Solid Oxide Technology for Ammonia Production and Use

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Haldor Topsøe A/S

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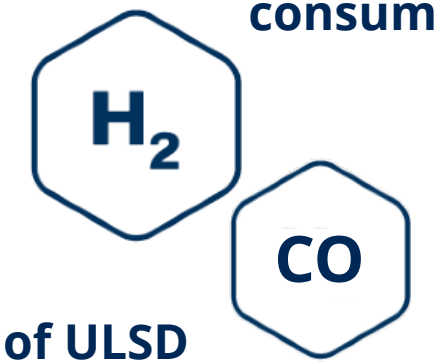
Where are Topsoe's catalysts and technologies used?

>60% of global NH_3 is made using our catalysts

40% of ULSD is produced using our technology



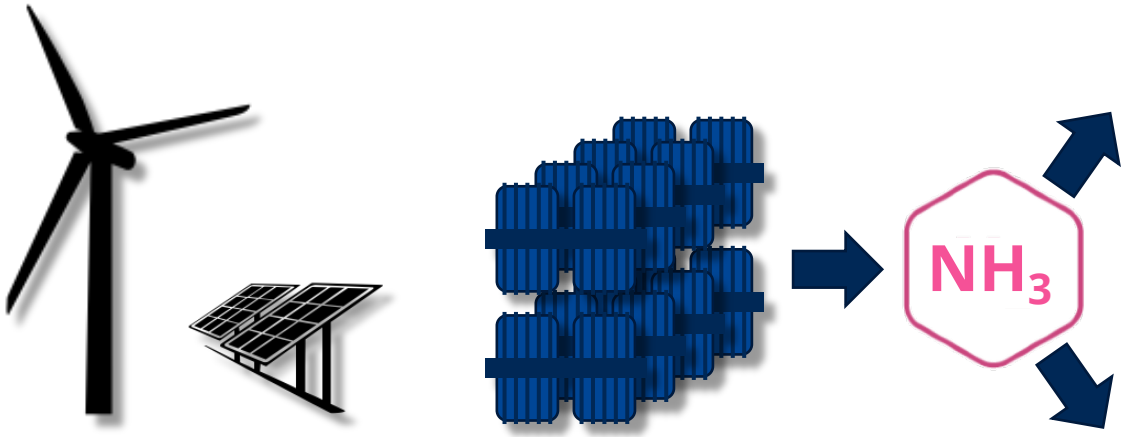
Best methanol catalyst in the world – significantly **reducing energy consumption**

>30% market share of H_2 catalysts.

Power-to-X, Haldor Topsoe's vision

Ammonia as a carbon free energy vector

41,000 wind turbines @ 8 MW



~1% World energy consumption

Half of world food production

~3 % World energy consumption

45 % of Denmarks CO_2 emissions

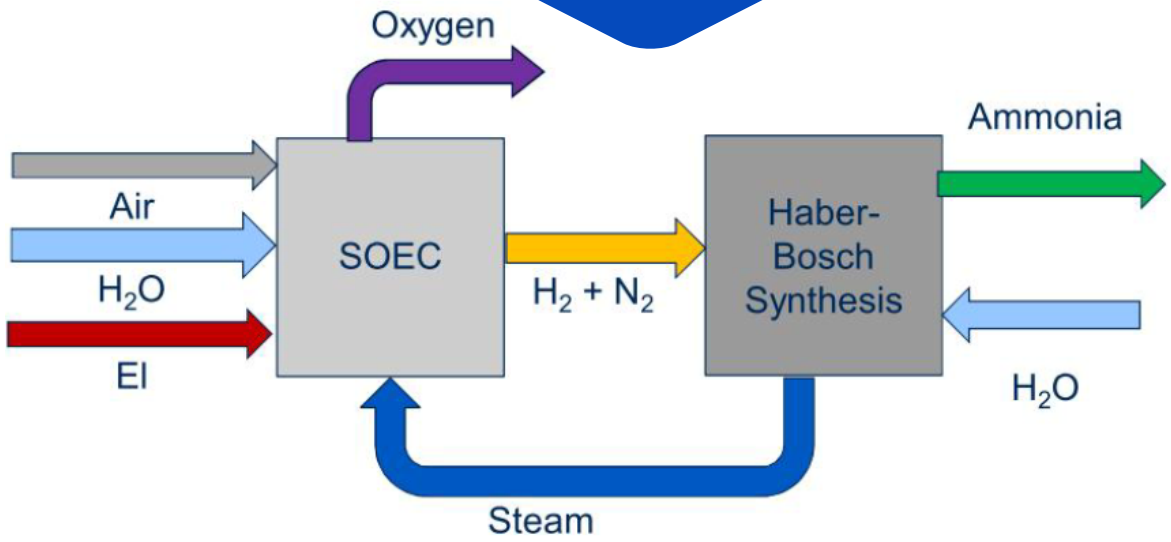
The upcoming markets have huge potential!

Power2Ammonia

Production of ammonia synthesis gas in an SOEC core

Project sum: 3.5 mio €

- EUDP funding obtained December 2018
- Project January 2019 to March 2022
- Work packages
  - WP1: Design and construction of SOEC unit
  - WP2: SOEC Plant Operation
  - WP3: NH_3 as SOEC Fuel
  - WP4: Design of Demo and Full Scale NH_3 plant
  - WP5: Project management and Dissemination
- Partners:



SOEC concept to be demonstrated in EUDP project “SOC4NH3”

- 50 kW SOEC (8 stacks)

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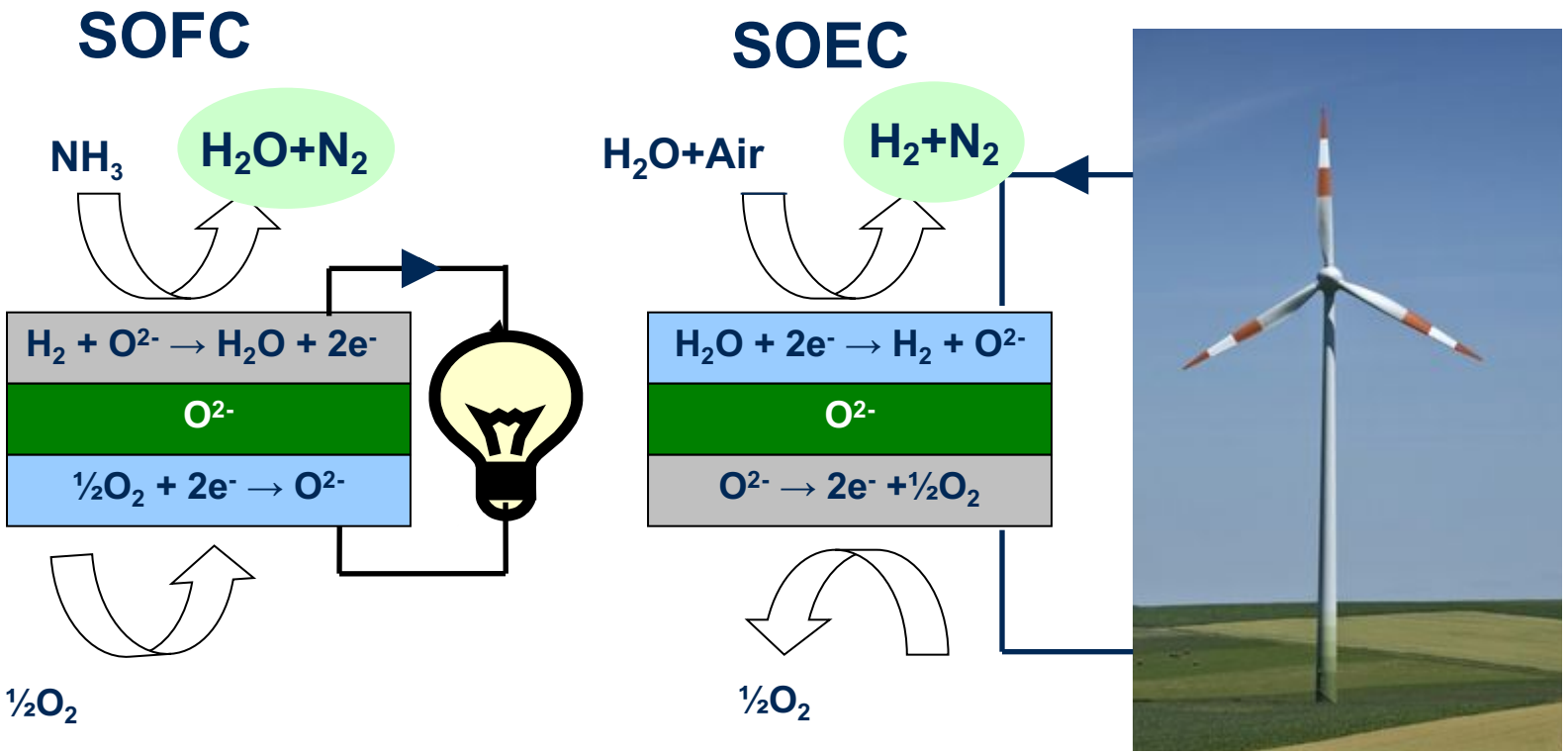
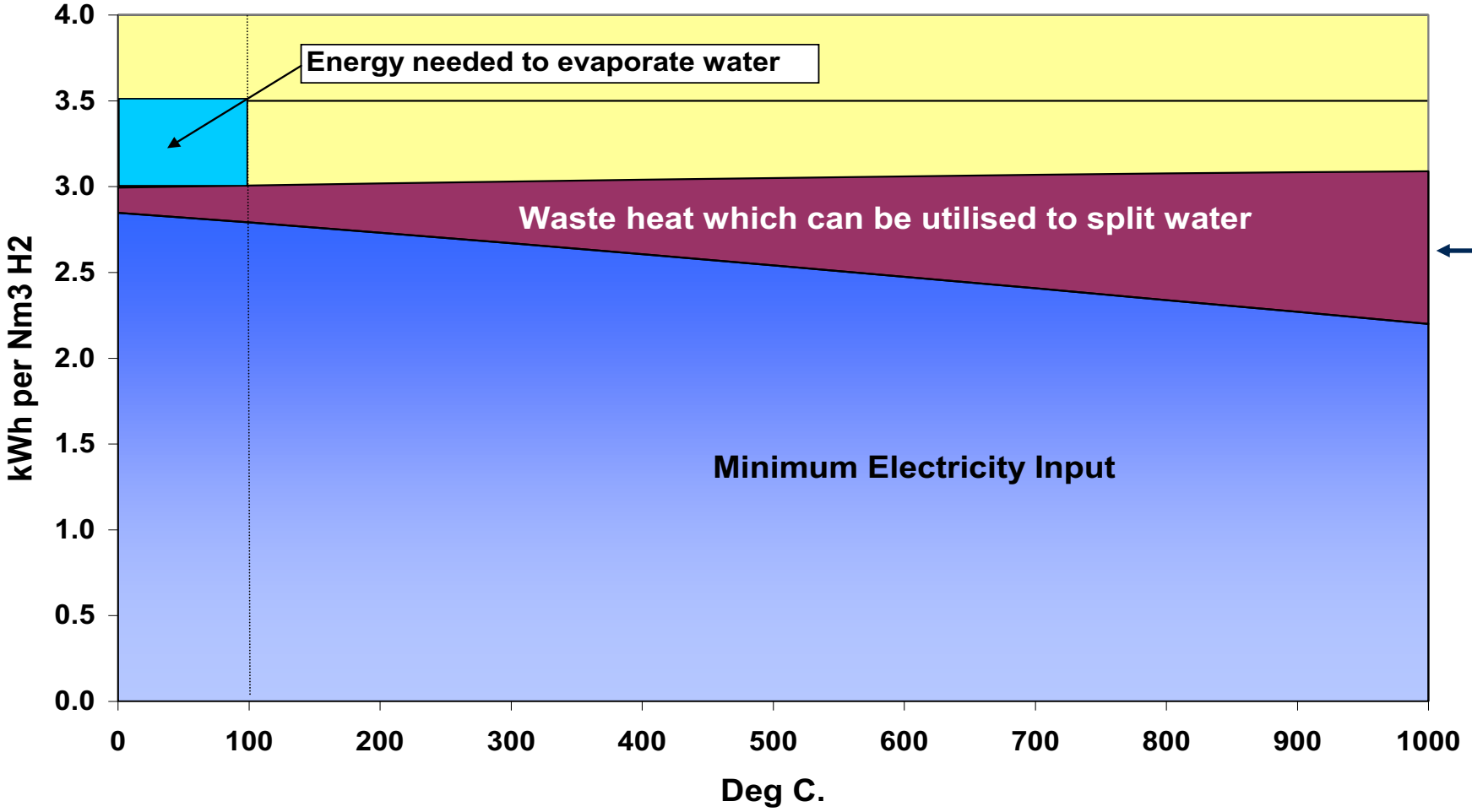
SOC Fuel Cell and Electrolyser



SOC also performs as

- Oxygen separation membrane
- Ammonia Cracker
- Heat exchanger

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



$Q = I^2 * \Omega + Q_{ext}$

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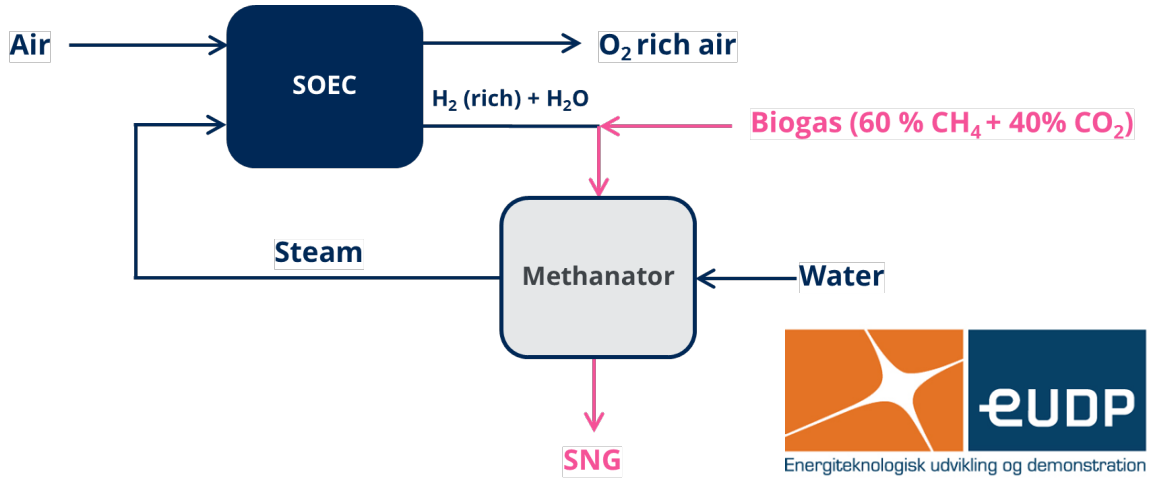
Power-to-X – using H_2 for upgrading CO_2 to methane



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

	CH_4	CO_2	N_2	H_2
Inlet (cleaned biogas)	56	43	1	0
Product gas	**97.69**	0.00	0.95	1.36

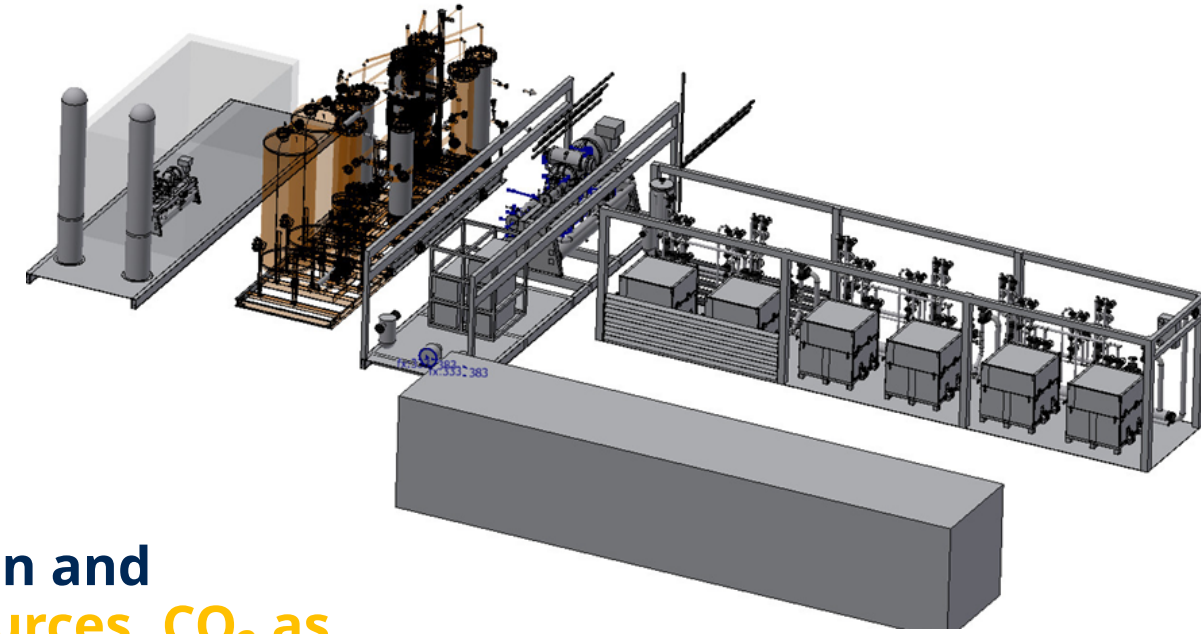
Typical SNG specification

	Mole%
CH_4	94 - 98
CO_2	0.2 – 3
H_2	0.1 – 2
CO	<100 ppm
N_2 + Ar	1 - 3

Stepping-stone approach

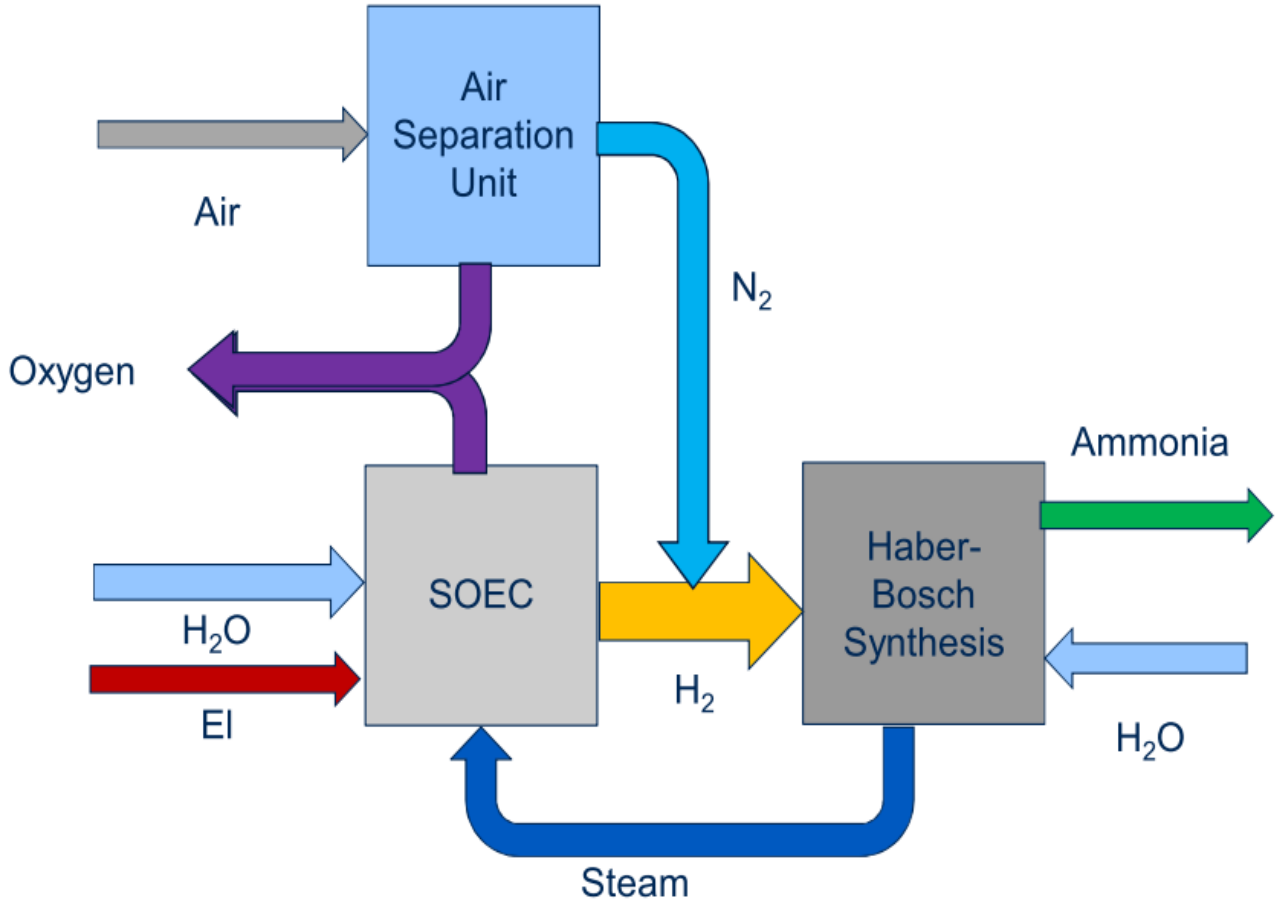
Niche markets – grow commercial confidence

- DeLille Oxygen Co. leases two eCOs™ units on cost-competitive commercial terms
- Each unit 100 Nm^3 CO/h (~340 kW SOEC)
- Commissioning summer 2020



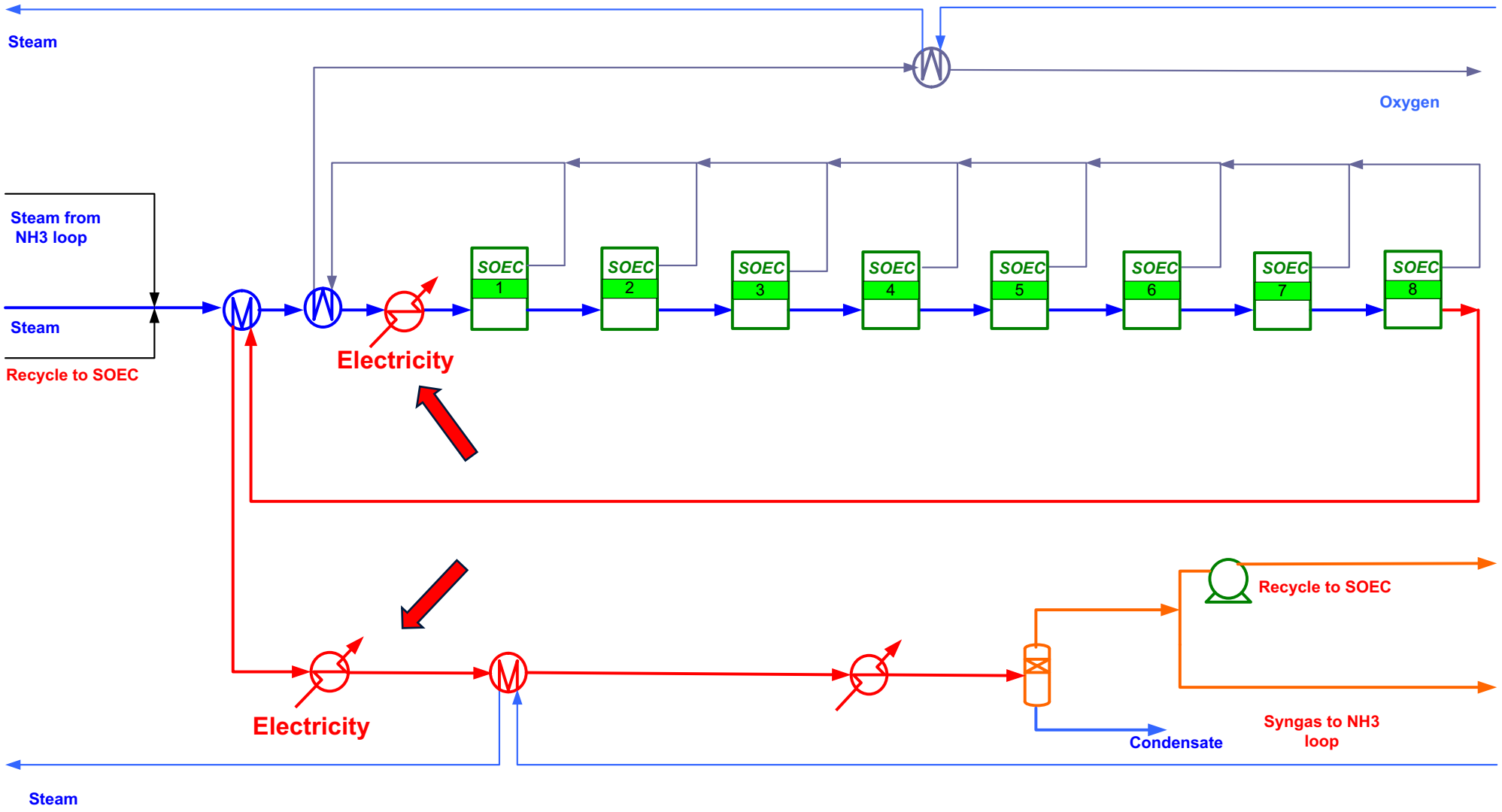
eCOs™ opens up for a whole new segment of green and sustainable chemicals from renewable carbon sources. CO_2 as a resource!

Ammonia production with SOEC and Air Separation Unit

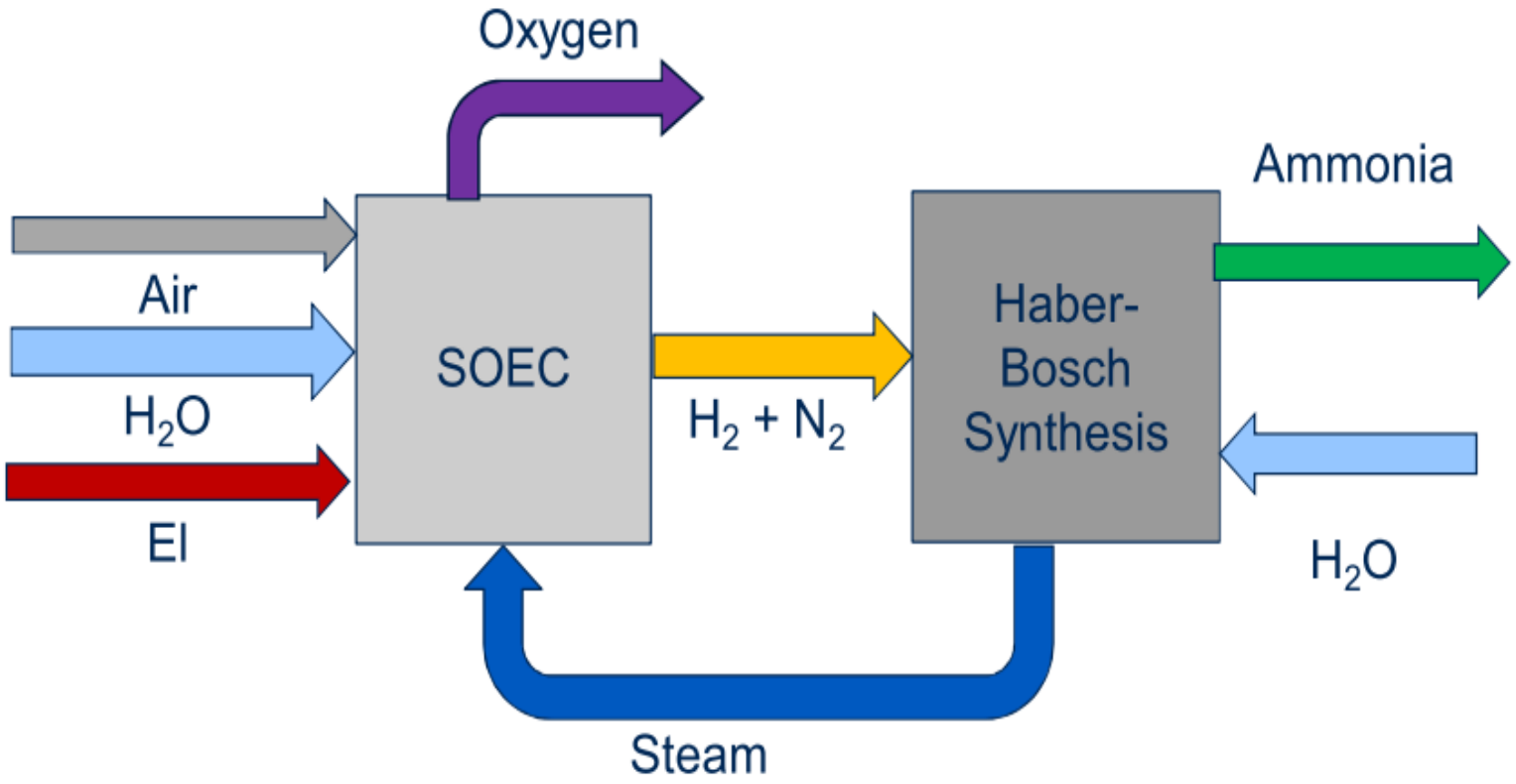


SOEC based ammonia plant with air separation unit

e.g. hydrogen production only

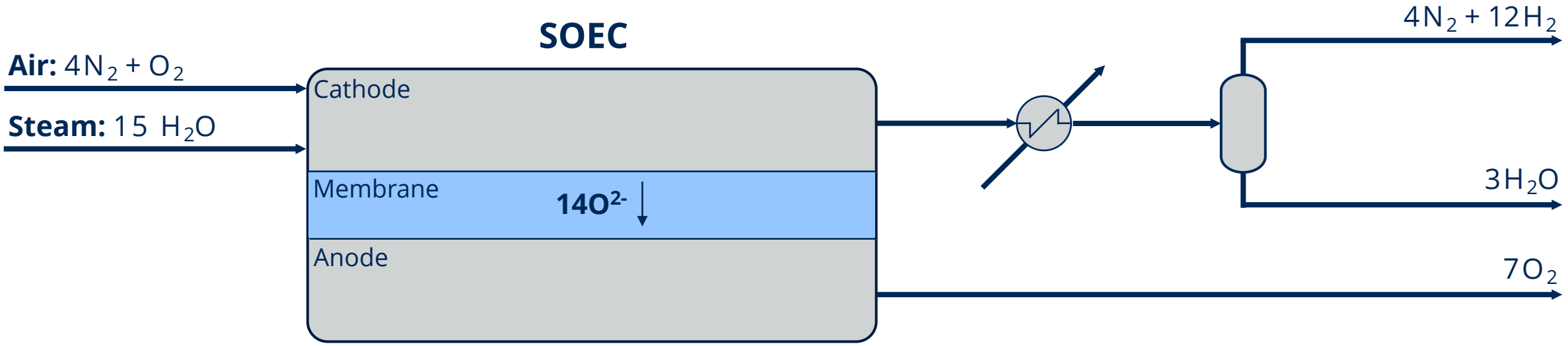


SOEC without separate air separation unit



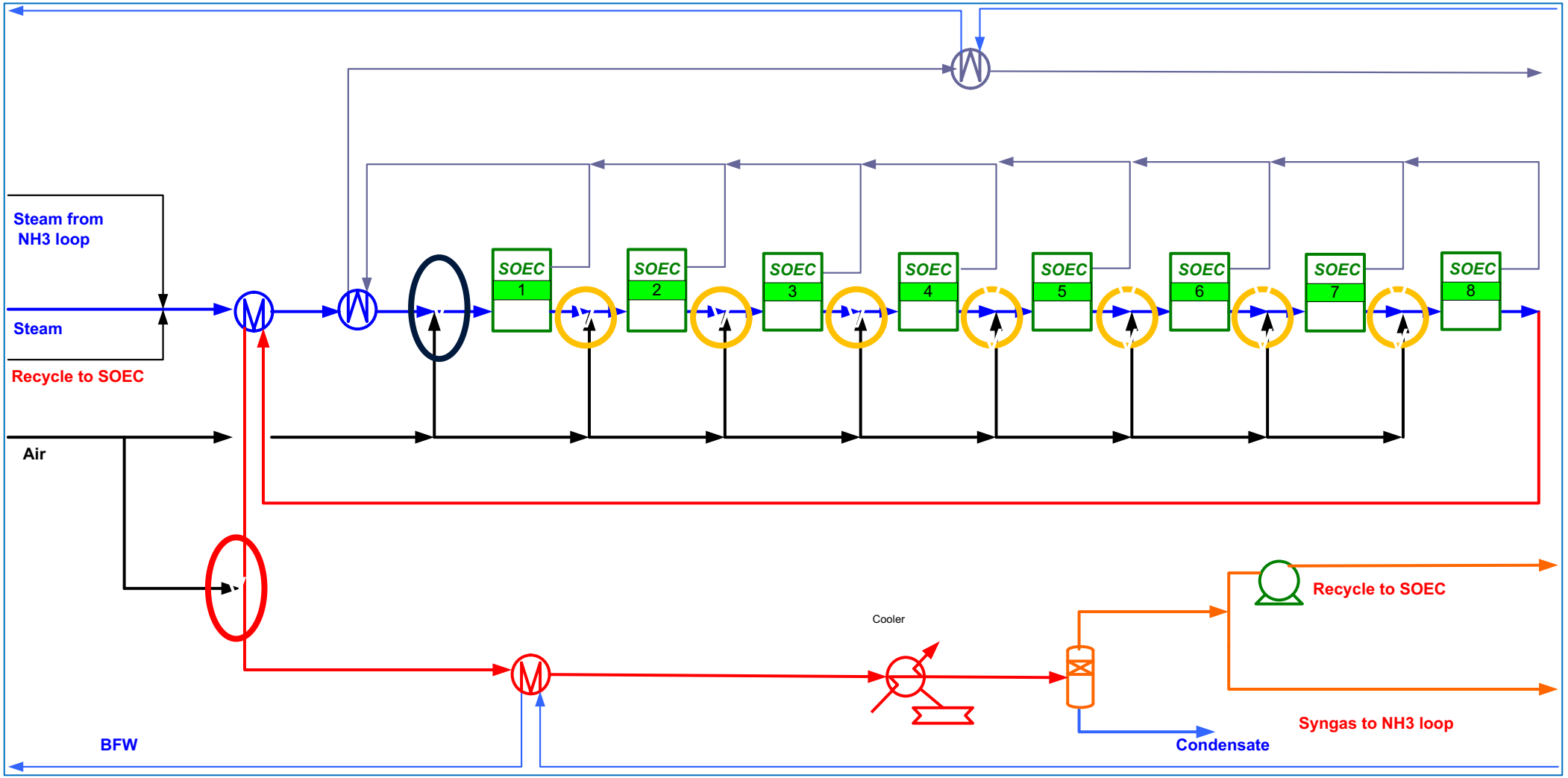
Ammonia syngas by SOEC

Approximate mass balances with Steam conversion 80 %



Ammonia Synthesis Gas Generation by SOEC – patent pending

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



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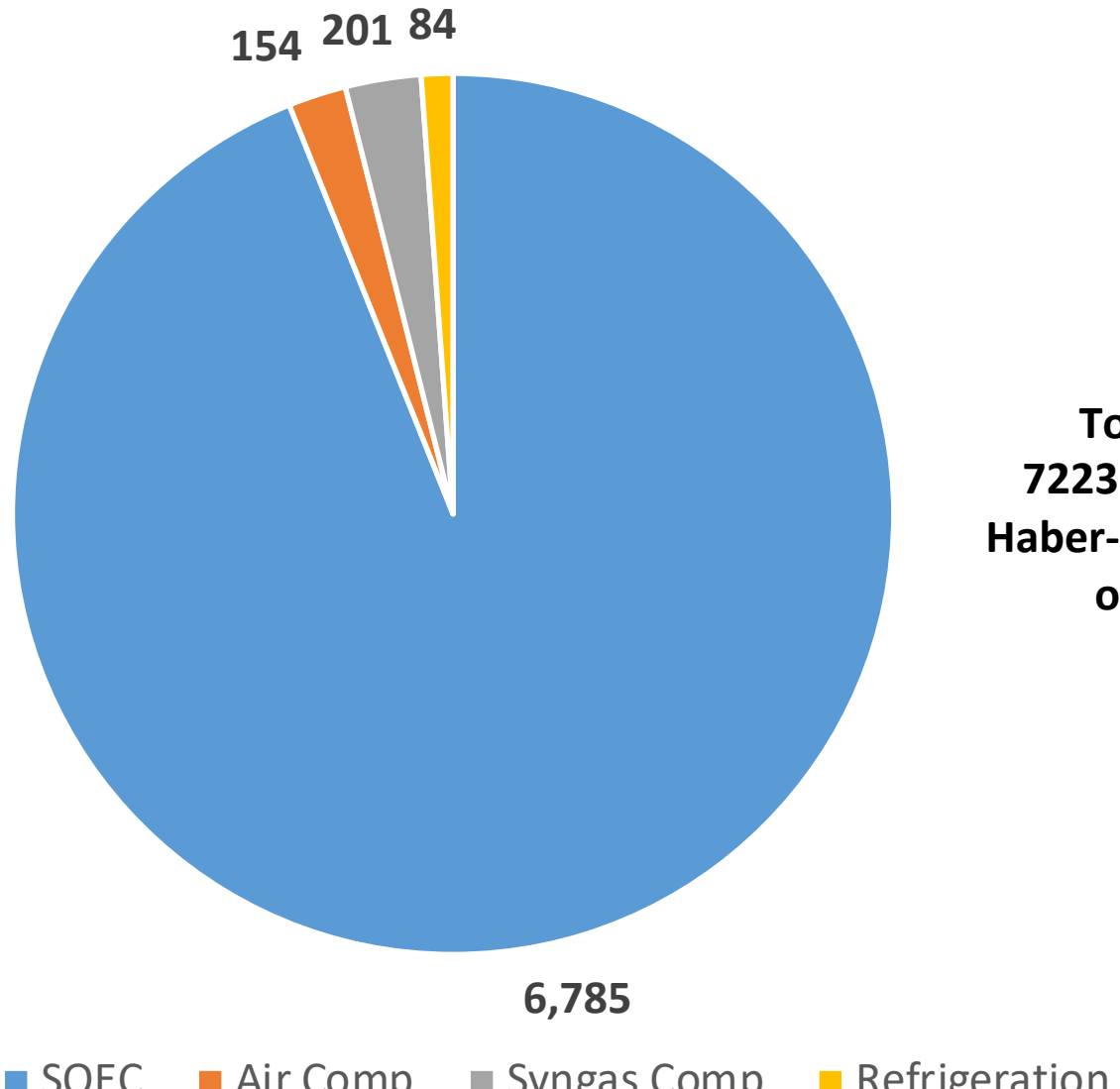
Breakdown of power consumption in kWh per MT ammonia



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

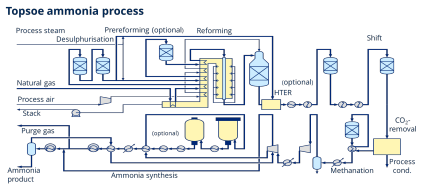
Green Ammonia
Road map

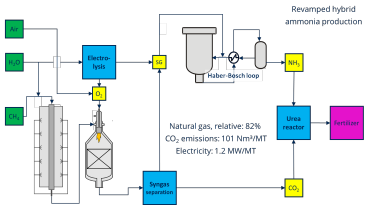
Alkaline electrolysis

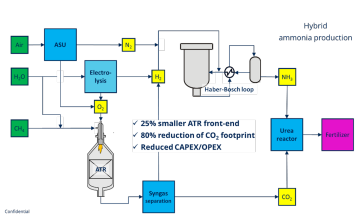
SOEC electrolysis

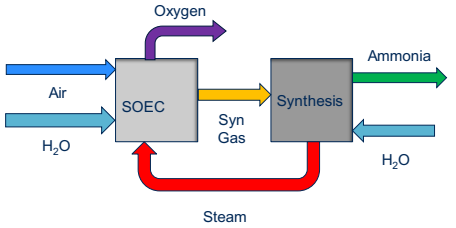
SOEC electrolysis – Development & maturing & Demos

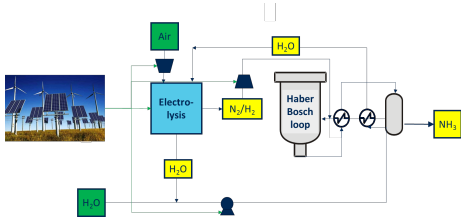
Conventional and SynCOR™ Processes	Hybrid revamp solution	Hybrid grassroots solution	500 – 1000 kg/d SOEC+HB Demo	Commercialize Electrolyzer+HB











Ammonia Track

2018 2020 2022 2025 2030

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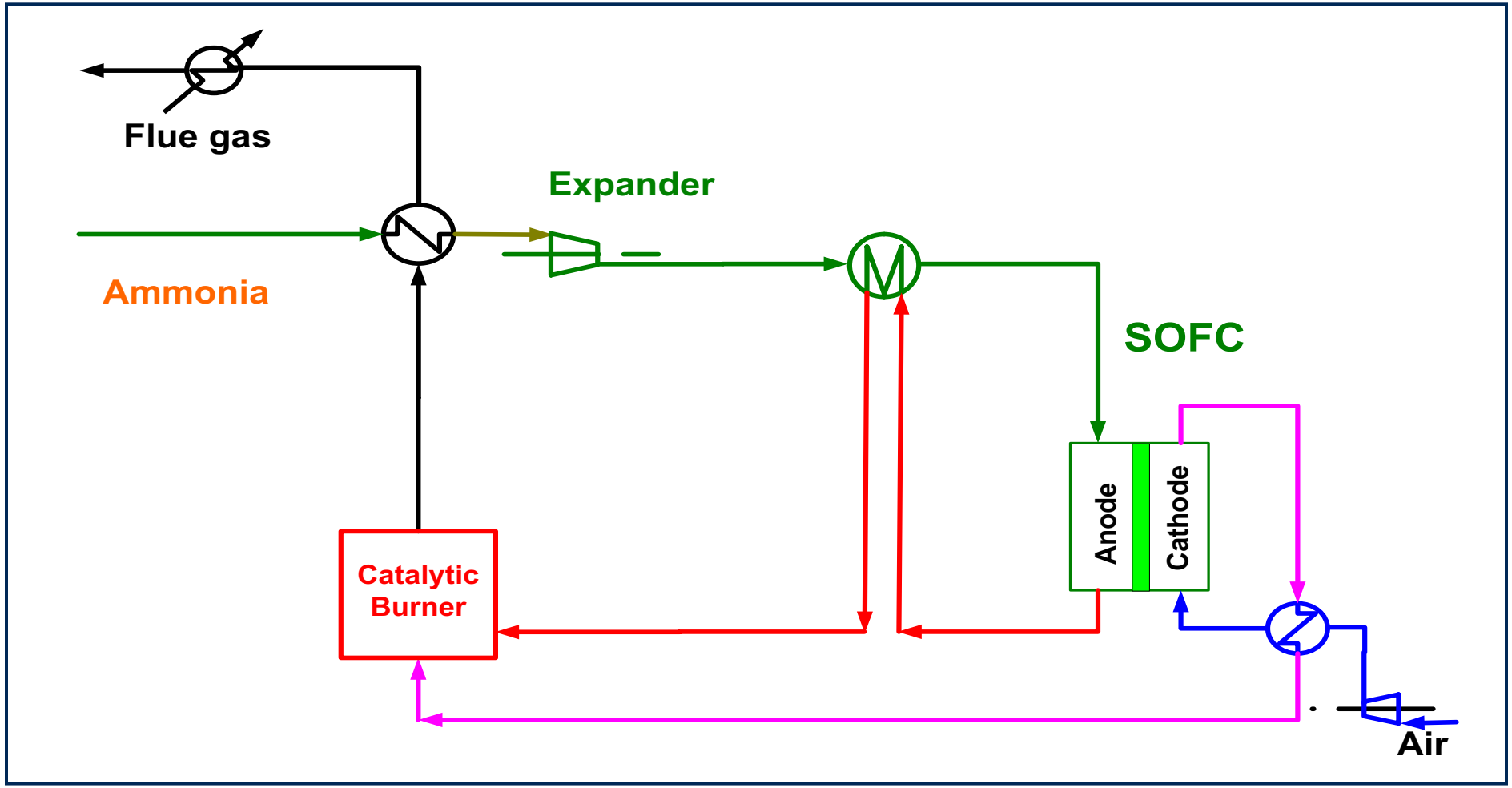
Direct use of Ammonia for SOFC
Electrical efficiency > 60 % LHV



Coupling of NH3 Cracking and Electrochemical Reactions

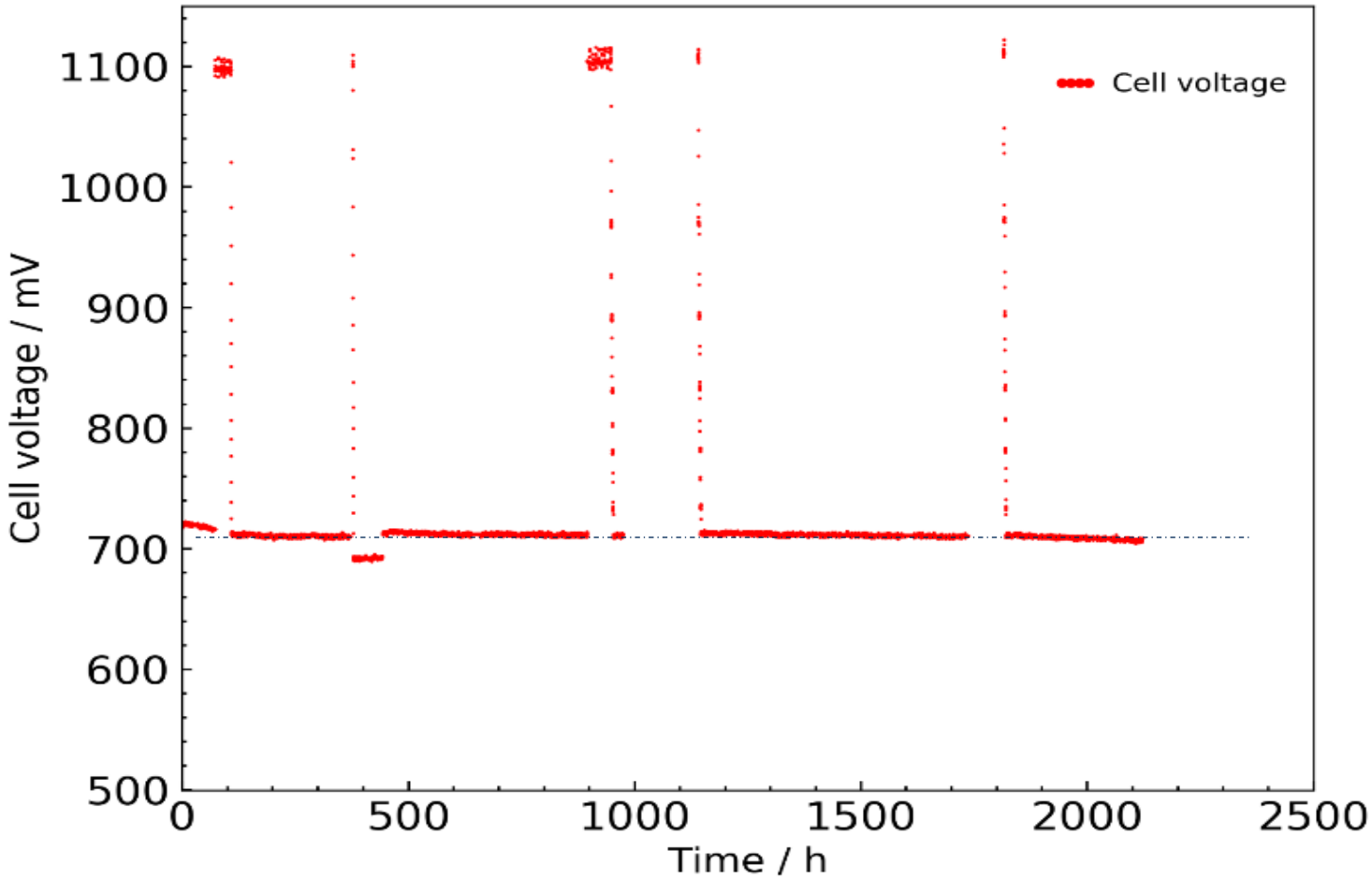
$$2\,NH_3 = N_2 + 3\,H_2 \qquad -Q_R \qquad -\Delta H^0_{923\,K} = -114\ kJ$$

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

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

Direct use of ammonia in SOFC

Experimental results from DTU Energy



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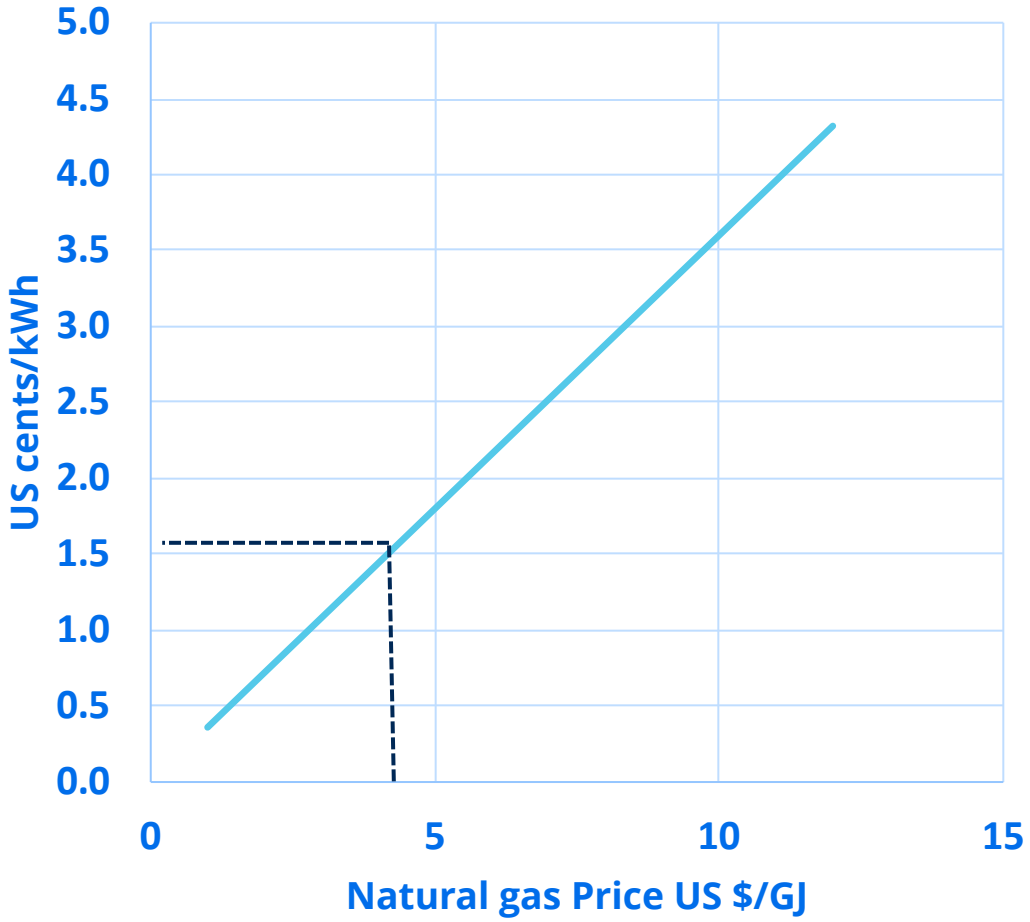
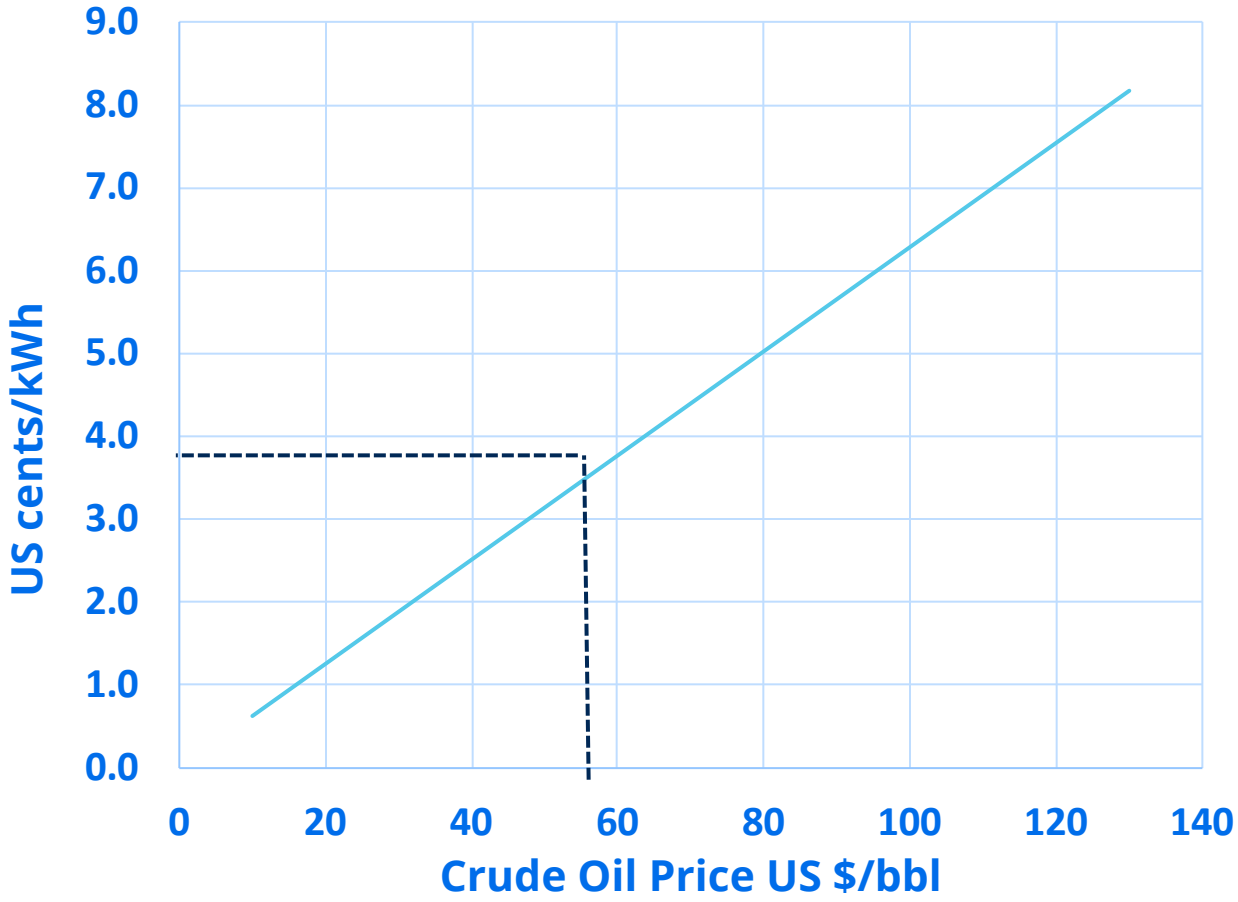
The Competition
Natural gas and Crude Oil





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