

Facilitating the Hydrogen Roll-out with Ammonia Cracking

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September 2022

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Agenda

1

Brief intro to Siemens Energy

2

Why consider ammonia as part of hydrogen economy?

3

What is the role of ammonia cracking?

4

Summary



We are a
**global leader
in the energy
business.**



~ 1/6

of global electricity generation
is based on our technology.

> 50%

of our portfolio is based on
technology that is relevant in
a decarbonized energy world.

We are present in

> 90 countries.

91,000

employees work as a team
to energize society.¹

¹ Number of employees as of September 30, 2021

We are building an integrated energy technology company



Low- or zero-emission power generation



Transport and storage of energy



Reducing CO₂ footprint and energy consumption in industrial processes



Silyzer 300 – Full Stack Array

The next paradigm in PEM electrolysis

Silyzer 300

Full stack array
(24 stacks) ...



... and close-up of 6
stacks (Linz plant)



17.5 MW

plant power demand

>75.5%

plant efficiency

24 stacks

to build a full stack array

335 kg

hydrogen per hour

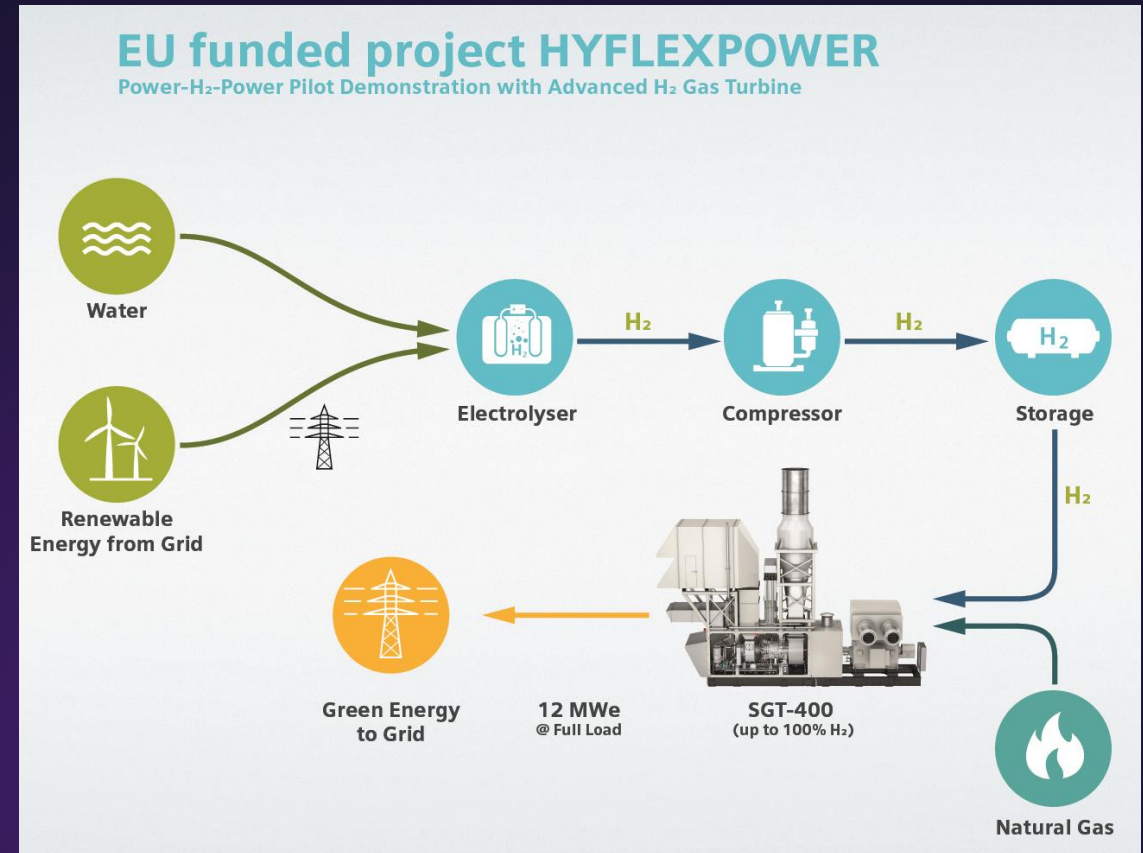
Recent Siemens Energy Hydrogen Developments



Air Liquide and Siemens Energy form a joint venture for the European production of large-scale renewable hydrogen electrolyzers

Paris, France, June 23, 2022

Hydrogen Press Releases



Part 2: Why consider ammonia as part of hydrogen economy?



How much hydrogen does it take to fuel a gas turbine?

1 HOUR
=
8x



Tube trailer ~500kg H₂

1 DAY
=
8km

1.4m pipeline



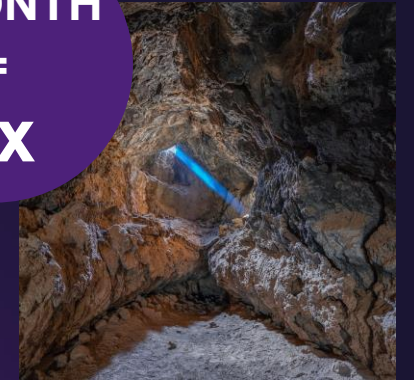
1.4m dia pipe @100bar

1 WEEK
=
3x



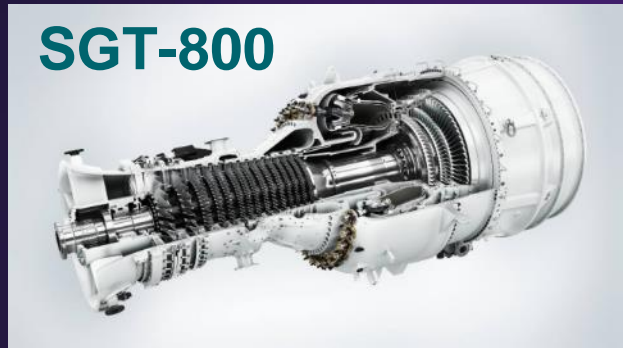
NASA Tank ~230 Tons

1 MONTH
=
4x



Teesside Salt Cavern
~810 tons

4.2
tons H₂/hr



80.7 MW*
58% eff
*CCGT

Assumptions: Tube trailer = 500 kg H₂, Pipeline¹: 1.4 Diameter pipeline at 100 bar (12 ton H₂/km), NASA Spherical Liquid Cryogenic Tank¹: 230 tons H₂, Teesside Salt Caverns² 810 tons (210,000 m³ at 45 bar)

1. J. Andersson and S. Gronkvist, "Large-scale storage of hydrogen," *International Journal of Hydrogen Energy*, vol. 44, pp. 11901-11919, 2019.

2. E. Wolf. "Large-scale hydrogen energy storage," J. Garcke (Ed.), *Electrochemical energy storage for renewable sources and grid balancing*, Elsevier, Amsterdam (2015), pp. 129-142

9000HL: How much H₂ onsite storage is needed?

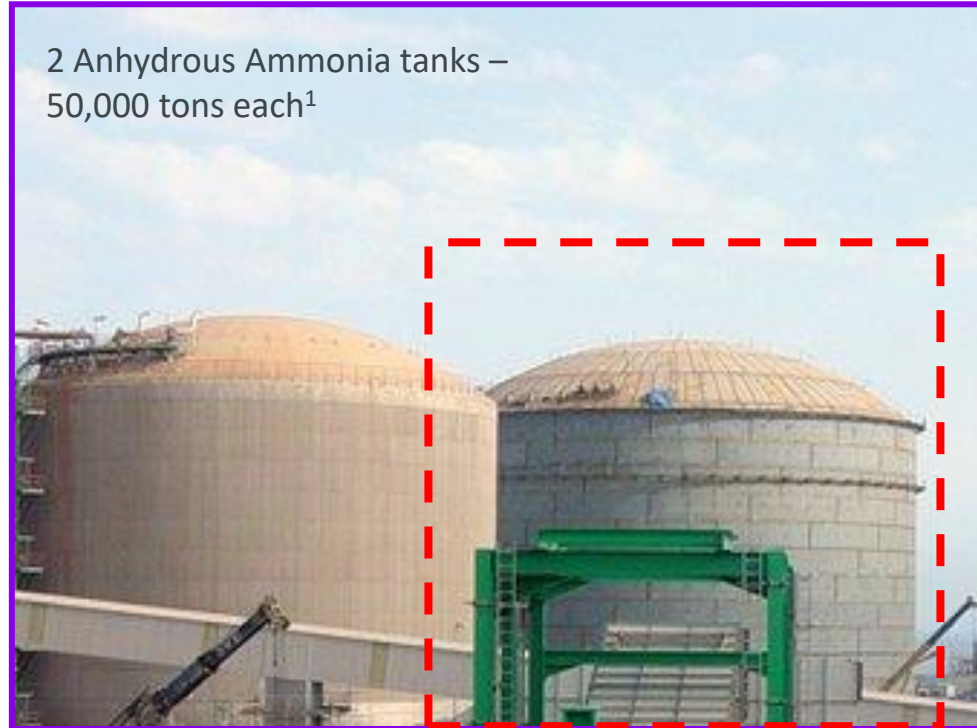


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Why use NH₃ to store H₂?



1x 50,000t NH₃
= 8,880t H₂

=

Salt caverns

11x

SGT800

3 months

9000HL

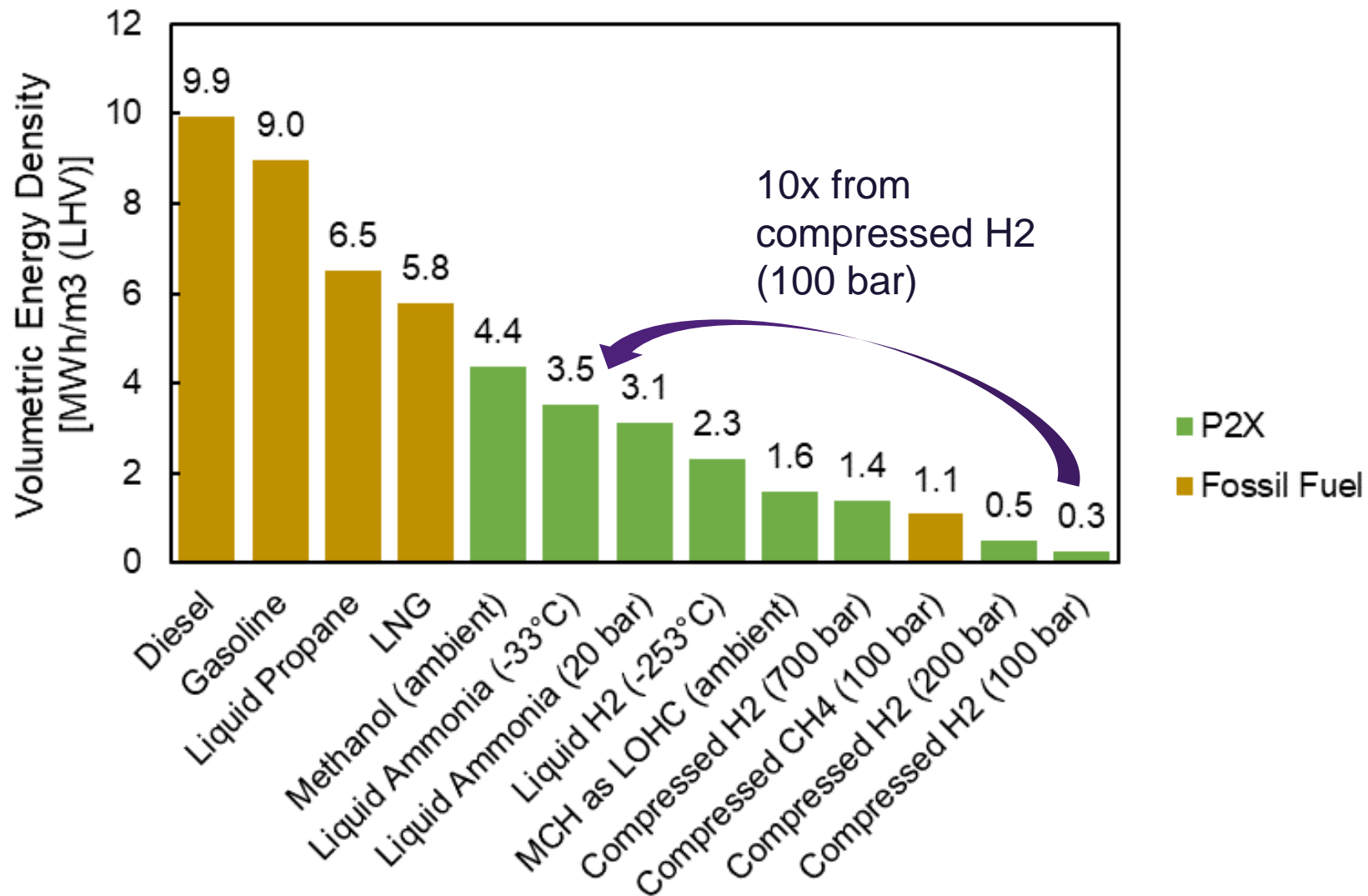
1 week



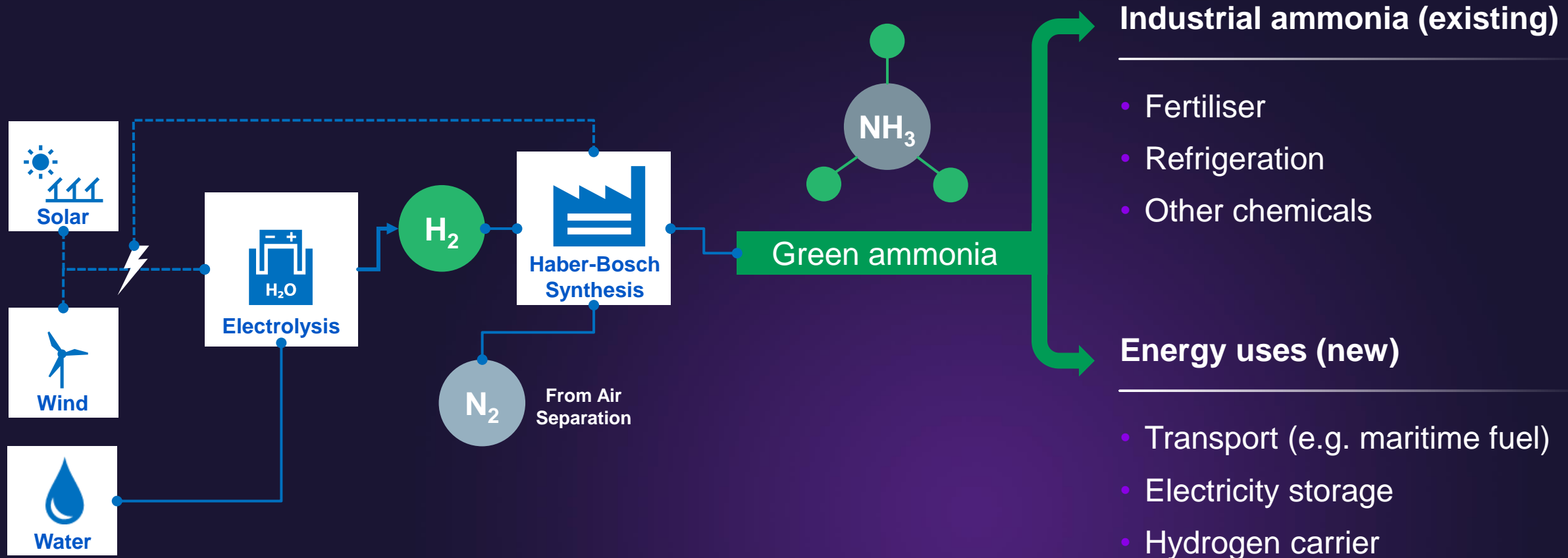
50,000t NH₃
= 8,880t H₂

1. <https://www.mcdermott.com/What-We-Do/Project-Profiles/QAFCO-Ammonia-Storage-Tanks> - tanks are approximately 50 meters in diameter and 40.5 meters high, single-wall refrigerated, concrete containment walls.

Ammonia is much more energy dense than hydrogen



Green ammonia is a carbon-free chemical with many applications



Green Ammonia Demonstration Plant Rutherford Appleton Labs in Oxfordshire, UK

World's first roundtrip green ammonia demonstrator: Power-to-Ammonia-to-Power



SIEMENS
Ingenuity for life



UNIVERSITY OF
OXFORD

CARDIFF
UNIVERSITY
PRIFYSGOL
CAERDYDD



Science & Technology
Facilities Council

Green ammonia is key for >5% GHG mitigation, >\$10bns of investment already announced

1. Fertiliser

- ~1.5% GHG emissions
- Projects announced:
 - Australia, Norway, Spain, Chile, Brazil, USA, etc.
 - First step: 'green' ~10% of existing plants' hydrogen feedstock



2. Shipping Fuel

- ~3% GHG emissions
- Projects announced:
 - Pilot ships 2023 (EU) onwards
 - MAN Engine by 2024, retrofit existing engines by 2025
 - Maersk giga-scale production (Denmark)



3. Energy/ Hydrogen trade

- ??% GHG emissions
 - To be used in transport, power generation, industry, heating, etc.
- Projects announced:
 - Saudi Arabia, Australia, Oman, Morocco, Chile, Namibia, etc.

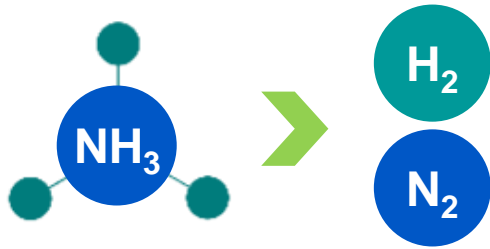


Part 3: What is the role of ammonia cracking?



Leveraging ammonia as a simple and cost-effective carrier molecule to overcome challenges in hydrogen supply

Ammonia cracking to release hydrogen **when** and **where** it is needed

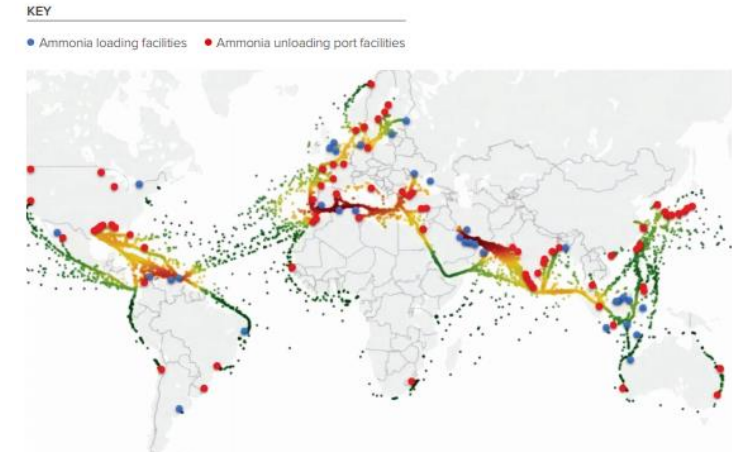


- Ammonia cracking is well known process
- Used today in metal annealing processes
- New applications require H₂/N₂ separation (e.g. PEM fuel cell purity H₂)
- Safe to vent nitrogen

Ammonia benefits from a **mature**, **low-cost**, existing infrastructure

- Produced in >60 countries at all income levels
- Handled at many ports around world
- 20 Million tonnes shipped per year
- >3,000 miles NH₃ pipeline in USA for farm fertiliser

Ammonia shipping infrastructure, including a heat map of liquid ammonia carriers and existing ammonia port facilities (2017).



Source: "Ammonia: zero-carbon fertiliser, fuel and energy store," The Royal Society, London, 2020.



What are the market and technology segments?

→ 3 active technology segments to watch



Decentralized cracking

USE CASE: hydrogen refueling stations (HRS), off-grid power, and on-board cracking (UAV, planes, ships),



Centralized cracking

Centralized cracking for bulk H₂ import (e.g. at port) for industry (e.g. steel), transport, heat (e.g. gas grid injection).



Uniper Plans to Make Wilhelmshaven a Hub for Climate friendly Hydrogen

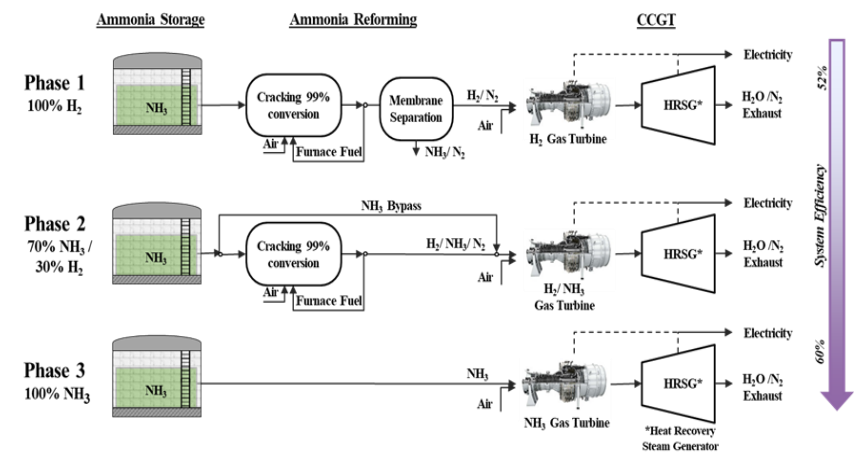
- "Green Wilhelmshaven" to act as a central hub for climate friendly hydrogen
- Import terminal to bring hydrogen to Germany
- In combination with electrolysis, around 10% of hydrogen demand in Germany could be met

Under the name "Green Wilhelmshaven," Uniper plans to establish a German national hub for hydrogen in Wilhelmshaven and is working on a corresponding feasibility study. A terminal for green ammonia is planned. The terminal is planned to be equipped with an "ammonia cracker" for producing green hydrogen and will also be connected to the planned hydrogen electrolysis plant. An electrolysis plant is also planned, which – in combination with the import terminal – would be capable of



Integrated with H₂ Gas Turbine

Crackers utilizing waste heat to crack NH₃ for H₂ Gas turbines

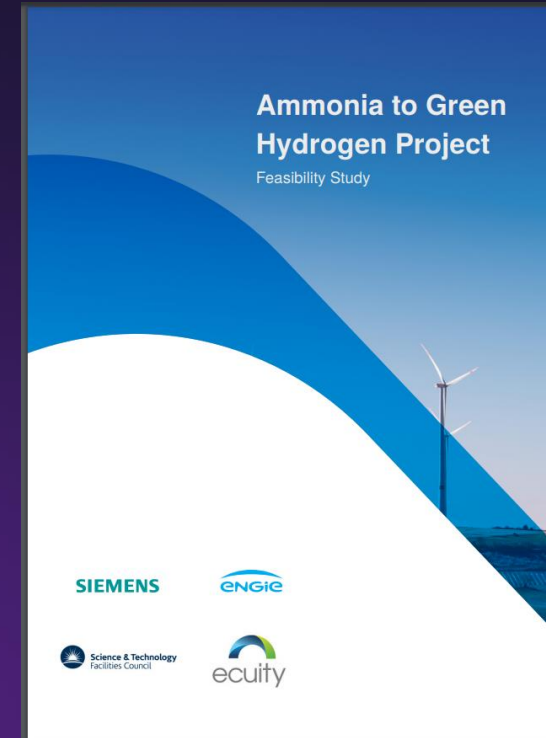


Source: Z. Cesaro, M. Ives, R. Nayak-Luke, M. Mason, R. Bañares-Alcántara, "Ammonia to Power: Forecasting the Levelized Cost of Electricity from Green Ammonia in Large-scale Power Plants", Applied Energy, 2021.

Ammonia cracking can help enable the hydrogen economy

Key messages

- Ammonia is a high density hydrogen carrier with unmatched existing infrastructure and knowhow
- Ammonia cracking is a known process, previously used for different applications (e.g. N₂ generation, forming gas for metal annealing)
- Decentralized ammonia cracking may have highest ability to pay in near term
- Centralized cracking and integrated with GT are mid-long term



[Link to report - 2021](#)

Contact



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