

# Advanced materials and Reactors for Energy storage tHrough Ammonia

## ARENHA



areNH<sub>3</sub>a

<https://arenha.eu/>

*This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862482*

*Duration: 4 years. Starting date: 01 April 2020*

*Contact: [joseluis.viviente@tecnalia.com](mailto:joseluis.viviente@tecnalia.com)*

*The present publication reflects only the author's views. The Commission is not responsible for any use that may be made of the information contained therein.*

1. Introduction
2. Objective
3. Partnership
4. Overall approach
5. Project Structure and planning
6. Progress
7. Impact

# I. Introduction

Nowadays, mankind is facing two of the most difficult challenges in its life:

- global warming and associated climate changes



- local pollution of urban areas.

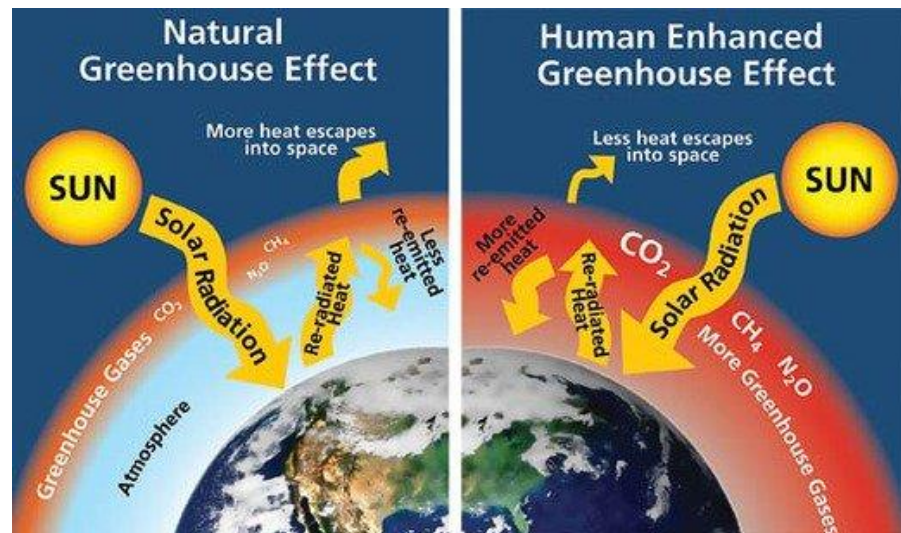


## Energy production 21st Century

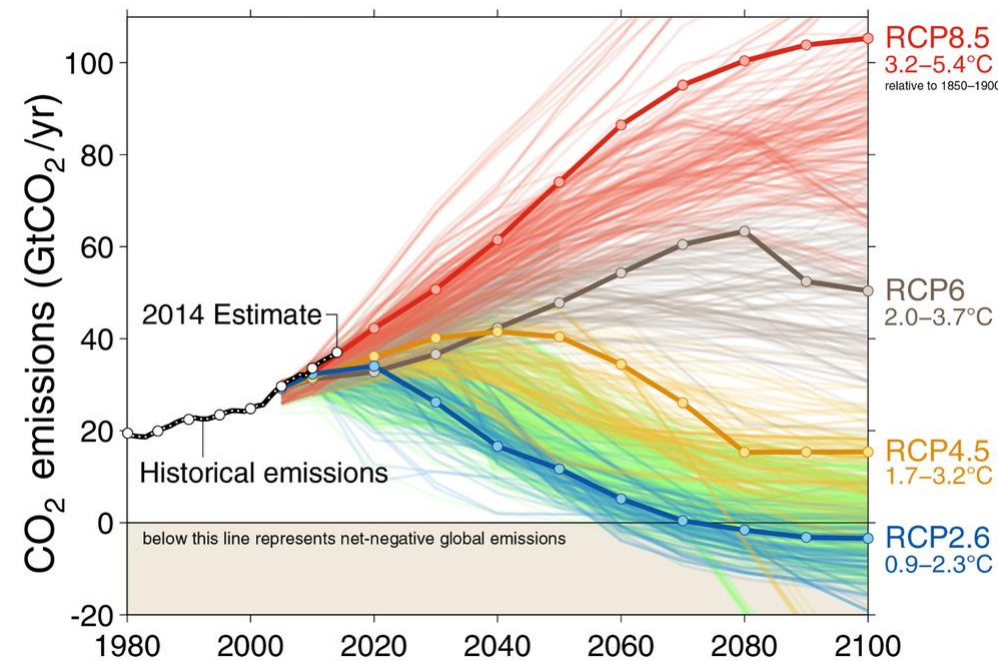
- Majority from fossil fuel derivatives (carbon based): Currently, more than 80% of global primary energy use is fossil based. Over the last decade, 85% of the increase in global use of energy was fossil based.
- CO<sub>2</sub> production

## Greenhouse gasses

- **Effect**  
Trap IR-radiation (heat)
- **Emission CO<sub>2</sub>**  
Natural & human activity



# I. Introduction



Global carbon dioxide emissions from human activity, compared to four different possible futures as depicted in IPCC scenarios. Fuss et al. 2014

The EU Commission's Low Carbon Roadmap (and the world climate contract) suggest a reduction of >80% of CO<sub>2</sub> emissions by 2050 compared to levels at the beginning of the 21<sup>st</sup> century.

**2018: 37,1 GtCO<sub>2</sub>**  
([www.globalcarbonproject.org](http://www.globalcarbonproject.org))

Transition process requires a new energy system without C at the end with radical technical solutions and infrastructure investments.



Climate Action in the UN's Sustainable Development Goals (SDGs):  
Limiting global warming to 1.5°C (<https://www.ipcc.ch/sr15/>)

## **Greenhouse gases. Reduce emissions to environment.**

- Increasing Energy efficiency;
- Carbon Capture, Utilizations and Storage
- Low carbon processes
- Net-negative global emission
- Search for renewable energy carrier: Hydrogen,.....
- .....

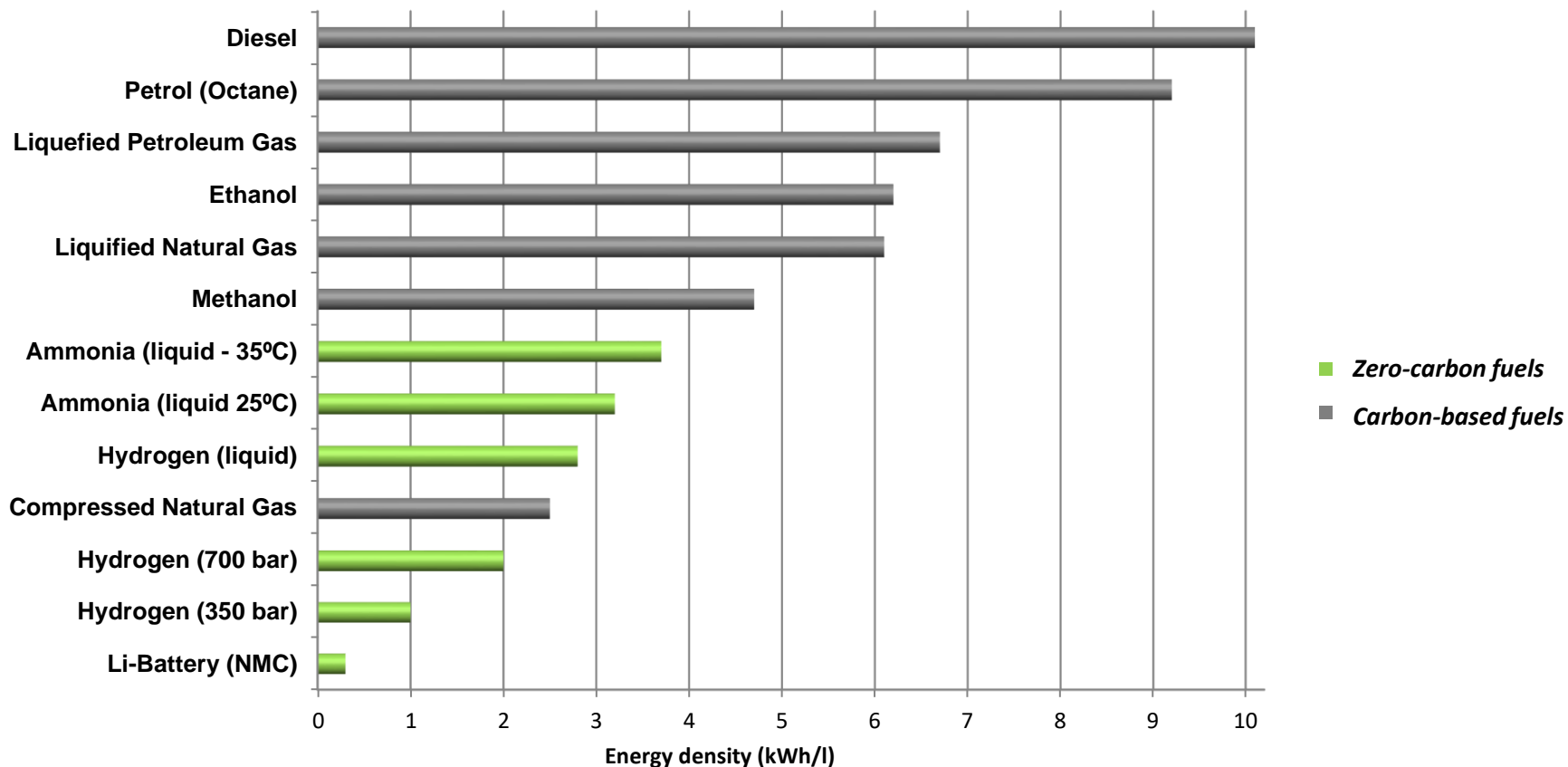
**European Green Deal:** Set of policy initiatives by the European Commission with the overarching aim of making Europe climate neutral in 2050.

- Maximise the deployment of renewables and the use of electricity to fully decarbonize Europe's energy supply.
- Increase renewable energy to at least 32% of the EU's final energy consumption by 2030
- By 2050, more than 80% of electricity will be coming from renewable energy sources.

- 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 is crucial for overcoming the inherent intermittency of renewable resources and increasing their share of generation capacity.
- Sustainable energy production can only work well when the specific different energy storage challenges are solved: provide the required capacity for grid-scale energy storage.
- 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, Power-to-Chemicals, Power-to-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

The volumetric energy density of a range of fuel options.



## 2. Objective



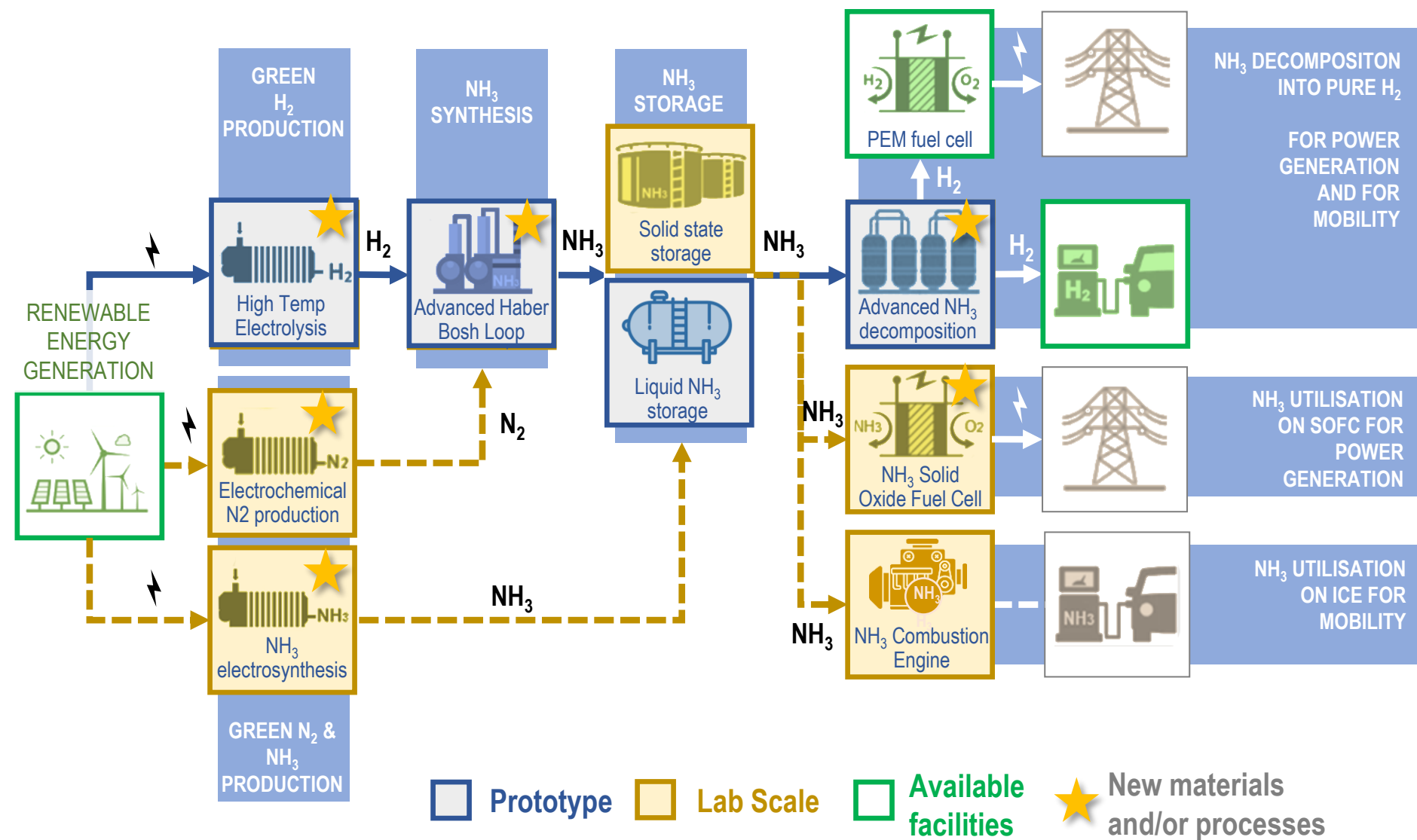
- The ARENHA project aims at using ammonia as a green hydrogen carrier and for that purpose it develops its main activities around the green hydrogen production, ammonia synthesis, ammonia storage and ammonia dehydrogenation.

Duration: 4 years  
H2020 funding 5,7 M€ approx.

- ARENHA main goal is to develop, integrate and demonstrate key material solutions enabling the flexible, secure and profitable storage and utilization of energy under form of green ammonia.
- ARENHA will demonstrate the full power-to-ammonia-to-usage value chain at TRL 5 and the outstanding potential of green ammonia to address the issue of large-scale energy storage.

## 2. Objective

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



# 3. Partnership



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

# 3. Partnership



*Coordination*

**tecnal:a**

MEMBER OF BASQUE RESEARCH  
& TECHNOLOGY ALLIANCE

*Universities*

**TU/e**

**DTU**



*Research institutions*

**tecnal:a**

MEMBER OF BASQUE RESEARCH  
& TECHNOLOGY ALLIANCE

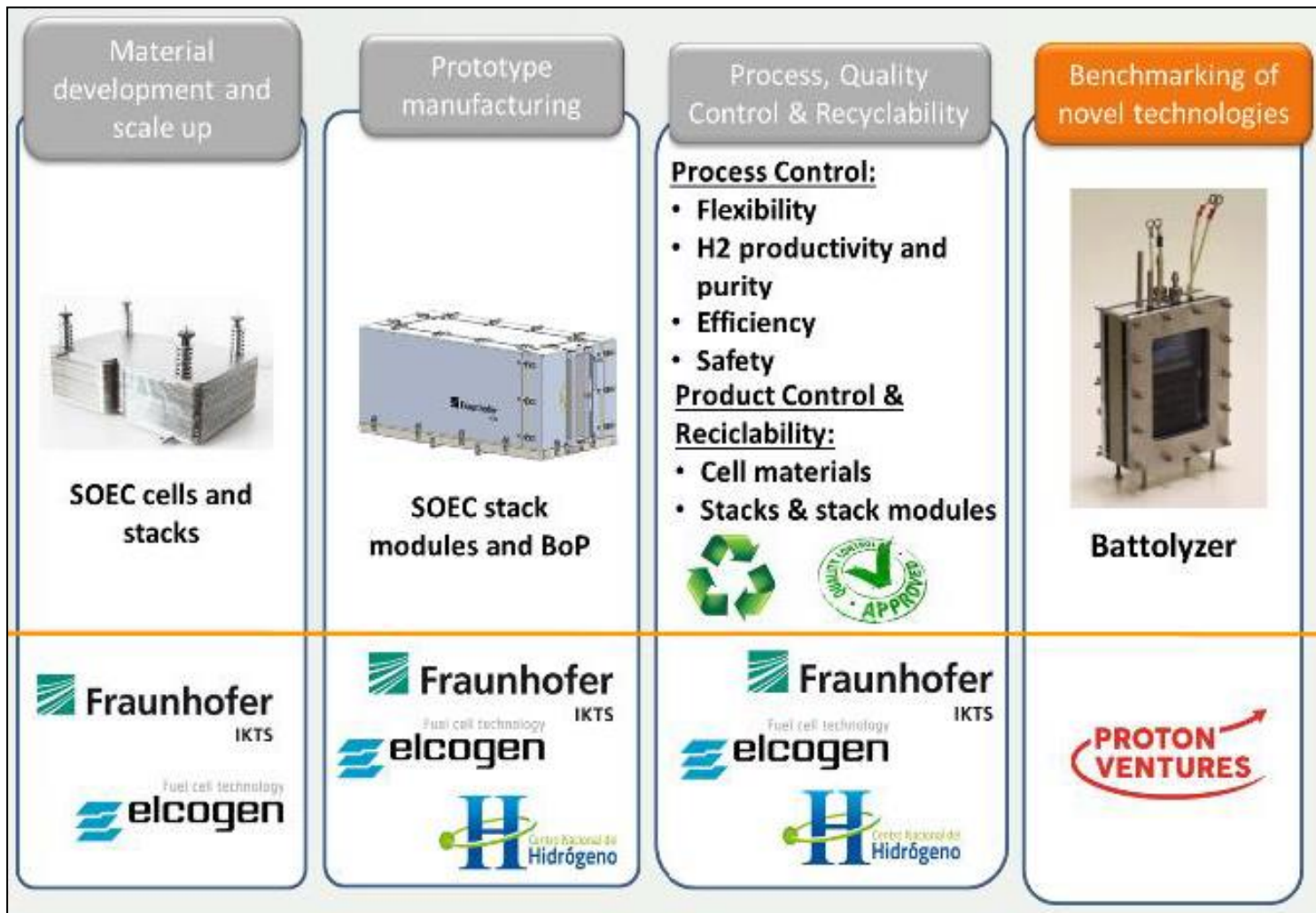


*Industries*



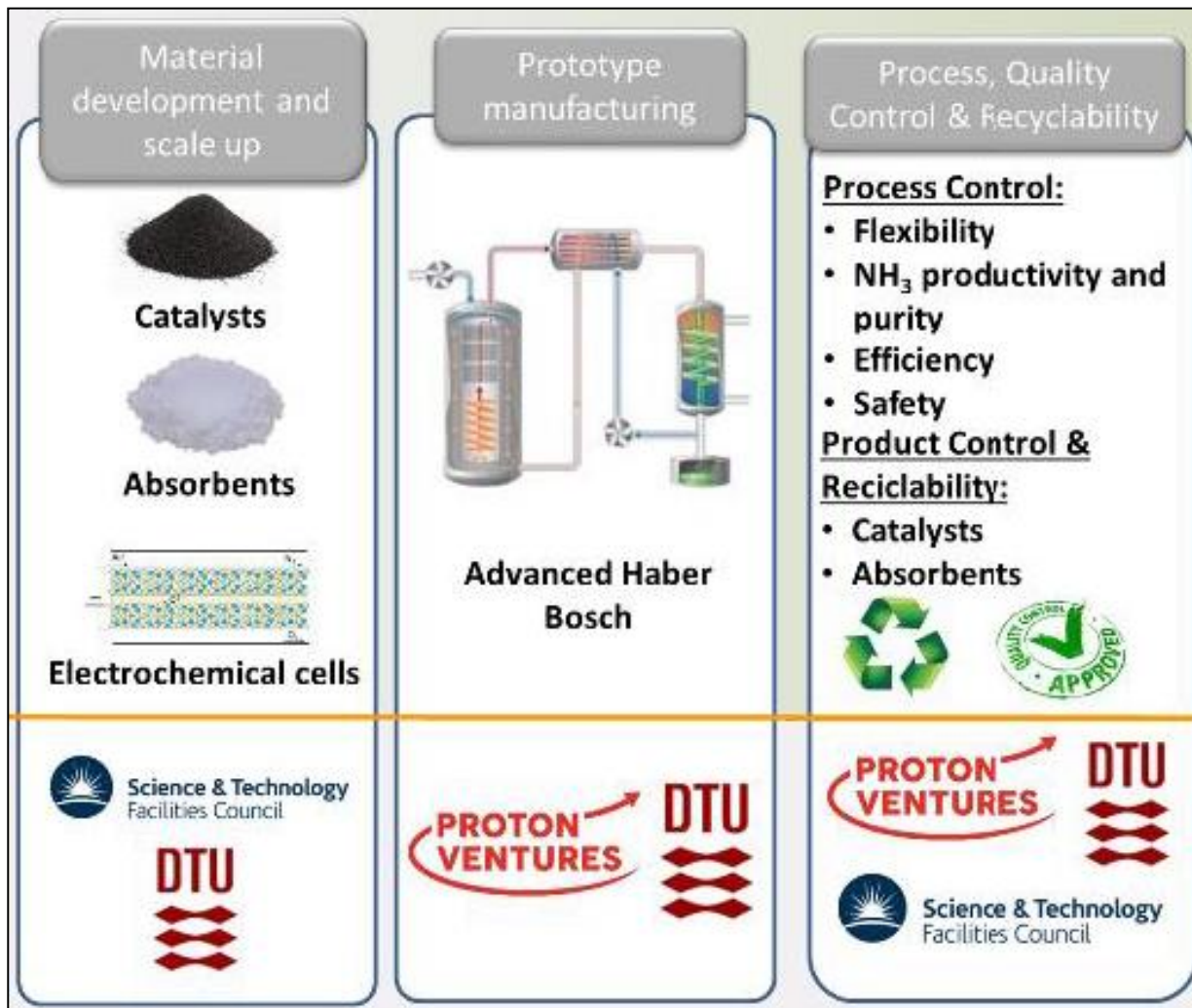
# 4. Overall approach

## GREEN HYDROGEN PRODUCTION



# 4. Overall approach

## AMMONIA SYNTHESIS



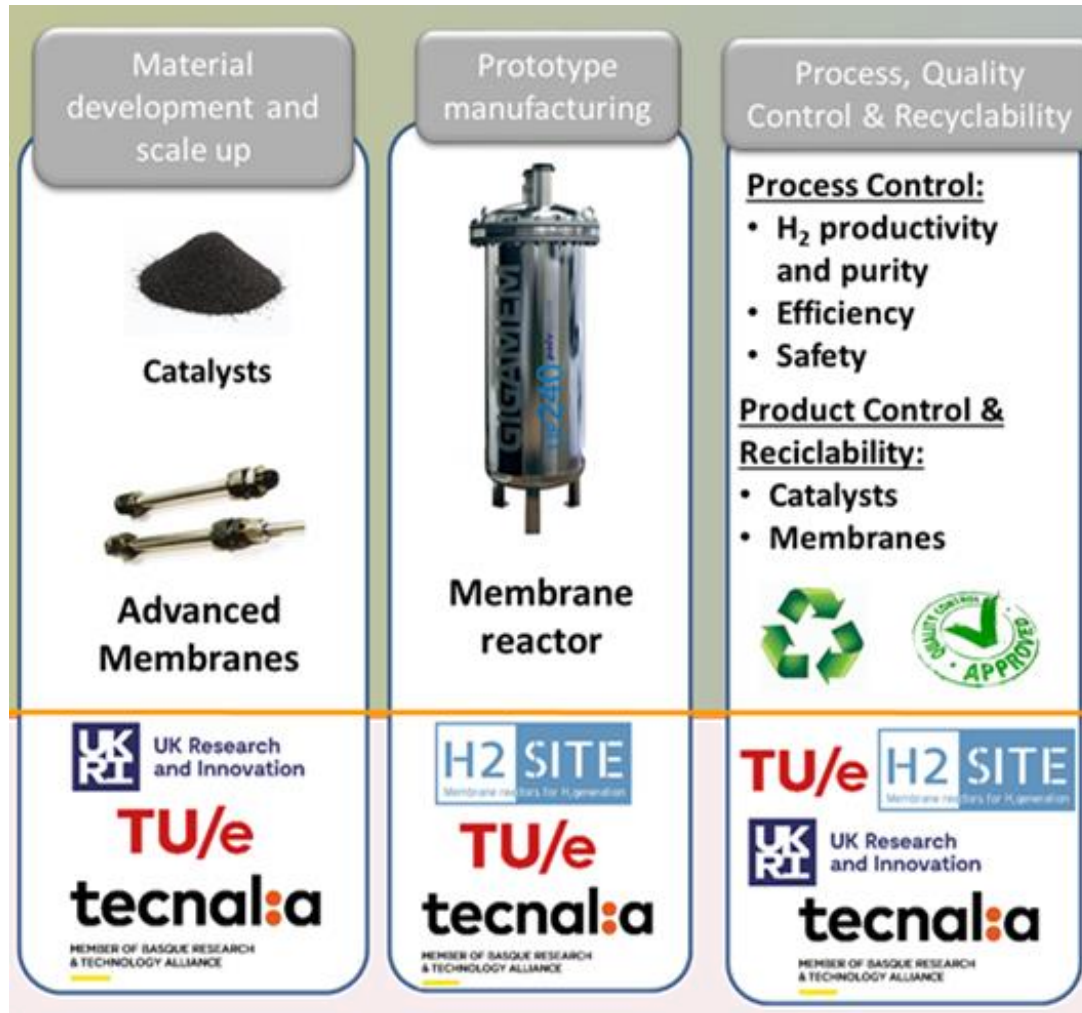
# 4. Overall approach

## AMMONIA STORAGE



# 4. Overall approach

## AMMONIA DECOMPOSITION



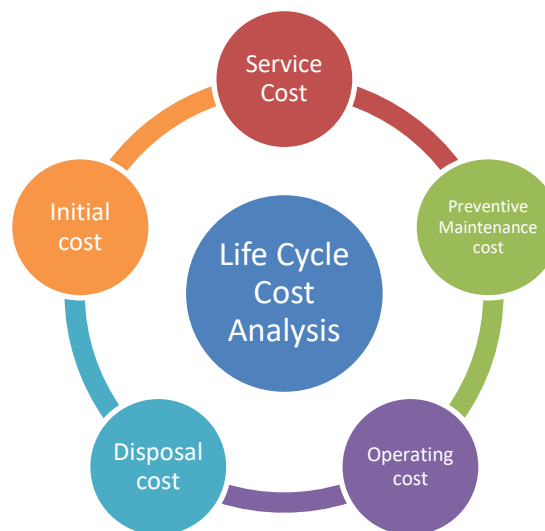
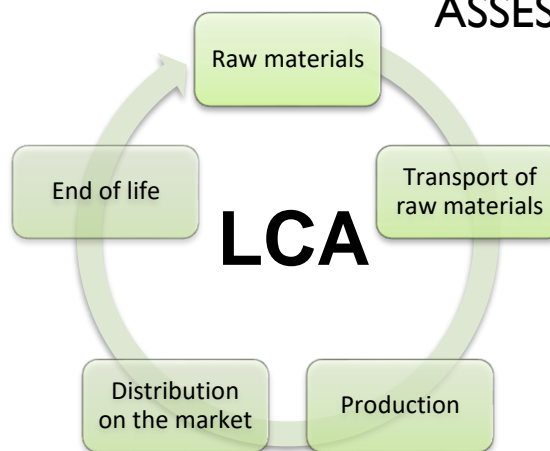
# 4. Overall approach



## AMMONIA USAGE

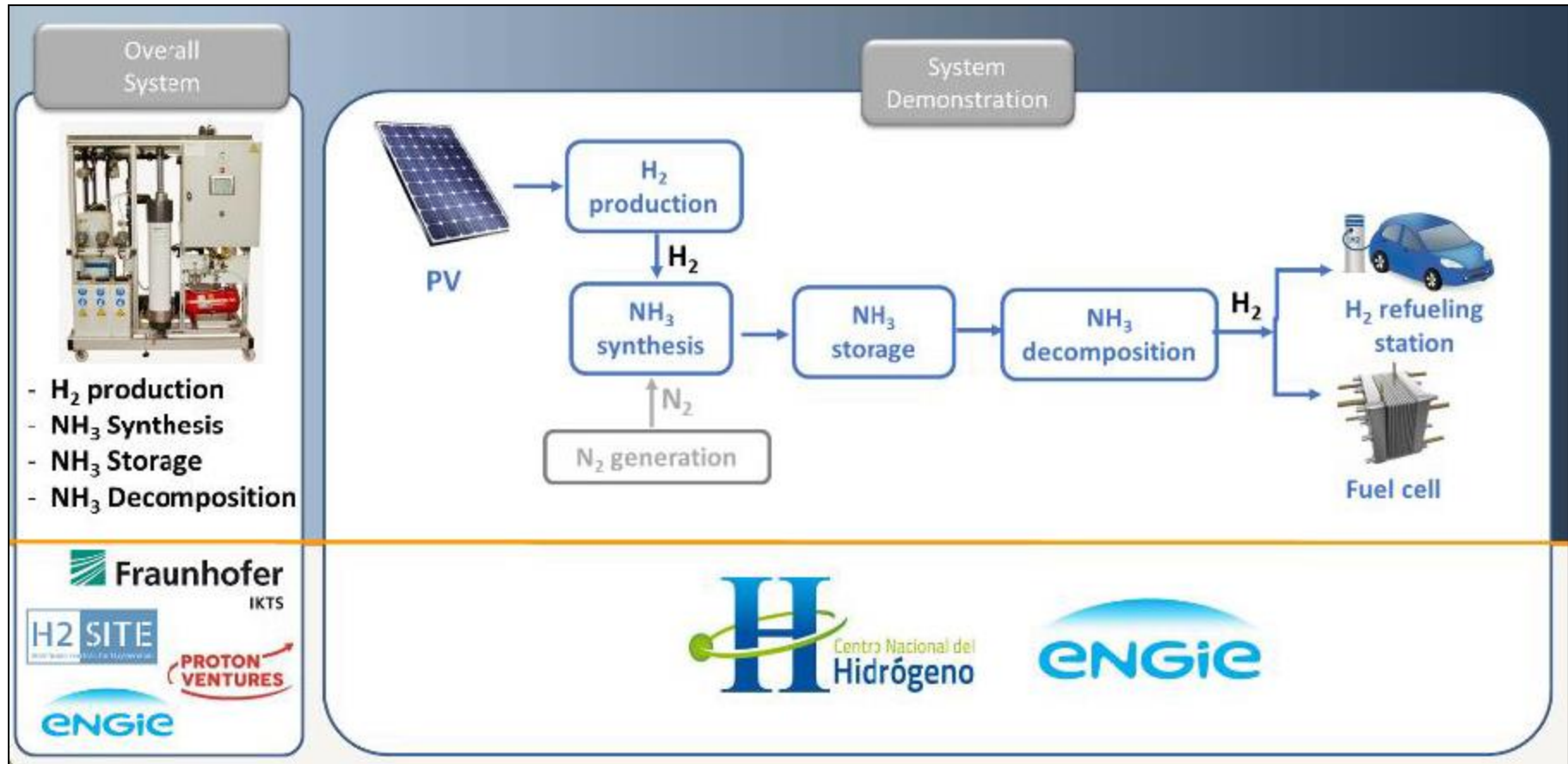


## ENVIRONMENTAL LCA, ECONOMY AND SAFETY ASSESSMENT



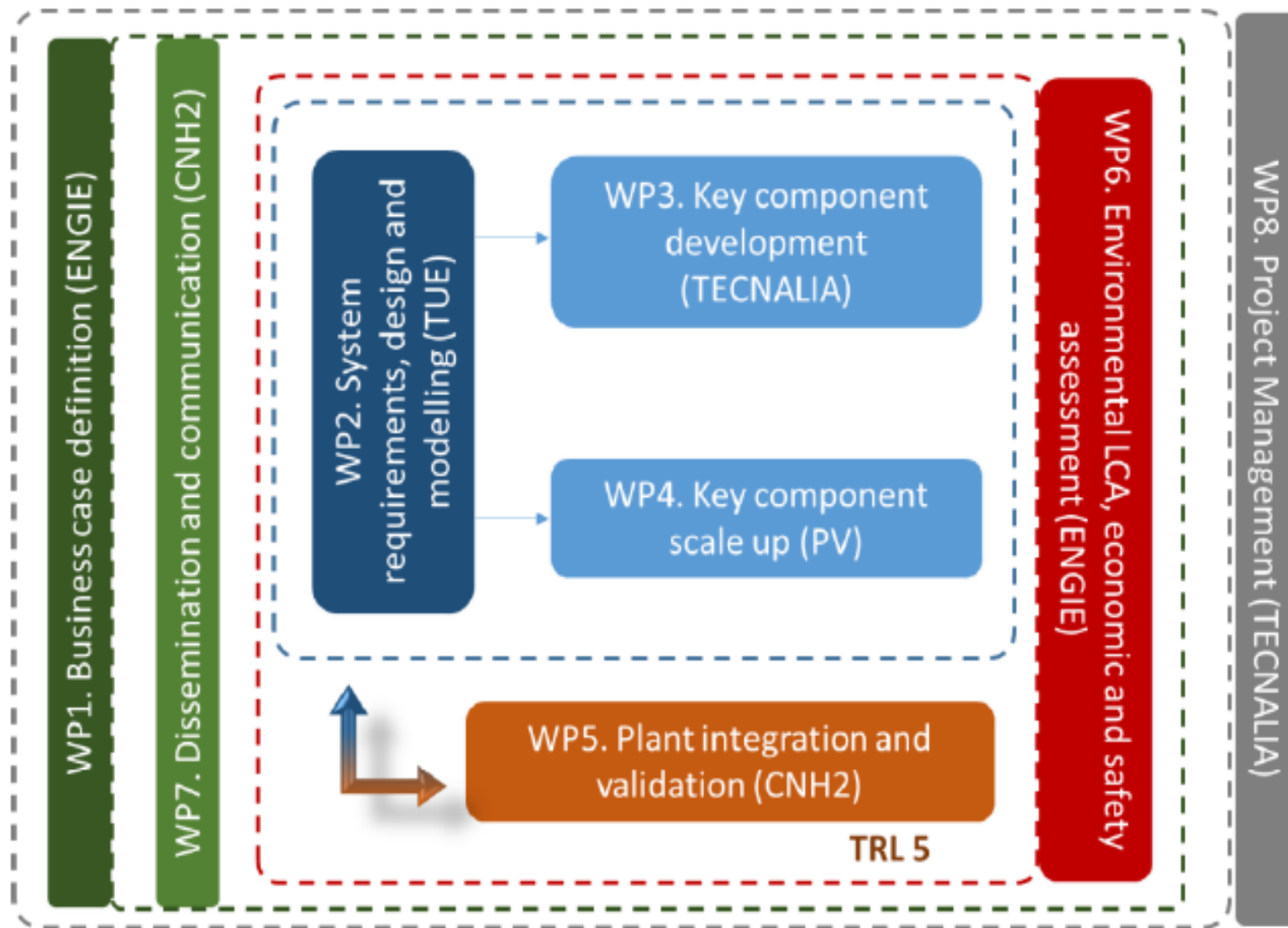
# 4. Overall approach

## SYSTEM INTEGRATION AND DEMONSTRATION



Demonstrate the full power-to-ammonia-to-usage value chain at TRL 5.

# 5. Project Structure and planning



## 6. Progress: WPI



- Market and stakeholder analysis focused on the present and expected markets considering ammonia production, transport and storage.

### 1- NH<sub>3</sub> market spotlight

#### Grey Ammonia market overview

- H<sub>2</sub> global market
- NH<sub>3</sub> global market
- Remaining capacity
- Importers vs exporters
- Ammonia infrastructure

#### Grey ammonia consumers

- Ammonia end-users
- Expected growth

### 2- RE market insights

#### Renewable Energy market overview

- Global renewable production
- Europe renewable production

#### Renewable energy market forecast

- Expected green electricity growth
- Expected technical offshore wind potential in Europe
- Curtailment issues

### 3- Business cases

#### Potential off-takers of green ammonia

- Possible end-uses of green ammonia
- Competition per end-use

#### Selected business cases

- Off-shore wind energy storage
- Large-scale energy import

### 4- Market drivers & stakeholders

#### Demand scenarios estimation

- Motivated sectors to pay for this premium product
- Forecasted size of the green ammonia market

#### Stakeholders

- Identification and categories
- Mapping

- Potential offtakes of green ammonia included the fertilizer industry, power generation, land transport sector, and maritime sector.

are  $\text{NH}_3$  a

- 
- | Renewable energy   | Electricity providers   | Feed gas producers  | Ammonia producers   | Distribution and storage  | Ammonia cracking  | Fuel cell technology | End user |
|--|---|---|---|---|---|----------------------|----------|
| <b>Renewable energy</b><br>ENGIE, Oge Energy, Tri-State Generation and Transmission, Arizona Public Service, AusNetEnergy, Netelectrica, Public Power District, AES Greiner, Asian Renewable Energy Hub, Enterprise Energy, IT Power Australia, ACWA, Gentree, Lightsource BP, Neoen, Gridcell | <b>Water electrolysis</b><br>Exxipor, Carumex, GreenHydrogen.de, Appli, heli Hydrogen, Hydroxymapp, Ballard Power Systems, PowerCell Sweden, Plug Power, Air Liquide, ITM Power, Fuel Cell Energy, Hoxagroup Composites, Fusion Fuel Group, Hoxagroup Energy, Nel ASA | <b>Green ammonia reactors</b><br>Genccol, ThyssenKrupp, Hevelor, Trapsac, Yara, Exxipor, Proton Ventures, Siemens, MAN Energy Solutions, ITM Power, Nel Hydrogen, Starline Energy, Balance Agri-Tech, GLG Group, Queensland Nitrogen, Van der Werf, OGP Morocco, Aris | <b>Tracking</b><br><b>Pipeline</b><br><b>Shipping</b><br>Transport and logistics, Transim, Goliathy Ferries, ESNH, Exmar, NYK Energy Transport, AP Moller Maersk, CDFOS Seaways   | <b>Ammonia crackers</b><br><b>Ammonia cracking companies</b><br>Cryotec Technology, Trading GmbH, InterCell, Mvts (E.ON/EDF/Enel), Hubertus Applikon, Laboratory, AirGas Process Technologies, Johnson Matthey, Hoxagroup, Borel, PEP, Batepays, Amer Foster Wheeler, Kinetics Technology | <b>M2 fuel cell</b><br><b>Fuel cell technologies</b><br>AFC Energy, GenCell Energy, BAF Cell, Enavigator AG, Carumex, Fuel Cells Boom Energy, Doosan Fuel Cell America, Robert Bosch GmbH, PowerCell, Plug Power Inc., Horizon, Intelligent Energy, Toshiba, Fuel Cell Energy, Cells Power, Ballard Power Systems | <b>Clients</b>       |          |
|  | <b>ASU</b><br>Praxair, Air Products and Chemicals, Air Liquide, Linde, Taiyo Nippon Sanso   | <b>Haber Bosch process</b><br><b>Oil and gas</b><br>Equator, Shell, Total, Woodside Energy, BP  | <b>Chemicals companies</b><br>Lofte Fine Chemical, Osaka Gas USA, Syntex, KBR, Monolith materials, OCI NV, Yara, Argon, Casale, Hoxagroup, L3B Industries, Proton Ventures, Starline Energy, ThyssenKrupp, Air Products, BASF, Linde, Schoeller-Bachmann Nitro, Valarsh Valley Resources, Air Liquide, Northern Nitrogen Inc, Johnson Matthey   |   |   |                      |          |
|  |   |   | <b>Engineering, manufacturing and technology companies</b><br>Cummins, Organic Group, Pacific Green Technologies Inc., Amangeli, Incolet Phos, JGC Corporation, Cans, Wank Materials, CH2 Technology, Outokumpu Engineering, SIDA Offshore, Tennet Energy, UFGHAC, Remusatronics Australia, MAN Energy Solutions, Microcell Power, Van Papeghem Group, Vesale, University of Cardiff, University of Minnesota, University of Oxford, Freyburger Siemens |   |   |                      |          |

**Stakeholder Power and Interest**

The chart displays the following stakeholders and their approximate positions on the Power and Interest axes:

- Green ammonia industrialists**: High Power, High Interest
- Chemicals companies**: High Power, High Interest
- Haber Bosch industrialists**: High Power, High Interest
- Nitrogen producers**: High Power, High Interest
- Transport and shipping**: High Power, High Interest
- Electrolyser companies**: High Power, High Interest
- Green ammonia startups**: High Power, High Interest
- Engineering, manufacturers and technologists**: High Power, High Interest
- Employees**: High Power, High Interest
- Fuel cell companies**: High Power, High Interest
- NH3 decomposition technologists**: High Power, High Interest
- Battery storage industry**: High Power, High Interest
- Social activist groups**: High Power, High Interest
- Public at large**: High Power, High Interest
- Community**: High Power, High Interest

- Many stakeholders belong to multiple stakeholder categories. This was mostly the case for large companies, whose activities encompass multiple stages of the ammonia value chain

- Identification and assessment of the possible exploitable results develop in the frame of the ARENHA project.

N°	Exploitable Result
1	Ammonia based energy storage system
2	Advanced Electrolyte Supported Cell SOEC electrolyser for renewable hydrogen production
3	Advanced Anode Supported Cell SOEC electrolyser for renewable hydrogen production
4	Elcogen stack module
5	Advanced ammonia synthesis unit
6	Advanced ammonia decomposition membrane reactor using DS Pd-based membranes
7	Carbon molecular sieve membranes selective to NH <sub>3</sub> in gas mixtures of NH <sub>3</sub> with H <sub>2</sub> and/or with N <sub>2</sub> .
8	System to produce ultrapure hydrogen from ammonia
9	Advanced Pd-based membranes for hydrogen purification
10	Carbon molecular sieve membranes for hydrogen purification
11	Software tools (Membrane reactor design)
12	Consulting services on LCA for ammonia energy storage and supply system
13	Electrochemical N <sub>2</sub> production
14	Ammonia electrosynthesis
15	Ammonia solid state storage
16	Absorbent materials for ammonia synthesis (based on Haber Bosch system)
N°	Exploitable Result
17	Novel catalyst for ammonia synthesis
18	Novel catalyst for ammonia decomposition
19	Recycling of Pd-based membranes
20	Ammonia SOFC, SOFC systems and system simulation for power generation
21	Ammonia combustion engine

Orange background: proposal KERs; Clear orange: original KER split in two.

## 6. Progress: WP2

### System requirements, design and modelling

#### Objectives

- Define the industrial requirements for a novel integrated system for ammonia-based energy storage system including a green hydrogen production unit, an ammonia production unit and an ammonia decomposition membrane reactor together with an ammonia storage
- Material modelling for selection of the best candidates
- Reactor modelling, simulation and design
- Process simulation (process design and optimization)
- Pilot plant simulation / Modelling of the complete system
- Techno-economic assessment of the integrated plant and comparison with benchmark technologies
- Define the roadmap for future technology deployment

## 6. Progress: WP2

### System requirements, design and modelling

The following tasks have been achieved:

- The industrial requirements for a novel integrated system ammonia-based storage energy supply system consisting of a SOEC electrolyzer, an ammonia production unit, an ammonia decomposition membrane reactor and an ammonia storage unit have been defined.
- SOEC electrolysis modelling
- Ammonia synthesis modelling
- Ammonia storage modelling
- Ammonia decomposition modelling

## 6. Progress: WP2

### System requirements, design and modelling

#### Industrial requirements

- The process parameters for the ARENHA process have been defined.
- Mass and energy balance of each individual process unit were conducted to define the inputs and outputs parameters of each process block.

## 6. Progress: WP2

### System requirements, design and modelling

#### SOEC electrolysis modelling

- Review of SOEC model with various level of complexity (from 0D to 2D).
- Identification of key experimental parameters required for lumped model definition.
- Summarize and review current level of development in modelling SOEC systems.
- Aspen Plus SOEC model updated with experimental results (FhG-IKTS).
- A first implementation concept of the SOEC-model in Aspen Custom Modeler was developed.



- Development of a steady state SOEC system model
- Development of a dynamic state SOEC system model

## 6. Progress: WP2

### System requirements, design and modelling

#### Ammonia synthesis modelling

- A dynamic model of the ammonia synthesis unit is required to optimize the reactor-catalyst synergy towards minimal losses due to pressure and temperature. The modelling will be used to translate the pilot plant results to relevant product-scale.
- Density Functional Theory (DFT) calculations and experimental characterization with Differential Electrochemical Mass Spectrometry (DEMS) were used to screen and optimize electrocatalysts for ammonia electrosynthesis
- The optimized composition of sorption materials and characterization of the absorption kinetics and thermodynamic equilibrium was determined with DFT calculation using a genetic-algorithm (GA-DFT).
- Dynamic simulation of the fixed bed absorption and regeneration processes. The geometry and design of the bed have been optimized by performing COMSOL Multiphysics 3D simulations.
- A quasi-steady state and a dynamic ammonia synthesis process simulation were built.

## 6. Progress: WP2

### System requirements, design and modelling

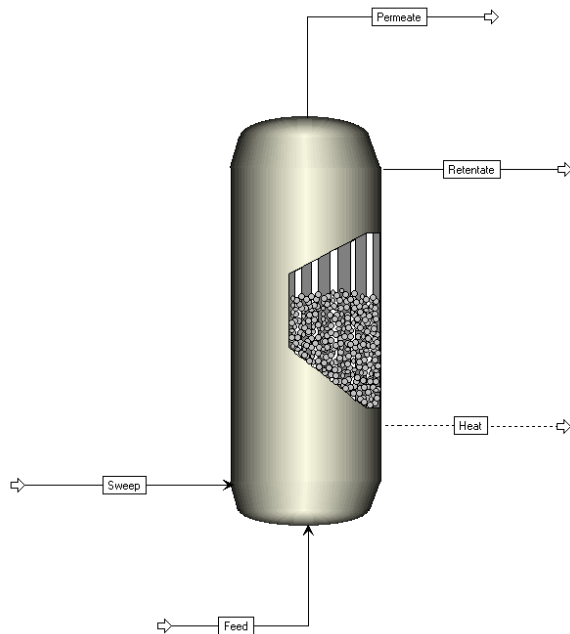
#### Ammonia storage modelling

- The composition of the mixed metal halides to be synthesized for ammonia storage have been selected at DTU by performing calculations with the GA-DFT algorithm.
- The expertise and knowledge acquired from the COMSOL Multiphysics 3D simulations on the absorbent bed have been used to develop a model for the ammonia storage.
- Model validation was also performed using experimental data obtained on 10 g of sorbent.

## System requirements, design and modelling

### Ammonia decomposition modelling

- A packed bed membrane reactor (PBMR) model for ammonia decomposition and pure hydrogen separation has been developed in ACM.



- The model was analyzed by means of a **sensitivity analysis**, showing that the model responds as expected to parameter changes.
- The model performance were **compared** to those of a model available in literature and it was concluded that the two models provide similar results
- A **validation with experimental data** obtained from lab tests was also performed and proved the model able to predict hydrogen production from ammonia decomposition with good accuracy.

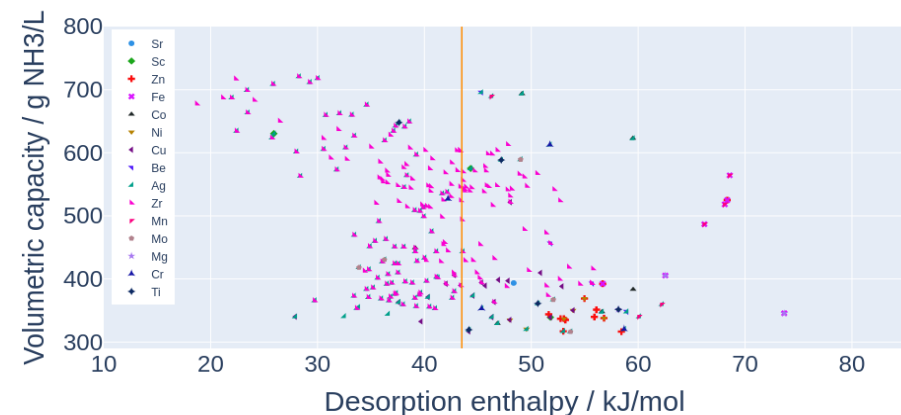


## 6. Progress: WP2

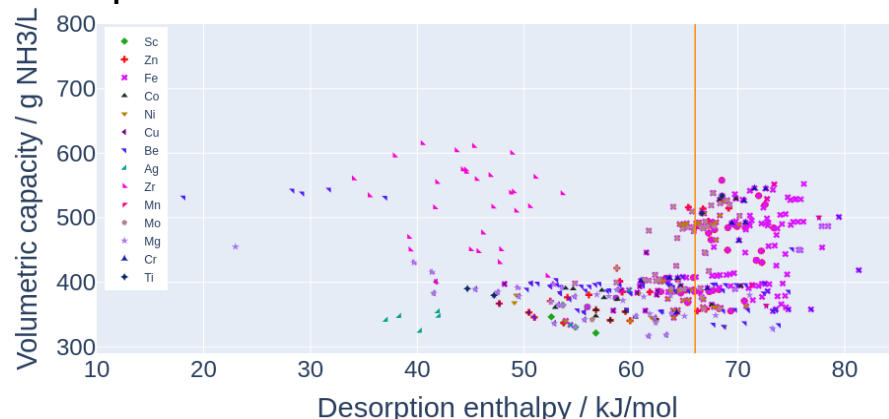


areNH<sub>3</sub>a

- Genetic algorithm with density functional theory for predication of NH<sub>3</sub> absorption and storage were finalized. Candidate materials are selected for further experimental validation

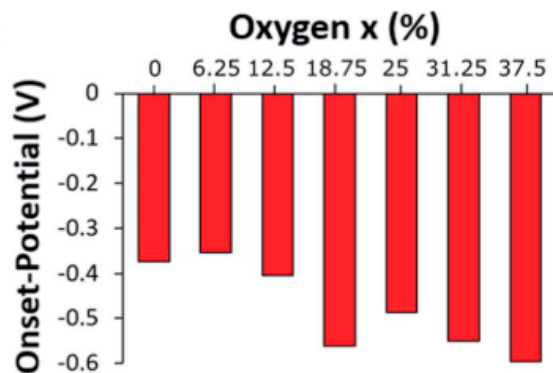


Candidate material for NH<sub>3</sub> storage. Targeted enthalpy: 43.5 KJ/mol

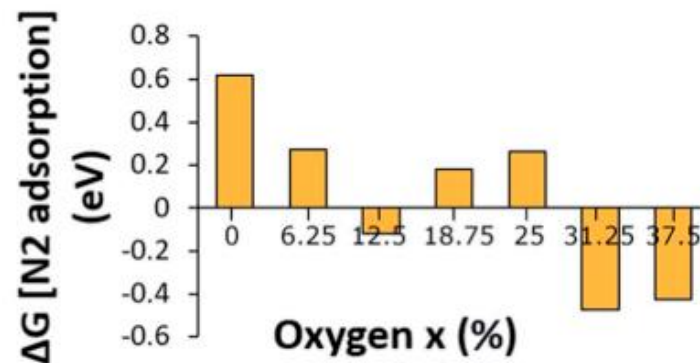


Candidate material for NH<sub>3</sub> absorber for HB process. Targeted enthalpy: 66 KJ/mol

- DFT calculation of electrocatalyst for NH<sub>3</sub> synthesis was finalized. VN materials with 12% O content (VN<sub>0.88</sub>O<sub>0.12</sub>) is considered the promising candidate electrocatalyst material.



Theoretical onset potential decrease with O concentration

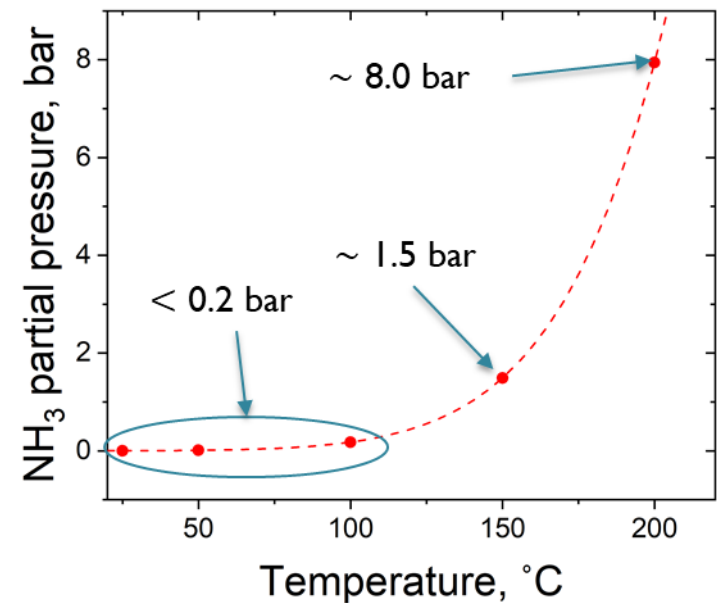
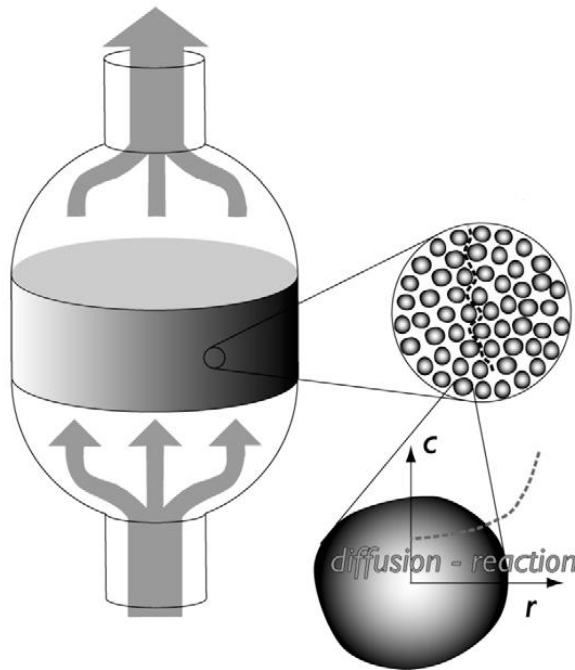


The thermodynamic barrier to N<sub>2</sub> adsorption decrease with O concentration

## 6. Progress: WP2



- COMSOL model with bi-modal porosity (macro- and microscales) were developed for modelling of absorber bed design
- Height of mass transfer zone (MTZ) and purity of outlet gas for various temperature and absorber radius

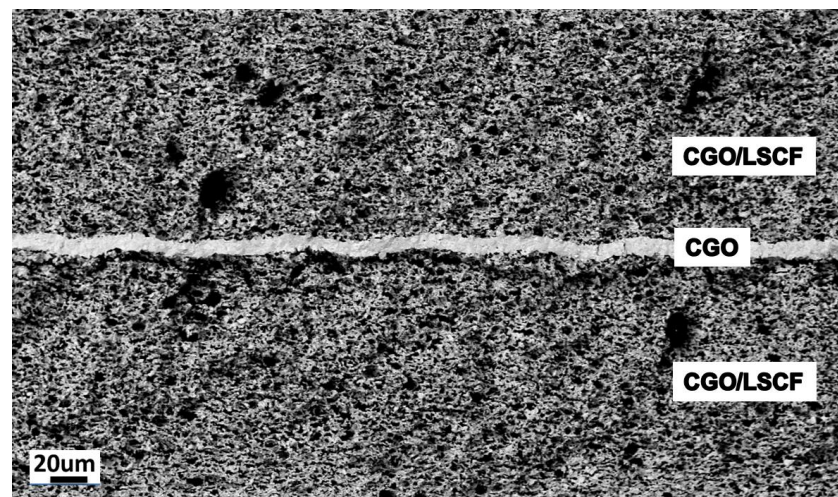
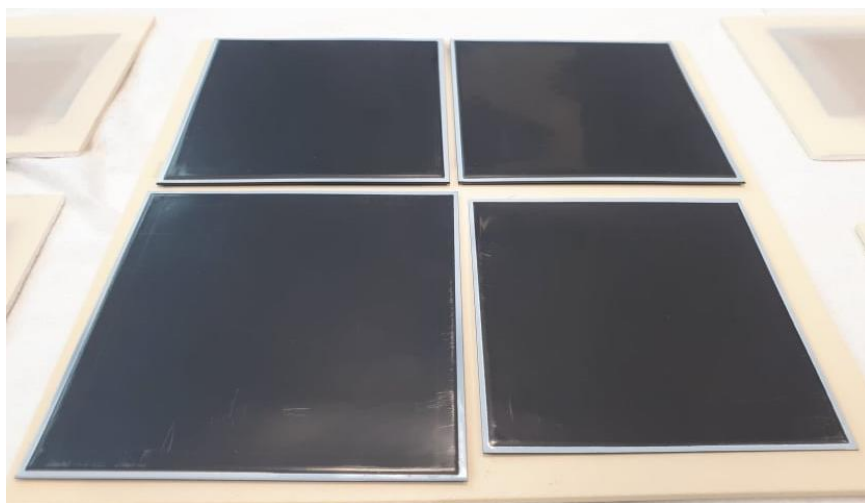


- Development of improved cell
  - Improvement on electrode architecture
    - Promising electrode powder compositions investigated by printing on full cells and characterizing by area specific resistance (ASR) amongst others
    - Decrease of ASR of full cells by approx. 25% at 800°C compared to standard cells
  - Utilization of thinner electrolyte
    - Investigation of electrolytes with thickness < 165 µm
    - Investigation of different adhesion layers with promising results for electrolytes with a thickness of 165 µm and 110 µm
    - Decrease of ASR of full cells with 110 µm electrolyte and adhesion layer by approx. 29% at 800°C compared to standard cells
- Next step: further optimisation of cells with thinner electrolyte

## 6. Progress: WP3

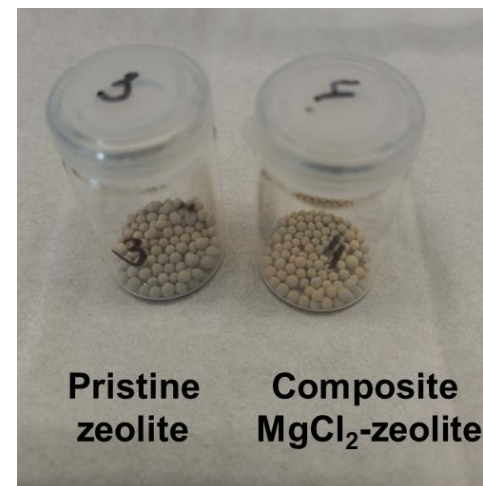
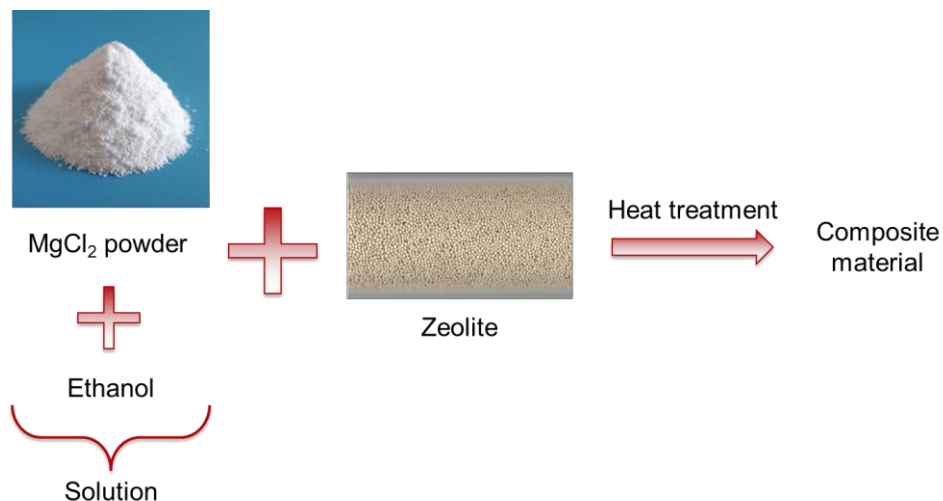


- Asymmetrical electrochemical cells with dense  $\text{Ce}_{0.9}\text{Gd}_{0.1}\text{O}_{1.95}$  (CGO) electrolyte and porous  $\text{La}_{0.6}\text{Sr}_{0.4}\text{Co}_{0.2}\text{Fe}_{0.8}\text{O}_{3-\delta}$ - $\text{Ce}_{0.9}\text{Gd}_{0.1}\text{O}_{1.95}$  (LSCF-CGO) composite electrolyte were successfully produced

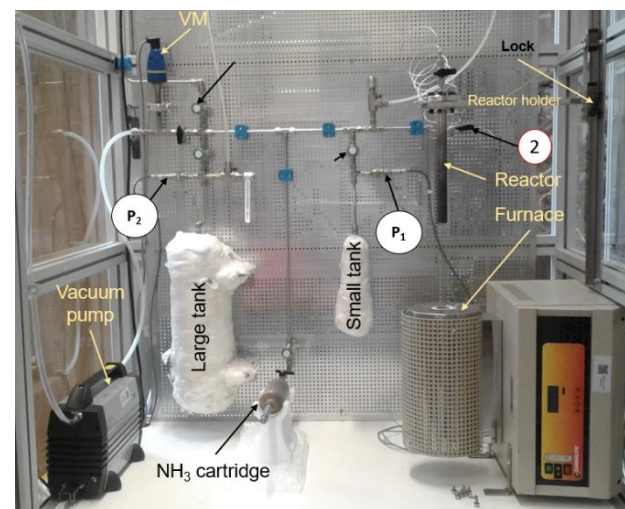


## 6. Progress: WP3

- Absorber materials MgCl<sub>2</sub> loaded in zeolite were produced

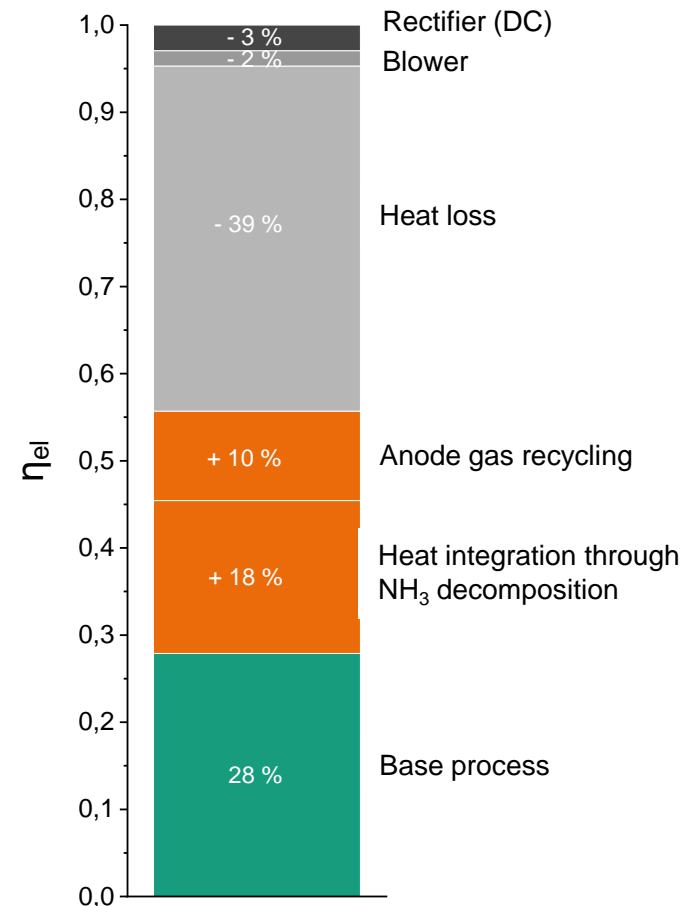
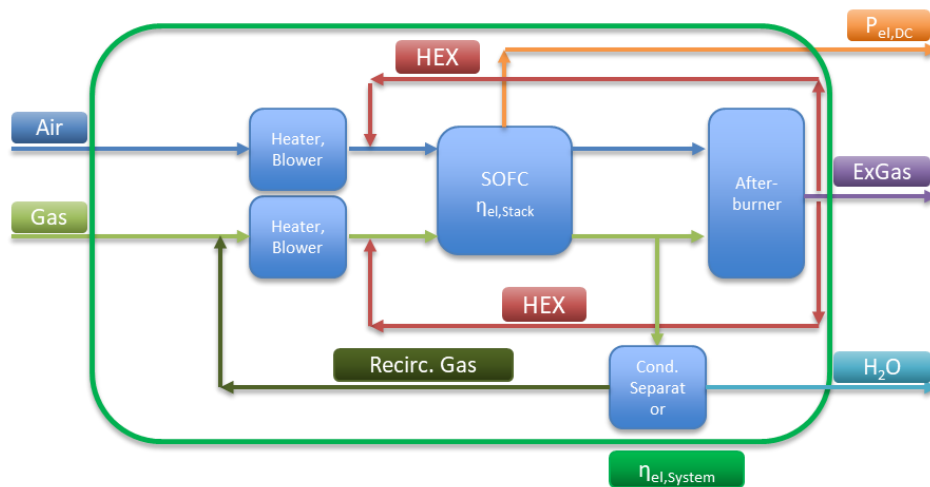


- Sieverts setup for identification of thermodynamic and kinetic parameters of absorber materials is upgraded.



## Characterization of SOFC system for power generation from ammonia

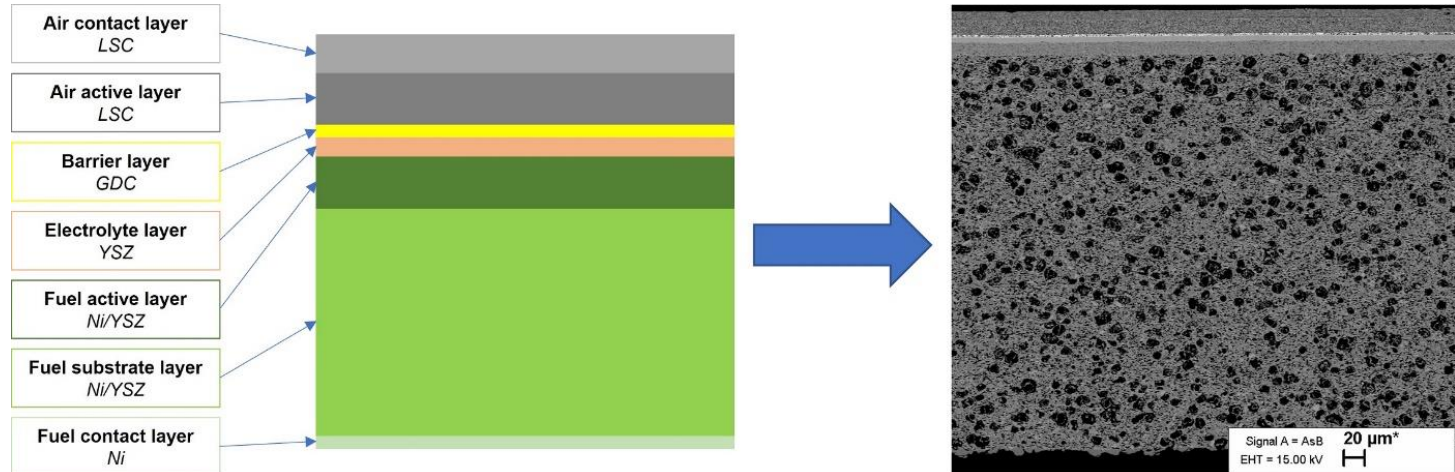
- Simulation of SOFC using ammonia fuel:
  - 100 % ammonia, anode gas recycling
  - System efficiency: 56 %



- Next step: SOFC stack tests with ammonia

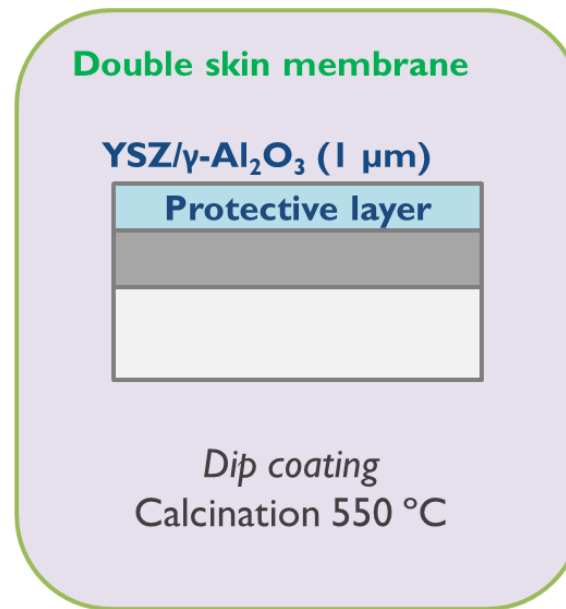
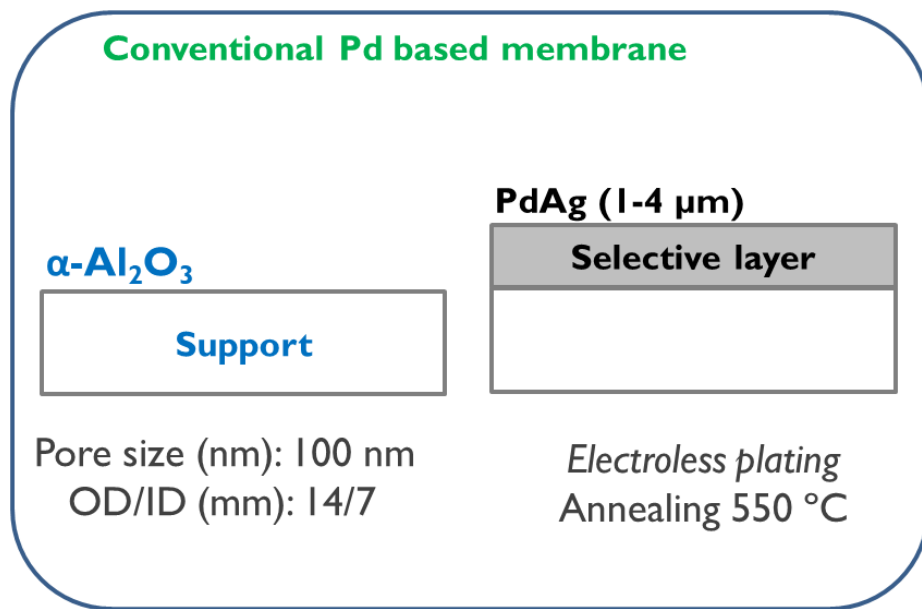
## Elcogen – Development of improved SOEC

- The state-of-the-art SOFC is not optimized for electrolysis operation at high current density.
- New materials and microstructural changes in the air active layer and fuel active layer have been explored to optimise cell for SOEC mode.
- New SOECs will be manufactured incorporating all the findings and then assembled in stack to be tested in a 5kW system for validation.



*Schematic representation (left) and polished SEM cross-section (right) of a State-of-the-Art Elcogen commercial cell.*

## Development of double skin (DS) Pd based membranes for hydrogen separation membranes for ammonia decomposition reaction



**Goal:** High H<sub>2</sub> permeance and H<sub>2</sub>/N<sub>2</sub> & H<sub>2</sub>/NH<sub>3</sub> selectivity

**Target:** Low N<sub>2</sub> permeance/leakage at RT

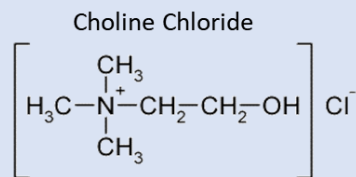
- 1<sup>st</sup> generation membranes:  $< 2 \cdot 10^{-10} \text{ mol m}^{-2} \text{ s}^{-1} \text{ Pa}^{-1}$  **Achieved**
- 2<sup>nd</sup> generation membranes:  $< 4 \cdot 10^{-11} \text{ mol m}^{-2} \text{ s}^{-1} \text{ Pa}^{-1}$  **Achieved**

# 6. Progress: WP3

## Recycling of Pd-based membranes

### Evaluation of different DES leaching medias

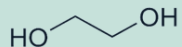
#### Hydrogen bond acceptor



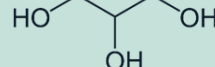
#### Hydrogen bond donors

##### Alcohols

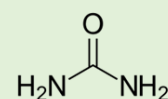
Ethylene glycol



Glycerol

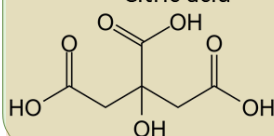


Urea

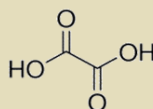


##### Acids

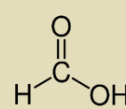
Citric acid



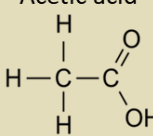
Oxalic acid



Formic acid



Acetic acid



#### + additives

Acid

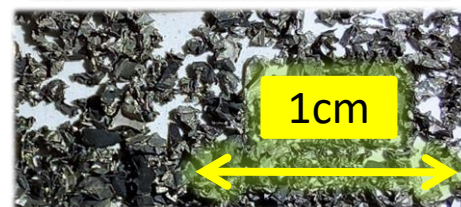
HCl

Chloride

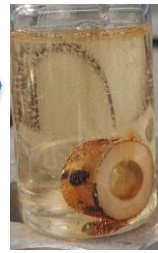
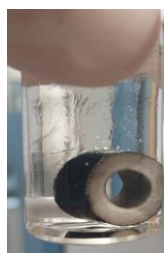
NaCl

Oxidizing agent

H<sub>2</sub>O<sub>2</sub>



>90% Pd & Ag leaching  
(grinded residue)



Similar recovery yield  
for full spent membrane

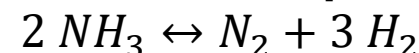


## 6. Progress: WP3

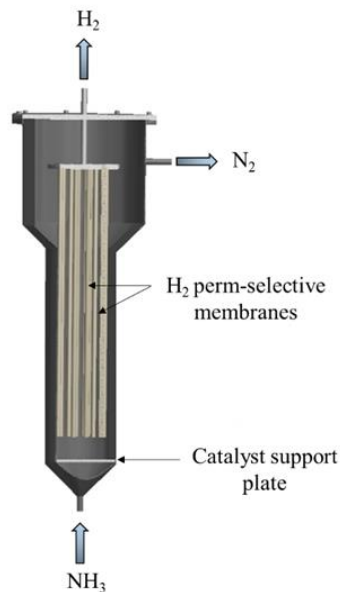
### H<sub>2</sub> production via ammonia decomposition

The Pd-based **membrane reactor** is a technology with high potential to efficiently recover H<sub>2</sub> from NH<sub>3</sub>

#### Ammonia decomposition



NH<sub>3</sub> decomposition reaction into H<sub>2</sub> and N<sub>2</sub> and high-purity H<sub>2</sub> separation are simultaneously performed

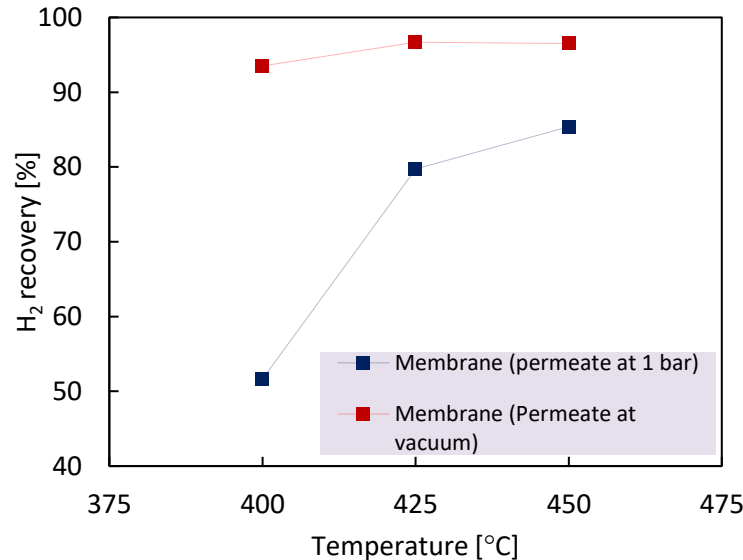
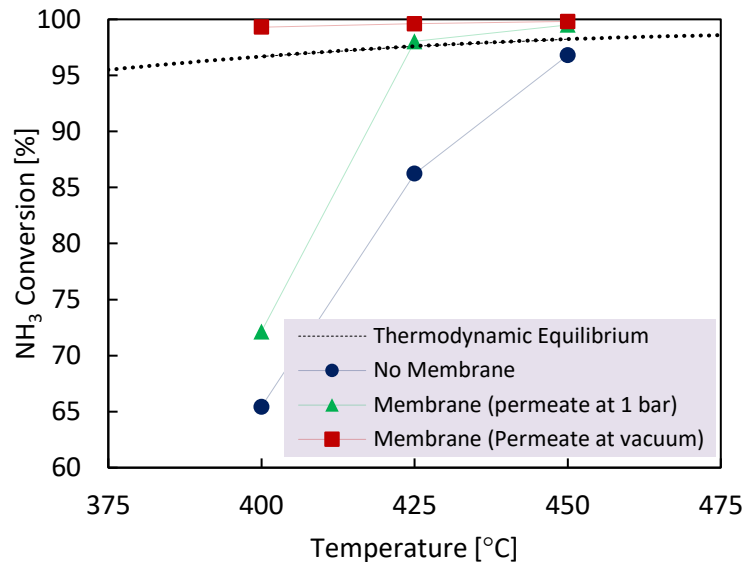


- the high-purity H<sub>2</sub> recovered through the membranes can be fed directly to FCs avoiding the need to introduce any costly separation/purification unit
- full NH<sub>3</sub> conversion can be achieved reducing the downstream cleaning of unconverted species
- high H<sub>2</sub> separation efficiencies of H<sub>2</sub> 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

## 6. Progress: WP3



### *The catalytic membrane reactor for NH<sub>3</sub> decomposition (\*)*



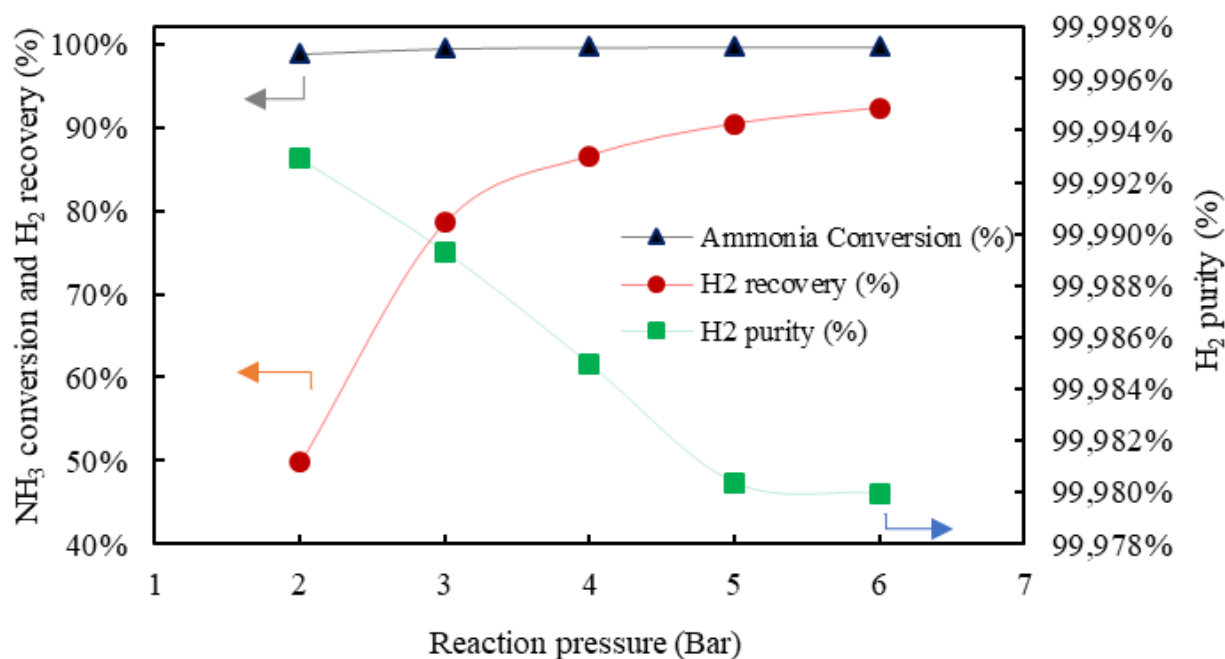
#### Experimental conditions

$\Delta P$	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<sub>3</sub> 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>

## Effect of pressure



### EXPERIMENTAL CONDITIONS

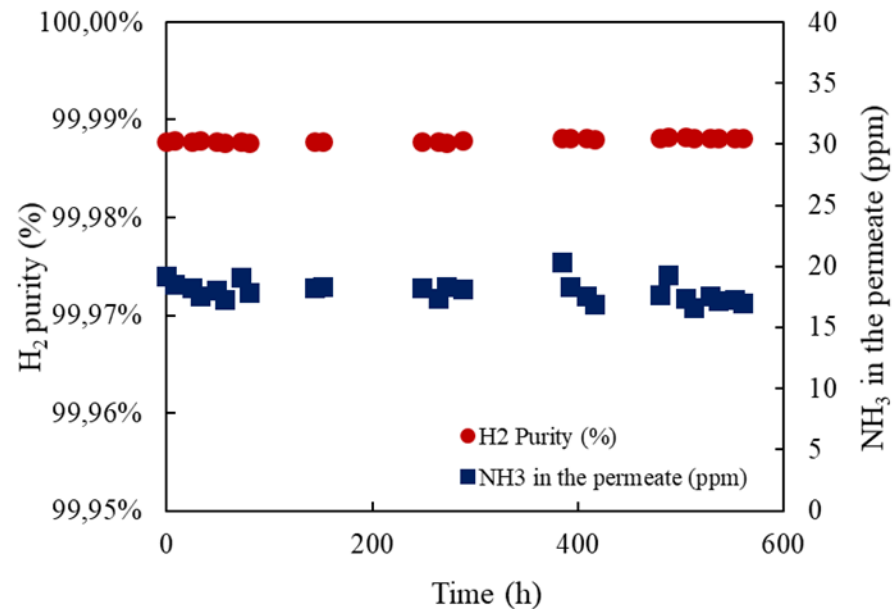
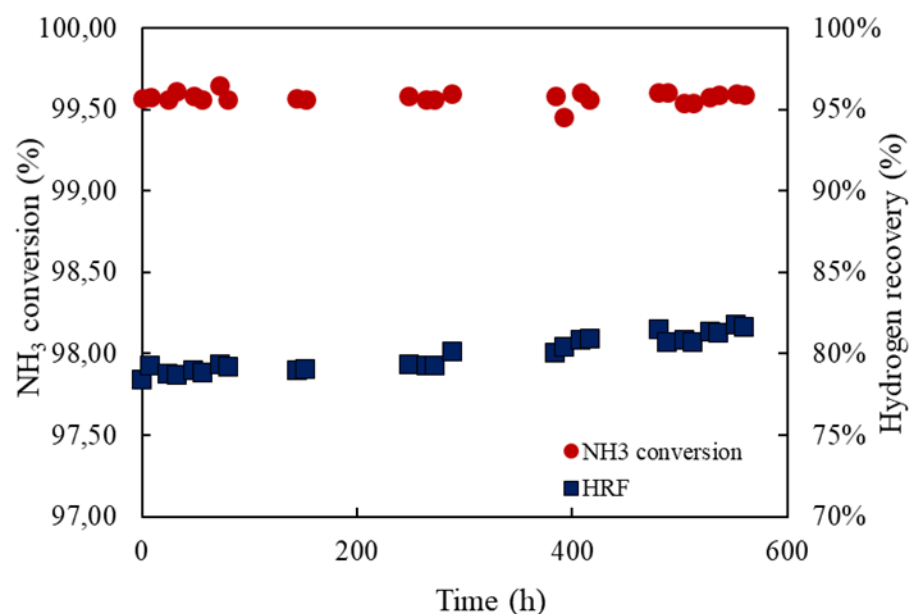
- T= 450 °C
- Feed = 0.5 L<sub>N</sub>/min NH<sub>3</sub>
- Pd-based membrane, dead-end configuration

**By increasing pressure in the retentate:**

- H<sub>2</sub> recovery increases. Values above 90% are achieved for operating pressures higher than 5 bar.
- H<sub>2</sub> purity in the permeate decreases.

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

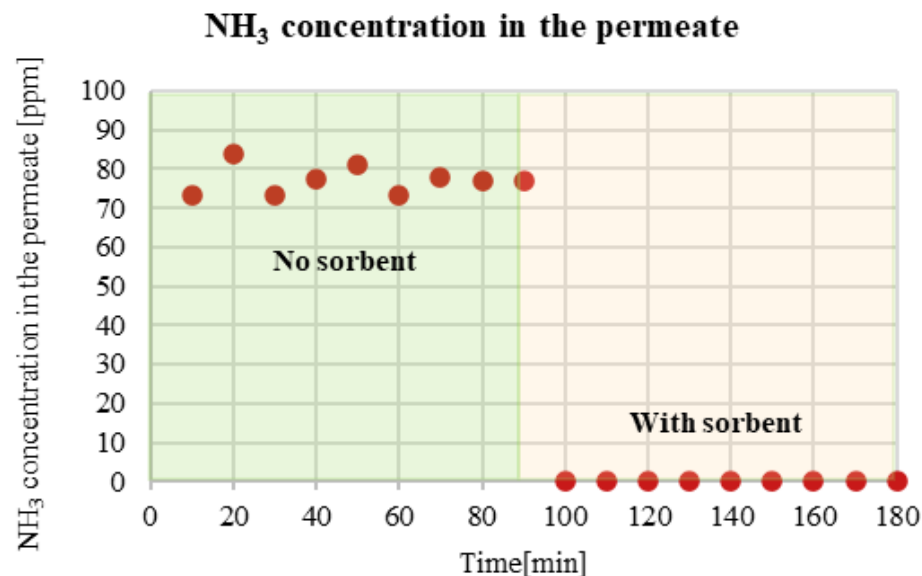
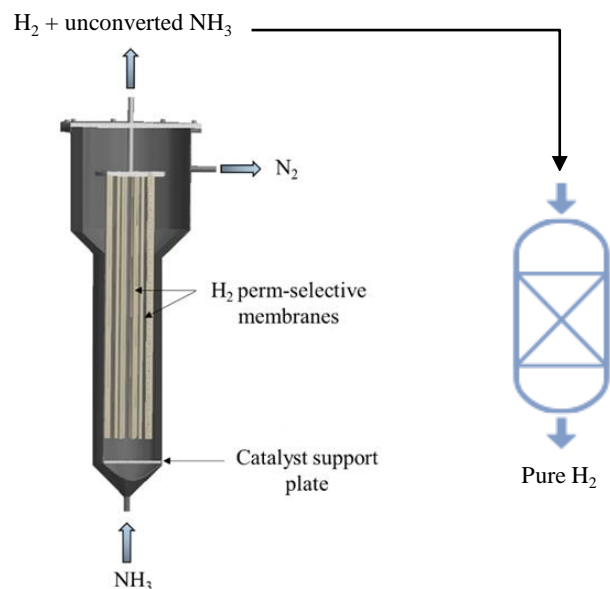
## Long term ammonia decomposition test in the membrane reactor (\*)



Experimental conditions:  $T = 450\text{ }^{\circ}\text{C}$ ,  $P_{\text{retentate}} = 3\text{ bar}$ ,  $P_{\text{permeate}} = \text{atmospheric}$ ,  $\text{Feed} = 0.5\text{ L}_N/\text{min NH}_3$

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

## Addition of a $H_2$ purification stage

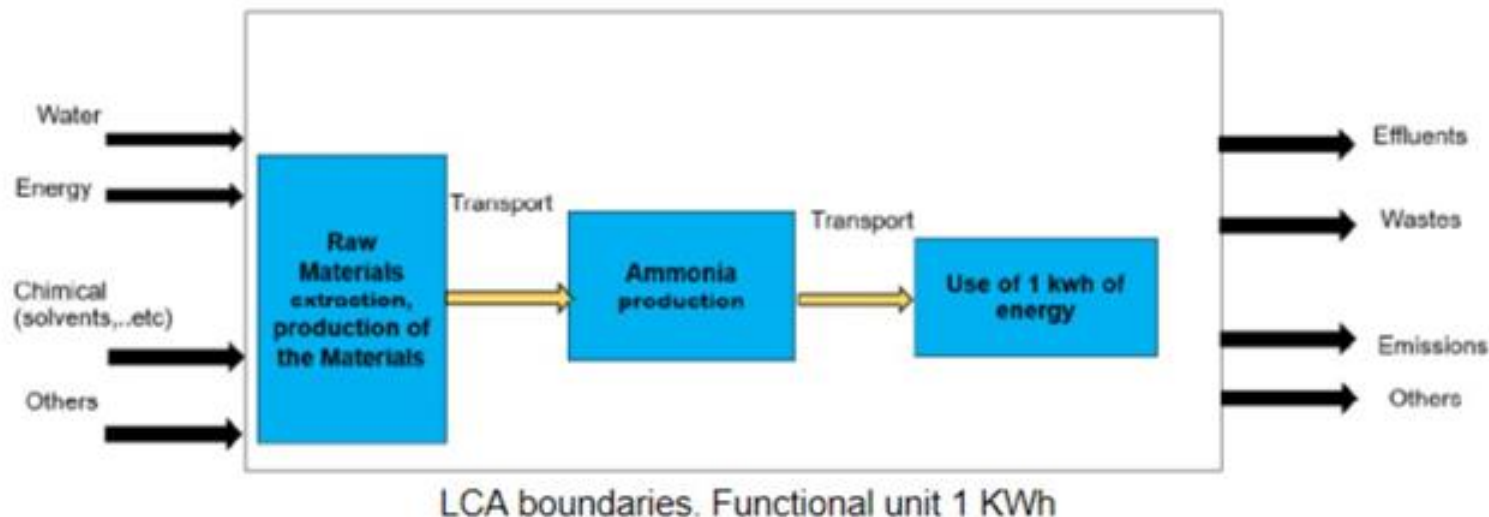


Experimental conditions:  $T = 400\text{ }^{\circ}\text{C}$ ,  $P_{\text{retentate}} = 3\text{ bar}$ ,  $P_{\text{permeate}} = 1\text{ bar}$ ,  
 Feed flow rate =  $2\text{ L}_N/\text{min NH}_3$ , Feed composition: 5%  $\text{NH}_3$  and 95%  $\text{H}_2$

- In order to purify  $\text{H}_2$  from unreacted ammonia produced during dehydrogenation reactor, a  $\text{H}_2$  purification stage on the permeate side of the membrane was added.
- A commercial **zeolite 13X** was tested as adsorbent material.

(\*) Valentina Cechetto et al. World Online Conference on Sustainable technologies. March 17-19, 2021.

- Goal and scope of the sociological survey and environmental LCA, LCC and LCS

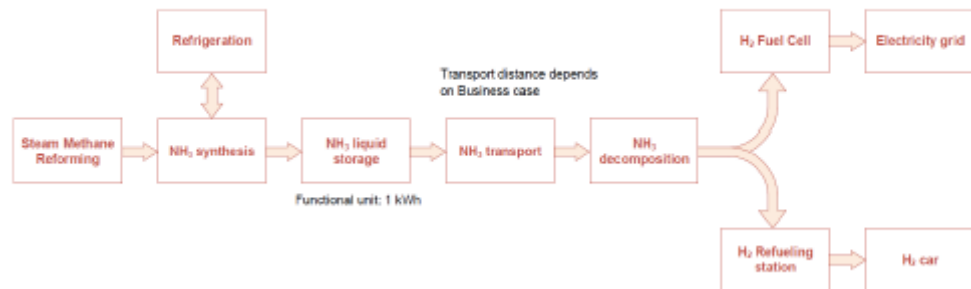


- Data collected by CNH2
- Preliminary LCA running on Simapro on going by ENGIE in order to identify most significant environmental impacts and sensitive parameters
- Detailed environmental will be performed at the end of the project in order to provide a complete LCA of the processes developed in the AREHNA

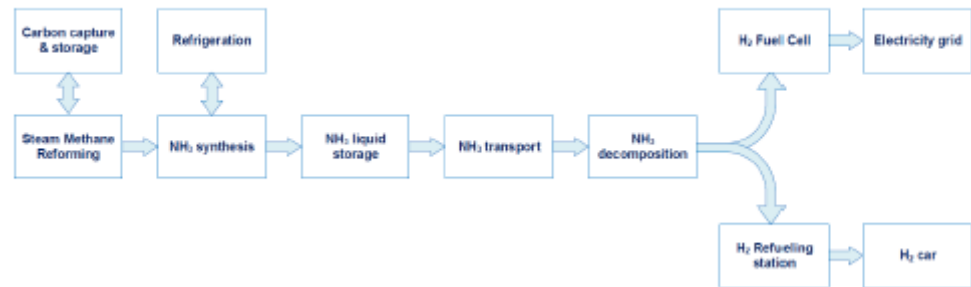


## 6. Progress: WP6

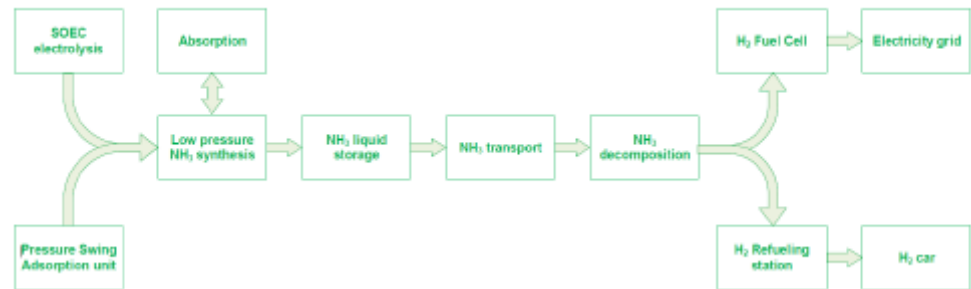
### SCENARIO#1 : Brown ammonia



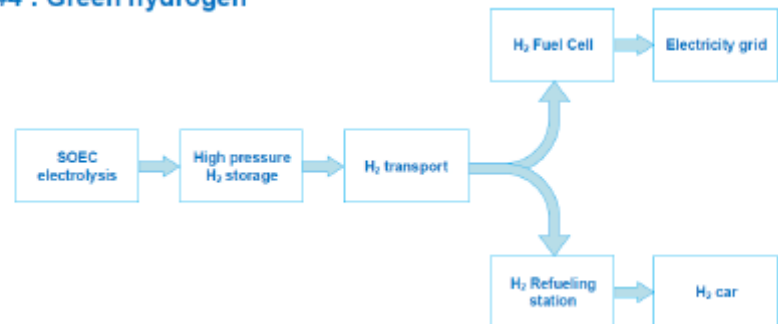
### SCENARIO#2 : Blue ammonia



### SCENARIO#3 : Green ammonia



### SCENARIO#4 : Green hydrogen

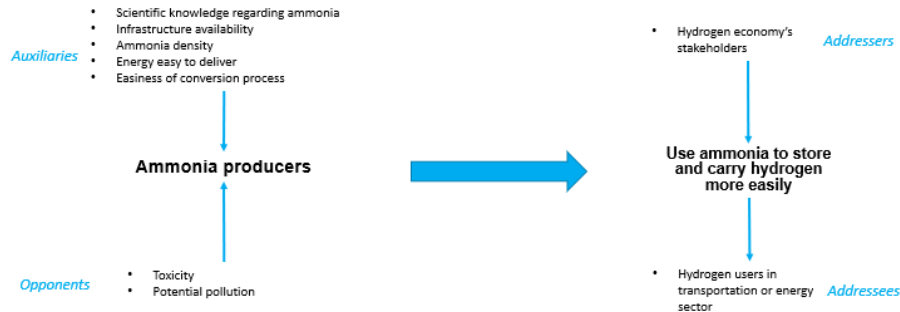


- 4 Scenarios to be studied: green, blue and brown ammonia and green hydrogen
- Literature review on going

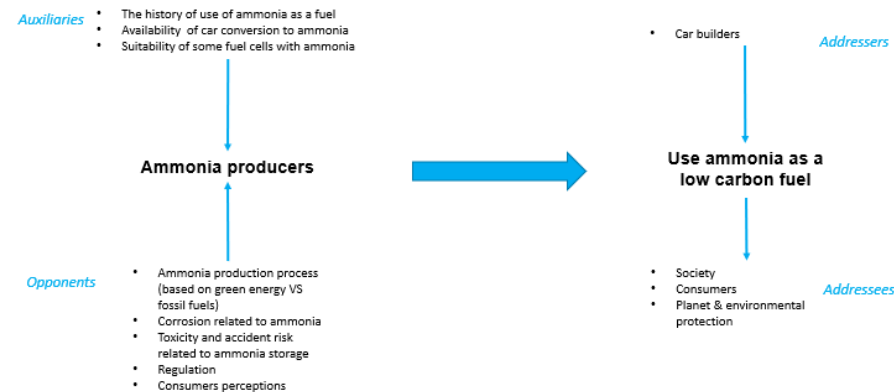


## Social Acceptance task : Identification of various narratives related to Ammonia

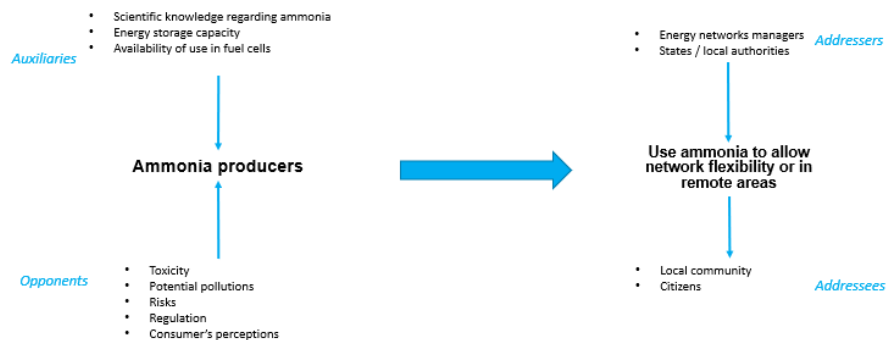
### Narrative regarding ammonia as a H<sub>2</sub> carrier



### Narrative regarding ammonia as a new fuel



### Narrative regarding ammonia stationary application



- Main narratives related to Ammonia where first identified in literature
- A deeper exploration through interview was engaged
- Next steps :
  - Continue exploration through interviews in shipping sector
  - Design & pass a questionnaire to test opinion on these narratives

# 6. Progress: WP7



- Project logo and set of public document templates
- Public Project website: [Home | ARENHA](https://arenha-project.eu)
- Dissemination and Communication Plan updated M3
- Dissemination and Communication Plan updated M12
- First Public Presentation
- 6 months periodic Project newsletter M6, M12 and M18
- ARENHA First dissemination video
- ARENHA dissemination activities ongoing



CNH2 - Centro Nacional del Hidrógeno • 1er  
Centro Público de Investigación en CNH2 - Centro Nacional del Hidrógeno  
1 año •

PRIMER FLYER de ARENHA Project!!! ARENHA Project es uno de los proyectos donde se encuentra trabajando actualmente el CNH2 - Centro Nacional del Hidrógeno. ...ver más

**The concept**

The ARENHA project aims at using ammonia as a green hydrogen carrier and for that purpose it develops its main activities around the green hydrogen production, ammonia synthesis, storage and dehydrogenation.

Innovative materials are developed and integrated into ground-breaking systems in order to demonstrate a flexible and profitable power-to-ammonia value chain but also several key energy storage processes. Specifically, ARENHA is developing advanced SOEC for renewable hydrogen production, catalysts for low temperature/pressure ammonia synthesis, solid absorbents for ammonia synthesis intensification and storage, catalysts and membrane reactors for ammonia decomposition for pure hydrogen (>99.99%) production.

Energy storage processors studied in ARENHA tackle various applications from ammonia decomposition into pure H<sub>2</sub> for ICEs direct ammonia utilization on SOFCs for power and ICEs for mobility.



**Partners and contacts**



Project coordinator: TECNALIA  
Dr. José Luis Vázquez  
jvazquez@tecnalia.es

Technical manager: TFC  
Prof. Paolo Galassi  
p.galassi@tfc.it

Dissemination manager: CNH2  
Dr. Alicia María Pérez  
amaria@cnh2.es

Exploitation manager: CNH2  
Dr. Carlos Martínez  
cmartinez@cnh2.es

Duration: 4 years (April 2020 – March 2024)  
UE funding 5.7 M€ approx.

ARENHA Project @arenha\_10000

**Advanced materials and Reactor for ENergy storage Through Ammonia (ARENHA)**



[www.arenha.eu](http://www.arenha.eu)

Acknowledgement: This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 862482. The present document reflects only the author's views, and the European Union is liable for any use that may be made of the information contained therein.

1 comentario

# 7. Impact



Decrease energy import dependency.

Promote the integration of offshore renewables for energy dependency.

Integration of renewable in power systems with large scale energy storage.

Strategic European leadership in energy storage.

Ammonia to diversify energy supply from third countries



**Alternative energy import through renewable electricity storage and long distance transportation.**

➤  > \$2.5 trillion per year

➤  > 5000 future jobs

➤ Reduction of NO<sub>x</sub>-emission = Increase quality of life

➤ Avoid 20 million barrels of oil per day



# Advanced materials and Reactors for Energy storage tHrough Ammonia



areNH<sub>3</sub>a

*Thank you for your attention*

Website: [arenha.eu/](https://arenha.eu/)

LinkedIn: ARENHA Project

Twitter: @ARENHA\_H2020