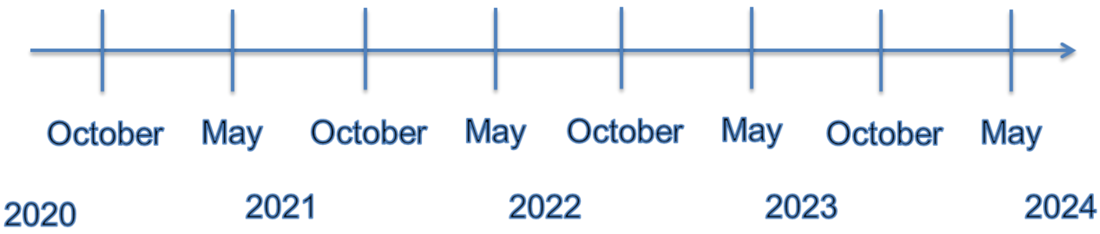
Advanced material and Reactor for ENergy storage tHrough Ammonia

Newsletter – June 2021



Editorial

Welcome to this 2nd ARENHA project newsletter. ARENHA is a European four-year project with global impact seeking to develop, integrate and demonstrate key material solutions enabling the use of ammonia for flexible, safe and profitable storage utilization of energy. Ammonia is an excellent carrier due to its high energy density, carbon-free composition, industrial know-how and relative ease of energy storage. ARENHA demonstrates the feasibility of ammonia as a dispatchable form of large-scale energy storage.

The present newsletter is the second release and it is presenting the progress on the project and highlighting information related to the R&D fields addressed. Hope you will find the info in this newsletter interesting. On our website www.arenha.eu you will find public presentations, all the public information of the project and many other interesting news. Stay tuned!

In this Issue:

What is ARENHA?

The concept

For decades, utility-scale energy storage has been used to balance load and demand within an energy generation system composed mainly of base load power sources enabling thus to large nuclear or thermal generating plant to operate at peak efficiencies. Energy storage has contributed over the time to meet peak demand and regulate frequency beside peak fossil fuel power plants that usually provided the bulk of the required energy. In the aforementioned context where inherent variability of the power generation asset was mainly a minor issue, energy storage capacity remains nevertheless limited for economic reasons storing electricity during low electricity demand and releasing it back into the grid during high demand, typically over a daily cycle.

In the current context of global momentum in favour of renewable electricity catalysed by spectacular levelized production cost decrease, higher storage capacity is required to ensure security and flexibility providing a portfolio of services from grid services to the decarbonization of energy intensive sectors like the transport, industry or heating and cooling sector.

For that purpose, hydrogen produced from electrolysis reveals to be a key pathway to unlock the full potential of renewable and especially for seasonal energy storage of large energy quantity and more specifically for all situations dealing with a large energy-to-power ratio situation. Hydrogen having a low volumetric energy density, it has to be compressed to high pressure, liquefied or combined as hydrogen carrier. Among all possibilities, ammonia is a carbon-free and dispatchable energy carrier allowing storing large quantities of renewable electricity. It is a primary candidate to allow a secure and clean supply of renewable energy for various stationary or mobile applications and with ability to provide a wide range of energy storage services using existing infrastructures and both well-defined regulation and acceptable safety history for over 75 years. If state-of-the-art ammonia production plants produce between 3,000 and 6,000-ton NH_3/day, its well-known process involves H_2 production from natural gas reforming. Technical challenges remain to be overcome in order to ensure a flexible and cost comparable production of ammonia from intermittent renewable electricity sources. In addition to that, efficient energy discharge processes from NH3 must be developed in order to best leverage the clean energy produced upstream by the renewable asset.

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 (Figure 1). 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 discharge 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 discharge processes studied in ARENHA tackle various applications from ammonia decomposition into pure H_2 for FCEV, direct ammonia utilization on SOFCs for power and ICEs for mobility.

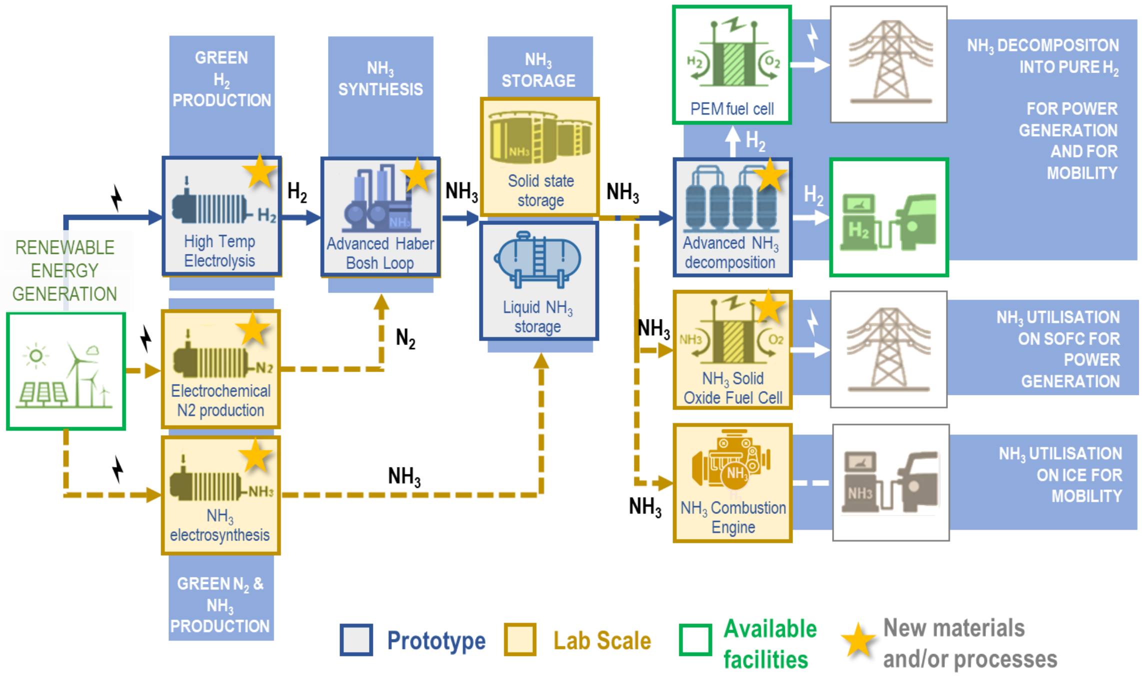


Figure 1. Power-to-ammonia-to-usage value chain in ARENHA

Project objectives.

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 through LCA, sociological survey, techno-economic analysis deeply connected with multiscale modelling. For this purpose, breakthrough technologies will be developed and integrated along the overall value chain. The main technical objectives on material and system level are the following:

- To develop and integrate innovative solid oxide cell materials into a flexible high temperature electrolysis demonstration unit producing 1.5 Nm^3/hr hydrogen at ambient pressure to be connected on a real PV plant.
- To develop and integrate innovative materials into a synthesis loop enabling to operate a flexible Haber Bosch production unit of 10 kgNH_3/day at lower pressure (<50 bar) and temperature (<450 °C).

- To develop and integrate innovative materials into a decomposition reactor able to generate 10 Nm^3/hr of pure hydrogen (>99.99%) from green ammonia.
- To develop and test innovative materials and solutions for the alternative direct synthesis and utilization of next-generation green ammonia.
- To demonstrate ammonia as a flexible energy carrier through the development of a fully integrated prototype for green ammonia synthesis and decomposition.
- To assess the social acceptance, techno-economic-environmental feasibility, and replication potential of the developed value chains.

Latest news from the project

The latest news from the project are now reported

Business case definition

Along the first year the activities have been focussed on the market analysis to identify promising opportunities for ammonia as a renewable energy storage solution and to pinpoint key stakeholders and competitors. Initial analysis with regards to the Value Proposition of the ARENHA concept has been concentrated on identifying the state-of-the-art technology, underlining the peculiarity about the developed concept, evaluating the impact of the concept on the end-user and assessing the state of development at the end of the project.

System requirements, design and modelling

During this period of ARENHA, the industrial requirements for the system including a green hydrogen production unit, an ammonia production unit and an ammonia decomposition membrane reactor together with an ammonia storage have been defined and all the activities related to the modelling of each single technology involved in the process system have started. The main achievements have been the following:

- Industrial requirement and interface definition for the ARENHA value chain.
- SOEC electrolysis modelling initialization and preliminary PFD of SOEC system definition.
- Process simulation model refinement and process flow diagram for the Arenha Haber-Bosch demo unit definition.
- Successful genetic algorithm run to suggest optimal materials in computational search for ammonia absorber materials with limited element pool.
- Optimization of ammonia absorber design in a 3D numerical model in COMSOL.

- Calculations of kinetic barriers to assess the selectivity of N_2 reduction versus hydrogen evolution in NH_3 Electrosynthesis.
- Ammonia decomposition operating conditions definition for further demonstration campaign.
- Refining of experimental kinetic data on membrane reactor model and definition of new set of kinetic parameters for ammonia decomposition.

Key component development

Regarding the key component development (WP3) the following progress have been achieved as describe hereafter. For the improvement of SOEC cells first tests using thinner electrolytes were carried out at the IKTS. Using standard electrodes, cells with thinner electrolytes with a thickness of 120 µm (standard: 165 µm) were sintered. The cells were characterized using impedance spectroscopy from which the area specific resistance of the cell was derived. The ASR describes the combined ionic resistance of the electrodes and the electrolyte in the cell normed by the area. The cell with the thinner electrolyte showed a by approx. 25 mOhmcm² lower ASR at 800°C compared to a cell with standard electrolyte thickness. Additionally, improved electrodes were investigated as well. Different powders were characterized according to IKTS specifications which includes particle size distribution, specific surface area, shrinkage and SEM. Preliminary results of the cells using improved electrode pastes showed an ASR decrease of approx. 15 % at 800°C compared to the standard electrodes. This difference is more pronounced at lower temperatures. Based on these results further investigations are planed including optimisation of the pastes, utilization of thinner electrolytes and further electrochemical investigations.

Elcogen continued developing and manufacturing experimental SOEC cells with the focus on material rather than architectural modifications. Bibliographic research was done to find new potential materials to be used or added to the existing state-of-the-art ELCOGEN solid oxide cell architecture. Also, new experimental cells were manufactured with modified active fuel electrode layers and modified air electrode layers.

DTU continue developing the absorbent material to be incorporated in the modified Haber-Bosch synthesis loop with lower temperature and pressure conditions than conventional methods. Based on the density functional theory (DFT) calculations modelling results, the appropriate composition of the mixed metal halides (absorbent material) are identified then synthesized and characterized. However due to COVID 19 imposed delays, the synthesis has not been started yet. On the other side, regarding the electrochemical synthesis of ammonia, materials for the support and electrolyte have been selected to be manufactured via tape-casting. Finally, for the solid storage of ammonia, an appropriate composition of the mixed metal halides has been selected while waiting for Density Functional Theory predications results.

TECNALIA continue preparing different types of membranes for H_2 separation (e.g. Pd-based double skin membranes) with improved separation properties. Regarding the recycling of Pd-based membranes a screening of different leaching media has been performed. Seven different deep eutectic solvents (DES) and as a benchmark two inorganic leaching media for recovery of Pd and Ag from the solid metallic layer of spent membranes have been tested. Additives were used to study the effect of increasing acidity together with the effect of oxidizing agents. As observed, DES leaching outperformed inorganic leaching media allowing an extraction rate of 59% Pd and 62% Ag vs 23% Pd and 0.4% Ag using the same additives. Those results show the potential of the ionometalurgical process vs conventional hydrometallurgical process for the recovery of critical raw materials.

Both, lab-scale permeation test using H_2/NH_3 mixture on the Pd-based membranes and ammonia decomposition tests in a Pd-based membrane reactor over a Ru-based catalyst have been carried out by TUE. A conventional packed bed reactor was used as benchmark for a comparison. The results demonstrate that the introduction of a membrane in a conventional reactor enhances its performance and allows to achieve conversion higher than the thermodynamic equilibrium conversion for sufficiently high temperatures. For temperatures from and above 425 °C, full NH_3 conversion was achieved and more than 86% of H_2 fed to the system as ammonia was recovered with a purity of 99.998%. The application of vacuum at the membrane permeate side leads to higher H_2 recovery and NH_3 conversions beyond thermodynamic restrictions. On the other hand, the reactor feed flow rate and operating pressure have not shown major impacts on NH_3 conversion. Long term permeation test resulted to be stable over time. No decrease in the hydrogen purity neither in the amount of hydrogen recovered were observed (.

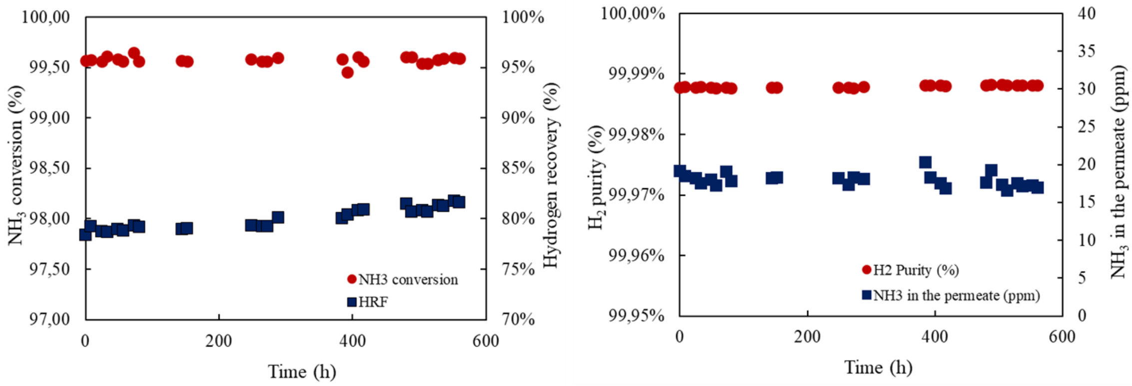


Figure 2. Long term ammonia decomposition test in the membrane reactor. Experimental conditions: T= 450 °C, $P_{retentate}$= 3 bar, $P_{permeate}$= atmospheric, Feed= 0.5 L_N/min NH_3 (see reference 2 in peer review articles section).

STFC have developed a new class of ammonia synthesis catalysts based on light metal amides. Sodium amide is the best in class at the current juncture with activities higher than that of ruthenium/alumina in a flow-over reactor configuration. For ammonia decomposition, there have been some technical problems with equipment, but investigations have continued into the effects of non-noble transition metals on the lithium imide-mediated ammonia decomposition reaction. The data analysis methods developed during UK lockdowns are now being fully utilised on the experimental data generated as part of this work package.

PSA ID and UORL demonstrated the potential of pure ammonia combustion in an internal combustion engine. A conventional Diesel engine was modified adding a spark plug for ammonia combustion ignition. For the first time, a pure NH3 combustion was performed over a large range of engine operating conditions. The Diesel high compression ratio, the piston bowl shape and the spark plug location seem to play a great role in the good combustion behaviour. These very promising results have to be deeply analysed and understood by the help of further experiments, like combustion process visualisation, and CFD modelling.

Environmental LCA, economic and safety assessment

The first year has been dedicated to defining the main goal and scope of the sociological survey, LCA, safety analysis and Life Cycle Cost assessment. These goals and scopes are back up with available literature work on both ammonia and hydrogen as energy carriers. These goal and scope frameworks will be detailed in the upcoming deliverable in the work package.

Highlights

ARENHA online M6 Consortium Meeting

Due to the current situation the month 12 consortium meeting was celebrated also online with success on October 20. Despite the COVID-19 progress have been made in all the actives WPs as detailed in previous section. Further information on the project can be found at the following link: https://arenha.eu.

Special issue on ammonia synthesis and utilization

Ammonia is a very important molecule. Its role is even becoming more important as it can also be used as energy carrier and fuel. A special issue dealing with ammonia synthesis and utilization is open in Catalyst, being Prof. Fausto Gallucci, Technical Manager of the ARENHA project, one of the editors. Submit your paper here: https://www.mdpi.com/journal/catalysts/special_issues/Ammonia_catal

Online joint workshop 2021
NON-BATTERY BASED ENERGY STORAGE
Four sustainable European solutions
September 15th, 2021

The online workshop is a joint effort of the RECYCALYSE project together with the European projects ARENHA, Next AEC and PROMETH2. The workshop is planned to be held on September 15th, 2021 from 09:30 to 12:30 (CET). The session's aim is to build a high-level meeting point for stakeholders across Europe to discuss and discover the following European projects within the non-battery-based energy storage sector. Registration. Further information will be available soon in the public website.

Dissemination activities, publications and presentations:

ARENHA public presentations as well as open access articles and public reports are available online in the dissemination section of the project website: www.arenha.eu.

Peer Reviewed Articles

1. Jaysree Pan, Heine Anton Hansen, Tejs Vegge. Vanadium oxynitrides as stable catalysts for electrochemical reduction of nitrogen to ammonia: the role of oxygen. J. Mater. Chem. A, 2020, 8, 24098- 24107. https://doi.org/10.1039/D0TA08313E.
2. V. Cechetto, L. D Felice, A. Arratibel Plazaola, F. Gallucci. Ammonia inhibition on H_2 produced via ammonia decomposition in a catalytic membrane reactor. Fuel Processing Technology 216 (2021) 106772. https://doi.org/10.1016/j.fuproc.2021.106772

Conference proceedings or presentations.

1. C. Mounaïm-Rousselle, P. Brequigny, S. Houillé, C. Dumand. Potential of Ammonia as future Zero-Carbon fuel for future mobility: Working operating limits for Spark-Ignition engines. International Congress on Energy and Powertrains (Rouen, France, November 2020). Oral presentation. https://www.sia.fr/evenements/193-sia-powertrain-energy-rouen-2020
2. Valentina Cechetto, Luca Di Felice, Jose Medrano, Camel Makhloufi, Jon Zuniga, Fausto Gallucci. Ammonia inhibition on H_2 produced via ammonia decomposition in a catalytic membrane reactor. World Online Conference on Sustainable technologies. March 17-19, 2021. Oral presentation. https://wocst.org/index.php.

Upcoming events

June 20-24, 2021	9th World Hydrogen Technologies Convention (WHTC 2021). Digital Edition. https://hyfcell.com/
July 18-23, 2021	17th International Symposium on Solid Oxide Fuel Cells (SOFC-XVII). https://ecs.confex.com/ecs/sofc2021/meetingapp.cgi
July 21-23, 2021	Power2Drive Europe: The smarter E Industry Days: The Digital Event https://www.powertodrive.de/industry-days/overview
August 25-27, 2021	Ammonia Energy Conference 2021 – Australia https://www.ammoniaenergy.org/event/ammonia-energy-conference-2021-australia/
September 14-16, 2021	GREENPOWER 2021. Poznan (Poland) https://greenpower.mtp.pl/en
September 14-17, 2021	EXPOQUIMIA. The International Chemistry Event. Barcelona (Spain) http://www.expoquimia.com/
September 15th, 2021	NON-BATTERY BASED ENERGY STORAGE: Four sustainable European solutions. Registration.
September 19-22. 2021	12th edition of the International Conference on Hydrogen Production (ICH2P-2021). https://www.ich2p-2021.org/index.html
October 6-8, 2021	Power2Drive Europe: EXHIBITION. Munich (Germany) https://www.powertodrive.de/home
October 20-21, 2021	Hydrogen Technology Expo Europe: Technologies & Solutions for a Low-Carbon Hydrogen Future, Messe Bremen (Germany) https://www.hydrogen-worldexpo.com/
October 27-28, 2021	HyVolution. Paris (France) https://www.hyvolution-event.com/en
November 8 - 10, 2021	HYPOTHESIS XVI Online 2021 (Hydrogen Power Theoretical & Engineering Solutions International Symposium) https://www.hypothesis.ws/
November 8 – 11, 2021	Ammonia Energy Conference 2021, Boston, MA (USA). https://www.ammoniaenergy.org/event/ammonia-energy-conference-2021/
Nov. 29 – Dec. 3, 2021	European Hydrogen Week 2021 https://www.fch.europa.eu/event/european-hydrogen-week-2021
December 7-9, 2021	Argus Green Ammonia – Virtual conference https://www.argusmedia.com/en/conferences-events-listing/green-ammonia

March 21-23, 2022	World Online Conference on Sustainable technologies (WOCST 2022). https://wocst.org/index.php
April 25-29, 2022	HANNOVER MESSE 2022. https://www.hannovermesse.de/en/
April 25-29, 2022	Hydrogen + Fuel Cells EUROPE. Part of HANNOVER MESSE 2022. https://www.h2fc-fair.com/en/
Spring, 2022	European Hydrogen Energy Conference 2022 (EHEC2022) Madrid (Spain) http://www.ehec.info/
May 16-17, 2022	11th Edition of International Conference on Catalysis, Chemical Engineering and Technology (CCT 2022), Tokyo (Japan) https://catalysis-conferences.com/
June 2-3, 2022	NH3 Event Europe 2022: 5th European Power to Ammonia Conference, Rotterdam (The Netherlands). https://nh3event.com/event/nh3-event-europe-2021/
July 31 – August 4, 2022	15th International Conference on Catalysis in Membrane Reactors Tokyo (Japan) http://iccmr15.org/

ARENHA in figures:

11 partners (6RES, 2 IND, 3 SME)

7 countries

5,684,325 € project

Start: April 2020

Duration: 48 months

Key milestones:

April 2023 - Ammonia synthesis and decomposition prototypes ready

April 2024 - Ammonia- based energy storage system integrated and validated

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More information about ARENHA (including a non-confidential presentation of the project) is available at the project website: https://arenha.eu/

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