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

Power-to-Gas concept and overview of HELMETH project

Prof. Maria Founti

Director of NTUA.HMCS

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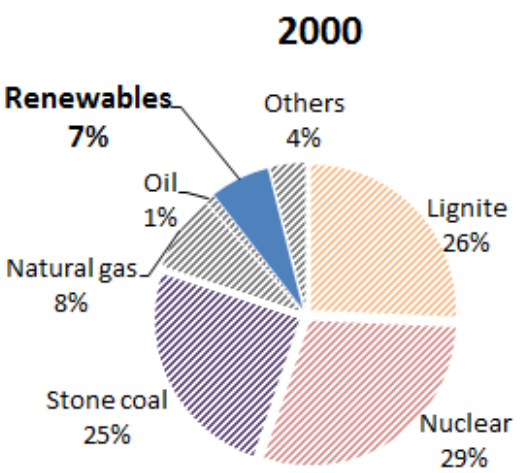
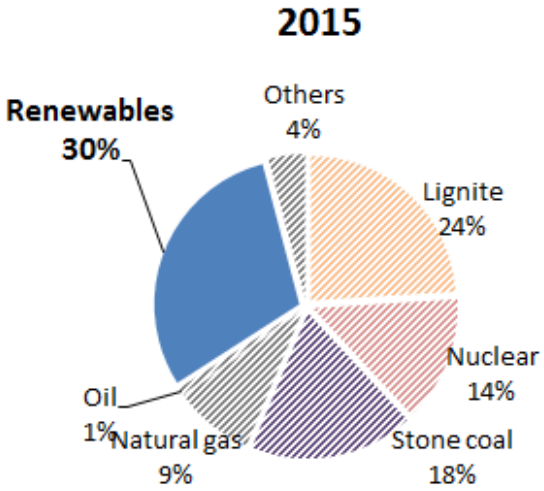
Motivation for Power to Gas

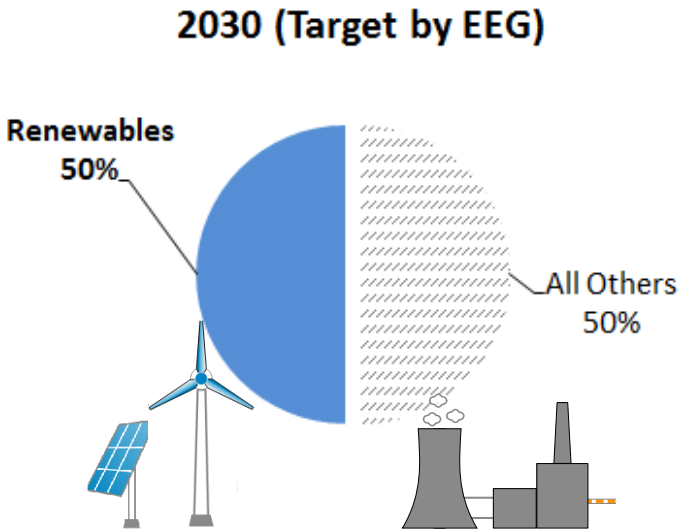
Gross Electricity Production, exemplary shown for Germany



AG-Energiebilanzen e.V.



AG-Energiebilanzen e.V.



EEG-2014

Further increasing share of renewables on electricity production in the future

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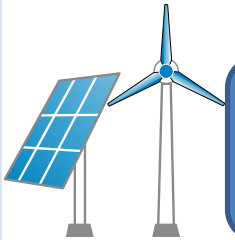
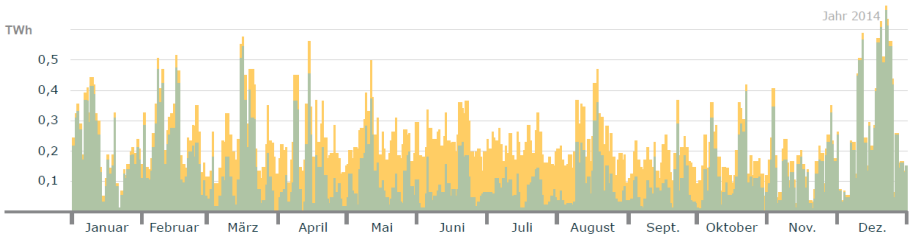
Motivation for Power to Gas



Production



Fraunhofer ISE

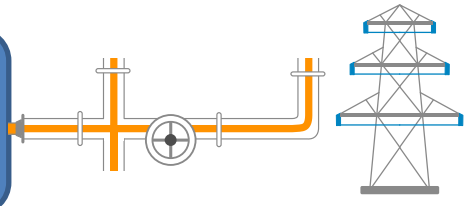
(Daily production of PV and WP in Germany 2014)

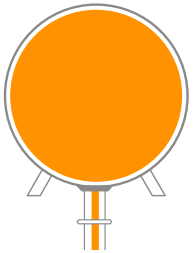
→ Fluctuating production

→ Compensation necessary

Power to Gas

Transport





Storage

- Higher transport performance of NG pipelines as power supply lines
- lower transport losses of NG pipeline

- Highest energy density of chemical energy carriers
- Storage capacity NG grid >> required capacity at 100 % renewable electricity in Germany

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The Power to Gas concept

Names: Power-to-Gas, PtG, P2G

PtH_2

$PtCH_4$

PtG, P2G, etc. :

- both options PtH_2 and $PtCH_4$ are under evaluation
- maximum H_2 concentration in NG grid is limited
- $PtCH_4$ is the only viable solution at very large scale

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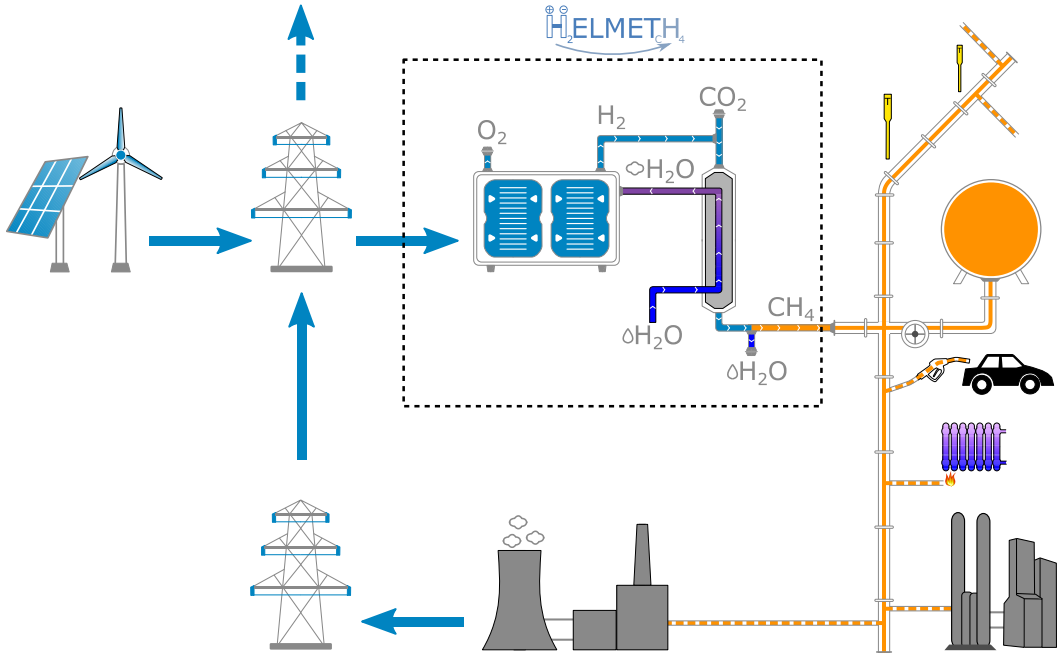
HELMETH Project

- Integrated **H**igh-Temperature **EL**ectrolysis and **METH**anation for Effective Power to Gas Conversion



- Proof of concept of a highly efficient PtG technology
- Technical feasibility of efficiencies $\eta_{PtG} = \frac{\dot{n}_{CH_4} \cdot HHV_{CH_4}}{\boldsymbol{P_{el}}} > 85\ \%$
- Output range: 30 - 60 kW_{CH4} (2.7 – 5.4 m^3/h STP)

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HELMETH Project

- Project duration: April 2014 – March 2017
- Project partners:
  - **Karlsruhe Institute of Technology**
  - **Politecnico di Torino**
  - **Sunfire GmbH**
  - **European Research Institute of Catalysis**
  - **National University of Athens**
  - **Ethos Energy Italy**
  - **DVGW Research Centre at Engler-Bunte-Institute**
- Project coordinator: D. Trimis

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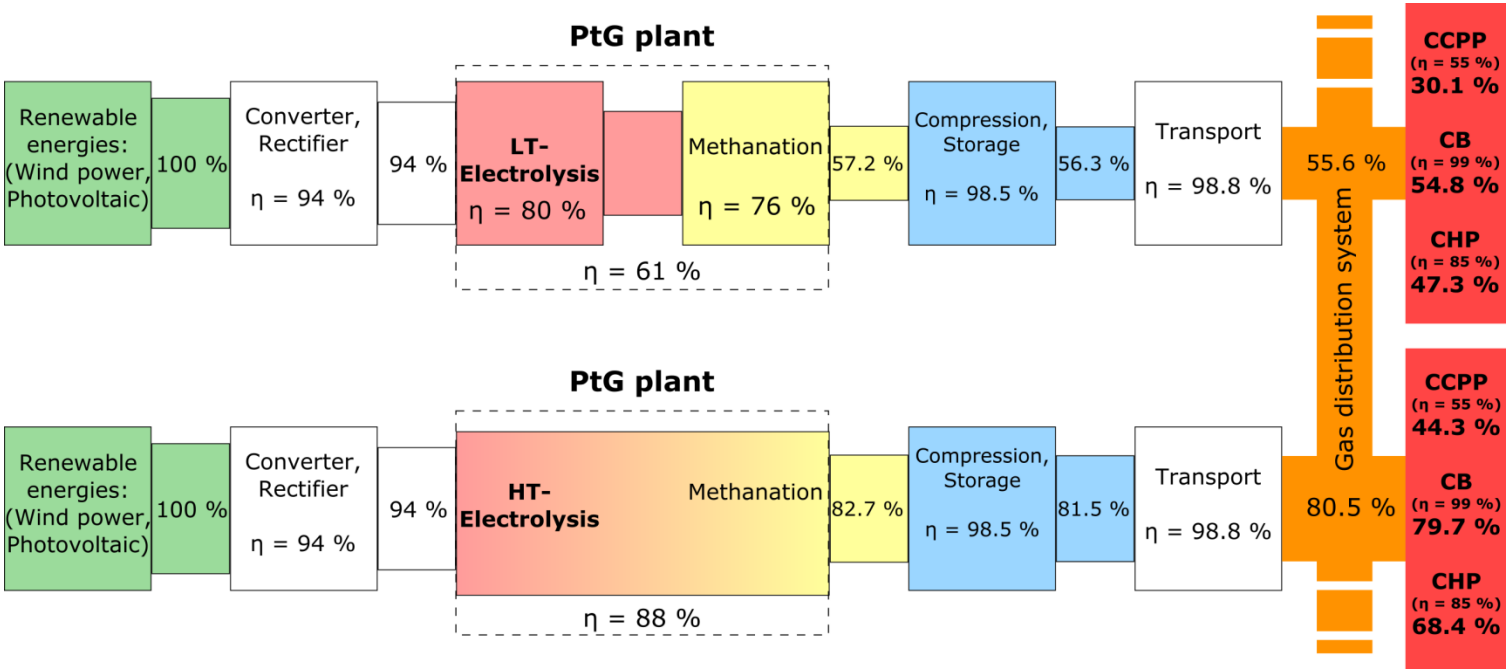
Coupling of electrolysis and methanation

Increased efficiency with the use of HT-electrolysis



S. Anger, D. Trims; *International Gas Union Research Conference 2014*

<u>Current electrolyzer technology:</u>

- Alkaline electrolysis (state of the art) → working range: 70-85°C; 1-30 bar
- PEM-electrolysis (Polymer Electrolyte Membrane) → laboratory applications - 2 MW_{el} ; working range: 50-80°C; 1-30 bar

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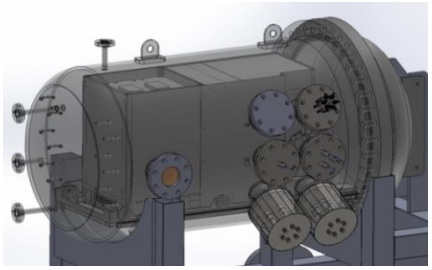
HELMETH component targets

High temperature steam electrolysis:



- Pressure ≥ 15 bar
- Low voltage degradation rates (< 0.5 % /1000 h)

Methanation module

- Produced SNG corresponding to (future) NG grid standards
  - → Multistep reactor concept
  - → Elevated pressure
- Continuous steam generation
- Modulation from 20 to 100 % load & stand-by operation

Thermal integration of both modules

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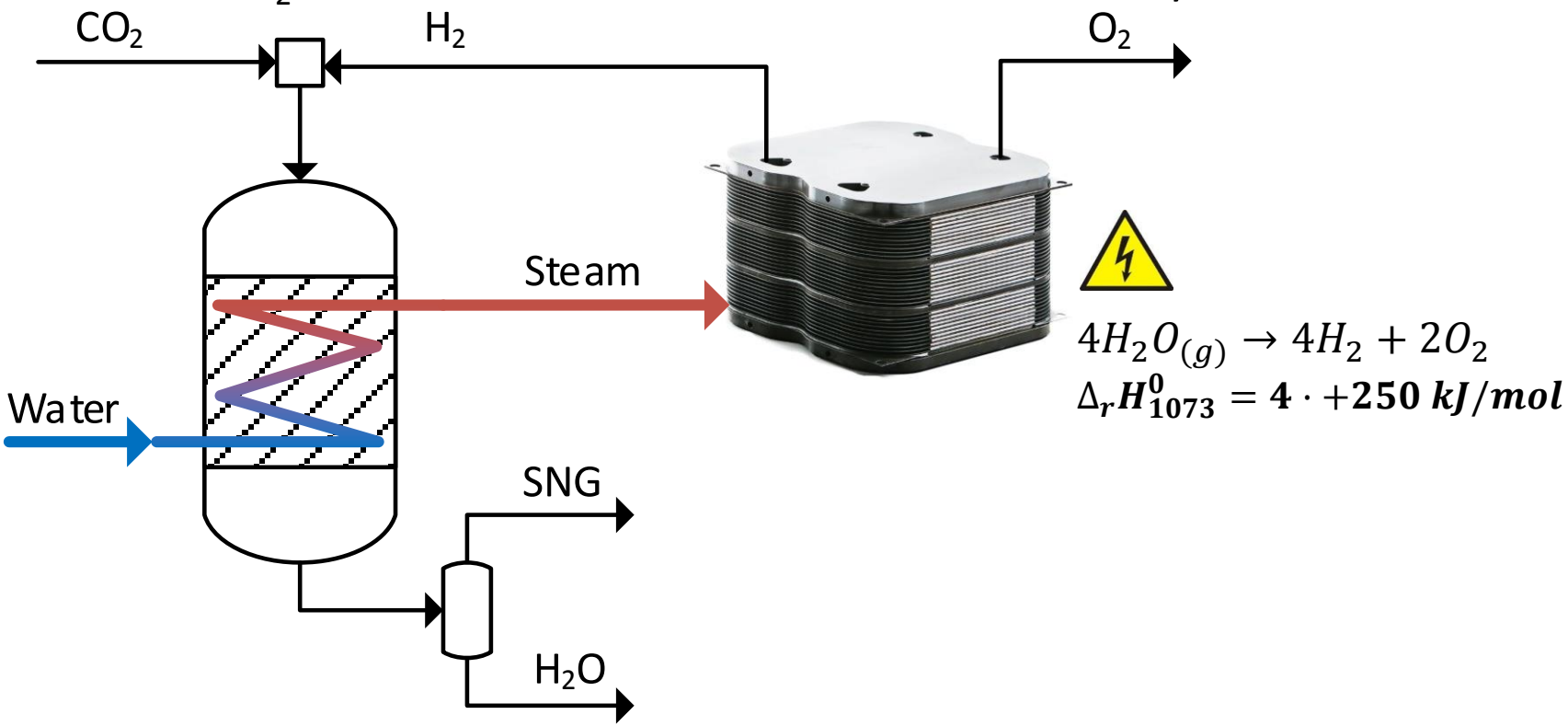
HELMETH concept

Thermal integration of:

exothermal CO_2-methanation & steam electrolysis



$$4H_2O_{(g)} \rightarrow 4H_2 + 2O_2$$
$$\Delta_r H^0_{1073} = 4 \cdot +250\ kJ/mol$$

$$CO_2 + 4H_2 \rightleftarrows CH_4 + 2H_2O$$
$$\Delta_r H^0_{298} = -165\ kJ/mol$$

Thermal integration

$$4H_2O_{(l)} \rightarrow 4H_2O_{(g)}$$
$$\Delta_{vap} H^0_{298} = 4 \cdot +44\ kJ/mol$$

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Electrolysis technologies

LT-Electrolysis

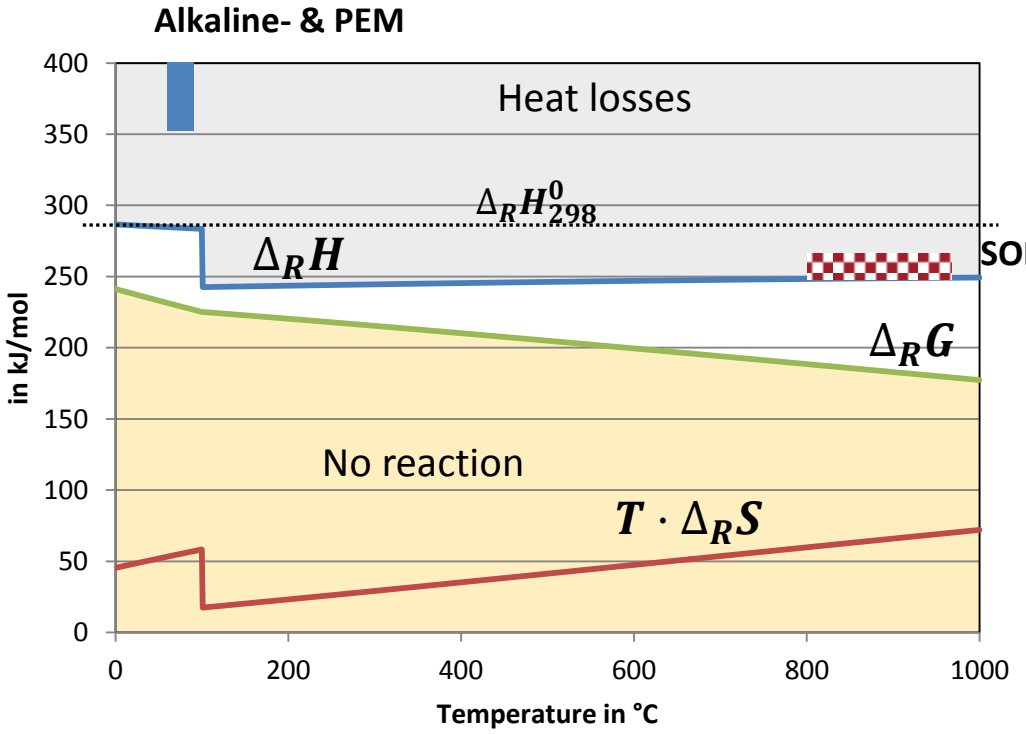
$$H_2O_{(l)} \rightarrow H_2 + \frac{1}{2}O_2 \qquad \Delta_R H^0_{298} = 285.83\ \frac{kJ}{mol}$$

HT-Electrolysis

$$H_2O_{(g)} \rightarrow H_2 + \frac{1}{2}O_2 \qquad \Delta_R H^0_{1073} = 250\ \frac{kJ}{mol}$$

latent heat of vaporization delivered by external source

http://dev.cep.daviesmeyer.com



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SOEC

Key characteristics of HELMETH SOEC *(Solid Oxide Electrolysis Cell)*

- Electrical input: up to 15 kW
- Operating pressure: 15 bar (30 bar in near future)
- Operating temperature: 800 – 850°C
- Current density: ≤ 1.0 A/cm^2

sunfire

Work done by:
J. Brabandt, R. Blumentritt, O. Posdziech

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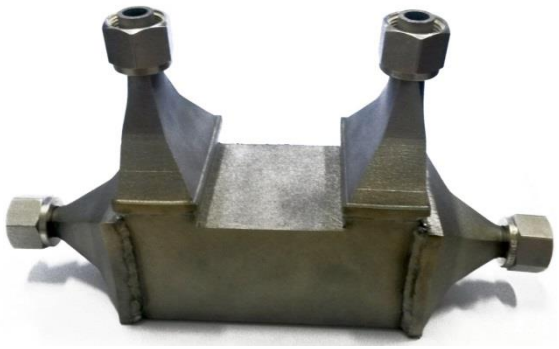
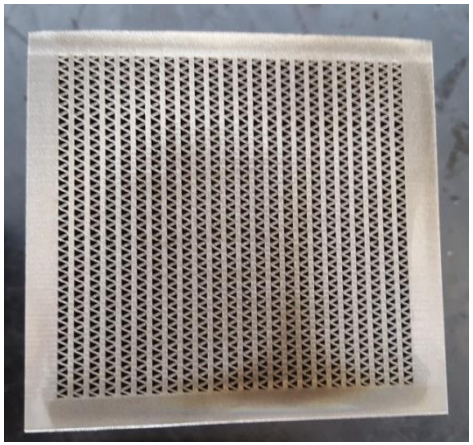
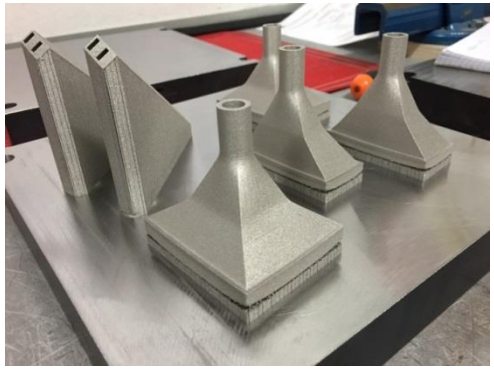
DMLS manufactured SOEC heat exchanger

- Fabrication of DMLS (**Direct Metal Laser Sintered**) gas-gas heat exchangers (Inconel 718)
- Operating temperature of up to 850°C
- Highly corrosive atmospheres (H_2 and O_2)
- Low pressure drop and efficient heat transfer required



Work by:
D. Manfredi, E. Ambrosio, F. Calignano, D. Ugues





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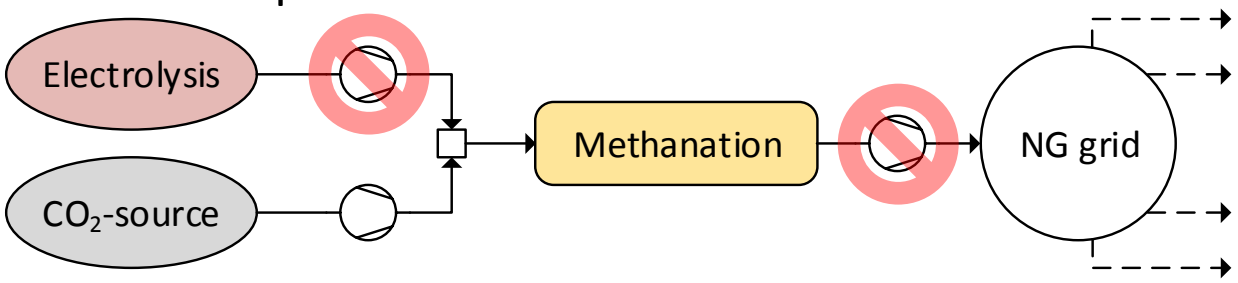
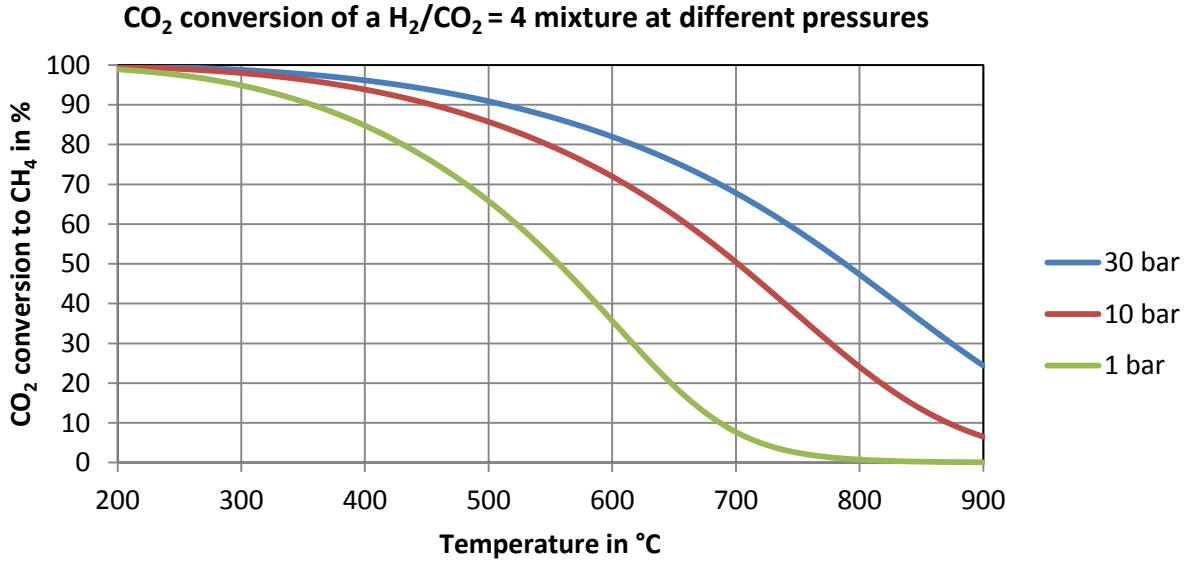
Advantages of pressurized operation

Operation of the PtG system at up to 30 bar:

- Reduces compression effort



- Shifts chemical equilibrium towards methane $CO_2 + 4H_2 \rightleftarrows CH_4 + 2H_2O$



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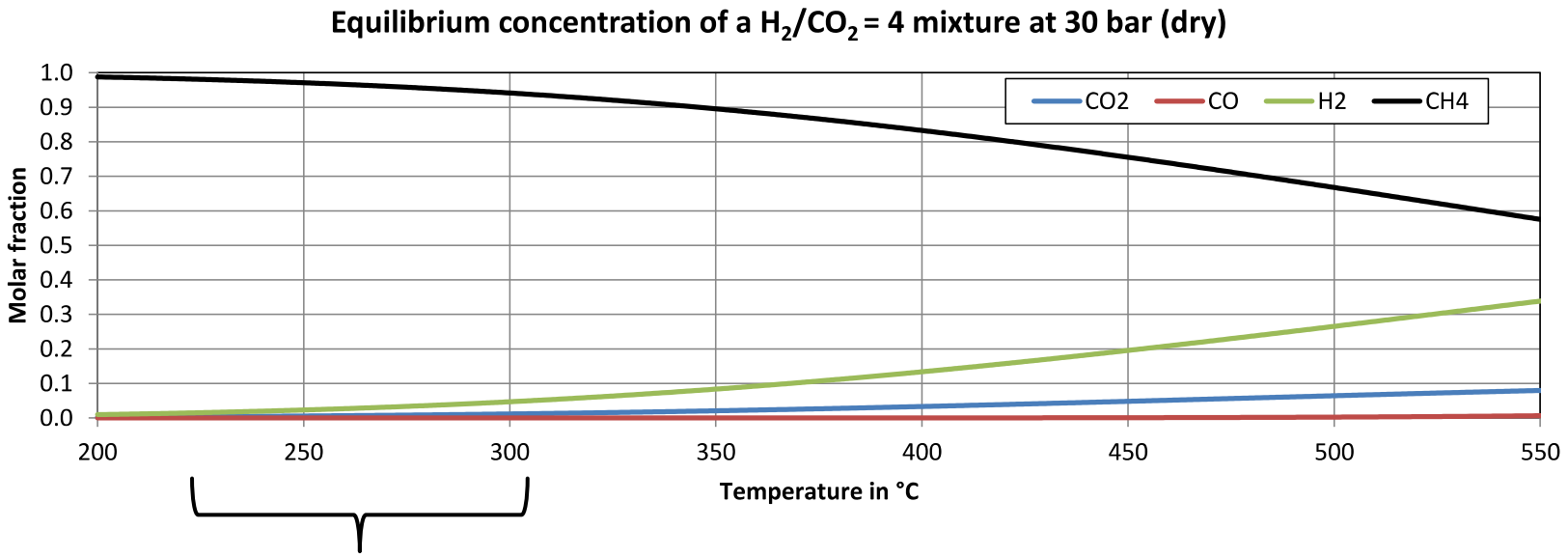
SNG quality requirements

Methanation module design for low hydrogen content in SNG



- 2 vol.-% H_2 at 240°C (current limitations from practice, e.g. DIN51624; However, unclear legal framework at the EU level, many different national norms)
- 5 vol.-% H_2 at 305°C (forecast for future European standards)

HELMETH targets: $H_2 < 5$; $CO_2 < 2.5$; $CH_4 > 92.5$ vol.-%

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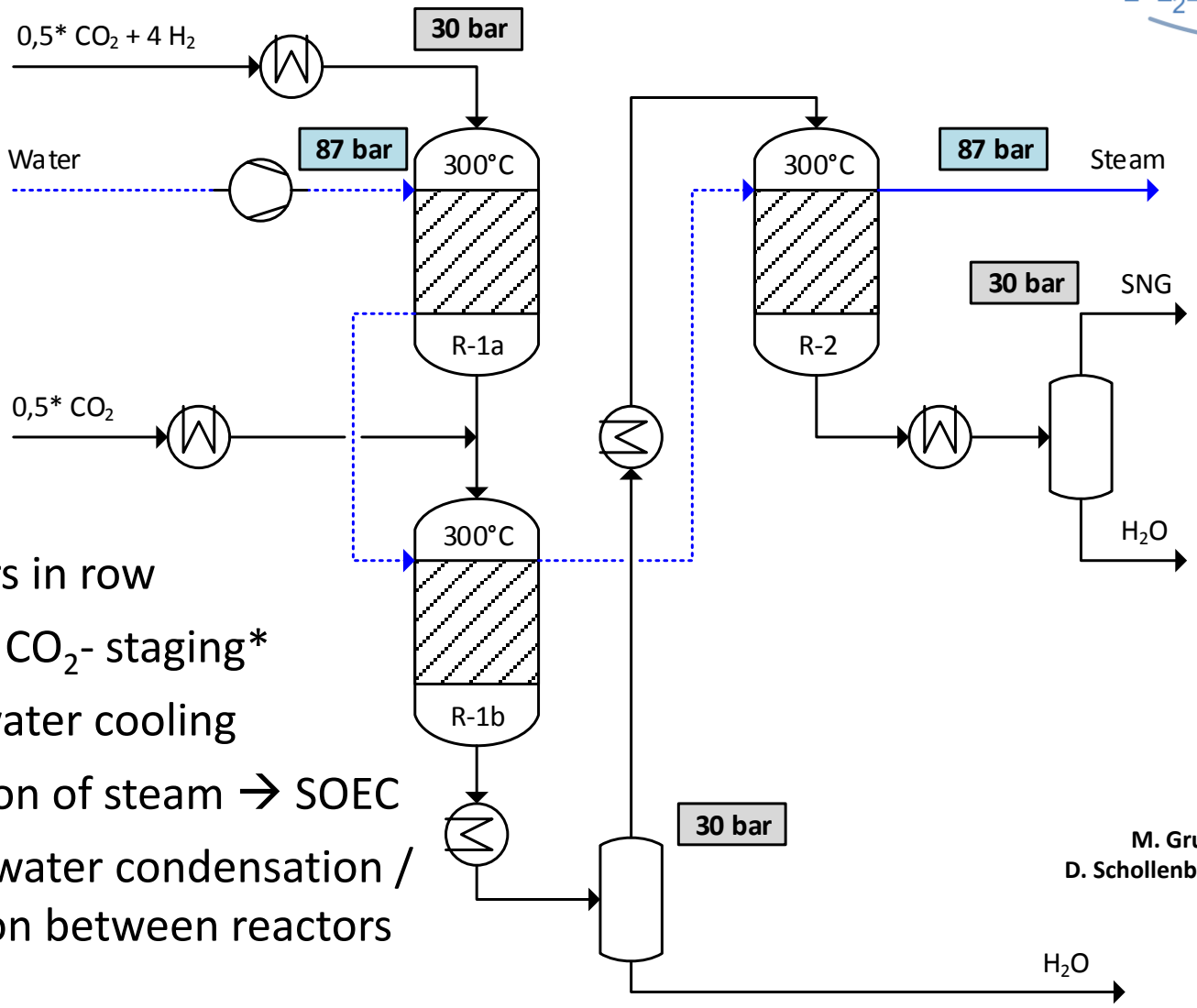
Methanation reactor concept



- 2 reactors in row
- Optional CO_2- staging*
- Boiling water cooling
- Production of steam → SOEC
- Product water condensation / separation between reactors

Karlsruhe Institute of Technology

Work by:
M. Gruber, S. Harth, D. Trimis
D. Schollenberger, S. Bajohr, T. Kolb

sunfire

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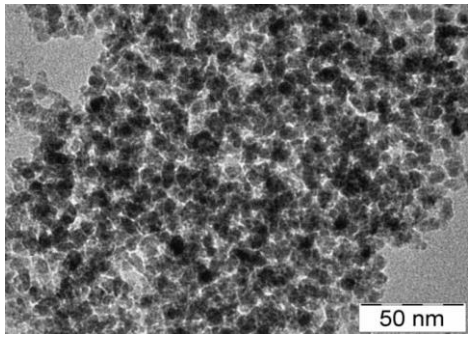
Methanation catalyst selection and optimization

Preparation of several Nickel-based catalysts

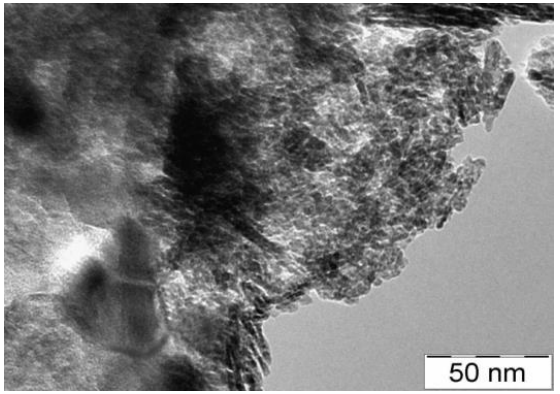
Nickel based catalysts

- Composite oxide supported catalysts
  - Impregnation and precipitation of γ-Al_2O_3 with different salt precursors
    - Composite oxides: Al_2O_3; ZrO_2; TiO_2; CeO_2
- Hydrotalcite derived Ni/Al_2O_3
  - Precipitation at three pHs: 8.2; 11; 12



Highly dispersed and round-shaped Ni nanoparticles & narrow size distribution

- Commercial Ni-cat. from 3 different companies



Inhomogeneous distribution and shape of Ni particles

Work by:
S. Abate, S. Perathoner, G. Centi

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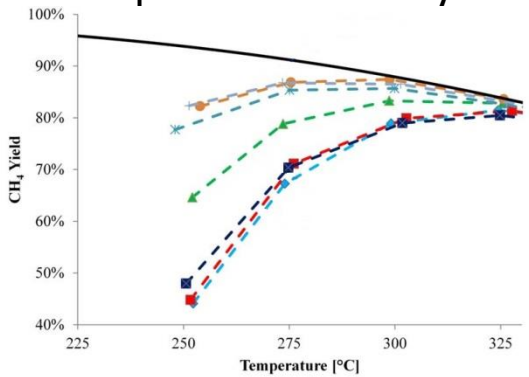
Catalyst testing and kinetic modelling

Methanation tests at pressures up to 27 bar

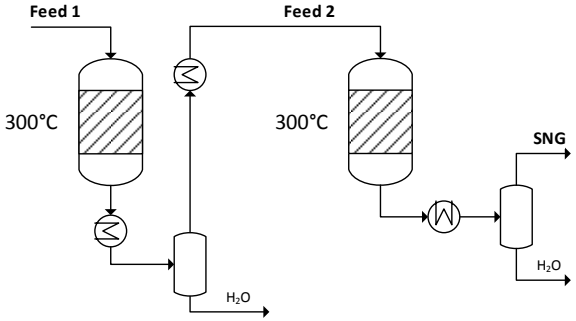
- Comparison of catalysts

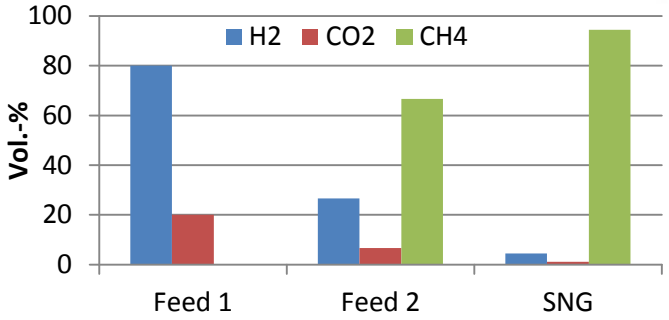


Atmospheric tests

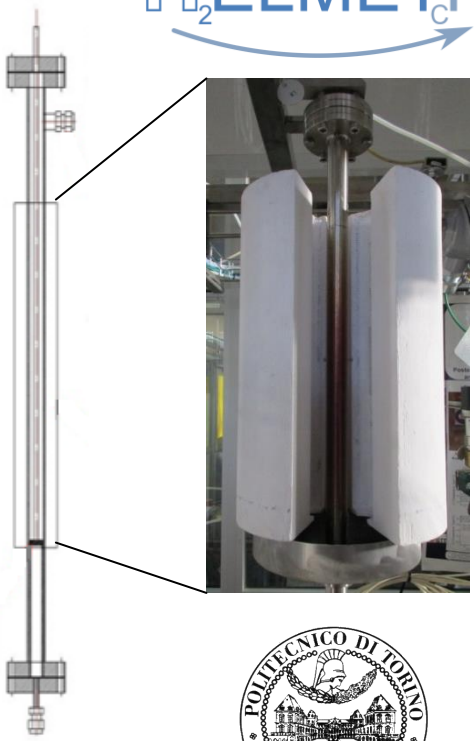
- Best performing self developed cat.
- Best performing commercial cat.
- Equilibrium

- Experiments with the conditions of both HELMETH concept reactors have been performed:





Results confirm the required overall conversion to reach the SNG quality criteria



Work by:
E. Giglio, F. Deorsola, S. Bensaid, R. Pirone

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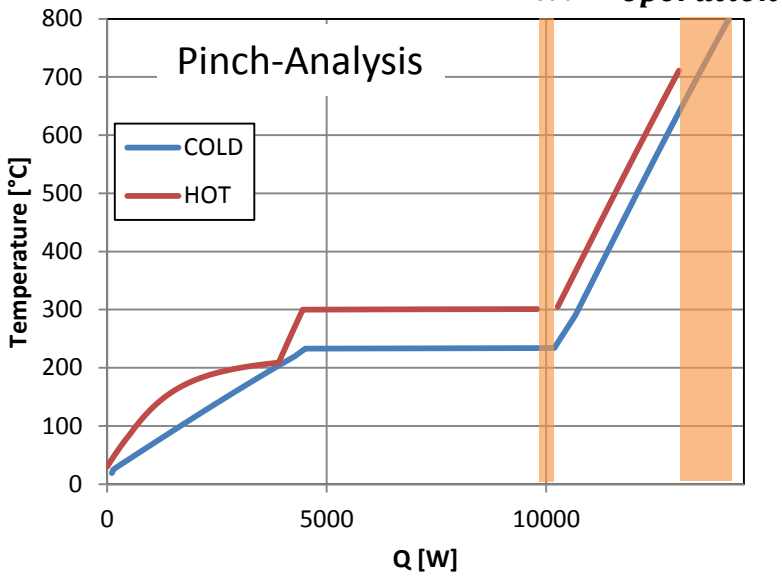
Detailed efficiency calculation

Coupled module with realistic thermal integration

SOEC

- Saturated steam feed
- Overheating through recuperation
- Steam conversion 80 %
- Exothermal operation P_{SOEC} (800°C, 1.31 V)



Methanation

- Cold H_2 feed from SOEC (25°C)
  (cooling and storage at SOEC outlet)
- Steam pressure reduction (87 to 30 bar) considered
- Additional electr. heating $\dot{Q}_{Meth}$ for energy balance at 80% SOEC steam conversion and 6 % steam loss through pressure reduction

$$\eta_{PtG-CH4} = \frac{\dot{n}_{CH4} \cdot HHV_{CH4}}{P_{SOEC} + \dot{Q}_{Meth} + heat\ loss} =$$

85.1 % (prototype with 8 % heat loss)
86.0 % (large scale with 2 % heat loss)

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Environmental aspects

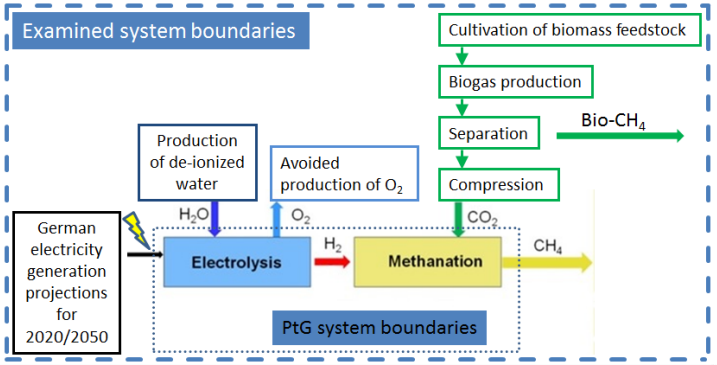
A step further than "environmental friendly" operation

The "carbon sink" effect potential of P-2-G technology

No direct emissions are expected from the operation → the environmental performance is determined by: (a) the quantity and quality of the electricity input and (b) the production of the CO_2 input stream

Mid-term case (2020) → **40% less fossil CO_2 emissions** than the typical reference case.

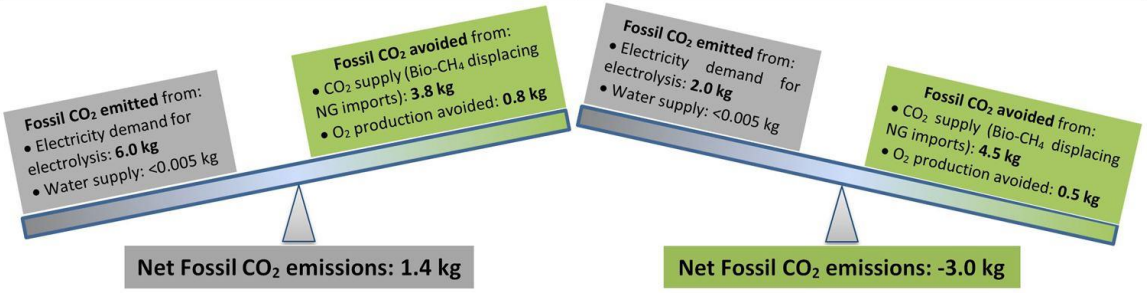
Long-term scenario → a **"carbon sink" effect**, since more CO_2 is avoided by the co-produced bio-CH_4 than emitted from the electricity demand for the electrolysis.



Fossil Carbon Dioxide Balance for the production and combustion of **1 m³ of SNG***

CO_2 source: Bio-methane plant

Electric input: German grid - Projection for **2020: 40% Renewable Generation**	Electric input: German grid - Projection for **2050: 80% Renewable Generation**



Reference case:
Fossil Carbon Dioxide emissions for the extraction, transportation and combustion of **1 m³ of fossil NG** (*Normal T and P): **2.3 kg**

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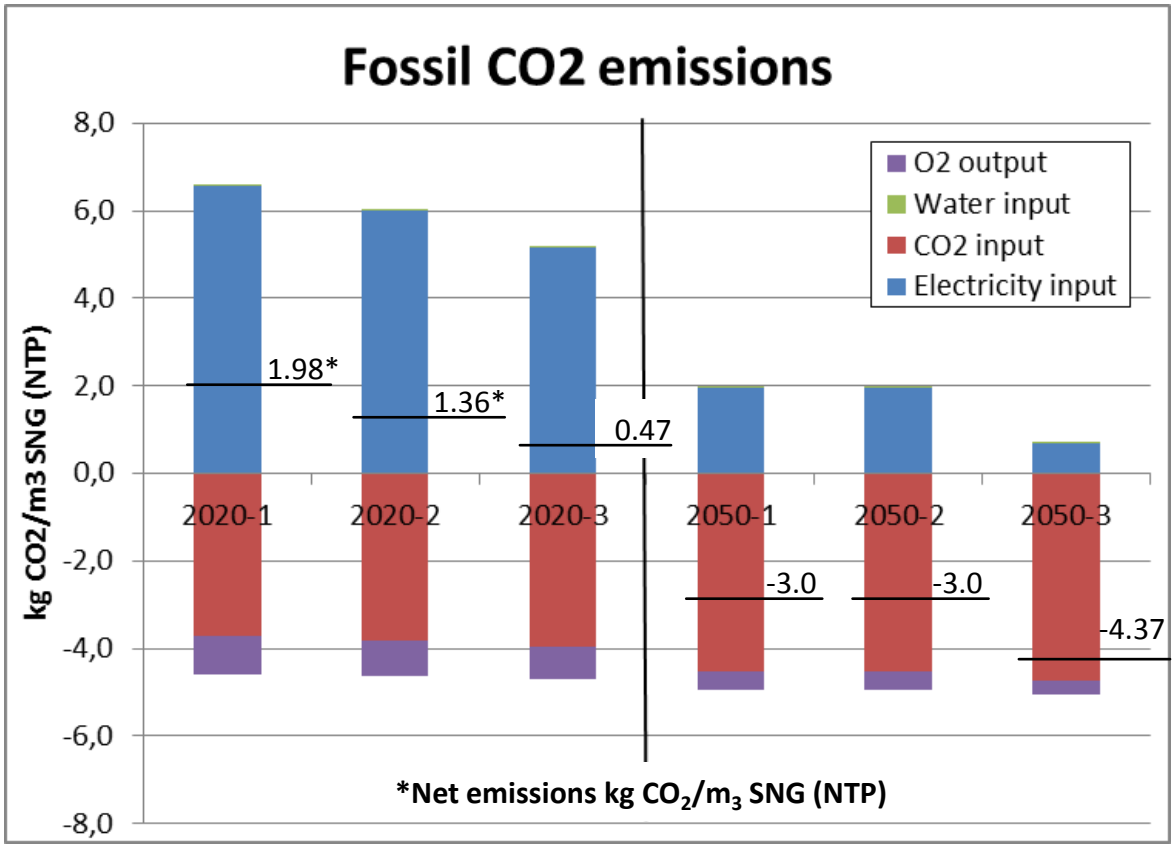
LCA Results

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 (2020 cases).

In 2050 scenarios, the "carbon-sink" effect is observed.



Fossil CO_2 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**.

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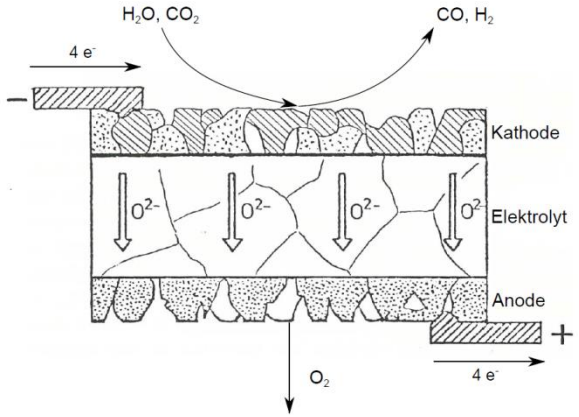
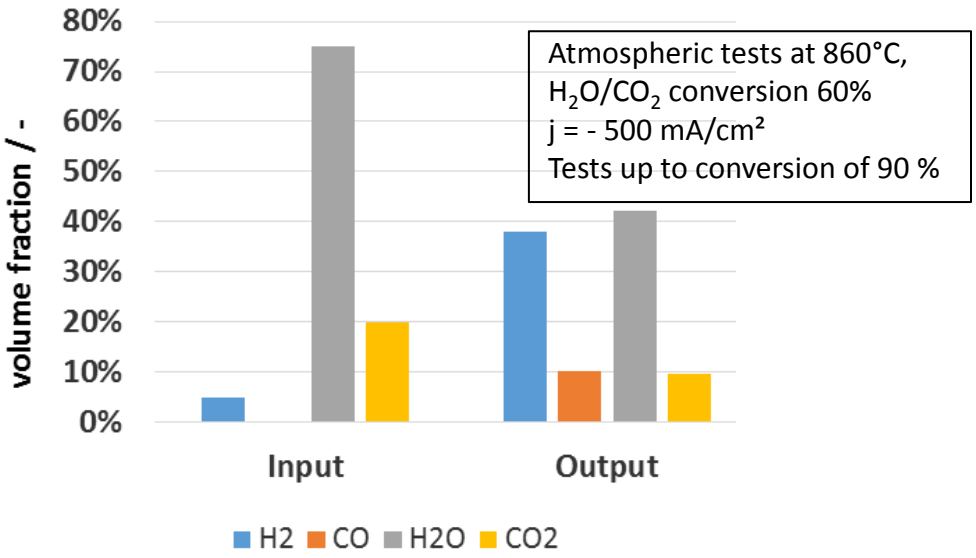
Additional research topic within HELMETH

co-electrolysis: simultaneous feed of steam and CO_2



$$H_2O + CO_2 \rightarrow H_2 + CO$$
$$\rightarrow O_2$$

$H_2O \rightarrow H_2 + 0.5\ O_2$ ⚠
$CO_2 \rightarrow CO + 0.5\ O_2$ (⚠)
$H_2 + CO_2 \leftrightarrow H_2O + \mathrm{CO}$



➡ Tests show feasibility of co-electrolysis

➡ Increasing of PtG efficiency possible by reduced SOEC steam demand (and methane formation in SOEC at high pressure)

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Summary and outlook

- SOEC stack tests show voltage degradation rates < 0.5 %/ 1000 h and feasibility of co-electrolysis
- Multiple nickel based catalysts were developed, tested (atmospheric and up to 30 bar) and optimized
- Multistep methanation module
  - SNG quality requirements are met (lab tests of reactor concept)
  - Steam generation (reactor cooling) for thermal integration with SOEC
- HELMETH concept efficiency ≥ 86 % for large scale plants based on realistic assumptions

<u>Outlook:</u>

- Operation of complete PtG prototype in early 2017

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Questions ?

www.helmeth.eu

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