

H₂



Hydrogen Frontiers

The Future
European
Landscape



Hydrogen Europe
Research





Hydrogen Frontiers

The Future European Landscape

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A Vision For The Future

Imagine a Europe where the air is pure, unaffected by pollution. Picture cities powered entirely by renewable energy, their skylines decorated with wind turbines and solar panels.



Luigi Crema
President, Hydrogen
Europe Research

Envision a continent where industries operate with zero carbon emissions, thanks to the revolutionary applications of hydrogen. From clean hydrogen-powered transportation to zero-emission industrial processes, hydrogen is at the core of this shift toward sustainability.

This is the Europe we are building—today, for tomorrow. A continent in charge of the global fight against climate change, setting new standards for sustainability and resilience. Together, we are forging a path toward a future where economic growth and the power of hydrogen go hand in hand, aligning the prosperity of people with the health of the planet.

Hydrogen is at the heart of an energy revolution that is transforming how we live and work. “*Hydrogen Frontiers: The Future European Landscape*” invites you to explore this vision of the future through stories of innovation and progress. From groundbreaking technological advancements to real-world applications, “*Hydrogen Frontiers*” provides a comprehensive look at how hydrogen is fostering a more sustainable future.

Join us in exploring how hydrogen is not just a part of the energy revolution, but a catalyst for a new era of environmental innovation. Discover the stories of visionaries and leaders who are pushing the boundaries of what is possible, and see firsthand how hydrogen is transforming industries, cities, and lives across Europe.



CHAMPIONS OF SUSTAINABILITY

Being a champion of sustainability means taking bold, innovative steps to reduce carbon footprints and enhance energy efficiency.

It is about pioneering new methods and technologies that not only meet but exceed environmental standards, setting a new benchmark for others to follow.

H2GLASS



H2GLASS

**A Horizon Europe Project
Coordinated By Sintef
Energy Research**

Text by: Marta Rubio, Marie-Eve Reinert,
Chiara Caccamo, Marta Bucelli

Images curtesy of: Tilen Sever

Pioneering Green Hydrogen in Glass and Aluminium Manufacturing for a Sustainable Future

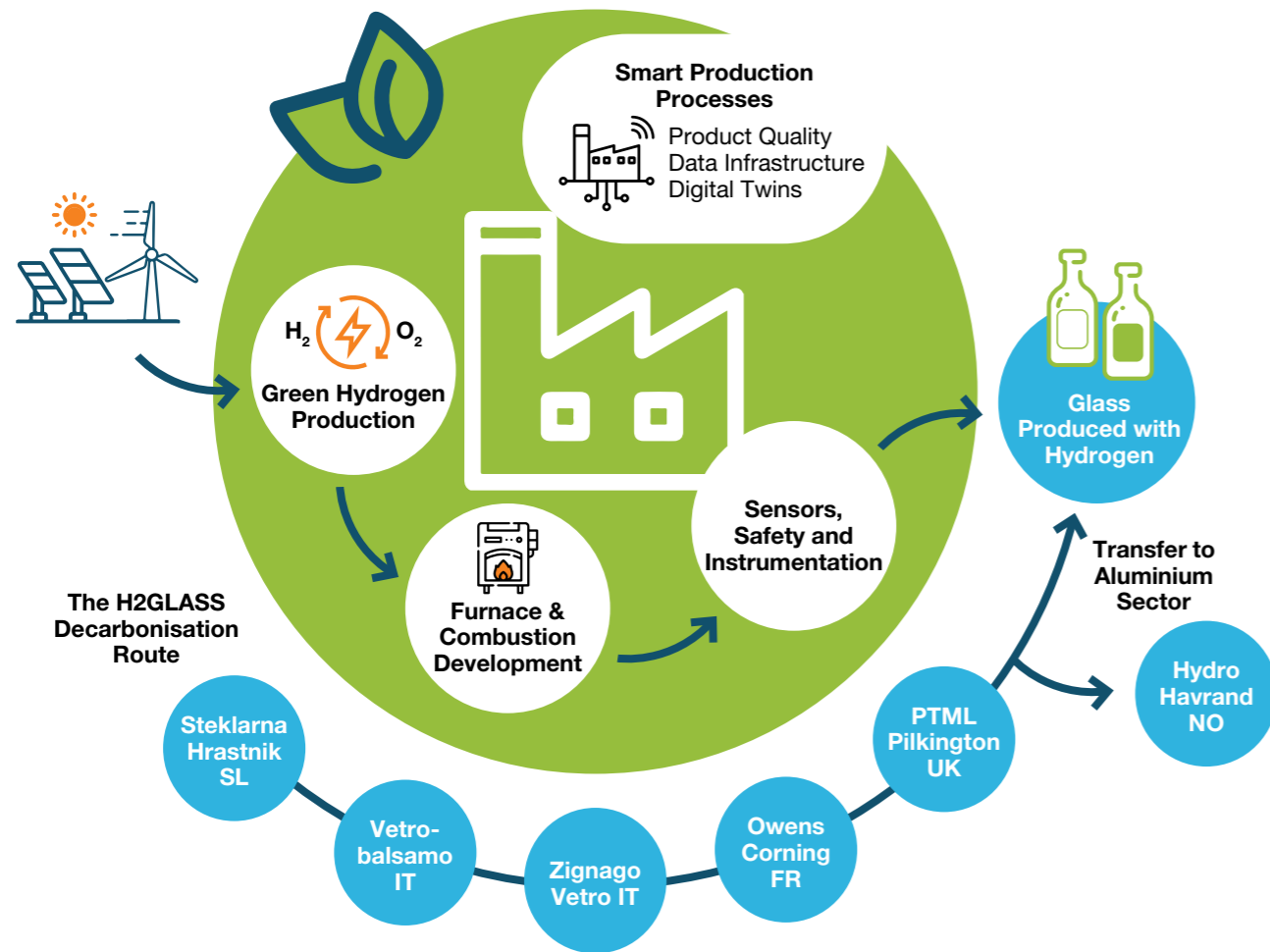
The H2GLASS project, an ambitious collaboration between glass manufacturers, industry partners and research institutions across Europe, is leading in revolutionizing the glass and aluminium manufacturing industry through the innovative integration of hydrogen technologies. Our mission is clear: to drive the green transition by drastically reducing carbon emissions by replacing natural gas with green hydrogen and to enhance energy efficiency in high-temperature energy-intensive industrial processes.

“A radical redesign and advanced heat recovery systems have been seen as a solution for the glass and aluminium industry, but even then, the energy efficiency increase would not be more than 10-15 percent as a maximum. This is not enough to meet the decarbonization goals set by the Paris Agreement.”

Chiara Caccamo

H2GLASS Project Coordinator and Research Manager at
SINTEF Energy Research

The technology platform in the H2GLASS project consists in the development of furnace specific systems with improved heat transfer for 100 percent hydrogen combustion to minimize greenhouse gas emissions. The action is extended to a flexibility and optimization analysis to adapt the industry uptake of hydrogen processes. Digital twin technologies will be developed and used for risk-based maintenance and optimised production and control of the combustion system.



The technology platform will be tested through six pilot demonstrators among the industrial partners. Green hydrogen will be supplied at the demonstrator locations by a mobile electrolysis unit. The results obtained from the pilot demonstrations will be analysed to assess the potential consequences of the implementation of green hydrogen as a carbon neutral alternative to natural gas in other energy-intensive industries.

The vision

The glass and aluminium production are high-temperature energy-intensive processes. In 2020, these industries have emitted approximately 21.5 million tonnes of CO₂ equivalent only in Europe. In the next 30 years, the glass and aluminium industries, like other sectors, must be completely decarbonized to meet the NetZero by 2050 targets set by the Paris Agreement. Given the lifespan of a single glass furnace (12-15 years), and similarly for the aluminium case, innovations are urgently needed now: the year 2050 is only two furnaces away.

H2GLASS is committed to make a substantial impact on environmental sustainability of the glass and aluminium industrial sectors by:

- Decarbonization:** By replacing natural gas with green hydrogen, H2GLASS aims at reducing greenhouse gas emissions associated with the glass and aluminium manufacturing processes. This shift is essential and of paramount importance for a more sustainable and environmentally friendly industry. Furthermore, by developing and implementing hydrogen oxy-fuel combustion technology, H2GLASS mitigates the risks associated with NOx emissions.
- Quality Assurance:** Ensuring that the transition to hydrogen combustion maintains the required product quality is a top priority for the glass and aluminium industries. H2GLASS aims at developing and demonstrating the technology stack that guarantees both environmental benefits as well as the consistent glass and aluminium quality required by end-users.
- Safety and Efficiency:** Addressing the safe handling and use of hydrogen to safeguard life, environment and assets at the industrial sites is a priority of the H2GLASS project. Hydrogen is a flammable substance and its introduction to new industrial applications needs to be carefully monitored to avoid setback and

loss of confidence due to accidental events. Safety risk analysis and management of the hydrogen fuel system is a pillar of the H2GLASS project. Research and development efforts are undertaken to model the loss of integrity mechanisms leading to hydrogen releases and their potential consequences and effects in terms of fires and explosions. Optimized and efficient technology platforms are developed to improve heat transfer efficiency while minimize emissions in a safe way.

“The goal is to develop both technologies and knowledge needed by the glass manufacturers and by the aluminium industry to meet their target of 100 percent hydrogen combustion at their furnaces. Product quality must not be compromised in the shift to a greener industry, and the H2GLASS project works exactly towards firstly understanding the impact of hydrogen on the furnace temperature profile and melt, as well as foam formation to propose solutions to minimize and remove their effects on the final product quality. Moreover, ensuring the safety of people handling hydrogen as a new fuel to the furnaces is of paramount importance to avoid accidents and setbacks. The risks associated with the flammability of hydrogen must be addressed and well understood, while the necessary measures for preventing or mitigate accidents must be deployed.”

Marta Bucelli
H2GLASS Technical Coordinator and Research Scientist at SINTEF Energy Research

Impact and Potential

The H2GLASS project is expected to generate innovation extended beyond its technological advancements. In particular:

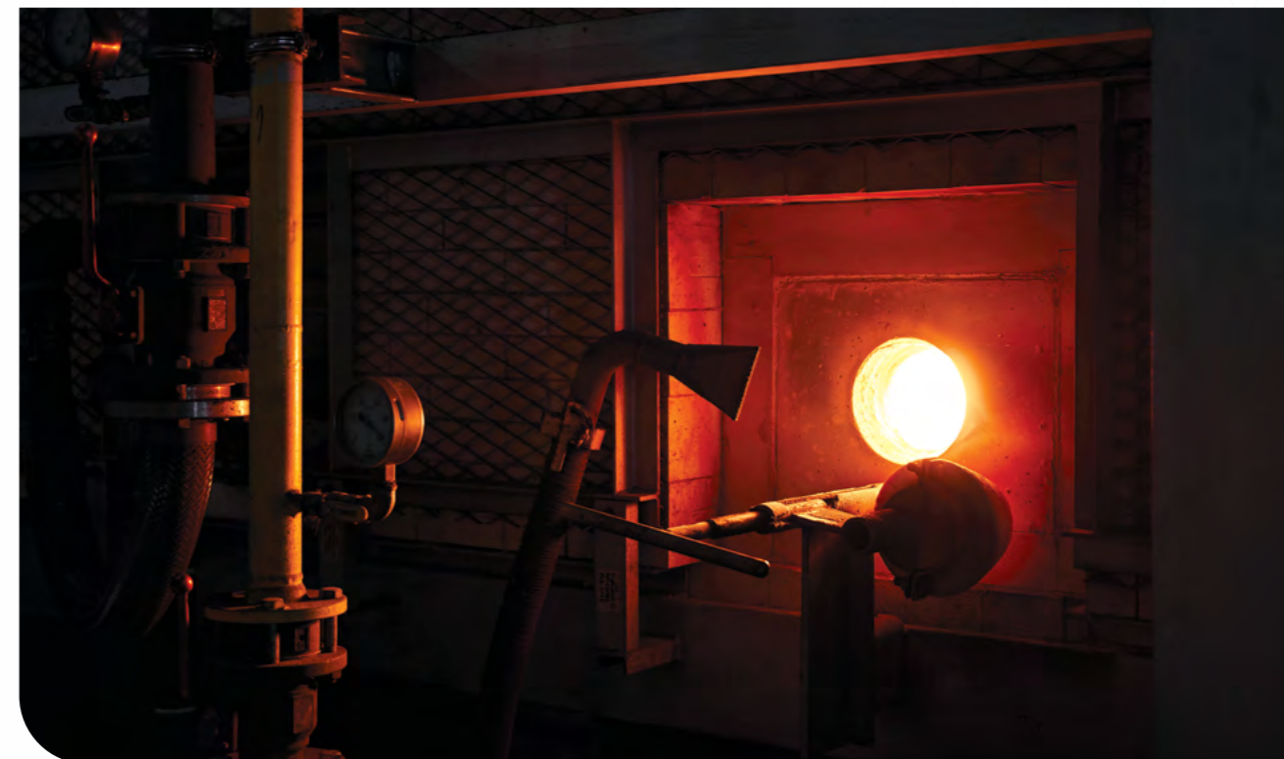
-  **Creation of new jobs:** The project has the potential to create 10 000 new jobs within the glass industry, driving economic growth and providing new employment opportunities.
-  **Revenue generation:** With the potential to unlock €1 – 5 billion in revenues related to glass technology deployment. This financial boost will drive further research and development.
-  **Investment attractions:** The project is expected to attract over €17 billion in investments, supporting the widespread adoption of green hydrogen and benefiting the broader energy landscape.
-  **Emission reduction:** By cutting emissions by approximately 80%, H2GLASS plays a crucial role in fighting climate change and promoting greener industrial practices.

H2GLASS unites six pilot industrial demonstrators from around Europe:

 HRASTNIK 1860 Steklarna Hrastnik (Slovenia)	 PILKINGTON Pilkington (United Kingdom)	 Owens Corning (France)
 Vetrobalsamo (Italy)	 ZIGNAGO VETRO Zignago Vetro (Italy)	 HAVRAND Hydro Havrand (Norway)

The pilot demonstrators develop, test and validate the solutions proposed by the H2GLASS project while ensuring robust and scalable outcomes.

The H2GLASS project receives strong support from its advisory committee, which enrolls main sectoral industrial associations as well as individual companies.





THE VALUE OF INNOVATION

Innovation in the hydrogen sector goes beyond technological advancements; it encompasses the economic and societal impacts of integrating hydrogen into our energy systems.

Hydrogen technology is not only crucial for environmental sustainability but also serves as a powerful economic driver.

PH₂OeNIX



PH₂OeNIX

Photovoltaic System With Directly Coupled Hydrogen Production Through Water Electrolysis For Energy Storage

Text by: Philipp Mayer-Ullmann & Marcus
Rennhofer

Images curtesy of: Philipp Mayer-Ullmann

Introduction and Background

To complete the transition from fossil fuels to renewable energy, an even greater expansion of energy sources (such as solar power or wind power) is required. Still, these technologies must further increase their performance, reliability, and flexibility. In addition, clean, field-proven solutions for sector coupling are called for. Here, hydrogen can act as a central bridge between the volatile power from solar or wind and the still dominant hydrocarbon-based energy system: hydrogen technologies, such as large-scale storage, electrolyzers, fuel cells, or gas engines, are already important elements in the energy technology spectrum and enable, amongst others, the conversion, transport and seasonal storage of energy in the required capacity range.

Unlike today's predominant production routes via fossil fuels, "green hydrogen" is produced entirely without CO₂ emissions through water electrolysis using renewable electricity. Green hydrogen can be used as a long-term energy storage or to decarbonise various applications e.g., transportation, and industrial processes such as steel and cement production. It can even be combined with captured CO₂ to produce carbon-neutral fuels or chemical feedstocks. Global decarbonisation is not possible without green hydrogen, but terawatts of renewable energy will be required to achieve it.

Misperceptions, current market failures, and fragmentation prevent clean hydrogen from reaching its full potential as the missing link in an integrated, sustainable, and clean energy system. Significant research and development efforts are needed to further improve the efficiency, cost, storability, and producibility of clean hydrogen.

In the hydrogen conversion value chain, cost-effective water electrolysis is the missing link. For example, the costs of proton exchange membrane electrolysis (PEM) systems must be reduced by scaling up and switching to sustainable materials with a low content of precious metals. On the other hand, high-temperature solid oxide electrolysis cells (SOECs) or direct photo-electrochemical conversion routes need to be developed towards commercial demonstration.

With regards to renewable electricity from solar power systems, performance and reliability are key for building and sustaining a reliable and affordable power sector. Therefore, degradation mechanisms of solar power components in interaction with new applications, uses, and weather conditions need to be understood and addressed, while the design, operation and maintenance (O&M) of solar power plants need to be fully digitised to further reduce the related levelised cost of electricity (LCOE).

This work is performed at the AIT Center for Energy, where more than 285 experts are working on the energy system of the future based on three central systems: Public Energy Supply Systems, Industrial Processes and Cities & Built Environment. Based on scientific methods, excellent research infrastructures and technology neutrality, AIT Center for Energy evaluates possible applications of hydrogen neutrally with regard to costs, benefits and sustainability and thus to reduce the implementation risk in innovative hydrogen projects.

Regarding renewable energy production by electrolysis, amongst others, AIT Center for Energy develops and evaluates stack components such as catalyst coated membranes and bipolar plates to reduce critical material content and improve system costs and reliability, respectively. Regarding PV, AIT Center for Energy has comprehensive long-standing experience in analysing and characterising degradation mechanisms both on module as well as on cell level. In addition to research on degradation mechanisms, AIT actively develops new technologies, manufacturing processes and characterisation methods for example for thin-film solar cells using innovative coatings and efficient manufacturing processes.

Project PH₂OeNIX

The vision



The production of renewable hydrogen is a key part of Austria's decarbonisation plan. Industrial processes and sites are significant due to their high energy demand, power consumption, and the need to provide electricity and hydrogen on-site. PV systems will play a crucial role in decarbonisation measures. While much of the storage will be electrical, both electricity and hydrogen need to be available, making hydrogen storage practical.

Electrolysers are ideally operated around the clock while connected to the grid. However, scenarios may arise where on-site hydrogen production with grid connection is not possible or desired, such as in remote areas, future hydrogen supply shortages, or weak grid infrastructure.

The project PH₂OeNIX investigates these less-studied system scenarios, focusing on the direct off-grid coupling of PV systems with water electrolysers. This project aims to integrate a photovoltaic generation system with a hydrogen-based energy system, independently of manufacturers/producers, and study all interfaces in detail. This approach differs fundamentally from previous ones that only considered individual components, such as photovoltaics, electrolysis, fuel cells, or storage, rather than the overall dynamic system behaviour. The electrolyser will not be grid-connected but purely PV-coupled to gain experience in the coupling behaviour of both sub-systems. Part of the PV-generated electrical energy will be stored as hydrogen and used efficiently and as needed for electricity supply during times without PV generation.

The project will investigate various PV technologies and topologies and different hydrogen generation technologies through precise measurements. PH₂OeNIX will particularly explore the impact of direct coupling of PV systems and water electrolysis systems of different technologies.

Key research questions include:



- Initial aging behaviour of modern PV module technologies.
- Yield suitability (i.e., production profile) of various PV system topologies for hydrogen applications.
- Self-consumption rates in real operation.
- Impact of direct system coupling (without grid-fed electrolysis) on hydrogen production.
- Overall efficiency and part-load capability.
- System compatibility of photovoltaic technologies.
- System configurations and hydrogen electrolysis technologies.

How the system works

As part of a new field test laboratory and research and development facility for hydrogen technologies and hybrid power plants, the AIT H2LAB, a demonstration unit is constructed on AIT's research campus in Seibersdorf: the P2P H₂-Demonstrator. In PH₂OeNIX, this H₂-Demonstrator investigates the operating behaviour of different electrolysis technologies under a dynamic load profile, particularly given through the volatile power generation of photovoltaics.

In contrast to conventional concepts, where the electrolyser is connected to the electricity grid to increase its full-load hours, the PH₂OeNIX H₂-Demonstrator draws its electricity for hydrogen production solely from a PV system. Figure 1 shows the system set-up of the device.

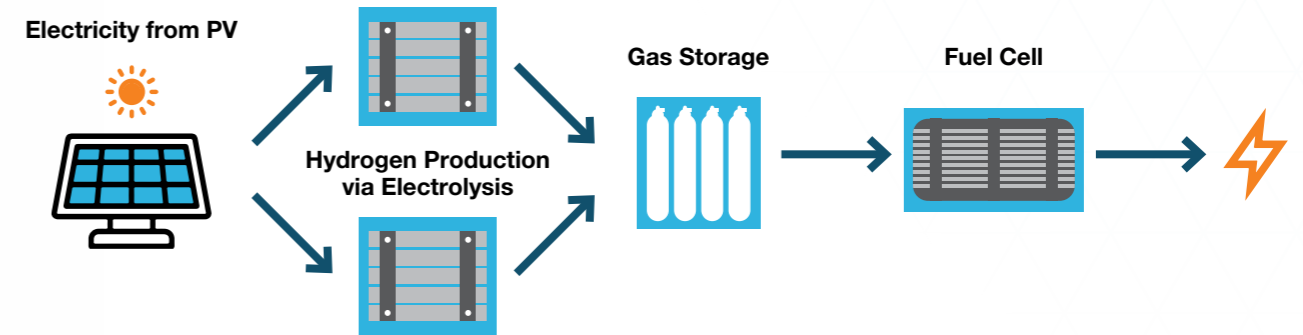


Figure 1: Diagram of the PH₂OeNIX P2P H₂-Demonstrator process.

The electricity from the PV system of a roof-top installation nearby feeds the two electrolysers. Each electrolyser has an electrical capacity of 10 kW. Two different electrolysis technologies are under investigation: The PEM and the younger Anion Exchange Membrane (AEM) technology. The PEM technology is known for its load flexibility and therefore capable of quickly adapting to the volatile electricity provision by the PV system. The AEM technology, on the other hand, claims to perform as well as the PEM in terms of quick response to load change, but at a lower system cost, as less amount of precious metals is required. The hydrogen produced during the day is stored in gas cylinders at the electrolyser output pressure, 30 bar. During the night or late afternoon, a PEM fuel cell of 8 kW electrical power utilises the stored hydrogen to produce electricity, thus closing the power-to-H₂-to-power (P2P) conversion circle.

But not only hydrogen generation is under investigation in this project: The rooftop PV system (63 kW_p dedicated out of 402 kW_p in total) consists of PV modules of novel n-type cells. In this cell technology the main material silicon is enriched (“doped”) with a different material than in the more common p-type cells. The doping with phosphorous, instead of boron in p-type cells, gives the base area of the cell a slightly negative charge, hence the name n-type. N-type cells are less prone to light-induced degradation, but they come at a higher cost. The modules are installed in different orientations, south-east and north-west, to achieve longer production hours during the day.

The H₂-Demonstrator is planned to be extended in the future by other technologies relevant for sector coupling. Connecting a battery storage system together with AIT's proprietary inverter technology ASGC (AIT Smart Grid Converter) is already under development for further system performance optimisation such as conversion efficiencies and reliabilities, and additional O&M strategies. Figure 2 shows the extended H₂-Demonstrator system set-up.

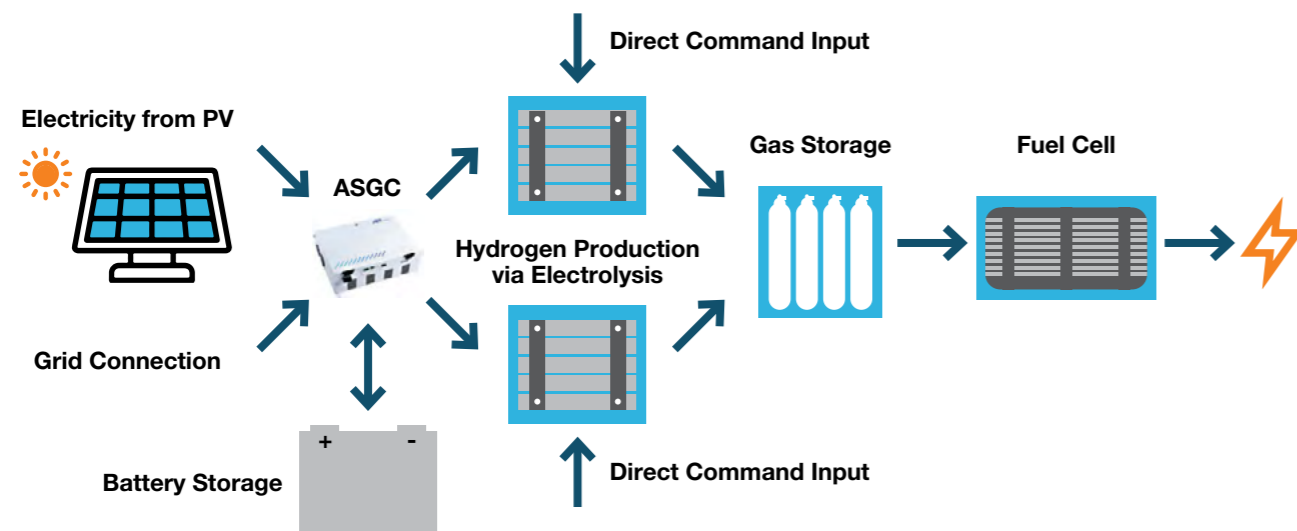


Figure 2: Diagram of the P2P H₂-Demonstrator process extended by a battery storage system together with an ASGC unit.

The ASGC as a both off-grid and grid-connected bi-directional converter acts as intelligent intermediary between electricity generation, storage, and consumption.

The process unfolded

The research questions in this project are answered using detailed initial component testing and precise plant monitoring. The monitoring concept includes standard plant monitoring (e.g., inverter and operational monitoring), as well as high-quality calibrated and traceable measurements in the lab to achieve the research goals regarding efficiency analysis and ageing analysis.

The comprehensive monitoring strategies in the project comprise a series of rigorous quality inspections and detailed analyses to track the reliability and performance of both the PV modules and hydrogen generation units:

- a) **Quality inspection of the PV modules before installation of the PV system:**
 - Performance measurement in AIT's PV lab and electroluminescence measurements on selected PV modules (new products).
 - Mechanical load test on a PV module to check the usability of the mounting solution.
- b) **Quality inspection of the PV modules after installation of the PV system:**
 - Visual inspection of PV modules, wiring, mounting system, etc.
 - Performance measurement (current-voltage curve measurement) and (night-time) electroluminescence measurements on-site on assembled module groups.
- c) **Quality inspection of the hydrogen generation units after installation:**
 - Measurement of peak power consumption and the amount of H₂ production.
 - Measurement of power-dependent conversion efficiency.
 - Analysis of initial H₂ product gas quality.

d) Monitoring and data analysis of the PV operating data:

- Reading, processing, and cleaning of monitoring data.
- Analysis of operating data and evaluation of results: Identification of errors, defects, degradation, and operational events.
- Analysis of the yield profiles of the PV systems concerning their suitability for certain H₂ technologies.

e) Initial degradation analysis of PV modules:

- High-resolution measurement and data comparison of the values before installation and after installation at 6 months and 12 months.
- Synchronisation of local weather data with monitoring data.
- Creation of a digital twin of the PV plant based on the first months of data, giving the opportunity to evaluate the plant.
- Analysis of the onset of degradation by comparing monitoring data and the results of the digital twin.
- Recording of individual events leading to yield reduction from plant operation.
- Evaluation of 10 selected modules from the best and worst strings through dark current-voltage measurements and laboratory measurements.

f) Functional analysis of the coupled hydrogen generation:

- Analysis of hydrogen yield depending on PV production.
- Analysis of conversion efficiency depending on load point (e.g., partial load forced by reduced yield of the PV system).
- Statistical evaluation of operating states in correlation with the condition of the PV system.

- Investigation of the dependence of H₂ production and efficiency on various PV system dimensions (e.g., reduction of the connected PV string number in the supply).
- Analysis of efficiency losses in storage and reconversion through energy balances.
- Continuous on-line gas quality monitoring during operation.
- Regular in-depth analysis of H₂ purity in the AIT laboratory.
- Comparison of the employed H₂ electrolysis technologies (PEM, AEM).

The journey so far

While the rooftop PV system was already installed and started electricity generation in the beginning of June, the P2P H₂-Demonstrator for the PH₂OeNIX is currently under construction. The combined monitoring phase including the electrolyser is scheduled to start beginning of October. The full P2P conversion cycle with the fuel cell will start operation in mid-November.

Figure 3 shows a part of the rooftop PV system which feeds the electrolysers. The PV modules consist of modern, high-efficient half-cut cells and exhibit 475 W_p nominal power. A sample of six modules showed a true power of approximately 470 W each at their maximum power point (MPP) at standard test conditions (STC) in AIT's PV laboratory, which is within the manufacturer's tolerance. The measured efficiency is 21.7 %.

The H₂-Demonstrator under construction is displayed in Figure 4. Most components such as the electrolysers are fit into in a 20-ft shipping container. The container will be equipped with all necessary connections for feed water, electricity, and product/feed hydrogen as well as wastewater and hydrogen and oxygen vent lines. Very important for safe operation are the device's automatic shut-off procedures with gas detectors and over-pressure valves. The produced hydrogen is safely stored outside the container in an off-the-shelf gas bottle bundle. Figure 5 takes a closer look into the H₂-Demonstrator container.



Figure 3: Rooftop installation of n-type PV modules in two orientations: SE and NW.



Figure 4: P2P H₂-Demonstrator overall set-up with 20-ft container and hydrogen gas storage.



Figure 5: Main components of the P2P H₂-Demonstrator, from left to right: PEM electrolyser, AEM electrolyser and cabinet with gas monitoring, measurement and control unit and fuel cell (from top to bottom).

Inside the H₂-Demonstrator both hydrogen generators, the fuel cell, and balance of plant equipment such as water purification, electrical converters as well as measurement and control devices are set up. When selecting the main components, attention was paid to the European origin of the devices. Thus, the PEM electrolyser, the PEM fuel cell, and the gas monitoring device are of German manufacture. The components of the AEM electrolyser are made in Italy, the gas storage bundle is from the Czech Republic. The measurement and control unit are an AIT in-house design and was assembled from components from Austria, Germany, and the Netherlands, among others. The device arrangement leaves space for future expansions.

Upcoming tasks include connecting the components to a supply infrastructure: electricity, water, and hydrogen, cooling system, communication, and data processing. The H₂-Demonstrator will be controlled remotely. Locally it will be possible to operate the infrastructure system especially during start-up and maintenance.

What we aim to achieve

PH₂OeNIX will explore the impact of direct coupling of PV systems and water electrolysis systems of different technologies. By addressing related actual key research questions such as yield suitability of PV systems for hydrogen applications, real-life self-consumption rates or overall system efficiency, PH₂OeNIX will make a valuable contribution to European hydrogen research, development, and innovation.

Moreover, to accelerate the market entry of innovative hydrogen applications, a key aspect of the evaluation of the PH₂OeNIX demonstrator plant is translating the findings into replicable use-cases derived from the direct coupling of photovoltaics and electrolysis. The project involves assessing various PV-H₂ application scenarios based on system combinations and monitoring. Application cases for industrial sites will be created and evaluated in terms of technical conditions and profitability thresholds. This will be followed by a technical analysis and conclusions on the sizing factors of PV systems, H₂ production, storage, and reconversion units, focusing on self-consumption rates, coverage ratios, and storage requirements (such as peak load shaving and load shifting). Finally, the results will be summarised and made publicly available, for instance, as a white paper on directly coupled PV-H₂ systems.

The H₂-Demonstrator will be an important cornerstone in AIT's research and development efforts in field-proven solutions for sector coupling. Connecting the H₂-Demonstrator to the local heat, cooling, and gas grids on the research campus or even using the hydrogen to produce carbon-neutral fuels are being discussed.

The PH₂OeNIX project also serves as nucleus of AIT's current ambitious laboratory project on the technology campus Seibersdorf: the construction of the AIT H2LAB, a research and development environment with field testing capacities on hydrogen and hybrid power plant technologies such as electrolysers and fuels cells, but also battery storage systems and power electronics.

In the planned laboratory facility, services in the field of research and development will be offered. These include, for example, individual tests commissioned by customers for prototypes and pre-series products, as well as certifications of series products according to relevant standards. Additionally, there will be the possibility to submit and conduct national and international research projects. The focus of the research and testing services will be on long-term trials and components with high electrical power, up to MW-scale containerised units.



ENVISIONING THE FUTURE

Visionary projects can pave the way for a sustainable tomorrow. We want to tell the journey from innovative ideas to practical applications that reshape industries and communities.

Envisioning the future means creating a roadmap to a cleaner, greener world, where hydrogen is integral to achieving the EU's ambitious climate and energy goals.

**Hydrogen Center Austria –
HyCentA**

E-Leaf



Hydrogen Center Austria - HyCentA

The journey from an idea to a 100 employees competence center

Text by: Marie-Gabrielle Macherhammer

Images courtesy of: HyCentA, Fronius, OMV, BRP Rotax, Photoworkers, Rene Knabl

The journey from an idea to a 100 employees competence center

In 2003, an idea was born by Prof. Helmut Eichlseder at the Graz University of Technology: due to arising challenges concerning fossil fuel combustion and increasing greenhouse gas emissions, an alternative energy carrier had to be introduced and promoted. To support this transformation of the energy system, Helmut Eichlseder initiated the foundation of an Austrian Hydrogen Research Center.

The HyCentA was founded in 2005 and started its work by setting up the first hydrogen testing infrastructure including a hydrogen discharge point at the campus of the TU Graz, see Figure 1 (left).

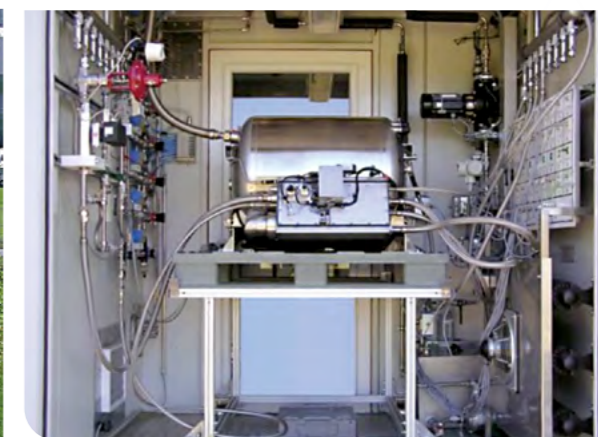


Figure 1: HyCentA infrastructure 2005 (left), testing chamber testing a liquid hydrogen tank (right)

The first generation of hydrogen infrastructure included a cryogenic liquid hydrogen tank with a volume of 17,600 l and gas conditioning to provide hydrogen gas with up to 450 bars. Additionally, several testing chambers could be used for component testing.

The first research projects of HyCentA were addressing research on liquid hydrogen refuelling stations and processes, including test runs of a liquid hydrogen tank produced for an BMW Hydrogen 7 (see Figure 1 right), material compatibility and hydrogen energy systems. Up until

2010 several mobility projects were conducted, including a hydrogen motor bicycle, a hydrogen cart and small logistic vehicles. From the beginning, hydrogen safety was elemental in all testing projects at HyCentA. A project concerning safe hydrogen storage ran from 2007 – 2009 and included an ionic storage hydrogen medium and safe hydrogen storage at room temperature.

One major milestone was the development of a multi-flex-fuel prototype vehicle with internal combustion engine for the operation with natural gas, hydrogen and gasoline, see Figure 2. This was the first hydrogen vehicle with public road approval in Austria in 2009.



Figure 2: Project HyCar, adapted Mercedes Benz E200 (left); engine adaptations on test bench (right).

From 2010 onwards, the HyCentA expanded its research areas towards production and infrastructure layout design, but also storage concepts like slush (2013). Several first applications and innovative ideas were developed and implemented.

The following sections describes the major milestones achieved by HyCentA:

E-LOG BioFleet I & II (2010 – 2016): This project included the development of a fuel cell range extender for industrial logistic trucks and the implementation in several prototypes as well as the implementation of an on-site hydrogen production plant (reforming of bio-methane) and the first indoor refuelling infrastructure in Europe, see Figure 3.



Figure 3: Project E-LOG BioFleet I & II with indoor refuelling infrastructure (left) and hydrogen production on-site (right)

Wind2Hydrogen (2014-2017): W2H implemented the conversion of renewable electricity into hydrogen for storage purposes and transport into the existing natural gas grid, including the development of a dynamic high pressure PEM electrolyser, the construction of a 100 kW plant, the operative experience of a power to gas plant with real life load cases of renewable energy and feed-in of hydrogen into the natural gas grid, see Figure 4.



Figure 4: Project Wind2Hydrogen with electrolyse plant (left) and periphery (right)

HySnow (2017 – 2021): The main goal of HySnow was the decarbonisation of winter tourism by hydrogen powered fuel cell snowmobiles. The project contained the construction of the first hydrogen filling station in an alpine environment (geographically highest altitude in Europe), the direct coupling of photovoltaic and electrolysis system, the development of a fuel cell system for snowmobiles and the operation and evaluation under real operating conditions, see Figure 7.



Figure 5: Hydrogen filling station for HySnow (left) and fuel cell snowmobile (right)

HyTechonomy (2021 – 2025): The project HyTechonomy accelerates the decarbonisation of the industry, energy and mobility sector by further developing and optimising hydrogen technologies. Based on the linkage of simulation and experiments, electrolysis, fuel cells and hydrogen storage systems will be improved in terms of cost reduction, extension of service life and efficiency increase while enhancing.

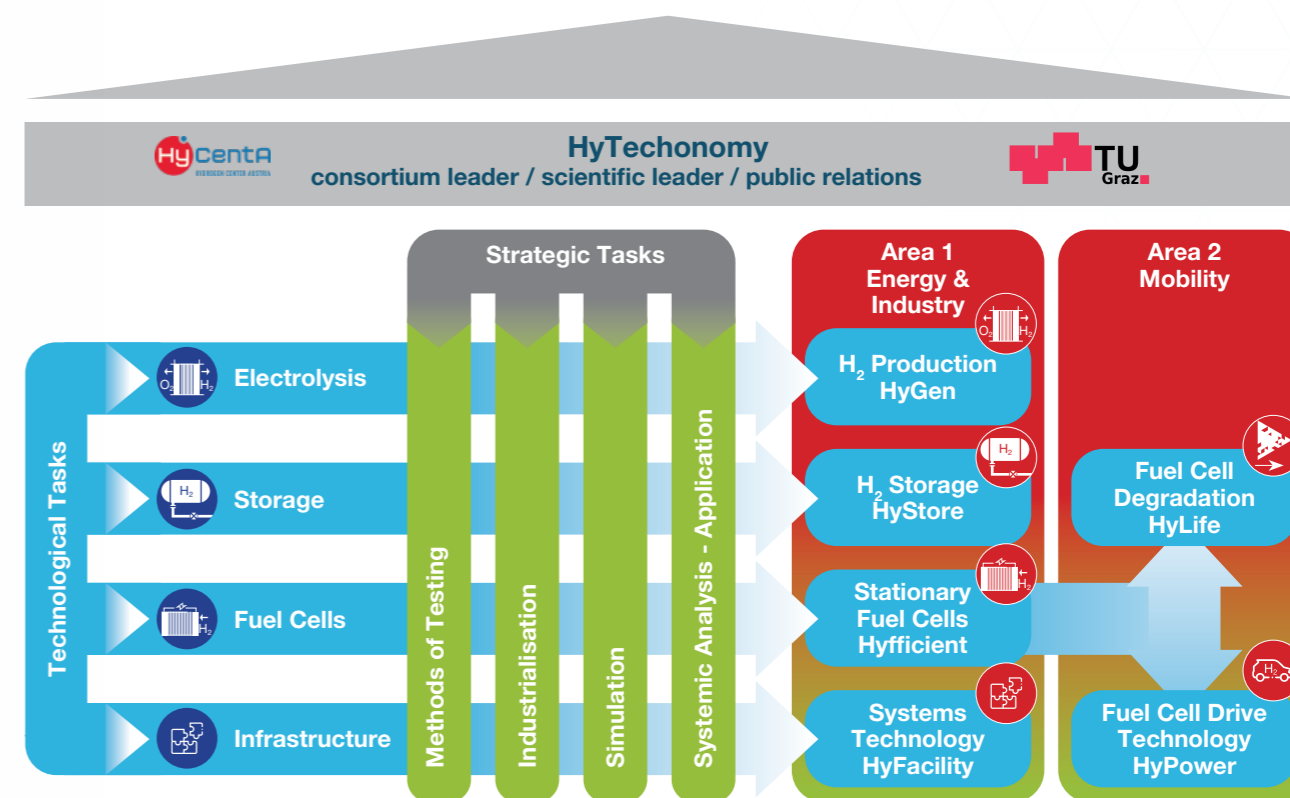


Figure 6: Technological and strategic tasks of HyTechonomy

Additional to the research projects concerning hydrogen production and application, HyCentA has also been working on continuously expanding the testing infrastructure. Among others, two important projects were implemented in the last years:

HIFAI RSA (2015 – 2018): Together with AVL List GmbH, the HyCentA developed and implemented the Highly Integrated Fuel Cell Analysis Infrastructure – Research Studio Austria, which consists of a PEM fuel cell system test bed with hardware in the loop and simulation of real-usage behavior of vehicle, driver and drive cycle for stationary and mobile PEM applications from 2.5 – 160 kW system power with the possibility of real ambient conditions (-40°C to 85°C and rH 5% to 95%) and high accuracy measurement equipment THDA, gas analysis, mass flow and so on, see Figure 7.



Figure 7: Highly Integrated Fuel Cell Analysis Infrastructure – Research Studio Austria

UpHy I & II (2018 – 2022): The projects UpHy I & II were meant to drive the expansion of the hydrogen refuelling station network by developing solutions for the official verification of gas quality and dispensed hydrogen mass at the refuelling station by developing modern measurement techniques for gas quality and hydrogen mass, thereby implementing a highly sophisticated gas analysis laboratory at the HyCentA, see Figure 8.



Figure 8: HyCentA gas analysis laboratory

Additional research projects in all areas along the hydrogen technology value chain have been and are still conducted at the HyCentA Research Center. Furthermore, the HyCentA is also founding member of the “Wasserstoffinitiative Vorzeigeregion Austria Power & Gas”, an association for funding the research and development in the fields of application, net and storage technologies for hydrogen and renewable gases. This association complements the participation of HyCentA in several international networks like Hydrogen Europe Research, the International Energy Agency, European Clean Hydrogen Alliance and Women in Green Hydrogen among others. The exceptional work is also reflected in the multitude of awards received by HyCentA: Energy Globe Styria and Austria Award (Wind2Hydrogen, FCREEV), Staatspreis Mobilität (HySnow, UpHy I), Innovationspreis Steiermark (Recycalyse), WKO Forschungspreis (Recycalyse) and several more.

At the beginning of 2023, the HyCentA became a COMET center, which included the transformation of the organisational structure to be able to serve market needs and integrate the exponential growth of employees to more than 100 heads, see Figure 9.

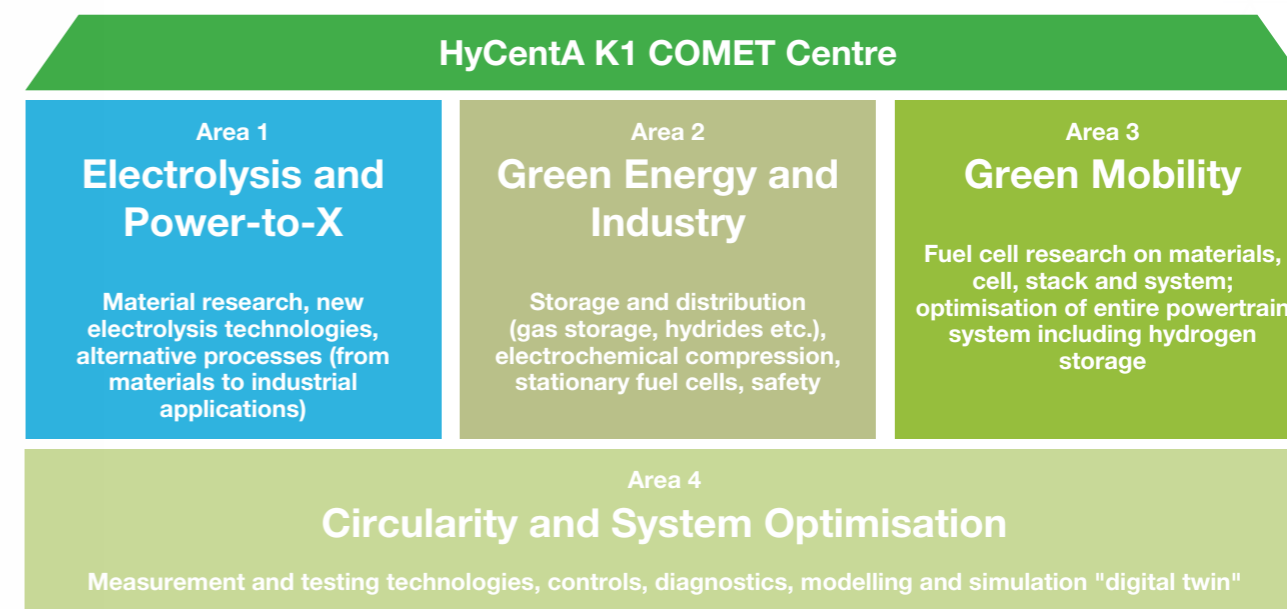
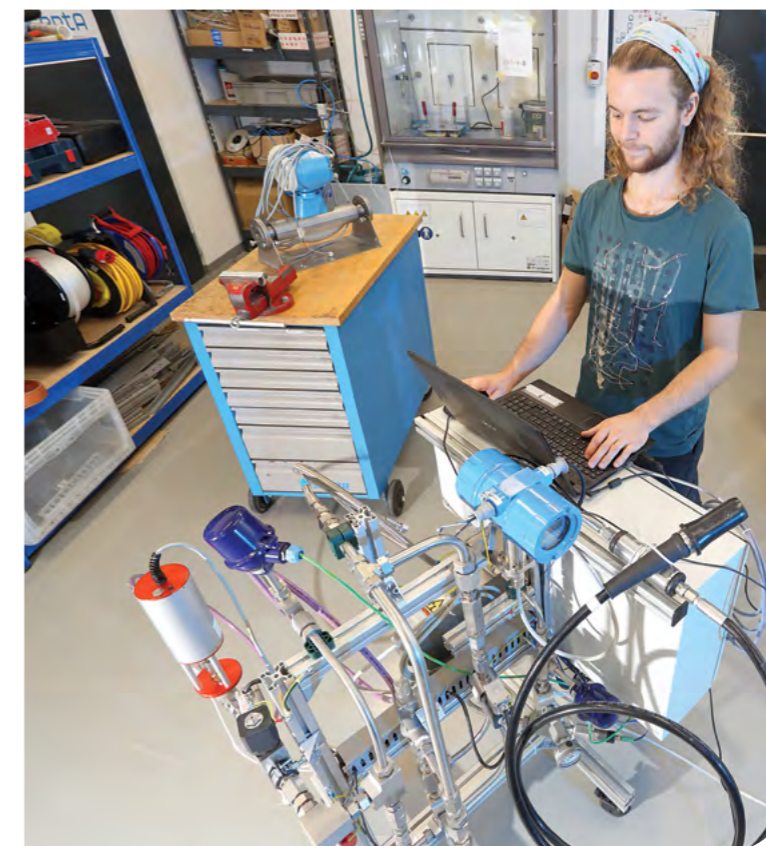


Figure 9: COMET center structure

This year, the HyCentA has invested additional funding to even further extend its testing infrastructure. A new building including several test benches and a material laboratory will increase testing and research capabilities on electrolysis, fuel cells and electrochemical compression.

Additionally, an electrolyser test field to test containerised systems up to 1.6 MW system power will be installed. Therefore, the HyCentA Research GmbH has not only the competencies in research and development but also the testing facilities to support the energy transition towards the renewable energy carrier hydrogen.

We are shaping the sustainable hydrogen society through research!





e⁻Leaf


Large area and high efficiency printed components for H₂ production and conversion

Text by: Diogo Garcia

Images curtesy of: Eurecat

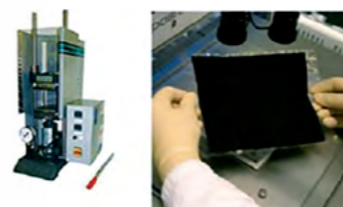
The purpose

The e-Leaf innovation is a membrane electrode assembly (MEA) system that improves Electrolyser (EC) and Fuel Cells (FC) efficiencies by decreasing the ion diffusion barrier and increasing robustness. Currently, the cost and availability of the PEM technology materials are two main hindrances for tech adoption, mainly due to the materials employed as electrocatalysts and membrane and manufacturing methods, which account for a large percentage of the EC & FC cell stack cost.

e⁻Leaf  e-Leaf patented technology aims to solve problems of materials provision in three strategic goals:

- 1) disruptive fabrication methodology of MEAs;
- 2) a novel composite proton exchange membrane (PEM);
- 3) novel printed components, eg. gas diffusion layers (GDLs) and bipolar plates based on novel formulated porous inks based on conductive nanoparticles.

e-Leaf methodology also changes the paradigm of MEA & cell design, since it allows unconventional geometries or shapes, and preparation of MEAs in continuous square meters areas by roll-to-roll processing, largely overcoming eg. the 40cm x 40cm area of standard GDL area available in the market.



Conventional MEAs

Laminated MEA prepared by assembly of three components in a multi-step mechanical process



e⁻Leaf

- ▶ Catalysts
- ▶ Gas Diffusion Layers
- ▶ PEM Membrane
- ▶ Printed MEA
- ▶ Bipolar Plates

Fully printed MEAs & Components

Monolithic fully printed MEA and printed components prepared by high throughput continuous and automated printing process

Scientific excellence

Rapid industrial growth and urbanization in the 21st century have led to exponential increases in energy consumption and a severe climate crisis. In the 1990s, global fossil carbon dioxide (CO₂) emissions increased by 0.9 % annually, accelerating to 3.0 % annually in the 2000s.

Since 2010, there has been a return to a slower growth rate of 0.9 % per year, with a more noticeable decrease from 2014 to 2016. [1] The goal is to achieve a zero-growth rate for these emissions. Fossil fuels are the primary resource used to meet the world's energy needs, accounting for over 70 % of the current global energy demand. This has led to the depletion of limited non-renewable resources, such as coal, oil, and natural gas, and has contributed to significant environmental pollution. Furthermore, it is foreseen that by 2050, oil and gas supplies will not be enough to meet the world's energy demand.[2], [3] Fuel cells (FCs) are a promising clean energy technology with the potential to improve energy utilization efficiency and reduce greenhouse gas emissions. [4] FCs operate by converting the chemical energy of a fuel such as hydrogen gas into electricity through an electrochemical process and can be considered a truly sustainable energy solution when hydrogen is derived from renewable sources.[5] Proton exchange membrane fuel cells (PEMFCs) for hydrogen conversion into electricity are particularly appealing for a sustainable carbon-neutral future because of their high energy-conversion efficiency, which ranges between 53-60% with potential zero emissions. [6]

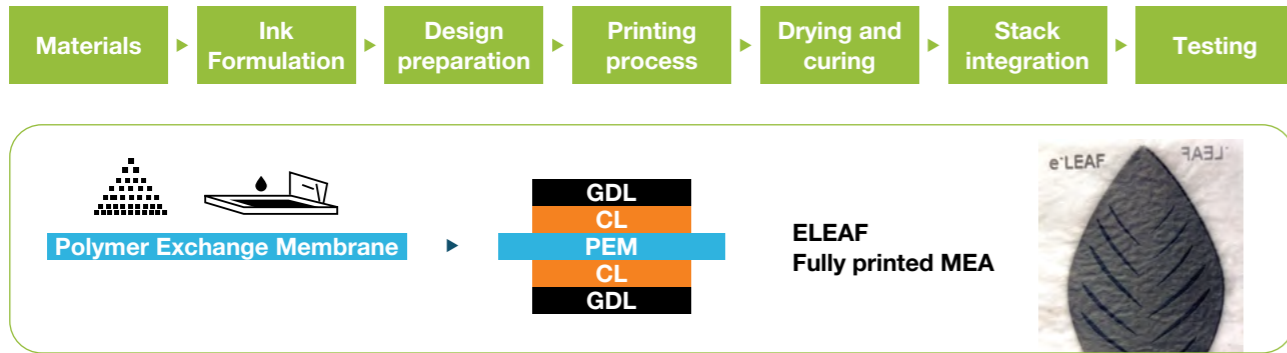
The basic principle behind PEMFCs is that hydrogen gas (H₂) is fed into the anode side of the cell, where a catalyst, typically platinum-based particles, mediates molecular hydrogen to split into protons (H⁺) and electrons (e⁻). The protons move across the membrane onto the cathode of the cell, whereas the electrons are sent via an external circuit, creating an electrical current. The protons, electrons, and oxygen (O₂) from air recombine on the cathode side, mediated by the 3 catalysts, forming water and heat, which are the only byproducts of this process [7],

together with energy losses related to ohmic resistance, charge transfer resistance, and mass transport resistance. The ohmic resistance in a fuel cell is primarily affected by the resistance created by the diffusion process at the interface catalyst-membrane and through the proton exchange membrane (PEM). Charge transfer accounts for 50-70 % of the total resistance and is caused by the saturation of the species in the catalyst layer (CL). The remaining resistance in the cell is attributed to the mass transfer through the membrane, which becomes more significant at high current densities, and accounts for approximately 23-45 % of the total cell resistance. [8] The overall performance of fuel cell devices is influenced by operating temperature and pressure, membrane properties, electrode properties, humidification, fuel purity, and fuel cell system design. Optimizing these parameters is crucial for maximizing PEMFC performance and making them a viable alternative for sustainable energy conversion and generation.[9]

The approach we took

e-Leaf technology is based on the sequential printing combining spray coating and screen printing of current collectors, gas diffusion layers (GDLs), catalyst layers and even polymer exchange membranes (PEM), as opposed to the conventional technology of the manual assembly of each of those components in discrete form factors.

The methodology is based in the use of functional inks that can present the ionic or electronic conductivity and the porosity needed for each layer. After the preparation of inks for catalyst layers, GDLs and PEM, the functional inks are deposited sequentially in an alternating printing and curing process that is described in Eurecat's patent to prepare the anode and the cathode side of the MEA to print a fully printed MEA. Moreover, this process is compatible with hot press conventional GDL or PEM, which allows a myriad of combinations of printing only anode or only cathode or only GDL, etc, and completing the MEA with conventional components. Therefore, this emergent technology has a high-risk high-gain approach, in the fully printed process, but it is also possible to reduce risk by using combined printed and hot-pressing discrete components, reducing also the time for industrial adoption.

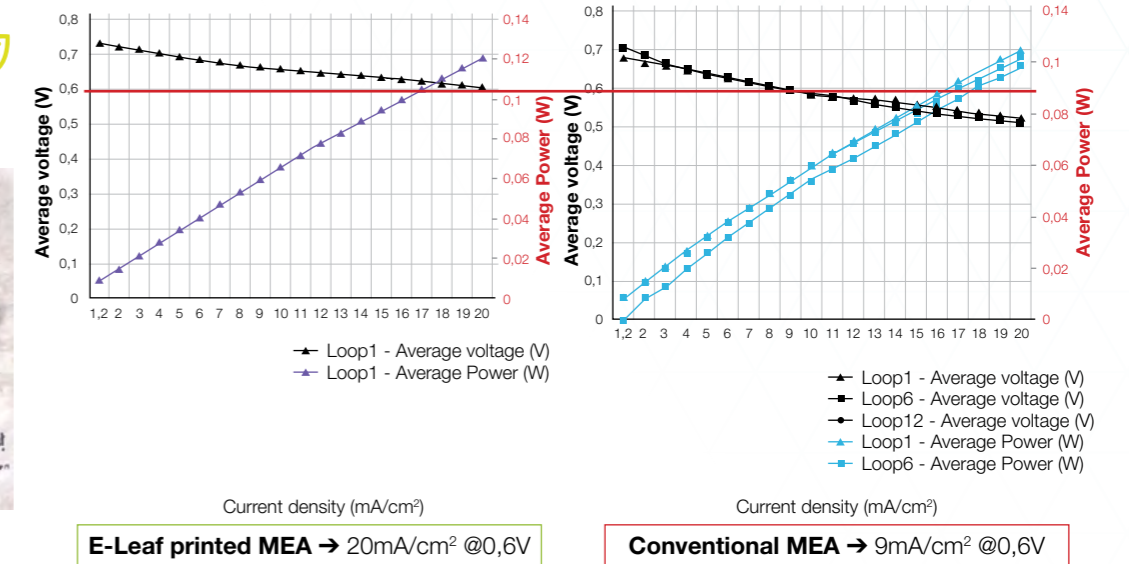


✓ Patented Technology
 ✓ National CEEC EmErgEnt Prize 2024

The End Results

e-Leaf TRL6 demonstrators of different MEA configurations in electrolyser and fuel cell for hydrogen production and conversion, respectively, were prepared and validated in the Eurecat pilot plant, obtaining good results of e-Leaf printed MEAs outperforming conventional commercial MEA tested in the same setup, returning the double of the current density of the last (Figure 1).

e-Leaf



e-Leaf technology technical viability and financial viability of the innovation is settled in:

- e-Leaf printed MEAs outperforming conventional Nafion based MEA in price (estimated price for e-Leaf of €5-10/kW, versus 18-173 eur/kW in bulk membrane found in materials bought in the competition)
- e-Leaf PEMFC overall cost 50% lower than a comparable cell with a conventional MEA.
- Two companies already secured licensing for industrialization of e-Leaf inks and printing process and funding secured for industrialization of the manufacturing process and ink production through an AEI/CDTI Transmisiones project granted over 2 million € (2024-2026) and two companies are secured for licensing printing process methodologies and ink production.
- It is expected maximum 2 years for the commercialization of eLeaf inks and three years for novel e-Leaf printed components commercialization (eg. MEAs, composite membranes and printed GDLs).

Currently, the next steps for commercialization are finishing the market study that is currently in process; secondly, the patent is entering national phases during 2024 and will be applied in selected countries following our market studies.

The licensing of the technology is starting now in 2024, and it is also under analysis the generation of a spin-off to dedicate to the commercialization of e-Leaf printed components and MEAs as final products for specific fuel cells and electrolyzers applications selected during the market analysis.

The KPIs obtained are resumed in (Table 1).

e-Leaf KPI	e-Leaf TRL5 stage results	Benchmark comparison
Price of printed components materials is at least one order of magnitude cheaper than conventional ones	eLeaf fully printed MEA 0,55 €/cm ²	5,65€/cm ² Conventional MEA cost on same purchase volume
e-Leaf membrane without swelling nor activation step required	€16/kW in 100 units volume production	€173.6/kW for Nafion in 100 units volume production ¹
Lightweight e-Leaf printed MEAs achieve 5kW/kg	achieved 65 kW/kg	Nafion bulk membrane is maximum 58.96 kW/kg¹
Lightweight PEMFCs with e-Leaf printed MEAs achieve at least 5€/kW	estimated 37 €/kW	Scenario projected for 20km/h production rate ¹

Table 1. e-Leaf KPIs analysis and comparison to benchmark.

1: Battelle Memorial Institute. Manufacturing Cost Analysis of PEM Fuel Cell Systems for 5- and 10-kW Backup Power Applications. *U.S. Dep. Energy* 124 (2016).

Motivation and innovation potential of our team

Dr. Diogo Garcia completed his Ph.D. (2018-2022) as part of a European joint doctoral program between the Université de Pau et des Pays de l'Adour (UPPA) in France and the Université de Namur in Belgium.

As a Marie-Curie fellow, his doctoral research focused on developing new porous functional materials for photochemical and electrochemical devices used in artificial photosynthesis and green hydrogen production, resulting in a patent on the preparation of electrodes, membranes, and MEAs for electrolyzers and fuel cells. He received his Master's degree in 2018, specializing in electrochemical energy conversion devices. In 2019, he published the results of his master's thesis on large-area paper batteries with screen-printed electrodes.

Currently, Dr. Garcia is the team leader of the Printed Energy Devices research group at Eurecat technological centre, dedicated to investigating novel membrane electrode assemblies for the energy and healthcare sectors, aiming for more sustainable and cost-effective systems. He coordinates and participates in several European and national projects and supervises several bachelor, master, and PhD students.

The research team also includes other collaborators at Eurecat, with extensive experience in the development of printed devices and electronic systems, membranes and fuel cells technologies, and IP protection and exploitation. Sofía Luján López obtained her Bachelor's degree in Chemical Engineering (2022) at the Polytechnic University of Catalonia (UPC). For her bachelor's thesis, she studied novel membranes for the valorization of seawater brines. The membranes were provided by different companies and modified by a research group from LUT University, using different coating techniques. She focused the study on the separation of multivalent ions from monovalent ones as a pretreatment to recover the different minerals of interest in the membranes. Currently, she is a student in the "Master's Degree in Hydrogen Technologies" at the Polytechnic University of Catalonia (UPC) and a researcher in Eurecat's Functional Printing and Embedded Devices unit, leading the development and characterization of Membrane Electrode Assemblies (MEA) for hydrogen conversion applications and in printed sensor devices.

Publication type/reference	Description
Publication/G. Paixão da Costa et al. Advancements in Printed Components for Proton Exchange Membrane Fuel Cells: A Comprehensive Review. <i>International Journal of Hydrogen Energy</i> (2024) just accepted.	State-of-the-art review concerning the application of printed methodologies in the preparation of MEAs for PEM fuel cells applications, with analysis of materials, system architectures configurations and the correlated cell performance, where it is found that emergent inkjet printing and screenprinting of catalyst layers are returning cell performances on the level of the spraycoating state of the art.
Patent/Delgado Simao et al, Fabrication method of a membrane electrode assembly (MEA), MEA, cell and uses thereof; Submitted patent EP21383086.2, Fundació Eurecat, (2021).	Patent application currently entering national phases about the e-Leaf technology
Publication/ Garcia, D. M. E. et al. Large-Area Paper Batteries with Ag and Zn/Ag Screen-Printed Electrodes. <i>ACS Omega</i> 4, 16781–16788 (2019). 10.1021/acsomega.9b01545:	Development of large area fully printed batteries based on membrane electrode assemblies for energy storage devices: its full preparation methodology and formulation of zinc nanoparticle based inks specially for the application

Project title	Description
h-Leaf - Nueva tecnología H-LEAF para la generación de hidrógeno verde (MIG-20232060) (2024-2026).	Proyecto Transmisiones AEI-CDTI coordinated by Dr. Simao for the development of the e-Leaf industrial methodology.
e-Leaf – Ensamblaje de electrodos de membrana de bajo coste, liviano y de alta eficiencia para vehículos propulsados por hidrógeno (2021-PROD-00203) (2022-2024)	This AGAUR – Producte project is directed by Dr. Simao is dedicated to demonstrate the viability of the printed components in the preparation of MEAs for PEMFCs.

Project title	Description
eSCALED (H2020-MSCA-ITN-2017 (Funding ID 765376)) (2018-2022).	The responsible scientist is the Principal Investigator at Eurecat in this european MSCA ITN network dedicated to the development of novel catalysts, membranes and electrodes for membrane electrode assemblies in electrolyser and fuel cells, aiming artificial photosynthesis. The principal investigator has co-supervised four PhD thesis, dedicated to her research field of fully printed electrodes, membranes and MEAs.

Table 2: Relevant recent publications and projects financed.

The future we are paving

Decreasing vehicle emissions since 2008 has already reduced by thousands the number of deaths attributable to air pollution and returned billions of euros in benefits to public health. However, only small progress has been made in reducing their climate impact. Among different clean energy solutions, Fuel Cells (FCs) are considered the topmost efficient solutions and are the basis for hydrogen-powered systems, aimed to constitute 27% of the European energy sources in 2050. Ion Exchange Membranes (IEM) technologies deliver low operation temperature, high power density, fast start-up ability, and suitability for intermittent operation, have been regarded as the most promising candidate for transportation applications.

Fuel Cells (FCs) can electrochemically convert the chemical energy of different fuels into electricity, just by choice of catalysts in their Membrane Electrode Assembly (MEA) that use a platinum catalyst in cathode and in the anode. On the other hand, to produce hydrogen it is required Electrolytic Cells (EC) to perform water electrolysis, which also use similar MEAs

in IEM technology, but in the anode use an Iridium or Ruthenium oxide catalyst, keeping the platinum catalyst in the cathode. On the other hand, to supply the needs of hydrogen as a fuel for this EU objective, must be secured the provision of the combustible and of the components to prepare both electrolysers and fuel cells, and novel manufacturing methods are required to solve these materials and components delivery. e-Leaf technology enables the mass production of components and MEAs for electrolyser and fuel cells to use hydrogen as energy vector, by using continuous sequential multilayer printing methodology instead of discrete components alignment, assembly, and lamination. Such ability unlocks local energy sovereignty, as combustible could be generated regionally across Europe. This is a key pillar that sustains the European strategy of hydrogen as energy vector and e-Leaf technology strongly contributes to it as it is relying in local manufacturing and already existing industrial value chain and high throughput methodologies.

Such compatibility with existing infrastructures is important for fast industrial uptake and road to market, both critical situations for the foreseen need of producers of components and high-volume manufacturing to sustain the demand of H₂ if it is adopted as energy vector in EU, e-Leaf is directly contributing to EU 3Ds policies for energy Decentralization, Decarbonization and Digitisation, as the process is more automated and reproducible. In that sense, the innovation contributes to the European Green Deal and has two ultimate impacts to society and environment: on the one hand, fuel costs reduction contributes to cheaper and more accessible transport, and, on the other hand, fuel savings and the use of renewable sources mean fewer pollutants emitted to the atmosphere, which contributes to a greener environment.

In that regard, e-Leaf is in line with the United Nations Sustainable Goal 13: Take urgent action to combat climate change and its impacts, Goal 11: Make cities inclusive, safe, resilient and sustainable, Goal 7: Affordable and Clean Energy and Goal 8: Sustainable economic growth employment and decent work for all.

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CULTIVATING EXPERTISE

The success of the hydrogen sector depends on the availability of skilled professionals who can drive and sustain its growth.

The initiatives we have selected focus on educating and training the next generation of hydrogen experts, ensuring a competent workforce is prepared to meet challenges while promoting a culture of continuous learning and innovation.

**The Hive Mindset: How
BE-HyFE Shapes Holistic
Hydrogen Experts**

H2 LAB

The hydrogen game



The Hive Mindset: How BE-HyFE Shapes Holistic Hydrogen Experts

Text by: Marijke Mahieu

Images curtesy of: Marijke Mahieu

BE-HyFE is a Belgian academic collaboration project, funded by the federal Energy Transition Fund, that brings together all Belgian knowledge institutes to join forces in fundamental research on the topic of hydrogen.

Challenging academic perceptions

The academic world struggles with certain perceptions and misconceptions, and the Belgian scene is no exception. Among the most prevalent is the belief that academics reside solely in their ivory towers, engrossed in research for its own sake, detached from real-world applications. Another perception is that there is significant rivalry between knowledge institutes, akin to competition in the industrial sector.

This rivalry often manifests in universities between themselves vying for research funding, publications, and recognition as leaders in their respective fields. Consequently, collaboration between Belgian institutions is sometimes overshadowed by the pursuit of individual acclaim. As a result, it can sometimes seem easier to collaborate with institutions abroad rather than with the ones we consider our neighbours. While both elements do occur in the Belgian academic sector, we believe they lead to many missed opportunities. This realization led us to the creation of the BE-HyFE consortium!

BE-HyFE stands for Belgian Hydrogen Fundamental Expertise and reads like 'beehive', which is what we aim to offer our entire hydrogen research community: an organized structure where researchers all work towards a common goal, gathering expertise (instead of honey!), cross-pollinating one another with knowledge, and seeing their role as ambassadors for the Belgian academic hydrogen network as a collective responsibility.





Why is this hydrogen research collective important?

Belgium has many assets in the field of hydrogen: the largest hydrogen pipeline network in the world crosses our country! Belgium has a strategic position in Europe and many companies in Belgium possess in-house hydrogen technology.

At various Belgian universities and knowledge institutes the academic hydrogen expertise is highly specialized and outstanding. However, the research is fragmented and collaboration between the institutions in the domain of hydrogen has been rather limited. For non-academic stakeholders, it is also often confusing to find the right academic expert.

With BE-HyFE, we want to strengthen the cooperation between the Belgian hydrogen research groups and, with additional fundamental research in hydrogen, stimulate an interdisciplinary approach to create an academic hydrogen backbone for the Belgian industry and policy makers. This is why we are proud to have all Belgian universities on board for this project!

Our goal is to establish a Belgian hydrogen homebase of academic knowledge and expertise by establishing a core group of 16 broadly trained and highly networked early-stage researchers (ESRs) to support Belgian industry in finding both technological and societal solutions and meeting our environmental targets.

What is the added value of this approach?

To ensure a broad and multi-disciplinary approach to the many hydrogen challenges in the Belgian context, it is important that the ESR team obtains excellence in its own research field, recognizes the importance of collaboration and positions the individual topics in the broader framework.

In-depth background training will enable the researchers to apply a holistic approach towards their own research and will make them experience the benefits of cross-pollination between disciplines and domains. This approach is implemented through the Innovative Training Network (ITN) methodology, based on three pillars:



Research:

Our knowledge partners host 16 carefully selected PhDs covering the whole value chain of hydrogen, in order to provide both technical and non-technical solutions for current and future hydrogen challenges. Internal rotation ensures maximum collaboration and cross-pollination between knowledge institutes, research groups and topics.



Training:

Our ESRs receive extensive training on scientific and technical skills, soft-skills and industrial orientation, within the context of both their own research and the Belgian hydrogen landscape. These skills enhance the multi-disciplinary aspect of their work. Some training events are also open for the entire Belgian hydrogen researcher community.



Community:

We aim to create a life-long network, starting with our core group and linking the larger Belgian academic community working on hydrogen. We provide collaboration and networking opportunities with industry and envision an international approach, linking with foreign companies, knowledge institutions and similar hydrogen networks.

How will this benefit the Belgian academic and industrial hydrogen sector?

By focusing on more than ‘just’ the research itself, we aim to deliver – at the end of the project – 16 well-rounded researchers who are broadly networked, understand how their specific work fits into the bigger picture, can see real-life applications and know how to communicate with industry, fully understanding other perspectives beyond the academic one.

Setting up this academic backbone will lay the foundations for many industrial innovations at Belgian companies and institutions, through which hydrogen will advance and shape the energy transition. By having a broad outlook on the entire hydrogen academic community, we can now also offer other stakeholders a consolidated overview of the available expertise they might need.

Does this collective actually work, or is it just a nice story on paper?

The BE-HyFE project is quite unique, specifically within Belgium’s complicated political structure, as it transcends internal borders and authorities, bringing together people from both Flanders and Wallonia. This means we now have the means and the framework to assemble the entire Belgian research community on the topic of hydrogen, stimulating more academic exchange and collaboration.

During the first half of the project the community could attend several workshops and academic hydrogen events, within the BE-HyFE frame. This culminated in the organisation of EPHyC in March 2024, the very first edition of the European PhD Hydrogen Conference, in collaboration with Hydrogen Europe Research, bringing together the Belgian and EU research communities.

EPHyC was unique, being a conference organized by PhDs for PhD, focusing on interdisciplinary discussions on various aspects of hydrogen, from engineering to socio-political and economic topics. Bringing this conference to life (from scratch), observing its success with more than 160 PhD participants and seeing it live on now for future editions was a very inspiring experience for our ESRs. Ten months of hard work was tough on our BE-HyFE team – combining EPHyC with their own research - but being part of the organizational team for this conference resulted in a whole new skills package for them, from abstract revisions to booking catering and building websites. It offered them the learning opportunity of a lifetime!

The interest from industry in our project is also impressive, with over 30 Belgian companies on our Industrial Advisory Board, a willingness to host our ESRs for industrial secondments during their PhD journey and them opening their doors for site visits, bringing research into the world of application. The many generous sponsors for the EPHyC conference also shows the enthusiasm of our industry to strengthen academic collaboration.

But the benefits of this approach are also manifold for our 16 ESRs in the core group who, as individuals and as a group, have achieved a massive growth. The ESRs have learned organisational skills through EPHyC, how to communicate with different stakeholder groups (with a focus in the industry sector), how to present their topics (with a video pitch each) and how to work as an agile team. Mostly, knowing they have the support of the entire team and being part of the BE-HyFE ecosystem has been invaluable throughout their research journey. Some quotes from the ESRs themselves:



“Personally, the best thing about this project is how they made a team from a group. I always look forward to opportunities where we can work together, in our case, the whole is stronger than the sum of its parts. I’m very grateful for all the opportunities they have been giving to us, guiding us through the PhD and forming us to be the best PhD candidates we can be. We will benefit from this the rest of our lives. To conclude, this was my once-in-a-lifetime opportunity which forms the basis for the rest of my professional career, and I’m grateful for that!”

Mauro Daese
KULeuven

“Being part of this research community has allowed me to get a deep understanding of topics related to my research, through the progress of colleagues at the same stage of PhD as me. This means that a community like this broadens the way of seeing one particular topic and enhances a more spherical perspective of research. Personally, I have learnt about aspects of my project that I wouldn’t have the opportunity to do so, and at the same time enhancing collaboration and communication which I believe is something that the academic environment doesn’t help to build under different circumstances.”

Foteini Lappa
ULiège/KULeuven

“Being a PhD student goes beyond dedicating four years to producing high-quality research outcomes. It’s a journey of professional and personal growth that cannot be achieved by working in isolation. Being part of the BEHyFE research team significantly enhances this journey by providing opportunities to engage in diverse research group activities and by fostering a vibrant community that organizes team-building events, workshops, seminars, and conferences. For me, the greatest added value of being part of BEHyFE is that it allows me to evolve into a well-rounded PhD graduate with a multifaceted skill set while becoming an expert in my specific research area.”

Negar Namazifard
VITO

We believe that BE-HyFE can be seen as a great example of a national training network and can inspire other countries to deliver all-round researchers who have a broad view of the hydrogen sector, while strengthening ties with their neighbouring universities.



H2 LAB

The Story of an Amphitheatre to Develop Critical Thinking and Innovation

Text by: Marisa Martínez Orduna

Images curtesy of: Marisa Martínez Orduna

The Story of an Amphitheatre to Develop Critical Thinking and Innovation

Inspired by the Roman Theatre, H2 LAB is a space open to reflection to contribute to the progress and development of society. In this space, we welcome every week groups of students of different ages and social strata. We invite them to reflect on the current environmental situation, encouraging their capacity for constructive criticism. And guiding them to find solutions using renewable energy, highlighting the potential of hydrogen in this energy revolution.

We believe in the development of green thinking (environmental awareness), based on solid arguments and the fruit of our experience. The whole team that makes H2 LAB possible has a STEM vision.

"I remember that when I was studying, many science subjects seemed somewhat boring to me because it felt more like an act of faith in the story the teacher was telling rather than understanding or facing problems or enigmas that I might encounter in my life. That's why, as an educator, I highly value the ability to materialize complex concepts and make science something tangible and experiential.

The H2 Lab experience provides me with the opportunity to achieve this. It allows visitors not only to get to know us and acquire a lot of technical knowledge but also to approach the world's challenges from multiple perspectives and find unique solutions."

Guillermo García

Consulting and Training Technician



Guillermo García, David Jiménez and Guillermo Giménez lead H2LAB at Aragon Hydrogen Foundation

“STEM skills have been, are and will be my travelling companions, not only to solve problems in my job, but in my day-to-day life. Being able to transmit to young students how these skills completely change the mind and the perspective with which we look at the world around us is something great and will surely generate a brilliant society. It should not be forgotten that STEM skills must be accompanied by personal, ethical and social values that generate synergies with the different technical knowledge around hydrogen, which means that research into solutions to the great challenges of today and tomorrow lies in finding a balance between efficiency, sustainability and social development. The eyes that science gives you make you understand your world better and, above all, to make it better”.

David Jiménez

Consulting and Training Technician

“As educators, we have the great responsibility to make technical knowledge accessible and engaging for all, especially for young learners. It’s crucial to bridge the gap between complex scientific concepts and curious minds, fostering a lifelong love of learning from an early age.

It’s incredible to witness how children apply their own logic to solve real world problems and come up with very creative ideas by applying scientific concepts and learning to think analytically.”

Guillermo Giménez

Consultancy and Training Coordinator

Education experts conclude that STEM education equips people with a range of skills that make them more employable and better prepared for the demands of the labour market. H2 Lab has witnessed this. The story of Guillermo Figueruelo is a clear example of the impact that the activities carried out in this setting have on a person's personal and professional life.

In 2008, when he was 16 years old and a student of the Technological Baccaureate at a high school in Huesca, he visited the Didactic Room of the Aragon Hydrogen Foundation. During this experience, he was impressed with the possibilities of hydrogen, the fuel from the stars that can save the planet. Years later, he decided to dedicate his life to supporting initiatives that are committed to hydrogen as a renewable energy vector.

And he wanted to do it from the same place that showed him this vision of the future: the Aragon Hydrogen Foundation. Today, Guillermo Figueruelo is Head of Strategic Area in FHa, and after more than 9 years working in the entity, he has coordinated the achievement of more than 30 European projects and more than 40 national projects and has just been elected for the third time as Member of the Board of Hydrogen Europe Research & Cross-Technical Committee Leader for Hydrogen Valleys.



Guillermo Figueruelo is Head of Strategic Area in FHa

A personal and professional success story that today inspires the stories he tells his daughter, supported by his wife's drawings: the sun that itches so much in summer, the wind that stirs her hair and the water that runs through the trees in the parks of his village on the banks of the river Ebro, are the natural and renewable resources necessary for the production of green hydrogen and they will support the creation of a new economic sector that will allow her to grow in a prosperous, sustainable and fair territory.



The Hydrogen Game

Text by: Pernille Gøtz, Anke Hagen


Images curtesy of: Green Skills for Hydrogen

Context and Origins

It is estimated that in 2030, 1 million workers in the EU will be employed directly or indirectly in the hydrogen economy. By 2050, this number is foreseen to reach 5.4 million workers. Businesses and organizations working with hydrogen soon will experience difficulties hiring skilled workers. Thus, if we want to accelerate the hydrogen economy, we must simultaneously accelerate both initial and continued education on hydrogen.

The Hydrogen Game is an innovative teaching tool developed to help accelerate the development and implementation of high-quality teaching and education on hydrogen in the EU. Specifically, the game is developed in the context of the EU-project *Green Skills for Hydrogen*, where more than 34 partners in 15 countries are exploring and developing the frontiers of hydrogen education.

The objectives of the Hydrogen Game are:

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to provide a flexible tool for facilitating knowledge testing and discussion;
- to contribute to education at different levels, such as initial and continued education, and the re-skilling and up-skilling workers for the hydrogen agenda;
- to inspire both teachers and learners to critically look at the complex challenge of the energy systems based on renewable energy sources, using hydrogen as the key element.

In the following, we will describe the methodology of the game, the outcomes from playing the game, and the possible future impact when the game is further rolled out.

Perhaps you will be the next to use it in your teaching?

Methodology

The purpose of the game is to support high quality learning about hydrogen through challenging existing knowledge in a broader (system) context and through meaningful and relevant conversations on a broad range of topics related to hydrogen. The game consists of:

a set of hydrogen related icons

a set of game descriptions

a set of game boards

All the elements are accessible for download in known formats like Word, PowerPoint, and PDF, making it printable and adjustable for most contexts and budgets. In that way, the Hydrogen Game is a scalable and flexible learning game. However, the magnificence of the game lies not only in the printable elements. It also lies in the pedagogic foundation behind the game design.

Challenges when teaching about hydrogen

When teaching about hydrogen, trainers face especially the following three challenges:

- 1. Learner prerequisites:** learners in a classroom often have very different levels and types of knowledge about hydrogen, which challenges the quality of learning and conversations around hydrogen.
- 2. System and detail:** when discussing hydrogen, people easily end up discussing either nerdy details or overall systems. Hydrogen teaching should equip learners with skills to flexibly discuss both the system and the details in a hydrogen energy system and economy.
- 3. Emerging technology:** hydrogen is an emerging technology which makes it challenging to grasp for learners.

There are of course more challenges, and the character of the challenges depends highly on whether you, for example, teach a class of engineering students or are doing a workshop for interest groups in a hydrogen valley. However, the above-mentioned are some of the challenges that occur in most contexts.



How the Hydrogen Game meets these challenges

To meet these challenges, the Hydrogen Game is based on the following theories and didactic measures:

Visible learning

(Hattie 2008): the game helps learners make their understanding visible, using the icons, the board and drawing/writing. Visible learning is the prerequisite of feedback, which is of high importance in all learning processes.

Differentiated teaching

(Tomlinson 1999): the diversity of icons encourages interaction for both new and experienced hydrogen learners. From there, teachers can adjust levels and types of teaching in accordance with classroom expectations, needs and learner prerequisites.

Dialogic pedagogy

(Philipson & Wegerif 2017): the best way to learn new concepts is by appropriating them in one's own language. Also, dialogue is the prerequisite for innovation and collaboration. The game supports dialogues in groups and with the teacher.

Research and case-based teaching

(Healey 2005): facts in the game are research based, learners are invited to imitate simple research processes in activities, and most activities revolve around real or authentic hydrogen cases.

Based on this theoretical foundation, the Hydrogen Game excels in supporting high quality learning by taking its point of departure into the learner's prior knowledge, both as individuals and groups. Instead of passively listening, learners explore concepts and cases together, thus co-creating the knowledge in the classroom with relevant feedback from the hydrogen trainer. Also, cases and input can flexibly be adjusted to the needs of, for example, local authorities, businesses, and educational institutions. In that way, practice implementation is at the core of the didactic design.

Outcomes

The game has been tested on several occasions, in purely online and in fully offline contexts. In both settings, the game has been very well received.

The data to measure the outcome is so far collected as qualitative data: observations of sessions, collection of reactions on the game, and short interviews with participants about their experiences participating in the game. In the upcoming roll-out phase of the game more extensive data will be collected as several pilot projects in the Green Skills for Hydrogen project will test the game.

However, the results so far are impressive, telling us that the game is ready for roll-out across member states. Let us give you some examples.



Example 1

At a project meeting in the Green Skills for Hydrogen Project, 25 project participants were introduced to the game. The participants were a mix of hydrogen researchers, trainers, and project managers meaning that in this workshop, the game's ability to support conversations about hydrogen in a diverse group was tested. The introduction took one hour and 10 minutes and happened late in the afternoon after a long day of travelling and project updates.

Positive outcomes from this experience were:

- Within one hour the participants both managed to discuss and compare energy systems with and without hydrogen *and* discuss and imitate the concept of three different hydrogen colors.
- The energy in the room rose even though people were tired.
- All participants engaged in discussions – not only those with academic background in hydrogen.
- When asked if anyone would use the game in their teaching most of the project members raised their hand. This is both an academic and practical excellent achievement, because the game was developed in Denmark, and the purpose of the workshop was to find out, if the pedagogy would resonate in other member states which it did.
- Participants, for example, spontaneously said:
 - “This is a very innovative educational material.”
 - “In such a short time, one hour, the game opened my eyes to new ways of teaching that I had never thought of before. Very inspiring.”
 - “I am an experienced hydrogen trainer, and you have just showed me how teaching about hydrogen can be done in a fun way.”
 - “I (a non-researcher, red.) made a researcher realize something new about hydrogen!”
- The workshops ended with great discussions about how the game forces participants to discuss, because not all elements have simple answers.

Conversations about the game, both the possible use cases and the academic discussions about hydrogen, continued throughout the evening at the project dinner and the day after. This is a testament that people were inspired and learned something new about hydrogen and teaching, and they learned it in a way that made them continue conversations.

This is the holy grail for teachers: That learners cannot stop discussing their subject.

Example 2

Another occasion was a fully virtual course about Power-to-X, where the teacher used the game to introduce his 28 students at BA level to PtX. The students had different backgrounds from e.g. physics, chemistry, and general engineering.

Instead of only delivering a lecture, the teacher made a short introduction, and then students in groups worked with the game in two rounds over the course of two hours. First, students used the icons to make visible their understanding of energy value chains and the role of hydrogen. Secondly, they started discussions in the groups about their PtX exam projects, again using the game.

One big challenge in online teaching is to make students active and engage in plenary sessions which was part of the teacher's motivation to use the game: could the game support a more interactive online session?

Positive outcomes from this experience were:

- Because the teacher made students upload screen dumps of their value chains to a shared online platform, the teacher could see that all students (or at least all groups) had been active in discussing PtX.
- Many students, at least half of the group, took part in the plenary sessions, meaning that they felt prepared and eager to contribute.
- The game gave the teacher a way for students to make their learning visible, which gave the teacher a better understanding of what the students found easy/difficult about PtX.
- Throughout the course and in the exam, many students used the idea of icons and visualizations to present their PtX-projects meaning that the game had an impact on student presentation skills and discussion methods.
- The students were very capable of engaging in the game virtually via the forwarded Power Point-file with the boards and icons.

From the session, we learned that feedback from a hydrogen trainer is important, and that what may seem easy ("make the value chain for hydrogen") was more difficult for the students than expected. This learning proves the point that making student learning visible is very important, because without that, teachers cannot know if or how students understood the content.

Impact

The Hydrogen Game is a brand new "product". Even though it has only been tried out a few times, the feedback was amazing, and it came from different European countries with different educational traditions. It is thus expected to contribute to hydrogen-related education at many educational levels throughout Europe. A large impact will be reached through integration into education within the Green Skills for Hydrogen project, which allows reaching a large audience as an initiation point.

The Hydrogen Game is very simple and can thus be easily executed and used by many teachers without extensive prior introduction and with limited resources.

The Hydrogen Game is very suitable for distribution through online platforms, which enables reaching an unlimited audience.

All in all, the impact of the Hydrogen Game will be effectively supporting learning and conversations around hydrogen in many contexts, thus accelerating the roll-out and implementation of hydrogen in the EU at both policy levels, in companies, and research.

Please visit our website www.greenskillsforhydrogen.eu to learn more about the game. Here you will find all the resources and instructional videos for hydrogen trainers (will be made very soon).

References

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The future is now

“Hydrogen Frontiers: The Future European Landscape” is more than just a publication; it is a glimpse into a cleaner, more sustainable future. It is a call to action for all of Europe.

The stories we published are pathways to a greener world: through **H2GLASS**, **PH₂OeNIX**, **HyCentA**, **E-Leaf**, **BE-HyFE**, **H2 LAB**, and **The Hydrogen Game**, we see the potential of hydrogen to transform our world. These projects are not just shaping the future—they are making it a reality today.

Hydrogen’s promise is no longer a distant vision. The energy revolution we imagined is already underway, driving innovation, empowering industries, and fostering sustainable cities.

The future is now. The steps we take today, supported by these pioneering initiatives, will lead us toward a decarbonized Europe where prosperity and environmental health are in perfect harmony.

Let us embrace this future, recognizing that with hydrogen, we are not just preparing for tomorrow—we are living it.



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