HySTrAm

Hydrogen Storage and Transport using Ammonia

Project Coordinator

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AAU Energy

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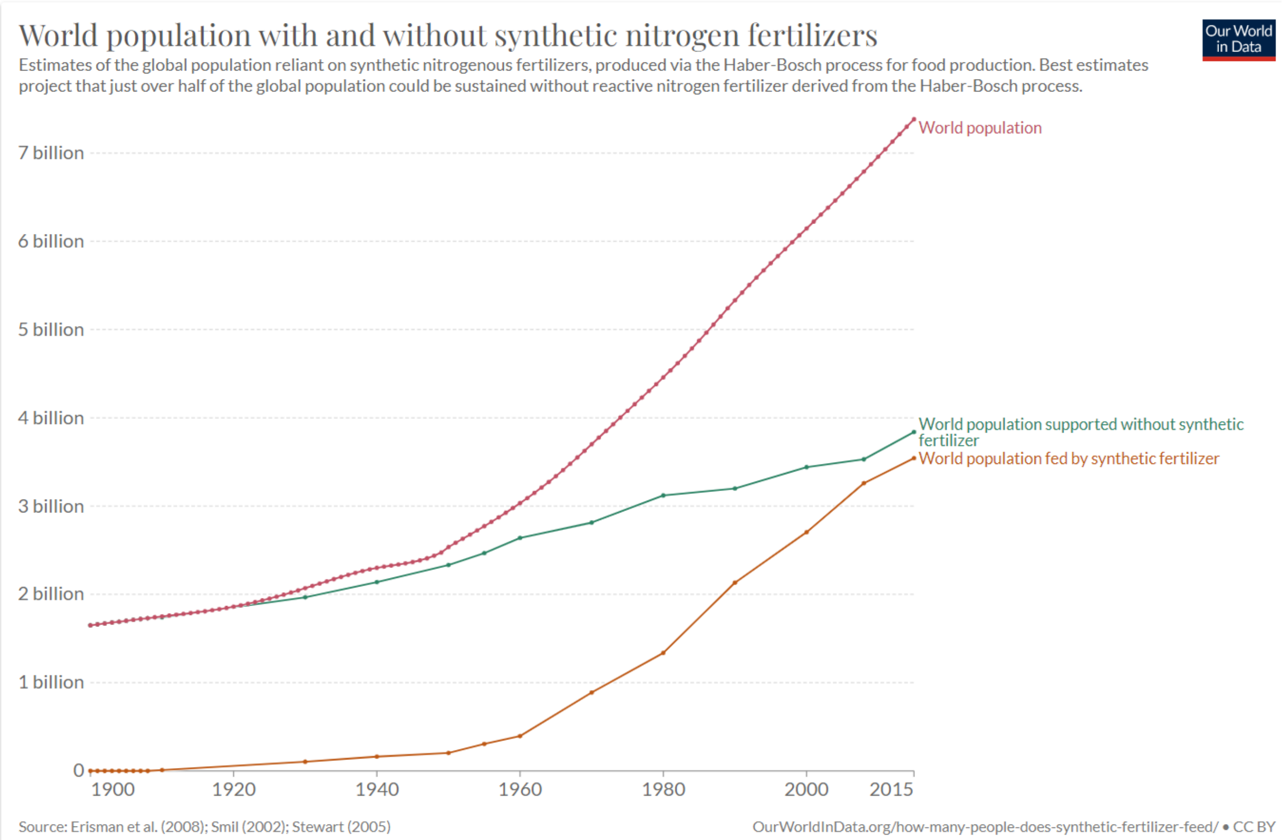
Grant Agreement N° 101058643

Ammonia (NH3) plays an important role in supporting the world population

- Nowadays ammonia is produced through the Haber-Bosch process from fossil fuel and is widely used as fertilizer ensuring reliable food supply in the world.
- Since the industrialization of the process, ammonia has significantly contributed to the world population growth.
- "Ammonia is the Most important invention of the 20th century" Vaclav Smil, Detonator of the population explosion. Nature 400, 415



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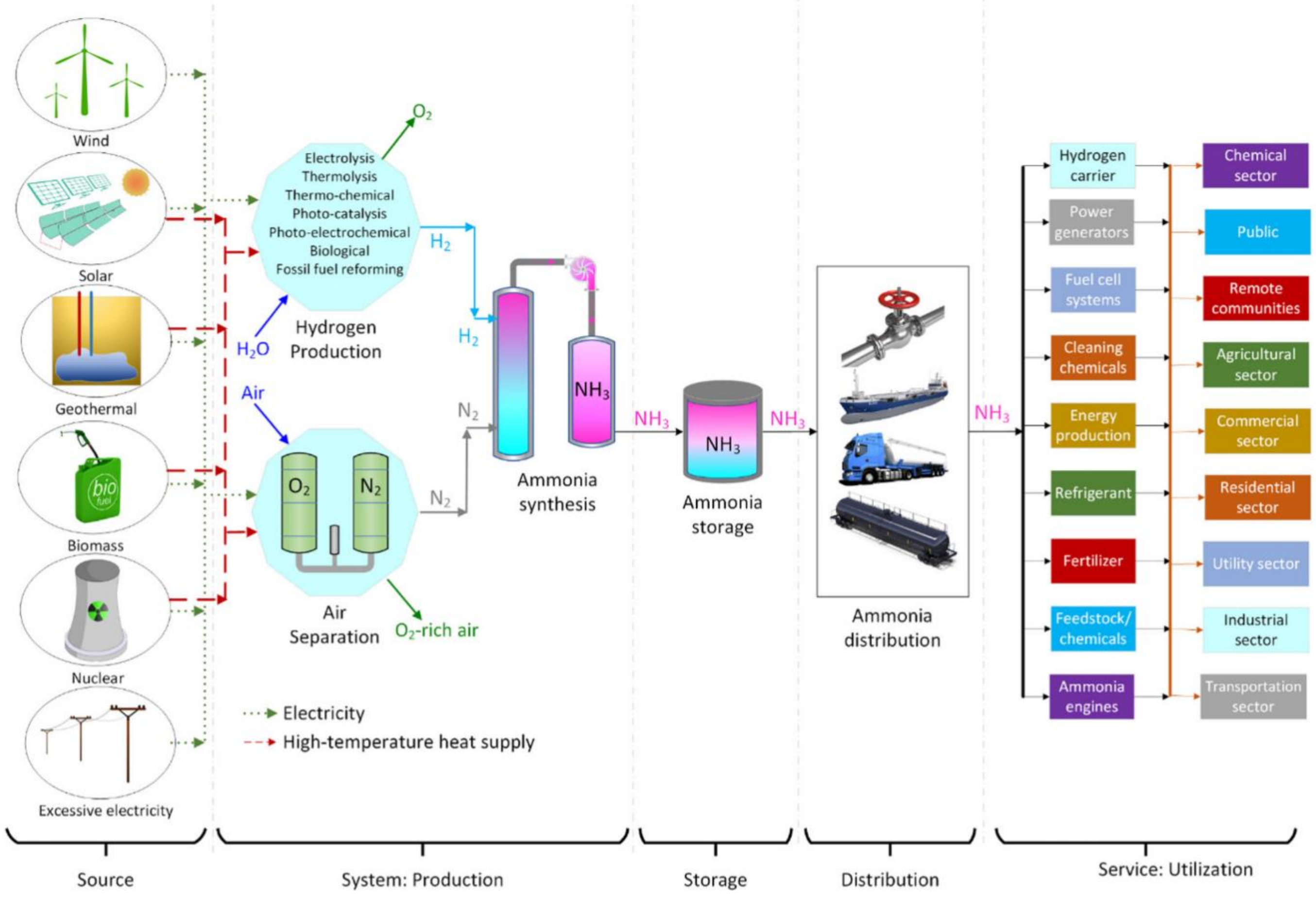
Ammonia: from production to utilization



A perspective on the use of ammonia as a clean fuel: Challenges and solutions
Dogan Erdemir,Ibrahim Dincer
First published: 25 November 2020 https://doi.org/10.1002/er.6232

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Ammonia production state of the art

Photo: Galveston County Economic Development)

- Ammonia production process is energy-intensive
  - 2% of the global total energy consumption
  - 1.3% of the CO2 global emissions come from ammonia production
  - It is the largest contributor of CO2 emissions from chemical industry

- Ammonia is generally produced in **large plants** operating at **steady load**
  - 100-150 Bar; 500-600°C
  - There are around 550 plants in the world
  - 30% are in China
  - The lifetime of a plant is around 20-40 years
  - Only a few companies license ammonia plants

https://ammoniaknowhow.com/short-history-of-ammonia-process-past-present-and-future/

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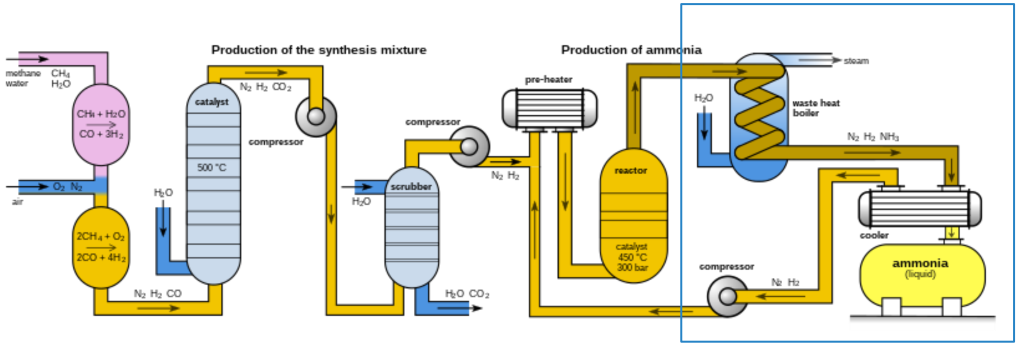
The Haber Bosch process

- Hydrogen is generated by natural gas through steam reforming
- N2 + 3H2 = 2NH3
- Cheap Iron-based catalysts offer low NH3 yeald
- Despite the process has been significantly optimized, reactants recirculation requires large amount of energy due to recompression and condensation and preheating
- CO2 is emitted during the reforming process to generate hydrogen



Source:https://commons.wikimedia.org/wiki/File:Haber-Bosch-En.svg

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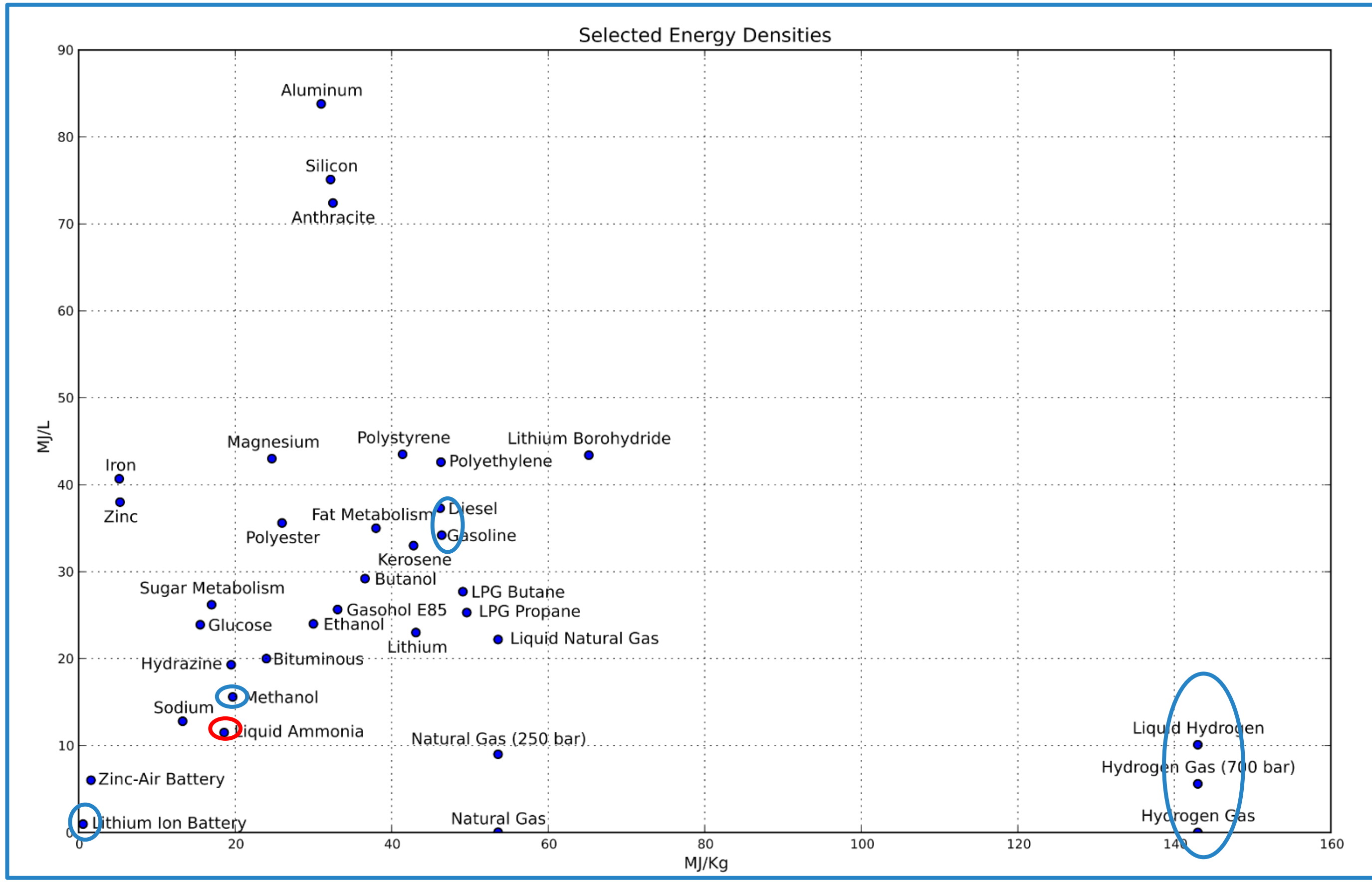
Ammonia energy density

- Higher energy density per volume compared to hydrogen
- Lower energy density per volume compared to conventional fuel eg Diesel and gasoline
- Not influenced by CO2 supply costs, differently by other C-based efuels



SOURCE: https://en.wikipedia.org/wiki/Energy_density

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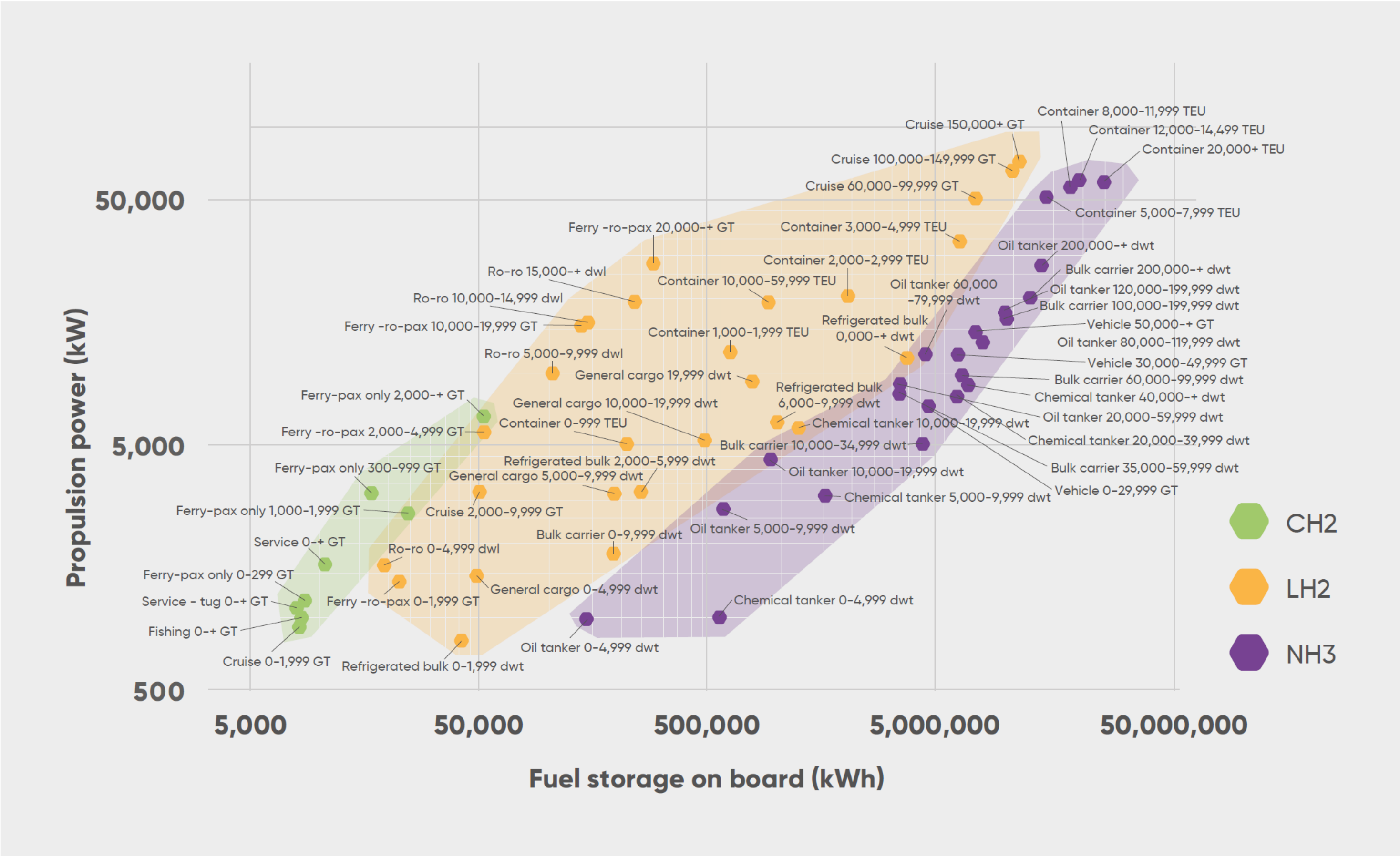
Ammonia: a good choice for the shipping industry

- For deep-sea shipping, where larger autonomy is requided, Ammonia can be a better option compared to Hydrogen

Figure 38: OPTIMUM ZERO-EMISSION OPTION FOR VARIOUS SHIP TYPES.
Source: HYDROGEN EUROPE, 2020.



CLEAN AMMONIA IN THE FUTURE ENERGY SYSTEM Bastien Bonnet-Cantalloube, Marie Espitalier-Noël, Priscilla Ferrari de Carvalho, Joana Fonseca and Grzegorz Pawelec.

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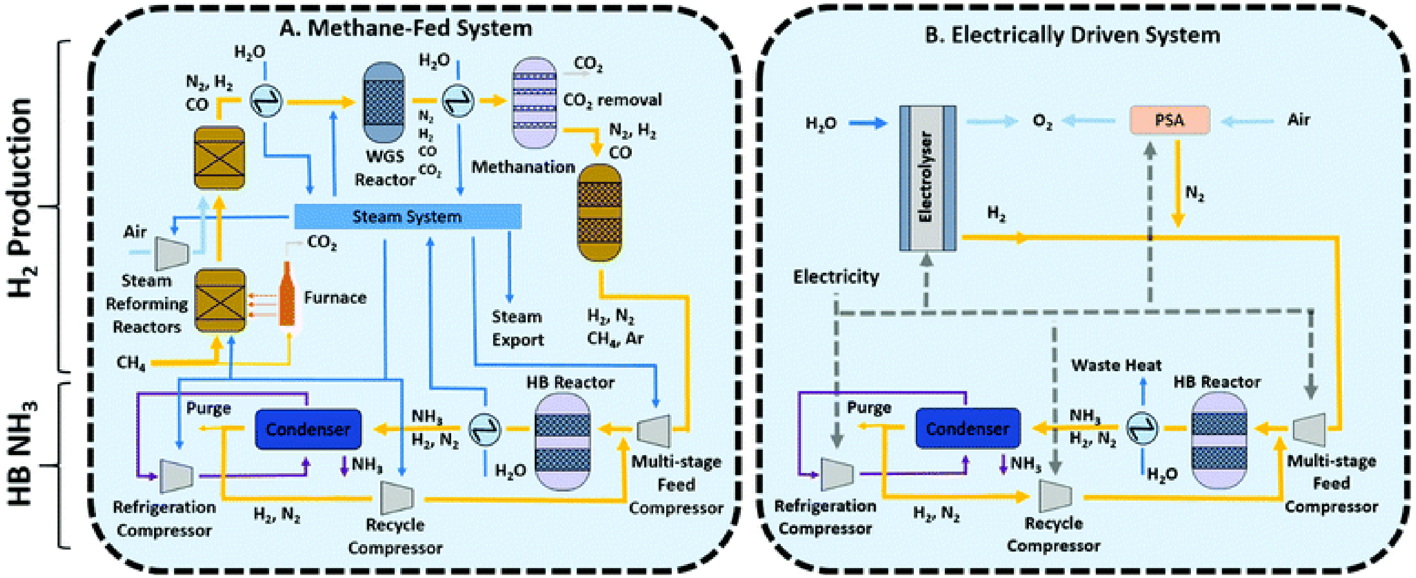
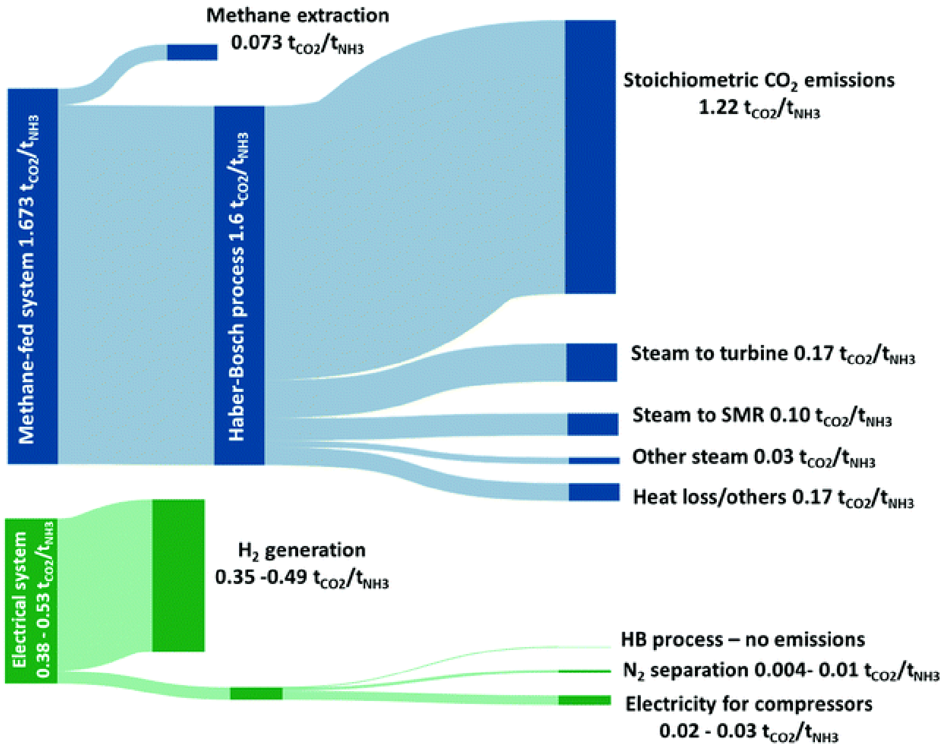
Current and future technologies

- Haber Bosch process vs Electrolysis + PSA





Current and future role of Haber–Bosch ammonia in a carbon-free energy landscape, Smith, Collin and Hill, Alfred K. and Torrente-Murciano, Laura, Energy Environ. Sci., 2020

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Why green ammonia and clean hydrogen?

Green ammonia - as a source of hydrogen - is essential for the European energy system of the future:

- ✓ Ammonia production is nowadays a major source of CO2 emission
- ✓ Renewable carbon-free fuels are not yet cost competitive compared to fossil-based fuels;
- ✓ European hydrogen ecosystem from R&D to scaling up production and infrastructure of international dimensions;
- ✓ Clean hydrogen as a viable solution to decarbonise different sectors;
- ✓ 6 GW of renewable hydrogen electrolyser by 2024 and 40 GW by 2030; and
- ✓ Ammonia is a source of hydrogen it is easier to store and transport.

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AIM of the HYSTRAM project

HySTrAm

To demonstrate a compact containerised ammonia synthesis system based on two main consecutive stages:

A short-term storage hydrogen vessel, buffer to store and transport hydrogen produced by electrolysis. Using a new ultraporous MOF material, identified and optimized through machine learning technology.

Ammonia synthesis reactor with improved the *Haber-Bosch* process where the stored hydrogen react with nitrogen forming ammonia. Use new catalysts and sorbents developed in HySTrAm.

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The project has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement N° 101058643.

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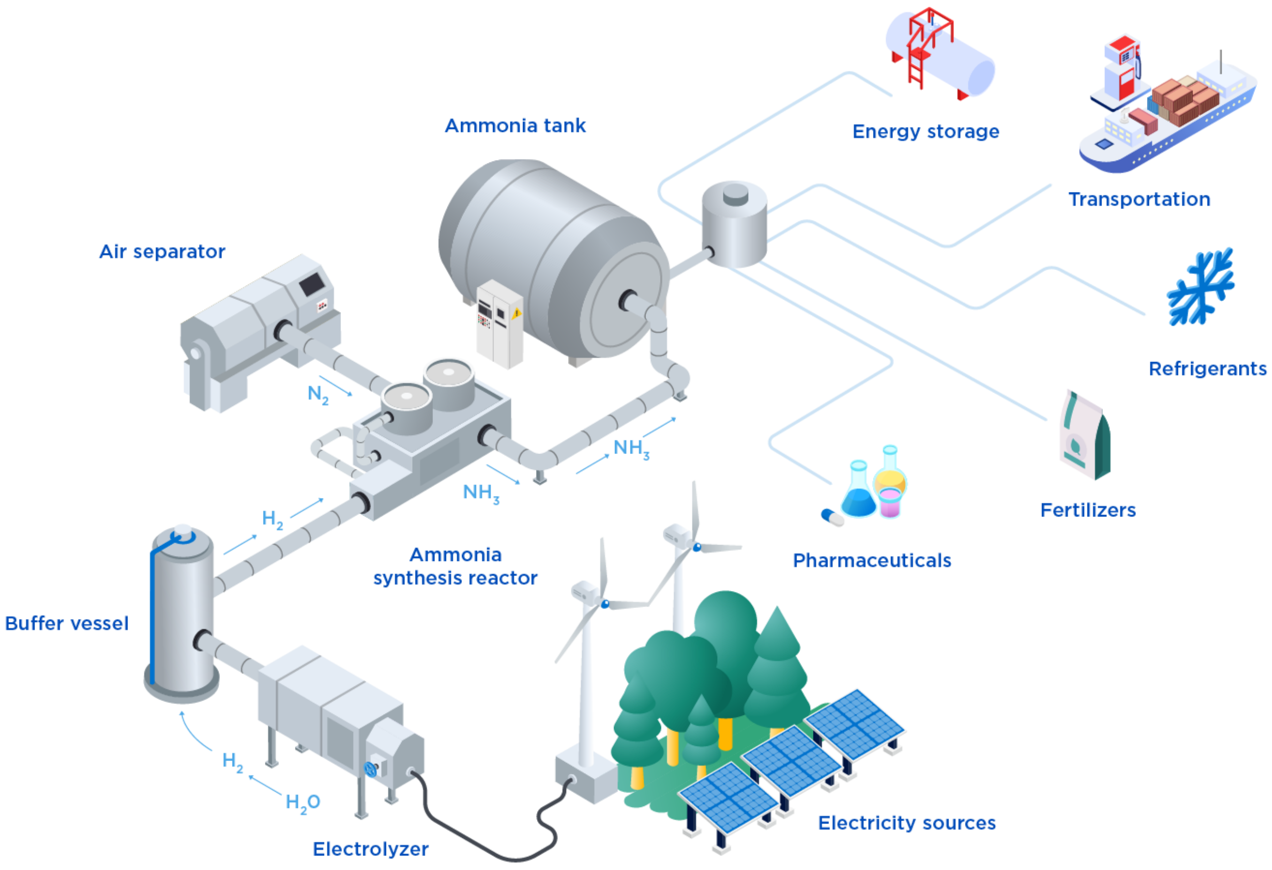
The HySTrAm concept



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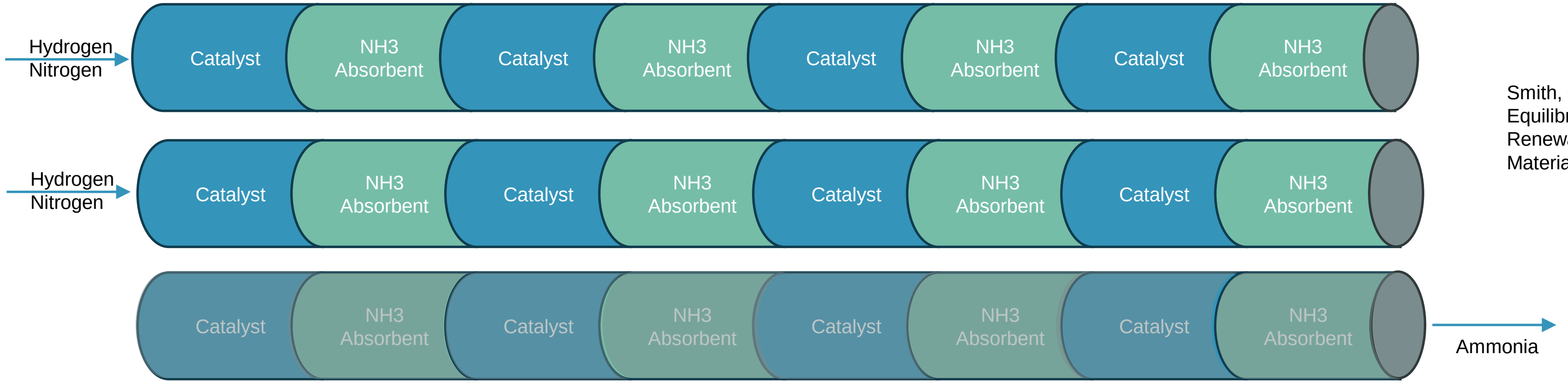
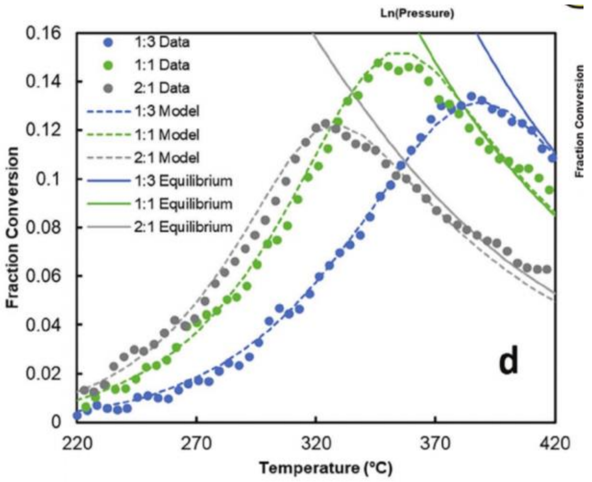
Ammonia Synthesis and Separation
Combined Catalyst-Absorbent System

- We target lower pressures and temperatures in comparison to the traditional Haber-Bosch process. This results in lower conversion.
- Several beds for catalyst and absorbent are necessary to achieve the desired conversion.
- During operation, ammonia is synthesized in the catalyst bed and absorbed in the absorbent bed.
- During regeneration, ammonia is released from the reactor by pressure and temperature swings.





Smith, Collin & Torrente-Murciano, Laura. (2021). Exceeding Single-Pass Equilibrium with Integrated Absorption Separation for Ammonia Synthesis Using Renewable Energy—Redefining the Haber-Bosch Loop. Advanced Energy Materials. 11. 10.1002/aenm.202003845.

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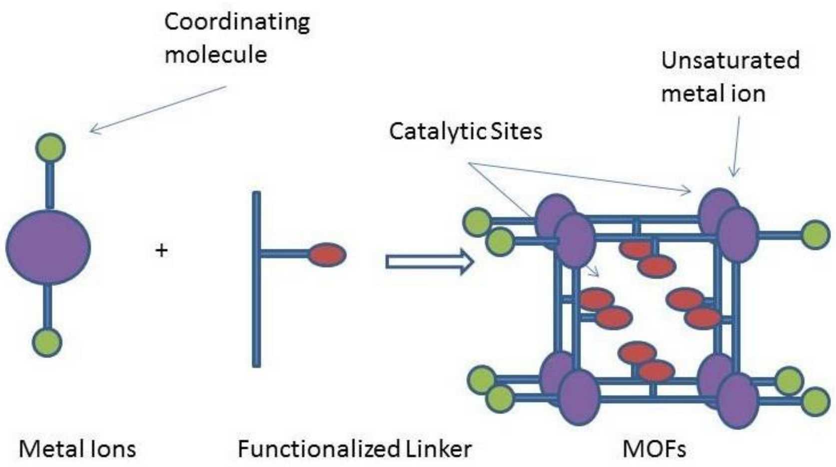
Metal Organic Material for H2 storage

- MOFs, are a type of porous material made up of metal ions or clusters linked together by organic molecules
- Key partners involved:
  - PROFMOF: SME developing MOF
  - UNIVERSITY OF OSLO: IA designing of the MOF
  - GASVESSEL PRODUCTION: Manifacturing of the H2 vessel



Schematic Diagram for MOF Catalysis
https://en.wikipedia.org/wiki/Metal%E2%80%93organic_framework#/media/File:MOFscat3.jpg

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HySTrAm

Project Overview

Grant agreement No: 101058643

Coordinator: Aalborg university (Denmark)

Participants:

16 partners from 12 countries

Spain, Norway, Belgium, Denmark, The Netherlands, Germany, Italy, Slovenia, Switzerland, The United Kingdom, Greece, Poland

Duration: 1 June 2022 to 30 May 2025 (36M)

EU Grant: €5,707,538.14

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HySTrAm

Challenges from Hydrogen to Ammonia

Storage and transport of hydrogen, faces important challenges which hinder its broad application as an alternative and zero emission fuel:

- Storage of hydrogen as a gas typically requires high-pressure
- Storage of hydrogen as a liquid requires cryogenic temperatures
- Ammonia is a promising vector if produced efficiently

HySTrAm builds on developing **physical H2 storage materials**, enabling **short-term storage** (buffering renewables dynamics), as well as three structural corner stones of flexible low pressure NH3:

- ✓ **Decreased Ru content catalysts**
- ✓ **High temperature NH_3 sorbents**
- ✓ **Induction-heated support granting (optimal) responsiveness**

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OBJECTIVES

1. Development of **functional catalyst/sorbent materials** for ammonia synthesis;
2. Development of MOF **new ultra-porous materials** with high H2 capacity;
3. Realisation of a **lightweight composite vessel** for physical-adsorption hydrogen storage;
4. Design, construction, optimisation and demonstration of **dynamically operated packed bed reactors** for ammonia synthesis;
5. **Demonstration of the overall HySTrAm solution at TRL5**; and
6. **Validation of a business case**

In addition, during the project the system will be modelled at different levels i.e.

- quantum level and microkinetic level simulations of the reactions
- higher level simulations of the reaction and process with machine learning and AI
- process level simulations

This holistic modelling approach will ensure that all aspects will be considered and make possible more robust results.

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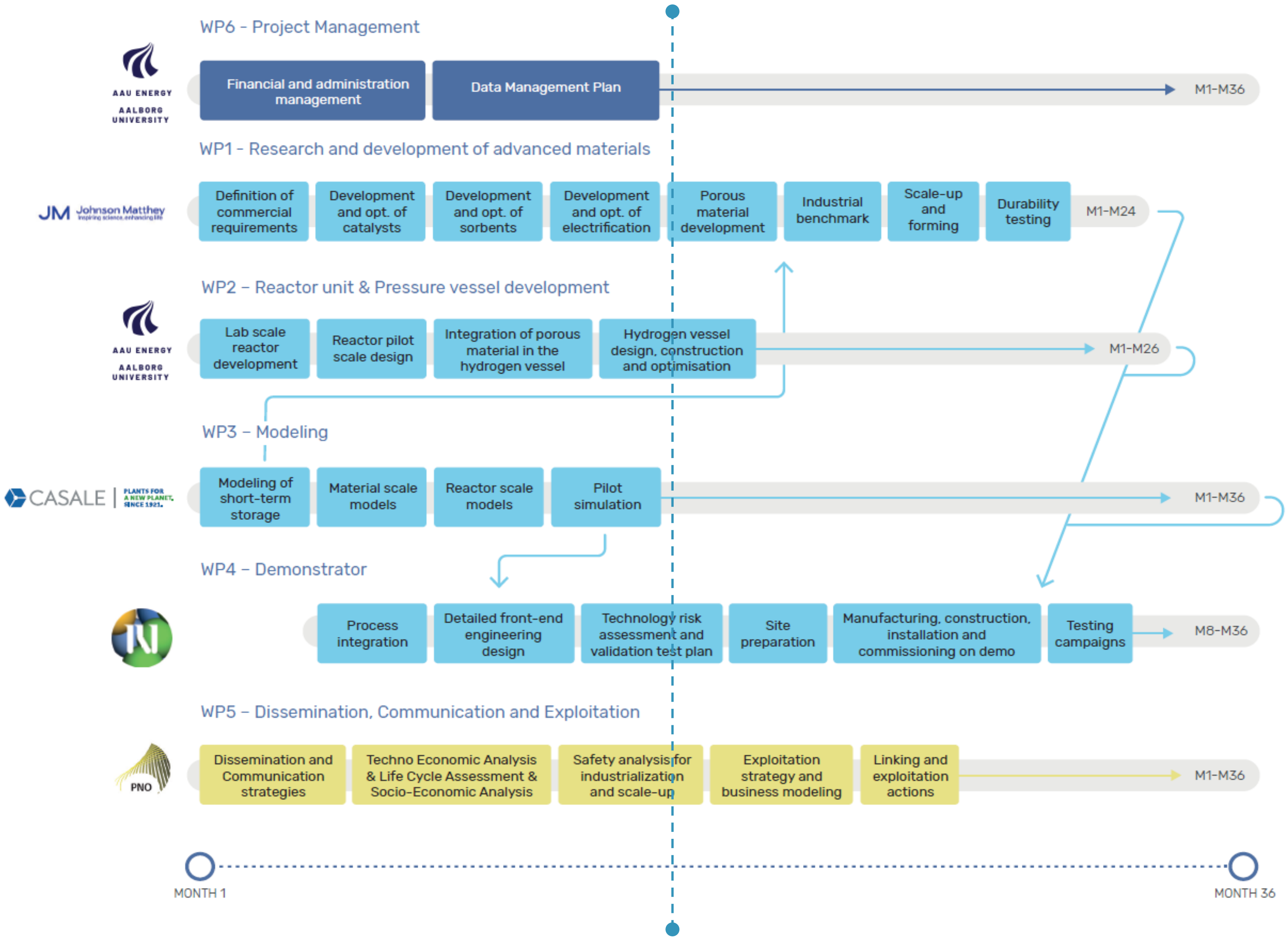
Work Plan



We are half away in the project!
With the first experimental design we are completing the system designing.

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Modelling and experiments workflow integration

from microscale to system level

HySTrAm

Activity levels	Roles	Activity
		LCA, Communication, Business development
		Plant fabrication
		System level simulation and designing
		Process integration
		Reactor level modelling and experimentation
		MOF, Catalyst and absorbent experimentation and modelling
		Microscale level kinetics modedelling ie quantum mechanics and molecula dynamics

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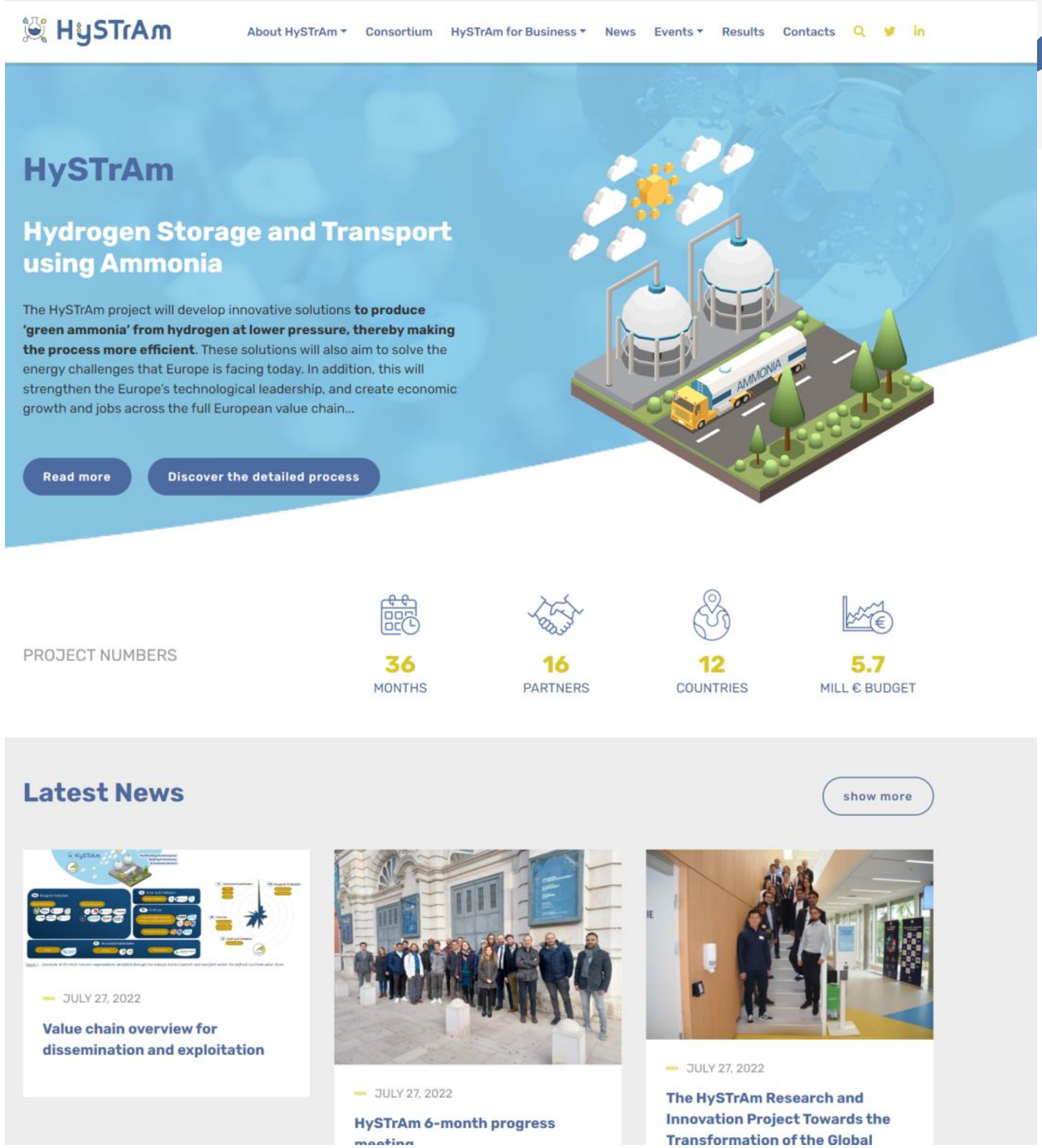
Thank you from all partners
Pls follow us on https://www.hystram.eu/



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Thank you

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