SYNERGI MELLEM BIOGAS-OPGRADERING OG SOEC

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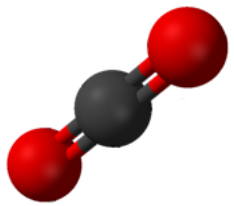
AU BIOGAS PLANT FOULUM

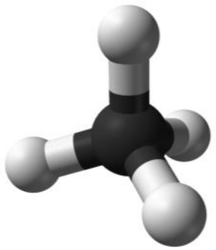
Biogas produced from manure

Production of 100 Nm3/h

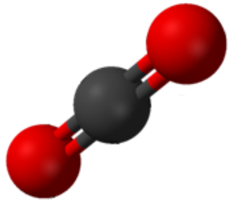


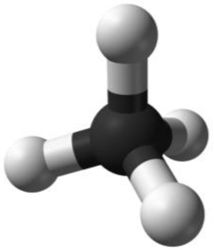
Biogas is 40% CO_2.

(Only 60% of the biogas has value)



BIOGAS AS SOURCE OF CO_2





The digestion of organic waste produce biogas. A gas rich in CO_2.

Biogas

Component	Amount
CH_4	60%
CO_2	40%
H_2S	~1000ppm
Water	saturated

Pure methane

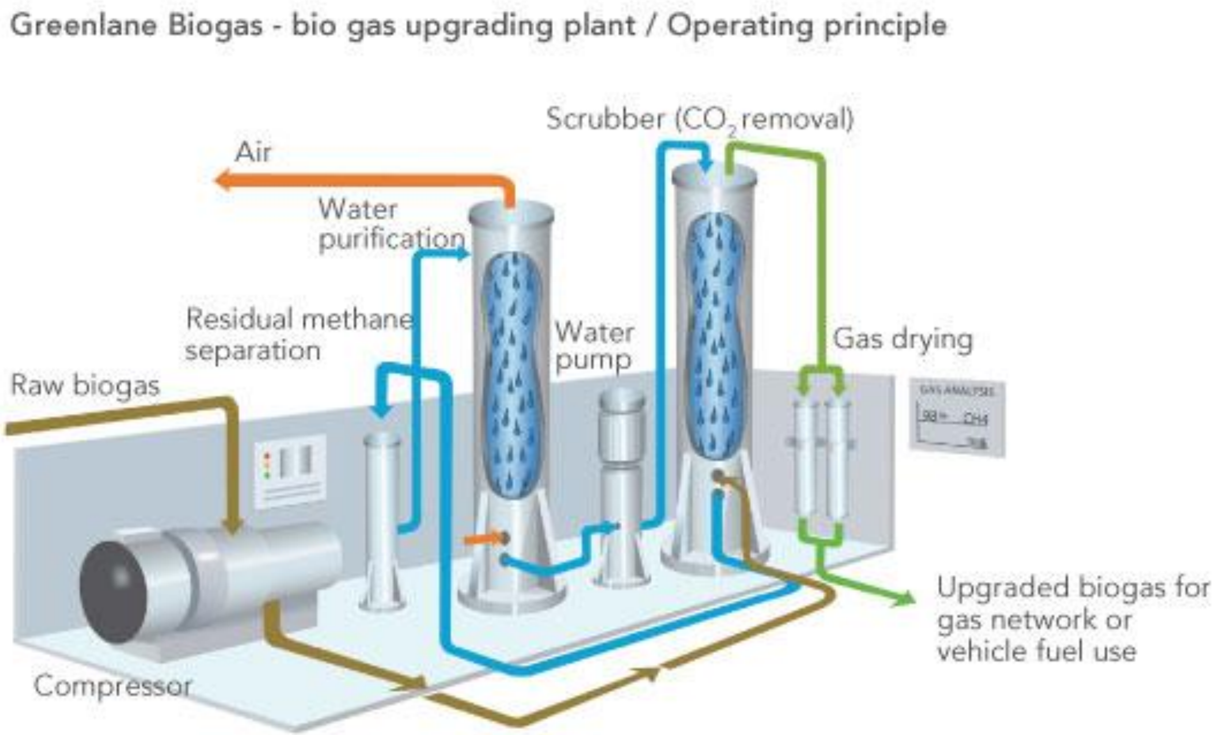
Component	Amount
CH_4	100%
CO_2	0%
H_2S	0 ppm
Water	nill

Natural gas

Component	Amount
CH_4	97,2% (min)
CO_2	2,5% (max)
H_2S	5 ppm (max)
Water	nill

”UPGRADING” OF BIOGAS

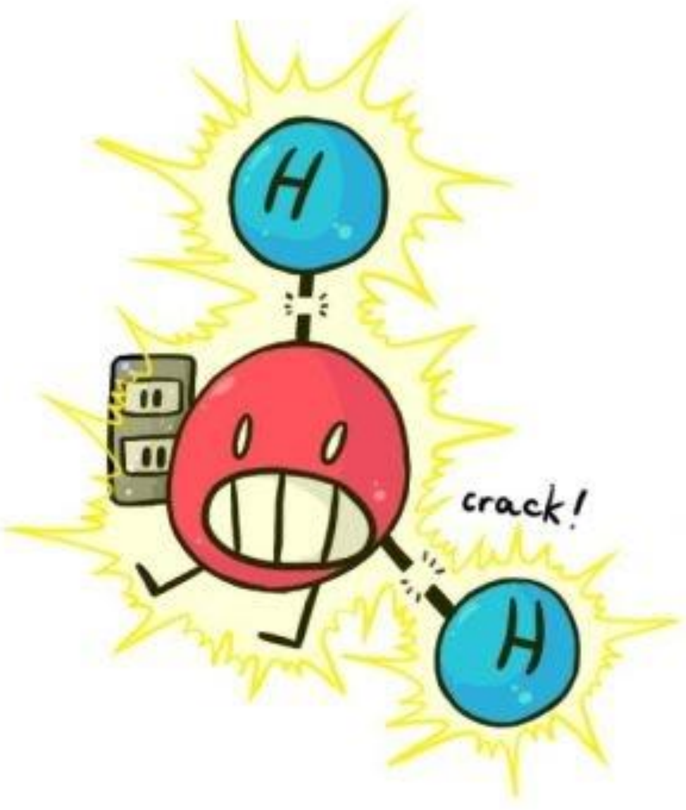
Current upgrading technology primarily based on CO_2 scrubbing.



http://www.sarlin.com/en/Energy-Technology/Biogas-purification-and-upgrading-plants

https://www.americanbiogascouncil.org/biogasProcessing/amineScrubber.html

UPGRADING USING HYDROGEN



Hydrogen added directly to biogas reactor

- Biological process
- Low temperature

Hydrogen used in post treatment of the biogas

- Catalytic process
- High temperature

Both solutions are currently being tested on a pilot level

CATALYTIC UPGRADING OF CO_2

The Sabatier reaction

$$CO_2 \quad + \quad 4\,H_2 \xrightarrow{catalyst} CH_4 \quad + \quad 2\,H_2O \qquad \Delta H_{300-1000°C} \cong -170\frac{kJ}{mol}$$

Reduction of carbon, inverted combustion.

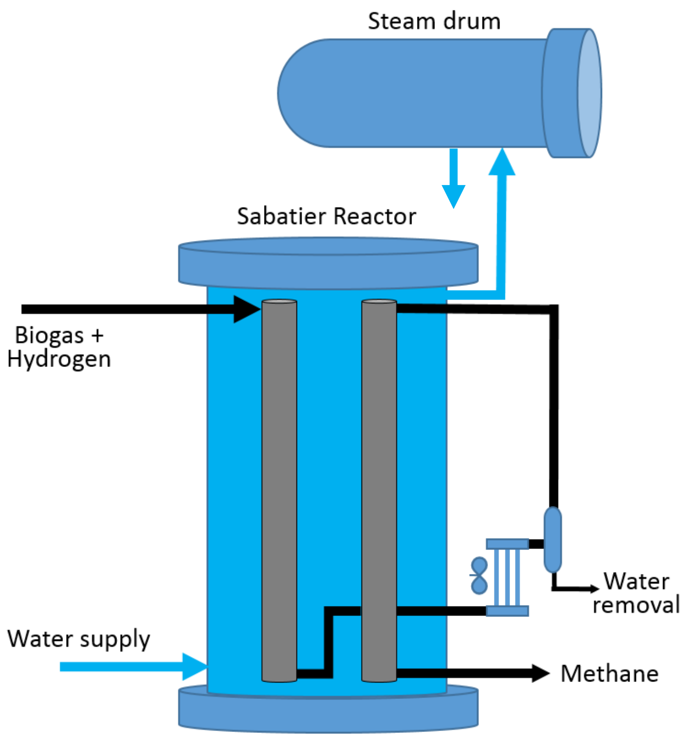
- Strongly exothermic
- Thermodynamically favorable ($\Delta G_{298K} = -131\,\frac{kJ}{mol}$)
- Significant kinetic limitations, thus require catalyst
- Heavy consumer of hydrogen

SYNERGY WHEN UPGRADING BIOGAS

The methane in the biogas serves as an excellent heat carrier in the reactor.

	Heat per cube ($\frac{kJ}{m^3K}$)
H_2O	1.552
CH_4	1.483
N_2	1.212
Ar / He	0.864

CH_4	+	CO_2	+	H_2	→	CH_4	+	H_2O	Adiabatic temperature
0		4		16		4		8	724 °C
6		4		16		10		8	489 °C

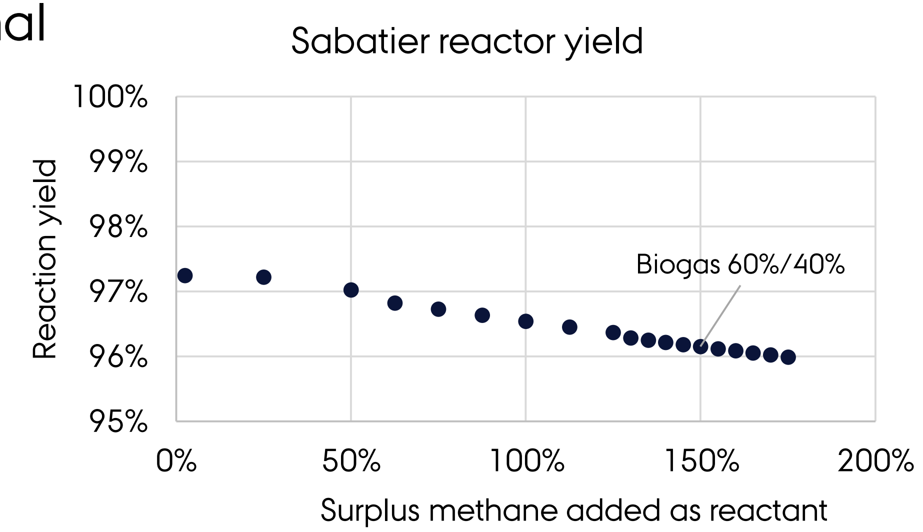


EQUILIBRIUM SHIFT?

Having surplus methane affects the reaction equilibrium

$$CO_2 \quad + \quad 4\,H_2 \xrightarrow{catalyst} CH_4 \; + \quad 2\,H_2O$$

Effect of surplus methane is minimal



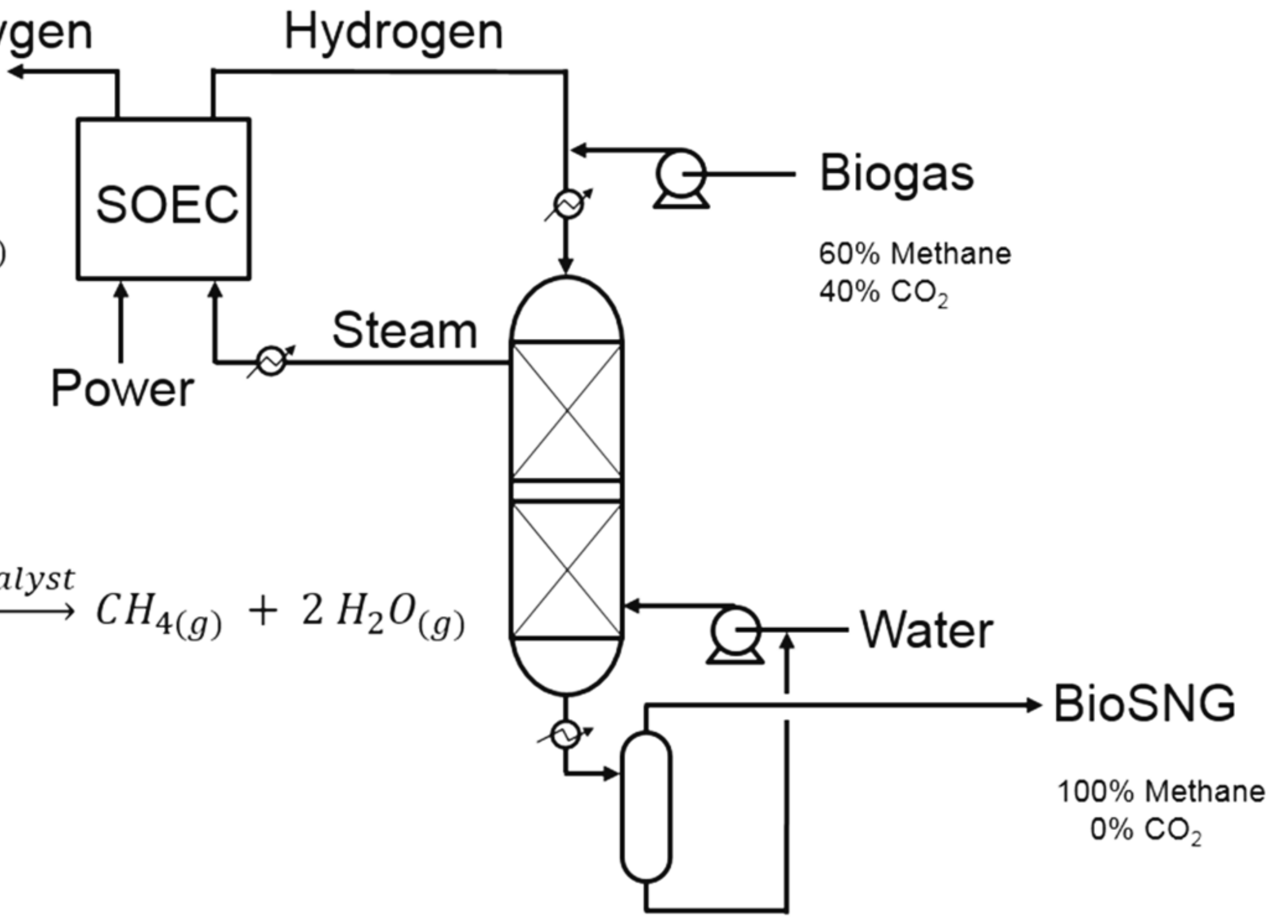
Reaction yield as simulated in Aspen Plus.

Simulation based on a Gibbs reactor at 300°C and 20 bar.

SYNERGIES BETWEEN SOEC AND SABATIER

Electrolysis of water

$$2\,H_2O_{(g)} \xrightarrow{Power} 2\,H_{2(g)} + O_{2(g)}$$



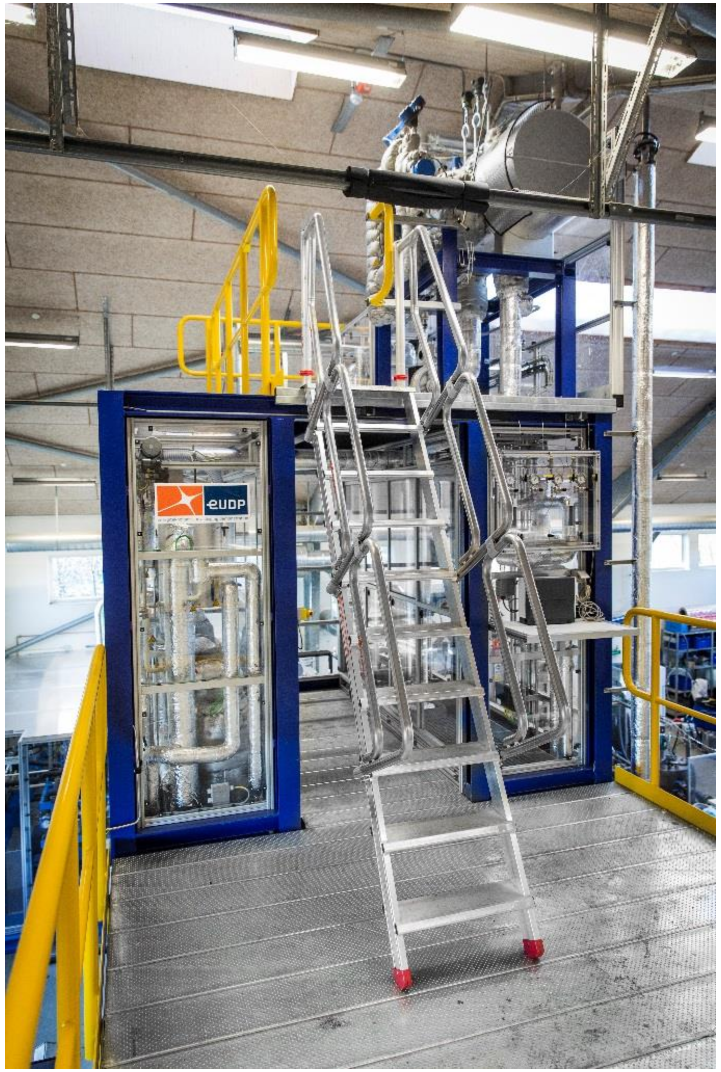
Sabatier Reactor

$$CO_{2(g)} + 4\,H_{2(g)} \xrightarrow{catalyst} CH_{4(g)} + 2\,H_2O_{(g)}$$

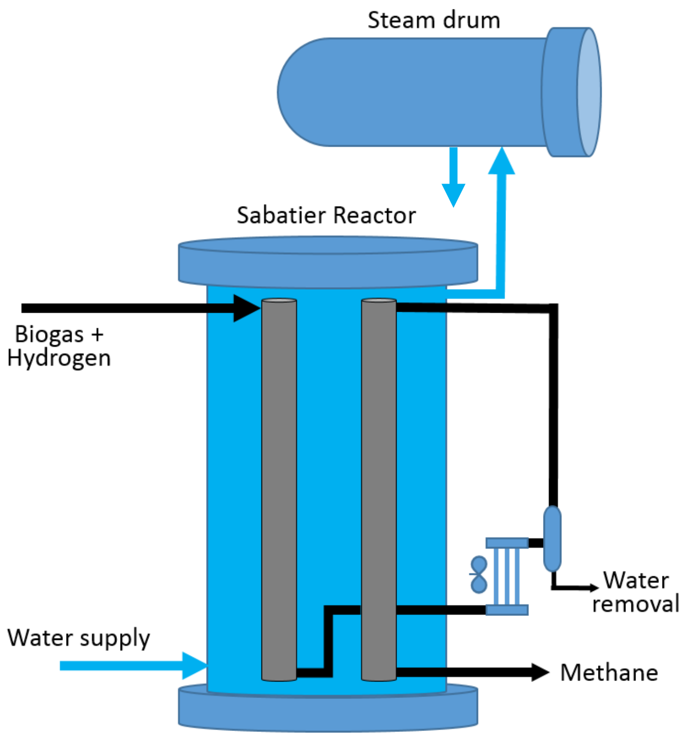
Water energy requirement	
Heat of evaporation	2.3 MJ/kg
Preheat to 300°C	0.6 MJ/kg
Heat from 300-800°C	1.1 MJ/kg

BIOSNG PILOT PLANT

BIOSNG PILOT PLANT



AVERAGE GAS COMPOSITIONS

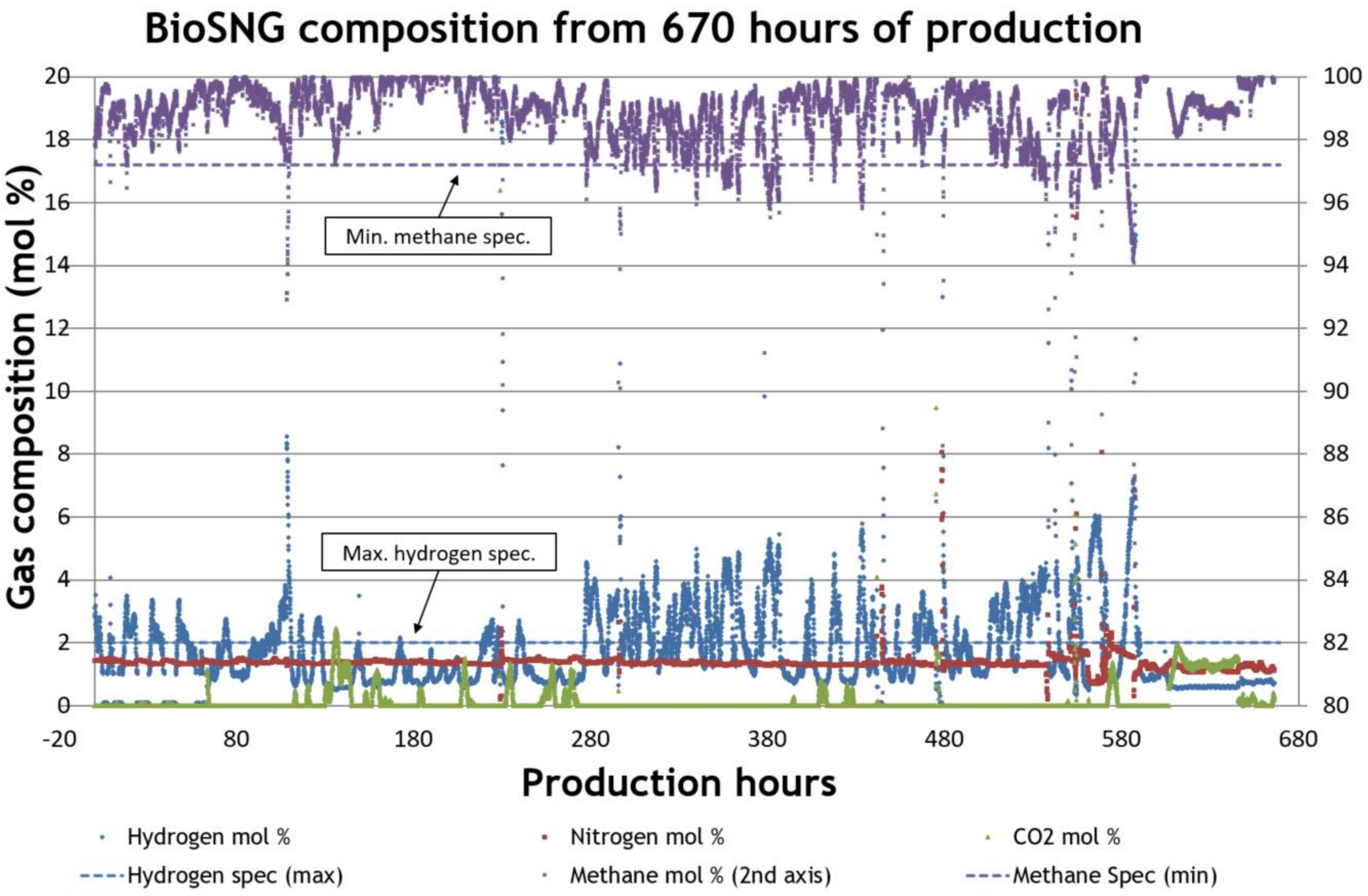


Position	CH_4	CO_2	N_2	H_2
Biogas	56	43	1	0
Exit 1st stage	94.58	0.27	0.91	4.23
Product gas	97.69	0.00	0.95	1.36

GAS QUALITY

New quality strategy:

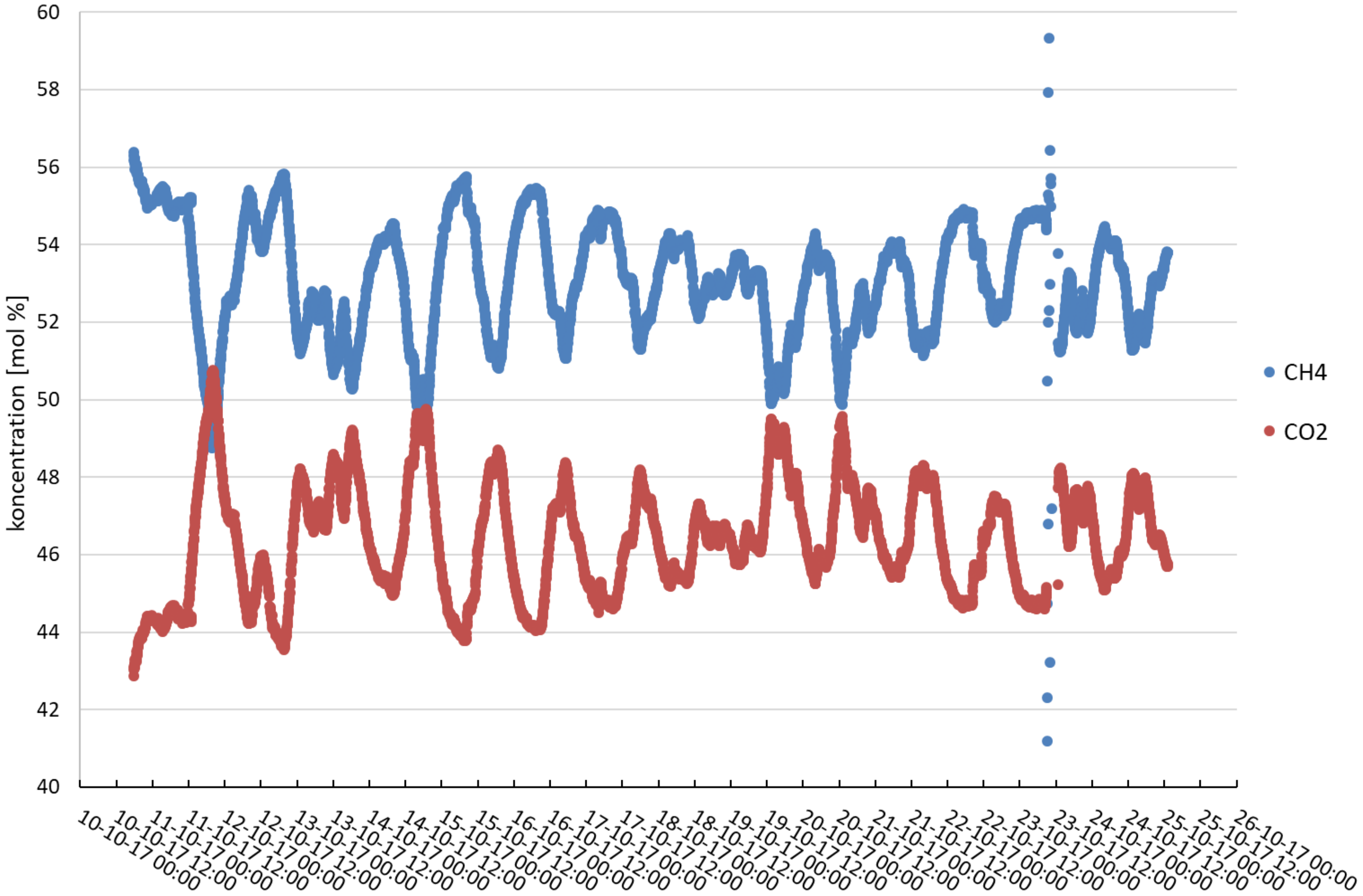
- No planned hydrogen surplus
- CO_2 leak accepted
- Significant quality improvement



VARIATION IN BIOGAS COMPOSITION

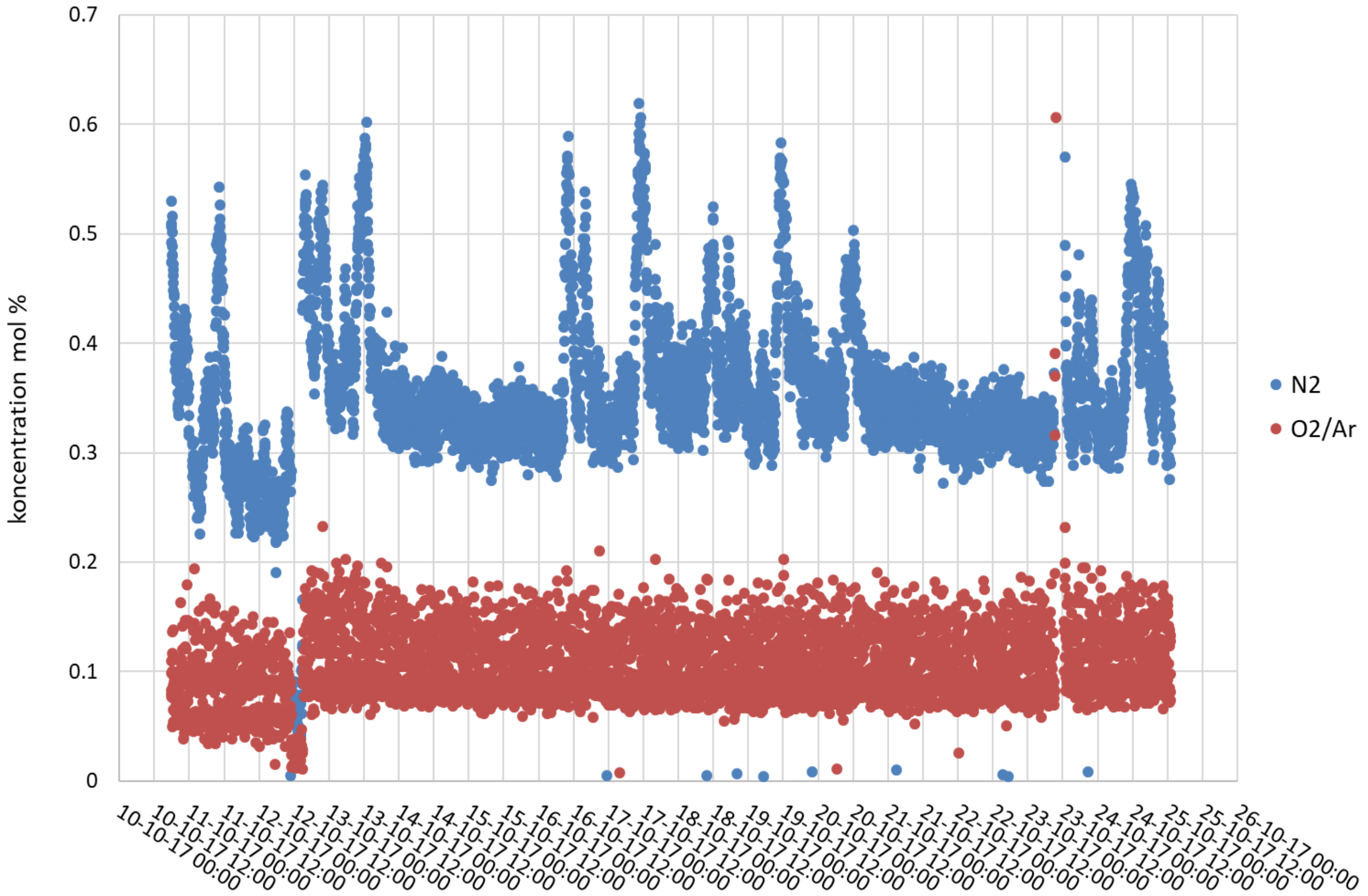
Large “natural” variation:

- Feeding reactor 3 times a day
- Clear day/night cycle
- 06:00 CO_2 low
- 18:00 CO_2 high
- Hydrogen demand to follow CO_2



BIOGAS CONTAMINATION

Contamination:
- Nitrogen contamination appear in spikes
- Oxygen contamination seems steady



FINDINGS

- Plant can produce pure bio-methane of pipeline quality.
- It is possible to operate the plant remotely (no operator on site)
- Sabatier reactor shows no sign of catalyst degradation.
- Synergies between SOEC and biogas upgrading has been proven

CURRENT PLANT CHALLENGES

Product quality

- Nitrogen contamination in BioSNG is high and close to spec limit.
- Biogas composition changes, requiring constant ratio adjustment

Plant operability

- Grid power failures prevents steady operation of pilot plant (and biogas reactor)
- Water separator on biogas compressor not draining correct
- DMW unit not suited for months of operation

CONCLUSION

Combining SOEC electrolysis with biogas upgrading is an ideal match for a highly efficient energy conversion from power to gas.

The catalytic methanation produces high temperature steam in two ways:

1. Steam is formed as a product of the Sabatier reaction, this covers half the SOEC water requirement.
2. The catalalytic methanation boiling water reactor produces most of the high pressure steam needed for hydrogen production in the SOEC.

Using biogas as CO_2 source simplifies methanation reactor design

1. The methane content already in the biogas results in a lower adiabatic temperature.
2. Fewer separate reactors compared to methanation downstream wood or coal gasifiers.

Bio-methane of pipeline quality can be produced from waste CO_2

There is no substitute for hard work.

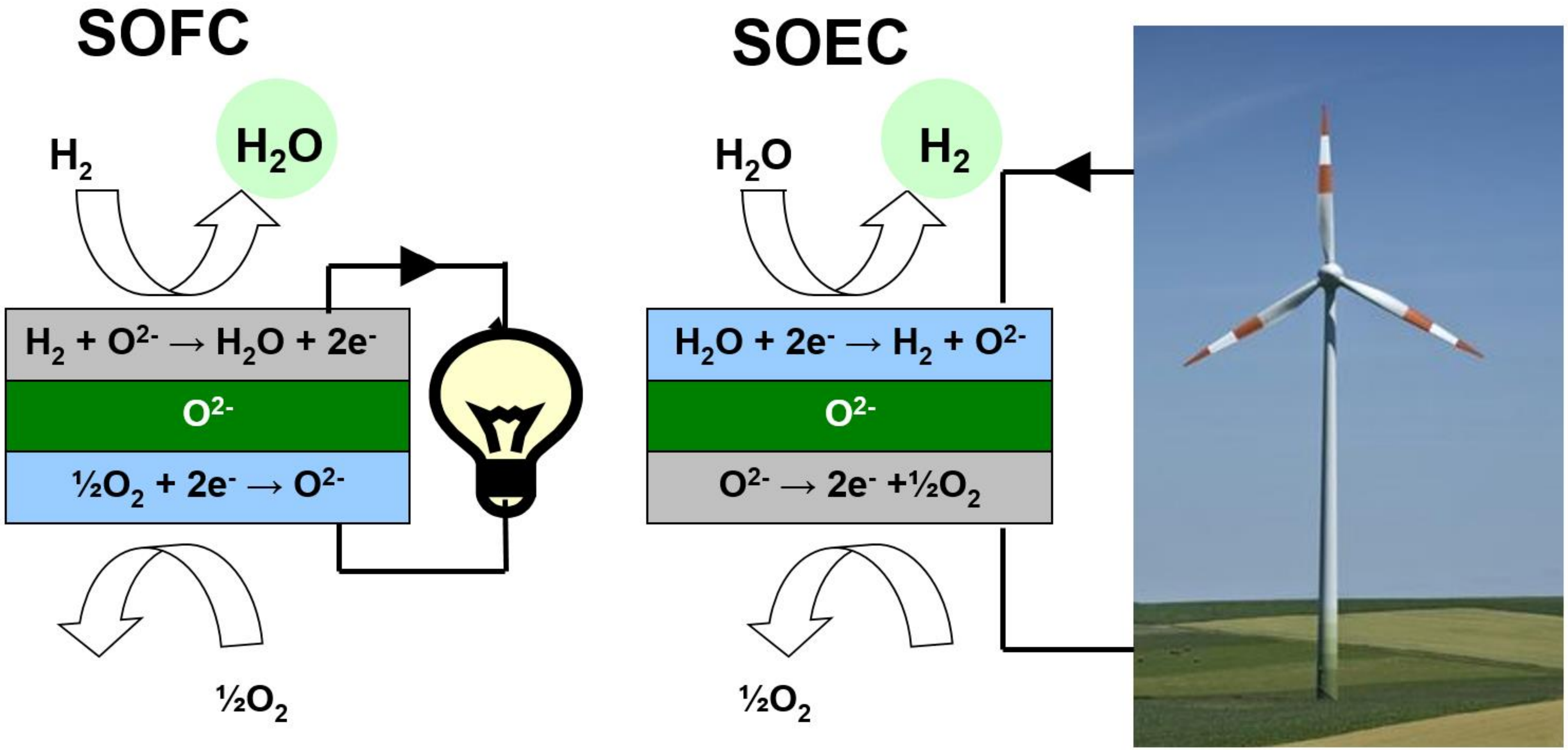
- THOMAS A. EDISON

AARHUS
UNIVERSITY

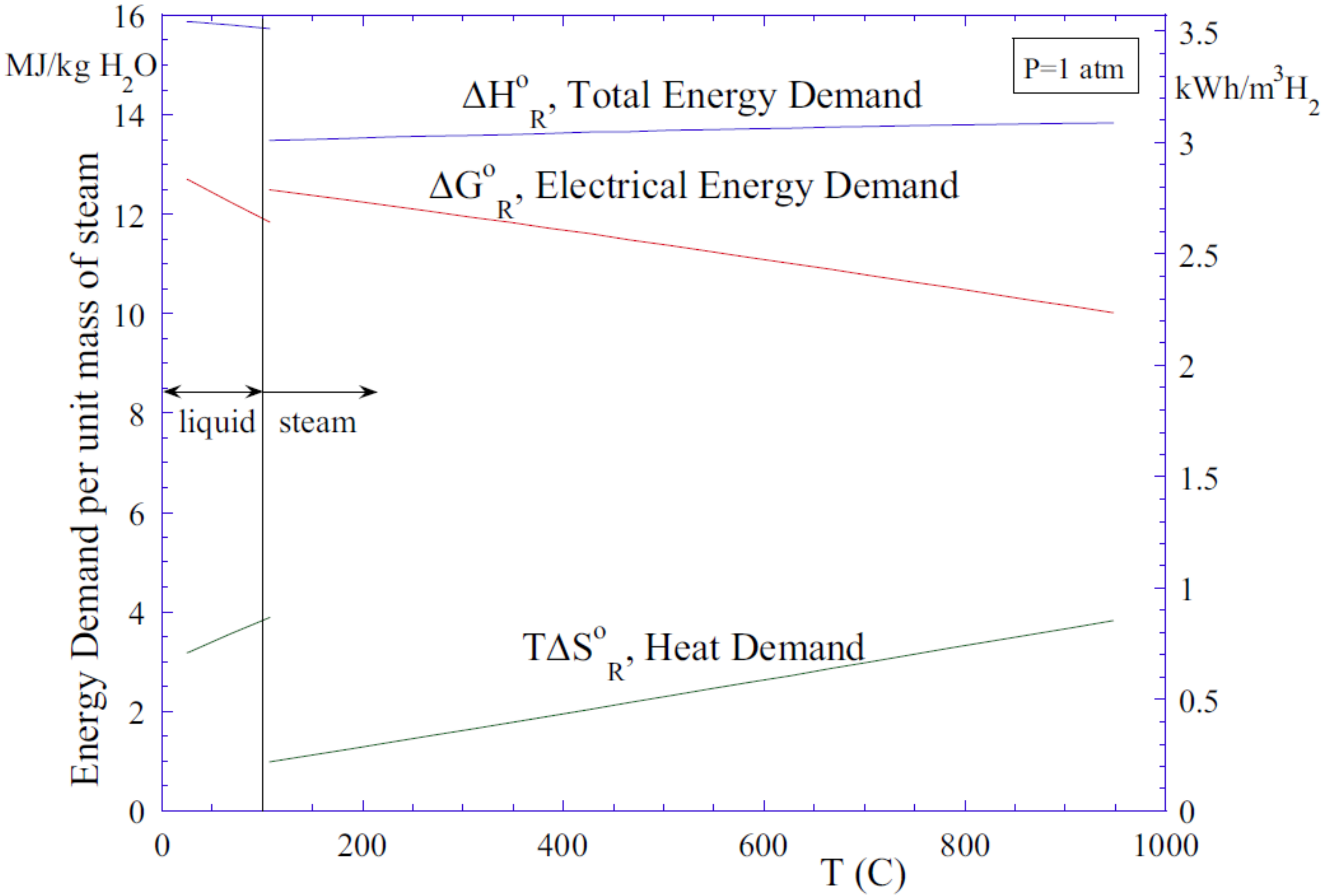
HYDROGEN DEMAND FOR UPGRADING

Local production of hydrogen is the cheapest solution when bulk volume is needed.

High electrical efficiency thru Solid Oxide Electrolysis (SOEC)



UTILIZING WASTE HEAT IN ELECTROLYSIS



From: J. E. O'Brien, Thermodynamic Considerations for Thermal Water Splitting Processes and High Temperature Electrolysis, Proceedings of the 2008 international Mechanical Engineering Congress and Exposition, Boston Massachusetts, USA, 2008