Clean Hydrogen Partnership

Hydrogen Production

Solid oxide electrolyser technology proves its power


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Producing hydrogen in sufficient volumes and for a variety of applications is a vital part of efforts to decarbonise Europe's energy, transport and industry sectors. Projects funded by the Clean Hydrogen Partnership are demonstrating the flexibility and scalability of solid oxide cell technology to make this clean energy carrier.

Towards low-CO_2 steelmaking

Steel manufacturing is a sector where it is traditionally difficult to reduce greenhouse gas emissions. To demonstrate how hydrogen can help decarbonise such hard-to-abate sectors, the GrInHy2.0 project installed a solid oxide electrolyser (SOEC) in the Salzgitter AG steelworks in Salzgitter, Germany. Waste heat from steelmaking is used to make steam which, with 'green electricity, powers a 720 kW electrolyser that produces hydrogen, which is used in steel annealing. The availability of high temperature steam reduces electricity use – one of the major cost factors in hydrogen production.

The GrInHy2.0 electrolyser produces 170 normal cubic metres (Nm^3) of hydrogen per hour and uses up to 20 % less electricity than low-temperature electrolysers.

Meanwhile, the SWITCH and REFLEX projects are demonstrating how reversible solid oxide technology can operate in electrolysis mode to produce hydrogen, or in fuel cell mode to generate electricity.

Turning up the heat on electricity consumption

The GrInHy2.0 consortium is laying the foundation for further market deployment of SOECs and gaining an in-depth understanding of their performance in fuel cell stacks. The project results will be disseminated among those decision makers who are likely to commission similar facilities.

SWITCH will be demonstrated at a hydrogen refuelling station in the Netherlands, and REFLEX will soon be providing heat and power to a technology park headquarters in France. Both projects are developing the know-how for SOEC applications such as heating homes or powering a grid.

TOWARDS GREATER EFFICIENCY

The application of SOEs in different contexts needs to be further demonstrated and must be accompanied by improvements in materials used in the fuel cells, to ensure better performance, greater durability and lower cost.

GENERATING MULTIPLE BENEFITS

These projects seek to demonstrate, at scale and in different settings, the greater electrical efficiency and versatility of SOC technology compared with proton-exchange membrane and alkaline electrolysis. SOC is capable of co-generating electricity, hydrogen and heat when operating in fuel cell mode using natural gas or biogas. **The goal?** GrInHy2.0, SWITCH and REFLEX are helping to attract further investments to ensure improvements to components and systems and reduce capital expenditure. **Key results?** GrInHy 2.0 is a leader in high-temperature electrolyser technology and is setting new standards for SOEC use. REFLEX has developed an innovative prototype stack and improved the efficiency of its electronics and software. REFLEX demonstrated the power-to-power round-trip efficiency of the technology and its flexibility, taking it from Technology Readiness Level 3 to 6.

FIND OUT MORE

Clean Hydrogen Partnership
GrInHy2.0 project
Reflex project
Switch project
@CleanHydrogenEU
Clean Hydrogen Partnership

KEY ACHIEVEMENTS

170 NM³ OF 'GREEN' HYDROGEN
produced per hour by the GrInHy 2.0 electrolyser

84 % ELECTRICAL EFFICIENCY
of the high temperature GrInHy 2.0 electrolyser, compared with around 60 % for alkaline or PEM versions

EUR 4 500
per kg of 'green' hydrogen per day Capex target achieved by GrInHy 2.0

100KG/DAY
hydrogen production expected by the SWITCH system

IMPACTS

MEGAWATT SCALE
demonstration of high-efficiency hydrogen production by GrInHy2.0

HIGHEST EFFICIENCY
on the market achieved by the SOEC technology used in GrInHy2.0

GUARANTEED AND COST-OPTIMISED
production of hydrogen by the combination of electrolysis (SOE) and fuel cell (SOFC) modes in the SWITCH system – depending on the price of electricity and natural gas

SUSTAINABLE AND SECURE
supply of hydrogen thanks to the SWITCH system

MORE COMPETITIVE REVERSIBLE SOC MARKET
expected by the REFLEX project through lower capital- and operating expenditure of reversible SOC technology

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Clean Hydrogen Partnership

Hydrogen: a vital element in decarbonising the gas grid

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The decarbonisation of the natural gas grid, from production and transport to end use, can help the EU reach its climate change targets. A range of projects funded by the Clean Hydrogen Partnership are demonstrating how green hydrogen can be safely blended with natural gas and transported using existing infrastructure.

Cleaner and greener

Europe needs to reduce its dependence on natural gas to achieve climate change targets and to avoid supply and price shocks. When produced in a sustainable way, hydrogen emits no greenhouse gas emissions over the whole production and use cycle. It can be fed into existing infrastructure and transported with natural gas and re-extracted for later use or combusted as a mixture with natural gas. The aim is to replace natural gas with hydrogen over the long term.

The HPEM2GAS and HIGGS projects are demonstrating how hydrogen can be safely injected into the natural gas grid. THYGA is looking at the effect that mixtures of natural gas and hydrogen will have on residential and commercial appliances.

Meanwhile, the HEAVENN (Netherlands) and GREEN HYSLAND (Spain) projects are developing 'hydrogen valleys' that combine sustainable energy generation, hydrogen production, storage, transport and use in a specific region.

Demonstrating the benefits

The Clean Hydrogen Partnership supports research and demonstration projects to perfect the separation and transport of hydrogen-natural gas mixtures, as these two gases will continue to be used alongside one another for the near future.

For example, HPEM2GAS built and demonstrated a 75-cell, 200 kW proton exchange membrane electrolyser in Emden, Germany.The pressure of the hydrogen produced was adapted to the operating pressure of the local natural gas distribution grid and successfully injected into it. This avoided having to change critical settings in gas supply and consumption. HIGGS, another project, studied the effect high levels of hydrogen could have on gas infrastructure and its components. An experimental site was built at the Aragon Hydrogen Foundation in Spain. The project identified technical, legal and regulatory barriers and enablers.

THE BURNING QUESTION

Infrastructure operators need certainty – along with the necessary policies and regulations – to commit to long-term investments in hydrogen technology. They need to know that the natural gas grid and appliances in homes, businesses and factories can be used safely with increasing concentrations of hydrogen.

BREAKTHROUGH TECHNOLOGY

Collaboration between SMEs, industry and research is helping to create breakthroughs in technology to make using hydrogen with natural gas viable in the short- to medium term. In parallel, work is being done to develop regulations and safety standards. **The goal?** To develop the market for hydrogen production and promote the large-scale adoption of hydrogen-natural-gas blends. **Key results?** HIGGS concluded that the high-pressure transmission gas grid is substantially hydrogen-ready, although parts of it need additional monitoring and testing. Even a low hydrogen blend can mean an important reduction in CO_2 emissions. The research done under the project determined that up to 20 % of the volume of natural gas can be replaced with hydrogen.

FIND OUT MORE

- Clean Hydrogen Partnership
- HPEM2Gas Project
- MEMPHYS project
- Bionico project
- HyGrid project
- HIGGS Project
- THyGA project
- Heavenn project
- Green Hysland project
- @CleanHydrogenEU
- Clean Hydrogen Partnership

KEY ACHIEVEMENTS

EUR 30 MILLION
combined subsidy from the Clean Hydrogen Partnership for the HEAVENN (Northern Netherlands) and GREENHYSLAND (Mallorca, Spain) hydrogen valleys, including plans for H2 distribution infrastructure

23
Hydrogen valleys in Europe at various stages of development

100 KG HYDROGEN PER DAY
produced by the BIONICO catalytic membrane reactor

144 CELLS
in each of the two stacks in the HyGRID system

85 NM^3/H
of gas mixture containing H_2 can be processed by the HyGRID system

7 %
reduction in CO_2 emissions when methane (the main constituent of natural gas) is replaced by a 20 % volume of hydrogen

IMPACTS

INJECTION OF HYDROGEN
into the natural gas grid demonstrated by HPEM2GAS

LOW CAPEX
feasible for an electrochemical hydrogen purification system for use with biogas or industrial waste gas demonstrated in the MEMPHYS project.

LARGEST
membrane reactor for hydrogen production from biogas in the world, built by BIONICO

SUCCESSFUL TESTING
of a dedicated membrane-based hydrogen purifier sub-system in HyGRID

FIRST PUBLIC
hydrogen refuelling station for trucks opened in Emmen, Netherlands as part of the HEAVENN project.

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Clean Hydrogen Partnership

Cleaner, quieter hydrogen-powered transport takes to the road

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Fuel cell electric vehicles (FCEVs) powered by green hydrogen can contribute to meeting climate goals and making Europe's cities more liveable. Projects funded by the Clean Hydrogen Partnership are rolling out fuel cell electric buses, taxis and hydrogen refuelling stations to develop the market for cleaner, quieter public transport.

Public transport leads the way

The EU needs to decarbonise its transport sector and increase its energy self-sufficiency. Several EU policies and directives have already laid the foundation for low-emission transport. By replacing 'captive' fleets ¬of taxis and buses – which have predictable driving and refuelling patterns – with hydrogen fuel-cell-powered models, the versatility, safety and reliability of the technology is being demonstrated to the public and decision makers.

ZEFER has deployed 180 fuel cell electric taxis in Paris, London, and Copenhagen. They have driven 8.3 million km. H2ME, which started in 2015, and H2ME2, to end in June 2023, aim at deploying more than 1 100 fuel cell hydrogen cars and vans and 49 refuelling stations across 8 countries.

The 3EMOTION project has put hydrogen buses on the roads of Pau, London, Versailles, Rotterdam and Aalborg. They have driven 3.1 million km by June 2021, saving 3.8 million kg of CO_2.Combined, the JIVE projects will deploy nearly 300 fuel cell buses (FCBs) in 22 cities across Europe by the early 2020s – the largest deployment in Europe to date.

Going the distance

Large-scale deployment of fuel-cell buses, taxis and refuelling stations in major European cities is allowing the public to experience first-hand the cleaner, quieter ride that hydrogen-powered vehicles offer. ZEFER has increased use of the refuelling station network, which is helping to make owning and operating the new technology commercially viable. The next steps include making it easier for bus operators to include hydrogen fuel cell buses in their fleets.

DRIVING DEMAND

Ensuring full commercialisation of fuel cell buses and vehicle fleets requires the appropriate regulatory framework, permits and certification schemes. Stronger demand is needed to drive down prices of hydrogen, vehicles and refuelling infrastructure relative to diesel-powered equivalents.

ON THE ROAD TO COMMERCIALISATION

The deployment of hydrogen vehicles and refuelling stations in major European cities is providing data on long-term performance and reliability and determining best practices for procurement, maintenance and operation. **The goal?** To convince local and national governments to regulate for zero emission public transport systems, paving the way to full commercial deployment. **Key results?** The price of an FCB has been reduced significantly to below EUR 625 000, and new 18 m articulated models of FCBs and coaches have been announced by bus manufacturers.

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FIND OUT MORE

Clean Hydrogen Partnership
3Emotion project
ZEFER project
The H2ME Project
Hydrogen Mobility Europe 2
The JIVE project
The JIVE 2 project
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Clean Hydrogen Partnership

KEY ACHIEVEMENTS

7 MILLION KM
driven by 120 hydrogen taxis deployed by ZEFER in Paris and London, and still counting

180
fuel cell electric vehicles in use in Paris, London and Copenhagen under the ZEFER project

3-5 MINUTE
refuelling time achieved by hydrogen vehicles, comparable to diesel or petrol vehicles

535
Hydrogen vehicles deployed between March 2015 and May 2022 by both H2ME projects

230+
Fuel cell electric buses deployed in Germany, France, UK, Scandinavia, Spain, Italy and the Netherlands

7
regional clusters, from Scandinavia to Iberia, now exist to advance fuel cell bus

IMPACTS

PROVEN ABILITY
of hydrogen vehicles to meet drivers' daily and annual needs

SAFETY
of refuelling stations and fuel cell systems proven by ZEFER

HIGH SATISFACTION LEVELS
from drivers, technicians and passengers at four sites where buses are in regular operation

CAPEX TARGET
of <EUR 650 000 (JIVE) and <EUR 625 000 (JIVE 2) per non-articulated bus met by several suppliers

LARGEST SINGLE ORDER
for FCBs in Europe to date (100) placed by Cologne regional transport in May 2022

SEAMLESS INTEGRATION
of FCBs with diesel buses, due to the same flexibility and operating procedures

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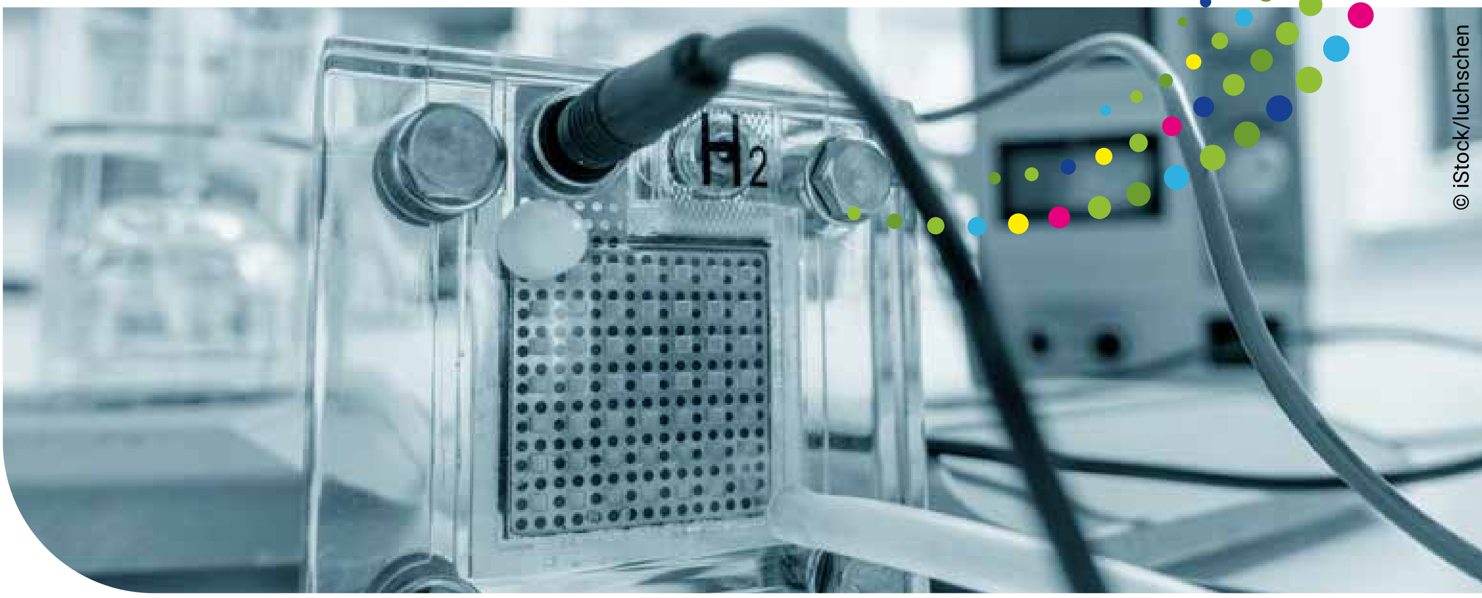
Hydrogen End-uses

An important step for fuel cell membrane technology



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Fuel cell stacks are the heart of power production in electric vehicles. The GAIA project, funded by the Clean Hydrogen Partnership developed and tested advanced fuel cell components that can satisfy stringent durability and performance requirements, taking the technology another step closer to commercial deployment.

The sum of the parts

The membrane electrode assembly (MEA) is the key part of the fuel cell where the chemical reactions that produces electricity from hydrogen fuel take place. Its components make up to 60 % of the total fuel cell cost. The use of innovative materials in MEAs is improving their performance and reducing production costs.

GAIA succeeded in increasing the power density of its high-performance MEAs by 20 % compared to the state-of-the art, meeting the 2024 Clean Hydrogen Partnership power density target for light-duty vehicles of 1.8 W/cm^2 at 6V.

It did so without increasing the amount of platinum on the catalyst. Previous projects like VOLUMETRIQ improved manufacturing technology and quality assurance for fuel cell stack components, while INSPIRE integrated stack components that can meet performance, durability and cost targets into a fuel cell.

Partnerships for success

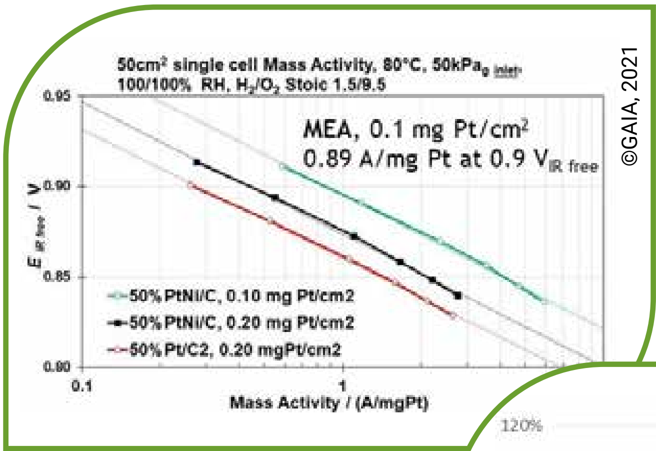
GAIA brought together 10 partners including research institutions, a leading multinational vehicle manufacturer and manufacturers of fuel cells and advanced materials like nanofibers. The MEAs developed were tested in a 4-cell stack. The project results were communicated to industry, academia, government bodies and the public. In the future, the project achievements will be validated in a larger 10-cell stack and over 6 000 hours of operation. The techno-economic feasibility of the MEA will be assessed, targeting a cost of EUR 6/kW, in line with the call topic.

MORE PERFORMANCE, LESS COST

To ensure the commercial viability of the technology, the longevity of MEA components needs to be improved and the high cost of manufacture, due to the use of a platinum catalyst, must be reduced.

A FOCUSED APPROACH

The advances were achieved thanks to coordinated research and innovation into MEA design and catalysts, ionomers, membranes and gas diffusion layers by industry, manufacturers and academia. **The goal?** To achieve increased power density, which will lower overall stack cost, in turn helping to support the large-scale adoption of proton exchange membrane fuel cell technology and decarbonise the transport sector. **Key results?** The European Commission's Innovation Radar determined that the power density achieved by GAIA's MEAs has market-creating potential. A cost analysis determined that recycling of catalysts and ionomers could significantly reduce MEA cost, bringing it close to the EUR 6/kW target of the public-private partnership's 2019 annual working plan.



KEY ACHIEVEMENTS

1.8 W/CM²
power density target achieved, at 0.6 V

20 %
increase in power density over state-of-the art

0.25 G PT/KW
of platinum-specific power density, reduced from 0.45g Pt/kW achieved by VOLUMETRIQ

11 µV/H AND -14 µV/H
degradation rate target achieved for the catalyst at various stack temperatures and current densities

8
articles published to date in international high-quality journals

IMPACTS

STRONGER
leadership of fuel cell technology thanks to progress achieved by GAIA

NEW MEA MATERIALS
developed and up-scaled by GAIA

FIRST TIME
use of an up-scaled electrospun reinforcement in the membrane used for the MEA in final stack testing

EXTREMELY LOW
degradation rate of catalyst and gas diffusion layers achieved

REPRODUCIBLE
power density achievement demonstrated in two full-size automotive MEAs

EXCELLENT PROGRESS
made towards durability and cost targets

SIGNIFICANT REDUCTION
of MEA cost possible with recycling of catalysts and ionomers

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The GAIA project
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Supply Chain

The shift to gigawatt-scale fuel cell manufacturing

© TU CHEMNITZ, 2021

The large-scale deployment of hydrogen technology for low- or zero-carbon transport and energy use requires massive fuel cell production. A project funded by the Clean Hydrogen Partnership developed innovative manufacturing techniques to lower costs and achieve volumes to help meet an anticipated surge in demand for fuel cells from 2025.

Turning up the volume

Clean hydrogen technology can play a leading role in meeting EU targets to decarbonise the transport sector. To achieve this, fuel cells and their parts have to be produced in large volumes, while meeting strict quality standards, and cost-effectively enough to give European manufacturers a competitive edge. The MAMA-MEA project focused on production of catalyst-coated membranes (CCM), that part of the fuel cell stack critical to its efficiency and performance.

MAMA-MEA scaled up the production volume of CCMs from over 50 megawatts per annum (MW/a) to over 3 gigawatts per annum. The power density of 0.8 watt per cm^2 (W/cm^2) achieved exceeded the target of 0.67 W/cm^2.

Taking it to the next layer

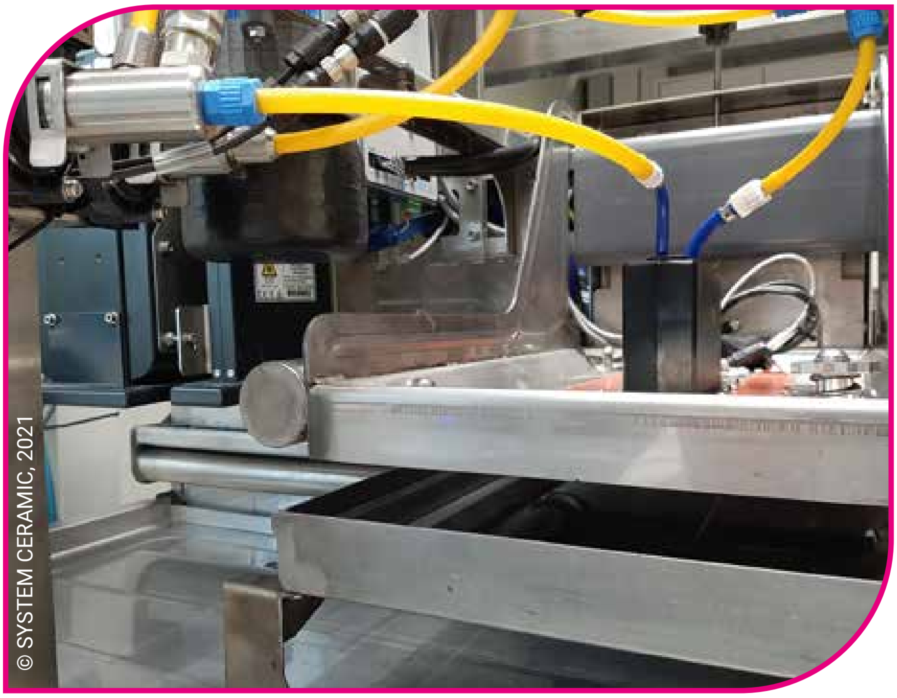
MAMA-MEA made use of innovative additive layer manufacturing to deposit CCM components – anode and cathode catalyst layers, ion-conducting membrane and edge seals – onto the membrane. With high precision and speed, each component can be laid down in thin layers, exactly where needed. The project consortium developed a single, uninterrupted manufacturing process for the CCM components. The process advanced from manufacturing readiness level 3 (proof-of-concept) to 6 (prototype system). Further improvements to production will include reducing waste of materials and better control over the placement of layers and their quality.

POWER AND RELIABILITY

The production of fuel cells and their parts must increase from tens of thousands to hundreds of thousands of units per year, while maintaining a level of quality that ensures they can provide the required power, reliably, over thousands of hours of operation.

A BLUEPRINT FOR SUCCESS

A consortium of industrial, institutional and academic partners with expertise in coating technologies and process design, from within and outside the fuel cell industry, funded by Clean Hydrogen Partnership, is bringing about innovation in manufacturing CCMs. **The goal?** To disrupt the emerging fuel cell market by reducing the time and cost of CCM manufacturing, without compromising on quality and fuel cell stack performance. **Key results?** The project increased the manufacturing rate more than 10 times compared with the state-of-the-art, and increased material use to 99 %. Material and manufacturing costs were reduced by up to 58 %.



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KEY ACHIEVEMENTS

10-FOLD
improvement in manufacturing rate of CCMs compared with the current state-of-the-art

99 %
material use thanks to additive layer manufacturing

3 GW/A
manufacturing volume per production line

0.8 W/CM²
power density achieved

4 000 HOURS
expected lifetime of CCMs under real-life conditions

IMPACTS

HIGH PRECISION
placement of CCM components thanks to innovative manufacturing techniques

SIMPLER
and scale-able production line developed

GIGAWATT
production scale achieved

COST REDUCTION
of materials and manufacturing by up to 58 %

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Market Uptake

Building a safe hydrogen economy

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Greater market uptake of hydrogen technology depends on public confidence in its safety. The Clean Hydrogen Partnership is funding projects on the safe development and use of this energy source in a wide range of settings, and supporting the work of the European Hydrogen Safety Panel (EHSP).

Ensuring that safety keeps up with innovation

Rapid development and implementation of hydrogen technology means more and more consumers are using it for the first time, in their homes, businesses and in transportation. A lack of experience and of harmonised laws, standards and regulations might jeopardise wider hydrogen uptake.

Several Clean Hydrogen Partnership funded projects are developing the know-how, systems, and training programmes to reduce these risks. For example, the HyTunnel-CS project consortium is researching the safety of hydrogen-powered vehicles in enclosed spaces like tunnels and parking garages. The HyTunnel-CS project has produced an innovative design for a hydrogen fuel tank that remains safe in a fire.

MultHyFuel project, due to end in December 2023, is studying harmonised permitting requirements and risk assessment methodologies for hydrogen refuelling stations in multi-fuel contexts. Other applications being examined include use of liquid, or cryogenic hydrogen (PRESLHY project), and hydrogen-powered passenger ships (e-SHyIPS project). HyResponder project is training firefighters to respond to hydrogen-related accidents. The EHSP is helping the Clean hydrogen Partnership in promoting a high-level hydrogen safety culture and ensuring that developments in technology are accompanied by safety innovations.

Teaching the skills

As fuel cell and hydrogen technology gains market share, more skilled workers are needed to design, build, operate and maintain it. Since 2021, the Clean Hydrogen Partnership has been supporting nine projects studying hydrogen safety through research, experiments and the design of solutions. Project results are made public via conferences, publications, online events and platforms.

The TeacHy project has developed an MSc course in fuel cell and hydrogen technologies. Eighty percent of the content is delivered online and the rest via in-person lectures by a network of participating universities. Hydrogen safety is one of the seven compulsory core modules. In future, the Clean Hydrogen Partnership will continue its work on hydrogen safety through projects and through the activities of the EHSP.

RAISING THE BAR ON SAFETY

Fuel cell and hydrogen technology needs to attain at least the same level of safety currently in place for fossil fuels, while avoiding overly restrictive measures.

A CULTURE OF SAFETY

A culture of safety, training and regular maintenance is being developed along the chain of production and use. **The goal?** To make hydrogen a leading clean energy carrier that contributes to decarbonisation of European economy. **Key results?** In September 2021, the EHSP published a Safety Planning and Management document, to help EU hydrogen projects incorporate safety lessons learnt. In addition, the EHSP published an analysis of events recorded in the updated European Hydrogen Incidents and Accidents Database (HIAD 2.0). The analysis includes lessons learned and recommendations for different hydrogen sectors and applications.

FIND OUT MORE

- Clean Hydrogen Partnership
- PRESLHY project
- HyTunnel project
- HyResponder project
- MultHyFuel project
- TeacHy project
- The e-SHyIPS project
- @CleanHydrogenEU
- Clean Hydrogen Partnership

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KEY ACHIEVEMENTS

19
recommendations formulated by PRESHLY on regulations, codes and standards to anticipate and mitigate accidents

14
European countries covered by a review of hydrogen refuelling station permitting procedures undertaken by MultHyFuel

11
national training workshops organised by HyResponder

12
partner universities form the core of TeacHy

70
associate partners – universities, vocational training bodies, industry – involved in TeacHy

IMPACTS

BEST PAPER AWARD
presented at the 9th International Conference on Hydrogen Safety (ICHS2021), for the EHSP's analysis and summary of lessons learned from events listed in the hydrogen incidents database (HIAD 2.0).

HIGH LEVEL OF SAFETY
achieved for liquid hydrogen production, storage, transportation and end uses, thanks to current codes, standards, regulations, and guidelines

GUIDELINES
for engineers on the safe design and operation of liquid hydrogen infrastructure published by PRESLHY in 2021

ACTIVE PARTICIPATION
by PRESHLY consortium members in regulations, codes and standards bodies, working groups and technical committees to ensure integration of project recommendations

GAPS
in the legal and administrative framework for hydrogen refuelling stations identified by MultHyFuel

REVISED
international curriculum on hydrogen safety training for responders developed by HyResponder

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