areNH$_3$a

Advanced material and Reactor for ENergy storage tHrough Ammonia

Newsletter – June 2022

Editorial

Welcome to this 4th ARENHA project newsletter. ARENHA is an 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 fourth 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 NH_3 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.

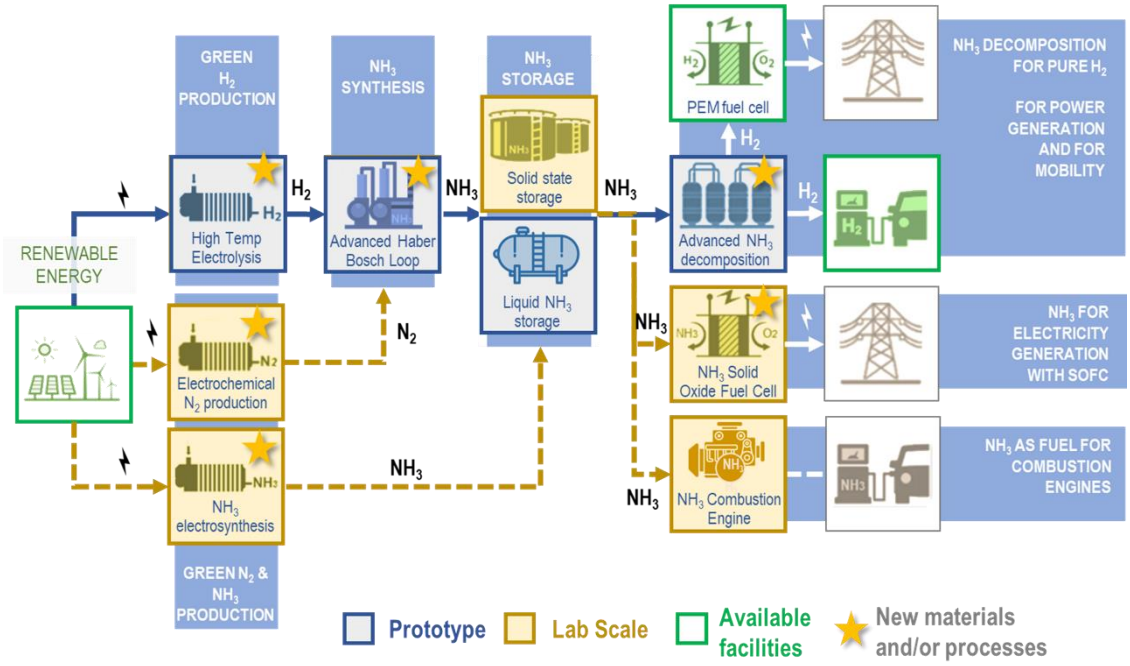

Figure 1. Power-to-ammonia-to-usage value chain in ARENHA

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.

Business case definition

Market and stakeholder analysis have been finalized and results were produced as part of deliverable 1.1. An overview of grey and green ammonia markets has been presented along with insights on renewable energy markets to provide input for the continuous development of the two business cases considered in ARENHA, import renewable energy at large scale and long distance, and transport of European offshore wind energy. Market structures along the ammonia value chain have been studied and were the basis for stakeholder analysis and mapping (Figure 2).

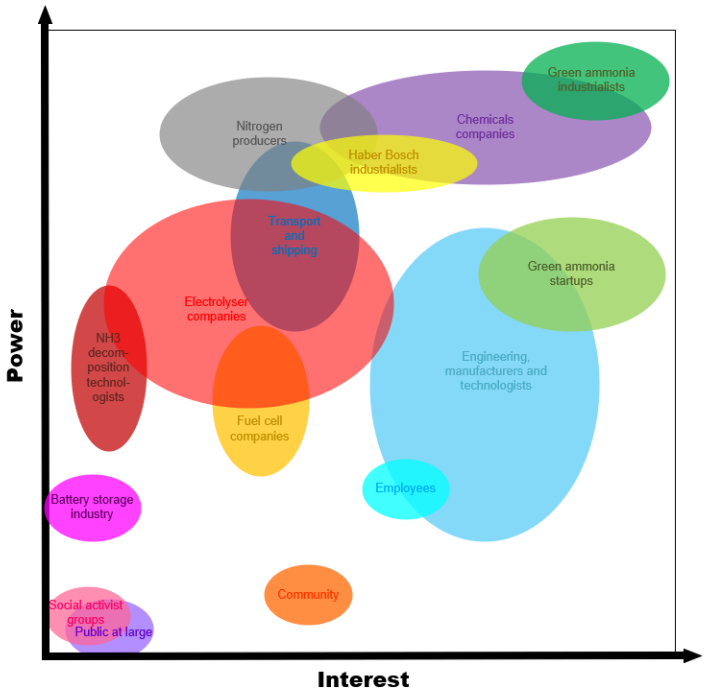

Figure 2. Stakeholder mapping as a power-interest grid

System requirements, design and modelling

Using SOEC experimental data provided by Elcogen and IKTS, ENGIE worked on the improvement of preliminary models developed for task 2.2. An in-depth literature research on cathode and electrolyte supported cells has been done for the validation of respectively Elcogen and IKTS SOECs models. After the creation of the steady-state balance of plant (BoP) for the system, a dynamic simulation has been performed and control strategies for the main SOEC parameters and BoP components have been identified and implemented. Next step involves the integration of electrolysis system with the ammonia production section and the subsequent sections of ARENHA as described in .

Key component development

The development of improved solid oxide electrolyser cells has made substantial progress at Fraunhofer IKTS. In the last period, the utilization of thinner electrolytes with a thickness of 110 µm and the addition of an adhesion layer to the air electrode were investigated. It was determined that the area specific resistance of the developed cells was significantly lower in comparison with the standard ones when the adhesion layer added and even lower when the thinner electrolyte was used. In the last period this phenomenon was further investigated by impedance spectroscopy. It was observed that the adhesion layer improved the cell resistance up to 40% compared to standard ones but had no influence on the ohmic resistance. With the thinner electrolyte the cell showed lower ohmic resistance, as expected. The sintering temperature had a mixed influence on the resistances of the cell. Lowering the sintering temperature improved the polarization resistance of the electrodes by approx. 20% independent from the operating temperature. On the other hand, the ohmic resistance of the cell increased at lower sintering temperatures. This effect was more pronounced at higher temperatures (up to 37% compared to standard) which resulted in an overall increase of cell resistance at higher operation temperatures when lower sintering temperatures were applied. Since the cells will be operated at higher temperatures the optimal sintering temperature is still under revision.

Elcogen continued working on modifications to the state-of-the-art solid oxide cell architecture (Figure 3). Experiments on single step microstructural changes and additives to the active hydrogen and oxygen layers are nearing conclusion. First iterations of cells that combine different promising modifications have been produced and are being analysed. The results of this development process will conclude in a new SOEC architecture that will be implemented in the SOEC stacks for the demonstration system.

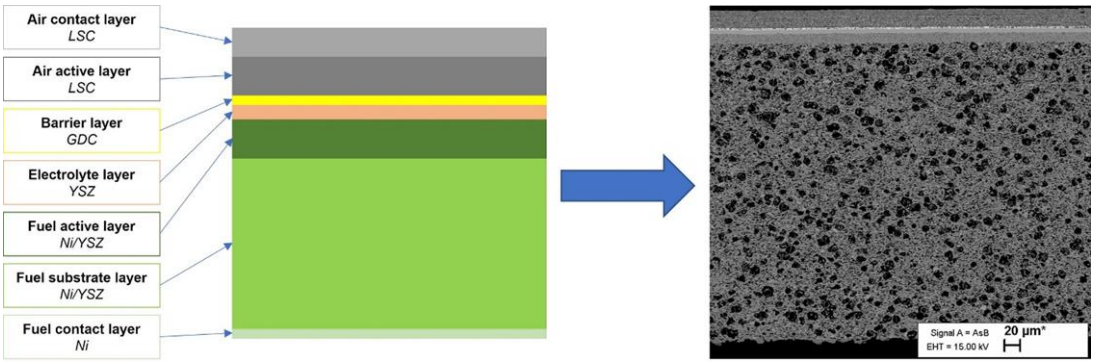

Figure 3. Schematic representation (left) and polished SEM cross-section (right) of a State-of-the-Art Elcogen commercial cell.

DTU continue with development of NH_3 absorber materials, advanced characterization for thermodynamic and kinetic studies have been performed with the newly commissioned test setups, which provide parameter inputs for modelling work on absorber bed and geometry design. For electrochemical N_2 production, electrode support cells with 10 µm thin electrolyte has been developed and characterized, new cells with cobalt free electrodes were manufactured.

Tecnalia continue with the development of Pd-based membranes and Al-carbon molecular sieve membranes for H_2 separation from ammonia decomposition in order to achieve high H_2 purities. Regarding the recycling of Pd-based membranes, the study of homogeneous and heterogenous phase electro leaching process were started, while further optimization of the selected DES leaching system with different additives was also performed.

As the purity of hydrogen produced via ammonia decomposition in a membrane reactor is not sufficiently high for fuel cell application, TU/e worked on investigating two strategies which could be adopted in order to increase hydrogen purity. Higher performance in terms of hydrogen purity can in fact be achieved in the membrane reactor by optimizing the reactor operating conditions and improving the membrane selectivity towards hydrogen by increasing the thickness of the membrane selective layer as well as by adding a hydrogen purification step downstream the membrane reactor to remove the undesired ammonia that permeates through the membrane.

STFC's work is continuing on refining the ammonia decomposition and synthesis catalysts. The most recent iterations of the catalysts have been successful in limiting catalyst escape while preserving excellent catalytic ability. High-resolution X-ray diffraction studies have shown that a whole family of catalysts with different stoichiometries exist, which goes some way to explaining the observed activities. These catalysts are inexpensive and contain no noble metals.

Environmental LCA, economic and safety assessment

After the definition of goal and scope of the sociological survey, LCA assessment, LCS safety analysis and LCC assessment, ENGIE and CNH2 have detailed their approach on both ammonia and hydrogen as energy carriers. Preliminary results have been presented on sociological, LCA, LCS and LCC part. In the next steps, short survey on social acceptance will be send to the consortium. Regarding LCC assessment, each subsystem considered in task 2.6 will be considered.

Highligths

ARENHA M24 Consortium Meeting (6th April 2022)

The first face-to-face meeting of the ARENHA project took place during April the 6th of 2022 and was held in the facilities of Engie in Paris. This meeting was the first presential meeting after the COVID-19 situation and boosted the cooperation between each of the partners of the project.

1st ARENHA workshop (7th April 2022)

The first ARENHA public workshop took place on April 7th, 2022. The workshop was focus on introducing the novel technologies related to ammonia-based energy storage. Around 67 participants attended the meeting (face-to-face and online). Presentation can be downloaded at the following link: https://arenha.eu/content/consortium-workshops.

ARENHA presented at the European Hydrogen Energy Conference 2022.

The ARENHA project was presented at the European Hydrogen Energy Conference 2022 (EHEC 2022). The conference took place on May 18th-20th, 2022. With more than 650 attendees from around 40 different countries. The conference is one of the biggest events related to Hydrogen.

ARENHA presented at the Conference on Industrial Technologies (IndTech 2022)

The ARENHA project had a booth at the EMIRI association village during the Industrial Technology conference that will take place in Grenoble (France) on June 27th-29th, 2022.

ARENHA at the 15th International Conference on Catalysis in Membrane Reactors

The ARENHA project will have several presentations in the frame of the 15th International Conference on Catalysis in Membrane Reactor that will take place in Tokyo from August 1st to August 4th (2022). A Keynote Lecture will present ARENHA project, and two oral presentations will describe some development related to hydrogen production via ammonia decomposition in a catalytic membrane reactor.

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. Christine Mounaïm-Rousselle, Pierre Brequigny, S Houillé, C Dumand. Potential of Ammonia as future Zero-Carbon fuel for future mobility: Working operating limits for Spark-Ignition engines. SIA Powertrain & Energy 2020, Nov 2020, Online, France. ⟨hal-03188481⟩.
3. 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
4. V. Cechetto, L. D Felice, R. Gutierrez Martinez; A. Arratibel Plazaola, F. Gallucci. Ultra-pure hydrogen production via ammonia decomposition in a catalytic membrane reactor. International Journal of Hydrogen Energy 47, (2022), 21220-21230. https://doi.org/10.1016/j.ijhydene.2022.04.240
5. C. Dumand, C. Mounaïm-Rousselle, P. Gaillard, E. Gérard, J. Dedeurwaerder, J. Op de Beeck. Ammonia powertrain for a carbon free mobility, SIA Powertrain & Energy 2022, June 15th-16th, 2022, Rouen (France).

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 17th-19th, 2021. Oral presentation. https://wocst.org/index.php.
3. Camel Makhloufi. Utilising Liquid Ammonia for Cost-effective storage and distribution of large Quantities of Renewable Energy. 14th Energy World Forum. May 19th, 2021. Oral presentation. https://energystorageforum.com/session/utility-utilising-liquid-ammonia-for-cost-effective-storage-and-distribution-of-large-quantities-of-renewable-energy#.
4. F. Kukka,b, S. Pylypkob, E. Lusta, and G. Nurka. Influence of active layer thickness of Reversible solid oxide cells on the electrochemical performance of water electrolysis. SOFC XVII conference. July 18th-23th, 2021. Oral presentation. https://www.electrochem.org/sofc-xvii/.
5. Christine Mounaim-Rousselle. Ammonia as zero-carbon fuel for Internal Combustion Engine: where are we today? 15th International Conference on Engines and Vehicles. September 12th-16th, 2021. Keynote Lecture. https://www.sae-na.it/.
6. José Luis Viviente. Advanced materials and Reactors for Energy storage tHrough Ammonia (ARENHA). Online workshop: NON-BATTERY BASED ENERGY STORAGE: Four sustainable European solutions. September 15th, 2021. Oral presentation. https://recycalyse.eu/recycalyse-joint-workshop/
7. Zançat Sahin, Valentina Cechetto, Luca Di Felice, Fausto Gallucci, H_2 Production through Ammonia Decomposition in a Catalytic Membrane Reactor: A computational and experimental study, 12th International Conference on Hydrogen Production (ICH2P-2021 – On-line conference). September 19th-23rd, 2021. Oral presentation. https://www.innomem.eu/event/12th-edition-of-the-international-conference-on-hydrogen-production-ich2p-2021/
8. J.L. Viviente, F. Gallucci, R. Campana, X. Sun, S. Megel, W.I.F. David, G. van Zee, S. Pylypko, J.A. Medrano, C. Dumand, C. Rouselle and A. Ramirez-Santos. Advanced materials and Reactors for ENergy storage tHrough Ammonia (ARENHA). European Hydrogen Energy Conference 2022 (EHEC2022). Madrid (Spain), May 18th-20th, 2022. Oral presentation.
9. C. Dumand, C. Mounaïm-Rousselle, P. Gaillard, E. Gérard, J. Dedeurwaerder, J. Op de Beeck. Ammonia powertrain for a carbon free mobility, SIA Powertrain & Energy 2022, June 15th-16th, 2022, Rouen (France). Oral presentation.
10. J.L. Viviente. vanced materials and Reactors for ENergy storage tHrough Ammonia (ARENHA). 15th International Conference on Catalysis in Membrane Reactors (ICCMR15), Tokyo (Japan). July 31st-August 4th, 2022. Keynote Lecture.

11. V. Cechetto, L. Di Felice, F. Gallucci. Adsorbent materials for residual ammonia removal from hydrogen produced via ammonia decomposition in a catalytic reactor. 15th International Conference on Catalysis in Membrane Reactors (ICCMR15), Tokyo (Japan). July 31st-August 4th, 2022. Oral presentation.
12. Z. Sahin, V. Cechetto, A. Rahimalimamaghani, F. Gallucci, M. Gazzani, L. Di Felice, M. Llosa Tanco, A. Pacheco Tanaka. Ammonia decomposition in Ru-based catalytic membrane reactors. 15th International Conference on Catalysis in Membrane Reactors (ICCMR15), Tokyo (Japan). July 31st-August 4th, 2022. Oral presentation.

Press articles

1. Katrin Schwarz, EU-Projekt ARENHA: Grünes Ammoniak für die Energiewende, on Fraunhofer IKTS website. https://www.ikts.fraunhofer.de/de/presse/news/2020_10_13_eu_projekt_arenha.html.
2. Christian Eckart, Ammonia as a tamer for green hydrogen. Public media article on the German newspaper "Background Tagesspiegel"
3. E. Monge, V. Sendarrubias, J. Martín, El proyecto ARENHA demostrará el potencial del amoniaco como forma de almacenamiento energético, Public media article on the Spanish newspaper "Energética". https://www.energetica21.com/revistas-digitales/septiembre-2021

Upcoming events

June 2-3, 2022	NH_3 Event Europe 2022: 5th European Power to Ammonia Conference, Rotterdam (The Netherlands). https://nh3event.com/
June 15-16, 2022	SIA POWERTRAIN & ENERGY, Rouen (France). https://www.sia.fr/evenements/263-sia-powertrain-energy-rouen-2022
June 26-30, 2022	23rd World Hydrogen Energy Conference (WHEC-2022), Istanbul, Turkey https://whecistanbul.org/
July 5-8, 2022	15th European SOFC & SOE Forum (EFCF2022), Lucerne (Switzerland) https://www.efcf.com/2022
July 31 – August 4, 2022	15th International Conference on Catalysis in Membrane Reactors Tokyo (Japan) http://iccmr15.org/
August 24-26, 2022	Ammonia Energy Conference 2022, Clayton, Victoria (Australia) https://www.ammoniaenergy.org/event/ammonia-energy-conference-2022-australia/

September1-2, 2022	1st Symposium on Ammonia Energy, Cardiff (UK)
September 12-15, 2022	66th Annual Safety in Ammonia Plants and Related Facilities Symposium, Chicago (USA). Link
November 20-24, 2022	EuroMembrane 2022, Sorrento (Naples, Italy) http://www.euromembrane2022.eu/
May28-June 1, 2023	18th International Symposium on Solid Oxide Fuel Cells (SOFC-XVIII), Boston (USA).
July 4-7, 2023	Low Temperature Fuel Cells, Electrolysers & H2 Processing (EFCF 2023), Lucerne (Switzerland) https://www.efcf.com/2023
July 9-14, 2023	13th International Congress on Membranes and Membrane Processes (ICOM 2023), Chiba (Japan). http://icom2023.jp/
October, 2023	16th International Conference on Catalysis in Membrane Reactors Donostia-San Sebastián (Spain)
May?, 2024	European Hydrogen Energy Conference (EHEC 2024). Bilbao (Spain)
July 2-5, 2024	15th European SOFC & SOE Forum (EFCF2024), Lucerne (Switzerland) https://www.efcf.com/

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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