Hydrogen Innovation Initiative (HII)

New UK Capability for Hydrogen Permeation Testing

An article about the development of a cryogenic hydrogen permeation test rig

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Introduction:

With recent updates to the UK Hydrogen Strategy, the Clean Energy Industrial Plan, and over £250 million committed to green aerospace projects, the UK hydrogen economy is beginning to shift from ambition to implementation. But alongside demand, investment, and government backing, all hydrogen infrastructure, equipment, and systems must ultimately be bankable. To be bankable, they must be insurable — and to be insurable, technical confidence in their safety and reliability is required. For insurers, asset developers, and end-users alike, questions around leakage, material degradation, and lifetime reliability remain key barriers to commercial sign-off and deployment. That confidence comes through certification via the testing of materials and technologies under real-world conditions.

In this article, we outline the development and recent upgrade of a critical testing system designed to accelerate the qualification of materials for use in cryogenic hydrogen environments — a key step in supporting the UK supply chain and ensuring the safe, certifiable deployment of next-generation hydrogen systems. Funded through the Hydrogen Innovation Initiative and NCC and delivered in partnership by the University of Bristol and the NCC, the project was led by Dr Lui Skytree and Dr Matt Kay to establish and enhance the UK's cryogenic hydrogen permeation testing capability and infrastructure for validating strategic materials.

Why does permeation matter?

One critical cross-sector concern is the escape of hydrogen, either via direct leakage or its permeation through a containment material. Permeation refers to the gradual passage of hydrogen molecules through a material — and in hydrogen systems, it presents a significant technical and safety challenge. Unchecked, permeation can lead to the loss of stored hydrogen fuel, degrade vacuum insulation systems, increase the risk of embrittlement in structural components, and ultimately compromise system performance and safety. For engineers & regulators the hydrogen permeability of a material is a key safety and performance metric for assessing their suitability for use as structural components with hydrogen, such as in composite storage tanks, piping, seals, and joints.

Understanding how materials behave at operational temperatures and pressures is essential for de-risking designs and accelerating certification pathways. This is especially critical in cryogenic hydrogen environments, such as liquid hydrogen (LH2) fuel for zero-emission aviation.

Why is Cryogenic permeation unique?

While the hydrogen permeability of materials has been reasonably studied at room temperature and above, our collective knowledge dramatically declines under cryogenic conditions. At LH2 temperatures (–253.15 °C), it remains unclear whether standard modelling assumptions remain valid, or whether extrapolations from higher temperatures are reliable. The challenge is particularly acute for composite materials, such as those proposed to enable hydrogen-powered flight, which can undergo cryogenic assisted defects (e.g. microcracking, fibre-matrix debonding, and delamination due to mismatched thermal expansion coefficients during thermal cycling) that can compromise mechanical performance and increase susceptibility to hydrogen leakage and permeation. Understanding composite permeation and leakage performance is paramount to their utilisation.

The challenge is further compounded by a well-recognised global data gap: very few laboratories worldwide possess the infrastructure to accurately measure hydrogen permeation under cryogenic conditions due to the increased complexity of combined extreme conditions (cryo, H2, high pressure & high vacuum) and extreme system leak management. Thus, there is a lack of data to validate materials, let alone a unified standard for testing. With minimal data and capability to test and validate materials for use in LH2 environments, the components and systems being designed for use with LH2 cannot be truly certified or achieve regulatory approval.

Cryogenic Hydrogen Permeation Testing Capability, UK.

Given the strategic importance of lightweight, high-performance materials in hydrogen transport and aviation in the UK, the University of Bristol and the NCC strove to address this critical measurement gap to build a pathway toward safe, certifiable, and internationally competitive systems for the UK hydrogen economy.

Led by Research Fellow Dr Lui Skytree (University of Bristol), the team took a highly complicated set of system requirements and turned it into simple, designing and delivering a prototype test rig known as CHyPr (cryogenic hydrogen permeation rig) - developed to evaluate the fundamental hydrogen permeation characteristics of composite materials under cryogenic conditions. The system was designed with a modular architecture and capable of dealing with a wide range of conditions safely - marrying ultrahigh vacuum (1E-6 mbar) with high-pressure hydrogen (up to 200 Bar), all the way down to liquid hydrogen temperatures, though its initial build was limited to 80 bar and liquid nitrogen temperatures for validation. In its development the team collaborated with National Physics Laboratory (NPL) and the University of Southampton to begin unification of testing protocols and methodology and increase calls for national testing infrastructure and standardisation.

CHyPr successfully demonstrated the ability to measure hydrogen permeability across both polymer and composite materials at ambient and cryogenic temperatures, providing proof of concept for direct measurement of cryogenic hydrogen relevant performance data needed to begin validating new, strategically important materials for the UK.   However, as many worldwide testing facilities can also acclaim, due to the extreme conditions involved, individual test cycles are extremely long and resource-intensive, limiting throughput and creating a bottleneck for wider material screening. This identified a clear need to enhance the rig's sensitivity, efficiency, and operability to meet the growing demand from industry for faster, scalable cryogenic materials evaluation.

Enhancing UK Capability through Targeted Rig Upgrades

With funding from the hydrogen innovation initiative, Dr Lui Skytree and the NCC conducted a system level review and troubleshooting exercise, leading to targeted upgrades to the permeation cell and the test bed, simplifying and improving the operability, sensitivity and sample throughout.

As part of these upgrades, the system's sensitivity was dramatically improved through changes to the size and design of permeation cell and sample holder, increasing the hydrogen flux in the permeation chamber by a factor of 16, significantly amplifying the measurable permeation signal. By accelerating the rate of pressure change in the downstream chamber the rig can now detect permeation rates up to two orders of magnitude lower than previously possible. These modifications substantially improve the signal-to-noise ratio and detection limits, enabling more confident characterisation of low-permeation materials and extreme test conditions. Furthermore, by accommodating thinner samples, the experimental time has been reduced to 25% of the original, increasing testing efficiency and throughput dramatically.

In addition to improving performance, the team simplified system operation by optimising the manifold and streamlining the workflow. By redesigning the setup to feature a moving test bed and a lift-mounted manifold, the system now enables easier integration of environmental test chambers and reduces joint strain during testing — enhancing both usability and measurement precision.

Industry Relevance and Strategic Benefits

Reliable cryogenic permeation testing offers broad value across the hydrogen value chain. For material developers, it provides critical performance data to de-risk materials and guide manufacturing. For design engineers, its data supports the selection of safe materials for composite storage tanks, piping, and vacuum-insulated systems. And for regulators and insurers, this underpins the safety case for certification and deployment of hydrogen technologies. The upgraded cryogenic hydrogen permeation rig serves as a basis platform for UK industry to accelerate its development of hydrogen ready materials and sub-system design for liquid hydrogen handling. Ultimately contributing to global competitiveness in zero-emission aviation and clean hydrogen transport systems.

Queries or feedback?

Hydrogen Innovation Initiative
iCentrum Innovation Birmingham
Holt Street
Birmingham
B7 4BP

contact@hydrogeninnovation.co.uk
www.hydrogeninnovation.co.uk

HII partners:

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