ARENHA project: Main activities and results

https://arenha.eu/

Contact: *José Luis Viviente*
joseluis.viviente@tecnalia.com

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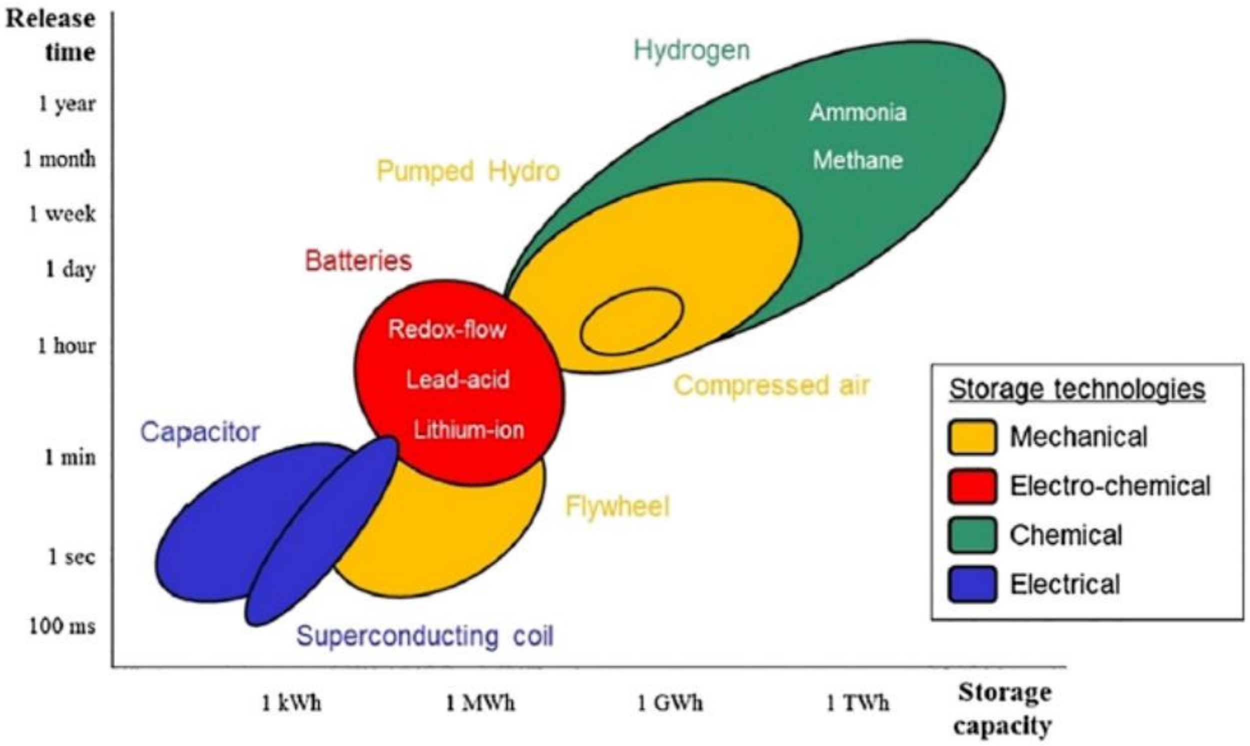
I. Introduction: challanges

Renewable energy is playing an important role in addressing some of the key challenges facing today's global society, such as the cost of energy, energy security and climate change.

Energy storage technologies

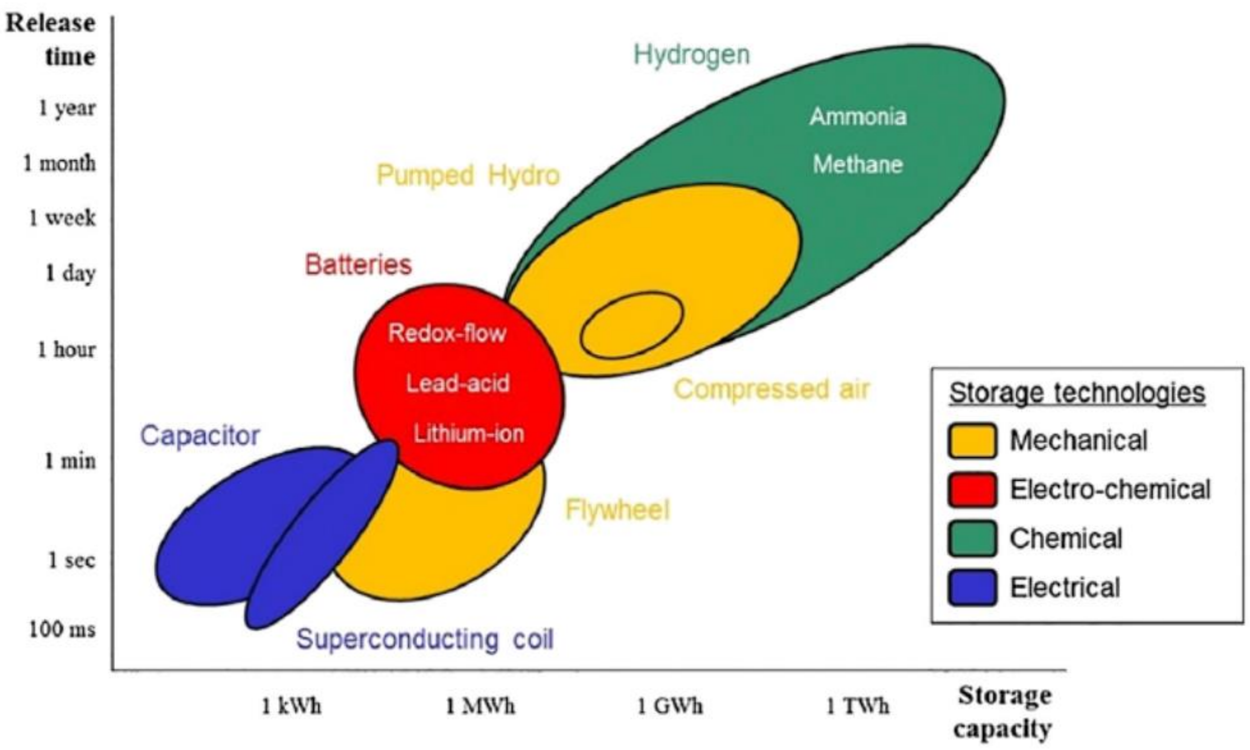


L.Ye et al. Reaction: "Green" Ammonia Production. Catalysis Vol. 3, Issue 5, p712-714, 2017
DOI: https://doi.org/10.1016/j.chempr.2017.10.016

- Sustainable energy production can only work well when the energy storage challenges are solved.
- Overcoming the inherent intermittency of renewable resources and increasing their share of generation capacity (i.e. integration of renewable energy in the grid).
- Other technologies have to be developed that can respond to these needs, and their readiness for market deployment has to be shown.
- New or improved materials for these technologies must be developed in combination with new design/architecture (i.e. improvement of electrolysers …)
- Economic competitiveness and environmental aspects have to be considered (i.e. recycling)

I. Introduction: challanges

Energy storage technologies



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- Batteries may not be the best solution to face all energy storage needs, due to cost, safety and environmental issues.
- Pumped hydro and methods such as compressed gas energy storage suffer from geological constraints to their deployment.
- Non battery-based storage technology, such as Power-to-X technologies (Power-to-Gas, -Chemicals, -Liquids) that allows transforming renewable electricity into synthetic gases (hydrogen, methane or other gases) and chemicals/liquids, can be suitable solutions for different energy storage needs.
- The only sufficiently flexible mechanism allowing large quantities of energy to be stored over long time periods at any location is chemical energy storage: via hydrogen or carbon-neutral derivatives.
- H_2 has gained considerable attention as an ideal and clean energy carrier:
  - H_2 combustion produced only water as by-product
  - High efficiencies for energy conversion are achieved when it is employed as feedstock for power production.

1. Project overview: Objective

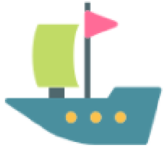
- The ARENHA project aims at using ammonia as a green hydrogen carrier and for that purpose it develops its main activities around the power-to-ammonia-to-usage value chain.
- Innovative materials are developed and integrated into ground-breaking systems enabling the flexible, secure and profitable storage and utilization of energy under form of green ammonia.

Why ammonia as a H_2 carrier?

High volumetric energy density

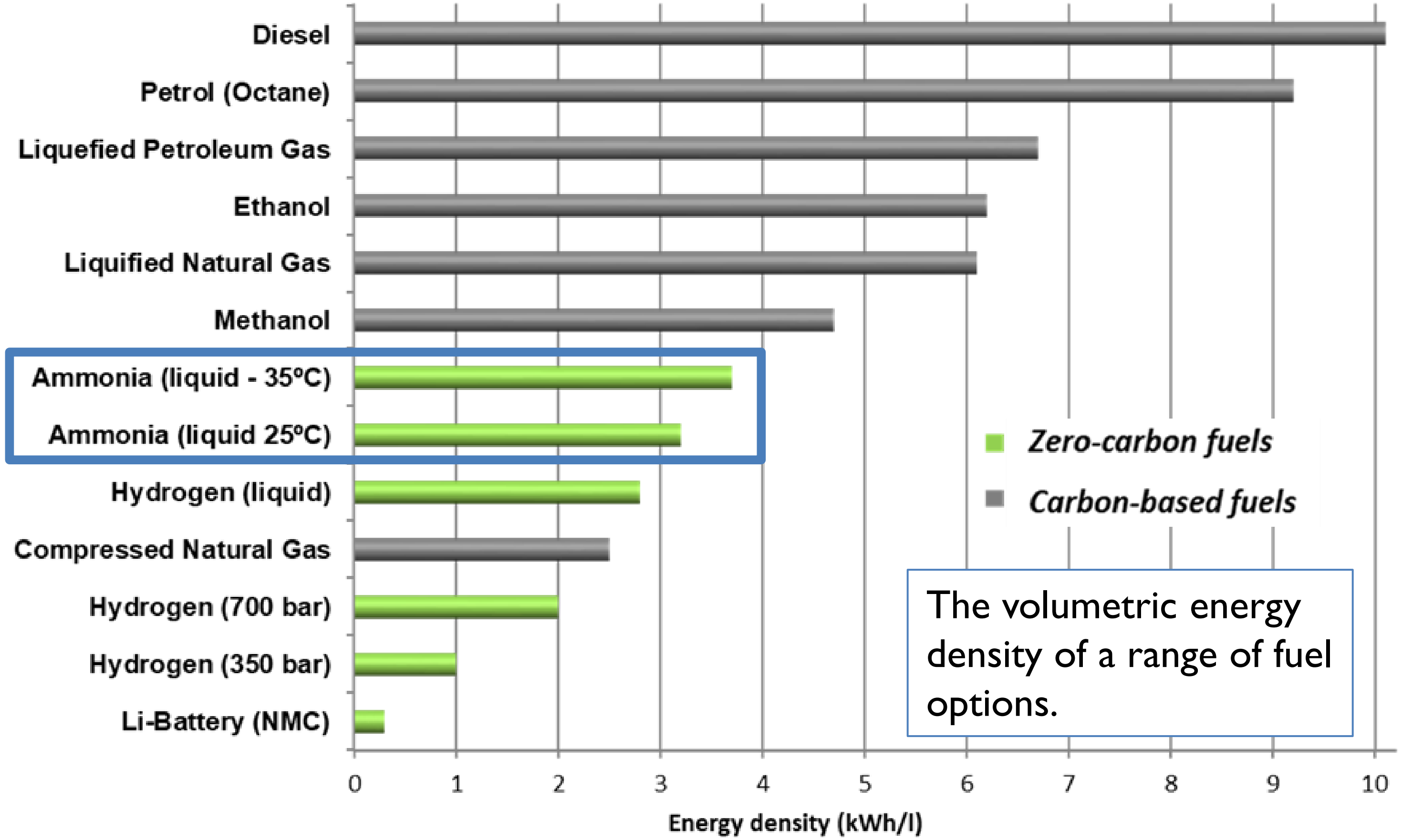
Relatively low cost

Easy to liquefy



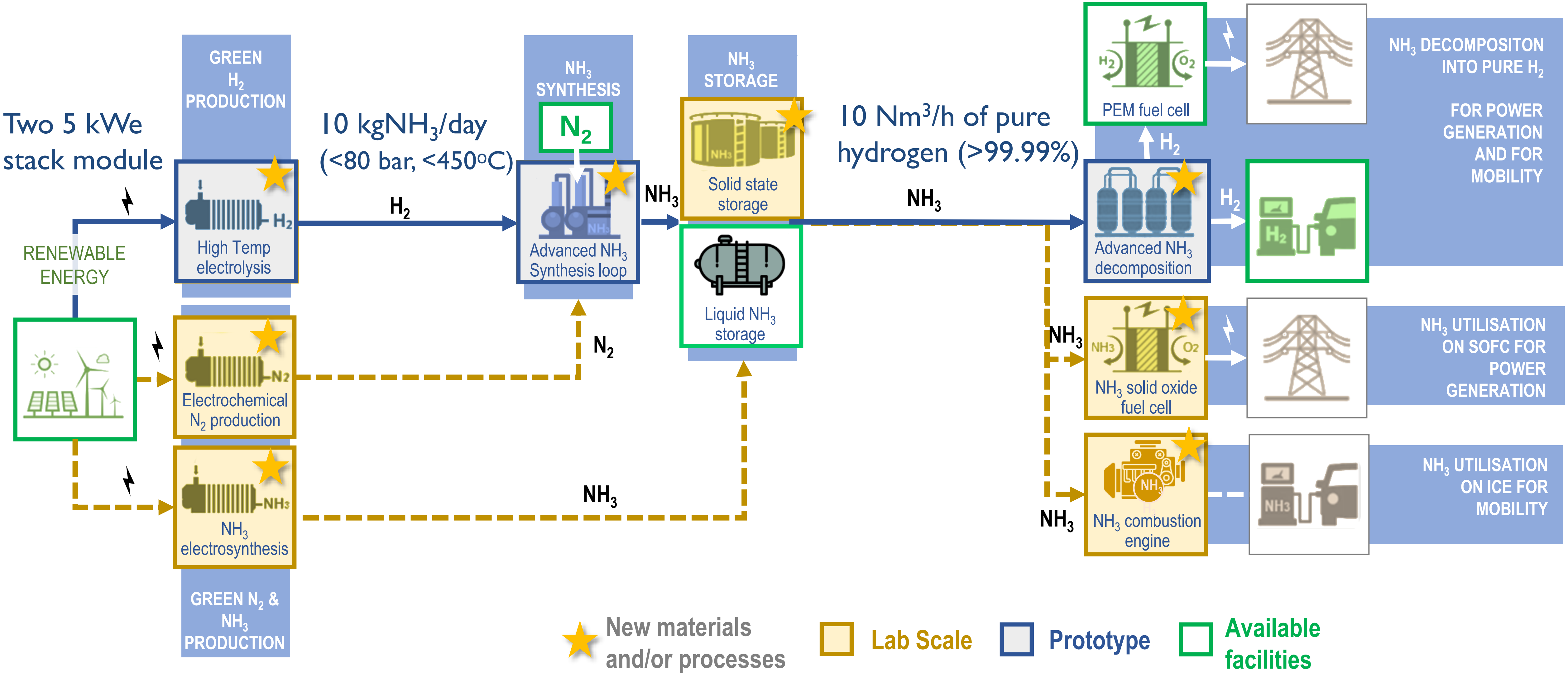
Easy to store and transport

Carbon free



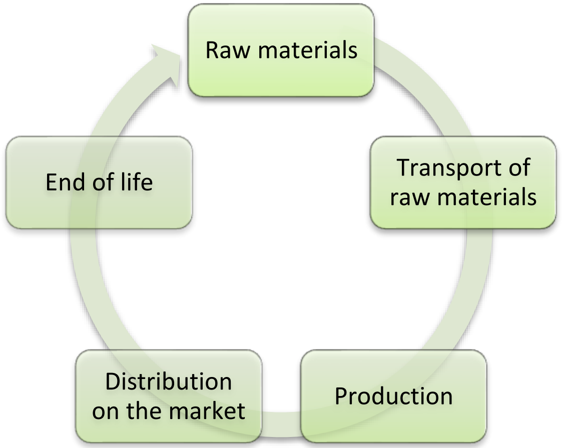
1. Project overview: Main goal and S&T targets (I)

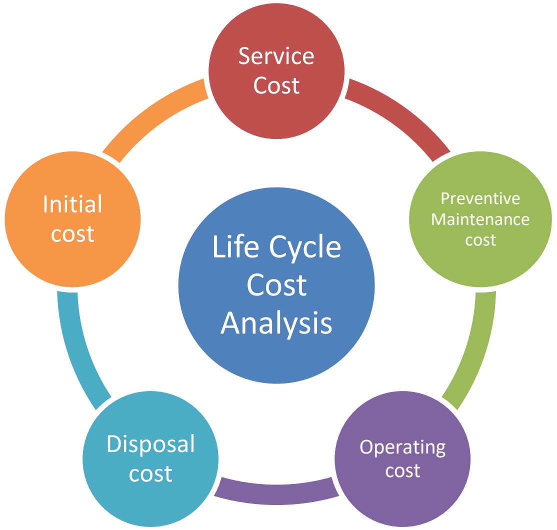
Power-to-ammonia-to-usage value chain in ARENHA



1. Project overview: Main goal and S&T targets (II)

➢ To assess the social acceptance, techno-economic-environmental feasibility, and replication potential of the developed value chains (LCA, LCC, LCS).





1. Project overview: Partnership

- Multidisciplinary and complementary team.
- 11 partners in 7 countries.
- Industrial oriented (45%): 5 SME/IND + 6 RTO/HES
- 3 SMEs & 2 IND

Universities

TU/e

DTU

Research institutions

tecnalia

MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

Centro Nacional del Hidrógeno

Fraunhofer IKTS

Science & Technology Facilities Council

Industries

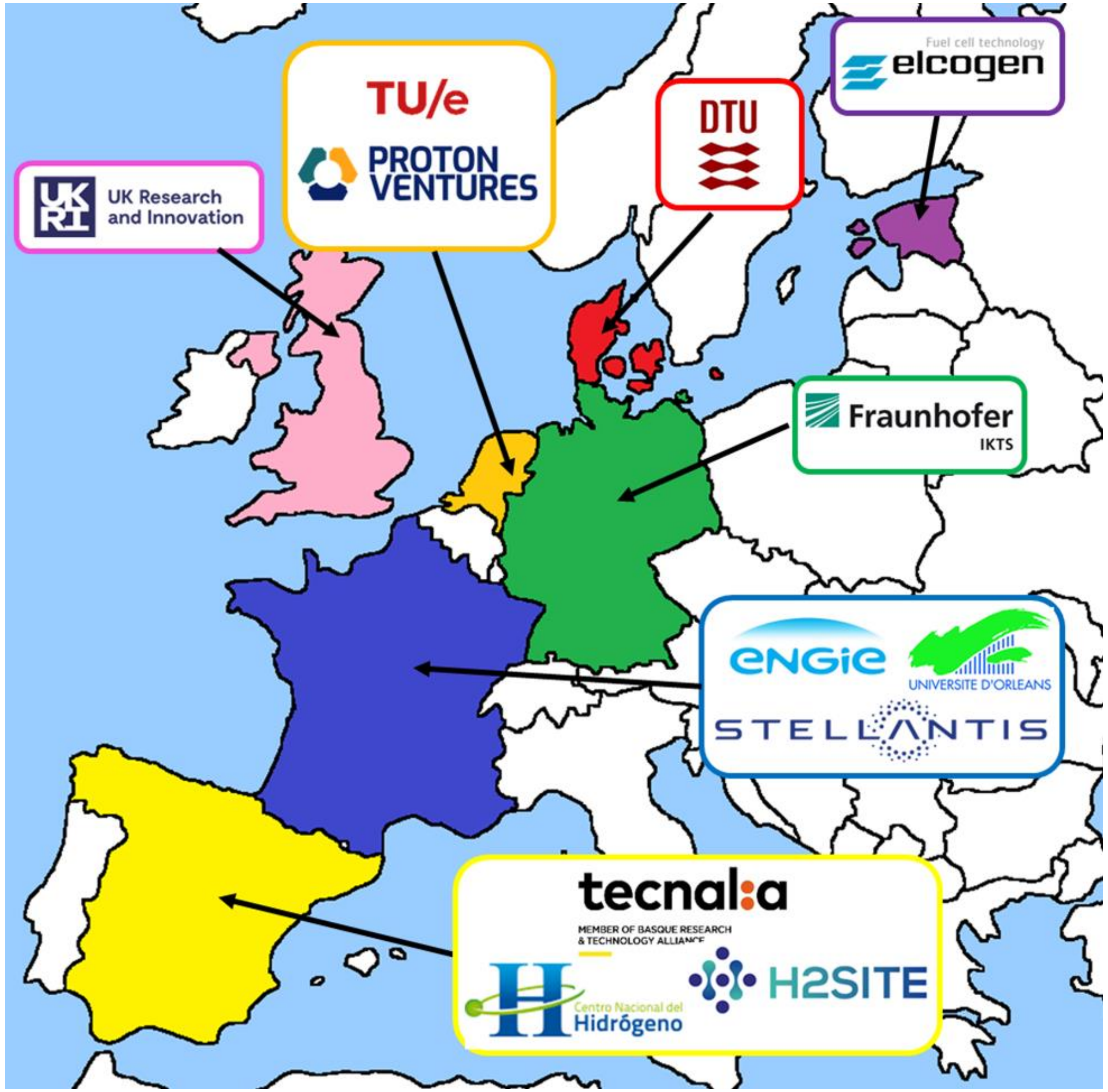
PROTON VENTURES

Fuel cell technology elcogen

H2SITE

ENGIE

STELLANTIS



1. Project overview: Approach

Green hydrogen production

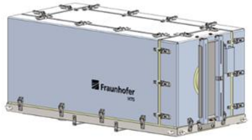
Material development and scale up

SOEC cells and stacks

Fraunhofer IKTS

Fuel cell technology elcogen

Prototype manufacturing



SOEC stack modules and BoP

Fraunhofer IKTS

Fuel cell technology elcogen

Centro Nacional del Hidrógeno

Process, Quality Control & Recyclability

Process Control:
- Flexibility
- H2 productivity and purity
- Efficiency
- Safety

Product Control & Reciclability:
- Cell materials
- Stacks & stack modules

Fraunhofer IKTS

Fuel cell technology elcogen

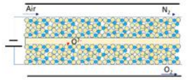
Centro Nacional del Hidrógeno

Ammonia synthesis

Material development and scale up

Catalysts

Absorbents

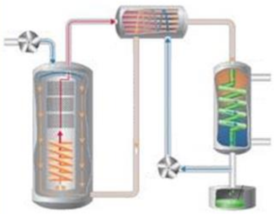


Electrochemical cells

UKRI UK Research and Innovation

DTU

Prototype manufacturing



Advanced Haber Bosch

PROTON VENTURES

DTU

Process, Quality Control & Recyclability

Process Control:
- Flexibility
- NH_3 productivity and purity
- Efficiency
- Safety

Product Control & Reciclability:
- Catalysts
- Absorbents

PROTON VENTURES

DTU

UKRI UK Research and Innovation

Ammonia storage

Material development

Absorbents

DTU

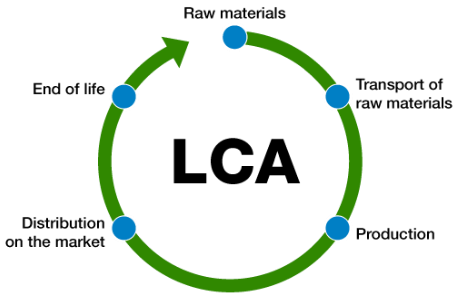
Process, Quality Control & Recyclability

Process Control:
- Flexibility
- NH_3 productivity and purity
- Efficiency
- Safety

Product Control & Reciclability:
- Absorbents

DTU

1. Project overview: Approach



Ammonia Decomposition

Material development and scale up

Catalysts

Advanced Membranes

UK Research and Innovation · TU/e · tecnalia

Prototype manufacturing

Membrane reactor

H2SITE · TU/e · tecnalia

Process, Quality Control & Recyclability

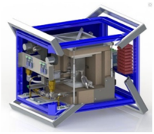
Process Control:
- H_2 productivity and purity
- Efficiency
- Safety

Product Control & Reciclability:
- Catalysts
- Membranes

H2SITE · TU/e · UK Research and Innovation · tecnalia

Ammonia usage

Benchmarking of novel technologies



SOFC NH_3

NH_3 combustion

Fraunhofer IKTS · STELLANTIS · Université d'Orléans

System integration and Demonstration

Overall System

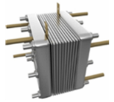
- H_2 production
- NH_3 Synthesis
- NH_3 Storage
- NH_3 Decomposition

Fraunhofer IKTS · ENGIE · H2SITE · PROTON VENTURES

System Demonstration

PV → H_2 production → (H_2) → NH_3 synthesis (← N_2 ← N_2 generation) → NH_3 storage → NH_3 decomposition → H_2 → H_2 refueling station / Fuel cell

H_2 refueling station



Fuel cell

Centro Nacional del Hidrógeno · ENGIE

1. Project overview: Impact

More efficiently and cheaper long-term energy storage in form of green ammonia

Hydrogen carrier:
Mobility, transport and industry decarbonisation

Increasing renewable shares in the grid with large scale energy storage.

Strategic European leadership in energy storage.

Decrease energy import dependency by using ammonia to diversify energy supply (i.e. H_2) from third countries

- Alternative energy import through renewable electricity storage and long-distance transportation.
- Secure and clean supply of renewable energy

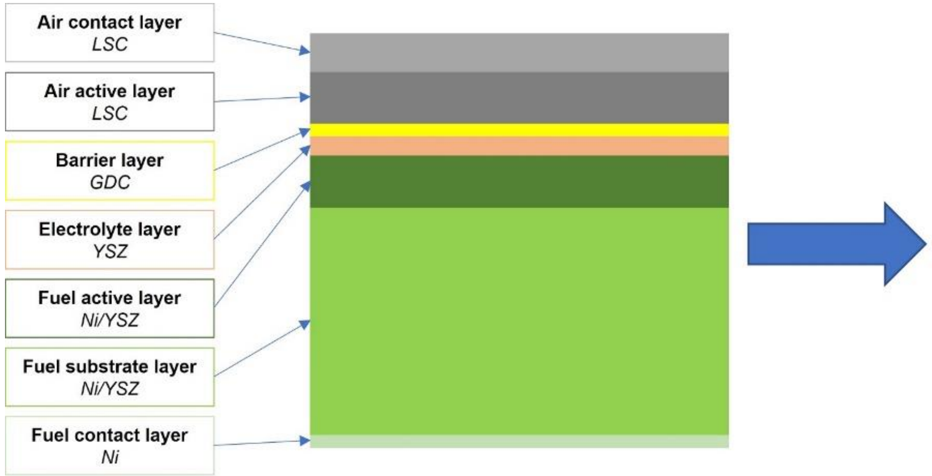
Support to the clean energy transition / European Green Deal.

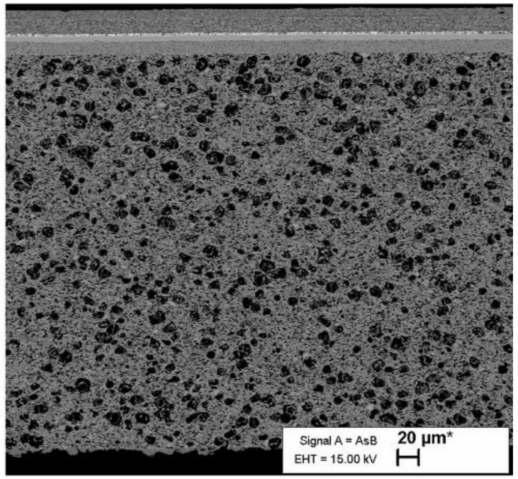
- Low carbon society using hydrogen.
- Replace natural gas, coal and oil in hard-to-decarbonise industries and transport sectors (i.e.; maritime).
- Reducing the amount of CO_2 emissions.

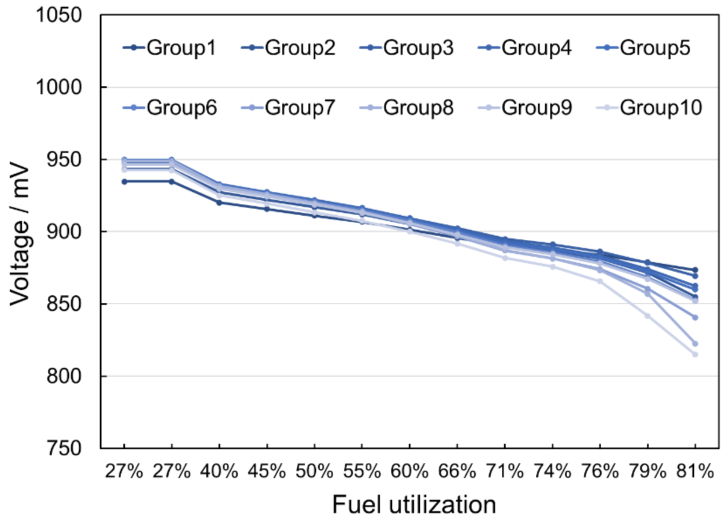
2. Main results: Green hydrogen production

Elcogen: Development of modified anode supported cells for SOEC

- The state-of-the-art SOFC is not optimized for electrolysis operation at high current density.
- Development of new Elcogen SOEC cell designs:
  - New materials in the hydrogen electrode active layer.
  - Changes to hydrogen electrode active layer microstructure.
  - New materials in the air electrode layer.
- Assembly of the 5-kW stack:
  - Manufacturing of SOEC with the chosen design was undertaken and finished.
  - The SOEC were successfully assembled into the 5-kW stack and conditioned.
  - The 5-kW SOEC stack was shipped to FhG-IKTS for validation.







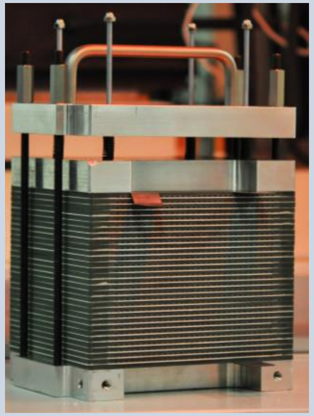
Preliminary demo stack performance test in fuel cell mode after conditioning

2. Main results: Green hydrogen production

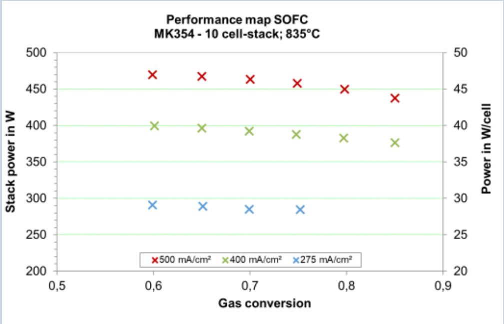
FhG-IKTS: Development of modified electrolyte supported cells for SOEC

SOEC stack tests

Cell and stack development ✓



SOEC stack tests with SoA & new cells & comp. ✓



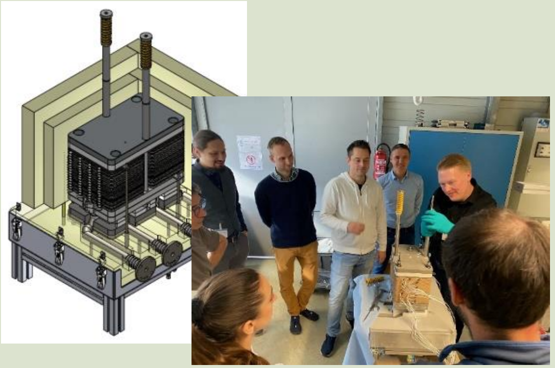
Performance map and 1000 h test

Selection of cells for stack module MS4 ✓

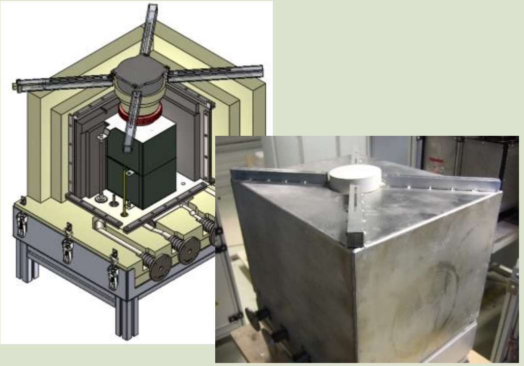
Stack manufacturing for stack modules ✓

SOEC stack modules

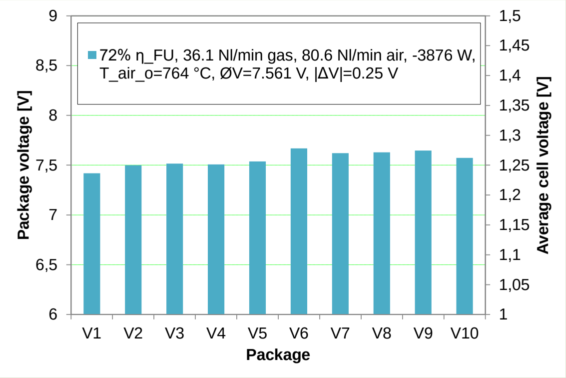
CAD and assembly of Elcogen stack module ✓



CAD and assembly of IKTS stack module ✓



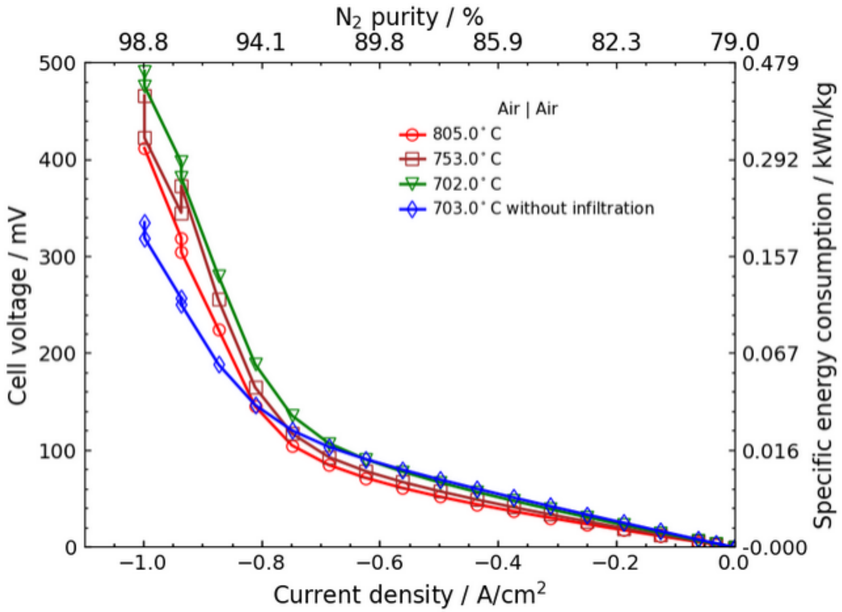
Commissioning at IKTS and operation at CNH2 ✓



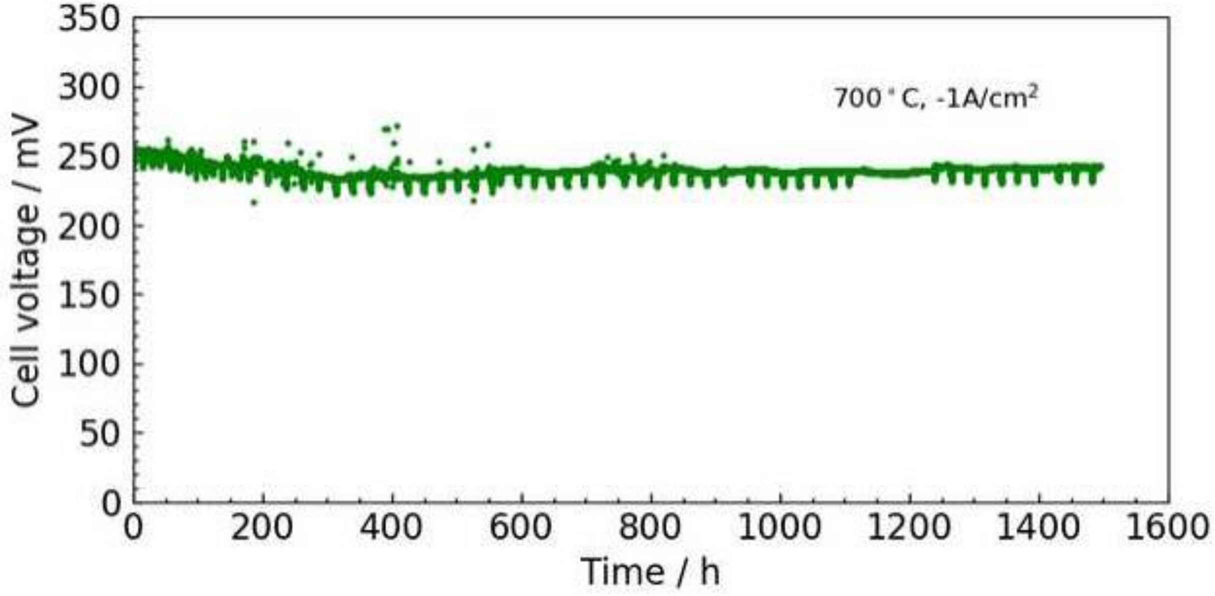
2. Main results: Green N_2 production

Electrochemical cell for N_2 production

DTU Technical University of Denmark



Pr infiltrated LSCF-CGO cell



Pr infiltrated LSF-CGO cell

- High purity of N_2 can be produced at a voltage below 500mV with Pr infiltrated LSCF-CGO cell.
- Demonstrated 1500 hours operation at -1A/cm^2 with N_2 purity >98.3% without degradation.

Advanced Ammonia Synthesis Integrated with Chemical Sorption for Ammonia Separation

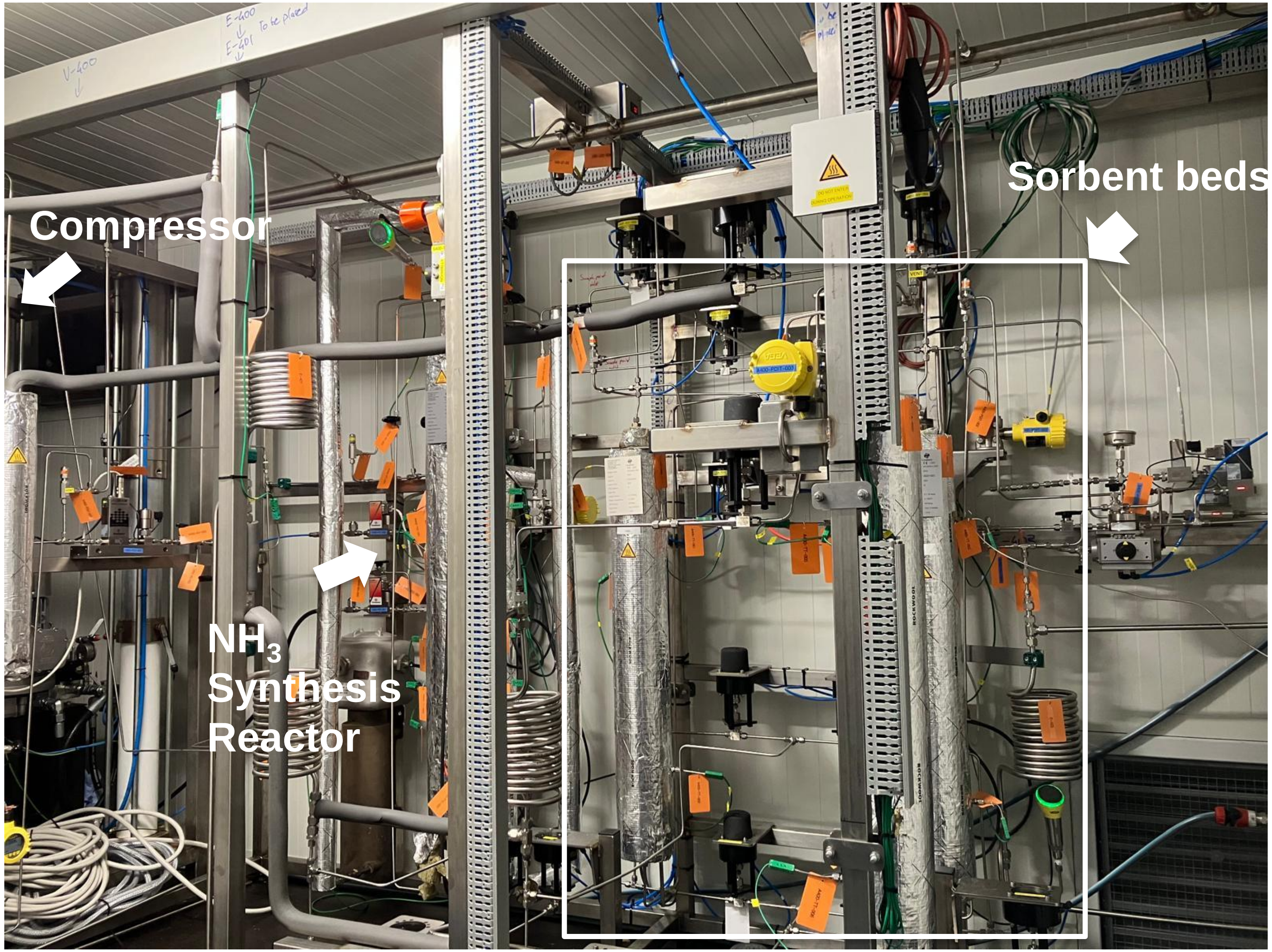
Design and Construction of the advanced NH_3 Synthesis System

- Operating pressure: 80 barg
- Iron-based catalyst from Clariant for ammonia synthesis
- Sorbent developed and manufactured by DTU
- The design has been developed from scratch to a demonstration unit. We have successfully completed the Factory Acceptance Test (FAT), confirming the system's operational feasibility.

2. Main results: Ammonia synthesis

Advanced Ammonia Synthesis Integrated with Chemical Sorption for Ammonia Separation

Design and Construction of the advanced NH_3 Synthesis System



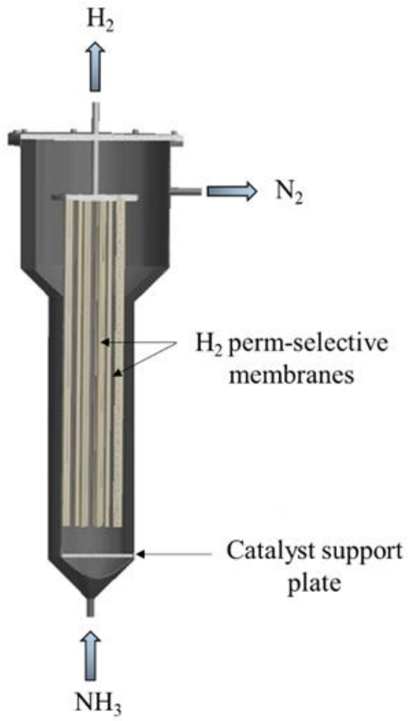
2. Main results: Ammonia cracker

H_2 production via ammonia decomposition

The Pd-based **membrane reactor** is a technology with high potential to efficiently recover H_2 from NH_3

Ammonia decomposition

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

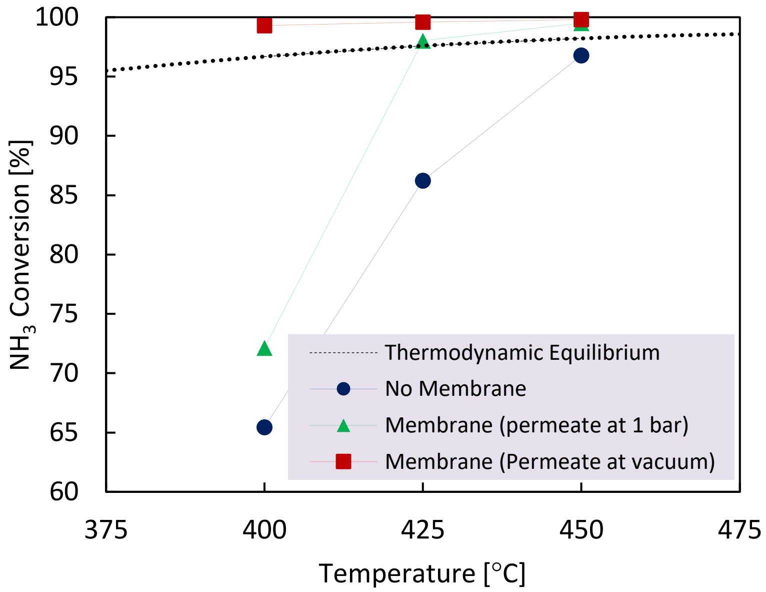


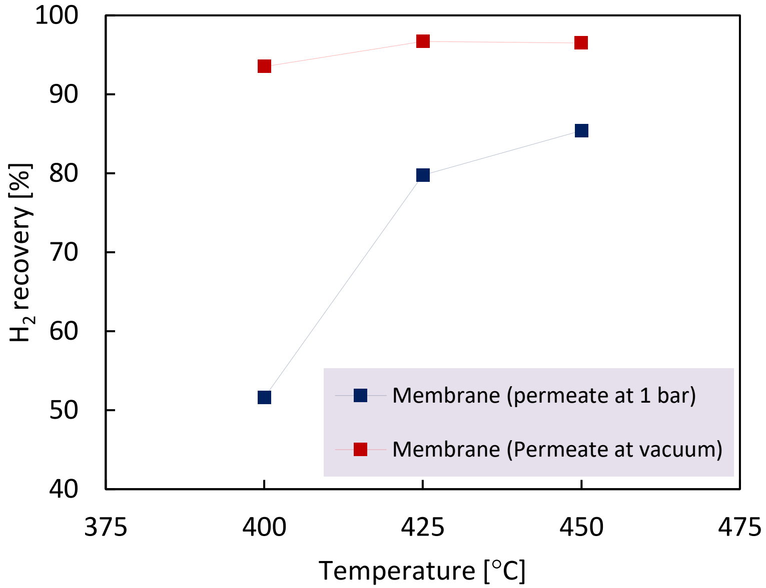
NH_3 decomposition reaction into H_2 and N_2 and high-purity H_2 separation are simultaneously performed

- the high-purity H_2 recovered through the membranes can be fed directly to FCs avoiding the need to introduce any costly separation/purification unit
- full NH_3 conversion can be achieved reducing the downstream cleaning of unconverted species
- high H_2 separation efficiencies of H_2 can be achieved at lower operating temperatures compared to conventional systems, with benefits from an energetic point of view
- since the whole process occurs in a single unit, the footprint of this technology is reduced

2. Main results: Ammonia cracker

The catalytic membrane reactor for NH_3 decomposition (*)





Experimental conditions	
ΔP	3 bar
Permeate pressure	0.01-1 bar
Feed flow rate	0.5 LN/min
Temp.	400, 425, 450 °C

- In a **conventional packed bed reactor**, the conversion achieved is limited and cannot reach the thermodynamic equilibrium conversion.
- When the **membrane reactor** is adopted, the conversion is increased and for temperatures from and above 425 ◦C NH_3 conversions higher than the equilibrium without the membrane are achieved.
- The use of vacuum at the permeate side of the membrane enhances the performance of the membrane reactor technology.

(*) Valentina Cechetto et al. Fuel Processing Technology 216 (2021) 106772. https://doi.org/10.1016/j.fuproc.2021.106772

2. Main results: Ammonia cracker

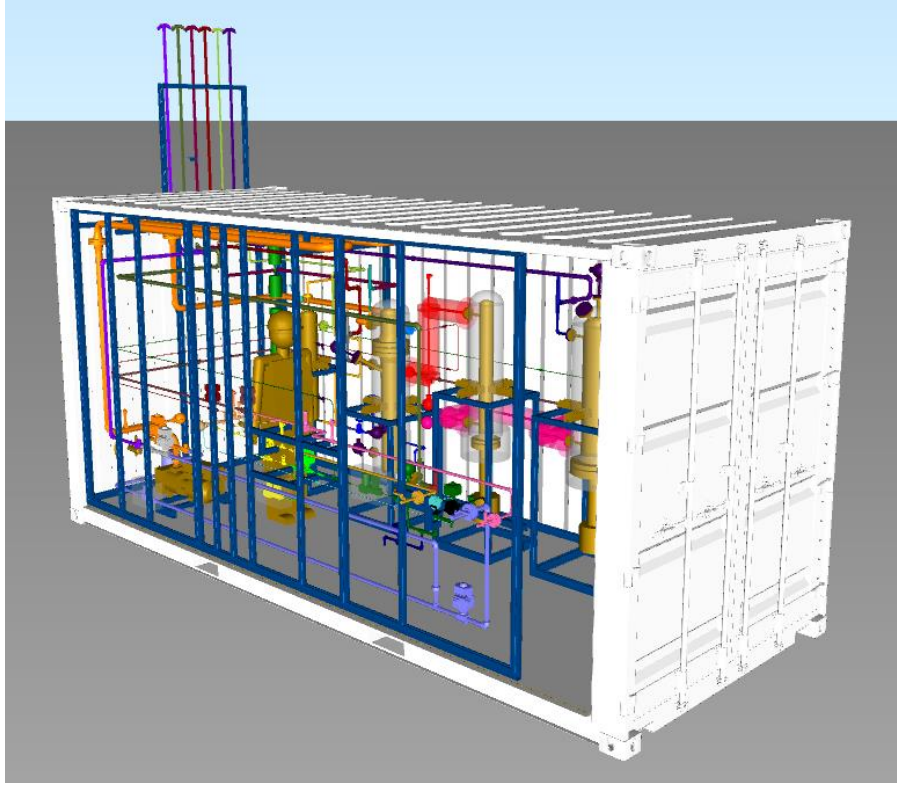
Membranes and catalyst for the ammonia cracker prototype

- Pd-based membranes
  - 50 ds- Pd-based supported membranes
  - Electroless plating
  - Finger-like or open-end alumina supports
  - Average length: ~ 45 cm long
  - Membrane area: ~1 m^2
- Catalyst: Commercial Ru based catalyst

2. Main results: Ammonia cracker

Design and construction of the ammonia cracker

- Designed in a 20' HC container:
  - Plug & Play
  - Helps contain ATEX zones.



2. Main results: Ammonia cracker

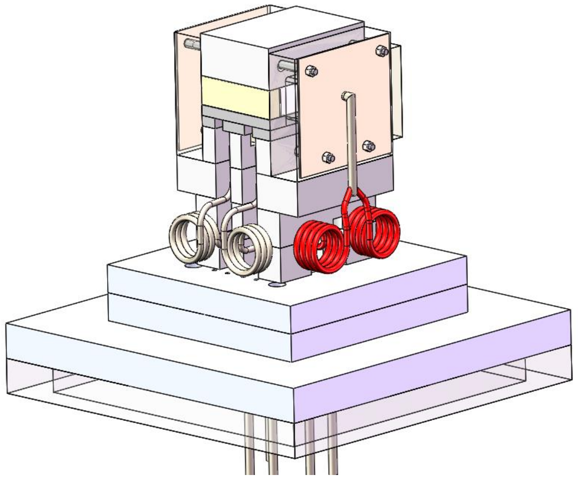
Operation of the ammonia cracker

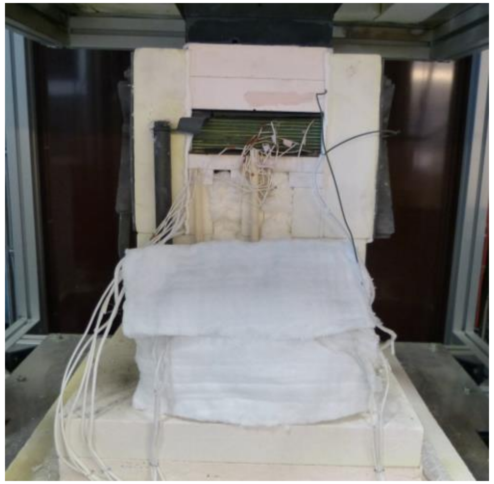
- CNH2 operated the cracker
- H2Site provided onsite training and remote monitorization via H2Site's remote Control Room.
- Great communication between both teams.
  - Thanks to the CNH2 team!

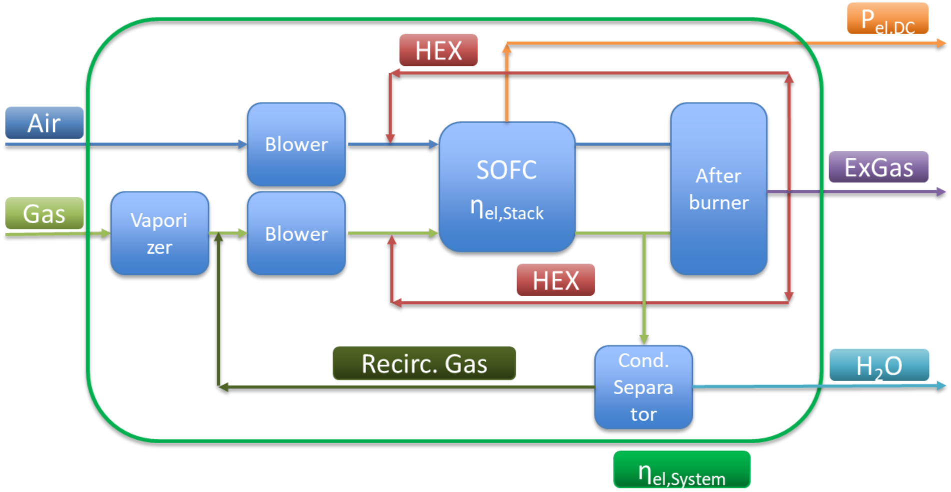
2. Main results: Power generation from ammonia

SOFC system for power generation from ammonia

- MK35x stack for SOFC and SOEC operation with wide temperature window 750-860°C
  - SOFC: up to 40 W/cell, ammonia operation comparable to H2/N2 mixtures
- Ammonia cracks at stainless steel surfaces >600°C
- High-efficient ammonia fueled SOFC systems possible with MK35x stacks
  - Less BoP: HEX at afterburner and no separate cracker, low blower power
- High temperature is a favor for NH3 operation (low nitridification)



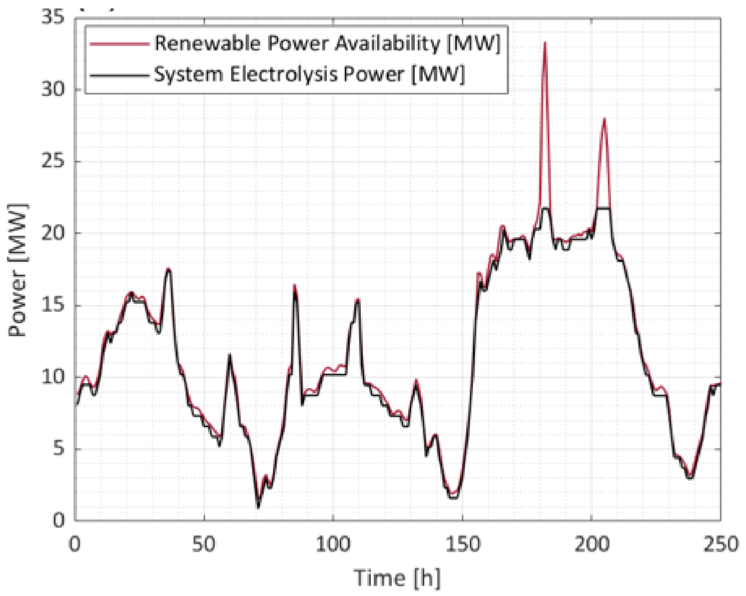


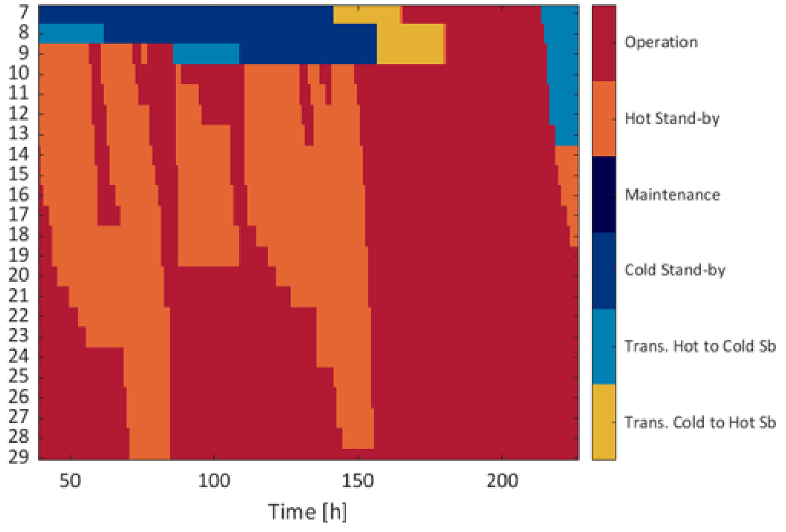


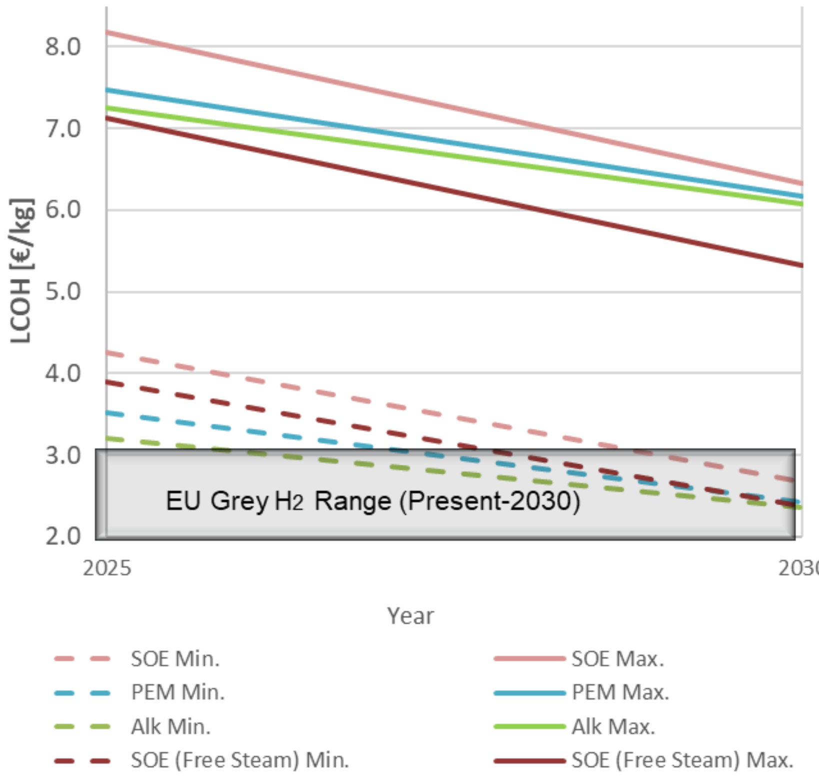
2. Main results: Techno-economic assessment

Modelling of Power-to-Ammonia and Ammonia-to-Power solutions

- Development of model utilities validated with experimental data for the estimation of performances and economics of ARENHA processes:
  - Power-to-Ammonia (Solid Oxide Electrolysis + Ammonia Synthesis)
  - Ammonia-to-Hydrogen (Ammonia Cracking)







- Technology benchmarking and economic comparison of different production and decomposition processes

2. Main results: Dissemination and communication

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Advanced materials and Reactors for Energy storage tHrough Ammonia (ARENHA)

Thank you for your attention

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