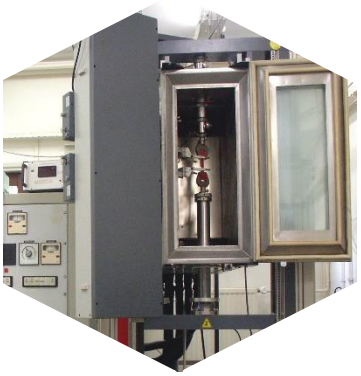
(LIQUID) HYDROGEN VALIDATION & SAFETY TESTING



TNO innovation for life

The transition to a hydrogen economy requires handling materials under extreme conditions. TNO Process Safety Solutions (PSS) bridges the gap between material science and industrial application. We specialize in "Extreme Chemistry", understanding the behavior of dangerous substances to ensure that production, storage, and transport are safe, secure, and reliable.

THE CHALLENGE: HYDROGEN AT -253°C

The use of liquid hydrogen (LH_2) is gaining rapid momentum for heavy transport, maritime, and aviation applications. However, handling LH_2 presents unique safety challenges, including material embrittlement, boil-off, and rapid phase transitions.

OUR VALUE PROPOSITION

We provide the "ground truth" experimental data needed to certify components and validate safety models. Our expertise covers the full chain:

Safety Testing: We execute tests in conditions ranging from cryogenic temperatures up to high pressures, handling everything from leak detection to explosion risks.

Infrastructure: We operate specialized bunkers and remote-controlled facilities designed for hazardous testing, ensuring safe validation of risky process conditions.

THE LIQUID HYDROGEN EXPERIMENT FACILITY

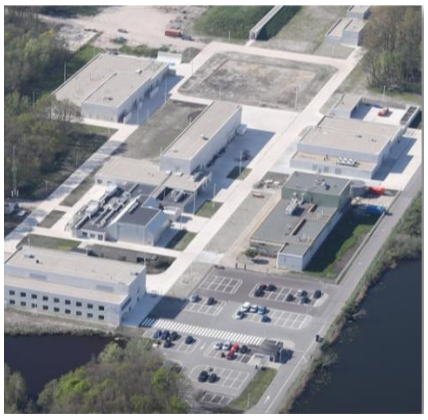
Located at TNO Ypenburg, our dedicated Liquid Hydrogen Experiment Facility is designed to test materials and components under realistic LH_2 conditions. This infrastructure bridges the gap between laboratory samples and full-scale industrial application.

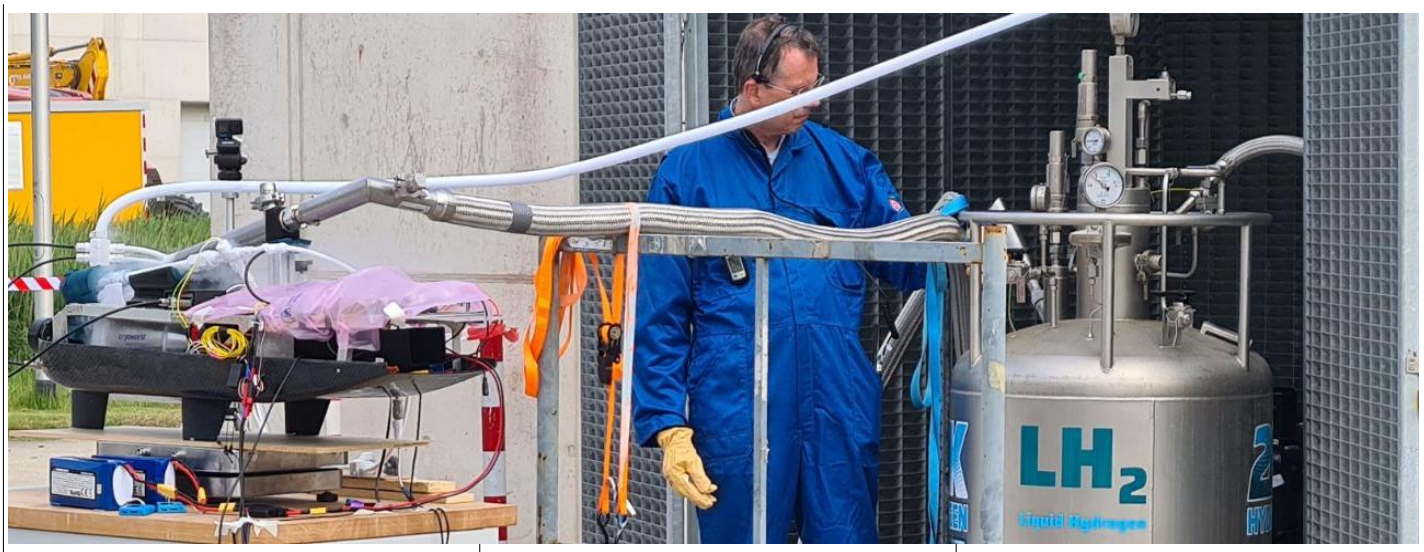
KEY CAPABILITIES:

Cryogenic Compatibility: Testing valves, seals, and storage materials in direct contact with LH_2.

Dynamic Conditions: Simulating operational stress such as filling/draining cycles and pressure fluctuations.

Boil-off & Dispersion: Experimental validation of release scenarios, dispersion characteristics, and safety distances to support quantitative risk assessments.





Our comprehensive testing portfolio allows manufacturers to bridge the gap between laboratory research and industrial application. We verify that technologies can withstand the extreme and often contradictory requirements of the hydrogen value chain, from the deep freeze of liquid hydrogen (-253°C) to the extreme mechanical stresses of high-pressure storage.

MATERIAL QUALIFICATION & TENSILE TESTING

We go far beyond static exposure testing. Our specialized Slow Strain Rate Testing setups allow hydrogen to permeate the material structure while it is actively being stretched and deformed. This provides critical, dynamic data on hydrogen embrittlement and material degradation that static tests often miss.

High Pressure: Our custom-made setups allow for testing at standard high pressures up to 500 bar, with extended capabilities reaching 650 bar to simulate extreme operational spikes.

Extreme Temperatures: We offer a versatile testing range from cryogenic conditions at -253°C up to 320°C, ensuring materials perform safely across the full operational envelope.

Fatigue & Fracture: Our capabilities include complex tensile, fatigue, and fracture mechanics testing within a pure hydrogen environment to identify surface cracks and failure points before they occur in the field.

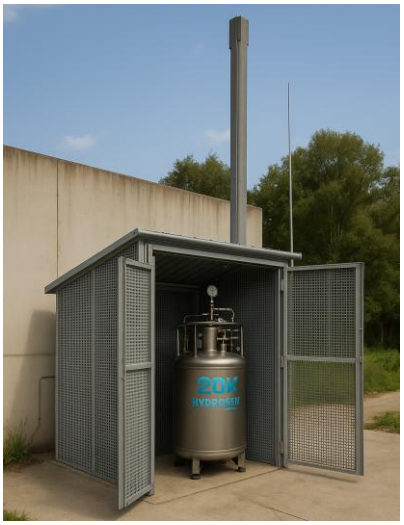
CRYOGENIC IMMERSION & ISOLATION

For the maritime and heavy storage sectors, verifying isolation integrity is paramount. We determine if isolation materials and coatings remain chemically and physically stable when subjected to the thermal shock and sustained cold of cryogenic liquids.

Capacity: We utilize dedicated cryogenic test vessels with a 100 L capacity, allowing for the testing of larger, representative components rather than just small coupons.

Duration: We perform long-duration immersion campaigns (e.g., 15+ days) followed by detailed post-test material analysis to detect micro-cracking, degradation, or loss of thermal performance.

Safety: All potentially hazardous experiments are conducted in controlled, remote-operated "fortified bunkers." These facilities are equipped with advanced leak detection, blast walls, and dedicated ventilation stacks to manage risks associated with boil-off or accidental release.



PERMEABILITY ASSESSMENT

For the development of new polymer materials, liners, and composites, determining the precise rate of hydrogen permeation is critical for certification and safety.

Standardization: Tests are strictly performed according to standard via a manometric method, measuring pressure as a function of time to provide validated permeation rates and diffusion coefficients.

Rugged Design: Standard equipment often fails under hydrogen conditions. Our custom test cells are specifically engineered to withstand material swelling and mechanical breakdown, ensuring accurate data even at high pressures and temperatures.

TNO.NL/PROSAFE

DEFENCE, SAFETY AND SECURITY

The independent Netherlands Organisation for applied scientific research (TNO) supports the Dutch comprehensive protection model. Our work in Defence, Safety & Security focuses on technological and behavioural innovations.

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