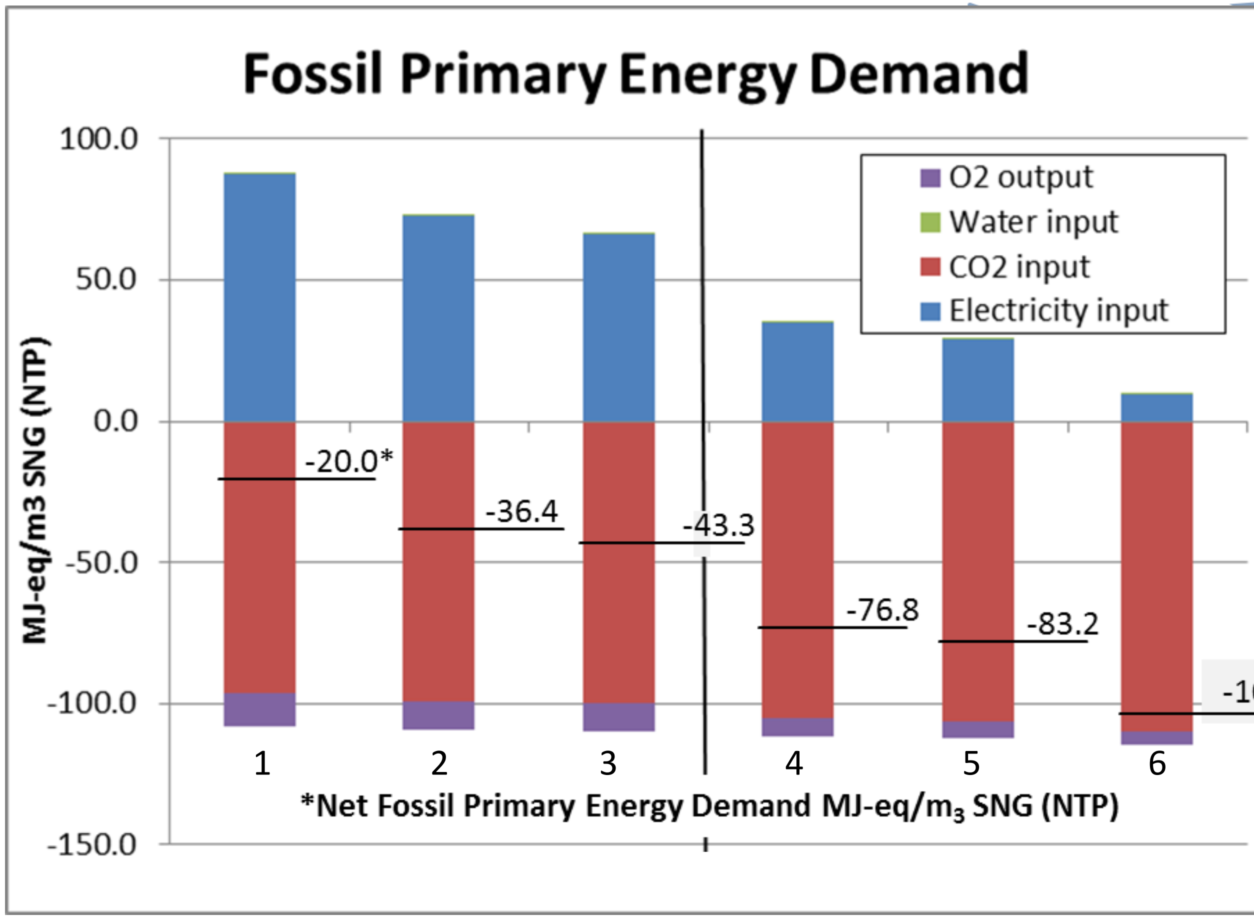


Fossil $_{CO2}$ emissions of extracting, producing, transporting and burning 1 m^3 of natural gas from Russia to Germany is estimated at **2.3 kg CO_2/m^3 NG**.

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 m^3 of natural gas from Russia to Germany is estimated at **50 MJ-eq/m^3 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, CO_2, water and O_2.
- 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-CH_4 and
  - secondly by avoiding conventional O_2 production

- Assuming a strong trend towards renewable generation and the utilization of CO_2 output of a biomethane plant showed a clear environmental advantage: the potential of **a “fossil CO_2 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 CO_2 emissions compared to fossil NG**, even when actual (non-fully renewable) generation mixes are considered.

Questions ?

www.helmeth.eu

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