

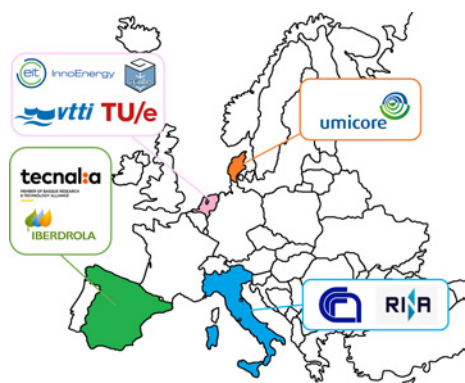
ANDREA H

AMMONIA BASED MEMBRANE REACTOR FOR GREEN HYDROGEN PRODUCTION



Project ID	101112118
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ -2022-02-04
Project total cost	EUR 2 980 361.25
Clean H ₂ JU max. contribution	EUR 2 980 361.25
Project period	01-07-2023 - 30-06-2027
Coordinator Beneficiary	FUNDACION TECNALIA RESEARCH and INNOVATION, ES
Beneficiaries	VTTI BV, 1 CUBE BV, UMICORE DENMARK APS, IBERDROLA CLIENTES SOCIEDAD ANONIMA, KIC INNOENERGY SE, RINA CONSULTING SPA, TECHNISCHE UNIVERSITEIT EINDHOVEN, CONSIGLIO NAZIONALE DELLE RICERCHE

<https://www.andreahproject.eu/>



PROJECT AND GENERAL OBJECTIVES

The ANDREA H HORIZON EUROPE project aims to effect a quantum leap in the development of advanced ammonia decomposition technologies to produce ultra-pure hydrogen (>99.998%) by developing an innovative system based on a catalytic membrane reactor for the cracking of Ammonia. The system will be based on the design, construction and testing of an advance ammonia cracker for ultra-pure hydrogen production (10 kg H₂/day) based on a catalytic membrane reactor in order to intensify the process of hydrogen production through the integration of cracking and purification. The advance cracker will include:

- An innovative, environmentally friendly structured catalyst with fewer critical materials, capable of operating at much lower temperatures than the state-of-the-art process.
- Innovative membranes for selective separation of hydrogen during the production process.

ANDREA H will also involve developing novel sorbents for polishing the hydrogen recovered by the membranes. In addition, the design and optimisation of all subcomponents for the balance of plant will be included, with particular attention to optimising thermal integration.

NON-QUANTITATIVE OBJECTIVES

- Designing and setting up a broad and complete network of value chains with world-class universities, research centres and industrial partners to develop the key building blocks for ammonia cracking.
- Developing a full life-cycle assessment, life-cycle costing and health and safety analysis of ANDREA H.
- Developing a set of flexible, cost-effective and environmentally friendly technologies that can be easily tailored for the decom-

position of ammonia into green hydrogen for different applications, such as energy and transport.

- Paving the way for the future exploitation of ANDREA H's key results by laying the foundations for new business opportunities in developing advanced catalysts and membranes. These will be integrated into membrane reactors to significantly intensify processes, enabling distributed hydrogen generation from ammonia as a long-term storage medium.
- Promoting the dissemination and communication of ANDREA H's results and expanding its impact.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

Main achievements in 2024 are in line with the planned activities:

- Market and stakeholder analysis.
- Kinetic modelling of catalyst and modelling of membrane.
- Development of the first and second generation of catalyst.
- Demonstration that a 1 wt% Ru based catalyst exhibits performances higher than the project target.
- First-generation structured catalysts developed on open-cell foams and 3D-printed periodic open-cellular structures.
- Development of three different families of sorbents.
- Development of a first-generation carbon membrane selective to hydrogen in a mixture of hydrogen, nitrogen, and ammonia.
- Preliminary integrated analysis of the new technologies based on sustainability pillars and circularity analysis – preliminary LCA, LCC, S-LCA analysis.
- Update of Dissemination, Exploitation and Communication Plan by mid-2024.

FUTURE STEPS AND PLANS

- Preliminary business model and exploitation strategy.
- Ammonia cracking modelling and sorbent modelling.
- Development of a second-generation structured catalyst on open-cell foams and 3D-printed periodic open-cellular structures.
- Development of a second generation carbon membrane.
- Development of sorbents and the sorbent kinetics sorption modelling.
- Development of ANDREAH's health and safety requirements.
- Review of the Dissemination, Exploitation and Communication Strategy.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year for reported SoA result
Project's own objectives	OPEX of the ammonia cracking system	k€/year	209.5		282.42	2020
	Decentralised cost of H ₂ production	€/kg	4.27		5.51	2020
	CAPEX of the ammonia cracking system	k€	211.74		384.72	2020
	Amount of Ru in the catalyst for low-temperature (<500C) cracking	wt%	<1		2 - 8	2021
	Amount of Pd per membrane	g	<0.1		2.6	2023

CANDHy

COMPATIBILITY ASSESSMENT OF NON-STEEL METALLIC DISTRIBUTION GAS GRID MATERIALS WITH HYDROGEN



Project ID	101111893
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ -2022-02-01
Project total cost	EUR 2 607 481.25
Clean H ₂ JU max. contribution	EUR 2 607 481.00
Project period	01-09-2023 - 31-08-2026
Coordinator Beneficiary	FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON, ES
Beneficiaries	SUMNISTROS INDUSTRIALES DIVERSOS SA, GRTGAZ, REDEXIS GAS SERVICIOS SL, REDEXIS SA, GERG LE GROUPE EUROPEEN DE RECHERCHES GAZIERES, RINA CONSULTING - CENTRO SVILUPPO MATERIALI SPA, UNIVERSITA' DEGLI STUDI DI BERGAMO, FUNDACION TECNALIA RESEARCH and INNOVATION

<http://candhy.eu/>



PROJECT AND GENERAL OBJECTIVES

- Performing a comprehensive review of the state of the art in European gas distribution grids, standards and testing codes for material compatibility with hydrogen, and hydrogen embrittlement mechanisms. The collected information will support the development of testing protocols to determine the properties of material classes studied in CANDHy under relevant operating conditions.
- Designing, developing and performing an experimental campaign to test the most relevant non-steel metallic materials found in CANDHy under different hydrogen levels in order to assess their tolerance towards this gas at operating conditions applicable for the distribution grid.
- Documenting and analysing the effect of hydrogen gas on the non-steel metallic materials tested in the aforementioned experimental campaign.
- Developing models for the prediction of hydrogen embrittlement mechanisms.
- Proposing guidelines, procedures and areas of development to support future standardisation of the testing and qualification of materials in the distribution network in the presence of hydrogen and natural gas blends.
- Developing a technical database on the hydrogen compatibility of metals as a tool to aid in the selection of materials for use in hydrogen gas distribution.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- A thorough review of the state-of-the-art of grid materials has been performed by creating a questionnaire and distributing it among DSOs and gas associations to collect relevant data (i.e. type of materials, year of installation, pipeline length, etc.).

- A review of the state-of-the-art of relevant standards useful for studying embrittlement phenomena in non-steel metallic materials has been performed.
- A literature review about hydrogen dissociation, solubility and diffusion in non-steel metallic materials was performed.
- The information extracted from the different reviews allowed the selection of the most representative materials to carry out the experimental campaign. In addition, it allowed the design of the experimental matrix to be followed in the campaign, which is currently underway.
- Experimental test matrix along with main characteristics of materials selected and specimen geometries were collected.
- Testing platforms were adapted to the new operating conditions (pressure level 16 bar) and to allocate the new kinds of non-steel metallic components.
- The selected testing materials were acquired and machining is under progress. The first specimens for slow strain rate testing were distributed among partners and testing is ongoing.

FUTURE STEPS AND PLANS

- Completing the machining of specimens for the Round Robin Test and begin the machining of specimens for individual testing.
- Continue with the experimental campaign, finish the Round Robin Test and start the complementary tests on non-steel metallic materials.
- Analyse the empirical testing results and start developing a semi-empirical method to relate the quantitative parameters obtained to the characteristics of each material.
- Create a database of gas grid metallic materials behaviour to serve as a repository of technical data.



PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Inventory of distribution grid materials	Km	Collect as much information as possible from European DSOs	2 471 198.91	✓
	Review of SoA standards related to hydrogen embrittlement tests	Number of standards	Review as many standards as possible	9	
	Database with compatible non-steel metallic materials	Number	Create one database	-	
	Study the impact of hydrogen on non-steel metallic materials	Number of materials analysed	Cover at least 5 materials	-	⚙️
	Semi-empirical model	Number	Construct 1 model to anticipate embrittlement	-	
	Harmonised guidelines	Number	Propose harmonised guidelines for future standardisation	-	

COSMHYC DEMO

COMBINED SOLUTION OF METAL HYDRIDE AND MECHANICAL COMPRESSORS: DEMONSTRATION IN THE HYSOPARC GREEN H₂ MOBILITY PROJECT

COSMHYC DEMO
INNOVATIVE H₂ COMPRESSION

Project ID	101007173
PRR 2025	Pillar 2 - H ₂ Storage and Distribution
Call topic	FCH-01-8-2020
Project total cost	EUR 3 773 858.75
Clean H ₂ JU max. contribution	EUR 2 999 637.13
Project period	01-01-2021 - 30-09-2025
Coordinator Beneficiary	EIFER EUROPAISCHES INSTITUT FÜR ENERGIEFORSCHUNG EDF KIT EWIV, DE
Beneficiaries	COMMUNAUTE DE COMMUNES TOURAINE VALLEE DE L'INDRE, EIFHYTEC, MAHYTEC SARL, Cavendish Hydrogen A/S, STEINBEIS INNOVATION GMBH, DE

<https://cosmhydc.eu>

PROJECT AND GENERAL OBJECTIVES

To meet the demands of a growing hydrogen economy, new technologies in the hydrogen-refuelling infrastructure, including those for hydrogen compression, are necessary. In COSMHYC DEMO, the innovative COSMHYC compression solution, which combines a metal hydride and mechanical compressor, has been shown to be ready for commercial deployment. At the test site in France, a public hydrogen-refuelling station (HRS) has been installed for a variety of vehicles (e.g. vehicle fleets and garbage trucks). The hybrid compressor will be used to supply hydrogen at both 350 bar and 700 bar.

NON-QUANTITATIVE OBJECTIVES

- COSMHYC DEMO will accelerate the deployment of hydrogen mobility by integration of the new compressor in a local ecosystem in which there have been previous hydrogen mobility activities and demonstration projects.
- COSMHYC DEMO will aim to increase public acceptance of hydrogen mobility.
- COSMHYC DEMO aims to include a smart gas hub for switching between on-site hydrogen supply storage, a hydrogen refuelling station and a filling centre for trailers. Therefore, a new gas panel will be designed which allows for smart switching between the filling centre, the hydrogen supply storage and the hydrogen refuelling station.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

The main achievement is the installation of the new hydrogen refuelling station on the demonstration site and the start of refuelling operation, mainly with the garbage truck of the HECTOR Interreg NWE project. Other main progress and achievements:

- The new membrane mechanical compressor as well as the innovative metal hydride compressor

were designed, manufactured and installed on the new HRS site.

- The compositions of the metal hydrides for all compression stages, were selected, without rare earth materials. These hydrides were produced in high quantities (approx. 1 000 kg per compression stage), and the compressive reactors have been manufactured and certified, including a brand-new heat exchanger, specifically developed within the project's scope.
- Also, the filling center gas panel is completed including safety studies. Indeed, the refuelling demonstration site of CCTVI will also be equipped with green hydrogen production, funded within the scope of the "Hy Touraine" initiative. The COSMHYC DEMO metal hydride compressor and filling center gas panel will also be used to compress hydrogen produced at HYSOPARC.
- The permitting process related to the installation of the metal hydride compressor on the demonstration site has been successfully completed.

FUTURE STEPS AND PLANS

- The testing phase can now continue at the HRS demonstration site in Sorigny (France), with all elements operational, including the newly commissioned metal hydride compressor.
- Certification of the metal hydride compressor is well advanced but still requires documentation.
- Data collection for the demonstration is ongoing, and the collected data will be integrated into a techno-economic analysis to demonstrate the expected economic performance of the entire system.
- The official inauguration event for the HRS and all related components will be organised in spring 2025 to bring together local stakeholders and the general public, including EU officials, at the demonstration site.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Refuelling protocol	-	SAE J2601 (light duty vehicles) SAE J2601-2 (heavy duty vehicles)	✓
	Noise	dBA	60	⚙️

DELHYVEHR

DELIVERY OF LIQUID HYDROGEN FOR VARIOUS ENVIRONMENT AT HIGH RATE

DelHyVEHR

Project ID	101137743
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ -2023-02-05
Project total cost	EUR 5 064 971.25
Clean H ₂ JU max. contribution	EUR 3 711 901.13
Project period	01-01-2024 - 31-12-2026
Coordinator Beneficiary	ENGIE, FR
Beneficiaries	TRELLEBORG CLERMONT FERRAND SAS, Fives Cryomec AG, CESAME-EXADEBIT SA, TRELLEBORG SEALING SOLUTIONS UK LIMITED, DEKRA SERVICES SA, ASOCIATIA ENERGY POLICY GROUP, EUROPEAN RESEARCH INSTITUTE FOR GAS AND ENERGY INNOVATION, BENKEI, ARIANEGROUP SAS, ABSOLUT SYSTEM SAS, ELENGY SA, UNIVERSITY OF ULSTER

<https://delhyvehr.eu/the-project/>

PROJECT AND GENERAL OBJECTIVES

DeLHyVEHR, coordinated by ENGIE, will develop a liquid hydrogen high-rate bunkering station with a refueling flowrate over 5 TPH and zero boil-off losses, dedicated to maritime, aviation and railroad applications. The project is expected to complete its demonstration by 2026. Alongside market maturity the cost of distribution is expected to be halved by 2030. DeLHyVEHR will drive the maturation of each main system constituting the large-scale refuelling station, with a specific focus on pumping (FIVES Cryomec AG), metering (CESAME-Exadébit SA), loading (TRELLEBORG) and boil-off gas management systems (ABSOLUT SYSTEM SAS) to the full demonstration apparatus (ArianeGroup SAS). Throughout the project, hydrogen safety management activities (UNIVERSITY of ULSTER) will support the maturation plan and de-risk design and operation. Technology, economic and environmental, policy and governance studies will allow the assessment and replication of the demonstration's performance.

NON-QUANTITATIVE OBJECTIVES

- Facilitate the industrialisation of high-rate refuelling stations for aviation, maritime, and rail applications.
- Reduce helium consumption—which could become a showstopper in liquid hydrogen development—by using gaseous nitrogen for sanitation.
- Provide harmonised guidelines and recommendations for the deployment of bunkering stations.
- Decarbonise heavy-duty vehicle transport and dedicated infrastructure to achieve a hydrogen-related carbon footprint in line with the second edition of the Renewable Energy Directive (below 3.38 kg CO₂/kg H₂).

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

The first designs of each component and their integration have been explored to prepare for the prototyping phase. This comprises the following activities:

- A global assumption book was created and presented at the project kick-off meeting, allowing to frame each partner's work and highlight their interdependency.
- The minimum requirements for the cryogenic pump have been defined, while sub-systems' design and quotation have been performed with selected suppliers.
- Following iterative improvement, FIVES delivered a prototype design and started the manufacturing process.
- A conceptual design review of the coupling system for the loading line has been conducted and is still ongoing, while a prototype has been tested with liquid hydrogen by Trelleborg UK.
- The vacuum jacketed flexible hose size has been frozen, and a first prototype has been manufactured and is ready to be tested.
- Technologies for liquid hydrogen and gaseous hydrogen and flowmeters for gaseous hydrogen have been analysed and pre-selected.
- Preliminary simulations performed with in-house model allowed to feed the consortium with first boil-off gas inventory. A qualitative selection of boil-off gas management strategies have been performed by AS and the preferred technologies will be studied in depth.
- Alongside the functional analysis performed that pre-defined the station's general architecture, a test bench design has been developed, validated and its most critical components are under contracting.

- Refinement of planning and budgeting for the prototyping and demonstration phases is ongoing.
- Preliminary cost estimations of the liquid hydrogen station for maritime and aviation business cases have been completed, including a Class IV estimate and a deep dive of operational expenses.
- An analysis of liquid hydrogen and refuelling station markets within the EU and worldwide has been launched and will be finalised.
- Finally, the safety studies identified the list of hazards to be considered for safety engineering and informed the initial project safety plan, which has now been completed.
- Multi-phase computational fluid dynamics model of liquid hydrogen fuelling through

the entire equipment of LS-LHRS is under development. In parallel the identified hazards are being studied with computational fluid dynamics simulations.

FUTURE STEPS AND PLANS

DeLHyVEHR will first define each application's high-level requirements based on a functional design analysis with the support of end-users from the advisory board. Through modeling, design, manufacturing and functional testings, the project will increase the technological maturity of each key component of the refuelling line in a dedicated track. These developments will feed into the integrated design and associated protocol specifications, forming components that will be assembled into a demonstration unit at ArianeGroup SAS's unique European facility in Vernon, France.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	LH ₂ flowmeter calibration uncertainty on the mass flow rate	%weight	0.6	
	Delivered liquid hydrogen flowrate	kg/h	5 000	
	Cryogenic pump design hydraulic efficiency	%	60	
	Endurance test duration on demonstrator	hours	10	
	Gas for connection/disconnection inserting operation	-	GN2	
	Number of connection-disconnection tested	Number	20	
	BOG recovery rate achievable	%	80	

EUH₂STARS

EUROPEAN UNDERGROUND H₂ STORAGE REFERENCE SYSTEM



Project ID	101137798
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ -2023-02-01
Project total cost	EUR 27 228 904.25
Clean H ₂ JU max. contribution	EUR 19 655 460.13
Project period	01-01-2024 - 30-09-2029
Coordinator Beneficiary	RAG AUSTRIA AG, AT
Beneficiaries	AXIOM POLSKA SP ZOO, TRINITY CAPITAL SL, AGGM AUSTRIAN GAS GRID MANAGEMENT AG, MAGYAR FOLDGAZTAROLO ZARTKORUEN MUKODO RESZVENYTARSASAG, EBN BV ENERGIE BEHEER NEDERLAND BV, AXIOM ANGEWANDTE PROZESSTECHNIK GES.M.B.H., ENERGIEINSTITUT AN DER JOHANNES KEPLER UNIVERSITAT LINZ VEREIN, LINZ STROM GAS WARME GMBH FUR ENERGIEDIENSTLEISTUNGEN UND TELEKOMMUNIKATION, SHELL GLOBAL SOLUTIONS INTERNATIONAL BV, MONTANUNIVERSITAET LEOBEN, NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO

<http://euh2stars.eu>

PROJECT AND GENERAL OBJECTIVES

EUH₂STARS (European Underground Hydrogen STorAge Reference System) is an ambitious, industry-driven flagship project with the motto 'Paving the way towards the future of European underground hydrogen storage'. EUH₂STARS aims to demonstrate competitive, complete and qualified underground hydrogen storage (UHS) in depleted porous natural gas reservoirs at technology readiness level (TRL) 8, by the end of the decade. RAG Austria AG contributes with an existing UHS pilot facility, developed to TRL 6 within the Underground Sun Storage 2030 project. EUH₂STARS combines implementation experience from the Underground Sun Storage 2030 project, with UHS project experiences from consortium partners to develop and define overarching rules and recommendations for UHS development across Europe. Furthermore, EUH₂STARS addresses the conversion of existing underground natural gas reservoirs into underground hydrogen storages and their integration into the future European hydrogen infrastructure. This will be demonstrated via several UHS replicator sites located in Austria (RAG), Hungary (HGS), The Netherlands (SHELL), and Spain (TES). In this way EUH₂STARS aims to deliver the following key results:

- Demonstration of the storage of pure hydrogen in depleted, porous reservoirs by operating four seasonal storage cycles at RAG's demonstrator and two storage cycles at HGS's replicator site. Each storage cycle considers different operational characteristics to demonstrate market-driven UHS operation at the project's end.
- Development of a beyond state-of-the-art hydrogen purification system and integration into the withdrawal process of RAG's demonstrator with the objective to demonstrate a successful separation of impurities from hydrogen within a real-world set-up.

During gas withdrawal from the demonstrator standardised hydrogen purification levels (e.g. hydrogen grade A or better) should be achieved.

- Achievement of a relevant green hydrogen certification for the demonstrator's power to hydrogen electrolysis and engage actively in green hydrogen certificate trading.
- Provision of guidelines to successfully manage all environmental, safety, legal and (future) regulatory, societal and market-related aspects to ensure a successful implementation of UHS facilities in Europe.
- Execution of an active stakeholder engagement strategy including an external expert advisory board to consider third parties' opinions and maximise public acceptance, transparency, visibility and exploitation of the project results.
- Set-up of a generic framework on the topic of health, safety, environment and quality, including a facility site monitoring plan to ensure UHS at an 'as low as reasonably practicable' risk level when operating RAG's demonstrator, the replicator and future commercial UHS sites.
- Presentation of transformation pathways to replicate demonstrator findings in full-scale commercial settings, both at existing underground natural gas storage facilities and at newly developed UHS sites in depleted natural gas reservoirs across Europe. This includes subsurface design, surface facilities engineering, and a comprehensive CAPEX assessment.
- Provision of best practice examples on how to integrate UHS facilities into regional, national and European energy infrastructure and markets by showcasing specific use cases in Austria, Hungary, the Netherlands and Spain, including integration into the European Hydrogen Backbone.



PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- EUH₂STARS started with a kick-off meeting.
- WP1 specified the to-be-used Societal Embeddedness Level methodology and guidelines for implementation.
- WP2 published a measurement, monitoring and verification plan for the UHS Rubensdorf demonstration facility and a Hydrogen safety planning.
- WP4 started initial works on UHS scale-up studies.
- In WP6 a communication and dissemination plan as well as a stakeholder survey and mapping including stakeholder engagement plan were developed.
- In WP6 a report on hydrogen value chain programs and structures, and on European

development projects was created.

- In WP7 the Data Management Plan as well as a project homepage and project folder were created.

FUTURE STEPS AND PLANS

In 2025 the consortium will physically meet in the Netherlands, allowing an in-person exchange between the partners across several topics. The project is expected to progress according to the Grant Agreement. Communication, exploitation and dissemination activities are expected to be carried out according to individual plans and gain traction as more results become available. After finalising and submitting the Rubensdorf operations plan, RAG's 100% hydrogen storage demonstration facility will commence its first of four seasonal storage cycles under the EUH₂STARS project in 2025.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Hydrogen purification achieved at exit of hydrogen purification unit	%	98 - Grade A according to ISO 14687	
	Hydrogen Recovery factor	%	95	

FRHYGE

FULL QUALIFICATION IN FRANCE OF LARGE-SCALE HYDROGEN UNDERGROUND STORAGE AND REPLICATION FROM GERMANY TO ALL EUROPEAN COUNTRIES



Project ID	101137892
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ -2023-02-01
Project total cost	EUR 27 240 481.25
Clean H ₂ JU max. contribution	EUR 19 994 886.40
Project period	01-03-2024 - 28-02-2029
Coordinator Beneficiary	STORENGY SAS, FR
Beneficiaries	GEOMETHANE, ECO MED, STORENGY DEUTSCHLAND BETRIEB GMBH, GRTGAZ, STORENGY DEUTSCHLAND GMBH, ESK GMBH, ARTELYS BELGIUM, GASNETZ HAMBURG GMBH, AXENS SA, STORENGY FRANCE, ENAGAS TRANSPORTE SA, CAPENERGIES ASSOCIATION, GEOSTOCK SAS, ARTELYS, ECOLE NATIONALE SUPERIEURE DES MINES DE PARIS, INSTITUT NATIONAL DE L'ENVIRONNEMENT INDUSTRIEL ET DES RISQUES - INERIS, ASSOCIATION POUR LA RECHERCHE ET LE DEVELOPPEMENT DES METHODES ET PROCESSUS INDUSTRIELS, IFP Energies nouvelles

<https://frhyge-project.eu>

PROJECT AND GENERAL OBJECTIVES

The limited technical feasibility and economic viability of large-scale hydrogen storage, as a solution to the intermittency of renewable energy sources, continues to hinder broad EU market adoption of renewables for decarbonising industry and mobility. Therefore, FrHyGe's main goal is to demonstrate and qualify the injection and withdrawal of hydrogen in an existing natural gas commercial storage site in industrial locations in France. FrHyGe will also consider the conversion process and scale-up strategies to foster replication of hydrogen storage in caverns within the EU, starting with an ongoing project in Germany to accelerate know-how transfer and economic viability. FrHyGe's objectives are:

- Development and implementation of two conversion processes from natural gas or brine caverns to hydrogen storage caverns.
- Demonstration of hydrogen storage and cyclability in a 3 000 tons potential cavern with 100 cycles from one hour to one week.
- Study of the local hydrogen value chain and the techno-economic impacts on local actors and the upscale and deployment of hydrogen storage along the European Hydrogen Backbone.
- Assessment of the risks and environmental impacts of hydrogen cyclic storage in salt caverns.
- Proposal for guidelines on safety, regulation and normative adaptations in Europe.

FrHyGe will open a path towards a potential of 38 kt of commercial hydrogen storage in several EU countries by 2030, and up to 1.5 Mt by 2050, through conversion and creation of caverns, leading to a CAPEX below 10 €/kg of stored hydrogen. Therefore, FrHyGe gathers a consortium of leading hydrogen industries and research centres in the EU, led by the worldwide underground storage actor Storengy, willing to realise large-scale and multi-site hydrogen storage in caverns.

NON-QUANTITATIVE OBJECTIVES

- Propose a conceptual design for the demonstrator.

Carry out all the required studies, laboratory tests (kinetics of the hydrogen solubility in cavern brine, hydrogen permeation in salt during cycling etc.).

- Develop geomechanics and thermodynamic predictive models for hydrogen storage in largely brine-filled salt caverns.
- Provide guidance on mechanical integrity testing and tightness testing of hydrogen caverns, assess the impact of gas quality requirements on the deployment of salt cavern and porous media storage, and outline technical options for evolutive salt cavern completions with subsurface safety equipment. This guidance will enable industrial-scale replication (3 000-ton hydrogen storage potential) of findings obtained at demonstration scale and through technical and scientific studies.
- Deliver an off-grid layout connecting two neighboring caverns, including engineering and demonstrator design.
- Provide a cost-benefit-analysis for the hydrogen storage projects GeoH₂ and SaltHy.

Provide a market uptake plan for the hydrogen storage projects GeoH₂ and SaltHy.

Estimate the development costs for site-specific underground storage at European scale.

- Provide a comprehensive risk assessment and deliver a safety plan for the demonstrator. Test administrative permitting procedure for the demonstrator.

Assess the environmental impacts of salt cavern hydrogen storage, including greenhouse gases.

- Issue the project communication plan and carry out all communication actions.

Coordinate the logistics and communication for events such as workshops, congresses.

Support for scientific publications and conference participation.

- Prepare a summary of the results in "Horizon, the EU research and Innovation Magazine".

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Project kick off - 20/03/2024.
- Participation in EU and national industry events: Club H₂ Sud, May and October 2024.
- HyUSPRe final conference, Utrecht - June 19, 2024; EAGE - GET24, November 6, 2024.
- European Hydrogen Week, at Brussels - Nov 18-22, 2024.

- Method definition and conceptual design in progress for the demonstrator, achieved by the end of February 2025

FUTURE STEPS AND PLANS

- 2024-2025: Study analyses for the Manosque demonstration site and SaltHy site replicability.
- 2026-2027: Construction phase.
- 2027-2029: Implementing 100 injections and withdrawal cycles, at Geomethane site. Studying Hydrogen reactions under various pressures. Comparing results with theoretical model forecast.
- From 2029: Commercial operations: 6 000 t capacity at Manosque demonstration site, 5 200 t at Harsefeld.

PROJECT TARGETS

Target source	Parameter	Target achieved?
Project's own objectives	To develop and implement two conversion processes from natural gas or brine cavern to hydrogen storage.	
	To perform 100 H ₂ cycles with duration from 1 h to 1 week for a cavern having the potential of 3 000 tons of H ₂ . Flow rate variation of up to 1 t/h.	
	To study the local hydrogen value chain and the techno-economic impacts on local actors and to upscale and deploy H ₂ storage along the European Hydrogen Backbone.	
	To demonstrate the safety and environmental acceptability of commercial storage of H ₂ in salt caverns.	
	To deliver a replication roadmap of hydrogen storages at pan-EU level.	

H₂REF-DEMO

HYDRAULIC COMPRESSION FOR HIGH CAPACITY HYDROGEN REFUELLING STATION DEMONSTRATION



Project ID	101101517
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ -2022-02-08
Project total cost	EUR 5 786 712.50
Clean H ₂ JU max. contribution	EUR 4 617 384.88
Project period	01-01-2023 - 30-06-2026
Coordinator Beneficiary	CENTRE TECHNIQUE DES INDUSTRIES MECANQUES, FR
Beneficiaries	FABER INDUSTRIE SPA, HYDAC TECHNOLOGY GMBH, HYDROGEN-REFUELLING-SOLUTIONS, H2NOVA, UNIVERSITA DEGLI STUDI DI MODENA E REGGIO EMILIA, UNIVERSITE DE TECHNOLOGIE DE COMPIEGNE

<https://heavy-v.h2ref.eu/>

PROJECT AND GENERAL OBJECTIVES

H₂REF-DEMO aims to further develop and quintuple the innovative compression concept developed in H₂REF, in order to address large vehicle refuelling applications requiring hydrogen to be dispensed at rates of hundreds of kg/h, such as refuelling bus fleets every evening at bus depots and refuelling trucks and trains. The concept is particularly well-suited for scaling up, thanks to the scalability of fluid power and composite pressure vessel technologies. As it incorporates the intrinsic modularity of fluid power technology together with that of pressure vessel technology, this disruptive solution will allow the different expected hydrogen supply to be addressed in a cost effective and reliable manner, in particular those that are the most suitable for large-scale refuelling applications where daily consumptions exceed one tone.

- On-site production.
- Road-delivery with high pressure trailers (e.g. 500 bar, in carbon composite), as these have an effective payload of around one tone.

Large-scale hydrogen refuelling involves two distinct types of compression:

- **Compression of hydrogen production for storage.** As production is the supply chain function with the highest cost, it tends to be performed through continuous (24/7) operation of production devices sized on the basis of daily consumption. Storage of the hydrogen produced requires compression at the same rate in order to keep storage size and footprint within acceptable limits.
- **Compression of stored hydrogen for high-capacity dispensing.** This compression function brings hydrogen from storage – that is a fixed vessel storing hydrogen produced on-site, a fixed vessel into which hydrogen has been delivered by trailer, or a trailer - maintaining the pressure required for dispensing at the rate required when dispensing takes place, for example at the rate required when dispensing takes place, for example at any time of the day when vehicles pull-in to refuel, or almost continuously during a certain time frame (e.g. 4-6 hours per day at a bus depot). The feed pressure of compression for dispensing is typically higher than that of compression for storage, however the

required throughput is also higher (as dispensing takes place only part of the time).

NON-QUANTITATIVE OBJECTIVES

The main goal of the project is to develop and test at full scale a high-capacity compression module (HCCM) capable of either hydrogen compression for storage prior to dispensing (1.2 tons/day) or hydrogen compression for high-capacity (35 MPa) dispensing (150 kg/h 2.5 kg/min), with 1 year's demonstration of use for high-capacity refuelling of heavy-duty vehicles in a commercially operated refuelling station. Particular attention will be given to design optimisation to minimise costs.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS MULTIPHYSICAL MODELLING AND SIMULATION OF THE HCCM PROCESS AND INITIAL SIZING AND ESTIMATION OF POTENTIAL PERFORMANCE.

- Functional specification of the HCCM based on a bladder accumulator and an elementary compression unit.
- Functional specification and material selection for bladder and tests on material.
- Design of the accumulator's shell.
- Development of an initial safety plan.
- Specification and simulation of the global refuelling system.
- Specification and simulation of the hydraulic power pack.
- Review of existing regulations, codes and standards and identification of gaps within the project activities.

FUTURE STEPS AND PLANS

- Selection of bladder material and manufacturing of bladders.
- Manufacturing of shells.
- Development of the accumulator and performance of the first tests.
- Develop the hydraulic power pack.
- Start gas skid development.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year for reported SoA result
Project's own objectives	CAPEX	k€/(kg/day)	1.2		2.2	2024
	Bladder durability	cycles	20 000		N/A	N/A

Project ID	101101447
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ -2022-02-09
Project total cost	EUR 3 453 685.00
Clean H ₂ JU max. contribution	EUR 3 453 685.00
Project period	01-01-2023 - 31-12-2025
Coordinator Beneficiary	SINTEF AS, NO
Beneficiaries	ORLEN LABORATORIUM SPOLKA AKCYJNA, LINDE GMBH, ENGIE ENERGIE SERVICES, AIR LIQUIDE FRANCE INDUSTRIE, EMCEL GMBH, ZENTRUM FÜR BRENNSTOFFZELLENTechnik GMBH, TOYOTA MOTOR EUROPE NV, EIFER EUROPAISCHES INSTITUT FÜR ENERGIEFORSCHUNG EDF KIT EWIV, ZENTRUM FÜR SONNENENERGIE - UND WASSERSTOFF-FORSCHUNG BADEN-WÜRTTEMBERG, NPL MANAGEMENT LIMITED, ENGIE, L AIR LIQUIDE SA, DEUTSCHES ZENTRUM FÜR LUFT - UND RAUMFAHRT EV

<http://hyqualityeurope.eu>

PROJECT AND GENERAL OBJECTIVES

HQE's goal is to increase the reliability of hydrogen refueling stations (HRSs) and the confidence of investors, operators and consumers in them. The objectives are:

- Collect representative data on the quality of hydrogen in European HRSs (300 spot samples in 100 HRSs).
- Develop an occurrence class and promote a risk assessment approach.
- Establish an open-source database to compile the results to allow HRS operators to take a risk assessment approach to ensure hydrogen quality.
- Test a network of six hydrogen analysis laboratories in order to certify them at EU level.
- Demonstrate the effectiveness of online analysis.
- Standardise hydrogen quality sampling and analysis methodologies for EU HRSs.
- Aid future research by defining the occurrence class of at least four new impurities beyond those listed in EN17124:2022 and ISO 21087:2019.

NON-QUANTITATIVE OBJECTIVES

HQE has extensively contributed to the development of ISO 14687, 19880-9 and 19880-8.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

The work of collecting information from HRS operators and performing sampling and analysis has started. The first laboratory comparison has been completed, with nine laboratories participating. All impurities listed in ISO 14687 were present in the comparison, which is the first comparison to be conducted of this type. A hydrogen quality workshop was hosted by ISO, ASTM and the National Renewable Energy Laboratory to disseminate some of the early project results.

FUTURE STEPS AND PLANS

The project will continue the sampling and analysis work, working towards a target of collecting 300 samples and further laboratory intercomparisons will be conducted. The project will also install online quality monitoring at three HRSs.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Number of samples collected from HRS	Number	200	100	
	Online monitoring of HRS quality	Months	12	3	

HYGHER

HYDROGEN HIGH PRESSURE SUPPLY CHAIN FOR INNOVATIVE AND COST EFFICIENT DISTRIBUTION



Project ID	101137867
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ -2023-02-04
Project total cost	EUR 6 769 096.25
Clean H ₂ JU max. contribution	EUR 4 991 009.88
Project period	01-01-2024 - 31-12-2026
Coordinator Beneficiary	EIFER EUROPAISCHES INSTITUT FÜR ENERGIEFORSCHUNG EDF KIT EWIV, DE
Beneficiaries	RE.CO.MA. S.R.L., HYPE ASSETS, EIFHYTEC, HYPE, STEINBEIS INNOVATION GMBH, UNIVERZA V LJUBLJANI, FRAUNHOFER GESELLSCHAFT ZUR FÖRDERUNG DER ANGEWANDTEN FORSCHUNG EV

<https://hygher.eu/>

PROJECT AND GENERAL OBJECTIVES

HYGHER aims to demonstrate the maturity of an innovative high-pressure hydrogen distribution value chain. This will include the installation of an innovative filling center able to compress hydrogen at high pressure, and the operation of two new high-pressure trailers to supply the fleet of taxis operated by HYPE in the Paris region. With a total budget of over 6.7 M € the seven consortium partners are working on improving and integrating all components along the new value chain. Through specific efforts on innovative compression, circularity and safety, HYGHER will allow sustainable and cost-efficient hydrogen distribution, removing one of the main barriers for the larger deployment of hydrogen mobility. The project started in 2024 and has an expected duration of 3 years.

NON-QUANTITATIVE OBJECTIVES

The main objective of HYGHER is to demonstrate the feasibility of an innovative, cost-efficient and reliable high-pressure value chain, by combining various innovative technologies ready for large-scale demonstration. The main progress expected beyond the state-of-the-art are:

- Build an innovative filling centre equipped with a metal hydride compressor, a mechanical booster, and cascade storage, enabling efficient distribution of over 2 t/day at 500 bar.
- Build two innovative trailers, each with a capacity of 1.25 t of hydrogen, operating at 500 bar and equipped with advanced control, monitoring, and communication systems to ensure efficiency and interoperability.
- Adapt a standard HRS by integrating 500bar trailers into smart storage cascade management, significantly improving efficiency and demonstrating increased capacity.
- Install and operate the entire value chain in the Paris region, close to trans-European transport network corridors, thereby strengthening the EU hydrogen infrastructure and preparing for replication and mass deployment.
- Demonstrate the new value chain under real commercial conditions by operating the equipment with HYPE's fleet of FCEV taxis and other 350bar and 700bar FCEVs.

- Validate the safety of the overall concept at 500 bar and prepare for a 700bar upgrade by reviewing regulations, codes, and standards, and performing safety analyses on system components and the overarching value chain.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

During the project's first year the consortium concentrated its efforts on the following activities:

- Definition of the overall high-pressure value-chain's specifications, setting the technical scope for seamless integration of all components to be developed along the hydrogen distribution value chain.
- Design of the subsystems of the HYGHER value chain, including an innovative metal hydride compressor, two high-pressure trailers, the filling center and a remote HRS to be adapted for high pressure supply.
- Analysis of the existing regulatory framework as a basis for technical developments within the project, and of proposed regulatory adjustments to accelerate the large-scale deployment of high-pressure hydrogen distribution.
- Development of a robust safety plan, establishing a joint safety approach for all development. In addition, preliminary safety studies considering all the components in the project's scope have been carried out. This will serve as the basis for the detailed and full hazard and operability studies that are scheduled for 2025.
- Preparatory work to set common assumption, scope and models for the different analyses to be conducted within the project, such as circularity, life cycle analysis and techno-economic analysis.

FUTURE STEPS AND PLANS

Main first steps of the project to be conducted in 2025 are:

- Optimisation of the design of sub-systems.
- Preparation of the construction phase for all sub-systems (ordering of components and planning the construction in the workshops).
- Data collection for the techno economic assessment study, life cycle analysis and scale-up analysis.
- Preparation of a promotional project video.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Number of trailers filled @ high pressure (500-700 bar)	Number/ day	2	
	Filling centers @hp pressure (500-700 bar)	t/day	2.15	
	HRS quantities delivered	kg/day	2 500	

HYLICAL

DEVELOPMENT AND VALIDATION OF A NEW MAGNETOCALORIC HIGH-PERFORMANCE HYDROGEN LIQUEFIER PROTOTYPE



Project ID	101101461
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ -2022-02-03
Project total cost	EUR 4 677 848.75
Clean H ₂ JU max. contribution	EUR 4 677 848.75
Project period	01-01-2023 - 31-12-2027
Coordinator Beneficiary	INSTITUTT FOR ENERGITEKNIKK, NO
Beneficiaries	MAGNOTHERM SOLUTIONS GMBH, ASOCIATIA ENERGY POLICY GROUP, FIVES CRYO, SUBRA A/S, IBERDROLA CLIENTES SOCIEDAD ANONIMA, SHELL GLOBAL SOLUTIONS INTERNATIONAL BV, HELMHOLTZ-ZENTRUM DRESDEN-ROSSENDORF EV, UNIVERSIDAD DE SEVILLA, UNIVERSITA DI PISA, UNIVERSITY OF ULSTER, ENGIE, TECHNISCHE UNIVERSITAT DARMSTADT, DANMARKS TEKNISKE UNIVERSITET

<https://www.hylical.eu>

PROJECT AND GENERAL OBJECTIVES

HyLICAL will contribute to:

- Achieving an energy demand of 8 kWh/kg and a reduction in liquefaction cost of 20% for small liquefaction volumes of 1-5 TPD/day.
- Reduced capital expenditures (CAPEX) and operating expenses (OPEX) by at least 20% in addition to the targeted energy savings.
- Decentralised (local) production of liquid hydrogen (LH₂), reducing the need for distribution and transport across long distances.
- Coupling of the magnetocaloric hydrogen liquefaction technology to hydrogen production from renewables (green hydrogen) for off-grid configurations.
- Integration into conventional liquefaction plants to increase their overall energy efficiency.
- Application of the processes for liquefaction of hydrogen and boil-off management of LH₂ tanks.
- Development and validation of a new magnetocaloric high-performance hydrogen liquefier prototype.

NON-QUANTITATIVE OBJECTIVES

- Development of an innovative concept for hydrogen liquefaction that is different from what is used today.
- Increased efficiency and reduced costs of hydrogen liquefaction technologies.
- Contribution to the roll-out of next generation liquefaction technology to new bulk hydrogen production plants.

- Positive impact on other Hydrogen Europe roadmaps related to liquid hydrogen.
- Improvement of the sustainability and circularity aspects related to the liquefaction of hydrogen.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Prediction of more than 150 new materials and compositions via machine-learning and computational materials design.
- Characterisation of more than 30 materials with respect to their thermo-magnetic and structural properties.
- Initial simulations of an active magnetic regenerator operating in the cryogenic region.
- Construction of a test bench for characterising magnetocaloric materials in the cryogenic region under process-relevant conditions.

FUTURE STEPS AND PLANS

- Up-scaling and processing of five to seven of the most promising materials to bridge the necessary temperature span (20-80 K).
- More detailed device simulations for the active magnetic regenerator and its integration into the liquefaction process, including heat exchangers, coldbox, liquid nitrogen pre-cooling etc.
- Construction of the liquefier prototype and performance test with optimised materials.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Energy efficiency	kWh/kg	8	
	Liquefaction cost	€/kg	1.5	

HYPSTER

HYDROGEN PILOT STORAGE FOR LARGE ECOSYSTEM REPLICATION



Project ID	101006751
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	FCH-02-7-2020
Project total cost	EUR 15 514 301.73
Clean H ₂ JU max. contribution	EUR 4 999 999.00
Project period	01-01-2021 - 30-06-2025
Coordinator Beneficiary	STORENGY SAS, FR
Beneficiaries	ERM FRANCE, ESK GMBH, ELEMENT ENERGY, S.A.S. BROUARD CONSULTING, STORENGY FRANCE, INOVYN CHLORVINYLS LIMITED, ENVIRONMENTAL RESOURCES MANAGEMENT LIMITED, EQUINOR ENERGY AS, AXELERA - ASSOCIATION CHIMIE-ENVIRONNEMENT LYON ET RHONE-ALPES, ELEMENT ENERGY LIMITED, ECOLE POLYTECHNIQUE, INSTITUT NATIONAL DE L'ENVIRONNEMENT INDUSTRIEL ET DES RISQUES – INERIS, ASSOCIATION POUR LA RECHERCHE ET LE DEVELOPPEMENT DES METHODES ET PROCESSUS INDUSTRIELS

<https://hypster-project.eu/>

PROJECT AND GENERAL OBJECTIVES

HypSTER aims to demonstrate the industrial-scale operation of cyclical hydrogen storage in salt caverns to support the emergence of the hydrogen energy economy in Europe in line with Hydrogen Europe's overall road mapping. The cavern is located in Etrez in Auvergne-Rhône-Alpes, France. For the production of green hydrogen, the Etrez storage site will rely on local renewable energy sources and a 1 MW PEM electrolyser. In the long run, this facility will produce 400 kg of hydrogen per day (equivalent to the consumption of 16 hydrogen-powered buses). The project's objective is to test industrial-scale green hydrogen production and storage in salt caverns and the technical and economic reproducibility of the process to other sites throughout Europe.

NON-QUANTITATIVE OBJECTIVES

- Assessment of the economic feasibility of cyclical hydrogen storage in salt caverns.
- Analysis of risk and environmental impacts.
- Definition of guidelines for regulation and normative adaptation in Europe.
- Study of the techno-economic replicability in Europe.
- Microbiological analysis.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- The workover of well EZ53 was successfully completed in 2023.
- All works (civil, piping, electrical, instrumentation, automation) have been carried out and all procured equipment has been installed and connected.

- Numerical simulation models for hydrogen storage in the salt cavern have been adapted.
- A risk analysis of underground hydrogen storage in the salt cavern has been performed.
- Commercial and microbiological analysis have started.
- The inauguration of the site was held in September 2023 in presence of Catherine Macgregor, CEO of Engie, and Mirela Atanasiu, Head of Unit Operations and Communications of the Clean Hydrogen Partnership. It was a key milestone and a highlight in the project's life.
- Nitrogen tightness test was successfully conducted in November 2023.
- Hot commissioning of the electrolyser was interrupted in October 2024 due to faulty transformers.
- A hydrogen tightness test was successfully conducted in October and November 2024.
- Cyclic tests started in December 2024.
- A public workshop was held in Paris in December 2024 with 140 participants, both in-person and online.

FUTURE STEPS AND PLANS

- Cycling tests finalised and post-trial assessments completed in summer 2025.
- Hydrogen production by electrolyser to resume in June 2025.
- Project wrap-up in summer 2025.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Power	MW	1	
	H ₂ Mass	kg	2 000	

HYUSPRE

HYDROGEN UNDERGROUND STORAGE IN POROUS RESERVOIRS



Project ID	101006632
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	FCH-02-5-2020
Project total cost	EUR 3 714 850.00
Clean H ₂ JU max. contribution	EUR 2 499 850.00
Project period	01-10-2021 - 30-06-2024
Coordinator Beneficiary	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO, NL
Beneficiaries	CENTRICA STORAGE LIMITED, MAGYAR FOLDGAZTAROLO ZARTKORUEN MUKODO RESZVENYTARSASAG, NAFTA AS, NEPTUNE ENERGY HYDROGEN BV, SNAM S.P.A., RAG AUSTRIA AG, EBN BV ENERGIE BEHEER NEDERLAND BV, UNIPER ENERGY STORAGE GMBH, ENERGIEINSTITUT AN DER JOHANNES KEPLER UNIVERSITAT LINZ VEREIN, EQUINOR ENERGY AS, SHELL GLOBAL SOLUTIONS INTERNATIONAL BV, FONDAZIONE BRUNO KESSLER, TECHNISCHE UNIVERSITAT CLAUSTHAL, THE UNIVERSITY OF EDINBURGH, FORSCHUNGSZENTRUM JULICH GMBH, WAGENINGEN UNIVERSITY

<https://www.hyuspre.eu/>

PROJECT TARGETS

Target source	Parameter	Target achieved?
Project's own objectives	GIS-based visualisation of suitable H ₂ underground stores and their H ₂ storage potential.	✓
	Develop future scenario roadmaps for EU-wide implementation.	
	Evaluate the amount of renewable energy that can be buffered versus time varying demands.	
	Establish cost estimate and identify the business case for H ₂ storage in porous reservoirs.	
	Establish geochemical, microbial, flow and transport, and geomechanical processes of H ₂ in porous reservoirs.	
	Map the proximity of hydrogen stores to large renewable energy infrastructure.	

PROJECT AND GENERAL OBJECTIVES

HyUSPre studied the potential of large-scale hydrogen storage in porous reservoirs in Europe. This includes the identification of suitable geological storage reservoirs and technical and economic assessments for large-scale hydrogen storage in these reservoirs. HyUSPre addressed specific technical challenges regarding storage in porous reservoirs and conducted an economic analysis to facilitate the decision-making process to develop a portfolio of potential field pilots. The techno-economic assessment, accompanied by environmental, social, and regulatory perspectives on implementation enabled the development of a roadmap for widespread hydrogen storage by 2050.

Main objectives:

- To establish the important geochemical, microbiological, flow, and transport processes in porous reservoirs in the presence of hydrogen via a combination of laboratory scale experiments and integrated modelling.
- To establish more accurate cost estimates to identify the potential business case for hydrogen storage in porous reservoirs.

- To identify suitable storage sites, and to assess their hydrogen storage potential.
- To develop a roadmap for the deployment of geological hydrogen storage up to 2050, including the evaluation of underground storage sites' proximity to large renewable energy production, the transport and import infrastructure and the amount of renewable energy that can be buffered to meet time varying demands. This will form a basis for developing future scenario roadmaps and preparing for demonstrations.

NON-QUANTITATIVE OBJECTIVES

- HyUSPre aimed to conduct a study assessing the potential match between hydrogen supply and demand sites, including the need for hydrogen to buffer time-varying renewable energy demands.
- HyUSPre aimed to conduct a study on the potential of European underground hydrogen storage to facilitate the achievement of a zero-emission energy system by 2050.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

The project concluded in June 2024.

NICOLHY

NOVEL INSULATION CONCEPTS FOR LH₂ STORAGE TANKS

NICOLHy

Project ID	101137629
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ - 2023-02-03
Project total cost	EUR 1 999 628.75
Clean H ₂ JU max. contribution	EUR 1 999 585.00
Project period	01-01-2024 - 31-12-2026
Coordinator Beneficiary	BUNDESANSTALT FUER MATERIALFORSCHUNG UND -PRUEFUNG, DE
Beneficiaries	NORGES TEKNISK-NATURVITENSKAPELIGE UNIVERSITET NTNU, ETHNICON METSOVION POLYTECHNION, DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV, ALMA MATER STUDIOURUM - UNIVERSITA DI BOLOGNA

<http://nicolhy.eu>

PROJECT AND GENERAL OBJECTIVES

NICOLHy aims to develop a novel insulation concept based on vacuum insulation panels that enables safe, cost and energy efficient storage of large quantities of liquid hydrogen (LH₂). Such large scale LH₂ storage technology is needed for establishing a hydrogen storage facility with dimensions from 40 000 m to over 200 000 m of LH₂. However, new design concepts are needed because the currently available technologies used in small and medium sized storage facilities are not suitable for upscaling. The main problems preventing upscaling are the long production time due to the process chain, the low failure tolerance and the spherical shape, which reduces the payload in technical applications by around 50% compared to other shapes. The novel NICOLHy concept will change these conditions by using a system which is modular, open-form, end time and cost efficient, while ensuring multi-failure tolerant production, operation and service, for onshore and offshore applications. The NICOLHy consortium consists of experts from the fields of cryothermodynamics, marine, chemistry, process, and safety engineering.

NICOLHy's technical objectives:

- Design a tank, along with its thermal insulation and supporting structure, which is suitable for the large-scale storage of LH₂, scalable, energy-efficient, sustainable, with low construction and operation costs, and with improved safety standards.
- Define materials and predict overall thermal insulation performance.



- Test novel insulation concept at laboratory scale.
- Perform safety and risk analyses during operation and fire scenarios.
- Perform circularity, sustainability and scalability assessments of the concept developed.

FUTURE STEPS AND PLANS

- Design and produce a test rig.
- Design and test diverse novel insulation concepts for LH₂ storage.
- Perform manufacturing, assembly, safety, circularity, sustainability, and scalability studies.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year for reported SoA result
Project's own objectives	LH ₂ tank capex	€/kg	20		100	2020
	LH ₂ boil-off	Mass-%	0.1		0.3	2020

OPHYCS

OPTIC FIBRE-BASED HYDROGEN LEAK CONTROL SYSTEMS



Project ID	101101415
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ -2022-02-02
Project total cost	EUR 2 499 428.75
Clean H ₂ JU max. contribution	EUR 2 499 428.75
Project period	01-01-2023 - 31-12-2025
Coordinator Beneficiary	ENAGAS TRANSPORTE SA, ES
Beneficiaries	GRTGAZ, FEBUS OPTICS, LUMIKER APLICACIONES TECNOLOGICAS SOCIEDAD LIMITADA, GERG LE GROUPE EUROPEEN DE RECHERCHES GAZIERES, FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON, FUNDACION TECNALIA RESEARCH and INNOVATION

<https://ophycs.eu>

PROJECT AND GENERAL OBJECTIVES

OPHYCS aims to develop a new system for continuous leak detection based on optic fiber sensor technologies, ensuring the safety and sustainability of a hydrogen-based energy system. Acknowledging the critical need for effective leak detection methods in light of the environmental impact of hydrogen emissions, OPHYCS introduces an innovative approach by developing a solution that includes cutting-edge coating materials for fibre Bragg gratings (FBGs) and the creation of a combined detection system merging FBGs with distributed acoustic and temperature-based detection technologies.

NON-QUANTITATIVE OBJECTIVES

The outcomes OPHYCS are poised to significantly impact the field, offering safer and more reliable solutions for the hydrogen-based energy landscape.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

Evaluation under laboratory conditions:

- Design baseline specifications and technical requirements for the H₂ sensing system were defined, in collaboration with all consortium partners, during the initial months of the project.
- Evaluation of FBG H₂ leak detection sensor prototypes under laboratory conditions.
- Ongoing assessment of H₂ sensor configurations.
- Development of coating materials for FBG sensors using advanced plasma techniques to ensure strong adhesion and enhanced hydrogen sensitivity.
- Initial evaluation of sensor configurations using Palladium and Tungsten Oxide, providing valuable insights for future prototype development and assessing the performance and adaptability of these materials in hydrogen detection applications.

Prototyping and manufacturing:

- Development and manufacturing of the first hydrogen leak detection sensor prototypes, exploring various coatings and configurations, and representing a significant advancement toward improving leak detection technology.

Development of a proof of concept and laboratory testing protocol:

- Establishment of protocols for proof of concept and laboratory tests to ensure proper control of critical variables such as humidity, temperature, and hydrogen concentration.
- A first field campaign in 2025, allowing for system optimisation, including the FBG interrogator and interpretative software. Subsequent field tests throughout 2025 will be crucial in assessing the system's performance and identifying the most efficient use cases within the H₂ industry.

FUTURE STEPS AND PLANS

- Ongoing optimisation of coating materials for FBG sensors using advanced plasma techniques.
- Laboratory tests enabling the evaluation of sensor responses under controlled environmental conditions, managing variables such as temperature, humidity, and hydrogen concentration.
- Development of FBG interrogators with focus on integrating optical components for signal amplification and testing configurations that enable a single interrogator to measure a large number of sensors. This breakthrough will significantly enhance the system's scalability while maintaining accuracy and response time.
- Multiple field campaigns throughout 2025 to further optimise the FBG sensors, interrogator, integration of various technologies, and final software solution. This marks the final stage of the OPHYCS project, including validation of the combined H₂ detection system in predefined use cases, such as pipelines, flanges, valves, and an operational hydrogen refueling station.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Minimum leak concentration detected	%	0.4	
	Time of response	sec	30 (Max. response time of 1 sec at a concentration of 0.4% -vol.)	
	Detection threshold	ln/min	0.4 (blending operation) 1.2 in pure H ₂)	
	Time of recovery	sec	20 – 60 (depending on application)	
	Potential interferences	-	The sensor's sensitivity to hydrogen is not affected by the presence of other gases.	

PILGRHYM

PRE-NORMATIVE RESEARCH ON INTEGRITY ASSESSMENT PROTOCOLS OF GAS PIPES REPURPOSED TO HYDROGEN AND MITIGATION GUIDELINES



Project ID	101137592
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ -2023-02-02
Project total cost	EUR 3 999 073.75
Clean H ₂ JU max. contribution	EUR 3 999 073.75
Project period	01-01-2024 - 31-12-2027
Coordinator Beneficiary	GRTGAZ, FR
Beneficiaries	SNAM S.P.A., SINTEF AS, ENAGAS TRANSPORTE SA, GERG LE GROUPE EUROPEEN DE RECHERCHES GAZIERES, FLUXYS BELGIUM SA, FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON, UNIVERSIDAD DE BURGOS, ONDERZOEKSCENTRUM VOOR AANWENDING VAN STAAL NV, FUNDACION TECNALIA RESEARCH and INNOVATION, FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV, COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

<https://pilgrhym.eu/>

PROJECT AND GENERAL OBJECTIVES

PilgrHym is an interdisciplinary project which aims to contribute to the decarbonisation of the energy sector by providing a European roadmap with comprehensive guidelines to assess the feasibility of safely and efficiently integrating pure H₂ into existing natural gas infrastructure.

NON-QUANTITATIVE OBJECTIVES

- Develop a database of material characterisation testing on representative steel grades of the EU gas grids, including tensile, fracture toughness and fatigue crack growth (FCG) properties.
- Establish harmonised testing protocols to support the repurposing of natural gas lines to accommodate hydrogen.
- Develop a numerical modelling approach for simulating and predicting hydrogen assisted fracture and fatigue.
- Optimise a more realistic fatigue crack growth rate master curve for the purpose of assessing fitness-for-service, in particular for low delta K values corresponding to the actual operating domain of the EU gas grids.
- Identify existing and/or innovative technologies for mitigation compatible with operational constraints.
- Engage with stakeholders to ensure cooperation and awareness.
- Facilitate the uptake and exploitation of PilgrHym results by the academic community, technology developers and end-users.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

PilgrHym delivered three main public reports in 2024:

- A literature and standard review focused on material mechanical testing in pressurised hydrogen gas. This review describes the testing procedures from more than 27 standards, highlighting their

incongruencies and gaps when it comes to pressurised hydrogen testing environments.

- A literature review of innovative modelling approaches, including more than 30 papers and four model frameworks, covering state-of-the-art modelling for fracture and fatigue applications.
- A transmission system operator (TSO) inventory which collects data on the transmission steel networks present in Europe. The questionnaire was sent out to all EU TSOs and various associations (GERG, ENTSG, EPRG and CEN TC234) representing EU TSOs. A total of 23 onshore TSOs replied, accounting for a global length of more than 78% of the total European grid.

PilgrHym has selected twelve materials to be tested (two for round robin tests and ten for the main testing campaign). The materials will be dispatched to the project's testing laboratories in 2025. The testing protocols have been established. The round robin test ended in June 2025. The results will be shared in a later update.

FUTURE STEPS AND PLANS

Following the round robin test, the main testing campaign on the other ten materials will be performed. In parallel numerical models will be developed. The expected outcomes of the project are:

- Definition of optimised testing procedures for hydrogen compatibility assessment of pipeline steels.
- Assessment of novel time and cost effective experimental procedures for material qualification in a hydrogen environment.
- Development of a database summarising the characterised relevant properties of pipeline materials in hydrogen gas.
- New and innovative models for hydrogen-induced fracture and fatigue cracking simulation.
- Development of improved and more cost-effective FCG-master curves, with a reduced number of experimental tests.



PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Number of km of the European grid covered - Information collected on the EU and connected countries H ₂ grid.	km	156 054	✓ (182 469)
	Different steel microstructures to be assessed (including 8 base materials, 2 welds and 2 heat affected zones).	Number	12	
	Dedicated testing protocols for H ₂ environments (tensile test, fracture toughness test and test on hollow specimen).	Number	3	
	Reports on suitable innovative technologies with proposed testing protocols.	Number	1	
	Guidelines (reports) on experimental characterisation of mechanical properties, mitigation techniques and master curves.	Number	2	
	Mitigation techniques identified.	Number	10	
	Numerical approach based on the performed experimental results.	Number	1	
	Optimisation of design codes and standards with reduced over-conservatism vs ASME B31.12 (reduction of over-conservatism on the master curve).	%	60	
	Fracture models	Number	1	
	Fatigue models	Number	1	
	Reduction of total testing time for fracture toughness (time reduction).	%	20	
	Dissemination of stakeholder analysis for the use cases and organised workshops and events.	Number	5	
	Dissemination of PilgrHYM's results towards the scientific, academic and standardisation community.	Number	2	

RHEADHY

REFUELLING HEAVY DUTY WITH VERY HIGH FLOW HYDROGEN



Project ID	101101443
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ -2022-02-10
Project total cost	EUR 4 734 730.00
Clean H ₂ JU max. contribution	EUR 3 999 381.50
Project period	01-02-2023 - 31-01-2027
Coordinator Beneficiary	ENGIE, FR
Beneficiaries	EMERSON PROCESS MANAGEMENT FLOW B.V, LAUDA DR. R. WOBSE GMBH and CO KG, TESCOM EUROPE GMBH CO KG, HYDROGEN-REFUELING-SOLUTIONS, ENGIE ENERGIE SERVICES, BENKEI, FAURECIA SYSTEMES D ECHAPPEMENT SAS, ALFA LAVAL VICARB SAS, ZENTRUM FÜR BRENNSTOFFZELLEN-TECHNIK GMBH

<https://rheadhy.eu/>

PROJECT AND GENERAL OBJECTIVES

RHeadHy's main goal is to develop components and hydrogen refuelling stations to enable the implementation, testing and market introduction of new very-high-flow refuelling protocols for heavy-duty vehicles.

NON-QUANTITATIVE OBJECTIVES

- Design and assemble a very-high-flow hydrogen refuelling line. The main goal is to provide components and refuelling lines for the required performance and operating conditions (very-high-flow rate, pressure, temperature, dynamic behaviour) with optimal trade-off between performance and constraint repartition among components.
- Develop new components needed for high-flow refuelling. The main goals are (i) to develop new very-high-flow components, such as cooling technology, flow meters, valves, heat exchanger, and make them ready-to-commercialise; (ii) to develop an advanced bidirectional communication interface; (iii) to test, optimise and adapt components already in the prototype phase of their development, such as breakaway, hose, nozzle and receptacle assembly.
- Develop and demonstrate a new protocol for refilling storage systems (WP4 and WP5). The main goal is the demonstration of new standardised refuelling protocols for heavy-duty vehicle developed in ISO TC 197 WG24 or other standardisation bodies.
- Ensure the fast and efficient refill of storage systems with H₂ at low cost. The main goal is to demonstrate the protocols, by using components, under the conditions mentioned above.
- Standardise and certify components for hydrogen refuelling stations to ensure a fast deployment (WP6). The main goal is to contribute to standard

development through participation in ISO TC 197 and CEN 268 WG5, and obtain certifications for all the components according to relevant standards (ISO TC 197, CEN 268 WG5, OIML R139).

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- All partners (product manufacturers) have manufactured their new products and the majority have planned the delivery to hydrogen refuelling stations.
- More than 350 simulations were done in order to aid the design of the different components. ENGIE Grigen worked mostly on pressure drop of the complete line, on the high-pressure storage configuration, and on the cooling system design.
- All external communication tools are in place (website and LinkedIn page) and are seen by the community. The profiles of the individuals of the community are in line with the project objectives.
- All management tools are in place (Dashboard, Benkeitori (for sharing of files), meeting planification and rules etc.).

FUTURE STEPS AND PLANS

The components for RHeadHy are being produced; cooling unit- LAUDA, heat exchanger - ALFA LAVAL, flow sensor - EMERSON MicroMotion, control valve and safety valves - EMERSON TESCOM, truck storage test system - FORVIA. They will be delivered to HRS for the assembly of the hydrogen high-flow distribution lines. In parallel, the testing sites (HRS and ZBT) are being prepared. Groundworks are well advanced, and the last pending decisions are being made to host the two hydrogen refuelling stations. Afterward, the two high-flow distribution lines will be tested on these two stations in order to validate the project's key performance indicators.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Time for refill for a 100 kg HD truck storage test system.	min	10	
	Time for refuelling - heat exchanger and cooling system hydrogen dispensed below -30C.	min	10	
	Pressure regulator and shut-off valve compatible with very high flow rate and high pressure (1 000 bar).	g/s	170 (mean flow rate) 300 (peak flow)	
	Peak flow for prototype breakaway, nozzle, hose.	g/s	300	
	Number of refuelling events demonstrated for the fully integrated chain.	Number	300	
	Number of refuelling simulations performed.	Number	1 000	
	Flow measuring device compatible with very high flow rate, targeting >100 kg total mass per refuelling.	g/s	170 (mean flow rate) 300 (peak flow)	

ROAD TRHYP

ROAD TRAILER DESIGN - USE OF TYPE V THERMOPLASTIC TUBE WITH LIGHT COMPOSITE STRUCTURE FOR HYDROGEN TRANSPORT



Project ID	101101422
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ - 2022-02-07
Project total cost	EUR 2 642 912.59
Clean H ₂ JU max. contribution	EUR 2 499 999.50
Project period	01-01-2023 - 31-12-2025
Coordinator Beneficiary	L AIR LIQUIDE SA, FR
Beneficiaries	ENVITEST J. PACHOLSKI SPOLKA JAWNA, SEGULA SLOVENSKO S.R.O, SEGULA ENGINEERING, COVESS NV, EFECTIS FRANCE, ECOLE NATIONALE SUPERIEURE DE MECANIQUE ET D'AEROTECHNIQUE, ARKEMA FRANCE SA, POLITECHNIKA WROCLAWSKA, UNIVERSITE DE POITIERS, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS

<http://https://road-trhyp.eu/>

PROJECT AND GENERAL OBJECTIVES

Today, hydrogen transportation solutions use tubes with a working pressure between 200 - 300 bar. ROAD TRHYP's overall objective is to demonstrate that using a trailer made out of new thermoplastic composite tubes (Type V) is a suitable solution to maximise the quantity of hydrogen transported while satisfying end-user requirements on safety and ability to be decontaminated, and enforced regulations, with a low total cost of ownership.

Therefore, ROAD TRHYP will design a trailer capable of handling a payload of 1.5 ton of hydrogen with 700 bar tubes and a capex lower than 400 €/kg. This enables the reduction of the number of transport rotations between the hydrogen production site and the delivery site, and thus a reduction of the environmental footprint of compressed hydrogen transport, but also a downsizing of the compressor at the hydrogen refueling station. In addition, ROAD TRHYP will investigate new fire testing methodologies and safety barriers for Type V adoption.

ROAD TRHYP's overall ambition is to develop Europe's value chain of Type V cylinder technologies. Beyond the targeted commercial Type V trailer applications, the knowledge developed on composite materials could benefit main actors in the mobility sectors or the hydrogen storage for inter-seasonal energy storage. Therefore, ROAD TRHYP intends to address all manufacturers across Europe who may benefit from the project's innovative process and materials. Thus, ROAD TRHYP will contribute to the European Green Deal making hydrogen a widespread energy carrier by 2030.

NON-QUANTITATIVE OBJECTIVES

Formulation of regulatory recommendations aiming at the technology's faster deployment.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Design of Type V cylinder completed.
- First tests show a gravimetric index higher than 7%.
- One licence of Type V cylinder sold by Covess.
- Certification in progress.
- Design of the trailer is finalised and lifecycle analysis of Type I and Type IV trailers are completed.

FUTURE STEPS AND PLANS

- Develop a cylinder with 700 bar working pressure based on the 300 bar design.
- Perform key tests based on the EN 17339 norm, including cycling tests, extreme temperature cycling tests and bonfire and validate the burst/leak model.
- Perform key tests according to cylinder usage such as decontamination and filling/unfilling, with the objective to identify the key parameters to optimise decontamination and validate a model to predict temperatures in the cylinder during filling/unfilling.
- Finalise the characterisation of the compartment of the material in fire.
- Manufacture the demonstration system made out of three cylinders.
- Perform filling/unfilling test and bonfire tests to validate models.
- Make recommendations to the ISO WG TC 197 for the interoperability of hydrogen trailers at a hydrogen station.
- Perform a lifecycle analysis for Type V trailers.
- Continue efforts to sell more Type V licenses and identify exploitation opportunities for the multi-element gas container.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Design Type V 700 bar tube	%	5.3	
	Water content in Hydrogen	ppm	<5	
	Ability of Type V tank to pass a bonfire test	-	-	
	CAPEX	€/kg H ₂ stored	400	
	Formulation of regulatory recommendations aiming at faster deployment of the technology.	-	Present recommendation to WG ISO TC 197 regarding interoperability between HRS and trailers.	

SHERLOHCK

SUSTAINABLE AND COST-EFFICIENT CATALYST FOR HYDROGEN AND ENERGY STORAGE APPLICATIONS BASED ON LIQUID ORGANIC HYDROGEN CARRIERS: ECONOMIC VIABILITY FOR MARKET UPTAKE



Project ID	101007223
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	FCH-02-1-2020
Project total cost	EUR 2 563 322.50
Clean H ₂ JU max. contribution	EUR 2 563 322.50
Project period	01-01-2021 - 30-06-2024
Coordinator Beneficiary	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, FR
Beneficiaries	KUWAIT PETROLEUM RESEARCH and TECHNOLOGY BV, HYDROGENIOUS LOHC TECHNOLOGIES GMBH, NOORDWES-UNIVERSITEIT, UNIVERSIDAD DEL PAIS VASCO/ EUSKAL HERRIKO UNIBERTSITATEA, EVONIK OPERATIONS GMBH, FRIEDRICH-ALEXANDER-UNIVERSITAET ERLANGEN-NUERNBERG

<http://sherlohck.eu>

PROJECT AND GENERAL OBJECTIVES

Liquid organic hydrogen carriers are attractive due to their ability to safely store large amounts of hydrogen (up to 7 % wt or 2 300 KWh/ton) for a long time and to release pure hydrogen on demand. SHERLOHCK targets the development of (i) highly active and selective catalysts with partial/total substitution of platinum group metals (PGM), (ii) a novel catalytic system architecture, with components ranging from the catalyst to the heat exchanger, to minimise internal heat loss and to increase the space-time yield; and (iii) novel catalyst testing, system validation and demonstration through the demonstration unit (> 10 kW, > 200 hours).

PROGRESS AND MAIN ACHIEVEMENTS

- Requirements have been defined for the hydrogenation and dehydrogenation catalyst, the type and quality of liquid organic hydrogen carriers, hydrogen quality, testing routine, and energy consumption, to ensure compatibility with the project objectives. This initial work has laid the foundation for SHERLOHCK.
- Benzyltoluene was chosen as the reference molecule and Pt-based catalysts from Clariant were selected as the catalysts' benchmark.
- The catalyst design through density functional theory predictive analysis has reduced the use of PGM catalysts. Calculations were made for the dehydrogenation of methylcyclohexane (to toluene) as a reference molecule instead of benzyltoluene which was too complex for the calculation. The overall dehydrogenation energies calculated for the various considered alloys showed that Co, Co₃Pt, SnPt, Sn₃Pt₂, Sn₂Pt, and Sn₄Pt could be potentially low Pt-based catalytic materials.
- Catalyst materials have been synthesised and tested on a lab scale with a standardised test protocol. Some Pt-X (X=Fe, Zn, Co, Cu) catalysts supported on alumina outperform the benchmark catalyst in activity. Pt-Co, with a cobalt content of 0.5 wt.% achieved almost the same dehydrogenation activity and selectivity as catalysts with 1 wt.% Pt but with

half the amount of this noble metal. PGM-free catalysts show very low activity.

- Experiments with model substances simulating by-product formation provided better insights into the dehydrogenation reaction and catalyst deactivation.
- Promising results have been obtained for the first catalyst reactivation procedures by oxidative regeneration with synthetic air executed in batch operation.
- Models and simulations were performed on structured heat-exchangers reactors combined with improved catalysts, in order to support the choice of possible reactor geometries, in particular, to define suitable heat conductive reactor structures. These results indicate that for both reactions, foam structure, catalyst activity, mass, and operating conditions are first-order parameters.
- 3D monolith structures have been prepared to integrate catalysts materials.
- A long-term test campaign has been launched and ran until June 2024.
- The communication activities carried out are integrated with the Project website (<https://sherlohck.eu/>), diffusion of activities on two social platforms: LinkedIn (<https://www.linkedin.com/in/sherlohck/originalSubdomain-es>) and 'X' (<https://x.com/SherlohckProj>) and participation to promotional events (conferences, workshops, newsletters, and press releases).

FUTURE STEPS AND PLANS

- SherLOHCK has integrated the catalyst into the thermal conductive support structure.
- Long-term testing in continuous operation (> 200 hours) was ongoing until June 2024.
- Testing of the resistance of catalysts to different poisons was ongoing.
- The modelling of the reaction kinetics for the design of new reactors has started for the dehydrogenation reaction.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year for reported SoA result
Project's own objectives	Catalyst selectivity	%	99.8	99.4		~100	2022
	Degree of conversion	%	90	88		~100	2022
	Catalyst productivity in dehydrogenation	g H ₂ / g catalyst/ min	3	5.3	✓	0.85	2022

SINGLE

ELECTRIFIED SINGLE STAGE AMMONIA CRACKING TO COMPRESSED HYDROGEN



Project ID	101112144
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ -2022-02-04
Project total cost	EUR 2 989 671.25
Clean H ₂ JU max. contribution	EUR 2 989 671.25
Project period	01-05-2023 - 30-04-2026
Coordinator Beneficiary	COORSTEK MEMBRANE SCIENCES AS, NO
Beneficiaries	GEA ENERGIA CRIO SL, SINTEF AS, FONDAZIONE ICONS, UNIVERSITA V LJUBLJANI, UNIVERSITAT POLITECNICA DE CATALUNYA, AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS

<https://singleh2.eu/>

PROJECT AND GENERAL OBJECTIVES

SINGLE aims to demonstrate the competitive advantages of proton ceramic electrochemical reactors for the production of high-purity, pressurised hydrogen (up to 20 bar) from ammonia. This goal will be achieved through the implementation of an innovative proton ceramic electrochemical reactor stack design integrated into a module capable for operation at a scale of 10 kg hydrogen per day. To reach this capacity the module will comprise of twenty individual stacks.

NON-QUANTITATIVE OBJECTIVES

- Optimise the proton ceramic electrochemical reactor catalytic activity for ammonia dehydrogenation.
- Optimise and qualify proton ceramic electrochemical reactor stacks and system components.
- Fabricate proton ceramic electrochemical reactor stacks including design, assembly, construction and testing of the 10 kg H₂/day module.

- Assess the life cycle, value chain economics and critical raw materials.
- Carry on dissemination, communication and standardisation activities.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Ni/BCZY support catalytic activity and stability had been optimised by infiltration of active metal.
- Candidate alloy materials have been identified for constructing and safe operating reactor housing under ammonia conditions.
- Cells, KETs and stacks have been manufactured.

FUTURE STEPS AND PLANS

- Stacks for 10kg H₂/day module will be fabricated.
- Design, assembly, construction, and testing of the 10 kg H₂/day module.
- The life cycle, value chain economics and critical raw materials will be assessed.



PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year for reported SoA result
Project's own objectives	Ammonia conversion (CATALYST)	%	> 98 at 600 °C	99.2	✓	98 % at 650 °C	2022
	Durability (CATALYST)	%	< 1 %/kh decrease in conversion at 600 °C	-		N/D for >1kh	2022
	Current density (CELL)	A/cm2	> 1	-		0.8	2022
	ASR (Current collector/electrode/ electrolyte) (CELL)	Ωcm2	< 0.5	-		1.2	2022
	NH ₃ conversion (CELL)	%	> 99.9	-		> 99.98	2022
	Faradaic efficiency (CELL)	%	> 98	-		98	2022
	Hydrogen recovery (CELL)	%	> 99	-		99	2022
	Durability (CELL)	%/kh voltage degradation on cell level at 0.75 Acm	0.8	-		0.8	2022
	Total current (STACK)	A	>85	44		67	2022
	NH ₃ conversion (STACK)	%	>99.8	98.4 (at 750°C)		N/A	N/A
	Faradaic efficiency (STACK)	%	95	96 (at 10 bar, 700°C)		>98	2022
	Hydrogen Recovery (STACK)	%	>98	86 (at 650°C)		98	2022
	Pressure Tolerance	Bar	30	15		31	2022
	Hydrogen Purity	%	>99.99	-		>99.995	2022
	Efficiency HHV	%	>90	-			
	NH ₃ Conversion (10kg/day MODULE)	%	>90	-			
	NH ₃ Conversion (10kg/day MODULE)	%	>99.5	-		N/A	N/A
	Hydrogen Recovery (10kg/day MODULE)	%	>95	-			
	Number of hours operated at 10 kg/day	h	>500	-			
	Pressure tolerance	bar	25	-			

UNLOHCKED

UNLOCKING THE POTENTIAL OF LOHCS THROUGH
THE DEVELOPMENT OF KEY SUSTAINABLE AND
EFFICIENT SYSTEMS FOR DEHYDROGENATION



Project ID	101111964
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	HORIZON-JTI-CLEANH ₂ -2022-02-05
Project total cost	EUR 2 941 312.75
Clean H ₂ JU max. contribution	EUR 2 941 312.75
Project period	01-06-2023 - 31-05-2026, ES
Coordinator Beneficiary	UNIVERSIDAD DEL PAIS VASCO/ EUSKAL HERRIKO UNIBERTSITATEA,
Beneficiaries	HyGear Fuel Cell Systems B.V., HYGEAR OPERATIONS BV, HYGEAR HYDROGEN PLANT BV, FRAMATOME GMBH, HYGEAR TECHNOLOGY AND SERVICES BV, HERAEUS DEUTSCHLAND GMBH and CO KG, HYGEAR FUEL CELL SYSTEMS BV, HYGEAR BV, NOORDWES-UNIVERSITEIT, COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS

<https://unlohcked.cnrs.fr/>

PROJECT AND GENERAL OBJECTIVES

By advancing breakthrough research on liquid organic hydrogen carrier (LOHC) technologies, UnLOHCKed aims to develop a radically disruptive, versatile and scalable LOHC-dehydrogenation plant. Firstly, highly active and stable catalysts without critical raw materials will be developed to reduce LOHC dehydrogenation at moderate temperatures. Secondly, a solid oxide fuel cell system will be developed to be thermally integrated in the dehydrogenation process. The heat demand of the dehydrogenation unit will be fully covered by the fuel cell, while generating electric power. The surplus of hydrogen will be exported. These innovative systems, when fully integrated, will allow significant increase of overall efficiency (>50%) of hydrogen and electric power production from LOHC.

The main objectives of this project are:

- To develop a critical raw material (CRM) free or low CRM-catalyst with high conversion rate, selectivity and productivity for dehydrogenation.
- To scale-up of one of the developed catalysts from a gram at laboratory scale to multiple kilograms for the demonstration plant.
- To develop a breakthrough integrated system in which the reactor is thermally coupled to an SOFC simplifying the dehydrogenation plant and improving the thermal efficiency.
- To demonstrate the feasibility of producing hydrogen and generating renewable electricity from LOHC-stored hydrogen by heat integration between endothermic hydrogen release and exothermic fuel cell operation.

NON-QUANTITATIVE OBJECTIVES

- To reduce capital expenditure (i.e. owing to the use of less expensive materials, no chemical reagents, no cleaning cycles and extended materials lifetime) and operational expenditure (i.e. owing to continuous mode of operation and optimised process controls).

- To decrease the cost of hydrogen transport and to demonstrate the feasibility and cost-effectiveness of LOHC technologies, from on-shore tank to on-shore tank, all inclusive.
- To develop a scale-up plan, through a techno-economic analysis, in order to improve techno-economic viability and to include comparisons with alternative hydrogen technologies for long distance transport.
- To develop a dissemination, exploitation and communication plan targeting key stakeholders and end-users at EU and international level to maximise the impact of UnLOHCKed results.
- To put the EU at the forefront of hydrogen technologies ensuring a competitive and commercial advantage in Europe in order to incentivise future investments.
- To reduce the environmental impact of hydrogen technologies by reducing the use and release of toxic substances and CRMs with a huge environmental impact.
- To contribute to the European Green Deal Goals through a fully CO₂-free dehydrogenation system.

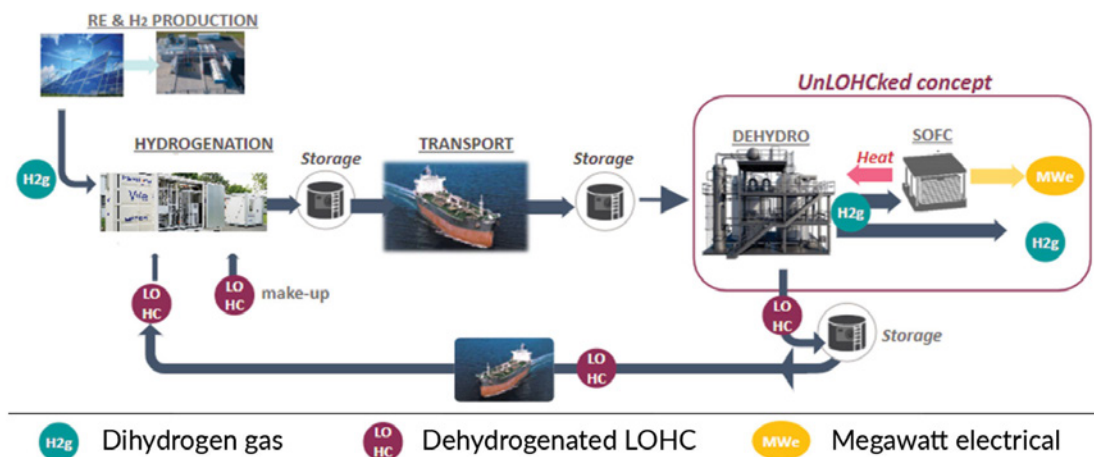
PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

After the first year and a half UnLOHCKed is in the middle of the scale-up of a low CRM catalyst. So far UnLOHCKed has achieved catalysts with conversions, selectivities and productivities higher than the state-of-the-art and is reaching the project's key performance indicators.

FUTURE STEPS AND PLANS

- Continue scaling up a catalyst from lab scale to industrial scale that reach the project targets.
- Continue the reactor design for the dehydrogenation unit integrated with a solid state fuel cell unit.





PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Grade of conversion	%	>95	96.6	✓
	Catalyst selectivity	%	>99.8	99.8	
	Catalyst productivity in dehydrogenation	g H ₂ /g catalyst/min	>0.02	0.031	
	No dissemination materials	Number	>8 (website, social media, videos etc.)	6	2 publications
	No peer-reviewed scientific publications and patents	Number	>10 publications and ≥1 patents	2 publications	
	Catalyst productivity in dehydrogenation	kg H ₂ /day	10	-	-
	Catalytic stability	%	Leaching of active material <0.1%/cycle Loss of performance < 0.1%/cycle: Grade of conversion >95%	-	
	Catalyst selectivity	%	>99	-	
	Hydrogen carrier specific energy consumption	kWh input/kg H ₂ recovered	>17	-	
	Operating hours	hours	>500	-	
	Overall efficiency	%	>50	-	
	H ₂ production	kg/day	10	-	
	Overall efficiency (electrical)	%	>50	-	
	Reduction in CAPEX and OPEX	%	CAPEX: 65 OPEX: 80	-	
	Hydrogen carrier delivery cost	€/kg	<2.5	-	
	H ₂ Production (TEA)	kg H ₂ /day	100-1 000	-	
	Reduction in the footprint	%	75	-	
	Reduction in CO ₂ emissions	% in the end-to-end UnLOHCKed process	>90	-	

WINNER

WORLD CLASS INNOVATIVE NOVEL NANOSCALE OPTIMIZED ELECTRODES AND ELECTROLYTES FOR ELECTROCHEMICAL REACTIONS



Project ID	101007165
PRR 2025	Pillar 2 – H ₂ storage and distribution
Call topic	FCH-03-1-2020
Project total cost	EUR 2 931 788.75
Clean H ₂ JU max. contribution	EUR 2 931 788.75
Project period	01-01-2021 - 31-03-2024
Coordinator Beneficiary	SINTEF AS, NO
Beneficiaries	COORSTEK MEMBRANE SCIENCES AS, SHELL GLOBAL SOLUTIONS INTERNATIONAL BV, ALLEIMA TUBE AB, ENGIE, UNIVERSITETET I OSLO, DANMARKS TEKNISKE UNIVERSITET, AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS

<https://www.sintef.no/projectweb/winner/>

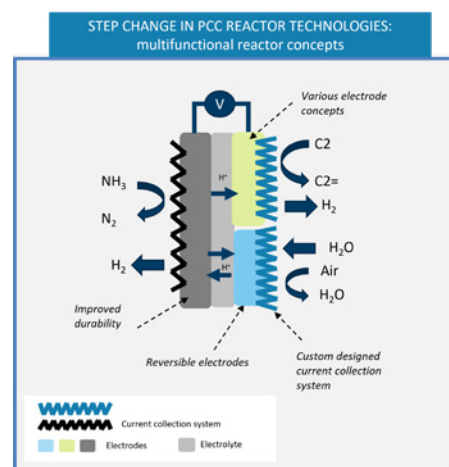
PROJECT AND GENERAL OBJECTIVES

WINNER contributes to the shift towards a more sustainable energy future by developing an efficient and durable technology platform based on electrochemical proton ceramic conducting (PCC) cells designed to unlock a path towards commercially viable production, extraction, purification and compression of hydrogen at small to medium scale through three process chains.

- Cracking of ammonia to produce pressurised hydrogen or power, where PCC reactors provide an innovative solution for flexible, secure and profitable storage and utilisation of energy in the form of green ammonia.
- Dehydrogenation of ethane to produce ethylene and pressurised hydrogen, where PCC reactors open new sustainable pathways for electrically driven processes in the chemical industry.
- Reversible steam electrolysis (using reversible protonic ceramic electrochemical cells), where PCC reactors allow the shifting of electric power generation to hydrogen production enabling grid balancing, improved matching of the demand and supply of electricity and more efficient use of renewable energy source.

NON-QUANTITATIVE OBJECTIVES

WINNER is developing a multi-scale multi-physics modelling platform integrating various disciplines (atomistic, electro-chemical, mechanical, fluid flow, reactor engineering, electric, heat) with the goal of establishing the rate-determining steps at a meso-scale in the electrochemical cell, and the most efficient dimensioning and arrangement of the cells in the multi-tube reactor design. The work is supported by relevant experimental data and enhanced experimentation methodologies applied in the project.



PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

SoA cells development:

- WINNER has developed novel tubular cells based on the production line established at CTMS. The half-tubular cells consist of Ni-BZCY72 electrode with BZCY81 dense electrolyte. Various electrode materials and architectures have been screened for the project's multiple applications.
- The following performance criteria were successfully met for the reversible electrolysis cells and ammonia to hydrogen cells: a cell area-specific resistance below 1 ohm.cm² at 650°C, a faradaic efficiency of 80-90%, and a degradation rate below 1.2% k/hour under reversible operation.

For the ammonia to hydrogen:

- WINNER has established an ammonia conversion above 99% with a hydrogen extraction above 98%.
- A tubular cell was successfully operating in reversible operation for more than 4 000 hours at 4 bar at 650 °C.

- Post-characterisation analysis showed some evolution of the cathode microstructure with the formation of Co-based nanoparticles, while no changes were observed in the other functional layers.

Engineering model:

- The partners initially created a communication platform to define common nomenclature, parameters and models and to establish a link between the different models and competences from atomistic scale to process scale.
- An engineering model has been defined for each of the WINNER applications, which is available in excel format and converted in an ASPEN file. The model is built based on the definition of the process flowsheet with necessary balance of plant and operating conditions, electrochemistry, kinetic and heat balance, etc.
- The tool is now functioning with multiple models integrated together (e.g. integrated atomistic + kinetics + electrochemistry models at cell levels, engineering tool + ASPEN models at cells, reactors and process levels, mechanical model).
- A computational fluid dynamics model has been initiated although its full integration into the engineering model is not completed.
- The outputs of the engineering tool are the energy demand per balance of plant and for the overall process for the selected input parameters (temperature, selectivity, conversion efficiency, cell voltage, Faradaic efficiency, etc.).

- The tool has been integrated in ASPEN for the establishment of the integrated process flowsheet and setting up the techno-economic assessment of WINNER applications.
- Several deliverables and one master thesis report on the findings from this assessment which will be discussed in a public exploitation workshop.

Life cycle assessment:

- A life cycle assessment evaluation for three applications has been conducted with user cases and benchmark cases defined for all applications. The results show the benefits of proton ceramic-based technologies versus the benchmark cases.

Multi tube testing demonstration:

- A multi-tube testing unit has been prepared at Consejo Superior de Investigaciones Científicas.
- Extensive software and hardware upgrades have been implemented to ensure high operational safety and functionality.
- Operational protocols have been defined, and commissioning has been done.
- Cells needed for testing have been produced.

FUTURE STEPS AND PLANS

WINNER was finalised in March 2024 with the delivery of the techno-economic analysis and lifecycle analysis. An exploitation workshop was organised in March 2024 together with HYDROGNI.