H2ELIOS

LEGACY PACK

Liquid Hydrogen Technologies for Sustainable and Climate-Neutral Aviation

2023 - 2026



- INNOVATIVE TECHNOLOGIES
- COLLABORATIVE RESEARCH
- TOWARDS CLIMATE-NEUTRAL AVIATION
- LASTING IMPACT

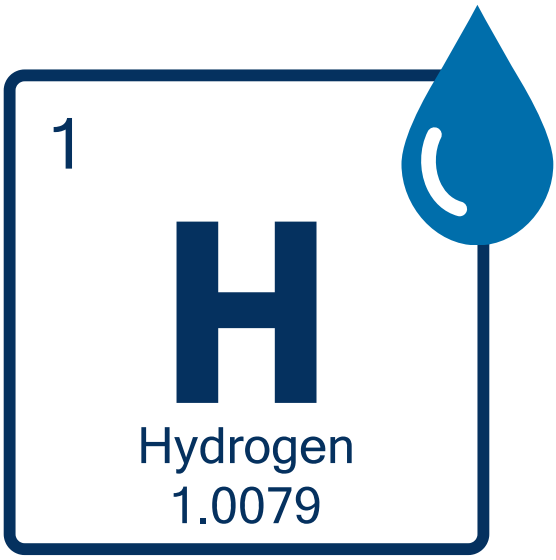
CLEAN AVIATION

Co-funded by the European Union

The project is supported by the Clean Aviation Joint Undertaking and its members. Funded by the European Union, under Grant Agreement No. 101102003. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or Clean Aviation Joint Undertaking. Neither the European Union nor Clean Aviation JU can be held responsible for them.

ABOUT H2ELIOS

H2ELIOS is a European research and innovation project focused on one of the key challenges facing hydrogen-powered aviation: the safe and reliable storage of liquid hydrogen (LH_2) onboard aircraft. Bringing together European research organisations and industrial partners, the project explored the technologies and engineering solutions needed to make LH_2 storage systems suitable for aviation applications. Its activities covered several interconnected areas, from tank design and advanced manufacturing to structural environmental monitoring, safety assessment, testing and certification. By addressing these challenges, H2ELIOS contributes to the development of the knowledge, technologies and capabilities needed to support the future introduction of hydrogen-powered aircraft and Europe's wider ambition to decarbonise aviation.



THE BOOKLET

What has H2ELIOS achieved, who can benefit from its results, and how can this work contribute to the future of aviation? These are the main questions explored in the H2ELIOS Final Legacy Pack. This booklet presents the project's key achievements and research outcomes, explaining their practical relevance and potential applications beyond the project's lifetime. It brings together the main technological developments, the stakeholders who can build on them, and their expected scientific, technological, economic and societal impacts. Written for researchers, industry professionals, policymakers, European institutions and anyone interested in sustainable aviation, the booklet offers an accessible overview of the work carried out and the knowledge gained. It also serves as a lasting reference to support knowledge sharing, future research and the continued development of liquid hydrogen storage technologies for aviation.

CONSORTIUM

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WP1

Building a Certification Pathway for Liquid Hydrogen

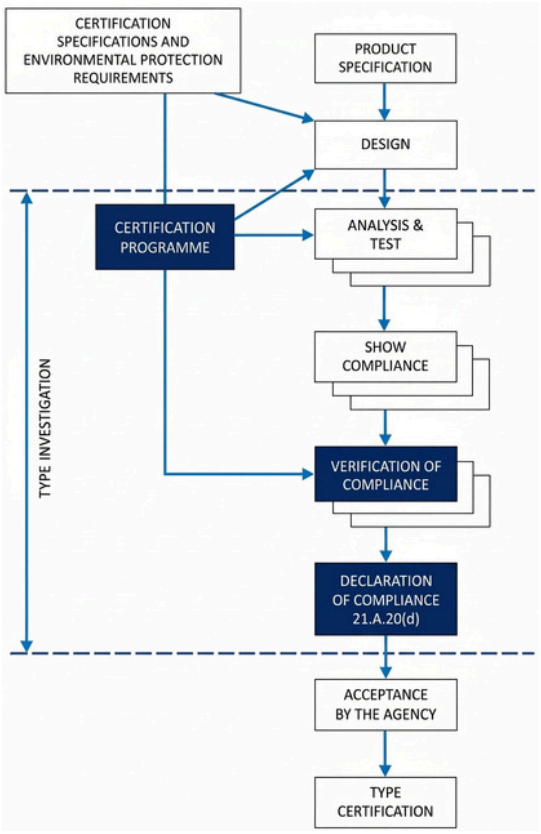
Creating a clear path from hydrogen innovation to safe aircraft integration

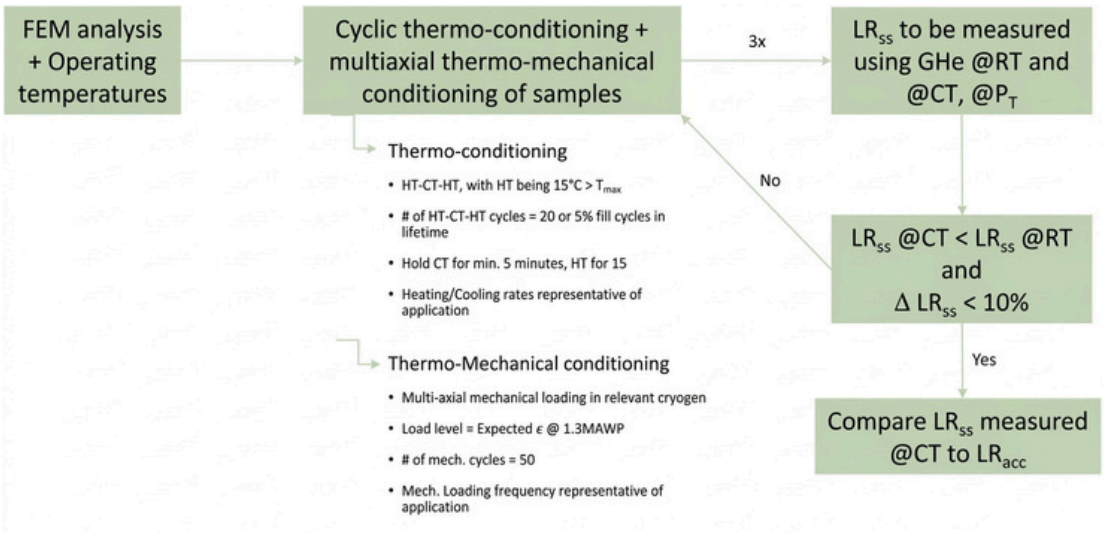
The project established the certification and specification baseline for the H2ELIOS liquid hydrogen storage system. It delivered the initial and updated Hydrogen Storage System (HSS) requirements, product and demonstrator specifications, the airworthiness certification approach, the means of compliance for cryogenic materials, qualification and certification planning, test requirement specifications, and the DEMO-vs-PRODUCT representativeness/TRL analysis.

A key achievement was the regulatory gap analysis performed with the European Union Aviation Safety Agency (EASA), which led to the change from a conformal integral tank to a non-conformal, non-structural Liquid Hydrogen(LH2) tank installed in a dedicated rear-fuselage compartment. The project produced tailored Conditioning Scenario (CS), CS-25 compliance matrices, defined means of compliance and load cases, and identified critical certification topics: crashworthiness, interaction of systems and structure, fire/explosion prevention, leakage/permeability, lightning/ High-Intensity Radiated Fields (HIRF) protection, and LH2-specific safety requirements.

The work done, led by Piaggio Aerospace, also defined the test pyramid and full-scale test sequence, mapped the project against Certification Readiness Level (CRL) 3–4 and Technology Readiness Level (TRL) 4, and prepared the roadmap towards future certification and exploitation, including entry into service (EIS) 2035. The work provides a structured basis for later design, manufacturing, subsystem development, integration, and testing activities.

Certification Process
(ref. GM1 21.A.239(a))



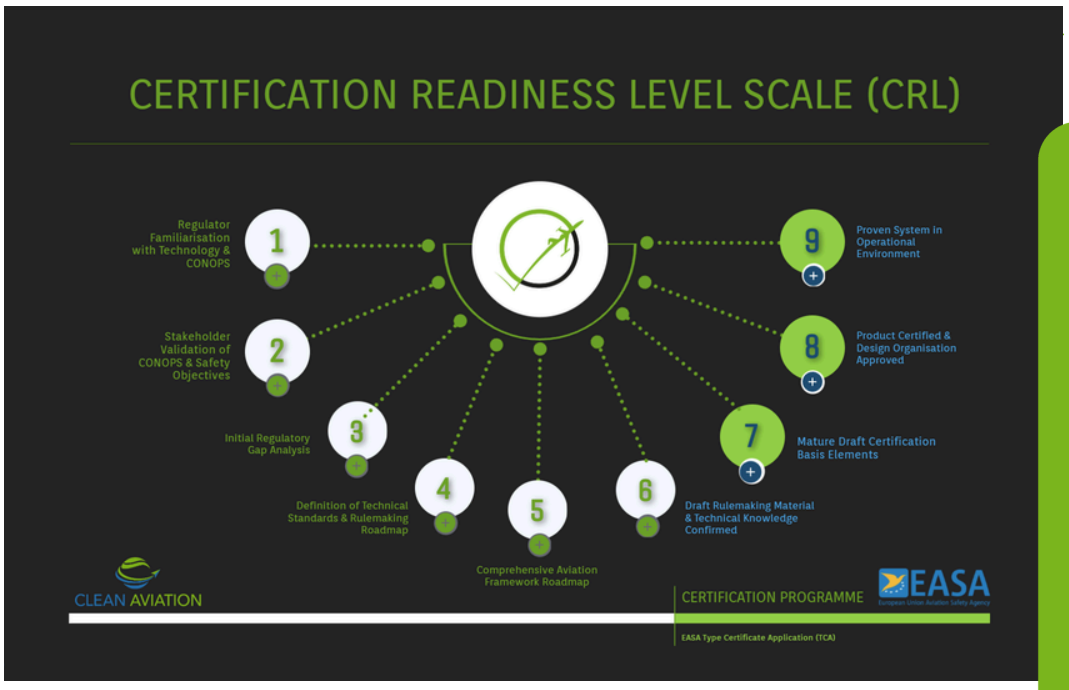


Flow diagram of the revised MoC for material in cryogenic conditions

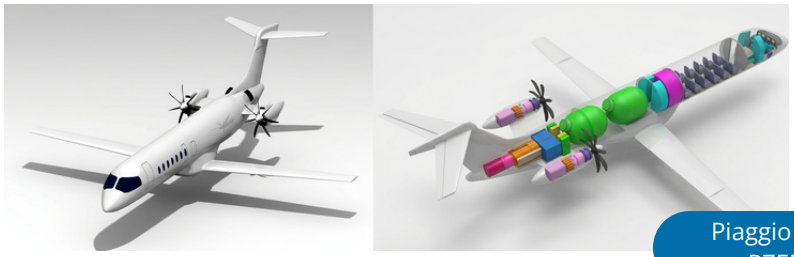
WP1

Building a Certification Pathway for Liquid Hydrogen

Creating a clear path from hydrogen innovation to safe aircraft integration



The results provide reusable requirements and certification roadmap for future LH2 tank development. They reduce regulatory uncertainty, support safe design, manufacturing, testing and aircraft integration, and help EASA and industry mature hydrogen-specific airworthiness rules. They also guide demonstrator testing, product scalability and future Clean Aviation phases.



Piaggio Aerospace aircraft layout concept PZERO and H2ELIOS tanks location

Beneficiaries & End Users

- General Public
- Researchers and research facilities
- Academia/Universities
- Industry
- Certification Bodies
- Other EU funded projects
- European Commission

Impact and Future Potential

Societal Impacts

Supports the safe introduction of zero-emission hydrogen aviation, helping to reduce aviation's climate impact while maintaining high safety levels. By enabling airworthiness pathways for LH2 storage, it contributes to cleaner air travel and public confidence in hydrogen aviation.

Economic/Technological Impacts

Reduces certification risk and development cost for European LH2 tank suppliers and aircraft integrators. It strengthens EU aerospace competitiveness and creates reusable know-how in cryogenic hydrogen storage, certification, testing and compliance. The outputs can be reused by future product programmes and Clean Aviation phases.

Scientific Impacts

Advances understanding of cryogenic composite permeability, damage tolerance, LH2 safety, fire/explosion prevention and certification methods. It provides a structured MoC for material permeability, a regulatory gap analysis, test specifications and a certification roadmap that can inform future research and standardization.

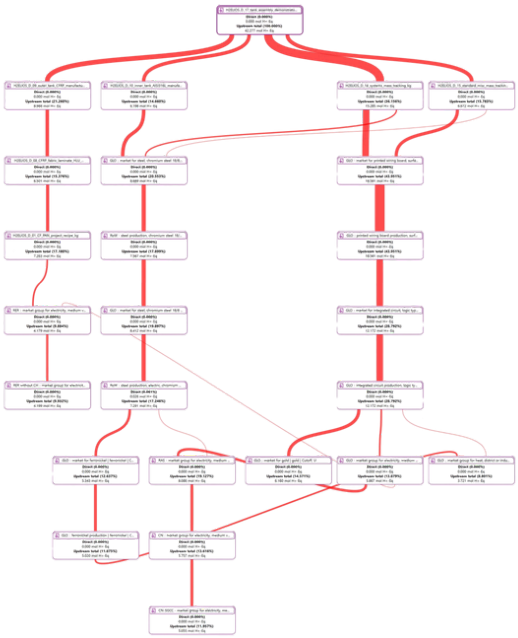
WP2

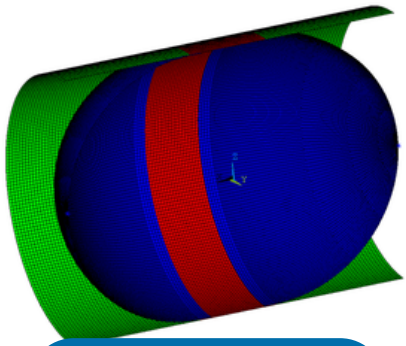
Liquid Hydrogen Tank Design and Development

Developing an innovative, lightweight and thermally efficient liquid hydrogen storage system through advanced tank design, insulation technologies and digital modelling for future aircraft.

WP2 delivered the complete design of the H2ELIOS liquid hydrogen storage system, establishing the technical foundations for manufacturing and validation activities. The work developed and matured the self-regulated low-pressure LH2 storage concept, including the architecture of the inner tank, outer tank, insulation system and hydrogen management functions. Feasibility, preliminary and critical design reviews were successfully completed, leading to a validated design ready for manufacturing. Advanced thermal, fluid and structural digital twins were also developed to support optimisation, scalability studies and future aircraft integration assessments. The activities generated key knowledge for lightweight cryogenic storage systems and supported the protection and exploitation of the project intellectual property.

Sankey diagram showing the contribution of the main processes to the climate change impact (kg CO_2-eq) of the full H2ELIOS demonstrator.





The structural model: FDR design phase

Results provide a validated design framework for future hydrogen aircraft storage systems. The developed architecture enables lightweight, scalable and more easily integrated LH2 storage solutions while supporting future certification, industrialisation and aircraft integration activities.

Beneficiaries & End Users

- General Public
- Clusters
- Academia/Universities
- Industry
- Certification Bodies
- Other EU funded projects
- National/regional authorities
- European Commission

Impact and Future Potential

Societal Impacts

The WP2 results support the development of future hydrogen-powered aircraft by enabling safer and more efficient liquid hydrogen storage solutions. By contributing to the adoption of hydrogen as an aviation fuel, these developments support the long-term reduction of greenhouse gas emissions and the transition towards climate-neutral air transport.

Economic/Technological Impacts

WP2 established the design basis for a patented low-pressure LH2 storage concept combining lightweight structures, advanced insulation technologies and digital engineering tools. These results strengthen European technological leadership in hydrogen aviation and support future industrialisation, certification and market deployment of hydrogen storage systems.

Scientific Impacts

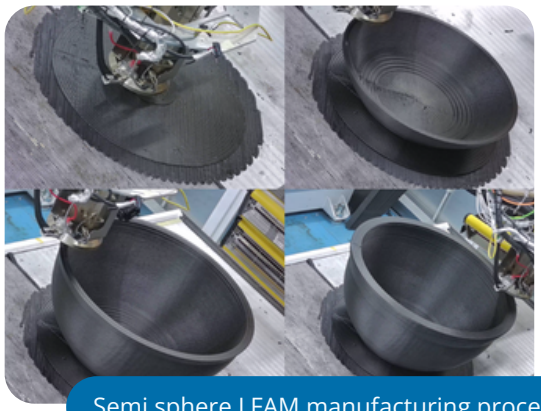
The work generated new knowledge in cryogenic hydrogen storage, aircraft integration, thermal management and digital twin development. The design methodologies and simulation capabilities developed within WP2 provide a valuable foundation for future research and technology maturation activities in hydrogen aviation.

WP3

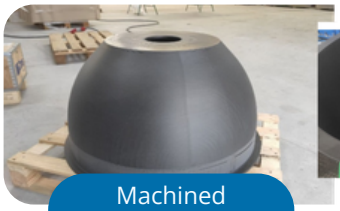
Advancing Manufacturing Technologies for Liquid Hydrogen Storage

Developing and demonstrating composite and metallic solutions for cryogenic hydrogen storage

WP3 transformed the H2ELIOS design into a full-scale demonstrator through the manufacturing, assembly and integration of key hardware elements. Sonaca España was responsible of the manufacturing of the external tank, the development and implementation of the insulation system, and the assembly of the demonstrator. These activities enabled the integration of structural, thermal and functional elements into a representative LH2 storage system, providing the basis for subsequent validation and testing activities. The work also generated valuable manufacturing know-how for lightweight cryogenic storage structures and advanced insulation solutions for future hydrogen-powered aircraft.



Semi sphere LFAM manufacturing process

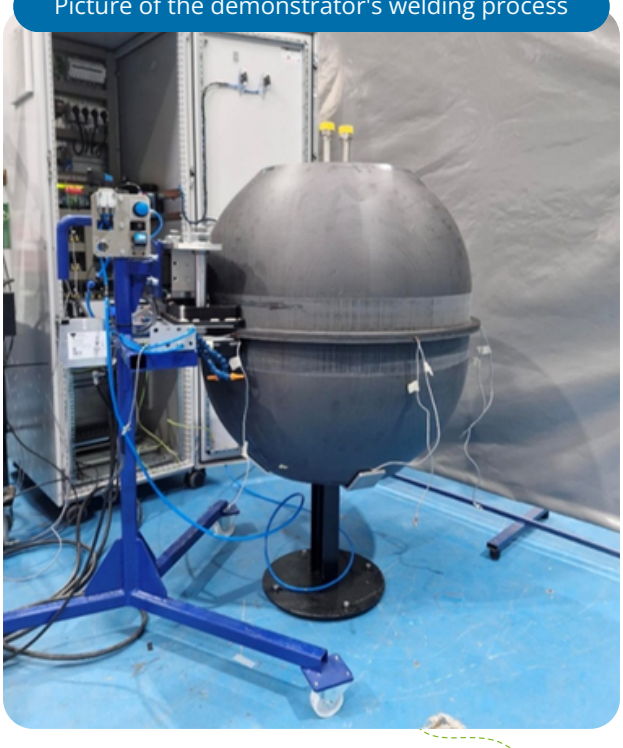


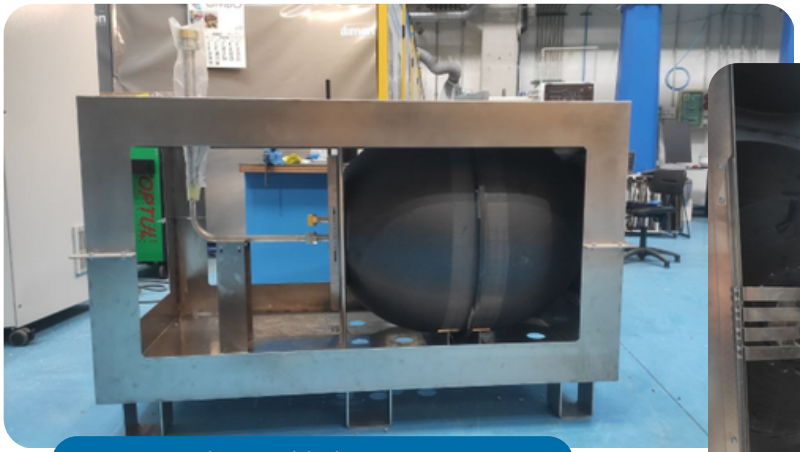
Machined semiesphere



Assembly of metallic plate and pipes

Picture of the demonstrator's welding process





LN2 vessel assembled into testing cage



Inlet pipe and Jhonston coupling filling valve detail

WP3

Advancing Manufacturing Technologies for Liquid Hydrogen Storage

Developing and demonstrating composite and metallic solutions for cryogenic hydrogen storage



Inner tank metallic on the machining

The developed manufacturing and assembly solutions demonstrate the feasibility of producing and integrating lightweight cryogenic storage systems for aviation. The results support future industrialisation, reduce manufacturing risks and provide practical experience for the deployment of hydrogen storage technologies in future aircraft applications.



Final metallic inner tank

Beneficiaries & End Users

- General Public
- Clusters
- Academia/Universities
- Industry
- Certification Bodies
- National/regional authorities
- European Commission

Impact and Future Potential

Societal Impacts

The manufacturing and integration of innovative hydrogen storage technologies contribute to the development of cleaner aircraft and support the transition towards more sustainable air transport. These developments help enable future reductions in aviation-related greenhouse gas emissions.

Economic/Technological Impacts

WP3 demonstrated manufacturing and assembly processes for advanced cryogenic storage systems, including composite structures and insulation technologies. The generated know-how strengthens European industrial capabilities in hydrogen aviation and supports future industrial deployment.

Scientific Impacts

The activities generated valuable knowledge on manufacturing methods, insulation implementation and system integration for cryogenic LH2 storage applications. The lessons learned provide a foundation for future research and technology maturation in hydrogen storage systems.

WP4

Making Liquid Hydrogen Storage Smarter and Safer

Combining advanced sensors, real-time monitoring and digital technologies to protect future hydrogen aircraft

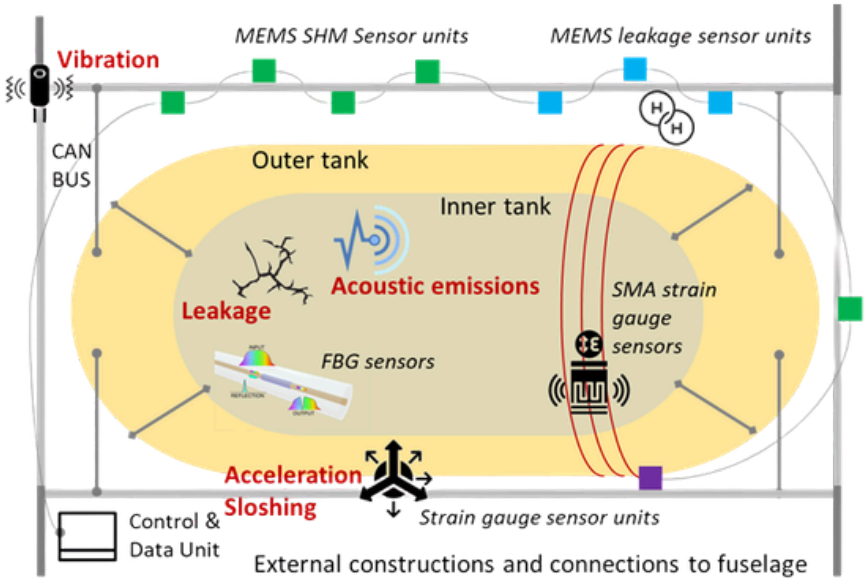
The project team established the subsystem and safety baseline for the H2ELIOS liquid hydrogen storage system. It delivered the detailed hydrogen system definition, the structural health monitoring system for the LH2 tank, the leak-detection system for the LH2 tank and its components, the initial and final boil-off performance assessments, an assessment of cycling sensitivity in boil-off performance, and structural health monitoring and leak-detection inputs for consideration in the final demonstrator design.

A key achievement was developing a multi-sensor Structural Health Monitoring (SHM) system for LH2 tanks, established within the H2ELIOS project. The system utilizes a three-layer approach, combining Shape Memory Alloy (SMA) strain sensors for direct crack detection (validated in cryogenic environments down to −196 °C), hydrogen leakage sensors to prevent false alarms, and Micro-Electro-Mechanical Systems (MEMS)-based inertial and acoustic emission sensors for long-term predictive maintenance via digital twins.

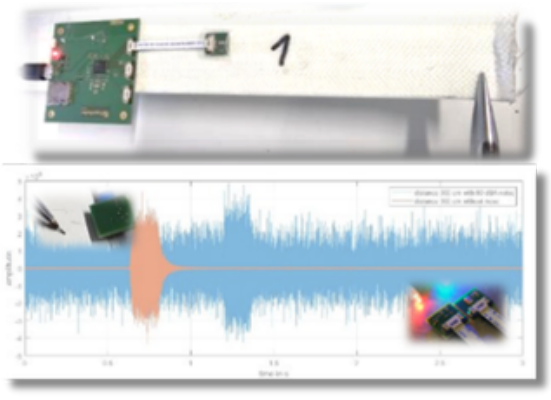
The project successfully designed, fabricated, and tested sensor subcomponents, including hardware and firmware for CAN-FD bus communication in IP68 housings. The network also includes distributed and concentrated FBG fiber optic and interferometric acoustic emission probes installed on the composite skin of the tank with the scope of monitoring the strain level under pressure loading and thermal distortions and potential cracks.



Carbon fiber reinforced polymer materials tests in cryogenic environment



Presented approach to the SHM concept of LH2 Tank



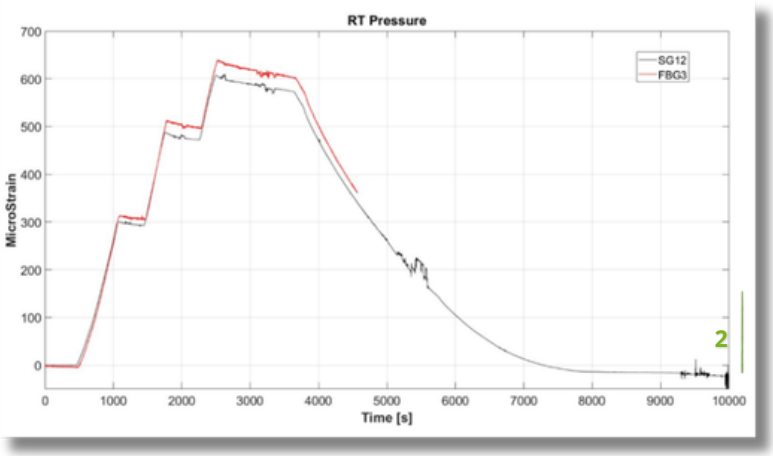
Pencil break tests – set-up and results

WP4

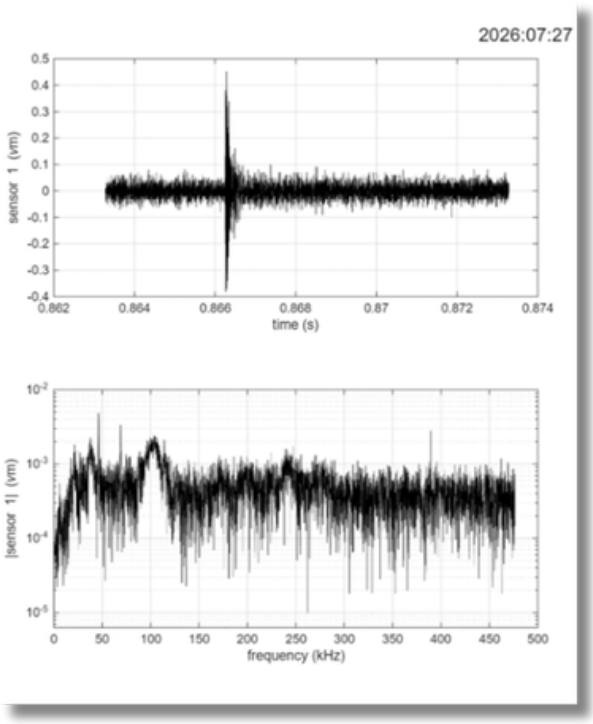
Making Liquid Hydrogen Storage Smarter and Safer

Combining advanced sensors, real-time monitoring and digital technologies to protect future hydrogen aircraft

The work mapped the hydrogen leakage sensors to TRL 3–4 and the MEMS sensors to TRL 4–5 and prepared the roadmap towards future field testing. The next stage involved integrating 14 sensor units on an LH2 tank demonstrator to validate data acquisition during a series of tank field tests, potentially achieving TRL 5. The work provides a scalable, cost-efficient redundant sensor network as a structured basis for ensuring the structural integrity and operational safety of LH2 tanks in aviation applications.



Strain measured by concentrated fiber optic during pressure tests



A spike due to stress redistribution acquired by acoustic emission probes during pressure tests



Assembled MEMS SHM Sensor patch

WP4

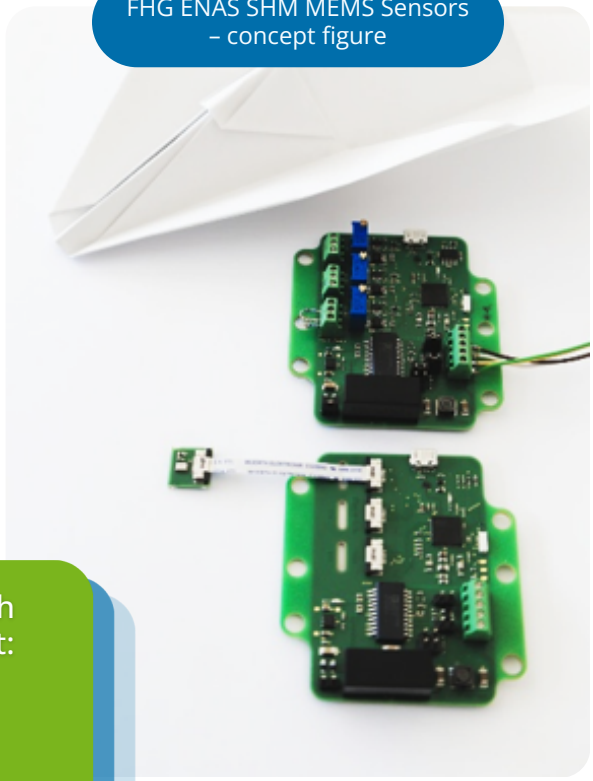
Making Liquid Hydrogen Storage Smarter and Safer

Combining advanced sensors, real-time monitoring and digital technologies to protect future hydrogen aircraft

Tank integrated with acoustic emission and fiber optic sensors during pressure tests



FHG ENAS SHM MEMS Sensors – concept figure



Results provide a scalable, multi-sensor structural health monitoring framework for future LH2 tank development:

- Reduce operational risks and false alarms;
- Support safe design, predictive maintenance via digital twins, and aircraft integration;
- Help the aviation industry mature hydrogen-specific safety and monitoring technologies;
- Guide LH2 tank demonstrator testing, sensor network scalability, and future Clean Aviation project phases.

Beneficiaries & End Users

- General Public
- Researchers and research facilities
- Academia/Universities
- Industry
- Certification Bodies
- Other EU funded projects
- Technology Transfer organizations, Networks & Associations
- Private Sector and SMEs, Startups
- European Commission

Impact and Future Potential

Societal Impacts

Supports the safe introduction of zero-emission liquid hydrogen aviation by preventing catastrophic tank failures and ensuring high structural integrity. By enabling real-time leak detection and predictive maintenance, it contributes to safer air travel and builds public confidence in hydrogen-powered aircraft.

Economic/Technological Impacts

Reduces maintenance and operational costs by enabling predictive maintenance and avoiding false alarms through a scalable, cost-efficient redundant sensor network. It strengthens EU aerospace competitiveness by creating reusable know-how in cryogenic SHM, digital twin integration, and sensor miniaturization suitable for aviation mass, size, and power constraints.

Scientific Impacts

Advances the understanding of shape memory alloy strain sensors and MEMS acoustic emission sensors in extreme cryogenic environments down to −196 °C. The work provides a structured methodology for multi-sensor data fusion, digital twin material modeling, and predictive maintenance algorithms that can inform future SHM research and standardization.



WP5

Tank Demonstrator Integration, Testing, and Validation

Integrating, testing and validating the H2ELIOS demonstrator to support future certification and industrial deployment.

TWP5 successfully integrated and validated partially the H2ELIOS demonstrator through a comprehensive testing campaign. Activities included subcomponent testing, structural verification, cryogenic validation, demonstrator integration and system-level assessments under representative operating conditions. The testing campaign generated valuable experimental data, verified key design assumptions and demonstrated the feasibility of the H2ELIOS storage concept. The results provided essential evidence for future development, certification roadmaps and industrial deployment of hydrogen storage technologies for aviation.

Results reduce technical risks associated with future hydrogen aircraft developments by providing validated experimental evidence on system performance and integration. The generated knowledge, testing methodologies and lessons learned support future certification activities, technology maturation and industrial implementation of liquid hydrogen storage systems.

Beneficiaries & End Users

- General Public
- Researchers and research facilities
- Academia/Universities
- Industry
- Certification Bodies
- RTOs
- Clusters
- National/regional Authorities
- European Commission
- Policy Decision Makers

Impact and Future Potential

Societal Impacts

The validation of hydrogen storage technologies contributes to the development of safer and more sustainable aircraft, supporting the long-term transition towards low-emission aviation. These results help accelerate the adoption of hydrogen as an alternative aviation energy source and contribute to European climate objectives

Economic/Technological Impacts

WP5 demonstrated the integration and partial validation of an innovative LH2 storage solution, generating experimental evidence that supports future industrialization and certification activities. The results strengthen European capabilities in hydrogen aviation technologies and reduce technological risks for future aircraft developments.

Scientific Impacts

The testing campaign generated valuable experimental data on cryogenic storage systems, system integration and operational performance. The outcomes improve the understanding of storage technologies and provide a foundation for future research, validation and technology maturation activities.

H2 ELIOS

Designed by EASN-TIS



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TETRAFLIGHTS safety in test > safety in flight

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