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Artur J Majewski

AmmoGen project

Funded by Research England

Lead academic partners ENERGY RESEARCH ACCELERATOR Keele UNIVERSITY MIDLANDS INNOVATION

Ammonia
saved the world once

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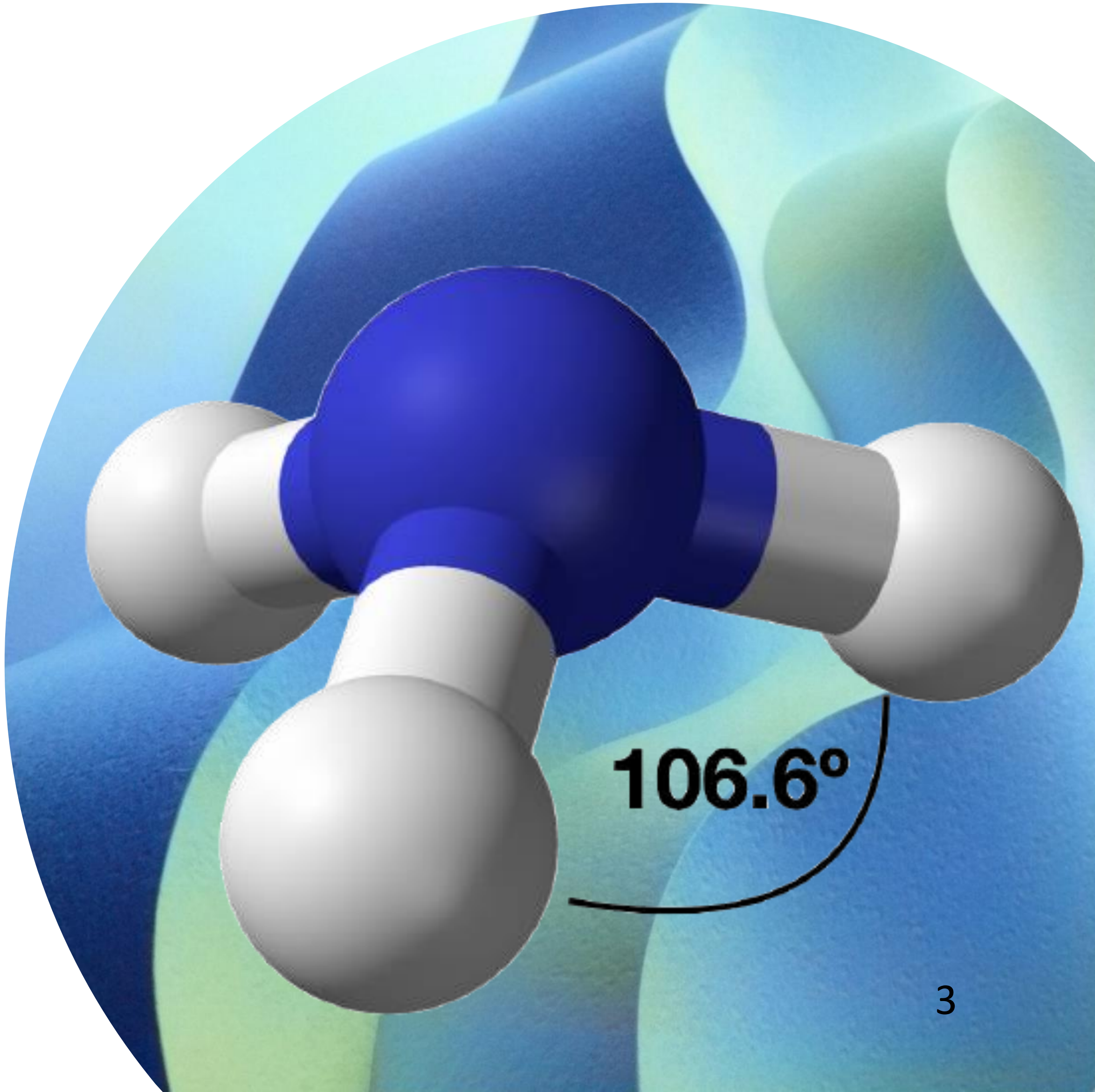
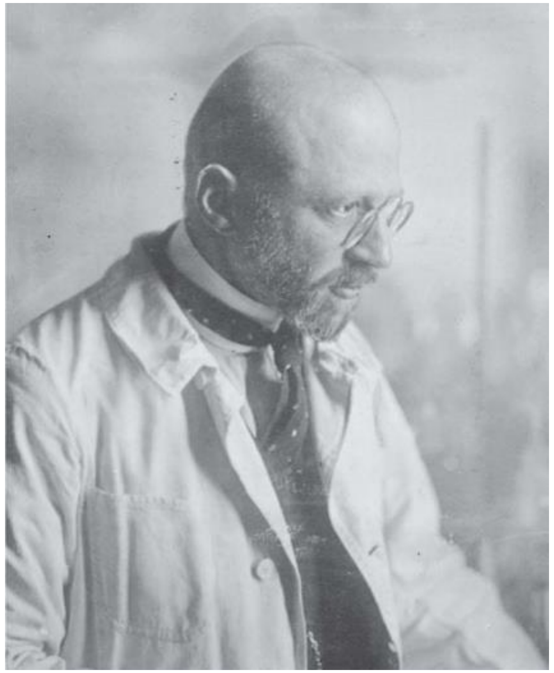
Ammonia facts

- 2nd most produced chemical worldwide
- 50% of world population rely on ammonia-based fertilisers for food
- 400 million tons of annual carbon emissions from ammonia manufacture
- 2% of global energy consumption is ammonia manufacture
- 3 kWh/L energy density – highest among zero-carbon fuels



Haber-Bosch process



Fritz Haber

The **Haber-Bosch process** takes nitrogen from the air and converts it to **ammonia**.

it makes possible to produce **synthetic fertilisers** and produce sufficient food for the growing population

But

It is also a key raw material in the production of high explosives

Carl Bosch

History of ammonia synthesis

Solving the problem earned Haber and Bosch two **Nobel Prizes** in chemistry: Haber in 1918, Bosch in 1931.

1774 Joseph Priestley, isolated gaseous ammonia.

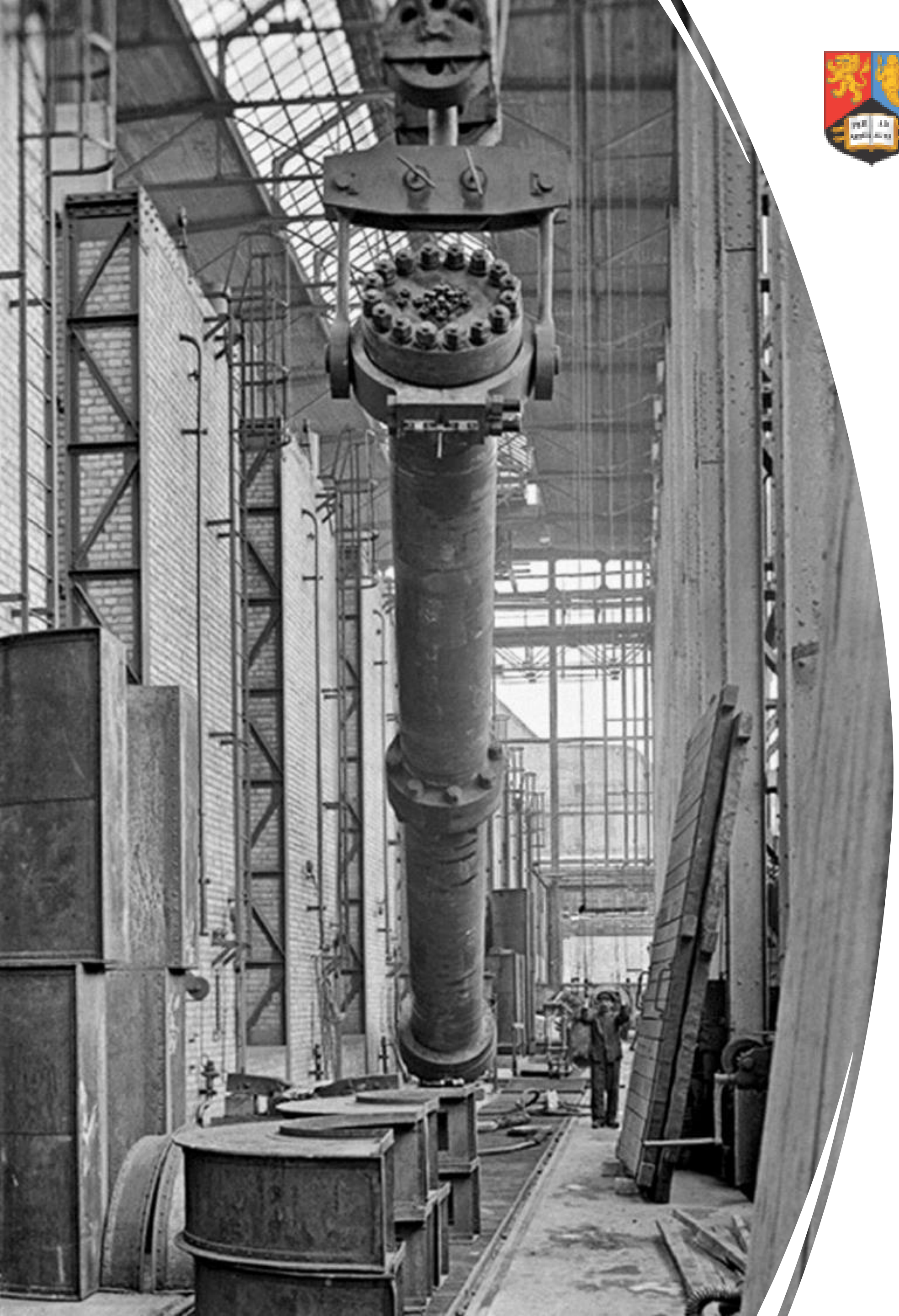
1785 ammonia composition determined Claude Louis Berthollet

1898 Adolph Frank and Nikodem Caro found that N_2 could be fixed by calcium carbide to form calcium cyanamide, which could then be hydrolyzed with water to form ammonia:

1906-8 Haber (with R. Rossignol), decided to use **high-pressure process** for ammonia synthesis

1909 – they **patented** this process – with yield 15% ammonia, at 175 atmospheres 550°C, over an osmium and uranium catalyst

1913 Badische Anilin und Soda Fabrik (**BASF**) engineer Carl Bosch started **scaling up the process**



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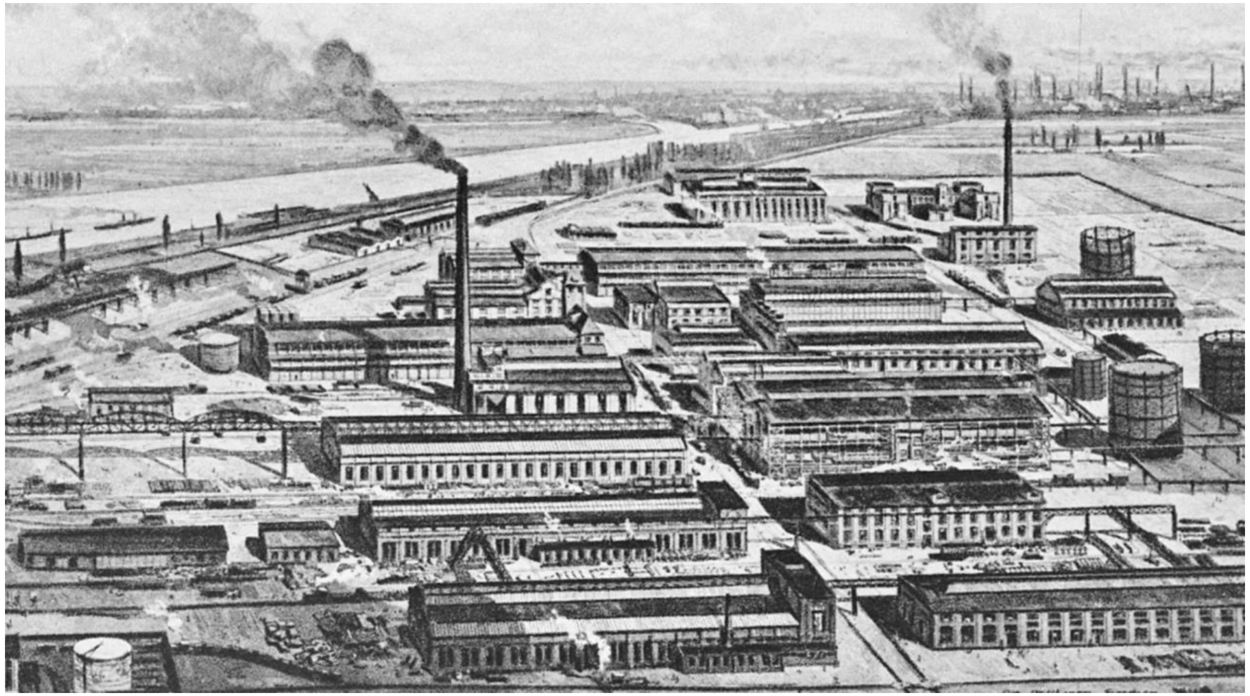
Challenges in scaling up

- Source of hydrogen (water-gas + Linde-Frank-Caro process = H_2)
- Catalyst - mixed catalyst based on iron oxide - still in use today
- Pressure vessels



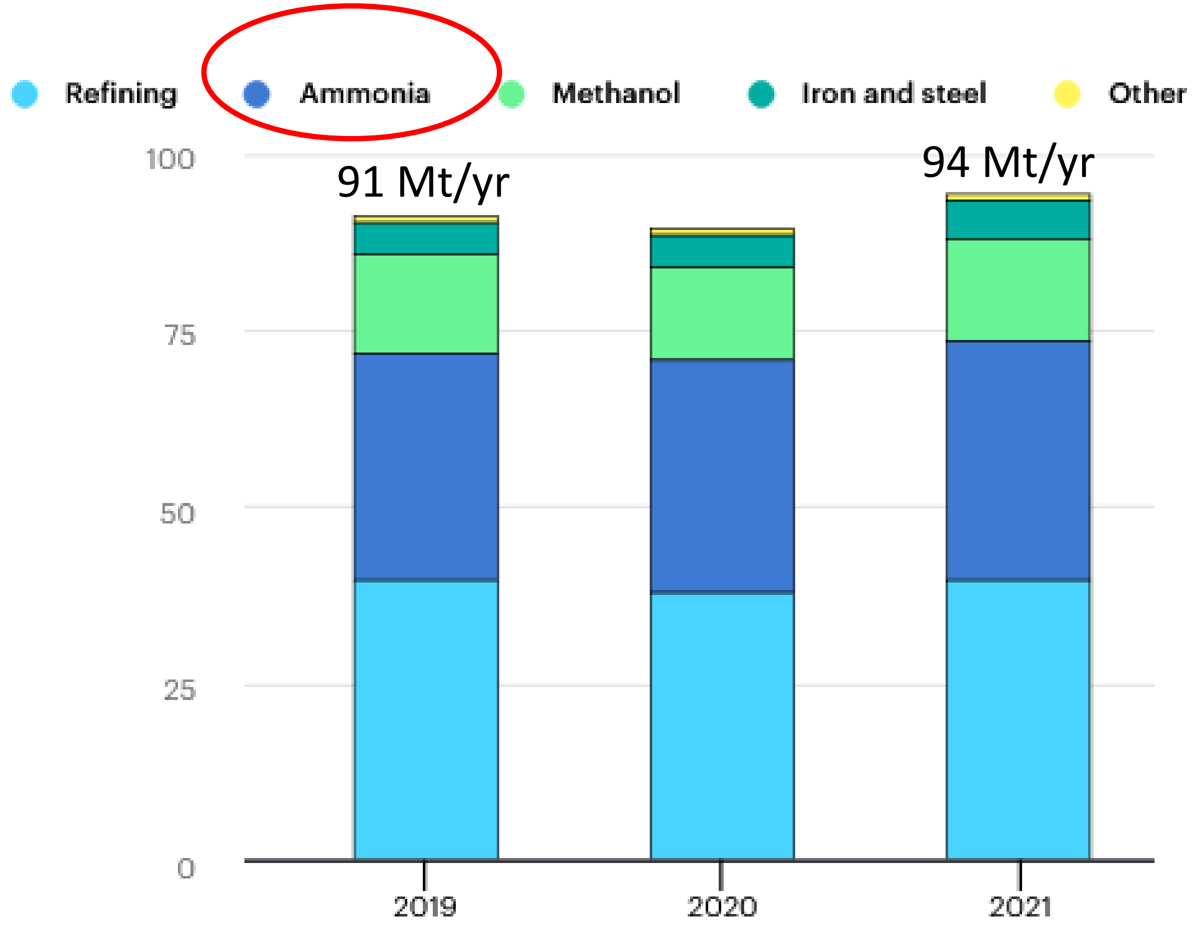
The first plant to use the Haber-Bosch process at industrial scale by BASF in 1913.

BASF designed :

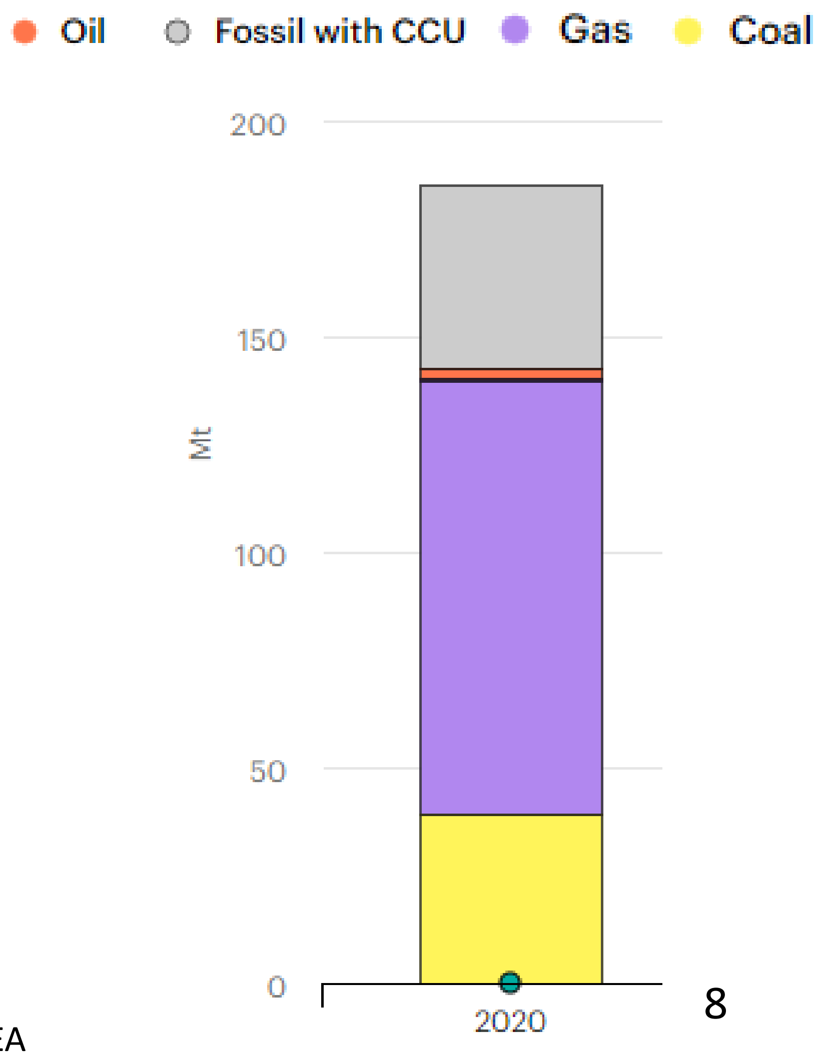
- externally-heated contact tube reactor (But the material became brittle, and the tubes burst).
- the first **lined reaction chamber** – a pressure-bearing steel jacket thinly lined with a soft steel.
- heating the reactor from the inside
- compressors, monitoring instruments to measure temperature, the intensity of the gas stream and the composition of the gas in the reaction chamber

Over 100 years on and nothing much has changed, and the process is still used around the world.

Global Hydrogen Markets

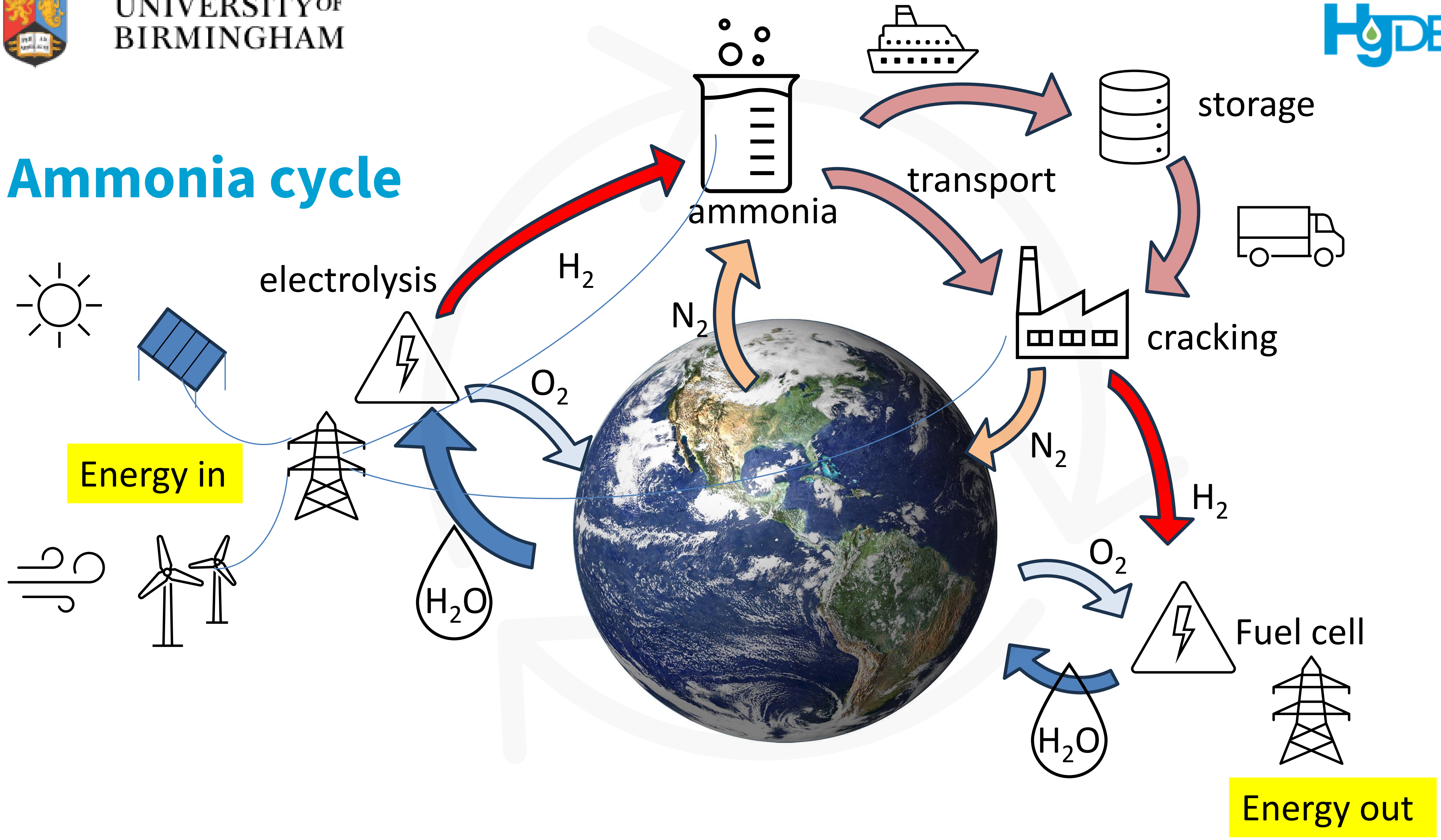


Ammonia production

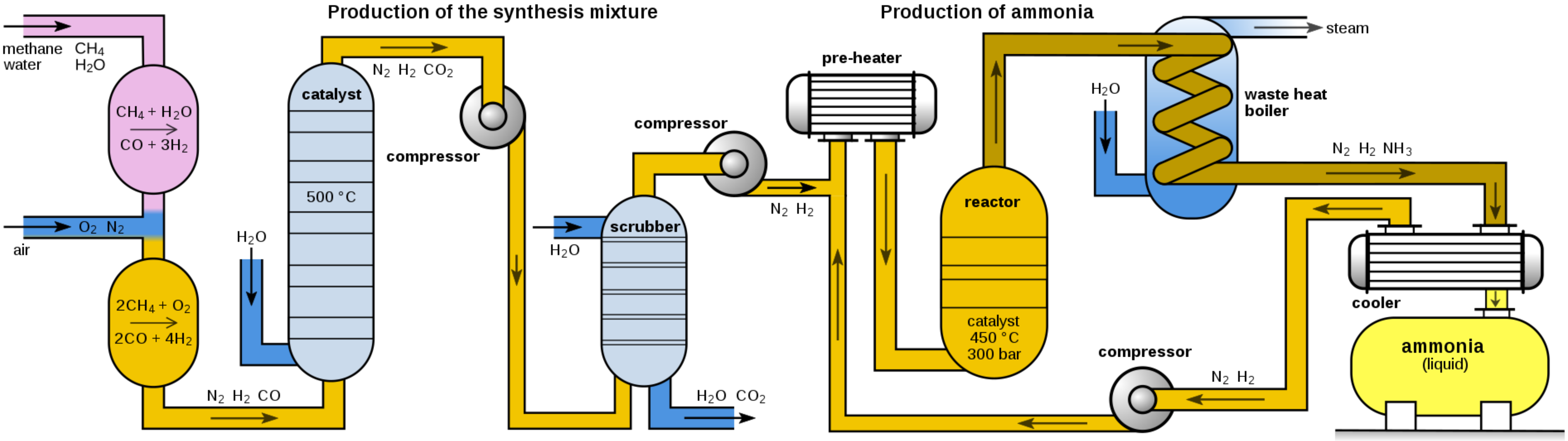


source: IEA

Ammonia cycle



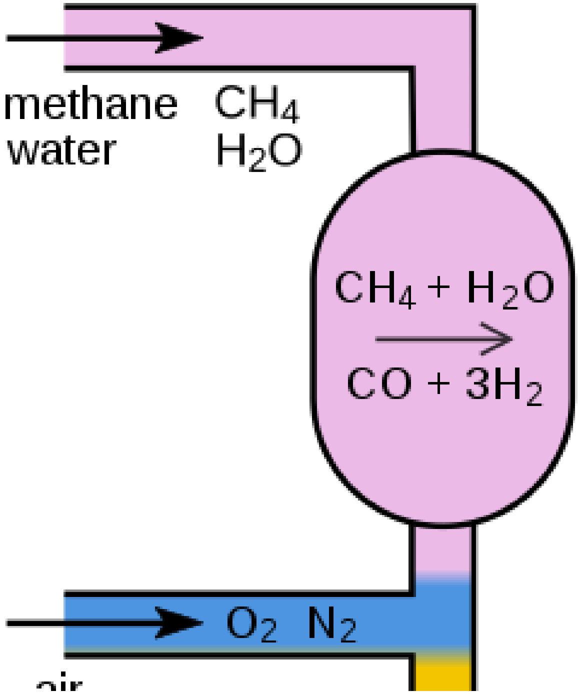
Haber–Bosch plant



$$N_2 + 3\,H_2 \rightleftharpoons 2\,NH_3 \qquad \Delta H^\circ = -92.28\ \text{kJ}\ (\Delta H^\circ_{298K} = -46.14\ \text{kJ/mol})$$

Haber–Bosch plant

Air
CH_4, H_2O



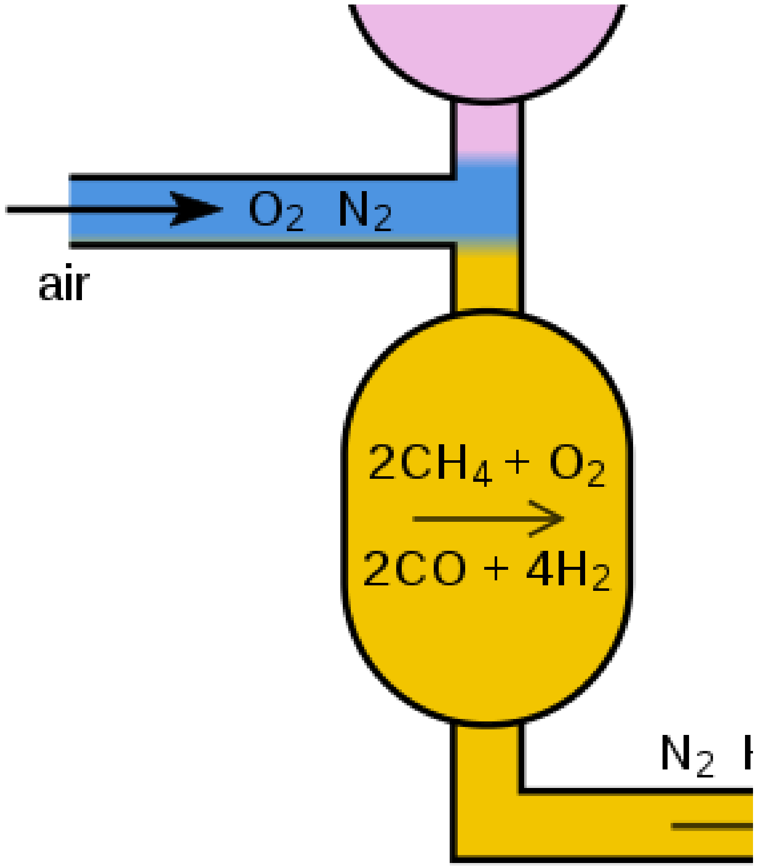
N_2
CO
H_2
CH_4

$$CH_{4(g)} + H_2O_{(g)} \longrightarrow CO_{(g)} + 3\,H_{2(g)} \qquad \Delta H = +206\ \text{kJ/mol}$$

Haber–Bosch plant

$$CH_{4(g)} + H_2O_{(g)} \longrightarrow CO_{(g)} + 3\,H_{2(g)}$$

N_2
CO
H_2
CH_4



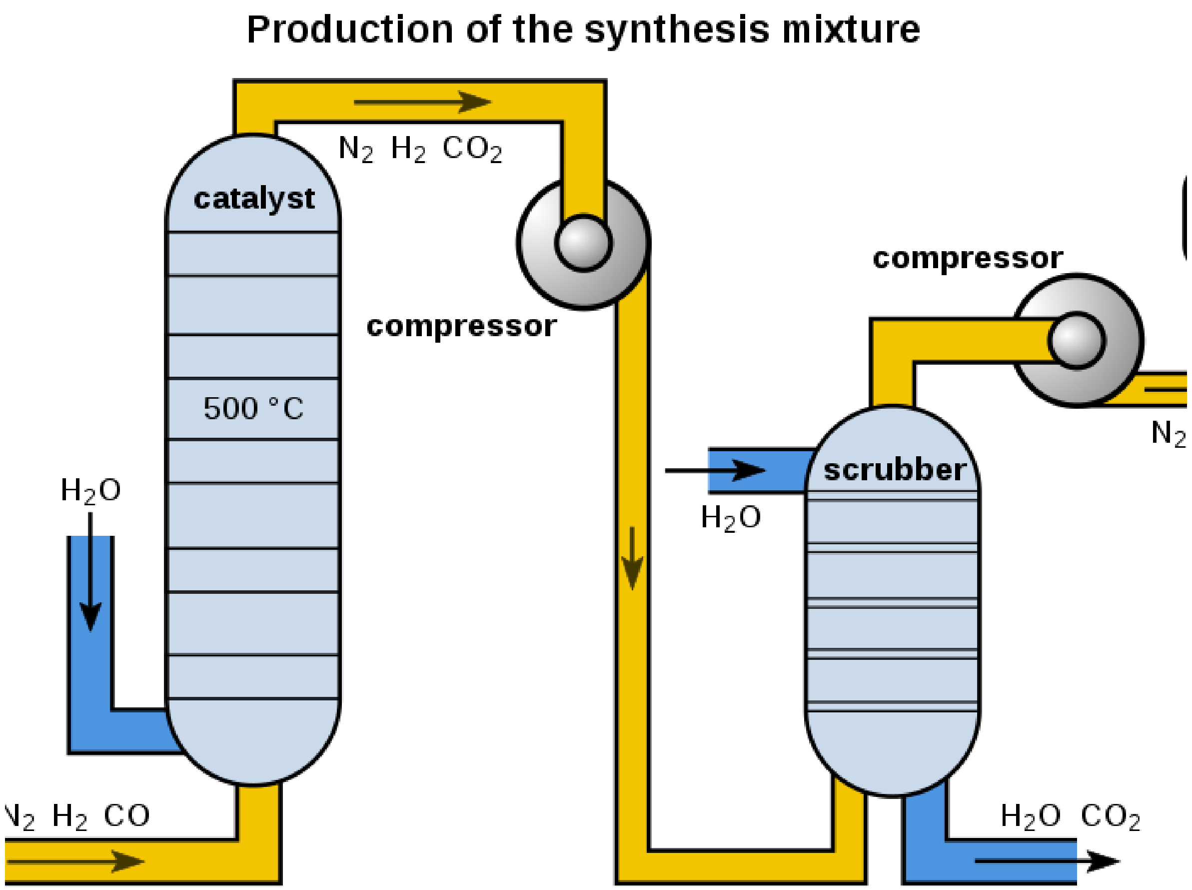
N_2
CO
H_2

$$2\,CH_{4(g)} + O_{2(g)} \longrightarrow 2\,CO_{(g)} + 4\,H_{2(g)} \qquad \Delta H = -71\ \text{kJ/mol}$$

Haber–Bosch plant

N_2
CO
H_2

H_2O

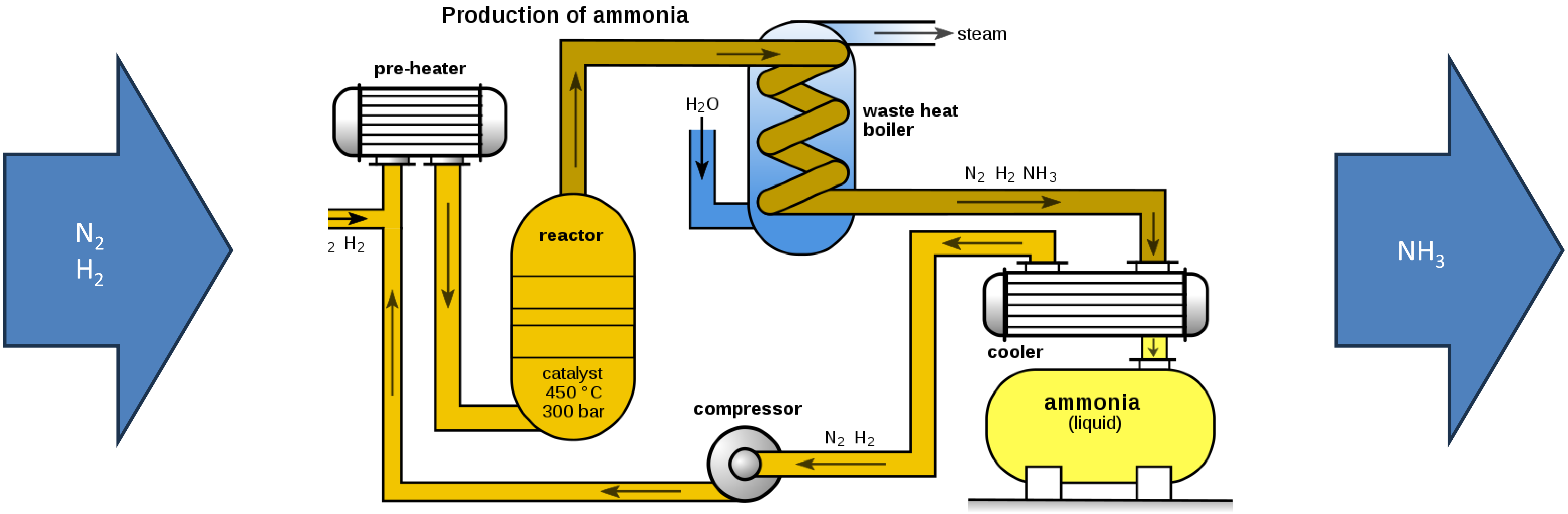


N_2
H_2

CO_2
H_2O

$$CO_{(g)} + H_2O(g) \longrightarrow CO_{2(g)} + H_{2(g)} \qquad \Delta H = -41\ \mathrm{kJ/mol}$$

Haber–Bosch plant



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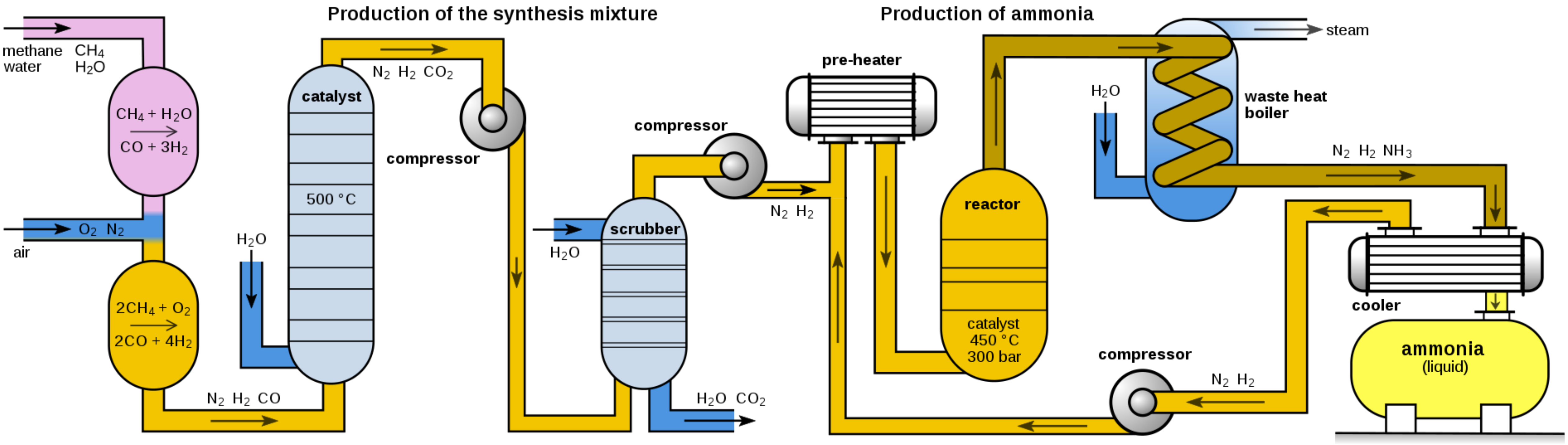
Haber–Bosch plant



$$CH_{4(g)} + H_2O_{(g)} \longrightarrow CO_{(g)} + 3\,H_{2(g)} \qquad \Delta H = +206\ \mathrm{kJ/mol}$$

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Ammonia Synthesis & Cracking

Haber Bosch:

Fe-catalyst, 500°C, 150-200 bar

$N_2 + 3H_2$ ------> $2\ NH_3$

- 92 kJ/mol

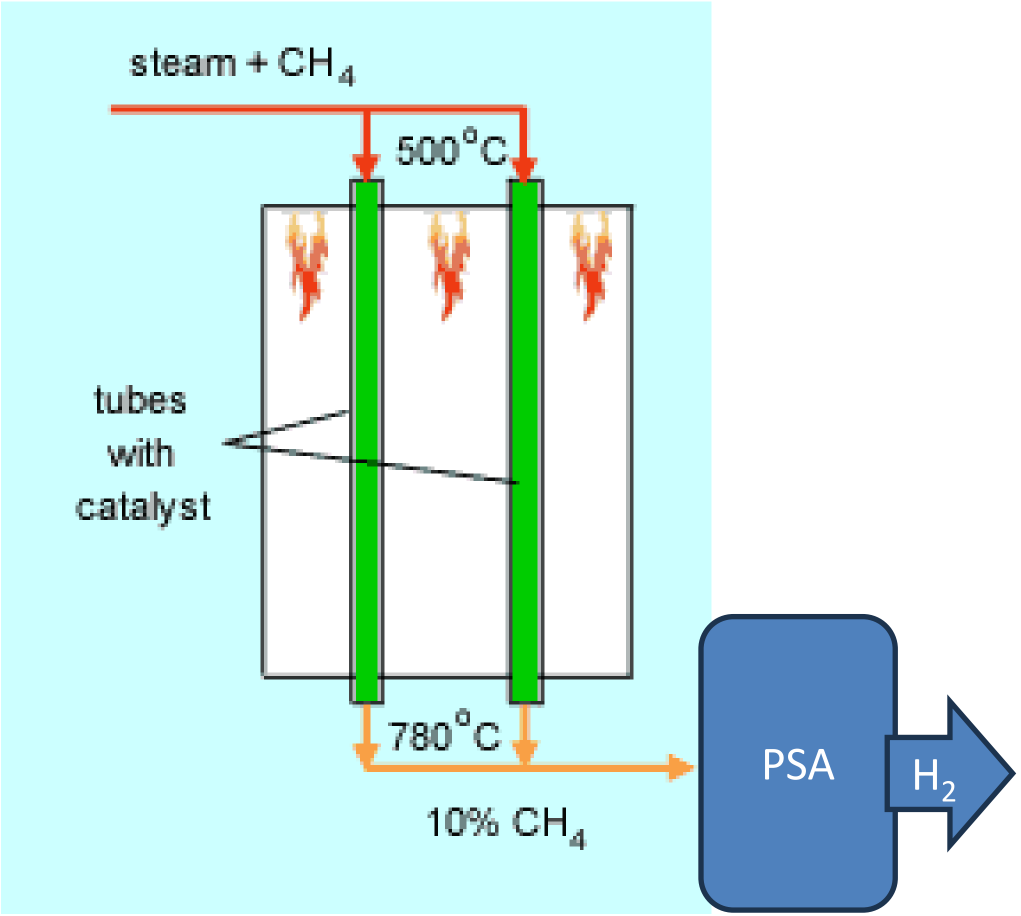
1.5 kWh/kg equiv. to 28% of LHV

Ammonia cracking:

$N_2 + 3H_2$ <------ $2\ NH_3$

1.4 MWh/to total energy input

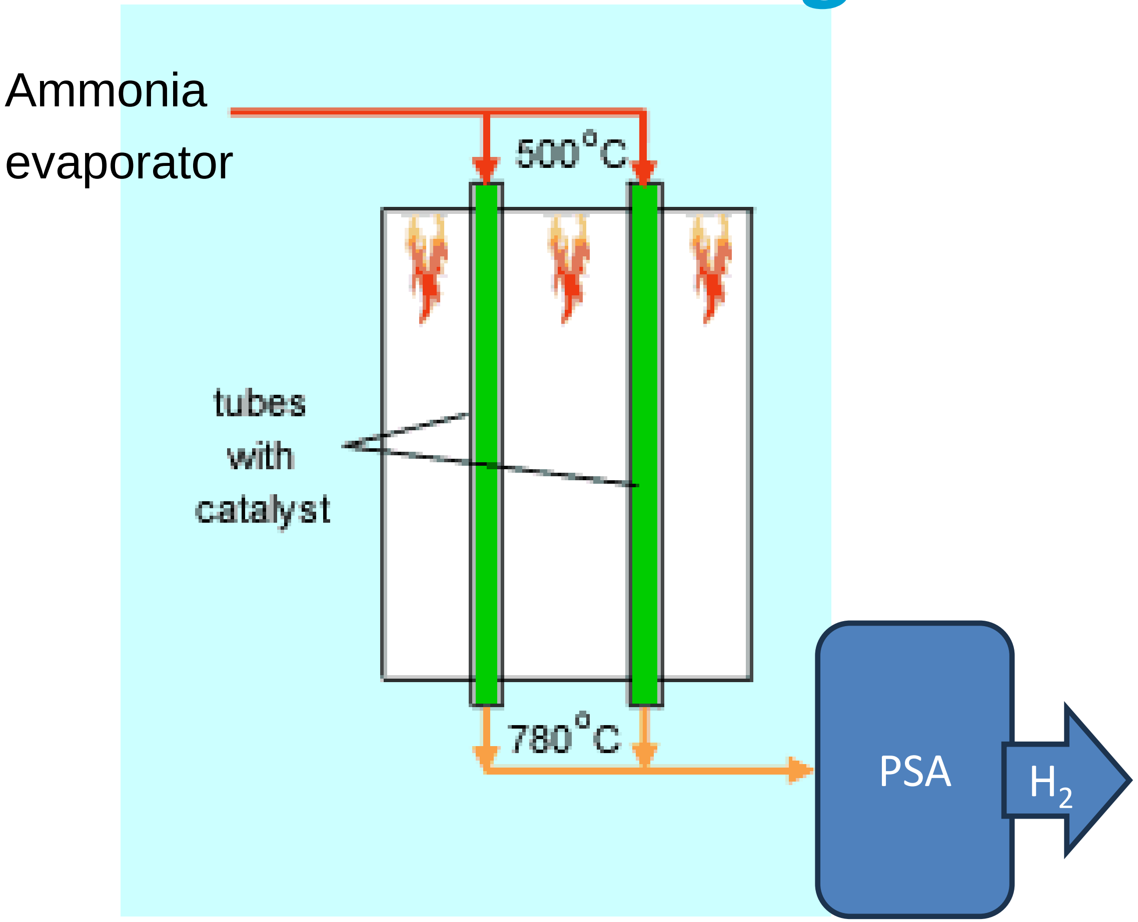
Steam Reforming (Diagram)



$CH_4 + H_2O \leftrightarrow CO + 3\,H_2$

$CO + H_2O \leftrightarrow CO_2 + H_2$

Ammonia Cracking (Diagram)



$2\,NH_3 \leftrightarrow N_2 + 3H_2$

Ammonia cracking catalyst

- Typically 700 - 950°C, Ni-based catalyst,
- 450 – 500°C, Ru/Co-based catalyst

- Pressure ~80 bar

https://matthey.com

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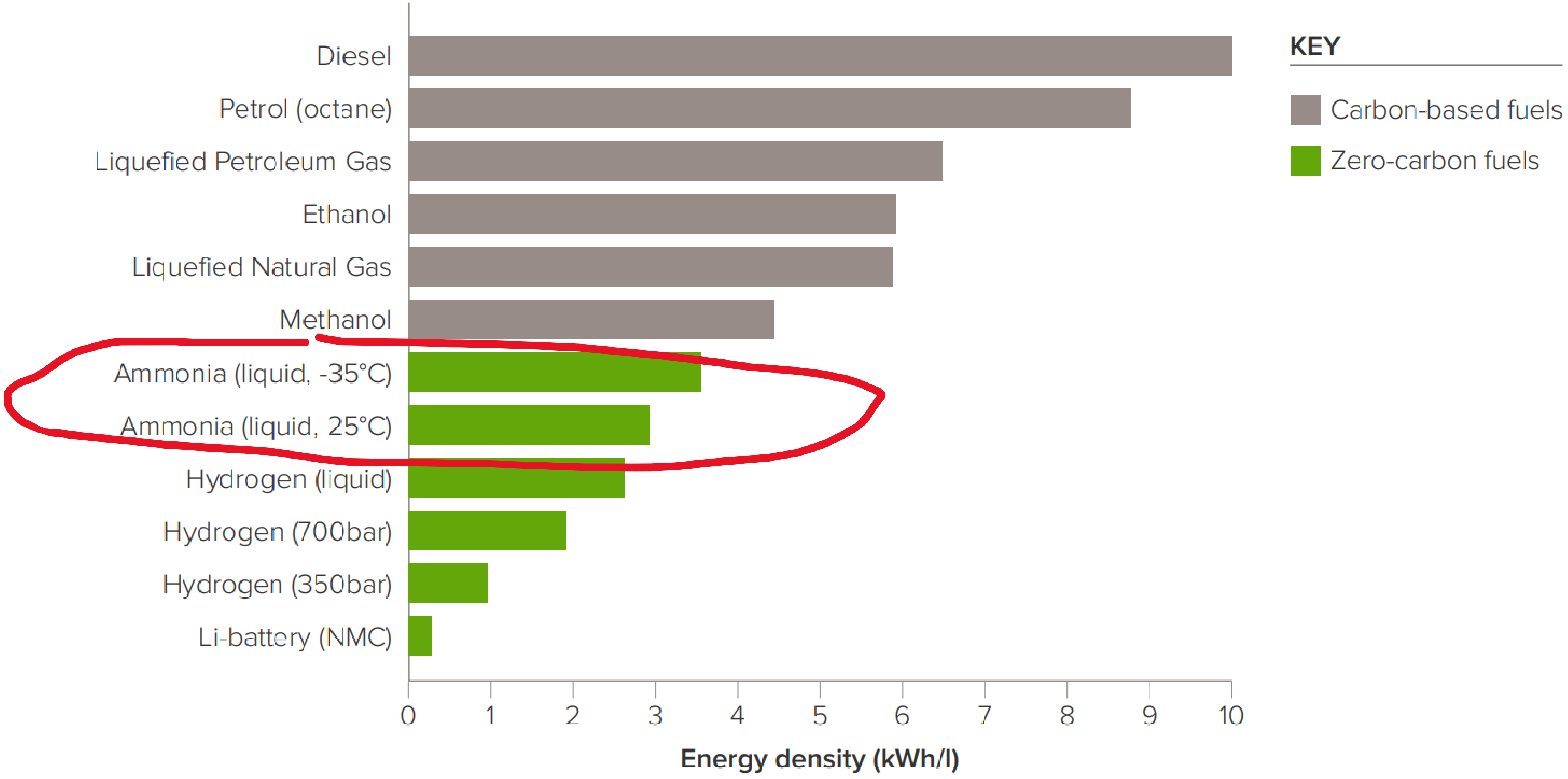
volumetric energy density of fuels



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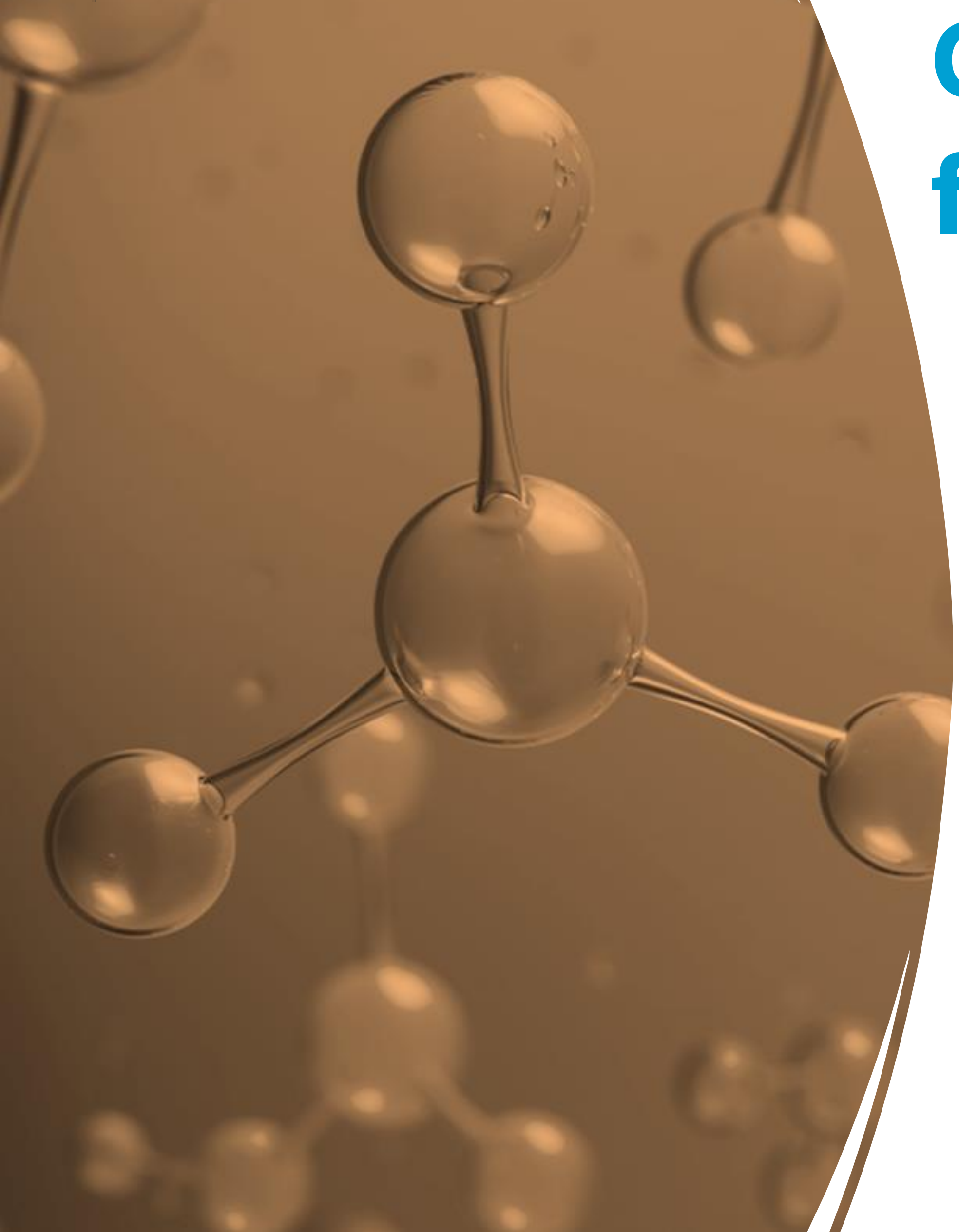

Challenges with ammonia as fuel and H_2 source

- Toxicity
- Corrosive to some alloys containing copper and nickel and to some plastics
- Difficult to ignite and doesn't sustain combustion well
- When burned at high temperatures, ammonia produces nitrogen dioxide and nitrous oxide
- Caustic in aqueous solution (high pH value, use as bleach), tanker spill could have considerable negative impact on sea life
- Energy intensive, ‘green’ ammonia will need to look carefully at the energy inputs

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ammogen

ammonia to hydrogen conversion project

Introduction to the AmmoGen Project

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Ammonia as a Hydrogen Transport Vehicle

1. use of low-cost green energy, e.g. Middle East, North Africa, Australia etc. to produce hydrogen
2. transport hydrogen to UK & Europe
3. feed low(er)-cost hydrogen into the energy system

Turning hydrogen into ammonia and back again allows for considerably more compact transport and thus lower cost of overall operations.

Team

Project management

operate and manage the facility

supply ammonia cracking technology

provide the host location for the project

funding for Ammogen

supply of liquid ammonia

Dissemination, ammonia storage

Research & Demonstration Questions

- what are the real-world issues around using ammonia for H_2 transport?

w.r.t.

- energy efficiency
- economic viability
- safety

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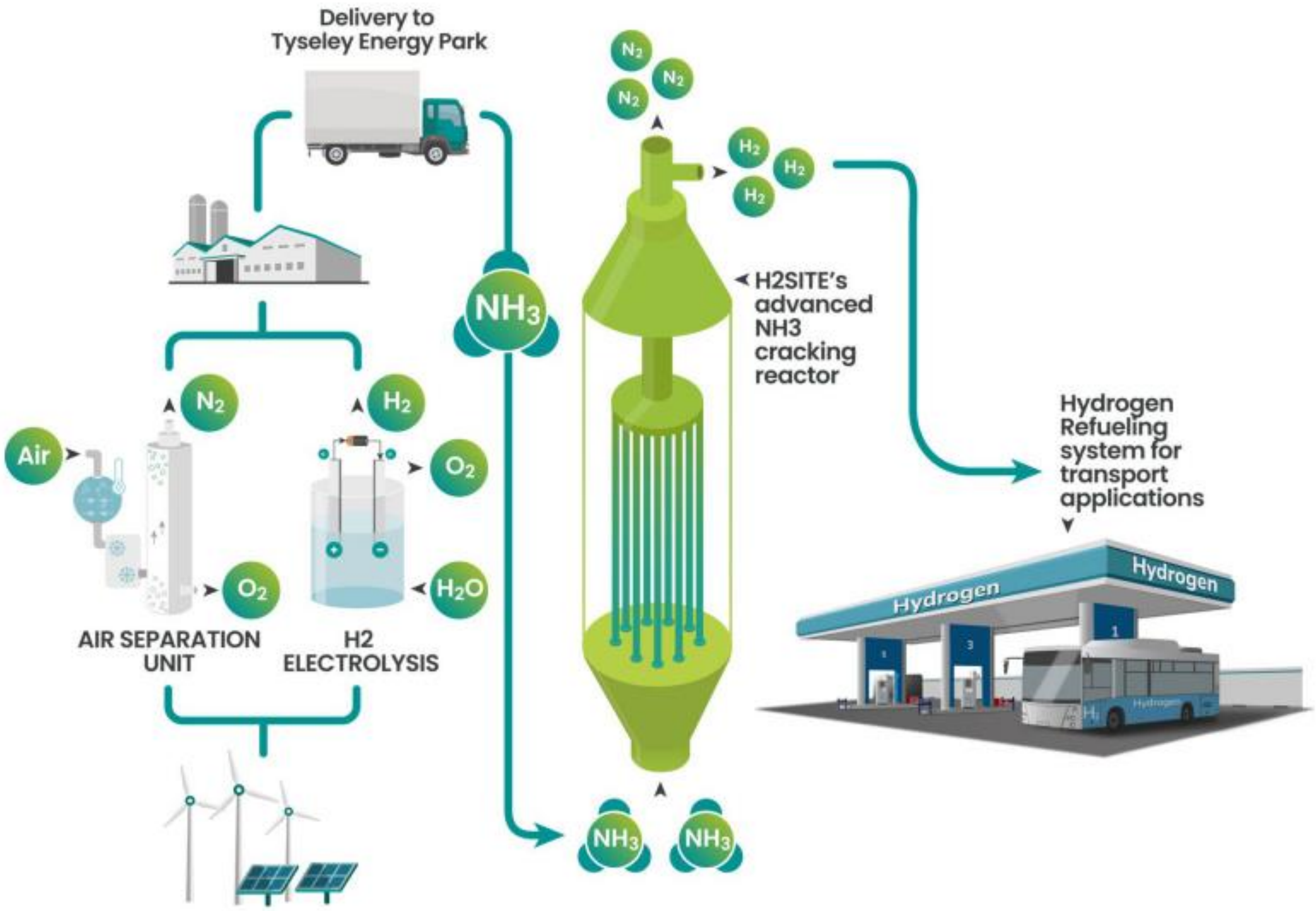
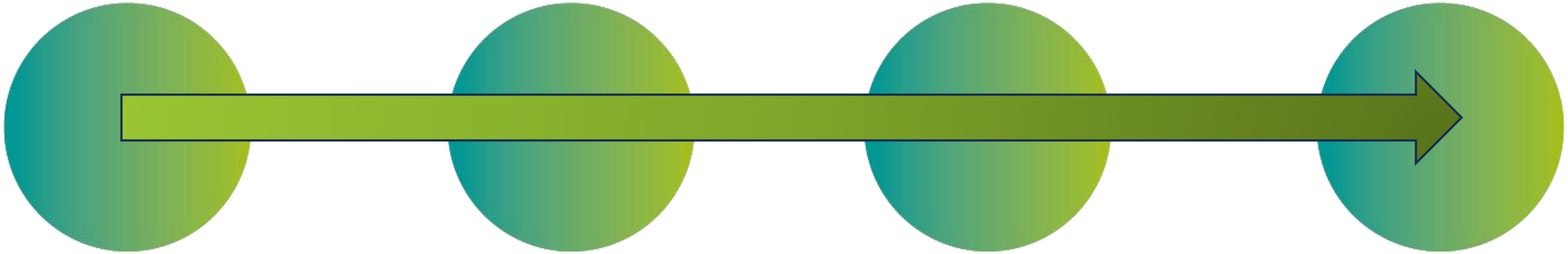
The Tyseley Energy Park – project concept



Timeline



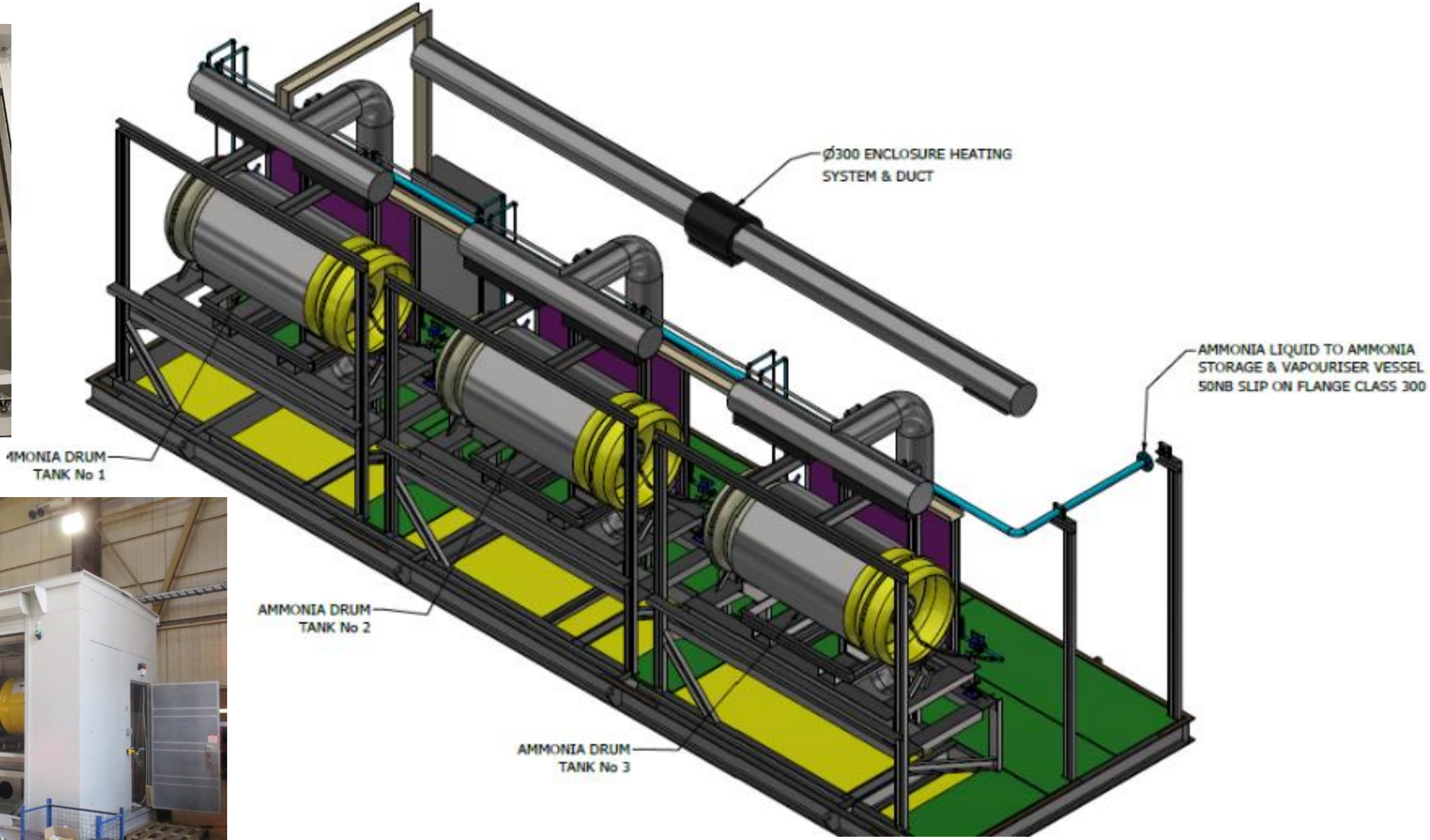
July 2023
construction starts

Q3 & 4 2023
building & commissioning, test operation

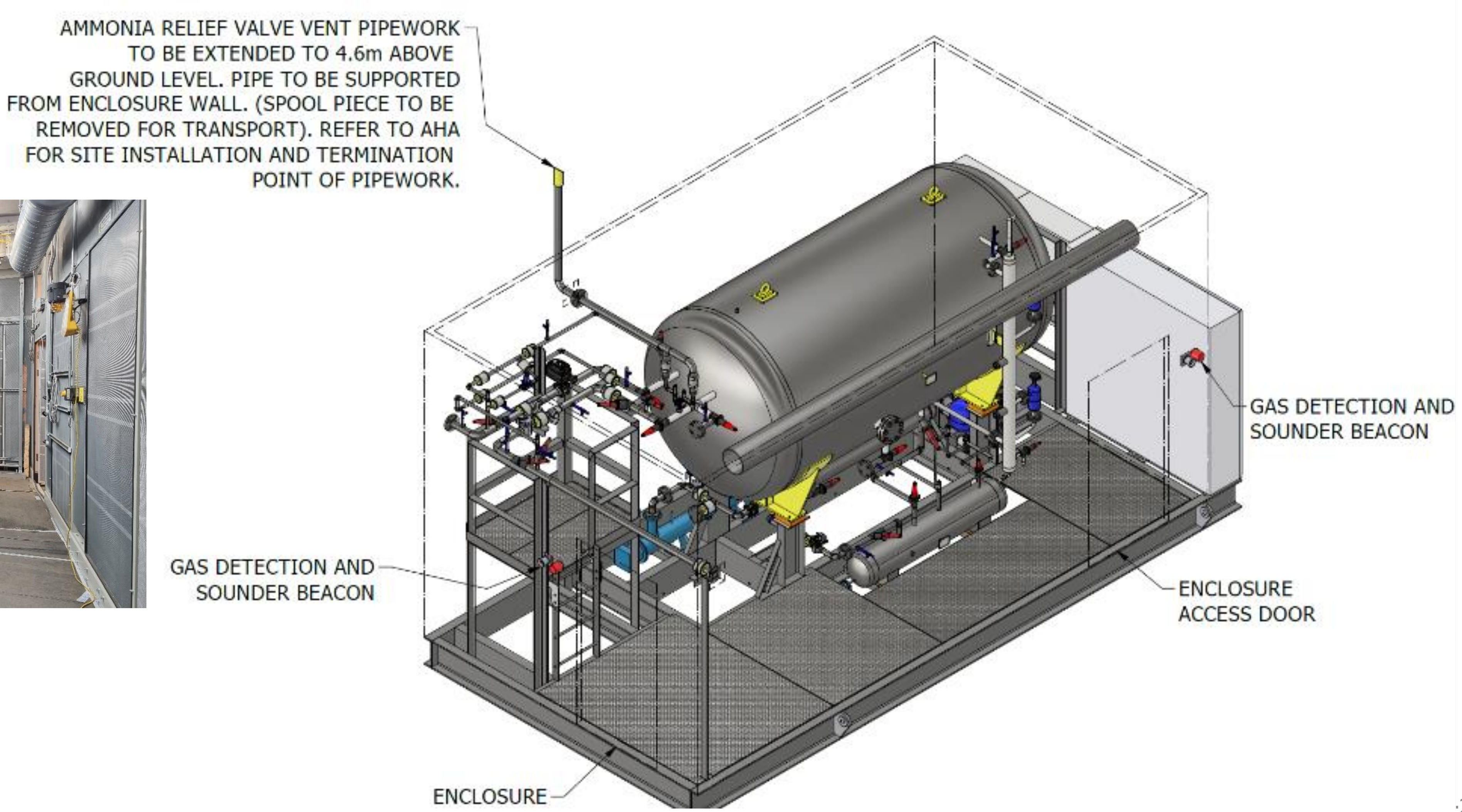
2024
full operation

12/2024
decommissioning

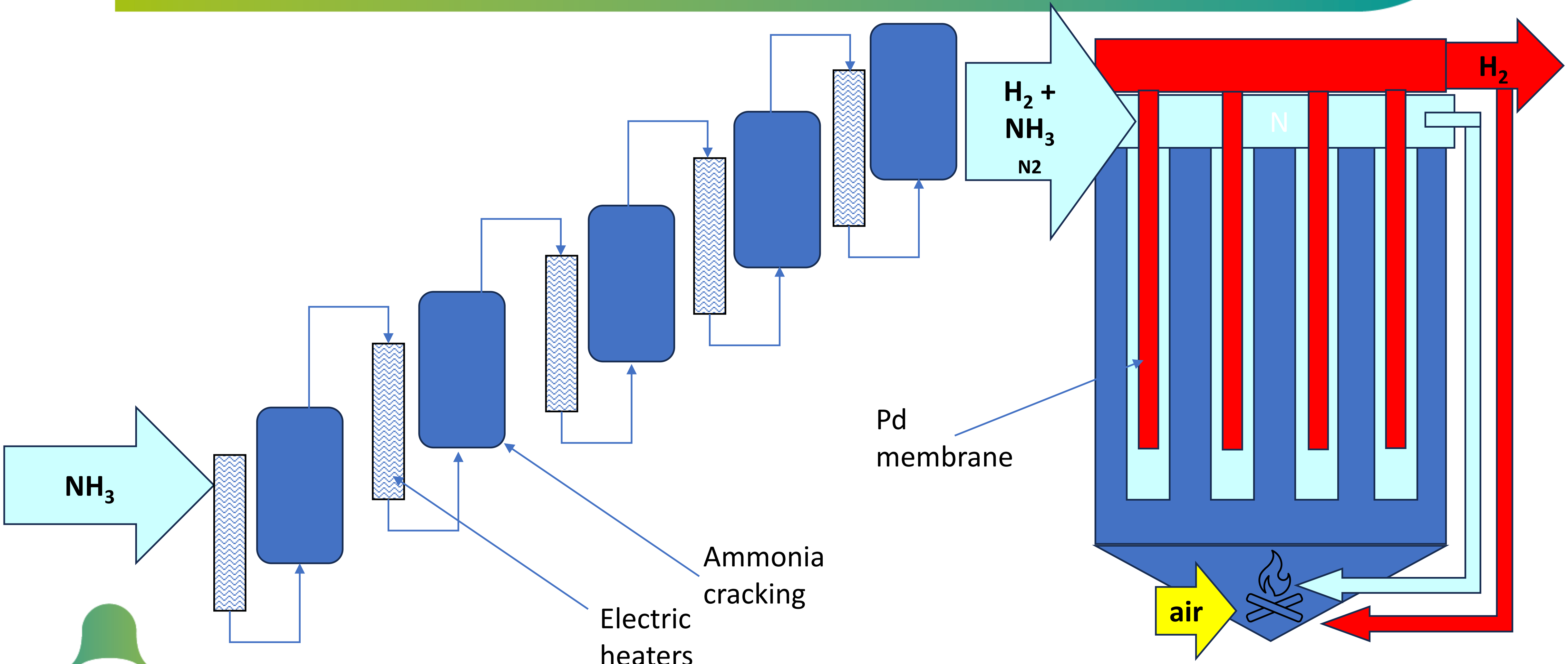
Ammonia drum decant



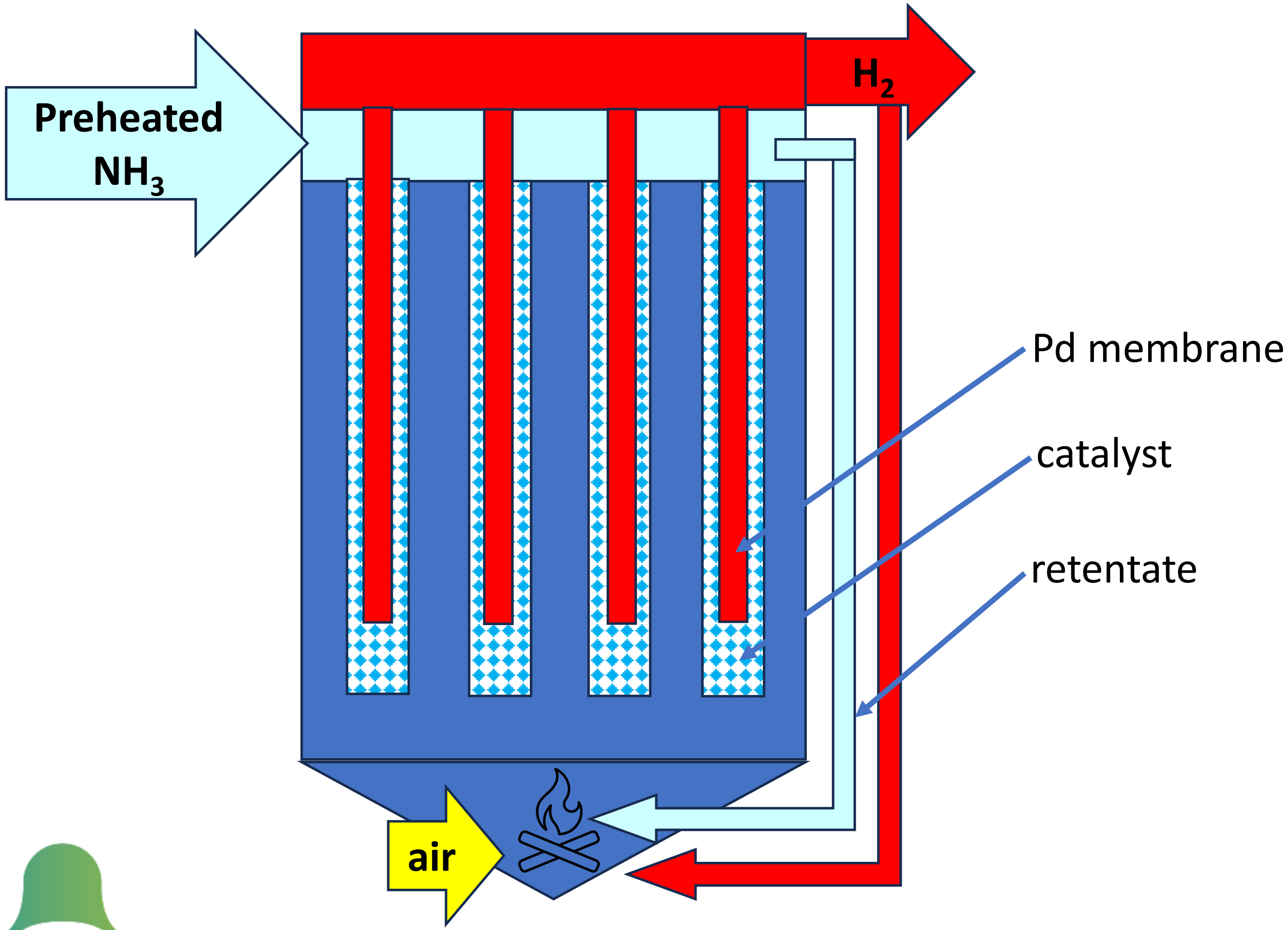
Ammonia vaporiser

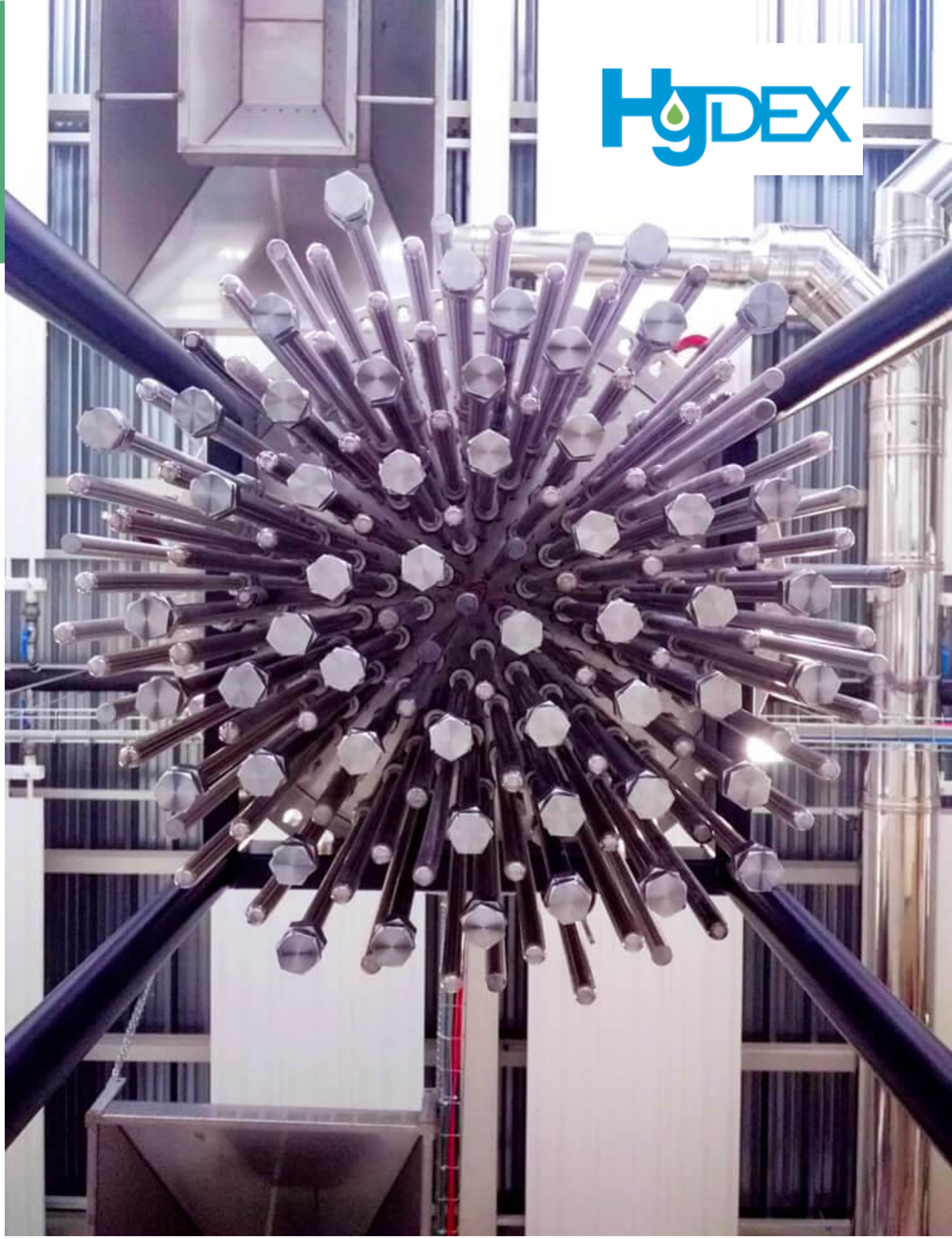


Ammonia cracking reactor v1



Ammonia cracking reactor v2





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Thank you

Funded by UKRI Research England

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