Power-2-X facilities Foulum

Sommerhack 2021

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HALDOR TOPSØE

Who am I?

Summery

Chemical Engineer graduated from Aalborg University
PhD at Aarhus University with co-supervisor from Topsoe (JBH)
Working at Aarhus University Biogas test site since 2015 (Foulum)


Christian Dannesboe

Engineer

I like numbers
Intrigued by good ideas

Core values

How do we move from theory to practice?
Can we verify through analysis?
Are results presented fair and just?

I love "pressure testing" challenging and awkward ideas

Site locations in Denmark

Haldor Topsoe HQ

Aarhus University Foulum

Aarhus University Campus

Aarhus University - Foulum Campus

National facility for agricultural research

- 90 ha of JB4 fields under crop
- Equipment development
- Emmisions testing
- Processing of livestock

Biorefinery Group of AU

- Biogas production
- Biogas upgrading (BioSNG)
- Continuous HTL plant
- Protein extraction

Upcomming

- PV farm
- Energy conversion
- Energy storage

700 employees on site, 400 scientists/Ph. D./Post Doc.

The challenge of today!

Not every day is windy…

How do we ensure a sustainable supply of energy?

Can we store surplus production in batteries?

Energy storage, what scale is required?

The Hornsdale Power Reserve.
A capacity of 129 MWh installed in Australia by Tesla.

https://www.theguardian.com/australia-news/2017/dec/01/south-australia-turns-on-teslas-100mw-battery-history-in-the-making

Energy storage

Horns Rev 3 Offshore Wind Farm

Windmills	49
Type	Vestas 8 MW
Production capacity	407 MW
Yearly production	1’700’000 MWh

The worlds largest battery-park would be able to store production from Horns Rev 3 for …

$$\frac{129\ \mathrm{MWh}}{1'700'000\ \frac{\mathrm{MWh}}{\mathrm{year}}} = 0{,}000076\ \mathrm{years} = 40\ \mathrm{min}$$

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Reference: https://renews.biz/50703/horns-rev-3-delivers-first-power/

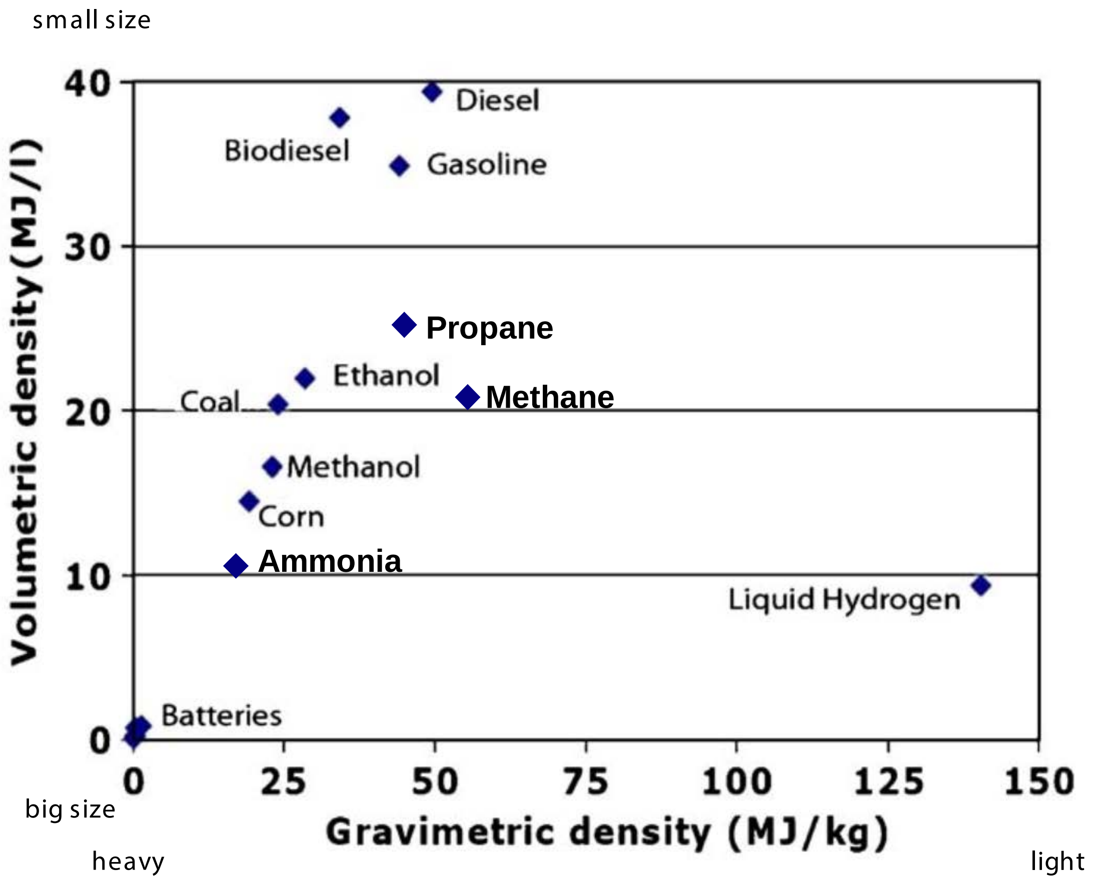
Chemical storage

Fossil fuels have a high volumetric energy density

Fossil fuels enable efficient storage and distribution of energy

Fossil fuel phase-out is both a desire and a challenge

Existing capacity for storage and distribution of fossil fuels will become vacant



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Reference: M. Fischer et al. / Energy Policy 37 (2009) 2639–2641

PART 1

Power-2-Methane

Production of synthetic natural gas

National gas grid

Pipeline grid to distribute natural gas (methane)

Covers most areas of Denmark

Transmission lines to

- Germany
- Sweden

Two storage facilities

- Lille Torup (salt diaper)
- Stenlille (aquifer)

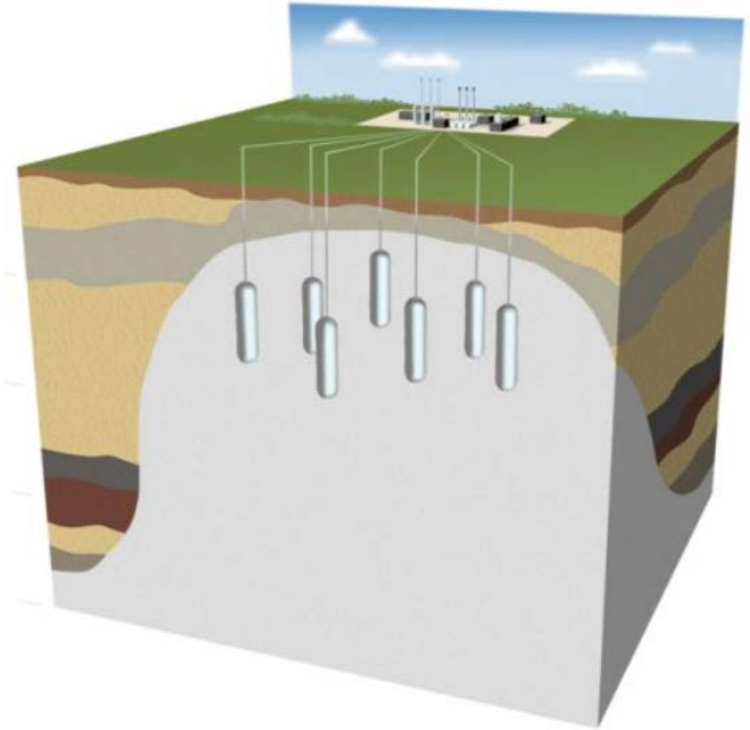
Reference: https://www.dgd.dk/skift-til-gas/godkendte-gasomraader/

Gas storage Lille Torup

Conversion of electricity to natural gas would enable:

Lille Torup

Caverns	7
Width x Height	50 m x 250 m
Total capacity	450 million Nm^3
Total energy capacity	45 million MWh



Lille Torup would be able to store production from Horns Rev 3 for …

$$\frac{45'000'000 \text{ MWh}}{1'700'000 \text{ MWh}} = 26 \text{ years}$$

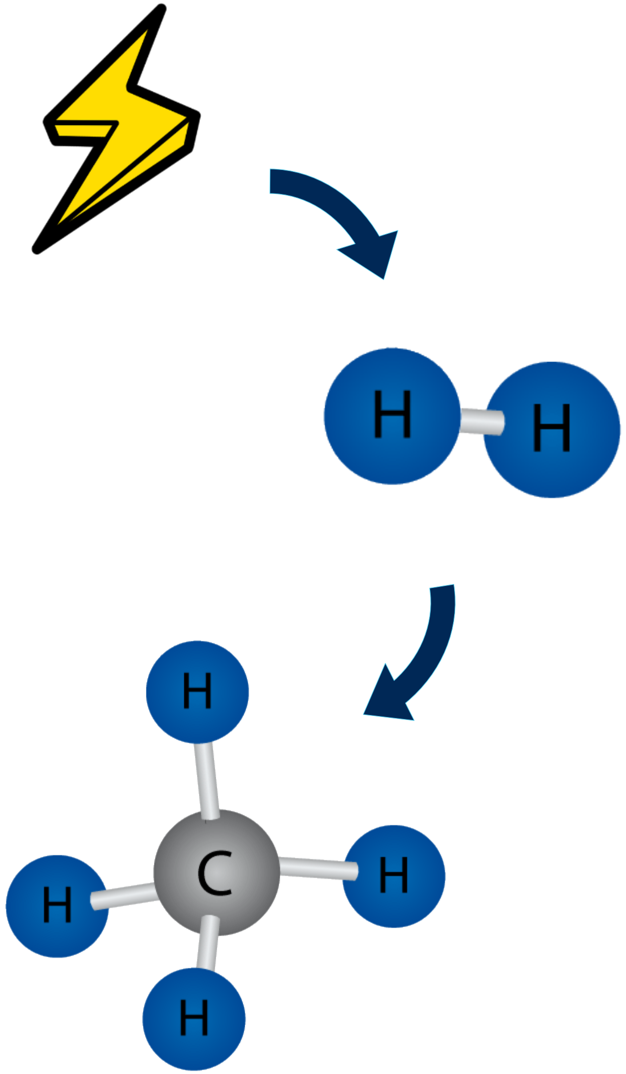
Energistyrelsen, 2011
https://www.ft.dk/samling/20101/almdel/EPU/bilag/126/946148.pdf

From electricity to natural gas

Storage of electricity as natural gas will require:

- Conversion from electricity to hydrogen
- Conversion of hydrogen to natural gas
- The gas must be pressurized to allow grid injection

The processes should allow full conversion without any loss.



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From electricity to hydrogen

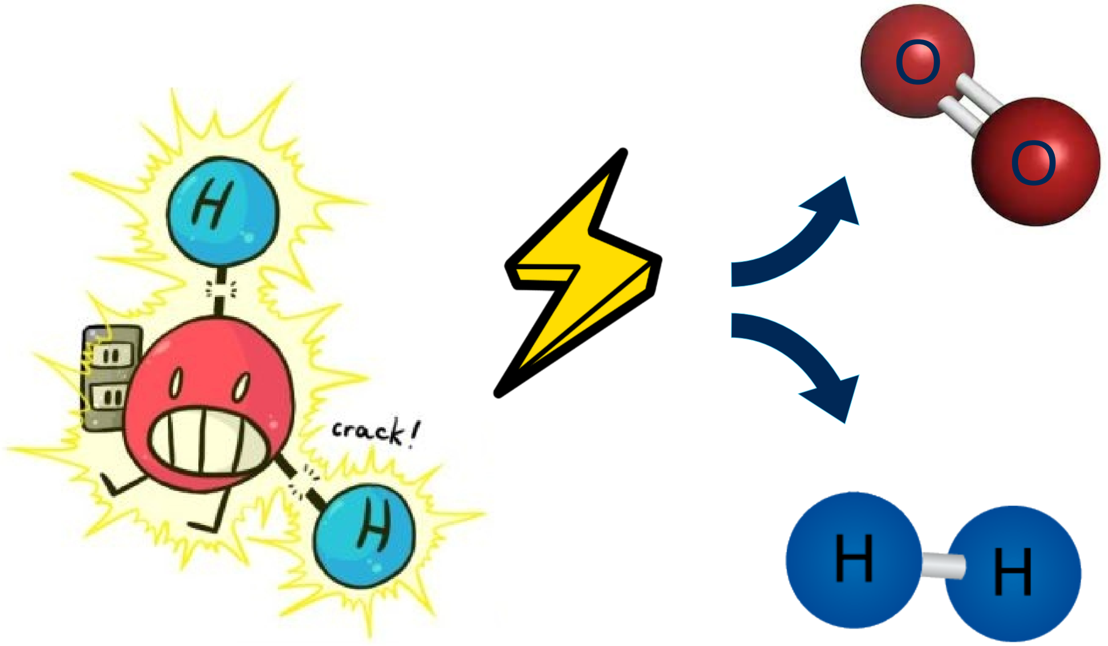
Electrolysis

<u>Enables</u>
- Conversion of water to hydrogen using electricity

$$2\,H_2O \xrightarrow{\text{electricity}} 2\,H_2 + O_2$$

<u>Requires</u>
- Electrolysis require water

<u>Challenges</u>
- Hydrogen is expensive to pressurize
- Low volumetric energy density



Technologies for electrolysis

Reference:
Renewable Power-to-Gas: A technological and economic review

Renewable Energy
Vol 85, Jan. 2016, 1371-1390

Manuel Götz, Jonathan Lefebvre, Friedemann Mörs, Amy McDaniel Koch, Frank Graf, Siegfried Bajohr, Rainer Reimert, Thomas Kolb

	Alkaline electrolysis	PEM electrolysis	Solid Oxide electrolysis
Development	Commercial	Commercial	Lab. scale
Largest plants (2016)	750 Nm3/h ~2.7 MW	450 Nm3/h ~1.6 MW	-
Cell temperature	40 – 90 °C	20 – 100 °C	800 – 1000 °C
Cell voltage	1.8 – 2.4 V	1.8 – 2.2 V	0.9 – 1.3 V
Power consumption (current)	5.4 – 8.2 kWh/Nm3	4.9 – 5.2 kWh/Nm3	
Power consumption (future)	4.3 – 5.7 kWh/Nm3	4.1 – 4.8 kWh/Nm3	
Advantages	Highest capacity Low plant cost Long plant lifetime	No corrosive substance Small plant size High pressure operation	High electrical efficiency Integration of waste heat
Disadvantages	Large plant size High maintenance cost	High plant cost Fast degradation	Limited long tern stability Not suited to fluctuations Expensive

Lower Heating Value
Hydrogen 3.00 kWh/Nm3

SOEC Technology

Lower Heating Value
Hydrogen 3.00 kWh/Nm3 (242 kJ/mol)

Enables

- Electric conversion efficiency close to 100 %

$$H_2O_{(g)} \rightleftarrows H_{2(g)} + ½\ O_{2(g)} \qquad \Delta H_{split} = 248\ \frac{kJ}{mol}$$

Requires

- Input is steam not liquid water

$$H_2O_{(l)} \rightleftarrows H_2O_{(g)} \qquad \Delta H_{vap,300°C} = 41\frac{kJ}{mol}$$

Challenges

- Small plants will have a high heat loss
- Thermal stress affects durability of the stack

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From hydrogen to Natural gas

Catalytic Methanation

<u>Enables</u>

- The reaction has a high yield
- The reaction releases a lot of heat

<u>Requires</u>

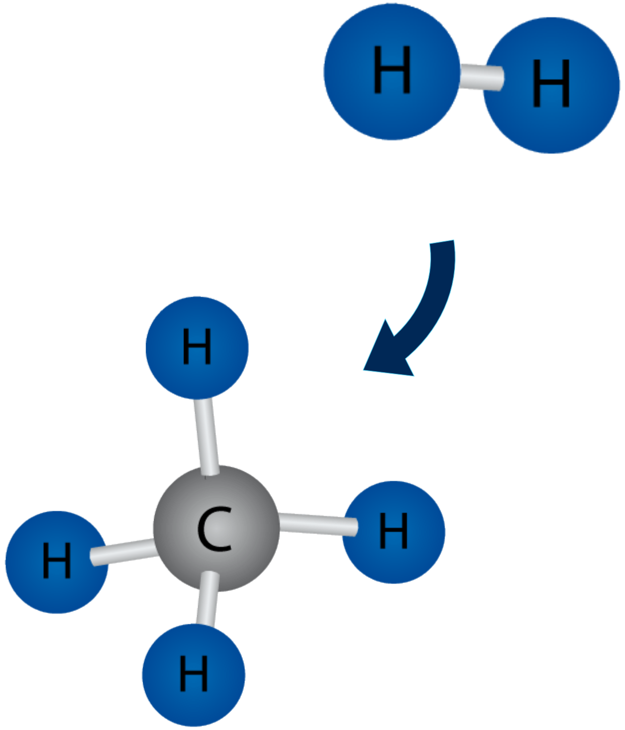
- The reaction requires CO_2
- The reaction requires a catalyst

<u>Challenges</u>

- Efficient heat dissipation is required

$$\frac{1}{4}CO_2 + H_2 \xrightarrow{\text{Ni-kat.}} \frac{1}{4}CH_4 + \frac{1}{2}H_2O$$

$$\Delta H_{300°C} = -41\frac{kJ}{mol}$$



How do we source CO_2?

Biomass

Biogas

Gas separation unit

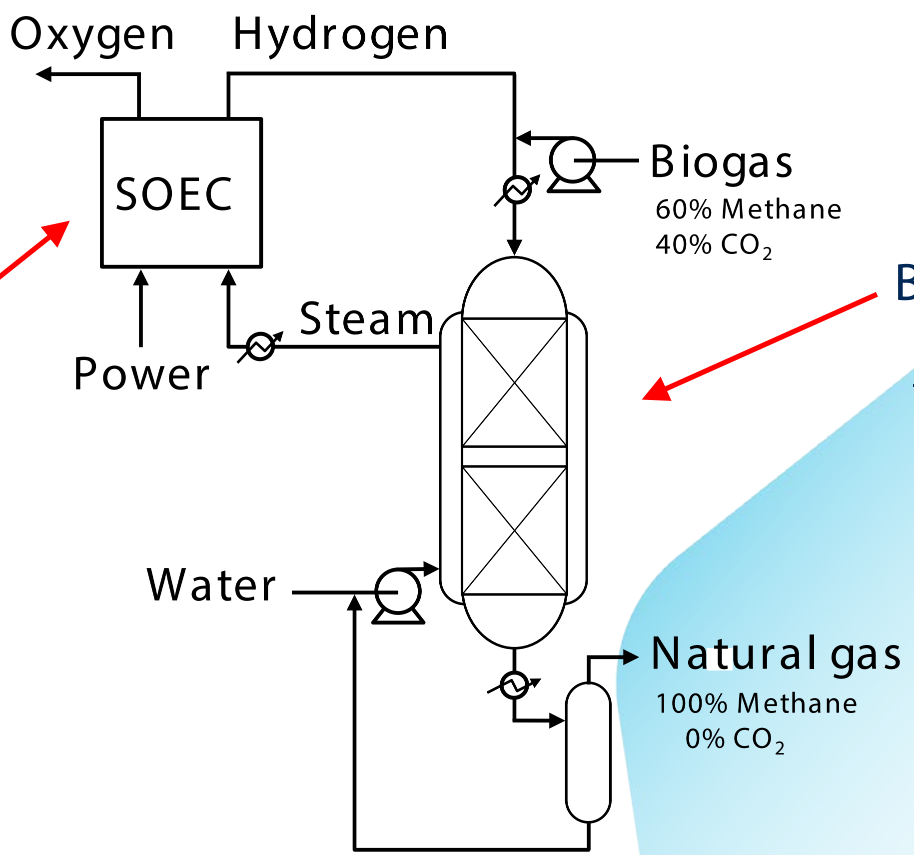
40 % CO_2 released to atmosphere

60 % CH_4 for grid injection

Combined plant

Solid Oxide Electrolysis

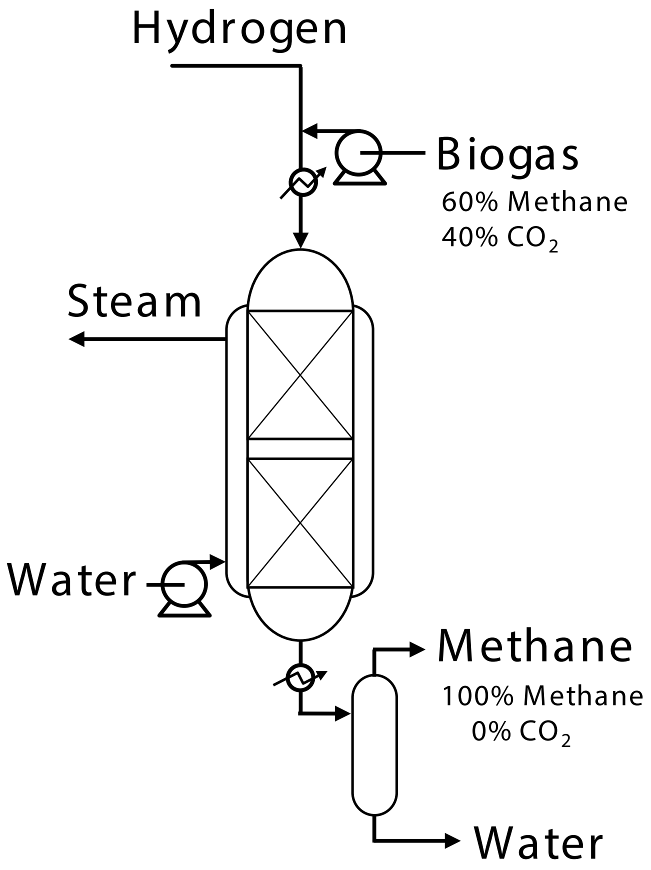
$$H_2O_{(g)} \rightleftarrows H_{2(g)} + \frac{1}{2}O_2$$

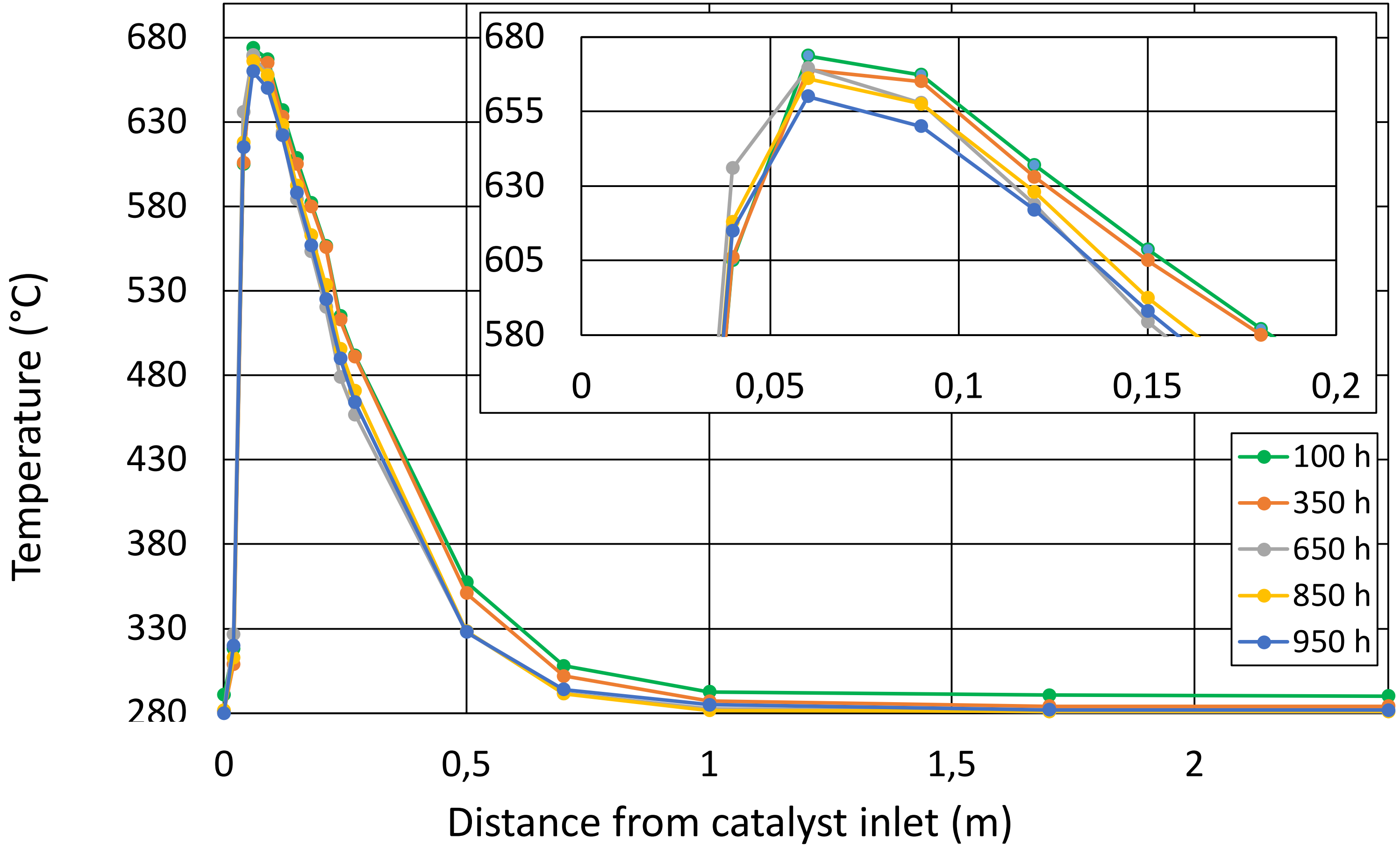


Boiling water reactor

$$\frac{1}{4}CO_2 + H_2 \xrightarrow{\text{Ni-kat.}} \frac{1}{4}CH_4 + \frac{1}{2}H_2O$$

Reactor temperature profile





Capacity:

- 10 Nm3/h biogas
- 50 kW SOEC
- 16 Nm3/h hydrogen

Operation:

- 20 bar
- 230 °C feed temp
- 70 bar BW (280 °C)

10.1039/c9re00351g

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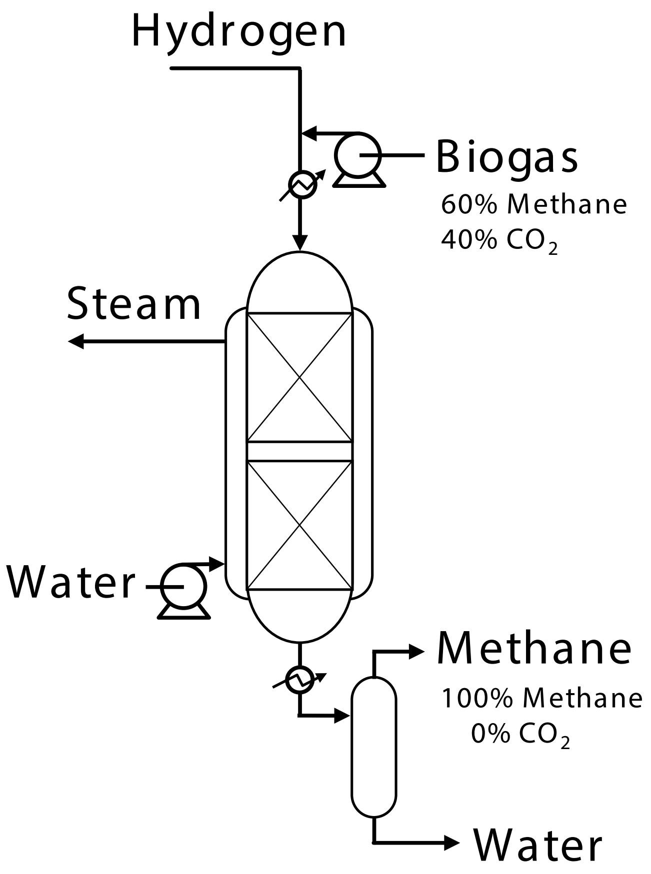
Quality of the produced gas

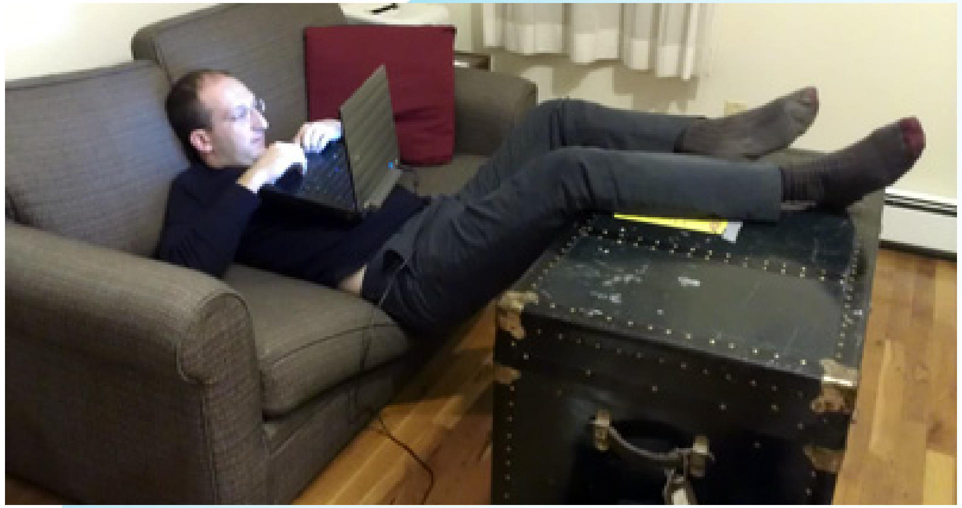


	Biogas	Methane	DK Spec.
CO_2	45.8 %	0.0 %	Max. 2.5 %
Hydrogen	0.0 %	1.4 %	Max. 2.0 %
Methane	53.1 %	97.9 %	Min. 97.2 %
CO	0.0 %	0.0 %	Max. 0.1 %
Nitrogen	1.2 %	1.0 %	Max. 2.8 %
Sum	100.1 %	100.3 %	

Remote operation

Couch Mode

- Plant is fully operational by remote connection
- Critical alarms sent directly via SMS
- Fully remote start and stop confirmed
- Only one operator required to run the entire plant



eSMR Pilot

Ammonia syngas pilot

Control room

BioSNG Pilot

Gas compressors

SOEC Pilot P17

Thank You