Science and Technology Facilities Council

ASPIRE

Ammonia Synthesis Plant using Intermittent Renewable Energy

Stephen Livermore

FRAZER-NASH CONSULTANCY
A KBR COMPANY

Energy Research Unit

ASPIRE Phase 1 Feasibility

Ammonia Synthesis Plant using Intermittent Renewable Energy

To determine if is technologically and commercially feasible to develop a green ammonia plant that can run off of intermittent renewable power.

Funded as part of BEIS hydrogen supply competition

- Premise

Large scale grey ammonia plants operate at steady state with hydrogen from steam methane reforming and with a direct grid connection.

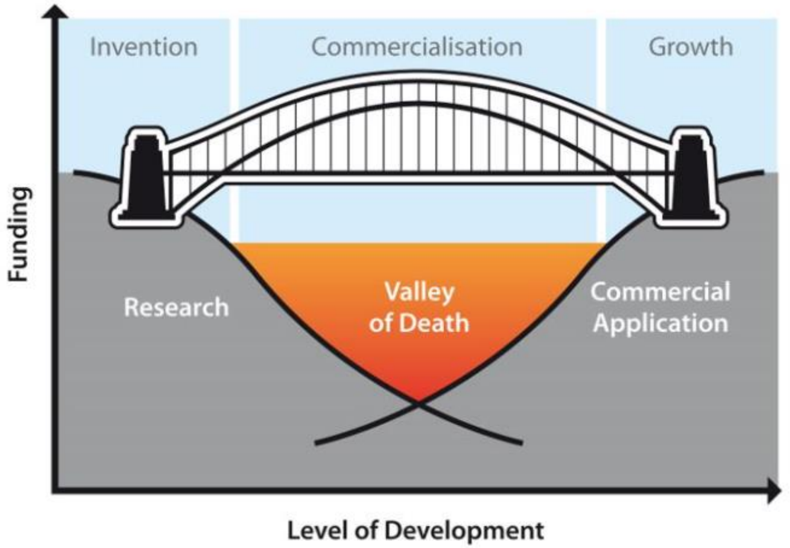
A flexible green ammonia plant capable of running from intermittent renewable energy sources could

1. Address traditional cost disparity between grey and green ammonia
2. Help transition current ammonia production from grey to green
3. Support a future grid with high penetration of intermittent renewables
4. Provide an energy vector for distant windfarms where electrical connection is prohibitively expensive

ASPIRE Phase 1 Team

UKRI Science and Technology Facilities Council
FRAZER-NASH CONSULTANCY A KBR COMPANY

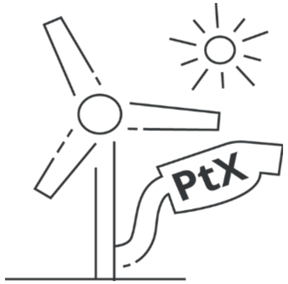
hynamics GROUPE EDF
JM Johnson Matthey Inspiring science, enhancing life
UKRI Science and Technology Facilities Council
UNIVERSITY OF BATH
ENGIE
FRAZER-NASH CONSULTANCY A KBR COMPANY
EnergyTec at Harwell MULTIDISCIPLINARY INNOVATION
DNV
Comhairle nan Eilean Siar
UNIVERSITY OF BIRMINGHAM
INTERLOCK ENERGY



ERU

Net Zero Challenges

- Increasing amounts of excess generation, peak imbalance of 30-50GW and 3.7 TWh of excess energy in a week by 2035
- UK will need between 10 and 50 TWh of hydrogen storage by 2050



Multiple hard to decarbonise sectors that currently use fossil fuels require an alternative fuel.

Energy Density Comparison

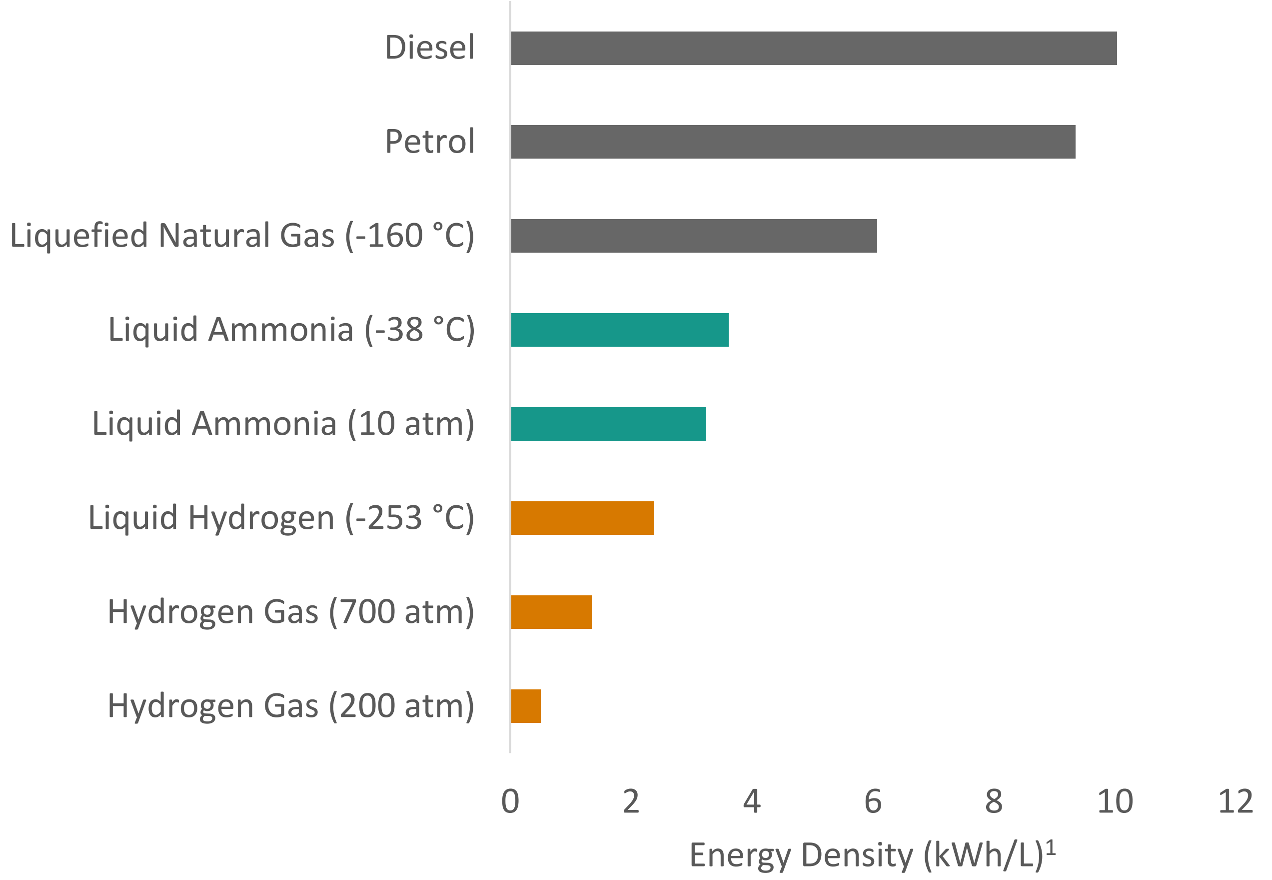
Key

Carbon-based fuels

Ammonia

Hydrogen

- For a zero-carbon fuel, liquid ammonia has a very good energy density.
- Cooling or pressure requirements for liquid storage are far less severe for ammonia



1. Energy densities are determined using the Lower Heating Value of combustion using data from NIST and h2tools.org. The state of each fuel is 15 C and 1 atmosphere unless otherwise stated in the y axis labels.

Storage costs - Hydrogen vs Ammonia

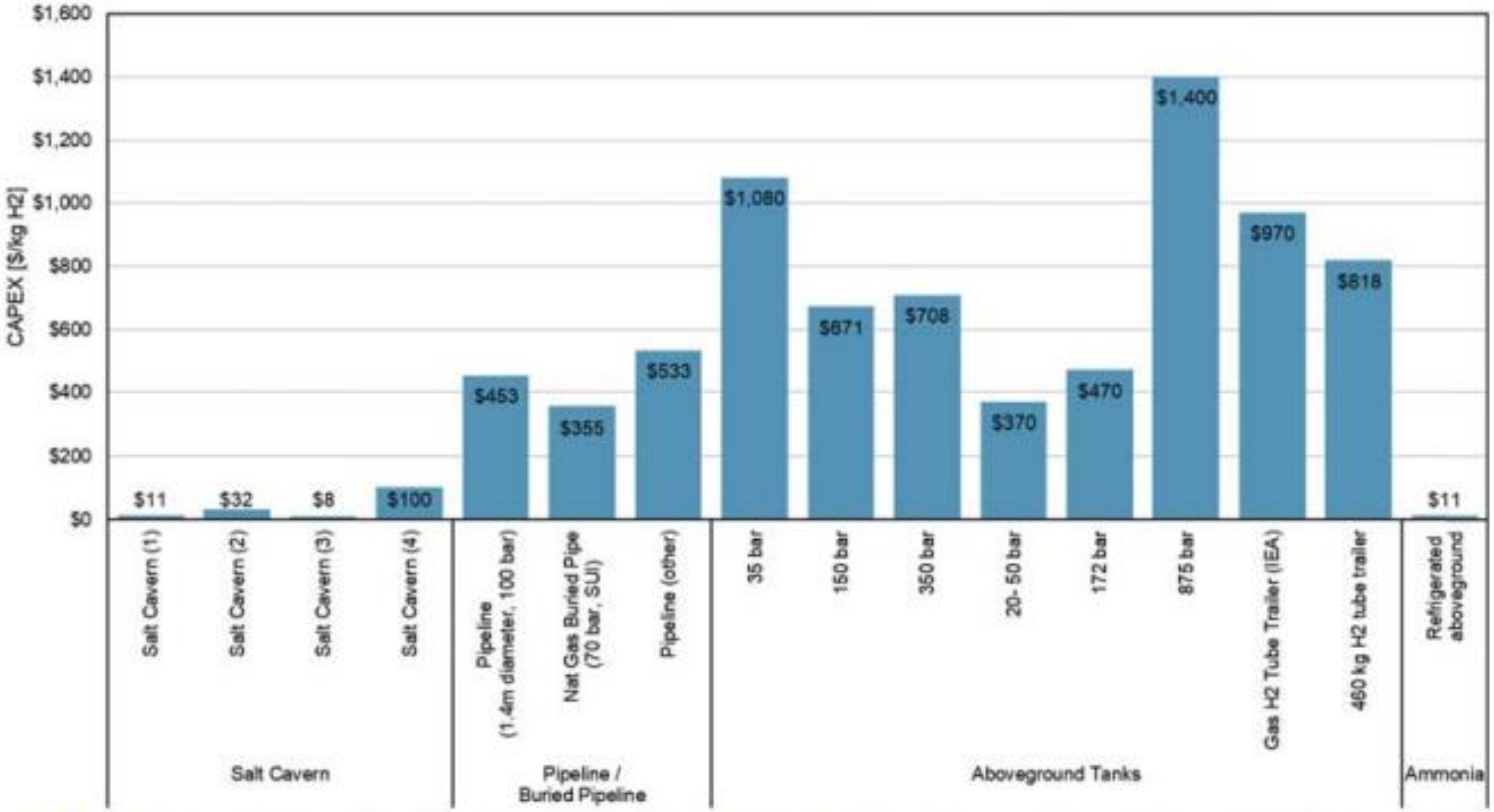


FIG. 2.4 Installed capital expenditure of bulk hydrogen storage options compared to aboveground refrigerated ammonia based on literature values.

Techno-Economic Challenges of Green Ammonia as an Energy Vector by Valerie-Medina & Banares Alcantara

- Salt caverns offer the only comparative cost with ammonia stores

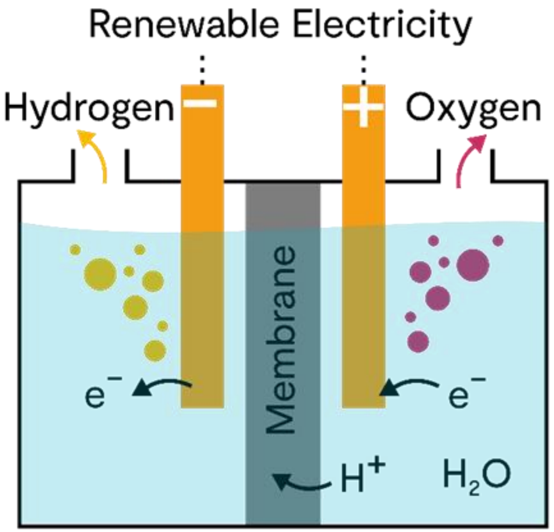
- Long term above ground gaseous hydrogen storage is uneconomic.

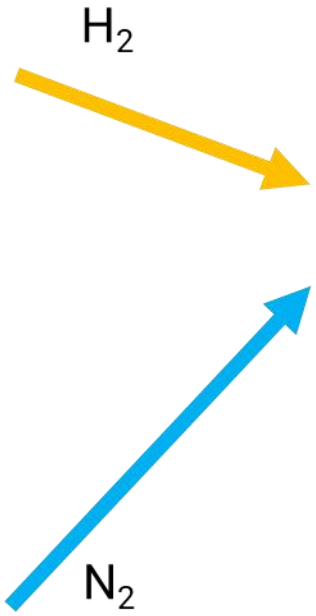
How is Green Ammonia made?

Science and Technology Facilities Council

FRAZER-NASH CONSULTANCY A KBR COMPANY

ELECTROLYSIS

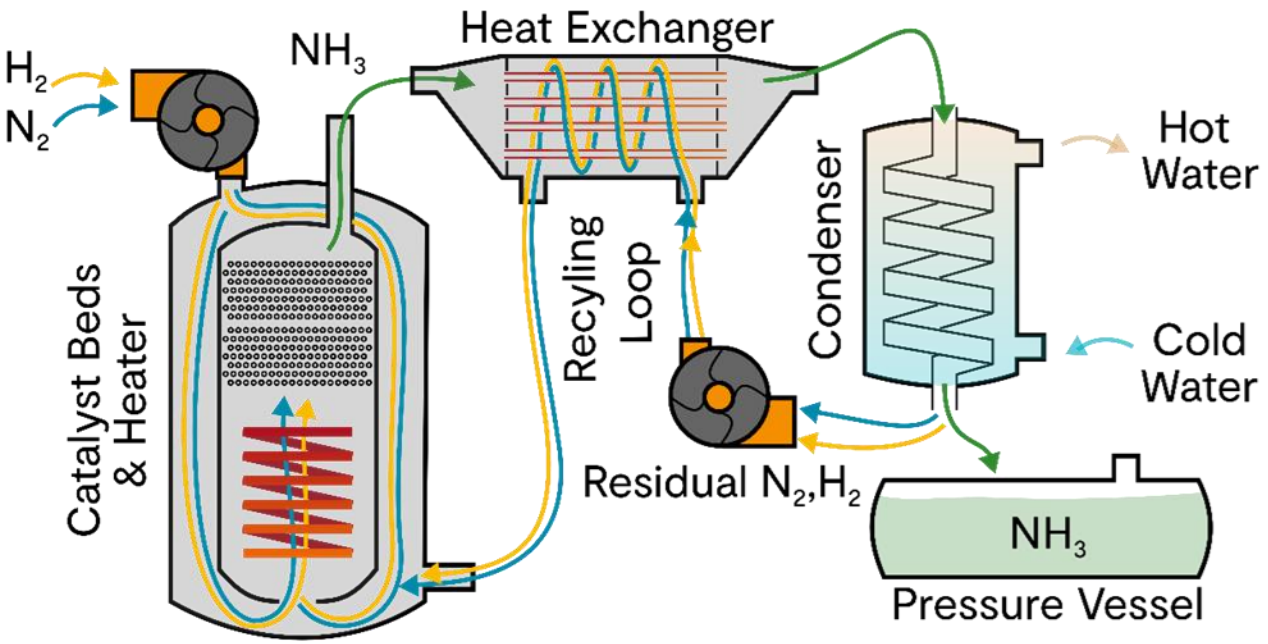




$N_2 + 3H_2 \rightarrow 2NH_3$ exothermic

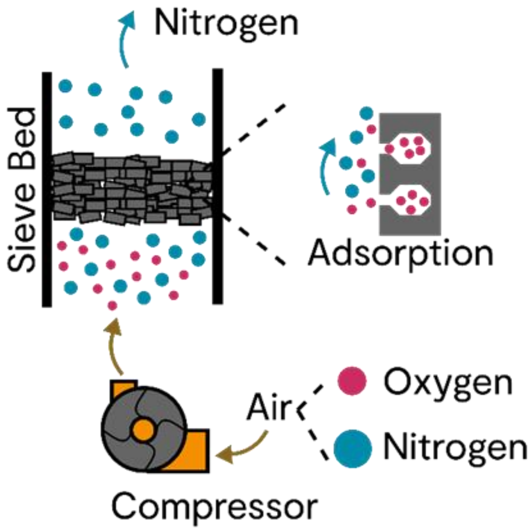
Losses due to synthesis loop components

SYNTHESIS



400°C and 200 bar

AIR SEPERATION

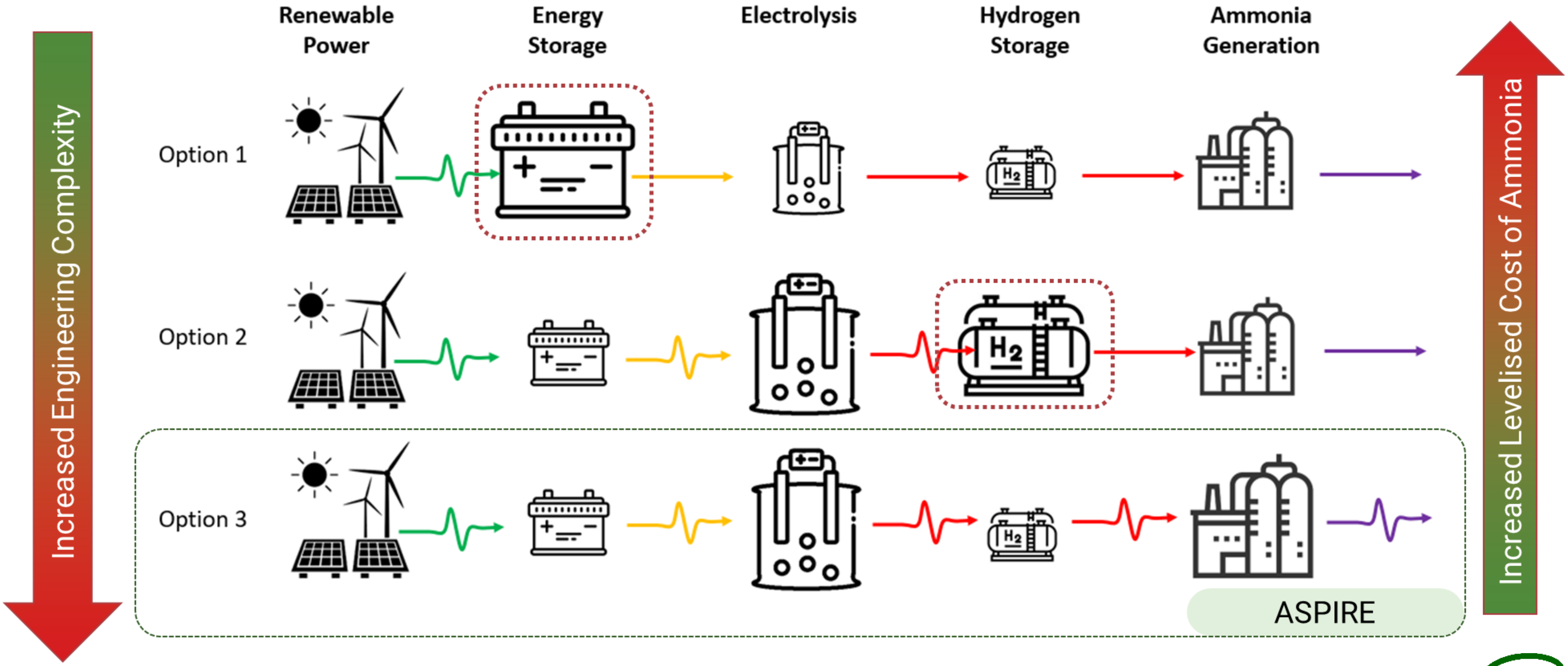


Range of stable operation limits flexibility

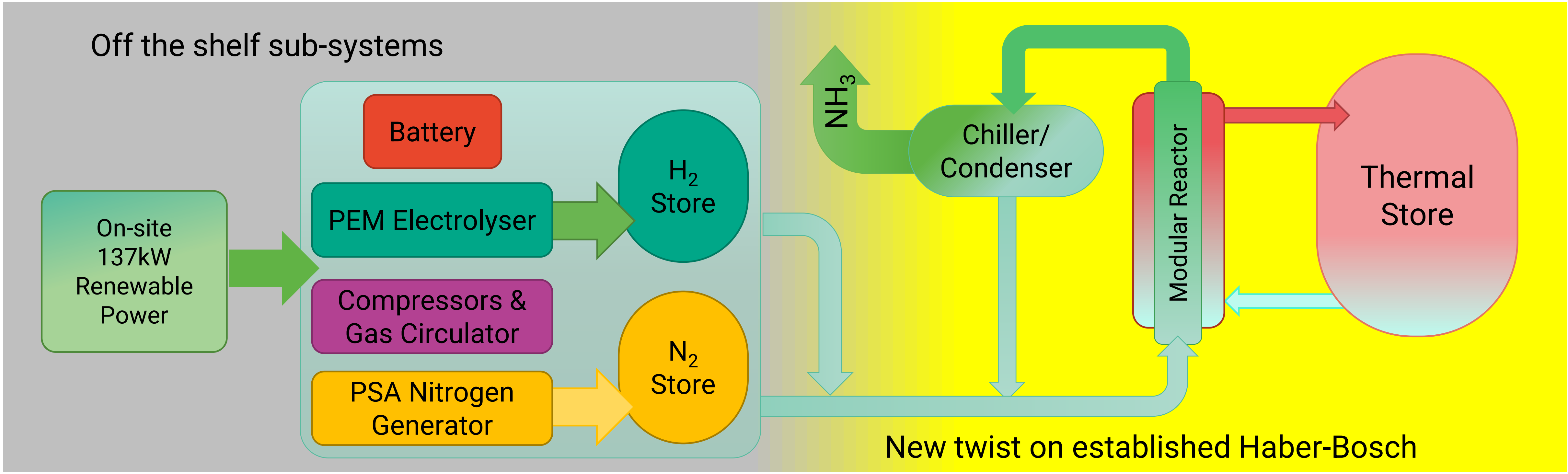
ERU

ASPIRE Design Options

Adding Flexibility:



ASPIRE Concept Design



Modular reactor with coupled thermal management system facilitates :

- High turn down ratio to 5% of full capacity and fast response rate
- Ammonia generation rate tracking available renewable power
- Minimal expensive energy battery & energy storage

ASPIRE Carbon Benefits Assessment

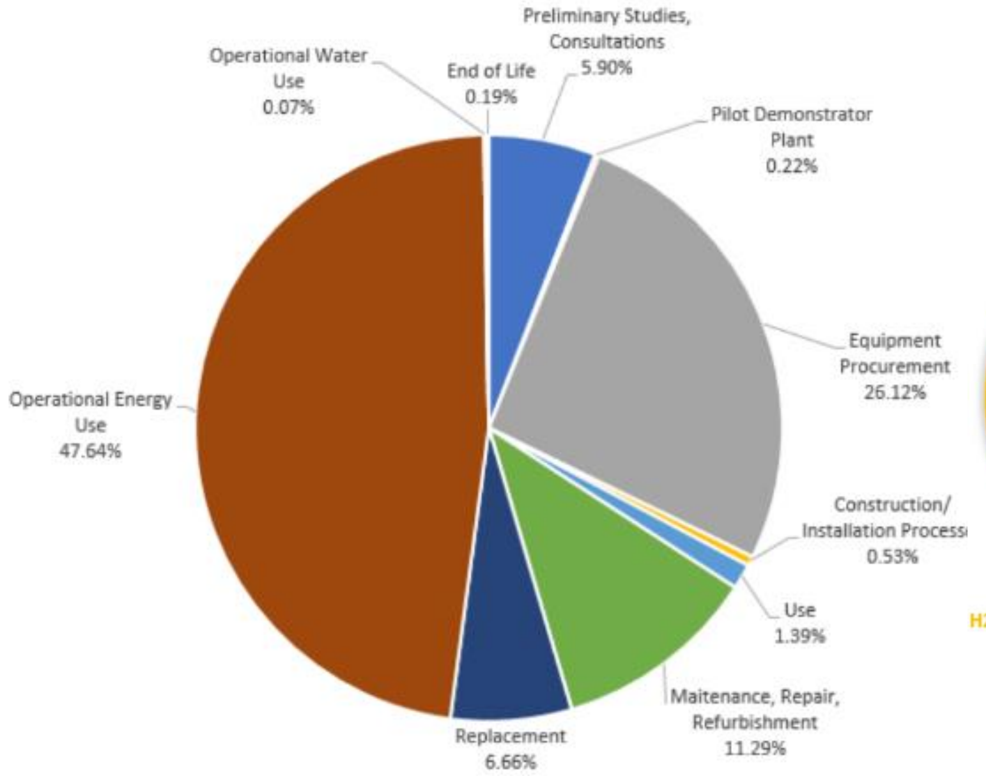
Science and Technology Facilities Council

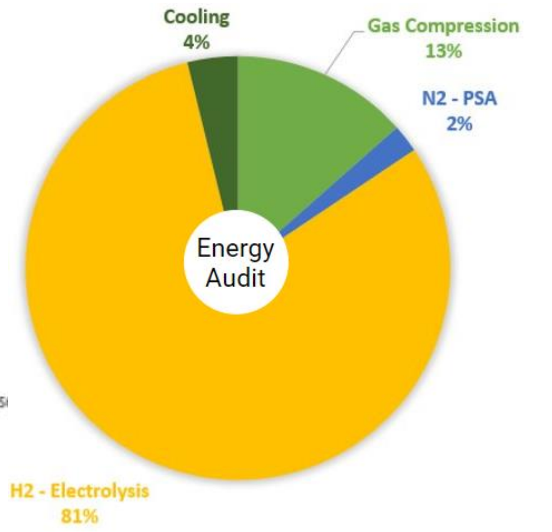
FRAZER-NASH CONSULTANCY
A KBR COMPANY

Life cycle assessment of a 10MW ASPIRE plant predicted 0.18 kgCO2e/ kg ammonia.

Threshold for low carbon ammonia is 0.42 kgCO2e/ kg ammonia (based on low carbon hydrogen standard)

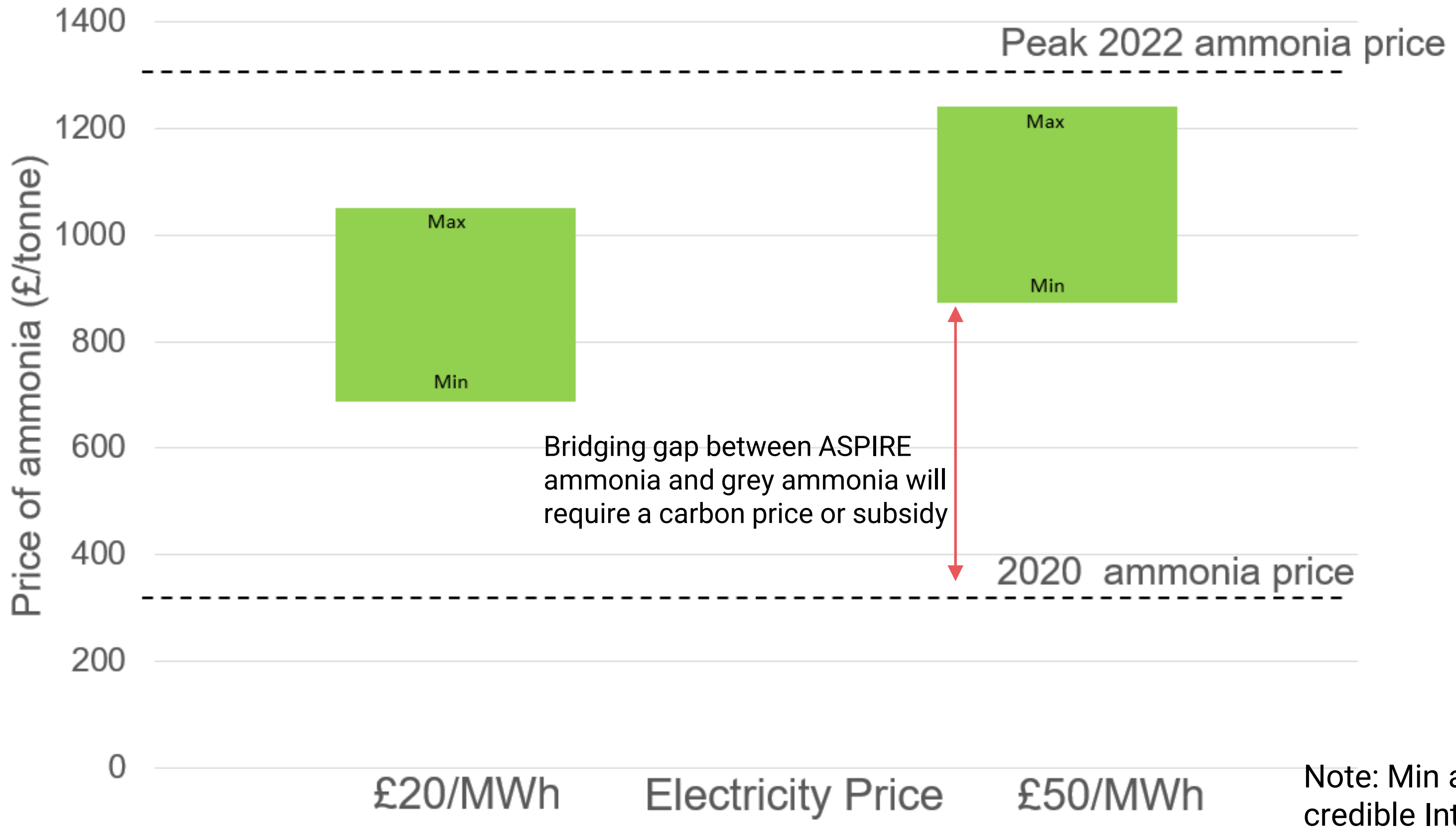
Ammonia produced from natural gas produces around 2.6 kgCO2e/ kg ammonia

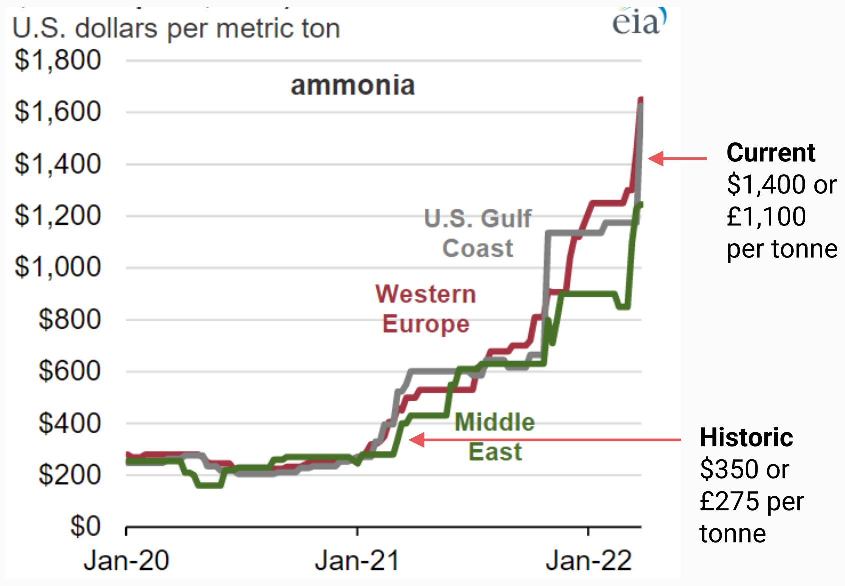




Calculated Price of ASPIRE Ammonia

A cashflow model has been developed to predict the price of ASPIRE ammonia. This is shown for electricity prices of £20 and £50/MWh as follows:





Source: US Energy Information Administration

Note: Min and Max in left figure have been derived using lower and upper credible Internal Rates of Return, annual maintenance and contingency costs

Price of grey ammonia is coupled to natural gas prices that have risen significantly in the last two years. Predicted price of ASPIRE green ammonia compares very favourably with current grey ammonia prices. It is currently more expensive than the historic, and possibly future price of ammonia.
However, ASPIRE green ammonia is insulated from the volatility of grey ammonia pricing which will help investment decisions.

Phase 1 Conclusions

At project commencement key requirements were outlined that would need to be achieved to demonstrate feasibility of the design. The following summarises the findings against these requirements.

- The plant can run on an intermittent source of electricity from a wind farm of output 10 – 200 MW, associated with onshore wind farm sizes.
- Technology exists to develop an operational plant within the next 3 years.
- There is a market for green ammonia produced from intermittent renewables at this scale.
- Through-life cost of the green ammonia produced from intermittent renewable power is competitive with other green ammonia technologies.
- Through-life carbon emissions of the green ammonia is the green ammonia is <0.42 $kgCO_2/kgNH_3$
- The technology meets all safety and regulatory requirements.