

# Power to fuel/chemicals teknologier og placering i energiforsyningen

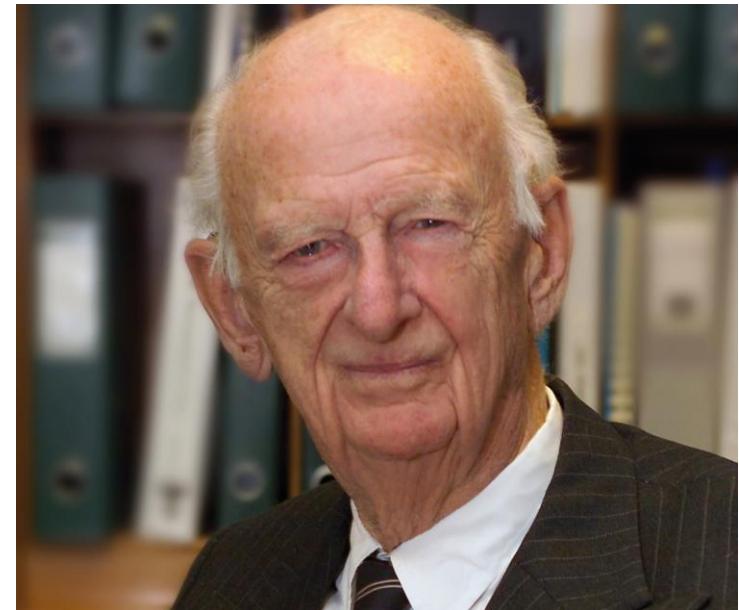


John Bøgild Hansen, Haldor Topsøe A/S

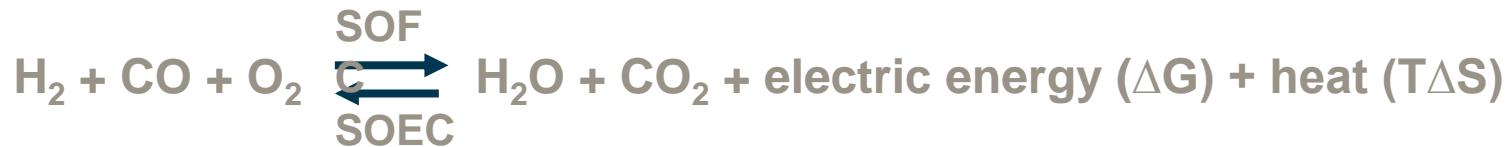
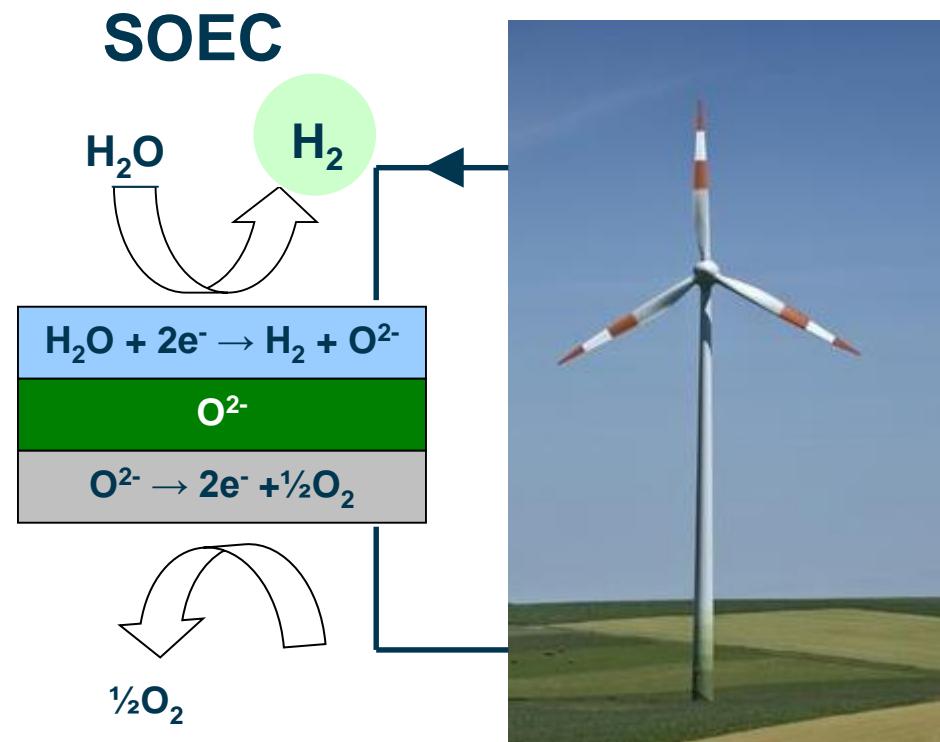
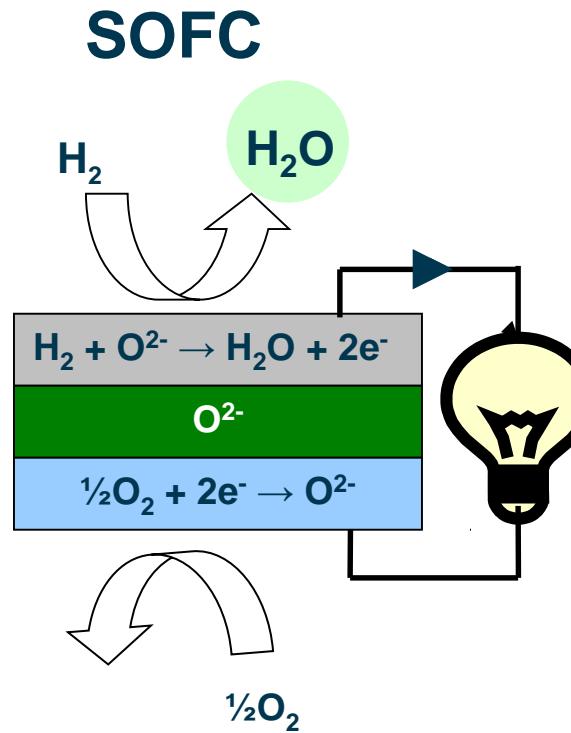
Biogaskonference, Skive, November 8, 2017

# We have been committed to catalytic process technology for more than 77 years

- Founded in 1940 by Dr. Haldor Topsøe
- Revenue: 700 million Euros
- 2400 employees
- Headquarters in Denmark
- Catalyst manufacture in Denmark and the USA

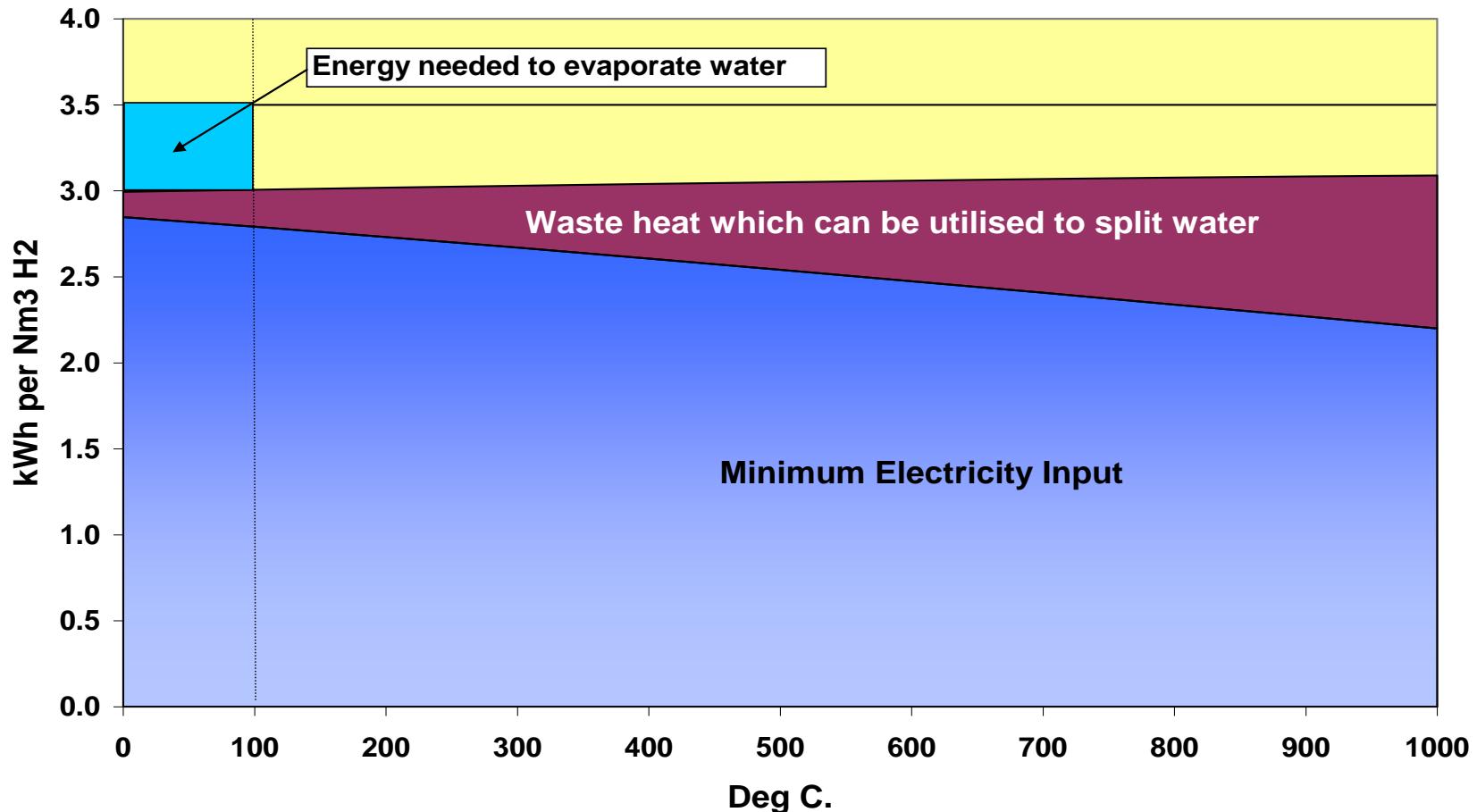


# Fuel Cell and Electrolyser



# SOEC more efficient than present Electrolyzers

## Internal waste heat used to split water



# Biogas upgrade by means of SOEC



# EUDP project

## 50 kW SOEC and 10 Nm<sup>3</sup>/h methane



**DGC** Dansk Gasteknisk Center a/s  
- rådgivning, udvikling og måling inden for energi og miljø



**Participants:**

Haldor Topsøe A/S  
Aarhus University  
HMN Naturgas  
Naturgas Fyn  
EnergiMidt  
Xergi  
DGC  
PlanEnergi  
Ea Energianalyse

**Coordinator:**

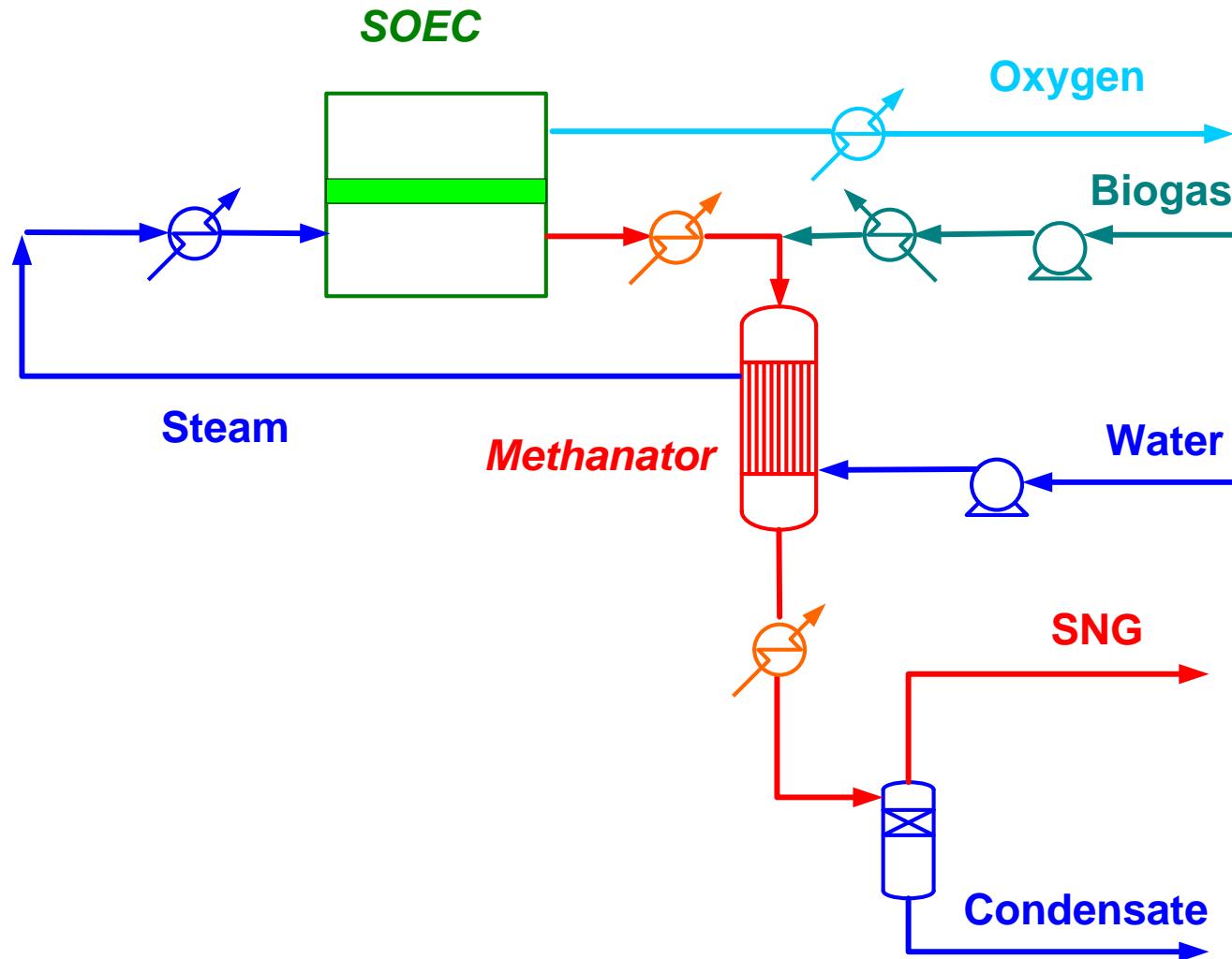
**HALDOR TOPSØE** CATALYSING YOUR BUSINESS

**Duration:**  
June 2013 -  
Dec. 2017

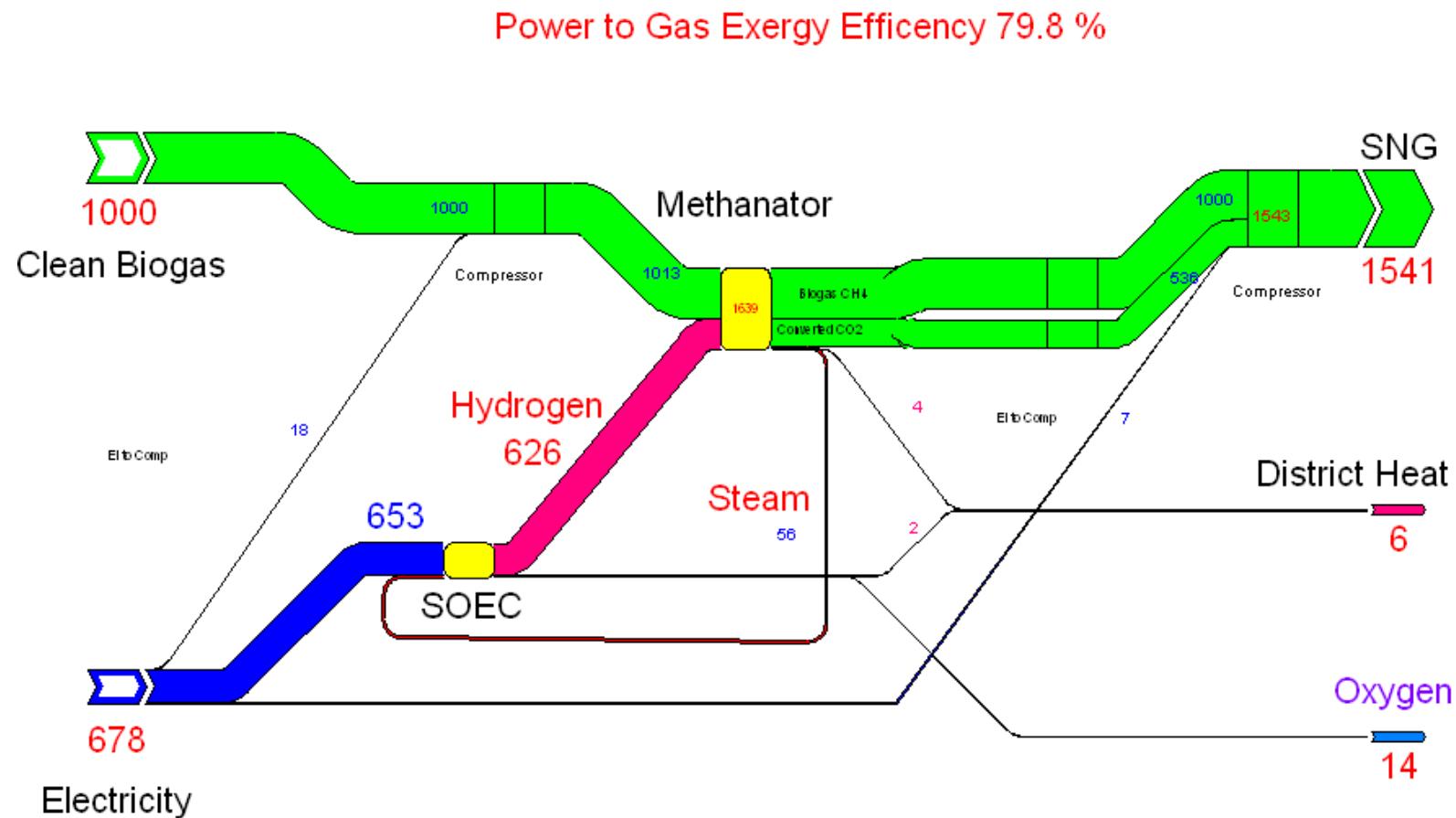
**Project sum:**  
5.3 mio €  
**Location:**  
Foulum



# Biogas to SNG via SOEC and methanation of the CO<sub>2</sub> in the biogas

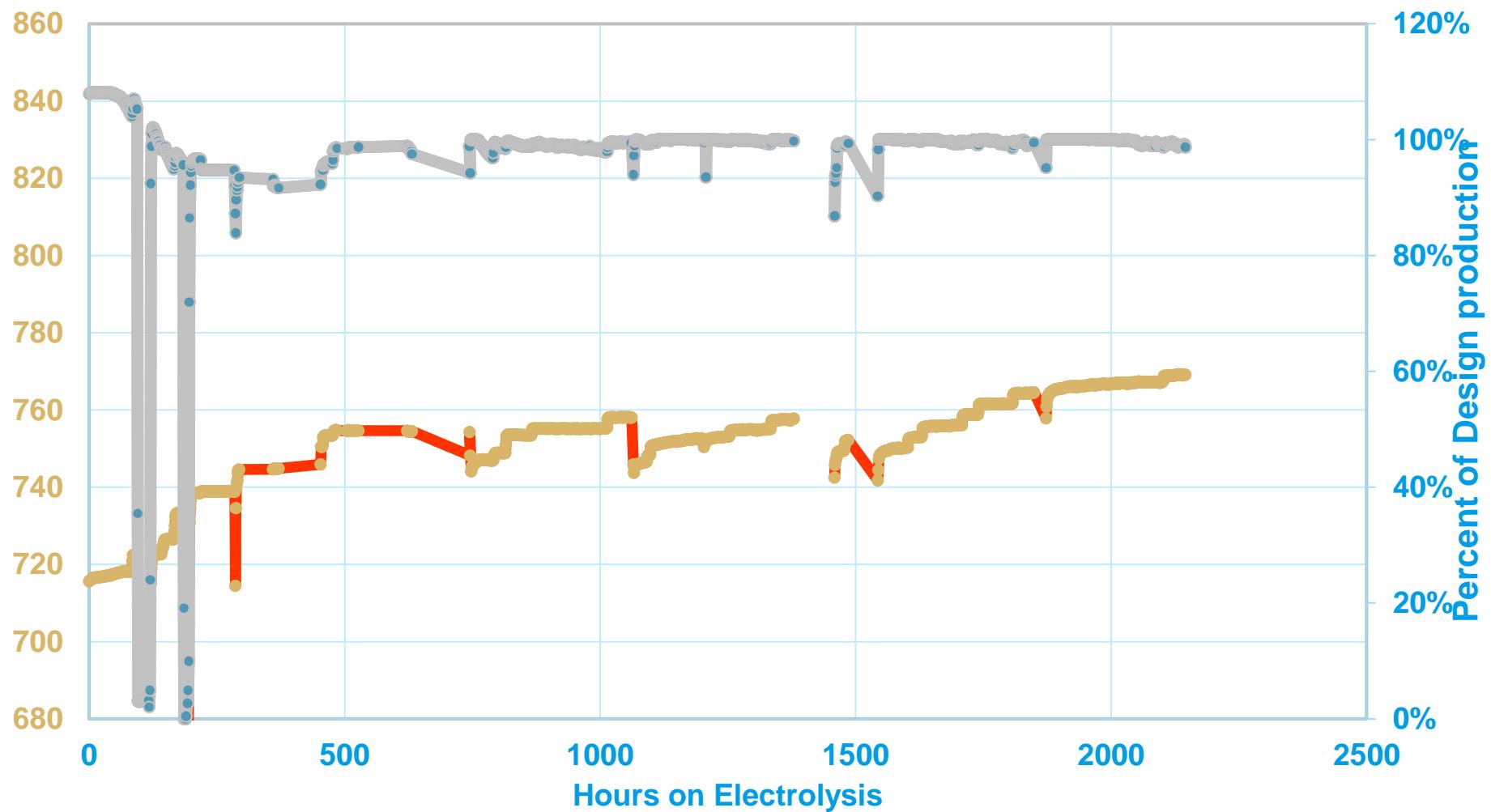


# SOEC 3.1 kWh/Nm<sup>3</sup> H<sub>2</sub>

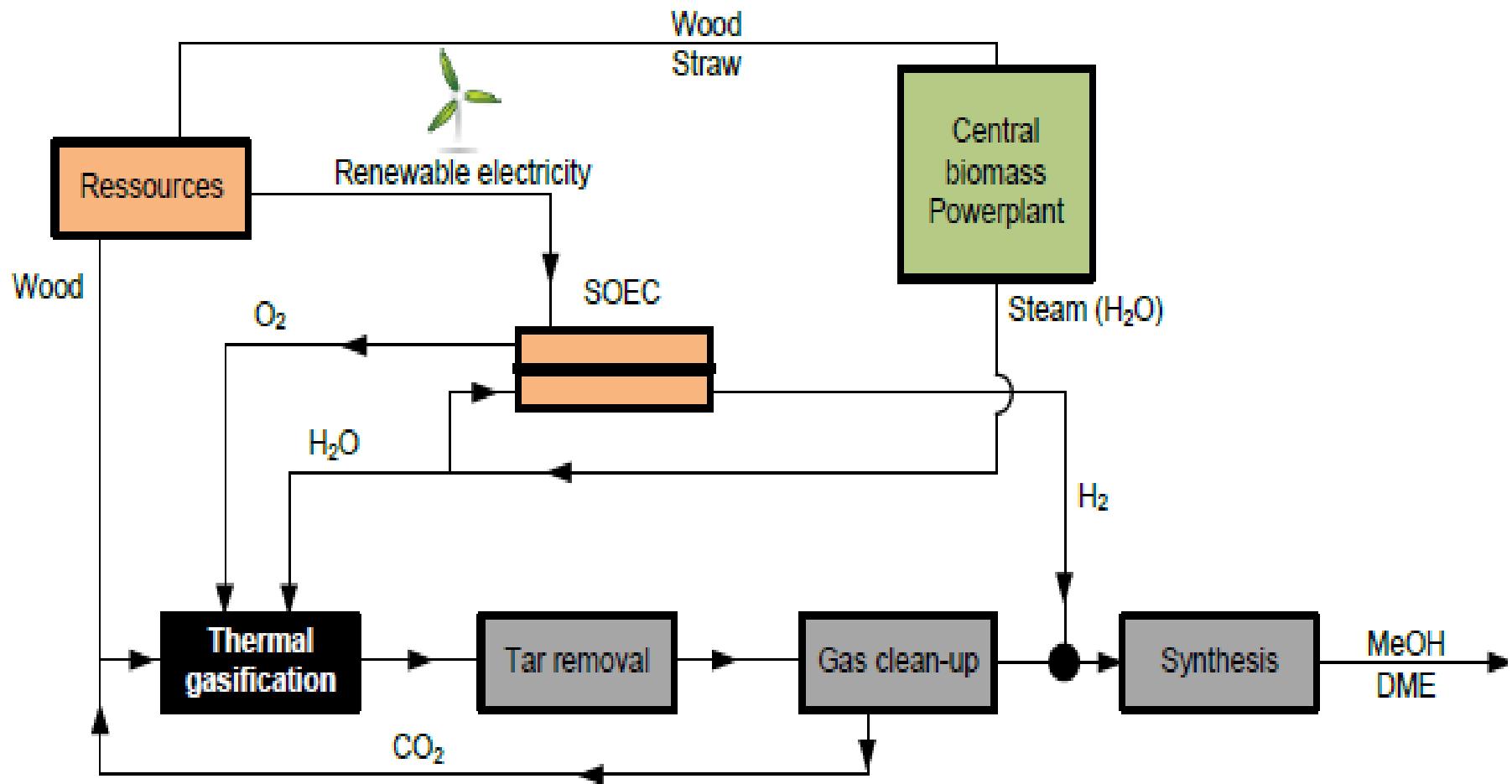


Production (100 % = 10 Nm<sup>3</sup>/h CH<sub>4</sub>)

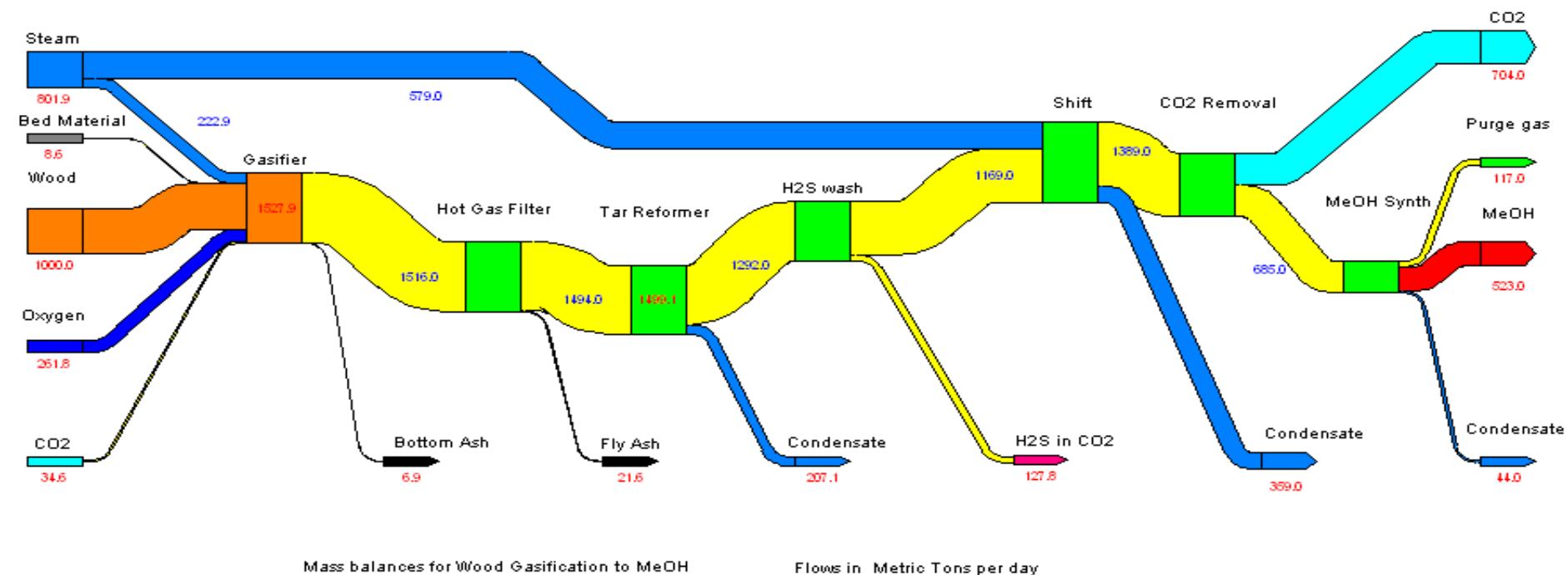
vs hours on stream. 3.1 kWh/Nm<sup>3</sup> H<sub>2</sub>



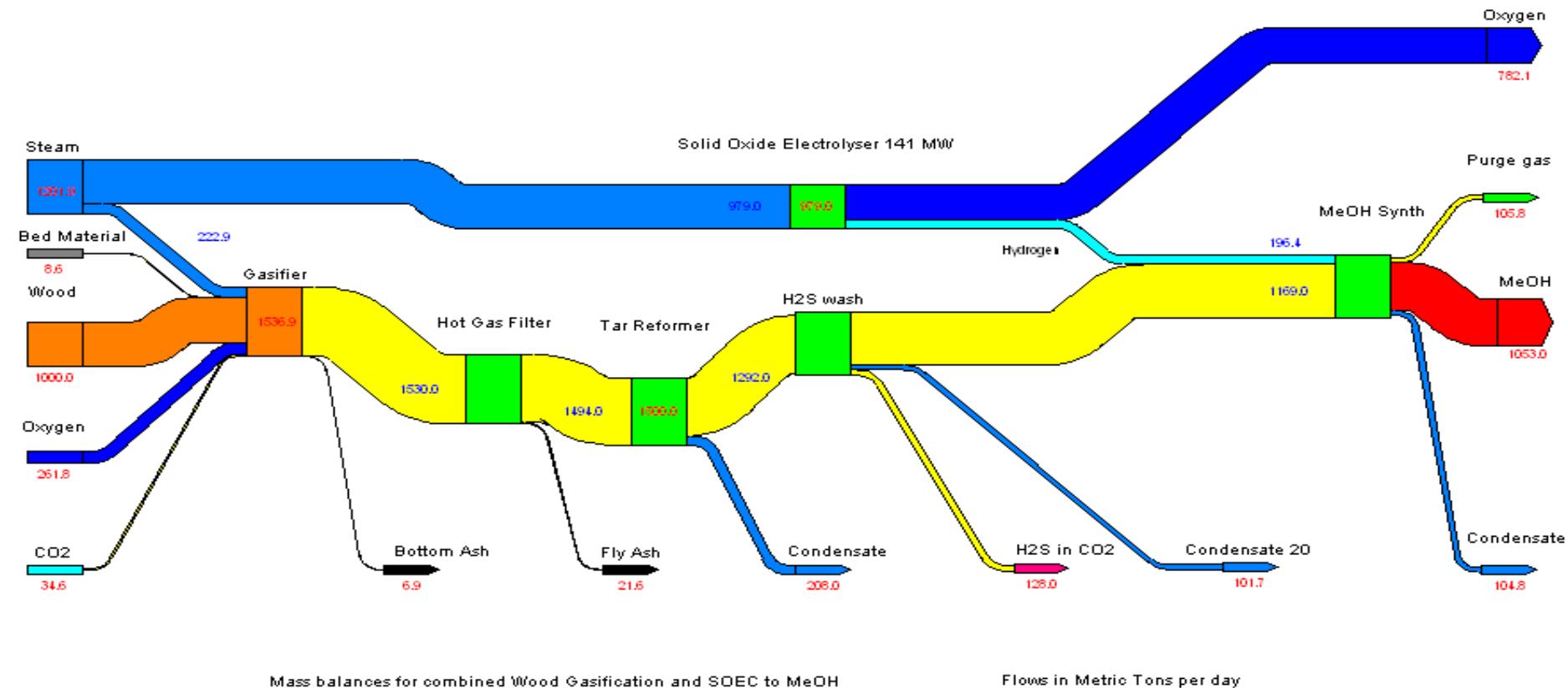
# GreenSynFuel Project



# Mass Flows in Wood to MeOH



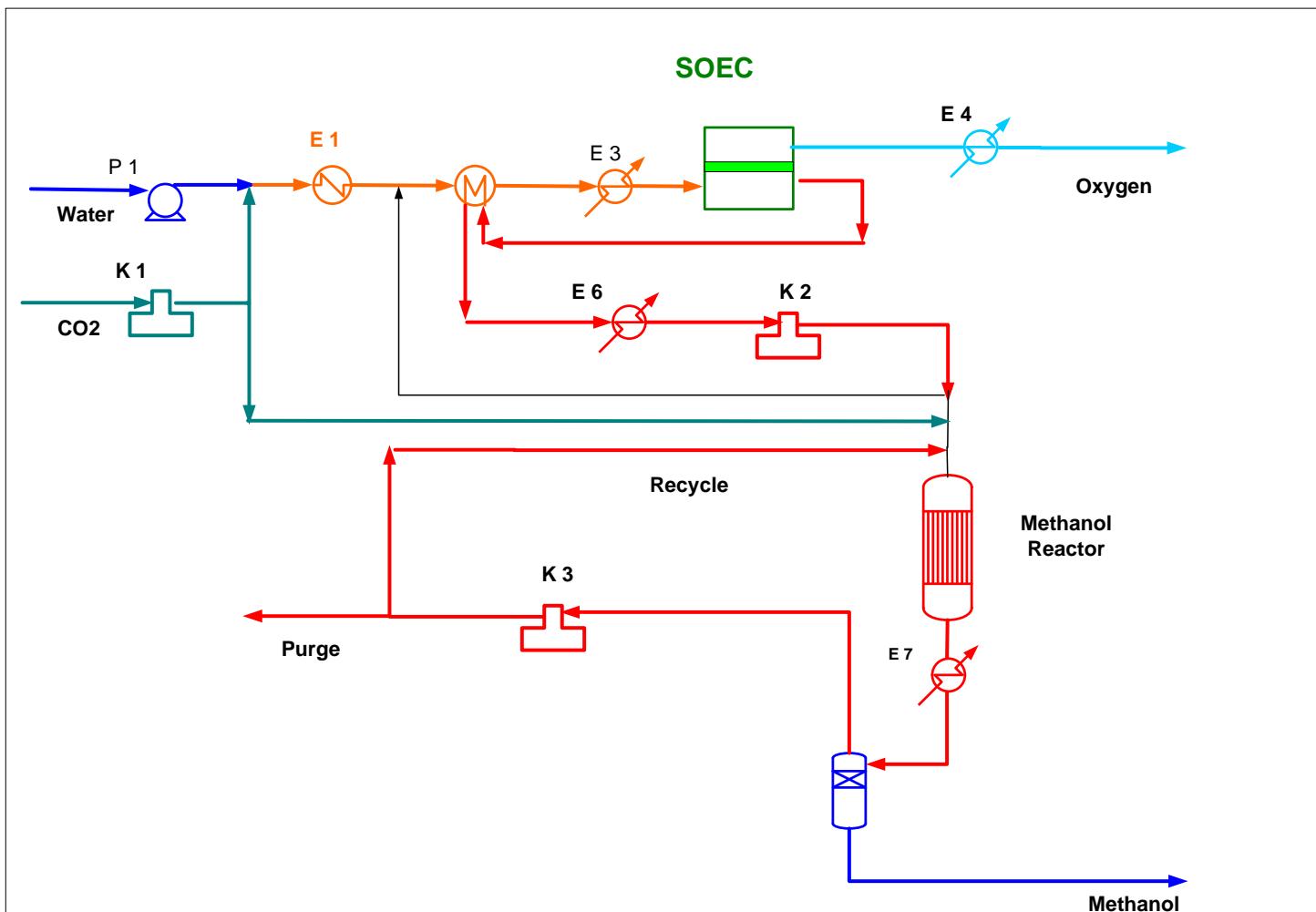
# Mass Flows in Wood + SOEC to MeOH



## Efficiencies: Stand alone wood gasifier and gasifier plus SOEC

LHV Efficiency %	Wood Gasifier alone	Wood gasifier Plus SOEC
Methanol	59.2	70.8
District Heat	22.6	10.8
Total	81.8	81.6

# Methanol from CO<sub>2</sub> and Steam



# Results of "to pressurize stacks or not"

<i>Product</i>	$\alpha$	<i>Syngas Comp %</i>	<i>CO2 Comp</i>	<i>LHV Efficiency %</i>
<b>Methanol</b>	90	6.8	0.1	75.8
<b>@50 bar</b>	90		1.9	79.5
<b><i>Ideally</i></b>				<b>83-88</b>

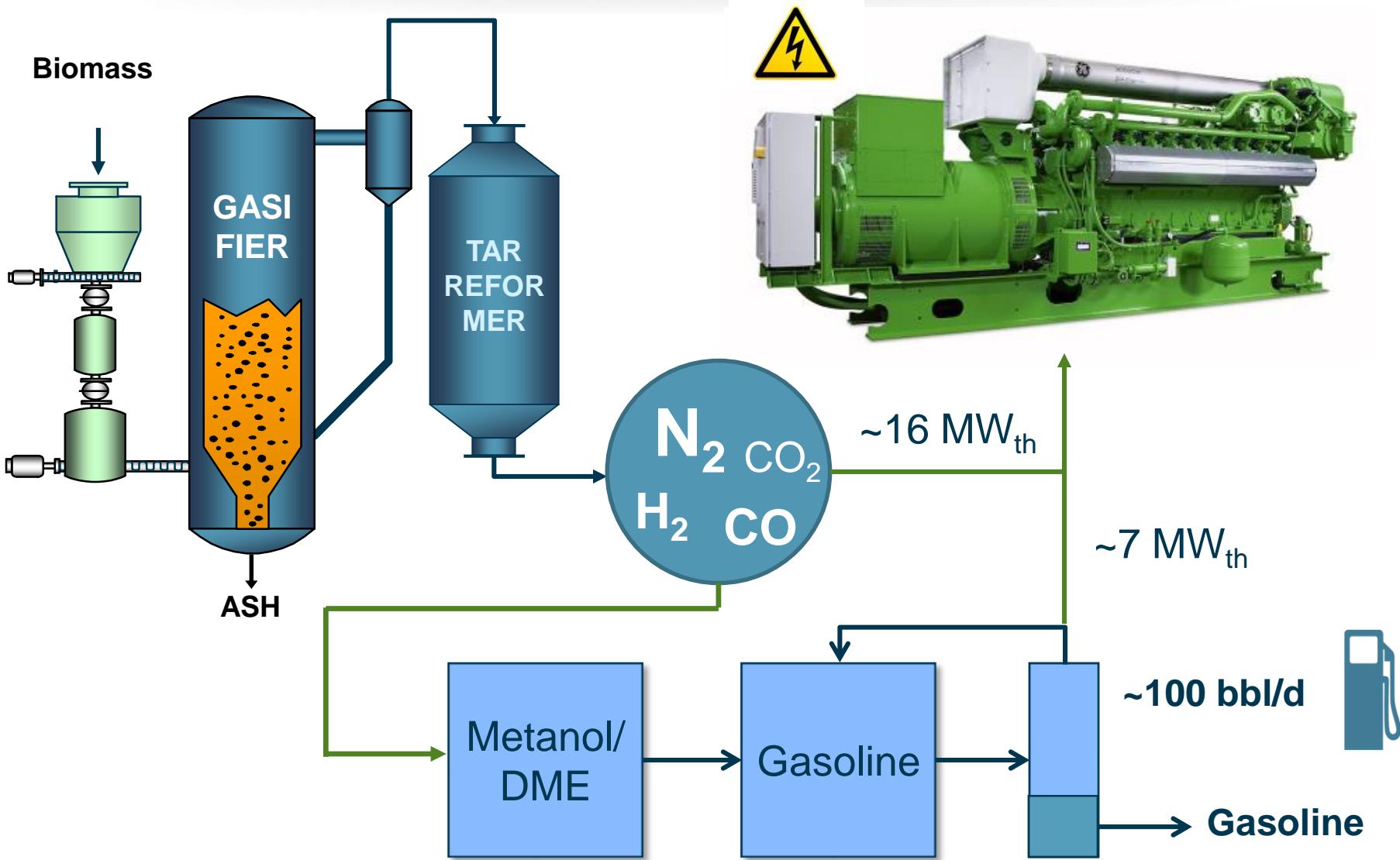
# Heat of Reactions per mole H<sub>2</sub> @ 280 ° C

Product	From CO kJ/mol	From CO <sub>2</sub> kJ/mol
Gasoline	79	37
CH <sub>4</sub>	72	44
DME	55	24
MeOH	50	20

Evaporation of 1 mol of water requires ~48 kJ @ 25 – 60 bar g

NB: Steam conversion is only 70 – 80 % in SOEC plants

# Thought experiment



# Skive > 20.000 citizens

6.000 households

6.000 cars

30 km/d (180.000 km/day)

11,3 km/l Gasoline



15.900 l Gasoline/day

100 bbl./day

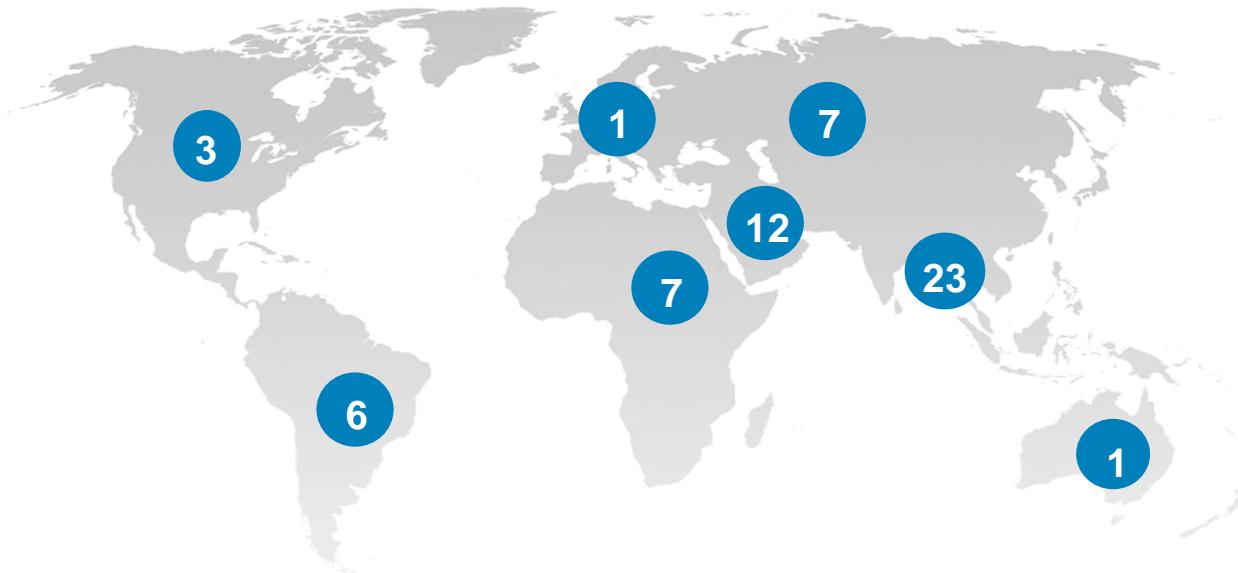


# Topsoe ammonia plants

Since 2000

Number of plants: 60

Accumulated capacity, MTPD: 99,505



# SOEC Operating temperatures as function of voltage and ASR

ASR = Area specific resistance

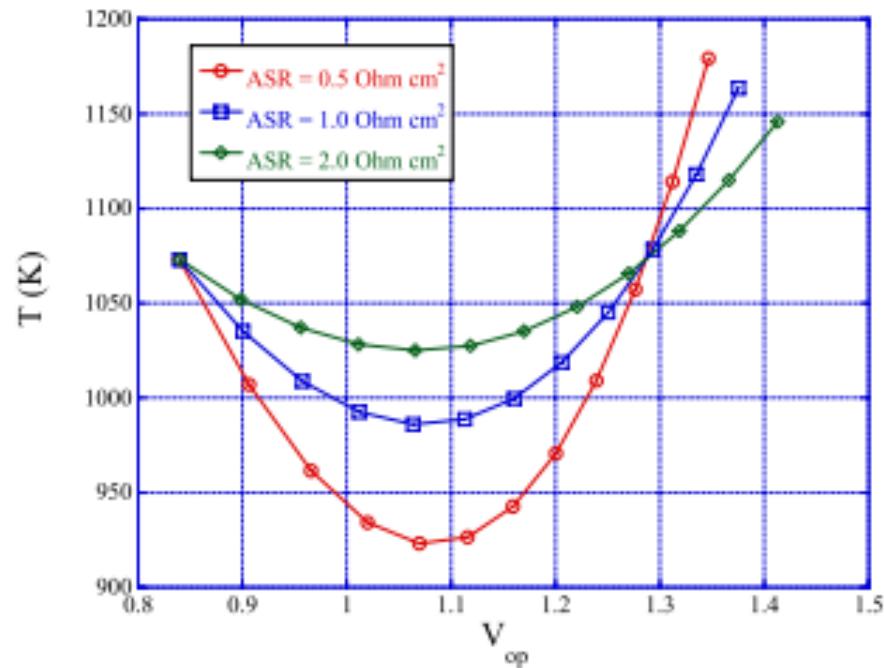
$$V_m = \Delta H_R / 2F$$

$$\dot{Q}_T(T) = I(V_m - V_{op})$$

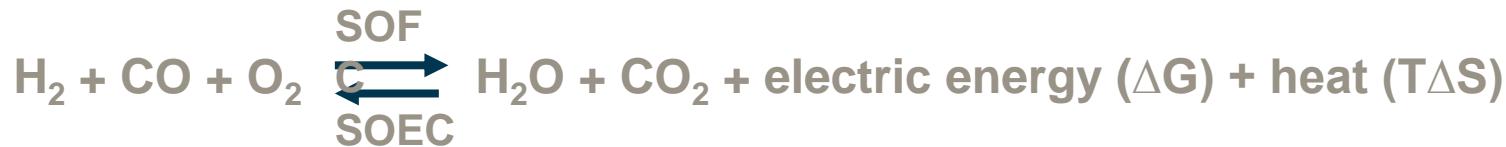
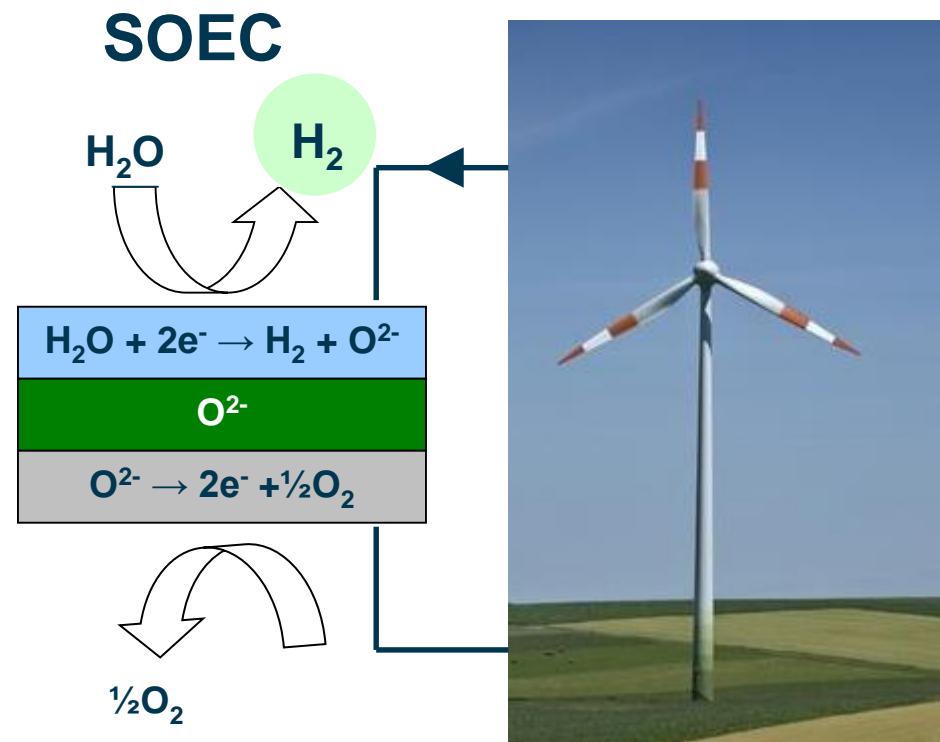
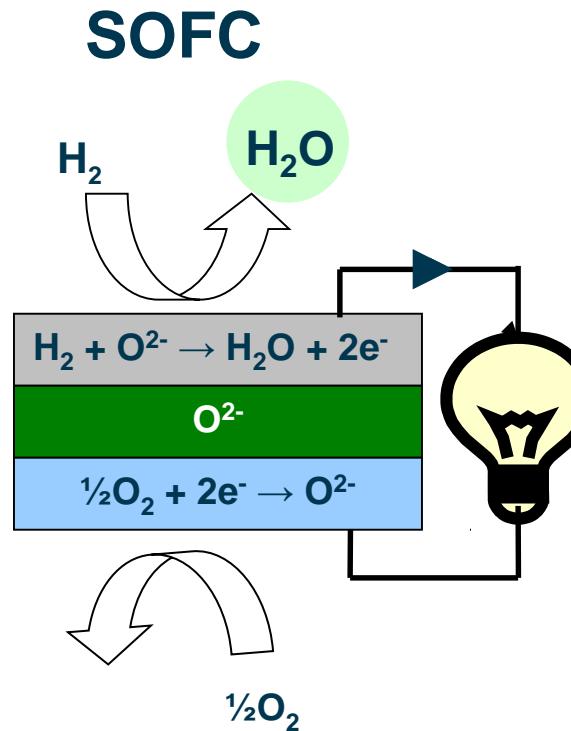
$$q''_{\text{Ohm}} = i^2 ASR = i(V_{op} - V_N)$$

$$\eta_e = \frac{\Delta H_R / 2F}{V_{op}} = \frac{V_m}{V_{op}}$$

Source: O'Brien IMECE 2008

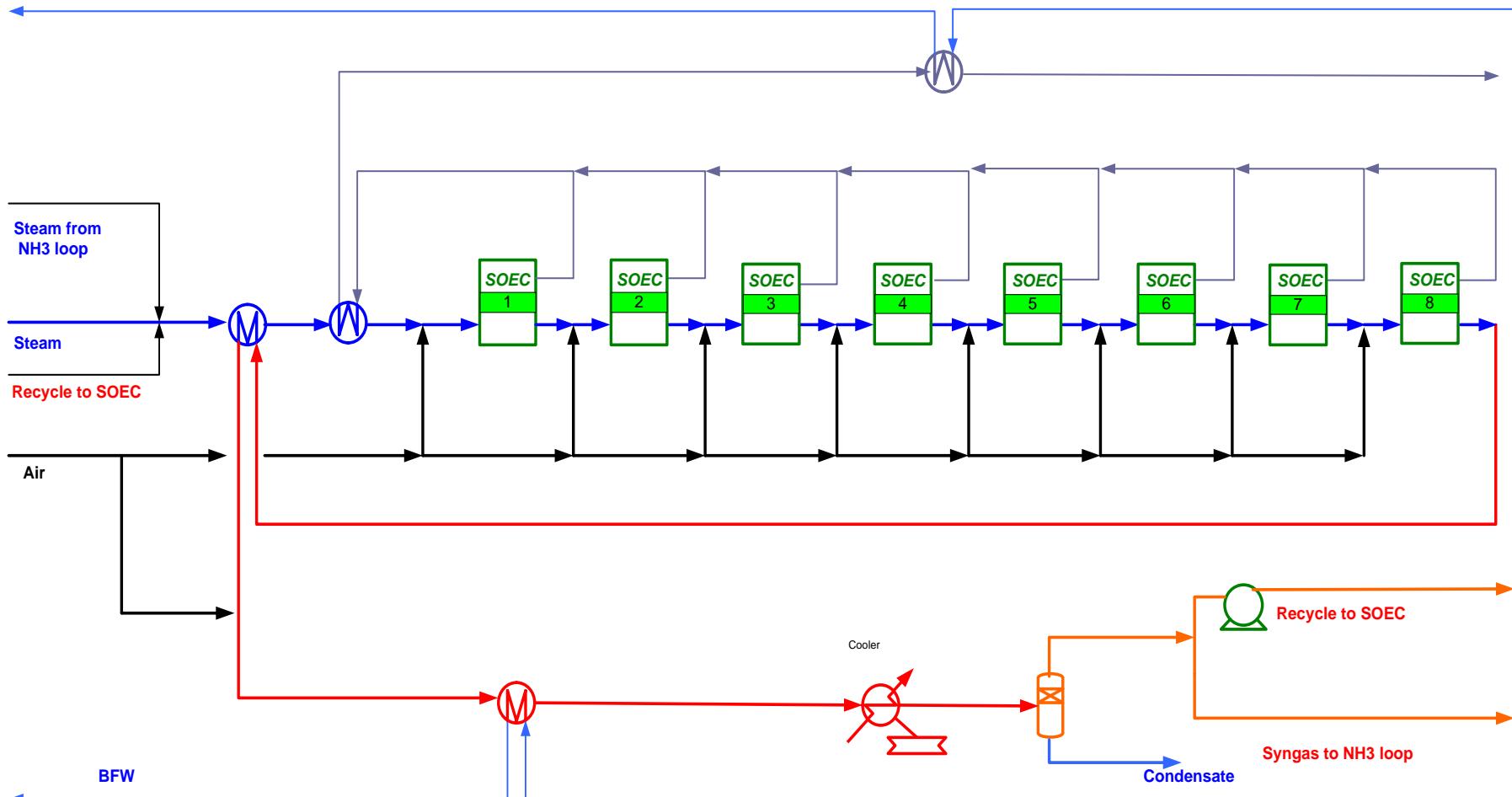


# Fuel Cell and Electrolyser

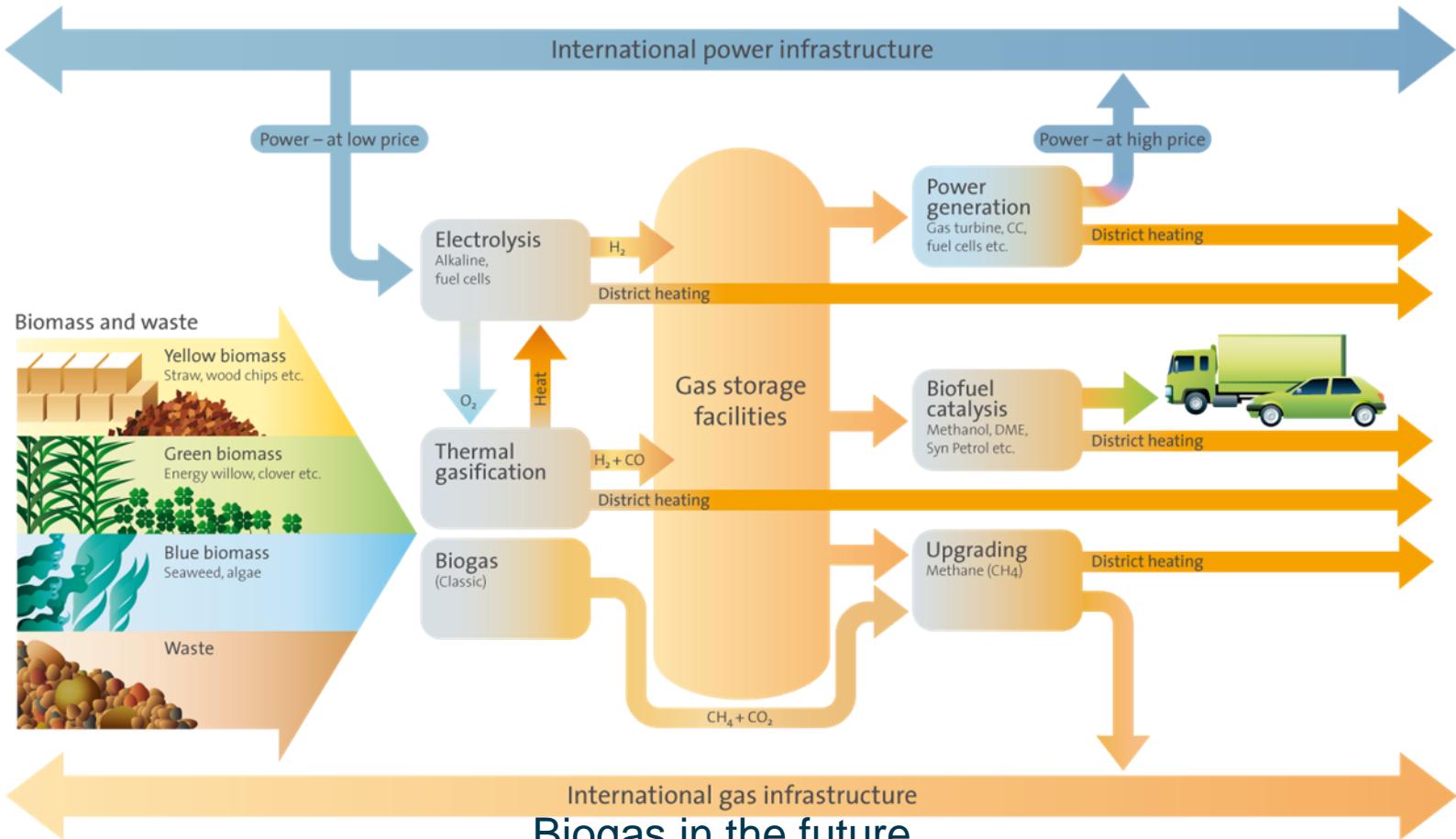


# Ammonia Synthesis Gas Generation by SOEC

Efficiency = 77 % on exergy basis – 71 % on LHV basis



# Using the gas system as a key integrator



**Biogas in the future  
integrated energy system**