High efficient Ammonia Synthesis Systems

John Bøgild Hansen

Haldor Topsøe A/S

Haldor Topsoe
In brief

- Established in 1940 by Dr. Haldor Topsøe.
- Market leader in heterogeneous catalysis and surface science for over 70 years.
- 2,300 employees in 11 countries across five continents.
- Headquarters in Lyngby, Denmark.
- Production in Frederikssund, Denmark, and Houston, USA.
- Spend more than 10% of revenue on R&D.

2018

Revenue AUD 1,220 million

EBIT AUD 154 million

EBIT margin of 13%

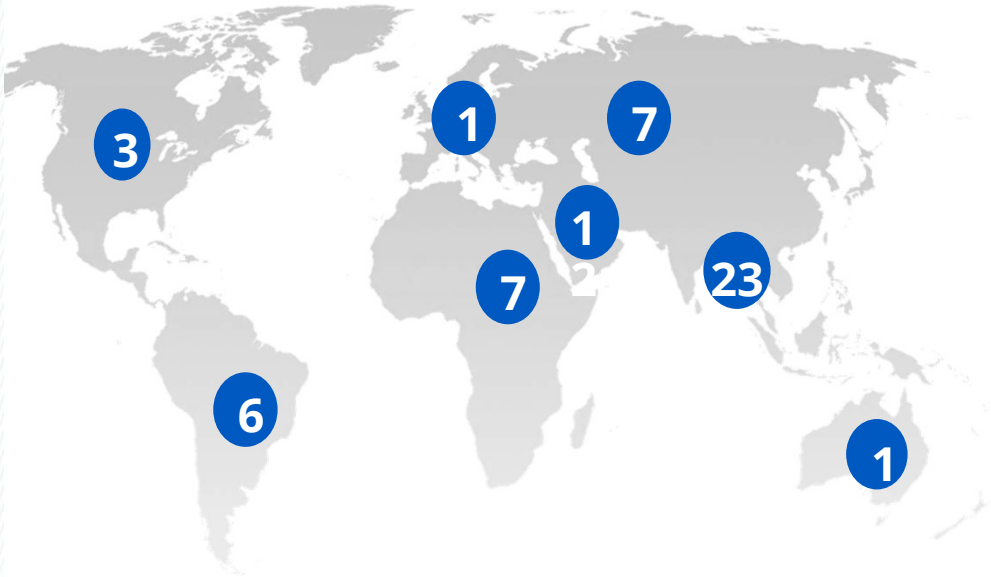
Net profit of AUD 107 million

Topsøe Ammonia Catalyst Charges and Ammonia Plants

Topsøe is the market leader

248 current catalyst references worldwide

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



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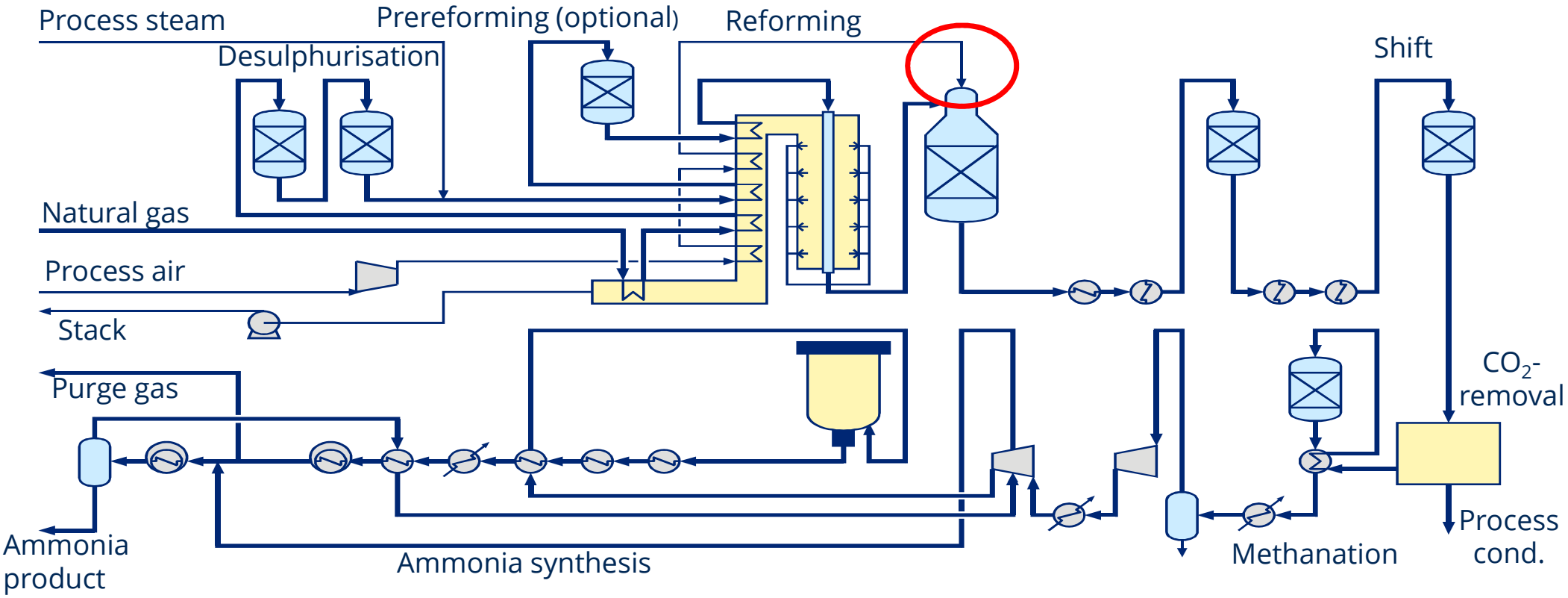
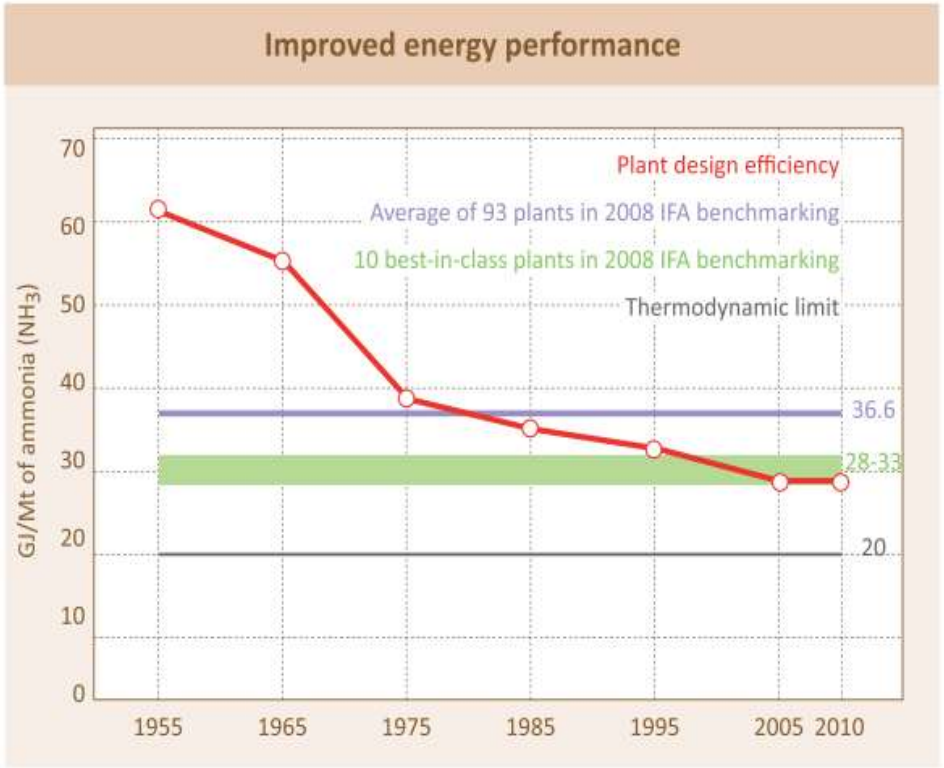
Topsoe classical ammonia process

Very energy efficient but emits 1.6 MT CO_2

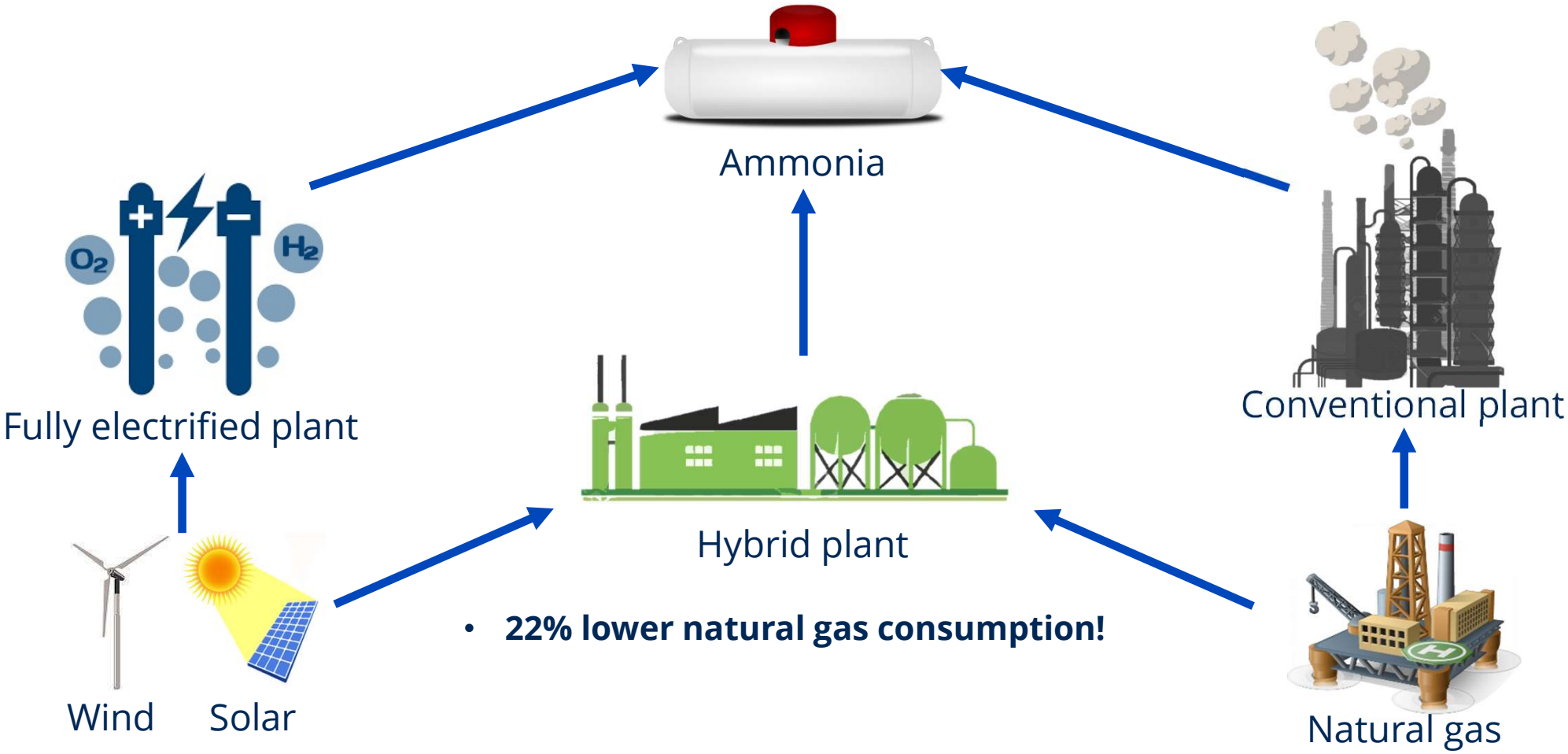


Power-to-X – electrification of ammonia production

- ‘Ammonia production accounts for approximately **1% of the global total energy use**
- Ammonia production accounts for 17 % of all chemical and petrochemicals energy use
- **Half the world food production** depends on synthetic ammonia
- 180 mio tons produced annually
- If produced at 7.2 MWh/MT with SOEC => equivalent to 325 GW @ 4000 h/yr wind or 41000 world class 8 MW turbines
- Ammonia LHV 18.6 GJ/MT=5.16 MWh/MT
- Ammonia excellent carbon free energy carrier of the future



The hybrid plant solution



- **22% lower natural gas consumption!**

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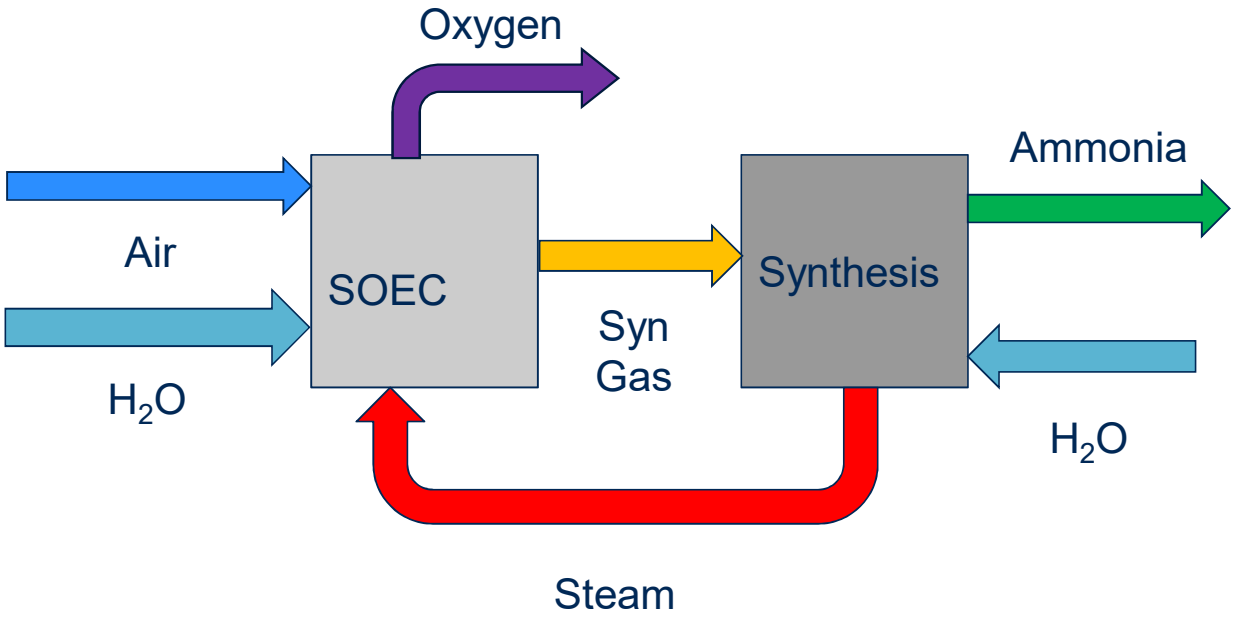
Power-to-X – electrification of ammonia production

Haldor Topsoe's future vision

- Electrolysis offers potential to **de-couple chemical synthesis from CO_2 emissions**
- SOEC is attractive due to its ability to separate oxygen from air and incorporate waste heat to save power resulting in **lower investment** and **higher efficiencies.**



New EUDP project : 1.5 kW SOFC and 50 kW SOEC producing 20 Nm^3/h NH_3 synthesis gas

Participants:
Haldor Topsøe A/S
Aarhus University
DTU
Energinet.dk
Vestas
Ørsted
Equinor

Coordinator:
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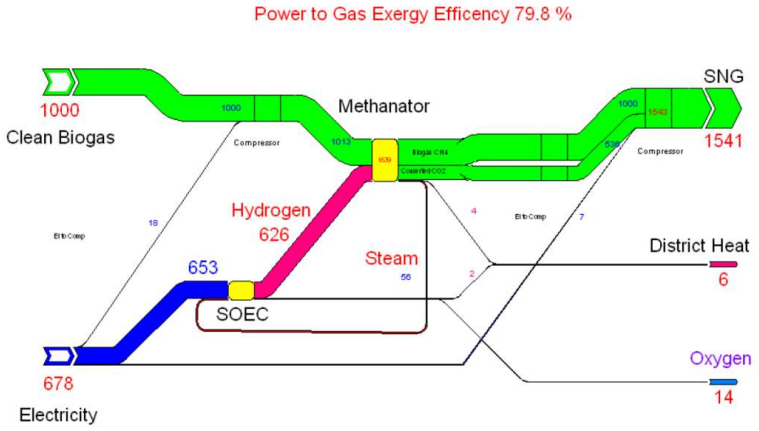
CATALYSING YOUR BUSINESS

Duration:
January 2019
April 2022
Project sum:
3.5 mio €
Location:
Foulum &
DTU

SOEC in Biogas upgrading Demonstration Unit

Operating in Foulum, Denmark

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



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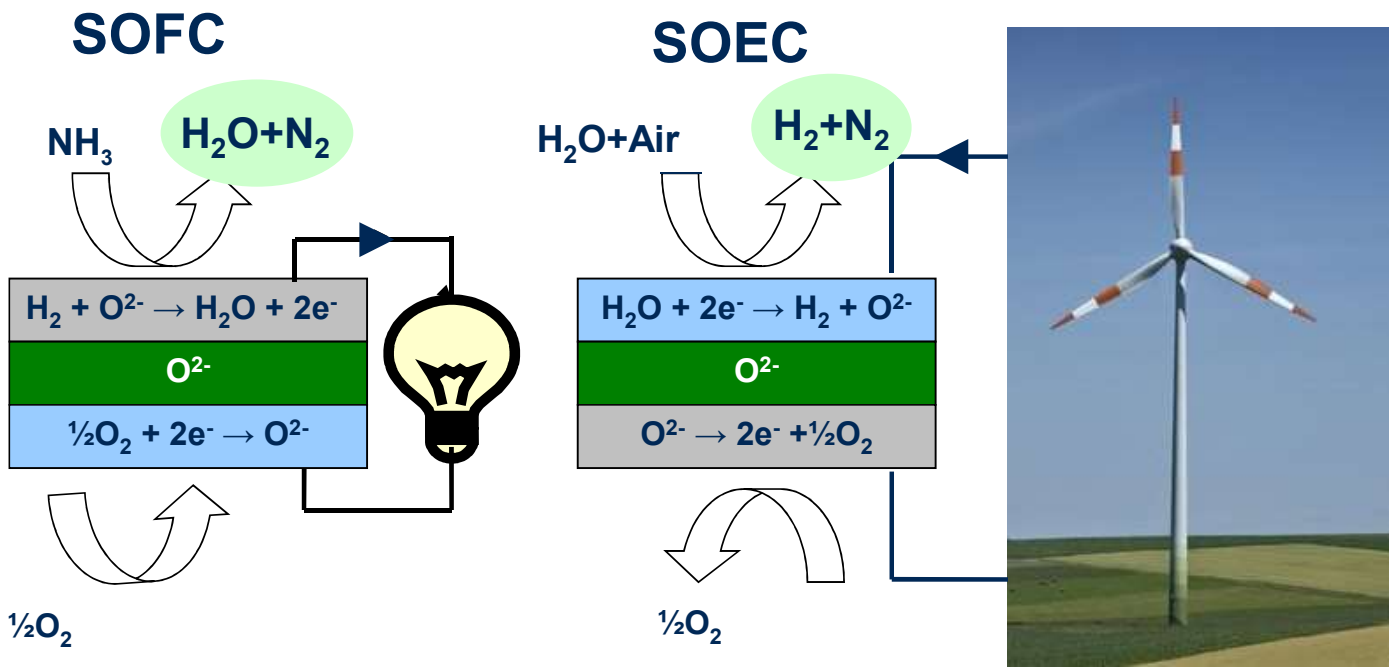
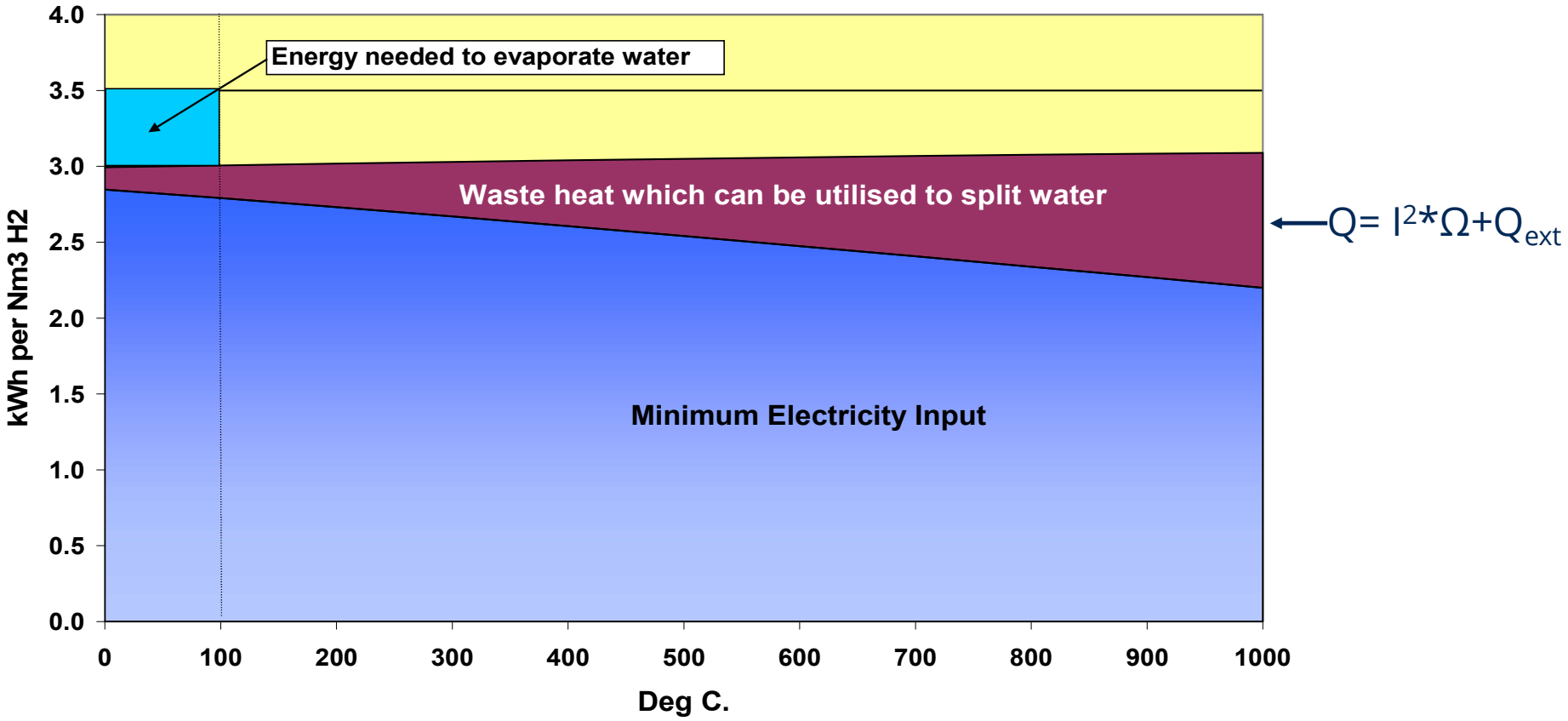
SOC Fuel Cell and Electrolyser



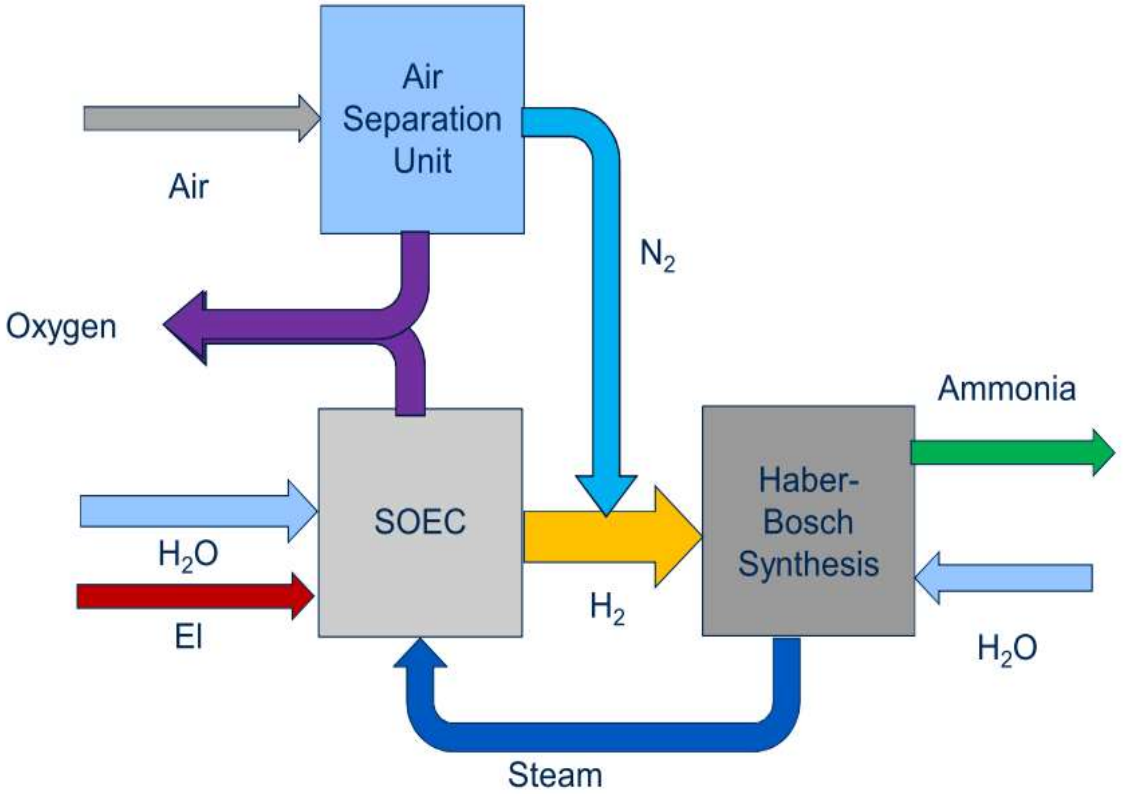
SOC also performs as

- Oxygen separation membrane
- Ammonia Cracker
- Heat exchanger

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

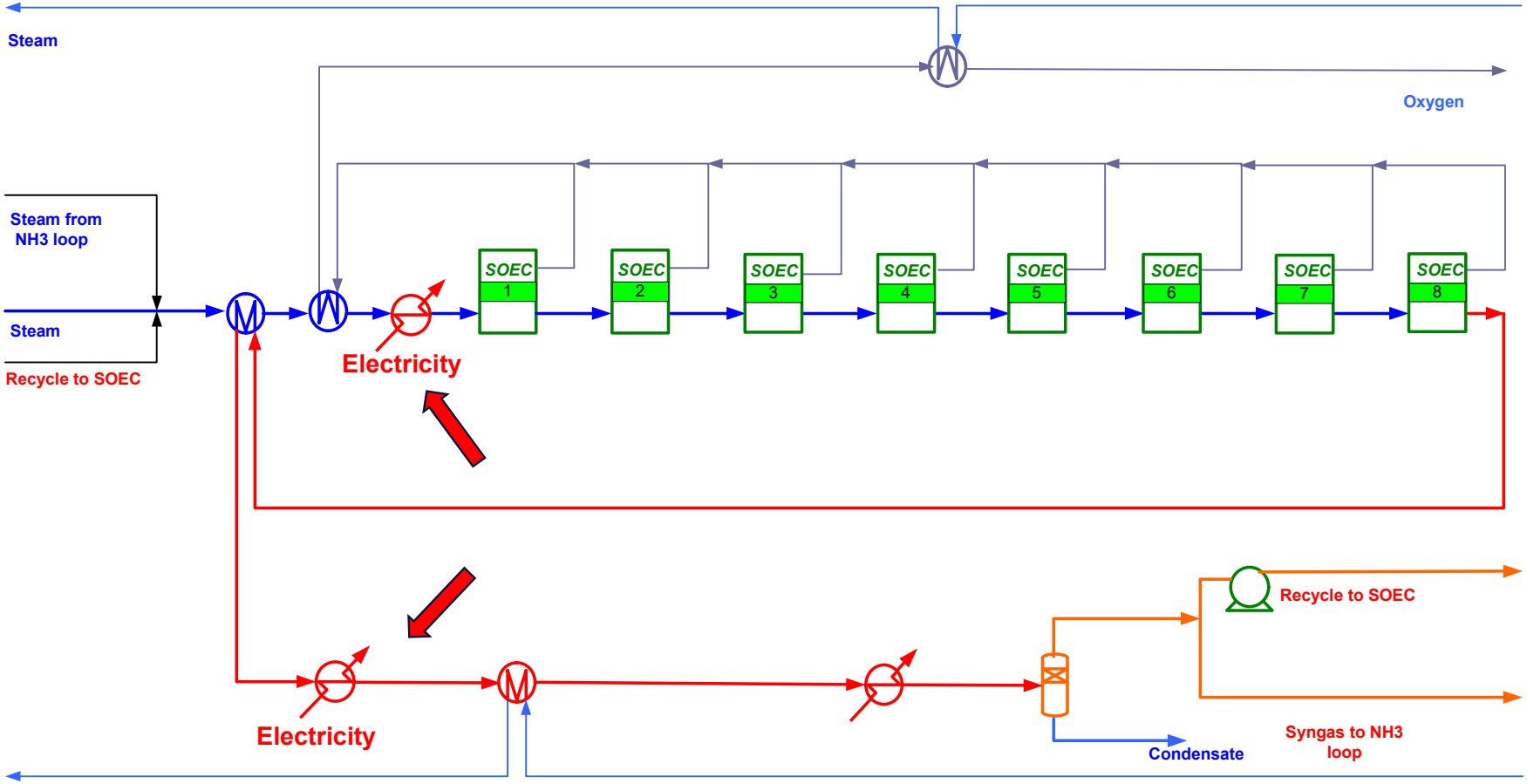


Ammonia production with SOEC and Air Separation Unit

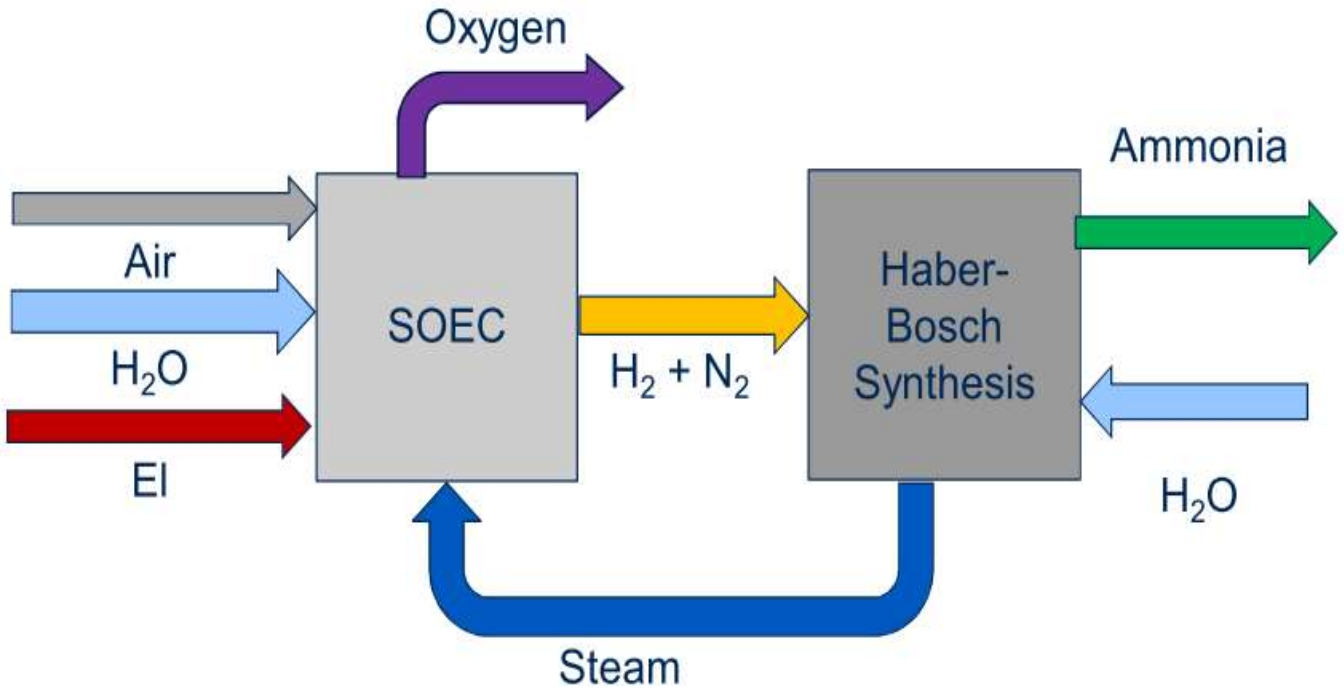


SOEC based ammonia plant with air separation unit

e.g. hydrogen production only

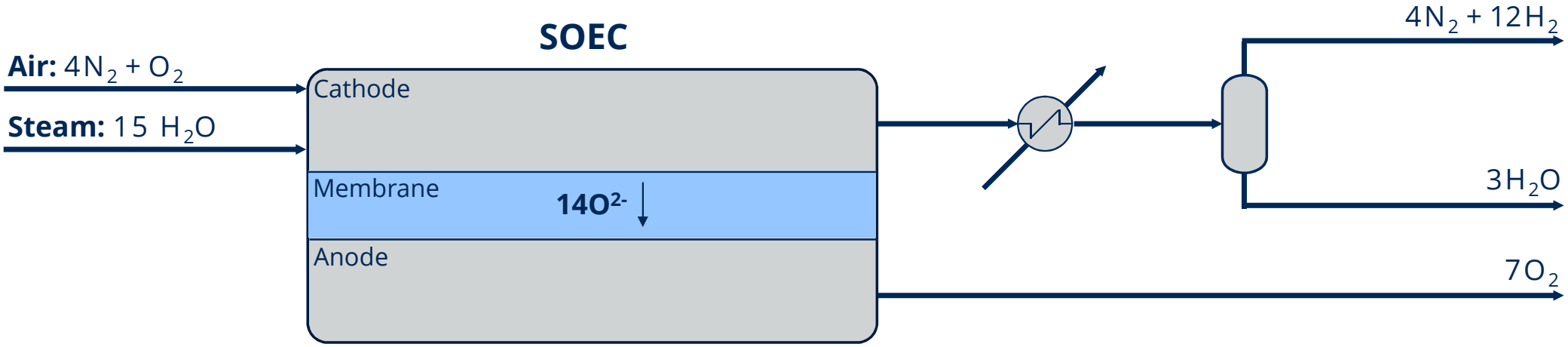


SOEC without separate air separation unit



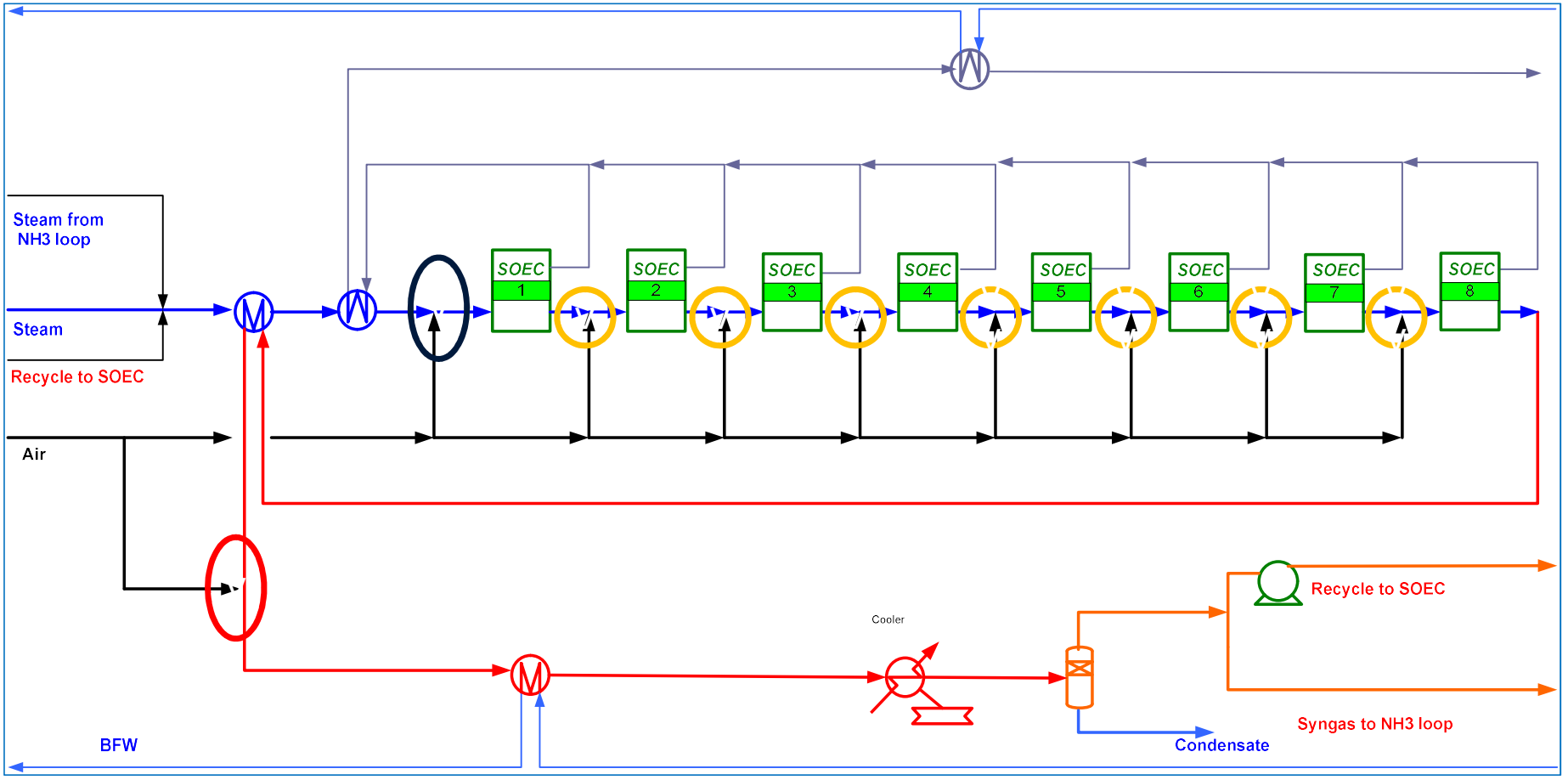
Ammonia syngas by SOEC

Approximate mass balances with Steam conversion 80 %

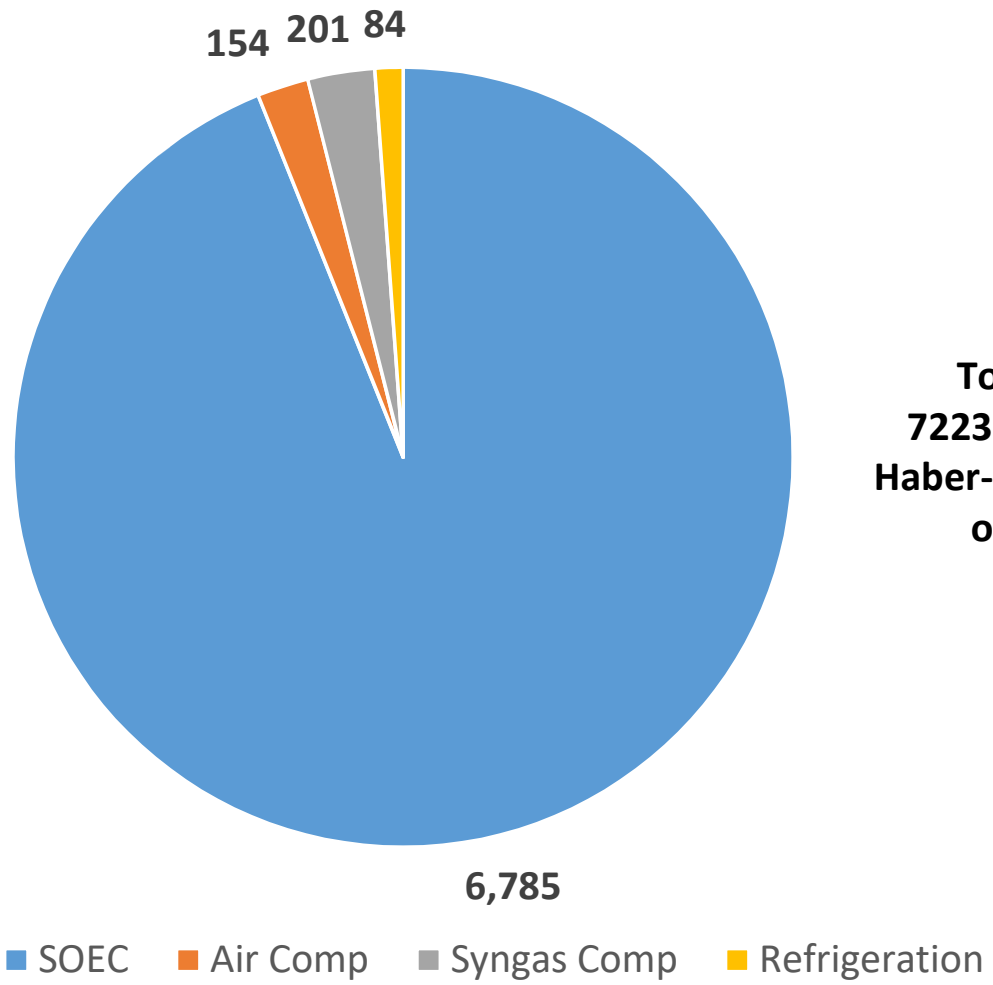


Ammonia Synthesis Gas Generation by SOEC – patent pending

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 % !

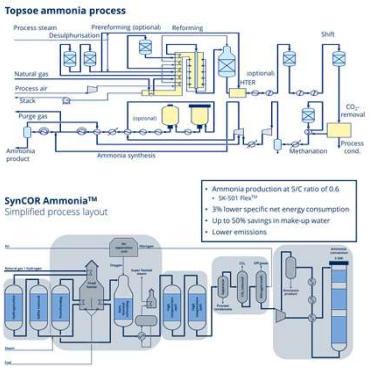
Green Ammonia
Road map

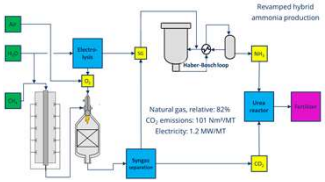
Alkaline electrolysis

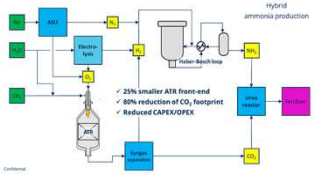
SOEC electrolysis

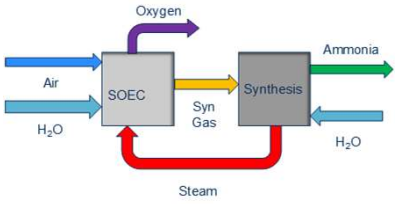
SOEC electrolysis – Development & maturing & Demos

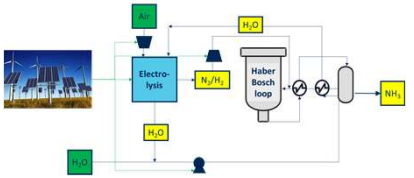
Conventional and SynCOR™ Processes	Hybrid revamp solution	Hybrid grassroots solution	500 – 1000 kg/d SOEC+HB Demo	Commercialize Electrolyzer+HB











Ammonia Track

2018 2020 2022 2025 2030

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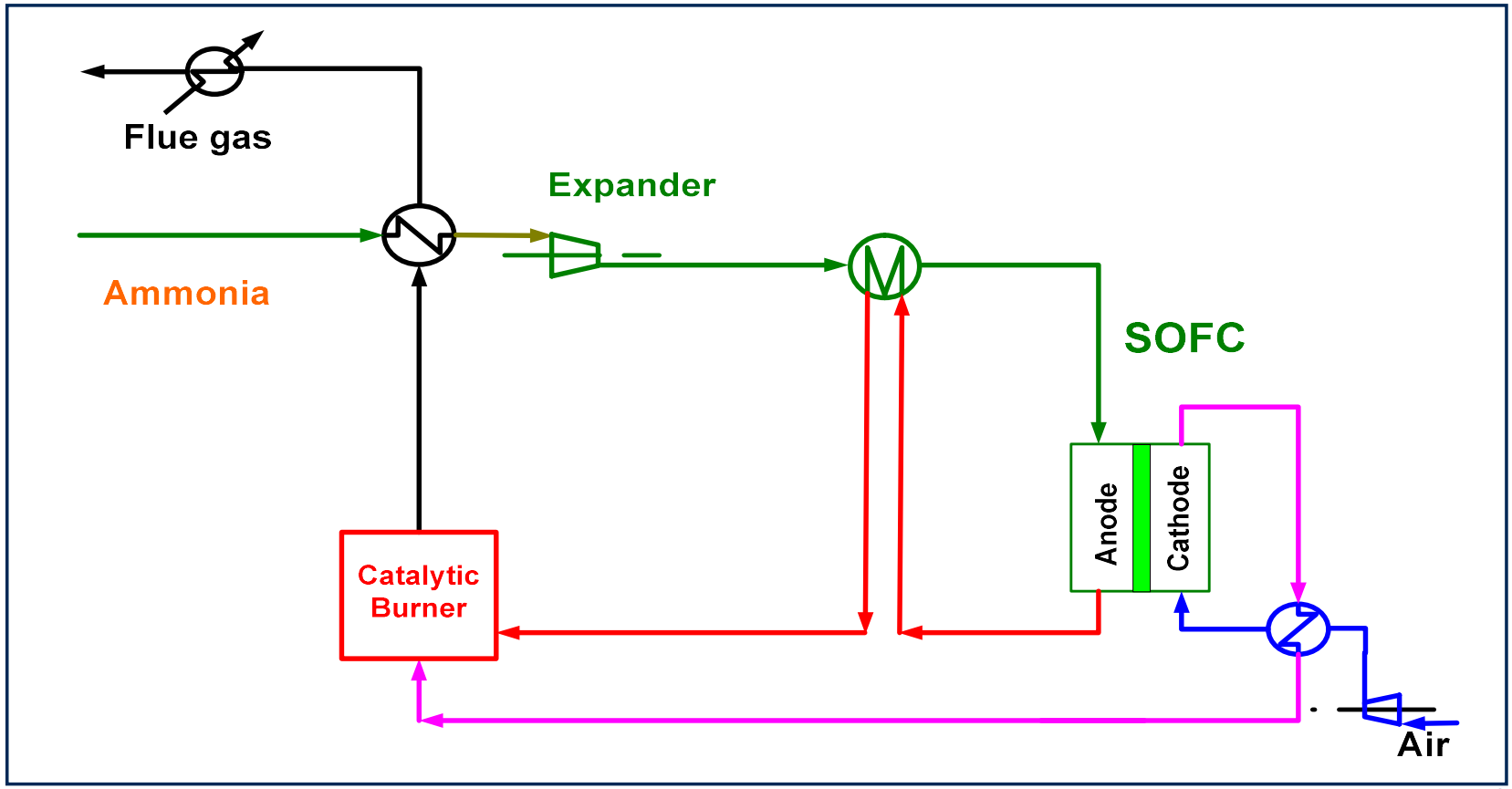
Direct use of Ammonia for SOFC
Electrical efficiency > 60 % LHV



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Coupling of NH3 Cracking and Electrochemical Reactions

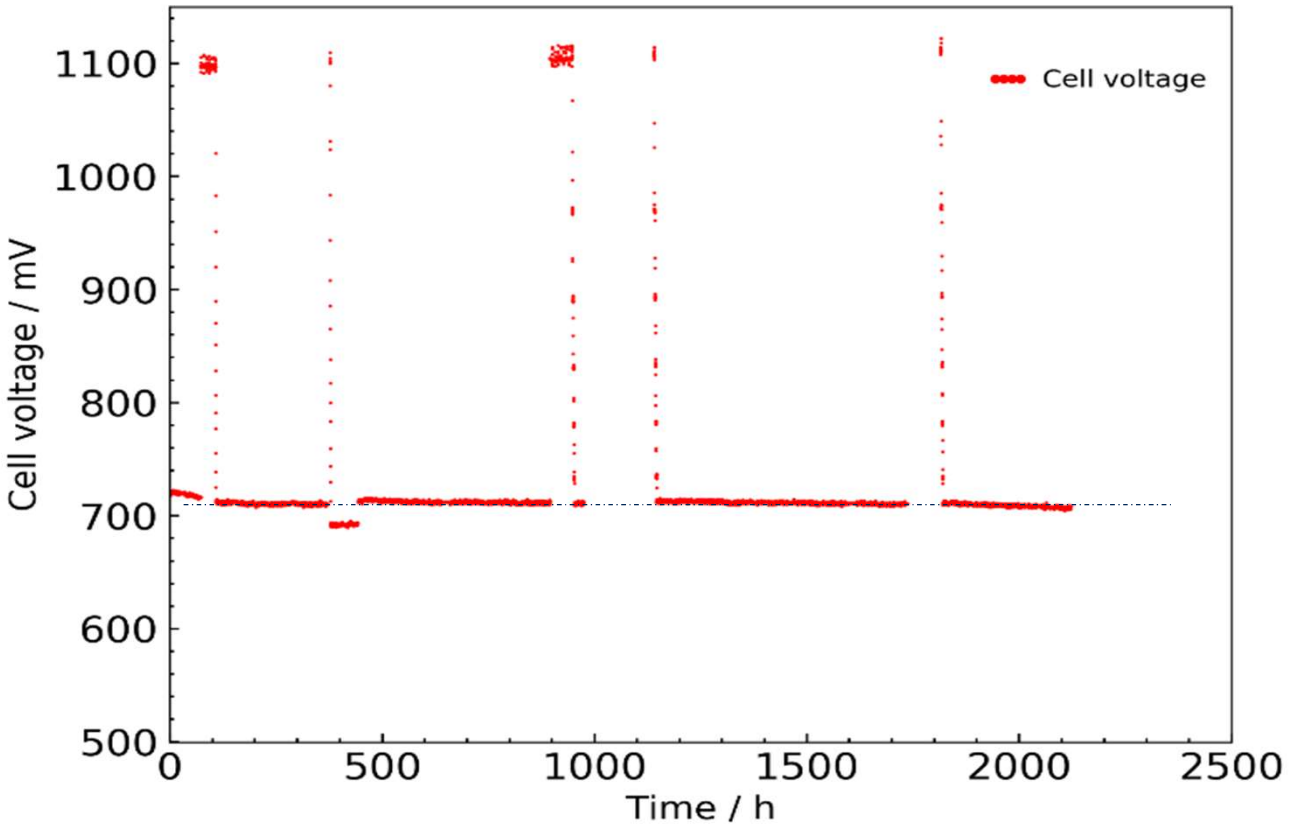
$$2\,NH_3 = N_2 + 3\,H_2 \qquad -Q_R \qquad -\Delta H^0_{923\,K} = -114\ kJ$$

$$3\,H_2 + 1.5\,O_2 = 3\,H_2O \qquad E + Q_C \qquad -\Delta H^0_{923\,K} = 744\ kJ$$

$$2\,NH_3 + 1.5\,O_2 = 3\,H_2O + N_2 \qquad E + Q_C - Q_R \qquad -\Delta H^0_{923\,K} = 630\ kJ$$

Direct use of ammonia in SOFC

Experimental results from DTU Energy



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Conclusions

- New Solid Oxide Electrolysis based synthesis gas process
  - Synergy with HB using steam from synthesis reaction
  - Eliminates air separation unit due SOC “built in” oxygen separation
  - Utilize heat of air combustion to split steam
  - Have very high efficiency
- Ammonia is the perfect fuel for Solid Oxide Fuel Cells
  - No fuel processing
  - No carbon problems => no need for steam addition => high Nernst potential inlet
  - Cooling by ammonia cracking


Making optimal
performance
possible