Institute for
Energy Technology

Our Hydrogen Activities

Institute for Energy Technology

720 employees from 35 different countries

1,3 billion NOK in annual turnover

4000 m^2 of advanced laboratories

135 scientific publications

200 international projects

Research for a better future

At IFE, we build bridges between research, education and industry. Since 1948, we have been a frontrunner in international energy research.

Our research field on Renewable Energy

- Solar Energy
- Hydrogen Technology
- Solar Cell Technology
- Battery Technology
- Wind Energy
- Energy Systems Analysis

Content

IFE Hydrogen Technology Center (IFE Hynor)

IFE Hynor is a fuel cell and hydrogen technology test center owned and operated by IFE. It's located at Kjeller in Norway.

IFE Hynor consists of the following research infrastructure

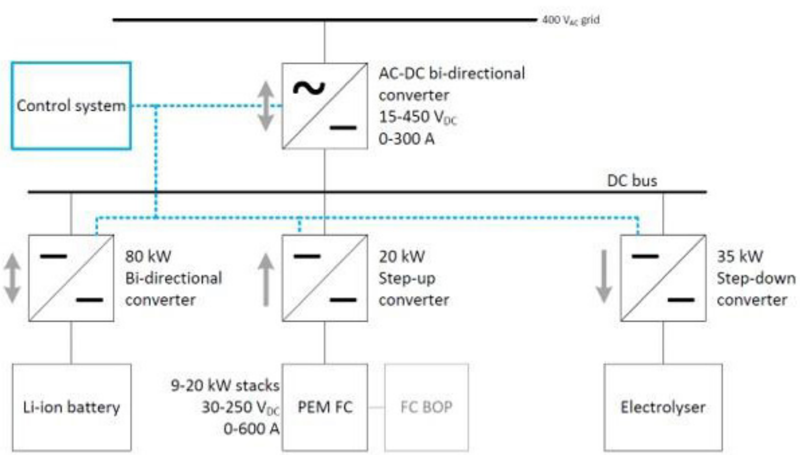
- PEM Water Electrolyser System Laboratory (33 kW) and Greenlight TS (3 kW)
- PEM Fuel Cell System Laboratory (20 kW)
- 3 *Dolphin ESS* Li-ion battery packs from Corvus Energy (30 kWh)
- Sorption Enhanced Reformer (SER) pilot plant (20 kg H_2 /day)
- Liquid Hydrogen Experimental Setup

In addition, IFE Hynor includes the following infrastructure that can be used for this test campaigns:

- PV-system (16 kWp)
- Power conditioning systems (AC/DC, DC/AC)
- Gas supply and storage systems (H_2, CH_4, N_2)

The IFE Hynor laboratories offer the possibility to perform research on water electrolysis and fuel cell stacks and systems. In addition, production of hydrogen with integrated CO2 capture from diverse gaseous hydrocarbons (biogas, biomethane, natural gas, syngas) can be tested in our SER prototype. IFE Hynor also cincludes a laboratory setup for production and experimental work with liquid hydrogen (LH_2).

A laboratory for testing of ammonia cracking and hydrogen purification will be in operation from 2025.



Power conditioning system: *The water electrolyser and fuel cell systems laboratories are connected to the same DC-bus as the Li-ion battery packs via dedicated DC/DC converters. The DC/DC-converters are custom-made to provide a large flexibility with respect to input voltages and currents, making it possible to test many different types of units. The DC-bus is connected to the local grid via an AC/DC bidirectional converter, which can be programmed to emulate different types of loads or generators. This setup is used to test and validate advanced Energy Management Strategies.*

READ MORE

Website: *Hynor Hydrogen Technology Center - IFE*

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Production

Water Electrolysis

Making green hydrogen production efficient, durable and affordable

IFE's Hydrogen Technology Department has decades of experience in testing and validation of low-temperature water electrolysis technologies. We provide the capability to test cutting edge PEM, alkaline and AEM components, as well as validating the performance and durability of established technologies.

Our focus

- High-pressure electrolysis (< 200 bar): suitable for offshore H2 production, e-methanol production, direct injection in the gas grid, etc.
- Integration in renewable energy systems: optimize design and operation of water electrolysis systems based on variable power from PV and wind to maximize efficiency, lifespan, and economy

1. Testing of short stacks and single cells PEM

a. Up to 33 kW
b. Up to 200 bar differential pressure and 30 bar balanced pressure
c. Characterising new electrolyser materials and components
d. Long-term durability testing
e. Testing and qualification of stacks and key system components
f. Validation of advanced control strategies and hybridization with Li-ion batteries

2. AEM/Alkaline testbench

a. Rated capacities: 200 A
b. Ideal for investigating single cell (up to 25 cm^2) performance and durability under different operational conditions (such as temperature, KOH molarity, different impurities etc.)

3. Integrated multicell EIS measurement

a. Cell testing in short stacks (up to 25 cells) simultaneously in a single cell measurement

4. Modeling of Components, Stack, Systems

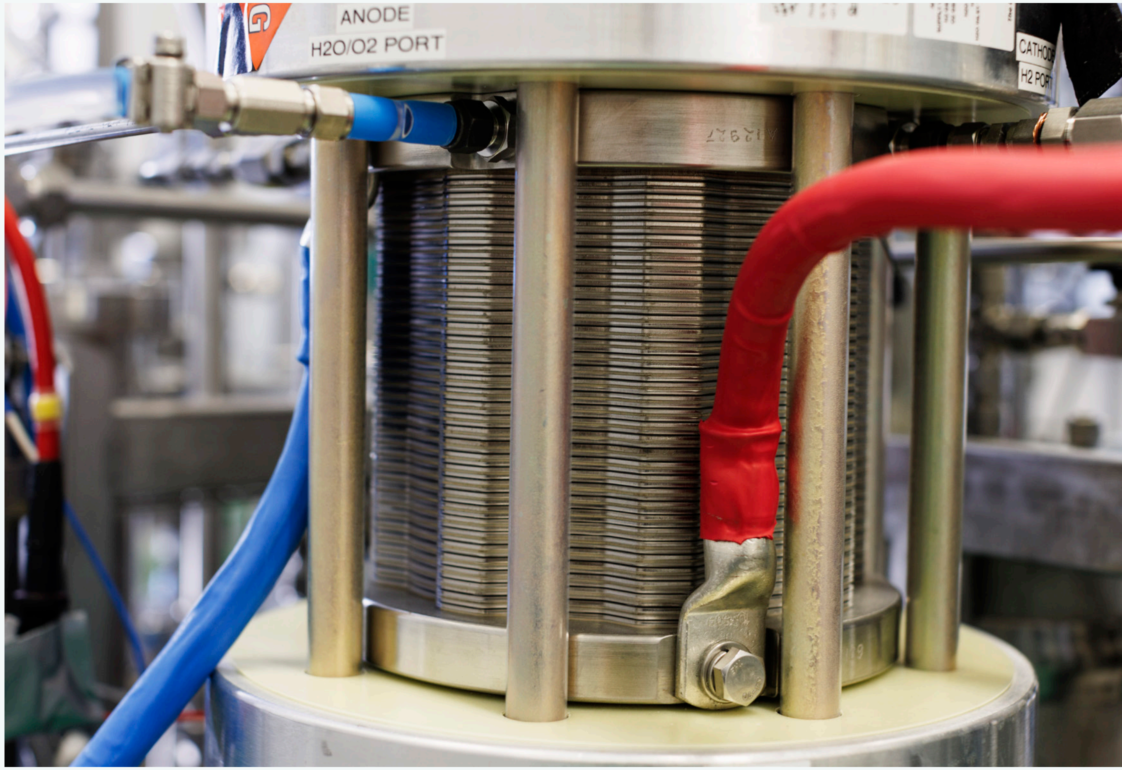
a. Thermal, Electrochemical ++
b. Physics-driven or data-driven

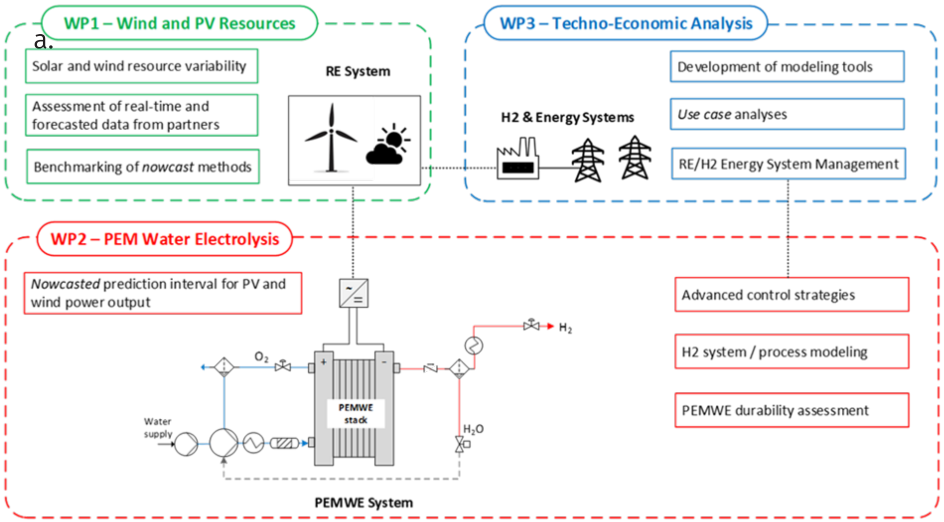
5. Advanced control strategies

a. Optimize integration of RE-power and hydrogen

Existing projects

IFE leads the national research project ***REHSYS - Renewable Energy Hydrogen Systems based on PV, Wind, and Water Electrolysis*** (2023-2027), co-funded by the Norwegian Research Council and Norwegian industry. The project objective is to study and optimize the design and operation of industrial scale water electrolysis systems based on wind, PV, and PEM technology.





REHYS concept

IFE leads the national research project ***REHSYS - Renewable Energy Hydrogen Systems based on PV, Wind, and Water Electrolysis*** (2023-2027), co-funded by the Norwegian Research Council and Norwegian industry. The project objective is to study and optimize the design and operation of industrial scale water electrolysis systems based on wind, PV, and PEM technology.

HYDROGENi

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Production

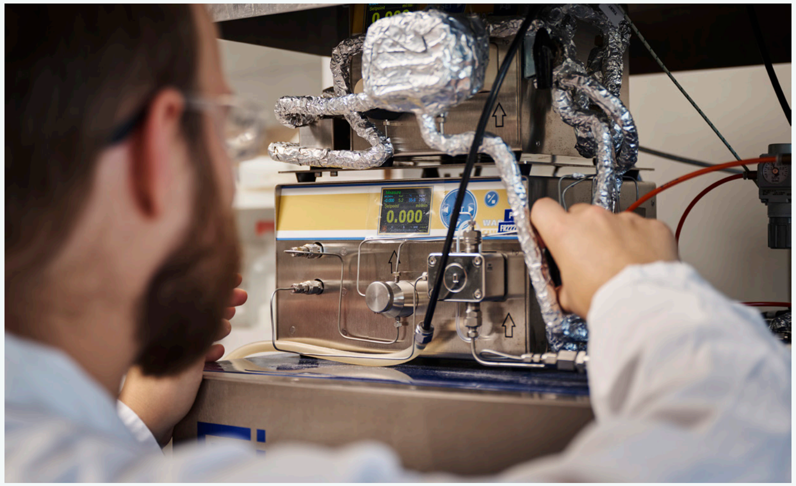
Hydrocarbon Reforming and Ammonia Cracking

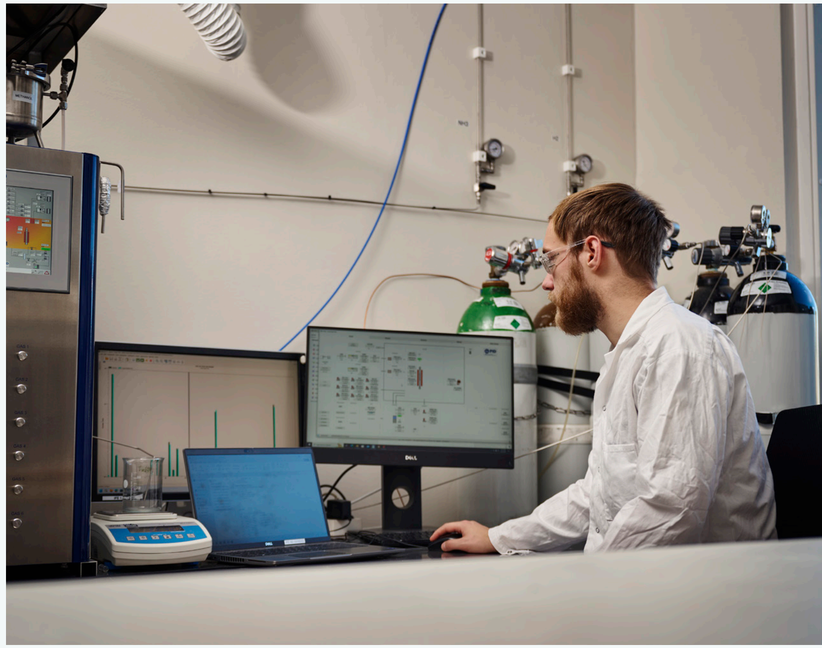
Through its expertise in material and process technology, the department of Environmental Industrial Processes at IFE develops new advanced materials and intensified processes for the production of cost-efficient low-carbon hydrogen and ammonia. Materials of interest are catalysts for reforming, cracking and synthesis applications, CO_2, water and NH_3 sorbents, as well as multi-functional materials.

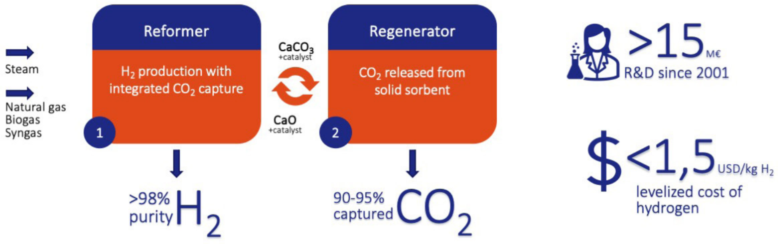
Our top-class laboratories include synthesis and characterisation equipment, as well as automated experimental rigs for performance testing (TGAs, flow-reactors, fixed/fluidized bed reactors).

We bring technology from proof-of-concept to medium TRL level. Our test facilities installed at the IFE-Hynor Hydrogen Technology Centre include a Sorption-Enhanced Reforming prototype and a test set-up for ammonia cracking and hydrogen purification.

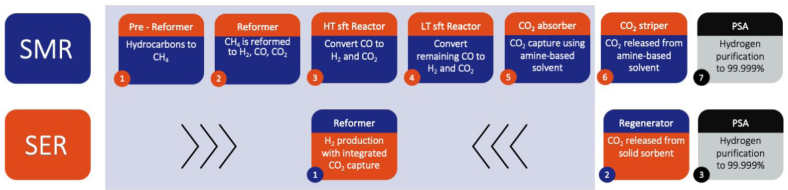
Our R&D in process intensification led to the development and experimental validation at prototype level of the Sorption-Enhanced Reforming process (SER) for the production of clean hydrogen from hydrocarbon feedstock with integrated CO_2 capture.







SER Technology



SER vs Conventional Technology - Process intensification

In the field of ammonia cracking, we are currently involved in a national project financed by the Norwegian Green Platform program (Norwegian Research Council project no. 340884) where we, in collaboration with Wärtsilä Gas Solutions, develop and test novel NH_3 adsorbents for the purification of the hydrogen product. We are also partner in the EDF-funded European project CALIPSO (101168041) where we will test at TRL5 in our facilities a novel palladium-membrane ammonia cracker reactor for military maritime application.

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Production

Corrosion

The IFE Corrosion Technology department offers materials selection and testing services for electrolyzers, including cell stack and BoP components. Corrosion and environmentally assisted cracking tests can be performed in autoclaves and flow loops at high-pressure H2 and O2 alkaline environments with temperatures up to 100oC. CRA and low-alloy steel test coupons can be machined to spec in our local workshop.

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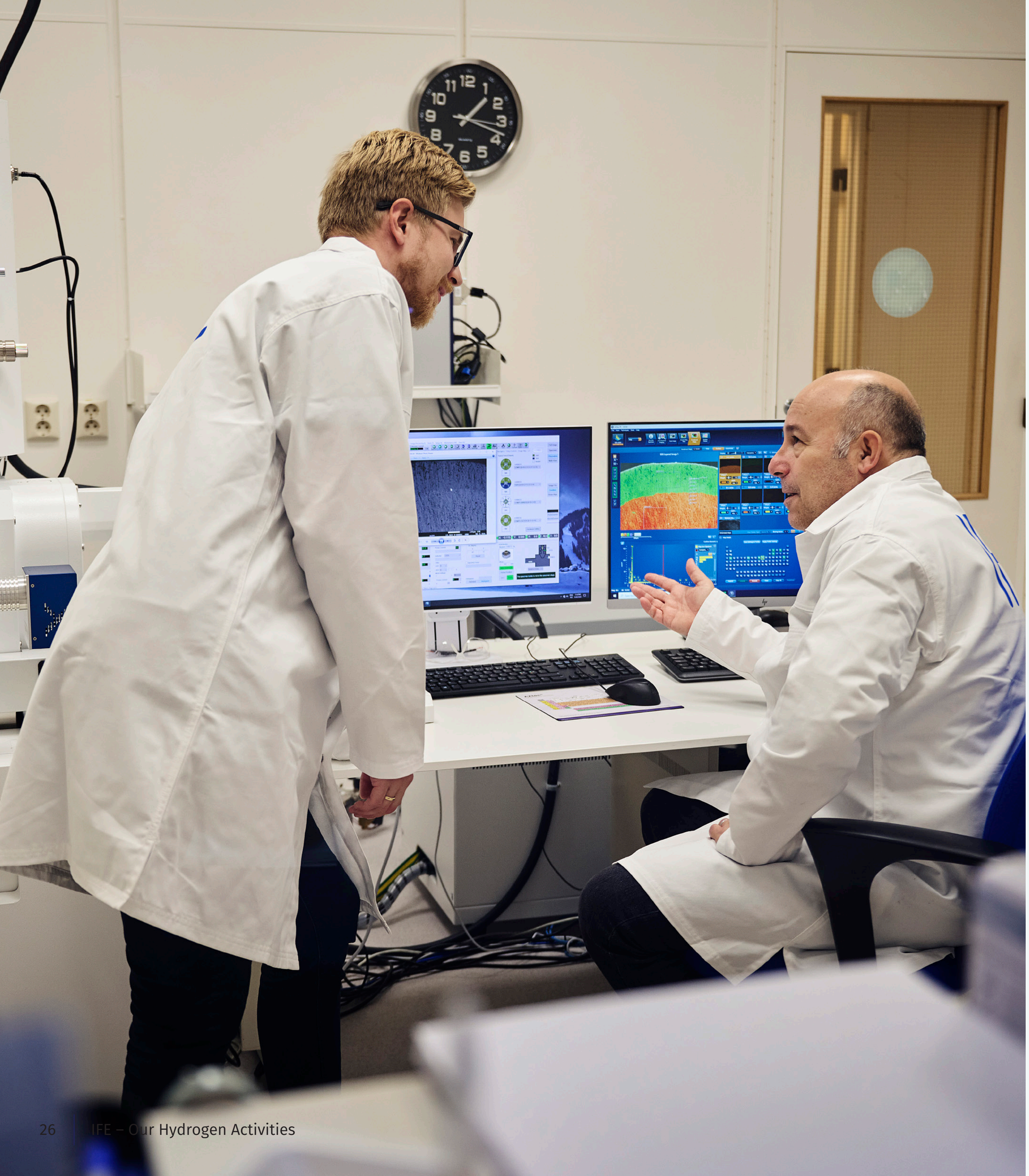


Storage

Liquid Hydrogen

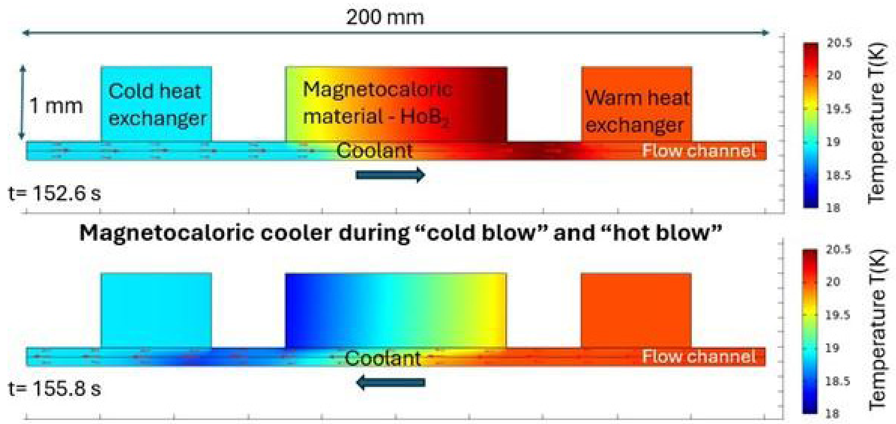
Magnetic cooling – a paradigm shift in hydrogen liquefaction

Motivation

Liquid hydrogen (LH_2) has 3 times the volumetric energy density of compressed hydrogen at 350 bar. However, cooling it below its boiling point of 20 K with the current vapor-compression technology eats up almost 1/3 of its energy content.

IFE is developing a greener and more efficient way of storing hydrogen as a liquid by employing the magnetocaloric effect. The magnetocaloric technology will become particularly attractive for localized storage of LH_2 in combination with green hydrogen production from renewables. It has the potential to

- Drastically reduce the energy consumption of hydrogen liquefaction (6-8 kWh/kg H_2)
- Lower CAPEX and OPEX
- Improve liquefaction performance, especially at small scale (1-3 ton/day).



Simulations: At IFE, we are employing simulation packages such as COMSOL Multiphysics to optimize the heat transfer process in the magnetic regenerator, the core part of the liquefier, to make the process more energy efficient.

Our Focus

IFE's research on magnetic cooling of hydrogen leverages our long experience in the generation and use of liquid hydrogen - an essential part of the advanced instrumental setup at the JEEP-II neutron source – as well as our position on the research frontline in advanced materials related to hydrogen and magnets.

Materials Engineering

Magnetocaloric Hydrogen Liquefaction relies heavily on the use of critical raw materials, e.g., heavy rare earth elements. Our focus is to search for alternative and less critical materials by means of Materials Informatics, employing machine learning (ML) and simulations in combination with experiments.

We use a range of different experimental methods for materials synthesis and characterization, including arc melting, mechanical alloying, XRD, TG DSC, neutron scattering, etc. In combination with experimental techniques, we use materials informatics to search for alternative and less critical magnetocaloric materials.

Existing projects

IFE is currently coordinating a large HORIZON EUROPE project (HyLICAL) that will deliver the first European small-scale magnetocaloric hydrogen liquefier by the end of 2027. The project has 14 partners from academia and industry and a budget of almost 5 M€.

READ MORE

Website: *Hylical.eu*

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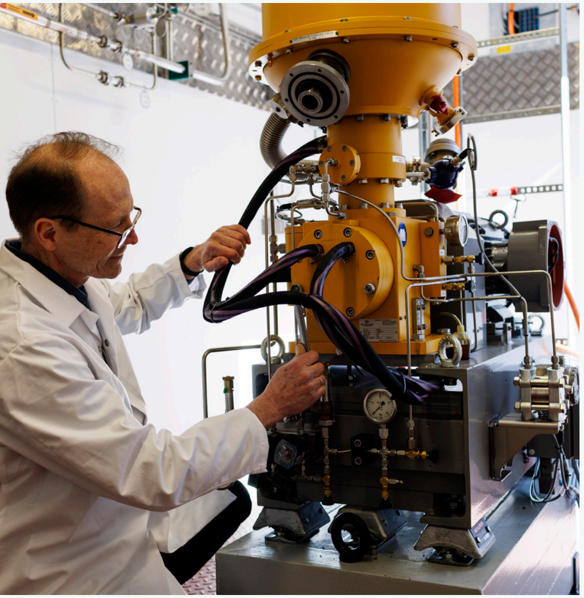


LH_2 production

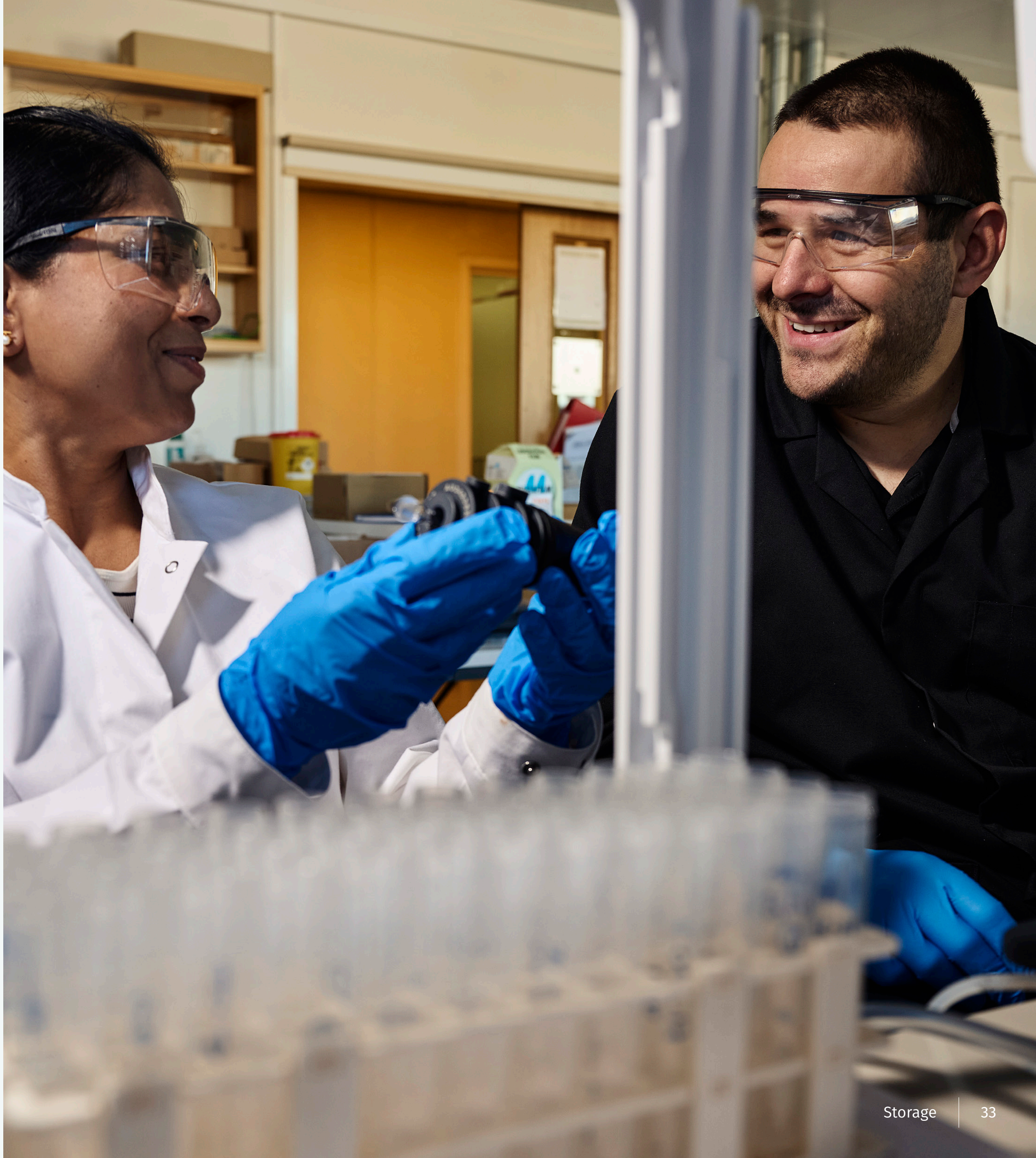
IFE has a small-scale setup for production of liquid hydrogen based on a Stirling-type cryomachine and a custom-made heat exchanger (cold-head). The generated LH2 was used as a neutron moderator in the JEEP-II reactor. This equipment can conveniently be integrated into a complete LH2 experimental research infrastructure.

Storage

Reservoir Technology

Department of Reservoir Technology is at the forefront of research on safe underground hydrogen storage, exploring both natural and engineered reservoirs. We employ cutting-edge laboratory experiments and proprietary simulation software to assess and enhance the safety of underground hydrogen storage solutions for the future energy landscape. The IFE Geochemistry Laboratory contributes to this initiative by conducting stable isotope analysis to characterize geological formations. This enables us to map interconnections between geological structures, which is crucial for understanding and optimizing hydrogen containment.

Leveraging knowledge from carbon capture and storage (CCS), our team applies well-established methodologies to ensure the integrity of hydrogen storage systems. By studying the effects of geological confinement, clay content, clay type, and water saturation on permeability, we are pioneering a comprehensive approach to hydrogen storage integrity. Our reactive flow apparatus enables direct

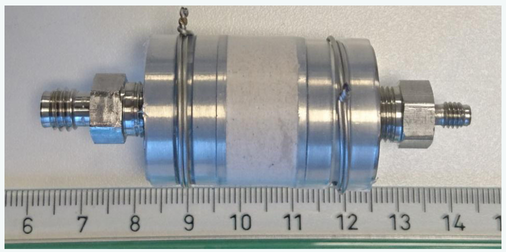


exposure of cores of rock (or similar materials) to a flow of hydrogen under conditions relevant to Underground Hydrogen Storage. Using a microfluidics approach, we are investigating the displacement of water or brine in porous materials by hydrogen, and vice versa, to simulate injection-withdrawal cycles and help tailor current reservoir models for this purpose. This integrated research effort supports the development of Underground Hydrogen Storage as a key component of a renewables-based energy system.

In addition to our research efforts, we offer commercial services for the purity analysis of hydrogen gas, ensuring compliance with industry standards. Our team conducts sampling and analysis of hydrogen gas for industrial clients, providing accurate assessments that are critical for quality control, safety, and regulatory adherence.

Existing projects

IFE is a partner in the National Centre for Sustainable Subsurface Utilization of the Norwegian Continental Shelf (NCS2030), where we lead initiatives focused on reservoir utilization for the energy transition. Our expertise includes developing innovative methods and tools to enhance the storage capacity of geological formations, such as salt caverns and porous reservoirs, for hydrogen storage, combining modeling and experimental approaches. Previously, we were a key partner in the EU-funded project "Metrology for Hydrogen Vehicles," supported by the EMPIR initiative and co-funded by the European Union's Horizon 2020 research and innovation program and participating states. This project aimed to advance metrology to ensure the safe and efficient use of hydrogen at refueling stations, promoting the growth of hydrogen as a sustainable energy source for the transport sector.



Reinier van Noort (IFE) Effects of confinement, clay content, clay type and water content on the CO2 and hydrogen-permeability of clay-rich sandstones and shales

READ MORE

Website: *Geochemistry Laboratory - IFE*

Website: *Reservoir Technology - IFE*

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Storage

Metal Hydrides for Hydrogen Storage

Safe and efficient hydrogen storage in the solid state

Motivation

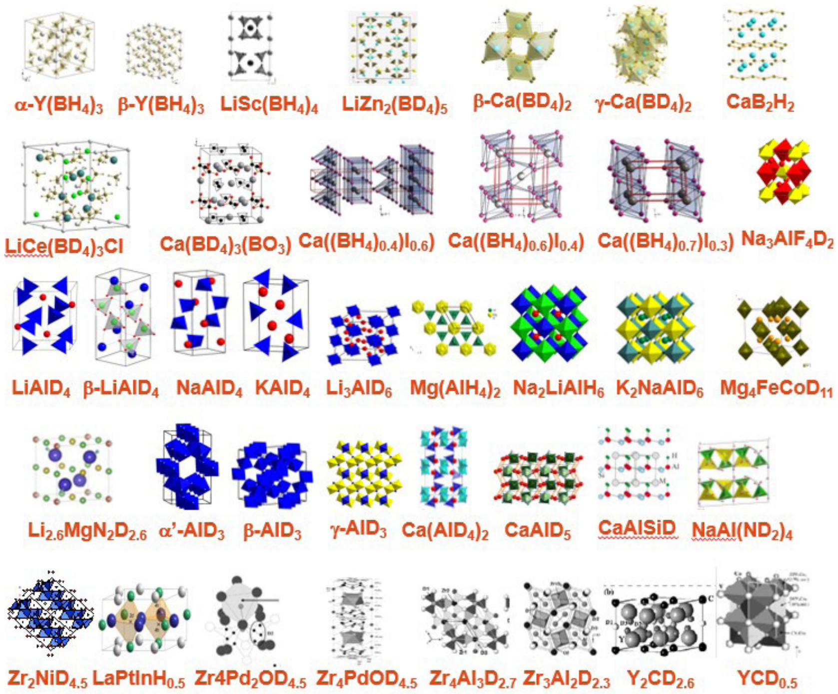
Hydrogen storage in metal hydrides is a safe and volume-efficient alternative to compressed and liquid hydrogen storage. Since hydrogen in metal hydrides is stored in the solid state and heat is required for desorption to occur, the risk associated with leaks in case of tank ruptures is greatly reduced. Additionally, storing hydrogen in metal hydrides does not require any liquefaction process or compression above a few tens of bar, making it an overall cheaper alternative in some well-defined scenarios where the cost of hydrogen is dominated by the liquefaction and compression infrastructure.

For over 70 years, IFE has investigated the synthesis and characterization of metal hydrides for energy applications.

We use advanced characterization techniques to investigate metal hydrides across different length scales.

What we do

IFE's research on hydrogen storage in metal hydrides builds upon the extensive expertise on materials synthesis and structural characterization, which took advantage of the easy access to neutron scattering techniques and instrumentation available until 2019 at the JEEP-II research neutron reactor. As the interest in metal hydride as solid-state hydrogen carriers has grown in the past two decades, our work has widened to study the more relevant functional properties and their sustainable application within the hydrogen value chain as a hydrogen storage media.



Selected metal hydrides investigated and structurally characterized at IFE since 2000.

Materials design and synthesis

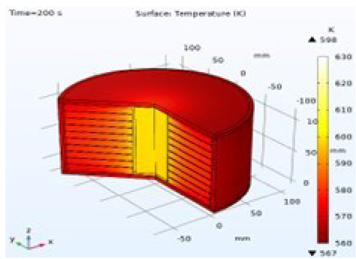
Metal hydrides can be very diverse with respect to their structural and hydrogen storage properties. Our focus is to investigate well-known systems, such as those based on TiFe, to improve their properties and reduce their production costs, without relying on expensive raw materials sourced outside the EU. At the same time, using experimental and numerical approaches, we explore new alloy compositions, such as those based on high entropy alloys, which have the potential of revealing increased hydrogen storage capacities while operating at low pressure and ambient temperatures.

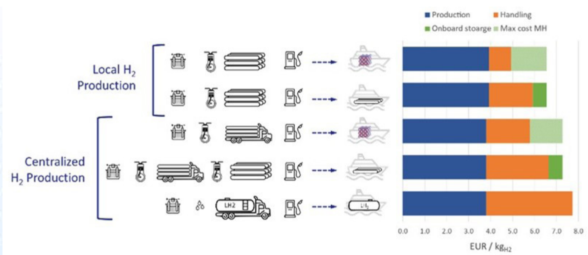
Advanced characterization techniques

At IFE, advanced characterization techniques using large scale facilities (synchrotron and neutron sources) abroad are employed to investigate the materials' properties covering length scales from 10-10 to 100 m. Understanding of the behavior of metal hydrides across different length scales, is instrumental to assess how if metal hydrides can perform in a technologically relevant setting.

Simulations and techno-economic assessment

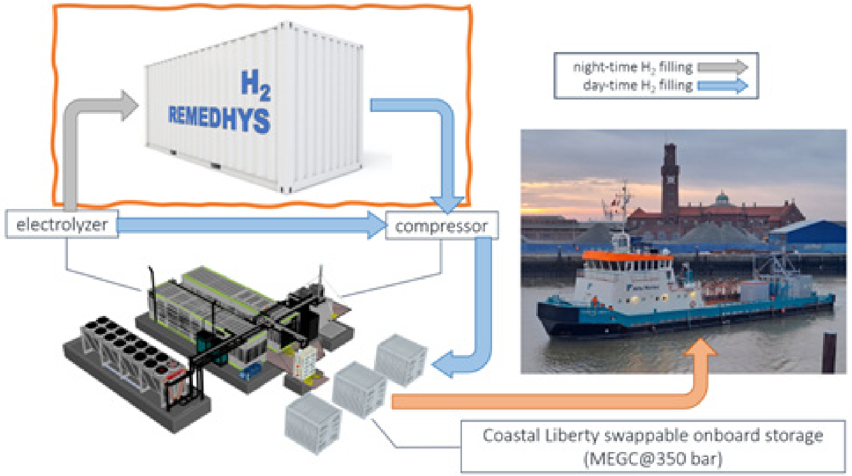
We employ simulation packages to i) quantify the heat management challenges that must be addressed when optimizing hydrogen storage tanks based on metal hydrides and ii) explore the integration of hydrogen storage in metal hydrides with hydrogen production (electrolyzers) and conversion (fuel cells). Additionally, techno-economic analysis is used to evaluate how the cost of the different supply chain alternatives varies depending on how hydrogen is stored.





Existing projects

IFE is the coordinator of the M-ERA.NET project HESSENSE, which aims at investigating high entropy alloys for safe and sustainable hydrogen storage. From 1st January 2025, IFE will also coordinate the HORIZON EUROPE project REMEHDYS, which aims at validating a modular hydrogen storage system with a capacity of 100 kgH2 in an actual end-use scenario and will adopt a novel approach in the production of metal hydrides utilizing recycled starting materials sourced in Europe. REMEDHYS has 10 partners from academia and industry and a budget of almost 4 M€.



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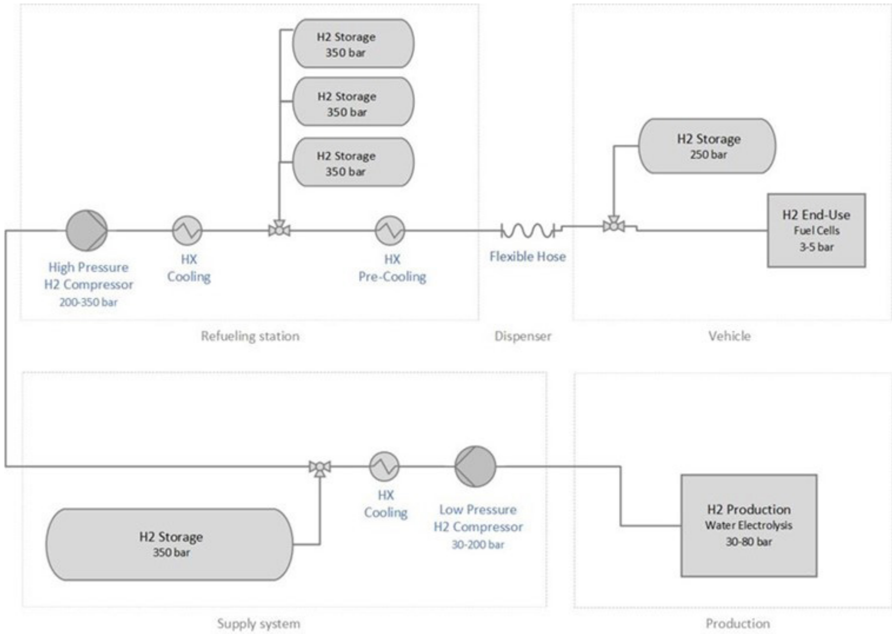
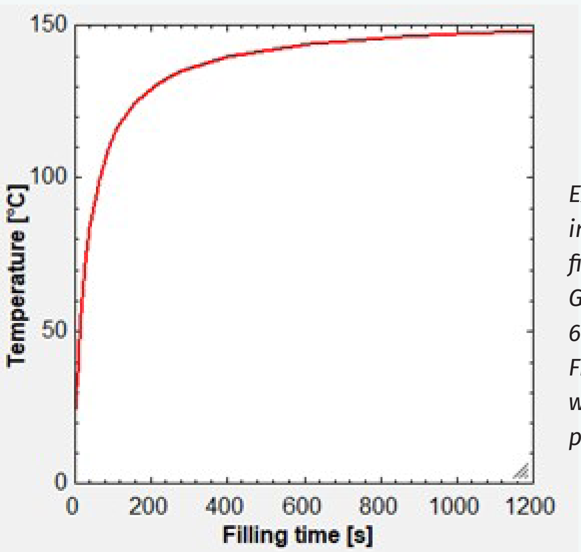
Usage

Gaseous Hydrogen Refuelling

High-throughput refueling systems is technically challenging and requires careful system optimization based on thermodynamic models. Hydrogen gas has the peculiar property that it heats up as the gas expands from a high-pressure state into a volume where the gas has a lower pressure. Such heating can lead to damaging of the walls of modern composite material storage tanks, and the heat must thus be removed during the filling process.

IFE develops high-throughput hydrogen refueling models for ferries and trains in order to transfer compressed gaseous hydrogen between storage tanks in a safe, energy and time efficient way. Thermodynamic modelling of the gas in the various states during the transfer is an important tool in this regard. Furthermore, dynamic processes during the GH2 flow may also be important during the depressurization on bunkering and may lead to large temperature differences inside a tank during filling process. Such dynamic processes require computational fluid dynamics simulation (CFD) models, which also is an important tool used in the hydrogen technology research at IFE.





Example showing temperature increase in end-user tank during filling at 20 °C of 620 kg of GH2 during 20 minutes from a 600 bar pressure storage tank. Final pressure in the small tank was 240 bar, and the gas was precooled to 5 °C during filling.

READ MORE

Webpage: *Compressed hydrogen - IFE*

Report: *IFE BRAGE: Efficient use of coolants in heat exchangers for hydrogen tank filling*

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Usage

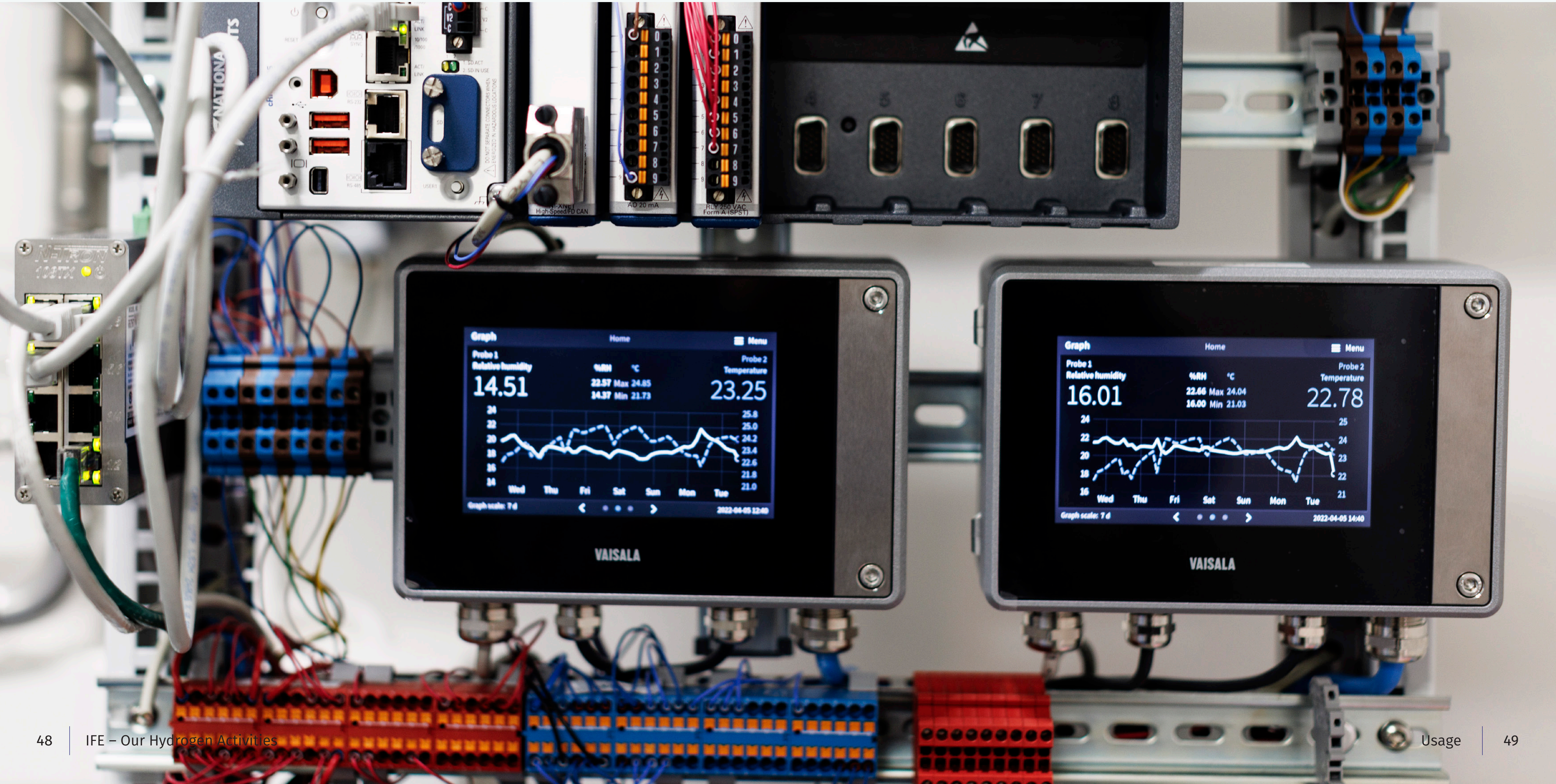
PEM Fuel Cell Systems

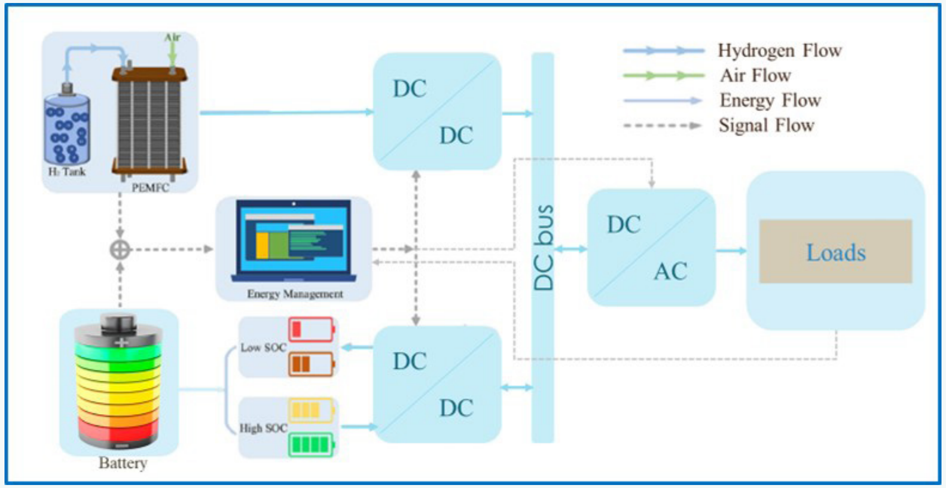
IFE has designed and built a flexible PEM fuel cell (PEMFC) system platform which is available for testing of small-scale hydrogen supplied fuel cell stacks up to 20 kW. The PEMFC-system is integrated with an advanced power conditioning system which makes it possible to emulate different load profiles (e.g., maritime, and heavy-duty vehicle load cycles). The PEMFC-system can also be hybridized with a Li-ion battery energy storage system and integrated with a 16 kW PV-system.

The highly configurable PEM fuel cell test rig at IFE is heavily instrumented and well suited to test and qualify new PEM fuel cell stacks and key system components for the overall balance of plant (BoP), as well as new advanced power control systems. The PEMFC-system is particularly suited for testing of hybrid fuel cell / battery power system configurations and operational schemes for maritime and heavy-duty vehicle applications. The PEMFC-system can also be used to validate small-scale (5-20 kW) hydrogen fuel cell-based uninterruptible power supply (UPS) system configurations.

What we do

- PEM fuel cell stack testing up to 20 kW
- Modelling and validation of advanced Energy management Strategies
- Testing of hybrid PEMFC / Li-ion battery power system configurations
- Testing and characterization of key PEMFC system and balance of plant (BoP) components
- Electrochemical in-situ characterization of stacks, including advanced impedance spectroscopy:
  - In-situ (on-line) determination of stack state of health
  - Study of degradation mechanisms in electrodes, electrolyte, and other key components
  - Determination of optimum operation conditions, cell design, and stack designs





Energy management strategies (EMS): appropriately designed control systems is essential to accurately manage the energy between the PEMFCs, batteries, and loads. IFE develops EMS for hybrid power systems based on fuel cells and lithium-ion batteries for marine propulsion using Aritifcal Neural Networks, fuzzy logics, and rule-based techniques to stabilize the DC bus voltage and minimize degradation. These strategies are tested and validated in the laboratory at IFE Hynor.

RESOURCES

***Paper:** Control and Power Management of Battery-PEM Fuel Cell Hybrid Power System for Marine Propulsion Systems*

***Web page**: Fuel Cell System - IFE*

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