Solid Oxide Cell Enabled Ammonia Synthesis and Ammonia based Power Production

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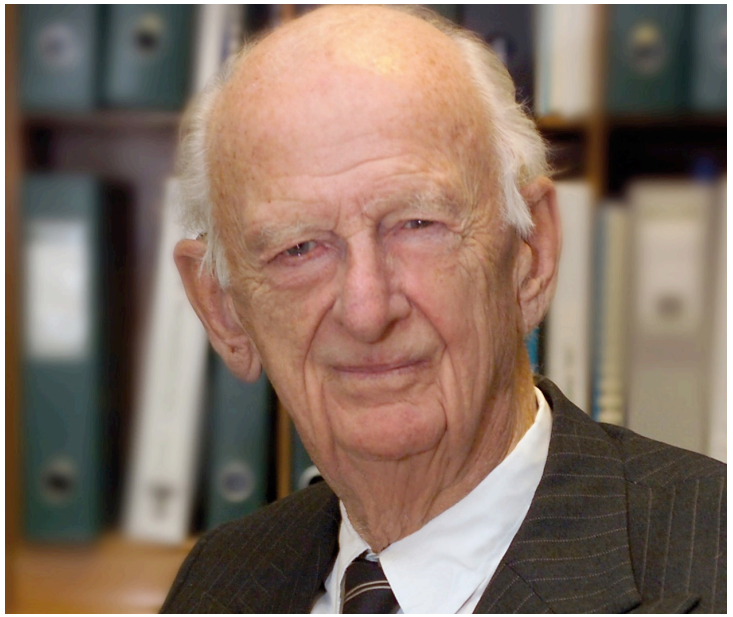
Haldor Topsøe A/S

HALDOR TOPSOE

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

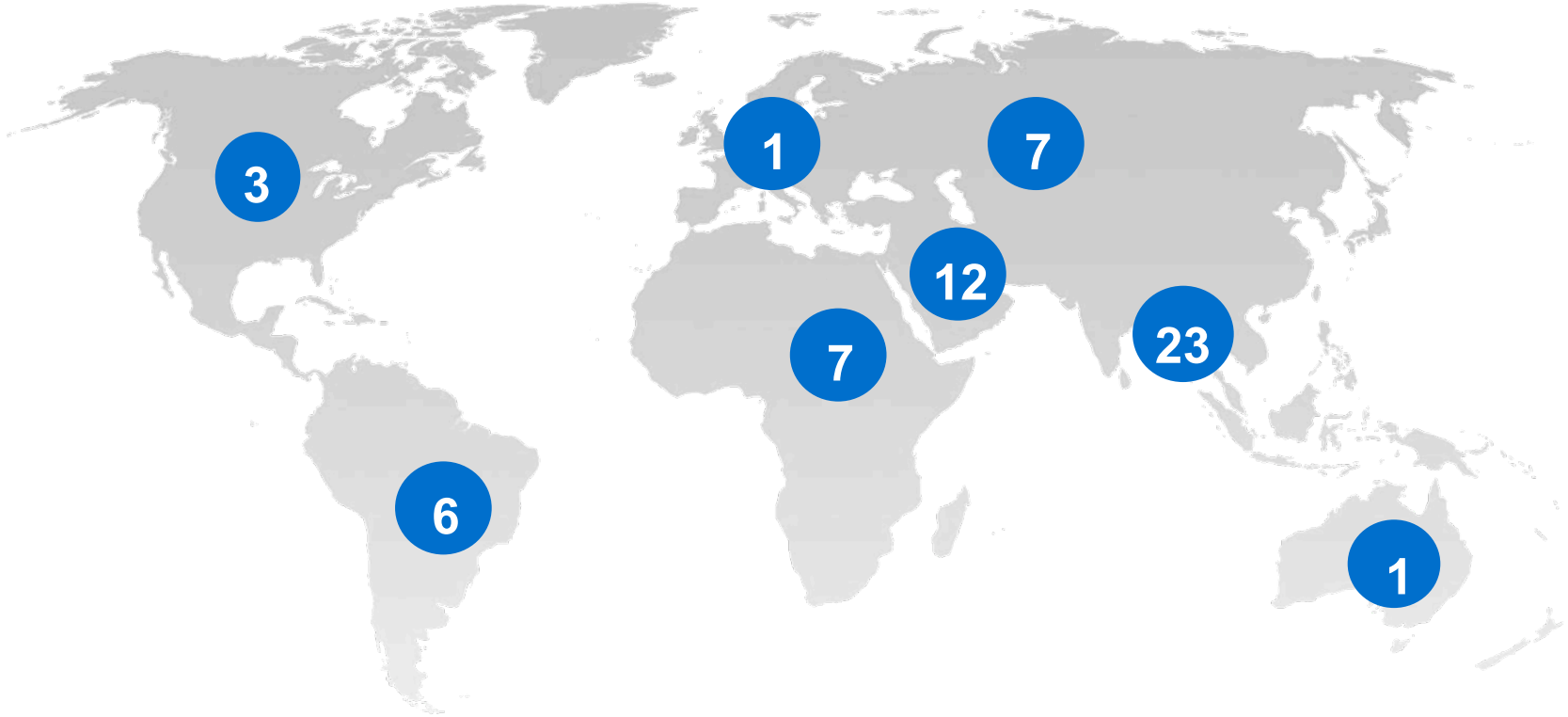


Topsøe Ammonia Catalyst Charges

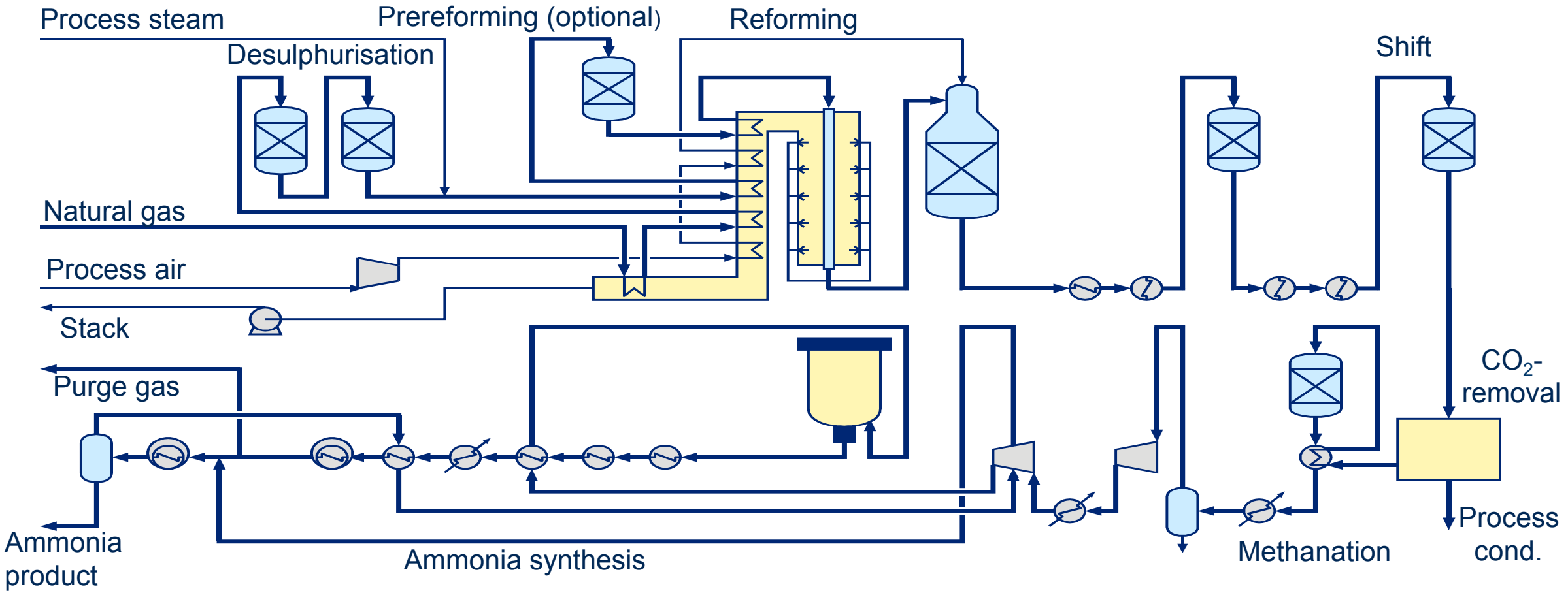
- 248 current references worldwide

Topsoe ammonia plants
Since 2000

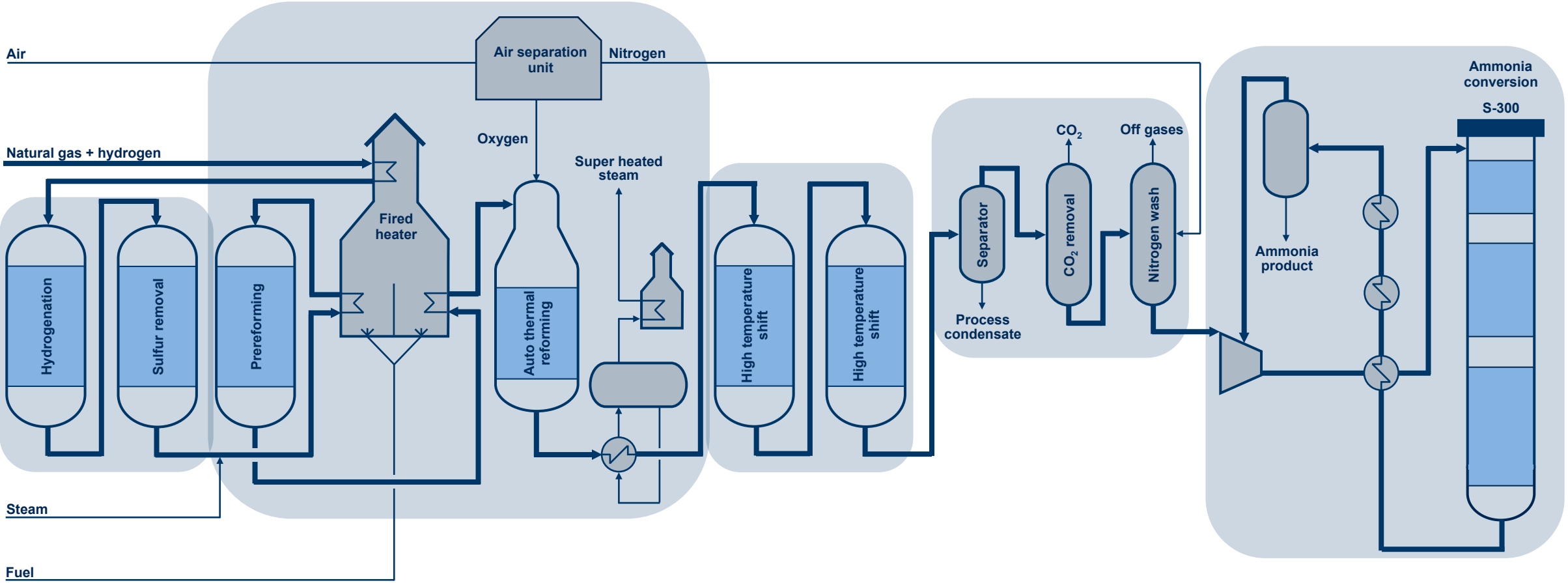
Number of plants:	60
Accumulated capacity, MTPD:	99,505



Topsoe ammonia process – alternative with prereformer



SynCOR Ammonia™
Simplified process layout



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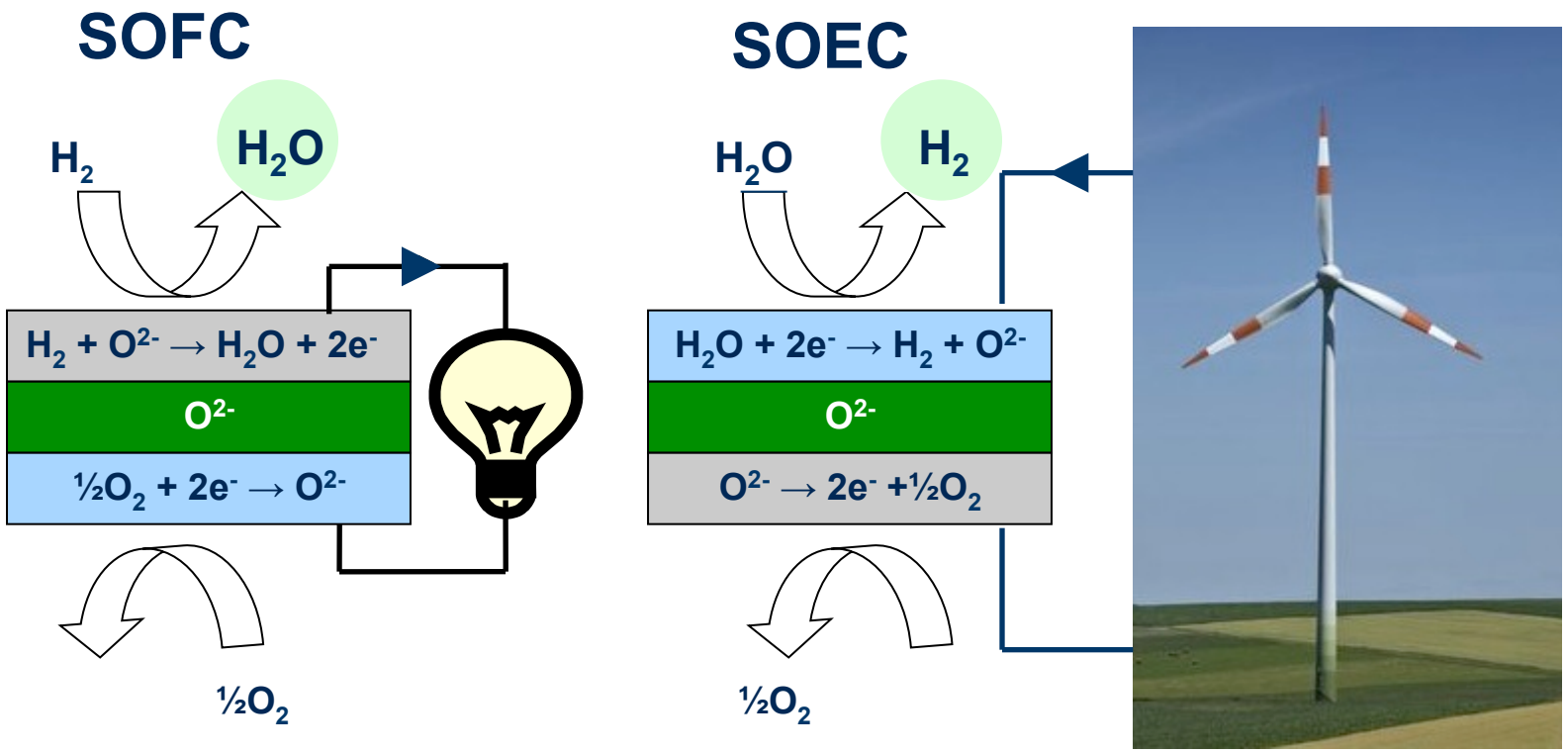
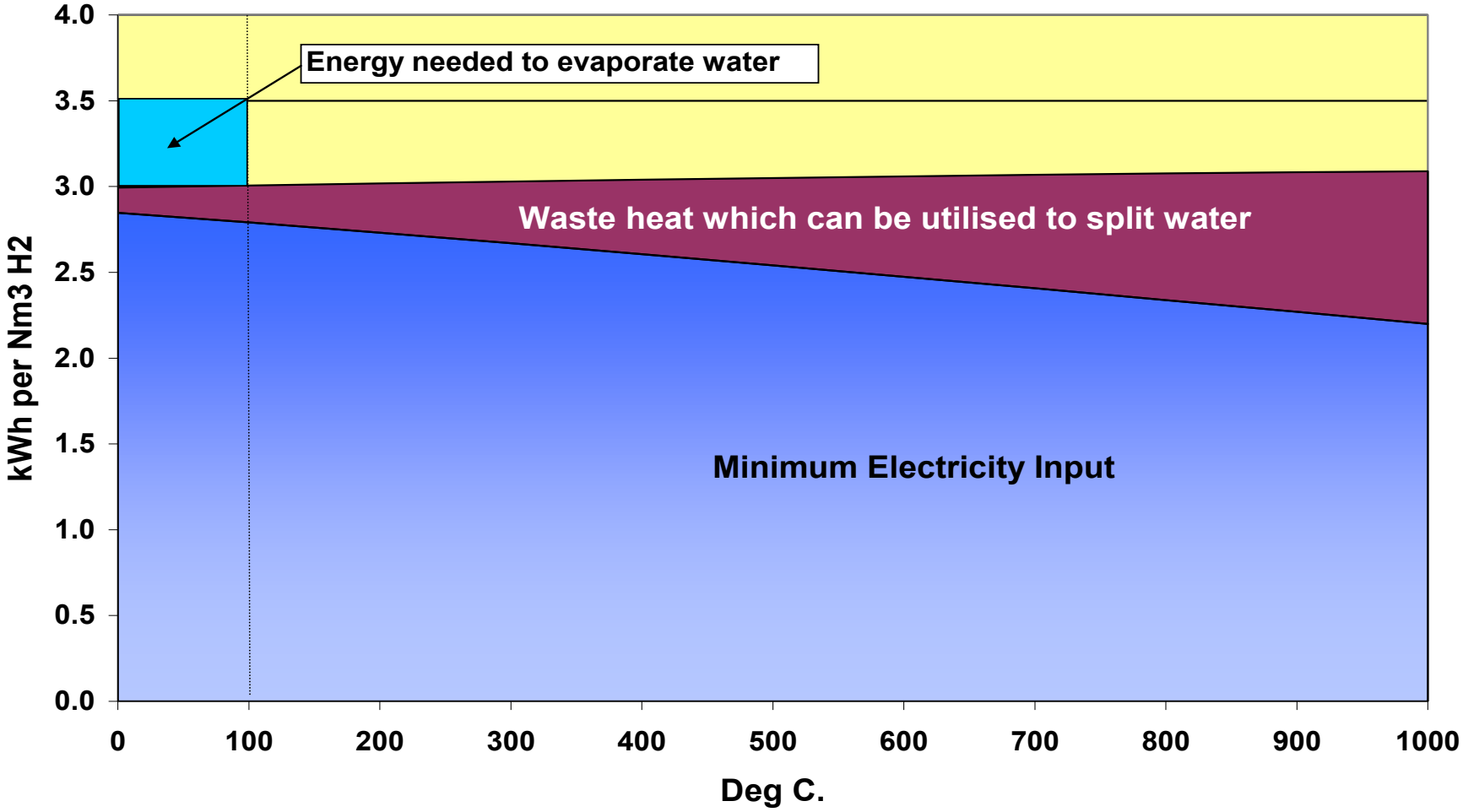
Fuel Cell and Electrolyser



$$H_2 + CO + O_2 \underset{\text{SOEC}}{\overset{\text{SOFC}}{\rightleftharpoons}} H_2O + CO_2 + \text{electric energy } (\Delta G) + \text{heat } (T\Delta S)$$

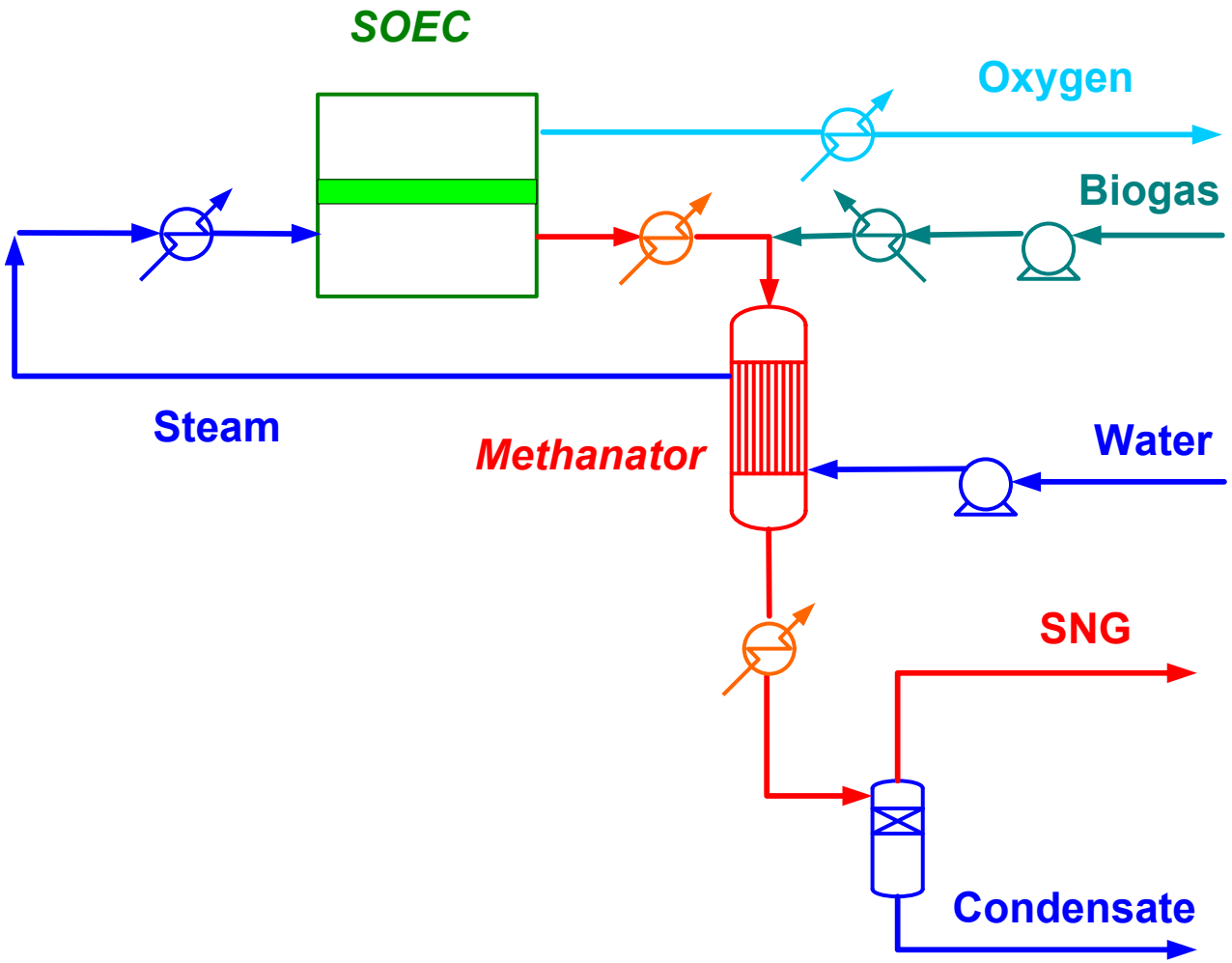
SOEC more efficient than present Electrolysers
Internal waste heat used to split water



Biogas upgrade by means of SOEC

$$CH_4 + CO_2 + 3H_2O + El \rightarrow 2CH_4 + H_2O + 2O_2$$

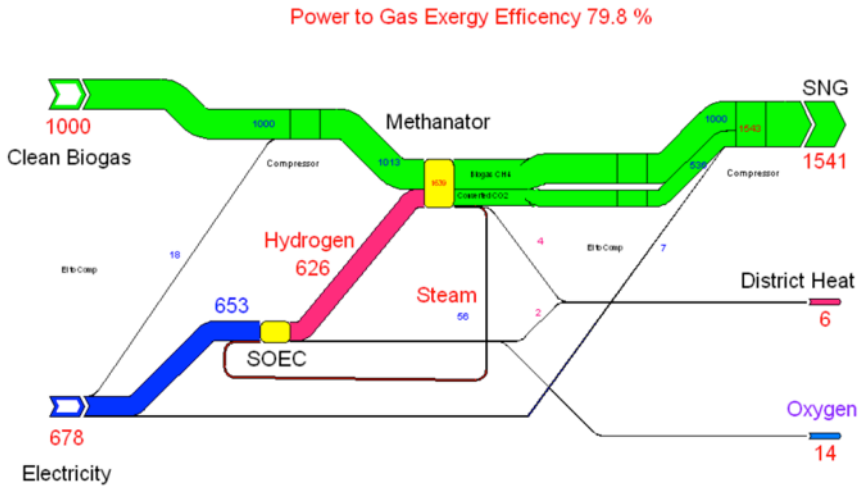
Biogas to SNG via SOEC and methanation of the CO_2 in the biogas



Biogas upgrading demonstration unit

Operating in Foulum, Denmark

- 50 kW SOEC unit for steam electrolysis
- Catalytic methanisation
- The CO_2 in the biogas is upgraded to pure methane with pipeline quality.
- High Exergy Efficiency of 80%



SOEC Operating temperatures as function of voltage and ASR

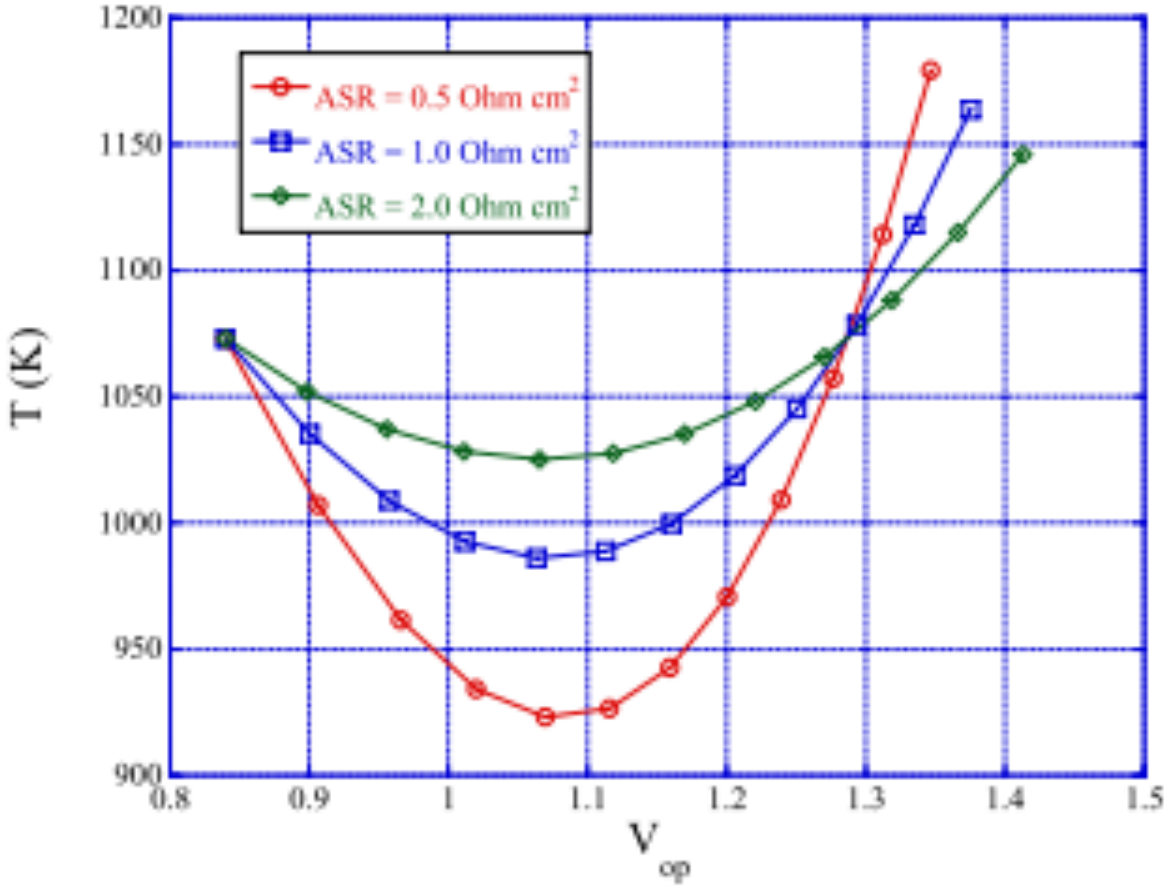
ASR = Area specific resistance

$$V_{tn} = \Delta H_R / 2F$$

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

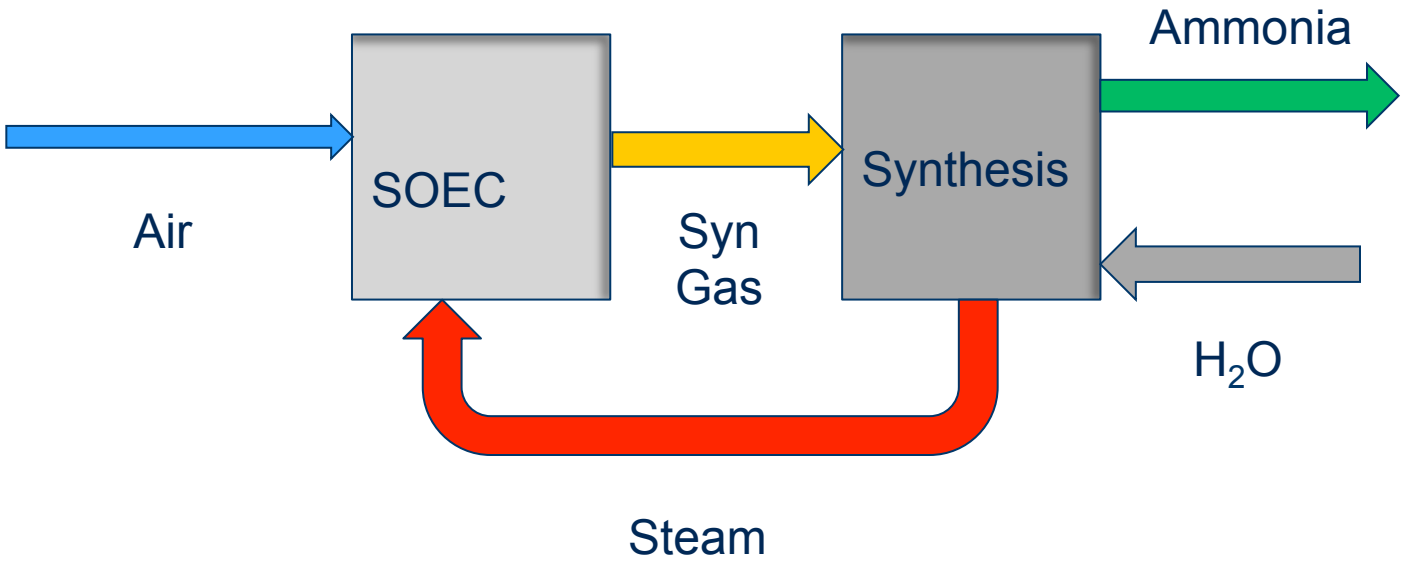
$$q''_{Ohm} = i^2 ASR = i(V_{op} - V_N)$$

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



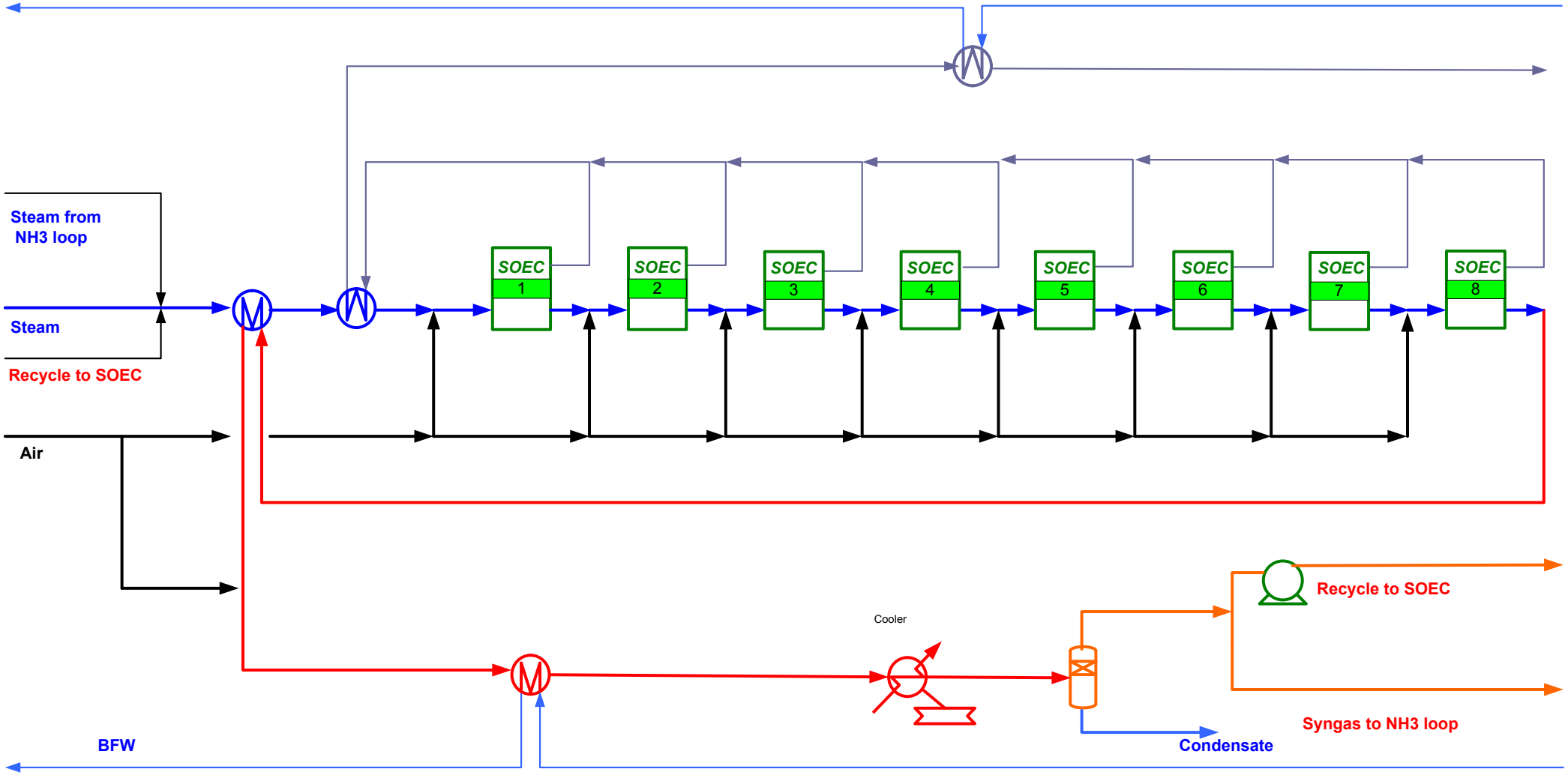
Source: O´Brien IMECE 2008

Synergy between SOEC and fuel synthesis

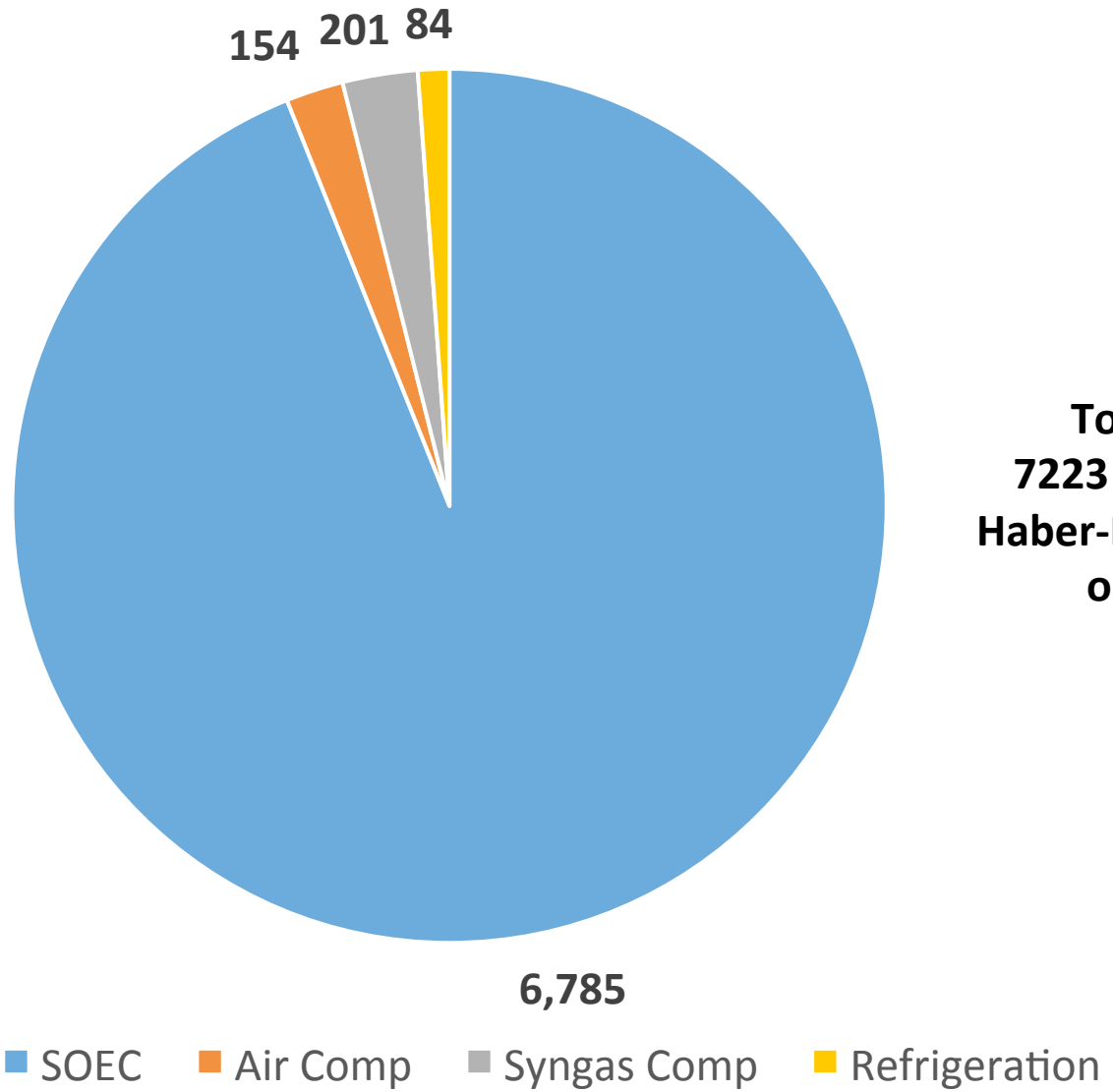


Ammonia Synthesis Gas Generation by SOEC

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



Breakdown of power consumption in kWh per MT ammonia

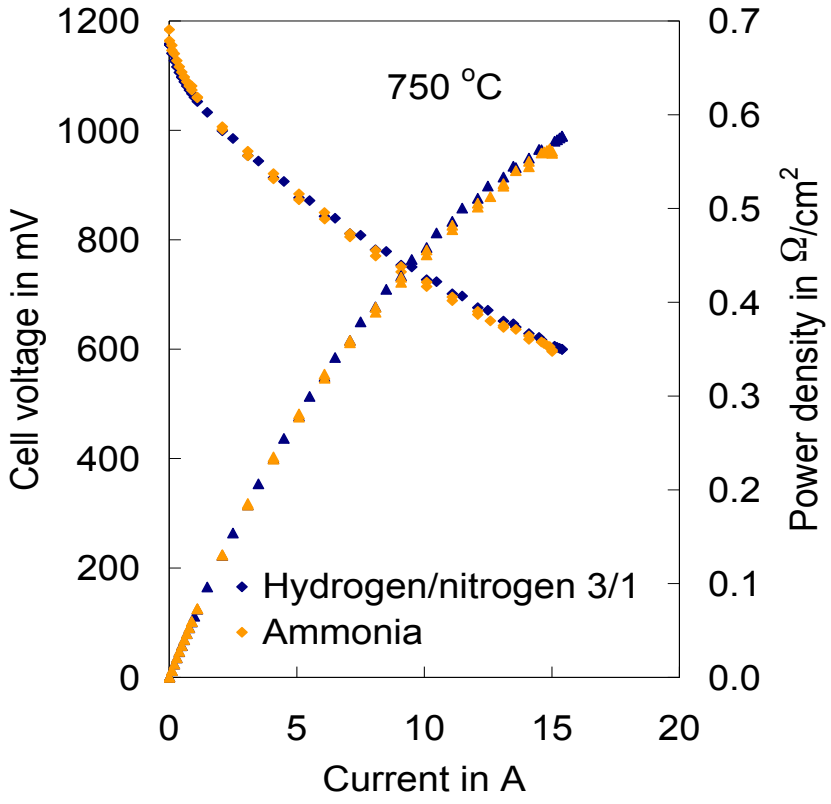


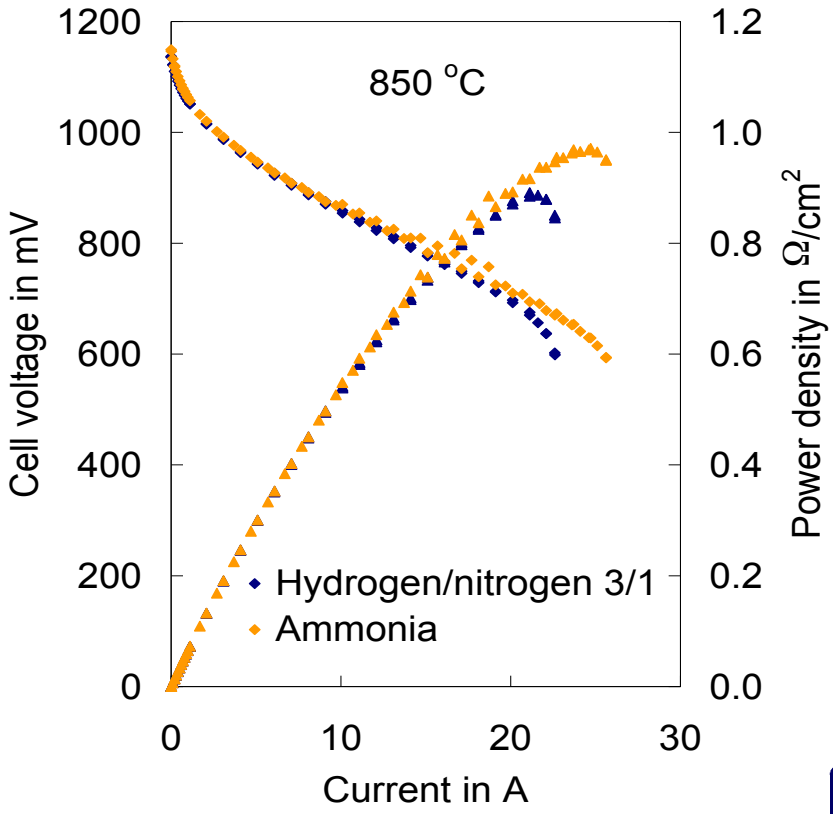
Total energy:
7223 kWh/MT NH_3
Haber-Bosch Synthesis
only 6.0 % !

Direct Ammonia SOFC

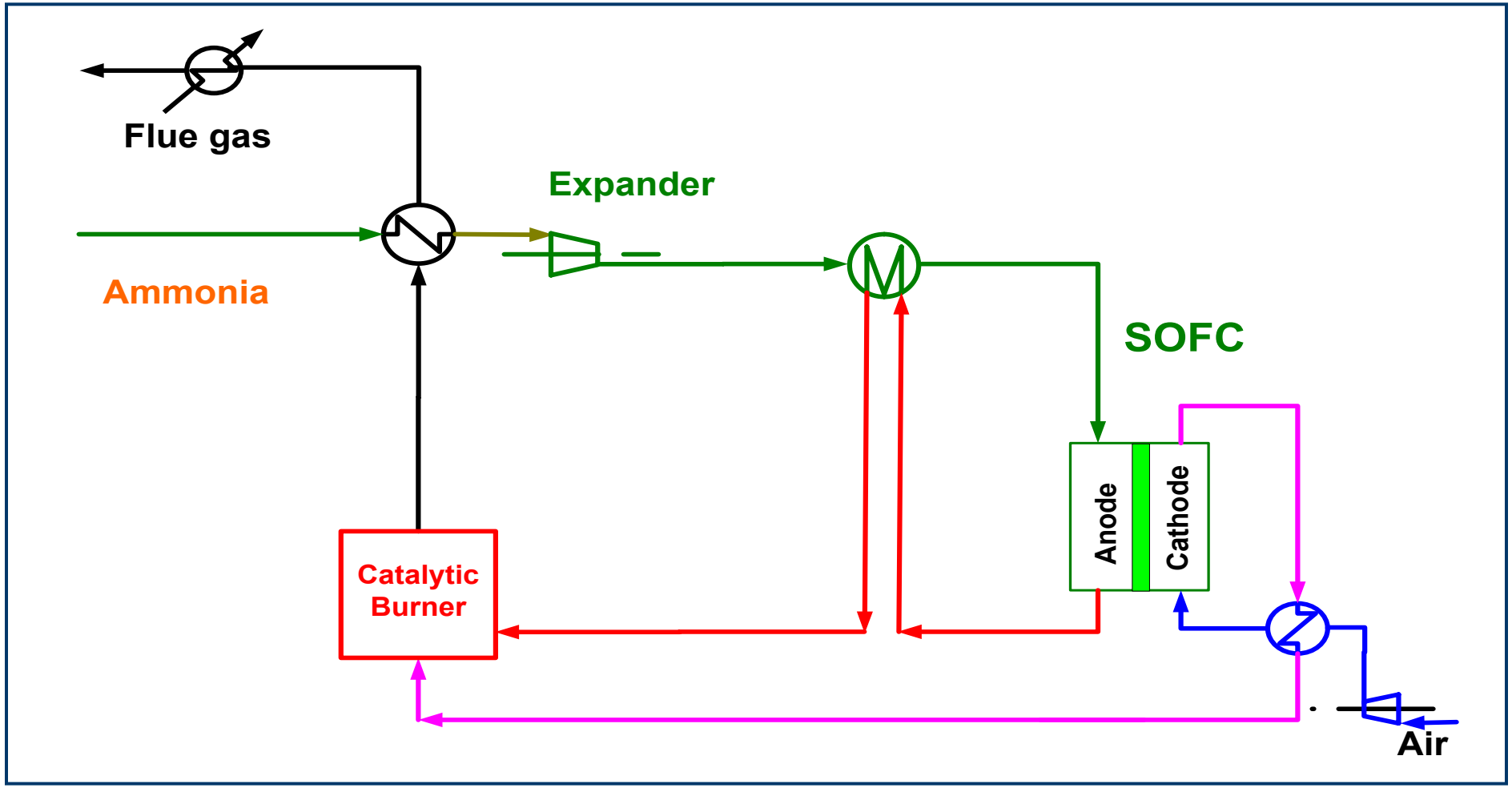
$2\ NH_3 \Rightarrow 3\ H_2 + N_2$

Same or better performance with ammonia as with H_2+ N_2 mixture





Direct use of Ammonia for SOFC
Electrical efficiency > 60 % LHV



Conclusions

- Haldor Topsøe A/S has been the market leader for both catalyst and ammonia technology for decades
- Recently introduced process scheme enables capacities above 6000 MTPD capacity based on auto-thermal reforming of natural gas
- New Solid Oxide Electrolysis based synthesis gas process eliminates air separation unit and have very high efficiency
- Ammonia is the perfect fuel for Solid Oxide Fuel Cells without the need for water addition or fuel processing

Thank You